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The Nature of Biomimicry: Toward a Novel Technological Culture

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Abstract

Biomimicry is a rising popular ecology movement and method that urges the derivation of innovative and environmentally sound design from organic systems. This essay explores the notion of nature in biomimicry as articulated by the movement's founder, Janine Benyus, and the nature of biomimicry as practiced by the Massachusetts Institute of Technology (MIT) media ecologist Neri Oxman. Benyus's approach, I show, promotes biomimicry as a science of nature in which nature is treated as a source for innovative design that can be emulated in technological apparatus. Such an approach is problematic, I argue, for its valorization of organic form, which results in both a rigid system of ethics demanding absolute separation of nature and technology. By contrast, Oxman's work, I show, pursues biomimicry as a technology of nature. In so doing, I argue, it mobilizes a neomaterialist style of interaction with organic materials that ultimately enjoins a radically different way of thinking nature, technology, and technoethics.

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It is not easy to be upbeat these days about the environment. With the planet's fresh water resources dwindling, the polar ice caps rapidly melting, and damaged nuclear power plants spewing radioactive junk into the air and water—to mention just a few of our unfolding ecocatastrophes—prospects for the earth and humankind do not look bright. Nevertheless, there was no shortage of optimism at the Biomimicry 3.8 Education Summit and Global Conference, which was held in the impressive and voluminous conference center located at the edge of Boston Harbor on the University of Massachusetts Boston campus in June 2013. The conference was preceded by a special one-day educational workshop held at the Thompson Island Outward Bound Education Center, which was aimed at helping educators of all levels integrate biomimicry into the curriculum. Bringing together "certified" and aspiring biomimics from the far corners of the world, the Biomimicry Summit and conference were meant to mark a milestone in the fifteen years since the birth of the biomimicry concept by demonstrating its successful dissemination geographically and intellectually across disciplines and among professions. Over the course of two and a half days of keynote speeches, plenary meetings, and breakout sessions conferees heard from urban designers, city planners, civil engineers, architectures, chemists, software developers, and educators who shared accounts of their efforts to integrate biomimicry into their work.

The biomimicry movement emerged around Benyus's (1997) publication of *Biomimicry: Innovation Inspired by Nature*. Although Benyus did not invent the term biomimicry, her book popularized it while articulating the initial principles of a biomimicry method, about which I will say more below. Benyus has worked tirelessly over the last fifteen years to promote the biomimicry message, giving countless interviews and a Technology, Entertainment, Design (TED) talk, most of which is accessible on the Internet. Benyus is a master of her trade. She speaks eloquently, conveying passion, calm confidence, and charisma. As a result, her efforts to spread biomimicry's message have paid off. Over the past decade, her work has spurred a wealth of biomimetic research projects alongside a rapidly expanding body of biomimicry literature in academic, business, and popular forums. Biomimicry has also made significant headway into popular discourse and has even been the subject of several special features aired during primetime on National Public Radio in the United States (Frank 2014).

Ostensibly, biomimicry is not a particularly complicated idea. It advocates the "conscious emulation of nature" as a means of producing anything from a single object to a large technological system, even a city, in an environmentally sustainable manner. Its premise (which rehearses to some extent Lovelock's [1979] *Gaia* hypothesis) is that over the course of its 3.8 billion years of evolution, nature has developed solutions to many design and engineering problems similar to those that humanity currently faces. To paraphrase Benyus, if we look at the way living organisms exist, we find that nature has been building, processing cellulose, optimizing packing space, waterproofing, heating, and cooling structures. But unlike us nature has been doing these things with great elegance, minimum energy use, and without fouling the environment. One of the most often cited examples of biomimicry is the emulation of the kingfisher bird's beak on the front of high-speed trains in Japan as a way of eliminating the buildup of atmospheric pressure as the train passes through tunnels (Figure 1).

But biomimicry is not just about optimizing technological design. It presents itself as a social movement in every sense of the word. It insists that we become "nature's apprentice," with the emphasis not only on nature as a source of genuine knowledge of craft but, more importantly, as an ethical system. Biomimicry thus aspires to be not just a technique but also a new science of nature that will inform a novel and ethical political, economic, and social order. Not surprisingly, such aspiration is not without a utopian tinge. Consider, for example, how Benyus envisions a biomimetic world in her 1997 publication:

> In a biomimetic world, we would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibers, ceramics, plastics, and chemicals. Our farms, modeled on prairies, would be self-fertilizing and pest-resistant. To find new drugs or crops, we would consult animals and insects that have used plants for millions of years to keep themselves healthy and nourished. Even computing would take its cue from nature, with software that "evolves" solutions, and hardware that uses the lock-and-key paradigm to compute by touch. (Benyus 1997, 3)

I find this vision compelling, particularly for the sense of optimism it conveys at a time when discussions regarding our ecological crisis and imminent planetary demise in the age of the Anthropocene tend to leave us with a sense of helplessness. What is more, while there has been significant work in recent years to criticize the complex relations of capitalism and environment, the aim of much of this work has been to foster a form of political and

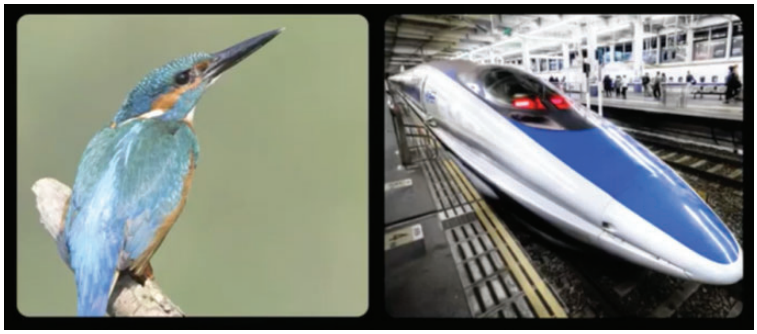

Figure 1. Kingfisher and bullet train.

cultural intervention by revealing the often difficult and messy imbrications of capitalist political economy and toxicity (see, e.g., Fortun 2001; Klein 2014; Murphy 2008). Insofar as such efforts endeavor to raise consciousness, they do not necessarily try to imagine alternatives. Biomimicry, by contrast, is more active than reflective, as it wants to establish an actual alternative relation with nature and a commensurate social ethics. At the same time, biomimicry distills the central theme of sustainability, which is that there is a "nature" out there that we can learn from, whose so-called intelligent design holds the secrets to the survival and future well-being of the human race. This premise is ultimately at the root of so many ecological arguments and practices that look to so-called traditional non-Western societies to discover indigenous forms of knowledge with the hope of recovering modes of ecological being supposedly lost with the onslaught of mechanized industrial modernity in the West. Such thinking is encapsulated in the deep ecology movement, which hopes to recover nature, asserting that "only a basic shift in humanity's self-understanding and its attitude toward nature will prevent social and ecological catastrophe" (Zimmerman 1994, p. 185).

