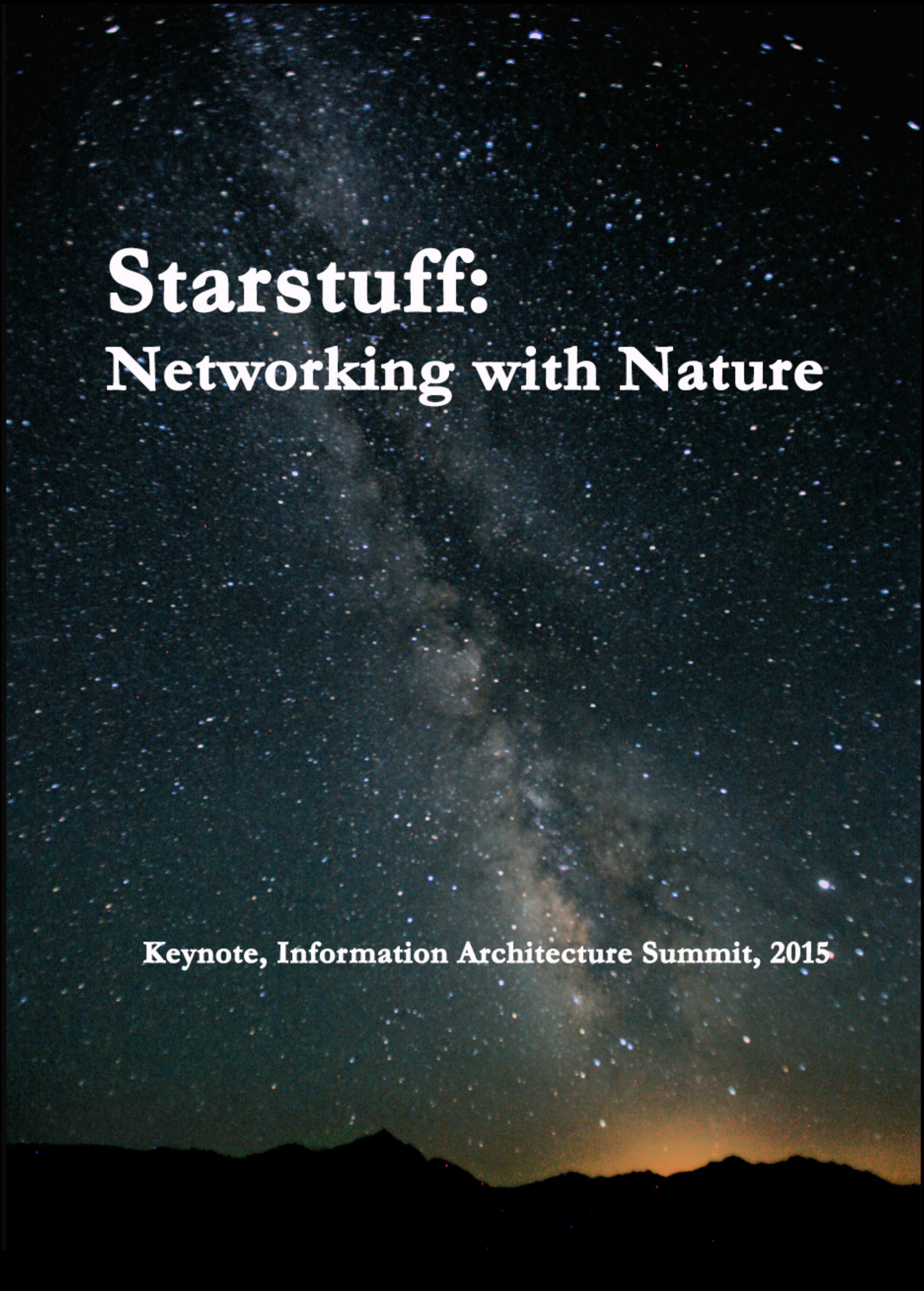

Starstuff:
Networking with Nature

Keynote, Information Architecture Summit, 2015

photo by Steve Jurvetson 🅭🅯 2007

STARSTUFF: Networking with Nature

Keynote, Information Architecture Society
Minneapolis, April 2015

We are all star stuff. After hydrogen, helium and lithium showed up during the origin of the universe, every other element was baked in the belly of a star. And eventually became us—it's starstuff all the way down. Even some molecules, like water and the precursors to amino acids, were formed in gigantic gas clouds in interstellar space, preceding the birth of planets.[i],[ii]

