Heat, Colonialism and the Geography of Recognition Machines

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ABSTRACT

This article attempts to place the energy-intensive project of mechanizing interpretive labour known as artificial intelligence (AI) in the context of the longer trajectory of post-18th century industrialization and the capitalist appropriation of human and nonhuman work. Using the mechanization of recognition as a case study, it proposes viewing AI as a set of entropic, globally-distributed machines for labour exploitation linked to particular geographic patterns of colonialism and ecological fatigue. In particular, it examines the contradictory relations through which the 'dead labour' crystallized in recognition machine networks must constantly recruit and degrade enormous quantities both of the 'living labour' of human recognition and of thermodynamic energy to perform its repetitive predictive tasks. As with the 19th-century industrial revolution, it argues, the geography of this process is better understood by treating energy not as a singular resource extractable from a variety of sources and then used up at various points of an essentially invariant landscape, but as the political reorganization of entropy gradients and exchanges across the borders of nonequilibrium systems. The article's purpose is to encourage activists and researchers to have more confidence in challenging the assumptions through which AI is usually defined and to provide a new perspective on the 'digital natures' it produces.

Keywords: artificial intelligence, labour, energy, thermodynamics, cognition, capitalism

1. Introduction

This article briefly develops two insights about artificial intelligence (AI) together in the hope that the combination may help in the understanding of contemporary political struggles. The first insight is that 21st-century AI consists of energy-intensive forms of mechanization that are continuous with those of 19th-century phases of capitalist industrialization, with all of their social and ecological characteristics. The article takes as a case study the recent advances in the mechanization of recognition that form a central part of the current AI boom. It seeks to grasp why today's recognition machines, like the industrial machines of the 19th century, are necessarily tied up simultaneously with efforts to tap deeper layers of living human labour and with extraordinary jumps in energy use, and how these relations might be expressed in geographic terms. The second insight, following recent work by historians, physicists and popular movements, suggests that it may be fruitful, in an age of accelerating climate change and anti-extractivist rebellions, to think of energy itself in different geographic terms than those long used by the academic and policy mainstream. On the view proposed, energy is better seen not as a resource that can be located and depleted, but rather as a geographic and political reorganization of entropy slopes. This reconceptualization is premised on picturing both the practice and the theory of energy since the 19th century as involving (1) continuous efforts to reorganize the earthly gradients between low and high entropy that are needed to sustain proliferations of energy conversion devices, (2) reinforcement of integral tendencies toward progressive erosion of these gradients within relevant bordered systems, and (3) expansion of colonial management across those borders to dispose of high entropy and curb trends toward local thermodynamic equilibrium.

Put together, these two insights suggest a research programme into AI as a particular set of entropic, globally-distributed machines for labour exploitation linked to specific geographic patterns of racism, patriarchy, colonialism and ecological fatigue. Implicitly critiquing the dominant academic and journalistic reification of recognition and data, the paper instead investigates AI as an emerging politics of human and nonhuman geography. In doing so, it tries to identify more effective and practical points for radical popular intervention than can be found in the prevailing academic literature.

The plan of the article is as follows. The second section introduces the concept of recognition machines as a fruitful avenue for investigation of AI, placing them within the longer history of capitalist mechanization and labour exploitation. The third section examines the accelerated rejiggering of entropy landscapes that has accompanied the rise of recognition machines and other aspects of AI, including their ecological and labour accompaniments. The final section summarizes the main points, arguing that the geographic framework advocated here can be a way of avoiding the fetishization of AI into which social science and humanities research into the subject can easily fall.

2. Recognition machines

For the sake of concreteness, this article focuses on an aspect of AI that it calls *recognition machines.* Here 'recognition' refers to basic classification and identification. Thus there are machines that are built to classify strings of optical characters (as belonging to the category of 't's, 'k's, various sentences or languages); images (as representing cats, chairs, crosswalks, traffic lights or species); colours; diseases; sentiments; intentions; risks; social identities; or citizens (in terms of their degree of good citizenship). There are also machines designed to identify, single out or put a unique name to entities such as fingerprints, faces, places, voices or DNA sequences.

Care must be taken, however, not to beg the question of whether recognition machines recognize, classify, identify or name anything in the ordinary senses. Thus 'recognition machine' will be used in this paper merely as a convenient shorthand for a certain class of AI in somewhat the same way that computers running AlphaZero or Stockfish are commonly referred to as 'chess-playing machines' in spite of the fact that there is no evidence that they have any idea what chess is, what a game is, what a rule is, what a right or wrong move is, and so forth, and cannot be said to have a desire to play or win insofar as having one desire presupposes having many others that they do not possess (Davidson, 2004: 89). Lacking a history of learning from causal interactions with objects within a community of other individuals observably reacting to the same objects, recognition machines cannot be assumed to have the concept of the possibility of their making mistakes (Wittgenstein, 1953) or of truth or objectivity (Davidson, 2004: 4-12), or indeed any concepts or thoughts about the external world at all, no matter how far their abilities to discriminate among different objects may exceed those of humans. This is not to say that such machines could not some day come to have such a history, to have concepts, to acquire what Donald Davidson (2004) calls the 'rudiments of the framework of thought', to be treated as rational conversation partners in the ordinary sense, to find 'means to understand the world of the embodied collective and the different worlds of practice within sub-communities' (Collins, 2018), and thus perhaps to create capitalist value alongside humans in the course of performing what Marx (2004 [1867]) called 'living labour'. But such 'artificial general intelligence' devices are not currently on the technopolitical horizon (Dennett 2019). At present, recognition machines must still be classed alongside 19th-century industrial machines as incapable in themselves of producing new capitalist value (Caffentzis, 2013).

Nevertheless, today's recognition machines are politically significant in ways that more primitive 19th- and 20th-century recognition machines were not. They augment, speed up or in some cases seemingly replace human recognition in a staggering spectrum of relatively new applications. Their outputs are familiar from the daily lives of the well over five billion people who use cellphones, Facebook, Amazon, Google or Alexa; who face police or employer surveillance; or who are taxed or collect benefits using biodata identifiers. In addition to performing as 'freestanding' devices for voice recognition, facial recognition and so forth, they are also a key building block of the more encompassing interpretation machines that constitute AI as a whole (Lohmann, 2020). They operate in machine translation platforms that need to be able to identify characters, sentences and languages in order to interpret texts; in self-driving vehicles that need to be able to react differently to traffic lights, motorcycles, crosswalks and bridges; in devices identifying, collecting, distinguishing and classifying the vulnerabilities of millions of separate humans to being made individually targetable by commercial or political behaviour and emotion modification projects (Lanier, 2018; Smythe, 2006 [1981]); in high-frequency trading programmes that need to distinguish prices from artifacts of mechanical feedback (Eisen, 2011); in automated farming or nature conservation contraptions that need to be able to tell apart different species of insects and plants; in search engines; in platform-advertising auctions; in cryptocurrency 'trust machines' (*The Economist*, 2015); in genetic engineering schemes; and in more complex forms of AI such as smart contracts and synthetic agents.

A focus on recognition machines has the virtue of specifying one relatively 'bite-sized' set of historical continuities and thus helping to pin down the nature of change. Recognition machines are nothing new as part of the industrial scene. Eighteenth- and nineteenth-century steam engine governors 'recognized' the speed of steam flow as part of an 'infomechanical relay between flows of energy and information' (Pasquinelli, 2015). Thermostats 'recognized' temperature and 'communicated the information' to furnaces or boilers schooled in how to 'read' it. Jacquard looms 'recognized' symbol types and translated them into one another (Essinger, 2004). Twentieth-century recognition machines were fused with humans in still other ways in autopilots and antiaircraft fire control systems. All contributed to composites in which some human recognition work could be avoided, reduced or supplemented but, equally importantly, qualitatively redirected toward machine care and supply. Marx's famous line about 19th-century workers having to 'stand to the side of the machine' never meant less aggregate work, just different kinds of work, including boiler and Jacquard loom maintenance as well as the vastly-increased quantities of toil needed to complement the directed power of steam engines, together with every other new variety of communicative, communal labour required by industrial production. The same is true of Second World War artillery targeting innovations, whose human-machine fusions aimed at faster and more accurate prediction of curving aircraft trajectories also redistributed human labour to new structural locations. Many other novel human-*cum*-recognition machine symbioses followed with the unfolding of the postwar computing age involving nuclear and thermonuclear weapon design and evaluation, command and control, cryptanalysis, radar, climate modelling and genetic mapping and engineering (Dyson, 2012). What is new about 21st-century recognition machines is their supercharged speed and scope and their unprecedented abilities to 'recognize' features not only of things and their behaviour but also of human action, thought and feeling.

