6

The Self-Organisation of the Cybernetic Mind

It has been rightly urged that a history of brain models is really a history of the literary and material technologies which are familiar to, and then used as metaphors by, brain scientists. Their metaphorical menagerie exhibits mental clocks, logical pianos, barrel organisms, neural telegraphs and cerebral computer nets. How do specific technologies get into this zoo? Claims that certain systems can mimic, or even exhibit, intelligence are sustained by social hierarchies of head and hand. Minds are known because these social conventions are known.

Simon Schaffer, 'OK Computer', 2001[1]

[The] wonder of our time, electrical telegraphy, was long ago modeled in the animal machine. But the similarity between the two apparatus, the nervous system and the electric telegraph, has a much deeper foundation. It is more than similarity; it is a kinship between the two, an agreement not merely of the effects, but also perhaps of the causes.

Emil Du Bois-Reymond, *On Animal Motion*, 1851[2]

1 Simon Schaffer, 'OK Computer', in *Ansichten der Wissenschaftsgeschichte*, ed. Michael Hagner, Frankfurt: Fischer, 2001, 393–429.

2 Emil Du Bois-Reymond, 'Über thierische Bewegung' (1887), 2 vols., translated by Laura Otis in 'The Metaphoric Circuit: Organic and Technological Communication in the Nineteenth Century', *Journal of the History of Ideas* 63, no. 1 (2002): 105.

> *The nervous systems . . . have been externalized, as part of the reversal of the interior and exterior worlds. Highways, office blocks, faces and street signs are perceived as if they were elements in a malfunctioning central nervous system.*
>
> J. G. Ballard, *The Atrocity Exhibition*, 1990[3]

A social history of the nervous system

In 2012, the AlexNet algorithm – a large artificial neural network – won the ImageNet competition, which is the international benchmark for image recognition software. Since then, 'deep' artificial neural networks, also known as 'deep learning', have led the machine learning revolution and have been regarded as the most effective technique of AI. Their success revived also expectations that the 'solution' to AI may be found in the secret logic of the brain's structures – an idea that dates back to the early days of digital computers. Neurophysiologist Warren McCulloch and mathematician Walter Pitts were the first to propose imitating biological neurons in a device.[4] In their 1943 paper 'A Logical Calculus of the Ideas Immanent in Nervous Activity', they presented artificial neural networks as an imitation of the brain's physiology, but their idea concealed also an external 'social' genealogy that this chapter intends to rediscover and excavate.[5] Rather than as a biomorphic artefact (i.e., an artefact imitating life forms), this chapter proposes to illuminate artificial neural networks from a different and unusual perspective – that is, as a technique for the *self-organisation of*

3 J. G. Ballard, *The Atrocity Exhibition*, annotated ed., San Francisco: Re:Search, 1990, 44n.

4 Warren McCulloch and Walter Pitts, 'A Logical Calculus of the Ideas Immanent in Nervous Activity', *Bulletin of Mathematical Biophysics* 5 (1943): 115–33. Artificial neural networks were discussed as an architecture of computation well before the term 'artificial intelligence' was introduced. Turing began to speculate about intelligent machinery in 1947, while McCarthy coined the term 'artificial intelligence' in 1955 (see the introduction of this book). Alan Turing, 'Lecture to the London Mathematical Society', 20 February 1947, in *Collected Works*, vol. 1, North-Holland Publishing Company, 1985; Christof Teuscher, *Turing's Connectionism: An Investigation of Neural Network Architectures*, Berlin: Springer, 2012, viii.

5 Margaret Boden regards McCulloch and Pitts's paper as an 'abstract manifesto for computational psychology', a founding text for the both the lineages of connectionist and symbolic AI. Margaret Boden, *Mind as Machine: A History of Cognitive Science*, Oxford: Oxford University Press, 2006, 190.

information. This hypothesis aligns their invention with the labour theory of automation which was expounded in the first part of this book. As much as the design of industrial machines emerged from the imitation of the organisation of labour, similarly, artificial neural networks (and machine learning algorithms in general) can be considered as machines that self-organise their parameters – their internal design – imitating the organisation of the external world. Rather than an 'ontological theatre' of the living, as historian of science Andrew Pickering has defined them, cybernetic experiments of self-organisation were essentially a laboratory of the social.[6]

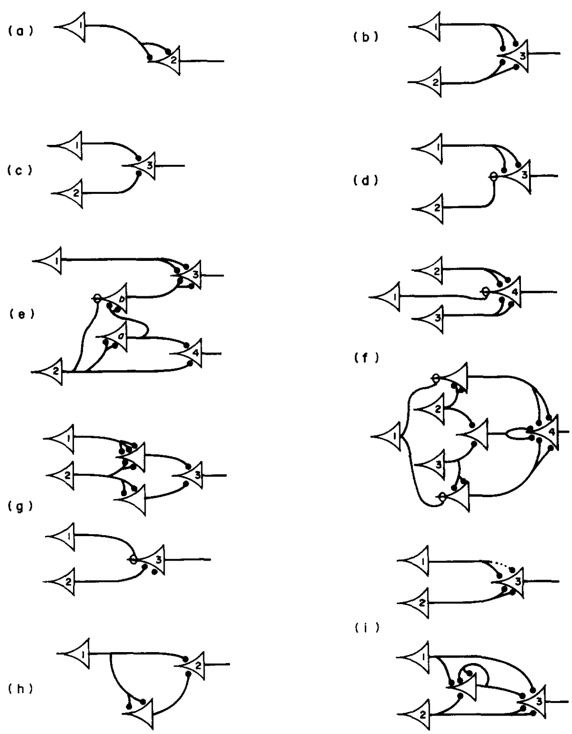

Figure 6.1. Sketch of artificial neurons. Warren McCulloch and Walter Pitts, 'A Logical Calculus of the Ideas Immanent in Nervous Activity', *Bulletin of Mathematical Biophysics* 5, no. 4 (1943): 105.

6 Andrew Pickering, *The Cybernetic Brain: Sketches of Another Future*, Chicago: University of Chicago Press, 2010; Andrew Pickering, 'A Gallery of Monsters: Cybernetics and Self-Organization, 1940–1970', in *Mechanical Bodies, Computational Minds*, ed. Stefano Franchi and Güven Güzeldere, Cambridge, MA: MIT Press, 2005, 229–45.

In 1943, interpreting laboratory findings in their own way, McCulloch and Pitts proposed to formalise the human brain as a 'nervous net' that performs logical operations (see fig. 6.1). They envisioned a network of computing nodes that could imitate human reasoning by reducing human logic to Boolean logic and its AND, OR, and NOT operators. The analogy between brain anatomy, logical inference, and computing devices was based on the observation that biological neurons display an 'all or none', or binary, behaviour. If the sum of the impulses which a neuron receives from its excitatory and inhibitory synapses exceeds a given limit, the neuron fires a signal to the synapsis of the following neuron; otherwise, it remains quiescent.[7] The novelty of the idea was not the *network form* per se but rather the *threshold logic* that, in such structure, impersonates the Boolean operators and the progressive steps of inferential reasoning. By adjusting the behaviour of their nodes, these machines were said to be 'learning' like brains – that is, to be recording complex information through their self-organisation.

