SCIENCE OF THE NOOSPHERE

Paul Rainey and Rick Michod

with

David Sloan Wilson

David Sloan Wilson: Okay, well welcome Paul Rainey and Rick Michod. I'm so eager to have this conversation. Teilhard's concept of the noosphere has this amazing sweep. He began with the earth before the origin of life, and he covered the origin of life and what he called the biosphere as a kind of a skin that covered the earth and began to influence such things as atmospheric processes. And then, the origin of humans and the noosphere as a kind of a second skin and that skin having a mental dimension, and then, ultimately, becoming a global superorganism. So how amazing is that? Even more amazing, I think, is how much modern science is kind of filling that in and that we have a coherent story to tell all the way from the origin of life to the human noosphere, that we call major transitions and transitions of individuality and so on.

And so, your specialty, both of you, is the origin of multicellular life, but you're wide range of thinkers on your own and your own thoughts, I think, extend all the way from the origin life to the human case. And so, this conversation is going to span that whole range while focusing on the origin of multicellularity. So with that introduction in mind, could I ask each of you just to tell us a little bit about who you are as human beings and how you wandered into this line of work? And Paul, let's begin with you.

Paul Rainey: Well, as a human being, let's start with my origins. I'm a New Zealander. I grew up in a nonacademic environment, but was always intrigued by life's diversity. I ended up just following my curiosity, and that took me through an academic route with increasing interest—well, initially, and still today—interest in exploring evolutionary processes in real-time using microbes as experimental tools, effectively. Rapid generation times allow us to look at evolutionary process in real-time. And certain aspects of those experiments brought me face to face, initially, with the evolution de novo of cooperation among bacterial cells, building a simple undifferentiated group.

And from there, into major evolutionary transitions was a gradual process that was fueled by my realization that simple groups are incapable of participating in the process of evolution by natural selection, because they don't come, necessarily, endowed with those critical Darwinian properties, variation at collective levels, replication at collective levels, and heredity at collective levels, that is necessary for the collective to participate in the process of evolution by natural selection. So grappling with that problem, "How do Darwinian properties emerge if they don't come for free?" Has been, to me, a really difficult problem, but one that's forced us to think about things quite differently, actually, leading to recent work that you perhaps saw thinking about the environment far more as an external imposer, if you like, of Darwinian properties on systems that lack these properties to get going.

DSW: Awesome. Oh man, that's so great. Rick, how about your trajectory?

Rick Michod: So I, like Paul, I guess, was brought up in a nonacademic family. My family was religious and Christian oriented so I was brought up going to Bible school and all that stuff. Anyway, as a young man, I could no longer sustain that belief in a caring god and I was fascinated with dinosaurs and primordial pictures of the origin of life and stuff like that. So I found in evolution, a kind of substitute to spirituality, a kind of connectedness with life that was very meaningful to me. And so, I seized upon that to fill this gap that my religious upbringing hadn't given to me. And so, then I started to follow it in school and went to graduate school, finally, in evolutionary biology at the University of Georgia, with a student of Theodosius Dobzhansky, Wyatt Anderson was my advisor's name.

And anyway, I was all over the place as a young graduate school student interested in lots of stuff. And when I did my prelims, which are done at the University of Georgia before you go into your research, they basically held me back. I basically flunked my prelims. And so my advisor said, "Rick, you really got to take some time here and regroup and all that." So at the time I had... So then I went to England and took a year off and went to study with John Maynard Smith, Brian Charles with Paul Harvey and a few other people. And that was kind of mid ‘70s.

And so, at that time, John was thinking about evolutionary transitions and cooperation/conflict. So I picked up on that when I went on in my career and that's kind of how I got into the business of studying cooperation. And then Wilson, E. O. Wilson his book on sociobiology came out while I was in graduate school. And that was huge for me because it painted this picture that social principles could apply at any level of organization, not just among primates and primate colonies or among social insects. Wilson's book was all about using social principles at all levels of organization. So that to me was a big eye opener and so I've continued with those interests really.

DSW: Well, that's a great way to begin. And to continue, I think I'd like each of you to basically describe the concept of major evolutionary transitions or the evolution of individuality in your own words. And then we can move on to your particular systems because you work on very different systems, microbes in the case of Paul and Volvox in the case of Rick. So first, a brief statement on how you would describe the concept of major evolutionary transitions, and then we'll proceed to your systems. So, Rick, why don't you go first on that point?

RM: So I like to distinguish between major evolutionary transitions and really transitions in individuality. So to me, there's lots of major events in the history of life without which life would be vastly different than it is today. But not all of these, the advent of life on land and in the air and so on, these were all major transitions, but they're not transitions in individuality. So I like to add that term "individuality" to this concept of major transitions to make specific that I'm talking about units of selection and adaptation and how they arise at new levels.

So in the models that I've used, there are, depending on how you divide it up, four or five different stages. One is the formation of groups. So you have individuals at some level, and then they form groups for some reason. Why they form groups is interesting and it's an interesting step in the evolution of a new individual.

Then there's the evolution of cooperation and conflict that occurs in these social groups. And the conflict can set up the stage for conflict mediation, which can then lead to enhanced cooperation and the division of labor within the group and especially the division of labor between survival and reproduction, these are the key components of fitness. The fitness of an individual requires that it both survive and reproduce. So when you get specialization in any one of those components, the member of the group that's specializing no longer has Darwinian fitness overall, it can't both survive and reproduce.

And then I like to speak of there being a transfer of fitness away from the individual level to the group level and a decoupling of fitness at the group level from the members of the group. So in a specialized group where you have cells, for example, in a cell group that are specializing in reproduction, specializing in survival, the cells no longer can survive and reproduce together outside the group. Sorry, I didn't say that well, can no longer survive and reproduce alone when they're outside the group. So I then speak of there being a decoupling of fitness of the group from the lower level. And then I would say that the group has now become an individual because it's indivisible, you can't chop it up, you can't take the cells out of the group, they won't survive and reproduce on their own. So they're committed to group living and the groups and individuals.