In the most lucrative 21st-century commercial mechanized recognition amalgams, advanced statistical prediction holds pride of place. Optical character recognition devices work by predicting how literate human subjects would react to certain orthographic shapes. Driverless cars work by predicting how human subjects would react to shapes in motion viewed from certain vantage points. Google Translate 'recognizes' languages by predicting how human translators would react to symbol strings. High-speed trading machines predict how human traders would react to numbers as prices. Sentiment-detecting machines predict millions of individuals' future emotional reactions to hypothetical situations on the basis of thousands of data points from multiple individuals' distant and immediate pasts. These acts of simulated recognition, represented but not interpreted within machines, are carried out at a velocity and in a volume of which even vast armies of humans would be incapable. They are made possible through self-adjusting deep learning algorithms, processors operating at unprecedented speeds, extensive human maintenance of both, and immense statistical samples produced by billions of cyborgs fusing humans, smartphones, computers, digital cameras, optical fibre lines, satellites and hydroelectric dams, engaged around the clock in digitizing sensory, linguistic and other types of human experience or negotiation for input to proprietary mechanical processes. Today's recognition machines, that is to say, are parasitic on efficient, continuous harnessing of acts of human recognition in unprecedented volume and on an unprecedented geographic scale, as well as on more conventional types of machine care. Like their 19th-century industrial predecessors, they depend on growing amounts of living human labour, without which they would be useless to capital; more than ever before, 'dead labour demands fresh living labour' to generate value (Kirsch & Mitchell, 2004: 696; see also Antunes, 2013: 97). The monetizable big data feeding contemporary recognition machines, which have propelled IT companies to the top of the world economy, rely on continuous living infusions (smartphone keystrokes, ReCAPTCHA inputs, microtasks by home workers, 'data exhaust,' and so forth) from billions of sensors grafted onto living subjects as well as gigantic catalogues of representations encoding living work from the past (image-identification and Google Translate data sets and so on). Facebook, for example, manages to be the sixth largest company in the world by market capitalization despite having only 48,000 paid workers because it has been able to recruit an additional 2.6 billion unpaid workers to donate labour to the firm, generally on a daily basis. Unceasing flows of living labour are also indispensible to AI-enabled 'Industrie 4.0' programmes (Pfeiffer, 2016) to animate their 'dead' statistical-predictive work. As in the 19^{th} century, what Gray and Suri (2019: 1-63) somewhat misleadingly call 'automation's last mile' is one that can never be traversed with improved algorithms or data alone. Indeed, every advance in mechanized 'recognition' can be demonstrated to require even greater increases in the use of basic interpretive human labour, whose unpaid or precarious status is essential in enabling accumulation to continue (Socialist Project, 2021), confirming Marx's old warning that the mechanized 'transformation of guild masters and their journeymen into capitalists and wage labourers' should not be confused with a universal, long-term 'displacement of the wage labourers themselves by the application of capital and scientific knowledge' (Marx & Engels, 1994 [1861-3]: 26). As with mass production generally, relatively low costs in energy per million manufactured units are achieved only through a stupendously-wasteful, energy-intensive overall system much of whose destructiveness is 'invisibilized' as an integral part of the economic process. None of the data needed for the operation of today's recognition machines are 'out there' in the world prior to the application of human labour-power, any more than fossil fuels or wage labour itself are 'out there' in 'nature'. They have to be created by complex geographic labour-control systems for appropriating or exploiting human and nonhuman activity simultaneously.

This is why a critique of those systems is in a sense analytically and politically prior to inquiries into who appropriates, owns, centralizes and uses the reified data banks that are the end result. Unfortunately, the latter still tend to dominate critical academic and journalistic work on recognition machines. There are profound reasons for this. 'Digitize and predict' might be the formula for success for some of today's largest corporations, from Alibaba to Alphabet, Amazon and Apple, but the accumulation of surplus via the quotidian human 'labour of perception' (Pasquinelli & Joler, 2020) has seldom before been a direct objective of capital to the extent that it is today, making it a form of labour relatively unfamiliar in academic debate. Indeed, this everyday, low- or zero-cost activity – including but not limited to recognizing new instances of old categories or exemplars and performed mostly unconsciously by every human being over the age of two nearly every second of every day, whether for pay or not, and requiring minimal training examples and unremarkable energy expenditure – has seldom even been *called* labour. This convenient mystification is still widespread even on the left, despite the fact that this activity has always been at least one component of all capitalist labour. Further obscuring the need for deeper critique is the fact that, for several billion socialized humans, whether children or adults, user interfaces have made the work of digitizing acts of recognition so easy as to seem unworthy of the name labour. No human programming or translation into machine language is involved; all that smartphone or computer users have to do is recognize, type or point, and press 'send'. As Harry Collins (2018) points out, user interfaces are designed to conceal this work in such a way that it often gets attributed entirely to machines; he places this 'attribution' work in the same often-concealed category as repair and care of machines by humans (Collins & Kusch, 1998). This is an updated version of the venerable 19th-century pattern that, as Marx pointed out, induced workers to credit production to machines rather than their own labour, and that also obscured the troops of outworkers surrounding every factory (Gray & Suri, 2019) and subtracted humans from photographs of the machinic marvels of colonial rule (Barragan, 2018; Toscano, 2016) as well as from portrayals of 'pristine nature' (Mann, 2006). At least equally important in hiding the human labour involved in recognition mechanization are long intellectual traditions of viewing knowledge as a matter of representation rather than answerability to conversational partners, human or otherwise. Richard Rorty (1979, 2001) identified Western philosophy's longstanding fixation on the idea that knowledge is founded on what he aptly called 'privileged representations' involving the structure of minds or language acting on or organizing given empirical contents through narrow interfaces (Haugeland, 1998) – one form of what Donald Davidson (1973, 2001) termed the scheme/content dichotomy. A parallel fixation has accompanied AI research since the field's beginnings: the algorithms/data ideology, in which data are treated as 'given' rather than as products of specifically capitalist labour. At one time, it was thought that algorithms, rules or instructions written by human experts to sum up their expertise and then installed inside machines could enable them to perform human-like acts of recognition. This was the age of so-called 'Good Old-Fashioned Artificial Intelligence' (GOFAI). Twenty-first century technological advances made it possible to revive a longstanding alternative approach that turned out to work much better for capital, that of neural networks, in which algorithms are continually adjusted by the machines themselves, often becoming opaque to human observers in the process. Neither approach models itself on human recognition, which is non-representational and unedifying to reduce to Turing machine read/write interfaces. Instead, both rely on recursive mass-production of standardized data using proprietary devices, converted into further digital objects using similarly codified algorithms. Both approaches replicate Davidson's scheme/content dualism, as spectacularly illustrated by one computer scientist's search for a 'master' algorithm capable of mutating itself in such a way that 'all knowledge – past, present, and future – can be derived from data by a single, universal learning algorithm' (Domingos, 2015: 26). In such conceptions, 'data' (comprising the 'content' in the scheme/content dichotomy, which was traditionally seen as deriving power and authority from being, in principle, an unassailably inhuman, pure Other out there waiting to be plugged into human circuits [Davidson, 1973, 2001; Rorty, 2001; Levine 2020] through interfaces including that of privileged scientific expertise) has become understood as also sourcing itself from a shape-shifting cyborg world that nevertheless maintains the imaginary status of an apolitical Other. Just as GOFAI as well as its successor projects have often continued to assume, *contra* the late Wittgenstein (1953), that rules ought to be able to interpret themselves (and now, repeatedly re-interpret themselves) once properly implanted into machines, so too many AI developers hold on to the idea that, at least once they achieve the scale of cloud-stored zettabytes matching the reach of the new self-correcting algorithms, data ought to be able to continue autonomously to validate representations mediated through expert interfaces as a privileged, disinterested form of knowledge about the world. Encouraged by the dwindling visibility to humans of the workings of deep learning algorithms, this belief becomes most audible today in recurring announcements that, when big enough, data will make scientific modelling obsolete (Anderson, 2000), that someday machine learning will be 'unsupervised' (Collins, 2018, Bechmann & Bowker, 2019), that its difficulties with agency and serendipity are on the way to being solved (Thorpe, 2021), and that with enough algorithm tweaks and additional zettabytes, AIs will cease their racist and sexist rantings (Buolamwini & Gebru, 2018; O'Neil, 2016; Jefferson, 2020) and fomentation of political strife (Lanier, 2018). Such beliefs will continue to be aired as long as the political and geographic organization of the 'labour of perception' and of conversation are neglected in accounts of big data.