A few years prior, in 1938, the US mathematician and cryptographer Claude Shannon had demonstrated that electric switching circuits could execute the Boolean logic operations. He designed the AND, OR, and NOT logic gates, which soon became incorporated in all transistors and microchips, thus laying the foundation of the computer age.[8] The emergence of neural networks as a key idea for AI is best understood by examining Shannon's logic gates rather than brain physiology. Essentially, McCulloch and Pitts argued that the brain's neural circuits perform the same operations as Shannon's electrical circuits. While machine learning textbooks reiterate that McCulloch and Pitts's idea of artificial neurons was inspired by the structures and behaviour of neurons in the brain, in fact the opposite is true: they saw, in the first instance, biological neurons as technological artefacts. McCulloch and Pitts implicitly envisioned brain physiology as homologous with the communication technology of the age, comprised of electromechanical relays, feedback

7 'To see how neurons might represent logical assertions, consider two examples. Suppose that both A and B are excitatory fibres, and that a pulse travelling along either suffices to cross the synaptic gap. This physical situation corresponds to the formal statement, "If either A or B is true, then C is true." ' Steve Heims, *The Cybernetics Group*, Cambridge, MA: MIT Press, 1991, 42.

8 Claude Shannon, 'A Symbolic Analysis of Relay and Switching Circuits', *Transactions of the American Institute of Electrical Engineers* 57, no. 12 (1938): 713–23.

mechanisms, television scanners, and, notably, telegraph networks. At the 1948 Hixon symposium on cerebral mechanisms, discussed in more detail in the next chapter, McCulloch urged his colleagues to 'conceive neurons as telegraphic relays'.[9]

To a historian of science and technology, McCulloch and Pitts's artificial neural networks appear not as a completely original idea but as an elaboration upon an old one. Laura Otis, for one, has shown that the analogy between the nervous system and electric networks was already established in the nineteenth century and drawn upon by, among others, the telegraph inventor Samuel Morse and physicist Hermann von Helmholtz.[10] As evidence of this intellectual climate, in an 1851 lecture on the subject of animal motion cited at the beginning of this chapter, the Berlin physiologist Emil Du Bois-Reymond expounded on the similarity between the nervous system and electric telegraph networks with a visionary fervour closer to science fiction than science.

The imprint of the infrastructures of communication extended beyond the 'neural telegraph' analogy of the nineteenth century: it can be found also in the twentieth century's cybernetic projects of self-organisation that remained crucial in the evolution of artificial neural networks. Indeed, the idea of self-organising computation capable of adapting to the environment and 'learning' in enduring fashion is a key part of the 'epistemic ensemble' of cybernetics that paved the way to machine learning.[11] Owing to the academic hegemony of symbolic AI and the widespread anthropomorphisation of technology, it is hard to imagine contemporary AI as a technique of self-organising information or 'spontaneous order' emerging out of data. And yet, this is a realistic description of what machine learning actually does. The link between the self-organising computation of twentieth-century and twenty-first-century AI has been concealed by a complex stratum of technological advancements, in which we lost sight of its origin and development. This chapter undertakes a 'dig' into this

9 Lloyd A. Jeffress (ed.), *Cerebral Mechanisms in Behavior: The Hixon Symposium*, New York: Wiley, 1951, 45.

10 See Laura Otis, 'The Metaphoric Circuit: Organic and Technological Communication in the Nineteenth Century', *Journal of the History of Ideas* 63, no. 1 (2002): 105–28. See also Laura Otis, *Networking: Communicating with Bodies and Machines in the Nineteenth Century*, Ann Arbor: University of Michigan Press, 2001; and Christoph Hoffmann, 'Helmholtz' Apparatuses: Telegraphy as Working Model of Nerve Physiology', *Philosophia Scientiae* 7, no. 1 (2003): 129–49.

11 See also Michael Castelle, 'Deep Learning as an Epistemic Ensemble', 2018, castelle.org.

stratum – into a prehistory of machine learning in which social, communication, and computational networks were all part of continuous (and contiguous) movements of self-organisation.

Mechanising self-organisation

In the second half of the twentieth century, self-organisation rose as a popular topic across a wide range of disciplines, including biology, chaos theory, neuroscience, thermodynamics, and even neoliberal economics (if one considers the peculiar interest in the 'spontaneous order' of markets). How should we interpret such a widespread quest for the principles of self-organisation? The first impression is of a diverse movement searching for an ontological principle of life; however, such a quest for 'life' principles appears to mirror the 'principles of self-organisation' that could be detected also in the societal changes of the post-war period.

Originally, it was modern political philosophy (with Spinoza and Kant) which conceived of self-organisation and autonomy as key notions for theorising the social contract and individual freedom. But, for some reason, in the mid-twentieth century, the principle of self-organisation migrated from the social ontology and was transformed into an extra-social ideal for vitalist philosophies (with its highest manifestation in James Lovelock's Gaia hypothesis, which deems planet Earth a super-organism).[12] In 1977, Ilya Prigogine was awarded the Nobel Prize for his studies on self-organising structures in thermodynamic systems far from equilibrium.[13] In the same year, Langdon Winner's book *Autonomous Technology* signalled a further mutation in the discourse of self-organisation, whereby technology rather than nature was newly perceived to be 'autonomous' from the human and dangerously out of control, thus reviving certain Frankensteinian narratives of the industrial age.[14] As these examples show, the concept of self-organisation has accrued, across different centuries and disciplines, a thick ideological

12 J. E. Lovelock, 'Gaia as Seen through the Atmosphere', *Atmospheric Environment* 6, no. 8 (1972): 579–80.

13 Gregoire Nicolis and Ilya Prigogine, *Self-Organization in Non-Equilibrium Systems*, New York: Wiley, 1977.

14 Langdon Winner, *Autonomous Technology: Technics-Out-of-Control as a Theme in Political Thought*, Cambridge, MA: MIT Press, 1978.

patina. When and how exactly did the contemporary idea of self-organisation consolidate?

Curiously, as philosopher of biology Evelyn Fox Keller has noted, it took cybernetics, which is a branch of electromechanical engineering and not a natural science, to reboot the scientific debate on self-organisation in the twentieth century.[15] In the 1940s, cybernetics took over the modern dream of building 'thinking machines', albeit by adopting a different technique from the previous century. In the industrial era, Babbage had envisioned the automation of mental labour through an 'engine' that implemented hand calculation. Human reasoning was then encoded as a logical procedure, as a linear sequence of step-by-step operations (which Alan Turing would associate later with the telegraph tape to envision his eponymous machine). Cyberneticians explored other ways of building 'intelligent automata'. Rather than imitating the rules of human reasoning, they aimed at imitating the rules by which organisms organise themselves and adapt to the environment. Self-organisation was understood, importantly, also as self-reproduction and self-repair. This was a key aspect that Kant stressed in his definition of 'organic beings', which remained a guiding principle for the cyberneticians.[16]

Cybernetics claimed to have found in all organisms a basic 'mechanism' of behaviour – that is, information as a medium of feedback with the environment and internal self-regulation. In one of its founding texts, Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow claimed that 'the broad classes of behaviour are the same in machines and in living organisms'.[17] Although different in narrow classes (organisms, obviously, do not have wheels, etc.), the article posited that both machines and organisms operate thanks to information feedback that shapes their purpose and teleology. This principle of cybernetics had, in fact, been anticipated in early-century biology by Jakob von Uexküll, who viewed

15 Evelyn Fox Keller, 'Organisms, Machines, and Thunderstorms: A History of Self-Organization', part 1, *Historical Studies in the Natural Sciences* 38, no. 1 (2008): 45–75.