So that's how I see it. And it's very similar to kind of the psychological stages in human group problem solving of Tuckman. So you have this theory of social group dynamics in humans about problem solving, forming, storming, norming, and performing. And these are very similar to the ETI stages. And so I see a nice parallel there with human group dynamics.

DSW: Yeah, we'll get there, we'll get there. That is so clear, Rick. So let's just proceed right to you Paul, as to... I'm going to build upon that.

PR: So I would begin by being in complete agreement with Rick in drawing attention to the importance of distinguishing between major evolutionary transitions and major evolutionary transitions in individuality. And I think the transition from cells to multicellular life concerns a transition in individuality. And so perhaps it's worth clarifying there exactly what I mean, at least, by individual. So I'm thinking about, let's say, a simple perspective on the transition to multicellular life begins with, of course, single-celled organisms that are themselves Darwinian, that is populations or individuals within populations vary one to another, they reproduce and the offspring resemble the parental type. As a consequence of those three essential Darwinian properties, the cells participate in the process of evolution by natural selection, they have no choice. It simply unfolds by virtue of the entity's concern, manifesting these properties.

The transition from cells to multicellular life begins with these cells and ends, at least in terms of the pivotal stages for me, when we have collectives of cells that manifest those same Darwinian properties that the cells manifested. So we start with cells that are Darwinian individuals, we end up with collectives or groups that are themselves Darwinian individuals. Now, once we have groups that are Darwinian, they of course participate in the process of evolution by natural selection. And barring some sort of catastrophe, those collectives will evolve into some form of complex multicellular life.

The thing that really needs explaining to me is how we go from Darwinian cells to Darwinian collectives. And so major evolutionary transitions in individuality, not just that from cells to multicellular lives but some of the others that perhaps we will talk upon, also have at their essence the need to explain how these Darwinian properties emerge at the higher level. And when you think hard about this, it's not obvious how they do emerge. Perhaps we come back to that later on. But to me, the transition in individuality is explaining the evolution of Darwinian properties at the higher level, at the level of collectives of cells, if we are thinking about multicellular life.

DSW: Okay. So now let's look at the model systems that each of you have developed in order to actually study those, not just theorize about it, but to study it, Volvox in the case of Rick and microbes in the case of Paul. And Rick, why don't you begin with this wonderful, wonderful model system of this multicellular algae that we know and love as Volvox?

RM: Well, of course the Volvox is a microbial system too. And I think Paul and I both enjoy working with microbes and the kinds of manipulations you can do with microbial systems. The Volvocine green algae are a naturally occurring system, you find them in pond waters around the world. And they are a lineage of green algae and they live in freshwater ponds, like I just said. And they illustrate in this small clade, basically, unicellular species, simple clumps of cells, just two or four cells with no division of labor, larger clumps of cells with different species have 32 or 64 cells. And then kind of the most complex and differentiated member of the group, Volvox, has thousands of cells, specialized cell types, cells that have flagella—are permanently flagellated.

There's a simple constraint in this lineage that cells cannot reproduce and be motile at the same time, the basal bodies, the spindles used for the flagella are needed for the mitotic spindle apparatus and so a Chlamydomonas cell cannot be motile and reproduce at the same time, except it can because the flagella are able to move even when the basal bodies are removed. But anyway, this constraint becomes operative at about a certain group size of about 32 cells. And in those species, you start seeing some specialization of permanently flagellated cells. So they're a naturally occurring group.

And unlike the animals and plants, the evolution of multicellularity has happened fairly recently, a couple hundred million years ago, we think. And so the remnants of these changes are present in the genome. We can find the genes responsible for division of labor and so on. And we can construct kind of a genomics as well as a phenotypic map of this evolutionary transition. So the main advantages of the system are, I feel it's like the most complete mapping of an ETI, evolutionary transition in individuality, that we currently have.

And the interesting thing about the lineage is not only that they had these evolutions of multicellularity, but that the complexity only went so far. In other words, we just have two cell types as opposed to like in humans, hundreds of cell types and so on. And we think we understand why they kind of ran out of steam and can't evolve even further and it has to do with the kind of soma that they evolved. Unlike the soma in our bodies which can continue to replicate, the soma in a Volvox colony is basically a starved cell. And starved cells cannot replicate, but they stay small, they keep their flagella and they allow the colony to move while the colony is reproducing. But because of this, the way they invented their soma, they can't evolve more complicated morphological forms through more complicated kinds of somatic cells.

So that, in a nutshell, is why we use this lineage and how we use it to study these evolutionary transitions in individuality. In Chlamydomonas, the individuality is at cell level, in Volvox, it's at the group level. And in between, we see individuality evolving continuously and plastically in response to stress in some of the smaller species.

DSW: Well, one point to make, Rick, is that the evolution of the so-called more advanced forms doesn't completely replace the so-called more primitive forms. And insofar as the entire range continues to exist in the present, that means that they're basically occupying different niches in the present. And there's some sense in which the lower forms, we shouldn't even be using the words "lower" and "higher", are the superior forms as far as survival and reproduction are concerned. And for the same reason, there's still lots of single-cell bacteria around despite the fact that multicellular organisms exist. So that's an important point to keep in mind across the board. Right?

RM: It's a very important point that the more complex forms, it's just an alternative stable state to the simple form. They're found in the same ponds. And so I guess the other lesson that I would like to just tease out of this with regard to just complexity generally, is that there has not been a progressive march towards higher complexity. We see reversions in some lineages, we see the loss of the specialized cell, see smaller groups evolving, we see a lot of stasis in the phylogenies of these species. So there isn't this progressive march towards complexity. There has been an emergence of a new level of selection, the multicellular Volvox, but it's not like a progressive stepwise march to it.