Molecules are assemblages of elements formed by electronic forces among their atoms. In the history of earth, at some point and with causative factors that are still largely unknown, groups of molecules arranged themselves so as to form single-celled organisms where molecules functioned as systems with behaviors such as tropisms. Some single-celled organisms became symbiotic, filing some of each others' needs. And some of these symbiotic organisms somehow merged, each dropping the genes for actions that were performed better by the other symbiont and becoming one. The late geoscientist Lyn Margulis shook up the world of evolutionary theory with her assertion that this emergenet behavior of organisms—symbiogenesis—is probably the primary means of speciation and evolution on Earth.[iii] Some of the most awesome examples are chloroplasts and mitochondria that, through symbiogenesis, are part of the collective progenitors of all eukaryotic cells. Her theories have increasingly gained acceptance as genetic evidence has been produced.[1] In fact, Julia Schwartz and her colleagues have discovered a living example of symbiogenesis in progress in a sea slug that, through ingesting algae for eons, has managed to incorporate and successfully maintain chloroplasts in its body. This creature with its solar sails can go for a year living on the sun's energy alone, but it still needs to eat the algae to get the chloroplasts until their incorporation into the animal's DNA is sufficient to produce them on its own.[iv]

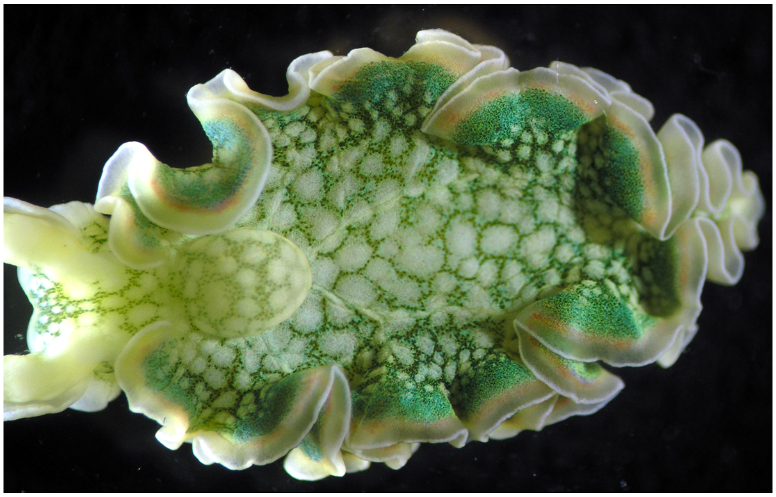

Fig. 1. *Elysia chlorotica*. Photo by Patrick King.

Let's take a moment to look at another sort of evolution highly colored by emergence: the evolution of technology.

Ever since humans began using things as tools, the story of human evolution have been progressively influenced by human thought and invention. Margulis points out that the line between biological and intellectual invention is tenuous at best, given the "inventions" of the microcosmic forms of life. While consciousness gives humans a unique experience of themselves, it is not clear that something produced by consciousness is essentially different from something produced by Nature. I view humanity's technological inventions to be just as natural as the adaptive abilities (biochemical, organic, or what have you) and extrusions (e.g., nests) of other living creatures.[v] Teleology is precisely the difference—humans can conceive of needed inventions and create them through the use of multiple abstract models.