Despite the continuing dominance of representational assumptions about recognition in critical work on its mechanization, plenty of underexploited materials exist for putting these assumptions in clearer perspective. Paralleling Davidson's critique of the traditional scheme/content dualism, for instance, is a large body of work in science studies arguing against the idea that 'nature and society or culture are self-contained components of the world that interact at localizable interfaces of human artifacts, bodies, and scientific language-or-concepts' (Rouse, 2002). The fundamental work of psychologist J. J. Gibson (1979) on human perception has inspired anthropologists such as Tim Ingold to elucidate the differences between, for example, what Ingold (2000) calls 'wayfinding' and mapmaking, map-storing and map-reading. Indigenous thinkers' insistence on non-representational understandings of recognition (de la Cadena, 2015) is a further essential contribution to this intellectual work. There is even a counter-tradition of 'Heideggerian AI' holding that the 'way human beings interact with the world is not necessarily mediated by representations' (Hui, 2014). Such materials help highlight the fact that the supposed 'materialism' guiding capitalist recognition machine design is of a very incomplete kind: while it evolves out of a historical series of material devices ranging from Jacquard's loom to Babbage's engines, Shannon's logic circuits, early von Neumann machines and Rosenblatt's perceptrons, it remains thoroughly Cartesian insofar as, based on dualisms of scheme and content and an ideology of privileged representations, it neglects other aspects of recognition's materiality involving the co-evolution of changing and unpredictable physical environments with recognition abilities exercised and developed by bodies in society moving through time along physical pathways. Signalling a continuing anti-materialist, deeply European institutional commitment to reproducing dualisms of representation/reality, idea/object, image/thing, thought/action, blueprints/building, calculation/measurement, rule/application, law/land, human/nonhuman, mind/body and culture/nature (Mitchell, 2002), 21st-century deep-learning recognition technologies, owing to their embeddedness in the general drive of capital to 'escape the finite' (McNally, 2003), have persisted in following a path diverging from that of human recognition. Partly because machine recognition does not occur 'inside' machines any more than human recognition occurs 'inside' humans, following this divergence is unavoidably a geographic enterprise all the way down to its most technical aspects.

The 21st-century mass production of predictions by commercial and state recognition machines invites a reconsideration of the longer evolution of recognition machines from their relatively unprolific beginnings. This historical contextualization is a useful heuristic insofar as it serves as a reminder that because the importance of what Marx called living labour to capital lies largely in its ability to deal with an uncertain future, replacing human with machine activity has, in a certain sense, always involved reaching for predictive capacity. Predicting what humans might do, after all, is the closest that machines, as historically conceived, can come to reproducing the core of living labour – that open-ended set of future-oriented social skills involving a history of experience among a 'plurality of creatures' visibly responding to 'shared external promptings' (Davidson, 2004: 143) that Wittgenstein called 'knowing how to go on' (Lohmann, 2020). In retrospect, for example, mechanical thermostats might be reconceptualized as devices for forestalling the need for human thermostats – hypothetical workers who would recognize changes in temperature and respond by running over and twisting a dial on a boiler – by predicting by mechanical means what humans would do and then doing it. Obviously this is a strange way of formulating things, but it is worth considering why. It is not that enlisting humans as thermostats would have been a waste of humans. As exhaustively illustrated by the industrial revolution, capital is constitutionally indifferent to that kind of waste. It is rather that humans just couldn't do the job of thermostats very well or at all, and certainly not cheaply or without revolting. They would need wages and are not sensitive enough to temperature changes or capable of acting reliably, patiently and quickly enough to keep the relevant feedback loops short. In this example, the other side of the coin – the *in*ability of mechanical thermostats to react flexibly to unforeseen problems and breakdowns – is easily compensated for by ensuring that the living labour involved in boiler control is directed not to *being* thermostats but rather to maintaining and repairing mechanical ones. In such a role, living labour is bound to be much less threatening or expensive to capital than it would be if it were assigned the role of thermostats themselves; it is no coincidence that Andrew Ure, the 19th-century prophet of labour control, was one of the inventors of such 'heat governors'. At the other end of the historical period in question is the current conjuncture, in which the behaviours that recognition machines are continually being called on to predict are vastly more varied, numerous and complex as well as less mechanical themselves. Good recognition machines today need to be able to predict that humans would identify a certain face as a human's and not a gorilla's, that botanists might be uncertain about the classification of certain species, that a Thai-speaking woman would recognize a ครับ as calling for a คะ. They need to be able to predict that a human would recognize the asking figure for an ordinary biology book on Amazon.com of US$23,698,655.93 (+$3.99 shipping) as a nonsensical artifact of a mechanical golem rather than as a workable price (Eisen, 2011). And they need to be able to produce billions of such independent, individualized prediction-units every second. Today's recognition machines can definitely learn to accomplish such tasks in the required volume with a certain efficiency (merely 'certain' due to, for example, 'black swan' cases in which statistical prediction is counterproductive). No army of human recognizers could match the scale, speed or accuracy of such performances any more than it could step into the figurative shoes of industrial thermostats. Nor could capital possibly pay the wages of that army, even if it were possible to find one. Nonetheless, those mechanical performances require being hooked up to reservoirs of past and real-time (cheap or zero-cost) living labour whose size dwarfs what was needed for the development and operation either of thermostats or of digital computers. The more data that recognition machines need in order to 'replace' human recognition labour, the more human labour is needed on the other side to digitize basic human experience. Nor does this labour itself remain by any means unaffected by the process, as the very commons of existing human communicative, creative and knowledge-building abilities that digital capital needs to survive is enclosed and degraded along numerous fronts. In the 21st century as in the 19th, individual capitalists' evolving attempts to replace 'knowing how to go on' with predictive capacity – that is to say, to mechanize – entail not only ever-expanding appropriation and exploitation but also increasing waste and fatigue. Capital's snowballing efforts to contend with the inabilities of each successive iteration of recognition machine development to duplicate living interpretive labour are directly related to these increasingly destructive effects. Conventional economic ideology tends to subsume such effects under the rubric of 'externalities', but a better term might be, following K. William Kapp (1950), 'cost-shifting successes'. How long these successes can be maintained is the central question for digital as well as conventional capital today.

3. The energy geography of recognition machines

The role of energy in the 'cost-shifting successes' of recognition machines is one that particularly requires exploration in any inquiry into 'digital natures'. In recent years, it has become a commonplace that today's new levels of mechanization of recognition and other aspects of interpretation – made possible by the renaissance of neural networks together with speedier processors and billions of worldwide sensors collecting big data in real time – have an exceedingly high energy cost. The statistics are familiar. Overall, digital energy consumption is growing by about nine per cent annually worldwide. The carbon emissions of blockchain 'trust machines' alone are already on the order of those of a medium-sized country, with each Bitcoin transaction nearly 1.2 million times as carbon-intensive as that of a bank-mediated Visa card transaction (Digiconomist, 2021). The CO_2 emissions resulting merely from the training (not the use) of a single deep-learning natural language processing model can run to 284 tonnes, five times that of a car driven for a lifetime (Strubell, Ganesh & McCallum, 2019). Naturally, the boom in energy use associated with the accelerated mechanization of recognition and other forms of interpretation is connected with specific uneven geographies of energy extraction. For example, sunk investments in surplus hydropower in relatively cold regions of China, Georgia, Sweden, Norway and the US Northwest have created zones of cheap energy and cheap processor cooling where cryptocurrency miners or other types of data centres seek to situate themselves (BitMEX Research, 2017; Starn, 2020; Butler, 2019, Lally, Kay & Thatcher, 2019), engendering particular dynamics of conflict.

