UNIVERSIDADE DE LISBOA
FACULDADE DE BELAS-ARTES

AESTHETIC INFORMATIONAL SYSTEMS

Towards an ontology of computer-generated aesthetic artefacts

Rodrigo Hernández Ramírez

Orientadores: Prof. Doutor Victor Manuel Guerra dos Reis
Prof. Doutor José Miguel Santos Araújo Carvalhais Fonseca

Tese especialmente elaborada para a obtenção do grau de Doutor em Belas-Artes, na especialidade de Multimédia

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2018

DECLARAÇÃO DE AUTORIA

Eu Rodrigo Hernández Ramírez, declaro que a tese de doutoramento intitulada "Aesthetic informational systems: Towards an ontology of computer-generated aesthetic artefacts", é o resultado da minha investigação pessoal e independente. O conteúdo é original e todas as fontes consultadas estão devidamente mencionadas na bibliografia ou outras listagens de fontes documentais, tal como todas as citações diretas ou indiretas têm devida indicação ao longo do trabalho segundo as normas académicas.

O candidato

Lisboa, 22 de Maio de 2018

RESUMO

Esta dissertação tem como principal objetivo ampliar o entendimento da natureza de objetos estéticos computacionais; iluminar o que os distingue dos seus homólogos «tradicionais» (não computacionais). O propósito de tal clarificação é, por sua vez, ampliar a compreensão de como os atuais desenvolvimentos tecnológicos afetam a conceção que temos da arte e das obras estéticas. Esta dissertação apresenta os computadores como verdadeiras máquinas de criação de modelos; ferramentas que nos permitem criar, representar, interagir com e objetificar entidades e experiências que não precisam de existir na realidade concreta (moderna ou «newtoniana»), mas tão-só como *informação*. Declara que uma forma melhor de descrever os objetos estéticos computacionais é como simulações: como representações dinâmicas, persistentes e tecnicamente mediadas de um sistema original, com diferentes níveis de abstração (granularidades). Mas também que estes podem igualmente ser encarados e analisados como *sistemas informacionais complexos*: como padrões, programas ou interfaces que, sendo interpretados, não só transmitem como geram nova informação factual.[1] Incidentalmente, é possível aplicar a mesma caraterização a objetos não computacionais.

A abordagem seguida por esta dissertação pode ser considerada pouco ortodoxa, por duas razões principais. Em primeiro lugar (e pelos motivos já enunciados), ao contrário da maior parte da pesquisa contemporânea, concentrada na relação entre as tecnologias de informação e comunicação (TIC) e a arte, a sua estrutura conceptual não se encontra completamente influenciada pela teoria dos meios de comunicação. Ao invés, baseia-se na filosofia da informação, na filosofia da tecnologia, nos estudos de software e — em menor grau — na teoria da arte generativa e na ciência dos sistemas complexos. Em segundo lugar, dado que o objetivo não é desenvolver uma taxonomia, mas antes uma descrição ontológica geral de objetos estéticos computacionais (daquilo que poderão ser), esta dissertação não apresenta um levantamento detalhado de obras de arte contemporâneas geradas por computadores.

As razões para evitar a recolha e a discussão de exemplos são sobretudo metodológicas, mas também práticas. Por um lado, existem já muitas descrições que proporcionam análises muito mais profundas de práticas estéticas contemporâneas do que as que poderiam ser apresentadas por esta investigação (e.g. Carvalhais 2010). Por outro, é possível afirmar que as TIC contemporâneas são das tecnologias que mais rapida-

[1] Uma descrição completa deste termo é apresentada na Secção 4.7.

mente mudam, tal como as «linguagens» dos objetos estéticos computacionais, cuja constituição informacional as torna extremamente propensas a «hibridização» (ver Manovich 2013). Se bem que qualquer sistema de categorização possa ser desafiado por mudanças emergentes, os mais vulneráveis são os que se encontram na dependência de mudanças tecnológicas de ponta. Exemplos hoje considerados notáveis e significativos de uma certa categoria de objetos estéticos computacionais podem facilmente transformar-se amanhã em meros casos irrisórios. Qualquer análise baseada na taxonomia precisa de ter em conta que a realidade em constante evolução dos sistemas tecnológicos poderá nunca se encaixar numa ontologia cuidadosamente organizada.

À luz destas circunstâncias, esta dissertação propõe um método «indireto» para analisar objetos estéticos computacionais. Em vez de coligir exemplos e tentar obter um sistema de categorização baseado nas caraterísticas formais, estruturais, processuais ou discursivas que possam partilhar, concentra-se na ferramenta utilizada para os produzir: o computador. Esta abordagem foi determinada pelo propósito de contornar as referidas falhas dos modelos taxonómicos tradicionais mas também pelo princípio fundamental que guia esta dissertação: para a compreensão de fenómenos, o conhecimento prático (técnico) é igual (se não maior) ao conhecimento teórico. Por outras palavras, esta dissertação parte do princípio de que saber realmente algo implica pelo menos uma noção básica das suas origens ou causas. Não sendo possível tomar em conta todos os processos utilizados por profissionais criativos, podemos então concentrar-nos no denominador comum das suas obras: a tecnologia computacional. Todavia, o que esta dissertação propõe não é uma análise geral de funções técnicas ou linguagens de programação, mas antes uma análise geral das circunstâncias (históricas, concetuais e outras) que permitiram que os computadores se tornassem instrumentos de criação artística. Para além de contribuir para a compreensão académica — conceptual — daquilo que os computadores podem, não podem e poderiam fazer no contexto de práticas estéticas e não só, esta descrição tem ainda o objetivo de proporcionar ideias das «coisas» que estas máquinas usam e transformam sempre que as utilizamos para criar objetos e experiências, ou seja: informação.

A metodologia utilizada é em grande parte uma adaptação do «Método de Níveis de Abstração» (*Method of Levels of Abstraction*) de Luciano Floridi (2008a, 2011d, 2011a). Trata-se de um instrumento filosófico fortemente inspirado por métodos formais da informática e originalmente criado para especificar e analisar o comportamento de sistemas (de informação).

Aqui, um nível de abstração (*Level of Abstraction*, ou LoA) é um conjunto de dados observáveis: caraterísticas ou componentes específicas de um sistema, que serão analisadas. A escolha de dados observáveis — e, assim, de LoA — é determinada pelos objetivos, pela perspetiva e pelo grau de pormenor desejado (granularidade) do observador. Os LoAs são aquilo que possibilita fazer análises do sistema; ao resultado de cada análise chama-se modelo. Os LoAs — e, por acréscimo, os modelos — não precisam de ser mutuamente exclusivos, nem hierarquicamente relacionados ou ordenados. Na verdade, podem sobrepor-se, ser distintos ou até encaixar-se uns nos outros. Quando determinado sistema é analisado através de vários LoAs, ao conjunto daí resultante chama-se *interface*. Na Secção 3.4.4 apresenta-se uma descrição mais alargada deste método.

No contexto desta dissertação, o sistema em análise é o computador, e os LoAs escolhidos são, em ordem progressiva: (a) o computador como tecnologia, (b) o computador como máquina de informação, e (c) o computador como «metamédio» ou máquina de simulação. Os dados observáveis são os aspetos históricos, técnicos e concetuais relacionados com cada LoA e que, nalguns casos, requerem maior clarificação. Isso acontece com os conceitos de «tecnologia», «informação» e «simulação». As ideias proporcionadas por esta interface são então utilizadas para demonstrar por que razão os objetos estéticos computacionais podem ser vistos como sistemas informacionais complexos. Por outras palavras, esta dissertação elabora uma série de «retratos» do computador, a partir de várias perspetivas, com o propósito de compreender a natureza ôntica dos objetos de produção no contexto de práticas estéticas.

Em termos estruturais, esta dissertação divide-se em seis capítulos semiautónomos, mas interligados. Cada um contém um resumo, uma introdução e conclusões; cada um apresenta uma única afirmação central que, por sua vez, faz avançar o argumento geral da dissertação. Após o último capítulo, também se apresentam conclusões gerais e um balanço das implicações, juntamente com uma lista completa de referências. As razões que levaram à escolha de uma estrutura assim, mais do que metodológicas, são práticas, já que o tema geral desta dissertação convida à discussão de muitos tópicos, alguns dos quais diretamente relacionados, outros não, que vão de discussões atuais sobre epistemologia e arte, a tecnologia militar, passando por teoria da informação e ciência dos sistemas complexos. Em vez de tentar inserir todas em secções monolíticas correspondentes, como «revisão da literatura» ou «estado das coisas», foram integradas em narrativas significativas ao longo dos vários capítulos. Contudo, tal organização não implica que a estrutura académica tradicional tenha sido completamente abandonada. Na verdade, os capítulos um a três correspondem (aproximada e respetivamente) às secções de «contexto», «teoria» e «metodologia» de uma obra científica «padrão»; enquanto os capítulos quatro a seis correspondem à análise. Para que esta metaestrutura se torne mais explícita, a dissertação foi dividida em duas partes principais. Os resumos de cada capítulo, abaixo apresentados, pretendem esclarecer quaisquer dúvidas que restem em relação à estrutura:

O Capítulo 1 debruça-se sobre as questões apresentadas no início desta introdução. Delineia as principais mudanças acarretadas pelas tecnologias da informação, com particular ênfase nas consequências epistemológicas e no impacto no estudo da arte. Em suma, o capítulo demonstra por que os investigadores de arte se veem forçados a reformular a postura tradicional e herdada em relação à tecnologia.

O Capítulo 2 recua às origens do conceito de «tecnologia» e proporciona uma visão geral das noções antigas e acuais deste termo. Também demonstra que a tecnologia é um aspeto fundamental da cultura humana e por que razão compreender como nos relacionamos com sistemas sociotécnicos é crucial para analisar como nos relacionamos com o mundo. Acima de tudo, este capítulo demonstra que a tecnologia computacional representa a quintessência da expressão da tecnologia da informação.

O Capítulo 3 aborda a pós-fenomenologia, bem como a filosofia da informação, e coloca-as em contraste com as abordagens «tradicionais» da teoria dos meios de comunicação. Assim, descreve o processo metodológico que será usado em capítulos subsequentes, ao mesmo tempo que proporciona um conjunto autónomo de argumentos que indicam como o estudo da arte pode beneficiar de abordagens pós-fenomenológicas e construcionistas. O objetivo principal deste capítulo não é instigar ao abandono de abordagens da teoria dos meios de comunicação, mas antes questioná-las, expandi-las e complementá-las com perspetivas das correntes filosóficas acima mencionadas.

O Capítulo 4 proporciona o primeiro «retrato» do computador como uma máquina de informação. Debruça-se sobre as origens históricas da tecnologia e aborda conceitos-chave associados, em particular o que é a informação e como pode esta ser descrita quer em termos técnicos, quer em termos filosóficos. O capítulo esclarece por que é o computador o primeiro aparelho verdadeiramente multifunções e também por que razão a informação é uma noção tão crucial para compreender não apenas esta tecnologia mas também muitos aspetos das sociedades e culturas contemporâneas.

O Capítulo 5 proporciona o segundo «retrato» do computador, visto como uma máquina de simulação. Aborda as primeiras aplicações do computador para a criação estética, bem como a sua evolução para o metamédio a que nos acostumámos. Este capítulo inclui uma discussão profunda do conceito de simulação e defende que só quando se tornou uma ferramenta para trabalho criativo (independentemente da área) é que o computador se concretizou de facto como máquina universal.

O Capítulo 6 sintetiza as análises dos capítulos anteriores para demonstrar por que podem os objetos estéticos computacionais ser considerados sistemas informacionais. Este capítulo também utiliza ideias da ciência dos sistemas complexos e da teoria da arte generativa. No seu todo, o capítulo defende a ultrapassagem da dicotomia entre o analógico e o digital.

Encarar tecnologias, computadores e objetos estéticos computacionais como sistemas lança luz sobre as suas complexidades e revela como as caracterizações monolíticas e generalistas de qualquer um deles dificilmente proporcionarão conhecimento a longo prazo. Embora tal só seja explícito em certas secções, o argumento subjacente avançado por esta dissertação é a de que quem se dedica ao estudo da arte deveria procurar desenvolver uma literacia computacional mais sólida, bem como pôr em causa certos preconceitos (românticos) quanto à relação entre arte e tecnologia. Esta exortação não tem a pretensão de se apresentar como nova, já que os apelos a que académicos das áreas das artes e das humanidades desenvolvam uma compreensão mais profunda das TIC se têm tornado mais frequentes ao longo da última década. A emergência de campos como os das humanidades digitais, os programas STEAM (*Science, Technology, Engineering, Arts, and Mathematics*) e o crescimento da arte algorítmica e digital representam respostas positivas a este processo. Não obstante, há ainda bastante trabalho por concretizar no que concerne a colmatar as lacunas entre as ciências, as artes e as humanidades.

Esta dissertação pretende contribuir para esse empreendimento, recorrendo a novos ramos filosóficos que poderiam proporcionar conceitos necessários e ferramentas analíticas para aproximar domínios de conhecimento artificialmente afastados. A guiar a investigação contida nesta dissertação encontra-se a noção de que uma reflexão filosófica com bases científicas pode proporcionar (a) o rigor conceptual que permanece ausente de muitas abordagens contemporâneas dos *media studies* à tecnologia, e (b) a perspetiva humanista crítica que muitas vezes falta a trabalhos da área das ciências e da engenharia. Posto isto, proporcionando explicitações de conceitos-chave como «tec-

nologia», «informação» e «simulação», com esta dissertação espera-se proporcionar aos leitores pontos de partida para o desenvolvimento de análises mais equilibradas e orientadas para a prática da relação entre a tecnologia e trabalhos criativos.

Palavras-Chave:

Arte computacional; Filosofia da informação; Filosofia da tecnologia; Método de LoAs; Sistemas informacionais estéticos.

ABSTRACT

Computer-generated aesthetic artefacts and the technology employed to create them have brought serious challenges for art scholarship. How should they be understood, described and categorised in relation to non-computational artworks, and how current technological developments are affecting aesthetic practices and our understanding of art in the Information Age are two of the most pressing questions in this field. To address them, this dissertation proposes a scientifically-informed conceptual inquiry and historical account of the relation between computational technology and art. The analysis here presented is based on insights provided by contemporary philosophy of technology and philosophy of information. These styles of analysis give access to a broader understanding of information and communication technologies (and computational technology in particular) that mitigates some of the epistemic shortcomings of media studies and critical theory.

This dissertation shows computers are the ultimate modelling machines; tools that allow us design, represent, interact with, and objectify entities and experiences that need not exist in concrete (Modern or "Newtonian") reality, but merely as *information*. It shows computational aesthetic objects may be better described as simulations: as dynamic, persistent, technically mediated renderings of a source system at different levels of abstraction (granularities). But also that they may also be regarded and analysed as complex informational systems: as patterns, programs, or interfaces which, upon being interpreted, not merely convey but generate new factual information. Ultimately, this dissertation shows that regarding computational technology and computational aesthetic objects as systems illuminates their complexities and shows why monolithic and overarching characterisations of either of them are unlikely to provide valuable knowledge in the long run. While only explicit on certain sections, the underlying argument advanced by this dissertation is that art scholars should care to develop a more robust computational literacy, as well as to question certain (Romantic) prejudices concerning the relationship between art, science, and technology.

Keywords:

Aesthetic Informational Systems; Computer-generated Aesthetic Artefacts; Method of LoAs; Philosophy of Information; Philosophy of Technology.

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Contents

Introduction

Since the 1950s, Information and Communication Technologies (henceforth ICTs) and computational technology in particular, have been radically changing every aspect of human life. They have transformed what we do and how we do it, what we know and can know; they are changing our environment and this, in turn, is changing ourselves at the social, cultural, and perhaps even physiological level. ICTs are transforming our economies, our politics, our education, our sciences, our social relations, our biology, and our philosophies. Technologies are now at the centre of most cultural phenomena; they have become active drivers of social and political change. Naturally, technologies are transforming aesthetic practices, both for practitioners and scholars. Therefore, it is safe to say that understanding contemporary art and culture presupposes understanding our relationship with technological systems.

Art and technology have a complicated relationship. These two concepts share a common ancestry (along with craftsmanship) dating back to Classical Greece (Gualeni 2015). At some point during the Renaissance, their paths began to diverge. By the late eighteenth century, art and technology came to be seen as opposing forces. The former regarded as the quintessential embodiment of human creativity; the latter as the embodiment, or rather, as the *application* of scientific reductionism.[2] However, in the last few decades, this tension has come to be seen as the product of a limited and pessimistic understanding of human–technology relations.

Twentieth-century aesthetic discourses and practices arguably emerged as a consequence of (and response to) the radical technoscientific developments that inaugurated this period and to the profound social and cultural transformations that accompanied them. Many vanguardist movements either denounced (Dada) or embraced

[2]Thanks in part to critical theorists, the term "reductionism" (like "determinism") has acquired a rather negative connotation. Nonetheless, in scientific contexts, reductionism is often understood not as an attempt to replace "one field of knowledge with another but of connecting or unifying them" (Pinker 2003, 70). As will be discussed in Chapter 6, reductionism, or rather *information compression* is a necessary aspect of scientific explanation.

(Futurism) some form of technoscientific rationality. Key artistic movements and concepts — from Russian Constructivism and the Bauhaus to high-brow Abstract Expressionism and Land Art — were directly influenced by technological change. The Avant-garde embraced ICTs such as photography and cinema and furthered their expressive potential; in later years audio and video technologies followed suit. By the early 1960s, computers were already being used to generate aesthetic objects. Such experimentation began only fifteen years after the first commercial electronic digital computer (the Manchester Ferranti Mark I) came out, and almost twenty years before the first consumer drawing software (AutoCAD) was introduced. This early computer art, however, was still in what mathematician-turned-artist Frieder Nake calls "the McLuhan phase", meaning that their creators were merely "trying out new ways of doing the traditional" (2016, 21). Nonetheless, in the last two decades of the twentieth century, everything would change for aesthetic practices, as computational technology finally became able to simulate all previous forms of audiovisual representation.

With the emergence of the PC, and hence of dedicated software for capturing, generating, and manipulating not just text but also images and sound, computational technology finally became available to non-programmers. More people could now adopt these new devices as their primary creative tools. Computers became indispensable for every significant intellectual, commercial and administrative task, they also assumed a central role in many aesthetic practices, particularly in architecture, cinema, design, photography, and music. As a result — to paraphrase Nake (2010), nowadays there are no images (or sounds) that have not been produced without the influence or the intervention of computers. This new technological regime has brought significative challenges for art scholars.

As computational technology grew capable of simulating all the functions of preexisting audiovisual modes of representation, the (ontological) claims of (high) modernism received a final blow. The adequacy of the fine arts system as a categorical model was called into question along with the role of the "medium" as the sole guarantor of the integrity of artistic practices. This shift caused considerable anxiety amongst art scholars. As more artists incorporated ICTs into their practice, art scholars found themselves engaging knowledge, tools and methods that the humanities had traditionally regarded as exclusive of engineering and science. Whereas, for creative practitioners, the possibility of simulating and freely mixing the tools, techniques and "vocabulary" of pre-computational audiovisual expressions within the same environment have significantly expanded their creative horizons. Above all, computational technology has turned the principles of "hybridisation" and cross-fertilisation into the norm of contemporary audiovisual artefacts.

Given this state of affairs, the most basic problems following the entrance of computational technology into the realm of aesthetic creation are: (a) the ontological status of *computer-generated aesthetic artefacts* — i.e., what they *are* at the most fundamental level and how they relate to "traditional" forms of representation; and (b) how technology is affecting (either positively or negatively) aesthetic practices and our general understanding of art. This dissertation deals primarily with the first problem, and only tangentially with the second.

Nominally, the disciplinary area in which this dissertation is embedded is "multimedia"; however, in practice, it is situated at the intersection of "new media studies", philosophy of technology, and philosophy of information. The reason for explicitly distancing this research from multimedia is twofold. Firstly, the term is conceptually innocuous; secondly, it is methodologically outdated. Multimedia, a term that became popular in the early 1990s, originally referred to the use of computational technology for distributing and accessing audiovisual content, rather than for producing it. It also alluded to the fact that such content was generally not found in the same place and at the same time. Those two aspects were relevant when CD-ROMs constituted state-of-the-art technology and Internet connections ran at (the now unimaginable) speed of 56 Kbit/s but have since then become anachronistic. Nowadays the overwhelming majority of audiovisual content we produce and consume is not (just) "multimedia" — i.e., created by juxtaposing different media — but technically, conceptually, and culturally *hybrid*.

More recent alternatives to "multimedia" are "digital media" and "new media", but both terms are also far from ideal. Digital media was popularised in the mid-1990s by Nicholas Negroponte (1995); scholars rapidly adopted it, often using it interchangeably with other variations of the term "media". However, in my view, there are at least two objections against using Negroponte's term as a category. The first one — to borrow an argument made by Dominic Lopes (2010) — is that being digital is not a property that is exclusive to computational objects. As an adjective, "digital" means that something is composed of discrete and discontinuous elements; thus, alphabets and numerical systems are also digital. The second objection comes from Lev Manovich (2013), and it concerns the fact that the qualities of computer-generated objects are not owed (solely) to the fact that they are digital, but to the features of the *software* that creates them. Alan Kay (1984) had already delineated this argument when he contended that "architecture dominates material", and thus understanding "clay" is not tantamount to understanding the "pot" it was produced from it. For its part, the problems with the concept of "new media" are: (a) its contingent and relational nature, and (b) its reliance on the "nowness" of a given technology. Therefore, in this dissertation, the (admittedly cumbersome) concept "computer-generated aesthetic artefact" will be used as an alternative. The term is self-explanatory, and it is both sufficiently ample as to admit any form of (aesthetic) "media", while also retaining a necessary explicit link to the phenomenon (and the technology) responsible for generating them: computing.[3]

The state of scholarship

Since the broader theme of this dissertation is the relation between (information) technology and art, some preliminary clarifications concerning current understandings of "technology" in general and ICTs in particular, are in order. As previously noted, the historical relationship between technology and the humanities has been riddled by tensions. Early philosophical accounts of technology (Martin Heidegger's in particular) portrayed it largely in abstract and pessimistic terms; as a potentially dangerous and restricting force that imposed a tyrannical, utilitarian view on the world. This "enframing" (*Gestell*) was seen not only as *essentially* different to the experiential outlook that art could provide but also as epistemologically inferior to it. Pessimistic accounts such as this one greatly contributed to shaping the humanities' attitude towards technology even to this day.

In the last two decades of the twentieth century, views on technology that challenged the "classical" assumptions above mentioned began to emerge. Scholars such as Don Ihde (2009a, 2010) and Bruno Latour (1987) started promoting more empirically-oriented philosophical views on technology. Ihde's *postphenomenology* and Latour's *Actor-Network Theory* (ANT) emerged as styles of analysis that focused on the relation between technologies and their users, rather than on the essential features of technology itself. Postphenomenology emphasises the notion that technological artefacts have always mediated human experience. It no longer regards *technoscientific*

[3]Manovich (2013), for example, notes that he fancies the term "media computing" in lieu of "digital" or even "new media", but he also notes that it is rarely used, except for certain computer science groups in Europe.

instruments as hindrances to the human spirit, but as tools that significantly influence the ways we sense and understand the world. Under such view, technologies are a fundamental (and inescapable) aspect of our humanity. Consequently, technological artefacts cannot be addressed independently of human circumstances and practices (Verbeek 2005), and vice versa: the human condition cannot be understood without taking into account technological mediation. This dialectical relation, postphenomenologists argue, does not imply that technologies are neutral, but rather that they lack essential features. It follows that our views of technological systems must shift according to the particular circumstances surrounding our interaction with them. This relational view greatly influenced the way technologies are regarded and approached throughout this dissertation.

Another point stressed by the postphenomenological view is that technology cannot and should not be regarded as a monolithic phenomenon. The reason being that if instruments have no shared *essential* features, it makes no sense to talk about "technology" but instead about various kinds of *technologies*. This dissertation focuses on computational technology, regarding it as a subset of the broader category of Information and Communication Technologies.

A dictionary definition of ICTs tells us that they comprise "all media and a mix of converging technology tools involved in the dynamic transfer and storage of analogue and digital data" (Khosrow-Pour 2007, 1:328). It follows that any technological system capable of generating, collecting, storing, processing, distributing, using, and recycling *information* qualifies as an ICT (Floridi 2010). Therefore, under this sufficiently broad definition, humanity's first information technologies were written languages, and the most recent one (but arguably not the last one) is computational technology.[4] Throughout the previous decades, computational technology has steadily incorporated *all* the functions previously scattered across different information technologies, being able to handle audio, images, and text. Consequently, it is fair to say that computers are not just a subset but *the* quintessential expression of ICTs, as Floridi (2009a) suggests.

In this dissertation, the term "computational technology" is used in the most general sense; thus encompassing all forms of hardware, software, and network systems. Similarly, the term "computer" here refers to any device, stationary or mobile, standalone or integrated into another system, with input/output (`I/O`), and processing and mem-

[4] Section 1.3 discusses some of the implications following this assumption.

ory components. The reason behind such choices is that whereas most creative practitioners use "regular" computers such as laptops, tablets, and desktops, a growing number of them are also incorporating less conventional appliances such as Raspberry Pi single-boards, Arduino chipsets, and other related hackable and custom-made instruments. While it is true that different devices may be used in different ways depending on the circumstance, all contemporary computational technology is based on the same technical principles.

While this dissertation follows many valuable insights from media studies, it deliberately avoids the idiom associated with media theory, as well as the tendency to create ad hoc neologisms. The reasons are conceptual and methodological. The most important being the nebulosity of the term "media" itself, and the fact that many tenets of media theory are inextricably tied to pre-computational information technologies.

Coined in the 1920s by the advertisement industry, the term "media" originally referred to the plurality of (printed) supports that could carry ads (Nerone 2003). In the following decades, the term was adopted and repurposed by scholars concerned with the cultural and political analysis of electronic mass communication systems, particularly radio. As used today, "media" refers to the various sets of institutions, technological instruments, practices, discourses, languages, genres, *and* content that (used to) make up each mass communication "medium". In other words, media as a concept presupposes the existence of intrinsic and distinct qualities that help to distinguish a given medium *and* the content or "message" it generates from every other medium. The implied idea thus being that different media should be analysed as particular integral objects or *systems*. Such is the postulate Marshall McLuhan ([1964] 1994) condensed in the first chapter of his book, and that eventually transformed into one of the most well-known aphorisms in communication science and media studies: "the medium is the message". However, while it is true that systems cannot be adequately understood (solely) by analysing their isolated parts, the idea that each medium has intrinsic qualities derived from its technological genealogy has become untenable thanks to computational technology. Once computers were able to simulate every previously distinct medium, a new media ontology[5] became a necessity, as Friedrich Kittler (2009) once

[5]From a (post) phenomenological standpoint, the term "ontology" may be effectively described as "the way in which a being structures its general understanding of a world" (Gualeni 2015, 6). However, in this dissertation, ontology is mainly understood as a specification; as a way to categorise and make sense of a given set of entities and their relations. In other words, as a framework for representing certain kinds of structured information within a system that may or may not interact with other systems (see Smith 2004). This dissertation is therefore not concerned "'Big *O*' ontology" but with "'Little *o*' ontology", to borrow the words of Poli and Obrst (2010).

suggested.

A new ontology is, to an extent, what software studies aim to offer. For this relatively recent field, there is now only one medium: software. Software studies understand "new media" as the result of the convergence of two technological trajectories: computation and media technologies. Therefore, everything we can do with a computer we owe it to software. When we look at and edit images, audio, and text, when we browse the Internet, when we organise files in directories we are interacting with and experiencing the *performance* of software (Manovich 2013). The implications are strong: the "properties" of new media are not to be found in the "content" or the "messages" themselves but in the particular software or collection of software applications we use. Truly understanding new media, their structures and languages — the reasoning goes — presupposes understanding the history, and role of software as a cultural artefact.

This dissertation partially endorses this view; nonetheless, software studies' characterisation of computational-aesthetic objects solely as manifestations of the interaction between certain data-structures and instructions remains, from an ontic standpoint, unsatisfactory. Pending is the question of what makes computational objects different (or not) from their analogue counterparts and this, in my view, implies understanding *what data is* in the first place. For this reason, this dissertation also incorporates insights from a discipline that can help in elucidating this problem: the philosophy of information.

The philosophy of information (PI) is concerned about the "conceptual nature and basic principles of information" (Floridi 2011a, 14). It deals with the analysis of this concept and all phenomena related to it from a historical and systematic perspective (Adriaans 2013). PI not only provides useful working definitions for "data,"[6] "information,"[7] and "reality" but also a method of analysis and a conceptual framework that allow to further clarify key notions related to computational aesthetic objects, such as "digital", "analogue", and "simulation" — a thorough account of PI and its methodology is provided in Chapter 3.

So far, this dissertation has been situated in a broader context (the information revolution), its general theme has been circumscribed (art and information technology),

[6]"Data" is the plural of *datum*, which means "something given", from the Latin root *dare*, "to give" (Hand 2008, 4). A *datum* is a "relational entity" that emerges from a "binary and symmetric" difference; "a lack of uniformity between two signs" (Floridi 2004, 43).

[7]As semantic content composed of well-formed meaningful and truthful data — see Chapter 4.

and its topic narrowed (the ontological nature of computational aesthetic objects). A general description of the state of scholarship concerned with this topic has also been provided, along with the clarification of fundamental concepts that will be used in the following chapters. The next section states the objectives and main arguments, provides an overview of the sources and methodology, a summary of the analysis, and a synopsis of the implications stemming from this research. Finally, a summary of each chapter is provided.

This dissertation

The main goal of this dissertation is to further our understanding of the nature of computational aesthetic objects; to illuminate what it is that distinguishes them from their "traditional" (non-computational) counterparts. The goal of this clarification is, in turn, to further our understanding of how current technological developments are affecting our conception of art and aesthetic practices. This dissertation shows computers are the ultimate modelling machines; tools that enable us to design, represent, interact with, and objectify entities and experiences that need not exist in concrete (Modern or "Newtonian") reality, but merely *as information*. It shows computational aesthetic objects may be better described as *simulations*: as dynamic, persistent, technically mediated renderings of a source system at different levels of abstraction (granularities). But also that they may also be regarded and analysed as *complex informational systems*: as patterns, programs, or interfaces which, upon being interpreted, not merely convey but generate new *factual information*.[8] A characterisation which, incidentally, can also be applied to non-computational objects.

Overview of sources

The approach followed by this dissertation may be considered unorthodox for two main reasons. First of all (and for the reasons already stated), unlike most contemporary research focused on ICTs and art, its conceptual framework is not entirely informed by media theory. Instead, it is based on philosophy of information, philosophy of technology, software studies, and — in a lesser degree — on generative art theory, and systems science. Secondly, since its goal is not to develop a taxonomy, but a gen-

[8] A full description of this term can be found in Section 4.7

eral ontological sketch of computational aesthetic objects — of *what* they might be; this dissertation does not provide a detailed survey of contemporary computer-generated artworks.

The reasons to avoid collecting and discussing examples are mostly methodological but also practical. First of all, there are already many accounts providing thorough overviews of contemporary aesthetic practices involving computational technology than what could be provided by this research (e.g. Carvalhais 2010). Secondly, contemporary ICTs are arguably the fastest-changing technologies we have ever developed, and so are the "languages" of computational aesthetic objects, whose informational constitution makes them extremely prone to "hybridisation" (Manovich 2013). While *any* system of categorisation is bound to be challenged by emerging changes, the most vulnerable are those subject to the logic of cutting-edge technological change. What today may be regarded as notable and meaningful examples of a certain category of computational aesthetic objects can easily become tomorrow's anecdote. Any taxonomy-based analysis has to take into account that the continually evolving reality of technological systems may never fit into a neatly organised ontology.

In light of this circumstances, this dissertation proposes an "indirect" method to analyse computational aesthetic objects. Instead of building a collection of examples and attempting to derive a system of categorisation based on their shared formal, structural, procedural, or discursive features, it focuses on the *tool* employed to produce them: the computer. This approach was devised not only to bypass the previously mentioned shortcomings of traditional taxonomic models but also obeys a core assumption driving this dissertation: that practical (technical) knowledge is of equal (if not of greater) importance than theoretical knowledge for understanding phenomena. In other words, this dissertation presumes that truly *knowing* something implies at least a basic grasp of its origins or causes. But, since we cannot possibly account for all procedures employed by creative practitioners, we can focus instead on the common denominator in their work: computational technology. However, what this dissertation proposes is *not* an overview of technical features or programming languages but a general analysis of the circumstances (historical, conceptual, and otherwise) that enabled computers to become instruments for art. Besides contributing to art scholarship's — conceptual — understanding of what computers can, cannot, and could do in the context of aesthetic practices and beyond, this account can also provide insights on the "stuff" these systems use and transform whenever we use them to design objects and experiences, that is: information.

The methodology employed by this dissertation is mainly adapted from Luciano Floridi's (2008a, 2011d, 2011a) *Method of Levels of Abstraction* (henceforth method of LoAs). A philosophical tool heavily inspired by formal methods in computer science and devised initially to specify and analyse the behaviour of (information) systems.

Here, a level of abstraction (LoA) is a set of *observables*: specific features or components within the system that are to be analysed. The choice of observables — and hence, of LoA — is determined by the observer's goals, perspective, and desired detail (granularity). LoAs are what make possible to conduct analyses of the system; the *result* of each analysis is called a *model*. LoAs — and thus models — need not be mutually exclusive, nor hierarchically related or ordered; in fact, they can be overlapped, disjointed or even nested. When a given system is analysed through various LoAs, the resulting collection is called an *interface*. A full description of this method is provided in Subsection 3.4.4.

Summary of analysis

In the context of this dissertation, the system under analysis is the computer, and the chosen LoAs are, in order of progression: (a) the computer as a technology, (b) the computer as an information machine, and (c) the computer as a "metamedium" or simulation machine. The observables are the historical, technical, and conceptual aspects related to each LoA and which, in some cases, require further clarification. Such is the case with the concepts of "technology", "information", and "simulation". The insights provided by this interface are then employed to show why computational aesthetic objects may be regarded as complex informational systems. Put in different terms, this dissertation elaborates a series of "portraits" of the computer from various perspectives to understand the ontic nature of the objects they produce in the context of aesthetic practices.

Structurally, this dissertation is divided into six semi-autonomous but interconnected chapters. Each one contains a summary, an introduction, and conclusions; each one makes a single overarching claim which, in turn, advances the overall argument of the dissertation. Following the last chapter, a general conclusion and an overview of the implications are also provided, along with a complete list of references. The reasons for choosing such structure are not so much methodological as they are practical. The general theme of this dissertation invites the discussion of many topics, some of them directly related, some of them not. They range from current discussions in epistemology and art to military technology, information theory, and systems science. Rather than attempting to cram them all into corresponding monolithic sections such as "literature review" or "state of the art", they have been integrated into meaningful narratives throughout the various chapters. However, this organisation does not imply that the traditional scholarly structure has been completely abandoned. In fact, chapters one through three roughly correspond (respectively) to the background, theory, and methods sections of a "standard" scientific work; whereas chapters four through six correspond to the analysis. To make this metastructure more explicit, the dissertation has been divided into two main parts. The following chapter summaries should further clarify any remaining doubts concerning this structure:

Chapter 1 elaborates on the issues discussed at the beginning of this introduction. It outlines the major changes brought by information technology with particular emphasis on their epistemological consequences and impact on art scholarship. Overall, the chapter shows why art scholars are being forced to reformulate their traditional, inherited stance towards technology.

Chapter 2 traces back the origins of the concept of "technology" and provides an overview of past and current understandings of this term. It also shows technology is a fundamental aspect of human culture, and why understanding how we relate to sociotechnical systems is crucial for analysing how we relate to the world. Above all, this chapter shows computational technology represents the quintessential expression of information technology.

Chapter 3 discusses postphenomenology, as well as philosophy of information and contrasts them with "traditional" approaches from media theory. In so doing, it describes both the methodological process that will be used in subsequent chapters while providing a standalone set of arguments that show how art scholarship could benefit from postphenomenological and constructionist approaches. This chapter's primary goal is not to call for the abandonment of media-theoretical approaches but to question, expand, and complement them with insights from the above mentioned philosophical strains.

Chapter 4 provides the first focused portrait of the computer as an information machine. It elaborates on the historical origins of the technology and discusses key concepts associated with it, in particular, what is information and how can it be described in both technical and philosophical terms. The chapter illuminates why the computer is the first truly multipurpose device and also why information is such a crucial notion for understanding not only this technology but many aspects of contemporary societies and cultures.

Chapter 5 provides the second "portrait" of the computer seen as a simulation machine. It discusses the early applications of computers for aesthetic creation, as well as its evolution into the metamedium we are now acquainted with. The chapter provides a thorough discussion of the concept of simulation and argues that the computer only found its realisation as a universal machine when it became a tool for creative work (regardless of the field).

Chapter 6 synthesises the analyses of the previous chapters to show why computational aesthetic objects may be regarded as informational systems. This chapter also draws insights from systems science and generative art theory. Overall, the chapter shows why the analogue vs digital dichotomy may be surpassed.

Synopsis of implications

Regarding technologies, computers, and computational aesthetic objects as systems illuminates their complexities and shows why monolithic and overarching characterisations of either of them are unlikely to provide valuable knowledge in the long run. While only explicit on certain sections, the underlying argument advanced by this dissertation is that art scholars should care to develop a more robust computational literacy, as well as to question certain (Romantic) prejudices concerning the relationship between art and technology. Admittedly, this exhortation is not new, as calls for scholars in the arts and humanities to develop a deeper understanding of ICTs have grown in frequency over the last decade. The emergence of fields such as digital humanities, STEAM programs, and the growth of algorithmic and digital art represent positive responses to this process. Nonetheless, there remains considerable work to do in terms of bridging the gaps between the sciences and the arts and humanities.

This dissertation aims to contribute to such enterprise by enlisting the help of new philosophical branches that can provide much-needed concepts and analytical tools to bring artificially estranged knowledge domains closer. Guiding the research contained in this dissertation is the belief that scientifically informed philosophical reflection can provide (a) the conceptual rigour that remains absent in many contemporary approaches to technology informed by media studies, and (b) the critical humanistic outlook that scientific and engineering accounts often lack. That being said, by providing clarifications of key concepts such as “technology”, “information”, and “simulation”, this dissertation hopes to provide readers with stepping stones for developing more balanced, praxis-oriented accounts of the relation between technology and creative practices.

Part I

Background, theory, and methods

Chapter 1

Living with technology

Summary

Computational technology has deeply transformed every aspect of human life; particularly how we understand and relate to the world, reality, and to each other. This chapter provides a general overview of the main epistemic and cultural transformations accompanying this process. It shows art scholarship still has a limited understanding of these changes and their broader implications owed to the inherent complexity of the circumstances but also to the historical and epistemological divides between the humanities and the sciences. It contends this tensions should be overcome and argues art scholars need to update their theoretical attitude and conceptual understanding of technology and its relationship with aesthetic practices. Ultimately, the primary goal of this chapter is to provide the background and contextual setting necessary for readers to engage the discussions that follow in subsequent chapters.

1.1 Introduction

Information technologies[1] (henceforth ITs) are changing our world in radical ways. In less than a century computers have directly or indirectly transformed almost every aspect of human life: how we communicate, work, do business, spend our leisure time, relate to each other and our environment, and how we make art. In the process, computers are also changing the way we conceive Nature, reality, and what it means to be human. Computers are genuinely multi-purpose devices; they have incorporated all the functions of previous ITs, thus becoming humanity's first "metamedium" (Manovich 2013). By simulating all previously distinct physical forms of communication and representation, computers have brought serious challenges for art scholarship. They have eroded the ontological boundaries that hitherto distinguished one medium from another, thus calling into question the pertinence of the fine arts system and its longstanding assumptions and concepts (including the very notion of "medium"). By enabling formerly unmixable media to "hybridise" (2013), computers have given rise to many new forms of artistic expressions that defy traditional categories. The widespread adoption of ITs in creative practices has forced art scholarship to engage technical knowledge and procedures that, until recently, were considered exclusive of engineering and science.

Even though artists have been historically prone to adopt (and subvert) new technologies, up until a few years, art scholars had remained indifferent to (if not wary of) technological knowledge. Like most fields in the humanities, art scholarship regarded science and engineering as realms beyond their scope of interests. In the last couple of decades, this attitude has come under heavy criticism from new strains of media philosophy, such as software studies. The critics call into question the belief that acquaintance with the technical aspects of computers is not indispensable for understanding the cultural impact of technologies (Mateas 2005), and therefore it can be ignored. They argue that practitioners and scholars throughout the humanities should improve their computational and "procedural literacy" and stop treating computers as black boxes. Above all, the criticism lambasts the notion that science and engineering on the one hand, and the humanities on the other, represent two distinct and competing "cultures", as the scientific commentator Charles Percy ("C.P.") Snow ([1964] 2012) argued.

This chapter shows that while art scholarship's limited understanding of computa-

[1] Also known as Information and Communication Technology (ICT).

tional technology may be attributed in part to the "two cultures" epistemic paradigm, it is also caused by the wider cultural and epistemic shifts brought by current technological developments. The analysis draws on the ideas of philosopher Luciano Floridi (2010), of media scholar Lev Manovich (2013), and of technology writer and commentator Kevin Kelly (1998). The chapter begins with a historical overview of the ongoing "information revolution", followed by an account of its epistemological and cultural impact. The next section discusses the impact of computational technology over art; whereas the last section analyses the origins of the "two cultures" myth and shows how it continues to influence art scholars' views towards science and technology. Overall, the chapter shows why art scholarship needs to shift its attitude towards technology — and particularly towards computers, while offering the reader the historical and epistemic context to engage the issues discussed in subsequent chapters.

1.2 More than a technological revolution

Human survival and development have always depended on information.[2] Perception, movement, and cognitive abilities rely mainly on our brains' capacity to gather and process large amounts of data — primarily in the form of chemical and electrical signals emitted by our sensory organs (Volkenstein [1986] 2009). Preserving and exchanging information, in the form of ideas, knowledge, culture, and technology has been crucial for the survival and evolution of societies. Human groups or communities who are unable to communicate with others or to maintain a relationship with their past risk destruction or, at the very least, some form of cultural erosion or stagnation (Diamond 1997; see also Pinker 2003). Being able to share knowledge such as how to track and kill animals, how and when to seed and harvest crops, in which direction to navigate, or how to build a shelter have been crucial components of our evolutionary success. For millennia, the only way to keep track of this information was by storing it in our biological and collective memories through images, stories, songs, and poetry. The invention of writing systems took the role of information to an entirely new level, signalling the beginning of many technological revolutions that would lead us into increasingly complex social systems.

[2]A proper discussion on the complexity of the term, as well as its various definitions will be offered in Section 4.4.

1.2.1 The information age

By definition, what we call History began some 6,000 years ago with the arrival of the written word (Floridi 2012b; Flusser [1983] 2006). Writing systems enabled humans to record meaningful data and make them available for future reference, thus relieving short-term memory, and enhancing long-term memory. Writing also enhanced our thinking and communication capacities; it revolutionised commerce, education, engineering, technology, and philosophy. Writing systems may be considered "one of the biggest advancements in neural enhancement" (Levitin 2014) and — under a sufficiently broad understanding — humanity's earliest information technology or IT (Floridi 2009a). It follows that History itself may be regarded as synonymous with the "Information Age" and that humans have lived not through one, but through *many* "information societies" (Floridi 2010) with varying degrees of complexity and dominated by a particular IT.

1.2.2 Three stages in the evolution of IT

According to Floridi, information technologies have three primary functions: (1) recording, (2) communicating, and (3) producing information. Throughout history, each of these functions dominated a particular stage in the development of ITs. As previously mentioned, the earliest IT — the "degree zero", so to speak — are writing and numerical systems, which enabled humans to accumulate information diachronically as "non-biological memory" (2009a, 227). In the West, this first stage in the evolution of ITs may be divided into two periods:

a. The first one, which constitutes the emergence and evolution of *recording* technologies, spans roughly from Plato to Gutenberg (fourth century BCE to fifteenth century CE, approximately);
b. in the second period, which was significantly shorter (roughly from 1751 to 1780), ITs experienced "a vast process of reorganisation & restructuring" (2009a, 227), marked by the exponential growth of written materials.

The second stage began in the nineteenth century with the emergence of the telegraph and spanned well into the twentieth century culminating with TV. The development of optical, electric and wireless telegraphy, followed by telephony, cinema, radio, and television defined ITs as (mass) *communication* technologies. The third and current stage in the development of ITs began in the middle of the twentieth century with the invention of the computer: the first appliance capable of *producing* information "by processing data electronically and automatically" (2009a, 228). It is important to highlight that information technologies generally evolve not by replacing functions, but by *accumulating* them.

Whenever ITs reach a new stage of development, it appears as if previous functions become obsolete; it happened with telegraphy, with photography, and with every subsequent IT system. As Floridi notes, cinema, radio and TV are usually described as mediums of mass communication, but we should not forget they are *also* mediums of "massive recording" (2009a, 228). Like writing, electronic mass media are capable of storing information; yet, despite being more efficient at transmitting it, they never made writing obsolete — contrary to what some extremely pessimistic accounts suggest (e.g. Sartori 2015). In fact, quite the opposite happened: in part thanks to text messaging and social media platforms, *more* people than ever before in history are communicating daily through writing.[3]

Having reached the third stage of development, our most advanced form of IT now harbours all three functions associated with information. The computer, an appliance which may be described as history's first "metamedium" (Kay and Goldberg 1977; see also Manovich 2013) or "super-medium" (Berry 2011), assumed all the tasks previously scattered through various information technologies. Websites, e-books, video streaming, podcasts, email, instant messaging, etc., serve more or less the same purpose that physical books, letters, radio programs, TV, and cinema played at a given time in history.[4] By allowing us to register, communicate and process information, IT has spurred the emergence of myriads of other technologies (Floridi 2012b).

1.2.3 From prehistory to "hyperhistory"

The evolution of IT has taken humanity from prehistory — a term coined in the middle of the nineteenth century — to history and, more recently, to what Floridi (2012b) calls "hyperhistory". By definition, prehistoric societies lack ITs or, at least, the means

[3]The widespread use of instant messaging apps such as WhatsApp or Telegram despite the ubiquity of alternative forms of real-time audiovisual communications (e.g. Skype or FaceTime) is proof of the resilience of humanity's oldest IT.

[4]The fact that many of the "old" ITs continue to be used (and thrive) alongside more recent ITS is, once again, proof that ITs tend to accumulate, modify, or expand — rather than substitute — the functions of their precursors.

to record information. While there are controversial reports of communities in the Amazon forest which still live prehistorically, it is safe to say that most of the world's population now lives "historically" (2012b, 129). Meaning that their use of IT is limited to recording and transmitting data and that their livelihood continues to depend on industrial technologies. Particularly, those devoted to processing natural resources and generating energy. There are, however, other regions in the world where people now live "hyperhistorically". In these societies, IT took over industrial technologies, becoming the "*necessary* [emphasis added] condition for the maintenance and further development of social welfare, personal well-being, and intellectual flourishing" (2012b, 130). Within these post-industrial "service economies" information and its by-products have become *the* fundamental resource.

By the mid-1970s, the average supermarket in the United States sold close to $9,000$ different products; four decades later, the number has risen to nearly $40,000$ and counting (Levitin 2014). Although contemporary societies are flooded with myriads of new industrial objects, future technological development is (paradoxically) geared to dematerialisation (Kelly 2010). The World's most developed regions are increasingly dependent on assets produced through information-processing such as online businesses, software products & services, property services, communications, insurance and finance, and entertainment (Floridi 2010). Their public sectors (including education, public administration, and health care) and policy-making are increasingly driven by data-analysis, with automatisation playing ever more critical roles in areas such as transportation and energy. All countries in the G7 Group now qualify as hyperhistorical information societies since at least 70% of their GDPs now depend on intangible information-based products (2010, chap. 1). Whereas developing regions still rely heavily on the outputs of human-powered manufacture, agricultural outputs, and fossil fuels.

1.2.4 Big Data

Every new object, idea or person that comes into the world generates data. The more we interact with ITs, the more data we produce. Our data footprint grows bigger every time we visit a website, check our email, post to social media, buy groceries online or at the supermarket, or withdraw money from an ATM. Thanks to data-mining processes, every click and every transaction, every opinion, every "like", comment or (traceable) decision we make generate new information. In 2003, it was estimated that in the period spanning from the invention of writing to the arrival of the electronic digital computer, humans had produced roughly twelve *exabytes* (EB) of data,[5] which is equivalent to a $50,000$ year-long DVD-quality video (Floridi 2010). By the year 2011, the *total* amount of information stored by humanity had grown to approximately 300 EB (Levitin 2014). But as Aiden and Michel (2013) note, no matter how unfathomable these datasets might seem right now, they are merely "the tip of the iceberg" since humanity's data footprint doubles each year. In 2013, the world's annual output of data was close to one terabyte (TB) *per capita* (2013),[6] and by the end of 2015, the total amount of information produced was estimated at 8 *zettabytes* (ZB),[7] and it is now expected to grow up to 35 ZB by 2020 (Floridi 2015b). "Big Data" is getting exponentially bigger. The data "exaflood" has grown into a "zettaflod" (Floridi 2010).[8]

Information overload, however, is by no means a new phenomenon. As journalist Clive Thompson (2013) notes, the arrival of every new information technology has given rise to a cycle of (a) data overproduction, (b) anxiety about how to manage the surplus, and (c) subsequent development of novel ways to process and index them.[9] From an epistemological standpoint, Big Data holds enormous possibilities and, to borrow the words of physicist Adam Frank (2013), it can very well constitute "the steam engine of our times". Just as Sadi Carnot's[10] modest attempt to understand steam engines and calculate their efficiency led to a new branch of science[11] that revolutionised our understanding of physical, biological, economic and informational phenomena, Big Data holds a similar promise for this century. By enabling humans to find new patterns and relationships amongst seemingly disparate phenomena and to develop previously unimaginable models, Big Data and information technology are transforming our *entire* epistemological edifice. That is, how much we know, how much we can know, and how we communicate and take advantage of this knowledge. Due to the profound implications of these changes, Floridi (2010, 2014) refers to this ongoing pro-

[5]One exabyte corresponds to 10^{18} bytes or one million terabytes.

[6]To put the number in perspective, if one was to write by hand in a straight line all the $0s$ and $1s$ potentially contained in one terabyte, the line would "extend to Saturn and back *twenty-five times* [emphasis added]" (Aiden and Michel 2013, Chapter 1).

[7]A zettabyte is equivalent to 10^{21} bytes or $1,000$ exabytes.

[8]Admittedly, as Floridi (2015b) points out, a considerable amount of this data is meaningless or worthless, but most of it is also potentially valuable.

[9]A particularly interesting example is *florilegia*; systematic collections or "clippings" of passages that offered scholars in the Middle Ages abridged and commented versions of books, and which Thompson (2013) compares to contemporary review blogs.

[10](1796–1832) French military engineer and precursor of the field of thermodynamics.

[11]More on the influence of thermodynamics (and its Second Law) over our understanding of complex systems in Section 6.8

cess as the "Fourth Information Revolution" in human self-understanding.

1.3 An epistemic upheaval

Over the last decades, a deluge of new gadgets and services has entered our world, enabling us to do things that previous generations might have considered as belonging to the realm of science fiction. The speed to which we have gotten used to instant messaging, long-distance video calls, online banking and shopping, GPS navigation, artificial personal assistants, etc., is a testament to the success of computers as a technology.[12] In regions of the world with ubiquitous Internet access, people spend a considerable amount of time-consuming, producing and exchanging data in all its currently possible forms. Either for work, leisure or communication, increasingly more aspects of our lives are mediated by ITs. Unsurprisingly, for many of those people (and particularly for the awkwardly called "millennials"), the distinction between being online and offline is anachronistic and irrelevant (Floridi 2011b). With unfathomable amounts of freely and permanently available information, specialised learning is no longer a prerogative of (institutional) formal education. ITs are shifting the epistemological boundaries of established disciplines, redefining curricula, areas of specialisation, methodologies, and knowledge itself. This shift has profound implications for our understanding of the world: ITs are not only redefining knowledge, commerce, education, work, politics, entertainment, privacy, and security but also *reality* itself.

ITs are not only transforming the world around us; they are transforming *us*. The Fourth Revolution is also leading to radical changes in human self-understanding, as Floridi (2010) notes, major scientific revolutions are so because they shift both our "extrinsic" and "intrinsic" outlooks. By changing how we conceive and interact with the world, they are also affecting the way we "present ourselves to ourselves" (Floridi 2009b). According to Floridi, over the last six centuries, three scientific revolutions[13] have had this mirror-like effect (2010). The first one came with Copernicus,[14] whose heliocentric model replaced both "the Earth and hence humanity from the centre of the

[12]Usually, the most successful technologies are those that become "invisible" and are thus rarely thought of as artificial — e.g., cooking, clothing, writing.

[13]Certainly many other scientific revolutions have had a profound impact on human societies, what sets apart these three is the reflective way in which they have changed our world.

[14]1473–1544

universe" (2010, Chapter 1). The next one came after Darwin[15] published *On the Origin of Species*, which placed humans back into the animal kingdom. Finally, after Freud,[16] humans had to accept that we cannot think of ourselves as entirely rational beings, nor that our minds are entirely transparent to ourselves, as Descartes had argued.

1.3.1 "Inforgs" and the "infosphere"

The way ITs are altering human self-understanding is (for the time being) considerably more inconspicuous and mundane, but no less profound, than transhumanist speculations (e.g. Kurzweil 2005; More and Vita-More 2013) suggest. Thanks to ITs, we are rapidly assuming the role of "interconnected informational organisms" or "inforgs" sharing an *infosphere* — the global environment of organised information — with a growing number of "informational agents" such as companies, organisations, and smart software (Floridi 2007, 2010, chaps. 1–2, 2014, chap. 4). This infosphere, however, is not a product of computational technology but of the information age itself. It harbours *all* informational assets, "spaces of information" (online and offline, analogue and digital), processes, agents and entities — organic or not—, along with their properties and mutual relations (2010).

