

Evolutionary Yarns in Seahorse Valley: Living Tissues, Woolly Textiles, Theoretical Biologies

Tissue, textile, and fabric provide excellent models of knowledge, excellent quasi-abstract objects, primal varieties: the world is a mass of laundry.
—Serres

Making a lung with a piece of esophagus sounds very much like making a skirt with a piece of Granny's curtain.
—Jacob

I'm poking a very odd-looking creature. Its exterior is variegated, blushing pink leaking into rust and green, its long composite body composed of various segments ruffled, polypous, tubular, spiral, and freeform. As it languishes limply in my hands, I note that its morphology is reminiscent of the frilly leaves and air bladders of kelp. The creature's curator, a woman named Margaret Wertheim, tells me in hushed tones that the remarkable thing I am now handling is the first of its kind that is not a "single-celled" species. In an article, she describes it as representnig its "own evolutionary path, which quickly developed into whole new genera of [. . .] reef organisms. These chimeric, hybrid, morphing constructions call to mind the seminal period in the history of life on Earth known as the Cambrian Explosion, around 500 million years ago. It was during this era that all the major animal body plans seen on our planet today came into being. So [this form] seem[s] to suggest the potential of all living things" ("Aviva"). But this creature isn't multicellular, or even unicellular. It's made of yarn (see fig. 1).

Figure 1
Aviva Alter's first
Cambrian explosion
form.

Photo © Aviva Alter.



The work of a Chicago artist named Aviva Alter, it is one of the crocheted artifacts composing the Hyperbolic Crochet Coral Reef (HCCR), a distributed venture of thousands of women who cooperatively fabricate a collection of yarn and plastic coral reefs. Under the auspices of a nonprofit organization called the Institute For Figuring, about which more below, these crafters use the technique of “hyperbolic crochet” invented by geometer Daina Taimina to make these woolly reefs, with the aim of drawing attention to the menace that climate change poses to the world’s fleshy coral reefs. Crochet is a fiber arts technique that uses a single hooked needle to loop together yarn to produce a fabric. Hyperbolic crochet is a method of fabricating models of hyperbolic geometry, a kind of non-Euclidean geometric space characterized by negative curvature (spheres, meanwhile, have positive curvature).¹ Many marine organisms have evolved to embody hyperbolic geometry; it affords them a maximum surface area with which to filter feed in a minimal volume.

What is the place of biology—and specifically of biological theory—in this project? What conditions enable the Reef’s makers to describe their work in explicitly biological terms, to speak of a “Cambrian explosion” and a “Silurian atoll,” to claim that they are fabricating new taxa, new genera, new species, to say that in abandoning geometric formalism, the models have come to life? In what follows, I first describe the Reef’s origins in geometrical modeling, then trace the manifold biological theories that inform Reef makers’ descriptions of their project, showing how they draw on contemporary, historic, and folk understandings of evolution and morphogenesis in describing their work. I argue that in so doing, they pose evolution as akin to handicraft—something open-ended, lively, time-consuming, perpetually becoming.

Analogies from the fiber arts run deep in the life sciences, as attested to by the preponderance of terms such as *strand*, *tissue*, *membrane*, *fiber*, and *filament* in anatomy and *net* or *web* in systems biology and ecology. And while critical and feminist science studies have made many of us well aware of the stale metaphor by which DNA is likened to text, book, or code, biologists have also described nucleic acids as “strings,” “strands,” or “threads” that “coil,” “unspool,” “knit,” and “knot.” Such metaphors are woven into Reef crafters’ biologically informed practice, as they thread together richly divergent biological theories ranging from Romantic biology to neo-Darwinism. In so doing, they are engaged in something that, I believe, professional life scientists are also engaged in: installing their own theories and apprehensions into the living things they seek to understand.

In her introduction to *Things That Talk*, Lorraine Daston writes that “like seeds around which an elaborate crystal can suddenly congeal, things in a supersaturated cultural solution can crystallize ways of thinking, feeling, and acting” (20). I here take the Hyperbolic Crochet Coral Reef as such a seed in cultural solution. It is an artifact—a culturally meaningful material thing—that condenses current ways of thinking and enacting biology. By figuring evolution as a mode of craft, biology becomes something whose evolutionary unfoldings Reef makers not only mimic but also analogically generate through their crafting of new crochet forms.

A Dip into Seahorse Valley

Coral reefs have long proven themselves good to think with. In Charles Darwin’s first monograph, conceived during his travels on the *Beagle*, the naturalist outlined many of his later theories while meditating

upon coral reefs: “In an old-standing reef, the corals, which are so different in kind on different parts of it, are probably all adapted to the stations they occupy, and hold their places, like other organic beings, by a struggle one with another, and with external nature; hence we may infer that their growth would generally be slow, except under peculiarly favourable circumstances” (76). More recently, the ecologies of coral reefs have animated the thinking of feminist science studies scholars, who use reefs to think about, among other things, collaboration, embodiment, sensation, and ecological entanglement. Donna Haraway compares academic citationality, the accumulation, consumption, and generation of text, to coral habitats: “[T]he written, collected, and published book of interviews becomes the finished scaffolding, the coralline reef, on which the next generations of spineless, non-bilaterally symmetrical entities will settle, eat each other and passers-by, and proliferate their drifting, always hungry, and seedy brood” (Foreword xi–xii).² Scholarly writing here is a living ecosystem that accumulates and flourishes as authors share, inherit, and filter-feed on textual debris. Eva Hayward meditates upon cup corals, using them as figures from which to spin her account of touching and feeling in human-coral encounter at the Long Marine Laboratory in Santa Cruz: “*B. elegans* have neither fingers nor eyes, not in the same way a human might, but through their sensing tentacles they and I, they and marine biologists, share sensorial resonance with different affects (responsiveness) and percepts. Through our mutual capacities to engage the other, we leave impressions as the residuum of our interactions” (581–82). Stefan Helmreich, riffing on Haraway’s scaffolding, proposes that coral might serve as figures that “can attune their human visitors and inquisitors to empirical and epistemological questions of scale and context” (“How Like”). Myra Hird tracks the sex changes the coral goby fish undergoes in its lifetime to reflect on the consequences of using nonhuman animals to make sense of human embodiment and sexuality. Coral’s dividuality,⁵ its mutable sexuality, its sensorial alterity, its invertebrate and inveterate nonbilaterality, make it a stunning animal other with which to contemplate human natures and cultures. It is, then, altogether fitting that coral reefs, which have more recently made headlines as sentinels of climatological crisis,⁴ now figure as object and artifact of the Hyperbolic Crochet Coral Reef, a project that melds biological and evolutionary apprehensions with ecological activism.

Margaret Wertheim, the Reef’s curator, is a well-known science writer and cofounder of the Institute for Figuring (IFF). On an

overcast and rainy morning in late November 2008, she invited me to the sprawling American Craftsman-style home she shares with her twin sister, Christine Wertheim.⁵ From this house, the headquarters of the IFF, the twins organize workshops and exhibitions and write about a web of mathematical and aesthetic activities that they classify as “figuring.”⁶ The IFF is, according to its directors, “dedicated to enhancing the public understanding of figures and figuring techniques. From the physics of snowflakes and the hyperbolic geometry of sea slugs, to the mathematics of paper folding and graphical models of the human mind, the institute takes as its purview a complex ecology of figuring” (Wertheim, “About”). The Institute for Figuring website reports that IFF headquarters “does not yet have a physical space, but [a] [. . .] permanent location in the conceptual landscape” known as the Mandelbrot set, a fractal mathematical space on the plane of intersection of the real and imaginary numbers, obtained by the quadratic equation $z(n+1) = zn^2 + C$. The IFF, the Wertheims say, sits at coordinates $-0.7475198, 10.1084649$, in a deep furrow between the “head” and “shoulder” of the Mandelbrot set.⁷ This neighborhood of the set is colloquially known by mathematicians as the “Seahorse Valley,” because it is composed of clusters of biologically suggestive stalks and fronds.⁸ In the lived world, Seahorse Valley roughly maps onto a quiet cul-de-sac in Highland Park, a neighborhood in northeast Los Angeles (see fig. 2).