In sum, biomimicry intrigues me. I want to take it seriously as I want to take seriously its message that there is a hope for our future and our children's future—that there is still time to make the planet right. The problem is, however, that biomimicry gets it wrong. Or rather, I want to argue that biomimicry misses the essence of its own radical innovation when it promotes itself as a new science of nature. What it potentially offers, I will argue instead, is a way of thinking about a progressive technics, by which I mean a step toward a new technical culture for

realizing a mode of living and becoming with technology, without reducing technology to mere functional instrumentality.[1] Importantly, this technical culture hinges on articulating a nature that is very different from the nature of Benyus's biomimicry.

My argument is divided roughly into two parts. In the first part, I offer a critique of what I call Benyus's mainstream biomimicry, which emphasizes biomimicry as a science of nature. I show that as a science of nature, biomimicry treats nature as a source for innovative design—a sublime blueprint, as it were—that can be emulated in a technological apparatus. Operating in a mimetic mode, this approach conforms to a "representational idiom" of knowledge in its aim to identify, categorize, abstract, and deploy so-called natural design for the benefit of human civilization and progress.[2] It is thus highly problematic, I argue, for the manner in which it objectifies nature, conceiving of it as a bounded resource for pure natural form. In the second part, I draw on the philosophy of the French philosopher Gilbert Simondon to consider biomimicry as an instantiation of progressive technics, which I find articulated in the work of the self-proclaimed biomimic and material ecologist Neri Oxman. Among the many presentations at the Biomimicry 3.8 Education Summit and Global Conference, Oxman's stood out for its challenge to Benyus's articulation of biomimicry. In my discussion, I explore the work that Oxman presented in her keynote speech in conjunction with the audience's reaction to the presentation. Oxman's work, I suggest, promotes inspiration rather mimesis while mobilizing a neomaterialist approach to generate design through interaction with organic materials. I call this approach analogically inspired thinking. At the same time, I argue that Oxman's work goes beyond neomaterialism to enjoin a radically different way of thinking about technology and technoethics.

Mimicry: Toward a New Science of Nature

Benyus's account in the opening pages of *Biomimicry: Innovation Inspired by Nature* of how she arrived at the notion of biomimicry sets the stage for her introduction of biomimicry as a novel and nonnormative science of nature. While working toward her degree in applied science with a focus in forestry, she explains, the methodology to which she and other students were introduced was "reductionist." Whether dealing with botany, soils, water, wildlife, pathology, and tree growth, each element of the forest was treated as a discreet and autonomous unit irrespective of its embedded context: "we practiced a human-centered approach to management, assuming that nature's way of managing had nothing of value to teach us." What

was missing, in her view, was the recognition of the "cooperative relationships, self-regulating feedback cycles, and dense interconnectedness" of nature, which could only come from listening to and learning from the natural environment. Frustrated with the understanding of nature imparted through mainstream pedagogical channels, Benyus felt compelled to search outside the university, where she encountered the research of individuals, or "biomimics" as she calls them, at the edge of other disciplines. Subsequent chapters of her book provide an in-depth account of these projects. We learn about such things as "farming like a prairie," "harnessing solar energy like a leaf," and "doing business like a forest." Each chapter follows a similar rhetorical arc that embarks from an exposition of methodological failure of existing science before moving to the biomimicry alternative in which design solutions are abstracted from processes and organisms found in the nature.

Biomimicry is thus not antiscience. Rather, it is against a Science (with a capital S) that Benyus perceives as an expression of Enlightenment thinking in which nature is treated as a field of competition and dominance. Such treatment of nature, she stressed in her keynote speech at the opening of the Biomimicry 3.8 Education Summit, is embodied in the theories of the American ecologist and botanist Henry Gleason that dominated thinking during her university days. By contrast, Benyus described biomimicry as adhering to a notion of nature as interdependence and communitarianism, which she attributed to Gleason's intellectual rival, the American plant ecologist Frederic Clements. To illustrate her point, Benyus gestured to images of sunlight angling through a gentle mist hovering amid lush green trees that came up on two enormous synchronized screens flanking the podium. "Science is telling us that we no longer have to be in competition," she declared triumphantly. "Now we understand that the moss on the trees actually works like a Wood Wide Web, a network of system effects. This is the *real* Natural world. Generosity, surplus, system effect. Competition is an old science—don't fall prey to old scientific metaphors."

Despite claims of novelty, there is little in the philosophy that Benyus conveys, including the network metaphors, that is not articulated in other iterations of ecological thinking and activism. Biomimicry echoes much of the charter of deep ecology or even the ecofeminist movement in its polemic with Enlightenment-driven science and reason as well as its determination to identify an authentic nature.[3] Biomimicry distinguishes itself from these forms of political ecology in its attempt to develop a conceptual methodology and technological apparatus for discovering and mimicking organic design. Design, in this regard, is understood to encompass three

interrelated dimensions: the functionality of an organism's morphology, its constitutive processes, and its mode of entanglement with its milieu. Formulating this in different terms, Benyus describes biomimicry's object as mimicking an organism's blueprints, its chemical recipes, and its ecosystem strategies. In order to facilitate the discovery of the first two dimensions of design (form and process), the Biomimicry Institute 3.8 has developed a classificatory system that it call its "taxonomy," which organizes nature according to eight fundamental functional processes, each of which breaks down further into various subcategories. Biomimicry's taxonomy then serves as a heuristic for reconceptualizing a design challenge in functional terms in order to produce a query for biomimicry's web-based asknature.org database, which houses an expanding collection of biological knowledge about plants, animals, and insects (Figure 2). How does this work? If designing a building for an arid climate, for example, the taxonomy facilitates conceptualizing the design challenge in terms of how to utilize the available water in the environment (http://www.asknature.org/article/view/biomimicry_taxonomy). Through the taxonomy, one would develop the question "how does nature capture water" to search asknature.org. The search produces a number of examples of organisms or organic structures with the function of capturing water. Each example provides an in-depth summary of the natural organism in a mixture of layman and biological terms. Biomimicry Institute members imagine a future where all production will happen through the taxonomy process. For example, when an automobile maker designing a new car needs a material to cover the body, she would simply log on to asknature.org and with a few keystrokes retrieve a biomimetic solution, for example, in nature of a material that is strong, waterproof, resilient, and aesthetically pleasing.

