DENNIS FREEMAN: Everybody would like to believe that they just simply sort of think about the subject a little bit, and it will come to them. It's kind of like the osmosis theory of learning. But in fact, the way you get good at something is practicing. It's the same for music. It's the same for sports. It's the same for academics.

So the way you get good in this subject is to work on the homework. We'll give two kinds of homework. There will be conventional kinds of problems followed by engineering design problems. The conventional kinds of problems are intended to be the kinds of problems that have simple, unambiguous, easily checkable answers-- so well-defined problem, single, unambiguous answer, the kinds of problems that you might be expecting to see on an exam, for example.

But then we'll also have engineering design problems. Engineering design problems are intended to be a little more ambitious, a little more fun, a little harder, perhaps, perhaps not completely well-specified, sort of more like the kind of a problem that your boss might give you after you've graduated. So part of the exercise will be figuring out exactly how to convince somebody that you've got the right answer.

So those kinds of problems are often-- it will often be the case that numerics will help you in making an argument. So it often will be the case that we'll ask you to plot something. Or maybe you just decide that a plot is the most effective way to communicate your result.

We are completely ambivalent about what programming language that you use. Since 6.01 and 6.02 are prerequisites, we assume you all know Python. So all the examples that I give in lecture handouts or in homework solutions will be in Python.

But if you'd rather use Matlab, I just don't care. OK, we're completely ambivalent about what programming language you use. But it will be important that in some of the problems you'll find that useful to be able to generate a numerical kind of solution.

These are very different kinds of problems. And to help you with both of them, we have a different idea about each. So to help you with the conventional problems, the kind that have precise, easy-to-check answers, we've developed for the first time ever over the summer a tutor-type environment for 6.003. So this was intended to be like the tutor environment that we use in 6.01. It's one of the more popular aspects of 6.01, the fact that you can put in an answer and hit the button that says Check. OK, so we're going to have one of those.

So the idea is going to be that in the case that we ask you a simple question that has a precise answer, we'll use a tutor environment to let you check your answer to see if you got the right answer. In the case of the engineering design problems, that won't be the case. It will not be the case that it's very easy at all to think about a computer program that would check you.

So the alternative is going to be that we will have extended office hours. So we're going to have something that I think of as open or block office hours. Monday and Tuesday afternoon and early evening, we've reserved the basement of Stata, 32-044, for use of this class, the idea being that that's a nice space you can just come there to work any time you want to

hopefully because it's nice, and hopefully because you all know that there will be other 6.003 people there, you'll just decide that's a good place to work. And that's convenient because in these engineering design problems, if you run into something that's unclear to you, we don't really want you to spend an hour pondering what was being asked. So we want to make it easy for you to get help. And you can get help from peers, from other students who are there, but we'll also make sure that there is at least one 6.003 staff member there all the time.

OK, so the homeworks will be due on Wednesday. That's the strategic value of Mondays and Tuesdays. So you can use that time to get ready for turning in the homework on Wednesday. Questions or comments?

OK, we're required to say something about what we mean by a collaboration policy. So in this course, we would like you to talk to each other and help each other figure out what's going on. At the same time, we'd like to reward you for being on the honest side, by which I'm going to mean, if you sign your name to something, you actually did it. So we'd like to believe that the homework that you turn in under your name, you did.

You're perfectly welcome to talk to each other, to talk to the staff, to talk to friends who took this course previously. Get all the help you like in trying to understand the concepts. But when it comes down to writing up your homework and turning it in, we expect that what you signed your name to is something you did.

If you got especially large amount of help at the conceptual level, we'd like you to acknowledge that. You don't need to acknowledge that the TAs helped you. We expect that. But if you collaborated with somebody to understand what the problem was, we'd like you to tell us that. Just write at the top, collaborated on figuring out the concepts with so-and-so. But we'd like you to have written your homework.