16 'In such a natural product as this every part is thought as *owing* its presence to the agency of all the remaining parts, and also as existing *for the sake of the others* and of the whole, that is as an instrument, or organ . . . The part must be an organ *producing* the other parts – each, consequently, reciprocally producing the others . . . Only under these conditions and upon these terms can such a product be an *organized* and *self-organized being*, and, as such, be called a *physical end*.' Immanuel Kant, *Critique of Judgement*, 1790, quoted in Keller, 'Organisms, Machines, and Thunderstorms', part 1, 49.

17 Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow, 'Behaviour, Purpose and Teleology', *Philosophy of Science* 10, no. 1 (1943): 18–24.

the organism as an information processing system struggling to adapt to its environment. Uexküll defined the exchange between an animal's nervous system (*Innenwelt*) and the outside world (*Außenwelt*, or *Umwelt*) as a 'function circle' (*Funktionskreis*). In Wiener's coinage, it should be remembered, the term 'cybernetics' (from the Greek *kybernetes*, or 'steersman') referred to the capacity of a technical, social, and living system to control itself via an exchange of information with the environment. It is quite evident that both Uexküll and cyberneticians derived from the communication systems of their age – the telegraph, telephone, and radio networks – an analogy for the interaction of living beings with their environment.

Although cyberneticians initially considered information under the form of analogue electromagnetic signals, they gradually shifted towards digital, discrete, and computational 'bits'.[18] For cybernetics, it was not simply machines in general but also digital computers (i.e., finite state automata) that could imitate the living being's principles of self-organisation.[19] The British psychiatrist Ross Ashby was the main theorist of self-organisation in cybernetics. His 1947 paper, 'Principles of the Self-Organising Dynamic System', was committed to demonstrating that self-organisation was not only a feature of the living but could be also of 'strictly determinate' machines, that is, computers:[20]

> It has been widely denied that a machine can be 'self-organizing', i.e., that it can be determinate and yet able to undergo spontaneous changes of internal organisation. The question of whether such can occur is not of purely philosophic interest for it is a fundamental problem in the theory of the nervous system. There is much evidence that this system is both (a) a strictly determinate physico-chemical system, and (b) that it can undergo 'self-induced' internal reorganisations resulting in changes of behaviour. It has sometimes been held that these two requirements are mutually exclusive. The purpose of this paper is to show that a machine

18 This is the subtle difference between the two information theories by Weiner and Shannon (analogue and digital, respectively). See Ronald Kline, *The Cybernetics Moment: Or Why We Call Our Age the Information Age,* Baltimore: Johns Hopkins University Press, 2015.

19 As Turing defined them, 'discrete state machines . . . are the machines which move by sudden jumps or clicks from one quite definite state to another'. Alan Turing, 'Computing Machinery and Intelligence', *Mind* 59, no. 236 (October 1950), in *Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life*, ed. B. Jack Copeland, Oxford: Oxford University Press, 446.

20 For a portrait of Ashby and his homeostat see Pickering, 'A Gallery of Monsters'.

can be at the same time (a) strictly determinate in its actions, and (b) yet demonstrate a self-induced change of organisation.[21]

Ashby put his theory into practice by inventing the 'homeostat' (whose name is a tribute to the homeostasis of living systems, as defined by Walter Bradford Cannon in 1926). Built from four bulky electromechanical units, however, its capacity of 'self-organisation' was rather the opposite of wilful adaptation to external stimuli. Grey Walter sarcastically called it *machina sopora* ('sleeping machine' in Latin), since 'its goal was to become quiescent; it changed state only when disturbed from outside.'[22] In a later article from 1960, 'Principles of the Self-Organizing System', Ashby fully ruled self-organisation under a mechanistic paradigm in a way to get rid of the metaphysics about life emergence: 'While, in the past, biologists have tended to think of organisation as something extra, something *added* to the elementary variables, the modern theory, based on the logic of communication, regards organisation as a restriction or constraint.' He concluded, however, in a way that is an illuminating example of the typical desire of automation to replace humanity and achieve invisibility: 'I think that in the future we shall hear the *word* ['organisation'] less frequently, though the *operations* to which it corresponds, in the world of computers and brain-like mechanisms, will become of increasingly daily importance.'[23]

Cyberneticians like Ashby did not pursue self-organisation simply as a key to the imitation of living structures but specifically of brain structures. Consequently, they studied the self-organisation of neural networks as the key to intelligent behaviour. A turning point in this debate came in 1949, when neuropsychologist Donald Hebb published a crucial book, *The Organisation of Behavior*, in which he claimed to have identified a basic rule of self-organisation in neural networks.[24]

21 Ross Ashby, 'Principles of the Self-organizing Dynamic System', *Journal of General Psychology* 37 (1947): 125–8.

22 Grey Walter, *The Living Brain*, London: Duckworth, 1953, 123; Pickering, *The Cybernetic Brain*, 164.

23 Ross Ashby, 'Principles of the Self-Organizing System', in *Principles of Self-Organization*, ed. Heinz von Foerster and George Zopf, New York: Pergamon Press, 1962, 255, 257.

24 Donald Hebb, *The Organisation of Behavior*, New York: Wiley & Sons, 1949. In this book Hebb defined his theory of neuroplasticity as 'connectionist' – a term later repurposed by Frank Rosenblatt to define 'connectionism' as the paradigm of artificial neural networks; see chapter 9.

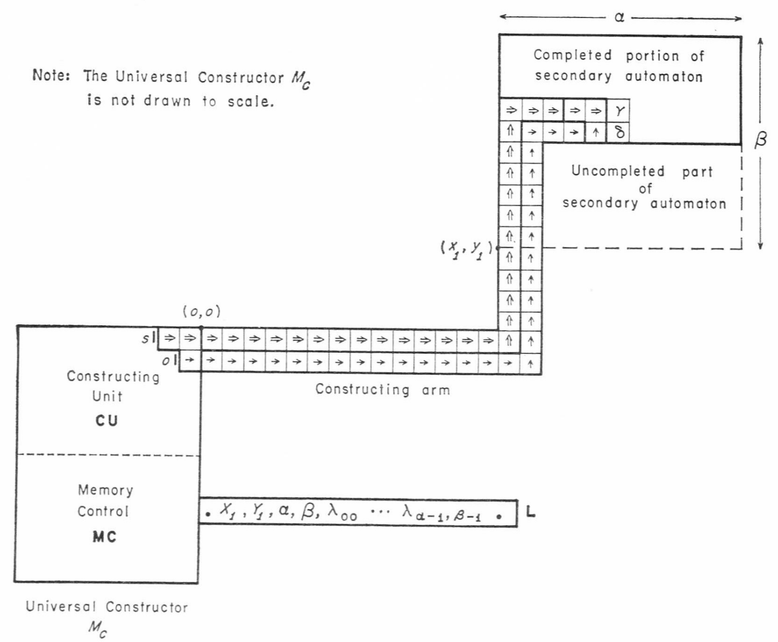

Figure 6.2. Operating arm of the universal constructor. John von Neumann, *Theory of Self-Reproducing Automata* (edited by Arthur Burks), Urbana, Il: University of Illinois Press, 1966, 371.