Of course, mimicking organic forms and processes does not necessarily guarantee an ethical outcome. Or, as Benyus puts it, one might use the taxonomy to derive an entirely biomimetic solution for producing a new kind of fabric and yet still have "missed the point" by exploiting sweatshop labor to weave it and then "[load] it onto pollution-spewing trucks and [ship] it long distances." This is where the third dimension of design, ecosystem strategies, becomes important. Whereas form and process are understood to be specific to an organism and its milieu, biomimicry treats ecosystem strategy as a universal guideline for ethical relations, which it abstracts into a system of six overarching protocol that it calls "life's principles."[4] Life's principles constitute what biomimicry understands to be the underlying protocol for the operation of nature as a complex network (Figure 3).

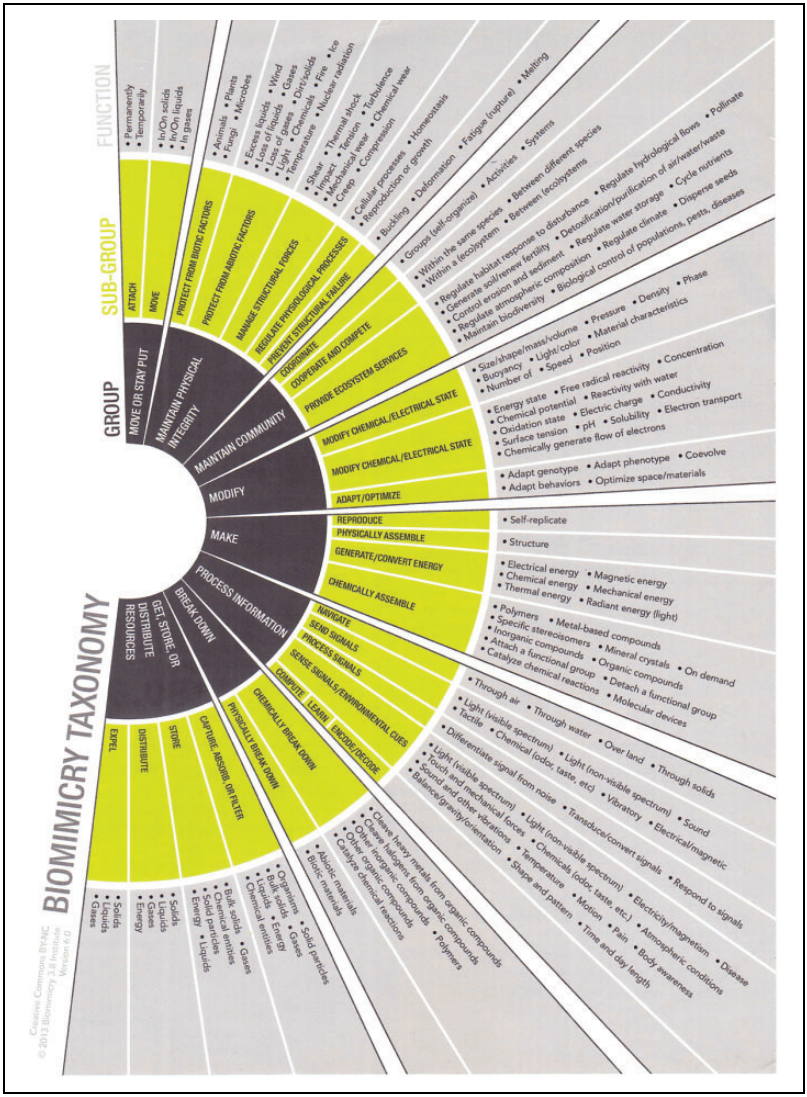

Figure 2. Biomimicry taxonomy.

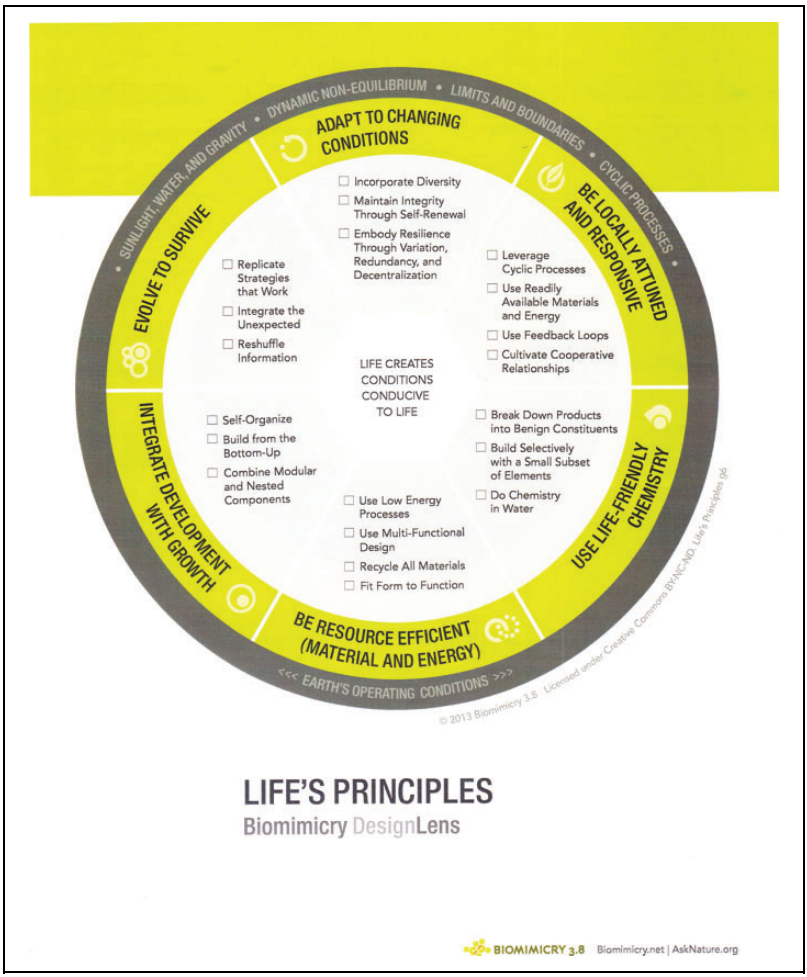

Figure 3. Life's principles.

The Limits of Mimicry

By virtue of its aspiration to harness organic potential, biomimicry resembles other so-called bio practices such as bioutilization and bioassistance. Such projects and fields of research have proliferated in recent years under the promise, typically made by corporations, of overcoming the seemingly irreconcilable conflict in capitalism between the pursuit of capital and care

for the environment. Similar to other bio-driven practices, biomimicry speaks the language of capitalism and political ecology simultaneously, mobilizing such corporate jargon as "cost performance" and "deliverables" together with declarations of genuine concern for nature and environmental sustainability. Yet biomimicry also claims to be ethically distinct and even rejects these other bioprojects and sciences, which as Stefan Helmriech (2009) suggests in his ethnography of marine biotechnology, want to produce biocapital by harnessing the reproductive or regenerative power of microorganisms.