So for example, we would like you not to say, I copied so-and-so's is homework word for word even though that's an honest statement, that's not something that we're actually looking for. OK, is that clear? We want you to work together, but we would like you to write up your own solutions.

OK, we have firm deadlines. The homeworks will always be due on Wednesday. You'll be able to slip on one without penalty.

So if you turn in one late, it won't change-- it won't have any effect on your grade whatever. If you do twice, that could have an effect. Unless you're excused by a dean or an instructor or a medical person, that submission will count half what it would normally count.

I should have mentioned when I was talking about homework, homework 1 is already posted. It will be due next Wednesday. The online submission part is almost ready to be posted and will be posted later this afternoon. So right now, you can see all the problems. But the online will become available this afternoon.

OK, here is 003 at a glance. It's not too unlike what you might have expected. Just a couple of things to point out, the order of coverage is not the same as the order of coverage in Oppenheim and Willsky. The reason for doing that is that having taught this class for 15 years, I just think there's some subjects that are easier starting points than others.

So I'm doing what I think is the easiest entry to this material with the idea that after you've got the easy stuff under your belt, it's easier to move on to the more difficult material. So the order is not precisely the same as that in Oppenheim and Willsky. But there is a map on the website that gives you a week-by-week breakdown of what part of Oppenheim and Willsky are we working on right now.

So Oppenheim and Willsky is the recommended text. But it's not quite in the regular order of Oppenheim and Willsky. See We will eventually cover exactly the same material that is in-- Oppenheim and Willsky was written for this class. We'll cover the same material, just not quite in the same order.

Another thing to notice is exams. We'll have three midterm exams and a final. The midterm exams are all evening exams, 7:30 to 9:30 on Wednesday evening. The idea is that there's intended to be a gentle ramp through the exams. Exam 1 is worth 10%. Exam 2 is worth 15%. Exam 3 is worth 20%. The final exam is worth 40%

so the idea is that if you have a mismatch on the way-- if you don't quite understand the way we're going to be asking questions and so forth, there's not a big penalty for screwing up the first exam. That's the idea. So there's intended to be a gentle ramp in how much of the exams count.

OK, and finally, I'd like feedback on what you think is happening. So I would like to ask for a few volunteers-- few is four or fewer-- who would be interested to meet with me once a week just to tell me what you think. Ideally, those people would be kind of outgoing and tell me things that other people think too. But if you're completely introverted and want to only tell me what you think, that's fine too.

So this is an opportunity for you to tell the staff, to give us feedback on how things are going. We're going too slow. We're going too fast. We're going too boring. We're intensely too interesting, that kind of stuff.

And it's an opportunity for you to understand our perspective. Well, the reason we did that was blah. And you can tell us, yeah, but that's not important. So it's an opportunity for you to convey to us how you think things are going and how you think things should be different.

It's also an opportunity for you to learn about teaching. So if you think about teaching as a career, it's a good thing to do-- completely voluntary, has absolutely no effect on your grade. If you think you might be interested, it's probably going to meet on-- we'll probably meet on Thursday afternoon. But that's negotiable since it's only four people. And if you are interested, please send me an email. And the first four people who ask, they're there. OK?

That's it on administration. Are there things you'd like to know about course administration before we go on to technical things? Wonderful.

OK, this course is about systems. This is not the first course you've had about systems. You've had lots of courses in systems. Every physics course you've ever taken is about systems.

What's different about this course is the way we think about systems. We think about systems in a particular way that turns out to be extraordinarily powerful, useful, shows up all the time.

And that's what the focus of the course is. That

The abstraction that we're going to use is we think about a system as a thing that has an input and an output. Given the input and the system, you can compute the output. Systems have one input and one output. It's a very special way of thinking about a system that turns out to be surprisingly powerful.

It's so powerful that that's really the thing that we will focus on in this class. So it's the thing that I will call the 6.003 abstraction. That's going to be the theme in everything we do, that representation.