The infosphere is the complex system of information that kicked off with the invention of writing, and which has expanded exponentially over the last four decades. As an environment, the infosphere is comparable to, but yet different from *cyberspace*[17] which is only one of its subregions (Floridi 2014). Whereas inforgs are not the creatures portrayed by certain futuristic accounts[18] — e.g.cyborgs with implanted hardware or genetically engineered beings — but regular human agents who learn to navigate and take advantage of the informational nature of their surroundings. By expanding the infosphere, ITs are leading us towards an informational paradigm that is radically different from the Newtonian (material) scheme of the world. As Floridi (2010) suggests, an effective way to understand why this is such a transformative process begins by

[15] 1809–1883

[16] 1856–1939

[17] Sci-fi writer William Gibson coined the term "cyberspace". In a recent talk at the New York Public Library see (Cox 2013), Gibson explained that he needed a name to call the "arena" or "territory" in which the characters in his 1984 novel, *Neuromancer*, would move. After coming up with other alternatives such as "dataspace" or "infospace", he settled for "cyberspace" in part because, although it appeared to be quite meaningful, in fact, it meant "absolutely nothing" back in those days.

[18] Certainly, recent developments such as CRISPR, a technique for "changing the DNA of nearly any organism — including humans" (Ledford 2015), stimulate our imagination, but technical and ethical constraints still limit the large-scale use of these technologies.

distinguishing between augmenting and enhancing technologies.

1.3.2 Augmenting vs enhancing

Enhancing technologies work in the cybernetic sense of bio-mechanical "extension and control"[19] (Dupuy 2009), they include devices such as spectacles, pacemakers, prosthetics and hearing aids. Whereas *augmenting* appliances work mostly as *interfaces* that enable agents to interact with "different possible worlds" (Floridi 2010); good examples would be the Mars Rovers, deep diving submarines, or the recently released "ARKit" and ARCore systems by Apple and Google, respectively.[20] Computational technology "augments" by actually "engineering" environments (2010) and allowing human agents to access and interact with them and with other agents within them; the most notorious example being video games and cyberspace. Now, for the last couple of decades, more and more aspects of our daily life (e.g., social interactions, business transactions, education, healthcare, etc.) are happening "online" hence requiring the mediation of ITs. Our habitat is being "absorbed" and re-engineered by ITs to fit into the infosphere. Because we are spending more time online than offline, Floridi (2010) argues this process qualifies as a kind of "migration" — perhaps comparable to those accompanying the agricultural and industrial revolutions. This time, however, instead of transforming hunter-gatherers into farmers, scattered clans into villages and cities, and artisans into industrial workers, ITs are turning humans into citizens of an informational environment populated by both organic and artificial agents. This kind of engineering is indeed unprecedented, and it is revolutionising our metaphysics — i.e. our conception of the ultimate nature of reality.

1.3.3 Metaphysical implications

For ancient Greek philosophers — and for Plato in particular, "reality" was that which remained unchanged.[21] Eventually, more or less after David Hume,[22] reality came to be understood as that which could be measured. Centuries later, reality became

[19] Media theorists in general and Marshall McLuhan ([1964] 1994) in particular usually characterise technologies as "extensions" of human capacities; this idea can be traced back to early philosophers of technology such as Ernst Kapp (see Section 2.4).

[20] Both are software framework for developing augmented reality (AR) products on each platform.

[21] Plato's distinction between *epistêmê* and *technê* (which will be discussed in Section 2.3) is heavily influenced by this ontological commitment.

[22] 1711–1776

that which could be experienced. Nowadays, for something to exist it does not need to be eternal and immutable or even empirically perceivable.[23] To borrow Floridi's words, "[t]o be is to be interactable, even if the interaction is only indirect" (2010, chap. 1). To illustrate this idea, we can think of the way we treat our digital possessions: even though we cannot touch nor see the contents of our digital storage units, we behave as though we could. Our language is filled with metaphors that allow us to treat digital objects as if they were concrete (we reify them[24]) we upload and download, share, save, copy and erase audio, images, text, etc.[25] What is more, our physical reality (our objects and institutions) are being progressively *enveloped*[26] to accommodate ITs and "a-live" (artificially alive) agents (2013b). Concepts such as property, ownership, privacy, security, and even theft are slowly (and sometimes painfully) adapting to the new metaphysical framework imposed by ITs.

For many of us (and particularly for those who remember life without the Internet), reality continues to be mostly "Newtonian", that is, "made of 'dead' cars, buildings, furniture, clothes, which are non-interactive, irresponsive, and incapable of communicating, learning or memorizing" (Floridi 2010). But within advanced information societies, this framework is steadily shifting. Many objects are now becoming artificially alive or "a-live" (Floridi 2007) and autonomous, as geo-fencing, haptics, smart wearables and the so-called "Internet of Things" (IoT) continues to develop.

A growing number of our daily online interactions are happening not only with other humans but also with "non-human informational agents" (2010) such as companies, organisations and public institutions personified by relatively autonomous software. Contravening the modern wisdom that treats animism as superstition, ITs is populating our world with a-live agents.[27] Which means that talking to, and not only through objects (such as phones) is no longer regarded as madness or even eccentricity. Thanks to this shift, we are transforming our self-image; we are now dealing with objects that, despite lacking human intelligence, have become "smart" enough to predict our

[23]A useful example is provided by particle physics, which has taught us to concede the existence of subatomic particles even when we are unable to perceive them. So long as we can handle, record and modify our interactions with a subatomic particle this entity exists.

[24]Reification is a phenomenon first described by Hungarian literary theorist György Lukács (1885–1971). In a general sense, reification "consists in fragmenting and isolating social objects as though they were self-subsistent things, like things of nature, related only externally, causally" (Feenberg 2016, 294).

[25]Although these are "virtual" activities, they have concrete repercussions in our physical world; e.g., in many countries, unauthorised file-sharing can land people in jail.

[26]According to Floridi (2013b, 134), "in robotics, an envelope (also known as reach envelope) is the three-dimensional space that defines the boundaries that the robot can reach."

[27]Raging from bots to every conceivable appliance that can be integrated the IoT.

wishes, our trajectories, and our habits.

Such paradoxical return to a kind of pre-modern metaphysics is but one example of how ITs are "re-ontologising" (2007, 2010) our environment. Since the abstract world of cyberspace and artificially alive agents is increasingly overlapped with the physical world of organic agents, reality is now better described as an informational — as opposed to a material — construct. This shift, however, should not be understood as a transition towards a dystopian, Matrix-like substitution of "real life" by a virtual construct. Instead, it should be understood as a *merging* between our physical and informational dimensions (2010, chap. 1). Accompanying this transformation is also the potential future development of artificial intelligence (henceforth AI) (Floridi 2015a), a circumstance which, by itself, would imply a further re-evaluation of what it means to be human, as it would be comparable to encountering sentient alien life. In summary, the information revolution is not merely a process of human extension, but of radical epistemic and ontological reformulation (Floridi 2008b). Understandably, the most visible manifestations of these shifts are to be found in social and cultural dynamics.

1.3.4 A "third culture"

The massive adoption of computational technology has given way to radical cultural shifts. Technology is swelling language with new idioms and concepts; it is fostering new practices, behaviours, codes of conduct, and values. As Kevin Kelly[28] (1998) notes, since the last two decades of the twentieth-century technology became too strong to be ignored; so much so that being a "nerd" became fashionable and mainstream. Figures such as Steve Jobs, Bill Gates, Richard Stallman, Linus Torvalds, Elon Musk and the like have become cultural icons. "Nerdism" (Kelly 1998) became a (extremely profitable) kind of global movement for the Nintendo generation and for those who embrace "tech" as their culture. Nerdism, according to Kelly, is "a pop culture based in technology, for technology", it is an "offspring of science", but it is simultaneously different from it. Nerdism stands as a *third culture*[29] halfway in-between the "two cultures" of science and the humanities — which C. P. Snow ([1959] 2012) portrayed as irreconcilable. Above all, this third culture is *pragmatic*; it wants neither to discover and explain the world's phenomena (like science) nor to express and understand the human con-

[28](b. 1952) Author and one of the founders of Wired magazine.

[29]Kelly (1998) concedes that it was C.P. Snow who prefigured the idea of an emergent "third culture" in the more conciliatory (revised) version of his famous Rede Lecture (see Snow [1963] 2012).

dition (like the humanities). What the members of this culture seek is to construct new ways to experience the world through technology. This third culture is a visible symptom of the radical cultural and epistemological realignments caused by the latest evolution of IT.

1.3.5 The epistemological shift: technology over science

Computational technology is changing science, the way we conceive it, and its cultural role. As Kelly (1998) suggests, regarding direct cultural influence, science has always been somewhat of an outsider. For millennia the cultural hub of Western civilisation were the humanities. As a comparatively young institution, science only began to gain large-scale influence over society in the nineteenth century. This influence reached its zenith in the Postwar period, but it would only start to be challenged at the turn of the century. Science was historically portrayed as a theory-driven enterprise that made technological progress possible. Science was described as the architect while technology was seen merely as the practical implementation of its discoveries. As IT and computers in particular began to acquire a more prominent place in society, technology began to "seize control of culture" — to paraphrase Kelly. The profoundly technological nature of science and human knowledge in general slowly began to emerge.

Oversimplifying, the (idealised) goal of science is to uncover the hidden truths of the universe through controlled, reproducible experiments, careful evaluation of data, and accumulation of evidence. To the eyes of those in the third culture, this is a bureaucratic and sluggish — even conservative — process. Nerdism is a culture of action and innovation, not of lasting explanation or transcendental understanding. It always frames and engages problems, even the most complex ones, in technological terms. The third culture creates practical solutions, not theoretical frameworks. It develops working but always perfectible models, not long-lasting paradigms. As Kelly (1998) notes, the third culture creates technologies faster than any scientist can develop theories — some of these technologies are thus solutions *waiting* for a problem. Let loose in the wild these artefacts trigger new cultural phenomena (both positive and negative) faster than any theoretical model is capable of explaining. To quote Kelly "technology generates opportunities: new things to explain; new ways of expression; new media of communications; and, if we are honest, new forms of destruction" (1998). Nerdism is the globalised culture of a maker's era.

The hacker (in the broadest sense of the word) is the quintessential expression of the third culture. She knows her way around math, the language of science; she is versed in materials and processes, the backbone of engineering; but she has no qualms about trading rational proofs for new experiences. She cares more for gaming, apps, coding, gadgets, digital fabrication, good food, social justice, and lifehacking than she does for "ivory tower" scientific research.[30] In her world, for her culture, "[t]echnology is simply more relevant than footnotes" (1998).

With the computer as a driving force, the third culture is blurring the lines between art, craft, design, engineering, and science, thus wreaking havoc among traditional disciplines and fields by rendering parcelled theoretical frameworks anachronistic. If curious about how the mind works or how living organisms develop, nerds do not resort to established conceptual models, but instead *construct* simulations — i.e., "dynamical representations of systems" (Floridi 2011a, 67).[31] For nerds, to learn and to research are synonymous with designing and constructing; their culture is one of *makers*, not of users.[32] The third culture engages problems through a "permanent beta" approach; it sees experiences as something that can always be enhanced or upgraded. The third culture sees the world not as something that is discovered, but as something that is constructed and experienced in novel ways. In this sense, the third culture resembles the attitude of the artistic Avant-garde.

1.4 Computational technology and art

Computational technology has been used for artistic purposes for over half a century.[33] Between 1962 and 1964, two German mathematicians (Frieder Nake and Georg Nees), and an American engineer (Michael Noll) took advantage of the access they had to early computers at their day jobs and began to experiment with algorithmically generated drawings. They are now considered pioneers of "algorithmic art" or "com-

[30] Certainly this rough caricature cannot account for all the concerns of technoculture; many issues have also become important for the members of the third culture, questions about class, race, gender, privacy, security, environment, etc. How the fourth revolution is reshaping these discussions is indeed a fundamental problem for our contemporary society, but they are not the immediate problem of this dissertation.

[31] For a full discussion concerning simulations see Chapter 5.

[32] See Chapters two & three.

[33] Although the first recorded case of a computer being used to represent a human likeness was in 1956 (see Chapter 5), whether this constitutes art is open for debate.

puter art" (Nake 2012a).[34] Nonetheless, in the context of art, computers would remain marginal tools for more than a couple of decades, mostly because they were not available outside specific sectors (such as finance, industry, education, military, and government) and they were difficult to operate (programming was a cumbersome process). In the 1980s and 1990s, the availability of cheaper PCs, Graphic User Interfaces (GUIs) and, more important, software for manipulating audio and images, made computers significantly more accessible and enabled a new generation of artists to experiment with them.[35] After 1995, the consolidation of the Internet and subsequent information technologies — such as mobile communications — led art through the same path of profound epistemic transformation that other regions of human activity were already experiencing. And in the process, it launched art scholarship into a complex process of redefinition.

Art scholarship may be seen as an ontology-laden discipline since its central task is to find adequate means to characterise and classify artworks: i.e., to approach them, interpret, and situate them within a network of artistic knowledge. For several decades, the central guiding principle behind this effort was the traditional system of fine arts, which emerged in the eighteenth century and led to the strict scholarly separation between different forms of representation according to the materials, techniques, and tools employed. In other words, it formalised what we now describe as the artistic *medium*. The system was based in the historical crafts that existed since antiquity and which further specialised throughout the Renaissance.

It was only with the rise of the historical Avant-garde at the turn of the twentieth century that the pertinence of the fine arts system began to be called into question. Specifically, the strict separation between techniques and materials and the criteria for establishing which type of artefacts counted as artworks and what kind of topics constituted acceptable artistic motifs. This critical process would define much of twentieth-century art and — following the incorporation of ITs as artistic tools — culminate in the outright reformulation of the concept of medium and its role within artistic expression.

Historically, art scholarship has always dealt with physical objects. Admittedly, it has also dealt with the sensory experiences artistic objects summon in the audience, with the "discourse" they convey, with their history and mutual relations, and with the social and cultural practices that originated them. Even throughout the so-called "lin-

[34]For a full account of early computer art and its pioneers see Section 5.2.

[35]See Section 5.3.

guistic turn" and the rise of conceptualism, where art came to be regarded more as an intellectual exercise rather than a technical practice, physical objects remained at the centre of art. The object was a symbol whose physical presence triggered a conceptual experience. And, while mediums could be combined to create novel aesthetic effects, most mediums remained constrained by the intrinsic limitations of their materials. More than actual mixing there was juxtaposition. But this all changed with the emergence of computational technology and what Manovich (2002, 2013) refers to as "media software".

Computers are capable of simulating most physical mediums, but also their techniques and tools, allowing anyone to freely mix them and give life to unprecedented forms of audiovisual artefacts. This "deep remixability" (2013), along with the (apparent) lack of materiality of computer-generated artefacts, is deeply troubling for art scholarship. To understand why we first need to make a digression and look at the origins of the modern concept of medium and why it continues to be such a resilient epistemic compromise for art scholarship.

1.4.1 The medium

Despite its importance for art scholarship, the definition of medium is far from being universally consensual. Initially, the word referred to both the raw materials, and the tools and techniques used to transform them into a work of art. In the second half of the twentieth century, high-brow modernist theorists such as Clement Greenberg ([1940] 1999) recast the medium as the logical conclusion of art's affirmation as an independent human endeavour.[36] The medium came to identify not only a particular set of technical means but to embody the *essence* of the different artistic disciplines.[37] The medium served two dialectically opposed functions; on the one hand, it marked physical and technical limits, on the other hand, it constituted the very material com-

[36] After finding itself liberated from "'Literature's' corrupting influence" (Greenberg [1940] 1999, 557).

[37] Painting provides a good example of these ideas. In line with the system of fine arts, High Modernism believed each medium corresponded to a particular mode of perception and to the way specific materials related to the Newtonian understanding of physical space. Hence, whereas sculpture, painting and photography belonged to the domain of vision, painting was a bi-dimensional imitative form of representation. Therefore, painting had no business in portraying neither tridimensional space nor any figurative image, for such was the job of sculpture and photography, respectively. Since literature, cinema and photography were better equipped to deal with narrative and realistic figurative representation (Bazin 1960), painting was left only with flatness, light, shadow and colour. Following the precepts of late modernism, "abstract expressionism" marked painting's descent into the *reductio ad absurdum* of its self-imposed limitations.

posing a work of art. The medium became the "enabling constraint" that harboured both the limits *and* the possibilities of artistic expression (Doane 2008). Therefore, according to the Modernist narrative, the job of the artist was to relentlessly push the (material or conceptual) boundaries of her medium without fully abandoning it, for it was only within its confines that the artwork could truly exist. In this sense, the medium became the *ontological* precondition and necessity for art's existence.

1.4.2 Medium specificity

If the medium implied extending boundaries without abandoning them to reinvent a particular mode of artistic expression, *medium specificity* meant the recursive adherence to this precept. What started as a method to achieve an end — i.e. to investigate the aesthetic qualities and possibilities of a definite set of materials — soon became an end *in itself* (McNamara and Ross 2007): a means to justify the autonomy, pertinence and realisation of a given art form. Medium specificity required putting technical and conceptual austerity (supposedly) at the service of artistic expression; thus, it involved maintaining the "purity" of a given medium by consciously preventing any alien idea, material or technique from polluting it.[38] For art theorists such as Greenberg, this was the natural way in which artistic disciplines could assert their independence against other human activities, and distinguish art from (utilitarian) disciplines such as design. Greenberg ([1940] 1999) believed every artistic discipline (and painting in particular) should strive to achieve "the condition of music", that is, to exist solely within the confines of its own medium. In this way — the thinking went, art would no longer be the handmaiden of other cultural practices; it would no longer serve representation or narrative, but stand as practice through and for its own merits.

Despite being often portrayed as a characteristically modern notion, medium specificity is a relatively recent invention, and in many ways represented a (conservative) reversal of early Modernist ideals. Since the late 1950s "High Modernism" portrayed the cultivation of medium specificity as the logical step for art's progress. This presumption was very much in line with the postwar *zeitgeist* that understood knowledge, Nature, and every other type of phenomena as things that could be fitted into preexisting categories bearing clear and perdurable boundaries.

Surprisingly enough, this view of modern art as the culmination of a process by which

[38] The thinking behind medium specificity is best summarised by Ad Reinhardt's ([1962] 1999) well-known claim about "art being art" and "everything else" (e.g., "life") being "everything else".

artistic disciplines emancipated and cloistered into their own mediums was also endorsed by postmodern criticism (McNamara and Ross 2007). Such belief in the teleological epistemic stability of modern art is the reason both late modernist and postmodernist accounts portray the emergence of "multimedia" as a "rupture" with modern ideals. But whereas modernist critics lamented the fall of medium specificity, and saw it as contributing to the blurring of the distinction between high and popular culture, postmodernism celebrated all the new possibilities offered by hybridisation. Nonetheless, for some postmodernist strands (particularly for those siding with critical theory) the growing prominence of technology and the apparent process of dematerialisation accompanying it seemed as potential threats to art.

1.4.3 The computer as a "metamedium"

Although frowned upon and ignored by high modernism, "multimedia" existed long before the invention of computers. Pre-computational multimedia involved a combination or juxtaposition of materials and techniques belonging to identifiably distinct mediums — with collage being perhaps the most notorious example. But for the best part of the twentieth century, the interaction between different materials and tools remained constrained by the physical limitations of each medium. Computational technology took the very idea of mixing to an entirely different level.

Although at the most basic level computers are merely capable of accomplishing two tasks: (a) performing calculations and (b) remembering the results (Guttag 2013), they are remarkably flexible tools. The "secret" behind the multi-purpose nature of computers is that both the "raw material" they handle, and the procedures they follow to do so are made of the same "stuff": data or rather, *information*.[39] It is this "permanently extendible" (Manovich 2013) architecture that allows computers not only to *simulate* all the techniques of most mediums but to mix them liberally. Computers are unlike any previous tool. Along with information technologies, they are not (just) mediums but actual *environments* or "ecosystems" (Manovich 2013) where audiovisual languages and techniques are free to coexist, hybridise, and speciate into myriads of new representational forms. Once again, the computer represents not only a new digital medium but rather a "metamedium" (2013) or "supermedium" (Berry 2011).

[39]A full discussion on this topic can be found in Section 4.3.

1.4.4 A technically complex appliance

While having most previously distinct media available within a single environment brings a new set of challenges for art scholarship, hybridisation is not the only problem introduced by computational technology. There are also technical and ontological issues. Figuring out what computational aesthetic objects *are* and what their emergence means for traditional media — i.e., how they are transforming our perception of physical reality — is also pressing questions. Computers are not tools in the conventional sense, nor they are mere audiovisual appliances. They are devices that enable and promote complex crafting and *tinkering*. Thanks to cyberspace and ongoing developments in AR and virtual reality (henceforth VR) technologies, computers allow us to interact with *different possible worlds* (Gualeni 2015).

Artists now have at their disposal means to influence our perception and even our metaphysical frameworks in a way that no pre-computational device could ever do. Many of these functions can be accomplished with fairly accessible software, but many other (presumably more powerful) contraptions require intricate knowledge and skills; the type that, until recently, was regarded by most scholars in the arts and humanities as the exclusive domain of engineering and science. Hence, it stands to reason that if developing complex artworks through computational means calls for certain specialised knowledge, this is also true for interpreting and analysing them from a scholarly standpoint.

1.4.5 Two ways of using a computer

Humans generally employ computers in two major but not necessarily exclusive ways: as users or as makers. This distinction also applies to aesthetic contexts and has significant consequences for how we are to understand the role of computational technology in artistic creation. Approaching the computer as a user involves dealing almost exclusively with ready-made software — which may or may not require specialised skills and knowledge. Design, photography, as well as audio, video, and text editing are some of the areas where the user paradigm is dominant, as there is a considerable amount of specialised consumer software devoted to these purposes. Through automation and predefined functions, the machine carries out much of the work;[40] it offers consistency and ease of use, but it does so in exchange of limiting the user's abil-

[40] It is fair to note, however, that many platforms support advanced usage such as scripting.

ity to alter or modify the functions to better suit her needs. Conversely, approaching the computer as a maker is more akin to the way artists have historically approached their tools.[41] Both materials and tools may be created on demand (provided the artist has the necessary technical skills). Producing art "algorithmically" is like "drawing by brain" (Nake 2012a); similar to writing but substituting human (private) visualisation by machine (objectified) visualisation (Gualeni 2015). Understanding computer-generated artefacts thus requires a new set of practical and theoretical skills and also implies overcoming some of art's inherited views on technology.

1.5 A complicated relationship

As discussed in the previous sections, information technology is shaking the foundations of our epistemological edifices; it is blurring the boundaries between disciplines and altering our metaphysical notions (our understanding of the ultimate nature of reality) and our self-understanding. These inherent complications make Information Technologies a difficult problem *per se*. Nonetheless, richer understanding of the impact of ITs on art is also hindered by art scholarship's traditional distancing from technological analysis. Lack of attention or interest in computational technology within the humanities is a symptom of the widely spread notion that knowledge of the world should be divided between two (sometimes antagonistic) camps: one ruled by the physical sciences and engineering, and the other by the arts and humanities.

The sharp separation between the humanities on one side, and science and engineering on the other, has been marked by controversy and, on some occasions, driven by mutual animosity. This epistemic tension has deep roots in Western philosophy and overlaps with many discussions about how the world should be described. As it stands today, the schism between scientific and "literary" thinking may be traced back to the Renaissance, a period which "initiated an era of specialization" which culminated in the separation of the arts, "natural philosophy", and engineering (Wilson 2002, 5). The Industrial Revolution furthered this gap, as empirical science emancipated from philosophy, and coalesced into a distinct epistemological project that sought to embody the modern ideals of reason, progress, technological development, secularism, and the overall triumph of "man" over Nature.

[41] For example, before the industrial revolution, grinding, mixing, and experimenting with pigments, and preparing surfaces from scratch were inherent activities for painters. Until the widespread adoption of digital photography, photographers had intimate contact with chemicals.

The growth of science's influence over culture and society was not without opposition. Apart from those with religious sentiments, the most vocal critics of science's quest to reduce the world's phenomena to explainable secular causes, but also of large-scale industrialisation and its human and environmental costs were some artists and poets associated with the Romantic movement. Following the steps of Rousseau's criticism of technology and civilisation, these intellectuals argued scientific rationalism and unrestrained technological utilitarianism constituted threats to imagination, individuality, nature, and the liberty of human spirit. Throughout the nineteenth century and well into the twentieth century these and other related ideas, such as the notion that art is the most effective antidote against techno-scientific reductionism, continued to be influential within the humanities. By the middle of the twentieth century, the division between literary and scientific "cultures" became deeply ingrained throughout the academic world. Art scholarship's views on technological development and science and engineering were naturally influenced by critical theory and cultural studies, schools of thought that have dominated the theoretical panorama within artistic discourse for various decades.

1.5.1 The Romantic concerns

The notion that all Romantic intellectuals had an "instinctive, deep-seated antagonism" against science can be traced to the so-called "Immortal Dinner" (Holmes 2008); a gathering hosted on 28 December 1817 by the British painter Benjamin Haydon.[42] Haydon — a "fundamentalist Christian" (2008) and self-professed "genius" (Hughes-Hallett 2012) who regarded science as a "godless" pursuit — had invited William Wordsworth, John Keats, and Charles Lamb to celebrate recent progress on his latest painting, *Christ's triumphant entry into Jerusalem*, which symbolised religion prevailing over science. As the evening progressed, the conversation evolved into a "playful and eventually drunken attack on the reductive effects of science"; with Keats accusing Newton of having "destroyed all the poetry of the rainbow by reducing it to a prism" (Holmes 2008, Chapter 7). This was a complaint that many other important Romantic figures[43] shared, and who saw in Newton the personification of science and the utilitarian mindset that triggered the burgeoning industrialisation and the

[42] 1786–1846

[43] For example, William Blake, who was not present in that occasion but once portrayed Newton as an "enemy of the imagination" and criticised him for his "perfection and rigidity" and for "departing from the particular by abstraction and generalisation" (Gleick 2003, Chapter 15).

ensuing "greying of Eden" (Gleick 2003).

Such a wary and, at times, inimical attitude towards science and technology have its match in the contempt some influential scientists now exhibit towards the humanities.[44] But the arrogance and self-importance that some identify with modern "scientism"[45] (see Mitcham 1994) along with science's privileged status throughout the twentieth century have overshadowed the fact that, in its early development, science was a kind of epistemic underdog. From a social standpoint, and despite the fact that many early scientists were members of accommodated classes,[46] science was regarded with contempt by the classically educated elite. This is not to say that nineteenth century's ruling classes did not comprehend the potential of science; after all, the Industrial Revolution was the ideal showcase for the economic and technological value science could bring when coupled with engineering. The problem was that the notion of a "proper" education remained profoundly influenced by classicism, which privileged literary and humanistic skills over technical skills and scientific knowledge.

For aristocrats, training in the natural sciences — as opposed to training in the humanities — produced at best a practically valuable specialist, but it could not build an "educated man" (Collini 2012). In practice, this meant accommodated people were more likely to quote classical Greek or Latin literature than to discuss topics that nowadays are considered part of elementary scientific literacy. Whether because it meddled with religious dogma, or because its propositions were deemed outrageous by the era's standards, science (particularly its early experiments) often became a source for spectacle and scandal. "Pure" science was regarded more as a hobby for eccentric, and well-to-do men, than as a truly respectable profession for a gentleman. C.P. Snow's ([1959] 2012) criticism of classically trained intellectuals in *The Two Cultures*, the Rede Lecture he offered at the British Royal Society in 1959, was a reaction to such deeply ingrained notions.

[44]One of the most appalling examples is perhaps Stephen Hawking's claim about philosophy being "dead" and unable to "keep up with modern developments in science" (Hawking 2010, chap. 1).

[45]For more information on this term see Section 6.2.

[46]In countries such as the United Kingdom, clergymen — particularly vicars, who had a combination of economic resources, free time, and sophisticated education — are often the best example of this situation (see Bryson 2010).

1.5.2 The "two cultures" divide

C.P. Snow was originally a trained chemist who became a relatively successful novelist. In his previously mentioned lecture, Snow ([1959] 2012) argued the languages and interests of the "literary" (i.e., humanistic) and "scientific" worlds had grown so different as to become two distinct "cultures"; hence, the practitioners of both camps were effectively incapable of communicating with each other. Snow portrayed science as a meritocratic and intrinsically progressive enterprise,[47] whose quest for universal and objective truths evidenced a higher moral ground and an indisputable commitment to better the future of humanity. Whereas he described "literary intellectuals" as "natural Luddites" whom, contrary to scientists, had "never tried, wanted or been able to understand the scientific revolution" ([1959] 2012, 22) and the benefits it brought to humankind. Snow's literary intellectual is a "straw man"; a caricature of the snobbish upper-classes and their (sometimes) scholastic understanding of the world.

Naturally, Snow's portrayal summoned a barrage of vitriolic responses, in particular from literary critic Frank Raymond Leavis (Collini 2012), with whom Snow engaged in an acrimonious debate following the publication of *The Two Cultures*. The discussion ended up being something of a head-butting contest between two highly respected but utterly arrogant intellectuals. Both Snow and Leavis were irremediably biased against each other's world views; hence, they were equally incapable of realising that their discussion was more about personal opinions and experiences than about the "true" nature of the intellectual domains they purportedly defended. Over the following decades, other figures joined the discussion, and the "two cultures" dichotomy continued to influence our understanding of the relationship between the humanities and science.

However controversial and reductive Snow's ideas might seem, they should be read in context. First of all, as Collini (2012) suggests, we should not forget Snow's arguments and characterisations were initially conceived for a speech; that is, an occasion where dramatic effects and simplification tend to trump clear thinking and careful argumentation. Moreover, the talk was mostly a discussion about the state of education in post-war Britain, a country that, unlike the United States, had not begun to invest as heavily on ambitious STEM (Science, Technology, Engineering and Mathematics) education programs. Furthermore, Snow imagined himself surrounded by a scientifi-

[47] As a kind of antidote against traditional British class division and promotion of social privilege, provided that, despite their family history, anyone sufficiently smart and hard-working could become a successful scientist (Collini 2012).

cally illiterate population whose children continued to be educated following calcified curricula that privileged ancient literature over science and engineering; skills which he considered fundamental for the modernisation of his nation. His worldview was profoundly shaped by his own experience growing up in a middle-class family and gradually climbing up the social scale thanks to his scientific training. Finally, it is fair to say that Snow's criticism is not directed against the humanities as a whole — he was, after all, a writer — but against British class privilege and its intellectual dogmas, which the literary critic embodied like none other.

Although trained as a scientist, Snow held the humanities in very high regard. In the second (revised) edition of his lecture, titled *The Two Cultures: A Second Look* ([1963] 2012), he adopted a far more conciliatory position. Amongst other things, Snow admitted the border separating science from the humanities was neither as clear-cut nor irreversible as he had previously made it seem. Moreover, he suggested that in various countries (including his own) a middle-ground, scientifically literate and humanistic "third culture" was already developing. But despite the clarification and nuance, Snow remained steadfast on his criticism of the vincible ignorance that some intellectuals within the humanities had about scientific and technological developments. To Snow's credit, he was not alone in making such complaints. In the first two decades of the twenty-first century, a growing number of scholars (Mateas 2005; Wilson 2002) have also criticised the humanities' voluntary lack of scientific and technological literacy.

1.5.3 Two conceptual systems

The debate Snow sparked is but a relatively recent episode in a broader and older tension in Western cultural history concerning our understanding of the ultimate natures of reality, the world, and the human condition. This debate overlaps with problems such as the eighteenth-century discussions between "Continental" Rationalism and British Empiricism and, more recently, the so-called "Science Wars" (Ihde 2009a) of the last decade of the twentieth century. Snow's two "cultures" correspond to the two conceptual systems or "system operations" — to borrow the words of video game philosopher Ian Bogost (2012) — that have more or less dominated twentieth-century Western epistemological discussions, namely: "social relativism" and "scientific naturalism". Oversimplifying, social relativism believes "everything in the world can be explained through the machinations of human society — particularly, the complex, evolutionary forms of culture and language" (2012, Chapter 1); whereas scientific naturalism conceives reality as existing independently of human life. In Bogost's words, while scientific naturalism defends "the Enlightenment ideal of true knowledge independent of history or context", cultural relativism stands "wagging its finger at the dangers of singular explanations that ignore the contingencies of those histories and contexts" (2012, Chapter 1).

Scientists generally regard Nature as something that is progressively *discovered* and whose inner workings may be decoded and translated into universal and atemporal laws. It follows they usually present science as the only method truly capable of revealing the truths of the universe. Conversely, social relativism conceives reality as something that is *constructed* or at least irremediably shaped by humans. Because it privileges culture above everything else, it regards science as yet another form of "narrative". Hence, social relativists argue that historical and social constraints determine scientific knowledge and that scientific claims and theories bear the biases of the people that formulate them. In other words, for social relativism, scientific "discourse" is but one amongst many other equally valid explanations of worldly phenomena. Therefore, for the social relativist, believing that science holds any privileged access to Nature's truths amounts to a "Modernist delusion" (Wilson 2002). Understandably, this and similar characterisation have been met with strong opposition from the so-called scientific community (e.g., see Pinker 2003).

The strict categorical separation between science and technology on one side and the humanities on the other side is as distinctively modern, just as the concept of the medium discussed in previous sections. But for many artists and art scholars, philosophical debates concerning the boundaries between science and the humanities carry little if no interest at all, so long as they don't interfere directly with their practice. Nonetheless, these Byzantine discussions do have strong epistemic and bureaucratic consequences for art, at both scholarly and practical levels. As previously noted art's understanding of science and technology has been heavily informed by the dominant theoretical viewpoints of the humanities and by romanticism. When not directly criticised, these subjects have been historically treated as foreign and exclusive to science.

The two cultures debate has directly and indirectly informed art scholarship's understanding of science and technology and their relationship with the humanities, as well as its ideas concerning the role that either of them should play in contemporary education (and in society at large). The problem is that if art scholars are trying to address the phenomena and consequences of an eminently techno-scientific device (i.e.the computer) they should strive to gain a deeper insight into its nature. This knowledge, of course, implies understanding what scientists and engineers have to say about it. Art scholars do not need to be mathematicians, programmers nor hardcore scientists to understand or appreciate the potential of computers as a new form of expressive medium; but to do so, they require a baseline technical understanding of this technology. More so when assuming a more engaged epistemic position towards computational technology is crucial for every area of human activity, since it constitutes *the* defining aspect of our present and future economy, our culture, and our knowledge of the world.

1.6 Conclusions

While art scholarship's limited understanding of computational technology may be attributed to the weight of the two cultures epistemological paradigm, the inherent complexities brought by the information revolution are also to blame. The humanities have been historically wary of scientific discourse and regard technology as its (potentially dangerous) embodiment. However, information technology is indeed transforming our metaphysical assumptions in radical ways. These two circumstances, as we have seen, are profoundly altering how we *think*, how we know the world and the way we portray ourselves within it. Furthermore, it means the old boundaries between entire areas of knowledge are being redefined. Even though the information revolution is a technological process affecting the practical aspects of our life, it is also bringing profoundly epistemological change.

Computational technology is here to stay. Computers are not just specialised tools but have become a crucial aspect of (popular) culture. A growing number of contemporary artists are what Kelly would describe as "nerds", and a significative part of their artworks involve technically complex usage of IT. Truly (critically) understanding this new form of art requires at least a baseline technical knowledge. The problem is that while information technology is transforming our reality, our theoretical models continue to be heavily influenced by pre-computational metaphysics. Thus, understanding the impact of computational technology on art requires not only computational literacy (as the software studies school advocates) but also a profound change of our ontological and epistemological frameworks. To tackle this problem, this dissertation proposes delving into the history of how technology *itself* became an object of analysis, and how different interpretations (some of them rooted in ancient philosophical problems) have influenced art scholarship's contemporary views on the subject. Such will be the subject of the following chapter.

Chapter 2

Understanding technology

Summary

In many current analyses, art scholars refer to technology in monolithic and vague terms. Following the insights of contemporary philosophy of technology, this chapter traces back the origins of this concept and provides a general overview of its past and current understandings. It shows technology is a fundamental component of what it means to be human and why understanding how we relate to sociotechnical systems is crucial for understanding how we regard the world at large. It contends technology should not be understood in monolithic terms, but as a network of systems. Above all, this chapter shows computational technology is the quintessential expression of information technology (IT), making the case that it is best understood by focusing on its common denominator, namely, information.

2.1 Introduction

From clothing to cooking, from communication to transportation, and from work to leisure, virtually every human activity involves or is facilitated by some form of sociotechnical system. And yet, we take most of our technological interactions for granted; we *naturalise* our tools and hence fail to recognise their influence over our lives and our conception of the world.[1] Nowadays, the word technology tends to be associated with computational artefacts and with the "tech industry", even though a myriad other artefacts in our lives — some of which have existed for millennia — are by no means computational. While in everyday language this synecdoche is innocuous, in a scholarly context it obscures the history, complexity and multiplicity of technological *systems*. Moreover, as a rule, art scholars tend to avoid any discussion or clarification regarding what they understand by "technology" and justifiably so, since — as we will see — in asking what this concept stands for one cannot expect a straightforward answer. It is not that the word is meaningless but that it refers to numerous things across many areas of human activity.

Odd as it may seem, technology was only recognised as a phenomenon worthy of philosophical analysis in the nineteenth century. As we will see in the following sections, the role technological systems have played in human development, as well as their influence over culture and society, were largely disregarded by ancient Greek philosophers and throughout the Enlightenment. Except for some Romantic intellectuals, who critically engaged the profound shifts triggered by science and technology, it was only after the Industrial Revolution that technology awoke the interest of scholars. And it was only after two world wars and a revolution in digital communications that philosophy of technology was fully established. Early or "classical" philosophy of technology began to emerge in the second half of the nineteenth century, but it was only in the early twentieth century that it began to distinguish itself as a subject. Classical philosophy of technology was concerned with the history and "essence" of Technology (with a capital *T*), treating it as a monolithic problem. Whereas contemporary accounts have taken a more pragmatic and less speculative turn, following a "bottom-up approach" that deals not necessarily with technological systems, but with the way they affect specific cultural practices and their contexts.

[1] The oldest and most powerful technologies are precisely those which are rarely described as technologies (e.g.cooking, clothing, and writing) because they have become "second nature" (Thompson 2013). This phenomenon is what philosopher Don Ihde (2009a) calls a "transparency" relation with technological artefacts.

Mainly based on a philosophical approach, this chapter traces the origins of the historical disregard for technology as a major factor of cultural change, both in the humanities and the "hard sciences". It shows that understanding how technology influences human development is a crucial step for comprehending how ITs and computational technology, in particular, are affecting contemporary societies and culture — and hence aesthetic practices. The chapter is divided into five sections. Section 2.2 traces the origins of the very notion of technology and its relationship with science. Section 2.3 contrasts the two philosophical traditions that have shaped our understanding of knowledge and our "attitude" towards technology. Section 2.4 describes the differences between the "humanities" and "engineering" conceptions of technology. Section 2.5 compares "classical" and contemporary philosophies of technology. Finally, Section 2.6 summarises the more recent definitions of technology as systems before establishing the distinction between computational and information technology. This chapter thus provides a broader understanding of technological systems than the ones usually offered in the context of art scholarship or media studies.

2.2 Tracing the origins of technology

Technology is as old as humans, and it permeates every aspect of our lives. While some primates and other animals fashion and use tools, the ability to manipulate and consciously transform our natural surroundings and our selves through technological means is a distinctively human trait. First through our opposable thumbs and, eventually, through more sophisticated (and indirect) means we have *crafted* our way to the top of the food chain. From hand axes to farming, human-made artefacts and techniques increased the biological success of our species ushering us into increasingly complex social dynamics. Throughout our history, every significant technological development has been accompanied by radical cultural and socio-economical transformations. The changes that ensued the invention of writing systems, the windmill, the printing press, the loom, and steam engine, and — more recently — the computer, are all testaments of this fact. It is therefore surprising that until the nineteenth-century technology had been absent from intellectual enquiries, not only as a subject but even as a *concept*.

A quick search in Google's *Ngram Viewer*[2] shows that before the 1920s the word "tech-

[2]A tool that allows users to visualise and compare in a graph the historical occurrence of any given

nology" appeared only scantly in writing.[3] This corroborates Kevin Kelly's (2010) observation that before 1939 the concept of "technology" was a stranger to colloquial language. Even Vannevar Bush,[4] in his highly influential article *As we may think* (1945),[5] speaks not of technology but of "techniques". It was not until the 1950s that the word "technology" as such began to appear in everyday discourse (Kelly 2010) — the *Ngram* graph shows a sharp spike around this time. Though the exact reason behind this surge is difficult to pinpoint, one may speculate that it had to do with the emergence of commercial electronic digital computers and the beginning of the Space Race. This parallelism might also explain why technology is regularly used as a synecdoche for electronic and computational devices, irrespectively of the fact that not all technologies are computational. Whatever the explanation, the question is why for most of our time on this planet our tools and techniques lacked a collective name and, consequently, recognition of their socio-cultural impact.

2.2.1 A brief history of the concept and its usage

Despite having a distinctively Greek origin, the word "technology" is a fairly recent invention. By most accounts, Aristotle was the only classical philosopher to speak of *technológos*; but he did it sparsely[6] and with a significantly different meaning than today's. Being a combination of *technê* — which might be translated as "craftiness" or "ingenuity" (Kelly 2010) — and *logos* ("speech" or "discourse"), "technology" for Aristotle meant something close to the the act of "studying" (Lee 2009, 17), the "knowledge" of, or the "art" of rhetoric. The person responsible for giving technology its contemporary meaning was Johann Beckmann,[7] a German professor of economics who lived in the midst of the Industrial Revolution. Beckmann noticed the growing number of tools and techniques around him were less "a collection of random inventions and good ideas" (Kelly 2010), than elements within a complex web of knowledge and practical skills spanning hundreds of years. Being a teacher, Beckmann became convinced

search term within the Google Books database.

[3]The graph can be accessed here.

[4](1890–1974) Bush was a key figure in twentieth-century science. As the head of the (American) Office of Scientific Research and Development (OSRD), Bush was in part responsible for the organisation of the Manhattan Project.

[5]In this article, Bush speculates on various potential future inventions. One in particular, which he called the "Memex", was very influential (at least conceptually) for the development of the Internet and computational devices (see Section 5.2).

[6]According to Kevin Kelly (2010), the word is absent from all other known classical treatises, and Aristotle mentions it in his *Rhetoric* no more than four times.

[7]1739–1811

that technical trades should be taught in a structured and systematic manner. Around 1802, he compiled a "unified curriculum" which included everything from chemistry to architecture and published it as a textbook under the title *Anleitung zur Technologie*, or "Guide to technology" (2010). This was the first time the word *technology* appeared in writing with its contemporary meaning. However, both Beckmann's realisation that technologies represent a complex system and the term he coined remained obscure for close to a century and a half, with most subsequent thinkers opting to speak instead of "techniques", or even "technics."[8]

2.2.2 Thinking about technology, a summary

With the notable exception of Francis Bacon's recognition of the value and role of practical knowledge, philosophical (and otherwise) interest on technology only began to emerge in the nineteenth century. For the majority of thinkers[9] living throughout the Scientific Revolution and the Enlightenment, technological development merely represented the (beneficial) outcome or application of systematic and progressive thinking. In the latter part of the nineteenth century, Karl Marx was amongst the first intellectuals to recognise technical means (of production) as a crucial component for historical, socio-economical and political change, but it was his compatriot, Ernst Kapp,[10] who recognised the need to philosophise *about* technology (Dusek 2009; Mitcham 1994). Later on, philosophers such as John Dewey[11] and Martin Heidegger[12] would set the tone for twentieth and twenty-first-century discussions and criticism of technology. The exact reasons why previous thinkers failed to acknowledge the crucial role technology plays for human development are varied; nonetheless, an important factor is

[8] Even Martin Heidegger did not use the word "technology" rather, he used the more ambiguous German word *technik* which, depending on the circumstances, could mean "technique", technics, or technology (Geoghegan 2013).

[9] Jean-Jacques Rousseau (1712–1778) being perhaps the only notable critic of modern progress as an intrinsically good process. As was discussed in the previous Chapter, Rousseau's ideas were highly influential for the later Romantic portrayal of science and industrialisation as threats to the imagination, individuality, and Nature.

[10] (1808–1896) Kapp is credited with being the first thinker to speak of "philosophy of technology", yet it is fair to mention that, like most of his contemporaries, he did not use the word "technology" but rather the already mentioned German term *technik*.

[11] (1859–1952) Philosopher and educator associated with American pragmatism. His reflections on technology date to the late nineteenth century, thus preceding Heidegger's work for various decades. Unlike his European counterparts, Dewey did not regard technology as intrinsically alien to human life (Pihlström 2011).

[12] (1889–1977) Disciple of Husserl, and a key figure in the development of philosophy of technology. His association with the Nazi party often overshadows his contributions.

the way *knowledge* was understood and categorised by Western philosophy since ancient Greece times and up to the early twentieth century.

2.2.3 A note on science and technology

In modern times, science, or at least a particular understanding of science is arguably to blame for our failure to recognise the epistemic role of technology. According to the "Eurocentric" (Ihde 2009b) narrative, what we now call "science" began to emerge in the sixteenth century with the publication of Copernicus' *On the revolutions of the heavenly spheres*. And yet, science only became the modern autonomous institution we now recognise in the early nineteenth century, when it became clear that it constituted more than the "natural" branch of philosophy.[13] Since its beginnings, institutional science established a close relationship with engineering which undoubtedly furthered technological development. Nowadays the relation between science and technology is regarded as one between equals, with both poles influencing each other's development in a more or less synergic manner. And yet, up until the Postwar period science had been consistently portrayed as the determining factor in the relation, and technology as its mere "application".

The idea of scientific theorisation being the sole originator of technological developments may be credited to logical positivism[14] (Scharff 2009; Dusek 2006). This philosophical school conceived science as a "theory-producing machine" (Ihde 2009a, 7), and portrayed experimentation and technical instruments solely as the means to gather the necessary data to evaluate and, eventually, prove or disprove a given theoretical postulate (Boon 2009, 29). As philosopher Don Ihde (2009b) notes, this can be explained by the fact that for most logical positivists the quintessential embodiment of science was theoretical physics, a distinctively abstract field where the role of direct observations was (and still is) considered secondary. Moreover, the outlook of logical positivism was heavily influenced by mathematical logic; hence its understanding of knowledge and truth was almost Platonic. This lead to a portrayal of science as a theoretically driven "ahistorical" and even "acultural" endeavour (2009b, 54), and of technology as its mere application. But to understand why technology was

[13] The term "scientist" was coined by British polymath William Whewell (1794–1866) around 1833 (Holmes 2008). Whewell also coined the term "physicist" and pioneered the modern "peer review" system for scientific publications (Baldwin 2017).

[14] The philosophical tradition that pioneered modern philosophy of science; its most notable and influential school was the Vienna Circle (Boon 2009).

denied an active epistemological role we need to go back two thousand years.

2.3 Knowledge vs practice

Major Greek philosophers barely discussed technology *qua* technology. The main reasons behind this omission may be found in the fact that the majority of them believed in a necessary distinction between (true) knowledge, or *epistêmê*, and practice, or *technê*. As a precursor of what would later be called "idealism", Plato believed the world accessed by perception was fleeting and distorted while the world of *epistêmê* was abstract, eternal, perfect and immutable. He believed *epistêmê* was formed by immaterial objects or "forms" that existed independently of the mind and the physical world; meaning they could not be perceived by the senses and could only be accessed through reasoning.[15] Whereas *technê* — often translated as "craftsmanship"[16] — referred to "the attitude, the methodology, or the skill aimed at the practical creation of a material thing" (Gualeni 2015, 1). *Technê* implied a kind of practical knowledge; a "know-how" (Lee 2009, 17), "cleverness or deviousness" (Mitcham and Schatzberg 2009, 33) associated with most traditional trades such as carpentry or metalwork, but also with rhetoric, politics and even medicine (Parry 2014). Because it dealt with physical objects, Plato believed this knowledge was narrow, concrete and specialised, in comparison to the more comprehensive and genuine wisdom offered by *epistêmê* (Dusek 2009, 131).

Throughout various dialogues, Plato not only endorsed the distinction between *epistêmê* and *technê* but went as far as to argue the latter was incapable of yielding *true* knowledge of the artefacts it produced. This privilege was reserved to the *user* of the artefact. This opposition between "maker's knowledge" and "user's knowledge", and the privileging of the latter is what Luciano Floridi (2011d) refers to as the "Platonic dogma". According to Floridi, Plato claimed the maker of an artefact — say a weaving shuttle or a set of reins and bits — would actually know *less* about it than the person that would be using it. Plato compared craftsmen and artisans to hunters whom, having brought down a beast, needed to ask the chef what was the animal they had captured. However, as Floridi notes, Plato does not provide sound arguments to support this particular idea. Indeed, Plato "writes as if it were utterly obvious

[15] Roughly speaking, this is the basis of his well-known Theory of Forms and the origin of what would later be known as Rationalism (Coyne 1997).

[16] Given that "*technê*" also referred to "the ability to outwit circumstances", Kelly (2010, chap. 1) observes the term "ingenuity" may, in fact, be the closest translation.

and uncontroversial that artisans could never possibly qualify as knowers with respect to their artefacts" (2011d, 286). Modern philosophers — including American pragmatist John Dewey and Floridi himself — argue the reason why Plato held "maker's knowledge" (2011d) under such poor esteem was because the Greek was "a slave-owning culture" (Haack 2003, 781). And since it was slaves who were in charge of virtually all manual labour, scholarly gentlemen such as Plato considered it to be "base, impure and degraded." (Kelly 2010, Chapter 1).

But despite his contempt for "maker's knowledge", Plato's callousness was not originally directed at craftsmen, but against, *imitators* whom "intentionally replace[d] reality by a chimera", as philosopher Paul Feyerabend (1996, 24) noted.[17] According to Floridi (2011d, 287), Plato's downplaying of *technê* was not intentional; it was more like "collateral damage" produced by his attacks against his true foe: artists. In Plato's view — to paraphrase Feyerabend (1996) — theoreticians found truths, artisans created useful objects, but artists did neither. In this sense, the artisan or craftsperson is merely a "first-class imitator" (Floridi 2011d, 287) and therefore is not as dangerous as the artisan. Since what the artisan does is making physical reproductions of ideal forms (created by the *demiurge* or god), the knowledge he can provide about such objects is necessarily imperfect. For Plato, the user of the object is better prepared to judge and give feedback regarding how good of an imitation is the object created by the artisan (2011d).

In hindsight, it is not difficult to argue against Plato's characterisation. Because upholding the Platonic dogma would be akin to suggesting that a person who buys an iPod knows more about it than Apple, or that the occasional user of Wikipedia is more acquainted with the information than those who generated it (2011d, 289). Nonetheless, the Platonic dogma still had a profound impact in the development of Western thought — particularly over epistemology — well into the nineteenth and twentieth centuries. Following the Platonic distinctions between *epistêmê* and *technê*, and between apparent and real, came the oppositions between body and mind, objective and subjective, and knowledge and opinion (Feyerabend 1996, 23) that proved so influential for Western thought. These separations became distinctive traits of what Floridi (2011d) refers to as *the user's knowledge* philosophical tradition, which includes rationalism, empiricism and logical positivism. To the "user's knowledge" approach we owe the disregard for the epistemological and cultural role of technology throughout many centuries.

[17](1924–1994) A key and controversial figure in contemporary philosophy of science.

2.3.1 The user's knowledge tradition

Continental rationalism is one of the most influential "discursive practice[s]" (Coyne 1997, 18) in Western thought; it has generally been associated with René Descartes,[18] Gottfried Wilhelm Leibniz[19] and Baruch Spinoza.[20] Like Platonism, rationalism saw cognition as independent of the material world; as something that belonged to an abstract plain and thus could dispense of a physical medium (1997, 18). This is the root of Cartesian dualism: the notion that body and mind existed independently of each other. Rationalism postulated that knowledge was either acquired *a priori* trough intuition and deduction or that it was (to varying extents) innate and that experiences merely triggered its "remembrance". For rationalists, experience could not provide the knowledge offered by reason and, therefore, it was *inferior*.[21] In summary, rationalism argued the human mind must contain some innate structure that allowed it to acquire knowledge independently of experience. Rationalism believed in the superiority of theory over practice.

Conversely, British empiricism, which is commonly associated with John Locke,[22] George Berkeley,[23] and David Hume[24] rejected the thesis that knowledge was either the product of intuition and deduction or that it was innate (Markie 2015). For empiricists, knowledge was always acquired *a posteriori*; thus it always depended on sensorial experience. Like Aristotle, they endorsed the idea of the mind as a *tabula rasa* or blank slate, i.e., as a receptor of sensory data devoid of innate structures (Gualeni 2015, 29–30; Markie 2015). For the empiricists, sensory experience was the sole source of ideas, meaning they did not only argue in favour of "empirical knowledge" but postulated that knowledge, in general, could *only* be acquired through experience. Despite privileging experience as the source of knowledge, British empiricists were no different from Continental rationalists when it came to how they regarded practical skills and technical knowledge.

Both rationalists and empiricists simply assumed that passive, contemplative thought, as opposed to active practical engagement was the sole means to acquire knowledge.

[18] 1596–1650

[19] 1646–1716

[20] 1632–1677

[21] Descartes, for example, argued a priori knowledge is certain beyond any doubt, whereas knowledge acquired through our senses was always uncertain (Markie 2015).

