

**BERNARD FRIEDEN:** Let me welcome everybody here to the second of this year's Killian Award lectures recognizing the professional achievements of Professor Jay Forrester off the Sloan School of Management. I'm glad to see many familiar faces here. Many of you, I know, were at the first lecture last week. But I think even more people are here today. So the word must be spreading that this man has some interesting things to say.

It occurred to me that some of you might want to do a little reading to follow up some of the points made in these lectures. And last week, particularly, Professor Forrester mentioned something about the background of computer technology at MIT and his role in the Whirlwind Project and other events in the 1940s and '50s.

And I've since come across the first book that I listed here by Wildes and Lindgren, which is an excellent history of electrical engineering and computer science at MIT, a very handsome book, well illustrated, with most of one chapter devoted to Professor Forrester's work on the Whirlwind Project.

I noticed in reading it that in addition to his work as a technologist, he was writing and speaking to the country at large as early as 1948 about both the problems and the potentials of high-speed computers. And in a 1948 talk, mentioned among possible applications, we might mention the control of industrial processes, military gunnery and fire control, and the centralized control of air traffic. I guess we still have aways to go on the last one. But we're getting there.

I've also listed Professor Forrester's books published by the MIT Press for those of you who might want to read further in the material that he's talking about today and last week. And if we have a third meeting, there will be a short quiz based on these readings.

Lastly, Professor Forrester spoke about his early work on simple models of social and behavioral systems and how they operate and with many interesting anecdotal examples. This week, he's going to speak more about complex models and applications of system dynamics.

To help set the stage, I might just say a couple of words about the difficult context that, I think, surrounds Professor Forrester's more recent work, a context that I've seen as one outside of the field. But first, those of us who have tried to do work at all related are aware of the increasing difficulty of collecting data from a resistant population that doesn't like to part with it.

And I can give you one good story to illustrate that. The daughter of a friend of mine was a [INAUDIBLE] in Boston during the 1980 Census and had been alerted to the fact that people are more and more reluctant to speak to census takers and give out information. And as she made her rounds in the South End, she rang one doorbell, and a very hostile woman came to the door and said, who are you and what do you want?

She said, well, I'm Franny Wood, and I work for the Census Bureau. What's that?, the woman snapped. And Franny said, well, we're part of the federal government. And we're trying to find out how many people live in the United States. And the woman said, well, listen, deary, you've come to the wrong house, because I don't know.

[LAUGHTER]

It does suggest some possible new ways of establishing a factual base of things by doing it through an opinion poll. I think the other difficult part of the context for large-scale modeling is that there's been so much disappointment with economic forecasting models.

Many economists, particularly consulting economists, have built models that report to forecast short-term and long-term what's happening to the American economy. And so many of those forecasts have been disastrous, particularly recently, that all sorts of stories go around about people who try to use these models.

I mean, one concern is to management executives who came to the Cambridge area for a special advanced training program, having been badly burned by a forecast that turned out not to be true. And while they were here, they visited the famous Mount Auburn Cemetery, which is a scenic spot in itself, but also the final resting place for many academic luminaries of this area. I came across a tombstone that said, "Here lies a great economist and an accurate forecaster." One of them turned to the other and said, gee, I didn't know they're putting them two in a grave.

Since Professor Forrester approaches this not as an economist, but as a computer technologist and a person who works at Industrial Dynamics, he is [? inspired ?] by that particular problem. I give you Professor Forrester.

[APPLAUSE]

**JAY** Thank you. Thank you, Professor Frieden. Last time, we had an opportunity to discuss the background, the  
**FORRESTER:** philosophy of the field system dynamics. And this afternoon, I would like to bring the discussion more up to date.

You will recall that we talked about the 30 years of background from 1930 to about 1960. Today, I'd like to start with another 30 years, but a more recent 30 years, 30 years that I have been especially associated with the field of system dynamics. I can't possibly cover the entire field and everything that has been done. So here, I am calling attention to those things that I have been most directly connected with myself and several rather interesting points, I think, to make about them.

You will recall in discussing the 30 years in computers and feedback control that we did say that there'd been 100 years of prior thought leading up to that implementation at MIT, beginning around 1930.

Well, there's been 100 years of prior thought about the possibility of coming to a better understanding of social systems. I'm indebted to my daughter for calling my attention to some passages from Leo Tolstoy's *War and Peace*, in which he discusses the problems of historians, and especially takes to task their tendency to look at events and people, rather than the underlying currents that led to historical change.

And he says in one set of passages, "Absolute continuity of motion is not comprehensible to the human mind. Laws of motion of any kind become comprehensible to man only when he examines arbitrary selected elements of that motion. But at the same time, a large proportion of human error comes from the arbitrary division of continuous motion into discontinuous elements."

A modern branch of mathematics conforms to the chief condition of motion-- absolute continuity-- and thereby corrects the inevitable error which the human mind cannot avoid when it deals with separate elements of motion instead of examining continuous motion.

Only by taking infinitesimally small units for observation-- the differential of history, that is, the individual tendencies of men-- and attaining to the art of integrating them-- that is, finding the sum of those infinitesimals-- can we hope to arrive at the laws of history."

And he has other passages bearing on this same theme. He was seeking the laws of history. And that's what we are talking about-- the laws of social systems today. A computer simulation model is a theory, or, if you like, a law of behavior, of the system that it represents. If it generates realistic behavior for the right reasons, it is a law in the same sense with the laws of physics, except that one is operating in a domain where there are a larger number of feedback loops, where randomness and noise have a greater impact on the behavior of the system, and all of those somewhat more difficult characteristics have to be taken into account.

If we look at this diagram, starting here and working around the outside, you see a chronology of what has gone on here at MIT in the last three decades or so. We spoke last time about the instability of a production distribution system. And I mentioned how that came out of some discussions with people at General Electric.

Then I had the good fortune to have Roberts Sprague, the founder of Sprague Electric, come to my office one day. He had followed our work in computers. He had adopted the practice of keeping in close contact with people in new branches of technology.

He would often provide them small quantities of the new components they wanted at almost no cost. Other people would be offering specially-designed small lot pulse transformers for \$1,000 apiece. And Sprague would say, well, we'll sell them to you for \$20 apiece. And out of this, of course, he kept in touch with the latest things in technology and was in a position to learn about it ahead of other people and to build an electronics business.

Well, against that background, after I'd come to the Sloan School, he came to my office one day. And he said, I don't know what you're doing here, but whatever it is, we would like to be a part. And out of that came our first actual in-the-company Industrial Dynamics modeling exercise, dealing with the interactions between a company and a market and some of the instabilities that can occur through the process of customers ordering ahead as the delivery delay gets longer.

As the delivery delay gets longer, they order further ahead. That increases the apparent number of orders in the system and can create an avalanche of essentially fictitious orders, orders that, once the suppliers have caught up, lead to a tremendous oversupply in the market.

My next, and even yet the most major corporate modeling that I've been directly associated with was to guide my own position on the board of directors of the Digital Equipment Corporation, having to do with the growth of high tech companies. I'll come back to some of the aspects of that.

Then as one keeps a certain flexibility, an open mind about where your career is going, and a willingness to change directions when new and interesting things come up, I had the good fortune to encounter John Collins, who had been Mayor of Boston for eight years. He came to MIT as a visiting professor of urban affairs. And out of contacts with him, we moved the whole field of system dynamics away from the corporations for the first time and into larger social systems, looking at the growth and stagnation of cities.

That study branched and led to two different activities, one to which I'm indebted to Carol Wilson for bringing me in contact with an organization called the Club of Rome, which moved our interests out into the larger environmental population, pollution, industrial development scene, looking at the interactions of the environment with the growth of technology and population and the growth of pollution.

Eduard Pestel, President of the Technical University of Hanover, was largely responsible for raising the money from the Volkswagen Foundation that led to the limits to growth study here. Two books-- the *World Dynamics* book, the *Limits to Growth* book-- probably had the greatest impact on public debate of anything coming out of the social sciences, at least for any comparable amount of effort.

The *Limits to Growth* book is available now in some 30 languages. Sold around 3 to 4 million copies, it has been a subject of fairly intense debate, with strong sides taken about it. It came in at the end of the concern about the environment that had been building up, in any case, through the 1960s.

It kind of put a capstone on that, gave it a focus, and probably triggered the backlash against the environmental movement, which has run through the Reagan administration and is essentially exemplified by James Watt and his view of the environment. And I think that's a necessary part of the give and take over a new set of ideas. And now you can see the undercurrent beginning of a concern about environmental affairs again coming into the ascendancy.