While it is hard to find fault with biomimicry's underlying intentions, its lack of critical reflection on its method and categories make it complicit on many levels with the very structures of dominance (social and natural) that it claims to overcome. In a series of highly insightful and critical analyses of biomimicry, the environmental geographers Elizabeth Johnson and Jesse Goldstein take the movement to task for such conceptual and methodological shortcomings, calling attention to its failure to overcome the human conceit and ontological dualisms that it sees as responsible for Western civilization's deleterious relationship with nature (Johnson 2010; Johnson and Goldstein 2015, 2016). In this context, they present an especially compelling argument demonstrating biomimicry's collusive entanglement with corporate capitalism. Biomimicry, contends Johnson in a single-authored piece, merely shifts capitalism's extractivist register from nature as a source of raw material to nature as source of "endless possibilities for solving barriers to production" (Johnson 2010, p. 187). Part of what makes Johnson's and Goldstein's critique so persuasive is that they also want to take biomimicry's attempt to produce an alternative and sustainable future with nature seriously but at the same time believe that this demands subjecting its categories and claims to rigorous scrutiny. Unfortunately, biomimicry does not fare well under their scrutiny. What emerges from these analyses is a clear understanding of how biomimicry succeeds marvelously in producing new sources of wealth for capitalism along with innovative design for military defense, while failing spectacularly to live up to its promise of producing an alternative ethical system of politics. It is worth adding here that one of the less enthusiastic participants in the biomimicry one-day educational workshop that preceded the main conference in Boston in 2013 distilled these contradictions perfectly when he confided in me his view of biomimicry as "claiming to be all about nature but what it really wants to do is just mine nature for Intellectual Property (IP). And in the end, someone uses that to build a fucking drone."

Johnson and Goldstein offer valuable insight into biomimicry's troubling relationship with capitalism. However, I want to draw attention to the

problem with mimicry as I believe that this is where biomimicry is most flawed and yet also where further scrutiny can yield a progressive nature of technological culture. Mimicry in biomimicry, as I suggested above, rehearses a representational idiom of knowledge that parallels the project in Western modernity of mapping the natural world with all its constituent curiosities, wonders, and (savage) cultural others. Mimicry thus rests on an epistemological conceit inherent not only to the natural sciences that it criticizes but also to Western imperial and colonial history. That is, in claiming to make available nature's design secrets for emulation, biomimicry claims an exclusive ability to know and represent the natural world. As much postcolonial theory has argued, representation in this regard is invariably a political act of power and privilege. To represent is not simply to render intelligible an objective reality but rather to produce a certain reality as an object of knowledge. In so doing, one claims the right to constitute oneself as an active subject vis-à-vis a passive object. Feminist theory has added to this critique, arguing that this right has historically been gendered as a male privilege while the passive object has been imparted with a feminine value.[5] Thus, while biomimicry reproduces the Cartesian dualisms that it claims to overcome, it conceals this in order to maintain (n)ature as an ontologically distinct and pristine domain divorced from human society—which it can then look to as an alternative source for (intuitive) design concepts and principles.[6] Its assertion, in this regard, is that access to this domain must be unmediated by human reason and its corollary constructs of power and knowledge. This was made especially clear in the one-day educational workshop each time the forty or so participants (including myself) were encouraged to "quiet our human cleverness" in order to perceive nature's elegant functionality manifest in various organic phenomena we encountered around the island.

As Latour (2004) argues in his critique of political ecology, such tropes of "direct access" to nature tend to obfuscate the intensive intermediary work of politics and science in the production of nature. Latour's assessment aptly captures the contradiction of biomimicry in which that intermediary work is done through the movement's taxonomy and life's principles. Biomimicry pretends that the taxonomy and life's principles are found as empirical objects. What is more, this initial reduction leads to yet another reduction, namely, of nature to biology. We find this specifically on the asknature.org website, where nature is rendered commensurable with a database of biological knowledge.[7] Such reduction leaves out of a vast amount of seemingly nonbiological material and related processes, such as rocks, gasses, and maybe even viruses. More importantly, it leaves out

the cultural, economic, and technical factors that contribute to the production of biology as a discipline and nature as its object of inquiry.

Neomaterialism

In light of the above problems with the notion of mimicry, the term biomimicry begins to seem like a highly unfortunate designation for a movement that wants to fix the world. Yet, mimicry, as we will see, opens the door to inspiration. Inspiration cannot be subsumed under epistemology. Its modality bespeaks something far more ontological and performative. Invoking the notion of breathing and breathing into, inspiration encompasses a sense of co-becoming, a coindividuation of form and matter rather than a copying of form. To be inspired is to be stimulated to do something, often something creative, by a force that one can feel and yet cannot represent. Consequently, not all that happens in biomimetic praxis is reducible to the kind of formalistic method that Benyus prescribes. Viewed through Oxman's work, biomimetic praxis is better described as a kind of inspiration that gives rise to a novel technical culture of nature. As such, innovative design is not something out there to be found in nature but rather something that emerges through inspirational technics of interaction with material nature. Biomimicry, in this regard, shares an ontological focus with what has been labeled "neo" or "new" materialism, which treats matter as animated. While building on traditional materialism, the "neo" of neomaterialism denotes a postvitalist proposition whereby what animates matter is explained through theoretical physics rather than attributed to a spirit or essence.[8] At the same time, neomaterialism wants to move beyond the social constructivist understanding of matter offered by Marx as well as think in nondialectics terms that, in opposition to conventional historical materialism, allow for an emergence without the presupposition of a negative force. But at its core, neomaterialism is an ethical project that develops an alternative conceptual premise to civil liberal society that is founded on the valorization of reason and the agency of the autonomous rational subject who organizes nature into civilization (Coole and Frost 2010, 66).