[22] 1632–1704

[23] 1685–1753

[24] 1711–1776

Their "user's knowledge" approach remained highly influential well into the twentieth century, playing a crucial role in — amongst other things — the development of early philosophy of science. This is somewhat surprising since one of the precursors of both British empiricism *and* the scientific method was Francis Bacon,[25] a key figure for British Enlightenment. Unlike his successors — which include the most prominent empiricists already mentioned, Bacon was one of the few thinkers that recognised the crucial role technology plays in human life and development. Bacon continues to be a rare exception in this regard.

2.3.2 Bacon and the "maker's knowledge" tradition

In Francis Bacon's time philosophy had become stagnated; focused on hair-splitting discussions and calcified by centuries of scholasticism, its role had been reduced to debating morality. Meanwhile, civil life, spurred by the ideas of the Renaissance, was increasingly focused on the practical applications of knowledge. Understandably, "philosophy was widely regarded as a useless discipline which fostered argument for its own sake, never getting anywhere and never producing anything of value" (Gaukroger 2003, 634). Trained as a lawyer and skilled in rhetoric, Bacon found in these two areas the inspiration for his inductive method (2003), the basis of which would become the scientific method. Contrary to Plato's dismissal of sensory perception as illusory, Bacon believed experience was, in fact, crucial for reaching truths about the world since pure reasoning and speculation often lead to errors (Dusek 2006, 42). Bacon argued knowledge of Nature should be actively and methodically acquired through test and observation, and not passively deduced from ancient general and immutable principles. Ultimately, he believed an understanding of Nature's principles along with knowledge of practical techniques were the most effective way to human progress.

Bacon took upon himself the task of reforming natural philosophy to give it a more practical purpose. To begin with, he sought to make natural philosophy the new core subject of conceptual analysis, thus displacing moral philosophy. At the time, natural philosophy was roughly divided into two major domains: alchemy and scholastic natural philosophy (Gaukroger 2003). Alchemy was esoteric but practical, and had little epistemic connection to established philosophy; Bacon considered it to be lacking in structure and consistency because most of its "results" were often the product of chance. Whereas the highly theoretical and systematic scholastic natural philosophy

[25] 1561–1626

was incapable of producing anything of practical use beyond its verbal sophistication (2003, 635). Bacon thus resolved to combine the strength of the two disciplines to formulate the basis of his project of philosophical reform. He believed the theoretical rigour of scholasticism and the practical application of alchemy could join forces to provide superior knowledge of Nature and the means to transform it for the good of society. In doing so, Bacon not only established the foundation of the scientific method but also set the tone for the modern conception of science as an intrinsically progressive and morally high-grounded enterprise — which intellectuals such as C. P. Snow ([1964] 2012) imagined and promoted.[26] Given his emphasis on technical knowledge and practical experience, Bacon is, according to Floridi (2011d, 291), a precursor of the "maker's knowledge" tradition.

The "maker's knowledge" tradition constitutes a significative break from Platonic epistemology and its downplaying of experience. This philosophical strain may be traced back to Aristotelian-Scholastic philosophy, which — amongst other things — postulated that true knowledge implied understanding the *causes* behind that which is known (Floridi 2011d). For Aristotle, genuine knowledge was *ontic*, meaning that it implied knowing the intrinsic nature of the known. Unlike Platonic rationalism (according to which, knowledge is innate or, at the very least, acquired through induction) Aristotle advanced the notion of the mind as a blank slate, thus emphasising the crucial role played by direct observation and *experience* in the acquisition of knowledge. It followed that if true knowledge is ontological and it is not innate, then knowing something (an object or phenomenon) and being able to account for it means being able to *construct* and reconstruct it (2011d, 290). Nonetheless, it was not Aristotle but Bacon who arrived to this conclusion. Aristotle still saw the acquisition of knowledge as a passive process of discovery, but it was Bacon who is credited with realising that we can only know what we can make. Knowledge for the "maker's" tradition is *poietic*: an act of (collective) creation. Unlike "user's knowledge" which is atemporal and subjective (the product of a highly intelligent and unique mind), maker's knowledge is more similar to engineering: it is accumulative, it has a component of trial and error and, above all it is a collaborative process that spans across generations (Floridi 2011a, 291).

[26]See Chapter 1.

2.3.3 Phenomenology and pragmatism

Two major representatives of the maker's knowledge approach are phenomenology and pragmatism. These two philosophical traditions were developed more or less simultaneously, the former in Europe — particularly in Germany — by Edmund Husserl[27] and Martin Heidegger, and the latter in the United States by Charles S. Peirce,[28] William James,[29] and John Dewey. Both phenomenology and pragmatism regard put *experience* at the centre of their analyses (Ihde 2009a), although for different reasons.

As its name implies, pragmatism emphasises practice over theory and action over contemplation. For pragmatists the more appropriate way to generate and evaluate knowledge is direct, concrete experience and practical implementation; not detached, abstract rationalisation. Whereas phenomenology emphasises not practice itself, but the *representation* of experience and how it affects practices.

Phenomenology is concerned with "how things appear"; with the description of human sensory experience as actual objects or *phenomena*[30] (Proudfoot and Lacey 2010, 300; Gualeni 2015). Like the Aristotelian tradition, phenomenology's approach is mainly ontological (Dahlstrom 2010). Phenomenology wishes to discern what is the (ultimate) *essence* of phenomena as experienced intuitively by the human mind. Thus, phenomenology's method is dialectical; it sees phenomena as a collaborative construction between the mind of the subject (with all of its conceptual and historical baggage) and the essential features of the object. Overall, phenomenology wishes to articulate how and why we conceptualise experiences the way we do, without focusing on mere emergent causal explanations.

For its part, pragmatism represents the strongest break with the Platonic and user's knowledge tradition. Originally developed as a theory of meaning by Peirce, pragmatism was later expanded by James into a theory of truth — basically claiming that truth could be understood as "agreed reality" (Capps 2011). But it was Dewey who turned pragmatism into a general framework for analysing the social, epistemic, and pedagogical impact and role of science and technology. Unlike phenomenology, prag-

[27](1859–1938) German, born into a Jewish family in present-day Czech Republic, mentor of Heidegger. In the latter days of his life, with the Nazis in power, he was forbidden to publish.

[28](1839–1914) Best known for his contributions to semiotics.

[29]1842–1910

[30]A phenomenon may be "any object, quality, or occurrence that is the subject of sensory experience" (Gualeni 2015, 167).

matism has no interest in questions concerning the ultimate essence of objects and phenomena (Ihde 2009a). Pragmatists contend the nature of truth, knowledge, language and everything else should be looked for not in some abstract or metaphysical[31] domain, but in everyday convention.[32] Hence, pragmatism sees the Platonic tradition as having outlived its usefulness (2009a, 10). Unlike rationalism, pragmatism evaluates knowledge in terms of its concrete consequences and applications within particular contexts, not in terms of immutable axioms and syllogisms (Dusek 2009, 138). For pragmatists, true knowledge implies knowing *how* to use and make (or reproduce) that which is known. For example, truly knowing music implies having not only a "good ear" to appreciate a musical performance, but also being able to read, write, and perhaps even play an instrument.

Above all, pragmatism emphasises practice and therefore rejects the rationalist (Platonic and similar) distinction between *epistêmê* and *technê*. For pragmatists there is *only* practice; consequently, they see theory *itself* as a practical activity composed of conceptual *instruments,* and the theoreticians that wield them as technicians. Being optimistic about technology, pragmatism aims to understand the impact of technological systems daily life. In the words of Richard Coyne, pragmatism may be understood as:

> a school of philosophical thought that embraces the primacy of human action, the practicalities of human involvement the materiality of the world, the interaction of the senses and the formative power of technology. (Coyne 1997, 17)

2.4 Engineering vs hermeneutics: Two philosophical approaches to technology

When compared to other philosophical schools, the philosophy of technology is a young branch; hence its early or "classical" period dates back only a couple of centuries. Most early philosophical accounts of technology may be classified into two major groups depending on whether they place technology or human affairs at the centre of their analyses (Mitcham 1994). Those which begin by attempting to under-

[31] Both pragmatists and logical positivists regard metaphysics with contempt, treating it as if it were a "bad word" more related to superstition than to knowledge.

[32] Propositions such as this one horrified figures of the stature of Bertrand Russell, who called pragmatism an "engineer's philosophy" (Haack 2003).

stand technology *itself* (e.g. its nature or essence) and then proceed to *explain* human practices and even biological aspects as manifestations of technological ingenuity belong to what Carl Mitcham calls the "engineering" approaches. Whereas those approaches that begin by analysing cultural practices and only then proceed to *understand* how they are affected by technological developments belong to the "humanities" or "hermeneutical" tradition (1994). Historically speaking, the engineering approaches have precedence over hermeneutical ones, and they include figures such as Ernst Kapp,[33] Friedrich Dessauer,[34] Juan David García Bacca,[35] and Mario Bunge.[36] Whereas the most significative figures in the hermeneutical tradition are José Ortega y Gasset[37] and Heidegger.

Engineering approaches tend to endorse "technological determinism,"[38] meaning that they see technology (or a combination of technology and science) and not culture as the defining characteristic and motor of human development. Engineering approaches take for granted questions concerning the "human condition" (e.g., "what does it mean to be human?"); they see little or no threat in technology for human existence. As heirs of the Enlightenment, they portray technology as a vehicle of progress and tend to have a blind spot for any ethical issues arising from the instrumentalisation of Nature. Technologies for them are extensions of human capacity, means to overcome our limitations and tools for conquering Nature. Engineering approaches are technologically and scientifically literate, they know technological appliances from the inside, they have the specialised knowledge required not only to operate them but also to manufacture them. In short, they see technology as the practical embodiment

[33](1808–1896) The first one to speak of "philosophy of technology" or rather of "philosophy of technics" (*Philosophie der Technik*).

[34]1881–1963

[35](1901–1991) Ibero-American philosopher, he portrayed technology as "the essential humanization of the world" (Mitcham 1994, 35).

[36](b. 1919) Played a significant role in the spreading of the very notion of "philosophy of technology" in North America, which until the 1980s was mostly used in Germany and The Netherlands. As a trained physicist and analytical philosopher, Bunge emphasises the close relationship between technology and science and, more important, he conceives the former in the amplest (epistemological) sense, including systems of knowledge, institutions and practices (Mitcham 1994, 38)

[37](1883–1955) One of the most influential Spanish philosophers of the twentieth century. As Heidegger, Ortega saw a deep relation between humanity and technology; however, he rejected the notion that the human condition could be exhausted by technology. More important, he rejected that the "essence" of technology could be grasped merely by looking at technologies (Mitcham 1994). For Ortega y Gasset, to understand one's condition, it is imperative to understand also one's context, therein his famous aphorism: "*Yo soy yo y mi circunstancia*" ("I am myself and my circumstance") (Ortega y Gasset [1914] 1966).

[38]According to Val Dusek (2006, 84), technological determinism "is the claim that technology causes or determines the structure of the rest of society and culture". It is closely related to autonomous technology, "the claim that technology is not in human control".

of human intelligence and as the *application* of science.

Conversely, the hermeneutical or "humanities" tradition seeks cultural and historical *comprehension* rather than technical explanation; its view of technology is mostly critical and even anti-technological or "techno-pessimistic". For the hermeneutical view, asking what it means to be human is the most crucial question. Unlike engineering approaches, the hermeneutical tradition values subjective qualifications over methodical quantification. For the hermeneutical tradition technology should not be addressed independently of a (human) context; and even though it recognises technology as a substantial part of being human, it does not see it as our most definitive aspect. The hermeneutic view calls into question the idea of technological progress and the notion of science and technology as inherently positive enterprises. Inspired by Romanticism, it insists there are alternative frameworks for understanding the world apart from the technological (and scientific) worldview. The hermeneutical view believes technological frameworks are not aware of their limitations and power, and this makes them potentially dangerous. Thus hermeneutical approaches believe technology should always be criticised from the *outside* to reveal its biases and reifications.

The engineering characterisations of technology are technically and scientifically savvy; they see technology as a continuation of science. They criticise the humanities' traditional lack of scientific literacy (in a manner that reminds C. P. Snow's and software studies' criticism), arguing techno-pessimistic portrayals are more the product of vincible ignorance than facts. Engineering approaches portray technology as a neutral and rational force with benefits that far outweigh potential dangers. The engineering view of technology is modernist through and through. Conversely, hermeneutical interpretations of technology see scientific theories and technical details that so enamour engineers as a limited discourse. They contend that understanding how technology works — or how it is produced, or what are the theoretical underpinnings supporting it — is not essential to comprehend its impact. Hermeneutical approaches are satisfied with seeing how technology is *used*. In fact, hermeneutical approaches often make a point of *resisting* the theoretical and technical underpinnings of both science and technology because they see them as inherently biased. For the hermeneutical interpretation, technology and the science behind it is more an *attitude* — a worldview — than a conglomerate of indisputable truths. Hermeneutical interpretations also see a synergy between science and technology but, contrary to the engineering tradition, they conceive science as a *product* of technology and not as its motor.

2.5 From "classical" to contemporary philosophy of technology

As previously discussed, early or "classical" philosophy of technology was concerned with comprehending the *essence* of technology; to find the historical and "transcendental" conditions behind it. Classical philosophy of technology is thus credited with realising that to fully understand society it is necessary to take technology into account. It is also credited with realising that technology is less about instruments and objects than about ways of life and that technology should be approached as a (complex) system. Nonetheless, according to Dutch philosopher Hans Achterhuis (2001), the most important contribution of classical philosophy of technology was the development of a technologically aware metaphysics, that is, an approach that recognises technology's active role in the way humans conceive reality. This is a radical break with the user's knowledge tradition and its belief that sense-making of the world was solely a product of language and reason; and that craftsmanship was subservient to "symbolic, cultural reality" (2001, 4). After classical philosophy of technology, understanding the relationship between humans and technology would involve choosing between a conception of human beings as *homo faber* or as *homo loquax* (Achterhuis 2001; see also Mitcham 1994), that is, between makers and users.

Classical (hermeneutic) philosophy saw technology's influence over the human conception of reality as potentially dangerous because it understood technology as something fundamentally distinct from *culture*. As heirs of Romantic idealism and the user's knowledge tradition, Heidegger and others after him equated culture with language and literature.[39] Technology for them represented "the other" of language and symbolism (Achterhuis 2001); it represented a mechanistic, artificial, instrumental but powerful framework alien to (human) nature.[40] In fact, they even realised that it was technological thinking that gave way to science and not the other way around. Some of this thinkers went as far as to consider the possibility of a technological culture was an oxymoron, if not an outright monstrosity (2001). Classical hermeneutic philosophers of technology believed the only way to maintain technology in check was to seek refuge in language and culture while treating technology as a hierarchically inferior understanding of reality. Believing that thinking and knowledge were fundamentally

[39] Hence, when Heidegger and other classically trained intellectuals speak of "art" they are most probably talking about literature and, particularly, of poetry.

[40] Most classical philosophers of technology from the hermeneutical tradition take for granted the idea that technology and modernity "disenchant" and instrumentalise nature.

opposed to technology, they thought it should be subjected to permanent criticism.

Classical hermeneutical philosophy of technology treats its subject in monolithic and abstract terms. It portrays technology as a teleological, autonomous and homogeneous force. Consequently, it refrains from addressing concrete technological practices and fails to appreciate how they can rapidly alter the normative and the framework of culture (2001). This implies that most classical hermeneutic accounts fail to recognise the complex intertwinement between technology and society, which, of course, bring about profound cultural changes. As noted before, classical hermeneutical philosophy of technology is notoriously ignorant of technical (engineering) implementations. That is why, in the last two decades of the twentieth century, a new generation of philosophers dissatisfied with the classical portrayal of technology developed a more "constructivist" approach and sparked what Achterhuis (2001) describes as the "empirical turn".

2.5.1 The empirical turn

In many ways, the empirical turn in philosophy of technology obeys the same logic that inspired the changes undergone by philosophy of science two decades before. Throughout the 1960s and 1970s, philosophers of science such as Thomas Kuhn,[41] Imre Lakatos,[42] and Paul Feyerabend began to call attention to the fact that social and historical circumstances greatly determine scientific developments — Ihde (2009a, 7) calls these accounts "antipositivists". These philosophers challenged the dominant portrayal of science as a process of uniform accumulation of knowledge (Kuhn 1996); arguing instead that science evolves in a punctuated (and sometimes haphazard) manner, and that "it does not contain one style of research, but many." (Feyerabend 1996, 26). In other words, these critics dispelled the image of science as an ahistorical and homogeneous enterprise by showing there are *many* kinds of science and that it is best to analyse each one of them in a specific social and historical context. The new generation of "empirically oriented" philosophers of technology saw fit to apply these same ideas to their analyses of technological practices.

The central task of contemporary philosophy of technology became "to understand the co-evolution of technology and society in modern culture" (Achterhuis 2001, 7).

[41] 1922–1996
[42] 1922–1974

Contrary to their predecessors, the new generation strived to analyse specific technologies and the practices they gave rise to. These new approaches see technology and humans as engaged in mutually constitutive dynamics; thus they reject any hierarchical relationship between the technical and the cultural aspects of human societies. For them, technology influences culture and vice versa. They recognise that when a new technological appliance is introduced into society, it sparks unpredictable and irrevocable changes. But technology cannot be described as an autonomous and exogenous force. Contemporary philosophy of technology rejects the idea of technology as being starkly opposed to nature and knowledge; and, in truly pragmatic fashion, also rejects the possibility of finding technology's "essence". For philosopher's such as Ihde (2009a) and Peter-Paul Verbeek (2005) technologies only acquire meaning and purpose when they are engaged in a particular human practice and context. Overall, contemporary philosophy of technology emphasises the role "maker's knowledge" plays in constructing our understanding of the world.

2.5.2 From technology *and* science to "technoscience"

As previously discussed, technology has often been described — mainly by logical positivists — as "applied science"; a characterisation that implies the epistemic precedence of science over technology. While a significant number of technologies could not have existed without basic scientific research, attempting to subsume technology to science is problematic for at least two reasons:

a. ontologically speaking, technology *predates* institutional science;

b. technology plays a decisive role in every scientific development.

Regarding the first problem, craftspeople, inventors and engineers crafted tools and procedures for millennia before the Scientific Revolution. Most of them did so by following "rules of thumb" (Boon 2009, 29) distilled from generations of accumulated experience. A diehard empiricist might argue this know-how constitutes a (rudimentary) prefiguration of the scientific method, but it does not resemble institutional science as we have been discussing it. As for the second objection, there are many reasons to believe that it was technological practices that gave rise to scientific developments in the first place.

Around 1917, American polymath L.J. Henderson[43] observed that science owed more to the steam engine than the other way around (Ihde 2009b). Without this invention, we would not have thermodynamics and every scientific development that came after it (i.e., everything from statistical mechanics and astrophysics, to information theory and modern cryptography). As Freeman Dyson[44] (1997) has noted, over the last 600 years the overwhelming majority of scientific changes have been sparked not by ideas or "concepts" but by the introduction of new "tools."[45] Dyson argues "concept-driven" scientific revolutions — those that occur when "old things" (phenomena) are explained in new ways — are extremely rare. Examples are Copernicus' debunking of the Geocentric conception of the universe using the Heliocentric Model, and Darwin's Theory of Evolution. Conversely, "tool-driven" revolutions, which are triggered when technologies reveal "new things that have to be explained" (1997, 50) are far more common.[46] It follows that "instruments [tools] are not passive technological spectacles through which we perceive the objects of science" (Boon 2009, 81) but *active* — sometimes indispensable — agents of their construction, and of the knowledge they yield.

Many contemporary technologies such as nuclear energy or wireless Internet would not have existed without theoretical science, but this body of knowledge was, in turn, made possible precisely by technologies such as glass or the steam engine. The interplay between science and technology thus appears more like a "chicken-and-egg" problem than a clear hierarchical relationship. In fact, classical philosophers of technology such as Heidegger and Ortega y Gasset (who were amongst the first to reject the idea of technology as applied science) see science as an *inherently* technological endeavour (Mitcham 1994, 35).

Instead of regarding it as the product of scientific rationalisation, philosophers now tend to see technology as its *embodiment*.[47] The distinction seems subtle, but it carries a significant implication: science and technology are but two cooperative manifestations or poles of the *same* phenomenon, which some philosophers describe as *techno-science*.

[43] 1878–1943

[44] (b. 1923) British-American polymath and a key figure in twentieth-century physics.

[45] An example supporting Dyson's claim is provided by glass, a technology to which we owe everything from Galileo's observations to the development of modern chemistry and biology.

[46] A classical example is Galileo's use of the telescope to conduct his observations.

[47] To put it in Ihde's terms (2009a, 35), science is now understood by philosophers of science as "*instrumentally, or technologically embodied*".

Technoscience is a historically-aware response or "reconceptualisation" of the relationship between science and technology, which falls in line with the pragmatic tradition that was earlier discussed. Unlike the positivist "applied science" model that endorses the platonic privileging of theory over practice (or "user's knowledge"), technoscience recognises the epistemic value of *technê*. Instead of describing science and technology as having an asymmetrical relationship, the concept of technoscience emphasises that it is best to think of them as a "hybrid" or "symbiotic" (Ihde 2009b) phenomenon; a dynamical conglomerate of practical and theoretical knowledge. By endorsing the concept of technoscience, contemporary philosophy of technology breaks with its predecessors' (still Modern) qualms about granting technology the possibility of being not only part of but a fundamental driver of culture. More than a categorical term, technoscience is an outright postmodern reimagining of science as a technologically embodied (i.e., practical) *system* of knowledge.

2.6 Defining technology

Throughout the previous sections we have seen how technology was neglected, recognised and finally engaged by philosophy, but we have not yet looked into how technology is being currently *defined*. Though technology can very well refer to "any creation system beyond the basic apparatus of the [biological] body" (Wilson 2002, 9), this definition is so broad that it is hardly useful. A more constrained alternative would be to call "technologies" only those physical items that qualify as human-made "hardware" (Dusek 2006), such as tools and machines. This definition is, in turn, is too restrictive, since producing "hardware" requires background knowledge, techniques, and procedures, that include everything from smelting to writing and programming. A second alternative would be to focus precisely on this "software" and regard technology as the product of knowledge, procedures and the institutions that allow us to produce tools and machinery. The strong version of this "software" or "rules-based" (2006) model is precisely the technology-as-applied-science model we previously discussed, and that has come under heavy fire from the proponents of technoscience. A more recent definition sees technology as a complex *system* involving both hardware and software.

2.6.1 Technology is a system of systems

In the first section of this chapter, we saw Johann Beckmann coined not only the term "technology" but also recognised its *systematic* character. We later saw Beckmann's insight was furthered by classical philosophers of technology who devoted themselves to understand the origins and, more important for them, the *essence* of this phenomenon. The problem is that technology, like science, is far from being a homogeneous phenomenon. It is rather a multifarious interweaving of everything that is involved in the production of artificial (as in not naturally occurring) things (whether abstract or concrete). It follows that it makes more sense to speak not of technology, but of "technologies". Each one comprising a set of relationships between specialised knowledge and practical application, but also involving a particular socio-historical context and the participation of agents (both human and non-human) who create and use them (Dusek 2006; Li-Hua 2009).

Along with its context of application, each technology may be defined as a particular complex dynamical system that involves:

a. *hardware* and *techniques*, which include instruments, machines, raw and specialised materials, processes and labour;

b. *knowledge*, usually scientific, but also skills, expertise, or even "intuition" (Li-Hua 2009), not only to produce but also to interact with the technology;

c. *organisation of production*, meaning the socioeconomic structures and interdependencies that allow knowledge and techniques to work together, but also governments and markets;

d. *the actual product*, the instrument or appliance that embodies the conjunction of all of the above.

These *technological systems* do not (cannot) operate in isolation, as they are connected with and dependent upon *other* technological systems, often across historical periods.[48] Technologies also beget technologies, usually because they give rise to unexpected dynamics within societies which require a new technological solution. A good example of this is the invention of the telegraph which arose almost parallel to the

[48] Thinking about everything that is involved in driving an automobile illustrates this idea: From the construction of roads, the invention of the internal combustion engine and oil refining, all the way up to planning and enforcing regulations for operating motor vehicles to finally learning how to drive, all these technologies contribute to the existence of this form of transportation.

wide-spread adoption of railroads and whose primary task was to avoid collisions between trains (Kittler 1999). Technologies thus may be understood as the manifestation of a biconditional relationship between knowledge and practical implementation, but ultimately dependent on a broader socio-historical context, which is mostly shaped by technology-wielding agents (individuals and institutions). Philosopher Val Dusek (2006, 35) hence defines technologies as "the application of scientific or other knowledge to practical tasks by ordered systems that involve people and organizations, productive skills, living things, and machines". Having provided this working definition, we can then address the relationship between humans and technological systems.

2.6.2 Technological mediation

The notion that technologies are fundamentally mediators has become widely accepted in philosophy of technology, but it is also a tenet of media theory;[49] the heterogeneous field of studies concerned with the "material structures of technologies" (Gane 2005, 29) and their impact over human culture. As Floridi (2011d, 300) notes, it was with Bacon that so-called "technological mediations" first became the subject of philosophical analysis, as they were increasingly perceived as the practical human-made means through which we engage, analyse and conceptualise our surroundings. In Ihde's words, the basic postulate is that technologies "mediate our way of experiencing a world" (2009a, 34).

Contemporary media theory was developed during what Floridi (2009a) classifies as the "second" (communication) stage in the development of (IT). The idea of *mediation* thus became overwhelmingly associated with mechanical and electronic mass communication systems or so-called "media."[50] Nonetheless, as Floridi (2013a) notes, mediation or rather "in-betweeness"[51] is a basic characteristic of *any* form of technology.

[49]Also known as "media studies", "media philosophy" or, as Friedrich Kittler (1999) would have it, *Medienwissenschaft* or "media science" (Gane 2005).

[50]Prominent theorists such as Marshall McLuhan and Kittler often spoke indistinctly of "media" and "technology". With the former popularising the idea of technology as "enhancement or 'extension" of our "senses" (McLuhan [1964] 1994), that some classical philosophers of technology, such as Ernst Kapp (Mitcham 1994) began to sketch in the nineteenth century.

[51]Even though Floridi does not mention it, choosing this neologism allows us to circumvent the baggage which prevents "media" from being a useful philosophical notion.

2.6.3 Technology's "in-betweeness"

At first glance, a sandal and an axe do not have anything in common; looking closely, we see the two objects "stand" in-between an agent — in both cases a human — and natural "affordances" such as the ground and a tree trunk, respectively (Floridi 2013a). The tools that involve this type of interaction may be classified as "first-order" technologies (2013a, 111). The fact that they belong to this category does not automatically imply they are less complex than other tools, as other accounts suggest[52] — a technologically complex device such as an assault rifle sadly also stands in between two humans whom, depending on the side, may be users or affordances. A more sophisticated level of "in-betweeness" is the one summoned by "second-order" technologies (2013a, 112), which have *other* technologies as affordances,[53] such as is the case with screwdrivers and cars, which allow humans to interact with screws and roads, respectively. First- and second-order technologies often have mutual dependency relationships;[54] and, in fact, many first-order technologies are effectively useless without second-order technologies. By far, the most prevalent type of current technologies belong to the second-order category.

First-order in-betweeness:

AGENT ⟶ TECHNOLOGY ⟶ AFFORDANCE

Second-order in-betweeness:

AGENT ⟶ TECHNOLOGY ⟶ AFFORDANCE — TECHNOLOGY

Second-order technologies (telephones, dishwashers, cars, etc.) are eminently modern, and the most recent of them are usually the product of scientific developments. The most notable second-order technology is the engine, that is, "any technology that

[52]Frieder Nake (2012a), for example, argues tools are a simpler form of technology than machines, and that equating both concepts erases the historical relation between the two.

[53]At the beginning of this chapter we saw that other non-human animals can produce tools, nonetheless, to our knowledge, only humans can build second-order technologies, since they require a much higher degree of specialisation.

[54]E.g., a car is fairly useless without an adequate road.

provides energy to other technologies" (2013a, 112) as it ushered an incommensurable amount of technological and social developments. With second-order technologies come more complex forms of social dynamics and technical interdependencies. But in recent decades a third order of technologies arrived; they are a powerful force behind "hyperhistory" — see Chapter 1. Third-order technologies are different insofar as they drive the human factor out of the equation. They become the *users* interacting with other technologies as affordances through other in-between technologies (2013a, 113).

Third-order in-betweeness:

AGENT — TECHNOLOGY ⟶ TECHNOLOGY ⟶ AFFORDANCE — TECHNOLOGY ...

Third-order technologies imply not only a certain degree of automation but also of *autonomy*. While "mechanical modernity" (2013a, 114) still depends on human agents, third-order technology can be fairly autonomous. With third-order technologies, human agents are no longer part of the mediation but become beneficiaries instead. A good way to illustrate this idea is to remember that humans cannot read barcodes, nor read machine-level code or participate in high-frequency stock exchange and that our services economies are increasingly dependent on this third-order ' in-betweeness'. Third order technology is "technology mediating with other technology through itself". And the paramount expression of this form of mediation is the one provided by IT and, in particular, by *computational technology*.

From a schematic point of view, all forms of in-betweeness beyond third-order are more complex third-order relationships, so there is no need to think upon fourth- or fifth- order technologies.

2.6.4 The paramount expression of IT

Throughout the previous sections, the terms "information technology" (IT) and "computational technology" have been used more or less interchangeably, tacitly placing the later as a subset of the former. Computational technology is not just a subset of IT but its "quintessential" (Floridi 2009a) expression. As we saw in Chapter 1, IT evolves not by replacing functions but by *accumulating* them. As characterised by Floridi, information technology refers to:

> any technology used to treat information in one or more of the phases in its life cycle: occurrence (discovering, designing, authoring, acquiring, creating, etc.), processing and management (collecting, validating, modifying, organizing, indexing, classifying, filtering, updating, sorting, storing, networking, distributing, disseminating, displaying, accessing, retrieving, transmitting, transferring, etc.) and usage (monitoring, modeling, analyzing, explaining, interpreting, planning, forecasting, decision-making, instructing, educating, learning, etc.). (Floridi 2009a, 228)

Computational technology is the paramount form of IT because it can perform all three historical functions of IT — i.e., registering, communicating and, *elaborating* information (2009a) — and, therefore, all of the specific functions above described. More important, computational technology is capable of doing so *autonomously* and, as we also saw in a previous section, automation is the hallmark of the Second Industrial Revolution. This is what separates computational technology from earlier forms of IT and, arguably, the reason why it is currently the most powerful, flexible and rapidly changing form of them all.

Although initially conceived as tools for solving specific (mathematical) problems within military, financial and scientific contexts, computers found a place within every region of human society and became the symbol of our times. With the invention of the microprocessor, the old single-task *mainframes* quickly became multi-purpose appliances. Computers are no longer *just* technoscientific instruments; to borrow the words of Freeman Dyson (1997, 50), they are "intellectual tools for clear thinking". Like writing, they allow us to solve problems, extend our memories and communicate with each other; they have attained a cultural role comparable to that of the mill in Middle Ages Europe and the steam engine of the first Industrial Revolution (Floridi 2009a). Computers are *fundamentally* information machines and — as we also saw in Chapter 1 — the driving force behind the ongoing information revolution.

Provided humanity does not destroy itself soon, computational technology as we know it will not be the last form of IT. Computational technology is undoubtedly the paramount embodiment of information technologies, and it shares many qualities with previous ITs. But from an ontological standpoint, categorising every single instance of IT in a manner that makes sense is anything but feasible. Information technology is always in a permanent beta-like state; it is continually evolving, shifting and cross-fertilising with culture and society. As noted in the General Introduction, the goal of this dissertation is to provide an account of computational technology as tools for artistic creation to understand computational aesthetic objects, but to do so implies dealing precisely with the complexity of describing IT. As Floridi (2009a, 228) suggests, a useful way to circumvent the permanent-beta problem is to focus not on the particularities of each instance of IT but on the nature of their common denominator, that is, on *information*. Chapter 4 will be dedicated to this matter.

2.7 Conclusions

Understanding what technology stands for — conceptually and culturally — is crucial for comprehending how current information technologies are transforming society and culture. While some of our present technologies are certainly unprecedented appearances wreaking havoc across our epistemological structures, technology, in general, is far from being a new-comer. Although crucial for human development, we have seen that technology was disregarded for most of our history and that this is greatly attributed to the ancient and now challenged separation between theory and practice. We also have seen this view has significantly changed over the last couple of centuries and even more in the last couple of decades. As a result, it is now clear that technology should not continue to be understood as antithetical to human beings and culture, but as a constitutive element of both. Clarifying what we mean by "technology" is not a matter of conceptual pedantry but a necessary step towards understanding how we interact and build our experience of the world and hence, how we represent it. Both of which are fundamental components of artistic experiences and practices.

In Chapter 1 we saw the profound changes brought by IT mean art scholarship needs to re-evaluate its attitude towards technology. This chapter provided a historical background as a first stepping stone for such reevaluation. At a glance, the main implication arising from the subject discussed is the fact that technology is not a monolithic and homogeneous force but a complex system of systems. Another implication is that understanding particular technologies involves seeing how they affect specific practices within specific contexts and at different levels of engagement. The next chapter will provide a methodological framework that would help us better understand the computer as an information tool and the nature of computer-generated aesthetic artefacts.

Chapter 3

A maker’s knowledge methodology

Summary

When addressing the impact of information technology (IT) on aesthetic practices art scholarship continues to rely almost exclusively on media theory. By making this style of analysis their de facto outlook, art scholars ignore alternative approaches that may provide novel and more fruitful ways to understand technological systems. This chapter discusses two of said alternatives: (a) postphenomenology, a contemporary style of philosophy of technology; and (b) a constructionist approach to the philosophy of information. In so doing this chapter describes both the methodological process that will be used in the following chapters while providing a standalone set of arguments that show how art scholarship can benefit from a postphenomenological and constructionist approach. The idea is not to reject or abandon media-theoretical conceptions but to question, expand and complement them with insights from the philosophical methods here discussed.

3.1 Introduction

In the previous chapters, we saw art scholarship struggles with information technologies (ITs) due to the continually evolving nature of technological systems, to their impact on our broader epistemological frameworks but also to the humanities' traditional wariness of technoscience. In this chapter, we will see art scholarship's handicaps are not only theoretical but also methodological. After WWII, art became increasingly intellectualised as both artists and art scholars began to emphasise theorisation and discourse over technical implementation. To say that art, particularly conceptual art, became a kind of *philosophical tinkering* — a form of philosophical speculation through objects — would not be an overstatement. However, as electronic information technologies gradually became both vehicles and motifs for aesthetic expression, and newer generations of technologically savvy artists began to take the stage, art scholars had to look for theoretical frameworks that would allow them to make sense of these changes. Media theory,[1] a style of analysis concerned primarily with the cultural impact of electronic mass communication systems became their natural ally and source of concepts, views and frameworks to understand the impact of so-called "new technologies" on art. For many art scholars media theory (in its multiple flavours) represented not only the most adequate but the *only* available approach for dealing with ITs within aesthetic contexts. This monopoly prevented them from being exposed to alternative frameworks such as the ones that will be discussed in the following pages.

Early analyses of mass communication systems tended to focus on their political and ideological role without paying much attention to their technical implementation. However, in the early 1960s pioneering media theorists such as Harold Innis and Marshall McLuhan began to call attention to the importance of the material-technological and psychological dimension of ICTs. The second generation of media theorists either reinforced this view — e.g. Friedrich Kittler — or upended it in favour of traditional discourse analyses. With the rise of the information society, the evolution of computational technology and its ability to condense all functions of previously distinct information technologies (or "media") the traditional ontological distinctions on which media theory had hitherto relied were called into question.

Media theory found itself in need of developing new ways to describe continually

[1]In this dissertation, the term "media theory" is used interchangeably with "media studies". Nonetheless, it is fair to note that even though media studies is now more fashionable, media theory is both epistemically and historically apter.

evolving ICTs, often by developing transitory neologisms and categories. Nonetheless, at the turn of the twenty-first century, a new branch of media analysis began to take form under the name of "software studies". The proponents of this approach were mostly technologically savvy, pragmatically oriented but culturally and media-sensitive practitioners. This field, along with philosophy of technology offers new insights and methods that can significantly improve our understanding of the cultural role of ITs.

This chapter discusses these approaches, their benefits and their shortcomings. It shows that media theory is by far not the only framework through which we can understand ICTs and hence computer-generated aesthetic artefacts. Furthermore, it argues that while media theory has offered valuable insights into the cultural impact of ICTs, postphenomenology and constructionism are better suited to analyse our relationship with these systems. The chapter begins by outlining the origins and general notions defended by media theory; the following section focuses on postphenomenology, and the third on constructionism. The last section discusses how these approaches improve our understanding of ICTs and computational aesthetic artefacts, and how they will be employed to conduct the analysis in the following chapters.

3.2 Media theory

In Chapter 2 we saw the idea that technologies may be seen fundamentally as mediators is now widely accepted by most contemporary philosophers of technology. In the humanities, the notion of mediation is more commonly associated with media theory or media studies: an interdisciplinary field concerned with the socio-cultural analysis of ICTs. This section presents an overview of the origins of media theory and outlines some of its core postulates, its contributions to our understanding of ICTs, and some of its methodological shortcomings. This account will offer the reader a basis for contrasting the frameworks discussed in the subsequent sections, which will integrate the concepts and methodology employed throughout the rest of this dissertation. Media theory and media studies represent a complex and rich field of study; thus it is important to note that the summary presented in the following pages cannot possibly exhaust everything there is to say about them.

3.2.1 From media to media studies

"Media" is the plural of "medium"[2] and, to the best of our knowledge, the former term first appeared in the 1920s within the advertisement industry, where it was used to refer to any communication supports that could be used for or contained advertisements (Nerone 2003). At the time, this included "the press" (i.e. newspapers, magazines, books, etc.) and the radio. Since the 1930s, and particularly after WWII, scholars concerned with the cultural socio-economical and political roles played by these and newer mass communication systems — especially electronic ones — began to appropriate and repurpose the term. Thus, the meaning of "media" expanded to include *every* type of communication appliance; from photography and film to television and, eventually, the Internet. Initially, what would later be known as media theory was seen as a dominion of journalism, but gradually it became clear the questions raised by communication technologies concerned everything from sociology and political science to psychology, anthropology, linguistics, philosophy, engineering, and art. This transdisciplinary nature makes the concept of media — and by extension, media studies — extraordinarily flexible but nebulous.

The word "media" often appears in both scholarly and everyday language yet, like any other complex notion, it is difficult to define in clear-cut overarching terms; therefore, its meaning is heavily dependent on the context of use. And yet, it is still possible to identify two main (interrelated) senses in which it is used by media scholars today:

a. the physical things that enable acts of communication, such as paper, radio waves, speech or technical appliances — i.e. cameras, TV sets, mobile phones;
b. the institutions that produce, distribute and organise content transmitted by the former — such as journals, magazines, TV and radio stations, production companies, etc.

But given there is a relationship of mutual dependency between these two dimensions, most theorists do not conceive media as concrete entities but as *means of mass communication*[3] (Laughey 2007). Nonetheless, most theorists do tend to focus either on the physical or material (*technological*), or the institutional (*cultural*) aspects of media (or

[2] The very word medium has ancient origins which can be traced back to Thomas Aquinas' translations of Aristotle. However, the modern sense of the term as a means of communication or channel can be associated with the emergence of the telegraph and, oddly enough, spiritualism (Peters 2015, 46–48).

[3] According to Niklas Luhmann (2000, 2), the fundamental aspect of mass media systems is the absence of direct interaction "between senders and receivers" during an act of communication.

some specific aspect of their interplay) as their determining factor. To paraphrase Italian philosopher Stefano Gualeni (2015, 134), media refers to any cultural product that affords meaning in ways that cannot be (solely) identifiable with those of written or spoken natural language.

Throughout the second quarter of the twentieth century, many important analyses on the impact of mass communication systems were published. Among them, Walter Benjamin's ([1939] 2008) highly influential essay, *The work of art in the age of mechanical reproduction*, which is widely considered a precursor of media theory, cultural studies, and modern art theory in general. Nonetheless, media studies as we know the field today — with its characteristically interdisciplinary approach — emerged in the 1960s (Winthrop-Young and Wutz 1999) mainly due to the popularisation of television.

The consolidation of TV in the 1950s as the quintessential mass communication and opinion-making platform[4] profoundly shaped the outlook and conceptual framework of media studies. Many ideas about the socio-cultural effect of information technologies that still pervade media theory, as well as the focus on communication, may be attributed to the fact that most early media-theoretic analyses were directed at the TV. Such emphasis on TV also limited media theory's historical horizon, with theorists treating information technologies as if it were exclusively a twentieth-century phenomenon.[5]

3.2.2 The "Canadian school": a pragmatic shift

Before the 1960s, most media analyses focused on specific platforms and treated them as independent and distinct cultural phenomena — e.g. radio, and concentrating almost exclusively on the contents and form of the messages conveyed through them. Their preferred topics involved reception, ownership, audience manipulation,

[4]Like radio, TV allows even illiterate people to have instant and simultaneous access to information in apparent privacy (Nerone 2003); unlike radio, TV makes the experience audiovisual and — contrary to cinema — individual. Such unprecedented level of reach and the engagement it elicits induced many theorists to believe that, in the future, communication would be overwhelmingly visual and that writing had its days counted, as it would stop being the primary source and driver of culture. But while audiovisual platforms have indeed become an even more powerful and ubiquitous presence in our post Internet culture, they have hardly displaced writing. If anything, our latest information technologies have increased the use of text in human communication, thanks to email, forums, messaging services (SMS, WhatsApp, Snapchat, etc.), social and content platforms, etc.

[5]To their credit, some of the most important figures in the field recognised the historical nature of information technologies, particularly the role of writing in the development of human communication and thinking.

political schemes, propaganda and criticism of dominant discourses and ideologies.[6] Whereas the "material" aspects, such as the technological infrastructure and specialised knowledge that allowed media to exist and function *as* media were usually taken for granted and thus rarely analysed. The so-called Toronto School of Communication Theory (see Introduction by Enns in Krämer 2015) or Canadian School of Media Theory,[7] whose most prominent figures were Harold Innis[8] and Marshall McLuhan,[9] was perhaps the first group to call into question the content-centric approach. The Canadian School proposed a (pragmatist) hermeneutical outlook that privileged the analysis of the historical, economic, psychological, and more important, the *technological* underpinnings of media. In short, this strain argued that to understand media it was necessary to understand its history and workings as sociotechnical systems.

Harold Innis was trained initially as an economist. Shortly before his death in 1952 he published two seminal works for media theory: *Empire and Communications* and *Bias of Communication*. In these books, Innis made one of the first attempts to interpret world history in terms of the development of different communication systems (Winthrop-Young and Wutz 1999, xiii).

As Innis saw it, communication technologies are a determinant factor in human affairs because they have the power to trigger new practices and ways of living (Laughey 2007). Oversimplifying, Innis contended that the crucial aspect of communication was the type of *medium* used and not the content that was conveyed (2007). In other words, what mattered was not that which was being communicated, but *how* — through which means. Innis resorted to historical events to support his claim; noting, for example, how the arrival of the printing press set in motion profound socio-cultural changes by eliminating the Clergy's monopoly on writing, and thus on the storage, reproduction, and circulation of knowledge (2007, 32–33).

For his part, Marshall McLuhan, Innis' junior and professor of English Language, developed a psychologistic interpretation of the cultural and historical effects of communication technologies. McLuhan correlated the history of media, which he saw as a teleological progression, with various stages in human cognitive development. Like Ernst Kapp before him — see Chapter 2, McLuhan conceived technologies primarily

[6] Such as the work of scholars associated with Richard Hoggart (1918–2014) and, eventually, with the Birmingham Centre for Contemporary Cultural Studies (Krämer 2015).
[7] A Moniker that may be attributed to Friedrich Kittler (Friesen and Cressman 2012).
[8] 1894–1952
[9] 1911–1980

as bodily "extensions" (hence the subtitle of his landmark book) which affected not only human physical abilities but also our intellect. This recognition of the "formative" (epistemological) power of technology was McLuhan's most important and "provocative" contribution to media theory (Coyne 1997). Moreover, in a true pragmatist move, McLuhan portrayed writing as one among many other technologies and, more important, he called into question its purported privilege as an epistemic device.[10] He saw the "electronic age" as a turning point in history, where the social and cultural hierarchies imposed by the dominance of writing were finally subverted (1997).

McLuhan's views were deeply in tension with the rationalist model that hitherto dominated media analysis. By arguing it was the "engineering" (technological) as opposed to the human (discursive, ideological) aspects that determined the workings of media he upended the humanities' traditional model. Instead of characterising technologies (media) according to the traditional view — i.e., as simple neutral means-to-an-end and as vessels of ideology — he portrayed them as active influencers of human conduct and world experiences. Understandably, McLuhan's pragmatist challenge was met with strong criticism from his colleagues (Peters 2015), particularly from those in the more anthropocentric Anglo-American tradition of cultural studies. His emphasis on the socio-cultural role of technology and his disregard for the human question led many of his critics to accuse him of endorsing "technological determinism."[11] McLuhan's media philosophy, according to (Coyne 1997, 47) points away from rationalism and towards pragmatism. However, across the Atlantic, in Germany, a similar technologically centred approach to media began to gain traction in the decades following McLuhan's publication of *Understanding media*.

3.2.3 Kittler and the German "media science" tradition

In post-war Germany, the first media analyses were heavily influenced by the German hermeneutical tradition and by the Frankfurt School's critical theory framework. In the 1970s, the second generation of media theorists began to distance themselves from these approaches and, with a mixture of French poststructuralism, American pragmatism, and early philosophy of technology, develop what would become the technocentric German school of "media science" or *Medienwissenschaft* (Winthrop-Young and

[10]In other words, McLuhan privileged "maker's knowledge" over "user's knowledge" — see Chapter 2.
[11]In the words of Val Dusek, technological determinism refers to "the claim that technology causes or determines the structure of the rest of society and culture" (2006, 84).

Wutz 1999). The most influential theorist from this generation was arguably Friedrich Kittler,[12] who developed a distinctive style of "media discourse analysis" (1999, xvi) strongly influenced by Foucault, Lacan, McLuhan and Heidegger. Oversimplifying, Kittler's goal was to reformulate media theory by steering the discipline's focus away from the usual literary and humanistic subjects and towards a historical and practical consciousness of technological logic. Like McLuhan, Kittler's approach was more pragmatic than rationalist; his analyses privileged engineering and celebrated what Kelly (1998) has called the "nerd culture" (see Chapter 1), emphasising the role of media technology pioneers such as Edison. Along with American pragmatism, Kittler's views on technology echoed those of German philosophers such as Ernst Jünger[13] and Heidegger (Winthrop-Young and Wutz 1999). To paraphrase John Peters (2015, 25), Kittler regarded media as world-enabling infrastructures, as *ontological shifters*, not as passive vessels of content.

The key to understanding Kittler's techno-centric approach rests in the long German tradition of technological reflection spanning from Johann Beckmann to Heidegger, but also in the way poststructuralism entered German academia. Unlike the United States, where "French theory" was publicly endorsed and repurposed by leading academic figures,[14] the more conservative German scholarly establishment was less welcoming. There, Derrida's deconstructionism was often denounced as an unoriginal (and dangerous) rehashing of the German hermeneutical tradition (Winthrop-Young and Wutz 1999, xvi). So it was in the periphery of German academic life, where Kittler stood at the time, rather than in the centre that poststructuralism began to exert its influence (1999). But whereas in the Anglo-American world poststructuralism led to the development of cultural and media studies approaches that placed human practices at the centre of their concerns, Kittler and his colleagues promoted the *exact opposite* approach. Proceeding from the techno-centric insights of early German philosophers of technology, Kittler repurposed the French model to deconstruct Western cultural development according to a teleological narrative of "media technology".

Kittler developed "a style of media analysis that could transversally join the themes and

[12]1943–2011
[13]1895–1998
[14]In 1966, the Johns Hopkins University, in Baltimore, organised a conference with the leading French intellectuals of the day, such as Roland Barthes, Jacques Derrida, and Jacques Lacan, amongst others. This event had enormous influence in the development of American cultural and literary studies in latter decades (Cusset 2008). And, incidentally, it would shape the outlook and preoccupations of contemporary theorisation about art and its language, which Rule and Levine (2012) christened "International Art English".

methods of literary criticism, psychoanalysis, philosophy, and electrical engineering" (Geoghegan 2013, 68). Like McLuhan, Kittler correlated cultural practices and historical transformations with the evolution of various information technologies. And also like McLuhan, Kittler did not think of media theory as one more interdisciplinary field, but as a kind of metafield which "could reorganize and engulf all the others" (Peters 2015, 26). It was this grand plan for *Medienwissenschaft* that led Kittler to famously begin the prologue of *Gramophone, Film, Typewriter* by arguing that "Media determine our situation" (1999, xxxix). A comment that led scholars associated with cultural studies to denounce him as an apologist of technological determinism.

In hindsight, however, the Canadian and German "materials" approaches had two important shortcomings. The first one was epistemological: for Kittler, the arrival of the PC and the resulting convergence of previously distinct supports into one "metamedium" implied not only the erasure of differences between various media (1999) but the end of history as previously known. For Kittler, digitisation and the consequential transformation of communication supports into undifferentiated information implied a *non plus ultra* for media and historical development as hitherto known.

The problem with these type of eschatological arguments is, as cultural historian Bernard Geoghegan notes, that "they don't leave you with much to talk about once history has come and gone" (2013, 68). Indeed, Kittler and his followers did not have much to say about media and its socio-cultural impact after the information revolution[15] of the early twenty-first century. The second shortcoming was blatant eurocentrism: Because in Kittler's narrative socio-cultural practices are dependent on the teleological development of *Western* technology, non-western societies, their practices and experiences are *de facto* taken out of this narrative's spotlight.

3.2.4 Contemporary trends in media theory, from remediation to Software Studies

Notwithstanding McLuhan's techno-centric views, the Anglo-American media studies and cultural studies schools have been historically wary of mass communication technologies. Heirs of a long tradition that regards visual images as entities which, if

[15] To his credit, shortly before his death Kittler (2009) did call for the need to develop a new ontology of media capable of dealing with the metaphysical changes introduced by computational technology.

not properly scrutinised, are capable of manipulating and even hindering human perception of reality, their analyses emphasised the sociological and political (mis)uses of so-called "media technologies". Although aware of the ontological shifts introduced by digitisation; these theoretical approaches continued to analyse computational objects in the same terms they analysed analogue media. In other words, they saw "new media" merely as an (exacerbated) continuation of "traditional media". This continuity is the core assumption behind J. D. Bolter and R. Grusin's (2000) concept of "remediation".

Remediation

According to Bolter and Grusin (2000), throughout the history of Western representation media have always promised immediate access to reality while simultaneously concealing their intermediation. In other words, all media "seek to put the viewer in the same [psychological] space as the objects viewed" (2000, 11), performing a kind of permanent *Trompe-l'oeil*. This is what they call the "double logic of remediation". Remediation is a recursive process of abstraction from reality, which did not begin with the arrival of digital technologies, for these represent only the most recent stage in a process that has spanned centuries of Western representational technologies.

For Bolter and Grusin (2000, 273) computational technologies merely "import" earlier media (their language and appearance) into a "digital space". Since analogue media have done this for centuries, the only transformation they see is methodological; that is, "new media" merely present the same content and fulfil the same roles as "old media" but through a different process. New media thus coexist but do not entirely substitute "old media"; rather the two engage in mutual cross-fertilisation. For Bolter and Grusin, "what is new about new media is also old and familiar: that they promise the new by remediating what has gone before" (2000, 270). As a result, they contend that characterising computational media as more than a simple remediation is but a symptom of Modernism's unresolved obsession with newness (2000, 270). They conclude that a true novel medium would be one "that did not refer for its meaning to other media at all" (2000, 271).

Bolter's and Grusin's tepid characterisation of the new media revolution is in many ways a more equanimous response to the changes introduced by ICTs. Particularly when compared to other more pessimistic and apocalyptic interpretations. However, while admittedly "old" and "new" media continue to exist and mutually inform each other, denying an important transformation in representational techniques is more than a little obtuse. Almost two decades ago, when Bolter and Grusin published their views, the Internet had only begun "taking shape as an established news medium alongside television, radio, and the press" (2000, 267). Therefore, to a certain extent, we cannot blame them for their lack of enthusiasm and their inability to foresee the extent to which not only the Internet but the information revolution in general, have transformed the way we conceive both media and reality. Bolter and Grusin's account is particularly lacking in any analysis of the technical aspects involved in the emergence of "new media". It is precisely this gap that other, newer approaches in media philosophy address.

Software Studies

One of the most important developments in media theory in the last decades has been the emergence of Software Studies (Truscello 2003). Kickstarted by Lev Manovich's publication of *The Language of New Media* (2002), this new school of thought contends that to truly understand new media it is imperative to enlist the help of computer science. For it is in this field that the categories and concepts that characterise computational aesthetic objects originate. Consequently, software studies challenge the humanities' longstanding disregard for this particular kind of technical knowledge.

Like McLuhan and Kittler before, scholars in the software studies school emphasise the material underpinnings of contemporary media. As Bolter and Grusin, this strain of media theory recognises a historical continuity in the formal aspects of representation, as software simulates, borrows and reinvents the look and feel of analogue media. Software studies do not interpret digitisation as the collapse or the end of media (as Kittler does), nor as a mere refashioning of old media as Bolter and Grusin suggest. Software studies see the new digital "metamedium" as a melting pot where, thanks to the transfiguration of matter into (ontologically) indistinct packets of data structures and instructions, "hybridisation", "divergence" and "modularity" (Manovich 2013) become the new formal, aesthetic, and stylistic norms.