DSW: That's very important, indeed. Okay, Paul, your system, please.

PR: Right. In a nutshell, it's very difficult to get that across in a nutshell. Let me start with where it began. So the bacterium we work with is Pseudomonas, it's a communal garden bacterium, the species is fluorescens, you eat it daily on your salad. It's a benign organism. And one of my first explorations in the field of experimental evolution was concerned with testing ideas about the origins of biological diversity. Why is life so complex? And an idea that had been around a long time, well, first of all, the recognition that much of life's diversity has emerged through successive adaptive radiations, and then an idea here was that adaptive radiations are fueled by ecological complexity, vacant niche space.

And so we set about to test this idea. The ideal experiment would be one where you took a single lineage and you allowed it to evolve in two different worlds, one, which has little ecological opportunity, few niches, and the other has a great deal of ecological opportunity. Now Rick mentioned the wonderful power of experimental evolution with microbes is you get to play god, effectively. So what we could do is create two different worlds, one complex, one simple with regard to ecology or number of niches, simply by taking one test tube and shaking it, it becomes a homogeneous environment, and take the same test tube, put in the same bacterium, but now don't shake it, leave it static. And that environment is ecologically complex. There's spatial complexity, it's a spatially structured world.

So what we saw is that in the homogeneous environment, the unstructured world, basically no diversity arose, whereas in the spatially structured, the unshaken test tube, an awful lot of genetic and morphological, phenotypic diversity arose. And of these different types, it was possible to show that they occupy very distinct niches within this unshaken test tube, the spatially complex world.

Now, one of the most intriguing, really, one of the most beautiful of these organisms is what we refer to as the Wrinkly Spreader. It depicts the name of the organism as it grows on an agar plate, so the colony has this wonderful reticulate phenotype. In the unshaken test tube, this Wrinkly Spreader type forms a mat at the air-liquid interface. So the ancestor, which is a single-cell bacterium, it's an obligate aerobe, it grows throughout the unshaken broth phase of the test tube, it depletes the oxygen. Basically, in the broth phase becomes anaerobic. The only place to make a living is that the air-liquid interface, but single cells can't stay there for all sorts of reasons, actually.

However, mutants can arise via many different independent mutations that cause overproduction of a cellulosic-like polymer, a glue, effectively. And that allows the cells, when they separate at cell division time, they don't completely separate because of the glues. And the consequence of these glues in the way the cells divide means they get to form a mat, a very thin film, initially, at the air-liquid interface. And gradually, that becomes a very thick structure. It's not buoyant, it doesn't float there. It cements itself, the mat cements itself to the rim of the glass tube.

Now, it turns out that these Wrinkly Spreader types that colonize the air-liquid interface do so by evolving cooperation among individual cells. And it has all the hallmarks that theory and our own intuitions suggest should be there. So we can measure these Wrinkly Spreaders, we can measure the growth rate. They grow more slowly than the ancestral types. They should be driven extinct. They aren't driven extinct, they are highly successful and they're successful as a consequence of what the collective of cells that forms this mat achieves. So a single cell or single cells acting individually cannot form a mat, a simple undifferentiated group, but a collective of cells interacting can. It's costly to produce this glue, but the collective benefits through access to oxygen.

Going on a little bit further, what one would expect from theory is that if this is a simple cooperating group, we should see the evolution of types that defect, types that so-called "cheat." And we do see those evolve de novo and relatively rapidly. These are cells that no longer produce the glue, so they no longer pay the cost of cooperation, but they reap all the benefits of being in the mat. So they grow unchecked, exactly like a cancer, they reap the oxygen, they contribute nothing to collective structure, and this causes the mats to collapse. So there we are. That was the experiment. That's the nutshell of the experimental system.

DSW: Well, I just want to jump in and say what a wonderful example of cooperation, altruism, and selfishness playing itself out in the microbial world. It's just such a wonderful, wonderful example, and so amenable to experimentation so please continue.

PR: Right. Well, it is wonderful and it's remarkable to be able to see this evolve de novo in an organism that is not overtly cooperative. It's gone from a leaf surface to this test tube environment which is utterly foreign to it, being presented with a new challenge and it's found a solution that's involved the evolution of cooperative interactions.

However, as wonderful as that seems, and we’re faced with the evidence of the shortsightedness of natural selection. So if we are thinking about the evolution of multicellular life, we think to the evolution of simple undifferentiated groups, we see those, so great. But then, as soon as they emerged, then we see their demise through selection for cells that defect. And so this puzzled me a lot. I started to think about these simple Wrinkly Spreader mats as raw material for the evolution of multicellular life and we get cooperation, but then we see the conflict and it's all over. So this could cycle.

Anyway, the way I began to think about this requires an expanded view, going beyond a single test tube. And I find the easiest way to try and have people picture this in the absence of pictures is a pond. So imagine a pond. Imagine the pond is studded with reeds. So we've got rid of the test tubes, but spatial structure is given in this pond by virtue of the placement of reeds. We've got the same problem, the ancestral type grows throughout the pond, depletes it out of oxygen. The only place to make a living is at the air-liquid interface. And these reeds provide a focal point around which a mat can form.

So let's imagine our reeds are evenly spaced across the pond and the mats that grow cannot connect with one another, they're separate. So we have variation among our mats. We have discreteness first at the level of mats by virtue of the placement of these reeds. There are many different mutations that can generate the first mat-forming type. So we have variation at the level of collectives here by virtue of the structure of the environment.

Now, what about the replication of these collectives? Well, from time to time, for various reasons, mats will collapse from around a reed. That presents a new space for another organism to colonize, or one of the existing mats to colonize if it can migrate. So if we had a collective on one reed, there's no collective on another reed, there's been a death event. So the extant one can somehow send up propagules to colonize the vacant space and recolonize it. By that sort of ecological process of migration, we get, what is in effect, a reproductive event of the mat.