In this sense, technological tools are natural extensions of human nature. Douglas Engelbart described the overarching power of computer technology to "augment human intellect."[vi] Tool use has been held to be the great shining artifact of "intelligence" that proved humans to be distinct from—and superior to—all other beings on earth. However, tools are evidently also natural extrusions of the nature of crows,[vii] otters, capuchin monkeys, and many other species, but human production and innovation leaves other species behind—at least, insofar as we understand them.[viii]

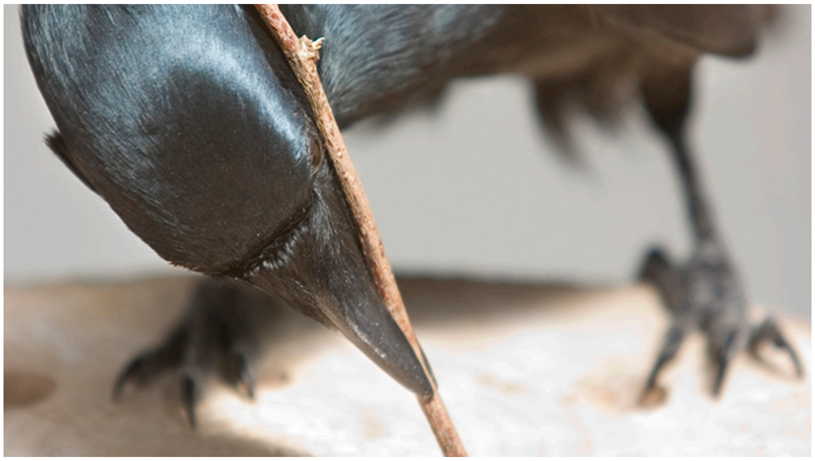

Fig. 2 Caledonian Crow using tools. Image by Susan Walker.

The Caledonian crow solves the problem of getting at food inside tight places with improvised tools. They also see opportunities for improvisational play with found objects.

Humans extrude tools through processes of improvisation, invention and design. Tools are never far from human wishes and needs (including a need to satisfy curiosity). One could argue that the many of our most significant tools are extensions of our own capabilities to ***see*** and to *know*: we grew the telescope, first to see ships at sea, but ultimately, with Galileo's improvements, to learn about the nature of the universe [see Fig. 3]; we extruded microscopes to look at the tiniest microorganisms [See fig. 4] and then on into molecules and even atoms, and now we can even observe the dynamic behavior of atoms in real time [see Fig. 5]. Why might it be, then, that we extruded computer technology as well as architectural elements like hyperlinks to navigate its digital seas?

Figure 3. Telescope and the Milky Way. Photo from *BBC Science*, 18 June 2014.

Fig. 4. Single-celled marine microbe Cryptopharynx under a microscope. Photo by David Patterson MICRO*SCOPE.

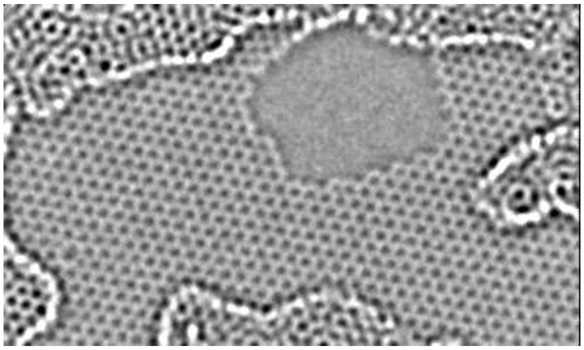

Fig. 5. Carbon atoms forming sheets of graphine. *Courtesy Zettl Research Group, Lawrence Berkeley National Laboratory and University of California at Berkeley*

NESTED ENTITIES

We define an entity as a thing that has a perception-representation-action loop; that is, that it can perceive its environment in some way, it has a representation inside itself that maps perceptions to actions through mechanisms as simple as chemical changes, and it takes some sort of action on the basis of that representation. Single-celled organisms with tropisms meet this definition, but more recent work shows that their very DNA contains entities.

The ability to make an adaptable representation comes much later in evolution, and with nervous systems, organisms can do increasingly improbable things like hunting across landscapes.[ix] For example, a wolf with its adaptive representation of its environment, learns that in certain seasons, she turns this way past the big rock then crosses the stream and intersects the migratory path of caribou. If she is a lone wolf, that knowledge dies with her. But if she is a member of a pack, others may learn by imitation. Humans, by contrast, can do much better at passing increasingly complex information along to future generations with their ability to exteriorize knowledge as story. The Lemombo bone, pictured here, is likely a 44,000-year-old lunar calendar [see Figure 6].