Hebb recorded a peculiar phenomenon whereby neurons that were simultaneously stimulated also strengthened their connection:

> When one cell repeatedly assists in firing another, the axon of the first cell develops synaptic knobs (or enlarges them if they already exist) in contact with the soma of the second cell . . . The general idea is an old one, that any two cells or systems of cells that are repeatedly active at the same time will tend to become 'associated' so that activity in one facilitates activity in the other.[25]

Since then, this brain behaviour has been known as the Hebbian theory of 'cell assemblies' and has been conveyed in the famous dictum 'Neurons that fire together, wire together.' Hebb's can be considered as both the first codified rule of neuroplasticity and the first rule of self-organisation for

25 Hebb, *Organisation of Behavior*, 63–70.

machine learning algorithms. Cognitive scientist Frank Rosenblatt accordingly conceived the first operative artificial neural network – the perceptron – as a self-organising machine and attempted to implement the Hebbian rule in its functioning (see below and chapter 9).

Theories of self-organisation and the early digital computer

The research field about self-organisation was at the time larger than it is perceived today: it would suffice to remember that sooner or later, all the key pioneers of the digital computer, such as John von Neumann, Konrad Zuse, and Alan Turing, explored self-organisation as a technique of computation. Von Neumann (the designer of the main architecture of digital computers that still to this day bears his name) was investigating radical forms of automation while working for the US military, speculating about a machine – the Universal Constructor – that could reproduce and repair itself (the army was of course interested in applying this idea to self-reproducing and self-repairing vehicles and pieces of artillery). The observation of processes of reproduction in 'living organisms' inspired their simulation in 'computing machines' and established the questionable analogy between organic cells and computational units.[26] The Universal Constructor was one implementation of the general theory of cellular automata – that is, a configuration of computational units that change and evolve like organic cells in a two-dimensional space (see fig. 6.2). In this space, basically, cellular automata are clusters of elements that change configuration and move according to the neighbouring 'cells', composing geometric figures that evolve, claiming to mimic, in this way, life forms in the natural environment. At the Hixon symposium in 1948, Neumann urged the other delegates to understand computation (including Turing machines and artificial neural networks) as a form of self-organisation, arguing that self-reproducing units could perform all standard operations of

26 It was Erwin Schrödinger's 1943 lecture 'What Is Life?', in particular, that inspired a link between the negative entropy of photosynthesis and the self-reproduction of life through a code (DNA had not yet been discovered). See also Peter Asaro, 'Heinz von Foerster and the Bio-Computing Movements of the 1960s', in *An Unfinished Revolution? Heinz von Foerster and the Biological Computer Laboratory 1958–1976*, ed. Albert Müller and Karl H. Müller, Vienna: Edition Echoraum, 2007.

computation just by replicating themselves like biological cells.[27] The idea of cellular automata would go on to register a lasting influence. Known for developing the first programmable electric computer in Berlin in 1938, Zuse proposed extending the logic of cellular automata to physics and the general laws of the universe. His 1967 book, *Rechnender Raum* (*Calculating Space*), considered the universe to be composed of discrete spatial units that self-organise as cellular automata – that is, according to the status and behaviour of neighbouring units.[28] According to Zuse, the energy interactions between atoms can be formalised as units of computation and, following this approach, one could rewrite the laws of physics – for instance gravitation – in a combinatorial fashion. In this sense, Zuse saw the theory of calculating space as a paradigm that would supersede quantum psychics in the way the latter had superseded classical physics.[29] From an epistemological point of view, we here encounter once again a mechanical paradigm that openly aspires to become a paradigm of nature, not of biological laws in this case but of physical ones. Precisely, a finite-state machine, such as the digital computer, is elevated to become the ontological model for the structure of the universe itself.

Turing's essay 'The Chemical Basis of Morphogenesis' (published in 1952, two years before his death) also belongs to the tradition of self-organising computation.[30] In this late paper, Turing envisioned the molecules of organisms as self-computing actors that, through their interaction, express complex autopoietic structures. He attempted, with this approach, to model tentacle patterns in hydra, whorl arrangements in plants, gastrulation in embryos, dappling in animal skin, and phyllotaxis in flowers as forms of self-organising computation. To generate such patterns (known since as 'Turing patterns'), he used one of the first mainframe computers of Manchester University, though he also performed a great number of calculations by hand (see fig. 6.3). Turing warned that

27 See also Alex Galloway, 'Creative Evolution: Nils Aall Barricelli's Mathematical Organisms', *Cabinet* 42 (Summer 2011).

28 Konrad Zuse, 'Rechnender Raum', in *Elektronische Datenverarbeitung* 8 (1967), translated as *Calculating Space*, Cambridge, MA: MIT Technical Translation, 1970.

29 Zuse, *Calculating Space*, 5.

30 Alan Turing, 'The Chemical Basis of Morphogenesis', *Philosophical Transactions of the Royal Society B.* 237, no. 641 (1952).

'this model will be a simplification and an idealization, and consequently a falsification', though he expressed, as any cybernetician would, the hope that 'the imaginary biological systems which have been treated, and the principles which have been discussed, should be of some help in interpreting real biological forms'.

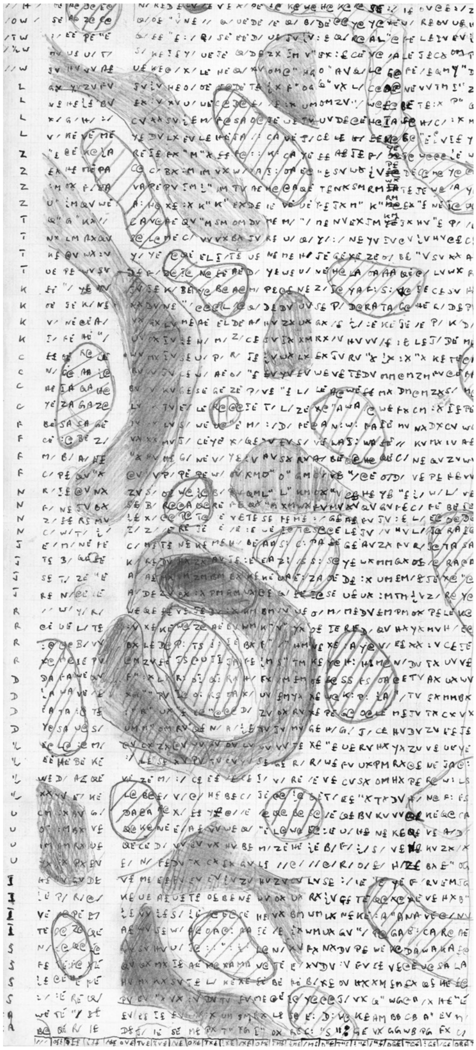

Figure 6.3. Diagram showing patterns of dappling and calculations. Alan Turing, ca. 1950. Sheet AMT/K3/8, Turing Archive, King's College Cambridge, particular.

