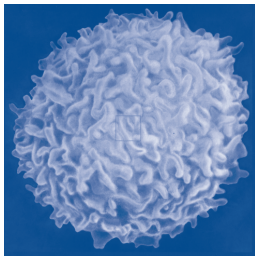
IGNACIO CHAPELA

(joined by Lisa Thompson and Iain Boal)

Microbial ecology,
University of California, Berkeley



We sat in Strawberry Canyon, high above the city of Berkeley, surveying the whole San Francisco Bay Area: the Golden Gate Bridge to the right, gateway to the Pacific Ocean, the end of the west, beginning of the east; and what the world knows as Silicon Valley to the left, locus of technology, innovation, and new economies. From this sweeping vista, a series of unexpected gifts seemed to appear out of thin air: a loaf of homemade bread from Ignacio's partner, Lisa Thompson; a passerby who recited a Robert Frost poem to us (see page 21); a family of deer and a herd of wild turkeys; and a surprise visit from social historian Iain Boal.

This spot provided views too of University of California, Berkeley's Molecular Foundry, and from this vantage point we tried to make sense of the axis connecting the Foundry and the rest of the Bay Area. Afterwards, Ignacio drew his own map of axis lines and asked his good friend Grey Brechin, a historical geographer at UC Berkeley and author of Imperial San Francisco, *to explain them. Grey wrote, "When E. O. Lawrence was looking for a site for the 184-foot cyclotron, his first thought was to put it back in Strawberry Canyon to shield UC Berkeley and the town from errant radiation. Instead, he chose the top of Big C Hill for its prominence. None of your lines quite do the trick. Run one from the cyclotron through Moffett Library and West Circle. You will find that it aims directly at the Golden Gate."*

(FIG. 1) Ignacio arrives.

1

IGNACIO: Look at this image (pointing to the cover of *California Agriculture*); this is a precious thing I keep *(FIG. 2)*. This is the millennium report, the most important publication from the University of California, which is the most important agriculture university in the United States, in the most important agriculture state. This is our statement to the world of what we want. Out of here comes the satellite, and the satellite instructs all these machines. There are no humans in the landscape. This might be a human, but maybe it's a robot, but it's also being instructed by the satellite. Isn't that amazing? And then when you look at the credits for the photo, "Illustration courtesy of the John Deere Company."

2

4

3

And this place, we are sitting in a crossroads of so many different fields. We are sitting on the slope of what is called Strawberry Canyon, a very impressive canyon, where most of the history of the West has had an expression. We are sitting just below the Lawrence Berkeley National Laboratory, which is the birthplace of the Manhattan Project. It continues to be the crown jewel of the whole national lab system. We are also sitting almost just above the Hayward fault, where two very important geological plates meet and collide. Our predecessors decided to build this military complex upon this very fast-moving rock, where the ground moves one centimeter per year. And it is also a place where the future is imagined, as we are also sitting just above the public side of the University of California, Berkeley campus, the crown jewel of the public education system of the United States, and in a way the crown jewel of the twentieth-century public university system as a whole. The dynamics between the private militarized and technologized part of this piece of land and the dream of the public place where we could think about our present and our future couldn't be more dramatic than at this spot *(FIG. 3)*.

MICHAEL: Can you tell us what is happening over there? (pointing to an ominous set of buildings tucked into the canyon behind the picnic) Do you imagine the experiments in there might represent new edges of understanding in your field? What kind of experiments do you think they are doing there?

IGNACIO: I *know* what experiments they are doing. That is the most recent building in that whole complex, it's very cleverly designed because it's very large if you look at it at the top, but from the campus, very few students know that this exists. It's really incredible. It's called the Molecular Foundry *(FIG. 4)*. I knew one of the people who was conceptually behind this, and he would talk about his imagination for this place. There is this dream still of manipulating, of melding the distance between the inanimate and animate and saying we're going to use the

tools that we have developed for inanimate manipulation to manipulate the living. So they're "forging" – they talk about building blocks, they talk about replaceable parts, circuitry, and the elements of circuits that can be used in new combinations. It's the old idea of the chimera, the Pegasus, but turned into perceived reality by the actual reality of Hiroshima and Nagasaki. After that, how could anybody question that they *will* do it. They did what they did in Hiroshima and Nagasaki, so how could anybody dare question that they *will* succeed in this quest?

