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Steps to an Ecology of Algorithms

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Abstract

Anthropological expeditions seeking out algorithms frequently return empty-handed. They are confronted with the challenge of the object: what to study when studying algorithms? In this article, I draw together a number of literatures to outline one possible answer to the question of how to study algorithms in social science. I argue that what we should study are algorithmic ecologies. I sketch five modalities of algorithmic ecologies and review concomitant literatures: (*a*) imaginaries, (*b*) infrastructures, (*c*) interfaces, (*d*) identities, and (*e*) investments and interests. The speculative propositions offered here are that algorithms are immanent to ecologies and that they are enacted across all the modalities of algorithmic ecologies.

INTRODUCTION: THE CHALLENGE OF ALGORITHMS FOR ANTHROPOLOGY

Here is a definition of algorithms: Algorithms are standardized ways of satisfying if-then conditionals, often working with Boolean binary values and running on electric circuits, operating autonomously, depending on varying degrees of freedom. Such a definition is of little help to social scientists or to anyone else for that matter. What does it mean to say that algorithms do things? What should anthropology, and social science more broadly, want from, and in, the study of algorithms? And what does it even mean to study algorithms? This review draws together a number of literatures to outline one possible answer to the question of how to study algorithms. That answer is that we should study algorithmic ecologies.

Algorithms have been studied as organizers of attention and addiction (Kockelman 2013, Seaver 2019), as shapers of taste and objects of care and capture (Seaver 2022), and as shapers of publics (Gillespie 2014, Crawford 2016). They have been considered as self-learning drivers of automation (Lowrie 2018) and as powerful fetishes (Thomas et al. 2018). Algorithms have been argued to reorganize modern rationality and vision (Erickson et al. 2013, Halpern 2014, Totaro & Ninno 2014). Studies have focused, among other things, on music improvisation labs (Wilf 2013), music recommender companies (Seaver 2017), precision warfare (Suchman 2020), dating website companies (Illouz 2013), search engines (Gillespie 2014), marketing and web analytic companies (Cheney-Lippold 2011), plagiarism software (Introna 2016), works of art (de Vries & Schinkel 2019), and Netflix (Hallinan & Striphas 2016). Programmatic texts have appeared, pointing the way forward for anthropological studies of algorithms (Dourish 2016; Seaver 2017, 2018), and there is now even an *Annual Review of Anthropology* article.

Yet it is by no means clear that all who study algorithms refer to the same things. Even if "algorithm" has a history in mathematics that predates its namesake Muhammad ibn Mūsā al-Khwārizmi (c. 780–c. 850), it is no longer a mere technical term, even if its popularization happened, according to Dourish writing in 2017, "only a few years ago" (Dourish 2017, p. 213). It can be considered as a placeholder for desires and anxieties (de Vries & Schinkel 2019), as an imaginary (Bucher 2017, Finn 2017), and as culture (Striphas 2015, Seaver 2017). A social science of algorithms is confronted with what can be called the challenge of the object. Are algorithms agents or patterns, culture or materials, subjects or objects, things or events, endogenous process or exogenous atmosphere? One strategy is to consider algorithms in their multiplicity, shifting from "algorithm" to "algorithmic systems" (Seaver 2017, 2019) or "algorithmic assemblages" (Lowrie 2018). Such strategies to lexically singularize heterogeneous entanglements do not abate the difficulty of observing algorithms. Algorithms are characterized by opacity and elusiveness (Pasquale 2015, Burrell 2016). They are black boxes, if only because they are proprietary technologies, and they are not readily locatable, which makes them ethnographically complex. The challenge of the object is amplified by algorithmic performativity (Kitchin 2017): Algorithms affect other objects of anthropological concern (Kockelman 2013), ranging from comparison and classification to race, markets, or media.

In this review, I eschew the desire (inspired by the discussions of the Linköping-based Algorithm Studies Network) to "grasp the algorithm" by looking "under the hood," to open up the black box of algorithms in favor of opening analysis up to the manifold relations in which algorithms (con)figure (Lee & Björklund Larsen 2019, p. 2; Lee et al. 2019). I sketch the organizing elements of an ecological perspective by discussing existing work on what I call the modalities of algorithmic ecologies: infrastructures, imaginaries, interfaces, identities, and investments and interests. The speculative proposition offered here is that algorithms are immanent to ecologies and enacted across all these modalities. This review is based mostly on studies written in English, which is a sign of its author's linguistic limitations, of Anglo-Saxon academic hegemony, and of the political geography of the particular academic fashion that is the social science of algorithms.