And the best way to get across, I think, how that's different from other representations that you're already quite familiar with is to just look at an example. So here's a system that I'm sure you all know all about. Right? This is not the first time you've seen this kind of a system.

So you all know how to do this. Free-body diagrams, F equals ma-- there's an enormous number of ways that you can analyze such a system. We're going to take a very special approach where we think about the system as having an input and an output.

OK, that's a little bit arbitrary. We'll say a little more in a minute about how arbitrary it is. But the idea is going to be that this system, the mass-spring system, the anvil with a spring, there's an input, and there's an output.

So for example, for some particular purpose, I might want to think that the input is the position of my hand. One reason I might want to think about that is it is under my control. So it might be reasonable to think about my hand being the input.

So for example, my hand can do this. Right? So I might think about the position of my hand being the input. So if I did that, then what I could do is characterize the input by some waveform, a signal.

In order to use the abstraction, I also have to say what the output is. I might be interested, for example, in knowing the position of the mass. Then the output would be the displacement of the mass.

That assignment of input and output is somewhat arbitrary. I get to choose that to make the problem that I'm interested in as easy as possible. So for example, if I'm thinking about this mass and spring system here, using my hand as the input, that seems kind of natural because that's the thing I control. Thinking about the position of the mass as the output, that seems reasonable because that's the thing you can take a picture of. It's the thing you can observe from where you are now.

But it's not unique. I might have wanted to think about the force that I'm putting into it as in the input. I might have wanted to think about the output being the acceleration of the mass. Maybe there's some limit to how much acceleration some mass can take.

So you get to choose the input and the output. But you have to choose an input and an output. That's part of the abstraction. And that's part of the power. We'll see later that part of the power of doing it this way is that you draw attention to the things of interest and push into the background the parts that are not of interest, at least not now.

This kind of an abstraction is an extremely versatile. Here's a completely different kind of problem. Imagine water flowing into a tank. The tank is leaky, so it flows out. There's a second tank.

OK, what on earth could this be? This could be-- maybe this is the-- it's appropriate today. It's raining, or it was raining. It was pouring. Rain When I came in, it was pouring.

Maybe this is nature delivering rain. This is the Woburn reservoir from which we get water in Boston. Maybe this is the Fresh Pond reservoir from which we get water in Cambridge. Maybe this is the rate at which water goes from Woburn to Fresh Pond. Maybe this is the rate at which water leaves Fresh Pond and goes into consumers' houses.

The point is that there's some abstraction. There's some physical-- actually, I didn't say that right. There's a physical thing-- rain, Woburn, Woburn reservoir, Fresh Pond reservoir, consumers' houses. There's some physical thing. There's some laws of physics that dictate things.

But we ignore-- or ignore is not quite the right way to think about it. We think about those rules of physics as rules that govern the input-output relationship. So we think about then the entire system.

Rather than thinking about it as reservoirs and rain and water and flow and all that sort of thing, we think about it as there's a signal in, rain, and there's a signal out, water usage. And we take all the details of the system and bury it in this box. It's an abstraction. It's a way to suppress some details to highlight others.

OK, and we use this in a huge variety of situations. We can think about a third example here, our cell phone. Cell phone is an enormously complicated system. But for the purpose of understanding the input-output characteristics, if what I really want to know is how good is the quality of the audio-- not that that's even a little bit important for cell phones. Right?

Cell phones are important for texting and taking pictures and have nothing to do with voice. But in the old days, cell phones had to do with voice. And I made this slide back when that was still true. So I apologize it's out of date.

So here, the important thing of the cell phone system was the sound in and the sound out. And the idea was to represent the cell phone system by the transformation between how the sound comes in and how the sound comes out.

OK, so we do this for an enormous number of reasons. One is that it's widely applicable. You can do this kind of a characterization for systems from electrical systems, mechanical systems, optical systems, acoustic systems, biological systems, financial systems, all over the place. That means that this kind of an approach is very powerful because it's so widely applicable.