Figure 6. The Lemombo bone is likely a 44,000-year-old lunar calendar.[x]

We have conversations with entities through language, science and empathy. In the Massif Central of France the artists who painted inside the Chauvet Cave were having conversations with horses, owls, even rhinoceri, and now we may have time-displaced conversations with the painters as well as with what they painted [see Fig. 7]. We may also infer that the paintings were made before the Mediterranean sea divided France from the African continent. The Chauvet paintings were descriptive conversations, but also in terms of their location in the cave, they were likely shamanic. Why leave such signs and symbols in places where people would not normally go? These horses by torchlight must surely have looked like an animation. The painting in Fig. 7 is approximately 41,000 years old and may even have been made by Neanderthals, since *homo sapiens* was just beginning to enter Europe at this time.[xi]

Figure 7. Horses in the Chauvet Cave. Photo courtesy of French Ministry of Culture and Communication.

Petroglyphs were often hidden, it seems, installed far from places where people lived. The exceptions tend to be pictographic handprints of children from colored clay. This portion of a petroglyph panel in Zion National Park is thought to be 1000 to 2000 years old. The images on the Zion panels were likely produced by three different civilizations; these are most often attributed to the Ancestral Pueblo. Various theories have been advanced to explain the images, but none has been conclusive. The central figure here may represent either life and death or birth. Squiggly lines are thought by some to reflect upcoming terrain for the traveler. There are sand worms, Kokopeli-like figures, rams with horns, and images of the "rain man".

Figure 8. Petroglyphs in Zion National Park, off the beaten trail. Photo ⓘ B. Laurel 2008.

CONVERSATIONS WITH ENTITIES

We all know that relics of entities can give us information about how they worked and the conditions under which they lived. Since moving to Northern California, I've become interested in abalone. They are both delicious and beautiful, and my husband and I hunt them twice a year. An abalone (see Fig. 9) is a kind of snail that lives in salt water. The red abalone shell pictured below has the characteristic respiratory holes along the outer line of the shell's equiangular spiral shape. These are also where sperm and eggs are released. The shell's color may reflect its diet, and its iridescence derives from a coating called "nacre", a form of calcium carbonate, that creates interference effects with different wavelengths of light as well as diffraction caused by crystalline nacreous layers below the surface.[xii] Nacre is also an extremely sturdy substance that is not yet entirely understood, but has been under consideration as a material for body armor. [xiii]

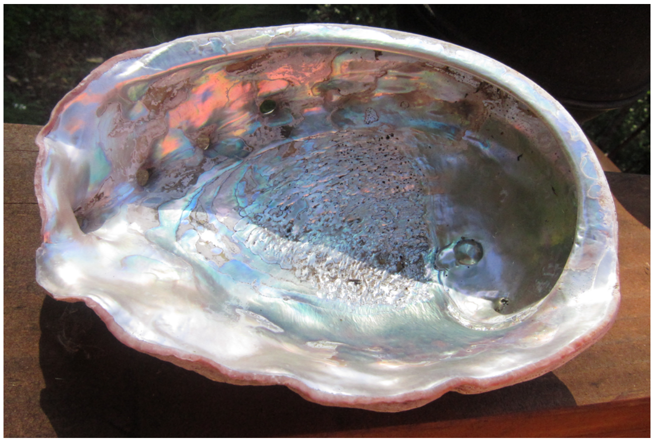

Figure 9. Red abalone shell from Northern California. Photo ⓘ B. Laurel 2015.

The oxygen isotope ratio in calcium carbonate indicates the temperature of the water in which the entity lived. Long-lived entities reflect changes in ocean temperature during their lifetimes. These are just a few of the things we know about this abalone shell, and many mysteries remain. The abalone shell is a rich information system, but to model it we need data from several different disciplines including biology, mathematics, physics, and materials science.

