

**INTERVIEWER:** Today is December 5, 2011. I'm Chris Boebel. As part of the MIT150 Infinite History project, we're talking with Professor Andrew Lo. Professor Lo is the Harris & Harris Group Professor of Finance at the MIT Sloan School of Management and the director of MIT's Laboratory for Financial Engineering.

His wide-ranging research interests include financial asset pricing models, financial engineering and risk management, trading technology, computer algorithms and numerical methods, financial visualization, hedge fund risk and return dynamics and risk transparency, and evolutionary and neurobiological models of individual risk preferences in financial markets.

His awards include-- to name just a few-- the Alfred P. Sloan Foundation Fellowship, the Paul A Samuelson Award, a Guggenheim Fellowship, and multiple awards for teaching excellence. He is a former governor of the Boston Stock Exchange and currently a research associate for the National Bureau of Economic Research, a member of the NASD's Economic Advisory Board, and founder and chief scientific officer of Alphasimplex Group, LLC a quantitative investment management company.

Professor Lo received a BA in economics from Yale University in 1980 and a PhD in economics from Harvard in 1984.

Professor Lo, thanks very much for coming in to talk to us today.

**LO:** Thanks for having me.

**INTERVIEWER:** So let's just start at the beginning. Where were you born, and where did you grow up?

**LO:** I was born in Hong Kong. And shortly after, I moved to Taiwan for about five years. And then, when I was five years old, I came to the United States. And I grew up in New York City.

**INTERVIEWER:** Tell me a little bit about that transition from a cultural perspective, that educational perspective.

**LO:** Well, it was a fantastic experience in many ways. So I grew up in a single-parent household in New York. And my mother worked pretty hard to put the three of the kids through school.

We went through public schools throughout, and the New York City public school systems are among the best in the country. Certainly, they were at the time, and so I feel I got a great education, and met some really, really interesting people during my time there.

**INTERVIEWER:** So you were an urban kid for most of your--

**LO:** I was. We lived in Queens, and I commuted to the Bronx. I went to the Bronx High School of Science. I'm very proud of that. I love that school, and I learned a great deal from my classmates. It was a lot of fun.

**INTERVIEWER:** So do you have very early memories from Taiwan? Or does your consciousness start in New York City?

**LO:** No, we have some memories. I've got a number of things that I remember well from those days: playing with fireworks was one of the favorite activities in Taiwan, but for the most part, my childhood was really in New York.

**INTERVIEWER:** So when did you start developing an interest in economics, math? I'm sort of interested in your entree to your field. Were there early signs?

**LO:** Well, actually, starting in high school. I had always been interested in science, of course. In third grade, my third grade teacher, Mrs. Barbara Ficalora, was wonderfully supportive, and made me the class scientist. And so I got an early introduction to doing experiments.

It wasn't until high school that I became exposed to real serious scientific reasoning, and also to the field of economics through a course that I took in social studies, where we read Heilbroner's *Worldly Philosophers*. And that really changed my thinking about the idea that you could apply interesting mathematical principles to problems in economics.

**INTERVIEWER:** Bronx Science is obviously kind of a legendary high school. Can you talk a bit more about your experience there? What were your career ambitions at that point in your life? And what kinds of things were you really studying in high school?

**LO:** Well, for me, Bronx Science was a really transformative experience, because, up until then, the junior high school and elementary school that I went to was really just local, kind of community schools, where you had a wide mix of kids, some of whom are interested in academics, but most of whom were probably not. And so in that kind of environment, to be doing well in school was to be a bit of an outcast.

It wasn't until I got to Bronx Science that it became cool to actually do well in school and to be interested in academics. So for me, it was really like an awakening. I had tremendous friends and activities in Bronx Science that I really couldn't have access to in any of the schools that I went to before that.

Also, for me, it was a little bit of an interesting experience in terms of the mathematics at Bronx Science. Right around that time, Bronx Science instituted-- as all New York City high schools-- the so-called New Math. And if you know the history of it, the New Math was an absolute disaster from the perspective of the majority of the students. But for me, it was actually transformative as well, because up until then, I had a particular learning issue, a slight case of dyslexia that we didn't know until much later on. And so for the longest time, I had difficulty with mathematical concepts, multiplication, and really basic things that other kids had no issues with. I had a hard time memorizing the multiplication table.

It wasn't until I got to Bronx Science that, because of the curriculum in mathematics-- it was transformed from the basic algebra, geometry, trigonometry to sets, rings, fields, abstract algebra-- that I turned from a C student to an A student in math, so for me, that was really an important experience.

**INTERVIEWER:** That's kind of an amazing story.

**LO:** I was one of the lucky ones that benefited from the unfortunate aspects of the New Math that was perpetrated on New York City high school students.

**INTERVIEWER:** At least there was one. So you mentioned your third grade teacher. Were there other mentors, significant teachers, experiences you had in high school or before that time that really pushed you in a certain direction?

**LO:** Oh, a number. One of the things that has always struck me is how important teaching is, because a good teacher can have such a positive influence on a student for the rest of his or her life. And similarly, a bad teacher can have tremendous negative consequences for that student. And so I've been very fortunate in that, during the years, I've had some good teachers, many good teachers, a few bad ones. So I have a good understanding of what's involved. And my third grade teacher, Mrs. Ficalora, stands out.

In high school, I had a number of teachers. Bronx Science is filled with really extraordinary faculty. In fact, we don't think of them as teachers. We think of them as faculty. Mrs. Mazen, my calculus teacher. I learned more from her about calculus than I think most college courses would teach their students. So there are a number of very talented instructors that I was very pleased and lucky to have.

**INTERVIEWER:** What were your career aspirations at that point, just before college?

**LO:** Well in high school, I think that most of my friends and I were interested in science and math. So at the time, my presumption was that I would go into one of those disciplines.

Being the youngest of three children, and having an older brother and sister that were also academically inclined made it relatively easy for me. My brother is a mathematician at the Jet Propulsion Lab at Caltech. And my sister is a biologist at the University of Pittsburgh. So they both followed very academic careers. And in my household, one had to get a PhD just to measure up to the older siblings.

So from high school on, I was very much interested in following some kind of a career path in academia, although my interests were somewhat on the more applied side, as opposed to purely theoretical kinds of issues.

**INTERVIEWER:** You mentioned a single-parent household. Was your mother at all academically inclined? Was it your mother that you were--

**LO:** Yeah, my mother was very much academically inclined, from the perspective of what she valued. She felt that the life of a scholar was among the most important and prestigious. She was a lawyer by training. But she had-- as most, I think, Chinese families did-- a deep and abiding respect for academic achievements. And so it was pretty clear, from the kinds of things that she talked about and the values that she held, that developing new knowledge was really important to her and ultimately to all of the children.

**INTERVIEWER:** So at that point in high school when you had to really start seriously thinking about the next steps-- going to college, what you might study-- tell me about that decision process. You ultimately went to Yale. And then talk a bit about your experience there.

**LO:** Well, I was a little confused about what I wanted to do. My sister went to MIT as an undergraduate. My brother went to Caltech. And so when I talked with my mother about where I ought to go for college, she said, well, maybe you ought to think a little bit more broadly about the kind of things that you're interested in.

And so rather than pursuing a somewhat more technical career path, I thought that maybe applying to a general liberal arts college would be a good idea. And I was thinking at that time that I might want to do a combination of mathematics and biology. I did a science project as a senior. I was a Westinghouse Finalist. Intel, I guess, now is what they call it. And I was very much steeped in molecular biology at the time.

And so Yale seemed to have a good compromise in very strong humanities, but also very good science programs. So I ultimately decided that that would be, really, the best compromise. I visited the school, and I was really enthralled with the campus. New Haven wasn't so great. But Yale, itself, was a wonderful physical space for students. And so it was a pretty easy decision, after I had gone through and looked at all the various different possibilities.

**INTERVIEWER:** You mentioned the Westinghouse Competition. It's amazing how many of our interviewees have a story about Westinghouse and participating in that.

**LO:** Well, it's a wonderful activity, and obviously not for everybody, but at Bronx Science, most of the students that I interacted with really got into it. And we learned so much from it. I still remember, to this day, every aspect of the experiments that I conducted on the infective pathway of bacteriophage T4.

And I actually corresponded with an MIT faculty, who, at the time, I didn't know. But Jonathan King actually had some strains of bacteriophage that I was interested in and was very generous in sharing it with me. So it was a wonderful experience in getting me to understand how research is conducted, and, really, what the academic style of interactions might be.

**INTERVIEWER:** So you chose Yale. You decided that that was the place for you. Tell me a little bit about your time there, how your academic and career interests developed, and just sort of what the experience was like.

**LO:** Well, I had a great time at Yale. It was a really remarkable experience in a number of different ways. When I arrived, I had thought that I was going to be doing math, biology, maybe applied sciences of some sort. But I ended up taking an introductory economics course that was completely different from anything that I had seen before. There was a substantial amount of mathematics involved. But yet the ultimate applications were really quite relevant to day to day experience. And that's quite different from math or physics, particularly at the undergraduate level. So I got very excited about that.