They are still riding on the coattails of Hiroshima and Nagasaki, the people who made that possible, and living off the credit of that, putting out a new promise, the promise that living things will yield to this new manipulation. So the term synthetic biology is another one that is floating around. These people have been smart enough to distance themselves from that and leave it to the biofuelers. There has been already in the last two years a schism between the people who work in that building (pointing to the Molecular Foundry) and people who work in buildings down below (pointing to the "public" university campus), who are being very successful politically at the moment, but are really painted to be shocked as soon as the politics change for having over-reached in their promise with synthetic biology – the promise that with synthetic biology they would be able to replace oil, and all sorts of energy we are using to move the economy. I think they overreached, and I think they're going to be shocked as soon as the politics change. These people (pointing again to the Molecular Foundry) will keep going – in my mind.

They have tried with different things, you know, the gene is one of them. They don't talk about genes, actually, in *Powers of Ten*. But at that time, I guess the whole modern synthesis was not available yet, which was the clicking of Mendel's gene, something to do with the genes, the DNA sequence in the unit, the search for this indivisible unit of life. It can be exchanged, which is the way the people in the Molecular Foundry speak and especially the synthetic biology people speak. There's even a place, like a catalogue, for replaceable parts. There is a website, like a clearinghouse for interchangeable biological parts, and they call them "bricks." If you discover a gene or a promoter, you enter it there, and then anybody who needs a promoter for their new organism can find it there, just like you would exchange a carburetor in a car, or the wheels from a car to another. That is the final commoditization of it, right, that you can exchange across boundaries and put a value to it and own it.

AMY: What power of ten do you align yourself with?

IGNACIO: Understanding life is understanding the problem of a mid-level scale, so I am interested in that 10^{-6} or 10^{-5} scale. I am a microbiologist by training, and I have endeavored all my life to force myself to think about the world the way microbes would think about it if they could think, and look at it from that perspective. And the world looks very different just by moving that one power of ten in the scale.

In my lab, we focus on a relatively small segment of the very large and disparate group of invisible life forms we call "microbes." We work with eukaryotic microbes, and mostly focus on those eukaryotic microbes living in terrestrial ecosystems.

(FIG. 5) Phylogenetic tree of life.

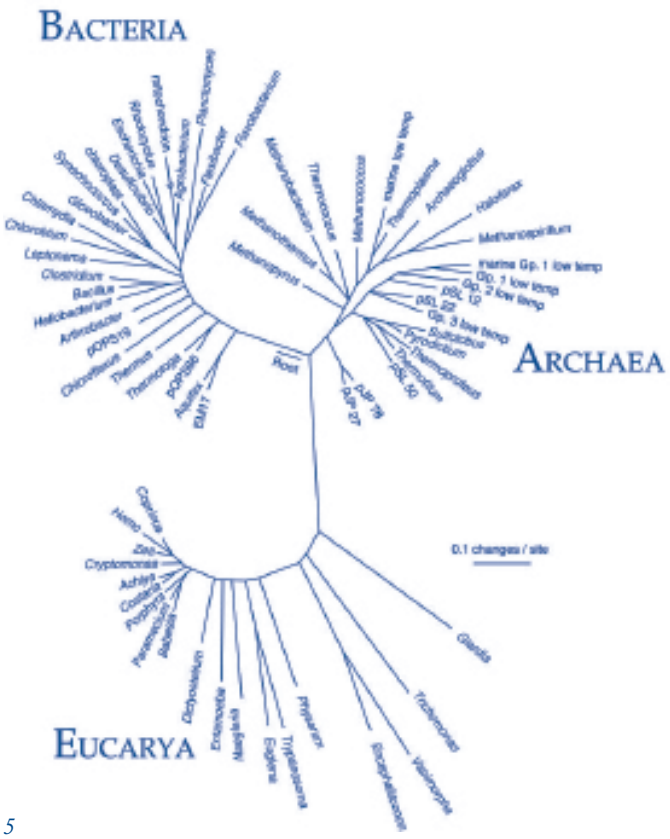
That would mean the unwieldy and multifarious collection of life forms we call fungi. In those terrestrial ecosystems, we ask simple questions: Where are microbes? How many of them? These are the basic questions of ecology: establishing patterns of abundance and distribution of organisms. For traditional ecologists, there was no question about the identity of the organism at stake: in a given place, deer are deer and wolves are wolves. Not so for microbes, where a given organism can take multiple shapes (for example, filamentous fungi turning into yeasts and vice versa; spores of various kinds can lead to multiple variations on the hyphal theme, and so on), and indistinguishable cellular structures can belie quite different phylogenetic and ecological characters.