What may be less widely understood is that this jump in energy use is in many ways a rerun of the energy transformations inaugurated during the 19th-century industrial revolution and the new natures that emerged as a part of it (Malm, 2015; Moore, 2015). Far from representing the dawning of a 'dematerialized' economy, AI constitutes a ratcheting up of essentially the same material violence against women, nature, colonies, people of colour and workers generally (Crawford, 2021), instituted for essentially the same reasons. However, a full understanding of this historical continuity (which should help illuminate both the past and the present) calls not only for a reconceptualization of AI as interpretation mechanization along the lines of the previous section, but also for a recasting of the 19th-century thermodynamic energy that drives it in terms of colonially-organized entropy gradients. That will be the main job of this section.

Capital's power both derives from and uses its ability to fragment, 'stupidify' and disentangle from previous contexts various elements in vital, evolved webs of human and nonhuman activity and recombine them under more centralized and profitable control within new webs of relationships that are more productive but also subject to more rapid deterioration. In combinations that can be more or less debilitating, divisions of labour tend to decompose integrated existing skill clusters into dumber and more quantifiable, repeatable, surveillable, and supervisable shards while fostering replacement coordination skills oriented toward competitive production. Agribusiness operations strip out certain communally-evolved plant and animal capacities, isolating and reorganizing them into similar patterns featuring widespread, rapid repetition under centralized direction. Mineral extraction separates out single aspects of geological formations, re-entangling them in networks of mass production whose lifespan is also limited. Such dynamics, moreover, tend to work in tandem. Thus, for example, 19th-century capital smuggled the activities of Latin American rubber and cinchona trees out of their original human and nonhuman contexts and brought them into contact with the abundant cheap, fresh, semi-proletarianized labour power it had helped create in Asia as well as increasingly fossil-powered forms of mechanization, engendering a progression of knock-on effects on humans, tree species, and earth systems alike that continues down to the present (Cuvi, 2015; Kohn, 2013). The capture and progressive exhaustion of the sedimented, combined historical energies of living beings through such complex processes of fragmentation, repatterning, repetition and replication is what defines the moving frontier that constitutes capital. The fragility of this frontier, the unending imperative to move it outward, inward or deeper, is one with its labour productivity (Moore, 2015; Walker, 2016). The frontier, and the need to extend it, perpetually threaten capital at the same time that they form its tissue. Hence the centrality of patriarchal, racial, class or colonial violence to its repeated reconstructions.

Nineteenth-century industrial automation accentuated and globalized this dynamic of profit, degradation and violence via thermodynamic practice and theory (Lohmann & Hildyard, 2014; Lohmann, 2021a and 2021b). Long before Taylorism, managerialism, digitization and AI, industrial machines and the newly abstract, 19th-century energy that drove them promised a practical way of further entrenching the disciplinary position of 'master manufacturers' at the 'intelligent' centre of a body of workers competing with one another for supposedly 'unskilled' or 'merely reproductive' employment, helping shape capital's versions of divides between mind and body, civilization and savagery further. It was growth in divisions of labour that had encouraged the development of a 'mightier moving power than that of man' (Marx, 2004 [1867]: 497) – a generic, superhuman force that wound up making possible ever faster, more regular, more widespread repetitions of stereotyped subroutines of transplanted human and nonhuman action – and not the other way around. This 'moving power' – a generic, superhuman force making possible the widespread and extremely regular repetition, at extremely high speeds, of the stereotyped, 'dumb' subroutines of human action that divisions of labour had already split apart and made more measurable, predictable and disciplinable – was the commensurated 'energy' that emerged as a new term of art and set of practices in Northern Europe and elsewhere between around 1800 and 1870. This 'birth of energy' (Daggett, 2019) – a new 'nature' – was essential in turn in enabling capital to subject the skills of still more enclosure-dispossessed workers – whose labour-power could now be more easily bought and concentrated by property owners – to centralized disassembly, reorganization and control, facilitating 'combined labour' on ever more populous factory floors globally (Tinel, 2013; Daston, 2018). The new abstract energy made it possible for 'slow' individual bodily human motions associated with, for example, spinning or stalk-cutting, which had historically been entangled and sustained within other social and ecological wholes, to be profitably isolated, made uniform, strengthened, and repeated trillions of times at unprecedented speeds within new manufacturing contexts. New relations describable using the emerging 'energy' concept and centred on fossil fuel conversion engines (and their thermostats) expanded worldwide alongside the wage labour relation (Huber, 2004). In agriculture, colonial plantation ecologies were similarly turbocharged for increased repetition, replication, volume, speed and globalized relations. Skills exercised by capital's exploding numbers of waged and unwaged workers, whether urban or rural, shifted decisively toward new assemblages required to 'comb the machine,' to cite a striking phrase used by a contemporary French auto worker (Carbonell, 2018).

The mechanization of recognition or interpretation has not been fundamentally different. Of course, AI's prediction-manufacturing apparatuses will never be perfectly comparable with the cotton- or steel-manufacturing apparatuses of the 19^{th} century. For example, it is post-19th-century divisions of labour theorized by computer science and robotics that directly underpin AI's regimes for delivering brute-force repetitions, and those repetitions – again in incomprehensible volume and at almost incomprehensible speeds – are of electronic motion sequences rather than stereotyped middle-sized mechanical actions. Nevertheless, the overall identity of thermodynamic and ecological structure between the two is unmistakable, as is their common genealogy, which follows much the same pattern involving class, race and gender conflict and capitalist competition, 'stupidifying' divisions of labour, the 'energization' thereof, the correspondingly huge requirements for cheap or zero-cost living labour to tend the operations, and the reinforcement of mind/body dualisms. Since the 1940s, the familiar mathematical, logical and computational term 'recursive' has acquired stark political and ecological connotations clearly reminiscent of those of the thundering repetitions on the factory floor that so mesmerized 19th-century observers. As with the 19th-century industrial revolution, too, ‘efficiency’ per stereotyped repetition has continuously skyrocketed: unit computations are already perhaps a trillion times cheaper than they were 70 years ago (Trustnodes, 2018; Routley, 2017; Dyson, 2012). And similarly to the 19th-century industrial revolution, the ‘energy efficiency’ of each of octillions of instances of a particular contrived repetitive action, especially when tied to the associated worldwide contruction of abstract thermodynamic energy as well as capitalist Jevons effects (Polimeni & Mayumi, 2015), fails to reflect either the violence or the ‘inefficiency’ of the overall system. With recognition machines, capital has merely doubled down on the unsustainable dynamics of 19th-century energy geography. In some senses, it would be pointless even to try to disentangle information technology’s energy use from that of the evolving older industrial technologies on which it is built (Schaffer, 1994; Daston, 2018; Ensmenger, 2018) and with which it operates in tandem. Turing machines have long been engaged in complex two-way interactions with heat engines (Caffentzis, 2013: 127-200). Nevertheless, as suggested above, the contribution of recognition machine applications to increases in energy use and exploitation of cheap living labour is obvious and growing.