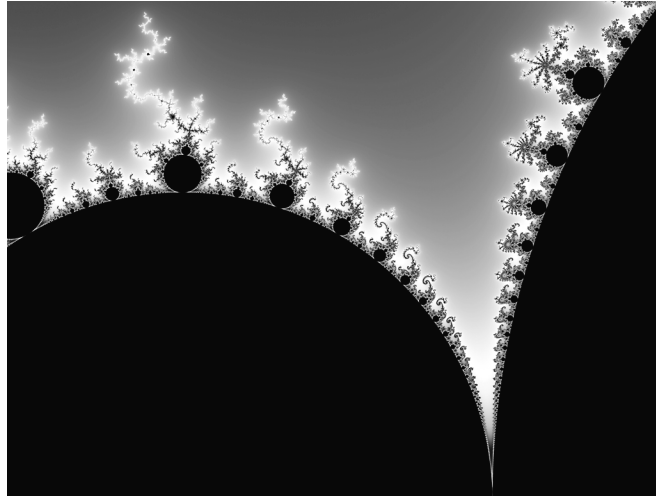
The twins Margaret and Christine Wertheim were raised in a Catholic family in Brisbane, Australia, two of six children born in the span of five and a half years. They learned many feminine handicrafts from their mother but taught themselves to crochet in high school and later taught their mother so that she could contribute to the Reef. Wertheim earned bachelor’s degrees in both physics and mathematics before embarking on a career as a science writer; Christine Wertheim received a doctorate in literature and semiotics and now chairs the writing program at the California Institute of the Arts. Wertheim has written about topics ranging from mathematical origami (“Mathematics”) to obsolete computational devices (“Things”). As a science journalist, she has written articles for the *New York Times*, the *Los Angeles Times*, the *Village Voice*, and *Cabinet* magazine; she has published three books on the cultural history of physics, most recently *Physics on the Fringe* (2011).

Besides the Hyperbolic Crochet Coral Reef, the Wertheims have presented exhibits on the Froebelian gifts⁹ and a Menger sponge.¹⁰ What unites all of the IFF’s diverse projects is a confluence of physical and mental labor, or what the Wertheims call “figuring,” which they recognize

Figure 2

The IFF is located in the Seahorse Valley region of the Mandelbrot set (pictured here) at the following coordinates: $(-0.7475198, i0.1084649)$. Created by Wolfgang Beyer with the program Ultra Fractal 3 and licensed under the Creative Commons Attribution-Share Alike license.

Source: Wikimedia Commons



in a broad range of cultural practices, including Indian paisley patterns and Islamic mosaic motifs, “from weaving, knotting and ‘string figuring,’ to origami, tiling, perspectival drawing, and holography” (Wertheim, “About”). Summarizing from the *OED*, Wertheim defines figuring as “to form or shape, to trace, to reckon or calculate, to represent in a diagram or picture, to ornament or adorn with a design or pattern” (“About”). Rather than taking mathematics as esoteric and disembodied, figuring—the repetitive labor joining abstraction to materiality—gives body to mathematics.

Wertheim’s understanding of figuring resonates with how figuring has been theorized by feminist science studies scholars seeking to articulate how knowledge is fleshed out. For Haraway, figuration is a move counter to traditional modes of historical representation. It is “about resetting the stage for possible pasts and futures. Figuration is the mode of theory when the more ‘normal’ rhetorics of systematic critical analysis seem only to repeat and sustain our entrapment in the stories of the established disorders” (“Ecce” 86). Materialized reconfiguration is a technoscientific project in which Haraway’s figures engage; it is a way, she argues, “to knot together,” and “a practice of turning tropes into worlds” (“Game” 60). Figuring as a fusion of the material and discursive also inflects the work of Karen Barad, who builds on Haraway’s materialized reconfiguration to speak of “ongoing material [re]configurings of the world” in a critical epistemological intervention she terms *intra-action* (152). Lucy Suchman emphasizes the *con-* in Haraway’s materialized reconfigurations

to think through how figures are constructed in relation to one another, asking how such entities could be figured otherwise (1). In examining the Hyperbolic Crochet Coral Reef, I am interested in understanding how figuring, understood as the confluence of conceptual (discursive, semiotic) and manual (embodied, tactile, material) labor, offers Reef makers access to a craft-based apprehension of biological form and evolution. I discern two sorts of figuring at work in the Reef: the first is the visceral sense for otherwise abstract concepts that accrues through time-intensive work, as, for example, in mathematical modeling; the second is the material expression of evolutionary theories by simulating liveliness, variation, and unpredictability in craft practice. The Reef is a way of telling stories— weaving yarns— about how evolution works.

Taimina invented hyperbolic crochet as a means of modeling geometric space. Reef crafters, while following her technique, use her algorithm as a starting point from which to digress and upon which to embellish in order to yield what they consider to be “biological” forms. “Liveliness,” for reef crafters, is best captured by swerving away from precision and repetition and toward messiness, error, dynamism, and open-endedness. In her work on protein modeling, Natasha Myers argues that liveliness is a narrative effect of researchers’ embodied work modeling protein conformations, a way of telling stories about biology that “keeps bodies in time” (“Modeling” 246) and “conjure[s] a living world that escapes capture” (250). The Reef realizes biological forms in abiotic media, but it is not the only example of the separation of biological form and function from living substance: other examples include Artificial Life research, which models lifelike processes in software; physical and digital visual modeling of biological objects; even Enlightenment automata. As living form strays from its substrate, liveliness is sheerly performative, a playful experiment in the forms “lifelike” things might take. That is, Reef crafters themselves generate the liveliness they identify with their woolly invocations of biological forms. Richard Doyle unpacks the rhetorics by which Artificial Life researchers conflate the “lifelike” with “life itself,” suggesting that the work of turning “models of life” into “examples of life” points to the absence of a coherent reference for life, even as it grounds life in abstractable formal properties (122; see also Helmreich, *Silicon*). Both Myers and Doyle emphasize that liveliness is rhetorical and narrative; life gets spun from the stories people tell about it.

Here, I am listening for such stories, the “evolutionary yarns” Reef crafters spin while trying to manifest evolution in yarn. *To spin a yarn*,

according to the *OED*, is nautical slang meaning “to tell a story (usually a long one).” A *yarn* is described as a “long story or tale: sometimes implying one of a marvellous or incredible kind.” Evolutionary yarns are indeed long ones, stretching billions of years, and as its etymology suggests, these “evolutionary yarns” are also maritime. Gananath Obeyesekere writes that “one technique in spinning a yarn is to make the fantastic seem matter of fact. [. . .] [Y]arnsters incorporate well-known ethnographic truths that then are turned inside out and woven into an episode in a story” (183). The yarnsters I describe here spin their tales from biological theory, including Romantic notions of life forwarded by the likes of Johann Friedrich Goethe and Lorenz Oken, as well as twentieth-century theoreticians such as D’Arcy Thompson, François Jacob, and, more recently, Susan Oyama and Niles Eldredge. As an ethnographic yarnster, I invert Obeyesekere’s formula—I am working to make the matter of fact seem fantastic.

*The Contours of Craft:
A Field Day at the LACMA*

Before touring the Wertheims’ home and its collection of woolly *objets d’art*, I explain the origins of the Reef and recount a visit to a hyperbolic crochet workshop the Wertheims hosted at the Los Angeles County Museum of Art (LACMA). I here consider how discursive knowledge (whether mathematical or biological) and experiential knowledge converge in hyperbolic crochet. While the Reef has become a “giant, ongoing, evolutionary, fancywork experiment” (Track 16 Gallery) and “a wormhole into an alternate universe of creative feminine energy” (Yury), it started as an exercise in mathematical form. What joins mathematical figuring and biological figuring is that they are time-intensive *experiments*: practices that are open-ended and dynamic, the product of which is unclear or unanticipated by those undertaking it, akin to Hans-Jörg Rheinberger’s experimental systems, which he characterizes as “dynamic bodies” that behave as “generators of surprises” (*Toward* 2–3). In diverging from geometric form, however, Reef crafters understand such surprising dynamism in explicitly biological terms.