In pursuing this goal, neomaterialism recognizes that material things are active participants in the creation of order in the world. Neomaterialism thus echoes Latour's call in actor–network theory (ANT) for the recognition of nonhuman agency. But neomaterialism also aims to go beyond Latour's thesis, specifically by articulating an inherent ethics of material entanglements.[9] The neomaterialist argument is thus that matter displays self-organizing emergent properties that tend toward increasingly complex

configurations and ecologies. As such, it demands that we acknowledge that human beings are merely participants in rather than masters over a complex ontological entanglement from which emerges a shared design for (human and nonhuman) lived reality. In other words, the argument is that there is a force of design irreducible to human intellectual reason. Design is understood rather as a system of organization that emerges from material itself. Ingold captures something of this approach when he suggests that materialism calls "for an alternative account of building, as a process of working with materials and not just doing to them, and of bringing form into being rather than merely translating from the virtual to the actual" (2011, 10). Design derived through human reason, according to this approach, appears as second-rate artifice in comparison to the complex self-organizing system that emerges from human and nonhuman interaction. This has important ramifications for thinking about ethics and social organization. Where liberal philosophy stakes its investment in the formation of social life contingent on an autonomous subject and rational mind, neomaterialism imagines the possibility for an inclusive social order in the absence of rational design. At stake is the idea of a nonnormative yet coherent ethical framework that is not the product of human design. It derives instead from a relational ecology of human and nonhuman actors. Yet neomaterialism ultimately falters in developing this point. While positing the important idea that matter is an active force in the creation of worlds and experience, it does not transform this idea into a system of ethics beyond suggesting that we need to pay attention to matter and the complexity of relations forming the world—thus falling back on an ANT model. Neomaterialism, as articulated by thinkers like Coole and Frost (2010), Ingold (2011), and Bennett (2010), stops short of realizing the radical implications of its insistence on form and matter as coemergent phenomena. Not only does this insistence devalue the inflated Western philosophical currency of reason while making ethics a matter immanent to lived relations in and with the environment (rather than principles abstracted outside it), it also circumvents dualisms of nature and culture, organisms and machines.

Among thinkers of ethics and techne of the twentieth century, the French philosopher Gilbert Simondon stands out as someone who put the coemergent relationship of form and matter at the center of his thought. Rethinking the relationship between form and matter was key for Simondon in his attempt to theorize a novel relationship with technology that would be at the same time an ethical relationship with nature. For Simondon, much was at stake in articulating this relationship. Whereas the critiques of capitalism in his time tended to focus on realizing a progressively ethical society

through the reorganization of labor, Simondon saw capitalism instead as a symptom of a misguided relationship with technology. Accordingly, he understood the mode of organization of labor under capitalism as an expression of this flawed relation. I will return to Simondon below in the context of my exploration of the work of the professed biomimic and MIT Media Arts and Science scholar, Neri Oxman.

Material Ecology

After Benyus, Oxman was the second most anticipated speaker at the Biomimicry Summit. Combining fashion design with academic sophistication and flair, Oxman embodies her work. Born in Israel to well-known academic parents (her mother a world renown researcher in digital architecture), Oxman attended medical school after completing a degree at Technion, Israel's leading technology institute. She later went on to do a degree in design at the Architectural Association School of Architecture in London and finally her PhD in design computation at MIT, where she founded the Mediated Matter Lab. Taking to the podium at the Biomimicry Summit with her team of graduate students, Oxman spoke for over an hour, moving swiftly through a dense distillation of her guiding conceptual philosophy before presenting three different phases of her work.

Oxman described material ecology as an emerging field that treats materials as living organisms. The focus of the field, as she told it, is to understand "the relationship between different materials, between matter and the environment, and between objects and other objects." For Oxman, this has involved exploring the relationship between matter and form, which she sees as picking up on the question posed by Louis Kahn, "what does a brick want to be?" As Oxman explained in her keynote speech, "this means asking how can we help material be what it wants to be. And how can we be mindful of its properties?" This is not an entirely new approach, Oxman stressed, but rather a conceptual trajectory with roots in the 1850s, when the German architect and art critic Gottfried Semper wrote *The Four Elements of Craft* and eight years later Charles Darwin wrote *The Origin of the Species.* Biologists and architects were moving in a similar direction at the time, argued Oxman, looking at various species in the biological world but also species of materials and species of crafts and how to work on these materials. But the industrial revolution truncated this line of thinking, displacing it with the values that have come to dominate the society today and which have had a deleterious impact on nature. Those values specify that whether we are dealing with buildings, cities, wearable

devices, cars, airplanes, and so on, we need to think in terms of an assemblage of components, each with its own particular function and material. The result is tremendous waste not only because of the number and quantity of materials involved in making the components but also because all the processes involved in producing the product are divorced from one another. As Oxman put it in her keynote address:

> We have the architects or the designers that are forming the form and we have engineers that are doing simulations or analysis, whether structural or environmental, and we have the fabricators or construction workers who are fabricating the actual piece, whether a 3-D printer, laser printer or what not. So the whole process takes place after form has been preconceived and after the engineer has done the calculations.

Adopting what she calls an "an antidisciplinary blueprint for how to think about thinking," Oxman wants to replace this schema with what she understands as happening in nature, where the processes are "integrated and form is not preconceived but rather morphogenetic, emerging from the self-organizing and emergent complexity of matter." Accordingly, form is thus not derivative of intellectual reasoning but rather a force of the lived material process and the environmental stimuli it encounters. The objective is for the production process to resemble more closely organic growth where, for example, as with growth of human bone, material takes shape in correspondence with the lived stresses and other performance criteria imposed on it. Key to implementing this approach at this point for Oxman is a system of computational form-finding whereby form is rendered from material through digital analysis of biological architectures. Also key is the 3-D printer, which allows for emulating biological growth through "additive manufacturing."

On two massive screens hanging to either side of the podium, Oxman displayed slides of objects produced in the initial phases of her work. This included avant-garde-looking chairs and wearable devices whose form had been determined by lived interaction with the bodies of their human users. Each project, explained Oxman, pushed the material and technique limitations of 3-D printing to produce a process more commensurate with organic growth.

The ultimate focus of Oxman's talk was a project entitled "The Silk Pavilion" that brings together the results of her early work. It is in this project that Oxman really begins to challenge the science of nature principle of biomimicry. The project, as Oxman introduced it, derives from looking at

nature not merely as a model to emulate but as a "computational and fabrication platform." In more tangible terms, Oxman framed the problematic behind the silk pavilion as the question, "If a Jacquard loom can design a birds nest, we ask can a Jacquard bird's nest design a loom? In other words, we know that technology recapitulates biology but can we, in a thousand years, be so good as to have biology recapitulate technology, entering an age of singularity between technology and biology?"