Software studies is a pragmatist approach; its leading proponents are not media theorists, but practitioners trained in computer sciences yet highly attuned to a humanistic outlook. These scholars do not only analyse, but *make* media; having "hands-on" knowledge of computation and software, they are keenly aware of the true possibilities and limitations of this technology. Their analyses are therefore less susceptible to the kind of speculation and apocalyptic futurology found in many critical theory accounts. Software studies proponents see computational technology as something already *embedded* within human culture, as a phenomenon with a history, and which exerts a direct impact on everyday human social affairs. More important they reject the notion that digitisation equals dematerialisation. Their general take on technology is considerably more optimistic than other approaches within the humanities. In many ways, software studies are the logical conclusion of the techno-centric branch of media studies that the Canadian School initiated, and it shares some aspects of contemporary philosophical understandings of technology, which have also been heavily influenced by the maker's knowledge tradition. One of such approaches is *postphenomenology*, a humanistic, yet pragmatist approach to technology.

3.3 Postphenomenology

In the previous chapter, we saw that two major representatives of the maker's knowledge tradition are phenomenology and pragmatism. To recapitulate, both philosophical styles date back to the late nineteenth and early twentieth centuries, and both have been quite influential for twentieth-century philosophy; phenomenology in the "continental" tradition, and pragmatism in the "analytic" tradition. Both phenomenology and pragmatism reject the Platonic distinction between *epistêmê* and *technê*, and contrary to Platonist schools, they privilege practice over theory. Both traditions also reject the sharp (rationalist) distinction between object and subject. Finally, they both understand phenomena as *constructions* that arise from our daily interaction with the physical world; hence, they argue that knowledge cannot exist detached from some form of practical (technological) implementation.

While both phenomenology and pragmatism regard technology as something that exerts a powerful and inescapable influence over the way humans experience and understand the world, the conclusions they draw from human–technology relations are markedly opposed. Phenomenology's general attitude towards technology was notoriously pessimistic, whereas pragmatism's stance is substantially more optimistic. The origins of this tension rest mostly in the way each tradition conceives knowledge and being. Phenomenology's primary goal is to elucidate how and why we experience "phenomena" (i.e. the "things" that arise dialectically from the interaction of subjectivity and objectivity) the way we do, but also to understand what is their *ultimate* nature. Conversely, from the outset pragmatism sees phenomena — particularly those related to meaning, knowledge, truth, and being — as the products of everyday conventions and of the context in which we experience them. In other words, while phenomenology seeks to understand the essence of things, pragmatism completely rejects the possibility of anything having any essential feature beyond those being manifested within emergent contexts and practices. Phenomenology's continental origins made it go virtually unnoticed in the Anglo-American philosophical world for the better part of the twentieth century. But since the late 1970s and early 1980s some American philosophers gained interested on phenomenology's pioneering work on technology, and particularly on Heidegger's contributions. Ihde[16] is perhaps the most influential figure of that generation; mostly because he is credited with developing a pragmatist, "posthumanist" (Gualeni 2014) reformulation of phenomenology, which he called *postphenomenology*. The key aspects of Ihde's methodology will be discussed in the following section.

3.3.1 What is postphenomenology?

Postphenomenology is a philosophical "style" (Ihde 2015) of analysis that focuses on human–technology relations (Rosenberger and Verbeek 2015). Postphenomenologists seek to understand how technologies "shape our choices, actions, and experiences of the world" and, consequently, how they "inform our politics, ethics and understandings of the basic features of our everyday experience" (Rosenberger and Verbeek 2015, 1). Postphenomenology stands between the "engineering" and the "hermeneutical" traditions of philosophy of technology (see Chapter 2).[17] According to Ihde (2009a, 23), postphenomenology may be regarded as a "hybrid phenomenology" that borrows some notions from its cousin, pragmatism; namely, an anti-essentialist stance and the rejection of absolute claims concerning the foundations of knowledge and reality. Postphenomenology may also be regarded as a (weak) kind of *posthumanism*[18] (Gualeni

[16]Born in 1934.

[17]Although for Mitcham (1994), postphenomenology is more tilted towards the engineering side.

[18]To the best of our knowledge, there is not a consensus definition of posthumanism. However, as Neil Badmington notes, the term:

> marks a careful, ongoing, overdue rethinking of the dominant humanist (or anthropocentric) account of who "we" are as human beings. In the light of posthumanist theory and culture, "we" are not who "we" once believed ourselves to be. And neither are "our" others. (Badmington 2011, 374)

For further reference on the subject, philosopher Tamar Sharon (2014) provides a rather extensive mapping of various strains of posthumanism.

2015),[19]. Nonetheless, postphenomenology generally keeps its distance from stronger *transhumanist*[20] positions (e.g. Kurzweil 2005) since it rejects the idea that human ontologies may be entirely transcended and that we can experience the world through anything but a human mindset (see Section 3.3.3 below).

Postphenomenology has an ambivalent relationship with classic phenomenology. On the one hand, it embraces phenomenology's emphasis on human experience as the source of knowledge; on the other, it rejects its monolithic and pessimistic conception of technology. Postphenomenology continues to endorse the belief that humans and external reality are not independent, pre-given, and stable, but mutually constituted, influenced and thus permanently subject to change. Postphenomenology rejects phenomenology's romantic idealisation of a technology-free past, arguing instead that technology is a fundamental component of what it means to be human. Therefore, instead of regarding technoscience (see Chapter 2) as something that alienates, hampers, or constrains the human outlook on the world, postphenomenology embraces technological mediation as a fundamental and thus inescapable feature of human knowledge. While phenomenological interpretations approached technology in abstract monolithic terms, postphenomenological analyses stress the heterogeneous nature of technological systems and the need to account for their context of use and particular material implementations. In short, postphenomenology renounces phenomenology's armchair generalisations about technology (in singular) developing original analyses of the interaction between specific *technologies* (in plural) and their human users.

Postphenomenology's pragmatic stance has led some philosophers to describe it as a kind of "empirical philosophy" (Rosenberger and Verbeek 2015, 30). However, unlike the social sciences, phenomenology does not seek to *explain* human behaviour, nor to describe the world at large in light of a grand, ultimate ontology — as classic phenomenology attempted to. Phenomenology's goal is *understanding* how human beings construct and relate to our world(s) and phenomena through technological mediation (2015). Postphenomenology stands in line with the Kantian tradition, which argues that *immediate* access to Nature in its ultimate form is unattainable[21] since it is us who

[19]Philosopher and video game designer, Stefano Gualeni (2015) describes postphenomenology as a posthumanist take on phenomenology.

[20]The term "transhumanism" was originally coined in 1957 by evolutionary biologist Julian Huxley (Sharon 2014). More radical than posthumanism, trashumanism advocates the improvement of humans at all levels, including the transcendence of our biological limits (2014, 25). A full account of this movement can be found in (More and Vita-More 2013).

[21]Postphenomenology endorses the Kantian framework, but rejects a distinction between object and subject.

shape it and, in turn, are shaped by it.[22] For postphenomenology, ontological commitments are always in flux and dependent upon historical and cultural circumstances, because human subjectivity and external reality and phenomena are mutually constituted. Overall, postphenomenology incorporates many of the shifts that marked twentieth-century philosophical reflection; and its theoretical approach is coherent with the general trend towards a new pragmatic epistemology discussed in Chapter 2.

3.3.2 Postphenomenological methodology

Like media studies, postphenomenology follows an interdisciplinary model; therefore, it is difficult to describe its methodology in strict terms. Nonetheless, it is still possible to identify at least two features that are common to every postphenomenological analysis. The first one is an emphasis on human–technology relations and how they alter and shape our relationship with the world. In other words, all postphenomenological analyses assume technological systems are first and foremost *mediators* (Rosenberger and Verbeek 2015). The second feature is a reliance on empirical research. Thus, instead of applying *a priori* philosophical models to elucidate the nature and dynamics of technology, postphenomenologists begin by observing the *actual* usage and context of a given technological system and only afterwards attempt to elucidate its influence over human experience (Rosenberger and Verbeek 2015; Ihde 2009a; Achterhuis 2001). Next comes an overview of postphenomenological methodology.

3.3.3 Relational ontology and multistability

Postphenomenology endorses a *relational ontology* (RO) which rejects any pre-given conception of either technologies or the humans using them. RO's central underlying assumption is that human subjectivity and worldly objectivity are mutually constituted[23] through technological mediation. The main argument being that through constant usage technological systems shape and transform our experience (perception, interpretation, etc.) of the world and, consequently, they have a strong, active influence over our self-understanding (Ihde 2009a, 44). In this respect, RO is closely related

[22]Media historian John Durham Peters puts it best when he notes that "[w]e are conditioned by conditions we condition. We, the created creators, shape tools that shape us." (Peters 2015, 51)

[23]Relational ontology condenses that which Floridi (2010) describes as the "extrinsic" and "intrinsic" changes introduced by great scientific revolutions — see Chapter 1.

to *Actor–Network Theory* (ANT), a model whose chief proponent is French philosopher Bruno Latour[24] (1987, 1993), albeit with some important distinctions.

Oversimplifying, ANT portrays the world as a network of relations between human and non-human "actants" who share a *symmetrical* relationship with each other. Consequently, ANT does not make any fundamental (ontological) distinction between human and non-human entities. This "continuity" allows those who follow ANT to explain away how non-human actants may have agency and influence in concrete and social terms (Rosenberger and Verbeek 2015). In contrast to ANT'S stronger posthumanist stance, postphenomenology's RO is more anthropocentrically conservative. For RO there are fundamental distinctions between humans and non-human entities, insofar as, to the best of our knowledge, only humans have the reasoning and intentionality required not only to act but to *be* humans. Furthermore, postphenomenology contends that our conception of the world is intrinsically and irrevocably constrained by our human mindset. The reason being that however far we stretch the limits of our understanding we cannot be, nor think, nor experience anything as other than human beings,[25] regardless of what we understand by this continuously evolving term.[26] Therefore, for RO the question is not whether non-human entities can have direct agency independently of a human being (clearly they do not) but what roles they play in human agency (Rosenberger and Verbeek 2015).[27] In summary, for postphenomenology, technologies only have epistemological and ontological power when and *if* human beings are involved and wielding them.

Multistability

RO is also the reason why postphenomenology sees technologies as necessarily *multistable* objects. Multistability is a concept inspired by Gestalt psychology; it refers to the fact that any given technological appliance can be phenomenologically "stable" —

[24] Born in 1949.

[25] Philosopher Thomas Nagel (1974) makes a compelling case on this respect in his famous article "What is it like to be a bat?".

[26] In fact, one could argue that the entire posthumanist project consists precisely in formulating and reformulating what it means to be human. For a thorough discussion of these ideas see Gualeni (2015).

[27] The growing presence of algorithmic systems in our lives and the fact that non-human computational tools increasingly aid their development may provide a strong argument against this idea. Nonetheless, we should not forget that, at least for the time being, both the development of algorithmic systems and the responsibility of using them still falls mostly on human agents and institutions.

i.e. can be coherently experienced — in a variety of different, albeit finite, manners and contexts. In short, independently of its original purpose, any technological system can be regarded and used in entirely different ways.[28] Granting that any technological appliance may be "many things at once" (Verbeek 2005, 112) implies accepting that the ultimate nature of technologies is *necessarily* undetermined. Multistability thus offers a strong argument against essentialist definitions of objects. However, this indeterminacy also implies that to be understood in depth technologies need to be placed in the context of specific human practices, for without human involvement any artificial object becomes nothing but mere "junk lying about" (Ihde, cited in Verbeek 2005, 112). Context-dependency also constraints the range of applications of any given technological instrument, for it is clear that we cannot merely do *everything* with any given device, no matter how multistable it might be.

3.3.4 Human–technology relations

Postphenomenology is not interested in classifying technologies but in understanding the type of relationships we establish with them and how these, in turn, affect our everyday experiences. In the last decades of the twentieth century, Don Ihde, the initiator and leading proponent of postphenomenology, identified what he thought of as the four most frequent types of human–technology relations (Rosenberger and Verbeek 2015). His classification, however, was by no means exhaustive and only applied to static or passive instruments. In the decades since, development in ICTs and particularly in computational technologies, has given rise to whole new sets of relations that fall way beyond Ihde's original classification but which are nonetheless being addressed by a new generation of postphenomenologists (Rosenberger and Verbeek 2015; Verbeek 2011). Ihde's original classification comprised relationships of embodiment, hermeneutic mediation, background transparency, and alterity.

Embodiment relations

An embodiment relation occurs whenever we see the "world" *through* a material artefact that has been incorporated "*into our very bodily experience*" (Ihde 2009a, 44). Embodied relations are symbiotic, the type we have with spectacles, binoculars, hearing aids,

[28] Take for instance a hammer, although it is an object designed to drive in nails and pull them out, in certain hands, it can become a weapon.

gloves or even hats; artefacts which shape and sometimes determine the range of our sensory apparatus.

Whereas ordinary technological mediation may be formalised as follows:

Human — Technology — World

Embodiment relations are represented as such:

(I — Technology) ⟶ World

Related to the notion of embodiment is *transparency*, i.e., the degree to which the artefact in question (e.g. a pair of spectacles) "fades" to the background of our awareness (Rosenberger and Verbeek 2015). Transparency depends on how accustomed the user is to the artefact but also on the context of use. As with all human–technology relations, embodiment involves mixed degrees of magnification and reduction of experience. For example, binoculars significantly extend the natural limits of our eyesight, but they do so at the expense of our peripheral view.

Hermeneutic relations

Hermeneutic human–technology relations are those which involve an *active* interpretation of the technology itself or its output (Rosenberger and Verbeek 2015; Ihde 2009a). This is the type of relation we establish with visualisation technologies but also with those that enable us to conceive, represent and quantify physical phenomena such as temperature, time, humidity, etc.

Hermeneutic relations may be formalised in the following manner:

I ⟶ (Technology — World)

Examples of artefacts to which we relate in a hermeneutical manner are clocks and thermometers; but also fMRI scans, X-rays plaques, heart monitors, etc. Most of these technologies prioritise visual interaction, but there are also those which depend on audible cues or a mixture of both, such as car alarms, smoke detectors or Geiger counters. The oldest technology with which we establish a hermeneutic relationship is writing. As it happens with written and spoken language, hermeneutic relationships with technologies involve a certain degree of fluency and familiarity with the device and its "readout" (Rosenberger and Verbeek 2015) or output; the complexity of which may vary from straightforward to complex. For example interpreting time, temperature or what the sound of an alarm stands for are relatively simple tasks; whereas operating and interpreting the output of a fMRI or an X-ray[29] involves a more complex set of skills. And the higher the skill required, the higher the transparency of the hermeneutic relationship that may be established.[30]

Background relations

Within industrial and postindustrial societies technological systems are so ubiquitous they effectively blend into the environment. Highways, roads, cars, houses all the appliances humming inside them such as refrigerators and air conditioners make up the *background* of our daily life. The type of relation we establish with these devices is different from the ones previously described. In a background relation, technological systems do not fade entirely from our perception, nor they become integrated with it; instead, they become "the backdrop of our experience" (Rosenberger and Verbeek 2015, 19). These technologies are in part responsible for the noises, sights, and smells of our daily lives. Background relations shape our conception of the world without requiring direct (conscious) interaction.

Alterity relations

Alterity relations are the ones established with technologies that resemble or mimic human interactions (Rosenberger and Verbeek 2015). "Robots" are surely the most immediate examples (Ihde 2009a, 43); however, strong Artificial Intelligence (AI) is not a prerequisite for this type of relation. Many of our daily interactions with technology fall within the alterity category. From a simple cash withdrawal at an ATM to

[29] X-rays are an interesting example since the images on the plaques are often quite straightforward (a broken bone) but sometimes require a specialists interpretation (e.g. to identify a tumour).

[30] For example, a highly experienced fMRI technician would manipulate this machine in such a way that it would seem second nature to her.

asking our mobile phone for directions, our relationship with "a-live" appliances is likely to become more ubiquitous and sophisticated as ICTs continue to evolve. Of all the different human–technology interactions described, this one requires significantly more refinement and updating,[31] that is why in recent years new generations of post phenomenologists have come up with categories that better reflect ongoing technological changes.

3.4 Constructionism

In the previous chapter we saw the maker's knowledge approach is partially rooted in the Aristotelian-Scholastic tradition which, amongst other things, postulated that truly knowing something implies understanding the underlying causes that bring that something into existence (Floridi 2011d). Knowledge, therefore, involves not merely knowing *that* something is the case but *why* and, more important, it implies being able to reproduce and employ that knowledge in a practical manner. It follows that, for the maker's knowledge tradition, we can only know the true nature of the things that we can build or model. This posture is related to the (Kantian) notion that humans have not created Nature and therefore we cannot know it in itself. It also follows that our access to reality is always partial and will always be conditioned and filtered by the apparatuses (physiological, cognitive, or otherwise) through which we experience it. Nonetheless, there is nothing that prevents us from improving our knowledge of Nature and reality and mitigating the limitations mentioned above; in fact, we regularly do so by *constructing* new conceptual or technical devices.

3.4.1 What is constructionism?

Like pragmatism, phenomenology, and postphenomenology, *constructionism* — with an "*o*", not to be confused with "constructivism", with a "*v*" — is rooted in the maker's knowledge tradition. Also, like pragmatism and phenomenology, constructionism is not a branch of philosophy, but a perspective, or "style". Constructionism may be better conceived as both a "general metaphilosophy" (Floridi 2011d) and a specific method of analysis. But unlike postphenomenology (which focuses on science and technology

[31] One of the main obstacles postphenomenology faces when it comes to addressing alterity relations is its steadfast anthropocentric perspective, which limits its ability to deal with the potential ontological problems that may accompany the arrival of strong AI.

studies (Ihde 2015) and in particular on human–technology relations) constructionism's main concern is epistemology and learning. Above all, constructionism emphasises making things as a crucial aid to learning, this along with emotional involvement in the process and tinkering are its tenets (Papert and Harel 1991) Papert's constructionist learning theory was highly influential for Alan Kay (1972), the pioneer of Object Oriented Programming (OOP) and the Graphic User Interface (Manovich 2013) — see Subsection 5.4.3. Constructionism is a key component of Luciano Floridi's *philosophy of information*. To understand how constructionism will contribute to further our understanding of computational technology and its products in this dissertation, it is necessary to discuss the philosophy of information. The following section will summarise the history, goals and methods of this new philosophical field.

3.4.2 The philosophy of information

Like contemporary philosophy of technology the philosophy of information is a recent field whose emergence can be directly attributed to the so-called "computer revolution". As was noted in Chapter 2, from a historical standpoint the potential of computational technology was first recognised and appreciated by the military, financial and scientific sectors. Only a few decades after the arrival of the first mainframes and with the promise of artificial intelligence (AI) some philosophers began to ponder the wider implications and the importance that computers would have in human life. AI served as a sort of "Trojan Horse" (Floridi 2011a, 3) to awaken a broader interest in computational issues within philosophy.

As computational research grew, new philosophical questions and methodologies emerged, and old problems came to be seen under a new light (2011a, 2). Philosophy of the mind, philosophy of language, philosophy of science, and the already mentioned philosophy of technology are some of the fields that were most impacted by this epistemological change. However, as Floridi notes, it took a few decades and a major revolution in communication technologies for institutional philosophy to realise that *information itself* could be in fact a subject around which a new philosophical branch could emerge. First perceived as a transdisciplinary subfield, such as cybernetics or semiotics, it was only at the turn of the century that philosophy of information indeed began to take shape (2011a, 6).

As it stands today, the primary objectives of philosophy of information are (a) to investigate "the conceptual nature and basic principles of information, including its *dynamics*,[32] utilization and sciences"; but also (b) "the elaboration and application of information-theoretic and computational methodologies to philosophical problems" (2011a, 14). In other words, the philosophy of information regards information not only as a phenomenon and a pretext for philosophical enquiry but also as a conceptual tool.

While the philosophy of information incorporates many concepts from computer and information sciences — such as Formal Methods — it should not be confused with quantitative "information theories" — which will be discussed in Chapter 4. Contrary to some of these theoretical approaches, philosophy of information does not seek to develop an all-encompassing theory of information. Instead, it aims to develop "an integrated family of theories to investigate the various principles and concepts of information" (2011a) grouped around the core notion of *factual semantic information*. Metatheoretically and methodologically, the philosophy of information is driven by a constructionist epistemology and therefore it "takes seriously the view that the maker's knowledge is the right approach from which to interpret all expressions of human knowledge, from our empirical interactions with the world to the self-reflective interpretation of our epistemology" (Floridi 2011e, 294).

3.4.3 The tenets of constructionism

Contrary to platonic and rationalist traditions constructionism argues that knowledge is not acquired by "passively recording reality" but by "hand[ling] it interactively" (Floridi 2011d, 291). In other words, it holds that knowledge is not a mimetic but a creative (*poietic)* enterprise. Like pragmatism and phenomenology, constructionism is strongly aware of technological mediation and its role in human cognition. For constructionism, our understanding of nature and reality does not come through individual discovery, as rationalism postulated, but it is rather collectively built and modelled by our conceptual frameworks and everything that supports them — including our technological systems. The constructionist view is rooted in the beliefs that (a) "genuine knowledge is knowledge of the intrinsic nature of the object known" (2011d, 290), that (b) there is no innate acquisition of said ontological "blueprint", and (c) knowledge of any phenomenon or object implies being able to account for its origins. That

[32] Meaning the "constitution and modelling of information environments", the information life cycles, and computation.

is to say, to borrow Floridi's (2011d, 290) words, that truly knowing something implies being able to produce and reproduce that something, being able to assemble and disassemble it, to improve it, transmit it, and answer questions about it.

Constructionism holds that knowledge involves not only intellectual reflection but mostly practical implementation. Knowledge thus becomes a matter of *designing and engineering concepts* and models which, in turn, shape our understanding of that which we call reality. Therefore, constructionism's central task is "soldering together the Platonic dichotomy between human making [*technê*] and divine making [*epistêmê*]" (2011d, 292). Constructionism's core presumption is that acquiring and analysing knowledge requires not only having the information that "something is the case", but also being able to provide a correct (logical, justifiable, factual) account of why that is the case (2011d). To paraphrase Floridi (2011d, 291), constructionism ultimately holds that we acquire knowledge by *building* the right type of "semantic tools" (concepts), and we do that by actively *modelling information*. Constructionism is therefore not only a pragmatic approach for solving specific philosophical problems, but a general outlook that understands philosophy in general as *conceptual engineering*.

3.4.4 The constructionist methodology of philosophy of information

As a specific methodological approach, constructionism, along with the principle of *minimalism* and the *method of levels of abstraction* (LoAs) make up the core of Floridi's approach to the philosophy of information. Oversimplifying, minimalism demarcates the scope and depth of the "problem space" opened by the philosophical question or problem under scrutiny, while the method of LoAs concerns the variables that are observed, the point of view from which they are seen, and how they are categorised.

Minimalism

The principle of minimalism establishes the criteria that should be followed to choose an adequate starting point to address a given philosophical problem, as well as the corresponding model. Philosophical or not, most complex problems are more easily approached when they are broken down into smaller, interrelated, sub-problems; this resulting network is called the "problem space" (Floridi 2011d, 294). The larger problem space and its sub-problems are usually related to other problem spaces[33] since every philosophical question carries with it a variable number of presuppositions.[34] Consequently, the effectiveness of any potential answer to any starting question can be measured in terms of how well it addresses the corresponding assumptions behind the starting question[35] (2011d). Following the principle of minimalism implies choosing questions that are not overly dependent on other more complicated questions, "thereby strengthening the final answer to the [initial] philosophical question." (2011d, 294).

Addressing a problem also involves choosing a suitable conceptual, virtual, or physical *model*[36] to analyse it, and here too the principle of minimalism proves useful. To begin with, an adequate minimalist model is (a) controllable (b) implementable, and (c) predictable. Controllability means that a model is flexible and that its features can be customised or fine-tuned according to the circumstances where it is employed. Implementability means that the model can take practical form "usually through the description of conceptual mechanisms (e.g., thought experiments, analogies, logic constructs, ideal models, counterexamples), through virtual simulations, and rarely (in philosophy, through physical realizations." (Floridi 2011d, 294). In short, implementability means that a model works as a "conceptual laboratory" capable of testing the constraints of the problem under scrutiny. Finally, predictability implies that the agent is capable at all times of inferring the consequences of using the model (2011d, 295).

Minimalism should not be equated with simplicity since the most fruitful problems — however minimal they might be — are not necessarily the easiest ones to solve. Minimalism (like complexity) is not an absolute but a *relational* principle. This means that no problem can be entirely minimalist since its existence always presupposes the existence of — and thus a relation with — the larger problem space under scrutiny (Floridi 2011d, 295). The relational nature of minimalism gives this principle another methodological advantage: it helps its users avoid false dichotomies by privileging triangulation whenever boolean alternatives arise. This means that while problems are often framed in terms of black vs white alternatives, the principle of minimalism empha-

[33]It should be noted that sub-problems may also become problem spaces with sub-problems of their own.

[34]For example, if I ask "what is the nature of reality? I am presuming there is something called 'reality" and that it may be knowable; two presuppositions which are not only extremely complex space problems in their own right.

[35]Philosophers of science call this the "explanatory power" of a theory, and it is closely linked to its "predictive power".

[36]For a full account of this concept see Chapter 5.

sises the fact that *any potential answer to a given problem is necessarily related to the way the question is framed.* When faced with two alternative but opposed answers to a problem, minimalism helps to see them as two points that can potentially reveal the coordinates of a third, more conciliatory (dialectical) solution (2011d, 294–96).

The method of Levels of Abstraction

The method of levels of abstraction (LoAs) or, method of abstraction, is a tool that emphasises the fact that any problem space can be analysed through different, non-exclusive points of view. The method is heavily inspired by *Formal Methods,* a theoretical area within computer science that analyses information systems through discrete mathematics (Floridi 2011d, 296, see also 2011a, 52). Nonetheless, understanding the basic notions behind the method of abstraction does not call for any mathematical formalisation.

To begin with, the method of abstraction regards problem spaces as *systems*;[37] as sources of information which may be described and understood at different "granularities". These "levels of abstraction" (or LoAs) may be defined as: "finite but non-empty set[s] [or networks] of *observables*" (2011d, 297). For its part, an observable is "an *interpreted typed variable*, that is, a typed variable[38] together with a statement of what feature of the system under consideration it stands for" (2011d, 297). In other words, observables are "uniquely named conceptual entit[ies]" (i.e., physical or abstract features) identified within a system.[39] The same system may be analysed through different LoAs, and the result of each analysis is known as a *model*. LoAs and the resulting models may "coarse" or more finely grained when compared to each other; LoAs may be "nested, disjointed or overlapping and need not be hierarchically related, or be ordered in some scale of priority" (2011d, 298). For its part, a *theory* comprises at least one LoA and its corresponding model. Since the granularity of the LoA determines the observables within a system, it also determines the ontological

[37]According to Mignonneau and Sommerer (2006) there is no exact definition of system, however, all systems involve "autonomous particles or agents" whose interaction leads to "emergent collective properties, evolution, and critical behaviour that exhibits universal characteristics" (2006, 172).

[38]As Floridi (2011a, 48) notes, a variable "is a symbol that acts as a place-holder for an unknown or changeable referent" — for example, changes within a complex system are generally triggered by the interaction between different variables. In programming, variables associate names with "objects" or values of different types (e.g., an integer or a string). Declaring a variable of type string would be something like `colour = blue`, where "colour" is the name of the variable and "blue" is its corresponding string.

[39]Observables need not be empirically perceivable, since the system may be entirely abstract.

commitments of the theory.

A collection of LoAs is technically called a *gradient of abstractions* but may be understood as an *interface*. An interface here means an "intra-system" that bidirectionally transforms the output of one system into the inputs of another system, causing a change of data types in the process. A LoA is fundamentally a network of observables linked to features or behaviours attributed to the system. All LoAs thus stand in-between the information present within the system and the agent analysing it. Since LoAs are not necessarily mutually exclusive, nor inherent to any given system, they may become crossroads (nodes) where various independent systems are seen as interacting with each other. Because it contains various LoAs, an interface can be used to analyse the same system from various points of view, whether methodologically related or not. To put it in Floridi's words:

> Through a LoA, an information agent (the observer) accesses a physical or conceptual environment, the system. LoAs are therefore interfaces that mediate the epistemic relation between the observed and the observer (Floridi 2011a, 76).

3.5 Discussion

As explained in the (general) introduction this dissertation has two interrelated goals:

1. To provide an ontological account — a specification — of Computational Aesthetic Objects; that is, to show how computational aesthetic objects may be described and categorised in relation with non-computational ("traditional") aesthetic objects.

2. To further our understanding of the impact of information technology (via computational technology) on aesthetic practices.

Because accounting for every instance, every variation, every type of computational aesthetic object is unfeasible, the *method* proposed in this dissertation will be to analyse the *tool* responsible for creating them (the computer) — my assumption is that this approach can provide a general idea of what these objects might be and what differentiates them from other (traditional aesthetic objects) — *as a technological system*

As was also noted in the introduction, these two objectives are grounded on the (pragmatic) assumption that accurate understanding of a phenomenon implies knowing its causes. Since in this context the phenomena are *artefacts* — i.e., things deliberately produced by human art, understanding them means understanding the nature of the tools and processes that led to them.[40] Thus, to recapitulate, this dissertation seeks to understand computer-generated aesthetic artefacts by analysing the computer itself (its origins and its status as a technology) and how we relate to it as a tool, both as an information machine and as a tool for art. How this will be done and what role each one of the theoretical frameworks discussed throughout the previous sections will play in this process is the subject of this next section.

3.5.1 What about media, or why not (just) media theory?

As it was noted in section, when it comes to understanding ICTs and their impact over aesthetic practices, art scholarship has relied almost exclusively on the concepts, methods and general views of media theory. One of the arguments advanced by this chapter is that by turning media theory into the *de facto* style of analysis many art scholars have willingly limited their methodological toolkit and their capacity for understanding ICTs. This is not to say that media theory is inferior to other descriptive methods nor that it has not or cannot contribute to further our understanding of the cultural impact of ICTs. The problem is that by ignoring alternative frameworks or styles of analysis, art scholars have made themselves unable to go beyond media theory's descriptive power and understand its potential epistemic limitations. This results in analyses that unknowingly inherit many of media theory's conceptual and methodological biases.

Media theory may be seen as an extension of literary criticism, or rather, as the use of literary (and cultural) criticism tools and methods to analyse certain aspects of ICTs. It is, overall, an approach for interpreting the *outputs* of audiovisual forms of communication; specifically, although not exclusively, electronic ones. Media theory was amongst the first forms of cultural analysis to recognise the impact of ICTs and the need to critically engage them. Along with philosophy of technology, media theorists were also the first to acknowledge that technologies play a fundamental role in the ways humans relate to each other and the world. In other words that, technologies

[40] The belief that the fundamental character of a cultural product is indissociable from the technology that produced it, and vice versa, is the crux of Marshall McLuhan's well-known aphorism, "the medium is the message".

act fundamentally as *mediators*. Overall, media theory may be described as a form of hermeneutical speculation on the products of electronic ICTs.

Methodologically speaking, media theory's general outlook on technology is informed by late nineteenth and twentieth-century information technologies. As we saw earlier, media theory emerged as a critical response to television. The concepts and "problem spaces" opened by early media theory were thus heavily influenced (and to this day continued to be) by television's character as an audiovisual, unidirectional, passive, and ubiquitous medium. Media theory's emphasis on visual culture and its focus on the epistemological, cultural, political, and cognitive role of images can all be traced to television's language and cultural impact. Being so closely tied to twentieth-century ICTs implies that media theory has little to say about earlier forms of technology or about any appliances that cannot be effectively categorised as mass communication systems.

Media theorists tend to disregard conceptual clarity. With few exceptions (e.g. Gualeni 2015), the concept of media is hardly ever defined by its users, who seem to take the meaning of this word for granted. As noted above, depending on the context media may refer to "contents" (audiovisual products), technological appliances, institutions, or all of the above. This indeterminacy shows how "media" is more a pretext for theoretical speculation — a problem space — than an actual analytical category. The problem, however, is that most people use it as a means of classification, i.e. as a conceptual device which, to make matters worse, is constantly expanded through ad-hoc suffixes such as "new media", "hybrid media", "transmedia", "hypermedia", etc. Such lack of clarity is not only an epistemic obstacle that hinders true understanding of the objects under analysis but also evidences media theory's lack of metatheoretical self-scrutiny.

Media theory is notoriously multidisciplinary; this offers "media studies" flexibility and breadth of scope that not many fields enjoy. There is, however, a downside to this openness. It is common for media theorists to indiscriminately borrow and apply concepts from other disciplines with little regard for the potential epistemic compromises that accompany them.[41] This tendency undermines the methodological and epistemological strength of media analyses, leading to muddled interpretations of phenomena filled with impenetrable jargon and decontextualised conceptual misappropriations.

[41] That is how we find ourselves talking about "media archaeology" or about various species of "hybrid media".

Media theorists rarely care to make a clear distinction between "media" and the larger category of "technology". In fact, most media theorists use both terms interchangeably, sometimes implying the existence of some hierarchical or historical link between the two notions — e.g., when they speak of "media technology". The problem is that while all media are technologies, not all technologies may be adequately described as media, at least without resorting to complex mental gymnastics. Surely, all technologies stand "in-between" an agent and an affordance but not all technologies are channels or containers that afford meaning beyond their own matter-of-factness.[42] The majority of technological systems we encounter on a daily basis (from clothing to sinks and microwave ovens, to subway carts) are not generally described as media.

Media theory focuses on the audiovisual products of ICTs and not on these technological systems as a whole. While most media theorists embrace the belief that channel and content cannot be conceived nor analysed independently from each other, in practice, they rarely focus their attention on the technical aspects that allow a given technology to do precisely what it does. It follows that media theorists tacitly reaffirm the notion that technical knowledge is irrelevant for truly understanding a technology. In other words, and unbeknownst to its practitioners, media theory endorses the user's knowledge tradition.[43]

Given the previous shortcomings (dependency on medium, focus on content and disregard for technical knowledge, lack of conceptual clarity, failure to deal with systems), it is clear that in the context of this dissertation media theory does not provide a sufficiently adequate method of analysis. The objective here is to develop a broad ontological characterisation of the computer to gain a deeper understanding of the nature of computational aesthetic objects.

Computers are not just perfectly capable of simulating virtually every form of audiovisual manifestation, but they are also capable of controlling the temperature in a room, beat a chess grandmaster, help to land a robot in Mars or carry out hundreds of stock exchanges in seconds. Understanding computers requires more than one interpretation of their use.

[42]Surely one could make the case that any object could be transformed into a medium, particularly in the context of aesthetic practices. A circumstance this is especially true in the case of conceptual art.

[43]It is fair to note, however, that pivotal figures of media theory such as McLuhan and Kittler did take technicalities in high esteem, they were pragmatists, yet many of their insights are lost behind obscure analogies, oversimplifications and even gross overarching claims.

3.5.2 Why postphenomenology?

Given the emphasis it places on (technological) mediation postphenomenology shares some common theoretical ground with media theory. Nonetheless, there are some important methodological differences between media theory and postphenomenology. First of all, postphenomenology's scope of analysis is not restricted to ICTs but encompasses *all* kinds of technological appliances. Secondly, postphenomenology does not regard technological systems as "things-in-themselves" (Rosenberger and Verbeek 2015), i.e., as entities that may be classified according to some rigid and pre-given ontological framework that exists irrespectively of a particular human context of use. Thirdly, unlike media theory, postphenomenology does not imagine technological systems (just) as means of communication, nor as independent bodily (or cognitive) extensions or prostheses; but as products *and* producers of human experience, knowledge and identity.

Contrary to what some media theorists claim, technological development is rarely, if ever, teleological. More often than not technological systems *emerge*[44] not as a consequence of careful planning, but of sheer tinkering and serendipity. Some technologies are undoubtedly developed as a response to known specific problems, but the vast majority emerge in fact as "solutions waiting for a problem" (Taleb 2010). Consequently, not only the sociocultural impact but even the practical application of many technological systems may take years to emerge;[45] not to mention that often the uses and consequences of a given technology are far from what their creators expected. That technologies often fail to find a place in society right away may be owed to poor social or economic conditions, the absence of supporting infrastructure or sheer lack of imagination. In the end, the fact is that technological systems are *ontologically unstable*, meaning that from a methodological standpoint it is risky to approach them as if they could be readily categorised.

The continually evolving nature of technological systems and human inability to foresee all of their potential uses and social consequences are in part why *a priori* definitions and categorisations are rarely adequate. Any form of classification carries, implied ontological and epistemological commitments. Thus calling some appliance "me-

[44]The technical meaning of "emergence" is discussed in Chapter 6.

[45]For example, since their invention, it took decades for nitrous oxide and centuries for (dyethil) ether to be employed as anaesthetics (Holmes 2008). Lasers and masers not only stood waiting for decades before being employed in the myriad ways we find them today, but these inventions were initially dismissed by figures of the stature of John von Neumann and Niels Bohr (Kean 2010).

dia" promptly imposes a limit on all the possible ways in which we may understand a system and our relationship with it. By rejecting the idea that technologies have any human-independent essence and focusing on how we relate to and experience phenomena through them, postphenomenology evades these methodological limitations. In other words, the postphenomenological approach does not immediately impose a category onto its object of analysis but instead, by looking at its features and how it is employed by human beings in particular contexts it attempts to map a type of relationship. This methodological flexibility is particularly useful when dealing with technological systems that may have not only different applications but values and meanings for the humans employing them. Such is the case with both computers and computational aesthetic artefacts.

Postphenomenology constitutes a more flexible, yet rigorous method for approaching technological systems than media theory in its current state. Media theory generally proceeds by categorising a given type of audiovisual expression according to certain selected features. This often results in the creation of *ad hoc* categories that are often abandoned with every new technological development. Conversely, postphenomenology analyses the type of relationship one may establish with a given technological system and not with its products. As an example, a platform such as Twitter may be described in general terms as a communication appliance with certain possibilities (open, searchable, constant, broadcast) and limitations (in 280 characters at a time). But it is in how different agents exploit these possibilities and limitations that the qualities of this tool become evident. It is only in the way a troll, a journalist, a politician, an artist, an institution, or any other agent *relates* to this tool that it acquires meaning and purpose.

In the context of this dissertation one conceptual tool provided by postphenomenology is of particular interest, namely the idea that technologies are *multistable*. Recapitulating, multistability implies that virtually all technological appliances can have a (limited) range of uses and meanings depending on who is employing them and where. A hand axe, perhaps the oldest material tool available, could be used as a weapon or as a tool for building other tools. Multistability accounts for the flexibility of technology, explains the absence of essential qualities and underscores the importance of context and human involvement for our understanding of technological appliances. Multistability is a notion readily applies to the computer, by far the most versatile tool humans have developed; hence its nature must always be understood in relationship to the context where it is employed (in this case aesthetic practices).

3.5.3 Why constructionism and the philosophy of information?

Constructionism and the philosophy of technology offer not only a conceptual framework but also a method of analysis. To recapitulate, constructionism presupposes that human knowledge of phenomena is constrained by our physiological and cognitive limitations, but that it can be expanded and improved through technical (artificial) means. Knowledge that is true is actively acquired, collectively verifiable, reproducible, and above all, creative and practical. Humans do not (cannot) disclose, nor discover *the* ultimate *true* nature of reality, but construct more or less effective knowledge systems and models that account for and make sense of phenomena occurring against that "backdrop" we call "reality"[46] — to borrow Stefano Gualeni's words (2015). These models may or may not be mutually exclusive, they may be malleable and extendible, but they always depend on the network of assumptions, supporting data, points of view, and technical systems employed in their development. Models are also historically and culturally grounded, which means they are always potentially open to scrutiny and revision. That is why constructionism emphasises that asking questions — e.g., in our case, "what is the nature of computational aesthetic objects?" — is always done from a given level of abstraction, that is, from a given context, with a given point of view and while assuming a given set of beliefs.

In the context of this dissertation, constructionism will be employed in the two senses above described. To ask what are computational objects and to attempt to obtain a general (decontextualised) response is problematic. This is where the principle of minimalism comes into place. We can ask the question indirectly, and instead of attempting to build a category of objects with all the shifting qualities of computer-generated aesthetic artefacts we can instead look for their common denominator: the computer. To *truly* begin to understand the computer as a tool, also requires some contextualisation.

Understanding the computer as a tool does not end at the level of art. First, we need to assume we are dealing with a specific and yet multistable form of technology. Constructionism tells us that no single description explanation can exhaust the problem at hand, for it merely tackles one or more levels of abstraction. This means that to understand the computer in general, we need to look at it various granularities, and even so we may never exhaust all there is to this system. For this dissertation, the two

[46]The philosophy of information regards the ultimate nature of reality as informational, we cannot access pure information, but we can surely manipulate it

main levels of abstraction (LoAs) will be (a) the computer as an information machine, and (b) the computer as a tool for art. This initial setting will provide the conceptual basis for understanding why computer-generated aesthetic objects, as it is argued in the last chapter, constitute informational systems.

3.6 Conclusions

In this chapter, it has been argued that media theory is by far not the only "programme of perception" — to borrow Bourdieu's (1991) expression — capable of providing valuable insight on ICTs. This, however, does not imply that media theory is a "bad" method for understanding computational aesthetic objects. Media theory undoubtedly played a crucial role in raising awareness on the importance of analysing the cultural and social impact of information technologies and, in the process, developed powerful insights not only about ICTs but about technology in general. Namely, the fact that technologies are extensions and, above all, mediators of our experience of the world. However, it is clear that media theory can no longer continue to be the only interface through which we ought to look at ICTs and their sociocultural impact. New forms of philosophy, with their critical outlook and conceptual engineering tools, can offer broader and richer ways of understanding human–technology relations.

Postphenomenology and constructionism complement each other; they both conceive their object as complex systems which cannot be engaged without attending to a particular context of use. Postphenomenology focuses on the relationship we establish with technology and shows that technologies cannot be defined in absolute terms. For its part, constructionism offers a more specific, detailed method for developing a multilevel analysis. In the following chapters, we will see how by applying the previously described methods we can gain insights on the various ways we relate to the computer as an information system, as a "media machine" or as a "metamedium". However, the first step will be to investigate the computer in the most general sense: as an *information machine*.

Part II

Discussion

Chapter 4

The information machine

Summary

In Chapter 2, we saw that technologies might be described as complex systems, that any of such systems whose purpose is to handle information qualifies as a form of IT, and that computers are the quintessential manifestation of this type of technology. We saw computers have been able to incorporate all the functions of IT because both their raw material and instructions are made of the same "stuff", namely, *information*. By offering an account of the origins and various meanings of this concept, this chapter will provide a first "portrait" of the computer as an information modelling device. It will begin with a short history of computation, from mathematical tables to Alan Turing's "Universal Machine". This is followed by a short account of the concept of information, from its earliest usage and decline to the development of Claude E. Shannon's Mathematical Theory of Communication. Next comes a discussion of the philosophical understanding of information, as seen by Floridi's constructionist epistemology. Overall, this chapter contends that to grasp the reason why computers can be such effective multipurpose devices requires understanding what the concept of information stands for.

4.1 Introduction

Even though the history of computation is now deeply intertwined with the history of media and communications, computers were not conceived from the outset as the "media machines" we know today. This is, in fact, a relatively recent state in their development. Electronic digital computers, like other electronic information technologies, underwent a dramatic evolution in a relatively short timespan. Originally devised as automatic, high-speed number-crunchers, electronic digital computers quickly found a place in the military, financial, scientific, and administrative sectors. Banks, insurance companies, aeronautical companies, stock trading; universities, scientific and engineering research centres; government agencies; communication companies; and generally any area and field needing to manipulate large volumes of data were the first to embrace (and spur) the computer revolution.

As is the case with most instruments whose origins lay outside traditional aesthetic practices, the emergence of the computer is usually taken for granted by art scholarship. And when art scholars discuss the history of this technology their scope is usually limited to the last decades of the twentieth century; i.e., to the emergence of the PC and afterwards. Some media theorists provide more thorough accounts. However, the more granular socio-cultural, economic, and epistemic aspects behind the conception and evolution of computation as we now know it are usually disregarded. Many contemporary discussions on aesthetic practices — as well as some practices themselves — originated *precisely* because computers became capable of simulating virtually all previous forms of media, yet most scholars rarely venture on the reasons *why* computers are such multistable devices. It may be argued that such matters fall outside art scholarship's epistemic responsibility due to their (admittedly) technical nature. Nonetheless, it is only by engaging them that we can begin to understand how and why it is that computers can do what they do. Otherwise, we risk losing sight of the historical and social circumstances, as well as the reasons that brought to life the technology now driving most changes in our world.

This chapter provides the first of the two "portraits" of the computer that compose this dissertation. It shows that, at the most elemental level of abstraction, computers are machines that handle and, more important, *generate* information, but that to understand what this implies, it is necessary to understand first *what* information is. The chapter begins with a narrative account of the history of modern computation, from mathematical tables to Charles Babbage's "engines". The following section discusses the origins of Turing's seminal paper, "On Computable Numbers", and provides a summary of its contributions both to mathematics and computer science.[1] Next comes a discussion of the concept of information, including Claude Shannon's Mathematical Theory of Communication (henceforth MTC). The following section deepens the account of Shannon's conceptualisation of information by resorting to its relation with cryptography. The last section provides an alternative understanding of information via Floridi's constructionist epistemology (see Chapter 3), and wraps up the chapter by arguing why the computer is and should generally be understood fundamentally as an information machine.

4.2 A short introduction to the history of computation

A decade ago, the term "computer" referred almost exclusively to "desktops" and "laptops". But the emergence of portable devices such as smartphones, tablets, and wearables — and with them, the notion of permanent connectivity, the idea of computation being confined exclusively to dedicated machines consisting of a display, a CPU, and peripherals began to fade.[2] Computers, or rather, computational technology has become ubiquitous; it is now directly or indirectly related to every major technological appliance. Along with mobility, our "telephones" have more processing power and storage capacity than high-end desktops and laptops from the previous decade. SLDR cameras are fitted every year or so with more powerful processors to take higher resolution images at faster speeds. Luxury cars are equipped with complex computers using software composed of several thousand lines of code (more than a fighter jet plane if we are to believe Ford's publicity). Even vacuums, lamps, power outlets and refrigerators are being equipped with computational technology, as the so-called "Internet of Things" (IoT) grows. In the words of media historian John Durham Peters:

> Digital devices have spread like rabbits in Australia. Organisms flourish when transplanted into habitats lacking in natural enemies, and computers have spread almost zoologically into our cars and ovens, clothes and

[1] It is important to note that the accounts provided in this section are extremely simplified. Thorough discussions of the technoscientific and cultural contributions of Turing, Hilbert, and Gödel can be found in the following sources: Cooper and Leeuwen (2013), Sommaruga and Strahm (2015), Copeland, Posy, and Shagrir (2013), and Copeland et al. (2017).

[2] Nowadays even the very word "computer" has become *passé* in both colloquial and academic contexts.

garbage, music and minds, clothing and bodies. (2015, 49)

As computation continues to be integrated into more objects and contexts, it becomes easier to forget that computers were once people — the majority of them women. Electronic digital computers (in their various iterations) are the substitute of both (electromechanical and mechanical) computing devices and machines,[3] and of actual human computers. Initially, "computers" were human technicians; assistants who performed calculations by rote, following a predefined systematic method. They did so first with paper and pencil, and later with the aid of contraptions (such as slide rules) and various other types of calculating machines.[4] Thousands of these individuals performed most of the tasks now routinely conducted by electronic computers; they worked in businesses, for governments, or in research facilities and, like filing clerks, they usually had little or no knowledge whatsoever of the ultimate purpose of their work[5] (Copeland 2004b). In the case of complex calculations — such as those conducted throughout the Manhattan project (1940–1946) — "several dozen human computers", each one using either pencil and paper or some computing device, could be involved (2004b, 40). In the following section, we will look at the history of calculation before the emergence of the electronic digital computer.

4.2.1 Information industrialised

Like so many aspects of modern societies, the need to process information at an industrial scale only became an imperative in the aftermath of the French Revolution. The arrival of new communication and transportation technologies and the large-scale systematisation of international commerce and administration turned high-volume information processing into a pillar of modern development. Like any other activity which, before the Industrial Revolution, had relied exclusively on human power, computing was first absorbed by the logic of manual mass production and later — once the appropriate means were developed — mechanised. Only then information morphed from a strategic resource to a commodity. The idea of building a machine capable of

[3]In fact, the very concept of "computing machine" was conceived to distinguish the human agent from the tools people used to aid computing — eg., slide rules. Whereas the concept of "electronic computer" was, in turn, coined to distinguish the new machines from the old mechanic and human computers (Copeland 2004b).

[4]For a thorough overview of many historical calculating machines see Martin (1992).

[5]As the debate over the impact of IT on manual labour is gaining momentum, it is good to remember that these people were the first to lose their jobs to a computer.

processing data *automatically*[6] and faster than any human could, was arguably a direct outcome of the *zeitgeist* of the Industrial Revolution.

Humans have used devices such as the abacus for thousands of years, but actual computing machines only started to be developed in the nineteenth century.[7] These devices were a technological response to the growing computational needs that arose in the Victorian era; an age characterised for the unprecedented investment in great physical, financial, and scientific infrastructure and research (Campbell-Kelly et al. 2014). And yet, even in this age of steam and mechanisation, the most common general-purpose calculation devices were not machines or even tools in the usual sense, but instead written *mathematical tables*.

4.2.2 Mathematical tables

Before the nineteenth century, the only thing capable of carrying out computations was the human brain. Writing technologies became the first artificial enhancement to this already robust system; it increased short and long-term memory, enabled diachronic communication and record-keeping, and gave abstract thought a physical grounding. Early on in history, it became clear that writing could be used not only to keep track of transactions but also as a practical tool to conduct them. Someday, someone in the Fertile Crescent figured out that instead of having to make a given calculation from scratch every time it was needed, he or she could pre-compile various results in a table and refer to them whenever the occasion arose.[8] And while more sophisticated calculation devices were later invented, such as counting boards (used by the Babylonians), abacuses, slide rules, mechanical calculators, and analogue computers, mathematical tables proved remarkably resilient — some specialised forms continue to be used to this day.

Mathematical tables allowed anyone — even those with sufficient mathematical know-

[6] Unlike contemporary computers, and despite being faster than their human operators, early computing machines were not entirely automatic. They mechanised much of the work, but each arithmetical operation (addition, subtraction, etc.) had to be manually conducted by a human, much like the non-programmable calculators we still see today (Copeland 2004b). Overall, computing machines could not do anything that a human could not accomplish with pencil and paper following a step-by-step method.

[7] As American historian of science, James Gleick (2011) notes, mathematicians John Napier, Blaise Pascal, and Gottfried Leibniz devised mechanical adding machines. However, all three devices were little more than improved abaci.

[8] The world's oldest datable mathematical tables were found in Iraq; they were created circa 2600 BCE (Robson 2007).

how to carry out calculations on their own — to obtain a result at a glance; more or less like present-day calculators. From highly skilled mathematicians to occasional enthusiasts, people compiled, copied and used tables for millennia. The ninth century Persian mathematician Muhammad ibn Musa al-Khwarizmi,[9] to whom we owe the names of *algebra* and *algorithm* (Thomas 2015), created some of the first tables of trigonometric functions — a kind of tables that were and are still used for territorial surveying and astronomy. Al-Khwarizmi's tables were copied innumerable times for centuries after his death; they were used throughout the Middle East, Europe, and even China (Gleick 2011). In the seventeenth century, table creation was significantly improved when Scottish mathematician John Napier,[10] published his invention of *logarithms*,[11] a mathematical tool that simplified and sped up calculations with complex numbers and that was further refined by English mathematician Henry Briggs.[12]

By the eighteenth century, numerous kinds of specialised tables[13] containing data for every imaginable trade — from lumbering to military engineering, navigation, and accounting — were regularly published and updated.[14] So important were tables for maritime navigation that in 1766 the British government commissioned the publication of a yearly set of tables containing, amongst other things, the position of the Sun, of various stars and planets, and the Moon at given times of the year (Campbell-Kelly et al. 2014, 4; Gleick 2011). To produce this *Nautical Almanac*, the British Government employed a fixed number of freelance calculators who worked from home in exchange for a yearly stipend. To minimise mistakes, the results of the calculations were done twice by two different calculators and then checked by a third person before being sent to print (Campbell-Kelly et al. 2014). Redundancy, however, did not prevent the spread of rumours claiming the almanac was plagued with errors; an accusation that was, for the most part, unsubstantiated (Gleick 2011). The Nautical Almanac has continued to be published uninterruptedly for over 250 years. And it was "the first permanent table-making project to be established in the world" (Campbell-Kelly et al. 2014, 4) nonetheless, its ambitions paled in comparison to the project commissioned by the

[9] 780–850
[10] 1550–1617
[11] According to Kenneth Falconer (2013), "[l]ogarithms are closely related to powers of numbers. The *logarithm* of a number, abbreviated to log, is the power to which 10 must be raised to give that number". Thus, for example, $log100 = 2$.
[12] 1561–1630
[13] To a certain extent, table specialisation prefigures what later occurred with commercial mainframe software — see Chapter 5.
[14] Already in 1582 Simon Stevin had produced *Tafelen van Interest*, a compendium of interest tables for bankers and moneylenders.' (Gleick 2011).

French government after the 1789 Revolution.