Wertheim first learned about hyperbolic crochet from an article in *New Scientist* about the “power of traditional handicrafts” like crochet, knitting, and glassblowing “to create otherwise unimaginable [mathematical] objects” (Brooks). The article mentioned Taimina, now an adjunct associate professor in the Department of Mathematics at Cornell

University, who fabricated the first robust physical model of hyperbolic space.¹¹ Taimina first came to Cornell as a visiting scholar in 1997, tasked with teaching David Henderson’s hyperbolic geometry course.¹² Henderson had constructed a physical model of hyperbolic space while on a camping trip in 1978 and used it in his course for the next nineteen years. He had fabricated the model using small paper annuli, or rings, which he then taped together, following a method he had learned from fellow Cornell geometer William Thurston.¹³ Taimina described the twenty-year-old paper model as “disgusting” and too flimsy and friable to easily handle or play with. That sturdiness was one property of a good physical model speaks to Taimina’s pedagogical bent: she wanted a model that students would not just look at but *handle*, and so set out to fabricate new hyperbolic models from yarn.¹⁴ Taimina learned needlework from her mother as a girl in Soviet Latvia. She describes the resourceful ethos that marked Soviet culture during her childhood, crediting her upbringing for her crafty approach to mathematical modeling: “You fix your own car, you fix your own faucet—anything [. . .]. When I was growing up, knitting or any other handiwork meant you could make a dress or a sweater different from everybody else’s” (Samuels). Taimina does not differentiate between geometrical formalisms and the grounded and mundane aspects of daily life; she points to the floppy fruiting bodies of wood ear mushrooms and the leaves of curly parsley as examples of hyperbolic geometry and uses the technique she developed to model the hyperbolic plane to fashion clothing.¹⁵ Beyond representing or intervening, hyperbolic crochet as a figuring practice points us toward a woolly tangle in which handiwork grounds mathematical apprehensions and vegetable gardens embody geometric structures.

After Wertheim read the article about Taimina in *New Scientist*, she decided to try Taimina’s technique. The article, however, was unclear about what Taimina’s technique had been, so Wertheim called Taimina to ask for further instructions. She and her sister started crocheting, making many mathematically accurate forms in the first few months. Wertheim was very particular about being true to the “pure geometry” of the forms, wanting to see how far afield they could go by following the rules of hyperbolic crochet (that is, increasing after a prescribed number of stitches and not varying the rate of increase), but Christine Wertheim started complaining that she was bored. Having crocheted piles of geometrically accurate hyperbolic planes, she one day said, “Screw geometric fidelity” and started diverging from the algorithm, “deviating into irregular rates

Figure 3
Hyperbolic Crochet Coral Reef by
 the Institute For
 Figuring, with sea
 slug by Marianne
 Midelburg.

Photo © the Institute
 For Figuring.



of increasing stitches and un-planar forms. To this algorithmic aberrancy she soon added fluffy and hairy yarns; she also started mixing yarns together—a bright orange synthetic with a hot pink mohair, for instance, or a deep green carpet yarn with a hairy cream bouclé. The effect was electrifying. Suddenly the models came to *life*—they began to look like natural organisms instead of Platonic ideals” (Wertheim, “Christine”) (see fig. 3).

In 2005, the Wertheims took a handful of the freeform hyperbolically derived forms they had crocheted and arranged them on their coffee table. Having grown up in Queensland, home to the Great Barrier Reef, the twins were attuned to the threat climate change posed to coral reefs, a problem that had been gaining attention in the popular press over the past decade. The arrangement of hyperbolic forms on their coffee table suggested a reef, and Christine Wertheim thought they should continue crocheting until they had fabricated an entire crocheted reef that they could exhibit. Wertheim soon realized that the work required to crochet a coral reef was much more than the twins could handle alone, so she posted a call on the IFF website, encouraging others to contribute time to crocheting the Reef.¹⁶

Since then, much of the Reef has been fabricated by the Wertheim sisters, with the help of around fifty prolific contributors. Many of the pieces are one-off objects that either arrive by post in boxes at the

Wertheims' front door or are made in workshops or craft circles in New York, Chicago, London, Scottsdale, Sydney, Riga, Toronto, and Tokyo. Some of the people who helped make the Reef are professional scientists—geneticists, earth scientists, mathematicians, computer scientists—though among its core contributors, I talked to librarians, artists, and housewives. In the last six years, it has traveled the United States, Australia, and Europe, like a great wooly ecosystem that disassembles and reassembles in galleries and museums. It most recently thrived in the Ocean Hall at the Smithsonian Institution's National Museum of Natural History. It has also twice appeared in the pages of *Science*, no small feat for a craft project.

My first visit to the Wertheims' home was a week and a half after I attended one such craft workshop at the Los Angeles County Museum of Art. The workshop they hosted was part of a larger event run by Machine Project, a nonprofit organization in Echo Park, California, that, according to its mission statement, “exists to encourage heroic experiments of the gracefully over-ambitious.”¹⁷ At LACMA, about twenty-five different groups hosted workshops for ten hours on a warm Saturday. The IFF workshop was stationed in a large gallery on the second floor of the Ahmanson Building, where the Wertheims arranged two tables into an L flanked by a few Pollocks and a Rothko.¹⁸

The sisters had covered the tables in butcher paper and arranged a number of crocheted pieces on each table, as well as craft materials: crochet hooks, scissors, and plastic bags. Their workshop focused on how to crochet plastic models, in reference to the threat plastic trash poses to the health of the world's oceans. To make a plastic trash hyperbolic crocheted coral, one must first make plastic yarn, and this is what Christine Wertheim set out to teach me once I sat down. Sitting beside me in the LACMA gallery, she first took two plastic bags, white with red lettering, and folded them lengthwise into quarters. After using scissors to trim the handles and bottom, she began cutting strips of plastic crosswise which, once unfolded, made plastic loops about half an inch wide. Folding and cutting my own plastic bag, I followed her lead. After we had both accumulated a handful of plastic loops, she showed me how to pass one loop over and then under a second one and pull it through, in the way one would make a chain of rubber bands. Once I had a good length of plastic yarn ready, I made a slipknot and began crocheting a chain, then worked my way back around the first thirty stitches, increasing every fourth stitch.

Christine Wertheim told me that she had set out several years ago to begin crocheting a single hyperbolic model that she would continue

to enlarge throughout her life, using crochet as benchmark and trace of the passage of time. She imagined that whereas the first few rows or rounds would take minutes to complete, because hyperbolic geometry is an “excess of surface,” the final row or round would take decades to unfurl.¹⁹ Her mapping of biographical time onto the efflorescence of hyperbolic geometry is an experiment in figuring, within which the time-intensive work of craft, the unhurried accretive business of evolution, and the discursive work of autobiography all hang together. In such labor-intensive work, “the making/marking of time is a lively material process of enfolding” (Barad 181).

Taimina suggests that such concentrated and meticulous labor is in fact central to hyperbolic crochet’s success as a pedagogical tool. For her, the material tactility of her fabrications—her mathematical figuring—is necessary to the comprehension of geometrical spaces that would otherwise remain purely conceptual and, to a large extent, unfathomable. That is, one learns about hyperbolic space by fabricating it more than by handling it. While certainly, handling a physical hyperbolic model allows one to apprehend the geometry of hyperbolic space better than equations or a two-dimensional diagram of hyperbolic geometry would, it only goes so far. What is most diagnostic of the intersection of handicraft and geometrical models is practitioners’ insistence that to understand these puzzling geometries, you not only need to interact with a physical model but must also take the time to *make* one yourself.²⁰ Wertheim told Taimina in conversation, “I have crocheted a number of these models and what I find so interesting is that when you make them you get a very concrete sense of the space expanding exponentially. The first rows take no time but the later rows can take literally hours, they have so many stitches. You get a visceral sense of what ‘hyperbolic’ really means” (Wertheim, “Crocheting” 21). The “visceral sense” of which Wertheim speaks means a deep material apprehension of a thing that is best imparted by making it, and more so, by making it slowly. It is the time and effort put into crocheting—and the improvisational experimental work of generating new forms—that offers crafters embodied understandings of biological form and evolution. Craftspeople, craft theorists, and historians of craft have shown that lived experience can cultivate discursive knowledge, that practice nourishes theory. Historian of science Pamela Smith writes that during the Scientific Revolution, artisans’ imitation of nature was regarded “as a learned bodily habit that became a cognitive practice and, finally, led to knowledge” (98).