ALGORITHMS AND/AS CULTURE

The anthropology of algorithms frequently encircles black boxes, and its expeditions seeking algorithms return empty-handed. As noted at many a conference on algorithms (Ziewitz 2016), algorithms are often found to be bewildering research objects, difficult to grapple with or even define. As Uricchio (2015) writes, "[T]he term 'algorithm' seems to conjure up responses disproportionate to the simplicity of its meaning" (p. 6). Yet from an anthropological perspective, there is nothing trivial about simplicity of meaning, which is a complex achievement that is unstable across contexts. In addition, Seaver (2017) has shown how software developers, too, often cannot point the ethnographer to an object. At the same time, Facebook users have become aware of the workings of algorithms (Bucher 2017). Moreover, there is widespread proprietary blackboxing (Pasquale 2015), and therefore there must be, paradoxically perhaps, identifiable algorithms whose invisibilization and mystification are legally enforced.

One manifestly anthropological way forward is to consider algorithms as culture. Dourish (2016) discusses an "algorithmic culture," in which algorithms figure as shaping cultural productions. Hallinan & Striphas (2016) show how algorithmic information processing changes conceptions of culture by analyzing a contest in which the accuracy of Netflix's recommender system was to be boosted. Striphas (2015) has argued that algorithms perform the work of sorting, classifying, and hierarchizing for which culture is the name, giving rise to an "algorithmic culture." And Seaver (2017) proposes to regard algorithms not "in" culture but "as" culture, i.e., "as the manifold consequences of a variety of human practices" (p. 4), where "culture" signifies not an object but "something people do." Yet there may be limits to solving definitional problems by subsuming algorithms under modern anthropology's master signifier, which equally lacks definitional precision but primarily serves disciplinary jurisdictional purposes.

One option is to consider algorithms as patterning technologies, which present a specific challenge to anthropologies of rule-following (cf. Das 1998). Building on Wittgenstein, Bourdieu (1977) famously argued against the "fallacy of the rule" and the codification of tacit knowledge as both intellectualist and determinist (pp. 29–30). But maybe algorithms, as coded rules (Daston 2022), introduce precisely the rule-like elements that Bourdieu dismissed as phantoms behind the regularities of practice. Certainly, coded rules are ubiquitous; billions of people are endowed with carry-on algorithmic devices (smartphones and other Turing machines) affecting their attention and capturing their practice in the form of commodifiable data. Consistent with Wittgenstein's idea that rules are characterized by an inability to determine their application, an anthropological answer to this question would nonetheless maintain that algorithms both act on and are acted on by their ecology of reference, and in the interval between recursive calculations lies contingency and agentic initiative, giving rise to interaction rather than one-sided action.

Perhaps the construal of algorithms as culture illustrates that anthropology, too, can be considered an algorithm: One inputs for ethnographic processing, and it gives "culture" as output. Just as predictably, the equivalent move in sociology has been to speak of a "society of algorithms" (Burrell & Fourcade 2021), which can also appear as a "black box society" (Pasquale 2015). But algorithmic entanglements exist both beyond and beneath the classical realms of "culture" and "society." For that reason, I propose an ecological perspective on algorithmic entanglements.

AN ECOLOGY OF ALGORITHMS

Considering algorithmic entanglements ecologically means to see them as "interlocking circuits of contingency" in which immanence takes precedence (Bateson 1972, pp. 146, 338). Bateson (1972) argued that "the computer is only an arc of a larger circuit which always includes a man and an environment" (p. 317), which holds for algorithms too. Notions of ecology have become part of the state of the art in media and communication studies (Altheide 1994, Fuller 2005, Peters 2015); in studies of digital environments (Halpern 2014, Gabrys 2016), knowledge production (Star 1995), and big data infrastructures (Borgman 2015); in infrastructure studies (Star 1999, Varnelis 2009); in robotics (Nourbakhsh 2013); and in architectural robotics and ubiquitous computing (Green 2016). Ecology should be understood not as an "environment" of something stable (i.e., "culture" or "society"), but as a "domain of entanglement" (Ingold 2011, p. 71), a dynamic composition of forces and effects (Bier & Schinkel 2016). An ecological perspective attends to the distributed character of practices and spaces. It does not afford ontological primacy to any one constituent element in an ecology but focuses on their entangled emergence as continuous accomplishment. As Choy (2011) writes, ecology signals "an emergent web of relationships among constitutive and constituting parts" (p. 11). He adds that ecologies are not given but "posited and established through scientific (ecological) research" (p. 12). This establishing is, of necessity, political. It flags a task of composition that always entails questions of ontological politics (Stengers 2018) that start from a refusal to know beforehand what the world is composed of.