Another way to have conversations with entities is to use computer technology to make them self-disclosing in real time. One example that I have developed is the notion of a "STEAM Park" (that's STEM with an A for Arts). It is a "movable park" that uses sensor arrays, authoring tools, and representations delivered to mobile devices to give visitors to a place an "annotated" experience of some of its entities or features. This idea is relatively simple and has been used in many art and science projects. What's novel about it is that it may be delivered as a kit and deployed in an environment of one's choosing. With the authoring tools, a teacher or scientist or curator can create custom content to annotate entities in a place. The examples I first developed are aimed at elementary- and middle-school children and have a bit of a pedantic air, I am told by NSF. A child enters the "park" and begins to search (rather like a treasure hunt) for places and things that have information to reveal. Soft sounds let them know when they are near such a place, and as they approach a photographic image of the destination appears on their device. When they spy the spot, they can line up the image and text and graphics or animations will appear overlaid on the image on their device. Here are a few examples:

Figure 8. Images from STEAM Park. 🅯 2014 Brenda Laurel.

Ours is not a world constructed merely of things or individuals.[xiv] Microbial entities live deep inside the crust of the planet—inside the deep, hot biosphere.[2] They are probably responsible even for the movements of tectonic plates. Without life on Earth, some scientists have concluded that the continents would be much smaller.[xv] The world where we live consists of nested entities in loose or tight relationships that may be symbiotic or competitive. There are even entities, such as transposons, inside of DNA. Remember that the ability to survive outside of its place in a whole organism or ecosystem is not a definitional quality for entities. So as we look "up" to higher levels of organization within entities, we may find cells, tissues and organs—each a kind of entity—that ends, sort of, at its boundary with its environment (skin, fur, feet, etc.). It's entities all the way down—and up.

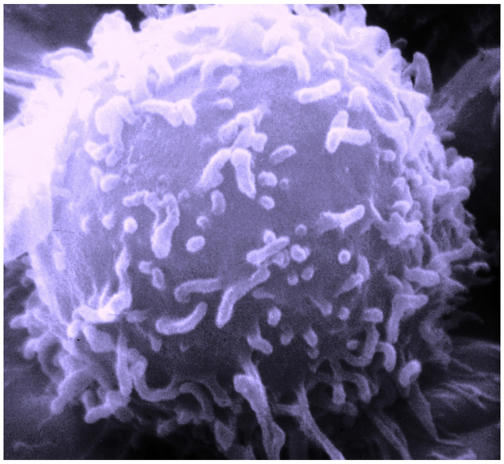

Figure 9. A human lymphocyte cell.

ECOSYSTEMS

An ecosystem is also a kind of entity composed of many different entities living at different scales and in varying relations to their neighbors. For example, what is called "chaparral" is not a plant but an ecosystem composed of various entities depending on place, climate and other factors [see Fig. 10].

Figure 10. Northern California Coastal Chaparral. 🅯 B. Laurel 2012

Chaparral near my home includes a wide variety of plants including sage and Manzanita, birds including quail and hummingbirds, insects including spiders, stink-bugs and tarantulas, and various lizards and snakes including rattlers. Some of its animal denizens are bobcats, coyotes, mountain lions, and various sorts of mice. These entities—whether in symbiotic or competitive relations with one another—maintain a kind of dynamic equilibrium that enables the persistence of the community we recognize as chaparral. In fact, chaparral can be seen as a dynamic information network that, like nested dolls, includes entities within larger entities.

There are ecosystems inside of entities as well. The recent discoveries and analyses of the human microbiome reveal that it is an ecosystem the makeup of which is essential to our health. Human microbiomes are ecosystems that live in our gut and other parts of our bodies. In fact, 90% of "us" consists of our microbiome according to the Human Microbiome Project. When we take antibiotics, many of the critters in the microbiome are killed, opening ecological niches for folks we don't like to multiply and perhaps cause illness (yeast infections, for example).

Figure 11. Yanomani people were not contacted until 2009. Photo by Cmacauley.