The close understanding borne of fabrication may be recognized elsewhere in scientific practice. In her biography of Nobel Prize-winning geneticist Barbara McClintock, Evelyn Fox Keller asserts that it was McClintock's "feeling for the organism" that afforded her the ability to notice and interpret anomalies in her model organism. While she never defines this "feeling," she suggests that it is about an intimacy, identification, and discernment of the thing being studied, which McClintock refined by cultivating her maize plants herself, sitting in the field and being willing to slow down and "take the time" with her organism (Keller, *Feeling*). "Taking the time" and the "visceral sense" that it engenders are necessary to and afforded by acts of mathematical and biological figuring in which an understanding of hyperbolic geometry and evolution gets worked out through fabrication.²¹

When I was seven years old, my grandmother taught me to crochet to alleviate my boredom and distract me from my carsickness on a long, hot, lurching bus ride. Yet, in 2008, when I read Wertheim's interview of Taimina, I had not picked up a crochet hook in over ten years, and my technique was rusty. In order to experience this "visceral sense" firsthand, I decided to try my hand at hyperbolic crochet. I bought three skeins of hot pink cotton yarn and a crochet hook at my neighborhood craft shop.²² At home, I took out Taimina's crochet instructions, which had been published in an issue of the craft magazine *Interweave Knits* (Lock) and made a slipknot.

I had expected to struggle at first but was surprised to discover that my hands remembered how to crochet, even if I did not. I knew how to grip the hook and maintain the tension in the yarn, in which direction to grab the yarn with the hook, and where to insert the hook into the previous loop. The first chain of twenty stitches took a few minutes to complete, as I had not yet regained the ease and momentum that comes with continued practice. The second and third rows, even when increasing every fifth stitch, took less time, but each row after that became considerably more time consuming. I worked on my model for a few hours most evenings over the course of two months; crochet is a repetitive gesture easily done while distracted, and sometimes I would look down at what my hands were doing and marvel at the thing taking shape. Artist and scholar Lou Cabeen, in writing about early twentieth-century embroidery, describes this satisfaction as "the sensuous pleasure of the work itself," which she articulates in a biological idiom of bringing forms to life: "cloth in hand, colored threads at the ready, the calming effect of repetitive motion, and the gratification

of watching a form grow as if by magic under your fingers, the sense that you were, in fact, *bringing it to life*" (216, emphasis added). Its negative curvature made the form fold, warp, and contort in my hands. Depending on how I adjusted its ruffles, it could take any number of conformations (what mathematicians call "embeddings in 3-space"): a tightly frilled sphere, a spiral chain, a fluted shallow bowl. Whereas I finished the first rows in minutes, I quickly gained Wertheim's "visceral sense" of what it means for surface area to increase exponentially: the last row took over a week to complete, and a third of the total yarn.

By the time I participated in the Wertheims' workshop at LACMA, I was once again an adept crocheter, and over the course of the afternoon made a hyperbolic coral out of reused shopping bags and a length of gift ribbon, while talking to other workshop participants and passersby. Seated across from me for much of the day was Clare O'Callaghan, a librarian and sometime ceramicist who makes her forms out of the royal blue plastic bags in which her *New York Times* is delivered, interwoven with plastic medical waste such as hypodermic needle covers and bits of tubing from iv lines. In turning now to the Reef itself, and to the work of Reef contributors like O'Callaghan, I ask what sorts of evolutionary yarns they narrate and generate by crocheting coralline forms.

*"An Evolving Woolly Taxonomy": A Dive
into the Hyperbolic Crochet Coral Reef*

Having sketched out the unlikely series of biographical, epistemological, and discursive swerves that entangle crochet, non-Euclidean geometry, marine biology, and ecological activism, I now track back to Seahorse Valley. The Wertheims' home reminded me of nothing more than a contemporary curiosity cabinet, and when Wertheim abruptly stood up from the kitchen table where we were sipping tea, saying, "Come with me. I'll show you some things," I learned that what she had in mind was a sort of architectural mnemonic, in which she introduced me to the Hyperbolic Crochet Coral Reef and the Institute For Figuring by guiding me on a tour of its artifacts, which were artfully arranged on every horizontal surface of their home.

Taking out a plastic sandwich bag, Wertheim arranged before me a series of orange pseudospheres, each about an inch or two in diameter. The work of a doctoral student studying paleoceanography at the University of California, Santa Cruz, these forms exhibited the sort of

mathematical precision with which the project had begun. Each pseudosphere was labeled with its rate of increase, varying from every six stitches, which produced a softly fluted form, to every two, yielding a tensely curled mat.

Recall, however, the Pygmalionesque moment in which, deviating from such geometric exactitude, Wertheim marveled that the models “came to life.” As soon as she and her sister started diverging from “pure geometry,” she reported, the forms began to look biological: “But we found that when we deviated from the specific setness of the mathematical code that underlies this, the simple algorithm crochet 3, increase 1, when we deviated from that and made embellishments to the code, the models immediately started to look more natural” (Wertheim, “Beautiful”).

What do the Wertheims mean when they say that they brought the models “to life”? Doyle characterizes Artificial Life as a field that “seeks to derive the formal nature of the living system, life’s algorithm, by abstracting it from its material, carbon-based prison” (121). Reef crafters also abstract lifelike qualities from living things; they think about evolution and morphology as general and abstractable characteristics that are not limited to “carbon-based” life. And as in the work of Artificial Life researchers, I discern in their craft echoes of and debts to theoretical biology, which I trace below. However, the Reef and Artificial Life also diverge in important ways: whereas Artificial Life researchers conflated form with formalism, here, I claim, Reef makers recognize liveliness precisely in *divergences* from mathematical algorithms.

Theoretical biologist D’Arcy Thompson wrote in 1917 in *On Growth and Form* that an organism’s morphology is shaped by mechanical interactions with its environment. Thompson promoted algebraic and geometric formalisms to account for living form.²⁵ Indeed, theoretical biologists throughout the twentieth century—among them Thompson, C. H. Waddington, and Brian Goodwin—have sought to generalize and formalize biological form and transformation using principles borrowed from mathematics and geometry. Life, they thought, conforms to mathematical formulae. In contrast, although HCCR contributors use a geometrical algorithm as a starting point for their coralline creations, in their view, the spark of life, or at least lifelikeness, resides in swerves *away* from geometrical precision. In this sense, Reef crafters’ understanding of biology, and the force of evolution in particular, as open-ended and extemporaneous owes more to Jacob’s and Oyama’s notion of “evolutionary and molecular tinkering,” which I delve into below.

