[DRAFT] Beyond Connecting the Dots: Mastering the Hidden Connections in Everything that Matters

Gene Bellinger   Scott Fortmann-Roe

2013-04-12

Contents

Chapter 1

Preface

Ludwig von Bertalanffy(1) first proposed, in 1937, that the same basic structures operated across all disciplines, and if one learned how these structures operated one could transfer much of their learning from one discipline to another. When moving from one discipline to another, one would simply have to learn the structures that were operating, and the labels on the elements of the structures. On first reading this may seem most profound, or maybe even preposterous.

However, if you think about it, maybe there is some truth to it after all. What follows is the introduction to a live Systems Thinking book presented from a cross discipline models perspective. Live in the sense that the models are presented in a form that allows you to actually interact with them.

von Bertalanffy wrote “Allegemein Systemlehre” which was translated into English as “General Systems Theory”(2) and I expect we’ve still not recovered from the translation error. What he intended was a “General Theory of Systems” or “General Systems Teaching,” a way to support learning about the structures which operated across all disciplines. Today there are a set of structures referred to as Systems Archetypes which I believe are just what Bertalanffy had in mind.

In the words of von Bertalanffy, “The student in ‘system science’ receives a technical training which makes systems theory – originally intended to overcome current overspecialization – into another of the hundreds of academic specialties”(1)

Systems Thinking is not a method though more of a way of looking at the world around us and understanding based not from understanding things though more from understanding relations and interactions between things. And while there are many who believe that Systems Thinking or a Systems Perspective provides the best foundation for creating effective approaches of dealing with challenges and shaping a better tomorrow. Yet even with that view, over the past 75 years it has not become widely adopted, even though during that period dozens of approaches have been developed with claim to embrace the Systems Thinking world view. I believe Pogo had it right when he said, “We have met the enemy and he is us." I have repeatedly commented to people that the greatest impediment to the adoption of Systems Thinking is Systems Thinkers.

This should provide you with a sense of why this book has to be different. Now let me offer you a view of how it will be different.

It is our intent to provide a basis for recovering from this overspecialization by offering an extensive series of models from everyday life that will show the value of looking at things though a different lense. We will then build on this to develop an understanding without all the terminology and complexity that typically drives people away from Systems Thinking.

References

- Davidson, Mark. 1983. Uncommon Sense: The Life and Thought of Ludwig von Bertalanffy http://www.amazon.com/Uncommon-Sense-Thought-Bertalanffy-1901-1972/dp/087477165X/

Chapter 2

Chapter 1 - It's The Pattern That Connects

Notes to Reviewers

Chapter Intent

Develop an awareness that the diverse world around us has a commonality that can be meaningfully represented by just a few interacting elements with rather simple attributes. The basic operation and interaction with embedded models must also be experienced and supporting aspects of Insight Maker explained.

Figure Captions

Each figure is followed by a sequenced figure caption line that starts with ** and these lines are also an internet link. These lines are inserted so I can easily get back to wherever that graphic originated should I need to create a revised version of it. These statements will be deleted by the post processor and replaced with figure captions which are embedded in the Markdown formatting.

Insight Maker References

I'm doing the best I can representing the version of Insight Maker I won't be able to see for a couple of months. The interactive Insight Maker models are embedded from Insight Maker and the model is owned my me. This means that when one looks at it in this chapter it doesn't look like it will look in the final book. Scott is creating a version of Insight Maker that will operate in a touch tablet environment. That version of Insight Maker will be embedded in the book and each book owner will own the models in the book. That means they will look different. As such I have to code something so I'll know what to include later and reviewers can look at and connect with the written words associated with it. Getting through this seems to be a tall order.

Macros

There are certain aspects of the text formatting we don't have figured out and have resigned ourselves to the fact that we won't have this figured out for some time. As such macros are being coded to be replaced in the content post processing phase. I sorry that it's likely to make the text a bit more difficult to read.