The other branch out of urban dynamics led into the present work in applying system dynamics to the behavior of the national economy. Most of our staff, many people, have been working on that. No room here to try to put in their names.

And then moving into-- well, there's been a thread through all of this-- the necessary computer software, Jack Pugh of Pugh-Roberts and his whole series of Dynamo compilers, which have had a very major influence on development of the field.

More recently, Barry Richmond at Dartmouth and High Performance Systems with his STELLA software that I will give you some examples of. And what I see as the most recent and newest work in system dynamics-- the turn to computerized management case studies with three members of our present staff-- John Sterman, Peter Senge, Alan Graham-- and our PhD students all very much involved.

My first comprehensive look at corporate modeling was, as I said, in connection with my being on the board of the Digital Equipment Corporation. And the question in that kind of a situation is, what lies behind high technology growth? What are the kinds of forces? And one has to decide, what is his task? How is he going to go about it?

And the task undertaken was to try to explain the very major differences between the growth scenarios that one could see in companies in the high tech field. There were those that were launched, grew a while, and failed, for one reason or another, a very large number that grow briefly and then move into a state of stagnation, those that have a continuing growth trend with repeated major crises, and a few very rare cases of sustained high growth with nothing in the way of severe crises. The question is how and why?

And the objective of a corporate model is not to study especially the one particular company or situation, but rather to study the family to which that one belongs to obtain a generic model that tells you why the differences between the performances of the different examples in the field.

And those examples cannot be explained by differences in products, because sometimes even the best products are coming out of the most troubled companies. And those differences exist between companies existing in the same industry, competitors of each other, and in the same environment. And so it must be something to do with the company, not something to do with the external world.

In order to approach this kind of problem-- and this goes back to a question that was asked at the end of the period last time-- what perspective should one follow? What viewpoint? What degree of aggregation? And one can be too close to the situation. I would say a production manager, a sales manager, or even the company president is too close to the corporation to be the right perspective from which to view the company and, therefore, too close to be the perspective from which to build a model.

Such a person tends to see the inside of the company, tends to feel that he has no control over the outside environment, and tends to see himself as reactive. On the other hand, if one moves to essentially the other extreme-- the public stockholder or, perhaps, the traditional economics-- one is so far away from the company that one does not see what is going on inside, what are the real information sources, what are the policies being followed.

My nomination for the right perspective for this kind of model would be one of the outstanding investment bankers-- a person who does not care whether the product is 14 inches wide or 18 or whether it's red or blue. But he's interested in a consistent set of policies that go with the particular proposition. He's interested in the integrity and the leadership of the people founding the company.

I'm reminded of a story that appeared in the press a few years ago retelling the history of the Mellon fortunes in Pittsburgh and telling about one of the Mellons coming out in the hall one day and seeing a man that he had met with a few months before, recognized him by name, knew who he was.

They had agreed to finance his new company, visited with him about how well things were going, and then, in parting, said, and oh, by the way, what business are you in? One of the less important questions. The nature of a man, his viewpoint, the consistency of his policies, the history of his past successes far more important than what he happened to be doing at that moment. And to understand that perspective, which is not a perspective on a particular product, but a perspective on the character and, essentially, the policies that lead to the dynamics of the organization, would be the focus of such a study.

The model that developed-- I see David Packer in the audience. He was a research assistant for me at the time and actually helped work through all of this-- was a model of about 60 levels, or integrations, a 60th-order system. It had in it about 250 variables. It's still a simple model compared to the reality of such a situation, but far more comprehensive than we can manage in our mental models trying to tie together what goes on in a company.

You might, as an interesting exercise, sit down and just try to make a list of 250 variables in a growth company. In other words, it's not a simple model, even though it is simplified from real life.

When we had developed this model, it turned out that fully 90% of the variables in it are what would ordinarily be called intangible-- variables which are not ordinarily measured, variables like integrity and courage and leadership ability and the ability to project one's goals onto an organization.

The model had in it a pressure system that connected one part of the system on to another, pressure for greater production, pressure for greater marketing, pressure for reducing the overload on people, financial pressures. And these were generated in various parts of the system and used elsewhere as part of the mechanism for tying things together, and then some explicit attention given to the nature of information channels.

I think there's a tendency to believe that information is information and it doesn't vary in its character. But it varies tremendously. And here are some of the different concepts that have been used in modeling to represent what goes on within information channels.

One is persuasiveness. Is the information in fact influential? Here, you come very close to what is called by many people the hardness or the softness of information. The hardness is the degree to which it can be measured. Inventories-- very hard data. You can imagine that they could be measured. You think they are being measured. They appear on the balance sheet to seven or nine decimal places. They look very, very accurate. They're likely to be wrong in the first place. But you, nevertheless, feel that there's a high persuasiveness to this information.

And contrast that with the much more important information, but the much less persuasive information, of, what do we think that the customers think about the quality of our product?-- a very slippery sort of information channel.

Oh, I might say that all of these terms seem to have a pejorative implication. And I do not intend that. Because you may want information to be more or less persuasive. You may want it to be more or less of any of these things. I'm just saying that there are these different characteristics.

Delay is fairly obvious. There is a delay in the transmission of information. But in particular, and most important, there is the delay in the comprehension or the acceptance of information. A person can be faced with information contrary to what he now believes. And he may sit there for 10 years still sort of discounting that information. There are some very long psychological delays before new propositions are accepted.

Distortion-- distortion means selective differentiation of different frequencies or periodicities in the data. One intentionally introduces distortion when you average sales data before you use it for planning production. You would not want to change your production up or down 100% every day as the incoming orders vary that much. You average it over a month or more and adjust the production accordingly. So you intentionally distort.

Bias is the orderly offset, or the continuing offset, between what the data is saying and what we believe. All these are most pronounced in the channels that come from the market back to a company.

Take the matter of bias. We would all like to think that we are doing a good job. You can go into many companies and find that they have a philosophy about satisfying the customer. It's not possible to satisfy more than 90% of the customers. There will be 10% that will buy our products that shouldn't buy them, that will use them improperly. There's bound to be 10% that aren't satisfied.

Now the stage is set for a situation where, when letters come in that are highly critical of the company and of the product, they say, oh, well, that's from one of the 10%. And those go in the wastebasket.

And then the favorable letters come in-- a few of them, a small number of them-- and they are from our valued customers. And of course, we know that satisfied people don't generally write letters. So there must be a lot more of them than we actually get. And those go on the bulletin board and reinforce our feeling that we're doing a wonderful job, whether we are or not.

Error is just the simple mistakes-- transposing two numbers and copying them down. Probably more effort goes into preventing error than is devoted to any of the other five on that list. And yet by all odds, it is the least important. Next month, that transposition will be corrected, anyway. And dynamically, error makes very little difference. It's a randomness on top of the randomness that permeates our systems, anyway. Tremendous amount of effort to prevent error and, for the most part, displaced.

Crosstalk is an interesting kind of defect in information channels. It's a telephone term. I don't know of a word anywhere else that quite carries the meaning. You're talking on the telephone, and you hear somebody else's conversation occasionally.

Tremendous amount of crosstalk in corporate and market channels. For example, suppose I have bought some piece of machinery that I use in my office. And it squeaks. And the paint is peeling off. And it drips oil on the carpet. I have decided I'm not going to buy another one from that company.

So the salesman comes around to try to sell me one. Now, do I tell him the problems? Not if I'm sensible. I don't tell him these problems, because I'm then on his turf. He will tell me when I say the oil drips that the oil seals have been redesigned and they don't drip anymore. And I can't protect myself against that. And I've decided not to buy.

And so I don't move into that trap. I tell him the price is too high. That's my prerogative. And that's my value judgment. And I tell him the price is too high. And he goes back with that message.

But suppose I don't. I tell him the troubles. I want to help out the company. So I tell him all the story and what's really wrong. What does he do? He's had the experience of going back and complaining about the designs and had his ears pinned back, because his job is to sell it, not to design it. So he goes home and says the price is too high.

But suppose he doesn't. Suppose he goes back and carries the message correctly to management. What do they do? They lower the price. Because they don't know how to fix the other things quickly. And they aren't sure they'll get them fixed. And so they lower the price.

Everywhere along this channel, the true story is transposed into a different message. We find this time after time in information channels. You have to be very alert to it.

That model, the corporate growth one, high tech one, I did. At that time, it was my practice in the second term of system dynamics to simply teach whatever I was doing and whatever I was interested in at the time. That model I began at the beginning of a spring term. And so the term consisted of every lecture describing what equations I had written up to that time and why I thought they represented what goes on in such a corporation.