In short, it is the integrated historical progression of industrial capitalism/digital capitalism, not one or another segment of it, that is increasing the intensity and vulnerability of capital’s regime of parasitism on various independently-evolved vital capacities of the living world. Repeatedly pushed from ‘formal subsumption’ toward ‘real subsumption,’ capital has continually sought, found and extracted fresh, low-cost fragments useful for machine operations deeper within the socio-biological capacities confronting it as labour-power (Boyd & Prudham, 2017; Moore, 2015; Walker, 2016; Burawoy, 1979). As capital’s debt to the past has increased with its excavation of more and more sedimented remains of photosynthetic work in the form of fossil fuels (Dukes, 2003), so too has its debt to the myriad evolved patternings (Kohn, 2013) of living organisms, more and more varied pieces of which it has also continually striven to attach to machines. With industrial automation and thermodynamic energy, the contradiction has only sharpened between capital’s own reproduction time and the ‘reproduction time of the web of life’ (Gaffney, Ravenscroft & Williams, 2019) that capital has had no choice but to continue trying to appropriate for free. None of these myriad ecological changes has ever been more than barely hinted at by the elliptical term ‘mechanization’. It has never been the case that there exist static, bounded activities – whether cotton spinning or recognition – which are then ‘mechanized’ in isolation from what happens elsewhere. It is rather that sweeping global ecologies involving vastly more numerous activities have been rearranged and set on increasingly precarious new pathways.

As hinted above, the heightened contradictions that came with the 19th-century development of energy were reflected in thermodynamics, whose First and Second Laws lie at the core of the modern concept. In 1865, the great German physicist Rudolf Clausius summarized these two laws as follows: (1) the *energy* of the universe is constant, and (2) the amount of *usable energy* declines (that is, *entropy* tends to increase in a closed system). The First Law inspired capitalists to try to put the entire universe to work (Caffentzis, 2013). It conceptualized a monolithic ‘energy’ that was both inexhaustible and interconvertible and in so doing helped inaugurate a new worldwide ‘nature’. Whatever capital needed to make machines run – mechanical force, heat, electricity, magnetism, light – could be conjured up from any other form of energy that was lying around, given enough ingenuity. In steam engines, heat became mechanical energy on a new scale. In batteries, chemical energy became electricity and vice versa. In turbines, dynamos and windmills, mechanical energy became electricity at thousands of new locations. In electric motors, electricity became mechanical energy. On today’s solar farms, the sun’s radiation becomes heat or electricity. In light bulbs and laptops, electricity turns into heat and light; all helping ensure that workers are impelled to continue donating their life activity to capitalists to create surplus value. In short, particular patterns of energy conversion on an ever-growing scale are intrinsic to all forms of industrial capitalism, digital capitalism above all. In an increasingly-entrenched hierarchy expressed in the First Law, every 'little energy' of the commons – cooking fuel collected from common woodlands, oil left underground, undammed streams – is seen as subordinate to an overarching, 19th-century, Big-E abstract Energy (Lohmann & Hildyard, 2014).

The Second Law interposes a somewhat soberer view suggesting that this new Big-E Energy is better conceptualized as sweeping geographical rearrangements of gradients between low and high entropy (Rovelli, 2016; Prigogine, 1961; Hornborg, 2001). It shows that the more that capital instrumentalizes river flow, fire, wind, coal deposits, magnetism and so forth as being mere aspects of a great pool of abstract energy, the less of the new energy actually becomes available for capital's own use. The more that energy is converted back and forth into different forms (Smil, 2017: 26), the more of it is 'degraded'. In each energy conversion theorized by the First Law, something is lost irretrievably. Sadi Carnot, the first genius of thermodynamics, called these conversions 'falls' (*chutes*), pointing to a fertile analogy with waterfalls. Once a sluice gate is opened to let water run downhill to drive a waterwheel, the water can't be induced back uphill to restart the process without expending more energy than has already been released. Similarly, when coal is burned, the resulting heat, ash and carbon dioxide can't be reassembled back into coal without using more energy than the coal generated. With each energy conversion, energy gets dispersed across a greater number of microscopic states. On this view, what capital needs for its machines is not energy as such but these 'falls' in the landscape – differences between low and high entropy. These include gradients between hot and cold in heat engines, between the binding energy of electrons in molecular bonds and the heat generated in chemical reactions, between short-wave solar radiation at around 5760 Kelvin and longer-wave radiation emitted by the earth at 255 K into an outer space standing at a temperature of 2.7 K, and many more. When capital burns oil or runs radiation from the sun through solar panels or industrial biomass plantations, it does not use up energy but rather (to adapt an illuminating metaphor formulated by the quantum physicist Carlo Rovelli [2016]) pulls open various doors – usually violently – through which an entire territory slips more rapidly down those gradients, eroding the gradient itself in the process. Naturally, the sequence and patterning of that door-opening has to suit the operation of capital's conversion devices. Sluice gates are useless if they can't be opened and closed at the right times; coal is useless if heat and oxygen can't be applied, and carbon dioxide vented, in rhythms and places that fit the functioning of machines in controlling, disciplining and increasing the productivity of labour of all kinds. A 'Carnot landscape' tailored to industrial machines, in other words, will necessarily be different from, say, a landscape in which relationships need to be maintained with 'earth beings' such as mountains, cared for as integral to human identity and place (de la Cadena, 2010). And yet another kind of hierarchy must be imposed to ensure its construction.

This does not necessarily imply that more entropy doors are opened in Carnot landscapes than elsewhere. Everywhere, the door-opening process is nothing less than 'what makes the world go round … what causes events to happen in the world, what writes its history' (Rovelli, 2016). The universe's hypothetical prolonged one-way trip toward what 19th-century physicists dramatically called *Wärmetod*, or 'heat death', is, paradoxically, what gives it life – just as capital's energy conversion devices function only when they move toward eliminating the gradients that make them work. But patterns of entropy flow and system boundary-setting are variable. Entropy increases unevenly, at different paces in different places. Often the pace is very slow. For example, hydrogen and oxygen molecules can float around peacefully in a bottle for centuries, despite the fact that their combined internal bond energies are greater than that of the water that they could produce. Only when a spark is introduced will they react explosively to dissipate some of that internal energy into heat, forming the higher-entropy H_2O. Similarly, low-entropy oil that is left underground won't react with air to form heat and carbon dioxide for millennia unless it is deliberately unearthed and burned, opening channels that abruptly change it from a pool of low entropy into a larger expanse of residual heat and other 'wastes' that capital is unable to recycle while still remaining capital. Similarly, earthly territories of flowing water that are so often the focus of communal care across the world are in a state of higher entropy than the solar particles that, combined with gravity and other factors, indirectly give rise to them. Indeed, they owe their continuing life to entropic processes that, according to thermodynamics, drive all closed systems (and perhaps even the universe itself) toward stasis. All the same, they constitute basins whose local rate of entropy increase can remain relatively low for millions of years, until capital suddenly boosts that rate by seizing control and converting the kinetic energy of those flowing waters into electricity via hydroelectric dams, again leaving behind a landscape of waste. In general, the more intensively capital converts energy from one form to another, the higher the entropy of the system. And if that system is closed, the closer that entropy changes come to halting altogether. This dynamic is reinforced by the fact that capital typically structures its unprecedented entropy increases in chains. Before hydroelectric dams and turbines can go about their entropy-increasing business, entropy-increasing concrete and steel manufacture has to take place. Entropy-increasing wind turbines can't be built without previous entropy-increasing steel manufacture in China and balsa extraction in Ecuador. Rising rates of entropy increase associated with the movement of electrons in millions of electric cars in the global North stem not only from the prior construction of dams, wind farms and other energy-conversion devices, but also from new waves of entropic lithium and copper extraction in the Atacama and elsewhere. These chains only multiply overall entropy increases. In coal-fired generating plants, 60 per cent or more of the fuel's chemical energy is lost as waste heat. An additional percentage of the electrical energy generated is then dissipated into heat in transit to – for example – those high-frequency trading server farms or cryptocurrency mines stuffed with computer processors that need built-in cooling systems to dispel their own waste heat. Even the most up-to-date efficient light fixtures lose at least 20 per cent of the electrical energy feeding them. Their light is then partly downgraded again into heat on contact with, say, a billboard on an empty street at night.