- *model attribute*
- ç
- *equation*
- *model primitive*
- *ui reference*

Relation to Table of Contents

What follows was presented in the Table of Contents as three separate chapters though the writing seemed to get away from me. The may be split into several chapters or the table of contents may be corrected. Presently it's a bit difficult to tell.

What you learn, and your capacity to learn, serves as the basis for everything you do in your life. Yet, have you ever thought about how you really learn about the world around you? Yes, there are some things you memorize early in life, like the times tables, and you learn to remember these, though is that really learning? Do you remember that if you put your hand on something very hot it will burn you, or is that something you learned? And if you learned that, how was it that that learning happened?

Consider the following

- I have a box that's about 3' wide, 3' deep and 6' high
- It's a rather heavy box
- The has a couple of doors on it
- When you open the doors it's cooler inside the box than outside
- One compartment is much colder than the other
- When you open the door a light comes on
- There's food inside the box
- The box is in the kitchen

- There are sticky notes all over the front of the box
- There's a collection of papers and stuff on top of the box
- If you move the box you'll probably find a lot of dust under it
- The box is plugged into an electrical outlet
- From time to time you can hear the box running

At some point in this sequence you probably became convinced that what was being described was a refrigerator. Now stop for a moment and ask yourself just how was it that you realized what was being described was a refrigerator? Yes it would have been easier if I had just shown you a picture of a refrigerator, though that would have spoiled it, wouldn't it.

As long as you knew beforehand what a refrigerator was, the statements could have been given to you in any order, and still at some point you would have finally realized what was being described. If you had never seen, nor heard about, a refrigerator before you would still be wondering what was being described and what to call it.

You have also most likely come to understand that all refrigerators are not identical. Some have one door with a separate compartment inside. Some have two doors and a drawer. Some are much smaller than others. Some can fit under a counter and some even fit on top of a counter. Some can be so large you can walk into them.

If you see any of these you quickly decide it's a refrigerator. How does that happen? Gregory Bateson, one of the great thinkers of our time, said, "It's the pattern that connects." If you reflect on this statement you should come to realize there are actually different ways to interpret what it means. In this particular case the pattern connects you to the following purpose

- The box keeps food from readily spoiling by keeping it cold
- Part of the box is a freezer which keeps food from spoiling for even longer

and you understand it to be a refrigerator. Though now that we've arrived at this point we still haven't addressed the question of how you know. You probably were not actually taught that it's the above purpose that defines the essence of a refrigerator. Most people were not, though they have essentially learned it over time.

Models

Models are the way we look at, and understand the world around us. All we have are our models. They are the way we understand everything. This is so because we build our understanding based on what we already understand. The world around us simply has too much detail for us to pay attention to everything. A refrigerator has many pieces though how many do you really

Figure 1. From the description you knew it was a refrigerator - but how?

Figure 2. Many kinds of refrigerators, or freezers - But how do you know?

pay attention to? Probably not many unless you build or repair refrigerators. We filter out much of the detail around us so we don't become overloaded and we choose what to pay attention to. Sometimes we do this consciously and sometimes subconsciously. In the midst of what we choose to pay attention to there are patterns. Whether we realize it or not it is these patterns that we pay attention to and attempt to make sense of. We understand these patterns by linking them to extend patterns we already understand. And much of the world around us we simply ignore for if we didn't we would just become overwhelmed.

Remember

A model is a simplified version of some aspect of the world around us to help us understand something.