Military concerns about self-organising networks

Self-organisation theories belonged not only to cybernetic dreams of living automata, but also to the armamentarium of Cold War rationality.[31] As often, the main sponsor of research in this field was the US military, which expressed interest in the logic of self-organisation as an alternative, more efficient, means of computation. At the end of the 1950s, the US Office of Naval Research (ONR) decided to sponsor a series of symposia on self-organisation that provide a historical documentation of the wide reception of artificial neural network research at the time. Strangely, even Margaret Boden's monumental history of AI failed to register the existence of these other symposia, with the result that historical importance is repeatedly granted only to the 1956 Dartmouth workshop on AI.

In May 1959, Marshall Yovits, head of the newly established Information System Branch at the ONR, chaired the conference on 'Self-Organising Systems' in collaboration with the Illinois Institute for Technology. Yovits invited cyberneticians from both the connectionist and symbolic AI camps.[32] Somehow anticipating the forthcoming confrontation of these two paradigms and the limits of the latter, he argued that

> certain types of problems, mostly those involving inherently non-numerical types of information, can be solved efficiently only with the use of machines exhibiting a high degree of learning or self-organizing capability. Examples of problems of this type include automatic print reading, speech recognition, pattern recognition, automatic language translation, information retrieval, and control of large and complex systems. Efficient solutions to problems of these types will probably require some combination of a fixed stored program computer and a self-organizing machine.

31 See Paul Erickson et al., *How Reason Almost Lost Its Mind: The Strange Career of Cold War Rationality*, Chicago: University of Chicago Press, 2013.

32 The conference was also attended by the representatives of symbolic AI – Allen Newell, Cliff Shaw, and Herbert Simon. See Stephanie Dick, 'Of Models and Machines: Implementing Bounded Rationality', *Isis* 106, no. 3 (2015): 623–34. See also Shunryu Garvey, 'The "General Problem Solver" Does Not Exist: Mortimer Taube and the Art of AI Criticism', *IEEE Annals of the History of Computing* (2021): 60–73.

The conference exemplified the interdisciplinary ambitions of cybernetics, with Yovits highlighting how researchers from the fields of life sciences such as psychologists, embryologists, and neurophysiologists were working together to comprehend the characteristics of self-organising biological systems, while on the other hand, 'mathematicians, engineers, and physical scientists were attempting to design artificial systems which could exhibit self-organizing properties'.[33]

The proceedings of the conference help cast a light on the debate on self-organisation beyond the canonical themes of cybernetics. Despite the variety of positions on display, the main focus of the conference throughout remained the self-organisation of computing networks. The electrical engineer Belmont Farley opened the conference with an overview of the main visual 'systems which automatically organize themselves to classify environmental inputs into recognizable percepts or patterns'. Farley's paper was the continuation of his studies carried out during World War II, when, during the bombing of London, he had been responsible for testing a new type of radar against the low-flying Luftwaffe, showing how the self-organisation of the visual field was clearly already a concern of military automation. Other contributors of the conference included zoologist Robert Auerbach, who attempted to describe 'the organisation and reorganisation of embryonic cells' in mathematical terms – specifically as a 'transfer of information (induction)' in living cells that were dubbed as 'growing automata'. In this extended research project to grasp the principle of self-organisation in nature, the British cybernetician Gordon Pask contributed the idea of initiating a 'natural history of networks' with the intention of proving a similarity of qualities between social and natural ones:

> [If] an observer wishes to use any self-organizing potentialities the network may have, then he must look at the network as though he were a natural historian . . . using the term 'network' in a general sense, to imply any set of interconnected and measurably active physical entities. Naturally occurring networks, of interest because they

33 Marshall Yovits and Scott Cameron (eds), *Self-Organizing Systems*, New York: Pergamon Press, 1960, v–vi.

> have a self-organizing character, are, for example, a marsh, a colony of micro-organisms, a research team, and a man.[34]

This 1959 symposium is important also to see, in perspective, McCulloch and Pitts's original idea of artificial neural networks, which were not just input–output black-boxed machines but systems seeking to imitate and embody neuroplasticity. A decade after his and Pitts's founding 1943 paper, McCulloch took part in the symposium to stress that self-organisation is key to neural networks and that the same principle should be used in the design of an 'infallible network of fallible neurons'. McCulloch's intuition (which is still today both the strength and the limit of machine learning) was that computation does not need to be accurate to be efficient but can instead be based 'on redundancy of calculation'. In the paradigm of artificial neural networks, 'information is brought to a lot of so-called neurons, and these crummy neurons, working in parallel computation, can come out with the right answer even though the component neurons are misbehaving'.[35]

A following event sponsored by the ONR was the 'Symposium on Principles of Self-Organization', convened by Heinz von Foerster in 1960 in collaboration with the Biological Computer Laboratory of the University of Illinois at Urbana-Champaign. The proceedings of this symposium also testify that McCulloch and Pitts's, as well as Rosenblatt's, artificial neural networks were part of a larger archipelago of similar research projects on self-organisation.[36] Most of the contributions were related to the fields of neural networks (also referred to as 'random networks') and covered issues such as learning techniques, error correction, inductive inference, distributed memory, pattern recognition, as well as prototypes of self-organising hardware units, or neuristors (what today would be called neuromorphic chips).

Among the participants should be noted the presence of the neoliberal economist Friedrich Hayek, who in 1952 authored an oft-overlooked

34 Gordon Pask, 'Natural History of Networks', in ibid., 232.

35 For McCulloch the brain had to be treated as an organisation of information abstracted from any energetic and material dimension: Warren McCulloch, 'The Reliability of Biological Systems', in Yovits and Cameron, *Self-Organizing Systems,* 265.

36 Heinz von Foerster and George Zopf (eds), *Principles of Self-Organization*, New York: Pergamon Press, 1962.

treatise on connectionism, *The Sensory Order* (see chapter 8). Hayek's presence signals the overlapping interests of the military, economists, cyberneticians, and industrialists regarding the subject of self-organisation. Cyberneticians, for their part, were eager to prove their theories for the benefit of the economy and industry. Not by chance was the symposium opened by Stafford Beer's 'electroencephalogram of one of Britain's largest steel mills', which considered the organisation of a factory as equivalent to a brain.[37] Beer had already proposed a 'sketch of a cybernetic factory' in his 1959 book *Cybernetics and Management*, which exemplified the political attitude of cybernetics to shape machines, organisms, and workers all in like manner. In spite of his later collaboration with the socialist government of Salvador Allende for the project Cybersyn in 1971, Beer maintained a managerial view of the economy. At this conference, his primary concern appears to be the self-organisation of industrial management – the eye of the master – rather than any other aspect of society.