Defying these trends in chosen zones where gradients between low and high entropy need to be maintained – in capital's case, in order to keep chains of labour-exploiting machines running – requires 'exporting' high entropy into surrounding regions. Capital's geography – collections of Carnot landscapes – is necessarily one in which boundary demarcation is constantly going on so that the environments of the increasing mass of energy conversion engines can be maintained in a nonequilibrium, dissipative steady state in which low entropy is constantly 'coming in' and high entropy 'going out' (Kleidon, 2016; Virgo & Harvey, 2007; Schneider & Sagan, 2005; Schrödinger, 1944). If industrial machines constantly need systematic 'activation' (Lambert, 1998) of metastable zones of low entropy, that is, they also need accelerated increases of entropy in other locations. Hierarchical Carnot landscapes of multiplying First Law conversion engines are also landscapes of increasing Second Law 'waste'. These, of course, are also hierarchically organized, in the form of relationships between energy beneficiaries and 'sacrifice zones' (Svampa, 2015). Both changes need to occur outside the machines themselves, as ordinarily conceptualized, involving wholesale shifts in the sites of energy dissipation. It is the resulting 'entropy balance' that 'sets the limit to the power of the engine' (Kleidon, 2016). Accordingly, if entropy is about territory (in a more than spatial sense), it is also about one territory's relations with another. In the vocabulary of physics, the 'extent to which the boundary is flexible in exporting entropy is a critical factor in calculating how far the system can evolve' (Kleidon, 2010), and for what period of time it can evolve, without collapsing into thermal equilibrium. In a more sociological vocabulary: 'unequal exchange in the world system is what reproduces machines, and machines are what reproduce unequal exchange' (Hornborg, 2001). Colonial projects are essential to restoring flattened-out entropy slopes.

The geographic images that tend to be associated with the First and Second Laws, like the meanings of the two laws for capital, persist in an interesting state of mutual tension. Despite the cautions of physicists (Bridgman, 1943: 115; Feynman, 2010: 4.1), the First Law encourages capital to take an abstracted view of energy as a unitary ‘thing’ independent of space and time, a singular resource extractable from a variety of sources and then ‘used up’ at various points of an essentially invariant landscape to make more and faster production possible. On this view, energy can be ‘depleted’ and ‘renewed’ (or not), in principle for the benefit of all human beings, who are conceived as autonomous entities existing independently of place. This is the geographic perspective of (for example) the International Energy Agency and its statistics about energy ‘consumption’. The Second Law, by contrast, calls up a different picture of energy as Carnot landscapes – a picture that makes much clearer to capital and to capital’s antagonists alike industrial capital’s intrinsically colonialist requirement for the constant reorganization of new entropy borders. On this view, what are called ‘Ministers of Energy’ are in reality ‘Ministers of Entropy Flow’. Their brief is to help wrench open their territories’ entropy doors and, if possible, keep their territories and others in such a state that they can continue to be wrenched open. From this perspective, the ‘energy’ that today’s policymaking classes chatter about is more accurately described as forcible territorial and interterritorial political reorganization in the service of the governance of capitalist labour.

From a Second Law perspective, for example, those cryptocurrency miners and data centres that situate themselves in cool, dam-studded landscapes owe their profitability to the cheap creation of temporary, steep entropy gradients destined to devolve into flatness as the dams, after having devastated local ecologies, are incapacitated by silt and have to be abandoned. For those gradients to be maintained, the reservoirs would have to be dug out at enormous energy cost and the resulting increased entropy ‘exported’ outside the borders of the hydroelectric system proper, with knock-on effects in extraction/pollution zones, including that of the entire earth system. Superimposing such boundaries over those defining previous, slower, differently-organized patterns of entropy increase is, of course, a political task. In many cases, the result will be to degrade territory-constituted human identities in addition to lives and livelihoods.

A First Law map is unlikely by itself to be able to depict such relationship and border changes. Typical treatments of ‘energy geography’ (e.g., Pasqualetti, 2011) often leave out what is arguably of most geographical significance about energy: evolving Carnot landscapes. Indeed, even a Second Law picture will be insufficient insofar as it abstracts away from what goes on outside the borders of any system tending to thermal equilibrium and fails to consider non-equilibrium thermodynamics as well. The 19th-century thermodynamics that, in ‘apolitical’ fashion, put a border around the whole universe, implying an eventual ‘heat death’ for everybody, reinforced the dominance of a single linear arrow of time as well as implicitly putting on everybody’s shoulders alike the burdens associated with the liberation of energy attributed to European intellectuals’ supposedly disinterested discoveries. But what Charles W. Mills (2014) calls this ‘sanitized and idealized White time’ necessarily overlay other histories of what is today called energy, steeped in the boundary politics that defines slavery, genocide, aboriginal expropriation and colonial rule over people of colour.

From this vantage point, today’s obligatory official moves toward ‘confronting’ the exorbitant energy use of recognition machines and other manifestations of AI – ‘greater efficiency’, ‘renewables’, ‘circular economy’, ‘net zero emissions’, ‘Nature-Based Solutions’, ‘carbon neutrality’ and the like – are also caught in a contradiction between the respective geographic images projected by the First and Second Laws. Insofar as these moves recycle the idea that energy is a colourless, genderless and all-inclusive substance, they cannot formulate the way forward as anything other than more careful global resource management. Nor can they formulate ‘energy justice' as anything more than fair distribution of a cleaned-up, essentially white substance (Lohmann, 2021a); reparational justice – which generally requires a sense of nonwhite time and anticapitalist territories – falls by the wayside. Claims to be able to 'compensate' for high AI energy use (as for high industrial energy use generally) meanwhile turn out only to open additional entropy doors outside the borders of the relevant nonequilibrium systems (Stapczynski, Rathi & Marawanyika, 2021). The fight against colonialist processes of organizing landscapes around capital-friendly entropy flows – represented by, to take one example, the struggle over the Dakota Access pipeline – is treated as if it could be ended rather than reinforced by, say, value-added lithium processing in Bolivia or expansion of geothermal or wind energy in some other landscape.

All this suggests that it is perhaps time for geographical research to pay greater attention to the distinctive geographic patterns of entropy door-opening characteristic of industrial/digital capitalism and the racial, patriarchal and class domination that make them possible and cheap. In particular, it will be useful for popular movements and their allies to trace and taxonomize the variety of cycles through which AI, using different arrangements of activation energies, sets up, rearranges, flattens and reconstitutes millions of new gradients between low and high entropy worldwide. Understanding such processes will be essential in identifying the concrete, distinctive instances of political violence centred on AI's appropriations from workers and nonhumans alike in the territorial web of life (Moore, 2015; Qiu, 2016) – a crucial aspect of the emerging 'digital natures' of the 21st century.

5. Conclusion

The social sciences and humanities are nowadays contributing a great deal to the critical understanding of artificial intelligence. The achievements of writers such as Collins (1990, 1998, 2018), Davidson (2004), Ekbia & Nardi (2017), Gray & Suri (2019), Dreyfus (1992), Zuboff (2019) and Crawford (2021) excepted, however, much political and social analysis of AI is handicapped by a seeming shyness about probing what AI, algorithms and data *are*, and what their intrinsic relationships are with historical and contemporary capitalism. Instead, it too often simply takes at face value various sloppy or inaccurate claims floated by AI proponents – for example that it is structurally capable of replacing living labour in capitalism, jump-starting a postcapitalist economy, decentralizing social relations, channelling the 'agency' of nonhumans or providing them with 'autonomy', reconstituting nature conservation, improving 'efficiency,' saving energy, furthering Indigenous conceptions of territory or rights of nature, performing its own science, or offering a pathway to 'luxury automated communism' (Bastani, 2019). Failing to grasp AI in terms of work – of capitalist mechanization and transformations surrounding nonequilibrium thermodynamic systems – many scholarly and journalistic approaches to the subject end up treating it as a black box that can only be assessed for appropriate 'applications' or possible 'implications.' If questions are raised about racism, colonialism, class conflict, patriarchy and ecological degradation, they are assumed *a priori* to be about the 'governance' of AI, not about the evolution and structure of AI itself.