The other thing that I found remarkable about Yale was that, really, for the first time since I started getting interested seriously in academics-- for the first time, I actually met people at Yale that I considered to be really smart, but who had no abilities to do mathematics. In high school, certainly at Bronx Science, you very often equated intelligence with technical abilities. You're good at math, physics, biology--- you were smart.

At Yale, I ran into a number of individuals that were extremely intelligent but were simply not numerate. Their form of intelligence I found really different and fascinating. And that is sort of the beginnings of my interest in economics. I realized that mathematics was not the only way of understanding interactions in a very deep way, and that yet you could actually put the two together in some interesting fashion to come up with some new insights.

**INTERVIEWER:** So was it sort of an immediate click? You mentioned the Intro to Economics class.

**LO:** No, it wasn't. I was very confused for a long time. What ultimately decided it for me was a teacher, a professor, Sharon Oster, who taught a fantastic intermediate microeconomics class. She was spellbinding. She provided intuition, developed some very rigorous mathematical models, and made it all relevant and really interesting. So I found her to be an enormously inspiring teacher. And from the moment I took her course, I took every other course she ever taught, and ultimately asked her to be my undergraduate advisor. And I was a research assistant for her, and ultimately wrote my senior thesis with her and some other faculty at Yale. It was a tremendous experience. And so I think that's really what ultimately made me focus on economics as the field that I went into.

**INTERVIEWER:** Some of those early ideas you've talked about, the relationship or the tension between mathematical models and human behavior, are still present in a lot of what you are interested in, which we'll talk about later. But that's an interesting kind of continuity.

**LO:** Well, it is. And I think it's also a part of my interests even back in high school, with *The Worldly Philosophers*, but also from the science fiction perspective. I, as a high school student, read Isaac Asimov's *Foundation Trilogy*. And the notion of using mathematics to predict the course of human evolution, I found completely captivating. And I didn't know it at the time, but economics was probably the closest field to this fictitious psychohistory that Asimov talks about. And so I suspect that that had something to do with it as well. But all of these pieces were really amorphous to me at the time. And only with the benefit of hindsight does some of it seem to make sense.

**INTERVIEWER:** It's funny. I just randomly, for some reason, over the weekend had picked up the first *Foundation*, the first of the trilogy. I had read it years ago. Were you a science fiction fan? Was that something that kind of drove your interest in science?

**LO:** I was. I read a lot of things in that genre as a high school student. But mostly Arthur C. Clarke. He was one of my favorite writers, Robert Heinlein. But Isaac Asimov was a favorite, not so much because of his writing style. I actually found Asimov's writing style not nearly as pleasurable as Arthur C. Clarke. But the range of ideas that Asimov had in his books were just astonishing, from *I, Robot* to the *Foundation* to all of the other short stories that he wrote, his field of vision was really tremendous.

And so that got me very much excited about the possibilities of science. And many of his ideas of science fiction have actually become science fact over the last couple of decades.

**INTERVIEWER:** So like so many people at MIT, you had an early interest in science fiction and science. But you chose to really move in kind of a different direction in college. Was it difficult to say goodbye to science? It's not saying goodbye. Maybe that's the wrong term.

**LO:** Well, that's just it. You see, I actually didn't think I was saying goodbye to science, although in many respects, I think I should have been. And we can discuss that later. But my thinking was that economics could be as rigorous a science as the physical and biological sciences.

And I remember having many dinner conversations with my elder siblings, who, of course, were scientists, and who, of course, as elder siblings do, spent a fair bit of their time torturing me, asking me to justify my existence. And so I've actually spent a fair bit of time thinking about whether or not economics is or is not a science.

I, of course, think it is. And when I was in college, my interest in mathematical economics was probably motivated by that drive. The ability to use formal mathematical and statistical models to make precise statements about economic phenomenon was what I thought I was doing and studying in college. And it wasn't until grad school that I had a bit of a rude awakening to that effect.

**INTERVIEWER:** We'll move on to grad school in just a moment. I just thought I would ask, were there other very formative or important experiences in college that pushed you in a particular direction or helped form your ideas?

**LO:** A couple. One was another professor, Herbert Scarf, who taught a graduate course in economics, microeconomics, and economic theory. And game theorists, Pradeep Dubey and Martin Shubik, I took their courses as well. And during those courses, it became clear to me that using formal models to study human behavior was both a bit of a treacherous exercise-- there is a lot of behavior that doesn't fit neatly into these models.

But at the same time, those were the heydays of general equilibrium analysis. And tremendous progress was being made in developing mathematical theorems that would demonstrate the existence and uniqueness of economic equilibrium.

So it was a heady time for the literature. And as an undergraduate, I got exposed to some of it through the faculty. Yale's economics program is really tremendous in that they do expose the undergraduate students to graduate level courses if and when they're ready and they're interested.

And because they also allow for opportunities to write an undergraduate thesis, you actually can engage in research even at that level. So my senior thesis was on game theory, and ultimately, I actually got it published. So that was a really fascinating process that I enjoyed and it gave me a taste for the academic and a sense that there's a lot that could be done with relatively simple mathematical tools.

**INTERVIEWER:** You decided to pursue graduate studies. You went onto Harvard. You went immediately from undergrad on? Or did you--

**LO:** I did. And in retrospect, that might not have been the best thing to do. But part of it was financially driven. Because we came from a single-parent household and we didn't have very much in the way of financial resources, I actually graduated from Yale a year early. And when I was thinking about what to do, I was actually choosing between law school and graduate school. Because I was also interested in applications and seeing how these ideas could actually affect reality in practice.

But then I did a very simple economic analysis. Law school was three years, and the tuition was however many tens of thousands of dollars. And graduate school was, for all intents and purposes, free. Not only was it free, I found that they actually *paid* you to go to graduate school! They gave you a stipend. And so, to me, the answer was clear. I have got to get a PhD. That, and also the fact that my brother and sister were PhDs, as I said, provided some motivation for me to achieve that level of success from an academic perspective.

So I think that ultimately I decided that going to grad school was the right decision. And given that my undergraduate advisor, Sharon Oster herself, received her PhD at Harvard and spoke very highly of the program, that was a very easy decision for me.

Actually, MIT and Harvard were the two choices that I had considered. At the time, I really didn't have much of an interest in finance. I didn't know what finance was about. And so, really, for my interest in mathematical economics, I thought that Harvard would be a better choice.

**INTERVIEWER:** Did you know Boston at all? Had you been here? I was actually going to ask if you had been to MIT? You had a sibling who had attended MIT.

**LO:** I have very fond memories of MIT because when I was in junior high school, my sister was an undergraduate here. And so we would come up every fall, and bring her up here by car. And I would stay here for a couple of days to make sure she got settled. And while here, I spent an enormous amount of time in the Student Center playing, at the time, pinball machines. I don't know if they have any pinball machines here now. But I spent a lot of time there and roaming the campus. So I loved it. And I developed early on an affection for MIT.

**INTERVIEWER:** But you went to Harvard, nevertheless. So tell me a little bit about your graduate school years. Again, I'm very interested in significant professors, mentors.

**LO:** Harvard was a bit of a rude awakening in a couple of respects. Probably the most significant was that the faculty member that I was hoping to work with ultimately ended up being on leave the year that I arrived, in 1980. So I ended up taking classes in micro, macro, and econometrics like all the other first year students.

And I was hoping that the material that I learned as an undergraduate would be expanded upon in graduate school. I knew that the models that we developed in undergraduate classes were relatively limited, and that with more mathematics and more understanding of economic concepts we could develop more realistic models. So I was actually quite disappointed when, after the first semester of my first year, I realized the models that we developed were pretty much identical to what I had done at Yale, and that there wasn't anything more. It was a bit frustrating for me.

In addition, at the time the Harvard economics program had some difficulties. They were going through a transition where some of their faculty were on leave. And the faculty that were there at that time were not really supposed to be teaching in a first year core. So the core was somewhat uneven. And a number of us became quite frustrated with that experience.

And so by the end of the first semester, I had actually filled out my application for law school. I thought I had made a bad mistake. And it wasn't until I happened to take a course in the spring semester taught by Bob Merton in finance here at MIT that changed my mind completely about graduate school. That was really the most formative experience for me, realizing that you can actually apply very sophisticated mathematics, but in very practical settings.

And that was what was missing from general equilibrium theory and game theory. I didn't feel that the mathematics really brought us to any closer understanding for practical kinds of situations, whereas finance seemed exactly what I was looking for. So after that point, I realized I wanted to do finance.

**INTERVIEWER:** So for the truly ignorant, such as myself, what do you mean when you say finance? I think people tend to gloss economics, finance, even business into one bucket. Talk about exactly what was appealing and what it was.

**LO:** Sure. In fact, they're very closely related, not surprisingly. Finance started out as a branch of economics. But it has gotten to the point where it has become so much more sophisticated in terms of the models and methods that are applied that it has taken on a life of its own. So in a nutshell, finance is simply applying economic and mathematical principles to the study of money, investments, in a world of uncertainty.