Halfway through the term, the model had been fully developed. When it was first put on the computer, it essentially immediately exhibited one of those standard modes of behavior-- growth trend with repeated major crises. At that point, I turned it over to the students to ask them to alter the policies and produce a better-behaved system, one that they would rather work for or run.

Now, they've been through six weeks of discussion of all the equations. They had all the equations. They could put it on the computer. They could get computer output of every variable on what was happening, if they wanted to. They had at least 100 times-- maybe 1,000 times-- more information about that system in the laboratory than anyone in a real company would have about the company. And they were now free to alter policies and improve the behavior. And they worked on it for the next six weeks.

It was before time-sharing computers. You had to take your problem over to the computer center and get it back the next day. So each group could do about two of these a week. There were 12 students. They were in teams of three, four groups. They could try about eight policy changes a week. They did this for six weeks. About 50 different policy changes they were able to try in that period of time.

I have never in all of my experience seen such a frustrated group of people. No one had found anything that substantially affected the behavior. It still had a growth trend. It still had repeated major crises. It was clear it was all hooked up. There were little differences. Things would happen, but nothing that substantially altered the behavior. This, it turns out, is the same experience that many, many [? jurors ?] around Route 128 were having.

You saw the students in the laboratory doing exactly the same things that the managers around Route 128 were doing. And it wasn't working either place. Except around Route 128, it was always blamed on the interest rates or the competitors or the customers or something outside of the company.

Here in the laboratory, you had to admit that, somehow or other, you hadn't come to grips with anything that mattered and, in fact, you were dealing with a set of self-defeating policies in which the moldable feedback loops in the system were able to compensate for policy changes. And I don't mean policy changes of a few percent. By the end of six weeks, these students were making factors of two and five differences in the parameters in the system without finding anything that markedly affected the behavior.

I was working on it, too, at the same time. And I should have done better, of course, having designed it and having thought it through. But I had gone into this without any understanding or expectation myself that it was going to be a recalcitrant system. This whole idea of low-leverage policies really began to emerge in that particular exercise. But I found that there were policies having to do with pricing and aggressive expansion that made a tremendous difference. And we talked a little bit about those last time in the context of a simpler model.

The urban work, at least my part of it, took a turn into larger social systems in the late 1960s. John Collins, who had been Mayor of Boston and spent his year in Boston politics, came to MIT and, by chance, took an office next to mine. And it was out of discussions with a newcomer that I began to feel out of his discussion of the urban crisis-- you may recall, some of you, that the main headlines of our great social problems in the late '60s were the urban crisis. The urban problem still exists. But they've been pushed off the front pages by more serious crises.

The urban crisis of high unemployment, economic backwardness, housing problems, all these were the social condition of our older cities in the late '60s. I talked to Collins about this and began to get a feeling that I've come to recognize in corporations-- it all seems to make sense. People have a good rationale for what they're doing. Point by point, it seems to be appropriate. And yet in some way, it doesn't hang together.

And so I said to him, wouldn't it be interesting if we would combine the background that we've had in a corporation with the knowledge of people like yourself in cities and see if we could come to any better understanding.

Now, a lot of people you make that offer to, and they say, well, it would be interesting to do that, but I'm too busy right now. Well, I suppose Collins wasn't too busy. But anyway, he wasn't the kind to drop an idea. And I said, we would have to have a group of people who knew cities not from reading about them, not from the library, but from really experiencing cities, their problems, watching what went on, knowing the internal politics and the difficulties.

And so he quizzed me more about the kind of people. And how much time would we need? I said, we'd need a half a day per week for nobody knows how long. We would have to talk and meet and see if we could make some sense out of it. Then he quizzed me on the kind. And his immediate response was, they will be here Wednesday afternoon.

And Collins' position in Boston at that time was such that he could call up almost anybody in business or politics and say, I want all your Wednesday afternoons for a year, and get them. And so he produced the group. And it was out of maybe four months of discussions that what came to be known as the Urban Dynamics model emerged.

I'm not going to go into much detail. But it's a model of nine principal variables-- newly constructed, medium-age, deteriorating industrial buildings, new premium housing aging into worker housing, additional worker housing being built, all of it aging into low-quality housing, such as you now see in Roxbury and Harlem. Those were premium houses at one time in many of those areas. But they have declined over the years. And then three categories of people-- the managerial, professional skilled labor and the underemployed.

The real essence of this model is that you build new structures until the land is initially filled-- given the technology and the number of stories being built and so forth-- till the land is filled. And then the structures begin to age.

And as the industrial structures age and move off to the right, the employment per square foot goes down. And as housing ages and moves to the right, the occupancy per square foot goes up. And so you have the stage set for a switchover in the relationship of people to jobs. I will show you some effects of that in a moment.

We said last time that rates of flow depend on the different system levels. In this particular model, each of these rates of flow probably depend on every one of the levels. And here is an example of the channels that run from the system levels to one of those rates-- the movement of underemployed people into the city.

There are a large number of non-linear table functions in the model. I will show you only one that I've already referred to-- the effective of land occupancy on construction. If there's essentially no city here yet-- there is some attractiveness, but not much. Not many people are going to move into a place where there is nothing-- but as the land becomes more and more occupied, it becomes more and more attractive as a center of activity.

So the so-called construction multiplier, the influence on construction from occupancy, goes up until the best land is used up and it's harder and harder to find the right place for the right thing. And naturally, at 100% occupancy, you can't build anything else. You have to clear something out. You have to back down from this in order to have room. Most cities run out here, I think, around the 80% level, more or less. And that's where the Urban Dynamics model itself runs, somewhere out in here, once it has reached equilibrium.

The behavior of this system is rather interesting. You can start with an empty piece of land. And the model will build a city. Here is a curve for skilled labor over a period of 250 years. Skilled labor peaking, declining some moving into equilibrium.

And I've given you two ratios out of the model-- the ratio of underemployed to jobs. If underemployed is low compared to jobs, the unity axis, unity ratio, being here, it means there is good economic opportunity. You can come and get work.

The underemployed with respect to ratio to housing is high. Large number of people compared to the housing. There is a housing shortage throughout this entire period of growth. And then as you reach the peak, as you reach the point where land is filled for the first time, a quick switchover in which the aging of the industrial and housing structures leads to a situation in which there is excess housing and a shortage of jobs. And you move then into a small number of underemployed relative to the housing and a high number of unemployed relative to the jobs, a description, essentially, of the urban stagnation situation that existed.

We looked at several national policies. And we found that all of the US national policies lay somewhere between neutral and highly detrimental from the standpoint of either the city as an institution or from the viewpoint of the unemployed, low-income residents-- either one.

Job training program can increase unemployment in the city. I discovered this one weekend in the model. I put in a job training program in the model one weekend at home, a perfect job training program. It simply took people out of the unskilled, underemployed area and put them into skilled labor, gave them all the cultural and all the educational background of being skilled labor. And furthermore, I didn't levy any cost on the city-- the absolutely perfect job training program. And I was rather surprised to find that unemployment went up in the city.

I brought this back the next week to our urban consultants and said, now what do you think of the model? If I put in a job training program, I have more unemployment. And they sat there in dead silence for about a minute. And then one of them said, oh. He said, Detroit has the best job training program in the country and the most rapidly rising rate of unemployment.

And then you looked at what was going on in the model, perfectly plausible. You were creating skilled labor beyond what was needed. You were creating an oversupply of skilled labor relative to what was there. This generated a spill off, a flow back into the underemployed, a fallout from that group.

Also, because you were supplying the skilled labor, it wasn't necessary for industry to reach into the unskilled pool and do its own training. So about half of what you did was lost by the system backing off and not doing for itself what you were doing for it.

And the other thing was that such programs have high visibility, and it drew people from other places. It was said that the Huff area of Cleveland almost emptied out in that period and went to Detroit because of the visibility of the job training program and the presumed opportunities that it would present.

Now, if you were in the late '60s and suggested that low-cost housing was not a good idea-- I think it's come to be rather much more widely accepted now than it was, maybe not fully. But at that time, it was a very emotional subject.

And one of the faculty members at our fine institution here came up to me after the book came out, looked right straight at me, and he said, I do not care whether you're right or wrong, the results are unacceptable.

Others, who probably felt the same way, put it a little more tenably. They said, it doesn't make any difference whether you're right or wrong. Those ideas will never be accepted by elected officials or residents of the inner city. It turns out those were the two groups we could count on for support if they got close enough to what was being said to understand it. Now, that's a very large if-- get close enough to understand it.

Our experience was that it took about three or four hours, almost one on one, to cross the boundary from emotional rejection to understanding what was being said. And my first exposure to this is still the most memorable.