An ecological perspective makes more readily understandable that search parties for the algorithm come up empty-handed. A useful analogy here is to see algorithms as vacuoles in ecologies. Deleuze (1995) once used the biological concept of "vacuole" in a conversation with Toni Negri to describe places of noncommunication or "circuit breakers" (p. 175). Vacuoles are membrane-enclosed compartments in the cytoplasm of cells. They contain, isolate, export, or delay molecules, and most importantly they sift, sort, and select. Considering algorithms as vacuoles (in terms not of substance but of operability) would mean to both account for their elusiveness and underscore the fact that, while much agency is ascribed to algorithms, they may operate less like conduits and more like circuit breakers or at least circuit benders. Algorithmic vacuoles are creative but in noncommunicative, elusive, and opaque ways. Thus, we eschew fantasies of smoothness and remain attentive to friction (Tsing 2004). Algorithms are not smooth passage points or portals for control but circuit benders and breakers, just as in Foucault power operates through passage points, such as bodies, that thereby constitute friction and resistance. This makes us attentive to the fact that, for algorithms to be forces of control or surveillance, work needs to be done (Neyland & Möllers 2017). As in cells, the membranes of algorithmic vacuoles are key, and these can be understood as sets of entanglements, for instance as infrastructures, interfaces, or imaginaries.

As a way of taming the challenge of the algorithmic object, the concept of ecology means taking seriously observer-dependency. It also opens up to the cosmopolitical injunction, put forward by Stengers (2018), to confer on algorithms as an issue the power to make us feel and think in ways that problematize our own concerns over, and commitments to, what algorithms can be. One way to do that is to recognize the different ecological entanglements or partial connections (Strathern 2004) in which algorithms figure and figure in inevitably multiple ways. I call such entanglements the modalities of algorithmic ecologies. I analytically distinguish five such modalities and review concomitant literatures: (*a*) imaginaries, (*b*) infrastructures, (*c*) interfaces, (*d*) identities, and (*e*) investments and interests. The speculative proposition here is that algorithms are immanent to such ecologies and are enacted across all these modalities.

Imaginaries

Algorithms have what Bergson and Deleuze have called a "fabulative function" (Deleuze 1966, pp. 113–14): They help shape and cut short infinite regress in social imaginaries, but (paradoxically) they do so recursively. Fabulation, the selective ways of imagining and imaging, of carving out what is seeable and sayable, is constitutive of algorithms, but imagined communities are also algorithmically mediated (Goode 2021, Mihelj & Jiménez-Martínez 2021), which is one example of how publics are algorithmically constituted (Gillespie 2014). We should avoid dialectical desires for sublation here and welcome the variety of entry points into ecological entanglements that this brings. Yet such social imagination needs to be situated in largely Western histories of calculative rationality (Erickson et al. 2013) and is not specific to, for instance, Yoruba logic and math (Verran 2001), even if imaginaries travel in tandem with imperialist infrastructures. Algorithmic imaginaries can be seen as a specific kind of "sociotechnical imaginary" (Jasanoff 2015, p. 4). However, a conception such as Jasanoff's threatens to place undue restrictions in assuming imaginaries' consensual underpinnings. So does Taylor's famous conception of "social imaginaries" as "that common understanding that makes possible common practices and a widely shared sense of legitimacy" (Taylor 2004, p. 23). Imaginaries point at background understandings, but these need not be, as Jasanoff assumes, "collectively held" or, as Taylor insists, "common" and "shared by large groups of people, if not the whole society" (p. 23). Such by now canonical conceptions are too invested in a consensual worldview, even if such a worldview lacks historical plausibility. For imaginaries to exist, consensus and shared understandings need not exist; shared misunderstandings, conflicts, and controversies suffice.

When proffered by corporations and governing bodies, algorithmic imaginaries are rearticulations of the "Californian ideology" (Barbrook & Cameron 1996). They exhibit what we might call a smart charisma that mobilizes desires, expectations, speculations, and calculations through associations with efficiency, utopian problem-solving, innovation, freedom, participation, and sustainability. Friction is thus imaginatively opposed to, and translated into, seamlessness. Inefficiency becomes optimization. Latency is fabulated into real time, material into virtual, glitch into code, and hacks are (re)appropriated when imagined as (security) control and optimization. Complexity is imagined as source rather than limitation when experienced as "smartness." Smart cities, smart homes, and the Internet of Things (IoT) are key sites of such algorithmic imaginaries, and the IoT sometimes figures as a meta-imagination of the network-connectedness of all objects. While the "smart city," for instance, is not a city but an imaginary accompanying patchworks of often fragmented and uneven implementations of sensor technologies, the seductive appeal of smart charisma lies in how it renders things as subject to optimization yet (un)available for public concern, commensurating a variety of issues beyond antagonism, even beyond (agonistic) deliberation. Optimization is a promissory logic. It is seductive because it depoliticizes issues and defers accountability and does so in charismatic ways, linking the smoothness of Silicon Valley logos and lobbies to the logistical problems of urban planners or even the slickness of the slides at anthropological conferences.