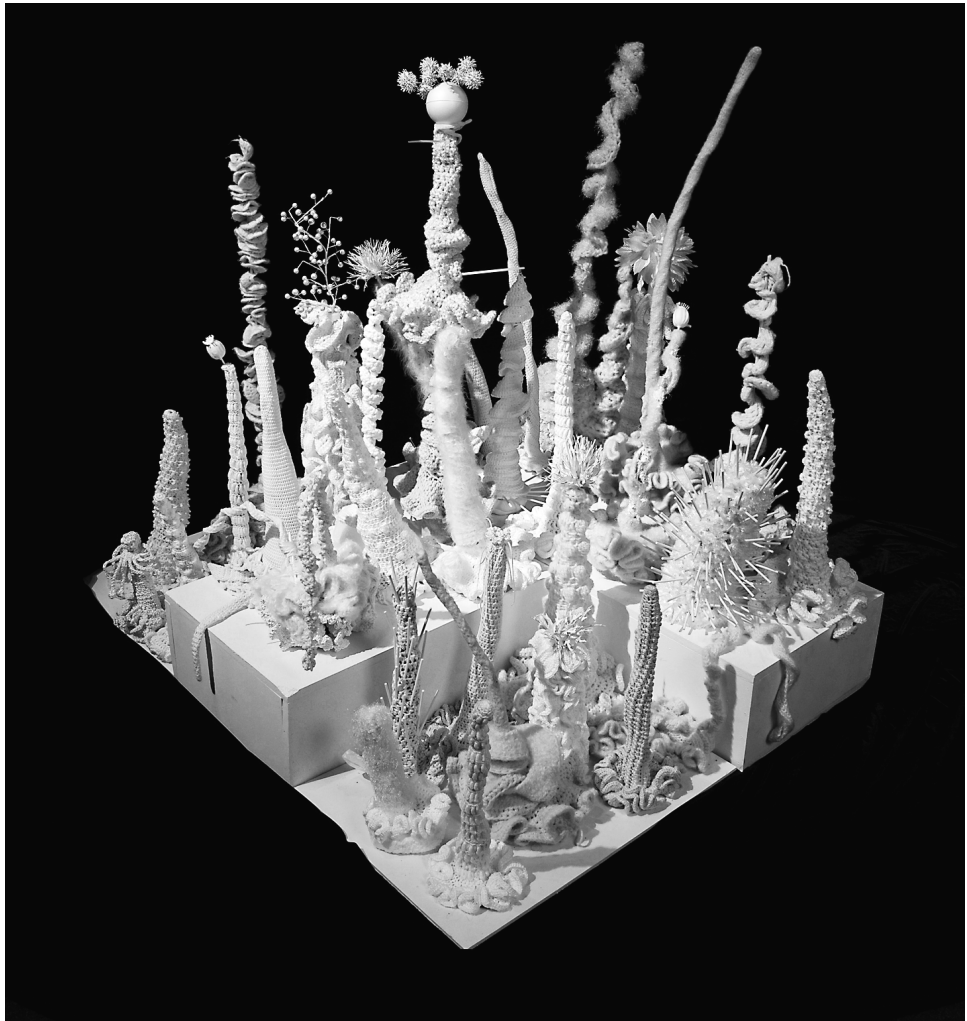
Further, the “code” Wertheim speaks of has multiple referents: it is the mathematical formula encoding the hyperbolic plane, the crochet pattern that materializes hyperbolic space, and the genetic code, “mutations” in which Wertheim and her contributors imagine engendering the production of new forms. Thinking about the code as “genetic” does not necessarily suggest an alliance with DNA; until the early twentieth century, “genetic” also had the broader sense of anything “generative; productive,” marking spaces of productive possibility including but not limited to biotic substrates (*OED*). Just as genetic mutations are one agent of evolutionary change, according to neo-Darwinian theory, the crafter’s prerogative to stray from a formal series of rules is what drives, in the Reef, the proliferation of new forms, which Reef makers describe as “species.” As one crafter explained her work, “over time, new ‘species’ of these organisms come into being as the patterns and underlying codes evolve” (Bruce, qtd. in Wertheim, “Anita”).²⁴

Of course, not all biologists narrate evolution as strictly molecular, nor even as genetic. Such an account revives gene-centric stories about genes as agents of individual evolvability, which had their heyday in classical molecular genetics and remain central to folk understandings of mutation and evolution. They do so at the expense of more recent biological theories that complicate and tangle Darwinian and neo-Darwinian explanations by accounting for phenotypic, population-wide, symbiotic, and epigenetic change as also vital to evolution. Such accounts emphasize how evolution occurs not through struggle and competition but by interspecies collaboration, implication, and communication, as well as complex relations between bodies and environments. Studies of epigenesis, lateral gene transfer, and endosymbiosis all challenge neo-Darwinian thinking (Margulis; see also Hustak and Myers).

Our next stop in my tour of the Wertheims’ home was a delicate purple creature with ruffled tentacles layered radially like the petals of a flower, perched in a wine glass on the kitchen sideboard so that its appendages draped artfully over the glass stem. It is the work of Evelyn Hardin, a middle-aged woman from Cedar Hill, Texas, who regularly ships boxfuls of her creations to Seahorse Valley (see fig. 4). Sometimes the Wertheims mail her offerings back, asking her to alter or tweak them in some way, and Hardin complies. Hardin, whom I later interviewed in Cedar Hill, often crochets until three or four in the morning. When we spoke, she was crocheting models whose rate of increase follows the Fibonacci sequence, which she said she thinks of as a “rate of growth” in organisms.²⁵

Figure 4
White tube-worm
grove by Evelyn
Hardin.

Photo © the Institute
For Figuring.



Moving from the kitchen into the living room, Wertheim took down from the wall a piece of lace mounted on black velvet. This piece was fashioned by Laura Splan, who enters digital images of viruses like HIV, herpes, and influenza into a graphics editor, and then successively into computerized embroidery software and a computerized sewing machine. This particular doily was stitched in the shape of the SARS coronavirus. On the floor beneath the viral doily was a huge pseudosphere of purple and orange pipe cleaners displayed on an overturned cardboard box, the work of twin artists Trevor and Ryan Oakes.²⁶ Following Wertheim upstairs, I walked into a room filled completely with shipping boxes. This was the Reef in storage. Wertheim picked up one box, bringing it back downstairs

into the kitchen, where she turned out the lights. Inside the box was an object sent to the IFF by Eleanor Kent, an elderly woman and self-described “visionary artist” who refers to her oeuvre as “granny tech”: a hyperbolic form crocheted from electroluminescent wire that, when plugged into the wall, illuminated and flickered like a strobe light or a bioluminescent deep sea creature.

Walking back into the living room, Wertheim pointed out the work of Anita Bruce, a British computer programmer who returned to school as an adult to pursue a bachelor’s degree in fine arts. Bruce knitted a series of marine forms, which she sealed in Tupperware containers and carried to the Hayward Gallery in London. In some moods, she claims they are unclassified species she found washed up on the beach near Norfolk, then took home to dissect. Wertheim writes of Bruce’s work: “Here was an entire invented taxonomy of magical sea creatures, all knitted out of fine scientific wire. Over several years Anita had been pursuing her own evolutionary path, beginning with very simple forms then letting the process of stitching guide the development of the ‘organisms’ into increasingly complex structures. Like us, she too was proceeding along a private Darwinian path, allowing the inner nature of her work to develop and grow organically” (“Anita”). An evolutionary algorithm Bruce developed dictates the morphology of the forms—how many bulbs, tentacles, or cones grow from their trunks, and in what configuration—which she then knits on tiny needles from scientific wire. The result is delicate, transparent lacy sea creatures that Bruce submits to a process of artificial selection, making more of those forms that she likes and retiring those she does not. In her artist’s statement, Bruce explicitly draws a parallel between craft practice and biological evolution:

Specimens are constructed in thread using simple elemental looping techniques, which are amongst the earliest used by man to construct fabric and practical objects such as nets and baskets. They reflect my interests not only in the evolution of life, but also in the archaeology and evolution of stitch. Simple stitches are the building blocks that create complex forms. The repetitions of stitch construct a fabric from thread that also references the generations it takes to create each new “species.” This cell-like network represents the life cycle and complex connections that balance the natural world. The linear thread of the

textile thereby draws on and mimics the continuity of life itself, as organised by the pattern of DNA. (qtd. in Wertheim, “Anita”)

On her website she explains that the “springiness” of her wire “brings the organic specimens to life” (Bruce, “Series”).