Now, the idea here, very specific to our system, involves something that I think is really important and it involves recognizing that that tension that we see between cooperating types and defectors, which is a big problem, Rick, in particular, emphasizes that, it's a big problem. The group that emerges is killed, if you like, its lifespan is diminished by the presence of the conflict or by the cheating types who bring about this conflict. In an appropriate ecological context, though, those cheating cells, I like to refer to them, actually, as non-sticky cells because they can perform an ecological function as a propagule.

And so what you have, given this ecological structure, actually, is a Darwinian process that unfolds, which critically, ensures, by virtue of this life cycle that involves a soma-like phase, the mat, and a propagule-like phase, the non-sticky cells, a birth/death process that unfolds over a longer-time scale. And that, to me, is critical. The birth/death process over a second timescale, we would typically call that a new level of selection, but it's the second timescale that really matters.

So integral to all of this is a life cycle. A life cycle ensures that you have a generation time of an organism that's much longer than the doubling time of the cells that make it up. Also, in that life cycle that arises from the tension between the interests of the cooperator and the cheats, you have the origins in this particular instance of the soma-germ distinction, and you also have the origins of a developmental process. They are all different sides of the same coin, so to speak.

If a multicellular organism is going to be successful, there needs to be an ecologically relevant part to it, it's got to be doing something. Here we have a mat that's getting oxygen for the collectives, that's its ecological role. To reproduce itself, almost all multicellular organisms go through a single-cell bottleneck phase. It has all sorts of implications for reducing conflict. If it's gone through a single-cell bottleneck phase, there needs to be a developmental process to recreate the soma-like phase. So life cycles, second timescales over which selection can operate, development, soma-germ distinctions, very much part of the way we've been thinking about, the way that this experimental system, in fact, has taken us.

DSW: Yeah. So that's where I want to go next with us, because Teilhard when he talked about the human organism talked about an anatomy, a physiology, a nervous system, information, all of these things we need to learn how to recognize in a cooperative human society at any scale. And we have an opportunity to see how they emerge in multicellular organisms. So let's speak a little bit about, in basic terms. I've always been a little bit confused, for example, with the distinction between anatomy and physiology. Is that a clear-cut distinction to you? So first of all, how would you distinguish anatomy from physiology? And then say a little bit about how it emerges in these nascent multicellular organisms, and development, I think we can put that in as well. So these terms, these key terms, which are, of course, fundamental properties of multicellular life, what are they and how did they emerge? Rick, why don't you begin?

RM: Well, in the Volvox in these algae, they're basically spherical. So the anatomy involves the inside and the outside of the colony as well as how the space is occupied within the colony. And what we see is that the somatic cells are on the outside of the colony because they need to project their flagella into the surrounding aqueous medium which allows the colony to move. The germ cells are located in the posterior portion to kind of anchor the colony as it moves forward, it gives it a directionality. And then the cells talk to each other either through the volume filling extracellular matrix, that's the inside of the organism, or through cell to cell connections.

So the anatomy is very simple but it emerges, spatially, out of the positioning of the different cell types. And the physiology has mainly to do with the conversion of sunlight into energy and growth of the reproductive cells. So I guess to your point about where does the anatomy initially emerge, it's the spatial organization of the group, is the initial kind of, I think, concept of anatomy.

DSW: Anatomy is structure, physiology is process, does that sum it up?

RM: That works for me, at least in terms of these critters. Yeah.

DSW: Okay. And communication, so the beginning of a communication system. It's not a nervous system or maybe it is, but it's a communication system, that's also required.

RM: That's right. There's a group of biophysicists that have gotten involved in Volvox movement. And one of the titles of one of their papers is Coordinating a Thousand Oars, like how does Volvox do that? And there isn't a top-down nervous system, it's all local interactions and there's a description of that emergence from kind of the properties of individual players, of the oars, how all that happens, but that's well understood. But there isn't a kind of nervous system, a top-down kind of organization.

DSW: That's, I mean, something. We call it simple, but then when you think of it as how do you coordinate a thousand oars then even that is not so simple anymore.

RM: Right. But it's all local interactions, that are set up by the polarity.

DSW: Yeah. And that's huge. I mean, basically, you've just described the concept of the invisible hand, the idea that society works well without any of the members knowing. And also in, I was going to say real multicellular organisms like you and me, how much it's taken place by cells responding to their local environment. So that idea of large scale coordination being accomplished by basically the small scale units responding to their local environments is very general. So Paul, how does this all reflect in the multicellular organisms that you're evolving?

PR: Well, this is perhaps where the use of a bacterial system has its limitations. So why haven't bacteria become more complex in their multicellular life? I don't know the answer to that. But one thing that is necessary for certain is the evolution of development and how that comes about is a complex problem. From our experiments, we see selection shift to work on a developmental program, which is the life cycle. Now that's the first important thing. And we do see the improvements in developmental control, but it's not the sort of development that you would perhaps expect to see in a multicellular organism. And it doesn't involve signaling a spot across space, it involves signaling across time, at individual cell levels. But there doesn't really seem to be much going on as far as we can see across a surface to give you that coordinated behavior across a body of cells.

And again, as I say, we've quite possibly reached the limits of what is available to this prokaryotic life that we are working with. So that life cycle that I described to you before, when it gets going, is very clunky. It relies on mutation, mutation at each stage. So a mutation generates the soma-like phase, the mat, a mutation generates the propagule, a mutation generates the next mat. Now, no developmental cycle works by mutation, but that's all this organism has at its disposal. And the thinking was that's perhaps enough to get going and then selection might refine it very quickly.