AMY: Can you talk about the time-space scale of the microbiological level?

MICHAEL: I think that most things humans think about are on the scale of things that we can really see, whether it's the mountain or the jar to drink water out of, or even the poppy seed. But once you get below the poppy seed, most of the time you are kind of forgetting about it.

IGNACIO: Or above it.

MICHAEL: And when you say a centimeter per year of movement for plates, this scale is really fast for the earth, but still, as a human, I rarely notice it until



5

there's a little tremor. The rest of the time, I'm just oblivious.

IGNACIO: Right. Even if we don't see and feel it regularly, you could say that it's so important and so consequential in so many ways. And if you look at the things we *can* deal with, they're all beings that are within our scale, both space and time. Typically, physicists think of space and time, and that's it. But I think biology needs to consider that other axis, an axis in the dimension of phylogeny – the actual development of a story that leads to who you are, this axis that is equally important. We deal with dogs, cows, and dolphins easily because they are in our scale of lifecycles – how long they live and when they die. But then, you have things like redwoods that are organized at just a slightly bigger scale, in the thousands of years. For a redwood to actually live, the unit that's important is the forest, not the tree itself. And because it's organized in the hundreds or thousands of meters, we just don't know, we cannot deal with it. By "we," I mean the people who are dominating the world right now. Other people have dealt with that and have been able to deal with these larger-scale issues through different ruses and ways. Like fish that might be here today, running up the creek, but then can exist in thousands of

miles of ocean that they occupy another part of the time. So I think if you look at it that way, understanding that scale problem would be really the crux of figuring out what to do and how we're doing it, ecologically speaking.

AMY: And what about what we can't see? Beyond your scale, in the movie they go to minus thirteen, where the voiceover of Philip Morrison says, "A single proton fills the screen. We've now reached the edge of present understanding." I would wonder what the edge of understanding is now in your field? And was that really their edge of understanding in 1968?

IGNACIO: Well, that was the "official" understanding, right, IBM or the National Labs or the National Science Foundation understanding? It was the understanding of what I would call the "program."

MICHAEL: What do you mean by "program"?

IGNACIO: There was a program initiated in about 1930 that pushed to define the understanding of the material world in very specific terms – atomistic terms, reductionist terms, mechanistic terms. And the inanimate, material world had already yielded a lot of information that made people think their understanding was really god-like, that it was *the* understanding to have. By 1930, the dream of the nuclear bomb really was just a question of time and investment of energy, and that is the origin of the National Labs. They pulled physicists from everywhere to work on this one exercise, to demonstrate that this way of understanding the material, inanimate world was right. And they demonstrated that it is right, by the demonstration of an explosion, right? In killing.

MICHAEL: Do you think that's in part why UC Berkeley has this status, as you described it, as a crown jewel? Is it because of all that focus on research for a particular atomic bomb?

IGNACIO: No doubt, because if you look at other places and things that have happened very significantly on this campus, they are all in a way ancillary to that mission. There is always this subversive force of Phoebe Hearst. William Randolph Hearst wanted a technical institute to push the discovery and exploitation of the inanimate world – the mining stuff. That's what this campus was supposed to be, and it was Phoebe Hearst who said it should be a university if all this money was going to be spent here. So there's always that force of subversion that all the money and effort is being put into this militarized exploitation of the inanimate world. The drive to go to those bowels, in the planet beneath the biosphere, drives the campus, and you get all these heavy metals, the things that we are suffering under today like arsenic, lead, mercury, cadmium, and all that. The "program" at that time also wanted to have the living matter explained the same way. And so for me, one of the most important things the *Powers of Ten* does is to portray both the animate and the inanimate as equal, as equally understandable. You know when they say this is the limit of our understanding up and then head back down, what you don't notice is that they very subtly slip over this mid-scale place and then go into particle physics. So they talk about, well, they don't call it the code, but they refer to it as the "language" or "alphabet."