Shortly after the *Urban Dynamics* book came out, we were putting on one of the periodic Urban Executives programs at the management school that were done every six months or so for a period of time. And I was asked to present the Urban Dynamics message and model and viewpoint on a Monday afternoon and a Wednesday morning for this program that was running for a month.

I have never had a lecture anytime, anyplace, on any subject go as badly as that Monday afternoon. In the audience was a man named Jean Calendar. He was with a group of Urban Executives, a man from New York City, and a department head in Lindsay's government in New York-- black, from Harlem, intelligent, articulate, not buying a thing I was saying and carrying the whole group with him.

He said, this is just another way to trample on the rights of the poor people. And it's immoral. He said, you're not dealing with the black versus white problem. If you don't deal with the black versus white problem, you're not dealing with the urban problem. When I said the trouble in Roxbury and Harlem is too much housing, not too little, he says, I come from Harlem, and there's certainly not too much housing in Harlem. And that's a sample of the afternoon.

Tuesday evening was a dinner for the group. Neither John Collins nor I were able to go. We weren't trying to avoid them, but we couldn't be there. But several of our students went. And after dinner, one of them called me up at home to report what was fairly obvious. And that was that the group was very hostile. Without encouragement, I started Wednesday morning.

About an hour into Wednesday morning, you could tell that Jean Calendar's questions or comments were changing character. They were beginning to be questions to elicit information. Two hours into the morning, he said, we can't let this subject drop at the end of this morning. We've got to have another session. I heard him the first time. But I don't think I let him know that I heard him. I wanted to see what would happen. I went on. And a few minutes later, he repeated it.

And I said, well, I would be happy to meet with them. I don't see any place in the schedule. But if you can arrange a time and place, I'll be happy to meet with you. I wasn't trying to put him off. But that's usually the end of that kind of exchange. But it wasn't. He went to the management of the program and got another session.

Then he made an appointment to come to my office. And what do you suppose he wanted? He said, would I come down to New York and discuss the urban problem with them?-- among his colleagues, his peer group, on his turf. He sat there just as relaxed as if he hadn't been to that last Monday session at all. He says, you know, it's not a race problem in New York at all, it's an economic problem.

He gave me a report out of his briefcase that didn't get to the *New York Times* for another nine months outlining the amount of empty housing in every burrow in New York and the rate of abandonment. The support for the idea that there was simply more housing than the economy of the area was capable of maintaining and supporting. That's what we meant by too much housing.

Two years later, a journalist came to me and wanted to know what had happened in the aftermath of *Urban Dynamics*. By that time, it had been a book debated in the PTAs and League of Women Voters over the country. And I said, well, I'm not the one to ask. Why don't you go and talk to some others? And I suggested that he talk to Jean Calendar.

Well, he did. He went to Calendar, interviewed for his article, and then called me up afterward-- the journalist didn't say that Calendar had told him that they don't just have a solution to the urban problem up there at MIT, they have the only solution.

Two years later back home, that conversion, that change was still with him. And I have seen it on two or three other occasions with people out of that particular kind of setting-- more and more negative, more and more emotional. And if you're watching closely, you can see when it happens. It just looks like they've been hit. Suddenly, everything that they have known fits into a new pattern, into a new kind of structure.

It's really quite a remarkable sort of transformation. But there's no solution yet to how you get very many people to go through that process. There's no mass production way that we yet know about that will really do it.

Out of this came the idea of an attractiveness principle for cities, attractiveness being all those things about cities that have anything to do with your liking them or not liking them-- the school system, the crime rate, the pollution, everything. And if you sum all of these up in some way, the assertion is that all cities are equally attractive to any particular class of person.

If one is more attractive than the other, there will be movement toward that city. And essentially, every dimension of attractiveness is depressed by rising urban population. The larger cities have a higher cost per capita to operate them. The crowding and all of its consequences reduce the attractiveness. And so there is a balancing process that essentially makes equal attractiveness everywhere.

And yet we find cities all the time trying to improve the attractiveness of the city, trying to improve something that is a weakness. And it never seems to work. Because it simply readjusts population, pulls them in. It would be much better if one would address the urban problem by saying, what are we willing to make worse? Because if you make something worse, other things will get better. But you have this balancing.

Just imagine the perfect city. Everything about it is the best you could ever imagine. What happens? It is flooded, unless you can, in fact, keep them out. I mean, some place like West Berlin-- very attractive city. But it's got certain things about it that make you not want to live there in the way of the political environment.

And so to even hold a population, all the physical aspects of the city have to be above average. And if you look around the world, you'll see, I think, that you can trace that idea of attractiveness into different contexts.

For the better part of a decade or so, we've been applying system dynamics toward a better understanding of economic behavior. This grew out of Urban Dynamics. I was giving a paper on Urban Dynamics at a joint NATO-US conference on cities held, of all places, in Indianapolis.

And out of the audience, William Beadle, who has recently retired as President of the Rockefeller Brothers Fund, came up and said they were thinking of doing something more than supporting the Boy Scouts, like they'd been doing, and he'd like to come up and talk about what we were doing and what we might have in common.

Out of that came a very large block of money to support the first four years or so of applying system dynamics to economic behavior. Since that time, the sponsorship has been diversified to 30 or 40 sponsors in the private sector. It's always been private sector money, almost no governmental money, except from Canada.

The approach here is to understand behavior-- going back to Professor Frieden's comment, not really for forecasting-- but to understand behavior and to understand how a behavior could be altered by changing the policies and structure of a system. That is the primary objective.

We entered it believing that what we discovered in corporations would prevail, namely if you build up a model from the internal [? find ?] structure of decision making, that you ought to find that it generates the behavior seen in economies.

Well, we succeeded, I think, beyond our expectations, or beyond our hopes. We find that we have an economic model that generates the major modes of behavior seen in national economies-- the short-term business cycle of three to 10 years between peaks, the economic long wave that I will come back to, money inflation, inflation due to rising money supply-- there are other dynamics of price change that go along with these dynamic modes-- and growth, growth from population, and growth from technological change.

The work that, I suppose, has caught people's attention most especially has been the work that we've done on the economic long wave. The economic long wave is the great rise and fall of the economic activity of some 45 to 60 years between peaks. The low points in those peaks have been the major depressions.

Now, what I'm telling you here is a personal opinion, an opinion of the group that we're in and an opinion shared by many people around the world who believe in the economic long wave. But there are many who don't. I would say in American academic economics, there's very little acceptance of the idea of there even being an economic long wave. So I gave you that warning and will proceed to give you my views on the situation.

The controversy, the reason why there's been essentially no belief in this phenomenon, is there's been no theory for how it could occur. And with no theory for how it could occur, there is a tendency to look upon any episode, like a major economic downturn as in the '30s, as being an accident, a happenstance, attributable to some non-economic external event, to a mistake by the Federal Reserve, or one thing, or another.

We got into it entirely unexpectedly. We got into it by having assembled some structures of consumer goods sector and a capital sector and finding that they interacted with each other to produce a huge rise and fall of activity with peaks some several decades apart.

Now, when you get an unexpected behavior out of such a model, your best guidance is to assume you've made a blunder, that there's something about it that is entirely unsatisfactory. But as I may have said last time, as the model gets better, there's a rising chance that it is telling you something about real life.

I'm reminded of Richard Foster, who did a system dynamics model of diabetes that [? weigh ?] the body controls insulin and glucose in various aspects of diabetes. And he found in his computer model some kind of patient behavior in response to some sort of test that had never been reported in the medical literature. And that raised the question about the model.

He took it back to the doctors at the Joslin Clinic. This was a Master's degree thesis in electrical engineering that he was doing with a professor in biology and his research with the leading doctors at the Joslin Clinic on diabetes in Boston.

He went back to the doctors at the clinic and said, now, how should we interpret this here? And he showed them the behavior and what had happened. They thought about it. And they said, well, we had a patient like that once, but we always thought it was a mistake in the measurements.

You see something unusual, very easy to dismiss in the complexity of real life. And a doctor who in fact catches those clues and eventually identifies something gets some new disease named after him, somebody's syndrome, you know, because he finally, by happenstance, saw what was going on. Well, here is the chance to find a new medical disease, sometimes even in a computer model.

Our interpretation of the long wave literature goes this way. It's a very controversial literature. First of all, there's the large block of people that don't believe there is any such thing. Then among those that do believe, there are many camps who believe in different causes, different unit causes-- it's caused by this, or it's caused by that. And very few see it as a system's behavior in which many things interlock.

The literature reminds one of the story of the four blind men and the elephant, each one looking at this phenomenon from a different viewpoint and drawing totally inconsistent opinions about what the real animal, the elephant, is-- is it a snake? Is it a tree? Is it a wall?, depending on what part you touch.