A recent study by J. C. Clemente et al. examined the bacterial diversity in an Amazonian tribe that had not interacted with Westerners until 2009. The researchers found that members of this tribe had the "highest level of microbial diversity ever reported in a human group."[xvi] (see Fig. 11). In fact, the diversity was two times that of an average American. The aboriginal microbiome even includes potent natural antibiotics. This Amazonian microbiome likely gives us view into aboriginal versions of ourselves and they suggest that Westernization reduces microbiome diversity. That, in turn, may be linked to diseases that plague Westerners more than members of traditional cultures. A co-author of the study and microbiome researcher at NYU, Maria Gloria Dominguez –Bello, says: "We believe there is something in the environments occurring in the past 30 years that is driving these diseases [e.g. obesity, asthma, allergies and diabetes]. We think the microbiome could be involved."[xvii]

The microbiome, one of our more recently discovered and explored ecosystems, has made very big news in the popular as well as the scientific press (see Fig. 10). Why? Because, damn, there's a lot of stuff living in us, and it's not just random. The microbiome as a whole can be considered an entity in itself with its own perception, representation and action loop. It connects to real-world inputs (e.g., food, vitamins, antibiotics) and can be sampled by real-world means (e.g., sensors swallowed with vitamins). Taking care of our own microbiome—through diet and practice—is something we can actually do.[xviii]

Figure 12. Cover of the journal *Nature*, March 2010 and *The Economist*, August-September 2012.

How do we build models of such entities so that they interconnect dynamically, as they do in nature?

CONVERSATIONS WITH ECOSYSTEMS

In the earliest days of ecological studies, and still today in many instances, our conversations with ecosystems are observational and descriptive. With further study into the dynamic relations between elements of ecosystems (the biological traits of the entities within as well as elements and forces such as water and weather.) we can begin to see the relationships that hold an ecosystem together as an entity. Figure 13 illustrates the usual characteristics of an Everglades ecosystem but does not indicate causal or relational factors within the representation.

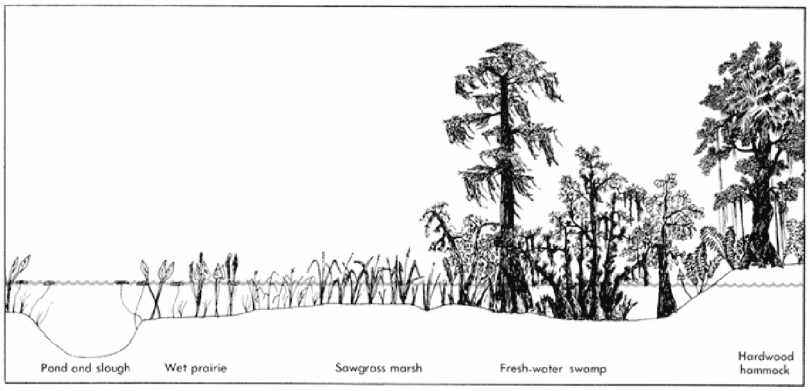

Figure 13. A cross section of vegetation and water levels in various Everglades Ecosystems.

Sensors like wildlife cameras and tagging can provide a sample function of life in an ecosystem, and one may extrapolate from a small sample the likely population of animals.

Figure 14. An American Alligator in Everglades National Park. Photo courtesy of NPS.

This American Alligator seems to be checking it out. But again, dynamic relationships are typically not part of what a webcam network can deliver.

The National Ecological Observatory Network is a continental-scale observation system for examining ecological change over time.

Figure 15. The National Ecological Observatory Network home page.

An approach that shows great promise has been developed by NEON, The National Ecological Observatory Network:

> NEON creates and provides a diverse suite of free, open data that support the study of complex ecological processes at large space and time scales. NEON uses standardized and integrated collection methods across field sites to provide data on ecological change across key science themes.[xix]

Data themes include atmosphere; biogeochemistry, ecohydrology; land use, land cover and land processes; and organisms, populations and communities. Data of these types can be retrieved from the NEON database and may, presumably, be used in modeling ecosystems. The important observation here is that NEON has developed domain-specific protocols; however, these appear to produce heterogeneous data types; that is, there is no more-or-less universal data protocol as yet, but the organization is clearly making progress in streamlining the acquisition and use of data to describe large systems, and these data may be used to infer dynamic relationships.