In 1791 the new Republican government of France set out to modernise the taxing system; this involved conducting a land survey of the country, as well as a census. Since the government had also decided to replace the old imperial system of measurements with the new metric system, this required the development of new logarithmic and trigonometric tables. The making of these *tables du cadastre* became the largest project of its kind ever devised (Campbell-Kelly et al. 2014). The person in charge was Gaspard Riche de Prony.[15] Inspired by Adam Smith's work,[16] *The Wealth of Nations* (published in 1766), De Prony set out to manufacture tables at an industrial level. He employed a select group of mathematicians who devised a simplified "method of differences"[17] that allowed between 60 and 80 barely literate human calculators — mostly unemployed hairdressers, if we are to believe Grattan-Guinness (2007) — to generate logarithms merely through addition and subtraction (Campbell-Kelly et al. 2014). Thus, even though the actual product was mathematical, the process was as mechanical as that employed by the pin factory workers in Adam Smith's example.

De Prony's innovation was "the application of an organizational technology, probably for the first time outside a manufacturing or military context, to the production of *information* [emphasis added]" (Campbell-Kelly et al. 2014, 24). De Prony's "factory" operated for a decade before being shut down due to the economic and political turmoil of the Napoleonic Wars. Although the tables were completed, they were never printed because it would have been too expensive; only the original specimens survived in the French Academy of Sciences. It was there that Charles Babbage (see next section) first learned of them while touring France in 1819 (Grattan-Guinness 2007), the same voyage were he got to know Joseph Marie Jacquard's automatic looms,[18] machines that weaved complex patterns using *punched cards*.[19] Both the *Tables du Cadastre* and

[15]1755–1839

[16]Smith (1723–1790), is considered one of the founding fathers of economic theory.

[17]As computer historian Charles Petzold (2000) notes, mathematical tables were *not* created by calculating a logarithm for each entry. Instead, the logarithms were calculated for selected numbers, and the gaps between them were calculated by interpolation. In this consisted the above mentioned *method of differences*.

[18]Jean Marie "Jacquard" (1752–1834), son of a master weaver, inventor, counterrevolutionary *and* revolutionary soldier, built upon previous inventions to speed up the hitherto "maddeningly slow and tedious" (Essinger 2004, 11) process of weaving silk using draw looms. At the turn of the nineteenth century, Jacquard developed a machine that was (a) completely automatic — it fed itself; (b) infinitely flexible — it could weave *any* pattern; and (c) was about twenty times faster than any manually operated loom that had preceded it (2004, 36–38).

[19]Punched cards were used throughout the late nineteenth century and for the better part of the twentieth century as data storage and as input and output devices for information systems. Most early computer systems used punched cards before being replaced by magnetic tape, hard drives, CD-

Jacquard's invention[20] would be very influential for the development of Babbage's difference engine, for his analytical engine, and for computational technology in general.

4.2.3 Babbage's idea

Charles Babbage[21] was a British polymath born into a wealthy family (his father was a banker); a mathematician versed in both Newton's *and* Leibniz's calculus notations[22] (Gleick 2011), but more important, a technologist and economist with a broad practical knowledge of manufacturing processes. Babbage was arguably amongst the first people to appreciate the potential of automatic, mechanical computing (Copeland 2004a). His unique (and for a long time under-appreciated) role in the development of information processing technologies was owed to his combined knowledge of mathematics and economy, which granted him an unparalleled insight into systematisation and organisation methods (Campbell-Kelly et al. 2014).

Babbage is a seminal figure in the history of ICTs; he combined Adam Smith's ideas on manufacturing (via De Prony) with the "scientific management movement" sparked by Winslow Taylor in the United States (Campbell-Kelly et al. 2014). Babbage's ideas, however, did not quite belong to nor were they completely understood by most people living in the age of steam. Despite the fact that Britain had fully embraced (and benefited from) industrialisation, Babagge's idea of treating numbers like any other *commodity* seemed at the very least an eccentric proposition (Gleick 2011). But even more eccentric seemed the method he conceived to achieve it: building a machine capable not only of *automatically* calculating but also printing the results; a mechanical contraption that would be faster and more accurate than any human mind.

ROMs, SSDs, etc.

[20] John Von Neumann (see following sections) also reportedly got acquainted with punched cards when his father, an investment banker with a heightened sense of technological know-how, explained to him and his brothers the mechanisms of the Jacquard loom (Dyson 2012, chap. 4).

[21] 1791–1871

[22] The differences between the two notations was the origin of an acrimonious debate between the two mathematical giants, and eventually became an ideological wall that prevented British mathematicians from developing the science further (Gleick 2003). By the time Babbage entered Cambridge University he was dismayed to find out his mathematical skills were better than his teachers'. Babbage's knowledge of continental notation granted him access to the work of French mathematicians (Gleick 2011), whom for the past two centuries, had transformed France into the Mecca for this science (Villani 2015). Babbage, along with his friend John Herschel[^171] — the son of German-British astronomer Willian Herschel — founded the Analytical Society, whose initial (and successful) goal was to promote the usage of Leibniz's notation (Gleick 2011).

Being an obsessive compiler of lists,[23] Babbage knew most errors found in mathematical tables were not the result of sloppy calculations but were more commonly introduced during printing and copying (Gleick 2011). It was this desire for eliminating errors that motivated him to embark on his revolutionary, but under-appreciated project. Babbage came up with the idea of building a table-generating machine around 1821, while he and John Herschel were compiling a set of tables[24] for the Astronomical Society (Singh 2001). Given the tediousness and lack of mathematical challenge imposed by this task, Babbage began to wonder if it would be possible to automate it using some kind of steam-powered contraption (Gleick 2011).[25]

Automation for Babbage was not a mere question of semantics but represented the actual measure of a machine's usefulness (Gleick 2011). Up until then, calculation devices such as the abacus and the tables themselves were moderately sophisticated inventions which undoubtedly contributed to speed up calculations, but they were still mere aides for the human brain. Babbage imagined a machine which could actually *prescind* of the human factor. To his eyes, this would not only improve the reliability of the data obtained, but it would also make the process faster, cheaper, and less labour intensive than any other method available at the time. Being a well-positioned figure, as well as a skilful advertiser, he managed to convince the British Government to fund his enterprise.

4.2.4 Babbage's machines

The machine Babbage conceived would be known as the "Difference engine" — the name alluded to the method of differences conceived and employed by De Prony for the *Tables du cadastre*. The device was essentially a large calculator (Petzold 2000); a rather "simple" device by our current standards, but an engineering and technological feat by every nineteenth-century measure. Babbage spent close to a decade designing and redesigning his machine which, although conceptually simple, proved to be extremely difficult to build. Mostly because Babbage had miscalculated both the costs

[23]According to David Kahn (1996), "Babbage was fascinated by statistical phenomena, compiling tables of mortality and logarithms, counting the proportion of letters in various texts, and measuring the pulse and breathing rate of any animals he encountered."

[24]Babbage and Herschel were not doing the calculations themselves, but comparing two sets of tables done by (human) computers. Nonetheless, whenever they found a discrepancy, they were not able to tell which of the two sets of tables was correct and thus had to calculate the result themselves (Essinger 2004, 66).

[25]Babbage reportedly said: "'My God, Herschel! How I wish these calculations could be executed by steam!'" (Essinger 2004, 66).

and availability of the required underlying technology and the manufacturing capacity of his day. This meant he ended up *inventing* most of the machine's specialised components and processes required to manufacture them. Babbage travelled throughout the British Isles and Europe looking for components, but in the process, he became one of the most knowledgeable specialists in the manufacturing economy (Campbell-Kelly et al. 2014). Financed by the Government and his own money, Babbage finally built a proof of concept in 1833; a smaller working prototype that lacked the printing section and capacity to make actual tables, but which nonetheless proved his idea was viable (2014). However, despite his initial success, Babbage ended up abandoning the project in favour of a more ambitious one: the *Analytical engine*.

Being Lucasian Professor of Mathematics at Cambridge University and Fellow of the Royal Society, Babbage was well aware of the limited scientific applications of the difference engine. While useful for calculating logarithms through mere addition and subtraction, the difference engine was ill-suited for more complex mathematical problems. And it was also cumbersome since it had to be *reset* for each new set of calculations (Essinger 2004). In contrast, the engine he now had in mind would be (in theory) capable of conducting *any* type of calculation because it would be *programmable* (Campbell-Kelly et al. 2014). Babbage got his inspiration from the pattern-weaving loom invented by Jacquard. Jacquard's machine used stiff pasteboard cards with holes[26] to control the rods for each step (row) in the weave, this enabled the automatic creation of complex patterns (Miller 2005). Unbeknownst to him, Jacquard had effectively introduced the world to what in the twentieth century would come to be known as a digital *programme*. Neither Babbage nor Ada Lovelace (see below) would refer to Jacquard's punchcard patterns in those terms, but they certainly understood their potential use outside the textile industry. What caught Babbage's and then Lovelace's imagination was not the complexity of the weavings produced by the Jacquard Loom[27] but how their patterns were *encoded* and fed into the machine (Gleick 2011). Babbage decided punchcards held together by ribbons would be the perfect input/output (`I/O`) method for his machine (Manovich 2002).

The complexity of the analytical engine, along with the British government's decision to stop financing Babbage's seemingly unending experiments meant the machine was

[26]As was already mentioned, these were the antecedent of the punched cards used by many computing systems in the twentieth century.

[27]Babbage owned a portrait of Jacquard that resembled an engraving but was actually a piece of silk woven by one of the punchcard-controlled looms. The image was complex; it was designed in 1838 precisely to showcase the capabilities of the Jacquard loom; it consisted of $24,000$ rows of weaving, each row corresponding to one punchcard (Essinger 2004).

never built and, contrary to the difference engine,[28] will likely never will.[29] The device would have been enormous. A "massive Victorian computer", a Steampunk fan's dream more or less "the size of a small steam locomotive" or a large contemporary van, containing some $20,000$ cogwheels (Essinger 2004, 84). Babbage continued designing and redesigning it, making hundreds of sketches, and speculating on more potential applications until his death in 1871. The analytical engine was, in concept, the closest thing to a modern computer (Petzold 2000), since it included the equivalent of a processor, memory storage, and a means to input data and output the result (O'Regan 2012). The most striking aspect of the analytical engine was that, by adopting Jacquard's punch card system, the device could be (in theory) infinitely programmable. This link between Jacquard's loom and Babbage's computer is often dismissed by computer scientists and historians (Manovich 2002); however, it is full of significance for media history and philosophy.[30]

By far the only person who understood not only the mathematical concepts and mechanics behind the Analytical engine but also its scientific *and* cultural potential — perhaps even better than Babbage himself (Fuegi and Francis 2003) — was Ada Lovelace.[31] Lovelace was Lord Byron's only legitimate child (Essinger 2004); at age 17 she met Babbage who, along with Mary Somerville,[32] became her mentor (Fuegi and Francis 2003). Throughout her short life (she died prematurely of cancer at age 37) she developed first-order mathematical skills, yet she was never allowed to become a scientist.

Lovelace, like no other person in Babbage's circle, was enthralled and insightful about everything the analytical engine could become. Whereas Babbage had focused almost exclusively on the calculating possibilities of the Analytical engine, Lovelace intuited that the applications of the machine could go way beyond mere number-crunching. She speculated on the analytical engine's capacity to compose music (Fuegi and Fran-

[28]Between 1989 and 1991, to celebrate the bicentennial of Babbage's birth, the London Science Museum under the direction of Doron Swade (at the time curator of computing) built a working replica of Babbage's machine, it came to be known as the Difference Engine No.2 (Campbell-Kelly et al. 2014, 307).

[29]Interestingly, there is a novel called *The Difference Engine* coauthored by William Gibson and Bruce Sterling ([1990] 2011) narrating events in an alternative Victorian era in the aftermath of Babbage's successful completion of his machine.

[30]Some writers go as far as to claim "that in essence a computer is merely a special kind of Jacquard loom" (Essinger 2004, 87).

[31]1815–1852

[32](1780–1872) Polymath and science populariser, amongst other works she translated Laplace's *Mécanique Céleste* and, along with Caroline Herschel (1750–1848), became the first woman to be elected a fellow of the Royal Astronomical Society (Holmes 2008).

cis 2003) and, above all, was able to devise useful metaphors to explain its workings and possible applications in simple terms. She described it as a device that essentially "'*weaves algebraical patterns* just as the Jacquard loom weaves flowers and leaves'"[33] (Lovelace as quoted in Essinger 2004, 141). Corresponding frequently with Babbage, Lovelace attempted to design what some consider to be the first programming language for the Analytical Engine (Adriaans 2013), yet she never managed to do it.

Although Babbage's ideas did not fully come to fruition in the form of an actual, usable technology, his influence can be found throughout the work of many computational technology pioneers. Howard Aiken,[34] designer of the Harvard Mark I, a general-purpose (i.e., programmable) electromechanical computer built by IBM, was heavily inspired by Babbage's work (Essinger 2004; Fuegi and Francis 2003). Konrad Zuse (See Chapters 5 and 6), John von Neumann, and Vannevar Bush also recognised Babbage's influence in their own ideas (Copeland 2004a; Fuegi and Francis 2003). Although in Turing's seminal paper *On Computable Numbers* (see below) there is no explicit mention of Babbage, Turing reportedly later recognised the potential of the Analytical engine (2004a). Some authors suggest that Babbage's Failure to build both the difference and the analytical engines led many would-be computing pioneers to conclude that building such kinds of machines would be unfeasible (Essinger 2004). It took almost a century before anyone was able to build a general purpose calculation machine capable not only of matching but surpassing Babbage's ambitious dream. The thing that enabled this technological development was a thought experiment thoroughly conceived by a young British mathematician to solve a challenging mathematical problem: the *Entscheidungsproblem* or "decision problem". The following section focuses on the origins and implications of these historical events.

4.3 Hilbert, Gödel, and Turing

In 1900, renowned German mathematician David Hilbert[35] was invited to give the first of various addresses to the Second International Congress of Mathematicians. By sug-

[33]This was a note in Lovelace's translation of an article (Petzold 2000) written by Italian engineer and mathematician Luigi Menabrea — who eventually became the seventh prime minister of Italy — based on a presentation Babbage gave in Turin in 1840 (Fuegi and Francis 2003).

[34]1900–1973

[35]1862–1943

gestion of his friend and colleague Hermann Minkowski[36] (Petzold 2008, 39), Hilbert dedicated his speech to outline the major problems mathematicians ought to tackle in the new century. Hilbert came up with 23 challenges involving various mathematical fields, some of them "quite esoteric; others were fundamental in their scope" (2008, 40). By 1917, with WWI still ravaging Europe, Hilbert addressed the Swiss Mathematical Society in Zurich. This speech was the first sketch of what, in the early 1920s, would come to be known as the *Hilbert Programme*, a plan whose ambitious goal was "the rigorous axiomatization of all of mathematics" (2008, 45). Hilbert, who by the 1930s "was virtually the pope of mathematics" (Copeland 2017b, 57) wanted his "science" to be put on indisputably solid grounds.

Two problems in Hilbert's list — number 2 and 10, or rather, what the results of tackling them revealed, had enormous implications not only for mathematics but for science and knowledge in general. These were not so much mathematical problems (theorems) as "problems *about* mathematics itself and what can be proven using mathematics" (Mitchell 2009, 58). Being related, the problems can be broken down into the following three parts, as outlined by computer scientist Melanie Mitchell (2009, 58–59):

(1) *Is mathematics complete?* Meaning, can every mathematical statement be proven or disproved from a given finite set of axioms?[37] Or, in other words, given a fixed set of axioms, is there a proof for every true statement?
(2) *Is mathematics consistent?* That is, can only *true* statements be proven?
(3) *Is every statement in mathematics decidable?* In other words, is there a definite procedure[38] that, when applied to a statement, can tell a mathematician in finite time whether or not that statement (or any other statement) is true or false?

Part (3) is more commonly known by its German name: the *Entscheidungsproblem* or "decision problem", and it was not originally formulated by Hilbert but by seventeenth-century mathematician Gottfried Leibniz[39] (Mitchell 2009, 58). By the spring of 1930, these problems remained unsolved, but Hilbert was confident that the answer to each of them would be undoubtedly positive. In yet another address given shortly before being awarded honorary citizenship of Königsberg,

[36] 1864–1909 Amongst other contributions, Minkowski coined the notion of *Zaumreit* or "spacetime" (Petzold 2008, 42)

[37] To paraphrase philosopher B. Jack Copeland, an axiom is a mathematical proposition so elementary that it does not require to be proven; all mathematical proofs begin with one or more axioms. Mathematicians prove theorems from axioms using rigorous logical deduction (2017b, 61).

[38] As Charles Petzold notes, Hilbert was, in reality, asking for an *algorithm*; however, the modern usage of the term only became popular in the 1960s (2008, 41–42).

[39] 1646–1716

his birthplace (Petzold 2008, 49), Hilbert reaffirmed his conviction. However, the day before the ceremony, Kurt Gödel,[40] a young mathematician who was visiting Königsberg to participate in a conference on mathematics (2008, 50), presented his *incompleteness theorem*, which "astounded the mathematical world" (Mitchell 2009, 59) and sparked nothing short of a revolution in mathematics, science, and philosophy. In short, Gödel's theorem established that if the answer to (2) were indeed positive (i.e., mathematics is consistent), then the answer to (1) would *necessarily* have to be negative (2009, 59).

Oversimplifying, Gödel showed there are statements in mathematics which, despite being true, cannot be proven solely through "a self-consistent 'recursive' system of axioms" (Volkenstein [1986] 2009, 185). His proof to support this claim is complex because it involved formalising (i.e., translating into the language of mathematics) the logical analysis of what in plain English may be summarised as: "'This statement is not provable'" (Mitchell 2009, 60).

Gödel's approach is related "in spirit" to the paradox traditionally attributed to Epimenides of Crete,[41] who reportedly asserted that "'all Cretans are liars'" (Volkenstein [1986] 2009, 185). If the sentence were true Epimenides would be lying, since he is Cretan; however, in so doing, he would *also* be telling the truth, thus making the statement false. The same paradoxical result, although with far-reaching consequences, is achieved by Gödel's exemplary phrase, as Mitchell (2009, 60) aptly explains: If Gödel's statement (let us call it G_s) could, in fact, be proven, it would be false since G_s says that it cannot be proven. This would imply false statements could be proven, thus rendering the axiomatic system *inconsistent*. Conversely, if G_s could not be proven, the statement would be true as it effectively claims to be. This, however, would mean there are true statements (such as G_s) which are true but cannot be proven. This, in turn, would render the axiomatic system *incomplete*. In conclusion, the axiomatic system has to be either inconsistent or incomplete, but it cannot be both.

Shortly after Gödel dispatched parts (1) and (2) of Hilbert's programme, British mathematician Alan Turing[42] did away with part (3). In 1935, twenty-three-year-old Turing was studying at Cambridge under the direction of the logician Max Newman;[43] it was Newman who introduced him to Gödel's (then recent) incompleteness theorem

[40] 1906–1978

[41] Also known as the "liar paradox" (Proudfoot and Lacey 2010, 221).

[42] 1912–1954

[43] 1897–1984 Newman was greatly responsible for propagating Turing's ideas, as well as the stored program principle in the UK (Copeland 2004a, 16).

(Mitchell 2009, 60). Following Gödel's steps, Turing took on the *Entscheidungsproblem*. Recapitulating, "the decision problem" asks if there is always a "definite procedure" for establishing whether a given statement is provable (2009, 60). "Provable" here means that it can be derived following a step-by-step logical deduction. Hilbert was certain there was such procedure and that it was only a matter of time before it could be found. Turing began to tackle the problem by first establishing what could be understood by the term "definite procedure". He took a cue from Leibniz[44] and formulated his definition by imagining a powerful calculating machine that could not only accomplish arithmetical operations but also manipulate symbols (2009, 61). Turing effectively reduced human computation to a set of simple procedures. In so doing he established that not even a Universal Machine could "decide" — i.e., "figure out" or "calculate" — whether a given mathematical problem was provable or not (Copeland 2017b, 59).

When conceiving his machine, Turing was not consciously devising electronic computers; he was "only" attempting to prove "the existence of mathematical realms that, in a certain sense, lie *beyond* the range of any computer, no matter how powerful" (Copeland 2017b, 60). However, as we will see in the following section, Turing's creation became the blueprint for the invention of the programmable electronic computer (2009, 61). Unlike Gödel, who took little or no interest in the practical applications of his findings beyond mathematics, Turing actively participated in their crystallisation. Throughout WWII, Turing decisively contributed to breaking German cyphered communications designing mechanical devices (such as the *Bombe*, the class of electromechanical devices that decoded Enigma messages) at Bletchley Park. After the war, Turing participated in the development of one of the first electronic digital computers, the Manchester, whose second version (the Manchester Ferranti Mark I) effectively became the first ever commercially available electronic digital computer in the proper sense.

[44]As mentioned before, Leibniz had in fact conceived a calculating machine that could add, subtract, multiply and divide (Look 2017). According to George Dyson (2012), around 1679 Leibniz saw binary coding as a key to a universal language, he developed simple algorithms for translating between decimal and binary notation and carrying out basic arithmetic operations on strings of zeroes and ones. As Dyson notes:

> Anticipating Gödel and Turing, Leibniz promised that through digital computing "the human race will have a new kind of instrument which will increase the power of the mind much more than optical lenses strengthen the eyes. Reason will be right beyond all doubt only when it is everywhere as clear and certain as only arithmetic has been until now." (2012, chap. 6)

4.3.1 The aftermath following Gödel and Turing's proofs

The nineteenth and early twentieth century was a time of optimism as far as science and mathematics were concerned. There appeared to be no limit to what could be accomplished by merely putting reason to use. As Mitchell (2009, 68) notes, Hilbert and other thinkers from his generation believed they were about to crystallise Leibniz's dream of finding an automatic means to prove or disprove *any* logical statement. Hilbert's own "dream of a universal, all-encompassing formalization" (Dyson 2012, chap. 6) of mathematics fell perfectly in line with the aspirations of Gottlob Frege,[45] Bertrand Russell,[46] and most logical positivists associated with the Vienna Circle. Gödel's and Turing's findings not only brought these dreams to a definitive end, "quash[ing] the hope of the unlimited power of mathematics and computing" (Mitchell 2009, 68). They also showed mathematics was not immune to the same uncertainty and sweeping changes that already had taken hold of physics, first with Einstein's Theory of Relativity and later with the emergence of quantum mechanics.

By the time Gödel announced his incompleteness theorem Hilbert was 68 years old and already retired from teaching; his reaction upon hearing about it was, according to Charles (Petzold 2008, 50), "rather strange for a mathematician: [h]e was 'somewhat angry'". As the Nazis took hold of Germany, all of Hilbert's Jewish colleagues were either deported or fled; consequently, the mathematics department at Gottingen University became, by Hilbert's own irritated account, virtually nonexistent (2008, 51). By the time Turing published his revolutionary 1937 paper, "On Computable Numbers" Hilbert had turned 74 years old and was under suspicion from the Nazis on account of his seemingly Jewish first name (2008, 52). Amidst loneliness and senility, Hilbert died in 1943. It would be easy to dismiss Hilbert as a tragical figure who happened to be on the wrong side of mathematics, yet it was him who directed everyone's attention to the problems that would be most fruitful. As Copeland (2017b) suggests, it was a mark of Hilbert's greatness to have been wrong in such an important way. Not many people can create such "high-quality ignorance", to borrow the words of Stuart Firestein (2012).

Life would turn no less bitter for both Gödel and Turing. Due to his association with the Vienna circle, Gödel's professional life under the Nazi regime became unbearable.

[45] 1848–1925
[46] 1872–1979

He and his wife left Austria for the United States in 1940 — oddly enough via Russia and Japan, he became a professor at the prestigious Institute for Advanced Studies in Princeton and enjoyed the friendship of figures such as Einstein. And yet, towards the end of his life, Gödel became mentally unstable and paranoid, fearful that he was being poisoned he starved himself to death in 1978 (Petzold:2008; Kennedy 2016).[47]

Turing, for his part, found himself at the wrong end of Britain's 1950s judiciary system. Being a gay man and homosexuality illegal at the time — not to mention very actively persecuted on both sides of the Atlantic, Turing was arrested and charged with "gross indecency" in 1952. Given a choice between serving jail time or probation and undergoing "drug 'therapy' (i.e., chemical castration) to treat his 'condition'" (Mitchell 2009, 69–70), Turing chose the latter. Forced to take hormones for a year, he grew breasts (Copeland 2017a), lost his government security clearance, and with it, a job offer with a generous salary to continue working as a cryptanalyst, as well as the possibility to travel to the United States. On 7 June 1954, days short of his 42d birthday, Turing was found dead at his apartment by his housekeeper. The cause of death was ruled as cyanide poisoning, by his bed the police found a half-eaten apple which, although was never tested, was believed to be laced with the poison. Turing's death was ruled a suicide, although B. Jack Copeland (2017a; 2017), one of Turing's most knowable biographers, contests this theory, arguing instead that it was most probably an accident.[48] Turing's premature death did not prevent him from becoming one of the most influential figures in computer science, artificial intelligence, computer engineering (Beavers 2013), and even theoretical biology (Woolley, Baker, and Maini 2017).

4.3.2 Turing's universal machine

"On Computable Numbers" (1937), is by far Turing's most influential and well-known work. As was noted in the previous section, Turing's original goal with this paper was to solve Hilbert's "decision problem"; this implied formalising — i.e., giving a precise definition — of the notion of "method" as an *algorithm*. This was Turing's main mathematical contribution (Hromkovič 2015), and it was not a small one, for it opened the

[47] During his last years, Gödel refused to be fed anything that was not directly cooked and given to him by his wife; after she fell ill and had to be hospitalised, he stopped eating altogether.

[48] Copeland and Bowen (2017) notes that the night of his death Turing was conducting experiments with circuitry in the spare room of his house. At the time, Turing had already completed his "treatment" and was quite enthusiastic about his new project involving computation and biology; the narrative of a lonely, disgraced, and suicidal gay man simply does not match Turing's personality.

possibility to explore the limits of computational automation. By proving that (a) if a problem can be translated into an algorithm its solution can be automatised, but also that (b) certain problems cannot be solved by existing computing machines, even though they can be described algorithmically, Turing founded a new field of research: computation theory or computability (Petzold 2008). A field that is concerned with the limits and potential of computation. In other words, what began as a "mere" solution to a problem, ended up charting new areas of mathematics. Along with Alonzo Church,[49] Turing opened the field of "problems too hard for any computer [human or artificial] to solve" (Copeland 2004a).

As was mentioned at the beginning of this chapter, around the time Turing wrote "On computable numbers", computers were not machines but human beings. This is an important fact to bear in mind because it shows that the "universal computing machine"[50] (or U) Turing described in his paper was an extremely simplified abstract[51] model of a human computer. Being the founding work of modern computer science, Turing's paper is "effectively the first programming manual of the computer age" (Copeland 2004b, 12). To paraphrase Petzold (2008), the so-called Turing Machine is an extremely mechanistic specification of what a human does when carrying out an algorithm. Oversimplifying,[52] the Turing machine has the following components:

Limitless or "unbounded" (Guttag 2013, 4) memory, or rather, "tape" divided into squares, on which zeroes, ones, and symbols from a finite alphabet can be written, erased, and read.

A scanner with stored primitive instructions for handling the tape, and which can read 1 square at a time, can erase and write symbols, halts, shifts position (left or right) one square at a time, and changes state (can "remember" strings of symbols that it previously scanned).

Since it can read instructions from the tape, the machine can carry out any task for which a "table of instructions" has been written. Despite its austerity, given sufficient tape, time and precise directions, Turing's Universal Machine can emulate the

[49]Church (1903–1995) was Turing's doctoral advisor at Princeton. Both Turing and Church independently developed a definition of computability (which forms the basis of Turing's proof in "On Computable Numbers") which is nowadays known as the "Church-Turing Thesis".

[50]Turing, of course, never spoke of "Turing machines" this now famous term was inadvertently in fact popularised by Alonzo Church in his 1937 review of Turing's paper (Copeland 2004a).

[51]Precisely because they are abstract, Turing Machines may carry out computations that no real computer may do (yet).

[52]Besides Turing's paper, thorough annotated descriptions of the Universal Computer can be found in Copeland (2004a) and Petzold (2008).

behaviour of *any* other computing machines (Dyson 2012), including other Turing machines. No matter how complex a digital computer can be, if it can be turned into an algorithm, it can be encoded on tape and read by U. Arguably, Turing's major contribution to computer science was the idea of controlling the computer by storing a program of symbolically encoded instructions *within* the machine's memory. In other words, Turing's thought experiment was an abstract, conceptual description of a stored-programme modern digital computer (Copeland 2004b, 15). Precisely the stored-programme paradigm that would propagate throughout both sides of the Atlantic and that would give rise to the computer age.[53]

In demonstrating that a single machine of fixed structure can be universal, Turing made a remarkable discovery: that it does not matter whether the instructions are "executed by tennis balls or electrons and whether the memory is stored in semiconductors or on paper tape" (Dyson 2012). By blurring the distinction between data and instructions, Turing showed that regardless of the implementation, in the end, what computers do, is to manipulate *information*. The following section will deal with this concept, providing a thorough description of its origins and definitions.

4.4 The concept of information

In Chapter 1 we saw information has always been an important asset for humankind but that in last few decades most advanced (i.e., "hyperhistorical" or postindustrial) societies have come to depend more and more on the byproducts of information processing. We also saw this "Information Revolution" has had a discernible impact on the way we do things and in the ways we relate with technology; changes which, in turn, are giving way to profound metaphysical transformations, beginning with our understanding of reality and what it means to be human.[54] However, we have not yet truly discussed what information *is* or, at least, how it may be defined. This section will attempt to carry out this task as best as possible. It will begin by tracing the origins of the concept and outlining the reasons why it is such a complex notion. This will be followed by an overview of the origins of information theory, and a discussion of information as a physical quantity, as well as of the more accessible definition provided

[53]The potential application of Turing's ideas for computation technology was disseminated in the UK by Max Newman, Turing's friend and mentor; and in the US by John von Neumann.

[54]Hence the reason why Floridi (2010) refers to this process as the "Fourth revolution" in our self-understanding (see Chapter 1).

by Floridi's constructionist philosophy of information.

4.4.1 A difficult term and its origins

Information, as Floridi (2010) notes, is a "conceptual labyrinth". The term can refer to so many things that asking what it means is more an opportunity for philosophical enquiry than an occasion for "dictionary explorations" (Floridi 2004, 40). However, such epistemic uncertainty has not prevented both theorists and non-theorists from talking about information in the most varied contexts as if we always had a clear notion of what we are referring to. That is why Adriaans and Van Benthem (2008, 7) describe it as a high-frequency but very low-content concept, more like a placeholder we use to refer to innumerable things: from facts to events, to data to ideas. However, this ambiguity is precisely what allows various disciplines to treat it as an empty quantity.

Information has its origins in the Latin term *in formare*, a construction reportedly used by Cicero and Saint Augustine when discussing Plato's Theory of Forms, and mainly by Cicero to refer to "'representation[s] implanted in the mind'" (Adriaans and Van Benthem 2008, 8). By the early Renaissance, the French word *information* began to be used in the sense of "'investigation,' 'education,' 'the act of informing or communicating knowledge,' and 'intelligence'" (2008, 8). But by the end of the seventeenth century, the original technical sense of the word had disappeared as British Empiricists (who had returned to Platonic sources) chose instead to use the term "idea" (2008), from "*eîdos*", the Greek word for Platonic Form (Dusek 2006). Only in the twentieth century did information regain a technical connotation.

Currently, most scientific fields subscribe to some variation of the definition of information developed by Claude E. Shannon[55] in his landmark work "A Mathematical Theory of Communication" (henceforth MTC). Shannon first published his theory as a paper in 1948,[56] but the following year he republished it as a book (changing the "A" in the title for "The") with a lengthy introduction by Warren Weaver.[57] MTC is a founding contribution to information sciences; its influence can be seen in myriads

[55] 1916–2001

[56] The same year that Bell Labs announced the invention of the transistor, an engineering breakthrough that earned his inventors, John Bardeen, Walter Brattain, and William Shockley the 1956 Nobel Prize in Physics. Transistors are electronic components which could do everything a vacuum tube could do, "only" more efficiently and cheaply, and all while taking up only a small fraction of the space a tube occupied (a hundred transistors could easily fit in the palm of one's hand) (Gleick [1992] 2011). To say the transistor ushered the world into an electronic revolution would not be an overstatement.

[57] 1894–1978

of applications, including but not limited to telecommunications, computer science, cryptography, and scientific fields such as the physical and biological sciences. No serious discussion of computation and even less of information would be complete without a discussion of MTC.

4.4.2 Shannon's Mathematical Theory of Communication

MTC is often referred to as "information theory", but this synecdoche is misleading for various reasons. To begin with, information theory is not exhausted by MTC. Like most landmark theories (e.g., Darwin's theory of biological evolution), Shannon's MTC now represents only a small, founding region of *information sciences*, the field it contributed to develop. Secondly, as its name denotes, MTC is not a theory *of* information, but rather of *data communication*. And while the theory does define information,[58] it is so intentionally constrained that it is hardly operational without the framework for which it was built. Being a statistical formalisation of data transmission under ideal circumstances, a more fortunate name for MTC would be — as Floridi suggests — *"mathematical theory of data communication"* (2010, 2004).

A decade before publishing the MTC, Shannon had already made a major contribution to electronic engineering and, especially, to the development of digital circuit design. In 1937, having recently completed his master's thesis, he published a paper describing a method for analysing and designing relay circuits with the aid of Boolean algebra[59] (O'Regan 2012); a marriage between electronic engineering and logic which proved to be revolutionary. At the time, setting up relay circuitry — which was used in telephony for routing calls, for the electrical wiring of industrial machinery and electromechanical calculators — was almost an artisanal task. Nobody had cared to systematise the process, and experienced telephone engineers would design and layout complex systems on a case by case basis (Gleick [1992] 2011). Shannon saw the two states of switching circuits (open and closed) overlapped with the truth values of boolean algebra (true and false). This meant that switch circuit layouts could easily be mapped, designed and analysed using logic gates, which are based on boolean functions and operators (such as "and", "or", and "not"). Shannon's model was not only an effective means to formalise circuitry, but in fact, set the basis of digital logic which

[58] As a measure of the freedom of choice an agent has when selecting the contents of a message.

[59] A branch of algebra which translates operations in terms of true and false statements, developed by the English mathematician Georges Boole (1815–1864).

lies at the core of electronic digital computing.

Shannon joined Bell Laboratories (the research branch of the telephone company) in the early 1940s after completing a PhD in mathematics. Throughout the War, this R&D institution developed secure communication systems for the American Military. As a cryptanalyst,[60] Shannon's primary task was to evaluate the strength of the encryption system that allowed Franklin D. Roosevelt and Winston Churchill to communicate directly over the telephone (Kahn 1996). According to Kahn, Shannon himself noted that throughout this decade his work as a cryptanalyst and his work on MTC overlapped and cross-fertilised, making it difficult to establish which influenced and led to which.[61] By the end of the decade, Shannon had two major papers, MTC, and "Communication Theory of Secrecy Sytems" (1949), the latter of which was immediately classified by the Military. Both papers are somewhat complementary; the first one — as it was already noted — was the precursor of information theory and sciences, while the latter was a theoretical condensation of cryptology in informational terms.

MTC was "by no means a wholly new theory", as Weaver (1949) noted, since it was built upon the ideas of Ludwig Boltzmann,[62] Leó Szilárd,[63] and John Von Neumann,[64] amongst others. In his paper, Shannon (1948) acknowledged that a couple of papers published in the 1920s by Harry Nyquist[65] and Ralph Hartley[66] — who also worked at Bell Laboratories — formed the basis of his theory. These two engineers were amongst the first to speculate on the possibility of quantifying the transmission of "intelligence" or rather, information through electronic means.[67] What prevented them from doing it was the lack of an adequate unit for measuring information. Shannon's major contribution was overcoming precisely this problems, and his success arguably had to do with the experience he acquired working as a cryptanalyst.

[60] Cryptanalysis is the "twin science of cryptography". The former undoes what the latter does. Cryptography is theoretical and abstract; it is based on mathematical truth and logic, whereas cryptanalysis is empirical and concrete; its method is closer to that of the physical sciences. In other words, cryptography devises algorithms while cryptanalysis tests them (Kahn 1996, Chap. 20)

[61] During these years, Shannon met Alan Turing, who secretly visited Bell Laboratories in 1943, after having successfully cracked the Enigma code. Due to secrecy protocols, neither of them were allowed to discuss their work on cryptanalysis, but they did have the opportunity to discuss Turing's paper, *On Computable Numbers* as well as their views on machine intelligence (Gleick [1992] 2011).

[62] 1844–1906

[63] 1898–1964

[64] 1903–1957

[65] 1889–1976

[66] 1888–1970

[67] In a 1924 paper, Nyquist proposed to measure "the speed of transmission of 'intelligence'"; four years later, in another paper, Hartley replaced this "anthropomorphic" term with information (Gerovitch 2002) — which he borrowed from the statistician R. A. Fisher (Byfield 2008).

4.5 Understanding MTC through the basics of cryptography

As Shannon (1949, 685) pointed out, from a cryptanalyst's perspective, "secrecy" (i.e., encryption) systems are remarkably similar to an extremely *noisy* long distance communication system. Long distance communication systems work by embedding or "transforming" messages into continuous signals suitable for transmission. These signals might be electrical — in the case of the telegraph, telephone or electronic digital computers — or sine radio waves — used in radio, television and most wireless technologies now available, such as mobile phones and WiFi. Travelling back and forth between locations, the messages are *interpreted* at each destination, depending on whether the system allows for bi-directional communication (e.g., telegraph or telephone) or unidirectional broadcasting (television).[68] That is to say that the messages are *encoded* and *decoded* at both points. Shannon thus realised the ultimate problem of communication consisted in making sure the receiver was able to reproduce *exactly* or at least approximately the same thing that was conveyed by the source (Shannon 1948).

Shannon, like Nyquist and Hartley before, had to find a way to measure this type of exchange which, in turn, implied establishing what exactly was the *thing* being communicated and how to break it down into quantifiable units. It also meant finding a way to measure how many of such units could be transmitted at any given time (i.e., the capacity of the transmission channel) and if there was a way to make the transmission more efficient. This last point implied finding out if there were optimal encoding and compression processes and how to diminish the inevitable effects of noise. MTC established that "information" is what is being transmitted, that it could be broken down and quantified as binary digits and that it may be conceptualised as *a measure of the freedom of choice one haves when selecting a message*. Whereas the maximum capacity of a channel is equal to the maximum rate at which information without added noise can be transmitted, and the most efficient encoding is that which matches the statistical characteristics of the source and the channel (Weaver 1949).

MTC thus breaks down communication[69] into various components, each one carry-

[68]For example, in the case of telegraphy, actual humans took care of this task, by translating Morse code into ordinary language back and forth in real time. In the case of other electronic and digital information technologies, the function is carried out by dedicated appliances.

[69]MTC regards "communication" in a very broad sense: as including "all of the procedures by which

ing out specific roles throughout the process. Every act of communication involves an "information source" which "selects a message out of a set of possible messages" (Weaver 1949, 11), a "transmitter" which *encodes* it into a suitable "signal", and a "receiver" who *decodes* the message back into intelligible form. During the transmission, certain things which were not intended by the information source are added to the signal and may cause errors in the transmission, these things are called "*noise*". To illustrate this scheme one may imagine a conversation between agent A and agent B happening on a street. Oversimplifying, agent $A's$ brain represents the information source and her vocal system the transmitter; while agent $B's$ auditory system is the receiver and his brain the destination (1949, 12). Because the conversation is happening on the street, the sound of passing cars and people represents the noise threatening the clarity of the conversation.

From a technical standpoint, *code* may be defined as the "mapping of a finite set of symbols of an alphabet onto a suitable signal sequence" (cited by Kittler 2008, 40). Codes may be intelligible, such as a written language (including those used in programming) or unintelligible. Unintelligible codes may be so due to practical or technical reasons (such as the case with machine code and barcodes, respectively), out of ignorance (due to illiteracy or lack of knowledge of a given language) or because they have been deliberately made obscure. Such is the case with *cyphers*.[70]

A cypher is essentially a method or *algorithm* for concealing information by deliberately transforming an otherwise intelligible message into apparent random gibberish to the eyes of unwanted and potentially prying third parties. To recover the hidden information, one must know the *key* to translate the gibberish back into something intelligible. Without it, decryption can only be carried out by reverse-engineering the cypher through some form of statistical analysis, through plain guessing (which is commonly known as a "brute force attack"), or through a combination of both.[71] The first step towards reverse-engineering or "cracking" (not brute-forcing) a cypher is

one mind may affect another" (Shannon and Weaver [1949] 1980, 3), this, of course, applies to *any* medium, from spoken words to audiovisual content. However, MTC is solely concerned with the technical/quantitative region of communication; hence, while it acknowledges the existence and importance of the other two, it essentially ignores them. That is why Shannon (1948) explicitly states the "psychological" aspects of communication are irrelevant to his theory.

[70]The term cypher has its roots in the Arabic word *sifr* which, meant "emptiness" and was also the name for "zero".

[71]In our post-Snowden era, where encryption systems are growing in popularity and becoming consumer products and expected features in communication services, codebreaking has also become pervasive. Because reverse-engineering encryption requires considerable computation power and time, most malicious codebreaking attempts resort to brute force attacks, middleman attacks or even "social engineering" or a combination of all of these techniques.

to look for some *pattern* hiding underneath the encrypted message. Luckily for code-breakers, patterns are more persistent that we would generally think (Gleick [1992] 2011, 179).

Patterns involve structure and, more important, orderly repetition. Superfluous or unnecessary repetition is said to be *redundant*. While redundancy is frequently equated to needless excess, it is intrinsic to languages. Shannon (1949) calculated English has a redundancy of roughly 50%, which means that about half the words in a message could be eliminated without rendering it completely unintelligible (Weaver 1949). But redundancy also operates at a more granular level. For example, in an English (or Spanish) text, virtually all instances where the letter "*q*" appears makes the following "*u*" redundant, simply because there are very few words where "*u*" is omitted from the "*qu*" pair or "digraph". Redundancy is also responsible for the fact that we can write something like so: "*if u cn rd ths*" and still be able to understand it (Gleick [1992] 2011).

In everyday communication, redundancy is a desirable feature[72] because it increases the chances of a message being correctly interpreted (Floridi 2004; Gleick [1992] 2011). Repetition counters equivocation and misunderstandings caused by the inevitable noise that accompanies all instances of communication. That is why, as Floridi (2004, 15) notes, "in a crowded pub, you shout your orders twice and add some gestures". In everyday language, it is easier to make ourselves understood by incrementing our "verbosity" (Gleick [1992] 2011). Thus, in this context redundancy works a method of *error correction*. Repetition does not make normal communication more efficient from a purely quantitative standpoint, but it certainly makes it clearer.

Lack of efficiency and clarity are precisely the opposite of what cryptographers attempt to achieve. Like all effective and "elegant" codes, good cyphers allow their user's to encode as much information in as little space as possible; all the while making it extremely difficult to be accessed without the appropriate decoding mechanism. Redundancy that leads to the recognition of a pattern is a cryptographer's nightmare

[72] Redundancy is also welcomed in the context of art. As Russian polymath Mikhail Volkenstein noted:

> Unlike non-artistic texts—in newspapers, for example—, in artistic ones repetitions are far from being always redundant, that is, far from being devoid of fresh information. In ornamentation—of tiles or wallpaper, for example—a repeating pattern may have an emotional impact precisely because of the repetition. And this holds not only for applied art. A repeated refrain in a poem or a passage of music has artistic significance. This shows again the importance of the integrity of an artistic work—the impossibility of delineating from it a rational content where repetition would indeed be redundant. (Volkenstein [1986] 2009, 188)

and a cryptanalyst's dream. Weak encryption is usually bad at concealing its structure. For example, simple substitution methods[73] — such as the "Caesar cypher"[74] — which merely shift the letters in the alphabet a fixed number of places are extremely vulnerable to *frequency analysis*.

Frequency analysis takes advantage of the *statistical structure* (Gleick [1992] 2011, 180) — and hence, of the redundancy — of languages.[75] Statistical structure refers to the fact that in every language some phonemes are more frequent than others, which in turn means that, in writing, some symbols and letters are more common than others. For example, both in English and Portuguese the letter "*e*" has the highest frequency, whereas, in Spanish, "*a*" is the most frequent one. Knowing this, a code breaker would crack a substitution cypher by matching the character with the highest frequency in the encrypted message with the letter with the highest frequency in the language used. She would then repeat the procedure with all subsequent letters in order of frequency until a recognisable pattern emerged. While frequency analysis was initially done by humans, after WWII the task was passed on to computers, which can be programmed to carry out the process much faster.[76]

The statistical structure is not limited to syntactics, as the level of abstraction grows more complex, frequencies become influenced by semantics (meaning), pragmatics (usage), and context. Thus, depending on the circumstances some words are more likely to appear than others. That is why MTC regards communication as a *stochastic*

[73]There are stronger substitution methods, such as the one developed by Renaissance polymath Battista Alberti, which remained unbreakable for centuries.

[74]The "Caesar cypher", named after one of its most illustrious users worked by shifting the letters in the alphabet four places; thus all "*D's*" were "*A's*", and all "*E's*" were "*D's*", etc. (Kittler 2008, 40). Needless to say that, under contemporary standards, its efficacy as an encryption system is virtually null, although it is not as weak as the one provided by ROT23.

[75]By most accounts, the first person to leave a written reference on the fact that in every language some phonemes and letters are more common, and also that their frequency could be used to crack encrypted messages was the ninth century polymath Aal-Kindi (ca. 800–870 CE), "The philosopher of the Arabs" (Singh 2001). The first Westerner to arrive at the same conclusion was another polymath, the Italian architect and mathematician Leon Battista Alberti (1404–1472), the inventor of linear perspective (Kittler 2008) and the "Father of Western Cryptology" (Kahn 1996).

[76]Frequency analysis as described above, is not the only code-breaking method, in fact, it is only useful against the weakest substitution cyphers. Since the Renaissance, when Leon Battista Alberti described a polyalphabetic cypher (which is essentially a cumulous of Caesar cyphers, but remained unbroken until the Victorian Era) cryptography has been evolving. Particularly after the two World Wars, both cyphers and cryptanalysis have become extremely sophisticated thanks to computational technologies. Nonetheless, statistical analysis and probability remain at the core of cryptography since, at a fundamental level all encryption systems comprise "a finite (though possibly vast) number of possible messages, a finite number of possible cryptograms, and in between, transforming one to the other, a finite number of keys, each with an associated probability" (Gleick [1992] 2011, 181).

system, meaning that is neither deterministic,[77] nor random, but probabilistic (Gleick [1992] 2011, 187).[78] But language, it turns out, is not only representative of a *stochastic system*, but also of a *Markov* process and — at least at the syntactic level — of an ergodic process.

A Markov chain[79] is a sequence of events in which the probability of each new event is determined by the outcome of the previous event, or in more complex cases, on the outcomes of various preceding events (Volkenstein [1986] 2009, 148). Ergodic processes are a subset of Markov processes, the difference being that any reasonably large sample taken from an ergodic process is representative of the whole system (Shannon and Weaver [1949] 1980). Human languages are Markov systems because certain words are more likely to appear when and if others have been uttered before — for example, in English, the article "the" is more likely to be followed by a noun or a verb than by any other type of grammatical unit. Language may be considered *ergodic* since analysing a regular book or even a newspaper can yield an accurate picture of the statistical structure of the language in which they have been written.[80] In short, for MTC, messages are *chosen* from a (finite) set of possible messages. The more unexpected the message, the higher the amount of information it carries; and vice versa, the more expected, and hence, redundant, the less informative. Following this logic, it is clear that the higher the randomness in a given dataset, the higher its informativeness.

[77]In the non-pejorative, mathematical sense, deterministic means that a system's states are caused by prior states with *absolute* certainty, rather than probabilistically (Pinker 2003, 112).

[78]Fair dice are an example of a stochastic system since it is possible to calculate the probability of getting any number between two and twelve at any given throw — seven being the most likely to appear, and each throw is subject to a certain amount of randomness or *entropy*. Whereas two extremely biased dice represent a deterministic system since, after a series of throws, one can be reasonably sure of what number will come next; thus, it is virtually devoid of randomness. Finally, a random system, i.e., one in a maximum state of entropy, is one in which the events carry no discernible pattern on which to base future predictions, for there is just no way to calculate the likelihood of any of its outputs.

[79]So named after Russian mathematician Andrey Markov (1956–1922) who proved this probabilistic phenomenon by analysing, amongst other works, Pushkin's Eugene Onegin. While literary in origin Markov's theory is successfully applied in the physical sciences and economics (Volkenstein [1986] 2009, 148).

[80]This was precisely what Samuel Morse did when conceiving the code that bears his name. Reportedly he counted all the letters in a Philadelphia newspaper to find out which were the most frequent ones and thus assign them the shortest symbols. Having found $12,000$ *"E's"*, followed by $9,000$ *"T's"* he decided to assign these letters a single dot and a single dash, respectively (Kahn 1996).

4.6 Information according to MTC

MTC treats information in a "special sense" (Shannon and Weaver [1949] 1980); as something devoid of intrinsic meaning. The theory was conceived to analyse *any* instance of information exchange in quantitative terms, but to do so, the model had to disregard all the "psychological" (Byfield 2008) — i.e. semantic — aspects usually involved in communication. MTC treats information as a "raw" (Floridi 2004, 51), "dimensionless" (Ben-Naim 2008, 203) quantity. Just like a kilogram of salt and a kilogram of gold constitute the same measure even though the particular characteristics and, more important, the value of these two substances may be significantly different, MTC understands information as a *placeholder*. To that extent, for MTC two messages, one heavily loaded with meaning, and the other composed of pure gibberish, may be equivalent when it comes to the amount of information they contain. In fact, the message containing nonsense could be considered as having *more* information than its structured counterpart simply because its contents are potentially more unexpected.

MTC is fundamentally a study of communication limits at the syntactic level; meaning that it is concerned with the *transmission* of information, and not with information itself. MTC does not offer a method for measuring information *per se* but for quantifying the amount of ignorance or uncertainty a given a message can "erase" at its destination (Floridi 2004). Shannon used the quantification of predictability and redundancy as a "'backward way of measuring information content'" (Gleick 2011, 191). This means that MTC has little to say about *reception* (which is of central interest to, say, media theory). Consequently, under this type of schemes, "the receptor has very limited capabilities: all it can do is distinguish one letter from another or one coded symbol from another." (Volkenstein [1986] 2009, 158). Overall, MTC is a very effective model in contexts where semantic value is not a priority — e.g., in electronic communications and computation, but its suitability diminishes considerably in circumstances where meaning is central to the analysis, such as in aesthetic practices. This is the main reason why the humanities often ignore MTC, the other one being that Shannon's understanding of *informativeness* confounds many scholars (e.g., see Arnheim 1971).

As it should be clear by now, Shannon's goal with MTC was not to provide an all-encompassing account of information, but rather to *measure* "the accuracy of transference from sender to receiver of a continuously varying signal" (Shannon and Weaver [1949] 1980, 8). This to determine what would be "the ultimate level of data compression" and what "the ultimate rate of data transmission" (Floridi 2004, 47). In other words, how much could a message's "size" be reduced before making it unintelligible and how fast could it be conveyed. Shannon's theory is a general description of the circumstances governing every instance where "not-yet-meaningful" data are transmitted (Floridi 2016); data which are represented by computable and interchangeable binary digits, or "bits". For MTC, "information" does not refer to what *is* being said, but rather to what *could* be said (Weaver 1949).

4.7 A philosophical understanding of information

Within the philosophy of information, there have been numerous attempts to reach a more general definition of information. Luciano Floridi (2004, 40–41) places these various characterisations within three main groups: "reductionists", "anti-reductionists", and "non-reductionists". Reductionists contend all instances of information could be reduced to one universal definition, usually Shannon's. Conversely, "anti-reductionists" claim information cannot possibly be defined by any single concept. A middle ground is occupied by "non-reductionist" approaches whom, in turn, are divided into "decentralised" or "multi-centred" positions on one side, and "centralised" positions on the other. Multi-centred approaches regard all notions of information as equally valid. Thus, "[d]epending on the orientation, information is seen as interpretation, power, narrative, message or medium, conversation, construction, a commodity, and so on" (2004, 41). Centralised positions — as the name implies — place *factual semantic information* at the core of the conceptual "archipelago" formed by the "various meanings, uses, applications, and types of information" (2004, 41). This approach capitalises on the "aboutness" of information, and its premise is simple: "In order to understand what information is, the best thing to do is to start by analyzing it in terms of the knowledge it can yield about its reference" (2004, 41).

The very reason MTC is such a useful tool for information technologies (namely, its disregard for semantic content) makes it comparatively limited for the humanities. Quantitative models neglect granular detail and individual cases because operating at a higher *level of abstraction* allows them to explain phenomena in more general terms. Science, after all, is about compressing the largest amount of information on any given phenomena in the shortest and simplest explanation.[81] In the context of art; however,

[81] Richard Feynman's often cited explanation of the value the atomic theory would have is a good example of this notion (Gleick 2011).

the assumption is that every artwork represents a unique, irreplaceable instance although it may share some qualities (physical or otherwise) with other examples of its class. When we approach works of art, we do it with a hermeneutical intent attuned to granular detail. The question is, what benefits does it have to talk about art in terms of information when the very formulation of this concept seems to ignore its most crucial aspects — namely, semantic content and its reception? Luckily, as Shannon ([1949] 1980) himself recognised, MTC's reductive characterisation of information is by no means the only one available.