The craft of crocheting hyperbolic geometries here operates as an analog for biological evolution, such that Reef makers narrate evolution itself as a sort of biological craft practice, and craft in turn as a mode of woolly evolution. For example, Wertheim describes Taimina’s models as “the generative seed for the Crochet Reef project,” within which “crochet ‘organisms’ mutate and evolve” (unpubl. ms). The notion of evolution as craft owes a rhetorical debt to François Jacob, the molecular biologist best known for his work with Jacques Monod on transcriptional regulation. In a series of lectures delivered in the late 1970s and early 1980s, Jacob put forward his theory of “evolutionary tinkering,” claiming that though natural selection is compared to engineering design, homology and exaptation suggest instead that natural selection “resembles not engineering but tinkering, *bricolage*” (34).²⁷ Quoting Claude Lévi-Strauss, Jacob describes the tinkerer as someone who “manages with odds and ends [. . .] old cardboard, pieces of string, fragments of wood or metal, to make some kind of workable object. As pointed out by Claude Lévi-Strauss, none of the materials at the tinkerer’s disposal has a precise and definite function. Each can be used in different ways [. . .]. This process is not very different from what evolution performs when it turns a leg into a wing, or a part of a jaw into a piece of ear” (34–35). Evolutionary tinkering, Jacob continued, is most apparent at the molecular level: “[I]t is difficult to see how molecular evolution could have proceeded if not by turning old into new by knotting pieces of DNA together—that is, by tinkering” (39). Susan Oyama used Jacob’s claim to rethink ontogeny, claiming that “both processes [of evolution and ontogeny] show the contingent quality of tinkering, in the sense not of randomness or disorder but rather of subtle and opportunistic dependence on particular conditions and materials [. . .]. Rather than the directedness of planned activity, it is such inspired tinkering that characterizes life processes, the marvelous results notwithstanding. In the case of normal development, however, the scraps and bits of twine are all at hand” (46). Jacob’s evolutionary tinkerer offers a compelling riposte to the teleological stories about evolution that snuck into theoretical biology with cybernetics, information theory, and sociobiology. This is evolution not as design or engineering but as messy, rudimentary, and incomplete

rehearsals for new organisms, mining the past and making use of the present to anticipate future living forms.

Another theoretical biology, one with origins in the German Romantic tradition, also lurks in the Hyperbolic Crochet Coral Reef. Wertheim describes Taimina's work as a series of "Platonic forms" from which a diversity of living forms has spawned. The notion of "Platonic forms" calls to mind Romantic biologists' preoccupation with Goethean *Urformen*, archetypes that change and transfigure as they branch out across the plant and animal kingdoms. Wertheim affixes epigraphs by German *Naturphilosoph* Lorenz Oken to the walls of Reef exhibits, declaring, "Everything has been created out of sea-mucous, for love arises from the foam." Oken, like Goethe, was interested in the ideal forms from which all living things ramify, and posited that bodies also contained potential living forms, as yet unrealized. The Wertheims recognize Ernst Haeckel, the German zoologist whose geometrically precise illustrations of marine animals influenced Art Nouveau style, as a "patron saint" who "hovers over the crochet reef as a guiding spirit." They cite his "hyperbolically detailed" scientific illustrations of marine life-forms as inspiration. Haeckel's view of a "fecund nature from whose creative depths greatly disparate forms could arise" also evokes the Reef's ambitions (Richards 9). Indeed, the Romantic emphasis on appraising living forms using one's cultivated aesthetic judgment also underwrites the Reef project. Robert Richards describes Haeckel's approach to evolutionary theory as the marriage of aesthetic ideal types to concrete forms and describes Haeckel's archetypal biological form as "a polymorphous organism—a perverse sponge artfully conceived," to which other organisms would display homologies early in their development (9). Haeckel's "perverse sponge" is nestled in contemporary fibrous realizations of geometrically inspired marine forms.

Wertheim says that "one of the most surprising aspects of the Crochet Reef project has been the way in which evolution takes place within this woolly world" and that "over time we have witnessed the emergence of a fantastical taxonomy of crochet reef 'species.'" The project, in her terms, "serves as a kind of spontaneous global experiment in Darwin's ideas" (unpubl. ms.). What seems to be vivified in rhetorical moves such as these is the reciprocal and improvisational attention to material that marks much handiwork, as well as the creative flourishes or personal idiosyncrasies that determine and get built into new crochet coral kinds. Nouns like *organisms* and *species* are quarantined in scare quotes while verbs like *mutate* and *evolve* are left to commingle in these analogies because

Reef crafters cast biology as process rather than substance, a process that may transpire in yarn as in other, more properly biotic, media. One way to put this distinction would be to say that the Hyperbolic Crochet Coral Reef, for those who make it, is not alive, but it does seem to be living (and mutating and evolving and spawning). Whereas Artificial Life researchers who posited that evolution is a universal category not limited to biological things collapsed life onto information, Reef crafters draw on widely held understandings of evolution to keep both form and matter in play in their models. Evolution might take place in abiotic media, but it nonetheless remains very much material.

The belief that crafted or manufactured artifacts can also evolve is not limited to Reef crafters. Philosopher of biology Gilbert Simondon arranged telephones and motors in series reminiscent of embryological atlases to demonstrate their “morphological evolution.”²⁸ Niles Eldredge, the paleontologist who, together with Stephen Jay Gould, advanced his theory of punctuated equilibrium in 1972, is a dedicated horn player who now analyzes the diversity of cornet (a soprano brass-wind instrument) morphological vectors (as he earlier studied trilobite morphology) in order to track what he calls “material cultural evolution.” Though many, including anthropologists (social evolutionists and cultural ecologists, in particular), have analogized culture to evolution, Eldredge tweaks this folk sensibility by suggesting instead that culture works more like lateral gene transfer. This perspective no doubt impacted Wertheim’s thinking about the Reef after she interviewed him for a *New York Times* article in 2004. She summarizes his understanding of lateral transmission of crafted objects: “[C]ulturally produced objects are also subject to what is called lateral transmission. Once a manufacturer comes up with an innovation—say a new style of cornet valve—it can easily be copied by others, spreading the new pattern across the population pool” (“Bursts”). The evolutionary yarn woven here is a knotty one, in which craft configures kinship and descent dissolves in cultural solvents (Helmreich, *Alien* 68–105).

But why do Reef crafters draw analogies between their own work and biological evolution? It is a commonplace of neo-Darwinian theory that evolution proceeds through environmental pressures acting upon random genetic mutations, which has the effect of promoting the survival and reproduction of those organisms whose mutations prove adaptive. Errors in replication drive change, according to this particular evolutionary yarn. So, too, craft theorists such as David Pye claim that craft is a “workmanship of risk.” By this he means that craft is driven by

open-ended flexible practice in which end results are not predetermined: “The workmanship of risk is a realm where individuals, not entire industrial systems, hold the key to success. [. . .] [E]very new beginning, every new product is a risk. Pye’s definition of ‘craft’ is not the extent to which an object is made by hand, but the extent to which it involves the workmanship of risk” (Press 263).

The thousands of people who made the Reef are doing more than casting about for a biological metaphor to describe their experimental craft practice. Rather, they are gathering and weaving together the diverse theories and narratives that have marked nineteenth- and twentieth-century biology. They indiscriminately mix and remix Goethe, Oken, Haeckel, Thompson, Jacob, Eldredge, and Oyama, as well as assimilate trends toward formalizing and abstracting living form in mathematical biology, computational modeling, and Artificial Life. In this sense, the Reef may be thought of as an “experimental system,” a material thing that accommodates myriad narratives: “An experimental system has *more stories* to tell than the experimenter at a given moment is trying to tell with it. It not only contains submerged narratives, the story of its repressions and displacements; as long as it remains a research system, it also has not played out its excess. Experimental systems contain remnants of older narratives as well as fragments of narratives that have not yet been told. Grasping at the unknown is a process of tinkering; it proceeds not so much by completely doing away with the old elements or introducing new ones but rather by *re-moving* them” (Rheinberger, “Experimental” 77–78). The result is a composite, materially instantiated theory of biological change that is wholly Reef crafters’ own. In this materialized theory, repetitive gestures recapitulate the protracted piecemeal depositions of polyps, and improvisation offers a tangible understanding of morphogenesis as craft-work. Their woolly corals are hybrid and freeform crafted objects; so, too, are their evolutionary yarns. This fact suggests that all biological models and objects—whether rendered materially, digitally, or in biotic media such as cells, tissues, and whole organisms—are material instantiations of sums of biological theories and knowledge.

Life in the Making

Margaret and Christine Wertheim describe the Reef as a “wooly testimony that now engages thousands of women the world over. Vast in scale, collective in construction, exquisitely detailed, the Crochet Reef is

an unprecedented, hybridic, handicraft invocation of a natural wonder that has become, in itself, a new kind of wonder spawned from tens of thousands of hours of labor” (Track 16 Gallery). What is it about the Reef that makes it “a new kind of wonder?” Most concretely, this is a reference to the Great Barrier Reef, one of the seven natural wonders of the world. But more so, this invocation of wonder aligns evolutionary change and its consequently diverse bestiary of biological forms with the manual labor required to fabricate hundreds of thousands of crochet forms comprising what Wertheim calls an “ever-evolving crochet taxonomic tree of life” (“Beautiful”) and a “complex woolen ecology” (unpubl. ms.).