DSW: Might you have found a developmental switch, so now the alternation between the phenotypes is not by mutation but by a developmental switch.

PR: That's right. So quite quickly we saw the evolution of a mutational switch which is a developmental program. It's just not as refined as you might expect. But we do now have genuine gene regulatory responses to environmental cues that determine whether an organism is in the soma-like phase or in the germ-like phase. So, we do see the evolution indeed of vastly improved capacity for this life cycle involving two phases, the division of labor, reproductive division of labor, it hugely improves. And I think, again, that's been very important for when selection shifts levels, it works on something new.

What is the kind of novelty that's available for selection to work on that is more than just the sum of the individual cells? So we have these cooperating mats. If you just continue to select on cooperating mats, you get better cooperating mats, but they don't become anything different. You get improved interactions. But once there was the opportunity for selection to work on a developmental program, going between the two stages where if you don't go through those two stages, you die, you get this birth/death process, then the focus of selection is suddenly on something very different. It's not on the cooperating phase, it's not on the soma phase. It's not on the germ phase, it's on the combination of the two, you need both and you need to switch between them. So I think, there were ideas, Van Valen in particular, this link between ecology and development, evolution being about ecology and development, I think is very true and very early on in the evolution of multicellular life, I think the foundations of those key innovations need to be laid and are laid early.

DSW: Yeah. But I want to correct a misimpression, Paul, there's amazing examples of social microbes such as the slime molds and so on, which are computationally very sophisticated. So microbes have evolved, not your system, necessarily, but there's wonderful examples of social and even eusocial or at least ultrasocial social microbes. Is that right?

PR: Well, yes. Yes and no. So there are plenty of examples of what people refer to as cooperation among microbes. And I think some of those are fair to say they probably are, but it's very, very difficult to test the hypothesis that a particular microbial trait is in fact cooperative. You need knowledge of the environment in which it evolved. It's certainly true that in the lab, you can create conditions where certain extracellular products will behave as public goods and people run from there to say they are cooperative traits and it was the evolution of altruism. You can contrive that in the lab, the extent to which that's true in nature is a very interesting question.

The point about slime molds, well, the classic dictyostelium, of course, is a eukaryote, but you have microbes such as myxococcus that produce fruit bodies, but they're very interesting. Perhaps we don't want to go there now but the extent to which selection works at the level of the collective there is unclear to me. I would always look to these organisms, say, to what extent do slugs of myxococcus xanthus display heritable variants in fitness? To what extent? What opportunity is there for selection to work at the level of slugs? Well, so then you start. So you look at the slugs and what you find is typically the slugs are chimeras, and that for most of the time, the cells are asocial, they're living separately. So no one really knows how often they come together to form the slug, for example.

Now, far too much for this time, but I could come up with or have come up with a way of thinking about dictyostelium, in particular, that drops altogether ideas of cooperation, of multicellularity. One could just look at it as an ecological lottery model. I think the thing to take away, these manifestations of multicellular life, and there are many of them among the single-celled or among the more primitive eukaryotes and in bacteria, demonstrate, once again, that it is not necessary to complete major evolutionary transitions in a paradigmatic way as has happened with much of the multicellular life we are working with. Rather like Rick was saying earlier on or you too, David, that just single-cell organisms can be super successful. And there's a whole gradient of life forms that go from clearly single-cellular to clearly multicellular. And in between this sort of gray area is very interesting in terms of what holds it together.

DSW: Well, in human life, I want to say, this is true of everyone's experience, the best group size and organization is very context specific, it depends on the task. There's tons of things that are best done by individuals. Only some things require groups or well organized groups. So that continuum that we're describing in the biological case holds big time for the human case.

Now, what I want to do, in the interest of time, we have two big jumps to make, one is now to think about how these ideas that we've been discussing might apply to the origin of humans, human sociality, and then how they might apply to the cultural evolution of widespread cooperation and the prospects of cooperation at the global scale. So, first, with the human origins, I know Rick that you've thought about this, and Paul, I don't know if you have, but Rick, if you could begin just to connect these ideas that we've been describing with microbes and Volvox. Isn't it amazing how these ideas might be salient for the transition from a not very cooperative society such as chimp communities to the highly cooperative societies of humans?

RM: You're right. So there, of course, we have to make the movement into the realm of cultural evolution and recognize that there are analogous properties happening in the cultural realm, analogous to Darwinian properties that happen in the biological realm. And when we make that move, of course, we have to recognize that the transmission of ideas, traditions, behaviors, in this cultural realm, is multifaceted, there's many ways in which transmission occurs. Whereas in biology, it's just almost all transmission is based on cell replication, cell replication on DNA replication, and so on. But in the cultural realm, there's a diversity of processes, and you've had guests on your program, of course, that are experts in this area and speaking to that.

What we tried to do is we tried to take those cultural models and ask, "Is there something analogous to an evolutionary transition in individuality occurring in these cultural models?" And we're in the process of using the Price equation. We haven't published on this yet, but the Price equation has been used in the biological literature to study evolutionary transitions and individuality and to kind of understand how the covariance at the group level becomes paramount and the within group change is reduced. That's the essence of an evolutionary transition in the biological realm.

In the cultural realm, the Price equation is also being used. And we are hopeful that we can look for the same principles there. We haven't published on that yet. The paper that you're referring to is, we took all the individuality criteria that we use in biology, things like indivisibility, genetic homogeneity, genetic heterogeneity, MLS1, MLS2, spatial and temporal distinctness, all these are part of the language of individuality in the biological realm. We've taken all those concepts and we've applied them to the Pleistocene kind of hunter group, and we've asked, "Has there been an individuality transition in the emergence of the Pleistocene hunter group collective?"