AMY: Right. They say: "*The nucleus holds the heredity of man in the coiled coils of DNA at ten to the negative seventh, we come closer to the double helix itself.*"

IGNACIO: Keep going to the next line or two, and this is where the god-like thing comes in as he says, "this is the language of life." He brings in the question of language. And then he makes a rhetorical move by sliding from up to down and saying if we understand those edges *this way* we have to understand what's in the middle. It establishes that there has to be this understanding of *this way* and *this way* only. And what's both discouraging, as well as really inspiring, is to discover how resistant life is to that understanding. To the point of present understanding, I think these forty years have been pretty much lost in terms of deeper understanding of what life is about. There were really good ideas and very good research up to the 1930s that were killed by this program. There were many ways of understanding physics that were killed by this program, and many physicists who had to step out because they either had to become particle physicists or nothing. And the same thing has happened to biologists.

MICHAEL: I was wondering about the amount of money that it costs to go to those other scales. I'm thinking of getting to the moon or Mars?

IGNACIO: Do you know why we go to the moon? Do we know why? There was no point, aside from showing we could do it.

AMY: You've mentioned this book before by Paul Goodman, *New Reformation*: *Notes of a Neolithic Conservative*, and I just opened up to this page today when we

6

came up here: "Space exploration has so far been an epitome of the grandeur and misery of man in our times. It presents us with all of our dilemmas. I'm writing this chapter in July 1969, when two men had just walked on the moon and five hundred million televiewers have watched it. Surely, this is mankind being great at several of our best things, exploring the unknown, making ingenious contraptions, cooperating with a will to do it, drawing on the accumulation of the culture and history, whether we think the equations of Galileo, Kepler, and Newton; or of the roving Polynesians, Vikings, Columbus, and Magellan. And we have satisfied our lust to see at a distance."

(FIG. 6) Iain Boal arrives.

IGNACIO: Our lust to see at a distance …

AMY: Iain, why did we send people to the moon?

IAIN: I wanted to go to the moon. I belonged to the British Interplanetary Society.

IGNACIO: You did? You do still?

IAIN: When I was fifteen. My utopianism took that form. I touched Arthur C. Clarke.

IGNACIO: Why did we send people to the moon?

IAIN: It was a cover for militarizing space, wasn't it?

MICHAEL: I like how you've jumped into this boyhood dream of going to the moon, and I think that fits in perfectly with our conversation about Paul Goodman's words on the space race. It's beautiful to start as the little boy. I'm curious how you got to this field of biology, and Iain, I'm curious how you got to this field of the commons.

IAIN: Can I just follow on that? I was sent away at the age of six to one of these total institutions in England in the countryside, an old sixteenth-century house that was a prison in a way. But it was in the new forest, which I only recognized later was a kind of a massive common. William the Conqueror had claimed it as a forest, which meant people could only be there on the basis that it was in the royal forest, but they could use it as a common, it was common land. My own great interest in radio and the bicycle go straight back to that boyhood, because I built a crystal radio set which was able to bring the world into me under the blanket in the dormitory after dark. And the bicycle – these were both technologies of liberation that allowed me to get out. Also, I think this desire and interest in space, you could see it as escapism, but it was also, I would like to think, some kind of false utopian fantasy. A lot of people were engaged and excited by it. For a while, I was ashamed of it. I hadn't seen through, but I think it's okay.

IGNACIO: I make no excuses for escaping, for trying to escape, I'm an escapee. Aren't we all on the west coast? For me, living in a place like Mexico City, an incredibly oppressive pot which is surrounded by these really tall mountains to make it impossible for you to get out,

at some point it became a real obsession with me. I had to get out on a regular basis, and it had to be by my own force. I guess the going into the world of microbes is this effort to look for other places where things could be different. Fungi is the way I go into that world.