Uncertainty is really the key, because, for the most part, economics is actually pretty well understood in the case of perfect certainty. If there is no randomness in the world, we actually understand a lot about supply and demand and how individuals engage in various kinds of economic decisions. The sole aspect of the world that makes finance interesting and nontrivial is the fact that we don't know what's going to happen tomorrow. And uncertainty really underlies all of what financial models are about.

So in trying to model the dynamics of financial markets, banks, asset management companies, hedge funds, investment decisions, corporate financing challenges, all of those are problems that ultimately involve economics, but financial economics. And because the tools of finance have evolved so rapidly and so differently from other areas of economics, it has really become almost a separate field unto itself. In fact, most finance research is done in business schools. Many economics departments, including Harvard, have now hired a number of very talented first rate financial economists. But for the most part, the majority of the financial economists are actually in business schools not economics departments.

**INTERVIEWER:** So you had this very, very significant experience taking this course with Bob Merton. Talk about how that influenced your path in grad school.

**LO:** Well, it really changed it completely. Up until then, my focus was really on mathematical economics and game theory. But once I took Bob Merton's course on introductory finance, I realized that there is so much more applications of genuinely substantive mathematics to problems that cannot be solved in any other way, and that yet can bring tremendous insight that ultimately affects practice. That's not something that game theory or general equilibrium theory has really been able to do.

So once I took Bob Merton's course in finance, I basically took every other finance course offered at the time at the MIT Sloan School. Fortunately, at the time, and even to this day, Harvard and MIT have a very collegial relationship, where students from one university can cross-register, and almost seamlessly take classes in the other university. So it worked out beautifully, where I was able to take all of my courses in finance at MIT. And when it came time for me to take my qualifying exams at Harvard, I petitioned to create a special field which was finance. At the time, they didn't have a field called financial economics. So I had to petition, and, fortunately, was able to get one of the economics faculty at MIT to examine me in that discipline.

**INTERVIEWER:** So the research you were interested in taking on as a grad student, just talk about it for a bit in light of this new interest that developed in finance.

**LO:** One of the things that I started out with thinking about in economics was investments. I was fortunate to have as one of my main advisers professor Andy Abel, who currently is at Wharton. But at the time, he was a junior faculty at Harvard. And Andy had been working on investment theory, the idea of how capital in the United States and elsewhere get created from various kinds of economic considerations. When you buy a machine, and you invest in it, you plan to use it for many years. What makes you decide to buy a machine, versus renting or postponing?

This kind of investment theory fascinated me. But I couldn't understand how the kind of investment in machines translated to investments in the stock market. I knew that the two had to be related. We both use the word investment in those contexts. And yet, the kind of models that were developed seemed really different. My finance courses seemed very different from my macroeconomics courses in that respect.

And so I spent a good part of my graduate days trying to reconcile the two. I remember talking with Fischer Black during his office hours and asking him how could it be that, as an economist, we use the word investment to mean purchasing physical capital, whereas in finance, when we think about investment, we talk about purchasing shares of a company? Those two activities ought to be related in some very fundamental way, shouldn't they? And Fischer Black said, yes, they should. And I said, well, but there's nobody who's working on that. How do we reconcile the two? Doesn't this bother you? And he replied that when he runs into contradictions and inconsistencies, that actually delights him. Because he realizes that means that there is work to be done!

And so that was a big insight for me, that I shouldn't get frustrated. I should actually be thankful that there was a thesis topic that was emerging. And ultimately, that's what I spent my years working on in my thesis, integrating real and financial investments in a mathematically consistent framework.

**INTERVIEWER:** One thing that I meant to ask you before-- I don't want to get sidetracked. But I'm just curious. Maybe you can sort of put it in the context of the work that you're taking on. What is general equilibrium theory? And what are what you saw as its shortcomings.

**LO:** General equilibrium theory is a fascinating idea that was developed centuries ago by French mathematician, Leon Walras, and others. And the idea sounds so simple. But actually, it's quite complicated to work out. The idea behind general equilibrium is that when you look at an economy, you have to focus on all the various different markets that exist, each one corresponding to a different commodity or good. And within each market, you've got individuals that demand a good and individuals that supply the good. And in each market, ultimately the intersection of supply and demand determines the so-called equilibrium price for that market.

Well, the fact is that all of these markets are going on at the same time. And so instead of looking at what happens in one market, in order to truly understand how an economy changes over time, you actually have to ask the question, how do all the markets equilibrate together?

General equilibrium does exactly that. It says that, given a collection of individuals that all consume certain commodities, and given a set of businesspeople that produce those commodities, there have to be a set of prices for all the goods that are traded in that economy so as to equate all the supply with all the demand across all the markets.

Now that seems like a really tall order, to expect that this kind of an equilibrium would occur across all of these different venues and settings. And the idea behind general equilibrium is to determine the conditions under which such a general equilibrium across all these markets could actually occur. Some beautiful mathematics are involved in this. And not only are there interesting mathematics about the existence of equilibrium, there's additional mathematics that say something about whether the equilibrium is unique, and what happens when you're outside of an equilibrium, and how you reach an equilibrium, how you move from one to the other. So it's an endlessly fascinating series of questions that actually relies on some very deep mathematics to understand.

But the problem with these so-called theories is that they have become so general, they are so abstract, that they've become divorced from reality. Because in fact, in practice, you actually don't see general equilibrium occurring. In fact, in many cases, as we've seen over the last few years, markets are often in disarray and in disequilibrium. Prices are moving around all the time, trying to equilibrate.

And unfortunately, the mathematics and the direction of the literature on general equilibrium hasn't really focused as much on the transitions, the dynamics from one to the other, as opposed to what occurs at an equilibrium. And so in that sense, I think finance has become a much more relevant discipline, because it actually has testable implications that have some very, very practical applications.

**INTERVIEWER:** To return to your graduate work just for a moment, you develop mathematical models to sort of compare investments in stocks, bonds, with goods or machinery, and so on. I'm no mathematician. But can you talk about what kind of relationships you found? And again, if you use your mathematical models it will not mean much to me, I'm afraid.

**LO:** Sure. Well actually, it's pretty straightforward. The results that I developed in my thesis really focused on what kind of investment policies of a corporation would be necessary in order to support the kind of real business activities that it engaged in.

And the answer is actually pretty simple, and harkens back to some research that was done by MIT economist, Franco Modigliani, years ago. In a market where there are no frictions, there's no cost to engaging in issuing stock or issuing bonds-- in a frictionless market and a market with no taxes, the answer is that the real economy and the financial economy are pretty much separable. It doesn't matter how you would finance a purchase of a new machine-- whether you use debt financing or equity financing-- because in a costless world where markets are perfect all the time, you can shift from one to the other pretty easily. And therefore, the financial side is almost an afterthought.

But the problem is that as soon as you introduce market frictions, that changes completely. And really, it's the frictions that make things interesting. You have to understand where the frictions are coming from and how they relate to the different sources of financing. And with market frictions, with taxes, it turns out that there actually is an optimal combination of equity and debt financing that will support the kind of growth that a real business activity entails.

And so working out the mathematics of it is really what I did in my thesis. And it was done in a dynamic context, so it was not just a static, one-shot kind of a perspective. It was really couched in the framework of a company that was engaged in multiple projects over the infinite future. And so that really gave me a deeper understanding for how to integrate the real and financial sides of the economy, and gave me an appreciation for why it is that frictions really are at the core of what we do in economics.

So much of economic theory is the frictionless case. And those are important cases, because you have to understand the frictionless case before you can start seeing how frictions matter. But we often forget that frictions do matter-- because we get so enthralled with a frictionless case, given that the mathematics are so beautiful-- that we don't go to the next step, which is to say, let's make it messy again by building in these frictions. And frankly, that's what I've been working on ever since.

**INTERVIEWER:** You mentioned Robert Merton. Were there other significant mentors, influences during your graduate years that we should talk about? I think you've actually mentioned a couple of others.

**LO:** Absolutely. Jerry Hausman was a critical figure in my intellectual development. Jerry is an economist at MIT, an econometrician. And it turned out that I got to know him because I took an econometrics course with him at Harvard. He was on sabbatical from MIT, and he decided to spend the year at Harvard. And so he taught a graduate econometrics course that I took and I did well in. Well, enough that he hired me as a research assistant that summer, and then hired me to TA that course the following year. And I really enjoyed it and enjoyed working with him. And ultimately, he became one of my principal thesis advisors.

He was the one who gave me the idea that you could actually use rigorous econometric techniques to apply financial concepts to the data and learn a great deal about how these theories actually worked in practice. And so the field that I ultimately spent most of my early career on, financial econometrics, grew out of my interactions with Jerry, and countless conversations, and free lunches and dinners that Jerry treated me to very generously, during the time that I was his student.

**INTERVIEWER:** We tend to think of graduate students, particularly at places like Harvard and MIT, as being involved within this all-consuming research quest for knowledge. Were there other things going on in your life that were really important to you or significant? Or did you find yourself getting really sucked into the work?