It also means that, for example, every engineering discipline everywhere has some course like this. It's just too powerful not to do it. So regardless of what department you were in, in the School of Engineering, for example, there is something like this.

Another reason this is interesting is that it provides a layer of abstraction that lets you focus on certain things. So for example, let's expand on the cell phone network. Imagine that sound comes into a cell phone. Well, the job of the phone is to communicate to a tower. And that communication is via some electromagnetic signal.

Then the job of the tower is to communicate with another tower. That happens in all kinds of ways. It could be a fiber optic link. It could be a satellite link. It could be electromagnetism. It could be lots of different things. There's a lot of different technologies for getting towers to talk to towers.

Then towers talk back to cell phones via electromagnetic signals just like these. And the cell phone eventually generates an acoustical output. The idea is that by thinking about the signals and systems approach, we have abstracted away everything other than the flow of information. It makes it easy to concentrate, to follow the flow of information through a complex system.

Because we have pushed every element into the same framework-- every element has an input and an output-- regardless of the underlying substrate, the analysis is similar. That means that components that are characterized using this abstraction are easily combined.

So we refer to this as-- we say that these systems are combinational. Their combinational in the same sense that Python was combinational in 6.01. If you represent things by Python functions, it's very easy to combine the functions to have a bigger function whose purpose and details can be understood without knowing what was inside every individual function.

Similarly here, by knowing the input behavior-- the input-output behavior of the cell phone, the input-output behavior of the tower, the input-output behavior of this tower, it's easy to compose then. And in fact, we'll spend a fair amount of time thinking through the rules of combination.

So that's kind of an overview of the most important thing we're going to talk about in this class, which is the 6.003 abstraction, the idea of representing a system by the way it transforms an input into an output. So with that kind of overview, what I want to do next is say a little more about what are signals and what are systems. It's the signals and systems abstraction. We're going to need to know some more details about what is a signal and what is a system.

So basically, a signal is just a mathematical function. In all the examples I talked about so far, and in many of the examples that we'll talk about throughout the term, the function is a function of time. And the signal can have many different dimensions.

So for example, the mass-spring system evolved as a function of time. The tank system, the leaky tank system evolved as a function of time. The cell phone system had acoustic signals that were functions of time. Time was the same in each case. But the dependent variable can be a variety of things.

Here it was position. So here it was flow rates, meter cubed per second of water. Here it was perhaps pascals, some unit of pressure to characterize the acoustic waveform.

So the point is that signals are generally functions. We'll see that just like functions in mathematics, there's a lot more to functions than dependent variables and independent variables. And in fact, that's going to be a key feature of our analysis of signals. But that's to come. So for the time being, the simplest and complete model for what a signal is is it's just a function.

The function doesn't have to be a one-dimensional function. In fact, a lot of the interesting applications of signals and systems is to look at multi-dimensioned functions. So for example, my research is in hearing.

I'm interested to study how do the cells respond to sound so that we can understand how broken ears work differently. When you have a hearing deficit, like I do, when you have a hearing deficit, what is the manifestation of that at a signal-processing level? How do the cells respond differently to people who have impaired hearing from people who have normal hearing?

In order to study that problem, we take video pictures of the cells at large magnifications and watch them wiggle when sounds hit them. So that's a picture-processing example. So the signals, the independent variable is not just time. It's a picture. So it might have x and y.

In fact, the pictures we take are three dimensional. So it has x, y, and z. And in fact, they're four dimensional because they change with time. We apply this kind of a technique on 4D signals-- x, y, z, time. But it's still the property. It still has a property that the signals of interest are functions.

We will be especially interested in this class in two distinct representations of signals. We will call them CT signals and DT signals. CT is continuous time. DT is discrete time.

We're very interested in that because we're engineers. A lot of physics lives in continuous time. OK, the mass-spring-dashpot system, the signals were functions of time. Time was a continuously varying independent variable.

