CHAPTER 6: FEEDBACK

PROLOGUE

> ***In times of change, learners inherit the Earth, while the learned find themselves beautifully equipped to deal with a world that no longer exists.***
>
> ***--Eric Hoffer***

In this chapter, we're going to be talking about how systems respond to changes in themselves and their environments at the most basic levels by introducing the idea of the feedback loop. Ideally, you'll be reading this chapter in the middle of doing Lab 5; that is, you should have started the experiment and gone as far as you can by yourself before hitting this book to see if you can find answers to some of your questions.

After working through this chapter, you should be able to walk around in your normal life pointing out feedback loops in different types of systems, both engineering and non-engineering. You should be able to formulate and present a plan for learning about the feedback loops you identify so that you can understand, model (mathematically, in computer simulation, in small-scale physical simulation, or otherwise) and ultimately change that part of the world to be more like what you'd like it to be.

STEP BACK: HOW'S THE CLASS GOING FOR YOU?

> ***If you don't like the way the world is, you change it. You have an obligation to change it. You just do it one step at a time.***
>
> ***--Marian Wright Edelman***

Before we launch into new material, let's take some time to step back and look at how your learning is going.

What did you find difficult about doing the lab? Where did you get stuck and why? Are these the same types of things you've gotten stuck on many times before, or are they changing? (If they are, that's usually a good indication that you're learning how to learn.) What things are going smoothly for you – what strengths do you have (whether it's doing math, explaining concepts to a friend, being able to see interdisciplinary tie-ins, drawing beautiful diagrams) and how can you capitalize on these? You don't need to turn in answers to these questions.

We'd also love to get your thoughts on how the course itself is going so far. Please email your responses to these questions to your NINJA.

1. About how many hours are you spending on this class per week outside of lecture, lab, and office hours?

2. How do you feel about the number you gave for (1) - is it too high? Too low? What can we do to make it the number you'd like it to be?
3. How have we been doing on covering the material so far? Are we going too fast? Too slow?
4. Is the material we're covering interesting to you? Is there a way we can make it more interesting?
5. This last question is a group assignment your entire class should coordinate however you see fit (it does not have to be a big production[1]; a 20-minute meeting should be sufficient for designing the metric and collecting data). Design and evaluate a metric to evaluate the effectiveness of the following components of the class to your learning (however you want to define any of the above terms): In-class lectures, lab sessions, NINJA tutorials, office hours, doing labs, creating lab deliverables, talking with classmates outside of the classroom, and at least two other components not in this list that your class comes up with. You may, of course, modify any of these instructions so long as you provide justifications for the modifications.

WHAT IS FEEDBACK, ANYWAY?

> ***I love feedback, I like to know when I hit something. Usually you know yourself, but you like to see that smile on the director's face.***
>
> ***--Skeet Ulrich***

The last section contained an erroneous sentence; we won't so much be "launching into new material" in this chapter as we will be looking back on old material with new eyes. Take a look at the answers you gave for section 2. Congratulations - you just gave feedback.

Technically, the feedback cycle will be completed when you hand us your answers to the questions above and we start acting on them, but that's a minor technicality we'll distract ourselves from at the moment. You did something (filled out a survey) in response to things we've done (taught your class) in the hopes that we will respond to your response[2]. Feedback in the technical sense isn't much different from feedback in the sociological sense, and you've been seeing it in your labs for a while, particularly Lab 5.

YOUR DEFINITION OF FEEDBACK

Take a minute right now to write down your own definition for feedback in the space below. No peeking on the next page until you do this. Go on, now.

[1] However, this is a great opportunity to learn how arbitrarily metrics are made. Perhaps it will shed some insight on why we don't give you any rubrics in this class.
[2] We will.

Now grab two people (they don't have to be taking this class; in fact, it's much more entertaining if they aren't) and compare your answers with theirs and the definitions below.

