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The Seed Salon

Chuck Hoberman + Lisa Randall

The inventor and the physicist meet up to talk about shape.

by ***Edit Staff*** • Posted June 25, 2007 11:59 PM

Chuck Hoberman *is the designer, architect, artist, and engineer best known for inventing the Hoberman Sphere, a geodesic globe that can expand up to five times its diameter. He won the Chrysler Design Award in 1997, and his creations have been displayed around the world. Harvard physicist* ***Lisa Randall*** *is renowned for her work on extra dimensions, and in 2004, she was the most cited theoretical physicist of the previous five years. This year, Randall was included in the Time 100,* Time*'s list of the most influential people in the world. Hoberman's unique use of shape, scale, and dimension in his transformable designs seemed richly analogous with Randall's use of extra dimensions and warped geometry in her research on the nature of the universe.* Seed *invited them to explore this conceptually common ground.*

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CHUCK HOBERMAN: You present yourself as a "model builder" in your book. That was something that stuck with me. You're a scientist doing advanced physics, but is there some aspect of your work where model building is really a kind of design?

LISA RANDALL: That's an interesting way of thinking about it. It's funny, because when we design physics models we'll often talk about it in those words—designing models or creating models. But what we're really doing is trying to reproduce reality by guessing what's out there and searching for ways to test those hypotheses. We're asking, "what are the underlying design principles that actually exist in nature?"

CH: Right. What does "reproduce" mean in that sense? Because you're not reproducing it, you're making a model.

LR: Well, in science, we make certain assumptions about what the relevant elements are in order to make predictions that match what we're able to observe. So, if we identify the correct starting point—the correct ingredients, the correct laws, or forces—then we should be able to reproduce relationships that would perhaps otherwise be mysterious. We take theoretical ideas, work out their consequences, and then see if the consequences are observable.

CH: So that would be a key criterion for model building—you want a model that has close-term predictive consequences?

LR: That's right. One of the exciting prospects for the future of physics—actually it was covered in *Seed*—is the Large Hadron Collider. It's going to collide together protons at higher energies than we've achieved before. In the process, it's going to test ideas about how particles get mass, and why gravity is as weak as it is. Right now all we have are models to answer those questions. We know the mechanism, something called the Higgs mechanism, that explains how particles get mass. But we haven't observed the underlying reality so we don't know which, if any of these models, is correct.

But let me ask you—when you build things, how abstract are your ideas in the beginning when you first start your designs? For example, Einstein is well known for thought experiments. I'd say that those are abstract but they are still very much tied to physical things that you can picture, like riding a beam of light.

CH: Right.

LR: So, when you conceive of your designs, do you have something physical in mind? Are you thinking in concrete physical terms or are you going beyond that?

CH: My engineering training is in kinematics and mechanisms. And a mechanism isn't defined by the physical pieces that make it up; it's defined by the relationships and connections between the pieces and the trajectories. So, in that sense, the thinking is quite abstract. But there is a very strong visual aspect—not pictures of a thing, but images of processes and relationships.

Can you picture a brane? Does it have a shape or is it simply that you posit a brane as something purely living in an equation world?

LR: It absolutely has a shape. It has geometry. It has a geometry that you can determine through working out Einstein's equations and figuring out what the energy distribution is and figuring out what the particular boundary conditions are. If we live on a brane, it would have to look like the observed universe, which is big and flat.

CH: This is something I think about a lot—the relation between visible shapes and their underlying mathematics. For example, in designing mechanisms, a very important concept is degrees of freedom. You can do a simple equation to determine if a mechanism is a fixed object, a smoothly movable object, or a "floppy" object—one that has multiple degrees of freedom. This equation gives you a single number that is associated with a particular object and that is a predictor of that object's behavior. But the equations will only tell you so much.

LR: Can you give me an example?

CH: Sure. A four bar linkage—four members that are connected by four pivots—has one degree of freedom. In other words, it has one variable that describes its state, for example, an angle between two links. Then, when you make something that has, say, a thousand pieces, you can calculate its degree of freedom, but the equation doesn't tell you quite the same thing. In that case, the single degree of freedom predicted by the equation—a thousand pieces moving synchronously—would, in fact, be a floppy mess. Why? Because you haven't accounted for the flexibility in the pieces themselves.