This 'normalizing bias' puts many nominal academic critics of AI effectively in the position of unpaid public relations consultants to IT industries. It tends to isolate them from popular movements who, from the global frontiers of extractivism and inequality, are already interrogating AI at a deeper, more historically-informed political level, particularly in the global South (GRAIN, 2021; ETC Group, 2020), and is bound to inhibit working practical connections with them. To be sure, research programmes that treat AI as a black box whose internal dynamics and political history are left unexamined can produce important and helpful results. They can reveal, for instance, algorithmic bias and useful information on energy use and the spread of state and corporate surveillance. But without cross-fertilization with social movements and other intellectual currents historically committed to more thoroughgoing analysis, such efforts can be easily diverted into regulatory channels in ways that lead to failure either to understand what AI is about or to engage constructively the political situation of which it forms a part.

This article will have achieved its purpose if, through exploring the geography of recognition machines, it has encouraged researchers in the social sciences and humanities to have a bit more confidence in challenging the assumptions through which AI is usually defined – or not defined – in their fields. By focusing on some of the thermodynamic, class and colonial structures of the industrial machine networks that comprise AI, it has tried to outline some of the advantages of seeing the phenomenon in terms of the history of landscape, interpretive labour and political struggle. Doing so, it has suggested, is one important key to grasping the character of the 21st century's new digital natures.

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References

Anderson, C. (2000). The end of theory: the data deluge makes the scientific method obsolete. *Wired,* 23 June. Retrieved from https://www.wired.com/2008/06/pb-theory/. Accessed 19 August 2021.

Antunes, R. (2013). *The meanings of work: essay on the affirmation and negation of work.* Trans. by E. Molinari. Brill.

Barragan, L. C. (2018). *The Egyptian workers who were erased from history*. *Egyptian Streets.* Retrieved from https://egyptianstreets.com/2018/09/14/the-egyptian-workers-who-were-erased-from-history/. Accessed 19 August 2021.

Bastani, A. (2019). *Fully automated luxury communism: a manifesto.* Verso.

Bechmann, A & Bowker, G. C. (2019). Unsupervised by any other name: hidden layers of knowledge production in artificial intelligence on social media. *Big Data and Society*, January–June, 1-11.

BitMEX Research (2017). *Why is China dominant in Bitcoin mining?* 15 September. Retrieved from https://blog.bitmex.com/mining-incentives-part-2-why-is-china-dominant-in-bitcoin-mining/. Accessed 16 May 2021.

Boyd, W., & Prudham, S. (2017). On the themed collection, 'The formal and real subsumption of nature'. *Society & Natural Resources*, 0.1080/08941920.2017.1304600.

Bridgman, P. W. (1943). *The nature of thermodynamics.* Harvard University Press.

Buolamwini, J., & Gebru, T. (2018). Gender shades: intersectional accuracy disparities in commercial gender classification. *Proceedings of Machine Learning Research*, 81, 1–15.

Burawoy, M. (1979). *Manufacturing consent: changes in the labour process under monopoly capitalism*. University of Chicago Press.

Butler, E. (2019). A high-powered bitcoin boom in Georgia. *BBC Business Daily,* 4 November. Retrieved from https://www.bbc.co.uk/sounds/play/w3csy741. Accessed 16 May 2021.

Caffentzis, G. (2013). *In letters of blood and fire: work, machines and the crisis of capitalism.* PM Press.

Carbonell, J. S. (2018). Les ouvriers de Peugeot-Mulhouse après crise (2008-2018). Ph.D. diss., École Normale Supérieure.

Collins, H. M. (1990). *Artificial experts: social knowledge and intelligent machines.* MIT Press.

-----------------. (2018). *Artifictional intelligence: against humanity's surrender to computers*. Polity Press.

-----------------, & Kusch, M. (1998). *The shape of actions: what humans and machines can do.* MIT Press.

Crawford, K. (2021). *The atlas of AI: power, politics, and the planetary costs of artificial intelligence.* Yale University Press.

Cuvi, N. (2015). Sobre las formas de apropiación de ideas y cosas: algunas reflexiones para el diálogo. In A. Acosta & E. Martínez (Eds.), *Biopiratería*, (pp. 183-202). Abya Yala.

Daggett, C. N. (2019). *The birth of energy: fossil fuels, thermodynamics and the politics of work.* Duke University Press.

Daston, L. (2018, November). *Calculation and the division of labour, 1750-1950*. Thirty-first annual lecture of the German Historical Institute, Washington, DC.

Davidson, D. (1973). On the very idea of a conceptual scheme. *Proceedings and Addresses of the American Philosophical Association* 47.

---------------. (2001). *Subjective, intersubjective, objective*. Oxford University Press,.

---------------. (2004). *Problems of rationality.* Oxford University Press.

de la Cadena, M. (2010). Indigenous cosmopolitics in the Andes: conceptual reflections beyond 'politics'. *Cultural Anthropology* 25(2), pp. 334-370.

Dennett, D. C. (2019, June). The Margaret Boden lecture 2019, Cambridge University. Retrieved from https://www.youtube.com/watch?v=etRqofuWHpo. Accessed 18 August 2021.

Digiconomist (2021). Bitcoin energy consumption. Retrieved from https://digiconomist.net/bitcoin-energy-consumption. Accessed 16 March 2021.

Domingos, P. (2015). The master algorithm: how the quest for the ultimate learning machine will remake our world. Basic Books.

Dreyfus, H. (1992). *What computers still can't do*. MIT Press.

Dukes, J. S. (2003) Burning buried sunshine: Human consumption of ancient solar energy. *Climatic Change*, 61, 31-44.

Dyson, G. (2012). *Turing's cathedral.* Pantheon.

Eisen, M. (2011, April). *Amazon's $23,698,655.93 book about flies*. UC Berkeley blog.

Ekbia, H. R., & Nardi, B. (2017). *Heteromation, and other stories of computers and capitalism*. MIT Press.

Ensmenger, N. (2018). The environmental history of computing. *Technology and Culture,* 59 (4), S7-S33.

Essinger, J. (2004). *Jacquard's web: how a hand-loom led to the birth of the information age.* Oxford University Press.

ETC Group (2020). *Algorithmic colonization*. Retrieved from https://www.etcgroup.org/content/5-algorithmic-colonisation-abeba-birhane. Accessed 16 May 2021.

Feynman, R. (2010). *The Feynman lectures on physics*, vol. 1. Basic Books.

Gaffney, M., Ravenscroft, C., & Williams, C. (2019). Capitalism and planetary justice in the "web of life": An interview with Jason W. Moore. *Polygraph* 28, 161-182.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin.

GRAIN (2021). Digital control: How big tech moves into food and farming and what it means. Retrieved from https://grain.org/en/article/6595-digital-control-how-big-tech-moves-into-food-and-farming-and-what-it-means. Accessed 16 May 2021.

Gray, M. L., & Suri, S. (2019). *Ghost work: how to stop silicon valley from building a new global underclass*. Houghton Mifflin Harcourt.

Haugeland, J. (1998). *Having thought: essays in the metaphysics of mind.* Harvard University Press.

Hornborg, A. (2001). *The power of the machine: global inequalities of economy, technology and environment.* Alta Mira.

Huber, M. (2009). Energizing historical materialism: fossil fuels, space and the capitalist mode of production. *Geoforum* 40 (1), 105-115.

Hui, Y. (2014). What is a digital object? In H. Halpin and A. Monnin, (Eds.), *Philosophical engineering: toward a philosophy of the web* (pp. 52-67). Wiley Blackwell.

Ingold, T. (2000). *The perception of the environment: essays on livelihood, dwelling and skill.* Routledge.

Jefferson, B. (2020). *Digitize and punish: racial criminalization in the digital age*. University Of Minnesota Press.

Kapp, K. W. (1950). *The social cost of private enterprise.* Schocken.

Kirsch, S. and Mitchell, D. (2004). The nature of things: dead labor, nonhuman actors, and the persistence of Marxism. *Antipode* 36 (4), 687-705.

Kleidon, A. (2010). A basic introduction to the thermodynamics of the earth system far from equilibrium and maximum entropy production. *Philosophical Transactions of the Royal Society B* 365, 1303–1315.