The end of the Cybersyn project is exemplary of the twisted fate of the politics of self-organisation. Cybersyn was a communication network for the management of the Chilean economy. It was contemporaneous with Arpanet (the progenitor of the internet funded by the US Department of Defense), yet less advanced. Arpanet featured a decentralised network based on packet-switching communication, while Cybersyn remained a centralised web of teletypes linked to a single mainframe computer. Arpanet was based on the idea that a decentralised communications network could survive an enemy attack, as the brain's neural networks reorganise themselves in case of injury. The US Army co-opted this idea of network plasticity before anyone else. The Cybersyn project was terminated when a CIA-backed coup d'état brought Salvador Allende's life (and Chilean democracy) to an end.[38]

37 Ibid., ix.

38 See Andrew Pickering, 'The Science of the Unknowable: Stafford Beer's Cybernetic Informatics', *Kybernetes* (2004); Eden Medina. *Cybernetic Revolutionaries: Technology and Politics in Allende's Chile*, Cambridge, MA: MIT Press, 2014.

From linear to self-organising information

From the vantage point of today's deep learning, it is the participation of Frank Rosenblatt in these conferences that appears of key significance. In 1957, at the Cornell Aeronautical Laboratory in Buffalo, New York, Rosenblatt developed the first statistical artificial neural network 'perceptron', which, after several generations of improvements, would ground the deep learning architecture. Rosenblatt attended these conferences to defend his prototypes, which were quite fragile experiments. Emerging from diverse theoretical and technical influences (see chapter 9), the perceptron was conceived as a self-organising computing network that, in order to recognise a pattern, would find the optimal value of its parameters by gradually adjusting them to the input data. As Rosenblatt remarked in one of these conferences, the perceptron 'arrives at its organisation spontaneously, rather than having it built into the system'.

What did the perceptron look like as a device? One of the first prototypes, the Mark I Perceptron, was an analogue-digital machine comprising an input device of 20 × 20 photocells (called 'retina') connected through wires to a layer of artificial neurons that resolved into a single output (a light bulb turning on or off, to signify if a pattern was recognised or not). The retina of the perceptron recorded simple shapes such as letters and triangles, passing electrical signals to a series of artificial neurons that would sum them up and memorise a result according to a cumulative logic – somehow implementing Hebb's rule to form cell assemblies, as Rosenblatt initially intended.

At the 1959 conference 'Self-Organising Systems', Rosenblatt's contribution was concerned with the generalisation of visual stimuli – that is, with the recognition of similar patterns in a noisy environment. His paper aimed at explaining 'how a brain, or brain-like system, can recognize similarity among the various possible transformations of a sensory pattern, or image'. The problem he addressed was the capacity of a statistical neural network for pattern recognition to generalise beyond the cases of its training dataset. In simple terms, it was 'the dilemma of distinguishing the [letter] N from the Z' under different visual orientations. The way Rosenblatt illustrated his project could still be used today to illustrate the working of a deep learning algorithm:

> This system is capable of 'abstracting' those transformations which are most common in a particular environment, and applying them to new stimuli, which may be quite different in form from any which it has seen. It seems to accomplish all of the results of more rigidly designed systems, but arrives at its organisation spontaneously, rather than having it built into the system. It is actually a system which 'learns to learn', in the sense that prior to the preconditioning experience it would be able to generalize from a given stimulus to its transform only by the slow and laborious method of contiguity generalization, while after having seen a suitable preconditioning sequence (not including the stimuli to be used for test purposes), it performs the same task directly and without the requirement of any appreciable learning period.[39]

As Rosenblatt explained at the 1961 conference 'Principles of Self-Organisation', the design of the perceptron was different from previous artificial neural networks precisely due to its self-organising behaviour, which was possible via its 'reinforcement control system'.[40] Although it was a 'brain model' according to Rosenblatt, the perceptron was far more about the self-organisation of information than the mimicry of organic structures. It marked, therefore, not so much a biomorphic turn in computation as a topological one. Computer scientists Marvin Minsky and Seymour Papert renamed connectionism, somewhat pejoratively, as 'computational geometry' because it was based on the calculation of spatial relations rather than being an instance of 'true AI'.

This topological turn marked, more generally, the passage from a paradigm of linear information to one of self-organisation under which, I argue, the large family of machine learning techniques should be considered. Indeed, it introduced a second spatial dimension into a model of computation that, until then, had been understood primarily within the linear dimension of numerical computers. Instead of processing a visual matrix via a top–down algorithm (as in a traditional program

39 Frank Rosenblatt, 'Perceptual Generalization over Transformation Groups', in Yovits and Cameron, *Self-Organizing Systems*, 95.

40 By comparison, Oliver Selfridge's Pandemonium network relied on handcrafted nodes to extract predetermined features. Oliver G. Selfridge, 'Pandemonium: A Paradigm for Learning', *Proceedings of the Symposium on the Mechanization of Thought Processes* 1 (1959): 511–29.

of instructions, following the scheme of the Turing machine), the perceptron computed the pixels of its visual matrix in a bottom–up and parallel fashion according to their spatial disposition. With respect to computational forms, artificial neural networks such as the perceptron implicitly marked the bifurcation between these two paradigms: that of *linear information* (broadly represented by media such as telegraphs and numerical computers, as well as symbolic AI) and that of *self-organising information* (represented by cybernetic systems, cellular automata, and, ultimately, connectionist AI). Historians of AI Hubert and Stuart Dreyfus summarised the epistemic distinction between the symbolic and connectionist schools in a similar way:

> One faction saw computers as a system for manipulating mental symbols; the other, as a medium for modeling the brain. One sought to use computers to instantiate a formal representation of the world; the other, to simulate the interactions of neurons. One took problem solving as its paradigm of intelligence; the other, learning. One utilized logic; the other, statistics. One school was the heir to the rationalist, reductionist tradition in philosophy; the other viewed itself as idealized, holistic neuroscience.

This book does not recapitulate the saga of linear information in the twentieth century – of cybernetic feedback loops, sequential media, and symbolic AI – but tells the parallel story of self-organising information which is necessary, however, to emancipate from the legacy of biomorphism and research paradigms such as Artificial Life.[41]

Computational thinking and mechanistic analogies of the mind

There exists a considerable misunderstanding about cybernetics' scientific aspirations. In reality, cybernetics was not a science but a school of engineering in drag – one with sufficient self-confidence to extend its informational and computational analogies to several aspects of nature and society. This book tries to clarify that, rather than designing

41 Hubert Dreyfus and Stuart Dreyfus, 'Making a Mind versus Modeling the Brain: Artificial Intelligence Back at a Branchpoint', *Daedalus* 117 (1988): 15–44.

machines like organisms (*biomorphism*) as they professed, cyberneticians ultimately envisioned organisms like machines (*technomorphism*), which were mirroring their own surrounding social order (*sociomorphism*). Like the philosophies of nature from earlier centuries (the canonical example being La Mettrie's *L'homme Machine* of 1747), cyberneticians projected on the ontology of nature and the brain the technical composition of their time, made up of telegraph networks, electromechanical relays, feedback systems, and television scanners. Cyberneticians did not pursue a scientific and experimental but rather a speculative (and often naive) method of *analogy*, mapping preconstituted rules onto nature rather than making hypotheses about new ones. McCulloch, Pitts, and von Neumann's insistence that brain neurons are 'switching organs' functionally equivalent to electromechanical relays is a good example of cybernetics' presumptuous analogies.[42]

The analogy between organisms and machines appears, at first glance, to be an issue of epistemic translation between the disciplines of engineering and biology, but, in fact, it points to a more profound attitude of cybernetic engineering: What are the ethical implications of seeing an industrial machine as an organism, a living being? As much as 'computer science', cybernetics was not a science but an artificial language, a manual of instructions for machine components – a 'machine semiotics' which happened to be forcibly translated into an ontology of nature.[43] But, if it is true that technology can influence scientific paradigms and models of the universe, it is equally true that technology has its own demons and is shaped by external forces within its own domain. Communications networks such as the telegraph, for instance, are not simply technical apparatuses but social institutions. Cyberneticians

42 'The neuron, as well as the vacuum tube . . . are then two instances of the same generic entity, which it is customary to call a *switching organ* or *relay organ* . . . The basic switching organs of the living organisms, at least to the extent to which we are considering them here, are the neurons. The basic switching organs of the recent types of computing machines are vacuum tubes; in older ones they were wholly or partially electromechanical relays.' John von Neumann, 'The General and Logical Theory of Automata', in Jeffress, *Hixon Symposium*, 12.