4.7.1 The general definition of information

Most fields related to information science now tend to agree upon an operational definition of information based on semantic content (Floridi 2011a). According to this "General Definition of Information" (GDI), semantic contents may be considered information if, and only if they are composed of "well-formed meaningful data" (Floridi 2004, 2011a).[82] Along with rejecting the possibility of data-less information, GDI requires data to have some form of representation (e.g. binary digits) and also — given the nature of current computational technology — physical implementation.[83] Now, regarding the question of how or why data can carry meaning in the first place is, according to Floridi (2004), one of the most difficult problems for semantics and philosophy. Nonetheless, it is possible to bypass this shortcoming by assuming the issue "is not how but whether data constituting information as semantic content can be meaningful independently of an informee" (2004, 45). Examples such as the Rosetta Stone[84] and the growth rings in tree trunks show the answer is that meaning is not — at least not exclusively — in the mind of the human subject (2004).

[82] The definition of "data" is itself contentious. Data is the Latin translation of the Greek word, *dedoména*; it is the utmost unit to which information may be reduced. In its singular form, "*datum*", is a fact concerning some difference or lack of uniformity within some context, e.g. the perceptible difference between two letters in the alphabet, or the difference between the presence or absence of an object (Floridi 2004, 2011d). That is why sometimes information is characterised as "a difference that makes a difference".

[83] It is important to note, however, that physicality does not necessarily entail materiality (Floridi 2010).

[84] Before its discovery, Egyptian hieroglyphics were indecipherable; the discovery of the stone provided an "interface" to access their meaning; this, however, did not affect their original semantics (Floridi 2004).

4.7.2 Two types of semantic information

Understood as semantic content, information comes in two major flavours: instructional and factual. Instructional information — also known as "imperative" information — is the kind one might find in stipulations, orders, recipes or algorithms. These instances have a semantic dimension since they have to be interpretable and therefore meaningful, but unlike instances of factual information, they cannot be correctly qualified as being true or false, only perhaps as being correct or incorrect.[85] Instructional information does not convey specific facts nor does it model, describe or represent ideas; it merely helps to "bring about" (Floridi 2016) (factual) information. For its part, factual information (also known as "declarative" information) is the most important of the two kinds of semantic content, but it is also the most common way in which information *in the capacity of* information "can be said" (Floridi 2004). Factual information "tells the informee [agent] something about something else" (2004, 45); for example, the location of a place, the time of the day, an idea, a fact, etc. To borrow a metaphor from Floridi (2004), factual information is like the "capital" or centre of the "informational archipelagos", since it provides both a clear commonsensical grasp of what information is and links all concepts related to information.

Information is a multifarious concept with many definitions and interpretations. It is the substance of our epistemic foundation; it is what allows us to understand the world, to communicate and grow as societies. Sociotechnical changes associated with the evolution of IT — such as ubiquitous computing, the emergence of Big Data and associated phenomena such as the Internet of Things (IoT), Blockchain technology and, eventually, some form of strong AI and quantum computing — are nothing short of a revolution. This idea could be easily dismissed as an exaggeration, but the truth is that we are experiencing a true epistemic revolution whose consequences we should not underestimate. Through our unprecedented ability to gather and process data, we have forever transformed notions such as intelligence, value, society, community, property and, of course, *art*. Just as science shapes our understanding of the world by attempting to make sense of observations (i.e., of data) and incorporating them into a coherent theoretical framework; art *informs* our perceptions by saying (communicating) things about the world and ourselves (i.e., by generating information). Information has to do with how we shape the world and our thoughts, that is why it represents a quintessential intersection between art, science, technology and philosophy.

[85] Consider for example a musical score or a piece of software, neither of them may be successfully qualified in alethic terms.

This reason alone should suffice to understand why it is crucial for art theory to *problematise* information. Art does not exist in a vacuum; its autonomy does not imply nor forces it to assume an extraneous position to the transformations of the world, more to the contrary. When our views on the world and ourselves are being so profoundly changed by technological developments, art is *necessarily* being proportionally transformed too. Understanding how this occurs and what can we expect to happen is crucial for art's epistemic underpinnings and its future. However, there is another more productive argument for problematising information from an artistic perspective: that its definition requires imagination in the amplest sense; it needs metaphors and analogies; it requires artistic creativity. Art offers parallel and creative thinking; it can make science graspable and easier to narrate. But art can also be informed by science; it can benefit from understanding the abstractions, the engineering and logic of technological evolution, it can see all of its tools as new opportunities for transforming the way we represent the world and its objects.

The notion of factual information, previously described by Floridi as semantic content that communicates something to somebody about something else is, incidentally, a useful way to describe art. Although simple, this formulation is not trivial because it emphasises the *communicational* nature of aesthetic practices without forcing in any problematic epistemic compromise. We could agree that most artistic manifestations are, essentially, acts, objects or ideas which point out to something in the world. The degree of interestingness and relevance of the "something" and the adequacy of the means chosen to do the "pointing out" are, of course, matters open to analysis and interpretation. It could be argued that Modernism came precisely as a reaction to art's historical use as a proxy — as a medium — for "literature" (Greenberg [1940] 1999), narrative and representation, and a quest for the systematic reaffirmation and independence of art from other disciplines. However, it could also be argued that the "pointing" merely became self-referential. Many contemporary works of art are content with conveying merely their sheer presence — their "aboutness" — without claiming to have any discursive intension or intention. Many other manifestations assume various forms of discursive stances, including a playful "alchemic" transformation of discourse itself. Nevertheless, in the end, it is justified to see art essentially as acts of conveying factual information.

4.7.3 The information machine

Computational technology is the embodiment of the accumulative tendency of information technology. Before 1945, the antecedent of what we now call the computer were electro-mechanical, single-tasked calculation machines whose "programming" (the term had not yet been invented', required changing the physical disposition of their components. This state of affairs changed thanks to the stored-program paradigm that John Von Neumann (inspired by Turing's paper) and his colleagues introduced as the basis for the architecture of the ENIAC (Electronic Numerical Integrator and Computer), the first electronic multi-purpose computer (Chun 2008; Campbell-Kelly et al. 2014). Besides conceiving a 5 component setting that included input, output, processing and memory components, Von Neumann and his team decided to use binary notation to represent numbers throughout the system. Consequently computers could now store both, data *and* instructions — i.e., *programs*[86] — within their electronic *memories*.[87] This "von Neumann" architecture allowed modern computers to become truly multi-purpose machines, since, at a fundamental level everything, from the instructions to the output became interchangeable strings of numbers whose only difference lied in the way they are organised or structured. The characteristic "modularity"[88] and "permanent extendibility" (Manovich 2013) of future software are a consequence of such flexible organising principle. But ultimately, everything comes down to the fact that computers are essentially information-processing machines.

As we saw in section two of this chapter, the main contribution of Turing's paper to computer science was formalising — i.e., putting on a solid mathematical foundation — the powers *and* the limits of digital computers (Dyson 2012). Although hypothetical at the time Turing published his ideas, Turing machines could translate back and forth between "bits-as-structure", and "bits-as-sequence" (2012, chap. 1). That is, they could treat programs (algorithms) and data interchangeably. And yet, in their theoretical state, Turing machines were highly impractical (they could only read/write/erase one square/symbol at a time). It was Von Neumann and his team

[86] A term which replaced "planning", and was adopted to distinguish machine from human computing (Chun 2008, 225).

[87] This term replaced "storage", which had been used since [Charles] Babbage's time. The reason being that Von Neumann — who was very interested in the organisation of the brain, relied heavily on a biological metaphor to conceive the 5-component computer architecture that now (somewhat unjustly) bears his name (Campbell-Kelly et al. 2014, 75–77).

[88] The design principle that allows programs to re-use snippets of code ("modules" or "subroutines") which are stored as "libraries" (Campbell-Kelly et al. 2014, 169).

whom, by making storage accessible *at the speed of light* truly unleashed the power of Turing's thought experiment. Precisely because they were abstract constructs Turing machines could carry out computations that no real machine could achieve.

Unlike Babbage, Turing did not see his machine as anything more than a concept; his' was a scientific distillation; a reduction in the best sense of the term. Turing was a programmer even though he did not (could not) see himself in that way yet. He reduced mental procedures to their smallest components (Gleick 2011). Turing's machine did not have to deal with obstacles of material implementation (as Babbage's engines previously had), there was no need to design and construct components. Turing's universal machine was, by all intents and purposes, one of the rare "concept-driven" scientific revolutions (see Chapter 2).

Stripped down to their elementary functions, Turing machines can be transformed into numbers, that is, data. A particular string of numbers can describe every possible state of a Turing machine. It follows that every Turing machine can simulate any other machine, provided there is a specification for it. To paraphrase Gleick (2011), by obliterating the distinction between data and instructions, Turing showed in the end "they were all numbers", data, *information*. Computers are in the most fundamental way, information machines. However, we should bear in mind that in the end, the power of computation is the power of *translation*; of the human ability to encode anything that can be encoded as procedures. Finding an adequate way to reduce any given problem into a set of instructions and thus being able to model it is what transformed the information machine into a modelling machine. That process required a series of conceptual and technological developments, in which artists, or rather, mathematicians with artistic sensibility played a fundamental role. Such transformation of the computer into a multipurpose media machine is the topic of the following chapter.

4.8 Conclusions

Computers are information modelling appliances that rely on information — i.e., "well-formed, meaningful and truthful data" as their raw material. Provided that someone is capable of formulating an adequate algorithmic translation of a problem, a sufficiently powerful computer will be capable of generating a simulation through various forms of perceptible outputs. In other words, computers make abstractions tangible in a way that no other technology is capable. Because of them, our ideas are progressively less constrained to the limits of our "mind's eye" or by the limitations imposed by laborious analogue representations. As epistemological tools, computers both augment and permanently extend our minds.

This chapter has shown why computers are such flexible devices. Furthermore, it has shown the importance that looking at the (conceptual and historical) origins of the computer has for understanding why they can do what they do. This historical account places computation deeply into human affairs; it calls attention to the human origins of computation and to the fact that these devices merely accomplish two tasks: make calculations and remember the results. Computers are models of a specific form of human thinking; they are reductions of one of our most potent abilities, to create and systematise processes. Computers are not unlike every other machine, but the nature of the raw material they operate on, or rather its *level* of abstraction is what sets them apart from any previous technology. In the first decades after their introduction, computers were still active mostly in an abstract domain, they assisted us in processing data, and transforming it into information. In that stage, they were still tools that enhanced our thinking. However, as computers continue to merge with every other technology, as they become the central tools in our lives, their scope of action naturally expands. Computers have become universal machines in a literal sense. The following chapter will deal with this transformation, providing the second "portrait" of the computer at a more recognisable level of abstraction for art scholarship.

Chapter 5

The simulation machine

Summary

In Chapter 4 we saw that at the most basic level the computer is an information modelling machine, and thus the quintessential expression of information technology. We saw the flexibility of the computer — its multistability — is owed to the fact that its "raw material" (data), as well as the tools and methods (algorithms) employed to manipulate it, are made of the same "stuff": information. This chapter deals with the first question guiding this dissertation, namely: how to understand the computer as a tool within aesthetic practices. It shows that while software studies' characterisation of the computer as a *metamedium* is a fertile model, it can nevertheless be expanded with the help of an informational framework, and by further clarifying some of the key concepts used by this approach, such as "simulation", "software", "and data". In so doing, this chapter provides a second "portrait" of the computer at a more accessible level of abstraction. It shows the computer is not (only) a metamedium but an *augmenting device* (see Chapter 1) that enables users to interact, tinker, model, and visualise objects within a plane of abstraction that hitherto was only accessible to our minds. More important, this chapter shows that even before becoming a media machine, the computer was already an machine for art.

5.1 Introduction

It took only two decades after the introduction of the first mainframes into the market for computers to become tools for art, and only two more decades for "media authoring" software to become a consumer product (Manovich 2013, 44).[1] Almost seven decades after the first general-purpose electronic digital computer became commercially available, images without some trace of digital art are virtually non-existent (Nake 2010). The same goes for many tasks whose accomplishment is now unimaginable without the aid of a computer (e.g., writing a book, editing video, or making calculations). Computers have transformed how we make literature, how we design, illustrate, take photographs, compose and play music, and edit films. In the process, computers have led to the development of new artistic genres, styles, and disciplines. Due to the prominence of computational technology, understanding its history is crucial for understanding contemporary culture, and so-called "new media".

This chapter shows how before becoming a media machine, the computer was already a tool for art. It looks at computational technology from a more familiar level of abstraction for aesthetic practices: as a machine capable of simulating virtually all forms of audiovisual manifestations. It shows software studies offers a powerful conceptual framework for understanding the emergent properties of contemporary aesthetic practices, the nature of computers as a tool for art, and the ontological status of computational aesthetic objects. It argues that some of the basic concepts used by this approach require further clarification, which can be provided by the constructionist and postphenomenological methodologies described in Chapter 3, as well as by Frieder Nake's semiotical characterisation of algorithmic art. The chapter begins by recanting how the computer came to be used by mathematicians and engineers with artistic inclinations in the early 1960s. This is followed by a history of the evolution of computers from the number-crunching machine described in Chapter 4 into the media devices we are now so dependent upon. The following section discusses the conceptual framework developed by software studies before discussing key concepts such as simulation, algorithm, and data. Finally, the discussion shows how this level of abstraction is enriched by the informational framework that has been developing throughout the previous chapters. This prepares the reader to engage the following chapter's discussion of artworks as informational systems.

[1]AutoCAD, introduced in 1982, is considered by most software historians as the first (successful) commercial media authoring program.

5.2 The computer as a tool for art

In the late 1950s, at the height of the Cold War, the American Air Force (in partnership with the MIT and IBM) spent billions of dollars to build a computerised system that linked 23 air defence monitoring sites: the Semi-Automatic Ground Environment or SAGE (Weinberger 2017a). The SAGE system combined state of the art radar with live input data from commercial flights to watch out for potential Soviet bombers. Each SAGE site depended on two vacuum tube digital computers to which dozens of terminal consoles were linked through time-sharing.[2] Each console had a 19-inch cathode tube monitor (CRT) which could display vector lines or alphanumeric characters on any portion of the screen.

Around 1958 or 1959 an unknown operator wrote a program that generated a drawing inspired by a pin-up girl illustration that had appeared in Esquire Magazine in 1956 (Edwards 2013). The program rendered the image as vectors, and it was encoded on a stack of more or less 90 punchcards. In effect, this image constitutes the world's earliest known instance of a computer being used both to draw *and* display a human likeness (2013). Whether this constitutes art or not is a matter open for discussion, but the anecdote prefigured what would become the norm in later decades, first with the advent of computer art,[3] and eventually with the emergence of the personal computer (PC) and "media software". The SAGE system would thus play a crucial role in the development of human–computer interaction (HCI), specifically in the invention of the mouse and the graphical user interface (GUI), two of the most important features contributing to the transformation of the PC into a media machine.

5.2.1 Computers and automation, military art, and computer art contest

In 1963, the pioneering computing magazine *Computers and Automation* published in the cover of its January issue an image generated by junior MIT technician Ebram Arazi while he attended an "Art for Engineers" course taught by modernist artist Robert O. Preusser.[4] To produce "[t]he weird group of 'electronic stalagmites' gracing [the] front

[2]Time-sharing was a setup that allowed many people to simultaneously use the same computer, giving each one "the illusion of being the sole user of the system" (Campbell-Kelly et al. 2014, 203)

[3]Also known as "algorithmic art" or "digital art".

[4](1919–1992) Born in Texas, he was a student of Bauhaus artist László Moholy-Nagy (1895–1945) at the New Bauhaus School — now the Chicago Institute of Design.

cover" (Berkeley 1963c) Arazi had used a modified television camera which produced "series of discrete readings indicating intensity as well as horizontal and vertical position. This data was then 'fed into a computer" plugged to an oscilloscope screen. The caption accompanying the image read: "A Portrait by a Computer As a Young Artist" — a witty and rather appropriate reference to the title of the first novel by James Joyce ([1916] 2008).

So enticed became Edmund C. Berkeley[5] (the founding editor of the magazine) by Arazi's image that in the following (February) issue, the magazine instituted an "informal" contest of "'computer art,'"[6] "[t]o encourage explorations in this new domain" (1963b). From that year until 1972 (when it rebranded to *Computers and People*) Berkeley's magazine showcased in the cover of the August issue the winner of that year's contest. *Computers and automation* thus became the first medium to regularly publish computer art, the first one to institute a contest, and hence a key promoter of the new art form and its pioneers.

On August 1963 the editorial of *Computers and automation* announced the results of its first-ever "computer art" contest. The winners of the first and second place were *Splatter Pattern* and *Stained Glass Window*, respectively. Both were produced by algorithms which ran in computers hooked to a drawing table called a "Dataplotter". After providing a brief description of the procedures used to create the two artworks, the editorial concluded with the following words:

> The editors of *Computers and Automation*, though without professional qualifications in the field of art, have agreed that these two designs are beautiful, and should be published. And we hope that the next Computer Art Contest which we shall run will call forth more such computer art, unusual, creative, beautiful. (Berkeley 1963a)

The names of the artists who submitted the winning pieces were never mentioned. The reason was that the authors of the computer programs that generated both patterns were employees of the Ballistic Research Laboratory[7] (BRL) of the United States

[5] 1909–1988

[6] A summary of these events, as well as a collection of early computer art images, can be found in Vincent (2015).

[7] It was founded during WWI. As its name implies, the BRL's main activity was the mathematical analysis of weapons. It was among the first institutions to acquire one of Vannevar Bush's "Differential Analyzers" (Campbell-Kelly et al. 2014, 67). The BRL was also the birthplace of the computer industry in the United States as it was there that the ENIAC, the EDVAC, and the BRLESC 1 were produced. The latter of which most likely played a role in creating the first examples of computer art in 1962–63 (Taylor 2014, 27).

Army. As media historian Grant D. Taylor (2014, 27) notes: "A military laboratory producing the first recognized award-winning piece of computer art in the United States is certainly unorthodox. In fact, there is no similar example in the history of art". The (politically) uncomfortable fact that computers had an indissociable relationship with the so-called "military–industrial complex" was in part responsible for computer art being initially derided by the art world.[8] But so were the deeply entrenched (romantic) beliefs that technology was necessarily antithetical to artistic expression (see Chapter 1), and thus anything created by a machine was automatically devoid of creativity and aesthetic interest. The fact that throughout the 1960s C.P. Snow's ([1959] 2012) infamous Rede Lecture was still stirring controversy (see Chapter 1) did not help computer art's case. To many established artists, the irruption of scientific and engineering methods into the realm of the humanities was nothing short of a "provocation" (Nake 2012b).

5.2.2 Laposky and Franke

The American mathematician and draftsman Ben Laposky[9] has been credited with "laying the foundations for computer art's aesthetic claims" (Taylor 2014, 67). In the early 1950s, using a modified cathode ray oscilloscope[10] and a camera, Laposky made thousands of images of waveforms, which he called "Oscillons". Like Harold Edgerton's scientific photographs, Laposky's images contributed to blurring the boundary between aesthetic and scientific objects. But going as far as to regard him as a pioneer of computer art is problematic for various reasons. First of all, Laposky's medium was photography and electronic imaging, and he "understood his practice through the paradigm of electronics, not computers" (2014, 67). Secondly, While the concept of a computer already existed when Laposky began to exhibit his work in the 1950s, the term "computer art" only began to gain traction afterwards. Finally, in the seventies, Laposky himself would end up associating his work with "Op art,"[11] and not with the then-recent wave of computer artists (2014).

[8] Military involvement in computer art was, however, more direct and persistent. Besides the fact that the first graphic objects recognised as computer art were in fact pattern visualisations with a scientific purpose, the military would continue to fund computer art exhibitions including the 1968 London *Cybernetic Serendipity* which was partially funded by the U.S. Air Force (Taylor 2014, 29)

[9] 1914–2000

[10] In the previous chapter we saw the oscilloscope played an important conceptual role in the development of information theory.

[11] Short for "Optical art" a strain of abstract art which emphasised optical illusions.

The relationship between Laposky and latter computer artists lies more in the techno-scientific foundations and mathematical conceptualisation that fed his creative urge. Like early computer artists, Laposky repurposed an instrument initially devised for scientific purposes and used it to create art. Also like early computer and electronic artists, Laposky wished to "invoke the pattern and form of nature" (2014, 69), to visualise otherwise imperceptible natural phenomena (such as the movement of electrons) and thereby transform it into a source of aesthetic experiences. In this sense, Laposky's work is more reminiscent of early claims about the photographic image's ability to bring forth and arrest previously imperceptible aspects of life, and to do so in a supposedly objective manner. Laposky regarded his work in the same light William Talbot and later theorists who regarded photography: as a method that allowed Nature to register its own image (2014, 69). Despite all these facts, Laposky's work did influence other electronic artists who would later become computer art pioneers. Such is the case of the Viennese physicist, mathematician, and Sci-fi writer, Herbert W. Franke.[12]

Although less known than his contemporaries, Franke is a key figure in early computer art discourse and practice. He, like Laposky, began his artistic career experimenting with modified oscilloscope photographs; he began exhibiting his images of parametric curves in 1956, but eventually transitioned to computer art, where he built a considerable corpus of practical and theoretical work (Nake 2009). Franke contributed to the conceptual grounding of computer art; he wrote a few academic articles (eg., Franke 1987) and was the first to write a historical account of the new art form (Taylor 2014, 10) — in fact, it was Franke who mentioned Laposky's work as a pioneering influence of computer art. Like Frieder Nake,[13] Georg Nees,[14] Manfred Mohr,[15] Vera Molnar,[16] and others, Franke was associated with the so-called "Stuttgart School" (Klütsch 2012),[17] a group of scientists–artists heavily influenced by the ideas of Max Bense.[18]

[12] Born in 1927.
[13] Born in 1938.
[14] 1926–2016
[15] Born in 1938.
[16] Born in 1924.
[17] In Frieder Nake's words (2009, 80), the Stuttgart School was "a loose and informal set of artists, writers, theoreticians, architects, and composers whose only common bond was the theory of information aesthetics".
[18] 1910–1990

5.2.3 The Stuttgart School and the birth of European computer art

Throughout the sixties and seventies, Stuttgart (then part of West Germany) was a European capital of Concrete Art and poetry (Nake 2012b, 69); by 1965 it became the epicentre of European computer art. Along with Concrete Art, the emergence of computer art in Stuttgart can be closely linked to art movements such as the *Zero group* from Dusseldorf, the *Groupe de Recherche d'Art Visuel* (GRAV) from Paris, the *New Tendencies* group from Zagreb, conceptualism, and constructivism via the Bauhaus (Klütsch 2012; Taylor 2014). But by far the strongest influences behind computer art were Max Bense, "one of the most radical thinkers and prolific scientific writers of post-war Germany" (Nake 2012b, 65), and "Information Aesthetics"[19] — the theory he developed along with Abraham Moles[20] between 1954 and 1965 (Klütsch 2007, 421), and which involved a mixture of information theory, cybernetics, semiotics, and (Birkhoff's) "analytical aesthetics".

Bense, was trained in mathematics, physics, and geology; he was director of the Institute of Philosophy of the University of Stuttgart — then still the Stuttgart Institute of Technology (Nake 2009) — where he "taught philosophy of technology, scientific theory, and mathematical logic" from 1950 to 1976 (Klütsch 2012, 66). Bense was also an essayist and (concrete) poet (Nake 2012b), he edited several magazines, booklets, and journals, such as *Rot* (*Red*) — whose number 19 "most likely became the first [European] publication ever on visual computer art" (Nake 2012a, 66) and *Grundlagenstudien aus Kybernetik und Geisteswissenschaft* or *GrKG* ("Fundamental Studies in Cybernetics and the Humanities").[21] In other words, Bense embodied the third culture idealised by Snow ([1963] 2012) in the second edition of his *Two Cultures* essay. Bense's intellectual charisma was magnetic, as Frieder Nake notes:

> Aided only by some scribbles on the back of a package of cigarettes [Bense] lived and demonstrated the mind in action. Things and ideas were all happening right here and now. Everything was authentic and exciting. '[W]hoever attended his lectures witnessed philosophy as performance. (2012b, 65–66)

Chronologically, the beginning of the Stuttgart School and of European computer art itself fall sometime between December 1964 and 5 February 1965 (Klütsch 2012). The first

[19]Information aesthetics is discussed at length in Chapter 6.
[20]1920–1992
[21]A journal which Nake (2009) describes as something close to "scientific avant-garde".

date marks the publication of George Nees' article "*Statistische Graphik*"[22] ("Probabilistic Graphics") in Bense's *GrKG* journal;[23] the article contained a set of three computer-generated drawings along with a detailed description of the algorithms employed to produce them (Nake 2009, 80; Klütsch 2012, 69). The second date is computer art's "day of inception" (2009, 69), when Nees exhibited close to a dozen drawings consisting of "thin black lines, matrices of little figures in variation, overlapping arrangements of rectangles, geometry in a playfully random appearance" (2009, 77). The exhibition took place at the *Studiengalerie des Studium Generale* ("Study gallery of the General Studies program"), the seminar room of the Institute of Philosophy at the University of Stuttgart.

Founded by Bense in 1958, the *Studiengalerie* regularly hosted exhibitions of Concrete and Constructivist art and poetry, typography and other experimental works (Nake 2009, 77). By the time the gallery closed in 1978, Bense had organised over 90 exhibitions "and borne witness to the rise and collapse of the Stuttgart School" (Klütsch 2012, 65).

Accompanying Nees' exhibition was issue 19 of *Rot*. *Rot* was a series of small, square booklets edited by Bense and Elisabeth Walther, which published almost exclusively the work of those associated with the Stuttgart School. It usually contained texts on "semiotics, concrete poetry, information aesthetics, text analysis, and typography" (Nake 2009, 80). Number 19, however, contained a small selection (six in total) of the exhibited drawings, along with Nees' description in pseudo-code of the algorithms used to create them (Nake 2012b, 70). More important, the booklet also contained a short text by Bense titled *Projekte generativer ästhetik* ("Projects of generative aesthetics") — the concept of "generative" being a direct reference to Noam Chomsky's "generative grammar" (2012b). In retrospect, Nake (2009, 80, 2012a, 66, 2012b, 73; 2016) regards Bense's three page text as the first manifesto of computer art.

[22] According to Nake and Nees (2016), "Nees" paper was probably the second scientific publication on algorithmic art', after Canadian artists, Arnold Rockman and Leslie Mezei published "The Electronic Computer as an Artist" also in 1964. Furthermore, Nake notes the title used by Nees, "Statistische Graphik" was a deliberate choice to "protect his engineering reputation", and that his writing appears "in terse, technical language, describing only the programming. Anything that could come close to the idea of art is carefully avoided." (2009, 80)

[23] Nees was already an avid reader of *GrKG*, and the articles he read there proved to be hugely influential for his work (Nake 2009).

Frieder Nake, Georg Nees, Michael Noll, and the Graphomat Z64

In the early sixties, Georg Nees was the leading specialist of the Engineering Computer Centre at Siemens, at the time, the company was interested in engineering graphics, and Nees had recently acquired on its behalf one of the first Graphomat Z64[24] (Nake and Nees 2016). The Graphomat was a flat-bed drawing table. It was initially developed to be used by cartographers and others requiring high precision etchings. The machine had a working surface of 1.2 by 1.1 m, it could drive a chisel or up to four ink-filled pens, and was controlled by instructions fed through paper tape (Nake 2009, 79). The Graphomat was sold without software, Nees' wrote the first drawing routines in Algol 60[25] and attempted to solve the balancing and trembling of the pens (2016). Through this direct experience, Nees (who since his youth had been interested in drawing and art) recognised the aesthetic potential of the new technology. Being allowed to experiment with the machine during the nights he created the drawings that he exhibited in 1965 (2016). Nees would eventually pursue a PhD with Bense as his advisor, his dissertation, *Generative Computergraphik* was arguably the first one on computer art. His research could be described as a practical implementation of Bense's linkage of philosophy, mathematics, and aesthetics (Klütsch 2012, 65).

Another computer art pioneer with a similar trajectory as Nees' is Frieder Nake. Nake has been called "perhaps the most radical computer artist" from the Stuttgart school (Klütsch 2012, 74). While pursuing his PhD in mathematics at the University of Stuttgart, Nake was tasked by his teacher, Walter Kandel, to write the software to control the centre's recently acquired Graphomat Z64, with an SEL ER56 computer (Klütsch 2007). To test his program, Nake began experimenting with drawings of more aesthetic than purely mathematical appeal. Being aware of Nees' exhibition, and after some experimentation, Nake approached Wendelin Niedllich — a close friend of Max Bense's — to see if it was possible to present some of his pieces at Niedlich's bookshop gallery (2012). Nake would exhibit his artworks for the first time on November 1965 along with Nees' drawings from the previous exhibition; at the inauguration, a text by Bense (who could not attend the event) was read (Klütsch 2012;

[24] The Graphomat was the last commercial product designed in 1963 by the German electronics inventor and computational technology pioneer Konrad Zuse (1910–1995) (Nake 2009, 78–79). Zuse is considered "father of the computer" in Germany, having independently built the world's first programmable digital machine (the Z3) in 1941, which was Turing-complete and stored programs on punched film (O'Regan 2012, 36–37).

[25] ALGOL was an early high-level programming language. The acronym stands for "ALGOrithmic Language". It was originally developed between 1957 and 1958, and went by the name ALGOL 58; the version used by Nees was released in 1963 (Petzold 2000).

Nake 2012a). The following year, Nake would again exhibit his work, this time along computer-generated texts by Gerhard Stickel, and computer-generated music by Max V. Matthews. But, contrary to previous exhibitions, this one received considerable attention from media outlets; it was covered by television, national newspapers, and art magazines (Nake 2009, 83).

In 1966, Nake won the first prize in the *Computers and Automation* annual contest for his drawing *Komposition mit Quadraten (Verteilungen von elementaren Zeichen)* or "Composition with Squares (Distributions of Elementary Signs)" (Berkeley 1966). By 1970 he had participated in numerous individual and collective exhibitions, including *Cybernetic Serendipity* (London, 1968), *Tendencies 4: Computers and Visual Research* (Zagreb, 1968), and the 1970 Venice Biennale (along with Nees and Franke). And yet, as Nake's recognition as an artist increased he grew more disenchanted by the art world and the general cooptation of computer art by commercial interests. In a piece published in *PAGE*, the bulletin of the Computer Arts Society, Nake complained that "the most important person in the art world" was "the art dealer", that it was them who "actually [created] a new style, not the artist" (1971, 18). He compared the mechanics of the "world of pictures" with the fashion industry always hungry for a new fad, arguing that it seemed that computer art had become "nothing but one of the latest of these fashions". On the previous year, Nake (1970) had publicly announced that he would stop exhibiting in commercial venues but implied that he would nonetheless continue his research on the aesthetic possibilities of computational technology within academia.

Across the Atlantic, two months after Nees inaugurated his 1965 exhibition, Michael Noll[26] and Béla Julesz[27], employees of Bell Telephone Labs, became the first people to organise a public exhibition of computer art in North America. The venue was the Howard Wise Gallery, in New York, and the event was sponsored by AT&T, the parent company of Bell Labs. Julesz, a neuroscientist, "was not pleased with the idea of using the term 'art' in the title of the exhibition" (Taylor 2014, 31); whereas Noll, an engineer, had no problems whatsoever in calling his images art. Nevertheless, they ended up agreeing to name the exhibition *Computer-Generated Pictures*. One of the key artworks presented at the exhibition was Noll's *Gaussian Quadratic* (created in 1962), the first digital artwork to be granted copyright, mostly due to pressure from AT&T (2014). Whereas both the vice president of research and the executive director of Bell Labs were supportive of the "digital art" and animation experiments that Noll and

[26] Born in 1939.
[27] 1928–2003

others were carrying out, the PR and legal departments of AT&T were nervous (Noll 2016; Taylor 2014). They worried computer art would be regarded as unscientific and lacking in seriousness.[28] Forcing Noll to obtain a copyright was "a way to disassociate the work from the scientific research undertaken at Bell Labs" (Taylor 2014, 33).

Unlike Nake and Nees, Noll's initial foray into computer art was not deliberate but rather inspired by a colleague's coding error. In 1962 Elwyn Kerlekam wrote a program to control a plotter machine that "produced a graphic mess", which Kerlekam "comically called" "computer art" (Noll 2016, 56). Understanding the aesthetic potential of such a process, Noll began writing programs which combined "mathematical equations with pseudo-randomness". The results of which Noll published internally at Bell Laboratories in a technical memo titled "Patterns by 7090" (Noll 1962). Noll won the 1965 *Computers and Automation* annual contest with *Computer Composition with Lines* (Berkeley 1965). Along with multiple computer art and animation works, Noll pioneered many contemporary technologies ranging from privacy systems to VR; he has published numerous scientific papers and granted various patterns. He remains one of the most prolific computer artists from his generation.[29]

5.3 From radio hobbyists to the PC

Those who were able to make computer art were engineers, mathematicians, and scientists; people with technical skills but, more important, with access to computers *and* output peripherals — both rarities in the mid-1960s. They mostly used "minicomputers" which, regardless of their name, remained expensive machines. Their cost could run up to several hundred thousand of (contemporary) USD. They could only be afforded by large institutions such as universities and research centres — although they were cheaper than the mainframes used by government institutions (such as the IRS), and companies requiring high volumes of data processing (e.g., financial institutions). The widespread availability of computers and peripherals only became a reality in the late 1970s with the emergence of the PC.

The main difference between mainframes and so-called minicomputers had to do

[28] This attitude towards artistic experimentation was not exclusive of Bell Labs. Nake (2009) describes how Nees, who also worked at a private research industry took pains to avoid referring to his visual experiments as "art".

[29] Noll's account of his experience with computer art can be found in (Noll 2016) as well as on his website: http://noll.uscannenberg.org.

more with the way they were sold than with the machines themselves. A company such as IBM sold, or instead leased, not only computers but business services. Machines were custom-designed and programmed to meet the client's requirements, along with this, IBM included the services of its engineers. The idea of a computer being used by a single person was unthinkable at that time. While in theory, the computer was a universal device, this was just in theory, in practice, the majority of early computers were fixed machines, whose reprogramming took a considerable amount of work. Minicomputers, on the other hand, were sold without all the strings that an IBM had, they were not customised and often had to be programmed by the people who bought them.

To understand the circumstances that enabled the computer to evolve from the rare specialised information machine to a consumer appliance and "media machine" two interrelated phenomena are of particular relevance: the invention of the microprocessor and the culture of computer hobbyists. To understand the "interplay of cultural forces and commercial interests" (Campbell-Kelly et al. 2014, 229) that stood behind the development of the PC, it is useful to compare it to the development of the radio in the early twentieth century.

In the late nineteenth century, "the phenomenon we now call radio was a scientific novelty in search of an application" (Campbell-Kelly et al. 2014, 230). By the turn of the twentieth century, radio broadcasting was still a generation away, so the first successful commercial harnessing of radio waves emerged in the form of "wireless" telegraphy. In 1901 Guglielmo Marconi[30], considered by many the father of this technology, successfully conducted the first transatlantic transmission — a constant repetition of the letter "S" in Morse code (Hong 2001). In 1910, a wireless telegraph sent from a ship allowed Scotland Yard to capture Hawley Crippen, a suspected murderer, in Canada.[31] In 1912, during the sinking of the *RMS Titanic* the telegraph played a significative role in the rescue efforts. These and others widely publicised events helped to consolidate the dominant position of wireless communications (2014).

In the following decade, telegraphy was steadily perfected and institutionalised by governments and newly formed companies — such as Marconi's. But the new technology also attracted the attention of hobbyists who enjoyed building and tinkering with wireless sets and voice transmission. At the end of WWI, there were close to

[30] 1874–1937

[31] In his book, *Thunderstruck*, American journalist, Erik Larson (2006) offers a thorough narration of these events and of Marconi's life.

fourteen thousand licensed amateur operators in the United States alone, and it was estimated that the number of unlicensed "receiving stations" was close to 150 thousand (Campbell-Kelly et al. 2014, 230). It was within this amateur engineering culture that the idea of radio broadcasting spontaneously arose. While David Sarnoff is credited with proposing the "radio music box" (Peters 2000; Ceruzzi 2003),[32] it was the amateur operators and listeners of "ham radio"[33] that truly prefigured the medium as we now know it. As Campbell-Kelly et al. put it, "[b]roadcasting needed an audience, radio amateurs constituted that first audience" and therefore, without them this mass communication platform might have never been developed (2014, 230). Once the first radio stations were formed — either by entrepreneurs or well established electrical engineering companies — and began operations, broadcasters and listeners "entered a virtuous cycle, more listeners justified better programs, and better programs enticed more listeners". By the 1920s several hundred radio stations were operating in the United States alone.

The role of radio hobbyists in the consolidation of twentieth-century ICTs cannot be overstated.[34] Not only did they "opened up the high-frequency radio spectrum for long-distance radio communications" (Ceruzzi 2003) after WWI; but they also directly contributed to the development of the Personal Computer (PC) throughout the 1970s. The similarities between the chain of developments that led to the establishment of radio as a medium and to the emergence of the PC are not casual, neither are the parallels in the social construction of both technologies. After WWII electronic hobbyists began to expand their activities beyond amateur radio, incorporating hi-fi music reproduction, television sets, robotics, and later, *microcomputers*. A significative surplus of electronic equipment leftover from the war ended up in the hands of amateur engineers thanks to hobbyist magazines (such as *Popular Electronics* and *Radio Electronics*) and places such as "Radio Row,"[35] in Manhattan (2003). Once this culture of electronic hardware tinkerers gained access to cheap microprocessors (the Intel 8080 via the Al-

[32]In 1915–16, David Sarnoff (1891–1972), a Russian immigrant and future founder of the American National Broadcasting Company (NBC) wrote a memo describing the potential of wireless telegraphy to become a "household music box" (Peters 2000). In this memo, he prefigured the concept of commercial radio broadcasting as we have come to know it.

[33]This was (and continues to be) a "technical culture" of radio enthusiasts, a full account can be found in Haring (2007).

[34]It is important to note that Richard Feynman (1918–1988), as well as Claude Shannon arguably owed much of their engineering expertise to their childhood tinkering with radio technology (Gleick [1992] 2011, see also 2011).

[35]An area in Manhattan which, since the 1920s had become the main market for electronics. The site was vacated and demolished in the late 1960s to make space for the World Trade Center twin towers (Gleick [1992] 2011).

tair 8800 microcomputer) and came into contact with the "computer liberation movement", the conditions for the PC revolution were set.

5.3.1 Enabling technologies: the microprocessor and the microcomputer

The microprocessor was developed between 1969 and 1971 by Intel; it was initially conceived by Ted Hoff,[36] one of the few employees of the company founded by Gordon Moore[37] and Robert Noyce. In 1969, Busicom, a Japanese manufacturer of calculators commissioned Intel to develop a chipset for their new advanced line of products which could carry out various functions. Hoff realised that instead of designing specialised (i.e., "fixed") logic chips for the calculator, a more elegant solution would be to design one general-purpose chip that could be programmed with different functions depending on the calculator model. This meant the chipset itself would be "a rudimentary computer in its own right" (Campbell-Kelly et al. 2014, 232) since it had "all the basic registers and control functions of a tiny, general-purpose stored-program computer" (Ceruzzi 2003, 220). In other words, it could be used not only in calculators but microcomputers too.

Shortly after commissioning Intel, Busicom went into financial problems,[38] Intel renegotiated the price in exchange for the rights to market the chip on its own to other companies. While it took a while for Moore and Noyce to realise the potential consequences and the cultural significance of their invention, the 4004 chip was eventually advertised by Intel in 1971 as "a microprogrammable computer on a chip!" (Campbell-Kelly et al. 2014, 232; Ceruzzi 2003, 220). In 1974, Intel replaced the 4004 with the 8008 chip, which became the core of many PCs. By then, other manufacturers (e.g., Motorola) had already begun to produce their own microprocessors, thus reducing the

[36] Born in 1937.

[37] In a now famous ([1965] 1998) paper, Moore (b. 1929) noted that since the invention of the integrated circuits in 1958, the number of them you could place in a board had doubled each year. Plotting this growth rate, Moore predicted that by the mid-1970s it would be possible for people to buy chips containing logic circuits that would be equivalent to the ones used in 1950s mainframes. The UNIVAC — which became famous for predicting the results of the 1952 U.S. presidential election, giving Eisenhower the victory over Stevenson (Taylor 2014, 55) — had around 3, 000 active elements (vacuum tubes); more or less the same as the first microprocessor (Ceruzzi 2003, 217). This relation between miniaturisation and doubling of power has come to be known as "Moore's Law".

[38] It became one of the many victims of the so-called "calculator wars". This economic phenomenon not only drove the price of these devices to a point where they became disposable consumer products but also opened the mass market to chips and consolidate the notion of a *personal* electronic information processing device (Ceruzzi 2003).

price of these devices from about USD 1,000 to approximately USD 100. By dramatically reducing the price of the central processor, the microprocessor became the enabling technology that allowed hobbyists to tinker with computers and contribute to the emergence of the PC in the last decades of the twentieth century.

5.3.2 Computer hobbyists, computer liberation and the Altair 8800

Many of the first computer hobbyists were active radio amateurs or had previously been radio amateurs and even those that were neither still owed much to the "ham radio" culture (Haring 2007) that began to develop in the early twentieth century. The typical computer hobbyist was "a young male technophile" with some professional technical competence and whose enthusiasm for computers stemmed from direct contact with this technology or the electronics industry. Many computer hobbyists had used "minicomputers" at work or school, and they longed for a machine with which they could experiment at home. (Campbell-Kelly et al. 2014). The problem, as noted at the beginning of this section, was that minicomputers were prohibitively expensive: they usually cost around USD 20,000 (more than a hundred thousand USD in today's money), a price tag way beyond the means of the average hobbyist (2014, 233). To those outside the culture of radio and electronics hobbyists (including big computer manufacturers such as IBM), the reason why somebody would want to own a computer remained a mystery. And yet, being the natural heirs of radio amateurs, most computer hobbyists could only conceive computers as a mere extension of the devices they were familiar with; consequently, they "were primarily interested in tinkering with computer hardware; software and applications were very much secondary issues" (2014, 233). That is until they met the advocates of "computer liberation" another highly influential group in the development of the PC.

In the mid-seventies, there were still remnants of a robust anti-establishment culture in the United States, particularly in California. The under-thirty population remained heavily influenced by the spirit of the anti-war and civil liberties movements of the previous decade. The American New Left remained opposed to the military–industrial complex and hence continued to be a vocal critic of the technoscientific establishment and everything that it represented. But there was also a less representative, more politically agnostic, group which has been called the "New Communalists" (2014). They were focused on developing alternative communities and also more optimistic and accepting of technology, which they saw as a potential means to achieve personal liberty and happiness. It was from within this environment that "computer liberation" advocates first emerged.

Before the early 1970s, computer technology was by no means accessible to anyone but was instead rigidly controlled by governments, educational, and private institutions. Even at universities, access to computers beyond specialised institutes was only available through time-sharing (see the beginning of this Chapter), and could cost between USD 10 and 20 per hour (2014) — between USD 50 and 100 in today's money. Those advocating for computer liberation wanted to change that, and their main inspiration was *The Whole Earth Catalog*, a magazine regularly published between 1968 and 1972 by Stewart Brand,[39] the leading voice for the New Communalists. Brand was profoundly influenced by Norbert Wiener's ([1948] 1985) cybernetics, McLuhan's media theory ([1964] 1994), the writings of Buckminster Fuller, and Vannevar Bush. Besides essays and articles, *The Whole Earth Catalog* promoted products for communal living, ecology, as well as information on all sorts of "do it yourself" (DIY) tools, including technological appliances. The catalogue became an inspiration for figures such as Steve Jobs, Douglas Engelbart,[40] and Ted Nelson, the latter of which was by far the "most articulate spokesperson for the computer-liberation idea" (Campbell-Kelly et al. 2014, 234).

Ted Nelson[41] was already a prolific promoter of computational technology. In the mid 1960s, inspired by Vannevar Bush's (1945) imaginary *Memex*, he had conceived the notion of *hypertext*,[42] the system of file navigation that Tim Berners-Lee[43] would later implement as the core feature of the World Wide Web (O'Regan 2012, 102). And yet, for hypertext to be crystalised, it was first necessary to "liberate" computing, "to make it accessible to ordinary people at a trivial cost" (Campbell-Kelly et al. 2014, 234). Throughout the seventies, Nelson promoted his ideas in conferences and computer hobbyist meetings; in 1974 he shared many of them in his self-published books *Computer Lib/Dream Machines*, which bore the slogan "You can and must understand computers NOW" (Nelson 1974).

[39](b. 1938) While a student at Stanford, Brand participated in the LSD experiments sponsored by the United States Defense Department. He also helped Engelbart with his 1968 presentation on interactive computing (Ceruzzi 2003, 207).

[40](1925–2013) Was the creator of the mouse and contributor to the development of hypertext. His 1968 presentation of a computer system that included almost all elements of present-day PCs has been called "The Mother of All Demos".

[41]Born in 1937.

[42]Douglas Engelbart, also influenced by Bush's imaginary device, would also independently conceive hypertext.

[43]Born in 1955.

Computer liberation's early notion of personal computing — much like Bush's *Memex* — was "that of a terminal attached to a large, information-rich computer utility at very low cost" (Campbell-Kelly et al. 2014, 235); whereas computer hobbyists thought of it in terms of existing (and expensive) minicomputers. What ultimately allowed these perspectives to converge was the introduction of the Altair 8800 in 1975, which was not only the first hobby computer but also the first one built around a microprocessor: Intel's 8008. The Altair 8008 was designed by Ed Roberts[44], owner of Micro Instrumentation Telemetry Systems (MITS), a small company that had specialised in selling kits for building calculators to hobbyists. While the Altair is often described as the first personal computer, this affirmation is contested (2014, 235) on the basis that the only thing that made the Altair "personal" was its low price (less than USD 400) but that in every other respect the machine was a traditional minicomputer. And yet, thanks to MITS's business model and clientele, the Altair arguably became the node where the technical and social forces that made personal computing possible converged (Ceruzzi 2003, 227).

The Altair 8800 was marketed and sold following precisely the same model used for other hobbyist kits: it was ordered and sent by mail, and the buyer had to assemble it himself. The computer did not always work as expected and even when it did, it was not that useful. The kit consisted of a box with a central processor, a panel with switches and lights in the front, and a minimal (256 bytes) memory. It had no display or keyboard and no way to attach it to a teletype. The only way to program it was by manually entering programs in binary code using the switches in the front;[45] and the only evidence that the program was, in fact, being executed was provided by a shifting pattern in lights. By any standard, the Altair was far from being a "rational" product, as it appealed only to the most dedicated hobbyists (Campbell-Kelly et al. 2014). Regardless, the Altair was a success[46] and, more important, it became "the grit around which the pearl of the personal-computer industry grew during the next two years" (2014, 236).

The rapid evolution of the Altair microcomputer from a hobbyist rarity to the direct antecedent of the consumer PC may be attributed to the fact that all the elements required to create a PC became simultaneously available: "keyboards, screens, disk

[44] 1941–2010

[45] Programming the Altair and other similar computers that followed it bore many resemblances with programming early mainframes: there were no high-level software tools, and programs had to be crafted and manually loaded in machine language, with every byte of the tiny memory having to be accounted for.

[46] Four months after introducing the Altair, MITS had earned over one million USD in orders.

drives, and printers", hence, "[i]t was just a matter of putting the pieces together" (2014, 238). Paradoxically, it was the Altair's limitations as a product that allowed increasingly more powerful PCs to emerge; that, and the fact that Roberts did not guard as a secret (like other companies did) the specifications for altering his basic model (Ceruzzi 2003, 229). With some tinkering, it was possible to expand the memory, as well as connect the computer to input and output peripherals — e.g., recorders for memory storage, and teletypes. Other companies and entrepreneurs began to produce "add-on" components, software, and even enhanced clones of the Altair (Campbell-Kelly et al. 2014, 238). All this transformed the hobby electronics culture at a pace and depth not seen since the emergence of radio. Within months of the Altair's launch, the "Homebrew Computer Club" was established in Menlo Park. "Besides acting as a swap shop for computer components and programming tips, [the club] provided a forum for the computer-hobbyist and computer-liberation cultures to meld." (2014, 237)

5.3.3 PC software

By late 1977, the pioneering "Trinity" (see Byte 1995) — the Apple II, the Tandy / RadioShack TRS-80, and the Commodore PET — had defined the PC physically as an artefact (Campbell-Kelly et al. 2014, 242). However, *conceptually*, the PC remained a nebulous device for most potential consumers. It was not yet clear why anyone would be interested in having their own computer at home or work. What ended up defining the appeal of the PC was not the hardware that hobbyists were so fond of tinkering with, but *software*. Unlike mainframes and minicomputers, whose reprogramming required specialised knowledge and hardware adjustments, the PC was a "ready to run" (Byte 1995, 100), all-in-one general purpose machine. With the introduction of the "trinity" the market for software *applications* — an unprecedented class of cultural product that would enormously contribute to the consolidation of post-industrial society — was finally open. Games, education, and business were the most important software categories, but the first one was the most profitable.[47]

[47]From the outset, video games were a major force behind the evolution of the PC. Stewart Brand's interest in the cultural role of computers grew after watching his colleagues at the Stanford Artificial Intelligence Laboratory play *Spacewar*. In Brand's words:

> *Spacewar* revealed computing as far from the do-not-fold-spindle-or-mutilate punched-card environment as one could possibly find. The hardware they were using was not "personal," but the way it was being used was personal: for fun, interactively, with no concern for how many ticks of the processor one was using. (Ceruzzi 2003, 207–8)

In August 1981 IBM officially entered the PC market; this meant personal computing was finally legitimised by a "serious" corporation willing to bet on the new technology. Whereas the "trinity" had certainly gained followers in the electronics enthusiasts and educational markets, before IBM introduced its Model 5150 most business users who had hesitated to buy an Apple or a Tandy (the Commodore was largely seen as an educational device) were finally convinced. To the news media, unaware of the cultural origins of the technological shift, the computer was an overnight phenomenon whose success surprised even IBM itself (Campbell-Kelly et al. 2014, 248). The following year, *Time* magazine dedicated its "person of the year" (in this case "Machine of the year") issue to the computer. Besides IBM, those who benefited the most from the economic success of the PC in the 1980s and 1990s were Intel and Microsoft, as virtually *every* computer built by all the major hardware manufacturers used Microsoft's DOS and applications,[48] and was based on Intel microprocessors (2014, 251). Apple was the only notable exception; rather than competing by building cheaper hardware, Jobs and company invested on improving software; namely, by introducing average consumers to the concept of *Graphical User Interface* (GUI) and thus "liberating" them from having to interact with the command line. The wide adoption of the GUI was one of the key factors for the transformation of the computer into a "media machine".

5.4 The technological road to the media machine

5.4.1 Licklider's vision

Joseph Carl Robnett ("J.C.R.") Licklider[49] was a research psychologist specialised in psychoacoustics (sound perception) although he was also trained in physics and mathematics. In the early 1950s, while working as associate professor at the Lincoln Laboratory of the MIT, Licklider became involved in the development of the *Semi-Automatic Ground Environment* (SAGE) air defence system[50] as head of the human factors team.

[48]Microsoft's origin and growth are inextricably tied to the Altair and IBM. In 1975, Bill Gates and Paul Allen convinced Ed Roberts, the owner of MITS, to buy from them a programming system for the Altair written in BASIC (the language used to program most minicomputers). In 1980, IBM was looking for a company that could develop the software for its PCs and ended up contacting Microsoft. The fact that the twenty-something Bill Gates got the job was a mixture of luck, family relations, and that he "showed a positive eagerness to accommodate himself to the IBM culture" (Campbell-Kelly et al. 2014, 263).

[49]1915–1990

[50]The Cold War computer system designed to link 23 monitoring stations to coordinate tracking of potential Soviet bombers in case of an attack that was mentioned at the beginning of this chapter.

The SAGE program was a behemoth; not only did it take more than a decade to be developed and implemented, but it did so at a prohibitive cost: each one of the 21 sites ran on two AN/FSQ-7 computers, each one of them costing approximately USD 1.9 billion in today's money (Edwards 2013). And yet, by the time SAGE became operational, it was already obsolete thanks to the recent development of intercontinental ballistic missiles (Weinberger 2017b). Nonetheless, for Licklider and other scientists involved in the project the experience with SAGE completely transformed how they thought about human–computer interaction.

The AN/FSQ-7 computer used in SAGE was indeed a technological achievement: "it was the second real-time computer with an electronic graphical display in history" (Edwards 2013). SAGE operators were the first computer users to have individual consoles that displayed visual information and, more important, which allowed tactile interaction with buttons and light pens (Weinberger 2017b).[51] SAGE became the first testing ground for interactive computing — were users could directly control and receive real-time feedback from the machine, and for "time sharing."[52] Inspired by his experience with SAGE, Licklider began to prefigure what he imagined the future of computing would be like: people interacting with *personal* consoles directly from their desks, rather than having to walk into a dedicated room to feed punch cards into a collectively used machine (2017b). While Licklider first outlined his new approach in a 1957 (unpublished) article[53] called "The Truly Sage System, or Toward A Man-Machine System for Thinking" (see Weinberger 2017b), he took his ideas a step further in the articles "Man–Computer Symbiosis" (1960) and "On-line Man–Computer Communication" (1962).

On 4 October 1957, the Soviet Union successfully launched *Sputnik 1*, the first artificial satellite in history. The event triggered the so-called "Sputnik crisis", a period where the political and scientific establishment in the United States began to seriously ques-

[51] This was truly revolutionary, as it was possible to interact with the information directly appearing on the screen.