What we found in the national model is that all of these different interpretations had some element of truth if you could see how they were all tied together and interacting with one another.

Now, this is also known as the Kondratiev cycle, named after Nikolai Kondratiev, who did his work in Russia in the 1920s. And he came early on to really quite a perceptive insight into the essence of what was happening. He said, essentially, that it was the process of building capital plant and the financial markets that allowed the financial capital to build and to overbuild the capital plant and the peaking, the crescendo of rise in the economic long wave, such as we have experienced in the 1960s and 1970s and on into part of the '80s.

It's a building and an overbuilding of capital plants worldwide. We are now at a situation where there's excess capacity-- given the prices and the debt and the other things that surround it-- excess capacity in most industries. And those are now putting downward pressure on prices, beginning to raise questions about the ability to pay back the debt.

Here is a computer run from the model just to give you a glimpse of what it looks like. The black curve is employment over a period of 80 years, somewhat more than one cycle. Inflation. The green, nominal interest rate, bank interest. And the red, real interest.

Real interest, you know, is the bank interest minus inflation. It is the interest rate that tells you whether you want to buy capital assets. If you have high inflation at any given interest rate, then you buy the capital asset, like farmland. You sell it at the end of the year. It's worth more. And so that reduces the interest.

And for American farmland, the real interest rate went negative in the 1970s. There was a scramble to buy farmland. Farmland was driven up because this was the protection against inflation. Everybody wanted to buy it. The price went up because everybody wanted to buy it. It bore no relationship to its productive capacity. Farmland was selling at a level where the interest on the investment was as much as five times the earning capacity of the land-- land with no development potential whatsoever.

And of course, at some point up here, people say, oh, I wonder if this is real. And a few people back off. And as soon as they stop bidding up the price, there's no reason for it to be up there at all. The only reason it was going up was because it was going up. Now you're sitting up here with an entirely untenable price. And prices in the speculative bubbles always go down faster than they came up.

There seems to be a progression through the economy. Farmland is the first one to be overpriced and then hit and, probably, the equities market, as we saw the beginning last October of a downturn, the equities markets being one of the last in the sequence of assets that get overpriced and then hit a period of deflation.

Here, the real interest rate prior to the peak can actually go negative. Great incentive to purchase capital plant, physical plant, factories, farmland, everything else. And then right after the peak, that real interest rate rises precipitously.

Now, this is ordinarily blamed, as it's happening now, high real interest rates blamed on the Federal Reserve. Or the Reagan administration-- the press says, unprecedently high real interest rates. That's not true at all. Real interest rates went to probably 12%, 14% in 1931, so that you have, really, a situation where this comes up out of the private sector of the economy. In the national model, you can change Federal Reserve policies by big amounts, and you do not change the fact that you get this precipitous rise in real interest rate right after the peak. You can change it in detail. But it's fundamental to the internal dynamics of the way banking, business, households interact with one another.

Some people say we wouldn't have another major downturn, another major depression, because we would have learned from the past one. But what did we learn? There's still no general agreement as to why the 1930s occurred. And if there's no agreement as to why they occurred, then what is the lesson from them? And how do you know that one isn't going to repeat?

I think in these very complicated situations, the only hope-- it's not a hope that's been fully accepted by any means-- but the only hope is eventually to move down this road of dynamic modeling that ties the microstructure of the economy to the macro behavior, or the same thing for corporations-- begin to understand what is happening, why, and then see if there are high-leverage policies that you want to use that would alter behavior and make it more desirable.

There is, however, free room to debate as to whether you want to eliminate the great depressions, because they serve some very useful purposes of cleaning up people's acts and weeding out the inefficient corporations and opening a window of opportunity for new technological change and a lot of things that some people would consider undesirable if you actually got rid of the major depressions. So we could have an interesting social debate another time on that.

Out of all this come some general insights about the characteristics of these complex systems. They have a great tendency, great ability to transfer problems between sectors. If you solve a problem one place in the system, it reoccurs in a different form somewhere else.

Suppose the city is being troubled by congested highways leading in. So we build a lot of throughways. Next thing you find is that people build houses at the end of those throughways. And now you don't have any room in town to park the cars. So you build parking garages. And now lots of people can come in, so you need bigger office buildings. And now more people live at the end of the highway and drive into town. And now you're back to the highway congestion.

Just keep moving from one set of problems to another, always trying to alleviate a problem, always raising the total population trying to focus in that place, rather than deciding what the long-term character of the city ought to be. And how are you going to control it? What are you going to make undesirable enough that, in fact, you can maintain the kind of stability that might be desirable.

Trade-offs between the present and the future-- the idea that a policy that is advantageous in the short run is disadvantageous in the long run, and vice versa, and almost always true-- an idea that comes down to us from antiquity from fables-- the ancient Greek fables, *Aesop's Fables*, the grasshopper and the ant is essentially the story-- play and make merry in the summertime like the grasshopper and freeze in the winter, work hard and store up food and survive like the ant. That idea runs through a great deal of our literature, our religions.

But modern society has, for the most part, I think, adopted the feeling that they have escaped from those great truths. That is not correct. You find throughout models of systems that the trade-off between the present and the future is always occurring.

I just suggest you take any personal thing you do and say, if you maximize the short run, is there or is there not a detriment in the long run? Borrow on your credit cards, live it up this month. You have to pay the bills next month. And so it goes with almost everything that one does.

Transfer the burden to the intervener. All of our systems have the characteristic that if you come in and do something from the outside for the system, you take the pressure off so the system stops doing that for itself. And this is where the role of the intervener has on the whole been an unhappy one, doesn't do anything but run up the total tax cost for the government to come in and try to solve some of these social problems because the local parts of the social system then give that job to the intervener and use their own resources for something else.

Very few high-leverage policies. Combine that with the resistance of most policy changes. If one is addressing a group of corporate executives and you ask them this question-- have you ever had the experience of a major corporate difficulty and you have adopted a policy to alleviate that problem and five years later the problem is still with you? And fully 3/4 will hold up their hands. Because we spend in all of our social systems a tremendous amount of energy debating what to do about policies that are essentially very low-leverage and have almost no effect, regardless of what you do.

I would go so far as to nominate tax policy, which is always the focus in Washington, as one of those low-leverage policies. If you shift the tax burden from one group to another-- from individuals to corporations or from here to there-- given enough time, prices and wages will shift the money flows so that it goes to where the taxes are extracted.

We have had progressive income tax for years, partly justified on the assumption that it would equalize the economic status of different parts of the population. And I think it certainly has not done that. Because it doesn't have the leverage to make that kind of social change. Tremendous amounts of political energy go in to the debating of issues that make very little difference and not much realization that there are a few high-leverage policies and not much time devoted to finding them.

This is an interesting field if you like controversy. Makes life interesting. The debates about most of these books have been intense. Probably the most widespread, most intense grew out of the *Limits to Growth* book. Highly polarizing. Certain segments of the society strongly for it, others strongly against. *Limits to Growth* sold 400,000 copies in the first summer alone in the Dutch language. And I asked a man from Holland once why.

It was also estimated that the *World Dynamics* books-- my *World Dynamics* book that preceded *Limits to Growth*-- was sent out to a dozen or so members of the Club of Rome in manuscript form for their comments. And it was estimated that 50,000 copies of that manuscript escaped into Holland before the publication of the book.

Why? I asked a man from Holland that once. He says, well, if you'll just rank the countries of the world in the order of GNP per acre, we're at the top of the list. And we're closer to all of those problems than anybody else-- problems of industrialization, pollution, population density.

But one shouldn't be surprised at this kind of controversy, because even in technology one has controversies over new ideas. It took us seven years after we had demonstrated that magnetic core memory would work before industry would believe it. And then it took us the next seven years to convince them they'd not all thought of it first.

This matter of living dangerously means that you need to walk on the edge of the unknown. It's a little like walking on the edge of a cliff. You need to practice it. It's something you learn how to do. You have to calibrate yourself to know how close to the edge you can go without falling off.

Any new and important work means controversy. If it's new and simply authenticates what's being done, that's interesting. But it's not going to change the state of the world and, therefore, hardly is worthwhile. If it's new and differs with what's been accepted, then it's going to run into controversy.

One might say that the value of a new idea can be measured by the degree of acceptance of the viewpoint that's going to be overturned or measured by the stature of those to be proven incorrect. One has to venture out into that territory.

One needs to work and one has the opportunity here of working in the area of messy and poorly understood problems. They are no more difficult to make progress in. I think they're even easier to make progress in than the well known problems and areas, because they haven't been attacked. There is more opportunity. There is more pay dirt to be uncovered. And usually, a very small amount of dynamic analysis yields major new insights.