So the leaky tank, the cell phones, those were all systems whose signals evolve in time. So they're all continuous. You can start with a second and break it in half and get a half a second and a half, and a half, and a half. And there's no limit to how many halves you can take.

By contrast, a lot of the systems that we will look at are things that evolve in discrete time. What's your bank account? Well it only gets computed once a day. So it doesn't make sense to talk about your bank account at 9 AM and 2 PM. Right? The bank updates your account once a day. So it's something that happens in discrete time.

It's something that happens in all computational systems. So computational systems generally operate on signals that are functions of discrete time. What was the state at time zero? What was the state at time one? What was the state at time two? So the system is something that eats a discrete time signal and generates a discrete time output signal.

And a unique part of this class will be converting between the two representations. Because as engineers, we often want to build something that operates in the physical world-- masses and springs and reservoirs and that kind of stuff-- and do the processing computationally. Ever since the advent of digital electronics, it's just much easier. Digital one, it's just much easier to process signals in the digital domain.

So we will often be interested in, how do you represent a signal who naturally lives in the physical world, and is therefore a part-- whose signals are continuous in nature, continuous time, how do you convert it into a discrete representation so you can crunch it on a computer? And in fact, how do you go back?

So for example, if we were thinking about processing audio signals, we might want to think about how we would take a signal of continuous time and turn it into a discrete time representation. That's precisely what we do when we want to record something in MP3. MP3 represents a sound.

A sound is something that I think of as a signal in continuous time. It's pascals as a function of seconds. But we want to represent it by a sequence of numbers because it's a sequence of numbers that's easy to store, to communicate, et cetera.

We do the same sort of thing with images. The images of the ear that I talked about in my research are things that I think about happening at continuous space. Every time we look at a smaller and smaller dimension, we get a different answer because the image has no quantization in space. But when I crunch it, I don't want to work in something in continuous space. I want to work in a sampled version like a JPEG version.

Similarly we want to convert back. I mean it would be useless for the case of the cell phone to convert it into a discrete representation and then not be able to hear it. So we'll think about the inverse process, which is reconstruction. If you had a discrete representation of a signal, how would you turn it into a continuous representation?

And there's lots of ways people do that here's a way that we call zero-order hold where you convert every sample into a corresponding voltage and just hold that voltage until the next sample comes along. This is the representation that is most commonly used in things like MP3.

By contrast, we might do something cleverer. We might literally extrapolate between samples. That is commonly done in picture processing. The reason we use the two different schemes is that psychophysically, the things that are important to your eyes and the things that are important to your ears are different.

So you would hear the errors more if you did the linear interpolation. And you would see the errors more if you did the other interpolation. And we'll do lots of examples later on in the course so you see why that's true.

OK, too much talking, not enough thinking-- so I've told you a lot about signals. Now, I'd like you to think about some signals. And so a common thing I'm going to do in this class is ask you to think about a question, talk to your neighbor, come to a consensus, and then vote. So that's what we're going to do here.

I'm going to play some sounds. You're going to try to figure out what signals were represented by those sounds. But I would like you to have an opinion before we communicate the answer because you can prove that people get more out of it when there's something at stake.

So I would like you to work with a partner. So in order to work with a partner, everybody stand up. Introduce yourself to your neighbor. Figure out a good partner. Figure out where they live.

[CLASSROOM CHATTER]

OK, so what I'm going to do now is play a computer-generated sound. This is a computer-generated speech sound made by Bob Donovan who did his PhD thesis figuring out how to do computer-generated speech. And then I'm going to play four transformations of that sound. And your task is to identify what's the mathematical representation of the transformations that I'm telling you.

OK, so first, the original. First is the signal that Bob Donovan made.

COMPUTER-GENERATED SPEECH: I must apologize for speaking [INAUDIBLE]. But you see, I have no brain.