Learning

When we experience something that experience falls somewhere between complete novelty, meaning that we can't connect it with anything in our past experience, and complete confirmation, meaning that it represents something we perceive as already completely understood. The things we experience which lie somewhere between complete novelty and complete confirmation provide a basis for learning. They represent a basis for connecting to understood patterns, extending our understanding, and what results is learning. {Cite: Jantach, Eric. 1980. The Self-Organizing Universe: Scientific and Human Implications. Pergamon Press. http://www.amazon.com/The-Self-Organizing-Universe-Implications-Innovations/dp/0080243118/}

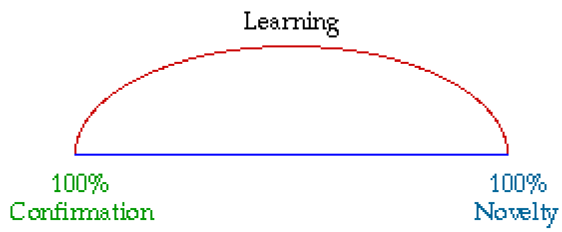

Figure 3. Experience between novelty and confirmation as a basis for learning

Consider running into a refrigerator that looks like no refrigerator you've never seen before. From an initial view you are likely not to perceive it as a refrigerator. As you inspect it to find it serves the purpose you've come to understand for refrigerators or if someone tells you it's a refrigerator you then expand or extend your awareness of the range of patterns that constitute a refrigerator.

A Basis for Flawed Learning

While reading the previous paragraphs did it dawn on you that much of this pattern recognition/connection/extension learning doesn't happen consciously? We connect with patterns and extend our knowledge at times without even being consciously aware that it is happening. And when it happens in an subconscious manner there isn't really any critical validation that happens along with the learning. Because this ongoing learning happens without critical validation there are things we learn and come to believe which are actually incorrect. We have perceived patterns and extended our learning in a flawed manner. The really annoying thing is that we then act on these beliefs, and when we produce results that don't go the way we planned we wonder why. Or even worse, we don't actually learn from the results and correct our flawed models.

When we act on flawed beliefs when attempting to solve problems we typically create more problems than we fix. It has been said repeatedly that the majority of today's problems are the direct result of yesterday's solutions. Wouldn't this provide a sense that we might really benefit from a better way to think about the world around us, develop better understanding, and develop solutions that don't come back to haunt us in the future?

Ladder of Inference

The best explanation of how we build our beliefs was developed by Chris Argyris {Argyris, Chris. 2013. Chris Argyris. Wikipedia.http://en.wikipedia.org/wiki/Chris_Argyris} and is referred to as the Ladder of Inference. When we consciously traverse this ladder we're in good shape. Though when we traverse this ladder subconsciously we often create learning that is not accurate. We then act on this inaccurate learning and produce inappropriate or undesirable results. {Bellinger, Gene. 2013. Ladder of Inference: Short Circuiting Reality. SystemsWiki. http://www.systemswiki.org/index.php?title=Ladder_of_Inference:*Short*Circuiting_Reality}

Figure 4. How we form beliefs and influence our actions

Because we live in the moment, even though we may think about the past, or the future, we tend to relate to things in the moment. It is this living in the moment that is mostly responsible for us tending to think in terms of cause and effect, i.e., A caused B. Even when we consider things that have evolved over time we tend to ignore the passage of time, and more often than not simplify situations to one dimensional cause and effect, e.g., Wall Street is responsible for the Financial Crisis; Corporations aren't hiring more people because their taxes are too high; Obama is spending the US into ruin; etc. And as you might have gathered from these examples the simplification often produces beliefs that may not even be true. It's our enduring need to make sense of things, along with our lack of a better way to consider things, that drives us to fabricate meaning, even if it is at times invalid.

As such, many of the models we develop to make sense of thing are actually flawed. And as previously stated, when we act based on models that simply aren't correct, flawed in some way, the results of our actions are generally simply not what we intended or expected.

A Better Way

Based on the understanding I hope you've developed to this point it should be obvious that we could benefit from a better way to develop models that are more likely to be correct as well as surface flaws in many of our current mental models.