Smart charisma often comes with a political imaginary of experimentality. Experimentality is materially expressed in formats such as the "laboratory," as in the proliferation of "urban labs" (Rahmawan-Huizenga & Ivanova 2022); test beds (Halpern et al. 2013); prototypes (Suchman et al. 2002, Jiménez 2014); experiments (Hodson & Marvin 2016); simulations (Suchman 2016); models (Batty 2007); scenarios (Amoore 2013); demos (Halpern 2015); explorations, trials, or versions (Kirschenbaum 2008); or pilots (Grommé 2015). Experimentality, often deployed as public policy strategy, is a technique of temporality that suspends histories and establishes an immanent timeframe. It embodies a logistical logic by coding the future as repetition of a present of optimization, for instance in dynamic pricing systems for services and commodities and in logistical representations of smart cities as spaces of seamless circulations. Likewise, in military contexts, "network-centric warfare" can be celebrated along with the heightened "situational awareness" (Suchman 2015) and "precision" that algorithmic warfare ostensibly allows (Cockburn 2015, Suchman 2020). And in what Grewal (2017) terms "drone imaginaries," the visual politics of techno war, humanitarianism, and empire find expression. The generalization of logistical logics entails the spread of such military technologies to civil life (Kaplan 2006, Graham 2010, Kanngieser 2013, Cowen 2014).

Imaginaries of smartness and optimization have performative consequences in the sense that algorithms increasingly operate on algorithmically sorted worlds, undergoing new iterations and recursive operations. When the world becomes a model of itself, politics may emerge as error, as friction, or merely as the parameterization in tinkering and experimentation with new versions. Since a demo always demonstrates, "failing" can replace "failure" (Kurunmäki & Miller 2013).

Next to, and sometimes in conjunction with, the logistical imagination of algorithms imbued with smart charisma there exist "algorithmic anxieties" (de Vries & Schinkel 2019). These arise precisely out of the fabulated and fabulating character of algorithms, out of their elusiveness and opacity as vacuoles and their nonetheless extended ecological effects as circuit benders and breakers, i.e., as performative operators of and on selectivity. As Seaver (2019) shows in an insightful anthropological analysis building on Jiménez (2018), an imagination of algorithms as traps is common. And the trap can be imagined as algorithmic (recursive) rationality as such (Totaro & Ninno 2014), animating desires for decoupling and kill switches (Stäheli 2021). Yet any algorithmic imaginary threatens to get trapped by a technological determinism that displaces the contingent histories of algorithmic technologies (cf. MacKenzie 2006, Ensmenger 2012, Kockelman 2013) and isolates them from, for instance, infrastructural entanglements.

Infrastructures

Infrastructures can be as invisible as algorithms (Star & Ruhleder 1996, Star 1999), but as Larkin (2013) argues, infrastructure may just as well be in your face. Both are true, and there is thus an obversity of infrastructure: Infrastructure is both façade and contrary, both frontstage and backstage. Infrastructures can be regarded both as systems of substrates (Star 1999) and as architectures of circulation (Larkin 2013). Infrastructures are material networks enabling other materials to move. They are durable (Edwards et al. 2009) but require constant work in order to endure, for instance the work of maintenance and repair or the work required because the different actors involved in creating and sustaining infrastructure need alignment. As "dispositif techniques," infrastructures not only consist of pipes, cables, roads, hardware, or wires, but are bundles of "technologies, techniques, administrative procedures, and cultural forms" (Bowker 2014, p. 116).

Algorithmic ecologies involve infrastructural entanglements of standards (Easterling 2014), code (Kitchin & Dodge 2011), (meta)data (Pomerantz 2015), protocol and naming conventions/classifications (Galloway 2004, Bratton 2015), cables (Starosielski 2015) and channels (Parikka 2012), devices (Singleton & Law 2013), data centers (Hu 2015), waste disposal (Gabrys 2011, Cubitt 2017), labor (Huws 2014, Dyer-Witheford 2015), and intellectual property rights (Pasquale 2015). Algorithmic ecologies are thus infrastructurally heterogeneous or "multi-infrastructural" (Vertesi 2014). But even as infrastructure warrants attention to both materials and (deep) time (Parks & Starosielski 2015), infrastructure is observer-dependent (Star & Ruhleder 1996). What is infrastructure from one perspective may be interface from another [such as a relay or an application programming interface (API)].