DICTIONARY DEFINITIONS OF FEEDBACK

1. *The return of a portion of the output of a process or system to the input, especially when used to maintain performance or to control a system or process.*

2. *Sound created when a transducer such as a microphone or electric guitar picks up sound from a speaker connected to an amplifier and regenerates it back through the amplifier.*

3. *The return of information about the result of a process or activity; an evaluative response.*

4. *The process by which a system, often biological or ecological, is modulated, controlled, or changed by the product, output, or response it produces.*

(The American Heritage Dictionary of the English Language, Fourth Edition, 2004)

How did your answers compare? Would you change any of your definitions or any of the dictionary's definitions to better reflect what you think feedback is?[3] Take a look at the following examples, and then ask yourself the same question again.

EXAMPLES OF FEEDBACK

A GENERIC FEEDBACK SYSTSEM

All of the systems you've made in your labs so far can be modeled (very simply) as one of these two diagrams. Which one has feedback? How can you tell whether you've got feedback operating in your Simulink code? (Can you go through your old Simulink models and identify 2-3 examples of feedback loops? If you want to check whether you've found them, show your NINJA.)

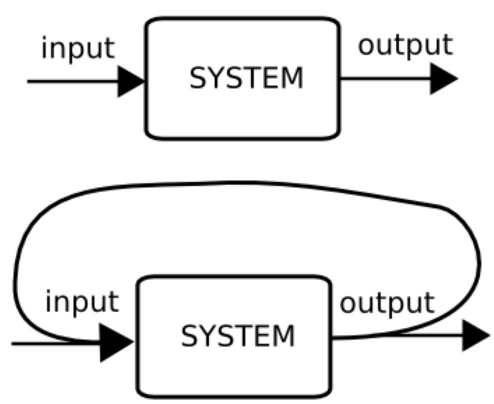

FIGURE 1: TWO KINDS OF SYSTEMS - WHICH ONE DISPLAYS A FEEDBACK LOOP?

[3] Just because it's from a book doesn't mean it's right, you know.

Once you've chosen one of the two diagrams as displaying a feedback loop (put a star next to it), see you can mentally overlay that system diagram over the examples that follow.

MICROPHONES

You know that awful squealing noise you hear when you bring a microphone too close to the speaker? That's the microphone picking up its own sound and re-feeding the sound to the speaker, which amplifies it into the microphone, which feeds it to the speaker, which amplifies it into the microphone…

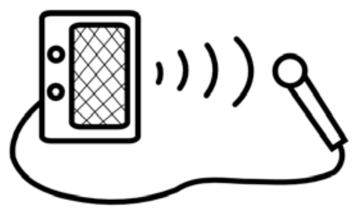

FIGURE 2: WHAT KEEPS THE SOUND FROM BECOMING INFINITELY LOUD?[4]

FUDGE

Have you ever made fudge? Because of the crystallization of the sugar determines the final properties of the batch of fudge you end up with, it's very important to monitor and control the temperature of the syrup in the pot. You stand with one hand on the dial and one eye on the thermometer. If you see (according to the thermometer) that the fudge is too hot, you turn the dial so the flames die down; if you see it is getting too cold, you turn the dial so the flames shoot up.[5] The raising and lowering of flame intensity heats or cools the chocolate accordingly, and the thermometer adjusts to read the temperature of the chocolate; you then see the thermometer…

Now imagine that you want to have fresh fudge every day, but don't want to stand over a hot stove for hours to get it. How could you design a system that would be able to monitor and adjust the fudge temperature by itself without your intervention? (Could you do it with the equipment you've been using to make your labs? What more would you need?)[6]

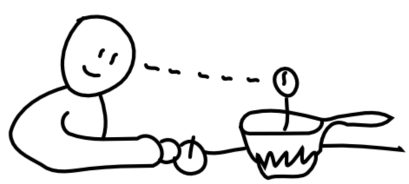

FIGURE 3: WHAT ARE THE SOURCES OF LATENCY IN THIS SYSTEM?[7]

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[4] Look up various definitions of the word "rails." Try to find the one that fits this example best.

[5] What are the "sensors" and "actuators" in this system? Hint: you count as part of the system. Is it possible for something to simultaneously be a sensor and an actuator? At the same time?