Ludwig von Bertalanffy first proposed, in 1937, that the same basic structures operated across all disciplines, and if one learned how these structures operated one could transfer much of their learning from one discipline to another.{Davidson, Mark. 1983. Uncommon Sense: The Life and Thought of Ludwig von Bertalanffy. J.P. Tarcher, Inc. http://www.amazon.com/Uncommon-Sense-Thought-Bertalanffy-1901-1972/dp/087477165X/} When moving from one discipline to another, one would simply have to learn the structures that were operating, and the labels on the elements of the structures. On first reading this may seem most profound, or maybe even preposterous. However, if you think about it, maybe there is some truth to it after all.

I'm not asking you to believe the previous statement just because it was provided here. Though if you give me a few minutes the experience that follows may allow you to arrive at a sensibility of the statement from your own perspective.

Consider the images in Figure 5 and ask yourself what it is that all these different items actually have in common.

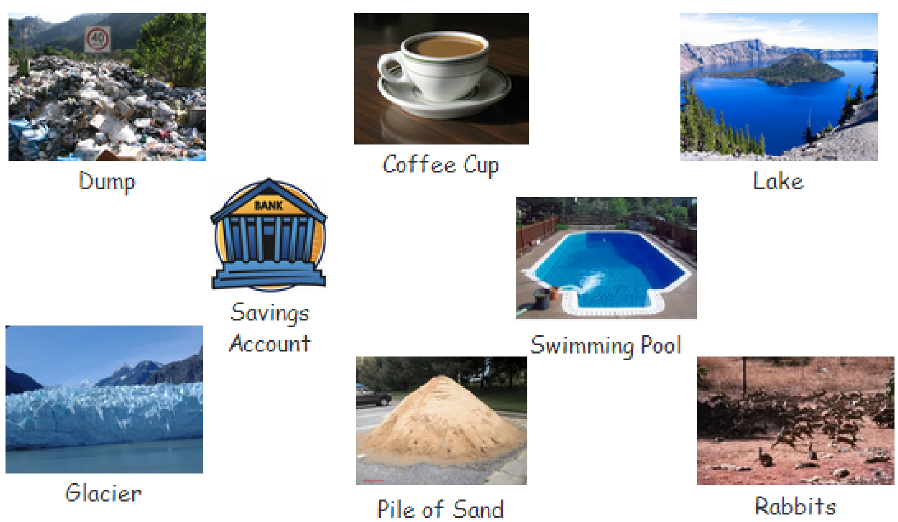

Figure 5. What do these items have in common?

Each of these items represents a collection of stuff. Admittedly each image represents different stuff though stuff just the same. Because in each case this stuff collected over time it's really more appropriate to refer to the the collections as accumulations. And as you will come to realize it is extremely important to remember that accumulations take time to accumulate, and often even longer to get rid of when you find out you don't want them.

The shorter term often used to refer to an accumulation is "stock." Just where this term originate I'm unsure and what you call an accumulation of stuff isn't nearly as important as remembering it's a bunch of stuff that collected over time. How much time is different for each one of the accumulations and now it's probably time to talk about how accumulations happen over time.

For each of the accumulations in Figure 5, how they change is a bit different, as are the time frames concerned. Time frame being the time it takes for some real noticeable change in the accumulation. Let me describe each in some detail.

Coffee Cup

You usually fill a coffee cup from a coffee pot and it takes a few seconds. Then you take a few minutes to drink the coffee as it's usually too hot to drink when you initially get it.

Dump

Generally a dump accumulates by the truckload after the garbage is picked up at houses or businesses in your community. If the dump were just getting started you'd probably notice it grow with each additional truck load. As it gets bigger and bigger it's gets more difficult to notice that it's growing, even though it is. While the dump is likely to grow almost every day we are probably more likely to think about the growth of the dump in months and years. And does it ever really go away? Usually when it gets to be too much a new dump is started somewhere else and the current dump is buried. Though when it's buried it doesn't really go away. It's still there and we'll probably talk more about dumps later on.

Glacier

A glacier is a long term accumulation of snow which packs down and turns to ice. Glaciers get bigger in the winter when snow falls and they get smaller in summer when some portion of the glacier melts. The time frame one usually uses to think about glaciers is years or even decades.