So while infrastructures are a key modality of algorithmic ecologies, which infrastructural elements matter depends on specific ecological moments and thus infrastructures cannot be considered as fixed or given prior to a specific observer standpoint. In algorithmically driven sensor actuators, for instance, sensing, deciding, and actuating draw on and activate different infrastructural constellations. Standards (e.g., the IEEE 802.3 Ethernet standard or the MQTT standard protocol for devices) and gatekeeper algorithms (Tufekci 2015) may be permanently relevant in wireless sensor ecologies, but many algorithms are active only in highly particular situations (Cockburn 2015). So infrastructure cannot be considered as a given base layer. The question is rather how and when particular infrastructural elements come to matter in conjunction with the topological foregrounding of elements of the other modalities of algorithmic ecologies. In some cases, sensor hardware matters crucially, for instance when facial recognition systems' performance depends on phenotype (Introna & Wood 2004). In other cases, code is key, as when built-in bias in targeting algorithms in weaponized drones (i.e., unmanned aerial vehicles) is contested (Cockburn 2015). At the same time, a focus on infrastructure may bring disparate sites and invisible forms of labor into view (such as offshored code writing; the travel of algorithms from financial markets to urban governance; waste, recycle, and repair management and labor) that are often erased from public deliberation but are nonetheless crucial for the political salience of algorithmic ecologies (Huws 2014, Mattern 2015a, Crawford 2021). How infrastructure matters is, thus, a matter of ontological politics.

Sometimes such politics is rather banal, and the arrival of algorithms on the (ob)scene of infrastructure can highlight that infrastructure can also mean structural stupidity. The current alarm at universities over ChatGPT, for instance, as giving rise to potential plagiarism, cannot be disentangled from an infrastructure that requires testing and grading and that configures testing, and education more broadly, as digitally mediated. Here, as anywhere, another infrastructure is possible. But because academic administrators, and unfortunately many academics too, tend to both prefer policing students (by testing and grading them) and enjoy the cost-effectiveness of digital testing, artificial intelligence presents problems that would not have arisen under different infrastructural conditions. A logistical logic of optimization will likely, at some point, turn against institutions plugged into infrastructures of optimization while purporting to perform something substantial, like educating young people.

Indeed, in what Deleuze (1995) has called "control societies," infrastructural power has shifted from container to circulation or from frame to platform. This is a shift from spatiotemporal (disciplinary) molds to constant modulation. Infrastructural materiality is thus extensive and pliable rather than contained and fixed, and yet it, too, has its groundings. These can be sites of friction as mundane as socket standards (Vertesi 2014), and they can be sites of struggle, as Starosielski (2015) illustrates in her study of Internet cables in the South Pacific, highlighting the entanglements between infrastructure and coloniality. In both cases, the power of logistics is key (Cowen 2014, Chua et al. 2018, Harney & Moten 2021), as logistical capitalism has given rise to securitized and militarized corridors of circulation driven by algorithmic calculation in the service of the optimization of efficiency and accumulation.

Interfaces

Infrastructure gives rise to questions of openness and control (Bar et al. 2008) that point at the crucial role of interfaces. Interfaces govern the connection between humans and technology, and hence they have been treated as valuable ethnographic fieldsites of human–machine interaction (Suchman 2007). They are both historically shaped material objects and effects (Galloway 2012) or zones (Drucker 2011) through which trajectories for relations are mediated. More than mediators, they make and enable (Hookway 2014). Interfaces calibrate conditions of exchange. They are spaces for the mediation of human and nonhuman agents, which involves historically situated forms of subjectivity (Galloway 2012). Interfaces interpellate subjects. Representational logics in interfaces for instance coconfigure the subjectivity of users (Mattern 2015b) and modulate user responses (Ash et al. 2018). Ontologically, interface is connection; epistemologically, it is simplification. Combined, interfaces can be regarded as both thresholds and translation zones.

Interfaces such as access or overview screens, dashboards, or process-switches often modularize the processes monitored in algorithmic ecologies—a process of cutting, connecting, and simplifying typical of logistical modes of operating. Recent research has focused on graphical user interfaces (GUIs) such as control screens and dashboards and on control rooms and operations centers (Medina 2011, Mattern 2015b, Luque-Ayala & Marvin 2016). Interfaces provide clues to how humans are inserted into algorithmic ecologies through embodied interaction (Dourish 2004), and they express and modulate the affordances of subjects. These may be experts with access to interfaces that can recalibrate algorithms (Dudhwala & Björklund Larsen 2019). Interfaces also provide sites to study the links between designs of algorithmic ecologies and the desires that animate them, such as desires for seamlessness, for modular order, or for intimacy in networked settings. Interfaces are thus at the crossroads between infrastructures and imaginaries, as they are ways in which systems make themselves visible—yet precisely in selectively organizing visibility, they hide as well (Galloway 2012). Dropdown menus afford and limit, and customization has its limits, so there are trade-offs between generality and specificity. And through repetition of representation, interfaces train (dis)articulation of forms of participation. By providing selective access, interfaces invisibilize options, which is one expression of Kittler's idea that computers are not optical media (Kittler 2010, p. 226). It is also a reason why, in keeping with the precept to struggle at the place of production, interfaces are sites of resistance and improvisation.