[52] Throughout the 1960s and early 1970s, time-sharing became the only way in which most people would come into contact with a computer. Time-sharing essentially meant that:

> multiple users could share computing resources by working at separate terminals and receiving slices of computer execution time as they were available. With high-speed computers, the user would not be aware that he/she was sharing the resource since the response time would be nearly immediate. (Alesso and Smith 2008, 61)

[53] This was a typed manuscript with various handwritten annotations (Kita 2003) dated 20 August 1957, and it is currently part of the "Licklider Papers" archive at the MIT Libraries.

tion the country's technoscientific dominance[54] (Campbell-Kelly et al. 2014). To tackle the perceived technological gap, the Eisenhower administration started an ambitious program to massively support STEM (science, technology, engineering, and mathematics) education, basic research, and RD (research and development). The Advanced Research Projects Agency or "ARPA" (later DARPA) was established only four months after the *Sputnik 1* launch (Weinberger 2017b) to coordinate research and allocate funding for it. ARPA's prerogative was not to come up with specific immediate results, but instead to promote RD to obtain long-term results. In the following decades, this Agency became one of the great cultural forces shaping the United States' and world's computing technologies (Campbell-Kelly et al. 2014, 207).

In 1961, Licklider was offered a job at ARPA to head the "Behavioural Sciences Council"; at some point around that time he:

> invited ARPA employees to a meeting at the Marriott hotel between the Pentagon and the Potomac River, to demonstrate how someone in the future would use a computer to access information. As the chief proselytiser for interactive computing, Licklider first wanted people to understand the concept. He was trying to demonstrate how, in the future, everyone would have a computer, people would interact directly with those computers, and they would all be interconnected. He was demonstrating personal computing and the modern Internet, years before they existed. (Weinberger 2017b)

By 1962, Licklider became head of the Information Processing Techniques Office (IPTO) at ARPA, a position he occupied until 1964 and which involved administering the funding for research on human–computer interaction (Ceruzzi 2003). Through this office, ARPA sponsored two laboratories which developed virtually "all the ideas in the modern computer interface" (Campbell-Kelly et al. 2014, 258). One was a large graphics research group at the University of Utah; the other was a small human-factors research group at Stanford Research Institute (SRI) founded in 1963 by Douglas Engelbart, who would eventually be regarded as "the doyen of human–computer interaction" (2014, 258). Licklider's role in the evolution of computational technology (and ICTs in general) cannot be overstated.[55]

[54]The article that C.P. Snow (1961) published in *Computers and Automation* perfectly exemplifies the anxieties that ensued after the Sputnik 1 launch.

[55]For a full account of Licklider's involvement with IPTO and the development of Arpanet — the predecessor of the Internet — see Chigusa Ishikawa Kita's (2003) article, "J.C.R. Licklider's Vision for the IPTO".

Engelbart (and Bush) and "The Mother of all Demos"

Since the mid-1950s, Engelbart had been attempting to obtain funding to "develop a computer system that would act as a personal information storage and retrieval machine" (Campbell-Kelly et al. 2014, 258). He had been inspired by "a chance encounter" (Ceruzzi 2003, 259) with Bush's seminal article, "As We May Think". In late 1962, Engelbart became one of the first persons to apply to IPTO for funding; he did so by submitting a project to develop "a conceptual framework" for "augmenting human intellect" (Engelbart [1962] 2003). The project was in tune with the ideas Licklider (1960) had outlined in "Man–computer symbiosis". The funding allowed Engelbart and his group to work in what they called the "'electronic office'", a system that integrated text and pictures in a way that was unprecedented at the time but has since then become the norm (2014, 258–59). By far the most notable contribution to human–computer interaction by Engelbart's group was the computer mouse, which was first described in 1967 and, after extensive research, showed to be more effective than the "light pen" used in the SAGE system, the joystick, and every other proposed interaction devices (Ceruzzi 2003).

On 9 December 1968, at the Fall Joint Computer Conference in San Francisco,[56] Engelbart and about a dozen other people — including Stewart Brand, editor of *The Whole Earth Catalog* — staged what is now known as "The mother of all demos". Using a video projector to enlarge a computer screen to six metres (Campbell-Kelly et al. 2014, 259), Engelbart showed a stunned audience the mouse, hypermedia, and teleconferencing; features that characterise the modern computing environment (Wardrip-Fruin 2009, 174). The "electronic office" system that Engelbart presented was, however, too expensive to be practical; nonetheless, the demo made a profound impression on many of those who would end up developing the first successful commercial GUI-based computers some fifteen years into the future. What hindered the practical implementation of Engelbart's model was the lack of cost-effective technology. At the time the mother of all demos happened, even the so-called mini-computers could cost the equivalent of hundreds of USD. Engelbart and his group developed the physical and conceptual tools for interacting with the computer, but it was the people from the University of Utah who established the foundations for the graphical language that would become the norm of the Personal Computer GUI and software.

[56] A full account of the work Engelbart and his colleagues developed can be found in the article "A research center for augmenting human intellect" (Engelbart and English 1968) published in the conference proceedings.

5.4.2 Alan Kay, Xerox PARC, the Dynabook, and the media machine

On May 1963, Ivan Sutherland[57] a recent graduate student from MIT presented his paper "Sketchpad: a Man–Machine Graphical Communication System" (1964) at the Spring Joint Conference in Michigan. The paper condensed Sutherland's (1963) PhD dissertation project,[58] which — as the name implied — consisted in the development of *Sketchpad*, a computer program that would revolutionise human–computer interaction, computer graphics, and the very notion of a computer. The basic goal of Sketchpad was to allow users to generate graphics not by writing code but by directly "drawing" over the the computer screen with a light pen — the same peripheral used by SAGE operators. With Sketchpad, Sutherland introduced a new paradigm of interactivity, wherein by manipulating an image displayed on the screen, "the operator changed something in the computer's memory" (Manovich 2002, 104). Sutherland's invention left a lasting impression on computer art pioneer Leslie Mezei who, in his 1964 article, "Artistic Design by Computer", wrote:

> In the system reported at M.I.T. called Sketchpad the form to be manipulated could be drawn on a display scope with an electronic pencil; then programmed manipulations could be produced at the console of the computer, and the result could be immediately seen on the output screen. The process could then be repeated and modified according to the desire of the experimenter. (Mezei 1964, 15)

In 1964, by Licklider's initiative (Campbell-Kelly et al. 2014, 280), Sutherland was appointed head of IPTO — the ARPA office Licklider had directed since 1962; a position Sutherland occupied for the following two years. In 1968, David Evans[59] invited Sutherland to join the Graphics Research Group he had founded at the University of Utah in 1965, and which was also substantially funded by ARPA grants (Ceruzzi 2003; Campbell-Kelly et al. 2014). The two of them also founded a company, *Evans and Sutherland*, which would have a lasting impact in the computer and software industry — among its former employees is John Warnock, co-founder of Adobe Systems. One of Evan's doctoral students at the Computer Science Faculty was Alan Kay,[60] a key figure in the redefinition of the computer as a "culture machine" (Manovich 2013, 64).

[57]Born in 1938.

[58]Incidentally, Sutherland's PhD advisor was Claude E. Shannon and Marvin Minsky (1927–2016), a neuroscientist and AI research pioneer, was a member of his PhD advisory committee.

[59]Evans was the founder of the Computer Science Department at the University of Utah, a place that would play a crucial role in the development of modern computational technology.

[60]Born in 1940.

As a doctoral candidate at the University of Utah, Alan Kay pursued an ambitious project that would culminate in his thesis, *The Reactive Engine* (1969).[61] In it, he specified a programming language he developed, called FLEX, as well as a personal information system. FLEX would form the basis of *Smalltalk*, a dynamic object-oriented programming language (O'Regan 2012, 133), whereas the system would become the *Dynabook*, a concept device that would significantly influence personal computing. In 1972, Kay joined the Xerox Palo Alto Research Center (PARC), a new laboratory which would end up being responsible for developing Ethernet, laser printing and — as we will see — the contemporary notion of the computer. Engelbart's "electronic office" and Kay's Dynabook were two technological models that joined to form not only the modern graphical user interface (GUI) but also the paradigm of contemporary human–computer interaction (Campbell-Kelly et al. 2014, 259).

The Xerox PARC was founded in 1970 to provide the company basic RD to sustain the growing pressure from competitors. Its first director was Robert Taylor,[62] who was heavily influenced by Licklider's vision of "man–computer symbiosis"; Taylor was responsible for recruiting top computer scientists from the major universities, including Alan Kay, and many of Engelbart's former colleagues (Ceruzzi 2003). In 1973 researchers at PARC began developing a computer prototype, the "Alto", which was heavily influenced by Kay's Dynabook –(1977) himself referred to the Alto as "the interim Dynabook"; as well as *Smalltalk*, the Alto's programming language, which was based on Kay's FLEX language (see Kay 1968). The Alto was designed as a desktop machine, it had a custom-built bitmap screen equivalent in size to a printed letter sheet of paper (215.9 by 279.4 mm) but positioned in portrait rather than in landscape orientation, as is now the norm (Alesso and Smith 2008, 78). The alto displayed documents that "look[ed] like typeset pages incorporating graphical images" (Campbell-Kelly et al. 2014, 260), and each one of its elements could be manipulated. Users could "scale letters and mix text and graphics on the screen" (Ceruzzi 2003, 262), which meant editing was effectively *WYSIWYG*, or "what-you-see-is-what-you-get". Having refined Engelbart's design, Kay and his team incorporated the mouse into the alto, along with the "now-familiar desktop environment of icons, folders, and documents" (2014, 260). The Alto was never commercialised, at USD 18,000 a piece — about USD 90,000 in today's money — (Ceruzzi 2003, 261).

Almost a decade after beginning development of the Alto, Xerox introduced a com-

[61] The title is an unmistakable nod to Babbage's "Analytical Engine" (see Chapter 4).
[62] 1932–2017

mercial version, the "Xerox Star" (known officially as the "Xerox 8010 Star Information System"), at the 1981 National Computer Conference in Chicago. The device was far ahead of its time in almost every aspect. Besides having a mouse and Ethernet, it was the first commercial computer to use a GUI, which was based on the office "desktop" metaphor that included simulated interactable objects such as documents, folders, trash bin, rulers, pencils, "in" and "out" boxes, etc. (Brey 2008). The granularity of this object-oriented system went even further since it treated *everything*: the page, paragraphs, sentences, words and characters as "objects" which the user could select and individually change. Object integration was system-wide, a document could hold charts, tables, and image modules along with text. Moreover, the system incorporated generic commands (such as move, copy, open, delete, and show properties) that applied to *every* object selected, using dedicated keyboard buttons. This further liberated the user from having to remember specific commands (e.g., `Ctrl + C`) to apply changes (Johnson et al. 1989). However appealing all these aspects might seem now that they have been integrated into contemporary systems, the Xerox Star was nothing short of a commercial flop (Campbell-Kelly et al. 2014; Ceruzzi 2003).

The Xerox Star was technically superior to virtually every other office machine available at the time (Ceruzzi 2003, 263), but it was *expensive*: it was sold for approximately USD 16, 500 including software, which was about five times the price of other computer systems (Smith and Alexander 1988, 238; Johnson et al. 1989, 24). And yet, the potential buyer (a business) would have to buy at least two or three workstations along with a file server and one or two laser printers to take advantage of the Star's distributed (Ethernet-based) nature. That meant spending between fifty and a hundred thousand USD (almost a quarter of a million in today's money). The other obstacle the Star faced was conceptual, and it involved Xerox's own salespeople and the potential buyers themselves. The notion of a "personal computer" was barely starting to become mainstream. The Star was advertised depicting an executive making calls, writing, and sending documents on his desk. Somehow the marketing department at Xerox overlooked the fact that early 1980s executives rarely, if ever, did any of those tasks (Ceruzzi 2003, 263). And even if a technologically curious executive would be willing to experiment using a computer, he or she could buy and experiment with a far cheaper standalone PC (Smith and Alexander 1988). In contrast to Xerox's strategy, other brands (such as the now-defunct Wang Laboratories) aimed their products precisely at the people whose work could be improved by incorporating a PC — secretaries and office clerks. The cultural environment for advanced personal information system such as the Star did not yet exist. It would take another three years (and a startling market strategy) for Ethernet, a mouse, and a windowed and object-oriented GUI to become attractive for the "average" consumer. And they certainly did with the introduction of the Macintosh in 1984.[63] This computer was the first successful commercial GUI-based system.[64]

To understand how computers evolved from mainframes to multipurpose devices it is indispensable to take the pat events into account. But to understand what it means for the computer to be a metamedium it is fundamental to clarify some concepts. The following section will leave the historical narrative behind and focus on the portrait of the computer as a tool. It will show how the computer is described as a software metamedium, a simulation environment in light of software studies. This portrayal will be supplemented with a conceptual analysis of the notion of simulation from a postphenomenological and constructivist perspective.

5.4.3 The software metamedium

Manovich (2013, 70) points out that Turing (1937) imagined his "machine" as being capable of simulating (or actually, of *computing*[65]) a vast class of machines — i.e., any machine that was computable; but it was Alan Kay who explicitly thought simulation could be extended to include "media":

> the ability to simulate the details of any descriptive model means that the computer, viewed as a medium itself, can be *all other media* if the embedding and viewing methods are sufficiently well provided. (Kay and Goldberg 1977, 31)

In their 1977 article, Kay and Goldberg clearly state that "simulation is the central notion of the Dynabook" (1977, 36). Whereas other computing pioneers such as Licklider and Engelbart had focused on improving human–computer interaction to "augment human intellect" (Engelbart and English 1968), Kay's goal was to develop an *enabling*

[63]Steve Jobs (1955–2011), the founder of Apple along with Steve Wozniak (b. 1950) and Ronald Wayne (b. 1934), visited Xerox PARC in 1979 and was quite impressed by the Alto computer. After witnessing the GUI, he convinced his partners to adopt this paradigm for Apple computers. According to Alan Kay's account (2017), and Jobs own later admission, he was so flabbergasted by the GUI that he missed the fact that the Alto had already incorporated networking and *Object-Oriented-Programming* (for a clarification of this term see the following section).

[64]Part of this success can be attributed to the famous Orwellian commercial used to launch it.

[65]It is important to note that Turing never used the word "simulation" in his paper, the term is rather the product of later interpretations of Turing's ideas.

tool for personalised *learning* (Coyne 1997, 33). If Kay spent over a decade researching the computer's potential as "a medium for expression through drawing, painting, animating pictures, and composing and generating music" (1977, 31), it was not due to artistic inclinations. Kay was interested in improving human learning potential, but he disagreed with rationalist conceptualisations.

Whereas Vannevar Bush imagined a database for information capture and retrieval; Licklider a future of human–computer symbiosis wherein "men will set the goals, formulate the hypotheses, determine the criteria, and perform the evaluation" while "computing machines will do the routinizable work" (1960, 4). Whereas Kay, did not conceive the computer as a delivery device, nor as a tool to "facilitate formulative thinking" but more like a "culture machine", a tool for modelling and realising one's ideas. A medium for learning and experimentation, and which could be used not only by adults but mostly by children. Influenced by the ideas of Jerome Bruner,[66] Seymour Papert[67] and Marvin Minsky,[68] Kay and his group at Xerox PARC imagined the computer interface as something that should be equally approachable to any human, regardless of age. Interacting with a computer should involve the three "mentalities" Bruner had identified: enactive, iconic and symbolic; as opposed to merely stimulating the symbolic mentality like the traditional command line interface (CLI) did (Manovich 2013, 97–98). In short, Kay wanted to offer the user a tool for *making* her own custom tools.

That is why Manovich regards Kay's "theoretical formulations" as a crucial turning point in the history of media (2013, 64). It was Kay and his group — argues Manovich — who for the first time integrated various existing programs to manipulate media (text, image, sound) within a single device. The new paradigm conceived at Xerox PARC did not involve a new class of computer-based media but the transformation of the the computer into a "platform for *all* existing expressive artistic media" (2013, 65); or to use Kay and Goldberg's own term, a *metamedium* (1977, 32). In Manovich's view, this new paradigm effectively changed how we conceive media in general—and the very notion of medium, given that for the past two hundred years:

> the modern discourse about media [had depended] on the assumption that different mediums have distinct properties and in fact should be understood in opposition to each other. (Manovich 2013, 65)

[66] 1915–2016

[67] (1928–2016) A pioneer of Artificial Intelligence research and constructionist education.

[68] 1927–2016

And while Manovich concedes that placing all previously distinct mediums within the same environment did not necessarily erase their differences, it did put them in proximity to each other. This intermingling had a profound impact not only in theoretical, but also in practical, and aesthetic terms. Rather than converging into an undifferentiated aesthetics, the collapse of the boundaries that hitherto separated previously distinct forms of representation brought potentially endless *hybridisation*. Medium-based ontological differences thus became irrelevant.

As a metamedium, the computer could now simulate most previously distinct forms of representation along with their tools and techniques. Digitisation translated physical procedures and outcomes into algorithms and functions. Media became dynamic; all possible elements within a given media object came to be represented with variables, which in turn could be fine-tuned through automatic computation. Every trait of every representational style could potentially become a transversal effect. Physical media came to be filtered by the modular logic of software. The hitherto physical (ontological) properties that characterised each medium are now the properties of software applications and how it handles specific data structures. Media is now — at least in theory — *modular*, deeply remixable, and permanently extendible (Manovich 2013).

The computer metamedium can support multiple cultural or artistic *metalanguages*. It is in effect a complex environment or system prone to aesthetic diversification. The intermingling of various media accelerates combinatorial speciation and the emergence of what Manovich calls a "new hybrid visual language" (2013, 252). Software allows the computer metamedium to be a massive and continuously expanding set of affordances. All media creation and manipulation techniques, interaction techniques, and data formats are potentially available to artists, designers, and programmers. Thus, Manovich contends hybridisation is not necessarily the consequence of universal binary code, but the result of the gradual development of interoperability (and portability) of software (2013, 336).

For Kay, a fruitful way to understand what computers do is through analogies: the computer is to computing what an instrument is to music. (1984, 53). The same stuff, the same "marks", that are used for creating "elevator music" are the ones used for creating Bach's fugues. Thus to use a more concrete figure, understanding what clay is not sufficient for understanding the pot informed by it. What matters is not the material, but "the architecture", how it is used and regarded by its creators. Kay concedes there is an important qualitative difference between the computer and previous means to construct physical and conceptual objects. The computer is a potent *simulation* device. With enough capacity to store "marks" and the simplest set of instructions (as Turing showed), a computer can build "any further representational mechanisms that are needed, even the simulation of an entire new computer" (1984, 53) Kay credits Ada Lovelace with having understood the power of this type of simulation (see Chapter 4). And yet, Kay also notes that regardless of how important the universality of Turing machines are from a philosophical standpoint — i.e. that "a simple mechanism can simulate *all* mechanisms" (1984, 53), this feature does not solve by itself all computational problems.

For Kay, interface turns the computer into a tool; it amplifies the user's ability to build simulations. The GUI and software free the user from having to deal with abstract intermediaries such as the command line. Whereas early programmers attempted to design programs solely on the basis of logic, the computer proved stubbornly literal. Thus, as Kay argues, "a new class of artisan" (1984, 54) had to take the mathematicians place. These artisans implemented a new aesthetics (in the epistemic sense) that privileged simplification via metaphors and analogies over literal and logical descriptions. Kay notes that simplification is not unique to science, as the role of variables, formulas and laws is precisely to condense as much knowledge in the smallest of statements. That is how the new paradigm of Object Oriented Programming (OOP) was born.

OOP capitalises on the computer's inherent ability to simulate but also exploits self-similarity[69] and the complexity that can emerge out of it. Traditionally, programs were designed as collections of functions or lists of instructions to be performed linearly. As Floridi notes, "OOP shifted the focus from the logic procedures required to manipulate the objects, to the objects that need to be manipulated" (2011a, 359) OOP conceives a program as a collection of objects that act on each other; with each one being able to send and receive messages and process data (O'Regan 2012, 132). As in fractals, in OOP each subpart of a structure is similar to every other part. OOP allows each element to have the same power as the whole, which in effect becomes a "super object". Conceptually, Kay notes, the computer is divided into "a number of smaller computers each of which can be given a role like an actor in a play" (1984, 56).

To illustrate this paradigm Kay refers to spreadsheet programs. In a spreadsheet, when a value is altered within a cell, all the other values that are linked o it are instantly re-computed. A spreadsheet, Kay contends, "is a simulated pocket universe that con-

[69] Self-similarity "is symmetry across scale. It implies recursion, pattern inside of pattern" (Gleick [1987] 2011). Self-similarity is best exemplified by fractal sets.

tinuously maintains its fabric" (1984, 57). Citing the historical example of VisiCalc, he notes that while its creators intended to develop a "smart editor" for accounting, they became surprised when most of its users used "to forecast the future rather than account for the past" (1984, 57). Kay's general understanding of the computer as a medium and simulation machine is best grasped through the following passage:

> The protean nature of the computer is such that it can act like a machine or like a language to be shaped and exploited. It is a medium that can dynamically simulate the details of any other medium, including media that cannot exist physically. It is not a tool, although it can act like many tools. It is the first metamedium, and as such it has degrees of freedom for representation and expression never before encountered and as yet barely investigated. (1984, 59)

However insightful the characterisation of the computer as a metamedium and simulating machine might be, it is still incomplete. Neither Kay nor Manovich clarify what they understand by "simulation" in the first place. Given the centrality that this concept has for their arguments, this is nothing short of surprising. The following section will remedy this gap by discussing various definitions of this the term.

5.5 Simulation

The etymological origins of "simulation" rest in the Latin term *simulare*, which itself derives from *similis*, the root of "similar". The traditional meaning of simulation was largely negative, as it was generally used to connote pretension, falsification, or "make believe" (Gualeni 2015). These acceptions are closely related to the notion of "simulacrum" that certain strains of French postmodernism popularised. However, in the contexts of engineering, epistemology, science, and (more recently) media philosophy, simulation is more commonly associated with the analysis and *modelling* of systems. Here, the traditional definition of simulation is that of a "dynamical representation of a system" (Floridi 2011a, 67).

In his influential essay "Simulation versus Narrative: An Introduction to Ludology" (2003), Uruguayan video game designer and scholar Gonzalo Frasca[70] offers what he calls a "working definition" of simulation that he claims to have distilled from vari-

[70]Born in 1972.

ous scientific sources. Frasca points out that simulations preceded the emergence of electronic digital computers — he cites scientific models, toys, games, and cybertexts[71] such as the *I-Ching* as examples relying on simulation; but suggests they are now easier to construct thanks to this technology. So much so that he describes the computer as "a natural medium for modelling reality and fiction" (2003, 234). And yet, he contends traditional scientific definitions are "too technical" and often involve a direct reference to computational environments; the problem with this being that simulations need not be electronic or digital. Frasca sees the concept of simulation as an alternative to the notions of representation and narrative.

Frasca claims that "to simulate is to model a (source) system through a different system which maintains (for somebody) some of the behaviours of the original system" (2003, 223). The key aspect here for him is the transference of behaviours; the fact that simulations "do not simply retain the — generally audiovisual — characteristics of the object" but also include "a model of their behavior" (2003, 223). This is, according to Frasca's view, what fundamentally distinguishes simulations from representations, which are more commonly associated with "traditional media". For example, a plane's photograph may provide information about some of its features, but as Frasca notes, the image "will not fly or crash when manipulated" (2003, 223). Conversely, a (toy) model plane or a flight simulation can reproduce some of the behaviours of a *real* plane. To put it in Frasca's (semiotic) terms, while traditional media are signs, simulations are "machines that generate signs" according to specific rules (2003, 224).[72]

It may be useful here to note the distinction Floridi makes between *proxy* and *degenerate*

[71]"Cybertext" is a neologism coined in the mid-nineties by Espen Aarseth (b. 1965), a pioneer scholar of game studies and electronic literature. Aarseth explicitly notes his concept was inspired by Norbert Wiener's ([1948] 1985) own concept (and discipline) of *Cybernetics*. Aarseth developed the concept as a framework for describing and exploring "the communicational strategies of dynamic texts" (1997, 5); cybertext is, therefore "more a perspective on textuality than a category of it" (1997, 24). In the nominal sense, "a cybertext must contain some kind of information feedback loop" (1997, 19). An early definition of the term characterised a cybertext as:

> a self-changing text, in which scriptons [an unbroken sequence of "textons", or basic elements of textuality] and traversal functions are controlled by an immanent cybernetic agent, either mechanical or human. (Aarseth [1994] 2003, 777)

However, a more mature definition stresses the methodological value of the cybertext concept:

> Cybertext, as now should be clear, is the wide range (or perspective) of possible textualities seen as a typology of machines, as various kinds of literary communication systems where the functional differences among the mechanical parts play a defining role in determining the aesthetic process. (Aarseth 1997, 22)

[72]Frasca is here paraphrasing Espen Aarseth's characterisation of cybertext as "machine[s] for the production of a variety of expressions" (1997, 3).

proxy. The word "proxy" originates in the late Middle English contraction of the legal term "procuracy", which referred to a "legitimate action taken in the place of, or on behalf of, another" (2015b, 487). A proxy has a vicarious relation to that which it refers, it both stands *for* and *in* the place of its referent. In mathematics, the term "degenerate" does not imply a negative qualitative evaluation but refers to an object that "changes its nature so as to belong to another, usually, simpler class" (2015b, 488). A degenerate proxy stands for but cannot behave on behalf, or act instead of its referent. Returning to Frasca's previous example, the plane's photograph is a degenerative proxy, whereas the toy plane and the flight simulation are true proxies.

Both Floridi's and Frasca's working definitions of simulation closely resemble Arturo Rosenblueth's[73] and Norbert Wiener's (1945) own characterisation of a scientific *model*. Noting the epistemic role of abstraction in scientific pursuits, the two pioneers of cybernetics first define a *material* (i.e., physical) model as a:

> representation of a complex system by a system which is assumed simpler and which is also assumed to have some properties similar to those selected for study in the original complex system. (Rosenblueth and Wiener 1945, 317)

And later define a *formal* (i.e., theoretical) model as a "symbolic assertion in logical terms of an idealized relatively simple situation sharing the structural properties of the original factual system" (1945, 317). They note that although useful, material models have limitations, particularly when dealing with complex systems. Abstract models permit an increase in granularity and sophistication thus allowing more concrete descriptions of theoretical structures. Material models are *necessarily* less complex than the systems they represent. As Rosenblueth and Wiener aptly put it, "the best material model for a cat is another cat, or preferably *the same cat* [emphasis added]" (1945, 320). That is to say that if a material model were completely thorough in its description, it would be rendered unnecessary for it would become a substitute for the actual system. This notion, Rosenblueth and Wiener note, was accurately described in *Sylvie and Bruno Concluded*, Lewis Carroll's ([1894] 2015) last novel, wherein a character argues the only truly satisfactory map of a country was *the country itself*.[74]

Regarding the relationship between reality and simulation, Ian Bogost notes that

[73] 1900–1970

[74] Interestingly, Borges ([1946] 1984) also suggested this idea in *Del rigor en la ciencia* ("On exactitude in science"), a short vignette published a year after Rosenblueth and Wiener's article came out. Borges' choice of title leaves one wondering whether the vignette may be a nod to Rosenblueth and Wiener.

Frasca's definition exposes the fact that simulations "represent the real world *in part* but not in whole" (2006, 98). Thus, Bogost contends that "bias is an especially important characteristic" of simulations (2006, 97). Bogost emphasises subjectivity and thus distinguishes between scientific and ludic simulations; between a game such as "Sim City" and risk management models. Whereas the former strives to be comprehensive and non-biased, video games explicitly intend to *represent* a small subset of the natural world in a subjective manner. In Bogost's view, simulation (games) are "biased, nonobjective modes of expression that cannot escape the grasp of subjectivity and ideology" (2006, 99). He thus reformulates Frasca's definition by stressing the fact that the less complex system that constitutes the simulation "informs the user's understanding of the source system *in a subjective way*".

For his part, Stefano Gualeni notes that many of the current definitions of simulation employed within media studies, game studies, and media philosophy, including those based on Frasca's "pioneering understanding" (2015, 49) emphasise a necessary connection between simulation and reality. Coming from a postphenomenological perspective, Gualeni argues that simulations are primarily engaged *as worlds*,[75] and that they are technically mediated. He thus reformulates the basic definition through the following characterisation:

> simulations can generally be described as intelligible and persistent, designed interactive ways to disclose complex source systems through less complex, technically mediated ones. (Gualeni 2015, 50)

Emphasising a relationship — or rather, a correspondence — with reality is problematic for many reasons, as Gualeni notes. Simulations involve processes of analogy with "already established ontologies"; they are *analogous* to the systems they refer to. They inherit ontological traits and possibilities from their source, but these traits can be distorted, deepened, or expanded; either intentionally or not. The logical causality and the behaviours that a simulation might exhibit do not need to have a strict correspondence to anything beyond the simulation itself. Consequently, "simulations can differ strongly from their original source or sources depending on their degree of fidelity" (2015, 51). Furthermore, the source system of a simulation *can be a simulation itself*. Finally, attempting to characterise a simulation in terms of its relationship with reality implies at the very least clarifying what is it that one understands by "reality in the first place". As Gualeni points out, Frasca and other scholars fail to "articulate what

[75] For postphenomenology, a "world" constitutes an experience that is intelligible, perceptually stable, self-changing, and interactive (Gualeni 2015).

it means for anything to be real in their theoretical frameworks", and this constitutes a significative "structural deficiency" in their characterisations (2015, 52). Thus drawing heavily on Heidegger's phenomenology and the Kantian tradition (see Chapter 3) Gualeni proposes:

> an understanding of reality as a term that indicates the most basic level of existence, the fundamental background for the perception of phenomena and the development of ontologies. (Gualeni 2015, 53)

5.5.1 What is a model? (a constructionist view)

Frasca's definition of simulation is heavily dependent on the notion of modelling, yet Frasca also fails to state explicitly what is it that he means by this word. The matter is not trivial since clarifying what a model is remains a controversial issue in the philosophy of science (Floridi 2011a, 67). To recapitulate, given the previous definitions, it is clear that to generate a simulation it is first necessary to extract a model, this, in turn, involves selecting some variables from the system under observation. Then, depending on whether the system is dynamical or static, one needs some form of update function to allow the variables in the simulation to change and behave as the ones in the source system. A model thus depends on which *observables*[76] one has chosen to follow.

To sidestep the problem of having to define "model" and "reality", it is possible to use Floridi's Method of LoAs described in Chapter 3 to characterise a simulation as *a relation*. A *simulation relation* is the one established between two sets of observables: those in the source system and those in the simulation (2011a, 67). What the agent dealing with a simulation does is "coupling the state evolution of two systems" by observing them at *different* levels of abstraction. What the agent does then is constructing an *equivalence relation* between the two. A system is not evaluated by its structure and the interactions of its elements but "by the functions it shows" (Floridi 2012a, 2011). The model of a system can thus be understood as "a function of the available observables" (2011a, 75). That is why it is possible to compare different levels of abstraction of a system and their corresponding models.

[76]Remember that in Chapter 3 an "observable" was described as "typed variable", a variable (a physical or abstract conceptual entity) together with a description of what feature of the system under analysis it stands for.

Levels of abstraction are chosen according to specific goals. Hence, for example, if the system under scrutiny were a building, the available levels and corresponding variables could be informed by architectural, emotional, financial, historical, or legal ends. Levels of abstraction (and hence models) are necessarily tied to the reason they are adopted (2011a, 75). From an epistemological standpoint, even a collection of levels of abstraction (i.e., a *Gradient of abstraction*) does not "describe, portray, or uncover the *intrinsic* [emphasis added] nature" of a system (2011a, 76). Systems can only be understood "derivatively", from the distance of a model. A level of abstraction and its corresponding model does not have to represent, copy, mimic, photograph, portray, map, or uncover the ultimate nature of any given system "no more than an igloo describes the intrinsic nature of snow or the Parthenon indicates the real properties of stones" (2011a, 78). From this constructionist perspective (as was noted in Chapter 3) the world is not discovered (as science often claims) nor invented (as constructivism holds) but *designed* by the agents that experience it. Reality, for constructionism, is not so much inaccessible, but "epistemically *inexhaustible*" (2011a, 331). In light of these arguments, a simulation may be thus understood as a dynamic, intelligible and persistent, designed interactive way to disclose observables from a complex source system through a given level of abstraction.

5.6 Conclusions

The computer, the PC as we now know it, was designed as a modelling simulation device. It was the crucial enabling technology of the microprocessor that allowed the computer to realise its potential, to be transformed from a theoretical Turing-universal device to the metamedium we know have. But for that to happen a series of cultural trends had to converge. Technology does not just happen. It is, for now, difficult to establish whether the first usage of the computer by artists influenced Kay's notions. But it is also clear that the desire to interact with the computer in a better, less abstract way (for other, military cognitive purposes) was also a dominant force. Kay saw the computer as an educational tool, as a learning device, a form of participatory enhancement, with a strong pragmatist root. Kay's machine, the machine we now have, is heavily inspired by constructionism (the philosophical model we discussed in previous chapters) There are various limitations, things that we cannot cover here. But for now, it is useful to see how, at the present level, the computer is mainly a simulation machine. In the next chapter, we will deal with the specifics of how we can understand the (aesthetic) objects created by the computer by converging ideas from all previous chapters.

Chapter 6

Aesthetic informational systems

Summary

Chapters four and five focused on the nature of the computer; portraying it, respectively, as an information machine and as a simulation machine. In this chapter, the object of analysis is the nature of computational aesthetic objects. The central claims here defended are (a) that these artefacts can be effectively described as *informational systems*, and (b) that the analogue vs digital distinction is, in fact, irrelevant for characterising these objects. The chapter provides a non-techno-pessimistic account for understanding why a quantitative measure of aesthetic value is unlikely to succeed, at least in the near future. Furthermore, it gives an ontological characterisation of aesthetic artefacts that may be applied indistinctly to computational and not computational aesthetic artefacts. The most salient implication arising from the analysis presented in this chapter is the possibility to overcome the necessity to treat analogue and digital phenomena as ontologically distinct and instead regard them as manifestations of information constructed at different levels of abstraction.

6.1 Introduction

As repeatedly noted throughout the following chapters, one of the central problems driving this dissertation is understanding what *are* computational aesthetic artefacts and what (if anything) distinguishes them from non-computational objects. In the previous chapters, we saw the raw "material" that computers work with is *information* and that they are quite effective tools for constructing simulations with it — i.e., models of other systems at different levels of abstraction. Consequently, it stands to reason that computational aesthetic artefacts may have a lot to do with information modelling. However, this preliminary characterisation of computational aesthetic artefacts as simulations has not yet answered the question of *how* they differ (ontologically speaking) from non-computational artefacts. Especially, given the fact that models can also be "analogue".

Most contemporary art scholars take for granted the existence of an ontic distinction between analogue and digital objects. In other words, that computational aesthetic artefacts and non-computational aesthetic artefacts are *fundamentally* different, and perhaps even mutually exclusive, types of objects. The former being abstract and discrete; the latter concrete and continuous. There are, however, reasons to believe this distinction might be a matter of point of view. Nake (2012a, 2016), for example, argues "algorithmic images" (i.e., computer-generated artefacts) are in fact composites with a dual analogue *and* digital nature. Whereas Floridi (2011a) contends analogue and digital are not features of the things we analyse (whether artistic or not), but features of the levels of abstraction from which we approach them (see Chapter 3). Coming from a semiotic framework, Nake characterises computational artefacts as "supersigns"; whereas Floridi, coming from the philosophy of information, speaks instead of (complex) *systems*.

This chapter shows that, as far as understanding the ultimate nature of computational aesthetic artefacts goes, the analogue vs digital dichotomy is an obstacle. Based on Floridi and Nake's insights, but also on a model conceived in the mid-1980s by the late Russian polymath Mikhail Volkenstein ([1986] 2009), it argues computational aesthetic artefacts may be better described through an informational — but not necessarily quantitative — paradigm. Specifically, as complex informational systems. The chapter begins with a short narration of the origins of systems science, before providing a detailed synopsis of information aesthetics, arguably the first attempt to employ an informational framework to engage aesthetic works. Next comes a discussion of

Volkenstein's model and Nake's arguments. The chapter closes with a synthetic analysis of all the previous sections.

6.2 The emergence of complexity

Since more or less the mid-nineteenth century and throughout the first half of the twentieth century, the dominant scientific paradigm consisted mostly of "totalising theories that established unequivocal relations between theory and observation" (Taylor 2014, 163). "Scientism" or the exaltation of the methods of natural science as the only valid means to acquire truths about the world (Ryder 2005), was by far the dominant view — an outlook that is exemplified by C.P. Snow's ([1959] 2012) "Two Cultures" lecture (see Chapter 1). This modernist scientific culture privileged reductionism, which, in its non-pejorative sense means the top-down process of "explaining phenomena by breaking them down into constituent components" (Galanter 2016, 15). After the two world wars, however, this state of affairs began to change; things became more nuanced as worldly phenomena started to reveal themselves more complex and challenging to fit in the neatly organised epistemic parcels of established scientific disciplines. Science — mainly for philosophy — came to be regarded in less monolithic terms, and also as something that was not independent but rather profoundly influenced by historical and technological circumstances (see Chapter 2). Coinciding with this shift was the emergence of a new holistic paradigm that placed the *complexity* and behaviour of natural and artificial systems at the centre of its preoccupations. This would eventually be known as complexity or systems science, a multidisciplinary field that would come to exert profound effects on science and the humanities.

Since the mid-1970s, complexity began to transform scientific views, promoting a bottom-up approach in place of the already mentioned top-bottom reductionist frameworks. Notions such as "complex system", "chaos", and "emergence" began to appear throughout many disciplines. A paradigmatic and enormously influential example of this trend was Benoit Mandelbrot's[1] work on fractal geometry. Mandelbrot's findings played a fundamental role in the recognition of the importance of complexity but, as art historian Grant D. Taylor (2014) notes, so did the publication of two landmark works of popular science literature: Ilya Prigogine and Isabelle Stengers' (1984) *Order out of Chaos* and James Gleick's ([1987] 2011) *Chaos*. Complexity

[1] 1924–2010

science acquired a new popular and attractive name "chaos theory". As characterised by Prigogine and Gleick, complexity science was a revolutionary paradigm that not only promised to subvert the epistemic edifice of scientism but also to reveal the inner workings of nature. Like cybernetics before, albeit more successfully, complexity theory began to be applied to numerous problems throughout many fields, from weather to economy, biology and medicine. On a wider cultural level, complexity became very attractive for postmodern thinking due to its promotion of randomness and its holistic and multidisciplinary origin. Unlike cybernetics, however, Mandelbrot's fractals, as well as "chaos culture", took hold of *both* science and the public imagination, particularly within the art world.[2]Before continuing with the topic of complexity we need to make a quick detour to discuss *information aesthetics*, a clear example of the problems that plagued reductionist approaches.

6.3 Information aesthetics

Information aesthetics is closely linked to the Stuttgart School and the birth of computer art in Europe (see Chapter 5). The theory was primarily developed by Max Bense in Stuttgart and Abraham Moles in Strasbourg between 1956 and 1958 (Klütsch 2012; Nake 2012a). Its main goal was to develop the means to measure aesthetic value objectively, and thus free aesthetic judgements from "subjective speculation" (Klütsch 2012, 67). The theory was further developed by Bense and others (mostly students of his) until the late 1960s, when many of its proponents began to abandon it, including Bense himself. The original texts on information aesthetics were written either in French or German, and very few have been translated into English (Nake 2012b). Of those that have, Moles' *Information Theory and Esthetic Perception* remains the major reference in the English speaking world. Regardless of the fact that Bense's ideas were by far the most influential.

The primary goal of Bense and Moles' theory was to "establish a rational and objective" aesthetics (Nake 2012b, 65), free from subjective speculation and judgement; and thus grounded on a rigorous scientific methodology. Ideally, information aesthetics would allow a scholar to measure the amount and the quality of the (aesthetic) information present in any given artwork, thus enabling a deeper and more objective evaluation than the ones given by "art historian chatter" (Klütsch 2012, 67). The goal, in other

[2]One might speculate that the appeal of fractals had to do with Mandelbrot's pioneering application of computational visualisations to mathematical analysis.

words, was to develop an aesthetics that could function much like a thermometer does (Nake 2012b, 65). This implied, of course, consciously disregarding any aspect of aesthetic judgement involving the observer — "at least in Max Bense's approach" (2012a, 87). Bense and Moles' theory was, by all intents and purposes, an *object-oriented aesthetics* (2012b, 87), since its purpose was to investigate the numerical value of aesthetic objects themselves.

Like any other theory, information aesthetics was grounded on a particular set of basic assumptions from which everything else was derived. Its "first axiom" (Nake 2009, 80) was that aesthetic artefacts are complex "supersigns": structures composed of elementary (or primitive) signs (2009, 80, 2012a, 86); material carriers (Klütsch 2007, 421) "in time or space" of "aesthetic states" (Nake 2012b, 66). These aesthetic states were supposedly independent of subjective observers (2012b, 66). For information aesthetics, aesthetic artefacts were so because they shared a particular set of *general* and *objective* features.[3] The second key assumption in the theory was that said states conveyed a particular kind of *aesthetic information*.[4] The third assumption, which was borrowed from American mathematician David Birkhoff[5] (1933), was that an objective "aesthetic measure" could be derived by determining "the degree of *order* relative to the degree of *complexity* in a given aesthetic artefact" (Nake 2012b, 67). That is to say, that given a class of objects (e.g., polygons), it would be possible to define their degrees of order (O) and complexity (C) in numeric terms, and then derive their aesthetic measure through the following formula: $M = O/C$ (2012b, 67). In summary, information aesthetics operated at the level of "primitives", attempting to reduce artworks to their elementary building blocks (signs) and then measure their statistical distributions.

Birkhoff, a mathematician and creator of one of the most influential theorems in ergodic theory,[6] developed his "aesthetic measure" in the 1930s. His goal was to create an objective method for assigning an aesthetic value to any artwork, whether a picture, a sculpture, a musical piece, or a written text. Birkhoff's measure was a function of the

[3]General because they could supposedly be found within any aesthetic object, objective because they could not be altered by the observer's gaze (Nake 2012b, 66).

[4]According to Nake (2012b, 68), Bense was the first one to use this concept, which he first mentioned in 1954 in one of his first volumes on aesthetics. Abraham moles adopted the term later, in 1958.

[5]1884–1944

[6]Ergodic theory is a whole branch of mathematics (Ben-Naim 2007). It was initially developed within statistical mechanics to quantify the trajectories of physical or dynamical systems (Gray 2011). The underlying assumption of ergodic theory was that regardless of the method used to prove a given system, any reasonably large sample obtained from it would be representative of the system as a whole (Shannon and Weaver [1949] 1980). Seen as such, ergodic processes are a special class of Markov chain processes (processes in which previous events influence the probabilities of a given event) ([1949] 1980).

order and the complexity supposedly present within the object under analysis. The elements that determined both factors depended on the medium used to generate the object. Birkhoff proceeded from the extremely simple assumption that an overall aesthetic measure can result from dividing the order by the complexity. To obtain the values for order, he considered features such as "vertical symmetry, stability, rotational symmetry, and the existence of a horizontal-vertical network"; whereas complexity was calculated by measuring the number of distinct lines (Mezei 1964). Birkhoff tested his formula on close to a hundred polygons, wherein the simple square received the highest score, and some complex polygonal figures received a negative score (1964). With these results, Birkhoff then designed figures (urns) that would purportedly meet the most desirable parameters. While Birkhoff obtained his results manually, Bense and others imagined computers would allow them to measure even greater sets and with more precision.

Besides Birkhoff's aesthetic measure and (Peircean) semiotics, information aesthetics also incorporated elements from Norbert Wiener's ([1948] 1985) cybernetics, Shannon's MTC, Noam Chomsky's (1956) generative grammar, and Gestalt psychology. Bense combined Shannon's analysis of the statistical structure of language (see Chapter 4), Birkhoff's mathematical analysis of aesthetic measurements and Chomsky's theory of grammar as a rule-based system (Klütsch 2007, 421). This provided both the means to determine the repertoire of primitive signs and the rules for combining them. With the aid of this *micro-aesthetics*, Bense thought he had all the required tools to build a model for determining the *macro-aesthetic* values of aesthetic objects. He adapted Shannon's purely syntactic model to human communication via cybernetics (2007, 421), portraying the existence of the work of art as consisting of two moments: (1) production and (2) consumption. The first moment or phase corresponded more or less to what the artist did, the "genesis" of the artwork; whereas phase two was reserved for the critic. In the first phase "the aesthetic object appear[ed] as adding to the world of pure being", in the second phase "the aesthetic object leave[d] the state of pure being and enter[ed] a sate of pure theory". What mediated between these two phases was "aesthetic perception" (Nake 2012b, 67).

Bense also incorporated concepts from physics into his theory — specifically, from thermodynamics. Perhaps the most important of them was the notion of *negentropy* or negative entropy. Bense regarded art as a phenomenon contrary to physical processes. He believed that creative processes generally produced order (Rigau, Feixas, and Sbert 2008) or "negative entropy" out of disorder. This idea is closely linked to

Boltzmann's identification of entropy with disorder (Ben-Naim 2007, 196). According to this interpretation, physical processes tend to change from initial more ordered states, towards a state of "mix-upness" — as described by the polymath J. W. Gibbs (2007).[7] Thus, as Bense saw it, while the physical world is inevitably poised towards chaos (i.e., to a state of maximum entropy), aesthetic creation strives towards order or "negentropy" (Klütsch 2012). It is in this relation between chaos (complexity) and order that aesthetic value lied. For Bense, this characterisation had all the value of a physical law. He believed aesthetic objects had special properties that went beyond their material vehicle; a "correality" that was determined by "macroaesthetic rules" which could be interpreted and *modelled* through objective algorithmic processes.

Abraham Moles, the other founder of information aesthetics, was trained both as a physicist and psychologist. Thus, unlike Bense's, his approach did not exclude the observer. Moles regarded *aesthetic information* as the counterpart of semantic information. That is to say, that the latter concerned *what* appeared in a message, whereas the former involved *how* it appeared (Nake 2012b, 67). For Moles, semantic information was "embedded into a universal logic" which could be "articulated and translated"; whereas aesthetic information could only be expressed precisely in the way it was expressed, and could not be translated (2012b, 67). Moles thus argued that aesthetic information generated "particular states of de mind" and thus depended on both "the sender and receiver". It followed that whereas semantic information was bound to conventional (interchangeable) signs; aesthetic information was tied to individual (irreplaceable) signs.

As Nake (2012b, 67) notes, a constant oversight when dealing with aesthetic appreciation is mistaking *measure* for *value* and vice versa. Measures are points located within a scale, which must be precisely defined. Scales are the product of agreements or conventions; it follows that, despite their aura of objectivity, measures are arbitrary numbers. For Moles, there was a clear distinction between measure and value, since the latter is based on judgement and thus depends largely on context and individual appreciation (2012b, 68). Consequently, Moles considered value judgements did not belong to scientific aesthetics; what did belong there was the *measure* of aesthetic information. Moles' conception of information was largely based on Shannon's MTC. Seen under

[7]Boltzmann and Gibbs (1839–1903) are key figures in the development of statistical mechanics. Working independently, they revolutionised the physical sciences by applying statistical methods to the analysis of thermodynamic systems. In so doing they came up with a method to treat the hitherto indistinct macroscopic flow of gases as conglomerates of discrete microscopic entities which could thus be studied quantitatively.

his terms, when information was low, redundancy was high, and thus one could make predictions about the artwork, which translated into a low aesthetic value due to "banality". Conversely, when information was approaching its maximum, redundancy was low, and predictions were useless. Because according to MTC maximum informativeness is equated to randomness, and randomness implies the absence of patterns, this also resulted in a low value, only this time it was due to "chaos". The "Goldilocks zone" for value judgement rested, according to Moles, somewhere between the banal and the chaotic (2012b, 68).

To recapitulate, between the early 1950s and mid-1960s Bense and Moles formulated a theory based on Shannon's MTC. Moles was interested in analysing music and spoken language, whereas Bense focused on images and text. Both of them believed it was possible to measure the aesthetic contents of artworks and thus achieve objective judgements of art. While the theory was initially appealing and inspired a considerable amount of research on the subject, the reductionist project of information aesthetics would eventually be abandoned by all of its promoters. Semiotic approaches would fill its place. Bense himself followed this path, and so did Nake. However, despite its failure to provide with an objective means to address art, information aesthetics had an important but unexpected consequence: the development of "generative aesthetics" and with it, the emergence of European computer art (see Chapter 5).

6.3.1 The problem with information aesthetics

While a specific definition of aesthetics is difficult to achieve, we may risk saying that this term is generally concerned with sensual cognition. That is, with the type of knowledge of the world we acquire not through logical deduction but through physical capacities and experience (Nake 2012b, 66). In its attempt to objectify and thus *automate* aesthetic judgement Bense and Moles' theory needed to exclude the living human agent or, at least, to reduce all the aspects involved in sensual cognition to an average measure. As Nake (2012b) notes, an automatic evaluation would only make sense for an automatic aesthetics; to evaluate the result of specific rules, it is first necessary to know the rules. Information aesthetics failed to accomplish both things.

The radical "anti-subjective" and reductionist program of information aesthetics should be understood, according to Nake (2012b, 74), as a reaction against the horrors caused by Nazi demagogy and, in particular, against its manipulation of aesthetics.

As Nake also points out, information aesthetics was flawed in its "anti-metaphysical" assumptions. The measure of information Shannon developed was intended for instances of continuous communication. In other words, what this measure yields is "a statement about the source" of a given message, not about the contents of a specific message (2012b, 74). Birkhoff's measure of aesthetic appeal in terms of order and complexity only works at a macroscopic level, whereas Shannon's measure of information is statistical and thus concerned with the microscopic. It Follows that information aesthetics effectively neglected the distinction between a class and a single instance. The theory promoted the reduction of an artwork to an instance of a class, treating it as an average, from wherein rules could be derived. As Nake (2012b) contends, what information aesthetics analysed were but probability distributions (of arbitrarily defined primitives). This is problematic because measuring statistical distributions of say, colour, points, or lines does not, by itself, yield any aesthetically relevant information about a work of art, about what it says or how it makes us feel. In summary, the main problem with information aesthetics was to confound *syntactics* (structure) with *semantics* (meaning).

But despite how flawed the objectives of information aesthetics might have been, these failures should not be interpreted as evidence that all informational accounts will necessarily follow the same path. Throughout the rest of this chapter, we will see how a non-quantitative informational model can serve as an illuminating tool for characterising not only computational aesthetic objects but artworks in general. But before delving into the model itself, it is necessary to clarify a few concepts that are crucial for the adequate comprehension of the arguments here being made. These notions are *system*, *complexity*, and *emergence*.

6.4 Complexity and its science

Although in everyday language "complexity" is often (erroneously) used to describe something that is "complicated", in the context of the current discussion this word will be used in its technical sense. The term "complex" comes from the Latin root *plectere*, meaning to weave or entwine. (Mitchell 2009, 4). A common dictionary definition of the term tells us that it something complex consists of interconnected or interwoven parts (Bar-Yam 1997, 1). Complexity is both an attribute of certain phenomena (systems) and a field of enquiry (complexity sciences). To date, however, there is no single "science of complexity", nor a single "complexity theory". As a field, complexity is a constantly evolving interdisciplinary cluster of sciences that emerged in the last decades of the twentieth century and whose main goal is to:

> explain how large numbers of relatively simple entities organize themselves, without the benet of any central controller, into a collective whole that creates patterns, uses information, and, in some cases, evolves and learns. (Mitchell 2009, 14)

In other words, the primary goal of complexity science is to understand systems. To understand what a complex system is or, at least, how it may be described, it is first necessary to clarify the term "system" itself.

6.4.1 Systems

The modern technical sense of "system" dates back to the mid-twentieth century, specifically, to cybernetics — Norbert Wiener's theory of feedback and control, and Shannon's MTC (see Chapter 4). Wiener did not emphasise the importance of systems in his theory, but he argued that *any* type of system could be understood via general laws or principles (Strijbos and Mitcham 2005). The success and popularity of cybernetics and MTC created the conditions for the development of a theoretical movement that emphasised organisation and regulation and, of course, systems as core principles in their approaches. The term became a catch-all notion used across various emerging fields that signalled a shift away from the previous scientific paradigm of reductionism and compartmentalisation, and towards holism and relations between phenomena.

Like many other (technical) concepts discussed throughout this dissertation, the concept of system lacks a single, overarching definition. Mostly because there are many types of systems — potentially as many as there are phenomena — with an equal variety of features. However, in the most general terms, systems are about parts, wholes, and relations (Mignonneau and Sommerer 2006); but also about, interactions, and time. To paraphrase Strijbos and Mitcham (2005, 1880), systems arise whenever a set of distinctive relations between a group of components interacting with each other and their environment by exchanging energy, matter, and or information, are identified. Usually, the individual properties and behaviour of a system's components may be different from the collective and *emergent* properties of the system as a whole. In other words, the system, as a distinct, and analysable entity exists only *because of* the interactions of its components.

6.4.2 Complex (and simple) systems

Complex systems are interwoven or interconnected networks of elements. Although there is hardly any exact or agreed-upon definition of a complex system (Mignonneau and Sommerer 2006), the first and most general way to understand this concept is by distinguishing it from simple systems. Both complex and simple systems are formed by smaller components that interact with each other. But in the case of complex systems, these smaller parts are not only much more abundant in number, but their behaviour and interactions are *interdependent*. These local interactions allow the system to *self-organise* without any intervention from external agents. Consequently, complex systems exhibit collective, emergent, and non-trivial behaviour involving signalling and information processing, as well as capacity for adaptation (Mitchell 2009). Examples of simple systems include a pendulum, a spinning wheel or an orbiting planet; examples of complex systems are insect colonies, the immune system, cells, economies, the world wide web, governments, the weather, corporations, a human brain, or a technology (Bar-Yam 1997; Mignonneau and Sommerer 2006; Mitchell 2009).

Self-organising systems are also dynamic (they evolve through time) and do not reach a stable equilibrium — meaning they are continually changing and always on the verge of dissipating (Galanter 2003). Some of these systems react to changes in their surroundings to maintain their integrity, they are known as *adaptive* systems. Complex systems are generally characterised by change, growth and, sometimes, death; they can "learn", adapt, and organise; they can mutate and evolve, replicate and expand their diversity.

