**draft for special issue of *Digital Geography and Society* on 'digital natures', 17 May 2021
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Heat, Colonialism and the Geography of Artificial Intelligence

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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 important contemporary political struggles. The first insight is that artificial intelligence consists of energy-intensive forms of mechanization that are continuous with those of 19th-century phases of industrialization, with all of their social and ecological characteristics. The second insight is that it can be useful to reconceptualize the relation between artificial intelligence and energy in geographic terms. This reconceptualization is premised on picturing the practice and 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 identifiable geographic patterns of racism, patriarchy, colonialism and ecological fatigue. Implicitly critiquing the dominant academic and journalistic methodology of blackboxing AI and then looking at political and geographic 'implications' of the existence of the resulting reified object, 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 white, middle-class 'regulate and reform' academic literature.

The plan of the article is as follows. The second section introduces the concept of recognition machines as one fruitful avenue for investigation of AI. The third section argues for the political importance of looking in geographic terms at the abstract, thermodynamic energy that was developed in the context of 19th-century industrial mechanization and continues to be central to 21st-century industrial interpretation mechanization. The fourth section proposes systematic research into the accelerated rejiggering of entropy landscapes that has accompanied the rise of AI, together with its ecological and labour accompaniments. A final section summarizes the main points, arguing that the framework advocated here can be 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 proposes a focus 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, 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.

A focus on recognition machines has several virtues for investigations of AI. First, today's recognition machines are politically significant in ways that more primitive 19th- and 20th-century recognition machines – contained in steam engine governors, thermostats, autopilots and so forth – were not. Contemporary recognition machines' 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. They operate in machine translation platforms, platform-advertising auctions, police investigations, self-driving vehicles, high-frequency trading programmes, automated farming or nature conservation, and household devices, augmenting, speeding up or in some cases seemingly replacing human recognition. That alone indicates the importance of treating recognition machines as a topic for geographic investigation.

Second, recognition machines are a key building block of the more encompassing interpretation machines that constitute AI as a whole (Lohmann, 2020). Accordingly, they offer one good way into an even larger topic. Recognition machines can be "freestanding" in the form of specialized applications such as devices for voice recognition, facial recognition and so forth and as such are economically and politically significant in themselves. But they can can also be components of bigger interpretation machines whose outputs are commonly described using terms other than 'recognition.' Thus translation machines must be able to identify characters, sentences and languages in order to interpret texts. Robots need to be able to classify insects and plants in order to execute automated farming. High-frequency trading machines need to recognize prices for what they are. Self-driving vehicles must be able to distinguish, at least in some attenuated sense, traffic lights, motorcycles, crosswalks or bridges. And so on for more complex forms of AI such as smart contracts and synthetic agents.

A third advantage to singling out recognition machines as a topic for dedicated investigation is that to do so is an opportunity to direct much-needed attention to the materiality of *human* recognition, and ensure that political and geographic critique are founded on an understanding of it. For many decades, of course, recognition machine developers themselves have been exploring the materiality of recognition process insofar as they base their programme on the assumption that recognition or facsimiles thereof can be carried out by physical objects – machines as well as human bodies. Founding itself on a history of material devices ranging from Jacquard's loom to Babbage's engines, Shannon's logic circuits, and Rosenblatt's perceptrons, their research and experimentation continues to be guided by an iconography featuring neuronic, robotic or other physical models. But recognition machine developers – and many critics as well – tend to neglect other aspects of recognition's materiality involving the co-evolution of changing and unpredictable physical environments with ongoing recognition abilities exercised by bodies in society moving through time along physical pathways (Ingold, 2000; Gibson, 1979). Even after the relative eclipse of the approaches to AI commonly described as 'expert systems' and 'GOFAI' (Good Old-Fashioned Artificial Intelligence) in the 21st-century, the idea has persisted that mechanized predictive algorithms might offer a short-cut around this aspect of recognition's materiality – that they ought to be able to "compress experience", to borrow the words of Ted Chiang (2010). Signalling a continuing Cartesian, anti-materialist institutional commitment to reproducing dualisms of representation/reality, idea/object, image/thing, thought/action, blueprints/building, calculation/measurement, rule/application, law/land, human/nonhuman and culture/nature (Mitchell, 2002), 21st-century deep-learning recognition technologies persist, ironically, in militating against a thoroughly materialist understanding of *human* recognition. Probing the ways in which this dependence on predictive algorithms underpins recognition machines' notorious racism and sexism (Bualomini & Gebru, 2018; O'Neil, 2016; Jefferson, 2020; Liebman, this volume?) and difficulties with agency and serendipity (Thorpe, 2021) is one effective way of grasping what AI actually is, and in connecting its programme historically with other modernist projects as well as the general drive of capital to 'escape the finite' (McNally, 2003).