LR: So there are degrees of freedom that haven't gone into it yet.

CH: The equations aren't quite describing it, but it sparks a thought process of how to come up with criteria by which you can pursue these more complex mechanisms and still predict their behavior.

LR: Is it really criteria or is it just that you haven't put in all the relevant degrees of freedom?

CH: It's probably the latter. For someone like me there's no point in analyzing or modeling past a certain point. But that's the difference between engineering and science.

LR: Right. So, is that how things work out for you that you accidentally find that there are degrees of freedom that you don't anticipate?

Chuck Hoberman *Credit: Julian Dufort*

CH: No, it's not accidental. I may design a mechanism that the equations will say is overconstrained and should be a fixed structure, because there are too many connections relative to the number of pieces. But, actually it moves smoothly because of symmetries within the underlying geometry of the structure. These symmetries reveal themselves as so-called invariants in the system, say as angular relationships that are unchanging even as the mechanism moves. It is precisely these extra connections that give the mechanism its structural integrity, so that it can perform two functions—it can hold its shape and form, and yet it can move in a precisely synchronous matter. Normally I don't actually describe my work that way but that is in fact the way I think about it.

LR: That's interesting and in some respects relates to one of the key features distinguishing creativity in science from other forms of creativity, which is the constraint that, ultimately, your models have to match reality.

CH: Which is the ultimate constraint, in a certain way.

LR: Yes. In terms of the actual doing of science, it's a creative challenge to figure out which problems you might ultimately be able to solve. In part it has to do with what you were talking about, with respect to the number of degrees of freedom: how many measurements you can make versus how many inputs you have to give. A lot of the time it's a question of building on what you had before, so that you have all the degrees of freedom you had before, and then you postulate, maybe, there's one or two more needed to more fully describe your system. Or maybe there's some underlying symmetry, or force, that you hadn't anticipated. So, you try to make models in a way that you're not introducing more additional structure than you need to so that you can make it as predictive as possible. You try to build a more encompassing theory that agrees with all known measurements.

CH: Right.

LR: Model bulding in particle physics has other constraints built in as well. Because of quantum mechanics, any interaction that could possibly occur, will occur. So you might say, "I'm only introducing a few interactions," but you find out you've introduced a mess of them.

CH: Is that the "anarchic principle"?

LR: Yes it is, but that's a term I introduced in my book motivated by suggestions of the physicists Murray Gell-Mann and Jonathan Flynn.

CH: I love it. All those little particles jumping around.

LR: Yeah. But these "virtual" particles allowed by quantum mechanics tell us that you can't necessarily say, "I'm going to introduce only three new variables." You often find more that tag along whether you wanted them or not. That's one of the things that came up in a theory called supersymmetry. People thought it was a simple thing—we're introducing a few new parameters—and then realized there really are actually many more parameters than were desired. Which then introduces questions like "which interactions are really permissible?" and "can I constrain those?"

CH: And which, actually, has virtually a one-to-one analogy with the design process, in the sense that just when you think you've hit upon exactly the right solution, the law of unintended consequences jumps in, and you find that you've opened up a whole new can of worms.

LR: Right. So there are elements or motions that you hadn't anticipated.

CH: Exactly—from a functional standpoint I've solved one thing, but I re-jiggered the design and now something else may not work.

"THE APPEAL IS THE APPEAL"

LR: What's driving you? How do you decide what you want to make?

CH: Well, because I have a business, if a client asks me, I respond. Actually, it's an interesting way to pursue what ultimately is an idea-based practice.

LR: What do you think people find appealing about your designs?

CH: A mathematician once told me that "the appeal is what mathematicians enjoy about math that they can't convey to people who don't do math." So, when people say "that's kind of mesmerizing," they're seeing something that is quite visceral, but they're perceiving relationships as opposed to things.