So just to kind of set the stage there, there's of course, a lot of specialized tasks that are needed to bring down a wooly mammoth or large game if you're a group of small humans. And everything from sharpening the stones to spearheads, to whatever, processing the meat, you had this amazing amount of meat all of a sudden, there's all these specialized tasks. And can we see them as crystallizing into an individual, the hunting unit? And can we accurately describe this as an individuality transition? And we argue, you can, that these notions in the biological realm transfer fairly naturally into the cultural realm.

But I think we got it wrong that we argued in that paper that the cultural unit is purely made up of cultural traditions, and I think that's probably wrong. That a hominid culture unit is the new unit. It's the hominids as biological beings and their cultural traditions that are the emerging unit.

DSW: Yeah. I want to make a point that I hope I cannot make too technical because as you know there's a class of models called walkaway models in which movement is strategic. Individuals move, for example, when a group becomes overridden with selfish individuals and the cooperators just get up and leave. And because partner choice is possible, then movement, strategic movement, actually has the effect of increasing variation among groups rather than eroding variation among groups. And so you can take what we know exists, a fission–fusion society with lots and lots of movement. And that could actually be favorable for the evolution of these kinds of cooperative systems.

So actually, the opposite of encapsulated groups is something that's important. And you hear in the anthropological literature many accounts of like, if somebody's bossy and they try to be the big man and push themselves around, well, everyone just leaves and they're standing there alone. And so this becomes a very important force in favor of cooperation. And so what you end up with are highly fluid groups that are also highly cooperative. Isn't that interesting? You don't need, I mean, some kinds of encapsulation, which you think might be important. Actually, no, not so much. And so, I think that that's an important point to be able to make. You could have a lot of fluidity and that actually acts on behalf of cooperation rather than eroding it. This idea of vertical transmission, you have to have it. Horizontal transmission is bad? No, I mean, it actually turns that on its head. And I wonder if you have thoughts about that.

RM: Well, I don't. I'm familiar with that, but I don't...yeah, it is interesting what you say that the vertical/ horizontal thing is turned on its head by that. There are these coalescent properties that happen in the cultural realm that don't happen in the biological realm and that can give rise to these nucleated cooperative units and maintain them. And it would be interesting to have a kind of a catalog of these different novel properties that happen in the cultural realm that maintain the cooperative groups. Is there such a thing being written or have people written about that?

DSW: We're at the forefront of this. But back to Teilhard, Teilhard has this wonderful poetic language in which he actually makes the distinction between biological units which are more or less united by kinship, let us say, and human units. And he talks about the remarkable, agglutinative, I'm mispronouncing that word, but the agglutinative properties of thought that basically the reason that human groups stick together is because the way they're thinking about it. And so much about human groups is social identity and so on and so forth that it's actually the culture that's providing the glue, the social glue that you might say, "Who do you regard yourself with? Are you a member of this clan or that clan?" or whatever. It's thought, it's the symbolic meaning system which is forming the groups and just about everything about them.

And he saw that. And also this is basically the way that we might think about the expansion of the scale of human society. Now, that agglutinative property is causing us to think of ourselves as Americans or Iraqis, or maybe even citizens of the world, in which case we could have a meaning system that creates the unit and maybe even the global unit. So I'm actually heading there. But Paul, first, over to you as to whether you've thought much about these ideas that you're thinking about in the context of microbes might actually apply to the origin of humans or, fast-forwarding to the present, our current situation.

PR: I've certainly thought some about cultural evolution and so on. I don't see though from our experiments with microbes, perhaps, too much that I would expand directly to thinking about the evolution of humans. I mean, for a start and the point that Rick made earlier too, my focus here, at least with the microbes, has been transitions in individuality. And when we are thinking about the origins of human societies, there's no doubt that various major things happened, language, transmission, horizontal transmission of ideas, and there's no doubt that these ideas can spread, good ideas and bad ideas can spread, political systems and so on. I always return to thinking, well, asking myself, "To what extent is there a selective process happening here that is beyond that of the individual idea? And that doesn't need to be, but when one is thinking about at least levels of selection and so on, that's where my thinking goes, to issues about the possibility for selection, working on societies, on ideas, where the ideas or the societies are themselves participating in the process of evolution by natural selection because they're Darwinian.

And one reason, particularly for thinking about this in the context, particularly of human evolution and ideas about the noosphere and so on is that the only optimizing principle that we know about from biology is natural selection, and we can see how that can work at various levels. So I look to a lot of the thinking about cultural evolution. I've asked myself, "What's the optimizing principle here? What's optimizing it? Is it an individual's idea that they, through various reasons and through various political constructs or religious constructs, wish to see spread, or maybe the individual doesn't wish to be spread, but it spreads for whatever reasons, for good, for bad?

DSW: Well, let me read a passage from one of my other guests on this series, a man named Tyson Yunkaporta, who is an Australian aborigine, and he's written a book called Sand Talk: How Indigenous Thinking Can Save the World. And thus, let me read you this passage. You'll get it immediately. And you'll connect it to your microbial mats immediately. He's talking about a folk figure of Emu, the bird emu, which is a folk figure in Aboriginal culture.

He says, "Emu is a troublemaker who brings into being the most destructive idea in existence. 'I am greater than you, you are less than me.' This is the source of all human misery. Aboriginal society was designed over thousands of years to deal with this problem. Some people are just idiots and everybody has a bit of idiot in them from time to time coming from some deep place inside that whispers, 'You are special. You are greater than other people and things. You are more important than everything and everyone. All things and all people exist to serve you.' This behavior needs massive checks and balances to contain the damage that it can do." And later, he says, "Containing the excesses of malignant narcissists is a team effort."

And so there you have it, the cheater problem, the problem that exists in your mats, the problem that exists in all societies, and the problem that was solved.

PR: I completely agree. I completely agree there. Taxpayers, cheats. I mean, yes, we can draw all those parallels with cooperation and so absolutely. No, I don't disagree at all.