Oxman's question is intriguing. What would it look like for biology to recapitulate technology? Moreover, since Oxman's formulation of the question assumes human involvement in the process, how does the possibility of biology recapitulating technology embody the concern for ethics that Oxman implies is part of her work? That Oxman uses the term recapitulation in place of mimicry is crucial. To recapitulate is to summarize, or restate in the manner of a review, which suggests a very different mode of relation than the emulation that Benyus advocates in biomimicry. Whereas Benyus encourages mimicry as a kind of unmediated channeling (quieting one's human cleverness), recapitulation suggests a relationship that is more analytic in its perspective and thus explicitly about mediation. In summarizing or reviewing, one is performing a certain cognitive labor that generates an object. Recapitulation, in this sense, recalls Simondon's emphasis on analogy as a mode for thinking across the disparate domains of the physical, the organic, and the psychic (Combes 2013, 9-14). For Simondon, thinking analogically does not mean simply collapsing the difference between otherwise incommensurate domains the way, for example, that Norbert Wiener's cybernetic analogy worked to reduce the technological, the biological, and social to equivalent expressions of an adaptive function within an information system (Combes 2013, 10). The stakes and method of thinking analogously will become clearer in the course of my explication of Oxman's work. For now, however, suffice to say that thinking analogously involves grasping the schema of an object's emergence as a process with different limits and possibilities as a result of the specificity of the materials and organization of the given milieu. I use the term "grasping" here for its tactual connotations so as to underscore thinking analogously as something that transpires on an ontological level. By this, I mean that when thinking analogously, one puts oneself into a material relation with an emergent process such that one becomes able to recapitulate (that is to say, summarize) that process as an operation within a different milieu with different materials and organization and thus different possibilities and limits. This is not about abstracting and applying a design in the way that mimicry dictates. It is about traversing and

inhabiting different milieux and their potential becomings simultaneously. There is nothing to say, moreover, that thinking analogically can only transpire in one direction, the way, for example, that Benyus's biomimicry insists that everything must derive from nature. Thinking analogically presumes reversibility. Thus, Oxman is able to ask us to imagine an inverse relationship—biology recapitulating technology—which biomimicry must reject entirely as part of its premise of nature as a pristine preindustrial, premodern object.

To recapitulate, then, mimicry makes one a slave to perfect reproduction and yet is never beyond artifice. By contrast, when one thinks analogically, one is in dialogue with difference to produce an innovative resemblance. Later in the question and answer part of the talk Oxman offered a picture of what thinking in an analogical mode looks like when addressing an inquiry regarding her participation in a current project at MIT aimed at mimicking geckos. "I often wonder to myself," she confessed, "whether the best way to mimic a gecko is to design a gecko, copying the morphology of its limbs and skin. For me, the beautiful part of being inspired by a gecko is the moment when I stop mimicking and start editing to produce something entirely different." It is precisely when "editing" commences that mimicry ends and thinking analogically begins. At that moment, Oxman is not "quieting her human cleverness" to channel an unmediated nature but rather explicitly deploying her cleverness to think about similarity and difference. Biomimicry's prescribed apprenticeship structure to nature with its explicit pedagogical hierarchy becomes irrelevant. It is superseded by a materially driven dialogue (woven with inspiration) between Oxman, the gecko, and technology. The gecko at that point is not nature in the way that Benyus imagines it. It is a technologically mediated potential. The question then remains, how does all this bespeak ethics? It is to Oxman's silk pavilion project that we must turn to explore that question.

Thinking Ethics with the Silkworm

Oxman began her silk pavilion project with mimicry. The idea, as Oxman relayed it to the Biomimicry Summit audience, was to extract the silkworm cocoon design and reproduce it for a human scale as a concept architecture piece using a 3-D printer. Oxman and her team went about this by gluing a tiny magnet to the head of a silkworm in order to map digitally the pattern of its cocoon spinning process. Once mapped, the pattern was to be translated to the 3-D printer, which would then produce the cocoon for a larger human scale of habitation.

The plan failed. The structure would not take form. But failure, as it turned out, was a crucial step as it compelled Oxman and her team to shift from mimicking to editing and thus from the question of how to emulate the silkworm cocoon to how to grasp the operation of the cocoon emergence as the formation of a structured relational becoming of heterogeneous realities. In more tangible terms, instead of trying to extract the cocoon pattern, Oxman and her team mobilized the silkworm in a "biological swarm" as a kind of bio-3-D printer within a novel assemblage of threaded hexagonal frames arranged as a scaffold shell, which was then suspended from the ceiling and overlaid with 6,500 silkworms. The silkworms' spinning of the silk was then oriented by means of a varied combination of intensities of gravity, light, and heat. The final product of this relational becoming—the silkworm pavilion—is irreducible to the purity of ontological categories demanded in (bio)mimicry's distinction between nature and technology. It embodies instead a putting into relation of earth (gravity), cosmos (light and heat), insect, human, and machine toward the emergence of a novel ensemble. Oxman ended her presentation with a six-minute video tracing this process in fast motion from start to finish against a soundtrack of the textured crunching of silkworms and new age ambient music.

As might be expected, the first query from the audience in the question and answer session following talk raised concern regarding the ethics of Oxman's ostensible bioutilization of silkworms. It is worth dwelling on this question and Oxman's response not only for its element of conference theater but more importantly because it challenged Oxman in ways that forced her to elaborate her thinking around the silk pavilion project and the ethics of its processes.

"I just want to know if you paid the silkworm a living wage," asked a woman in the audience who introduced herself as someone interested in economics and concerned with the ethical aspects of the silk pavilion project. The question drew laughter from the audience, although it conveyed obvious disapproval of Oxman's apparent exploitation of nature, that is, the silkworm. Oxman tried to respond. While she did not seem totally caught off guard by the question, her response was also not entirely coherent. She began with an anecdote concerning her father's reaction to the film, regarding which Oxman laughed while the audience did not. The audience clearly did not understand what she was trying to say. She then went on to confess that the question of exploitation was something that she and the team took seriously and even convened a special meeting to discuss before the project. The issue was resolved, she explained, once they realized that the silkworm could go through a healthy and complete metamorphosis and that even the

silkworm that had a magnet superglued to its head had not been harmed. "Once we knew this," she said, "we were okay." Aiming to elaborate further what she meant by being "okay," she explained her general disappointment in learning that the entire silk industry is based on the domesticated *Bombyx mori* silkworm, which is unable to go through its natural metamorphosis—something that Oxman said she found "incredibly sad." They could not override that, she explained, and MIT health and environment would not let them use undomesticated wild silkworm. Trying to put a more positive spin on the matter, she added that the 6,500 silkworms they used laid enough eggs for silkworms to produce 250 more pavilions. "And if you think about refugee camps and the tents used," Oxman concluded, "this would be a great way to support it."