LR: One of the challenges in communicating physics—and obviously it's not something big and sculptural that people can look at—is actually being able to express what questions are driving us.

CH: Right.

LR: One of the things that drives us is what you were talking about. We like fitting things together, we like puzzles, and we like seeing consistency. But the reason we're physicists and not just puzzle-solvers is that we do ultimately have some underlying questions and we would like to see them latch on to reality.

It's kind of interesting to think about motivation or appeal in terms of design and sculpture. Because it sounds like, for you, one of the appeals is being able to make things work and fit together, but the appeal to the onlooker can be quite different.

CH: Unfortunately, one difference is that while everyone else is going "ooh!" and "ah!" at the sculpture, I'm thinking, "Gosh, I hope the cable isn't wearing out." Because I know too much and I can't really see it the way other people see it.

LR: That's always a fascinating feature of any creative work. The person who created it often sees it so differently from the outside observer.

THE VIRTUES OF IMPERFECTION

CH: In science, the concept of elegance or aesthetics often comes up as something desirable. Perhaps you wouldn't want reality to be inelegant—it would be a disappointment. I'm wondering if that's still an important idea?

Lisa Randall *Credit: Julian Dufort*

LR: You know, it's really interesting because I thought about this quite a bit when I was writing my book. For example, string theory is often described in terms of elegance. But for the kind of modeling work I do, one of the things to understand is how symmetries can be broken in a compelling way that still retains elegance. You don't want something that looks like you really had to just jimmy everything through some sort of Rube Goldberg machine. You want something that is elegant and explains what we actually see. I mean if everything were symmetric, it wouldn't be as challenging a problem, right? But the fact is, most of the symmetries are broken when we look at the universe around us. The question is, how can the underlying thing be symmetric and still yield what we observe today?

CH: How do you describe broken symmetries?

LR: There are different types of symmetrybreaking. One known as spontaneous symmetry breaking can probably best explained through examples. One I give in my book is that you're seated around a dinner table on which are placed wine glasses to everyone's right and left. The table is completely left-right symmetric. But, as soon as someone chooses one of the glasses, say the right-hand glass, everyone's going to choose their right-hand glass, and then the symmetry is broken. In this example, the symmetry is broken by the actual state of the system, but not by the underlying laws.

CH: Right.

LR: Another thing is that there's a scale associated with the symmetry breaking. In other words, at high temperatures, for example, the universe manifests symmetries for which the symmetry breaking is noticeable only at low temperatures.

CH: It's interesting, symmetry has a different connotation in terms of design. I give a lot of talks to architects and architecture students. They'll often look at my work, which can have a kind of mathematical regularity to it, and they'll say, "Oh, it looks so symmetric." And they're quite disappointed.

LR: The fact is most things in the physical world aren't the most beautiful when they're completely symmetric. It's sort of the small breaking of symmetry that is always intriguing, I think. So I'm curious what people say about your things being symmetric.

CH: Well, the way that an architecture student thinks about it is pretty much in terms of the look of a thing. And they may feel that it should look different from what came before. So, I think there's a sense that symmetry is old-fashioned in terms of a style.

The point which I try to make to them is that symmetry is never an absolute. There are degrees of symmetry. A glass, for instance, is rotationally symmetric, but in other ways, it's not symmetric.

LR: Right—a glass respects some symmetries and breaks other symmetries.

CH: Precisely. It's a more complex situation than to look at a particular artifact and say it is symmetric versus asymmetric.

LR: When you build something that's completely symmetric, do you ever have an instinct to make it asymmetric, to just wonder... what if that piece was out of place?

CH: Well, you know, I'm not really primarily motivated in my designs by the way things look. Their look emerges out of other concerns and constraints. I try to design things not to look a particular way, but to perform in a particular way.

LR: So, when you look at it, is that what you're seeing? You're seeing the performance?

CH: Yeah, that's much more my focus.

SEEING IS BELIEVING?

CH: One area that we work a lot in, especially for our product designs, is foldability—making furniture or tents or even toys that fold down small.