COMPUTATIONAL MODELS

In the twentieth century, it became possible to make Turing-complete representations on computers; in other words, stories could be turned into actions with computers—the beginning of our capability to construct models of phenomena and entities that are more than descriptive. This is a huge leap in human evolution.

In 2012, a team at Stanford led by Markus Covert created what is said to be the first complete computational model of a living thing. Taking findings from hundreds of scientific papers and transforming them into more than 1900 experimentally determined parameters, the team created a model of every molecular interaction that takes place inside the world's smallest free-living bacterium, *Mycoplasma genitalia*, which unfortunately causes sexually transmitted disease.[xx] But let's put that fact to one side long enough to wonder at what these scientists have created (see Figure 16). The team showed that:

- an entire organism [can be] modeled in terms of its molecular components
- complex phenotypes can be modeled by integrating cell processes into a single model
- unobserved cellular behaviors are predicted by model of *M. genitalium*
- New biological processes and parameters are predicted by model of *M. gentalium*[xxi]

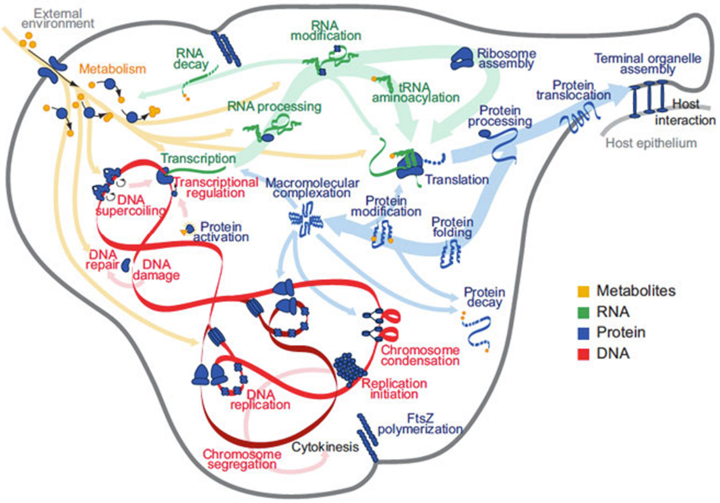

Figure 16. A schematic diagram of a single *M. genitalium* cell, with its characteristic flask-like shape, depicting all 28 submodels Covert developed. Illustration: Markus Covert, Stanford Bioengineering. - See more at: http://engineering.stanford.edu/research-profile/bioengineers-produce-first-complete-computer-model-organism#sthash.o46xsYve.dpuf

Many other kinds and scales of models have been created with the help of computers, from weather to climate to flocking behavior and wind moving through grass. The Stanford model of a living organism is remarkable for its completeness and robustness. It is also interesting in its use of submodels in its construction. The work it took to create it was extraordinary, but the process lends clues for streamlining the process in future research projects.

A NETWORK OF MODELS

How might we connect such a tiny, brilliant piece of computer modeling as the Stanford accomplishment to the rest of the world? It sounds like an impossible task. Yet, we know that things proceed both inductively and deductively, and that science is always climbing up and down ladders of scale and complexity, data and inference.

Quite a different process of modeling has its roots in Google Earth. The ability to see the whole earth with graceful interleaving changed our view of this world almost as much as the first picture of earth from space. It was that picture that provoked Alan Watts to muse that "the earth has grown eyes with which to see itself." It also led the Grateful Dead to sing "We are the eyes of the world."

Now a young company, Skybox Imaging (recently acquired by Google) is deploying a network of low-earth-orbit satellites that can give is a view of our earth, 24/7. The resolution is good enough to identify the crowns of separate trees in the Amazon. What if such an image could be overlaid with into a different model that could predict carbon uptake over time? This brings up the notion of being able to drive through or layer on different models from the initial representation. While GIS systems can help with some of this by converting disparate data protocols into a smaller set of data formats, they do not do as well with scale.