**LO:** Well, no doubt, graduate school was very intense. But it was a fun intense, in the sense that it was, for the first time, an experience where I was surrounded by people that were all interested in the very same relatively narrow field that I was. So that was a new experience and a very enjoyable one.

At the same time, I was also working as a research assistant and as a tutor, because financially, it was a bit challenging for my family. And so I learned about the real economic life of making money for supporting myself.

I was also dating a girl who ultimately I married. My wife, who, at the time, was an undergraduate at Yale still. And so we had a long distance relationship for my days at Harvard. And I remember spending enormous amounts of money on phone bills. And it was really then that I got into the habit of staying up late at night, because after 11 o'clock, the rates went down. And even so, had we been able to avoid these long night phone calls, we probably could have purchased two cars by the end of my graduate school days. So that was probably the most significant other activity that I was focused on during that time.

**INTERVIEWER:** So you're a newly minted PhD. What's next?

**LO:** Well, when I went on the job market, my wife--- my girlfriend at the time--- was a graduate student in a PhD program in finance at the Wharton School at the University of Pennsylvania. So I was fortunate enough to be interviewed by them. And they flew me out to give a job talk, and made me an offer the next day. And I accepted the next day after. So by the middle of January I was actually done with recruiting because my girlfriend was there. And so it was pretty easy.

Also, the Wharton School is renowned in the area of finance, and it was a bit of a new thing at the time for an economist to be hired by a business school. At the time, most business school faculty were hired from business school PhD programs. And there was some crossover, but not a lot, and certainly not a lot of crossover in finance. Finance was really a field unto itself at the time: that was really more a business school activity. And economics departments were only really beginning to start thinking about offering classes in finance, never mind concentrations in that field.

So when Wharton made an offer, to me, it was an ideal situation. My girlfriend was there. It was a bona fide and very well respected finance department. And my only fear was whether or not I was going to be able to measure up to a finance department where I was an economist, an outsider.

**INTERVIEWER:** Did you ever think twice about pursuing an academic career, as opposed to Wall Street or other options?

**LO:** Well, I did a little consulting when I was a grad student because the summer between college and grad school I was a summer intern at a company called Data Resources. It's a software company started up by some Harvard faculty--- Otto Eckstein, Dale Jorgensen, and others--- and at DRI, I actually was working on developing software for engaging in a variety of economic analysis. Maximum entropy spectral analysis was my project that summer.

And so I did a bit of consulting for DRI during my years as a grad student. So I thought a little bit about going into industry. But because I was so fascinated by the kind of questions that came up in my thesis and I wanted to continue on, and, I think, because the family upbringing that I had clearly valued the academic lifestyle-- my brother and sister were both academics at the time-- it really was clear to me that I wanted to follow an academic path.

**INTERVIEWER:** Let's talk a little bit about your years at Wharton. What were your research interests? What kinds of things were you engaged in? And also talk a bit about teaching as a young faculty member.

**LO:** It was a very interesting mix of experiences that I had, even in my first year at Wharton. When I started in Wharton in 1984, I was 24 years old, which is relatively young for a business school faculty member. In fact, I remember very clearly my very first day of class, I was clearly younger than most of the students in that introductory finance class.

There must have been 100 people in the room. Wharton has quite a large program, and they have big classes. And before I actually began lecturing, literally the very first day of class, a student raised his hand. And so not knowing any better, I called on him and the student said, Professor Lo, before you begin, we just have three questions. And I should have known right away, when they use the royal we, this could not have a good ending.

He said, first, can you tell us whether you have ever taught this course before? Second, can you tell us what kind of consulting experience you have in this area? And third, can you tell us how old you are?

And not knowing any better, I answered the questions. I said, no, this is my first year. I've never taught this course before. I have no consulting experience, really, to speak of. And I'm 24,

at which point literally half the class got up and walked out of the room, because they decided that they wanted to go to another section with more experienced faculty. And I guess I can't really blame them. They're paying a lot of money for their tuition.

But that was a sobering experience. And it only went downhill from there. So I was baptized in fire, in terms of MBA teaching. And so that was a very important experience, a formative experience for me.

But on the bright side, the experience at Wharton was tremendously productive for me and the other junior faculty, because it turned out that in that year Wharton hired nine assistant professors just in the finance department, so I was one among nine. And the good thing about it was that because we came in en masse, we became very close very quickly, the nine of us,

socializing with each other after hours, basically hanging out all the time, because as an assistant professor, there's not much else to do anyway. None of us had families at the time. Some of us had girlfriends or wives. But we didn't have any children. So we spent a lot of time together.

As a result, the department had to get used to us more than we had to get used to the department. And that was an incredibly important experience because it allowed us to ask really interesting research questions without the concern that some tenured faculty member would disapprove. Because frankly, the tenured faculty members weren't even around to interact with us, given their priorities and activities.

So we spent a lot of time interacting with each other, challenging each other, talking with each other about ideas, and ultimately one of the most fruitful collaborations that I had in my career started in that year with Craig MacKinlay, who was another assistant professor from the University of Chicago.

**INTERVIEWER:** Presumably, your experience with the students got better from that low point?

**LO:** It did get better. And as I said, I learned very quickly that MBA students are very demanding, and with good cause. They are spending a lot of money on their tuition, and they obviously have to start thinking about paying it back in many cases with student loans afterwards. It became clear to me that relevance was really key. But, more importantly, that there was a certain impatience among MBA students with respect to abstract theories that may or may not lead to some very specific practical implications.

And in time I learned to appreciate that perspective, and begin to take it more seriously myself. Not to say that academic theories are devoid of practical consideration. But there is a very important divide between theory and practice. And I don't think that academics necessarily appreciate that as much as perhaps they might or that they would if they, themselves, were placed in kind of a practical environment.

**INTERVIEWER:** How did your research interests evolve as a young faculty member?

**LO:** That was a wonderful thing about Wharton: it's that we didn't really have any particular directions that we were expected to take as junior faculty. And so we were pretty much free to think about whatever it is that appealed to us.

And my thoughts as a first year faculty member were really in the direction of this notion of market efficiency, and the ability for the real and financial sides of the economy to engage in pretty much separate kinds of directions.

As an econometrics student in Jerry Hausman's econometrics course, one of the things that I looked into was the ability of testing the random walk hypothesis using a particular statistical procedure. Really, it was just an exercise at the time to see whether or not one could use fancier statistical methods to test the age-old idea of whether or not you could use past stock market prices to predict future stock market prices.

One of the foundations of efficient markets hypothesis is the notion that all the information about the future of a company is actually contained in its current price. And if that's true, that means you can't use past price realizations to forecast future directions of the market.

And as a student in Jerry Hausman's econometrics course, I developed an idea for using a statistical test to capture that hypothesis. So when I got to Wharton, I started talking with Craig MacKinlay. He and I had lunch pretty much every day. And over lunch I would tell him about these ideas. And he would say, well, we can actually take it to the data. In my thesis, I spend a lot of time testing various ideas,

but I hadn't really done much with stock market data at the time. So he and I began to work on this. And shortly thereafter, we came up with a rather startling conclusion. Using the tests that we developed and applied to the data, we came to the conclusion that US stock market prices actually don't satisfy this random walk hypothesis. Stock prices aren't actually purely random.

And at first, we thought that we had made a programming error. But in fact, after several repeated attempts to explain away these findings, we came to the conclusion that this is exactly what the data had to say.

And so we tried to get the paper published, and when we presented it at a conference we were completely trashed by our much more senior and well-respected discussant who simply didn't believe the results. His view was that markets could not possibly be that inefficient, and that somehow you must have made a programming error, which in our business, is worse than calling your mother a four-letter name.

So we got very excited and agitated, and went back to our computers and reprogrammed, and looked at the results. And ultimately, we were vindicated in the sense that this really was a feature of the data and from that point on, for about a period of 10 years, Craig and I wrote a number of papers to try to explain this anomaly, and ultimately published a book that collected all of our papers to try to understand this phenomenon.

**INTERVIEWER:** How long were you at Wharton? And then how do you ultimately move on and come to MIT?

**LO:** I was at Wharton for four years, from 1984 to 1988. In 1988, my wife graduated. She finished her PhD; she got a job in Boston, and so we were able to move. That same year, I gave a talk at MIT and the faculty offered a position to me. Given my interests and the role that Bob Merton played in my career, and Jerry Hausman, it was a very easy decision. I accepted the offer pretty much immediately. And we moved up to Boston in '88.

**INTERVIEWER:** Let's talk a little about MIT in 1988 or the late 1980s. Your experience obviously stretched back before that as a graduate student. What was it like then? Have you seen significant changes-- in either the study of finance or in the student body-- in the culture of the place?

**LO:** Well, certainly some things have changed. But I think a number of things have stayed the same. And the things that have stayed the same are really the reasons that drew me to MIT. I guess probably the most important draw for me was that I believe that modern finance, finance as a scientific endeavor--- really began at MIT.