DSW: So what it speaks to is what was really needed for human ultrasociety was social control. A solution to the cheater problem, not so different from your mats, that if anything, what you would expect in your experiments over time is that there'd be some form of control of those cheaters that don't make that glue, that physical glue.

PR: But you see, in our experiments, ecology provides a solution to that problem. So policing, which is, of course, a complex problem itself. Evolution of self-policing systems, leaving aside the human dimension for a moment, is complex. That doesn't come for free. That requires some ability to distinguish self from other, is arguably a collective level, it is a developmental process. And yet, as Rick points out too, the problem of cheats arises really early. So the way we've thought about things here, the problem of cheating is solved by integrating it into a component of the larger level, the higher level so the cheats become an integral part of the whole, which I always thought, that's an interesting thing to take.

DSW: It's actually reflected quite a bit in Tyson Yunkaporta's narrative also. So great parallels, great parallels. And I wish we had even more time. But I want to finish up talking about the present moment. And I mean, golly, just look at current events and it's all about failures of cooperation at a massive scale. We don't need to dwell upon that because it's in our faces every day of our lives.

And so how can some of these ideas actually help us to solve some of these problems of cooperation and coordination at the larger scale and work towards, what I think, doesn't matter how you describe it, whether you want to describe it in Teilhardian terms or any other way you want, we need global cooperation is what we need. And if you want to call that a superorganism or the omega point, be my guest. But what we need is global cooperation. Everyone knows that. But what do we have to contribute as evolutionary scientists, working as we do, to some of these problems of our day? Paul, why don't you begin with that and then we'll pass to Rick?

PR: The need for cooperation is immense. But what would I draw from my knowledge of evolutionary biology here? So as an individual aspiration, we might be able to create a political or ideological or cultural meme or so on, a set of ideas that's persuasive. But as we know, cooperation is always undone by cheating types. My feeling is...I mean, I'm rather pessimistic, although we could go into some more optimistic ideas in a moment, but they're perhaps are more in the realms of science fiction. But I'm pessimistic as to the extent to which much is going to come from evolution by way of solution. I think we see the problems perhaps more clearly than others.

If there were some organizing principle, a selective process that was happening at the level of cooperating groups, where those groups were Darwinian, I could see potential, indeed, for some solution. But the way our societies are structured, they are, perhaps, marginally Darwinian. So we are not the equivalent of eusocial ant colonies, whereas clearly selection could work potently between ant societies. Now, we could possibly, with a bit of genetic engineering and perhaps some despotic political ideas, create structures that forced human societies to become the equivalent of ant colonies. But I don't think we really even want to think about what that would mean. And still-

DSW: Maybe China is going there, but that's not my choice.

PR: But even if we achieved that, we would then be faced with societies that are going to fight against societies. So I don't really see that solving the problem. But I'm sure I'm not touching on all the subtleties or nuances that need to be brought on board here. So of course, David, I'd be interested to hear from you, but Rick, I guess, is going to come first.

DSW: Yeah. So Rick, and then I will say just a little, just this much.

RM: Just picking up where Paul left off, the basic problem is there's no selection operating at the noosphere level, there's just one noosphere. And so it's not like this planet can be competing with another planet and the one that's most integrated and cooperative's going to win, as happens with groups of cells. But even though there's not the benefit of group selection happening at the noosphere level or the level of the planet, to create cooperation at that level, we can learn, I think, from what happens…what am I trying to say? Well, the problem we have to solve is we don't have group selection anymore at the planetary level, but we have to engineer what group selection at that level would produce somehow. Or we have to imagine the engineering like Paul does with his bacteria. I think we have to do that. I don't think there's any choice that we now have to imagine how to engineer things and, at the planetary levels, so that we do cooperate and we do have global cooperation.

And I'm thinking of things not any deeper than, how do you introduce fairness when you share a piece of cake? You have that simple rule that we all do you, you cut it and I'll choose.

DSW: You cut the cake and you're the first to choose.

RM: Yeah, and the other person chooses. So just by engineering society, I think we can enhance cooperation. But how do we do that engineering without having some kind of centralized control? And I know with some of your guests, there's been discussion about socialism and the problems with that because centralized control just becomes a new body politic and so on.

But I think the problem is simple, that is, we don't have group selection at the level we want, but we want to somehow have the benefits of that selection at that level without having the mechanism. And because we did evolve, we're real social creatures as we know, we evolved in small structured groups. So we're just primed to cooperate, but we're also primed to cheat, and to lie, as is abundantly clear with all the things that are going in Facebook and the Internet now, that we can do both very well. And so we have to somehow create the higher levels so that we put our efforts in the cooperation and not the cheating part of social life.

DSW: Yeah. So, I get to have of my say here. And it's so interesting because I think that, first of all, let's remain at relatively small scales or intermediate scales before we try to go up to the global scale. And there, when we try to get things done, it's very much like what Paul describes for his mats forming around reeds, you have some but not all of an evolutionary process, you've got your variation, but you don't have a targeted selection or a replication mechanism. And that's in fact what you need. And so what's needed is to socially construct a fully fledged inheritance system.

What does that mean? It means we have to have a target of selection, which is typically a fairly systemic target, like a smart city, just to make it concrete. Then you need to orient variation around that target. And that's a deliberative process, not just any variation, but the kind of variation that might make sense based on the target. And then you have to identify and replicate better practices, realizing that it might be sensitive to context. And repeat that again and again and again. And if you do that, then you have a full blown inheritance system surrounding the target of selection at that particular scale.

And do you know? That's happened again and again without people using the E-word or thinking about it explicitly in evolutionary terms. In fact, whenever you see something that works, that has worked, you find this pragmatic, experimental approach where people have some kind of target in mind, they try stuff out, and they replicate it. And so this is not something that's new, there's many positive examples to choose from. But we could make it work much better by being explicit about it. And so there we have the deliberate construction of a cultural inheritance system, which is much like what takes place in genetic evolution, only rarely, right, only rarely because we know that these transitions of individuality, they only happen, actually, very infrequently.