[6] Also, how much would it cost? Would it actually be cheaper to buy fudge from the local candy store? Look up the meaning of the acronym COTS; how does that definition relate to this discussion?

[7] You may not have heard the word "latency" before. Behold the power of spiral learning. For now, take 10 minutes to look it up and take a guess at what this question means – we'll return to it in a later chapter.

CLASS

As we discussed before, the survey you filled out in part 2 of this chapter is an excellent example of feedback. Draw a diagram of the system in the space below and explain why it is a feedback loop. There are two cases to consider: when your professors are doing something wonderful that you'd like them to continue and do more of, and when your professors are doing something that frustrates you and that you'd like them to stop.

LAB 5

Go back to Lab 5 and find the feedback loops in both your circuit setup and your Simulink model. What parameters can you adjust in either the circuit or the Simulink model in order to make your experimental output look like what you want it to look like? We call this *tuning*[8].

TAKE A LOOK AT THAT DEFINITION OF YOURS AGAIN

I promised we'd ask you this question a second time. What is your definition of feedback now? How has it changed (if it's changed at all)? Try to put your definition in another form; if you wrote it out in sentences, try drawing it as a diagram, if you did it as a diagram, put it into a mathematical formula, if you did it as a formula, write it out in English, and so forth.[9]

Write your new definition in the space below. If it's the same as your old one, draw a purple cow.

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[8] Musicians will notice that this is the same word that's used to refer to the process of adjusting one's instrument in order to get it to play at the correct frequency (note).
[9] Better yet, try to do all three, and then find some other forms of your own.

POSITIVE AND NEGATIVE FEEDBACK

In the previous section, you drew a diagram of the course feedback loop between professors and students. You did this for two cases – one in which you liked what your professors were doing and wanted to *amplify* it, the other in which you disliked what they were doing and wanted to *damp* it.[10]

You may have heard the terms *positive* and *negative* feedback before in either technical or nontechnical contexts. What do you think they mean? (Yes, the space below is for you to write it down.) After you write down your own definitions, swap notes with some friends and look up other definitions together.

POSITIVE AND NEGATIVE FEEDBACK, EXAMPLES 1-3

Go back through the three examples we worked through in the previous section: the microphone, the fudge, and the classroom. Which ones are examples of positive feedback? Which ones are negative feedback?[11]

TWO BALLS, TWO HILLS

What can you say about positive and negative feedback in these pictures?

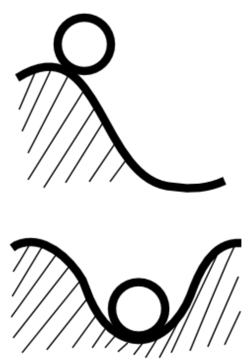

FIGURE 4: TWO BALLS, TWO HILLS

[10] Take a moment and look up the definitions for "amplify" or "amplifier" and "dampen" or "damper." Check out the etymology while you're at it; the history behind engineering terminology is often amusing. (Why are we called "engineers" in the first place?)

[11] The microphone is positive feedback (it continuously makes itself louder), the fudge is negative feedback (it minimizes the amount the sugar varies from a set temperature) and the classroom has both positive and negative feedback (positive when you encourage the professors to do something, negative when you ask them to stop).

For fun or homework: How would you model these two systems in Simulink or MATLAB? Some variables you might want to think about are the mass of the ball, the friction between the ball and the hill (it may be easier to pretend the ball is a block so you can use sliding friction first), and the slope and height of the hill at a given x-value (horizontal position).[12]

A play in two acts

Your task: match Act A and Act B with Commentaries 1 and 2 as appropriate. What does this have to do with feedback? Can you create a mathematical model for either situation?[13]

Act A: Interpretative dance

Professors: "We're going to do a small interpretative dance to explain this abstract mathematical concept."

Students: "Wow, that was awesome!"

Professors: "That worked so well that we're going to do a longer dance explaining lab 4!"

Students: "That was fantastic!"

Professors: "And now a fully choreographed 2-act ballet on Maxwell's equations!"

Students: "Hurrah!"

Act B: Huge problem sets

Professors: "We're assigning you a 2,000 question problem set; it's due tomorrow."