Human–machine interfaces are not the only relevant interfaces (Hookway 2014, Bratton 2015). These also exist between various nonhuman actors. All kinds of switches and relays within infrastructures (for instance, across sensor nodes, backhauls, and gateways), and between forms of code, such as APIs, are pivotal in configuring algorithmic ecologies, ensuring, for instance, interoperability. In what is imagined as an IoT, ever more objects gain forms of ecological awareness and become interfacial. Yet the rise of platforms has meant access restrictions for APIs, which narrows interfaces (Bruns 2019). The example of APIs, mediating between layers of abstraction, also illustrates the role of interfaces in producing scale. Since algorithmic ecologies are topological ensembles, "where" they are depends on how scale, which is never a naturalized given (Marston 2000), is "done" as interface, switch, or relay. Interfaces thus filter options, structure connections, and (in)visibilize infrastructure by calibrating affordances.

Identities

I use the shorthand "identities" to designate the subject positions emergent in algorithmic ecologies, primarily for reasons of consistency of alliteration. Algorithmic ecologies enable specific ways of configuring subject positions, and subjects have their tactics for resisting or amending the affordances that such ecologies offer. Use of digital technologies can contribute to fundamental changes in how people experience their world, as the example of the effects of the global positioning system (GPS) on Inuit wayfinding illustrates (Aporta & Higgs 2005). But this relation is never deterministic. Technologically enhanced environments extend "embodied awareness in highly specific, local, and material ways that would be impossible without electronic prosthesis" (Hayles 1999, p. 291), but forms of identity or subjectivity are not given with such awareness. Rather, they unfold in the sutured spaces between different modalities. So it is key to denaturalize prevailing conceptions of, for instance, "users" (Suchman 2007, Bratton 2015, Mattern 2015b, Hyysalo et al. 2016). One way is to consider how users get "configured," for instance in usability trials (Woolgar 1990); another is to trace the genealogies of such identities, which emerge as highly entangled with, for instance, infrastructures or imaginaries. The network computer user, for instance, constitutes a subject position that became possible with the technology of time-sharing (Hu 2015). Dashboards (interfaces) visualize subjects as endowed with both needs and control. Corporate strategies imagine a blurring of citizen, policy maker, and entrepreneur. And contemporary consumer identities are coshaped by military, logistical logics materialized in the use of geographic information systems and GPS for "targeting" (Kaplan 2006). Likewise, "the other" is configured in war simulations of sensation and actuation that blur the boundaries of the material and the virtual (Suchman 2016).

One example of the configuration of identities is the way that the smart home may configure inhabitants as managers of the house, where the house becomes reconstituted as a bundle of processes. Then the question is what other subject positions become possible, for instance by appropriating the extensions of the house or the city in claiming a "right to infrastructure" (Jiménez 2014). Subjectivity in algorithmic ecologies is thus characterized by a practical situatedness and partiality. These are general features of any subjectivity, since, as Foucault teaches, there are never quite subjects; there is only subjectification. Yet the speed with which the circulation of both algorithmic calculation and device actuation occur makes subject positions especially volatile and flexible. I live without a mobile phone, and the generalized addiction to touchscreen fingering (or teeny-weeny window washing) that has developed in little more than a decade never ceases to amaze me, and it seems to give the concept "user" yet another meaning. The normalization of algorithmic carry-on devices in everyday life signals the degree to which algorithmic media may not be McLuhannite "extensions of man" but belong to human selfhood as such.