It began decades ago with Paul Samuelson. His interest in finance sparked the interest of one of his most productive and most talented students, Paul Samuelson's student Bob Merton, who joined as a graduate student in 1969, and became immediately Paul's close companion in rewriting the entire corpus of finance theory from the ground up.

To me, that was just a tremendous draw and the MIT finance tradition that developed subsequently. And the many other faculty members that were drawn to this environment, including Stew Myers, Fischer Black, Myron Scholes, Franco Modigliani, John Cox, any number of-- Steve Ross. We have tremendous faculty here that have really built the edifice of modern finance theory. So for me, it was an easy decision.

What's changed over time is that we now have a deeper understanding of the kind of limitations that the early theories exhibit, and are now more and more aware of and open to alternatives to explain those departures. The '70s, '80s, and '90s were a terribly exciting time for MIT for the traditional finance paradigm: efficient markets, rational expectations, and all of the various ideas and products. The multi-trillion dollar derivatives industry really came out of ideas that Samuelson, Merton, Black and Scholes, Cox and Ross pioneered. And so that was an incredibly exciting time for that literature.

But over the course of the last decade or so, we're beginning to see the emergence of some new ideas that really demonstrate that not only are there limitations to the existing theories, but there are ways of extending them so as to be able to develop a more rational, more internally consistent perspective on how markets succeed and fail in different circumstances.

**INTERVIEWER:** Turning now to your research interests, as I mentioned at the beginning, there's a very almost intimidating array of topics that you've tackled. But there are also some consistent themes throughout that we've already touched on. Thinking specifically about the work that you've done since coming to MIT, what are some of the most important themes, from your perspective, that you've attempted to grapple with?

**LO:** I think that there's actually a pretty clear direction and evolution in my research agenda, which really grew out of the work that I did as a grad student and at Wharton. And that's really to try to understand the dynamics of financial markets. When I got to MIT, I was still very much in the midst of this notion of a random walk and whether or not one could create profitable trading strategies from historical information. And it took me quite a few years here at MIT to try to understand exactly what all the nuances are of the various different types of activities that financial investors engage in.

And ultimately, I came to the conclusion that, really, you could not explain a way these anomalies as simply being exceptions that prove the rule. There were just too many of them. And they were too stark and significant from both a statistical and economic perspective. And so that got me to try to take a little bit more seriously the kind of departures from rationality that people in the industry observe all the time.

What made it frustrating, though, was that the alternative to the traditional economic and financial paradigm of rational expectations and market efficiency was so-called behavioral biases that psychologists and experimental economists documented. The problem is that, in my view, it takes a theory to beat a theory

and the anomalies literature, which was really just getting off the ground at the time, doesn't constitute a theory. They're a collection of counterexamples, and very important, by the way, but they're not really an alternative to the traditional paradigm. So really, much of my work after concluding that markets really don't follow random walks and that you have to take these exceptions as very serious challenges to the received wisdom, much of my work has been trying to understand how to reconcile these two contradictory schools of thought.

**INTERVIEWER:** And how do we do that?

**LO:** INTERVIEWER: Well, it actually took me a while to come up with the answer. In fact, at first I thought you couldn't. You just had to pick. Pick your favorite flavor, and then stick with it. But ultimately, because I spent more time thinking from a number of different disciplines and perspectives-- including psychology, the cognitive neurosciences, and evolutionary biology-- that I've actually finally come to a reconciliation of the two. And in a way, it seems almost simple to me now, even though to this day it's certainly not received wisdom, by any means. It's still fairly controversial.

The reconciliation that I came to is the recognition that economic phenomenon and economic institutions are creations of human activity in much the same way that an ant hill or a beaver dam are creations of living creatures that are adapting to a particular set of challenges in their environment. And viewed from a biological perspective, everything is different, everything looks different. Rather than arguing about whether or not behavior is rational or irrational, a much more productive perspective is to ask what kind of adaptations have emerged in the face of certain societal, cultural, economic, and social challenges.

And so it's really the confluence of evolutionary biology with the revolution that we've had in the cognitive neurosciences that has been able to allow me to put together these different pieces because, ultimately, we're focusing on human behavior. That, I think, is the key. It's that all of the different disciplines that I've ultimately ended up learning about-- in order to answer the question, why do people behave the way they do in economic contexts?-- are studying the same thing: human behavior.

We may be focusing on different elements of it, but we're all studying humans. And because of that, our theories should be mutually consistent. They may not be focusing on the same thing, but as the great evolutionary biologist, E. O. Wilson, wrote in his book, *Consilience*, these facts have to be mutually consistent with each other, because we're explaining the same phenomenon.

And so, really, that's what my recent work has been about. It has been about using different aspects of human behavior to try to understand the whole, to create an integrated theory of human behavior that spans the various different contexts and activities that we are likely to engage in.

**INTERVIEWER:** Let's drill down just a little bit and maybe focus on some examples or an example or two.

**LO:** Sure.

**INTERVIEWER:** I'm an economic actor. We all are. I make irrational decisions all the time. I'll confess. What's the theoretical explanation for that? Why would I make really, really bad investments that can be sort of demonstratively bad, or make bad financing decisions?

**LO:**

To answer that question, we should first ask the prior question, which is, how do decisions get made? Or how does behavior emerge? And obviously, we trace much of behavior to the brain. So we need to spend a little bit of time talking about neuroanatomy, and ask the question, what are the components of the brain that neuroscientists have been able to identify that are linked to specific actions?

Well, we know a few things at this point. We know, for example, that there is a part of the brain that is relatively primitive from an evolutionary perspective, the so-called midbrain or the amygdala, and the structures surrounding it. This part of the brain is really focused on relatively instinctive kinds of activities, so-called fight-or-flight response, fear, greed, sexual attraction,

and we know that this part of the brain focuses on those activities through imaging techniques that neuroscientists have conducted. So that describes one set of activities.

Another set of activities that neuroscientists have also deduced as focusing on a different part of the brain is higher thought functions that we would normally associate with humans uniquely; things like language ability, mathematical ability, logical deliberation. That part of the brain is, from an evolutionary perspective, the newest part, and it is given the name neocortex to indicate that.

One of the things that we know from the neuroscience literature is that these two components, the amygdala versus the neocortex, in many cases they work together. They're obviously connected in many different ways. But in other contexts they work antagonistically, to the point where when an individual is faced with very strong emotional response that will actually physiologically restrict the flow of blood to the neocortex.

I illustrate this with my students by asking them to think back to periods in their lives when they were dating, and they were trying to meet very attractive partners, that ultimately they concocted a relatively staged kind of a scenario in which to talk with them for the very first time and ask them out on a date. And when that accidental meeting arrives, you would think that they'd be able to charm this other individual into going out on a date with them. But more often than not, when the moment occurs, we end up becoming tongue tied, hopelessly and embarrassingly inarticulate, and unable to impress this individual. Why does that happen? Well, it happens because strong emotional stimulus--- which includes sexual attraction--- can actually reduce the flow of blood to your neocortex. It makes it harder for you to use that part of your brain. For all intents and purposes, love makes you stupid!

And that's an example of a constraint, a biological constraint, that has some very reasonable evolutionary underpinnings. Obviously, when you are getting chased by a saber-toothed tiger, it's more important for you be scared and run like heck than for you to be able to solve differential equations, even if you're at MIT! And as a result, these kinds of neurophysiological constraints have a very strong implication for financial markets.

When we are subjected to strong emotional stimulus, we will react in predictable ways. We will have difficulty in using the logical faculties that, for the most part, we're able to make use of for other decisions. But under extraordinary circumstances, those mental faculties are not available to us.

And this has to do with another basic evolutionary principle about diversity. Typically, when we think about markets in general-- the journalist, James Surowiecki, wrote a book describing them as the wisdom of crowds, the idea that when you have a crowd, and if the crowd is relatively independent in its thinking and evaluations, then by pooling the collective evaluations of this crowd, you get some very, very wise decisions.

For the most part, financial markets, and most economic markets work in that manner. Two things can violate this principle of the wisdom of crowds. One is if you don't have a crowd: small number of individuals. But second and most importantly, if the crowd is not independent, if they all think alike, if we all think exactly the same way we don't get the wisdom of crowds. We get the madness of mobs.

And the distinction between the two is really one of diversity--- diversity of thought. If we are all thinking exactly the same thoughts, if we all want to get out of a crowded theater because of a fire, we know that the exits are going to be a real constraint. That's going to create problems.

If we are all thinking alike, and we want to get out of the stock market at the same time, that's going to create a stock market crash. And so the key to understanding periods of financial market dislocation and so-called irrationality-- and that's a very loaded term. It's not at all clear that it's irrational to get out of a crowded theater if you smell smoke-- the fact is that those periods, when we all think alike, when we don't have the wisdom of crowds, but we have the madness of mobs, we react very differently. And economic theory, the way it has been developed, really goes out the window.

We need to develop a better theory that takes into account these periods of coordination and correlation, and I think that that can be done through understanding a bit more of the neurophysiology of decision making and then some of the evolutionary dynamics of diversity.