LR: People love that, too. In addition to the actual practical element, for some reason, seeing things that can fold up or become compact, is something people respond to.

CH: My sense is that people's perception of an object that expands is closely tied into physiological sensations of organic growth. After all, we started small and then we got big, so the scaling of an object becomes associated with a living quality. In that sense, my approach is a form of bio-mimicry, the close connection between the human-made and the natural, which I think has a very basic appeal.

LR: Yeah. Also, the idea that solid material is mostly empty space is rather mysterious to most people. Yet the idea that you can have something big fold up into something small—which means implicitly that the big thing has to be mostly empty—is so readily understood and accepted.

CH: Oh, 100 percent, yeah.

LR: Why is that less confusing?

CH: I think because you hold it in your hand. The ability of my sphere to expand and contract may be slightly mysterious to people, but its tactility gives a sense of familiarity. I think one of the reasons why people enjoy our toys is that it's like a magic trick, but there's nothing hidden. So one might say "Oh, I see everything! But wait a second. Why does it work?" And then you scratch your head...

LR: Right.

CH: I could explain to you simply and precisely why it works but it's a bit like you explaining your physics. If you're not into trigonometry, even after the explanation, the question just gets repeated: "Yes, but why does it work?"

LR: And then, can they go off and design one of their own?

CH: Well, that's interesting. As a toy designer, I always hoped to inspire another generation of folding mavens. And pretty regularly I'll get some 11-year old geometry whiz sending me fantastic origami bits and all of that...

LR: Really? That was you when you were young, I bet. How did you get into making transformable objects?

CH: I originally studied art, and I made kinetic sculptures, which sometimes didn't work very well—this was my motivation to go to engineering school. Around the time I graduated I wanted to find an art problem to focus on. This was the mid-80s, and personal computers were still pretty new, so I was turning over the idea of pixelization and the thought came: You know, maybe I should build a sculpture which will have three-dimensional pixels. The next thought was "OK, I need each pixel to be able to turn on and off. When it's on, it's visible, and when it's off, it's invisible. So, I have to make something that can disappear." And then, "Well, I can't really make it disappear but what I can do is make something big get small." That was my framing problem, if you will. I got quite involved with this notion of a three•dimensional pixel that could appear and disappear, and eventually forgot about the sculpture itself.

LR: That sounds like quite an interesting idea.

CH: It was a good starting point. That magic of appearance and disappearance is still very much a pursuit in my designs.

LR: Yeah, it's funny. One of the things that underlies so much of physics is the notion that literally seeing is only one way of detecting things. I'm always trying to find ways to, in some sense, find the invisible.

CH: So, what does that mean? That you see it in your mind's eye, or that you have a familiarity on some other level?

LR: From a scientific point of view, seeing means detecting. So you may observe it at a nonvisible wavelength of light but it's still detected because a detecting device is recording it.

CH: Okay.

LR: So in a sense some forms of "seeing" scientifically are less intuitive. I often get asked about this because for some people that would be less real, less authentic.

CH: Right.

LR: For example, I will say we see quarks, and people ask "You don't really see quarks, do you?" And the fact is, we observe the experimental evidence of the existence of quarks. If it's a heavier quark you will detect what it decays into; if it's a lighter quark you will see that it's a strongly interacting object, you will see that it has energy, you will observe that it has interaction cross-sections, you will observe that it has all the properties you say a quark should have.

CH: So it is simply mediated in a way that directs your eye to something.

LR: But there is a little bit of theory. You have to understand the theory to understand what the consequence will be. For some people that leap is so indirect that they will say you're not really seeing it. For us, as scientists, we are seeing it.

CH: But of course in a certain way science is just making explicit what we all do.... The way we make sense of the world is because we have models of the world. I mean, right? That is what brain science tells us.

LR: In fact, we have many reasons, as you know, to not always directly trust our senses. I mean there are all sorts of optical illusions and all sorts of ways people have shown that we don't actually always see exactly what is there. It depends on how we are looking. So, it's nice that there are more precise ways of recording it and actually being able to ascertain what is really there.

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