When I asked Wertheim what all the IFF projects have in common, she replied that what interests her is the connection between highly conceptual ideas and “hard manual labor.” All the IFF projects combine formal or abstract ideas with thousands of hours of human labor, and it is this combination, in her words, that produces wonder. Wonder, she said, arises when one is able “to feel the crystallization of human time” when looking at an artifact. To look at the crocheted reef is to appreciate the tens of thousands of hours devoted to making it. She compared this recognition to the wonder one feels when looking at the pyramids and being awestruck by the human labor that went into their construction (an analogy also made by Charles Darwin when he marveled at coral reefs), but when looking at the crocheted Reef, she is struck by the “woman’s labor” put into its fabrication.²⁹

The Reef is a crystallization of hundreds of thousands of hours of labor performed by thousands of women, as the Great Barrier Reef, the largest structure in the world constructed by organisms, is the calcification of the concerted production of billions of coral polyps over the course of 20,000 years. When Wertheim talks about the collective effort of the thousands of contributors to the Reef, her description of collaborative craft rhymes with marine biologists’ narrative of the living reef. Helmreich, in suggesting coral as a Harawavian figure with which to grapple with questions of scale and context, quotes anthropologist Alfred Kroeber likening the labor of coral depositing calcium carbonate to construct the Great Barrier Reef by infinitesimal degrees to the cultural production of humans (“How Like”).⁵⁰ Perhaps coral provides an apt figure for the craft collective that spawned the Hyperbolic Crochet Coral Reef—its contributors number in the thousands, some contributors working prolifically to make dozens of pieces, but most contributors offering only one or a handful of crocheted objects, building the Reef piecemeal as a calcium

carbonate reef would slowly sediment from the brooding contributions of millions of polyps.⁵¹

As Kroeber's analogy indicates, the comparison of cultural to biological production is nothing new. In the introduction to *The Division of Labor in Society*, Émile Durkheim compared the specialization of labor to biological evolution, arguing that the differentiation of trade skills in society parallels the development of complex systems in an organism:

The law of the division of labour applies to organisms as well as to societies [. . .]. This discovery has had the result of not only enlarging enormously the field of action of the division of labour, but also of setting its origins back into an infinitely distant past, since it becomes almost contemporaneous with the coming of life upon earth. It is no longer a mere social institution whose roots lie in the intelligence and the will of men, but a general biological phenomenon, the conditions for which must seemingly be sought in the essential properties of organised matter. The division of labour in society appears no more than a special form of this general development. In conforming to this law societies apparently yield to a movement that arose long before they existed and which sweeps along in the same direction the whole of the living world. (2–3)

While such biological analogies are often mobilized to license, naturalize, or otherwise justify economic and labor relations, when Reef crafters speak of the “evolution of stitch,” comparing thread to DNA, something altogether different is at work. Rather than naturalizing the “will of men,” here labor—a craft identified as women's work—overturns divisions between mental and manual labor, discursive and experiential knowledge. Women put their hands to work materializing theory. The analogy being drawn between evolution and craft is not meant to argue prescriptively that social institutions should mimic biological phenomena but instead to recast biology in a craft idiom. Biology, both the discipline and its object, is here deployed not as an analogy for labor, neither as its precedent nor as its herald but instead as its product. Biology is always something that is made, but more important, it is always something *in the making*.

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Notes

- 1 The simplest way to think about curvature involves parallel lines. In a plane, which bears zero curvature, for any point p and a straight line L_1 outside that point, there is only one straight line L_2 passing through p that does not intersect L_1 . This describes Euclid’s parallel postulate. In non-Euclidean geometry, however, the parallel postulate does not hold. A sphere is an example of elliptical geometry. It has positive curvature because there are *no* lines that do not intersect L_1 ; all lines meet at the poles of the sphere. In negatively curved hyperbolic space, however, there is an *infinite* number of lines running through p that do not intersect L_1 , since the lines that meet at p extend away from one another and from L_1 . Wertheim gets a lot of mileage from contrasting the seeming formality of Greek mathematics with the eminently approachable crocheted hyperbolic models. In a 2009 TED (Technology Entertainment Design) conference lecture, she held up a floppy red hyperbolic model, announcing to the audience that “here in wool, through a domestic feminine art, is the proof that the most famous postulate in mathematics is wrong” (“Beautiful Math”).
- 2 I thank Stefan Helmreich for drawing my attention to this quotation in his Web-published rumination on coral reefs (“How Like”).
- 3 I borrow *dividuality* from Marilyn Strathern, who argues that Malanesian persons recognize one another as dividuals rather than individuals, “frequently constructed as the plural and composite site of the relationships that produced them” (15).
- 4 The anthropogenic rise in atmospheric carbon dioxide concentration triggers ocean acidification, which places coral reefs under stress, causing coral bleaching (when corals expel photosynthetic zooxanthellae) and placing global reef ecosystems at risk of collapse (Harvell; Hoegh-Guldberg et al.; Hughes).
- 5 Hereafter, when I write “Wertheim,” I am referring to Margaret Wertheim unless otherwise indicated. Christine Wertheim is referred to by her full name.
- 6 The acronym IFF also abbreviates the logical biconditional “if and only if” (i.e., a necessary and sufficient condition) in mathematics and logic notation.
- 7 An imaginary number is a real number (any rational or irrational number) multiplied by the imaginary number i , which is equal to $\sqrt{-1}$. In the complex number plane, imaginary numbers are on the

- vertical axis, perpendicular to the horizontal axis of real numbers.
- 8 Wertheim wrote two letters to Benoit Mandelbrot requesting his permission to draft a 99-year lease on Seahorse Valley. His secretary responded to her first letter by informing her that mathematical objects are in the public domain; her second request was unanswered.
 - 9 German crystallographer Friedrich Froebel, inventor of the kindergarten, developed a series of twenty “occupational gifts,” pedagogical explorations of form using paper folding, weaving, and sewing, which were employed in his kindergartens beginning in the 1830s.
 - 10 The Menger sponge is a three-dimensional fractal. In the 1FF exhibit, electrical engineer and computational origamist Jeanine Mosely built one entirely out of business cards.
 - 11 Previous models had been purely conceptual, such as the Poincaré disc model, but in the mid-twentieth century, geometers identifying with the intuitionist school of mathematics “wanted to have a more direct experience of hyperbolic geometry—an experience similar to handling a physical sphere” (Taimina qtd. in Wertheim, “Crocheting”) and began searching for a physical model.
 - 12 Hyperbolic geometry was explored in the 1820s by Janos Bolyai, a Hungarian cavalry officer who spent his free time dueling, playing the violin, and trying to prove Euclid’s fifth postulate (Gardner 177). Also known as the parallel postulate, Euclid V states that given a line and a point outside that line, there exists only one line intersecting that point parallel to the first line (see note 1). Many mathematicians believed that Euclid’s V could be derived from his first four postulates, but by the end of the eighteenth century, no one had yet successfully done so and the postulate had become a two-thousand-year itch mathematicians could not scratch. Bolyai focused his attention on the parallel postulate after his father, Farkas, had tried unsuccessfully to tackle it (Lines 41). So maddening did Farkas find the parallel postulate that he wrote to Janos, “For God’s sake, I beseech you, give it up. Fear it no less than sensual passions because it too may take all your time and deprive you of your health, peace of mind, and happiness in life” (Gardner 176). Other sources quote Farkas, a man clearly prone to hyperbole and nay-saying, petitioning his son: “I admit that I expect little from the deviation of your lines. It seems to me that I have been in these regions; that I have traveled past all reefs of this infernal Dead Sea and have always come back with broken mast and torn sail” (Meschkowski qtd. in Greenberg 162). Persisting in this work, Janos discovered that a self-consistent geometry could be envisioned by rejecting the parallel postulate. He wrote to his father in 1823: “I have not quite reached it, but I have discovered such wonderful things that I was amazed [. . .]. *[O]ut of nothing I have created a strange new universe*” (Greenberg 163). Bolyai shares recognition for the discovery of hyperbolic space with Russian mathematician Nicholay Lobatchevsky, who worked on the problem at the same time as Bolyai but published earlier.
 - 13 Thurston was not the first to devise a model of hyperbolic space made out of paper: “In 1868, the Italian mathematician