This is one of the reasons why biodiversity is such an important part of the environmental movement. It's because having a diverse set of species will allow you to be much more resilient in changes to the environment.

That same principle, literally--- the same principle--- applies to thought. By having a diverse group of individuals, diverse in their thinking, we are much more likely to survive changes in our economic environment and be able to move on in a somewhat more rational manner. But without it, without that kind of diversity, we are risking the same kind of punctuated equilibrium that we see in evolutionary biology.

**INTERVIEWER:** You mentioned a couple of minutes ago that love can make you stupid. Is the idea that money can make you stupid too?

**LO:** In a different way, yes, that's right! So again, neuroscientists have done experiments where they've imaged to individuals' brains while they receive certain kinds of monetary reward. They play certain games where they win small cash prizes.

And what they've identified is that the neural mechanisms for financial gain are very much the same as for drugs like cocaine. Your brain is stimulated to releasing dopamine into the nucleus accumbens, the pleasure center of the brain. Certainly not as much, and not as intensely, as when you are on a drug like cocaine, but nonetheless, the mechanisms are actually one and the same

and so it's easy to see how, over periods of great prosperity, during bull markets, people can get addicted to that kind of an experience. The more money you make, the more money you want. You would think that after earning \$10, \$20, \$30 million that should be enough. But in fact, it has nothing to do with the amount. It has to do with the experience and the kind of pleasure it generates in the brain.

And so all of these elements actually come to play in developing ideas about how economic decisions get made. It's not just pure mathematical deliberation that will guide individuals in their decision making; it's a much more complex amalgam of different decision making components. And by understanding how the components work together-- sometimes in tandem, sometimes antagonistically-- we have a better chance of coming up with a more realistic theory of financial market dynamics.

**INTERVIEWER:** I was very interested in preparing for this interview, also, to read some of the things that you've written about risk and uncertainty and how that drives human behavior, or how human behavior changes in those circumstances. Can you talk about that a bit?

**LO:** Sure. First of all, let me explain that by most dictionaries and thesauruses, risk and uncertainty are considered synonyms. But in fact, from the economist's point of view, Frank Knight--- the University of Chicago economist--- distinguished the two by calling risk the kind of randomness that one can parameterize, for example, mortality tables for life insurance or the odds of winning in a lottery. What he called uncertainty was the kind of randomness that you actually couldn't put numbers on, that you couldn't quantify.

And he argued originally that uncertainty really explained why it was that certain entrepreneurs, like Bill Gates would become multibillionaires, whereas others who don't take that kind of bet, actually, only end up earning normal economic profits, nothing nearly as outsized and grandiose.

But there's a very important emotional underpinning to this distinction that Knight really didn't focus on, but now, with the benefit of decades of research in the cognitive neurosciences, we understand much better and that really has to do with fear. The fact is that the most potent form of fear is the fear of the unknown and so if we can't put a statistical probability on certain events, if we can't quantify them in some manner, then we are actually not dealing with well-defined randomness, namely risk. We're dealing with completely unknown kinds of outcomes and so as a result, people tend to be much more averse to uncertainty than they are to risk.

The case in point is the recent experience that we've seen in the stock market. Clearly, people are happy to take on the riskiness of the stock market because, for many years, the stock market has done just fine with a certain level of volatility and a certain level of expected return. But over the last five years, the stock market has been extraordinarily erratic. And erratic particularly in terms of its level of volatility, because during the fourth quarter of 2008, when Lehman Brothers went under, the volatility of the US stock market hit a spike of something like 60 percent per year, and on an intradaily basis even higher.

At that level of volatility, most investors would say, cash me out, I really don't want to be part of this anymore! And the fact is that the volatility of volatility in the US stock market has been tremendous over the last few years to the point where we're seeing a lot of individual investors having taken most of their life savings out of the stock market and putting them into cash, which is ultimately not a very successful way to plan for their retirement.

But that's an example of the fear of the unknown. If you don't know what the rules are, if you don't know whether the house is going to confiscate all of your earnings at any point in time, then your simple decision will be not to play. And I think we're seeing that played out now on a much bigger stage over the course of the last few years.

**INTERVIEWER:** So obviously here, nearing the end of 2011, these kinds of conversations are not just academic. We witnessed the financial meltdown in 2008. We're now seeing a really significant crisis brewing in Europe. Talk about these kinds of massive crises that sweep through the markets, through the sort of global financial structure, in terms of some of these things that we've been talking about.

**LO:** Well, I think that's part of a much larger theme that one can only really see from the perspective of evolutionary biology, and that is that I think crises of all sorts are the manifestation of the combination of technological advances and human behavior.

In particular, over the course of the last 12,000 years, the human population has grown really dramatically. If you take a look at typical estimates of population during that time period, and you plot it on a graph, you see that the prototypical hockey stick exponential growth applies perfectly to the population of humans. The way that we've been able to reproduce so successfully in an otherwise hostile environment is through technology--- through the collective intelligence that we've been able to develop over hundreds of thousands of years of evolution to tame our technology to our physical needs.

And those technologies-- whether they're agricultural, or information technologies, or manufacturing technologies, or financial technologies-- they often have unintended consequences. For example, DDT was a tremendous technological advance for agriculture, but it led to birth defects. Automobiles were a wonderful invention, but they led to air pollution. And of course, industrial activity now seems to be responsible for climate change, global warming. And I would argue financial technologies-- things like securitization, insurance contracts, derivatives-- are wonderful inventions, wonderful advances in technologies that also can lead to unintended consequences.

And these unintended consequences really are the result of the fact that the technologies provide us with much greater power in certain domains. But the greater power oftentimes is not controlled properly because human behavior has not changed that much in the last 60,000 years. We are still very much wired the same way we were back at the time when we first became fully sentient, and our neocortexes developed into what they are today.

And as a result, the fact that we're dealing with, in many cases, relatively ancient, hard-wired brains, but we're dealing with technologies that allow us to do things that we were never intended to do in our original environment, has led to some challenges. Those challenges can be dealt with. But the way that we're going to deal with them is by developing smarter technologies, more advanced technologies.

Humans may not have been meant to fly the way that we fly now, but air traffic control and safety measures allow us to do so relatively safely today. And I think that we are now at a stage where financial technologies have become so advanced that we can now do things that we were never able to do. We need to develop the safety mechanisms to prevent us from doing the things that we ought not to do with those powerful technologies.

**INTERVIEWER:** Are you saying that it's a bit-- and I don't know if this analogy captures it, but-- sort of this idea that we all crave things like sugar, salt, saturated fats, that we've evolved to crave. And they end up killing us, because they're no longer so scarce. And we just take too much of them.

**LO:** Exactly! So for example, certainly sugar was present in the diets of humans 60,000 years ago. But they were few and far between. Occasionally, you would run into a fruit tree. And you would have a pear or an apple. And that was enormously attractive, but it came on occasion.

That's very different from being able to eat deep fried Twinkies every other day, which I don't believe we were adapted to do. Now maybe if we keep doing that, over the course of the next 50,000 or 100,000 years, we will have the ability to process that kind of a sugar intake. But our current biologies are not wired to engage in these kinds of activities.

And a good case in point is the internet. The internet is really a relatively new invention, just a matter of a couple of decades. And if you think about what we can do now on the internet-- well, for one thing, at this point in time we are able, with a click of a mouse, to wipe away half of our retirement investment in a bad investment decision. That has never been possible in the history of financial markets; it is possible today.

And so if you think about the power that individuals have to do good and to do harm, they're both magnified by technology. And so we need to develop the guardrails, the safety mechanisms that will prevent us from doing the kind of damage that we are now able to do with the very advanced technologies that we have at our disposal.

**INTERVIEWER:** So let's talk a bit about those guardrails, because I'm very interested in asking you about the relationship between these kinds of theories, this kind of thinking, and policy making, and prescribing solutions for some of these intractable problems. What do you see as your role? And how do we go about doing it?

**LO:** I have to admit that for much of my early academic career I wasn't interested in policy at all. In fact, I was much more focused on the dynamics of private markets, and really never even thought about what was going on in the public arena, simply because my presumption was that policy was being formulated by the experts in policy making, and that the challenges, the intellectual challenges, were really in trying to understand the dynamics of private markets.

It didn't occur to me until relatively recently that there are challenges in the policy arena that are at least as great and if not greater in terms of affecting a much larger group of individuals. And so over the course of the last 10 years, I've spent more time thinking about the interplay between policy and private activity.

The first thought that I've been spending time on is really the underpinnings of policy making to begin with. Economists and policy makers formulated a number of policy prescriptions with the implicit assumption that individuals, and therefore institutions, are rational actors. The efficient markets hypothesis or rational expectations have been applied to macroprudential regulation as well as to financial markets.

And the first observation that I think needs to be made is that the same limitations that we found to the kind of investment theories that private financial markets exhibit really have to be applied to more general policy settings. In other words, the kind of madness of mobs that we see in financial markets have to be applied much more broadly to economic settings in formulating policy.