Whatever Oxman meant in this long reply was not at all clear and one could sense a palpable frustration among hardcore biomimics in the audience. To make matters worse, subsequent questions brought up biotechnology, inquiring whether Oxman and her team had thought about genetically engineering the silkworm. Oxman became clearly excited by this and went on to elaborate how she was working to produce transgenic silkworms using recombinant processes to splice spider DNA into the silkworm in order to create a silkworm capable of producing superstrong spider thread. While the audience was still trying to grasp this notion, Oxman took the matter to yet another level, envisioning an approaching singularity in which genes would be spliced into robots, yet again collapsing the boundary between technology and nature.

Oxman took a few more questions, some of which eagerly pursued the biotechnology angle. In the meantime, the conference center catering staff carried away the trays of pastries and the coffee that had been laid out in the morning for the audience on table at the side of the room. The talk had gone on for over an hour and a half and the audience was ready for a break. But Oxman had clearly diverged too far from the biomimicry message and Janine Benyus could not risk letting the matter go unattended, even if only for the short break. Too many in the audience had been excited by Oxman's ideas. Others seemed confused about whether Oxman still qualified as a biomimic. Before the audience could begin leaving the room after the talk, Benyus seized the podium, asking if everyone was willing to give up the planned break and even their "biobreaks" for the discussion to continue a bit.

Benyus's response was somewhat predictable. Over the course of twenty minutes, she reframed Oxman's work in accordance with biomimicry doctrine as the emulation of organic design. More importantly, she reiterated

the urgency of making an absolute division between nature and the human pursuit of technological development. Biomimicry's ultimate goal, she emphasized, is the total cessation of human dependence on the reproductive capacities of natural organisms, whether through bioutilization, bioassistance, and or biotechnology, which for Benyus means rejecting everything from the human use of trees, insects, and even microorganisms. Benyus explained,

> What this [Oxman's work] shows is that we are in process of learning from other fabricators and we have other fabricators making things for us. If you are wearing cotton, a plant made it for you. If you had honey in your tea, a bee made it for you. That's bio assisted technology. If you go out and you harvest wild honey or you harvest wild silk that's bioutilization. You are using something that something else made for you. The next step is for us in biomimicy is for us to learn to do it ourselves . . . . I think what you saw there in the silk pavilion is us learning from those organisms how to do that. There has to be a time when we make our own materials. And we learn their patterns, we learn their process. There's got to be a day when we make those silk pavillions ourselves. But right now we have to be grateful to other organisms. The other thing is that we want to use their genes, in order to make stuff. I think we have to get away from that as well.

Benyus's last statement rejecting biotechnology was received with enthusiastic clapping. She went on to propose a shift in attention in biomimicry from mimicking form to emulating process, which was clearly meant as delicate critique of Oxman yet failed to realize that Oxman's work treated form, process, and material as inseparable. What is more, Benyus's redirection of the discussion distracted, I think, from a real consideration of the ethics of Oxman's silk pavilion project. Thus, I want to suggest that when Oxman framed the matter of the silkworm's exploitation as a question of whether it could go on to realize successful metamorphosis, she began to articulate what we can understand as the ethical premise behind her material ecology approach to design in technological development. As we will see, the central question in determining the ethical integrity of the project becomes the degree to which the project enables the flourishing and further becoming of its various participants. But this was not immediately clear from Oxman's response. Part of the problem with Oxman's response was that it did not elaborate why her team's unease about exploiting the silkworm was abated by the realization that the silkworm could still go through with its metamorphosis after spinning silk for the pavilion? Why did this

resolve the issue of exploitation? The answer to this is related, I think, to her disappointment in learning that the silk industry is based on the domesticated *B. mori* moth. What was essentially "incredibly sad" for Oxman is that domestication has broken a coherence of functions between silkworm and its environment that are necessary for it to transform. Domestication, in other words, has transformed the silkworm from an organic individual into what Simondon would call an "artificial object" whose delicately intermeshed relation with the surrounding milieu has been destroyed in order to exploit its reproductive processes for a specific human need (Mitchell 2012, 78). In breaking that coherency, the technology of silk production undoes thousands if not millions of years of the organism's evolution, co-opting its reproductive process entirely for the generation of capital while silk is merely the by-product. The ethical failure of domestication is not simply that it undoes this long history of entangled relations. It is rather that it disconnects the silkworm from relational milieux of becoming and confines it to an overly determined enclosure.[10] As such, we are no longer able to ask what the silkworm wants to be, which is a question of ontogenesis not ontology. We can only think of the silkworm as an object with a specific designation. It is an instrument of capital. Silk is merely a by-product of capital. We do not need to look very far to find other examples of ethically flawed domestication. Salmon farming is an exemplary case. In her ethnography of the salmon farming industry in Norway, *Becoming Salmon: Aquaculture and the Domestication of a Fish*, the social anthropologist and science and technology studies scholar Marianne Elisabeth Lien provides a detailed understanding of how farmed salmon are produced as a market commodity whose exchange value is determined entirely by biomass (Lien 2015). Contrary to Lien's title, what the text shows is an unbecoming as the salmon is stripped of the dynamic functional coherency that enable its active adaptation to a complex topology of local milieux, which it stitches together in its becoming nitrogen for forests and food for orcas, bears, fish, birds, and humans.[11] Through various forms of dietary, temporal, and chemical manipulations, the salmon becomes fish enclosed, relegated to a faux complexity of commodity relations organized under a single value—capital.

When Oxman explained that they were "okay" once they found out the silkworms they used could still undergo transformation, what she meant is that they realized that they were not further rendering the *B. mori* an artificial object. What she might have added, which would have strengthened her position, was that unlike conventional processes of silk production that require boiling the silkworm in its cocoon in order to extract the silk,