Lake

Lakes are bigger than a pond and smaller than an ocean and usually filled with fresh water, not salty that is. The lake is filled by rivers and streams that flow into it as well as rain water. One might think of this in terms of gallons per hour or gallons per minute in the case of a large inflow such as at Niagara Falls where the water flows into Lake Ontario in the USA. Water leaves the lake through rivers and streams as well as evaporation into the air. For a lake one might think about the water flowing into our out of the lake in hours though when considering the level of the lake itself the change might be considered over days or weeks. It sort of depends on what you're interested in.

Pile of Sand

The pile of sand probably showed up in a truck that dumped it right where it is. While it may have taken the truck a while to drive from the wherever it started it probably only took a couple of minutes to dump the truck once it arrived. And the sand is probably referred to in cubic yards, which is how much sand it takes to fill a box that's 1 yard wide, 1 yard deep, and 1 yard high. How long it takes for the sand to go away depends on how it's taken away. If you use a wheel barrow then you have to shovel the sand into the wheel barrow and take it to wherever you're going to use it. At this rate it may take days to move it. If you move it with a small piece of machinery, a Bobcat or a Backhoe, then will will probably only take a few minutes to an hour to get it moved.

Rabbits

A population of rabbits gets larger with new rabbit births and gets smaller with rabbit deaths. Have you ever heard the phrase "multiply like rabbits?" What it means is that it doesn't take very long for a few rabbits to become many rabbits, as long as there is a good food supply and not to many predators like wolves and coyotes. The time frame for considering a rabbit population is probably months to years.

Savings Account

A savings account is a bank account where if you put money and if you keep it there the bank will periodically give you money just for keeping it there. They won't give you very much, though some. If you keep putting money in your savings account every so often and never take it out one day you'll be rich. Yet, for some reason that doesn't happen to too many people. We'll have to talk about that sometime later in the book. One generally thinks about the money associated with a savings account in dollars, the interest rate as a percentage, and the time frame in months and years.

Swimming Pool

Swimming pools usually hold thousands of gallons of water and you usually have a couple of options to fill one. You might use a garden hose, which will take days, or a hose from a fire hydrant, which will take a few hours, or from a tanker truck, which probably takes a few loads. In each case the water filling the pool is probably measured in gallons per hour. Once you fill the pool you loose a little water when people get in and out of the pool, thought not too much. Most of the water loss from a pool is though evaporation due to the sun and when you backwash the filter used to keep the pool clean. The change in amount of water is usually measured in gallons per hour.

Exercise

Take a few minutes and identify half a dozen situations you're familiar with where there are stocks that accumulate over time. What are the quantities for those stocks, e.g., gallons, pounds, kilograms, etc.. What are the flows that increase and decrease them and what are the time frames over which you think about the accumulation of that stock?

At this point you may be wondering why so much time was spent making you walk though all these examples for the accumulation of stuff. Since we said this was an interactive book you're probably wondering where the interaction is.

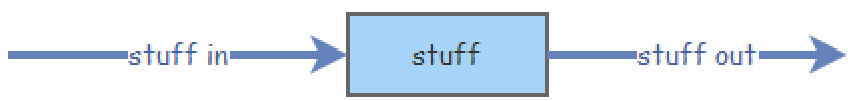

Figure 6. The Accumulation of Stuff

All the accumulations depicted in Figure 5 can be represented in a general form by the model in Figure 6. Remember we defined a model as a simplified version of some aspect of the world around us to help us understand something. It doesn't get much simpler than this does it?

Some amount of stuff flowing in causes stuff to increase over time and stuff flowing out causes stuff to decrease over time. With both of these happening at the same time stuff increases if stuff in is larger than stuff out. And if stuff out is greater than stuff in then the accumulation of stuff gets smaller. The most critical aspect of this to remember is that it takes time for stuff to increase or decrease. How fast the change happens depends on the amount of stuff in the flows.