And there are a number of policymakers now that do have that perspective, but not nearly enough. And certainly not enough to really affect yet the direction of policy. I think that's the first insight, to begin with. And from that point on, all other policy implications will follow very readily. And changes in policy, more importantly, will be suggested by this kind of a different perspective. If we look at markets not as static, stable, physical systems that have underlying laws that are immutable, but are actually biological institutions that can evolve over time and as a function of market conditions, I think we're much more likely to formulate policy prescriptions that are themselves adaptive and much more likely to succeed in a variety of different environmental conditions.

**INTERVIEWER:** It's obviously a very hot political issue right now, just what exactly the role of governments are in all of this. What's your view on that?

**LO:** In my view, government is, itself, an evolutionary adaptation. Without a doubt, the institution of government is critical for resolving a number of challenges that we face as a society because markets cannot work perfectly by themselves. They do break down from time to time. And actually, implicitly, I think we already recognize that.

For example, in this studio, there are a number of laws governing the fact that there have to be sprinkler systems, there have to be well-lit exit signs, the fact that there have to be certain protections for all of us, in case of fire. Why do we institute such expensive features of this particular setting? It's because we recognize that we can't leave it to the discretion of the builders of any institution to put these in place, because, left to the choice of a real estate developer, they will almost never choose the more expensive option if they can avoid it. The probability of fire seems relatively low. And if you allow people to choose whether they want to build a building with fire protection versus another building without, they will choose the cheaper alternative, unless there's an absolute demand for the more expensive one.

And for most days, there isn't an absolute demand. That absolute demand occurs right about when there's a fire. Of course, by that time it's a little late.

We know this about ourselves. We know human nature. We know that we will not gladly pay a higher rent for a facility that has fire protection if we are given a choice. And so after a number of very severe fires with many, many casualties, we as a society decided to institute a law by government that says that all buildings have to have fire protection if they have a particular function to the public. And so this is an example of how laws and how government takes into account human frailties in a very explicit way.

Well, if we understand this about something as basic as fire protection, it has now come time to make that same leap of understanding for all sorts of contexts, including financial ones. We now have to build in financial protections that prevent us from doing the things that we know we're going to want to do, particularly after extended periods of prosperity.

After many, many decades of the economy growing rapidly and financial markets generating lots of value added for all the market stakeholders, at some point, we're going to say to ourselves, you know what, we don't really need as many protections as we had in the past. It's time for us to perhaps loosen up some of these protections that have been reducing the growth rate of our economy. We don't need seat belts anymore. We don't need leverage restrictions anymore. We don't have to have constraints.

That's a natural reaction from decades of no car accidents or no big financial meltdowns. And that kind of human tendency is something that we have to recognize. We do recognize it in limited context, like fire protection. We don't yet recognize it in economic settings.

**INTERVIEWER:** Libertarians see all of this, of course, in terms of maximizing individual freedom, as opposed to restricting or regulating that freedom. What's your thinking or your response to that kind of approach, which seems to be very, very different?

**LO:** Well, in fact, I would say that individual freedoms are absolutely critical. And one of the unique aspects of *Homo sapiens* is the fact that we can actually choose how we wish to live our lives. And I think that that's an absolutely fundamental aspect of human society. There are very few societies that are so regimented across the board that will actually last-- even totalitarian regimes will ultimately fall, because humans want to be free.

However, freedom doesn't necessarily mean that *any* action and activity should be permitted; because of a very important aspect of human society, which is what economists call externalities. If my activities have negative consequences for you and your family, then we have a problem. We have a challenge that we have to resolve. And so because of the success of population growth, we are now at a point where a number of activities that we have previously engaged in have externalities, or spillover effects.

When the economy is relatively small the kind of spillover effects that we're talking about today are really remote. But when the economy gets big enough, when human society gets to where we are today-- seven billion people, as of the end of this year-- these externalities become much more significant. So we have to balance the human drive for libertarianism with the acknowledgement that individual actions very often have much broader consequences.

And ultimately, that's really the political process. That's what we really rely on politicians to resolve. They haven't been doing such a great job lately. But eventually, they will and they must be able to come to terms with these very difficult decisions. And ultimately, by understanding the dynamics, the spillovers, the externalities, we actually have a better chance of creating a much more palatable solution for all stakeholders involved.

**INTERVIEWER:** I also wanted to ask you about financial education for, I guess, what I'll call the layperson. I am a relatively unsophisticated investor. How much education should a person who's not a business person, not particularly interested, frankly, in those kinds of issues have? And what is the role of making people more sophisticated and more aware of these things?

**LO:** I have to confess that to someone with a hammer everything looks like a nail. So if you're going to ask an academic how much education they should have, the answer is, lots and lots. But I think that this is actually part of a much broader trend that we see across all aspects of our existence today.

Life has gotten more complicated in many ways. It's obviously also gotten simpler in yet other ways. But the fact is that, with various advances in the sciences, we now know a lot more about all aspects of our day- to- day existence. And therefore, we can make more informed choices.

Take for example, diet. In the 1950s, the advice that most people received from their parents was eat to your heart's content. There was no discussion of cholesterol, or carbohydrates, or various kinds of health issues that we now understand to be quite significant and that we can do quite a bit about by watching our diets. And so the advances that the medical sciences have offered have, in many cases, made our lives simpler. We now can take a flu shot and be assured that there will be relatively minor consequences of a bad flu season.

But it has also made our lives much more complex in that now you have to decide how much fiber you're going to have, how much protein, how much carbohydrates and are you taking enough vitamins and minerals each day? So we have each had to become a little bit more expert in diet.

By that same token, I believe that we have been given tremendous opportunities to engage in a variety of different investment activities that would have been impossible to us even 10 years ago. Now you can buy an ETF that invests in many different countries, whereas in the past, you would have had to go to various different brokers to engage in those kinds of transactions.

So in that respect, our financial lives have gotten simpler. We have had more access to investment opportunities. But those additional opportunities mean that we have more complex decisions that we have to make.

So I think that in the short run investors really should spend a lot more time thinking about their investment portfolios. Typically, an investor will think about their portfolio maybe four times a year, once a quarter, certainly once a year when they have to do their taxes. But if you think about that level of attention to your financial health, that's actually a pretty limited amount of time that you spend compared to how much time you spend on your physical health. You have a check-up of annually, but you'll have other visits that involve various different specialties.

So we spend more time now thinking about our physical health than we do before, because we know more. By that same token, we need to spend more time thinking about our financial health than we have before.

I believe that over time as economists, particularly financial economists, make greater strides in taking into account human frailties in various different financial products, eventually we'll be able to develop smarter products. In the same way that an iPhone almost eerily knows what you want to do when you want to do it and makes it simple for you to do, we need an investment- kind of an iPhone device that will allow us to reach our ultimate financial goals without having to spend too much time thinking about it. We're not there yet. And until we get there, we need to spend more time understanding how financial investments work and how they may or may not be consistent with our ultimate goals.

**INTERVIEWER:** I know that teaching is, in fact, a very important part of what you do and a big part of your life. Talk a little bit about that. And also, how do you balance it all?

**LO:** Teaching is important. And I have to say that early on, because of my experiences in third grade with Mrs. Ficalora and throughout, I realized the benefits and tremendous costs of having good and bad teachers. Having an inspiring teacher can open your life to an amazing series of discoveries and pleasures that would never have been possible. And similarly, a bad teacher could close a mind forever to a subject, which I think is just a crime.

I think that teachers are underpaid-- particularly at the elementary, middle school, and high school levels-- because if we could measure their impact on society, if we could really measure the impact of having a good 11th grade trigonometry teacher on what that individual does 15 years from that point on, we would pay these teachers a lot more. We would be a lot more careful about tenure. We would be a lot more focused on developing good teachers at that level because that's where minds are opened and where minds are shut.

So to me, teaching is one of the most important activities that we can do because that's the way that we replenish the stock of intellectual capital in our society, the way that we encourage collective intelligence, and frankly, the way that we're going to solve the challenges of society for the next few decades. The future scientists, and engineers, and economists that cure cancer, and fix global warming, and find new sources of energy, they are our students today. And so if we think in those terms, I think we'd take teaching a lot more seriously than we do now.

**INTERVIEWER:** What's it like teaching MIT students?

**LO:** That has just been a real pleasure. One of the constants that drew me and many of my colleagues to MIT is the quality of our students here. And it's really noticeable. I really view teaching our students here as a privilege, not a burden. We all like teaching students that are good students, that are excited to learn, and that have a certain degree of creativity and energy.

Well, MIT students have that tremendously. They are not only creative, but they have this entrepreneurial spirit that really makes them extraordinary students to teach because they don't take concepts for granted. They will take an idea and work out five different implications, and really challenge the teacher to really think about these ideas from a much deeper level.

So I have to say that I've learned more from the students here than I think I've taught them because of the challenges that they've thrown out, the creativity that they bring to the process, and ultimately the energy that they have for learning. Our students are absolutely hungry for knowledge. And they drink it up at an amazing rate. So it's really a tremendous environment for faculty.