One of our PhD graduates who went to the Department of Energy told me in a visit once he was absolutely appalled at how much power and leverage a second or third-order model could have over the thinking in the Department of Energy. So there just isn't any dynamic thinking. And very simple models can have tremendous impact.

The academic culture, perhaps, leads to many PhD students and junior faculty into taking the small, safe steps. That, I think, is unfortunate. I try to challenge PhD students to answer the question, how will the world be different if you succeed? And if there's no answer to that, look for some other topic. Because there are these opportunities all around us.

Turning now to the future for a moment. The idea of computerized case studies, management case studies-- one area close to my interests in corporate management education world-- there is now an opportunity of bringing together some threads that have been developing throughout this century combining two threads of background.

The Harvard Business School launched around 1910 management education using descriptive case studies. Essentially, look at the situation from all angles. See what's going on. What policies are people following? What are the problems? How do they seem to be related? And talk about it in a comprehensive and evenhanded way. And try to come to an understanding of what's going on.

Very powerful source of information. It falters on the step where, having put all this together, you are then faced with that 20th or 30th-order dynamic system that you can't solve in your head. And so very often, the case study leads someone down the wrong avenue when it comes to what you do about it. But it's very powerful in mining information out of the mental models about the relationships between people and what they are doing.

From 1950 on at MIT, Carnegie, many other places, various aspects of mathematical analysis were brought to bear on managerial functions, largely in functions and not to a great extent in the overall dynamics of how the parts of the business and the market interact with each other-- to some extent, but not, I would say, very extensively.

The future going down this road, I think, is to combine the power, the information sources of the mental models with the computer simulation models that can give that mental information a context and show the dynamic implications of the interactions that are being discussed. Let me illustrate that with one example, what we call the [? Beadle ?] Express case. But first, I'm going to show it to you in the context of Barry Richmond's STELLA modeling software.

The STELLA software runs on the Macintosh computer and allows you to build on the screen-- even as you talk about the situation-- build a model of the relationships you're discussing. These little wells over here along the left side have the icons, such as you see out here, which you click on one and locate it where you want it and connect them together.

And as you do this, in the background, the structure of the equations is set up. And you open another window, and it prompts you as to what things you must properly connect up and say something about.

This is a little link out of training people, which we will see a more elaborate version of in a moment, where you hire people, they become trainees. After a certain training delay, they become experienced people. There's a lot of misunderstanding about what goes on in those chains. Down here is a hand that you use with the mouse to push these things around and get them where you want them.

A little more elaborate version of the same idea-- the inexperienced and the experienced people drawn out of the People Express case, which was originally developed by John Sterman, being pushed forward now by Peter Senge and our PhD students into some of the new ways of presenting it with the computers and working toward the idea of how you really use it in education.

But here, one sees hiring of new, inexperienced customer service managers, as they were called in the People Express Airline. They become more experienced people. And then you recognize that the inexperienced ones aren't fully productive compared to the experienced ones. And

Furthermore, the ratio of the two is very important. You flood the system with inexperienced people, and it actually requires experienced ones to train them. So you could possibly even reduce the total productivity of your customer service people, the ones handling tickets and baggage and arrangements and looking after the airline's customers.

People Express Airline was a very interesting story. At one time, it was the most rapidly growing corporation that the US, I think, has ever had, at least that got up to anywhere near the same size. It was discussed in the press as the great new phenomenon. Don Burr, who was president, was in great demand to make speeches to management schools and to managerial forums about his policies that were leading to this great success.

Don Burr's policies were well known. They were discussed in the *Business Press*. The Harvard Business School wrote up a case about them. Burr was very outspoken about his policies for how you build a great corporation. The policies that were discussed, I think, were the true policies that were actually followed. And John Sterman built a model based on this publicly available information about how People Express was being run.

The model itself in reduced overview form is there. I will just point out that there are seven of these rectangles in it. Therefore, a seventh-order system. Not very complicated. But it has some extremely interesting characteristics.

You take the well known published policies, and you get a behavior from them that looks like this. Very rapid growth. The passenger capacity represented by new airplanes rising like this, but faltering on this matter of service.

Don Burr started out to build an airline that had the lowest price and the best service. It was going to be the outstanding pleasure to ride on People Express. He under-priced at a factor of 2 under other companies and, of course, didn't have the revenues to give that high-quality service.

And then we talked about [? eroding ?] goals last time. Starting out with the idea that this is going to be your life's great experience in airlines-- and then as they failed to bring the service capacity up to the passenger capacity, service declined, the reputation went down, and Don Burr is quoted toward the end of his tenure as having said, "It's good for people to be under stress."

Profits went up like this and then down like that, because the load factor-- in other words, percentage of planes full-- ran from essentially 100% off to a level that could not be run profitably at the fares that they were charging.

Another very promising and interesting thread is the experimental beginning of this field encroaching into high schools, or being experimented with in high schools. Brattleboro, Vermont has a group of teachers who have for several years now been working in this area. Peter Bittner, who is in the audience, has been very much a part of that. He's from Brattleboro. If you're interested in firsthand information, he could tell you about it after the meeting.

The Educational Testing Service that runs these college admissions tests have some people that are following it and are interested. And I mentioned last time at the beginning that I came into this field under the tutelage of Gordon Brown. Now Gordon Brown has moved around to the other end of the field. And he is acting as the messenger to carry system dynamics into the Tucson, Arizona high schools.

A framework for organizing information-- the students already possess an extensive mental database about what goes on in families and school systems and towns. They would like to see that more organized. It becomes more effective information if they can organize it and put it together. I'm talking here about a dynamic framework into which to put what the person already knows at whatever point in the life he happens to be.

Personal computers, of course, make this-- and the STELLA software-- make this practical now in high schools. Nancy Roberts more or less wants this with her PhD thesis in education, a number of years ago doing experimental teaching of system dynamics at the fifth and sixth grade levels. The focus has been more on high schools recently.

Now, you might wonder why complicated, high-order dynamic systems can be dealt with at the fifth and sixth grade levels and high school. I've had some of our colleagues here argue, you can't do it until they're in graduate school. The reason is that we focus on systems in the context of integrations, not in the context of differential equations, or differentiation. And this, I think, is very fundamental.

Differentiation, I suggest to you, is a figment of the mathematician's imagination. It's been very hard to explain to students. And the reason that it's hard to explain is it doesn't exist. I defy you to find anywhere in nature where nature differentiates. Nature only integrates. Nature only accumulates. There are no processes of differentiation in the natural or social world.

And you see this immediately when someone tries to solve differential equations. Going back to Vannevar Bush's differential analyzer-- it wasn't a differential analyzer. It was built out of six integrators. If you want to put differential equations on a digital computer, you always reshape them into integrations.

This is important. It's not just a side issue. Because focusing on real life through differential equations and differentiation has an insidious effect on many students. It causes them to get an ambiguous, or even a reversed sense of causality. They do not see what is actually happening in the system or what the direction of causality is.

I've had students argue that there is no difference between saying that the water out of the faucet is filling the glass as against saying the rising water in the glass is forcing the water to flow.

Now, I gave you a diagram before where there is a control system and the rising water controls the flow rate. But if you just look at a steady flow rate, you don't properly look at it as something where it is the rising water that causes the flow. It is the flow, I suggest, that causes the rising water. Unless you get that direction of causality firmly in mind, and so firmly that you can see it in all sorts of physical world and social world situations, then there is a great deal of opportunity for getting things backward.

And to go back to the fifth grade and the high school, any child who can fill a water glass or steal toys from a playmate knows what accumulation or integration is. It comes absolutely naturally. And you don't ever have to suggest that it's difficult. And it never seems difficult.

And they can move right into Macintosh STELLA simulation. There are videotapes of high schools where the students are just riveted to what is going on and intense discussions among them as to what is happening, because they're completely involved in the dynamics of the processes they're looking at.

Going back to my opening comments about Tolstoy's vision, I think we should look forward to a bridge between the two cultures-- between technology and the humanities, between technology and the liberal arts.

There is a foundation underlying all of these fields, the ability to combine the technical, the social, the demographic, scientific, psychological, managerial, economic, and political into systems models to combine them when and as necessary so that one can see how they interact with each other.

I see this as, really, the great frontier of the next several decades, a frontier that is just opening up. But we'll address many of the major issues that modern societies are faced with.

[APPLAUSE]

I'll take questions, discussion. Anybody that wants to join this now? Yes.

**AUDIENCE:** My question is, what are the high-leverage policies that you see for this country in general? Perhaps we should speak on the global scale. Because it seems like things are, in fact, so connected now on the global scale that we are to talk about high-leverage policies, high-leverage issues on the global scale. And I agree with you about the [INAUDIBLE] issue.