The thing about fungi is that they have this amazing duality because they can be the largest organism. The largest organism on the planet is a fungus. And then they are also microbes. So I do remember as a boy, that's a really good way of approaching it. With plants, you know, you can always just dig it out and find its root or try to get to the bottom of its entrails. And with the fungi, with the mushroom, you cannot get to the bottom, no matter how careful you are. I would spend a lot of time trying to understand where this thing was coming from and then losing it. It just goes away. You would never be able to tell where it was. Much later, when I understood it – it just goes microbial, but then it's macrobial. So it's really an incredible gateway organism to go into that world and into that way of thinking. And it flips back and forth. Originally, I was interested in them because I felt I could understand something. Fungi are close to us, but also very different. In the difference, I might find things that can apply to understanding myself or understanding us as humans. I lost that interest in humans, I guess, later on, after killing too many rats.

AMY: Ignacio, which books did you bring to this picnic?

IGNACIO: (pointing to *What is Life?*, by Dorion Sagan) Dorion Sagan is the son of Carl Sagan. It's an interesting response to the idea that we really understand how the world is put together, and that there is one system that accommodates all forms of life. Look at all the scales here in the timeline.

AMY: Oldest Giant? (pointing to the timeline in the book) What is that?

IGNACIO: (reading from the book) "*Acanthomorph acritarchs*, probably algae." They have a true scale timeline. Even though it's mounted over time, it's the telling of the story of how life was put together. It is the depiction of that idea of the phylogenetic axis. This book presents a different way of understanding where living things come from, how they are put together, and so on. But we just don't want to hear it, so I thought we should have that presence here.

I also brought *Evolution in Four Dimensions* by Eva Jablonka and Marion J. Lamb and *The Religion of Technology* by David F. Noble. David Noble's book concerns the breakdown of understanding and the inappropriateness of the model of that "program" that we were talking about. It goes back and forth through questions of genetics, physiology, developmental biology, evolution, and environmental biology. This book is one of the newest contributions that tries to generate a different understanding of what life is about, and to discuss where that previous model doesn't work. It resonates with that other book, *What Is Life?*, which is itself a response to a 1944 book with the same title by Erwin Schrödinger, the physicist, who was one of the people establishing that biology was going to be solved the same way that physics was, that physicists were going to take over and run the undertaking of understanding biology. I think they are very good responses to that really failed way of thinking about life.

AMY: Where were you in 1968, when this movie was being made?

IGNACIO: In 1968, I was in Mexico City, breaking up a television.

MICHAEL: I have this picture of a hammer and a television.

IGNACIO: It's a funny story. There was a TV in a hallway in

my house. I'm the eleventh of eleven, so it was a household full of people. There was no switch on the TV; it was just connected to a circuit, and you had to join the wires to turn it on. One day, I was completely spacing out, playing with the wires, seeing the spark and seeing that the TV would come on and come off and come on and off, until it didn't come on again. And that was it, I killed the TV, and it was right before the Olympics. Everyone hated me for that. Its funny, I hadn't thought about that in a very long time.

MICHAEL: I like this picture of your experiments with media.

IGNACIO: Yes, electrical experiments.

MICHAEL: Ten other siblings at your throat for your inquisitiveness.

AMY: In your class the other day, you said you banned your students from using the words "nature" and "natural." I just wanted to hear your reasoning.

IGNACIO: For a student who is just growing into the field of biology, it's a very poisonous word because it prevents a young person from imagining him or herself in any other way but as separate from that other thing that is called the environment; that other thing which is called nature. From a more practiced personal point of view, I mean, just look at where we are. We are surrounded by rampant invasive biology here, and things that are completely introduced. And at the same time, a mountain lion comes and visits us, so the separation between nature and non-nature is a complete artifact that is not helpful. I really try to train them to avoid that word until they know this difference and then they can use it carefully, you know.

MICHAEL: Is there a third word you use instead?

IGNACIO: No, you don't need it. Same thing with "gene." I also banned the word "gene" from my classes, from my students. It's not necessary; it's convenient. Another word I banned is "issue." Some people come to study at a university to learn how to use the word "issue," and they learn how to use the word "actually" instead, don't you think? And so "gene" is a word just like that, it's not useful. It's not necessary, and it actually makes you think that there is something there that you should know or you know but doesn't exist. It's like talking about, I don't know, a flying tiger. Same with the word "nature." You don't need it.