**INTERVIEWER:** Speaking of entrepreneurial spirit, I also wanted to shift gears a little bit and ask you about some of your forays into that world. Talk about that a bit. And why has it been important for to do it?

**LO:** As I mentioned, when I started in economics my interest was very much on the applied side. I love seeing ideas put to work. And one of the fascinating things about Isaac Asimov and the *Foundation* series was that some very abstract mathematics was applied to some very practical situations. And so from the very beginning, my interest was in seeing ideas implemented.

And so during the period where I was studying the dynamics of financial markets, the random walk hypothesis, it nagged me to no end that here we were teaching our students that markets are efficient, it's impossible to beat the market, you should focus on risk and reward, and I had actually never taken any of these ideas that I had developed into practice. I had never tried to see how it is that these investment ideas did or did not work in actual settings.

And so in 1999, I decided to start my own investment company. I took a two- year leave of absence from MIT, and worked with some of my former students and consulting colleagues, and created a company to try to undertake some of these ideas from a more practical setting. And over time, I've learned an enormous amount about how markets really work from trying to use these ideas in practice, and seeing how they succeed and fail over various different kinds of market environments.

**INTERVIEWER:** Maybe just to follow up, what kinds of things have you learned? I can imagine that that might seem like an obvious question.

**LO:** Well, there are few things that I think I discovered quite to my surprise. One is that it's very painful to lose money. But it's *a lot* more painful to lose other people's money than to lose your own.

That aspect of human nature, I think, is something that we don't really spend enough time talking about in our investment classes. I do now. But before I engaged in this activity I didn't realize just how important that emotional aspect is, and why it's so important for investors to engage in third party financial advisors.

In a way, it's much like the medical practice of never allowing a doctor to operate on his or her own family members, because you're too emotionally invested. And in many respects, managing your own wealth can be a very challenging activity, unless you are trained to think somewhat more remotely, somewhat more objectively about these kinds of decisions.

Managing other people's wealth has that very same feature to it. You don't want to disappoint others. You don't want to engage in practices that are too risky. But at the same time, you are stewards of their wealth. And so they're expecting you to be able to make good investment decisions. So the processes by which you can provide that type of stewardship and the emotional toll that that can take on an individual is something that I learned about firsthand. And I found it very valuable. And ultimately I think it's reflected in the research that I've done and what I teach my students now about how they might engage in these kinds of activities somewhat more productively and with somewhat more preparation for the kind of challenges.

**INTERVIEWER:** Thinking a bit more about MIT, as we sort of start to wind down, the MIT economics, finance departments-- it's obviously a legendary a group of people. We've touched on some of your colleagues over the last 20 years. Who are some of the other luminaries that you would like to talk about? And are there any really interesting stories that we could gather?

**LO:** There are so many. One of the things about MIT that I love-- but it's also something that one has to get used to-- is that there are so many superstars that are here that nobody really feels like they need to be catered to or treated any differently. This kind of an egalitarian ethic is actually very different and unique, I believe, to MIT.

I have been a student at Harvard, a student at Yale, a faculty member at Wharton. I have visited most of the major business schools and economics departments over the last few decades giving talks. And I have to say that MIT is really unusual in the ethic that has developed over the years, particularly in the economics department and in the Sloan School. And the ethic is really that we are all part of the same college of ideas

and you're judged by the clarity of thought and the creativity of your research. It's really that kind of motivation that keeps us young, and it keeps us thinking. And there's very little in the way of formalism that we engage in so we interact in a very open and collegial manner. That's one of the things that I value most about MIT.

In that setting, I have to say that there are a number of individuals that I've learned a great deal from in a variety of different departments. One of the things that I discovered early on was that MIT is really like, for me, the world's biggest candy factory in that there are so many different interesting things going on in different departments. In particular, in addition to the Sloan School and the finance group, I've interacted with individuals in the economics department, with the brain and cognitive sciences department, with electrical engineering, and computer science, with the AI Lab, years ago when it was called the AI Lab, and now the CSAIL, the computer science and AI Lab together. All of these individuals, I think, have really contributed to a better understanding of human behavior from my perspective.

So it's hard for me to name any one or two individuals. But certainly in the pantheon of greats, Paul Samuelson, Bob Merton, Franco Modigliani, Patrick Winston, Noam Chomsky, Marvin Minsky, and Tommy Poggio, all of these individuals, I think, I've learned tremendous amounts from over the years. And many more who have contributed to my education.

**INTERVIEWER:** That's quite a list.

**LO:** There are a lot of impressive people here at MIT.

**INTERVIEWER:** So thinking ahead just a little bit, maybe just give us an assessment, as we wind down, on what you feel your impacts might have been as a researcher, as a thinker in finance. And where do you want to take your work? Obviously, the world is full of challenges right now, in particular, in this area. And where do you want to go?

**LO:** In terms of where I've been, let me start with that, and then talk about where I hope to go. The early phase of my career was really focused on applying rigorous concepts of econometrics and statistics to financial models to develop the field of financial econometrics. And I believe that that field is now very healthy and well-developed. And we now understand that it's critical to use the proper methods of inference for understanding the empirical anomalies that we identify in financial circumstances.

Those empirical anomalies leave a lot of room for innovation and creativity because they illustrate that the traditional paradigm is simply not satisfactory. There are missing pieces of the puzzle. And over the last 10 years of my career, I focused on trying to fill in those pieces of the puzzle by bringing ideas from evolutionary biology and the neurosciences to provide a deeper and more nuanced understanding for human behavior.

Where I think I'd like to go over the course of the next decade or so, if I'm lucky enough to continue being active, is to take those ideas and work out their implications for human behavior writ large. In other words, I'd like to develop a complete theory of human behavior. And by complete, I mean one that applies across all contexts--social, cultural, political, and economic. Because we are not so compartmentalized that on one day you're an economist, on another day you are a psychologist, on another day you're a biologist, in terms of the way you act.

We're talking about humans. And human behavior cuts across all of these siloed disciplines. And so what I've been spending time on recently is trying to understand how to integrate all of these different silos in a more complete theory of human behavior to the point where we understand so much about human behavior that we can actually create it artificially.

This might seem like a program in artificial intelligence. But in fact, it's much broader than that. I think it was Marvin Minsky who said that he didn't want to create a computer that he could be proud of; he wanted to create a computer that could be proud of him. And I think that that's a very important insight because it says that the notion of behavior is something much deeper than simple actions.

We can now automate lots of behaviors. There are wonderful factories that have very few human actors and are extraordinarily efficient. But somehow we don't consider them to be human. And the behaviors, frankly, are very stupid in the sense that they're highly stylized and they are not robust to changing environments.

Going forward, what I'd like to be able to do, what I think we now have the wherewithal to do, is to develop a theory of behavior that allows us to replicate human interactions, human decision making in the way that humans actually make them.

So the Turing test is a well-known idea, pioneered by Alan Turing, who said, that if at some point by typing messages back and forth with another party, you can't distinguish between the responses you get from that individual and the responses that you get from a human, then that computer is for all intents and purposes intelligent and human.

I actually think that that's a relatively low threshold for what we need to achieve. I actually think that a much more relevant test for whether we have achieved an understanding of human behavior is to create a computer that can engage in activities to such an extent that seems to replicate humans that, at some point, if someone were to decide to terminate that machine, a number of us would object on moral and ethical grounds.

That, to me, is the ultimate Turing test of human behavior. If we can create behavior that can actually mimic not just the look and feel of human behavior, but actually the mechanisms by which behavior adapts to new settings and can develop its own type of creativity, at that point I think we will have achieved something spectacular.

**INTERVIEWER:** So this has been really wonderful. Is there anything else you'd like to add that we haven't talked about?

**LO:** It's been very complete and wide-ranging. Social responsibility?

**INTERVIEWER:** Sure. We have a few minutes, if you'd like to--

**LO:** The financial industry has obviously undergone a great amount of turmoil over the last few years. And it has received many black eyes at this point in terms of the behavior that we have observed. But I think that we are at the risk now of throwing out the baby with the bath water when we start to engage in regulations that will ultimately hamper financial market development. Because ultimately, while there may have been excesses and even crimes that were committed during the financial crisis, the fact is that financial markets are critical for all aspects of society, and that some of the biggest challenges that we have in front of us-- things like cancer or global warming or the energy crisis-- ultimately, those are going to be challenges that we will face collectively. And we're only going to be able to overcome them if we can unite in some coordinated fashion.

And one of the most important aspects of that kind of unity is to be able to create proper incentives. The financial system is designed to do just that. I believe that to some of the biggest challenges of society can be addressed with the right kind of financial structures, and that they will be virtually impossible to address without them.

So we need to have more and smarter individuals involved in the financial sector. We certainly should not relegate that to the financiers because we know what they might do with it, and we know that excesses will occur.

Instead, we need to spend more resources studying these issues, becoming much more nuanced in how we construct the appropriate financial structures to be able to support innovation. And I think that if we can do that, if we can find the right structures to create the wisdom of crowds and to support the kind of innovation that we desperately need, we can face virtually any societal challenge successfully with those kind structures.