**JAY** Well, in general, we haven't discovered the-- we haven't known the high-leverage policies before we started.  
**FORRESTER:** They only emerge out of a study of the system. The high-leverage policies are not always easy to implement. You may find that they are politically difficult. It will take a great deal of education sometimes in order to implement them.

Going back to the urban model, the only high-leverage policy that we found in that model was low-cost housing. And you should take it out, not put it in.

One published critic, one critic of the urban dynamics model, said, it's a very bad model, because he hadn't been able to find anything in it that affected the behavior. Well, that's just the experience of mayors for 20 years in cities. All those things they did essentially produced very little in the way of results.

The high-leverage policies seem to be those which are not embedded in a set of feedback loops powerful enough to defeat them. In other words, they produce a result without being counteracted by forces. You see the low-leverage policies, of course, all around us. Every president since 1960 has said he's going to come in and reduce the federal deficit. And every administration has doubled it.

And on the other hand, it need not be so. If there was enough conviction, if there was a realization that the trade-off exists between the short run and the long run, if there was a realization that in order to get to the good result, you're going to have some difficulty-- there's going to be political backlash, there may be some actual difficulties, problems that will emerge-- that there is this reversal. You must be aware of that and, therefore, plot a strategy with enough power and enough persuasiveness and enough support to carry you through that short period.

The short period may be pretty long. Because if you talk about this 50-year economic long wave, the transient dynamics of a 50-year phenomenon is decades long. And to alter it will take decades.

And I'm not sure of my facts here. We haven't really studied this carefully enough. But I would expect that if we had engaged in extremely tight monetary policy from 1960 to the present time, we would have choked off the excess investment in farmland. We would have choked off the high prices that have now become the source of so much difficulty. We would have choked off this massive merger movement that always occurs at the end of a long wave crescendo. We would have choked off a lot of the mischief being done there. We would have not seen all of these second and third mortgages on houses that are potentially a disaster area.

So let us say for the sake of discussion, with holding open the question of whether I'm entirely right, suppose that a very tight monetary policy from 1960, and engaged in for 25 years, would have been the right thing to do.

Now, I ask you, what constituency in this United States would have supported it? You can hardly imagine any constituency that would support it given the circumstances of the past. I'm optimistic. People accuse me of being a pessimist. But actually, I consider myself a realistic optimist.

And the optimistic part is that if we understand and if we find ways to teach and convey and if we get the whole idea of the nature of systems embedded early enough in our educational system, that in fact we could do even things like a tight monetary policy for 25 years if we felt that was the right thing to do. But it will take a different kind of view of systems than prevails right at the moment.

**AUDIENCE:** That has been done in other countries, though.

**JAY** Yes. You know, countries differ a great deal. And Germany has held a fairly tight monetary policy, has held down their inflation out of the trauma of the runaway inflation in the 1920s. Our government, which has mismanaged its economic policy and its inflation and its monetary policy, trying to get Germany to do the same thing. Maybe the Germans will hold their ground. Question over here?

**AUDIENCE:** I just have a short, little question about how some of your advice applies to things close at home, say, MIT, for example. Some people say that an optimist is one who thinks that things are controllable from within. And so if MIT is an optimistic organization, looking from your example of the long wave and where you mark the end of the long wave, how are you advising MIT or other groups that you advise on handling its investments?

**JAY** Well, there are lots of domains in which you could advise MIT, investments being only one.

**FORRESTER:**

[LAUGHTER]

But from the standpoint of investments, my advice is that you've got to, first of all, decide what your bets are relative to inflation. And that's essentially a political bet. Are we going to have a government that floods the system with money to bail itself out of debt or in the face of worsening economic difficulties? There is a potential for creating a runaway inflation like Germany in the '20s.

Right at the moment, it looks like deflation is the more likely. And deflation has always been historically what happens in a long wave downturn. We certainly have deflation in farmland. We have the beginning of deflation in the equities markets. What happened in October, my guess is, is the beginning, not the end. But one must decide how he's betting on inflation.

If you're betting on deflation, then, clearly, you want to invest in money assets, bonds, something of that sort, where they won't be defaulted, which is an interesting question to face. On the other hand, if you believe in runaway inflation, you want to invest in physical assets-- land and equities. And if you don't want to be all or nothing and want to hedge your bets, then half and half and know that you're going to be half wrong.

Basically, there's no place for everyone to hide in this kind of situation-- no place for everyone to hide. And so there will be a fair bit of carnage around here and there in any situation that works out the existing imbalances. The problem now are the tremendous imbalances in the system-- imbalances of too much production capacity in many industries, imbalances in people working in industries that will no longer be needed, the most obvious being those producing capital plant where we have too much of it.

But also, the service industry is highly vulnerable. It has normally resisted short-term business cycle three to 10-year fluctuations. But in a major economic downturn, the entire service sector is vulnerable.

And then there is the overhang of debt. The Latin American debt is greater than the net worth of the entire American banking system. The agricultural land debt is greater than the Latin American debt. The junk bonds debt used to acquire corporations is greater than the debt of Brazil. And the US government debt is skyrocketing.

And in a time of emerging adversity, there will be a scramble to try to unravel that debt. There will be defaults on some of it. But then there will be a tendency not to take out more, but to pay back, instead. And you can move into the so-called debt deflation spiral.

If corporations now start to pay back their debt-- they pay it back to a bank. You go into the bank and say, I'm going to pay back my loan. They say, fine. They mark off your note. And they subtract it from your checking account. And the money has disappeared. The banks make money and the banks destroy money in the process of making loans and having them paid back.

And so you buy things from the corporation. And they siphon money back to pay their loans, rather than hiring people. And so you have a falling money supply, which puts a downward pressure on purchases and production and prices. And you can get into a spiral in which even as debt is paid back, it becomes more and more burdensome relative to the prices and income that exist during that downward spiral.

Now, that's the sort of thing that happened in the '30s. We do not necessarily believe or say that the pattern has to be exactly the same another time. But we have an economy that's poised in a considerable state of imbalance. So the best advice, I think, I have is to hedge your bets and be cautious about the equities market, unless you want to take your risks on runaway inflation. But everyone to his own choice. And it takes all kinds of views to make the system run.

**AUDIENCE:** I have a two-part question. It has to do with Michael Dukakis. Have you advised him? Or do you happen to know what his [INAUDIBLE] thinking is?

**JAY** I am unaware that Michael Dukakis has any tendencies to accept system dynamics of [? life. ?] I have never talked to him. Albert Gore came up for a full day, spent a long, intensive day with us a year ago last summer. He was well-prepared. He'd done his homework. He asked very penetrating questions and gave every evidence that he-- well, said that he'd learned vastly more than he'd known before about economic behavior. But then these people are under so much pressure that they generally slide into a mode where they do not feel that they have time to learn.

**AUDIENCE:** What is the relationship between your sort of computer modeling and so-called artificial intelligence?

**JAY** I'm not really sufficiently immersed in artificial intelligence field to compare it with what we're doing. I'm afraid I would stereotype it and perhaps do it an injustice to comment on it. But that part of it that I know about tends to be more logical decision trees epitomized, perhaps, by automatic medical diagnosis-- here are the symptoms. What do they suggest? And you go through it down through a decision tree according to various rules to arrive at an answer. I'm not aware that it's gone very far into this ongoing dynamic interactions between parts of the system.

There have been people that feel there ought to be linkages. I don't hold any real opinion one way or the other, because I've not seen enough of where those linkages might be. It would be interesting. I would like to. But so far, I, at least, have not. Some members of our staff have been interested. Janet Gould has done some work in that intermediate area, and perhaps others. But so far, system dynamics and artificial intelligence are, I think, running their own independent courses.

**AUDIENCE:** It strikes me from what you've talked about today and also, I think, the brief mention of last week that there could be substantial application of systems dynamics thinking to psychotherapeutic models or, let's say, for individual, personal, as opposed to the urban growth or national growth, or whatever. And I was wondering if any work has been done along those lines that you might be able to say about that.

**JAY** The question deals with the possibility of system dynamics in psychological psychotherapeutic models. I think there is a very considerable opportunity here. And there has been some work.

I started myself many years ago working with Warren Bennis and Douglas McGregor one spring to move into the area of how groups interact with each other and how they build confidence and trust and what happens in, let us say, a group of businessmen getting together for one hour to discuss the United Fund, assuming it would be the same model, basically, as what happens to a group of corporate managers who get together to start a company over a period of 10 years, that you would see the same dynamics run over an hour when it didn't matter much to people that takes 10 years to play out when it really is crucially important.