43 For the expression 'machine semiotics' see chapter 2 of this book and Simon Schaffer, 'Babbage's Calculating Engines and the Factory System', *Réseaux* 4, no. 2 (1996): 280. Herbert Simon tried to define 'the sciences of the artificial' in the homonymous book, but the result is far from rigorous. Herbert Simon, *The Sciences of the Artificial*, Cambridge, MA: MIT Press, 1969.

projected the technical composition that was implied in their own profession, in the form of their labour and knowledge, onto a new paradigm of the world. Specifically, they projected onto nature forms of self-organisation that were already part of the division of labour and technical organisation of their surrounding society. The way cyberneticians claimed to imitate the self-organisation of living beings to build machines implicitly revealed more about the organisation of society and labour relations of their age than about nature.

McCulloch once claimed that 'every robot suggests a mechanistic hypothesis concerning man'.[44] This thesis of cybernetic epistemology argues that the invention of machines may help discover insights about the workings of the human, following the reductionist idea that machines and organisms exist in the same universe and thus must obey the same physical rules. But the word 'robot' is here revealing, because of its industrial and feudal legacy, and it can suggest another meaning. Interpreted in its full implications, this thesis may actually imply that every form of labour automation says something about the cognitive models of a given age. At the end, it confirms one of the main concerns of historical epistemology: that the organisation of labour in a given epoch influences the formation of technologies and instruments, and thereafter of scientific paradigms, conceptions of nature, and models of the mind too.

What has been illustrated for the industrial age appears to be true also for the information age: the *means of production* (not simply telegraphs and computers, in this case, but also artificial neural networks) imitate – in their inner design – the *relations of production*, that is the extended organisation of labour in society. Information technologies increased their hold over society by this adaptation, not by the power of a technological a priori (as techno-determinists maintain), but through a social a priori – that is, by their inborn capacity to capture social cooperation. The nineteenth-century *labour theory of automation* finds confirmation also in the information age.

Eventually, it comes as no surprise that the most successful AI technique, namely artificial neural networks, is the one that can best mirror,

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44 Warren McCulloch to Hans Lukas Teuber, 10 December 1947. Quoted in Ronald R. Kline, *The Cybernetics Moment: Or Why We Call Our Age the Information Age*, Baltimore: Johns Hopkins University Press, 2015, 46. The term 'robot' derives from the feudal-era Czech word for 'servant'.

and therefore best capture, social cooperation. The paradigm of connectionist AI did not win out over symbolic AI because the former is 'smarter' or better able to mimic brain structures, but rather because inductive and statistical algorithms are more efficient at capturing the logic of social cooperation than deductive ones. By tracing the evolution from linear to self-organising information, the history of data analytics, machine learning, and AI can begin to be seen in perspective as a grand process of self-organisation within the technosphere to follow the transformation of the social order.

The disciplines and denominations of information theory, cybernetics, artificial intelligence, and computer science all consolidated in the 1950s.[45] While the US military, as we have seen, played an important role in funding many of these projects, it would be mistaken to presume they deserve sole credit for the origination of these disciplines. Indeed, this book looks to widen this established genealogy. Against technodeterminist and strong internalist readings of information technologies, I have proposed an equally strong externalist hypothesis: that the design of information machines responded – even at the level of the logical forms of their algorithms – to the forms of social interaction at large.[46] In the twentieth century, in other words, it was not information technologies that primarily reshaped society, as the mythologised vision of the 'information society' implies; rather, it was social relations that forged communication networks, information technologies, and cybernetic theories from within. Information algorithms were designed according to the logic of self-organisation to better capture a social and economic field undergoing radical transformation.

45 Respectively, information theory was introduced by Shannon in 1948, cybernetics by Wiener in 1948, artificial intelligence by McCarthy in 1955, machine learning by Arthur Samuel in 1959, and computer science by George Forsythe only in 1961. See George Forsythe, 'Engineering Students Must Learn Both Computing and Mathematics', *Journal of Engineering Education* 52 (1961); and, in particular, Donald Knuth, 'George Forsythe and the Development of Computer Science', *Communications of the ACM* 15 (1972). For the other references see above.

46 For an opposite reading, see Friedrich Kittler's thesis that World War II was the main driving force behind the development of the digital computer. See Geoffrey Winthrop-Young, 'Drill and Distraction in the Yellow Submarine: On the Dominance of War in Friedrich Kittler's Media Theory', *Critical Inquiry* 28, no. 4 (2002): 825–54.

Autonomy and automation

In the second half of the twentieth century, 'Autonomy!' emerged as the common slogan for both cybernetics and the emerging counterculture. High-level cyberneticians funded by the US army were discussing 'principles of self-organisation' in organisms and machines just as anti-authoritarian movements were proposing the same for social and political institutions. As such, these two tendencies debated, for different purposes, the ability of a system to give itself new rules over and against an external ruler (which is, in fact, the original meaning of 'autonomy'). They were both, each in their own respect, forms of political avant-garde and a response to the dominion of outdated regimes: European fascism, Stalinist totalitarianism, and American capitalism. The terms 'cybernetics' and 'beat generation' were both coined, coincidentally, in 1948. A few years later, Norbert Wiener defined both fascism and Western corporatism as ideologies of 'the inhuman use of human beings' against which cybernetics purported to offer a more 'human use of human beings'.[47] But, where cybernetics in fact bolstered US military primacy during and after World War II, the counterculture and the student movement firmly boycotted the Vietnam War and the arms race. The project of autonomy obviously meant different things to these different parties. For anti-authoritarian movements, it represented the freedom of self-determination and a means to constitute new institutions and alternative forms of life. For the cyberneticians, it was the technological utopia of full automation and enlightened societal control: a military and industrial fantasy which also included the project of AI. That even the military – that most traditionally hierarchical structure – also had a vested interest in forms of distributed communication and self-organising networks is a sign of deeper transformations.