DENNIS FREEMAN: And now, I'm going to play a sequence of four transformations-- one, two, three, four. And the question is going to be is this the correct mathematical representation for this sound. The sound you just heard was f of t. Is the following sound, which by definition is f1, the same as f of 2t?

COMPUTER-GENERATED SPEECH: [INAUDIBLE].

DENNIS FREEMAN: You're allowed to talk.

[CLASSROOM CHATTER]

OK, remember that answer. Now, is the following sound minus f of t.

COMPUTER-GENERATED SPEECH: [INAUDIBLE].

[CLASSROOM CHATTER]

DENNIS FREEMAN: OK, remember that answer. Is the following sound f of 2t?

COMPUTER-GENERATED SPEECH: [INAUDIBLE].

[CLASSROOM CHATTER]

DENNIS FREEMAN: And finally, is the following signal one third of f of t?

COMPUTER-GENERATED SPEECH: I must apologize for speaking [INAUDIBLE]. But you see, I have no brain.

DENNIS FREEMAN: OK, confer with your partner. Figure out how many are true. Because in 30 seconds, I'm going to ask you to raise your hand.

[CLASSROOM CHATTER]

Question or?

AUDIENCE: Question, f of t [INAUDIBLE]?

DENNIS FREEMAN: f of t was the original signal.

AUDIENCE: I know, but like [INAUDIBLE].

DENNIS FREEMAN: Ah, pressure, pressure in the acoustic waveform.

AUDIENCE: If you were to have minus f of t, your ear wouldn't [INAUDIBLE].

DENNIS FREEMAN: That's true.

OK, how many of those statements are true? Raise your hand with some number of fingers, keeping in mind that you're voting having collaborated with your partner. So it's not your fault. You have a-- right, anyway.

OK, so how many? Everybody raise your hands. I want to see. OK, it's about 90%-- no, less than that about 85% correct.

OK, so first one, was that f of 2t?

AUDIENCE: Yes.

DENNIS FREEMAN: Why do you think that? Everybody seems to be saying yes. It was fast. It sounded faster. So what's faster mean from a signal point of view?

AUDIENCE: [INAUDIBLE].

DENNIS FREEMAN: Change the time scale. That's a very good way of thinking about it. So if we thought about-- if we made a simple representation for f-- ignore what it really is. Let's say it's that. What would f1 look like in order to make it sound faster?

AUDIENCE: [INAUDIBLE].

DENNIS FREEMAN: OK, we have people doing this. And we have people doing this. And I'm not quite sure what that means. So could somebody be a little more descriptive? Hand gestures are fine. Yes.

AUDIENCE: Squished.

DENNIS FREEMAN: Squished, exactly right. So what we want to have happen, in order to sound faster, we want to have it come out faster. So we would like that to happen to it. So it's all over in one second if the original was all over in two seconds. Right? That's what faster means.

So we would like that to be true. Is that what's going on in that function? Yeah. OK, so that's right. Secondly-- yes.

AUDIENCE: Is that the reason also why it was higher pitched?

DENNIS FREEMAN: That also makes it higher pitched. In fact, we will talk a lot about this later. But pitch has to do with a related kind of waveform. If I thought about a waveform that was a single tone, that might look like this.

So if you were to play an oboe and play just a C constantly, you'd get some periodic waveform. If I did the same transformation on that periodic waveform, what would happen to that waveform? What would happen to this if I did transformation one? Squish, what's squish mean? More higher frequency, more cycles per second. Yeah.

AUDIENCE: So how can you make the same waveform go twice as fast, but have the same pitch [INAUDIBLE]?

DENNIS FREEMAN: That's very hard. In fact, I worked on that as a research project. So one of the techniques that we used to try to fix people's ears-- it turns out that people who have hearing disorders like mine can more easily understand male speech than female speech just because of the shift in frequencies. Male speech is primarily about an octave lower on average than female speech.

So we tried to convert every female into a male speaker and every male into the Jolly Green Giant. And it worked. Males sounded like the Jolly Green Giant. And females sounded like males. And it didn't help hearing at all.