Despite being an ensemble of smaller components, the properties of a complex system cannot be easily derived by merely analysing the behaviour of its parts. To understand a complex system it is necessary to understand not only the individual behaviour of each component but also how they collaborate with each other to produce the behaviour of the whole system. Since the whole cannot be described without taking each part into account, and each part must be described in relation to *every other* part, it is not surprising that complex systems are so difficult to analyse (Bar-Yam 1997). Furthermore, due to the interdependencies of their components, complex systems often react in a nonlinear[8] manner (Taleb 2012). For example, artificial (human-made) complex systems (e.g., the economy or a city) tend to develop cascading and "runaway" chains of reactions, which eliminate any hope of predicting the system's behaviour (2012). That is why systems with severe interdependencies, are better engaged in ecological terms, assuming that introducing even the smallest change can disrupt the behaviour of the entire system in the most unexpected ways (Taleb 2010).

6.4.3 Emergence

A fundamental concept for understanding complex systems is *emergence*. In a general sense, emergence refers to the "rising patterns, structures, or properties" exhibited by a system, and which "do not seem adequately explained by the system's preexisting components and their interactions alone" (Mignonneau and Sommerer 2006, 172). This should not be understood as meaning that the system's collective behaviour cannot be captured by the behaviour of its subcomponents. The collective behaviour *is* contained in the parts, and it can be grasped if they are analysed in the context where they are found (Bar-Yam 1997). That is why there is a difference between *local* and *collective* emergence: rising patterns found only in certain regions of the system, and behaviour exhibited by the system as a whole.

Complex systems not only interact with each other but may also be nested within each other. The subelements of a complex system are often complex systems themselves, but this is not always the case, sometimes complex systems are conformed by simple elements. That is why emergence can be either complex or simple (Bar-Yam 1997). There are systems made up of simple elements whose collective behaviour is complex. For example, the movements of a set of billiard balls on a table: despite being fairly simple objects, calculating the trajectory of the ninth ball being hit after the opening shot would require taking into account the gravitational pull of a person standing by the table (Taleb 2010). But there are also systems made up of complex elements and whose emergent behaviour is simple. The most basic example is a planet orbiting around a star; the Earth's movement is fairly simple and predictable even though both our planet and the Sun are quite complex systems by themselves. This difference between *emergent complexity* and *emergent simplicity* illustrates why it is fundamental to always

[8] Nonlinearity inherently implies that long-term predictions become impossible (Juarrero 2005). For example, doubling the dose of a medication or the number of employees in a factory, the results are not merely doubled, but can be either larger or smaller than expected (Taleb 2012).

take into account the scale at which any given system is being analysed. Seen from a smaller (micro) scale a system may behave complexly, but on the larger (macro) scale these complex details may become irrelevant (Bar-Yam 1997, 5).

6.4.4 Defining and measuring complexity

Central to systems science are the problems of how to characterise and measure complexity. One of the most well-known approaches to do so is *algorithmic complexity*, also known as algorithmic information content (Galanter 2003), or Kolmogorov-Chaitin complexity,[9] a fundamental concept in Algorithmic Information Theory — a rich subfield of information science. The primary assumption behind algorithmic complexity is that, in principle, any object may be encoded — and hence, described — as a sequence of zeroes and ones (Volkenstein [1986] 2009, 182). The degree of complexity of a given system (object) thus corresponds to the amount of *information* contained within that sequence or description (Bar-Yam 1997, 12). Specifically, to the size (measured in bits) of the *shortest* program (algorithm) capable of outputting that same sequence (Adriaans 2013). In the words of Russian polymath Mikhail Volkenstein, the complexity of an object corresponds to "the length expressed in bits, of the most economical program for generating a binary sequence describing the object" ([1986] 2009, 182). This means that the more complex something is, the more difficult it will be to describe (specify) it, the larger the size of this description (program), and the higher the amount of information contained within it.

Algorithmic complexity is really about information content and *compression*. Volkenstein ([1986] 2009, 182) provides a useful example[10] to illustrate this point, which involves two binary strings and the respective hypothetical programs used to generate them:

(4) `0101010101010101`
(5) `0110001011100101`

[9]Named so after Andrey Kolmogorov (1903–1987) and Gregory Chaitin (b. 1947) the two mathematicians who, unaware of each other's work, formalised this concept independently in 1965 and 1969, respectively (Adriaans 2013; Gleick 2011). It is fair to note that neither of the two knew of the work of Ray Solomonoff (1926–2009), who published his method of *algorithmic probability* in 1964. Algorithmic probability and Kolmogorov-Chaitin complexity are closely related; nonetheless, the former is mostly based on information theory, whereas the latter was conceived as a general method for assigning probabilities in inductive reasoning (Adriaans 2013).

[10]Philip Galanter (2003) also provides a similar example.

It is not difficult to see that (4) has a recognisable pattern; and hence, that it is more "ordered" than (5). It follows that part of the information in (4) is redundant and can be *abbreviated* — i.e., compressed — using a simple, minimal instruction without sacrificing either intelligibility or compromising the string's integrity. The program to generate (4) would thus need to state "`print 01 eight times`" in plain language, $(01)^8$ in mathematical notation or, alternatively, something like the following pseudocode:

```
begin
    value = 01
    print value * 8
end
```

Conversely, (5) has no recognisable pattern; it is less "ordered" and therefore lacks any redundant information that could be dispensed or abbreviated to shorten its description. Assuming this string is truly random, the smallest program needed to reconstruct or generate it would have to be at least *the same size* as (5) itself, and it would look more or less like the following pseudocode:

```
begin
    print 0110001011100101
end
```

It follows that, in light of Kolmogorov-Chaitin, string (5) is not only more complex than (4) but also contains *more irreplaceable information*. This relationship between complexity and randomness is the source of many confusions, and it lies at the heart of MTC's most recognisable paradox;[11] namely, that maximum informativeness (or, in this case, complexity) equates maximum *randomness*.

The human brain has evolved to respond to patterns and regularities; it is partly through them that we learn, communicate, and navigate the world. Patterns are the source of knowledge, but they are also the source of bias — that is often why religious figures appear in burnt food or mouldy walls. Anything that seems to lack an immediately recognisable pattern is automatically deemed difficult to understand. By definition, randomness lacks regularity or structure, hence equating it with complexity seems reasonable in principle. The problem, however, is that the term complexity is often used in a qualitative sense, usually in connection to human intellectual prowess. Something (an idea, a theory, a phenomenon, or a work of art)

[11] See Chapter 4.

may be qualified as "complex" because it might be difficult to produce or understand it but not *impossible* to explain it. Whereas randomness, being antithetical to regularity and "order", resists any form of levelling.

It is precisely due to its relationship with randomness that Murray Gell-Mann considers the Kolmogorov-Chaitin method unsuitable as a measure of complexity. He makes his case by noting that, if quantified under these terms, Shakespeare's works would have a lower degree of algorithmic complexity than "random gibberish of the same length that would typically be typed by the proverbial roomful of monkeys" (1995, 16–17). Gell-Mann thus proposes instead a measure of "effective complexity" that would, in theory, allow to cull out purely random systems. What Gell-Mann fails to acknowledge, however, is that complexity is a relative feature (Bar-Yam 1997; Volkenstein [1986] 2009).

To borrow Floridi's words, expecting questions or — in this case — definitions to be unique, correct, and absolute independently of context, purpose and level of observation often leads to paradoxical nonsense (2011c, 553). Complexity — regardless of the method used to measure it — is a relative notion because, ultimately, "it depends on the level of scrutiny, that is, of perception" (Volkenstein [1986] 2009, 183) from which we approach it; "on the level of detail required in the description" (Bar-Yam 1997, 12). To illustrate this point Volkenstein ([1986] 2009, 182) provides another useful example: for a biologist, a bull's brain may be a highly complex system whose detailed specification might require millions of bits. Whereas for a butcher the same description would merely involve some five bits since the brain represents one of the roughly 30 parts of the animal destined for human consumption, and $\log_2 32 = 5$. Complexity regarded in absolute terms can, at best, characterise a system's structure, but without context, it tells nothing about the *value*, and thus, about the *irreplaceability* of the information contained within it.

Any measure of complexity is, in reality, a measure of the complexity of the gradient of abstraction (see Chapter 3) used to analyse a given system, not of the system itself. Algorithmic complexity measures a model's thoroughness. The word "cat", a bitmap image of a cat, and a video of a cat all refer to the *same* entity sleeping on the chair, each one of these descriptions contains a different amount of information. Neither of the three contains *all* the information required to describe the appearance, movement, organs, particular traits, sounds made, etc. of the cat through every day of its life. That is why, as noted in Chapter 5, the most accurate description (model or program) of the cat in absolute terms is the cat itself. In this sense, the information contained in the system called "cat" is *irreplaceable*.

The same applies to human beings. As Volkenstein notes "[w]e consider each person to be uniquely valuable, and therefore that human beings are not to be encoded by a program shorter than their own actuality" ([1986] 2009, 182). In other words, there are no "'substitutes'"; human beings are all irreplaceable. Nonetheless, when we shift our level of abstraction and consider human beings from a biological standpoint, specifically as members of a species (*Homo sapiens*), an order (primates), a class (mammals), and a kingdom (animals), all members of each subdivision may be considered equivalent ([1986] 2009, 183). If the goal was to come up with the minimum program for *Homo sapiens* every person regardless of sex, complexion, volume, or age is equally complex; there are no "irreplaceables" ([1986] 2009, 183). Furthermore, at the level of the animal kingdom, a human being would be equivalent to a fruit fly ([1986] 2009, 183), whereas at the level of family we are equivalent to chimpanzees. According to this biological *interface* complexity, and hence the required length of the program of specifications, increases from the most general to the more specific classification.

Complexity and irreplaceability are related but not necessarily mutually dependent. In fact, as Volkenstein notes, irreplaceability is often *more* important than complexity due to its relationship with value. Complexity, as stated before, refers to the entire structure of a system, whereas irreplaceability concerns functionality. As Volkenstein, argues, from an evolutionary standpoint, "although complexity may decrease in some situations, irreplaceability, that is, the value of information always increases" ([1986] 2009, 184). Elements of a system may be more or less complex when compared to each other, yet their larger role within the system as a whole is not necessarily proportional to their individual complexity. Phytoplankton provides a good example, these photosynthesising organisms may be less complex than fish, yet their role in marine ecosystems is more important than that of other species.

Algorithmic complexity can be used to characterise virtually every phenomenon. Finding the most economical way to condense information is already present in many aspects of life. DNA is the most obvious example, but compression is a fundamental aspect of language too. We use π as a shorthand for the decimal representation of $3.14159\ldots$, we use the word "dog" rather than speaking about a "domesticated furry mammal that wags its tail". Concepts, images, and symbols, such as Chinese ideograms or traffic signs, are all things that may be characterised in terms of minimal programs. However, algorithmic complexity is by no means a purely descriptive notion; it is also an epistemic principle upon which scientific theorisation and many contemporary technologies are built. Algorithms for data encoding, transmission, encryption, and decryption that is, for data manipulation with countless applications, such as CGI (Computer Generated Imagery), take advantage of the possibility of finding programs whose output is considerably larger than themselves.[12]

For all its usefulness, there is an important down-side to algorithmic complexity: it is ultimately uncomputable. As discussed in Chapter 4, Kurt Gödel's "incompleteness theorem" proved there will *always* be statements that are true but not provable, regardless of how the axiomatic system used may be constructed. Gödel's finding had dramatic consequences, not only for mathematics but science in general. As Volkenstein ([1986] 2009, 186) notes, "the goal of science has always been that of finding a minimal program encoding and explaining the complex totality of facts being investigated". Albert Einstein aptly summarised this idea, when he said that "[t]he grand aim of science is to cover the greatest number of experimental facts by logical deduction from the smallest number of hypotheses or axioms" (quoted in Domingos 2015). As Volkenstein argues, after Gödel it became clear that knowing and understanding the world solely through deductive means (i.e., through "the smallest number of hypotheses or axioms") is virtually impossible.

Now, concerning algorithmic complexity, Gödel's theorem shows that "it is in general impossible to prove the minimality of a given program that generates or encodes a sufficiently complex message" (Volkenstein [1986] 2009, 185). This caveat, however, does not imply that it is impossible to find a minimal program, only that nobody can *prove* that it is in fact minimal. Consequently, it is also impossible to prove solely through logical argumentation the degree of irreplaceability (i.e., value) of the information present in a given system ([1986] 2009, 186). "Something" else is always needed to do it. Volkenstein thus suggests that the something is *intuition*, which he defines as "the direct judgement of truth in the absence of logical argument" ([1986] 2009, 186). "Intuition has always necessarily accompanied logical argument in scientific discoveries", argues Volkenstein, but it is also a key component in artistic creation.

[12]A good example is the use of fractals to simulate natural patterns in computer graphics. "Fractality is the repetition of geometric patterns at different scales, revealing smaller and smaller versions of themselves. Small parts resemble, to some degree, the whole" (Taleb 2010). A typical (natural) examples of fractals are trees, rivers, and ice formations. A program, consisting of a simple set of mathematical instructions carried out by a computer can output highly complex images (Taylor 2014, 166) composed entirely of fractals. Rather than having to store all the bits required to form a large illustration, the image can be generated according to pre-established parameters.

6.5 Volkenstein and the artwork as an integral informational system

In the last chapter of his book *Entropy and Information*, Volkenstein ([1986] 2009)[13] sketched a model for describing artworks in informational terms. Volkenstein's core premise is that creating art implies, at the most fundamental level, *generating new and irreplaceable information*. Artworks thus may be regarded as non-isolated "integral informational systems". Non-isolated because, even though they constitute autonomous objects, they interact with the audience, while maintaining a relationship with their creators. Integral because, like living organisms, every single one of their features is indispensable for their proper functioning, and even the slightest change in their internal structure can alter their entire stability and meaning. For Volkenstein, just like a change in a single gene can have a dramatic impact on the overall constitution of an organism, a single word in a poem can transform a masterpiece into a mediocre and tacky piece. Volkenstein's model is heavily based on Shannon's concept of information, complexity theory, and thermodynamics. His notions of art and aesthetics are (much like C.P. Snow's) classical, since he implicitly describes literature, and poetry in particular, as the quintessential form of artistic expression.

6.5.1 Volkenstein's model

For Volkenstein ([1986] 2009, 187) art is personal and collective; a product of the artist's individual "peculiarities" but also of the society where she lives. Artwork's "resemble living organisms", complex integral systems whose workings are the product of the collective interplay of their constitutive features. But also, by being the creation of a person, artworks are "a manifestation of life, the product of a creative mind" ([1986] 2009, 187). Artworks convey information. The value of this "artistic information is of an aesthetic kind", and it is determined "by the amount of influence it exerts on a receptor with the necessary preparation" ([1986] 2009, 187), and is therefore capable of apprehending it. That is, of "feeling it deeply and imaginatively, and of evaluating it" ([1986] 2009, 187). Every artwork regardless of its particular features is open to interpretation; every person is entitled to say whether he or she likes it or not. However, a competent and serious evaluation calls for certain training on the part of the observer.

[13] 1912–1992

She must possess what Volkenstein calls a "thesaurus": specific background knowledge, aesthetic sensibility, and willingness to interpret the artistic information being conveyed.

Volkenstein characterises aesthetic engagements as processes of information transmission (as acts of communication). Reception of artistic information, however, is not a passive act. It involves a partial loss of the available information, but also its "enhancement". Aesthetic engagements, like any other instance of information exchange, are always accompanied by noise[14] generated by the physical and environmental conditions surrounding a transmission (see chapter 4). Given the insurmountable gap between "the mind" of the artist and the minds of her audience, a certain amount of information conveyed by her artwork is bound to dissipate in the process of being received. As Volkenstein ([1986] 2009, 187) notes, such loss is "inevitable" yet also "trivial". What is not trivial is the fact that the artwork "activates or *programs* [emphasis added] a stream of associations, thoughts, and feelings in the consciousness of the receptor" ([1986] 2009, 188) thus stimulating the creation of *new* information by him or her. The receptor thus effectively plays the role of co-creator of the work of art; artist and audience engage in "collaborative creative work" ([1986] 2009, 188).

How valuable is the information created by an artwork depends mostly but not exclusively on its singularity and irreplaceability. Volkenstein contends the value of individual elements (e.g., words in a poem) are higher in works of art than in other types of informational systems such as scientific documents. Changing even a word can "damage the integrity" of a poem, whereas scientific ideas can be expressed in varied ways without affecting the semantic value of the text — at worst the writing can become more obtuse or less enjoyable to read. As is the case with other informational systems, the more novel and unexpected the information conveyed by an artwork is — i.e. the less redundant it is, the more valuable it will be (see Chapter 4). But regarding this point, Volkenstein ([1986] 2009, 188) notes an important caveat: whereas for MTC redundancy is normally equated to low informativeness, in the context of art this equivalence cannot stand since many artworks use repetition precisely as an aesthetic device. This is yet another example that shows the importance of integrity in works of art, and why attempting to derive "rational content" on a purely logical basis is misguided.

This is not to say, however, that artistic information cannot be redundant, and therefore "valueless" ([1986] 2009, 188). For Volkenstein, a redundant and thus uninformative

[14]That is, "unwanted data" (Floridi 2016) received along with a message and with the potential to impede its adequate apprehension.

artwork will be characterised by "cliche, banalities, and pointless repetition". In his view, even a single stereotypical trope is capable of tainting the value of any work of art, turning it tacky or derivative.[15] Lack of informativeness in an artwork can also be owed to a work being solely based on technical prowess. Volkenstein uses the example of naturalistic painting (hyperrealism), wherein an artist merely attempts to produce "an illusory encoding of reality", a mimetic reproduction containing "only a minimal amount of new information" ([1986] 2009, 189) Volkenstein thus generalises: the value of a work of art may be understood as directly proportional to the novelty and unexpectedness of the information it conveys. Nonetheless, even this condition (however necessary) is not sufficient as a measure of artistic value, merely adding another exemplar to an already established genre — another instance within a *class* — does not guarantee artistic irreplaceability. A true artwork not only conveys but also stimulates the production of new information. The actual value of an artwork resides not in the object itself but in what it does with the audience.

Volkenstein is aware that aesthetic judgements do not occur in a (socio-cultural) vacuum, but that the way artworks are interpreted changes according to context. Reception of artistic information is both a collective and a personal matter subjected to historical and cognitive fluctuations. That is why yesterday's mediocrity may become today's masterpiece and vice versa. The masterpiece is the artwork to which we "return" repeatedly over the course of our lives, and that always seems to offer something new. In this sense, true "genius", argues Volkenstein ([1986] 2009, 190), "is unlimited informativity". In Volkenstein's interpretation artists create order out of primaeval chaos, but it is a peculiar form of new order and *knowledge* of the world. Like any other human activity, art is a product of the interplay between logic and intuition, but art is capable of exhibiting that which escapes logic and formalisation. Art "proves the unprovable" ([1986] 2009, 194) and demonstrates "the cogency of intuitive inference". Volkenstein portrays art as something directly opposed to entropy, but here it is chaos that allows the *poietic* (whether artistic, epistemic) "negative entropy" to exist and be noticed. It is chaos, the lack of uniformity that allows uniformity to appear and be noticed in the first place. Contrary to more fatalistic interpretations of entropy, Volkenstein sees it as an indispensable condition for life and art since, without it, there would be no movement, no transference.

As it is clear from the previous account, Volkenstein's sketch of artworks as infor-

[15]Having what we could call "classical" conception of aesthetic value, Volkenstein's model would have a difficult time measuring up with postmodernist icons such as Jeff Koons, and the like.

mational systems was based on "traditional", i.e., non-computational artefacts. He did not specify, nor insinuate whether this model could be employed to characterise computational aesthetic artefacts. Given the fact that the computer is an information modelling machine, there is no reason to deny the possibility of describing computational aesthetic artefacts as informational systems, more to the contrary. However, before analysing how Volkenstein's model could be adapted, it is necessary to solve two pending problems. The first one concerns the distinction between analogue and digital and its potential role in understanding the nature of computational aesthetic artefacts. Secondly, while it is clear that Volkenstein subscribes to Shannon's MTC, it is unclear what he means by artistic information or "information of an aesthetic kind". The following section will address the first problem by resorting to Nake's and Floridi's insights, whereas the second issue will be addressed in the discussion.

6.6 Nake and the double logic of algorithmic images

As Frieder Nake (2010, 55) notes, there are no images today without traces of digital art. Being digital is neither new,[16] nor the most important aspect of "postmodern" (i.e., posthistorical or hyperhistorical) imaging. In fact, Nake contends there are no digital images *at all*. The reason being that for something to be an image it must be visible, and "the digital is invisible" (2016, 12). Digital refers to numbers, and counting has been a part of human life for a long time. Digital refers to the discrete, the conceptual; whereas "analogue", its counterpart refers to the continuous and the perceptible. Nake contends neither the world nor anything within it is digital but analogue. Digitality, he claims, is a mental concept (2016, 18). Only with the invention of computers did digital acquire prominence.

Images *qua* digital objects are not visible, they are perceptible because they exist in a *double mode*, as an "algorithmic sign" (Nake 2016, 13). "So-called" digital images, argues Nake, are in reality a new kind of image; a *composite* made of a (visible) surface, and an (imperceptible but manipulable) "subface". The surface is analogue and perceptible; the subface is its digital shadow. The subface is computable; it is the algorithm, a description, but (as spectators) we have no access to it since it is hidden and internal to the computer as "program-and-data" (2016, 16). For its part, the surface is what we perceive on a screen, whether still, dynamic, passive or interactive. This unity of surface

[16] Lopes (2010) makes a similar argument.

and subface is what, according to Nake, comprises all "algorithmic images"; making them objects that contain their own "operational description" (2016, 21). Such ontic unity can only be separated in the realm of analytic thinking. According to Nake, any aesthetics of algorithmic images should start by assuming this duality and the fact that we are now dealing with "art in its algorithmic dimension" (2016, 21).

Algorithmic images in the sense above described, have their origins in early computer art (see Chapter 5). But usage of algorithms for aesthetic purposes is a relatively old practice (Galanter 2003). Algorithms, as Nake argues, "exist as descriptions, and are, therefore, semiotic entities, that is, signs" (Nake 2016, 21). Early computer art was "interesting and revolutionary" insofar as it inaugurated the "principle of all [contemporary] algorithmic art": that each work involves the *description of a class*, i.e. of an infinite set of structurally similar instances (2016, 15). Each instance in the class is structurally similar or identical to the others; its differences rest solely on specific features.[17] In algorithmic (or computer) art, it is the machine that renders each instance of the class, whereas the task (and "contribution") of the human agent consists in writing down the instructions in detail. The artist creates from a distance; she draws "by brain" rather than "by hand" (2012a, 73).

This setup has far-reaching consequences for art in general, as Nake duly notes. First of all, the "art" (the *poiesis*) in algorithmic art is no longer found in the specific instance but the *class*. This, for Nake, is a "revolutionary departure from all other forms and modes of art" (Nake 2016, 15). But it is also "somewhat tragical" since a class (being infinite) a whole can only be conceptualised; although we can visualise it partially through its instances. Artists creating algorithmic art think the images but do not realise them. It follows that algorithmic art *is implicitly abstract*; So much so that Nake contends it is, in fact, a branch of conceptual art (2016, 16).[18] A far stronger implication brought by algorithmic art is, according to Nake, the disappearance of the masterpiece.

[17]It is fair to note that Flusser ([1983] 2006, 33–40) makes a similar claim concerning photography. In his description, photography as a medium is conditioned by the categories programmed into the camera. The photographer chooses a set of categories to create images, her ability to choose is constrained by all the possible combinations *programmed* within the camera.

[18]Yet he notes there is a substantial difference: algorithmic art is "operational", whereas conceptual art can prescind of execution. In Nake's words:

> In conceptual art, the concept is considered more important than its realization. Algorithmic art goes the other way. Ideas and their descriptions, in algorithmic art, must be codes that incorporate their own execution. Where conceptual art dances around the possibility of, perhaps, realizing a piece and drawing pleasure from imagining it, algorithmic art immediately delivers the conceptualized piece free of charge. (Nake 2010, 57)

Nake does not venture to establish what are the criteria for a work of art to become a masterpiece. In his view works of art are social constructs; artists create artefacts which society, through "intricate and interwoven processes, full of unpredictability and uncertainty" (2016, 24) turns some of them into works of art. Some of them — presumably by similarly intricate processes — are then elevated to the rank of masterpieces. Nake contends the double nature of the algorithmic image "destroys all master-likelihood". The reason is that the art in algorithmic art is to be found in the class, not in the particular instance. The lack of physical presence, its existence solely as a sign is a prerequisite for a class to be a class, and it the exact opposite of what we have historically looked for in a work of art. Being necessarily abstract, a class cannot be hung on the wall, taken into a room, observed or appreciated (2016, 24–25) as any masterpiece would. For Nake, there is no reason to lament the disappearance of the masterpiece since the algorithmic work is the source of a (potentially) endless stream of works; unlike masterpieces, algorithms exist in time much more than they exist in space. Algorithms are fluid.

6.7 Informational realism, an alternative to digital ontology

A more general way in which the analogue vs digital distinction can be addressed is provided by Floridi (2011a). He contends this underlying Boolean dichotomy is but the most recent recasting of the age-old question of whether things in the world may be continuous and discrete. Floridi's broader metaphysical account is a critique of digital ontology in favour of an informational (structural) ontology. In concise terms, he proposes moving away from an ontology of things "to which it is difficult not to apply the digital/discrete vs analogue/continuous to an ontology of structural relations" for which said dichotomy is irrelevant (2011a, 334).

By most accounts (Copeland, Sprevak, and Shagrir 2017; Petzold 2008) the German computer scientist Konrad Zuse is the originator of Digital ontology. What is now known as the "Zuse thesis" (Copeland, Sprevak, and Shagrir 2017) essentially states that "the universe is being deterministically computed on some sort of giant but discrete computer" (Floridi 2011a, 319)

Zuse's 1967 book *Rechnender Raum* (translated as "Calculating Space")

> sketched a new (even mind-bending) framework for fundamental physics. Zuse's thesis was that the universe is a giant digital computer, a cellular automaton (CA).20 According to Zuse, the universe is, at the bottom, nothing more than a collection of ones and zeros changing state according to computational rules. Everything that is familiar in physics—force, energy, entropy, mass, particles—emerges from that cosmic computation. (Copeland, Sprevak, and Shagrir 2017, 449)

Digital ontology contends that, ultimately, the universe is an enormous digital computer — perhaps a Turing machine — and thus reality is fundamentally composed of digits, rather than of matter or energy. Material objects are secondary manifestations of bits. Reality is not smooth and random but granular and deterministic. Time, space and every entity and process is ultimately discrete. It follows that the evolution of the universe is *computable*, and thus the output of a (presumably) short algorithm (an appeal to Occam's razor). To repeat, the physical laws governing the universe are *entirely* deterministic. Our world, our lives, everything around us is a simulation running on this device.

Informational ontology is a form of (structural) realism,[19] and is thus "committed to the existence of a mind-independent reality" (Floridi 2011a, 339). For informational ontology, knowledge of the world is knowledge of its structures. It regards reality as a system constituted by the totality of structures or objects dynamically interacting with each other. These objects are neither substantial nor material (they might be, but we have no way of knowing it), but informational. Consequently, it holds the ultimate nature of reality is informational. At its core, this information is raw data,[20] entities whose only properties are being "epistemically virgin" but "ontically distinctly existing"; in other words, *placeholders*. This reality is epistemically malleable; knowing it means interpreting it constructively, not portraying it passively.

Informational ontology stands on the Kantian tradition; it contends unmediated access to reality *qua* reality (reality in itself) is untenable. It treats the ultimate nature of reality as relational, as something that depends on the way it is accessed. Reality might have certain properties, it *could* be discrete, as digital ontology claims, or it could be

[19]Its more technical name is Informational Structural Realism. Structural realism (SR) argues that the structural properties of reality are knowable in themselves (Floridi 2011a, 340).

[20]The concept of data employed by Floridi (2011a, 367) is that of "a mere *differentiae de re*", meaning "mind-independent, concrete points of lack of uniformity in the fabric of Being". A *datum* (the singular of data) exists only as a difference; nothing can be a datum per se, just like a husband and a wife cannot exist conceptually without each other.

continuous ("analogue") but, since we have no way of knowing we are not forced to choose either. Reality is *complex* (in the sense discussed above); thus, there is no way to account for *all* the possible ways in which it could be modelled. Our access to it will always be incomplete.

Informational ontology does not argue reality is inaccessible, only (epistemically) *inexhaustible*. It is the resource out of which all of our knowledge is constructed. Consequently, as Floridi (2011a) puts it, it is pointless to try to determine what are the *exact* properties of reality independently from the point of view from which we are observing it. In other words, independently of the Level of abstraction or LoA, from which we are proceeding. And here is the fundamental claim of informational ontology: The features that we usually ascribe to reality are, in fact, characteristics of the LoA.

It is not the systems that are, in themselves, discrete or continuous (digital or analogue) these are features *determined* by the LoA (approach). Reality can be characterised in multiple ways, some of them contradictory. For example, quantum mechanics shows elementary particles behave in a dual manner, as discrete objects, but also as waves. Thus informational ontology suggests moving away from an ontology of entities and towards an ontology of structural relations. It is crucial to note that what Floridi (2011a) is arguing is not that some LoAs show reality to *be* digital and other show it to be analogue. But instead that some LoAs *are* digital and some are analogue, and, depending on the one chosen, reality will be *modelled*, i.e., *constructed* as digital or analogue. To further reinforce this point, Floridi notes that while a structure such as the Parthenon is "as concrete and objective as anyone may wish it to be it does not represent marble" (2011a, 371). Or, to use another example, a model does not have to represent the intrinsic nature of its source system, anymore "than an igloo describes the intrinsic nature of snow" (2011a, 78). The late philosopher of science Paul Feyerabend made more or less made the same point a couple of decades before:

> In a way, individual scientists, scientific movements, tribes, nations function like artists or artisans trying to shape a world from a largely unknown material, Being. And just as stone permits the construction of artworks vastly different in appearance (as an example compare the Pantheon with a Gothic Church), in the same way Being permits the construction of different *manifest worlds*, as I shall call them. Or, *researchers are artists who, working on a largely unknown material, Being, build a variety of manifest worlds that they often, but mistakenly, identify with Being itself*. (Fey-

> erabend 1996, 27)

The constructionist metaphor was also favoured by Kay (see Chapter 5), but he used it to make the opposite point: that understanding the nature of the (source) material does not necessarily entail understanding the nature of the model built from it:

> As with most media from which things are built, whether the thing is a cathedral, a bacterium, a sonnet, a fugue or a word processor, architecture dominates material. To understand clay is not to understand the pot. (Kay 1984, 53)

6.8 The consequences for digital and analogue

What follows from these accounts is that "analogue" and "digital" are not properties of systems, but of the ways we model them. We experience, conceptualise, and know reality (or "Being") as discrete or continuous depending on the level of abstraction we, as "epistemic agents" (Floridi 2011a), assume. We cannot know whether reality is analogue or digital not only because of the intrinsic mediation of the (Kantian) "spectacles" through which we access it but also because reality in itself might be the wrong thing to which these categories are applied (2011a, 325). The analogue vs digital boolean dichotomy is untenable when applied as an ontic absolute to our understanding of reality or, for that matter, to descriptions of the ultimate nature of systems. To return for a moment to Nake's dual nature of algorithmic art, we could note that it is not the case that images now exist in a "double mode" but that only now we have the means to model them through either level of abstraction.

6.8.1 Not artistic but semantic information

The very reason MTC is such a useful tool for information technologies (see Chapter 4) — namely, its disregard for semantic content — makes it comparatively limited when addressing problems within the humanities. Quantitative models neglect granular detail and individual cases because operating at a higher *level of abstraction* allows them to explain (and reduce) phenomena in more general terms. Science, after all, is about compressing the largest amount of information on any given phenomena in the shortest and simplest explanation.[21] In the context of art; however, the assumption is that *every* artwork represents a unique, irreplaceable instance even though it may share some features (physical or otherwise) with other members of its class. When we approach works of art, we do it with a hermeneutical intent attuned to granular detail. The question is, what benefits does it have to talk about art in terms of information when the very formulation of this concept seems to ignore its most crucial aspects — namely, semantic content and its reception? Luckily, as Shannon (Shannon and Weaver [1949] 1980) himself recognised, MTC's reductive characterisation of information is by no means the only one available, nor does it have any pretence to explain every phenomenon.

Most fields related to information science now tend to agree upon an operational definition of information based on semantic content (Floridi 2011a). According to this "General Definition of Information" (GDI), semantic contents may be considered information if, and only if they are composed of "well-formed meaningful data" (Floridi 2004, 2011a).[22] Along with rejecting the possibility of data-less information, GDI requires data to have some form of representation (e.g. binary digits) and also — given the nature of current computational technology — physical implementation[23]. Now, regarding the question of how or why data can carry meaning in the first place is, according to Floridi (2004), one of the most difficult problems semantics has yet to solve. Nonetheless, it is possible to bypass it by assuming the issue "is not how but whether data constituting information as semantic content can be meaningful independently of an informee" (2004, 45). Examples such as the Rosetta Stone[24] and the growth rings in tree trunks show the answer is that meaning is not — at least not exclusively — in the mind of the human subject (2004).

When regarded as semantic content, information comes in two main flavours: instructional and factual. Instructional information — also known as "imperative"

[21] Richard Feynman's often cited explanation of the value the atomic theory has as an epistemic tool is an excellent example of this notion (Gleick [1992] 2011).

[22] The definition of "data" is itself contentious. Data is the Latin translation of the Greek word, *dedomena*; it is the utmost unit to which information may be reduced. In its singular form, "*datum*", is a fact concerning some difference or lack of uniformity within some context, e.g. the perceptible difference between two letters in the alphabet, or the difference between the presence or absence of an object (Floridi 2004, 2011a). That is why sometimes information is characterised as "a difference that makes a difference" (Byfield 2008).

[23] It is important to note, however, that physicality does not necessarily entail materiality, as Floridi (2010) notes.

[24] Before the discovery of the Rosetta Stone, Egyptian hieroglyphics were indecipherable; the stone provided a translation "interface" to access their meaning; this, however, did not affect their original semantics (Floridi 2004).

information — is the kind one might find in stipulations, orders, recipes or algorithms. These instances have a semantic dimension since they have to be interpretable and therefore meaningful, but unlike instances of factual information, they cannot be correctly qualified as being true or false, only perhaps as being correct or incorrect.[25] Instructional information does not convey specific facts nor does it model, describe or represent ideas; it merely helps to "bring about" (Floridi 2016) (factual) information. For its part, factual information (also known as "declarative" information) is the most important of the two kinds of semantic content, but it is also the most common way in which information *in the capacity of* information "can be said" (Floridi 2004). Factual information "tells the informee [agent] something about something else" (2004, 45); for example, the location of a place, the time of the day, an idea, a fact, etc. To borrow a metaphor from Floridi (2004), factual information is like the "capital" or centre of the "informational archipelagos", since it provides both a clear commonsensical grasp of what information is and links all concepts related to information.

6.8.2 Beyond analogue vs digital

Granting that artworks are informational systems shows the "analogue vs digital" dichotomy is an epistemic rather than ontological construction. The difference between analogue and digital is one of *encoding*; they are both levels of abstraction, but with different granularities, they are specifications. Humans experience aesthetic artefacts through the same sensory *aparata* despite their purported ontological status; the information in them is processed just the same by our brains. The artwork exists as an object because we impose a level of observation on it, but at the most basic level what we are always dealing with is information. As a fundamental unit information is interchangeable, there is no essential difference between one unit and the next one, what we identify as the object-artwork is in truth a stable pattern, the sum, and arrangement of a given amount of information units. An informational approach is equally useful for traditional aesthetic artefacts as it is for digital artefacts.

Volkenstein shows us the artwork is "telling" us something we did not know, conveying factual information, describing something, a certain view of the world; in so doing something changes, something gets triggered in another system: the viewer's mind. The work of art as a system is open and in flux. Information begets informa-

[25]Consider for example a musical score or a piece of software, neither of them may be successfully qualified in alethic terms.

tion; it is something alive, a pattern that is to be *constructed* and expanded. The rarity, the unexpectedness of the potential information generated is what begets value. The artwork is a pretext in the amplest sense of the word; a program with uncertain and unlimited outputs. Birkhoff and the creators of informational aesthetics understood beauty and aesthetic value as something lying about within the object, static, while Volkenstein looks for value in intuition, in the knowledge that falls outside logical proof. For Birkhoff and the proponents of informational aesthetics, artistic value is to be discovered and explained, for Volkenstein, it is to be *constructed*. The uniqueness of an artwork is the unquantifiable instance of an interaction between minds and all the potential interpretations that can come out of this engagement.

Volkenstein makes two key points: (a) that artworks may be regarded as complex systems, and (b) that artistic value has to do with novelty and irreplaceability but, most of all, with (unlimited) informativeness. Volkenstein's model does not enter into contradiction with other interpretations of aesthetic value but complements them; it does not force us to see or to understand artworks *just* as information but to see them as different configurations, as types of encoding. Unlimited informativeness is endless interpretability, which in turn depends on the individual engaging the artwork and the circumstances accompanying this relation. Each time we run the artwork-program through an interpreter we obtain a new iteration of the program, which in turn may lead to other programs and variations.

6.8.3 Complex systems are difficult to quantify, and therefore the possibility of measuring aesthetic value is untenable

Regarding artworks structurally as complex systems clarifies why purely quantitative and supposedly objective measures of aesthetic value are unlikely to succeed, at least for the time being. Since the properties of the system are the result of the mutual interaction of its components, a complex system cannot be analysed by focusing on isolated observables, or even on some of the causal relationships already known to exist between them. Furthermore, the isolated "behaviour" of a system's element might not even reflect back on the general ensemble. Complex systems call for a somewhat "ecological thinking" (Taleb 2012) since even the slightest change or disturbance can potentially alter the equilibrium of the entire ensemble. That is why, as Volkenstein suggested, complex systems are (necessarily) integral.

Like complexity, specified observables are always relative to the level of analysis employed. Being the source of information about the system, observables are *chosen* based on the outlook, presumptions, theoretical framework, goals and desired granularity of the observer. Selecting a given observable implies making an ontological commitment — i.e. accepting its existence — which in turn is supported by a more extensive network of beliefs, knowledge, practices, intentions, and instruments (technologies) mediating the experience of the observer. This is why the same system may be analysed and described through different approaches that may or may not share the same observables or even the same definition of a particular observable — and for that matter, of the system as a whole. Hence, observables are not universally "objective", some of them may be subjective or at least fare more dependent on the theoretical approach than the observer would like to admit. Such is the case with the notions of complexity and "order" used by Birkhoff and information aesthetics.

Order is a relational as well as a multifactorial phenomenon; it does not exist in isolation nor is it a universal value. Patterns, however, are far more common and easier to formalise. As noted earlier, information aesthetics sees art as something that creates order or "negative entropy" and sees entropy, and randomness as equivalent to disorder. Since owing to the Second Law, entropy always increases in every system, according to the previous interpretation the world is moving towards a state of chaos, uncertainty, and disorder. Along with pessimistic and subjective, this interpretation is misleading. A more useful way to interpret entropy is simply as the tendency of systems to assume their most probable configuration or path (Ben-Naim 2007), whether that corresponds to "disorder" is a qualitative but not quantitative judgement. This also elucidates why maximum randomness involves maximum informativeness: the absence of a clear-cut pattern allows many other patterns to emerge; for more information to be chosen. This probabilistic interpretation also shows why art is not antithetical to entropy. Just as life could not exist without motion (Volkenstein [1986] 2009, 169) — without the transference of energy, chemicals, etc. — patterns cannot exist without chaos and randomness. Entropy and "negative entropy" are opposite but complementary processes.

Aesthetic objects are never engaged *in vacuo*; they are, to put it in Volkenstein's terms, always judged against a more or less apt "thesaurus". Art is the product of a sociocultural "judgement" (Nake 2012a, 74), artworks have no magical intrinsic qualities, they are objects that display and convey an intentional pattern, information. Genres, styles, movements, formal qualities, they are all social constructs. Art is *relational*, it arises from the interaction between the object-pattern, and the audience, and the context. The value of an artwork depends as much on the way it is *in-formed* by its creator as on the way it is interpreted and judged by the audience. Without risking exaggeration, this relational process involves myriad variables, from perceived technical prowess of the artist to the viewer's knowledge and mental state.

It follows that an accurate measure of aesthetic value should not only account for all the structural elements present in any given artwork and their mutual interactions, but also for every possible context and thesaurus involved in its interpretation. Doing so, of course, presumes that somebody has found a way to break down an artwork into minimal objective units and also figured out the rules governing how they are structured and interpreted. Given the intricacy of both tasks, it is safe to say that attempting to objectively quantify every single one of these variables remains an unfeasible task.

6.9 Conclusions

Volkenstein, like Birkhoff, saw order and complexity as oppositional terms but drew a diametrically distinct interpretation out of their relationship. For Birkhoff, orderliness meant intelligibility, which translated into a better grasp of the intrinsic aesthetic structure and value of the artwork. Complexity obscured order, diminishing clarity. As previously noted, Volkenstein understood complexity as a matter of *encoding.* Though it is possible to manipulate and even duplicate certain kinds of artworks, as Volkenstein ([1986] 2009, 183) argues, it is impossible to devise a minimal program for *Anna Karenina* without affecting its integrity. Admittedly, it is possible to write a program capable of generating exemplars of a given artistic class, say, "adolescent poetry" but, however entertaining, this is not the type of artistic value Volkenstein had in mind, no matter how complex it might be.

Complexity is a matter of structure while irreplaceability, seen in terms of informational value, has to do with *added functionality* (Volkenstein [1986] 2009, 184). Under Volkenstein's framework, it is the fact that we learn and do something else — that we create new information — with whatever we grasp from an artwork that genuinely determines its artistic value. It is not orderliness and recognised formal patterns that are aesthetically pleasing, but unexpected knowledge.

Volkenstein describes artworks structurally as complex integral informational systems, but functionally as *programs* which, upon being read trigger the generation of information that was not previously in them. This simple metaphor allows us to imagine our relationship with art in a more contemporary manner. We may describe the artwork as a "bootstrap loader" that launches our "thesaurus", thereby allowing us to generate ideas and connections that we could not have conceived otherwise. We may also think of an artwork not as a pre-compiled program, but more like a complex "script" that may be run through a myriad interpreters and produce an equally different number of outputs. These could include value judgements ranging from the total lack of interest to considering the artwork a true masterpiece. Nonetheless, like all metaphors, this one has limits too. Unlike computers, our interpreting abilities are not limited to performing numerical calculations and remembering their results; we humans establish complex semantic associations without even trying. As interpreters, we "choose" which information present in the artwork we pay attention to and which we ignore. Our interpretations are shaped by our mental and emotional states, by our intellectual and personal backgrounds, and by the very historical and cultural circumstances surrounding our engagement with objects in the world.

Regarding its impact on aesthetic practices — and far from constraining and flattening expressions — the computer opens an entirely new domain of aesthetic possibilities for practitioners thanks to its unprecedented simulation capabilities.

By altering our epistemological boundaries (whether by turning the notion of "medium" into a mere operational category or by encouraging transdisciplinary approaches) computational technology has forever changed the way we structure knowledge. Computers are radically transforming not only how we regard certain phenomena within a demarcated scientific field, or how we communicate and entertain ourselves and represent the world; they are changing our view on physical reality *itself*. They are transforming how we understand perception and experience, two fundamental aspects of all human activities, in particular for aesthetic creation. Of all the ways computers are changing art and media, the most radical are not necessarily those associated with practical matters, but those resting at an intellectual level.

Conclusions

As stated in the general Introduction, the main goal of this dissertation was to further art scholarship's understanding of computer-generated aesthetic artefacts via a scientifically-informed conceptual analysis of the tool used to generate them, i.e., computers. Throughout the previous chapters (and specifically in Chapter 4), I have shown that at the most elemental level, computers are the ultimate modelling machines. That is to say, tools that enable humans to design, visualise, manipulate and gather *information*, and, thereby, objectify entities and interact with environments that are no longer constrained by the Newtonian characterisation of reality. Following this preliminary result, I have shown computer-generated aesthetic artefacts can be described first and foremost as *simulations*: as ("real" or imagined) dynamic, persistent, technically mediated renderings of source systems at different levels of abstraction. And, furthermore, I have shown these artefacts can hence be described (and analysed) as *complex informational systems*; as patterns, "programs" or interfaces which, upon being interpreted by a receptive audience, not only convey but generate new factual information.

A second (subsidiary) objective of this dissertation was to illuminate what is it that distinguishes computer-generated aesthetic artefacts from their "traditional" (i.e. analogue) counterparts. In the last few decades, this has been a major topic of discussion for aesthetic practices, particularly for media theorists, and cultural critics, who tend to assume this difference is *ontological* and therefore, an intrinsic quality of the objects. However, in this dissertation (specifically in Chapter 6) I have shown that being analogue or digital is not necessarily a feature of objects themselves *but of the level of abstraction from which we approach them*. This implies that the same object can be studied either as a digital or analogue system. Furthermore, I have also shown that regardless of whether a computer generated them, no artefact can ever be experienced as a discrete (digital) construct, but *always* as an analogue manifestation. The reason being that ontologically speaking, numbers are abstractions, and even if we could experience the source code responsible for generating a given computational artefact in real-time, it would not only be meaningless but also already an analogue rendering of machine code. At this fundamental level of zeroes and ones, code can only be "read" by machines. That is the reason Nake (as also discussed in Chapter 6) speaks of computer art as having both a digital "subface" and an analogue "surface".

The third (and also subsidiary) problem tackled by this dissertation was to further our understanding of how current technological developments are affecting our notions of art and aesthetic practices. While there is not a straightforward answer to this question, in this dissertation I have shown that computational technology is enabling new forms of *tinkering*, that is, of unsystematic, creative, and experimental work in virtually all areas of human activity, including, of course, aesthetic practices.

As the first truly universal, or rather, multistable tools, computers can be employed in a seemingly endless arrange of ways. They have opened new avenues for making and experiencing audiovisual content, they have given rise to entire new expressive fields, such as data visualisation, video games, and other immersive environments such as AR and VR. Contrary to what some theorists claim, computers have not subsumed art to a reductive technoscientific logic, but instead created new opportunities for hybridisation, divergence, and for understanding and using artistic materials, methods, processes, and discourses. With the help of ICTs, an emerging maker or "nerd" culture is blurring the lines between craft, art, science and engineering; wreaking havoc amongst traditional disciplinary divisions and making hitherto neatly divided epistemic parcels seem anachronistic. In many ways this is not new; as was stressed throughout Chapters 1 and 2, artists have always been quick to adopt technological innovations, while theorists and scholars attempting to explain the implications of those changes have generally tended to lag behind.

To put it simply, this is a promissory age for artists and engineers, because computers offer artists and generally anyone (with economic capacity) unprecedented creative possibilities, but it is a rather challenging context for those seeking to understand and keep track of these changes. But more important is the fact that by enabling us to construct and interact with virtual environments, to model and objectify different possible worlds, to construct permanently extendable objects, computers have deeply transformed how we conceive our world and everything within. Static knowledge is being replaced by distributed, dynamic information clusters guided by a "permanent beta" logic of design and engineering. Computers, and ICTs in general, are thus changing the foundations of our epistemic edifice, expanding its boundaries and reshuffling its internal divisions; in other words, they are profoundly transforming how we structure and categorise knowledge, and what we mean by knowledge itself.

The information revolution is forcing art scholars and educators to engage knowledge and practices which were traditionally regarded as alien to the humanities. The old disciplinary line separating "hard sciences" and engineering from the liberal arts is giving way to new forms of transdisciplinary practices and research wherein deep understanding of ICTs is a crucial skill. Art scholarship is thus confronted with the need to reevaluate its attitude and views towards technology in general; to call into question the assumptions that it inherited from certain strains of critical theory and early media theory.

It is precisely to contribute to such effort that in this dissertation I have provided a comprehensive account of the most current philosophical views on technology and science, and also balanced and yet rigorous definitions of terms that are usually taken for granted by media theory. This striving for conceptual rigour is much needed to provide valuable insights into the current state of our technologically-driven cultures. In my opinion, it is still absent in many contemporary discussions, wherein discardable neologisms, passing out as useful concepts, abound and confuse. Enlisting the help of conceptual analysis was the most effective way I could find to overcome this problem.

A necessary step for rethinking art scholarship's attitude and views on ICTs involves recognising that technology, in general, is an intrinsic feature of being human. Following the insights of postphenomenology, in Chapters 2 and 3 I have shown technological systems cannot be analysed independently from the human contexts and practices in which they are embedded, for it is only there that they have meaning and purpose. It follows that the reverse is also true: human practices and circumstances — including those pertaining to art — cannot be properly analysed without taking into account the technological systems supporting them. Two consequences follow from these arguments: (a) that we cannot continue to see technology as a monolithic phenomenon, but as a complex network of systems, and (b) that technologies are not necessarily antithetical to human nature, nor can they evolve independently from human cultural processes. To continue treating technology as something imposed over human life — and hence as something that we can move away from — is not only reminiscent of a naïve romanticism, but also the mark of a skewed conception of what humans are in the twenty-first century.

A more complex but equally necessary challenge art scholars need to overcome involves technical knowledge and skills. As more artists turn programming and hardware tinkering into their medium, more difficult becomes appreciating their work without at least a basic procedural or computational literacy. While it may be argued that many artistic objects do not require the audience to know how exactly they were constructed, most contemporary artistic explorations involving ICTs use the very possibilities and constraints afforded by computation as their aesthetic pretext. In this dissertation, I have sought to offer a robust account of concepts that are crucial for understanding contemporary technological developments and yet are rarely discussed in depth. These include system, complexity, simulation, model, and — most important — information.

The method of LoAs, the philosophical approach employed in this dissertation is, to my knowledge, never been applied in the analysis of aesthetic practices. Admittedly, the main reason behind this omission this is the relatively recent origins of this method, but also the tendency of art scholars to rely on media-theoretic, hermeneutical or semiotic approaches. Given its origins in computer science — but also its portability, scalability, and interoperability, the method of LoAs is a rather powerful tool to analyse computer-generated artefacts. Due to its flexibility, it can be used alongside other methods, such as the ones previously mentioned.

While traditional accounts of aesthetic objects focus on developing single interpretations, the method of LoAs assumes from the outset that systems under observation can *always* be analysed from multiple (even contradictory) points of view. In this dissertation, I have shown that as a tool, computational technology can (and always should) be observed from multiple angles. While the underlying principles and operations are always the same, the specific ways in which computers are used varies greatly depending on the social and operational context in which they are embedded. Even within aesthetic practices, the range of usages is considerably diverse as was discussed in Chapter 1. Notwithstanding potential exceptions, designers, photographers, or musicians, generally tend to employ computers as *users* of software, whereas certain artists might be more prone to use computers as developers and programmers do. While this distinction is admittedly simplistic and, perhaps a little misleading (strictly speaking, programmers are also users), it is still a useful separation given the difficulty of categorising every specific form of human–computer relation.

Regardless of the context of use, or rather because of it, computers, like any other technological system, cannot be explained in monolithic terms; each type of use involves idiosyncratic features that easily escape categorisation. And this is nowhere more true than in artistic environments. In fact, it was in the hands of people with an artistic sensibility that computers first began to transform into the ultimate *multistable* (and hence hardly categorisable) devices. As we saw in Chapter 5, two decades before transforming into universal media machines, computers had already become tools for art. And already then, some of the questions that are in vogue today concerning the way machines and AI, in particular, could supplant humans in multiple areas began to be raised not by tech moguls, but by artists.

The relation between humans and technologies will continue to evolve in unexpected ways, as they have done so since we first learned to craft our tools and systematise processes. Attempting to provide definitive answers to the question of how ICTs will transform aesthetic practices in the following years cannot be something more than an exercise in futurology. What I have tried to convey in this dissertation on this respect is that technologies, their history, functions, and implications need to become central problems for the humanities, and in particular, for aesthetic practices due to their close relationship. Art and technology are linked in more than an etymological sense. Art, irrespectively of how we define it, is and will always be an intrinsically *artificial*, and therefore technological enterprise. It is therefore unsustainable to continue insisting on the existence of a mythical tension between technological and artistic *poiesis*. Technologies are by no means neutral, but they are ultimately what we make of them. It is the responsibility of those with the power of intuition and imagination to craft new, more beneficial ways to relate to our tools. Learning their languages, operations, and histories are the first step towards creating meaningful ways to critique, understand, and re-design them and us along the way.

Many topics and discussions were left outside this dissertation. The ethical, political, and economic impact of ICTs are some of them. Such omission should not be understood as a deliberate attempt to negate the importance of keeping a critical stance towards certain technologies and the ways they are transforming our political and economic systems. What may be understood as a somewhat optimistic view on technology assumed by this dissertation is rather an attempt to provide readers with a balanced account of how technology can be understood from a philosophical standpoint. I believe that giving clear concepts — rather than seductive but ultimately hollow neologisms — goes a long way towards enabling fruitful discussions about phenomena. More so when these phenomena are both rapidly changing and have such a broad impact on human life.

There is still much work to do and much to be said about art, technology, and how ICTs are changing human life. In bringing together so many (apparently) disparate issues this dissertation hopes to awaken the curiosity of readers and invite them to pick any of the many threads of discussion that remain open in the previous chapters. There, they should find matters to be contested, arguments to be challenged, ideas to be furthered, links to be made, and — to paraphrase biologist Stuart Firestein (2012) — more high-quality ignorance to be made.

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