That didn't go very far, because McGregor died that summer. And it was never picked up by that particular group. There is a paper that I found interesting-- there's some controversy in the system dynamics field as to its soundness. I've read it and found it very interesting-- by a psychologist or psychiatrist in Holland. That paper is available. I can't tell you the citation at the moment.

But it's a paper that deals with something called Freud's counterwill theory-- I'm on very thin ice here-- and purports to have made a system dynamics model based on what Freud said about such patients and that the model does behave like such patients. And to what extent Freud gave enough information to base it on, to what extent the model builder and others rounded out the story in order to make the model, I simply don't know.

But it's an interesting paper. And I was surprised at the sort of depth and, I would say, the satisfactory nature of the system dynamics insights that were expressed there. I think there have been a number of papers presented in the system dynamics annual national meetings. I haven't paid enough attention to them to give you citations.

There may be some articles in the *System Dynamics Review*. I would say those are two places if you want to link system dynamics to the psychiatric dynamics, then those proceedings of the annual meetings will run anywhere from 500 to 900 pages sometimes and have a lot of low-grade papers in them, but some interesting ones, also.

And I'd be happy to talk to you about it sometime in more detail. And maybe some other members of the staff at that time would have something to say on it.

**AUDIENCE:** Yes. I was wondering about the environmental models and if they [? remind ?] you that [INAUDIBLE].

**JAY** How I view what?

**FORRESTER:**

**AUDIENCE:** [INAUDIBLE], essentially a systems model of the environment.

**JAY** I'm not familiar enough with, I guess, the model or the hypothesis to address it directly. But there have been a

**FORRESTER:** good many people who have modeled various aspects of environmental interaction. An interesting paper that I encountered a while back was a woman at the [? Ohio ?] State University in Albany who had done modeling of the New York State's policies about the clam beds in Long Island Sound.

It seems the clam beds are being invaded by the whelks. I think they're these things with the big shells you find on the shore. And apparently, there's been no experimental demonstration yet of the maximum number of clams that a whelk can eat. It seems to be unlimited. And they are killing off the clams. So there've been various policies to deal with this, like seeding more clams. Well, that just feeds more whelks.

And so she went through the various policies, and even the politics of the different policies, and had some interesting conclusions. And there were some policies that came out of it that showed promise. I've forgotten whether it was a good policy or not, but one of them was to subsidize whelks for use as cat food. Yes.

**AUDIENCE:** What's the availability of the STELLA software?

**JAY** I beg your pardon.

**FORRESTER:**

**AUDIENCE:** How is the STELLA software available [INAUDIBLE]?

- JAY** STELLA software is available from a little company called High Performance Systems. I think it's in-- is the address Dartmouth, John?
- JOHN:** It's Lyme, New Hampshire.
- JAY** Lyme, New Hampshire. It's close to Dartmouth College. Barry Richmond's a faculty member at Dartmouth College. You could reach him there. My office can give you the actual address and phone number if you want it. It's a very nice system and a great contribution to the field. It is elementary. It's beginners.
- If you're really an expert in the field, you, at some point, certainly want to change over to Jack Pugh's Dynamo compilers, which are more powerful and in many ways more professional. But I would say for anyone beginning in this field, there's a very nice interface with STELLA. And so most of our people use both, depending on what they're up to.
- AUDIENCE:** [INAUDIBLE].
- JAY** Would you speak up just a bit?
- FORRESTER:**
- AUDIENCE:** In [INAUDIBLE], a common statistical technique called regression is usually applied to dependent variables to determine their sensitivity as they [INAUDIBLE] affect the independent variable. I was wondering if in system dynamics there's some similar approach to determine the sensitivity of feedback loops, how they may affect the overall levels in one's model.
- JAY** There have been various-- various people have looked at the problem of automatically searching a model for the sensitivity of different parameters. David [? Peterson ?] developed a program called [? Gypsy ?] that was used to tie historical data into a system dynamics model.
- Other people-- Nathan Forrester here in his PhD thesis and other people-- have taken matrix algebra processes a step beyond getting eigenvalues, or a couple of steps beyond, in order to search for the sensitivities of parameters and also which loops in the model are contributing to which kinds of behavior. Those techniques are all relatively new and, I would say, haven't been shaken down yet to know just where their major contribution is or the extent to which they will become an essential part of the field. Very promising, very interesting, but largely frontier and exploratory without the final story, really, of being in yet on them.
- AUDIENCE:** Some people say that our problems [INAUDIBLE] are due to the fact that people tend to focus in the present and not on the future, that they care more about what is going on now and that they don't care much about what will happen. Would you like to comment on this [INAUDIBLE]?
- JAY** Yes. The comment has to do with people focusing on the present, not caring about the future, or the implication of that to the state of our social systems. Well, there's certainly an element of truth in that. But in some ways, it's a recent phenomenon.
- You know, those of us, at least from the European background, are not very far removed from societies that could take 400 years to build a cathedral. Can you imagine this country embarking on something that would be 400 years to complete? Not really.

But my own background-- as the introduction last time mentioned, I grew up on a cattle ranch in Nebraska. My father was the original homesteader, the first private owner of the land. We're that close to the American frontier. And in that kind of setting at that time, there was a very long-range view. People knew what the future was going to be. They were wrong, but they knew what it was going to be.

It was going to be like that which they had always known. And they built buildings and barns and land for their children and their grandchildren, believing that they would live there. It is only since that time that the great mobility of the industrial society has begun to upset those values and those interests in the long run.

I would say that from the standpoint of the goals of a society, we tend to drift into the short run in our business and professional lives. But we all have a kind of a split personality. We're interested in a long-term future for the good of the country and our children and grandchildren and yet, on the other side, perhaps take very short-range decisions when it comes to creating that future, or take actions in the short run that defeat that future that we are really interested in.

I think my own analysis is that the great attraction of the *Limits to Growth* book, the popularity of it, the way it penetrated all kinds of society has to do with this issue of the latent interest in the long run, that it gave people a way to see how what we're doing now begins to tie together and what it could lead to, at least various possible scenarios for the future. I think part of the interest in those books is because there is a very deep concern in the long run.

And if we look at our various goals, our religious goals, the things that come down to us through our religious institutions-- have the role and purpose of providing some long-term goals. That's not always evident. I don't think the opportunities are always fulfilled. But there need to be institutions in our society that really focus on the long run and keep those images in front of us.

As I talk about this subject of the short run to members of Congress, I believe what they tell me that I'm going to tell you-- they know that they're doing more harm than good. And they're just as unhappy about it as they ought to be. But they don't know what to do instead.

They know that there's a short run/long run trade-off. But they don't know what the long run is. And when they're not able to cope with the long run, then they are pushed by the circumstances of the moment into what amounts to the short run.

I've had members of Congress tell me-- and I think they're sincere-- that if they just understood what was going on, they could then take a long run view. And if they understood what was going on, they could take even unpopular long run views, and they could carry their colleagues and their constituents. But, he says, if I don't understand what's going on, I'm helpless. I can't make a story that hangs together.

And so they are to be pitied, rather than censured. It is a very tough situation dealing with that kind of complexity. And those trade-offs are all around us all the time. I'm told that the *Denver Post* back in the '50s and '60s always had a little box on the front page, "The good news for today"-- "The good news for today," like the new factory being started.

You look back at these, and they're all the basis for the bad news of now. The good news of the '50s has that reversal. Denver was reported the other day the most polluted city in the United States, largely because of past good news.

**AUDIENCE:** If what you say about members of Congress is true-- and I think it may be true-- then it seems to me that the most high-leverage policy would be to educate the members of Congress.

**JAY FORRESTER:** The question is, wouldn't the highest-leverage policy be to educate members of Congress? Ideally and in principle, yes. But all you have to do is to sit in the office of a congressman for an hour, and you will see some of the problems.

There's that clock on the wall with blinking lights and bells inside it that tell you you have to vote. He has to get to the floor. He gets up, and some staff member passes him a slip of paper. It says, this is the way you want to vote on that one. And constituents coming in and, of course, already a firmly-established paradigm as to what makes the world work. And hard to shake yourself out of that.

And so I think, really, I come back to the high school understanding of dynamics, that, yes, you should teach congressman, but I think you need to teach congressman who are now 12 years old. All right. Maybe we have come to [INAUDIBLE].

[APPLAUSE]

**BERNARD FRIEDEN:** Jay, I think the audience has already thanked you for two wonderful and informative lectures. But on behalf of the MIT community, let me thank you for your many contributions over the years, including the one still to come. And I think you've given us the name of your next book-- *A Realistic Optimist*.

[APPLAUSE]