A fourth advantage of studying the mechanization of recognition is the ease with which it can be shown to be dependent, like its 19th-century industrial predecessors, on increasing amounts of what Marx (1867) called 'living labour,' without which it would be useless to capital. It is obvious that the monetizable big data that have propelled IT companies to the top of the world economy rely on continuous living infusions ('data exhaust,' ReCAPTCHA inputs, microtasks by home workers, and so forth) from billions of sensors grafted onto living subjects as well as gigantic catalogues 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 'Industry 4.0' programmes (Pfeiffer, 2016) to animate their 'dead' statistical-predictive work. Indeed, every advance in mechanized recognition can be demonstrated to require corresponding increases in what Collins and Kusch (1998) call human RAT work – "repair, attribution and all that" – to fix and cover up for AI's ever-reduplicating failures to do what its proponents say it is doing. This analysis, too, can be helpful in opening the black boxes that still litter many academic studies of AI. It offers a reminder of the relevance to digital geography of Marx (1867), who cautioned 150 years ago 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'.

3. Energy geography

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 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 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. Growth in divisions of labour encouraged the development of a "mightier moving power than that of man" (Marx 1867) – 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. This 'moving power' was the commensurated 'energy' that emerged as a new term of art and set of practices in Northern Europe and elsewhere around 1800-1870. The 'birth of energy' (Daggett, 2019) 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). With energy, 'slow' individual human motions associated with, for example, spinning or stalk-cutting, which had historically been entangled and sustained within other social and ecological wholes, could now be profitably isolated, made uniform, 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 expanded worldwide, together with 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). All this only increased the intensity and vulnerability of capital's parasitism on various independently-evolved vital capacities of the living world. Repeatedly pushed from 'formal subsumption' toward 'real subsumption,' capital 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 increased with its excavation of more and more sedimented remains of photosynthetic work in the form of fossil fuels (Dukes, 2003), so too did its debt to the myriad evolved patternings (Kohn, 2013) of living organisms, more and more varied pieces of which it also continually strove to attach to machines. With industrial automation and thermodynamic energy, the contradiction sharpened between capital's own reproduction time and the "reproduction time of the web of life" (Gaffney, Ravenscroft & Williams, 2019) that capital 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 – cotton spinning, say – 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.

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. Despite the efforts of many physicists themselves to clarify its meaning (e.g., Bridgman, 1943, p.

115; Feynman, 2010, 4.1), the First Law has tended to encourage capital to take an abstracted view of energy as a thing independent of space and time, a unitary, interconvertible 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. The Second Law interposes a contrasting, soberer view, suggesting that the 'energy' that industrial capital (as well as life itself) relies on is better conceptualized as sweeping geographical rearrangements of gradients between low and high entropy (Rovelli, 2016; Prigogine, 1961; Hornborg, 2001). In contrast to capital's image of energy as a *resource*, to whose essence geography is irrelevant and that can be 'depleted' and 'renewed' (or not), in principle for the benefit of anybody, the Second Law – and nonequilibrium thermodynamics in particular – points toward a picture of *landscapes* where 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; Schrodinger, 1944). Industrial machines constantly need systematic 'activation' (Lambert, 1998) of metastable zones of low entropy as well as accelerated increases of entropy in selected environments elsewhere. They require wholesale shifts in the sites of energy dissipation. Both changes need to occur outside the borders of the machines themselves. That implies a broader political geography of energy than the 'resource' picture is capable of accommodating. Energy geography cannot confine itself to the study of the 'effects' of 'its' use on extraction points or consumption points or any points in between, or on the planet. It also needs to take 19th-century energy out of this black box in order to grasp it as a violent alteration in the earthly self of what some Indigenous peoples of the Americas call 'territory' itself. That entails understanding energy in a much more political sense than has typically been available to even its more radical academic critics.

4. The AI jump

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). And so on.

What may be less widely understood is that this 'AI jump' is mainly just a more intense phase of the same geographic transformations inaugurated by the 19th-century industrial revolution. Far from representing the dawning of a 'dematerialized' economy, it constitutes a *ratcheting up* of essentially the same material violence against women, nature, colonies, people of colour and workers generally (Crawford, 2021). Pre-industrial capitalist divisons of labour underlay the 19th-century industrial revolution's regimes for delivering speeded-up, strengthened, indefinitely-repeated motion sequences analytically derived from bodily motions associated with, for example, historical activities of spinning or stalk-cutting. Newer divisions of labour theorized by computer science and robotics now underpin AI's regimes for delivering brute-force repetitions of electronic motion sequences in almost incomprehensible volume at almost incomprehensible speeds, with correspondingly huge requirements for cheap or zero-cost living labour to tend the operations. As with the 19th-century industrial revolution, '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). Yet, as with 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*. In general, the unsustainable dynamics of 19th-century energy geography have only been exacerbated.