We can find data and models in many places and in many forms. It's like shining a flashlight through the forest and exclaiming, oh, there's one! But they live in isolation and we do not have the intention of making them speak to one another. The entity does not relate to the ecosystem. And if nature is any guide, that is a problem.

The next best step for us is to strive for pluggable models—that is, where the output from one model can serve as input to another at a different scale or measuring different variables. For example, we might overlay a weather model on a near-earth view and then make it connect gracefully to a model of bird migration. We might want to examine the birds, zooming into a flocking model and onward to a model of an individual bird. We might want to zoom out to combine our weather model overlay to one of ocean currents. What would it take to make this possible?

Four things. First, we would need a small set of data protocols for interoperability. Second, we would need a corresponding set of model protocols that would accept new data as inputs. Third, we would need to a protocol for authoring the "interstitial" layers that act as the connective tissues between one model and another in ways that allow us to represent causality and relationships. Fourth and most important, we would need to be committed to creating a Gaian view of earth.

While Margulis quibbled with the terminology, her work deeply supported that of James Lovelock, who gave us the theory of Gaia. In his 1979 book *Gaia: A New Look at Life on Earth*, Lovelock takes the view that all of the nested entities and ecosystems in Earth's biome as well as its elemental make-up work together to create a dynamic whole with a characteristic he calls "homeostasis." This characteristic keeps our planet, its atmosphere, and all of us in a state where life can survive the dips and swings and changes that the earth goes through. He stresses the importance of biodiversity and atmospheric resilience in maintaining this dynamic equilibrium. As climate change encroaches, both of these variables are being severely impacted. Lovelock's theory was at first considered to be extreme or metaphorical, but as science has progressed his theory has come to have a large degree of acceptance among scientists.[xxii] The initial criticism was that the notion seemed teleological, but an abundance of evidence from chemistry, atmospheric science and biology has been produced to support the Gaia Hypothesis. We should be disturbed by his most recent book, *The Vanishing Face of Gaia*, that suggests that we are, as usual for this generation, doing too little too late.

We have talked about establishing data and model protocols as well as the need for interstitial layers between models that communicate dynamic relationships. That's all well and good, but we also need to take some steps that are more in the social domain to do this job of creating interconnectable models. [slide] If we are going for the goal of modeling Gaia, then first and foremost we must expose our code and our data to others and adapt protocols that make them useful beyond the current project in any lab. I would love to see a day when it was not respectable to publish a paper without publishing your code and your data. The wonders of Internet 2.0 were built on open source; it increased both the velocity and utility of change. A closed system like Xanadu would not have done that for humanity.

I have lived to see a world without computers to one where Computer Science degrees are awarded for Game Design. Isn't it about time that we view creating data-model protocols for modeling the earth and the forces that make life possible as being as relevant a use of computers as designing games? Right now, it's more respectable to *create* a world than to understand our own in a way that will ultimately fuel, not only solutions to climate change, but also a deep understanding of the Gaian system. As far as we know, we are the only intelligent life in a million million galaxies. If we are to go into space and procreate, we need to understand the characteristics and dynamics of a world that would support life such as ours. But if we choose to stay home and keep evolving here, we need a deep understanding of the Gaian system to save the environment that makes our lives possible. And yes, we can use our understanding to make some awesome games.

WHAT IS THE GOOD?

What is the Good? The Epicurean philosophers said that a philosopher *may* marry; the Stoics said that they *must*—to be *in* the world and *of* the world. And so I invite you—information philosophers—to embrace the idea of Gaia, the enormous multifaceted whole of which we are part, and to think about what it means to represent it. Who knew, when folks started cultivating rice 8,000 years ago that they would take the first step in human-caused climate change? Who knew, at the beginning of the industrial age, how slender and fragile was the sheath of our atmosphere? Our goal must be not to lay blame, but to boldly go toward a new understanding that may save us from what past and many present practices are dumping in our laps. Climate change is a global problem, and we need a global view to solve it—a network of models that reflects the nested entities and interlocking relations that represent Gaia to us at levels where we can best see, discover and understand it. It isn't harder than going to the moon, and it's way more important. Information architects can adopt this goal. Let's go do this thing.

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