But the "human" is a somewhat too generous category here. Often, the human refers to a particular historical modality of humanity, one that Wynter (Wynter & McKittrick 2015) designates "Man2," i.e., the genre-specific, modern, biocentric *homo oeconomicus*, subject to the narcissism of overrepresentation. It signals the ways coloniality and race operate as infrastructures enabling only specific subjects to be recognizable as human. This provides a much more potent way of describing how algorithmic ecologies sort and configure subjects. Rather than a concern over "bias" (Introna & Nissenbaum 2000, Tufekci 2015), which never fails to buy into the generalized anthropology of Man2 and merely points at inconsistencies in modern technological ecologies, waiting to be detected and corrected, the fundamental ways in which race and white supremacy are endogenous to electronic infrastructures need to be emphasized. But they should be seen primarily as innovations in the means of racist population management, intersecting with gender differentiation and domination, as Browne (2015) makes clear when she writes "surveillance is nothing new to black folks" (p. 10). To fight bias is to fight for the norm, i.e., to be invested in racial capitalism. As Benjamin (2019b) writes, "algorithmic neutrality reproduces algorithmically sustained discrimination" (p. 143). Situating smart city technologies in the longer histories of racial capitalism, Jefferson (2022) concludes that "algorithmic governance is the *latest vector* of white supremacist political economy" (p. 245, emphasis in original). Algorithms can be seen as "formats" that shape racialized redlining in cities (Koopman 2021). For Benjamin, writing about the United States, this notion is expressed in a "New Jim Code" (Benjamin 2019a,b). Algorithms can appear as automatons of everyday ontological hierarchization in, for instance, discrimination in job hiring algorithms (Tufekci 2015), racial profiling and predictive policing (Scannell 2019), the racialization of health care decisions (Ledford 2019), the incorporation of white supremacy in facial recognition algorithms (Benjamin 2019b), or the algorithmic and biometric constitution of borders (Amoore 2013). One ominous recent introduction has been a supermodel created by artificial intelligence in the appearance of a black woman that has been featured, among other places, in *Vogue* (Yates 2022). Its creator is a white man, which marks not only a repetition of a long history of white exploitation of black (cultural) production, but a potentially new stage in which the very participation of black people in such exploitation has become algorithmically redundant. All the while, this algorithmic incarnation of blackface can be presented as doing "diversity." One may wonder whether calls for "algorithmic equity" do not signal an investment in imaginaries of improvement (Harney & Moten 2021) that ends up repeating racial capitalism by algorithmic means. That, at least, seems to be the case in the recent Dutch scandal over childcare benefits, in which the Dutch tax agency algorithmically selected mostly single mothers of color in what was termed welfare fraud detection. Even after the scandal, racializing use of profiling systems such as SyRI continues in the Netherlands (Davidson et al. 2022). What we have is not algorithmic bias, but racial capitalism by algorithmic means.

Investments and Interests

A fifth and final modality, discussed here under the rubric of investments and interests, points at the role of capital and control, i.e., of political economy in algorithmic ecologies, and at the contributions of such ecologies to capital accumulation. This, however, is where several strands in the literature on algorithms part ways. The anthropology of money remains attentive to how algorithmic technologies reconfigure the ways that commensuration is achieved through payment practices, special-purpose moneys, and what Maurer (2012) has called "mobile money" such as M-PESA. Yet this work has not been strongly connected to research in political economy seeking to work through the connections between class and computerization (Huws 2014, Dyer-Witheford 2015, Wark 2019). Even though Marx (1981, pp. 569–91) already signaled the significance of automation (as ultimately helping to undermine capitalism), and some signal a current information-centered economy beyond capitalism (Wark 2019), most work on algorithms has not adopted a class-based perspective, which also raises the question of the relations that social scientists have with what has been termed the "coding elite" (Burrell & Fourcade 2021). What has not yet appeared is a political economic analysis of the industry affiliations and funding of anthropologists studying algorithms, which at least at first sight appear more common than in, say, the anthropology of race or gender.

Despite claims to decentralization, openness, and sharing, network-based technologies involve new forms of profit, power, and control (Galloway 2004, Hu 2015). Reconfigurations of sovereignty and cloud computing infrastructures move beyond "data politics" (Hu 2015). It is key to outline how algorithmic ecologies are governed in ways that mix private and public actors (including social scientists), redefining these very notions of public and private, and to consider the economic and political privileges expressed and preserved therein. Such outlining involves mapping the corporate stakes in algorithmic ecologies and the legal architectures of intellectual property rights. A neoliberal imagination of entrepreneurialism and flexibility figures prominently in algorithmic ecologies, as in influential definitions of smart cities (Allwinkle & Cruickshank 2011, Söderström et al. 2014, Hollands 2015, Luque-Ayala & Marvin 2016).

The modality of investments and interests therefore also points at the role of financialization, speculation, leveraging, and venture capital in algorithmic ecologies (Halpern 2014). This requires attentiveness to how monitoring is connected to monetizing, through the immaterial labor of citizens when they act as data sources for monetized processes and perform unpaid labor. Sociality itself becomes a source of extraction and accumulation because connecting with loved ones on WhatsApp means both to perform unpaid labor and to be a source of extraction (Dean 2018). From this angle, algorithms can be seen as regulating the connections between living labor and abstract labor. Algorithmic ecologies thus occupy a key node in contemporary accumulation and are both shaped by and shapers of the political economy in which they figure. Rent extraction and the calibration of (always artificial) scarcity are increasingly algorithmically calibrated. In the process, workers become part of a digital proletariat (Huws 2014). This entails the generalization of precarious labor, including the loss of effectiveness of existing ways of resistance (e.g., unionization).