Exacerbated how much, and in what respects? In some senses, of course, it would be pointless to try to disentangle information technology's manipulation of entropy gradients 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 two-way interactions with heat engines (Caffentzis, 2013: 127-200). Nevertheless, as suggested above, some numbers can be put to hint at the extent to which recognition machine applications (say) are increasing rather than decreasing aggregate global energy use and exploitation of cheap living labour. More important, however, might be to trace and taxonomize the variety of cycles through which AI, using different arrangements of activation energies (Lambert, 1998), sets up, rearranges, flattens and reconstitutes millions of new, essentially geographic gradients between low and high entropy worldwide, and to identify them as concrete, and in many cases novel, instances of political violence centred on appropriations from workers and other parts of the territorial web of life (Moore, 2015; Qiu, 2016). To take a simple indicative example, sunk investments in surplus hydropower in China, Georgia, Sweden and Norway have created an environment of cheap, steep, unevenly-distributed entropy slopes where cryptocurrency miners or other types of data centres can now situate themselves (BitMEX Research, 2017; Starn, 2020; Butler, 2019), in theory until the dams, after having devastated local ecologies, are incapacitated by silt and have to be abandoned as the entropy gradients flatten out. AI's prediction-manufacturing apparatuses will never be perfectly comparable with the cotton- or steel-manufacturing apparatuses of the 19th century in every detail, but the identity of their respective global *thermodynamic* and *ecological* structures is unmistakable. As is their common genealogy, which follows much the same pattern involving class conflict and capitalist competition, 'stupidifying' divisions of labour, the 'energization' thereof, and the resulting colonial projects needed to restore flattened-out entropy slopes. Artificial intelligence engenders stupidity in much the same sense that classical assembly lines do. In a sense, it represents yet another energy-intensive attempt to reproduce the mind/body dualisms central to contemporary capitalism.

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), Ekbia & Nardi (2017), Gray & Suri (2019), Dreyfus (1992) and Crawford (2021) excepted, however, much political and social analysis of AI is handicapped by its failure to inquire what AI *is*. Instead, it too often simply takes at face value various sloppy or inaccurate definitional claims floated by AI proponents, for example that it is structurally capable of replacing living labour in capitalism, jumpstarting a postcapitalist economy, decentralizing social relations, channelling the 'agency' of nonhumans or providing them with 'autonomy', reconstituting nature conservation, improving 'efficiency,' furthering indigenous conceptions of territory or rights of nature, 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 has somehow irrevocably irrupted onto the scene and can now 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, never about AI itself.

This 'normalizing bias' puts many nominal academic critics of AI effectively in the position of unpaid consultants to IT industries. It tends to isolate them from popular movements who, from the global frontiers of extractivism and inequality, are questioning 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 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 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 or to engage constructively the political situation of which it forms a part.

This article will have achieved its purpose if it encourages researchers in the social sciences and humanities to have a bit more confidence in challenging the assumptions through which AI is usually defined in their fields. By focusing on the thermodynamic, class and colonial structure 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, labour and political struggle. That contextualization, it has suggested, is needed in order to understand the technical details of what AI actually is.

References

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

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, accessed 16 May 2021.

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.

Chiang, T. (2010). The lifecycle of software objects. Subterranean Press.

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

----------------- (2018). *Artifictional intelligence.* 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 *Biopiratería*, (Ed. by Acosta, A., & Martínez, E.), 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). Calculation and the division of labour, 1750-1950. Thirty-first annual lecture of the German Historical Institute, Washington, DC, 9 November 2017.

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

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.

Dyer-Witheford, N., Kjosen, A. M., & Steinhoff, J. (2019). *Inhuman power: artificial intelligence and the future of capitalism.* Pluto.

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.

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

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

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.

Kleidon, A. (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.

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

Liebman, A. (forthcoming). Crop ontologies, digitization and the renovation of racialized expropriation in development agriculture. This issue.

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 *New dialectics and political economy* (Ed. by Albritton, R., & Simoulidis, J.). Palgrave Macmillan.

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

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.

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

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.

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.

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

Starn, J. (2020). Bitcoin miners in Nordic region get a boost from cheap power. *Bloomberg*, 27 December. 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.

Strubell, E., Ganesh, A., & McCallum, A. (2019) Energy and policy considerations for deep learning in NLP. Fifty-seventh Annual Meeting of the Association for Computational Linguistics, Florence, Italy, July, http://arxiv.org/abs/1906.02243. Accessed 16 May 2021.

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.

Trustnodes (2018). Vitalik Buterin: Blockchains of the future will be thousands of times more efficient, 11 December. 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. *Advances in Artificial Life*, 123-132.

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.

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