So if we have all that in place, and if we kind of get an intuition about all of that at a intermediate scale, actually, that can be done at a global scale, more or less without modification. And so the selection that's taking place is the selection among alternatives, that can take place at a global scale without requiring interplanetary selection or anything like it. What it requires is thinking of a decision making process as an evolutionary process. And there's all kinds of stuff to unpack there that we're not going to unpack in this meeting, but I hope it gives a flavor, for me at least, I think, for us to a degree, although we have lots to discuss among ourselves about these ideas.

And I think that's the main thing I'd like to leave our listeners with — is that, in some sense, we're dealing with a set of ideas that are so general that we can be applying them to the origin of multicellular organisms, the origin of ourselves as a species and what we might do in the present. That's what we have on offer. And of course, we're making it up ourselves. I mean, it's clear from our conversation how provisional all of this is, but I also hope that it's clear how powerful it might be to make these ideas, make them more current, more widely known, because hardly anyone knows this or thinks about this. That's my experience. And I wager, it's your experience also. So that's, I think, the benefit of this series and this conversation is to just bring these ideas more to light, to share them and to have them discussed more widely, basically. You increase literacy in modern evolutionary thinking in relation to the evolution of cooperation and so on. So that's my final say.

RM: David, you must have some thoughts on how to incentivize something like Facebook where it's been incentivized to build on conflict. Somehow, the designers of Facebook, my understanding is the designers would make more money if they replicated or made more likely the transmission of conflictual ideas.

DSW: Yeah. Yeah, they're making money off it. Yeah.

RM: So how would you incentivize, how would you structure Facebook so that a global cooperative—it seems like that's your model, right? If you can do it with social networking, then it should work. Right?

DSW: Right. And so this is where other guests of mine, especially Tim O'Reilly come in. But it's very simple. Tim O'Reilly, he's an internet pioneer. But this is where I think the fundamental import of multilevel selection theory, and it's so simple, anyone can get it. What it says basically is that the metaphor of the invisible hand is profoundly untrue. It is not the case that the pursuit of lower level interests robustly benefits the common good. Not. That's what multilevel selection tells you. You don't hit a target unless you aim for it. So if the global good is what we're working towards, then that has to be what we aim for, that has to be the target of selection.

And if you could get a Leviathan organization such as Facebook or Google or Amazon, just to get that, just to understand that that's the way the world works, then they will become solid citizens, and they will earn their status by their reputation. Once it gets established intellectually, that the only way to achieve global cooperation is to work directly towards that, to make that the deliberate target of selection. At that point, you can be judged as a solid citizen or not. And if you want to be a solid citizen, then you must do certain things. There must be transparency. There must be whatever it takes to earn a reputation.

And all of those ideas are already familiar to us at a smaller scale. These ideas are scale independent, so that makes the global village inhabited by nations and giant corporations little different than an actual village inhabited by individuals. So, there it is again in a nutshell, but that's how I would. But let me have a final checkout basically. Paul, and then Rick. And I'm so happy to have captured all of this on video.

PR: Well, it's been a pleasure, David, both to connect and to be part of this. I don't have anything particularly profound that I could say following on from that. But I think there are some very interesting possibilities of actually engineering a selective process at the level of societies, particularly at the context of egalitarian transitions, which I think are actually scarily achievable between individual humans and their individual artificial intelligence devices. It just needs to be a phone, effectively, something that you interact with, and where you have a unit of selection right off. Why?

Well, you are presenting a vision of an individual that could spread. And if you had individuals that interacted with an artificial intelligence device, you have that interaction. We've got variation among us. Replication, well, humans already replicate. We don't need to put the artificial intelligence device into into our germ line, we simply have to make sure, by some rule or law, that the device, the contents of the device is passed to the offspring, and voila, you have new units of selection.

Now, it gets scary here because who controls the information that goes forward? You could have a benevolent Facebook that ensures that the information going on the artificial intelligence device, which is going to affect your fitness, perhaps, by taking you to this dating site or that dating site. But anyway, there's some interesting possibilities there. If one has a benevolent society that had aspired in a particular way along with that that you present. I could see it being achieved rather quickly, but it could be used for horrible wrong at the same time.

DSW: There's lots of ways for this to go wrong.

PR: Yeah.

DSW: Rick?

RM: The first thing I want to say is thank you, David, for organizing this, not just our particular chat this morning, but for elevating evolutionary science and taking it into this realm of social cooperation, global village and global cooperation. Thank you for doing that. And I guess, the only thought that I think we need to be more clear about is the importance of conflict. I think conflict can be the engine of enhanced cooperation. And that's what I think we see in multicellularity, that a lot of the mechanisms that mediate conflict would not be there unless there was conflict. So somehow in this global village and the re-engineered Facebook or the social networks that I want to join, that we have to allow conflict to emerge. Yeah. We need conflict.

PR: I agree with that very much.

DSW: That's a great thing to end on. This is highlighted by Peter Turchin and among others and his view of human evolution, how 10,000 years of warfare created the greatest cooperators on earth. And the way I would end it is that, I mean, change requires replacement, basically. So any form of cultural evolution, positive or negative, requires the rapid replacement of better practices with worse practices. And so that's a form of competition and that has to be operating with a vengeance for any form of change to occur, including positive change. We have to have some competitive process, comparing the better practices with the worse practices. But of course, in order for it to be aligned with our normative values, then that competition, like a sports' competition, has to be refereed. I think of it as just like sports where it's intensely competitive, but also very highly refereed. And so I think that's the kind of competition that we need to strive for so it takes that form.