- Eugenio Beltrami had described a surface called a pseudosphere, which is the hyperbolic equivalent of a cone. Beltrami made a version of his model by taping together long skinny triangles—the same principle behind the flared gored skirts some folk dancers wear” (Taimina qtd. in Wertheim, “Crocheting”).
- 14 “So I spent the summer crocheting a classroom set of hyperbolic forms. We were sitting at the swimming pool with David [Henderson]’s family, my girls were learning to speak English and swimming, and I was sitting and crocheting. People walked by, and they asked me, ‘What are you doing?’ And I answered, ‘Oh, I’m crocheting the hyperbolic plane’” (Samuels). Taimina quickly switched to crochet after finding that knitting was not the ideal technique for fabricating hyperbolic models: to knit a hyperbolic model requires that you increase every N stitches, and when knitting, all the stitches in a row must remain on the needles. Depending on your rate of increase, you very quickly run out of room on the needles, as there are too many live stitches in play. In crochet, on the other hand, only the current stitch is kept on the hook, so the number of stitches can increase exponentially without crowding the crochet hook. Also, crochet yields sturdier and less floppy forms than does knitting.
- 15 In an interview with *Discover* magazine, Taimina points out that hyperbolic crochet is good for more than geometry: she also uses the technique to make her own clothing. She crocheted a hyperbolic godet skirt to wear at a talk at the IFF, “after which the film director Werner Herzog took her to dinner and then kissed her good night. The skirt is made of
- 10 skeins of cotton yarn, each of which is 68g feet long” (Samuels).
- 16 The first exhibit was not, however, strictly coralline. Instead, the forms were displayed as a cactus garden and kelp forest in the gems and minerals cases in the tapestry hall, as part of the Fair Exchange exhibit of the 2006 Los Angeles County Fair. The cactus and kelp were exhibited, Wertheim recounts, between the quilts and the Christmas ornaments. Around the same time, one of the first responses she received to her online call was from the Andy Warhol Museum in Pittsburgh, which was organizing an exhibit on global warming and wanted to exhibit the Reef. Wertheim remembers, “I laughed and said, ‘Well, we’ve only just started it. You can have a little bit of it’ (“Beautiful”).
- 17 This aim pans out in regular classes that teach curious amateurs how to program in Arduino (a physical computing platform designed for use by hobbyists and technoartists), use a sewing machine, build a synthesizer, or pickle vegetables.
- 18 In 1947, Rothko, champion of color field painting, described his work in a way I find sympathetic to fellow Latvian Daina Taimina as “unknown adventures in an unknown space” lacking “direct association with any particular, and the passion of organism” (84). But sitting between Jackson Pollock’s *Black and White Number 20* (1951) and Rothko’s *White Center* (1957), I noted the disjuncture between the IFF workshop’s aims—to teach a craft technique first used to materialize a mathematical abstraction—and the Modernist, and in particular Abstract Expressionist, setting. Many craftspeople and scholars of craft eye Modernism, with its

- “distrust of skill and fine craftsmanship,” with suspicion. Jeweler and author Bruce Metcalf comments, “The history of modern art records a gradual abandonment of the traditional crafts [. . .]. By the late 1940s, Jackson Pollock could pour house paint on a canvas, throw his cigarette butts onto it, and be heralded as the hero of American painting. The uncrafted gesture now stands for authenticity and raw emotion” (14). It was here, in a gallery ostensibly applauding the “uncrafted gesture,” that the Wertheim twins set up shop to teach curious passersby how craft may be pressed into service when embarking on “unknown adventures” in hyperbolic space or in celebrating “the passion of organism.”
- 19 Christine Wertheim plans to abandon work on this project soon, as she has already generated so much surface area that the edge of her crocheted form has curled in upon itself, making it difficult to add to it. It is also becoming increasingly hard to carry around.
- 20 This is the claim made by University of Bristol geometers Hinke Osinga and Bernd Krauskopf, who in 2004 published instructions in the *Mathematical Intelligencer* for crocheting the Lorenz manifold, a geometrical surface related to the Lorenz attractor, a well-known model of nonlinear deterministic dynamic systems, which has practical applications in predicting weather patterns (think of the Butterfly Effect). In their publication, Osinga and Krauskopf write that the three-dimensional crocheted model of the manifold is able “to convey the intricate structure of this surface in a ‘hands-on’ fashion. This article tried to convey this, but for the real experience you will have to get out your own yarn and crochet hook!” Osinga, whose mother taught her to crochet when she was seven, explained in an interview with *Craft* magazine that while she had previously developed computational models of the Lorenz manifold, “the crochet project was ‘driven by the need to see and feel the real thing’” (48).
- 21 For other accounts of scientists gaining a “visceral sense” of their objects of study, see, for example, Downey; Myers (“Molecular”); and Traweek.
- 22 While Taimina recommends using cheap acrylic yarn to give models more structural integrity, the craft store I went to shunned acrylics in favor of organic sustainable textiles spun from soybeans and alpacas, so I settled for a fairly elastic Greek cotton.
- 23 With the advent of digital computing in theoretical biology in the 1970s, Thompson’s work experienced a renaissance among evolutionary and theoretical biologists. For more about Thompson’s work and its reception, see Keller, *Making*.
- 24 This quotation is from the Artist’s Statement of Anita Bruce, a British artist who contributes to the Reef and whose work I describe in more detail below. More information about her work can be found online: <http://www.anitabruce.co.uk>.
- 25 In the Fibonacci sequence, each number is the sum of the two preceding numbers, beginning with 0 and 1. Its first appearance in Western mathematics was in the arithmetic text *Liber Abaci*, written by Leonardo of Pisa in 1202. Thompson first pointed out that many plants bear leaves arranged in the Fibonacci sequence; identifying examples of Fibonacci sequences in nature has since

- become an almost numinous quest in both professional and popular accounts of evolutionary biology (Green, “Expression” and “Inheritance”; and Kauffman).
- 26 Many of the pieces Wertheim showed me were either not strictly hyperbolic in form, not manufactured using crochet, or not meant to evoke coral, although the vast majority of the pieces in the Reef meet all three criteria. Some work (Splan’s) meets none of them but is included nonetheless because it cites biological form using some medium of traditionally feminine handicraft.
- 27 One version of this lecture was published as a *Nature* article; it has been cited at least 949 times, mostly by biologists and other stripes of evolutionary theorist, among them, Steven Pinker, Stephen Jay Gould, and Francis Crick.
- 28 For a historical account, see Schmidgen.
- 29 During his voyages on the *Beagle*, Darwin marveled, “We feel surprise when travelers tell us of the vast dimensions of the Pyramids and other great ruins, but how utterly insignificant are the greatest of these, when compared to these mountains of stone accumulated by the agency of various minute and tender animals! This is a wonder which does not at first strike the eye of the body, but, after reflection, the eye of reason” (490–91).
- 30 In “How Like a Reef,” Helmreich identifies three figurations of coral reefs, tracking them from “their emergence as nineteenth-century architectures of curiosity, to their fashioning as twentieth-century polymorphs inviting immersive and fleshy encounter, to their twenty-first-century rewriting as nodes in global genetic networks.”
- 31 The January 2009 issue of *Reef Encounter*, the newsletter of the International Society for Reef Studies, cashed in on the parallels between crochet and calcium carbonate reefs when it described the proliferation of crocheted coral reefs in anthozoic terms: “A local reef is beginning in Sydney, Australia, one will be made in Arizona for inclusion in the Scottsdale show, and interest has been shown in Latvia. So just as living reefs send out spawn to produce new reefs, so also the Crochet Reef is spawning around the world” (2009).

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