And that's primarily because it's a hard problem. But we will say more about that as we go on through the course. That is a hard problem because you end up having to do other than just squish.

OK, second one, is this is the right transformation? No, why not?

AUDIENCE: [INAUDIBLE] so most of the speech is measured in the frequency domain. But if you just flip over the amplitude, it shouldn't really make a difference

DENNIS FREEMAN: If you flipped over the amplitude-- so flip over the amplitude, you're saying that didn't do it. What was the transformation? If it wasn't flip over the amplitude, what is it? Yeah.

AUDIENCE: f of minus t.

DENNIS FREEMAN: f of minus t-- it was flipped this way. Right, flipping this way is largely inaudible. If you had a pressure waveform versus a rarefaction waveform, positive pressures versus negative pressures, it's very hard to tell. Not impossible, if you're one of those audio types like me, you can probably hear the difference. But it's very hard. Hearing this, not hard.

OK, how about this one? Obviously wrong because this one was right. OK, how about this one? Yeah. So the idea was that there were two that were correct. So the 85% of you or so who got two, presumably you got the right two. Right? But I won't ask.

OK, here's an image processing question. Think about this picture of Stata. I know it's hard to think about pictures of Stata. That's OK.

Think about this picture is Stata. I have indexed x and y. And I've written that as f, a signal that depends on two independent variables, x and y. And I've got three transformations-- the f1 transformation, the f2, and the f3.

The question is, is this the right mathematical representation for transforming that picture into this one? Is this the one for that one? And is this a representation for this one? Is this the representation for that one? Take 30 seconds, talk to your partner, and figure out how many of those transformations are correct.

[CLASSROOM CHATTER]

OK, so how many of the transformations are correct? Raise your hand. Everybody raise your hand. That's a zero or a three? OK, just checking. OK, about 85% correct again. OK, probably a different 85%.

So how do you think about this problem? So there's a variety of ways you could think about it. Let me show you a way that focuses on an idea called mapping because I think it's a very powerful way. So if you think about a map, how does the t variable in the first problem map to the t variable in the second problem?

So a way you can think about this is if this is true for all x and y, it's true for a particular x. So let's ask is it true for x equals 0. So how does the point x equals 0 map from one image to another?

So if you substituted x equals 0, then f1 of 0-- so if you look at this transformation, the claim would be that f1 of 0 is the same as f of 0. Is that true? So f1 of 0 bisects Stata. f of 0 bisects Stata. So yeah, that's the right thing. Everybody see that?

Is the statement true for x equals 250? Well, f1 of 250-- so f1 of 250 is through the right-hand side of Stata sort of where the steel and the bricks come together. Is that the same as substituting in here, if x is 250, then f of 500-- f of 500 is off the screen. So is that transformation hold at the point x equals 250?

No. OK, it can't be right. OK? One bad sample proves that it can't be the general transformation. OK, everybody see that?

Similarly, for the second transformation, let's just try some points. If we try the point x equals 0, this says that f2 at location 0 should be f at location minus 250. Is that correct? So f of 0, well, that's the left-hand side of Stata. And so f2 of 0, that's the left-hand side of Stata. f of 2 times 0 minus 250 is f of 250 minus 250, that's also the left of Stata.

OK, so by using that reasoning, you can go through and see if certain points map to the corresponding place where they were supposed to go. That's the idea of mapping.

And in this particular case, if we traced two points, and the map 2x minus 250 is a linear function of x, so two points determine a straight line. So after you've determined two points, you're done. Seem right? So similarly, you can figure out that the particular points didn't work here. And so the answer is that only one of those transformations was right.

OK, so I spent a fair amount of time on signals. In the last minute, oh, minute, no, I'm not going to do that am I. OK, I spent a fair amount of time talking about signals. Next time, we'll talk about similar ways of thinking about simple systems. So have a good weekend.