-------------. (2016). *Thermodynamic foundations of the earth system.* Cambridge University Press.

Kohn, E. (2013). *How forests think: toward an anthropology beyond the human*. University of California Press.

Lally, N., Kay, K. and Thatcher, J. (2019). Computational parasites and hydropower: a political ecology of Bitcoin mining on the Columbia River. *Environment and Planning E: Nature and Space.* 2514848619867608. https://doi.org/10.1177/2514848619867608.

Lambert, F. (1998). Chemical kinetics: as important as the second law of thermodynamics? *The Chemical Educator* 3 (2), 1-6.

Lanier, J. (2018). *Ten arguments for deleting your social media accounts right now.* Henry Holt.

Levine, S. (2020). Rorty, Davidson, and representation. In A. Malachowski, (Ed.), *The Wiley-Blackwell companion to Rorty,* (pp. 370-394). Wiley,

Lohmann, L. (2020). Interpretation machines: contradictions of 'artificial intelligence' in 21st-century capitalism. *Socialist Register 2021*, 50-77. Retrieved from http://www.thecornerhouse.org.uk/resource/interpretation-machines. Accessed 16 May 2021.

---------------. (2021a). Is energy white? And if so, what does that mean for left strategy? http://www.thecornerhouse.org.uk/resource/energy-white, accessed 16 May 2021.

---------------. (2021b). Heat, time and colonialism. Forthcoming in *Energía y equidad.* Retrieved from http://www.thecornerhouse.org.uk/resource/heat-time-and-colonialism. Accessed 16 May 2021.

Lohmann, L. & Hildyard, N. (2014). *Energy, work and finance.* The Corner House. Retrieved from http://www.thecornerhouse.org.uk/resource/energy-work-and-finance. Accessed 16 May 2021.

McNally, D. (2003). Beyond the false infinity of capital: dialectics and self-mediation in Marx's theory of freedom. In R. Albritton & J. Simoulidis, (Eds.), *New dialectics and political economy*. Palgrave Macmillan.

Malm, A. (2015). *Fossil capital: the rise of steam-power and the roots of global warming*. Verso.

Mann, C. C. (2006). *1491: new revelations of the Americas before Columbus*. Vintage.

Marx, K. (2004 [1867]). *Capital*, vol. 1. Penguin.

Marx, K. & Engels, F. (1994 [1861-3]). *Collected works.* Vol. 34. Lawrence & Wishart.

Mills, C. W. (2014). White time: the chronic injustice of ideal theory. *Du Bois Review* 11(1), 27-42.

Mitchell, T. (2002). *Rule of experts: Egypt, technopolitics, modernity.* University of California Press.

Moore, J. W. (2015). *Capitalism in the web of life: ecology and the accumulation of capital.* Verso.

O'Neil, C. (2016) *Weapons of math destruction: how big data increases inequality and threatens democracy.* Crown.

Pasqualetti, M. J. (2011). The geography of energy and the wealth of the world. *Annals of the Association of American Geographers*, 101 (4), 971-980.

Pasquinelli, M. (2015). Italian operaismo and the information machine. *Theory, Culture and Society,* 32 (3), 49–68.

-----------------. (2019). On the origins of Marx's general intellect. *Radical Philosophy* 2.06, 43-56.

----------------- & Joler, V. (2020). The Nooscope manifested: AI as instrument of knowledge extractivism. *AI & Society.* https://doi.org/10.1007/s00146-020-01097-6.

Pfeiffer, S. (2016). Robots, Industry 4.0 and humans, or why assembly work is more than routine work. *Societies* 6 (16), 1-26.

Polimeni, J., & Mayumi, K. (2015). *The Jevons paradox and the myth of resource efficiency.* Routledge.

Prigogine, I. (1961). *Introduction to thermodynamics of irreversible processes.* Wiley-Interscience.

Qiu, J. L. (2016). *Goodbye iSlave: a manifesto for digital abolition.* University of Illinois Press.

Rorty, R. (1979). *Philosophy and the mirror of nature.* Princeton University Press.

----------. (2001). *Objectivity, relativism and truth*. Cambridge University Press.

Rouse, J. (2002). Vampires: Social constructivism, realism and other philosophical undead. *History and Theory,* 41: 60-78.

Routley, N. (2017). Visualizing the trillion-fold increase in computing power. *Visual Capitalist.* Retrieved from https://www.visualcapitalist.com/visualizing-trillion-fold-increase-computing-power/. Accessed 16 May 2021.

Rovelli, C. (2016). *The order of time.* Penguin.

Schaffer, S. (1994). Babbage's intelligence. *Critical Inquiry* 21(1), 203-27.

Schneider, E. G., & Sagan, D. (2005). *Into the cool: energy flow, thermodynamics and life.* University of Chicago Press.

Schrödinger, E. (1944). *What is life?* Cambridge University Press.

Smil, V. (2017). *Energy and civilization: a history*. MIT Press.

Smythe, D. (2006 [1981]). On the audience commodity and its work. In Meenakshi G. Durham and Douglas M. Kellner, (Eds.), *Media and cultural studies* (pp. 230–56). Blackwell.

Socialist Project. (2021, June). *Far from over – class struggle and union organizing at Amazon*. Retrieved from https://socialistproject.ca/leftstreamed-video/far-from-over-class-struggle-union-organizing-amazon/. Accessed 19 August 2021.

Starn, J. (2020, December). Bitcoin miners in Nordic region get a boost from cheap power. *Bloomberg*. Retrieved from https://www.bloomberg.com/news/articles/2020-12-27/bitcoin-miners-in-nordic-region-get-a-boost-from-cheap-power. Accessed 16 May 2021.

Stapczynski, Rathi & Marawanyika. (2021, August). *How to sell 'carbon neutral' fossil fuel that doesn't exist*. *Bloomberg Green*. Retrieved from https://www.bloomberg.com/news/features/2021-08-11/the-fictitious-world-of-carbon-neutral-fossil-fuel. Accessed 19 August 2021.

Strubell, E., Ganesh, A., & McCallum, A. (2019, July) *Energy and Policy Considerations for Deep Learning in NLP*. Fifty-seventh Annual Meeting of the Association for Computational Linguistics, Florence, Italy. Retrieved from http://arxiv.org/abs/1906.02243. Accessed 16 May 2021.

Svampa, M. (2015). Commodities consensus: neoextractivism and enclosure of the commons in Latin America. *South Atlantic Quarterly* 114 (1), 65-82.

The Economist. (2015). The trust machine. 31 October.

Thorpe, V. (2021). If you enjoyed that, you will like this: but can we break free from the algorithms' grip? *The Guardian*, 4 April. Retrieved from https://www.theguardian.com/culture/2021/apr/04/if-you-enjoyed-that-you-will-like-this-but-can-we-break-free-from-the-algorithms-grip. Accessed 16 May 2021.

Tinel, B. (2013). Why and how do capitalists divide labour? From Marglin and back again through Babbage and Marx. *Review of Political Economy,* 25 (2), 254- 72.

Toscano, A. (2016). The world is already without us. *Social Text* 34 (2), 109-124.

Trustnodes (2018, December). *Vitalik Buterin: Blockchains of the future will be thousands of times more efficient*. Retrieved from https://www.trustnodes.com/2018/12/11/vitalik-buterin-blockchains-of-the-future-will-be-thousands-of-times-more-efficient. Accessed 16 May 2021.

Virgo, N., & Harvey, I. (2007). Entropy production in ecosystems. In Almeida e Costa F., Rocha L.M., Costa E., Harvey I., Coutinho A., (Eds.), *Advances in Artificial Life* (pp. 123-132). Springer.

Walker, R. (2016): Value and nature: Rethinking capitalist exploitation and expansion. *Capitalism Nature Socialism.* http://dx.doi.org/10.1080/10455752.2016.1263674. Accessed 16 May 2021.

Wittgenstein, L. (1953). *Philosophical investigations.* Cambridge University Press.

Zuboff, S. (2019). *The age of surveillance capitalism: the fight for a human future at the new frontier of power*. Public Affairs.