Analyses of "cognitive capitalism" have pointed out the role played by financialization, "immaterial labor," and the enrollment of the psyche and the "general intellect" in the digital production of surplus value (Virno 2004, Lazzarato 2011). But it is important to also consider the often invisible material labor that sustains immaterial labor, in maintenance, distribution, waste disposal work, and the extraction of raw materials (Jackson et al. 2012, Huws 2014, Dyer-Witheford 2015, Crawford 2021). This infrastructural labor in algorithmic ecologies warrants attention to the extended geographies of the work that sustains them and the often gendered and raced affordances and exclusions that this entails (Richardson 2018). The logistics of maintenance, distribution, and waste, for instance, are key to contemporary forms of dominance (Cowen 2014, Cubitt 2017). Diagnoses of "cognitive capitalism" appear out of touch with the longer histories of racial capitalism and the continued relevance of primitive accumulation, which algorithmic ecologies help organize (Koshy et al. 2022). The same might be said for the exhaustively predictable preoccupation with privacy among liberal scholars replicating desires for self-possessed individuals. Algorithmic ecologies require intersectional analyses that do not forego their own positionalities.

CONCLUSION: MAPPING ECOLOGY

I have sketched five modalities of algorithmic ecologies as a way of addressing the challenge of the object in the anthropology of algorithms. Imaginaries, infrastructures, interfaces, identities, and investments and interests provide points of entry into algorithmic ecologies, and the speculative proposition I have sketched is that algorithms are immanent to an ecology of entanglements, enacted across all the modalities of algorithmic ecologies. To give this a Spinozist inflection would be to say, one algorithm, many modalities. Along with these modalities, algorithms are thus observer-dependent, which simply means, as James (2003) said, "one and the same material object can figure in an indefinitely large number of different processes at once" (p. 66). A pragmatist perspective helps: For social scientists, it hardly ever makes sense to define algorithms as I did in the opening lines of this article. Everything socially consequential and politically urgent happens in ecological entanglements.

When taking into account their different modalities, algorithmic ecologies are less geographical than topological (Ruppert 2012), finding constancy in the recursive reformations of their modalities. These can be seen as topological foldings of entanglements (Lee et al. 2019). Even body-worn devices such as smartphones do not occupy rigid geographies (Kitchin & Dodge 2011). As locational devices, they topologically expand and contract with the mobility of device-wearing subjects. Likewise, urban automation networks configure spaces that vary with elements of infrastructural architecture such as network type, sensor node, sensor notification periodicity, backhaul, and gateway (all of which for instance vary with power supply decisions or routing requirements). As topologies, algorithmic ecologies can be mapped, but always provisionally. Next to and complementing ethnographies, mapping can be a media-archaeology-inspired "deep mapping" (Mattern 2015a), and it can involve "datawalking" (van Es & De Lange 2020), as well as close scrutiny of application use (Light et al. 2016). Mapping the modalities outlined here might yield an "i-Map" insofar as future ecological evolution allows alliteration.

The concept of algorithmic ecologies does not assume either a set of nested, neatly bounded environments or a blanket concept of an Internet of Everything. Neither does it mean a retreat to what Seaver (2018) has called the "analog slot": opposing the digital to the analog, the machine to the human. Rather, it is meant to remain sensitive to (in)commensurabilities across the entanglements I have called modalities of algorithmic ecologies. Such ecologies are fragmented and fraught with friction. Algorithms sift and sort, commensurate and categorize. They also excite and incite desires, hopes, anxieties, and fears. But they do all of that because they do not do it as isolated agents. Theirs are ecological effects, which means that, inspired by Ingold's (2022) recent critique of conventional concepts of ecological inheritance ("Would it not make more sense to say that the water inherits the fish?") (p. S52), we might as well say that our capital (investments and interests), cables (infrastructures), and concepts (imaginaries) have given birth to algorithmic vacuoles that then come to perform key social roles such as classification, sorting, ranking, gatekeeping, and valuing. The modalities of algorithmic ecologies are partial connections across which no commensurability can be assumed. And yet nobody can claim to have exhaustively studied algorithms without taking into account the investments and interests in them or the imaginaries through which they enter the realm of signification. The answer to the question of where an algorithm is must be that it is immanent to an ecology of entanglements and finds expression and enactment across the different modalities of that ecology.

Algorithmic ecologies produce contingent outcomes subject to constant modulation because their outcomes steer actuations that, in turn, affect input. These contingencies can be amplified in controversies and through struggle. Put another way, such ecologies involve an ontological politics that, for anthropology, warrants attending to the question of what their existence means for ways of composing worlds (Stengers 2018). Should there be a "design anthropology" (Artz 2022) so that we can be algorithmically correct and avoid bias? Or is a state-incorporated "new anthropology" that deploys algorithmic government on the rise (Anderson 2022), and, if so, what do we do about it beyond slick terminological innovations on politically inconsequential fieldsites? Since the composition of worlds can be done in more or less violent ways, the anthropology of algorithms is tasked with the urgent challenge to consider which interventions in power it wants to make and which powers it wants to confer on its inventions.

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