the silk pavilion did not result in the demise of the silkworm. We can think of the silk pavilion as actually reversing to a certain degree the domestication (the making artificial) of the *B. mori* in that it restores its regenerative process while lending it novel plurifunctionality in the form of silk and potentially 250 more silk pavilions. Whereas conventional silk production can acquire silk only by disrupting and destroying the set of relations that allow for the silkworm's transformation, Oxman and her team obtain the silk by positioning the silkworm within a novel and dynamic topology that enfolds intensities from systems of different orders of magnitude—gravity of the earth, heat and light from the sun, and robotically threaded hexagonal frames. In so doing, they are enacting an ethical practice, where "enacting" carries the sense of making or producing something. Enacting is thus antithetical to conforming to a prescribed system of ethical guidelines, as articulated, for example, in biomimicry's life's principles. It specifies the ethical as a quality that is emergent within a system of relations rather than something that is realized under a binding logic. What emerges as ethical in the silk pavilion, then, is how putting the silkworm into relation reintroduces the condition of possibility for asking "what does the silkworm want to be." To be able to ask this question is to be able to think about the silkworm as what Simondon calls a "singular point in an open infinity of relations" (Simondon 1992, cited in Combes 2013, 65). If we follow Muriel Combes's explication of Simondon's ethics here, we can only ask this question when we have amplified the silkworm's capacity (as a system of relations) to enable the same question to be asked of all the other sets of relations that it enfolds over the course of its life and transformation (Combes 2013). Oxman seems to invite us to think this way when she suggests that the 250 pavilions that can be grown from offspring of the 650 silkworms can supply tents for refugee camps. Of course, we could take this statement at face value. Except that silk does not make for durable or weather resistant tent material, especially under conditions in a refugee camp. Thus, the statement is better understood as a gesture to the open and generative potentiality of the silkworm enfolded into the silkworm pavilion project. This "generative potentiality" may in fact be material, but it is more understandable as conceptual. It is important to recall, after all, that the silk pavilion is conceptual architecture and thus not meant to be inhabited. It is something that is good to think with because it is an evolving process that elicits from questions concerning the ethics of technology. Contrary to Benyus's insistence on the establishment of clear and impervious borders between nature and technology, the silk pavilion asks us to reject boundaries and thus anything that looks like nature as a bounded ontological

reality. To borrow again from Simondon (channeled through Combes), nature, instead, becomes that "which renders social transformation thinkable" (Combes 2013, 54-55).

What kind of "social transformation" does the silk pavilion make thinkable? We might start by returning to the salmon and the question of how we might reintroduce the conditions of possibility that would allow us to ask "what does the salmon want to be." This would not mean trying to recover a natural or wild salmon, as a number of researchers, including Lien, have shown that humans and salmon have a long and entangled relationship (see, e.g., Swanson 2013). Rather, it would involve finding a way to amplify the salmon's pluripotentiality by enabling its open-ended and generative relationality with all the other creatures and systems (forest and air) of which the salmon can become. It would mean transforming our concept of farming from one that can only imagine enclosures dictated by a logic of capital to one that thinks of networks as milieux of active becoming for humans and nonhumans.

Conclusion

When Janine Benyus adopted the title *Biomimicry: Innovation Inspired by Nature*, she set up the possibility for two different approaches to nature in the subsequent movement that coalesced around the text—mimicry and inspiration. Mimicry is not inspiration. Mimicry is forever troubled by the premise of a relationship to an original. As such, it easily becomes entangled in a binary structure of power as the question of who is in position to issue evaluative judgments on the degree to which emulation succeeds in reproducing the quality of the original becomes a matter of who has authority to speak. This is precisely where biomimicry becomes problematic. In its initial conceptualization, biomimicry sets nature up as the author of a supreme ethical framework, based on the idea that it is a complex self-ordering dynamic network in which the evolutive interaction among organisms over the course of billions of years has produced a guiding framework for a morally coherent system of mutually sustaining relations. At the same time, biomimicry reserves for itself the role of nature's interpreter, developing what it declares is the authentic reading of the nature's underlying organizing principles. In so doing, biomimicry follows in the troubled tracks of many ideologies and political movements that have staked their power on the claim of a privileged relation to nature. By contrast, inspiration is not burdened by notions of original and reproduction. Nor is it encumbered by the need to produce a domain of nature

set apart from the world of human activity. Where mimicry invokes imitation, inspiration bespeaks the process of being drawn into a dynamic dialogue. Original, reproduction, authentic, and imitation are terms that have no specific meaning in relation to inspiration. Nature is treated not as an authoritative diagram of relations that one must follow but rather as an ecology of material iterations with which to think. This mode of inspiration, I have tried to show, is what we find in Oxman's work. Although Oxman embarks with a process of mimicry when she draws on organic systems to innovative designs in technology, that method transforms at some point into one of inspiration. What ensues is a process that is not categorizable as belonging to nature, the human, or the technological but rather something that invokes a common charged potential that animates all toward a new arrangement of becoming.

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Notes

1. My definition of technics draws here mainly from the work of Simondon (1958) and also from Mumford (1963) and Deleuze and Guattari (1987). While all these thinkers were highly critical of the effects of technological development under capitalism, they recognized the potential for a novel and progressively innovative becoming of human society through the symbiotic interaction of technology, natural environment, and human culture.
2. I borrow the term "representational idiom" from Pickering (1995).
3. Deep ecology places the blame for ecological degradation on the long history of anthropocentric humanism in Western philosophy, science, and social movements (including Marxism). It calls for attention to the interrelatedness and interdependence of human and nonhuman life while refuting

the idea of human exceptionalism. Ecofeminism offers a similar argument but focuses specifically on dismantling Western society's system of patriarchy, which it sees as enabling the subjugation of nature through male-dominated science (for an insightful analysis of these various movements, see Zimmerman 1994).

4. Janine Benyus, "A Biomimicry Primer." https://biomimicry.net/b38files/A_Biomimicry_Primer_Janine_Benyus.pdf (accessed January 12, 2017).
5. There are many texts one could turn to for a demonstration of this theory. The text that I tend to draw on is Beauvoir's ([1949] 1968) *The Second Sex*.
6. I find myself in agreement here with Johnson's and Goldstein's assessment that "Benyus disavows the domination of nature, but does not give up the division between nature and society upon which such narratives rest. Nature remains conceptualized as the 'first nature' of Enlightenment thought, a universal and extensive world 'out there' for human civilization to work on and through" (2016, 68).
7. Nocek develops a similar critique in an exploration of biomimetic design in architecture (Nocek 2014).
8. Neomaterialism's postvitalist proposition is one of its main conceptual contributions. As Dianna Cole and Samantha Frost explain, new (or neo) materialism wants to provide an understanding of the immanent capacity of matter to act and transform without resorting to notions of an inner spirit or essence that were key to vitalism. In other words, neomaterialism wants to preserve the idea of material vitality without vitalism (Coole and Frost 2010).
9. While actor network theory has inspired and guided a generation of anthropologists, it has been criticized for its functionalist approach and failure to engage ethical issues around technology and science (see, e.g., Fortun 2014).
10. In their critique of biomimicry, Johnson and Goldstein point to the way it produces "enclosures." Drawing from Marx, for Johnson and Goldstein, enclosure delineates an initial process of abstraction in the rendering of resources into surplus value (Johnson and Goldstein 2016). By contrast, I use the notion of enclosure in a more literal sense to denote a process of closing off through domestication.
11. For a beautiful explanation of salmon becoming, see Morton (2002). See also Morton's interview on CBC Ideas entitled Saving Salmon, http://www.cbc.ca/player/play/1736348440 (accessed January 12, 2017).

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