Students: "Oh, please no."

Professors: "Okay, a 100 question problem set, due next week."

Students: "That's better, but we're still not very happy about it."

Professors: "How about 10 questions, and two weeks to do it?"

Students: "That sounds pretty reasonable, but we'd rather do the lab instead."

Professors: "All right, no problem set - work on your lab."

Commentary 1: Quiet back down there

Note how each response "damped" the size of the problem set down to a reasonable length. Think of a rubber ball dropped on a tile floor, its jumps growing shorter with each successive bounce, or a petri dish that's too full of bacteria that it stops being able to feed them all, or . Negative feedback quells disturbances; it says "please quiet down back to your normal level." Negative feedback makes change stop happening.

Commentary 2: Please, sir, may I have some more?

Note how each response amplifies the next. Think of exponential growth of an investment, a population explosion where more people have more babies who grow up into people who have yet more babies, or students

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[12] For fun, look up the term “Calculus of variations” and the word “brachistochrone.”

[13] Where would you get the numbers? What would you be measuring, and how can you decide how to quantify it?

encouraging professors to do more of what they're currently doing. Positive feedback is reinforcement; it says "I like what you're doing, please do more." Positive feedback makes things change and happen.

BACK TO THE ENGINEERING WORLD

> ***"Everything is a signal and a system!" --Electrical engineers***
>
> ***"Everything is a transfer function!" --Mechanical engineers***
>
> ***"Everything is a feedback pathway!" --Biological engineers***
>
> ***"Everything is a differential equation!" --Applied mathematicians***
>
> ***"You're all saying the same thing." –ECS students***

By this time you should have a pretty good intuitive grasp of what feedback is and how it operates in the world both inside and outside of engineering.[14] Now it's time to go back and see how this applies to what you've been doing in your math, physics, and engineering classes.

LOOKING AT OUR BREADBOARDS

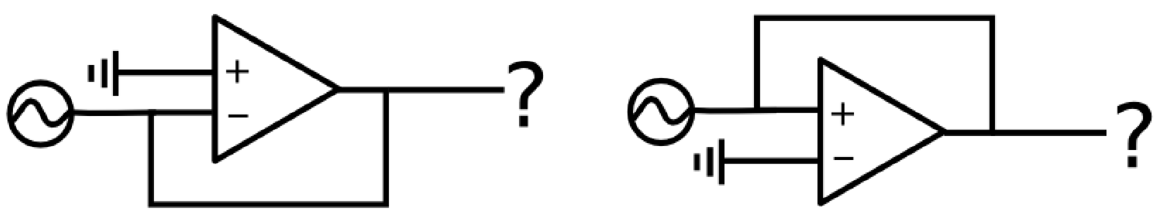

FIGURE 5: OP-AMPS

1. Can you find either of these op-amp[15] systems[16] on your circuit diagram?
2. What do they do?[17]
3. Remember the image of those two balls on hills earlier in this chapter? How do these diagrams relate?
4. What have we left out of this picture?[18]

In Chapter 2, we discussed a mathematical model of an op-amp and implemented it in Simulink. Can you model this system mathematically or in Simulink as well?[19] If you can do this, you're well on your way to completing the simulation portion of Lab 5.

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[14] If not, sit down with your NINJA and teach him/her about feedback. Teaching is a great way to learn.

[15] You should have learned what an op-amp does in Chapter 2. If you need a refresher, skim the section again, then take 10 minutes to either ask a neighbor, your NINJA, or to do some online research to remind yourself.

[16] By the way – the circle with the squiggle inside it is a signal source (a function generator, in your circuit).

[17] This is a broad question with a wide range of possible answers. It's your choice as to how you interpret it.

[18] Again, this is a broad question with a wide range of possible answers. Have we left out numbers? Parts? Labels?

[19] If you're trying to figure out what happens when two wires are attached together, look up "Kirchoff's Current Law" and "Kirchoff's Voltage Law." If you find these intriguing, see what you can find on the conservation of energy, symmetry, and a mathematician named Emmy Noether.