In the 1960s, the Free Speech Movement at the University of California, Berkeley, rightly condemned the first mainframe computers as technologies of war and social control in the hands of government and corporations. Media scholar Fred Turner remembers when, on 2 December 1964, in front of more than five thousand students at the University of California, Berkeley, activist Mario Savio delivered an

47 Norbert Weiner, *The Human Use of Human Beings*, Boston: Houghton Mifflin, 1950, 71.

incendiary speech in which he 'uttered three sentences that would come to define not only the Free Speech Movement at Berkeley, but the countercultural militancy of the 1960s across America and much of Europe as well':

> There's a time when the operation of the machine becomes so odious, makes you so sick at heart, that you can't take part, you can't even tacitly take part. And you've got to put your bodies upon the gears and upon the wheels, upon the levers, upon all the apparatus, and you've got to make it stop. And you've got to indicate to the people who run it, to the people who own it, that unless you're free, the machine will be prevented from working at all.[48]

For Turner, Savio's speech evoked memories of the pre-digital era, with images of workers physically wrestling with machines on factory floors. However, he also linked the term 'machine' to the modern society's dependence on information technology, which was beginning to significantly organise social relations as well.[49]

Such criticism of information technologies changed polarity in the following decade: computer science absorbed the aspirations of the earlier counterculture, while the counterculture itself claimed the emancipatory potential of information technologies (and eventually mutated into the so-called cyberculture). The controversial imbrication of social autonomy and technological automation was already present, albeit underground, in the debates of the 1960s. Components of the counterculture, especially those inspired by Eastern spirituality, developed a naive attraction to cybernetics.[50] The *Whole Earth Catalog*, published in California between 1968 and 1972, came to represent a culmination and synthesis of both cybernetic and ecological traditions. Richard Brautigan photographed this convergence in his famous satirical poem 'All Watched Over by Machines of Loving Grace'.[51] On the other hand,

48 Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism*, Chicago: University of Chicago Press, 2010, 11.

49 Ibid., 11.

50 See Pickering, *The Cybernetic Brain*.

51 Richard Brautigan, *All Watched Over by Machines of Loving Grace*, San Francisco: Communication Company, 1967.

European voices such as that of Herbert Marcuse from the Frankfurt school and the autonomist Marxists reclaimed automation in the battle of emancipation from industrial labour. In Italy, a famous slogan of the *autonomia* cried: 'Lavoro zero e reddito intero, tutta la produzione all'automazione' (Zero work and full income, all production to automation).

The terms 'autonomy', 'autonomous', 'automation', and the more ambivalent 'autonomisation' (meaning, depending on the context, 'being automated' or 'becoming autonomous') are not equivalent and also differ from 'self-organisation'. Etymologically, the classical Greek term *autonomia* – from *autos* ('self') and *nomos* ('law') – signifies the power to give oneself new habits, rules, and laws. Modernity recognises this power as one belonging to legislative institutions, especially to the constituent assembly that founds the political order of the state.[52] Autonomy is simultaneously a constituent and destituent power: each time a new rule is invented, an old one can be subverted, nullified, or incorporated by the new invention. But the opposite is also true: any time a rule is broken, an anomaly takes form and a new constitution – a new vision of the world – is implied.

In cybernetics, autonomy was defined as the capacity of a technical system of multiple agents to find a new organisation and equilibrium in relation to external inputs – namely, the capacity to adapt to the environment. In this way, a technical system was said to show emergent properties that might be perceived as 'intelligent' by a human observer. These questions continue to haunt the dream of artificial intelligence, even now: Can a finite-state automaton – that is, a computer – show properties of autonomy? Can a computer programmed to follow strict rules rebel against its core instructions and invent new ones? If autonomy is the power to invent a new rule, automation can be defined as the blind following of a rule, as is the case with computation. In this regard, the Austrian philosopher Ludwig Wittgenstein remarked that 'following a rule' will always have a different meaning for a human and a machine.[53]

52 In early research, the German system theorist Niklas Luhmann noticed that the institutional order had to face the growing normative role of technical apparatuses: Niklas Luhmann, *Recht und Automation in der öffentlichen Verwaltung: Eine verwaltungswissenschaftliche Untersuchung*, Berlin: Duncker & Humblot, 1966.

53 See Stuart G. Shanker, *Wittgenstein's Remarks on the Foundations of AI*, London: Routledge, 1998.

Considering the recent debates on AI bias as well as the speculation on the risks of 'superintelligence', one wonders whether the game of AI is still being played within the domain of automation (following a rule) rather than the domain of autonomy (that of breaking rules).

To conclude, a competing claim: technologies of automation have always been responses to social autonomy, and cybernetic techniques of self-organisation such as artificial neural networks, similarly, have been avatars of the emergent social relations of their day. In hindsight, both cybernetics and the post-war social movements were directly related to the autonomisation of knowledge and information in labour processes and social behaviours, which had triggered the rise of new media and technologies. These points have over the years become a conventional interpretation in theories of knowledge society and information economy, to the point that even neoliberal economic paradigms, such as Hayek's spontaneous order of markets, or 'catallaxy', can be considered responses to the increased exchange of information in society at large (see chapter 8). Materialist historians concede the dialectical relations of the two movements – between the drive for social autonomy by new generations of workers, on one hand, and the appearance of new technologies of automation, on the other. Ultimately, the diverse projects of automation after World War II were a way to govern developing social forces – that is, to organise a 'control revolution' (as Beniger defined it) against a more rebellious society.[54] It is not by chance that, at least in the Global North, students and computer programmers were transformed into a new political subjectivity similar to the industrial workers' movement, given a global economy more and more dependent on information, knowledge, and science as key economic drivers.

In the late 1960s, political philosopher Mario Tronti proposed to reverse a thesis which was then mainstream also in Marxism: capitalist development was always considered to shape workers' organisation and their politics. To the contrary, Tronti claimed that capitalist development, including technological innovation, was always triggered by workers' struggles. Interestingly, for a European intellectual such as Tronti, 'the working-class struggle reached its highest level of development between 1933 and 1947, and specifically in the United States',

54 James Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society*, Cambridge, MA: Harvard University Press, 1986.

which are coincidentally the years that witness the rise of cybernetics and digital computation.[55] Radical and unconventional perspectives like this should be explored to narrate the combined evolution of society and technology throughout the twentieth and twenty-first centuries. Across the historical transformations that this book attempts to analyse, it appears that the project of AI has never been truly *biomorphic* (aiming to imitate natural intelligence, as mentioned earlier) but implicitly *sociomorphic* – aiming to encode the forms of social cooperation and collective intelligence in order to control them.[56] The destiny of the automation of intelligence cannot be seen as separate from the political drive to autonomy: it was ultimately the self-organisation of the social mind that gave form and momentum to the project of AI.[57]

55 Mario Tronti, 'Postscript of Problems', in *Operai e capitale*, 2nd ed., Torino: Einaudi, 1971, translated as *Workers and Capital,* London: Verso, 2019, 294. See also Raniero Panzieri, 'Sull'uso capitalistico delle macchine nel neocapitalismo', *Quaderni Rossi* 1 (1961): 53–72.

56 See also Matteo Pasquinelli, 'Abnormal Encephalization in the Age of Machine Learning', *e-flux* 75 (September 2016).

57 For an overview of the ideas of the social brain and collective intelligence in contemporary political theory, see Charles Wolfe, 'The Social Brain: A Spinozist Reconstruction', *ASCS*, Proceedings of the Ninth Conference of the Australasian Society for Cognitive Science, 2009, 366–74.