Lets take a specific instance. Figure 7 represents Figure 6 in Insight Maker, an interactive modeling environment. We'll talk about how this was done shortly. Now suppose we have a swimming pool and we start filling it with a hose that fills at 50 gallons an hour. If we let the hose run for 24 hours how much water will be in the pool? Admittedly the math is pretty straight forward though the idea here is to show how you can use a model to show changes over time.

If I set up the model in Figure 7 with stuff = 0, stuff in = 50 and stuff out = 0, set the Time Settings for 24 hours, and then click the Run button, the model produces the graph in Figure 8.

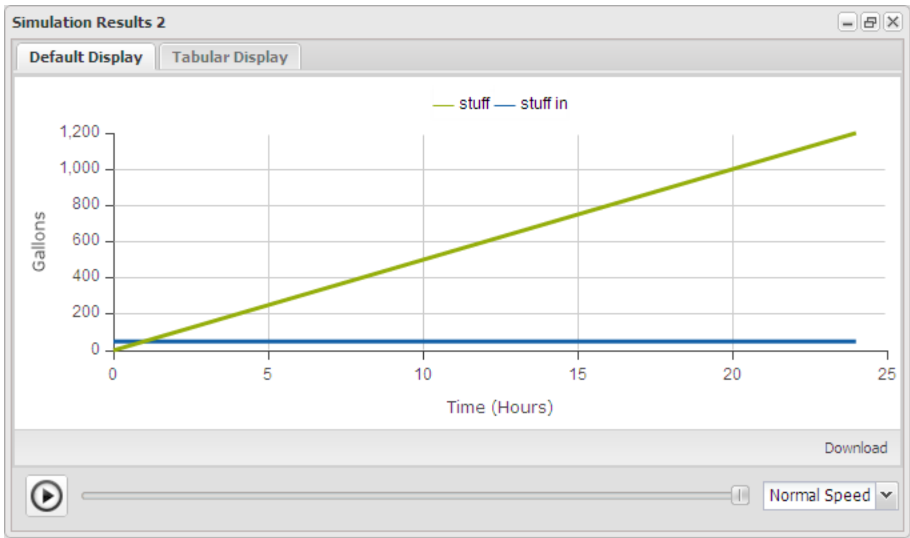

Figure 8. Adding water to the swimming pool

This graph indicates that the after 24 hours the swimming pool with have 1,200 gallons of water in it. I know, it's about as interesting as watching paint dry. Actually, as you will come to find out, that's a good thing because this is really easy. A more interesting question might be, if the swimming pool holds 20,000 gallons of water how long with it take to fill with water at 50 gallons per hour? We'll get to this shortly.

Modeling Notes

As various models are developed and used I'll present aspects of the modeling environment that you'll need to do the exercises. I won't spend a lot of time on pieces you're not going to use immediately so please don't let any of the displays overwhelm you. I think it's far easier to remember things when you actually use them.

Canvas

The center area is the work area where you create models. This area may be scrolled if necessary. I'll talk about how to actually create models in the next chapter.

Stock

A rectangle indicates a quantity of something that accumulates, and accumulation takes time. Stocks don't change in the blink of an eye, well unless you blink for a long time.

Flow

A directed arrow representing the flow of something into or out of a stock. Remember that a stock can only be changed by a flow. Hand waving and magic don't work. The flow has to be explicit to cause a stock to change, and it takes time.

Toolbar

Notice in the upper right corner there is a small down arrow. If you click on this arrow it will open the toolbar displayed in Figure 9. The toolbar contains all the tools you will use to build and modify models. Yes, you get to do everything on a single screen, with a few pop up windows of course.

Figure 9. Toolbar

Parameter Tab

Just below the arrow you clicked to open the top toolbar is a right pointing double caret. If you click this the parameter tab will close and the right pointing double caret will now point left and can be used to open the parameter tab. This tab serves two different purposes.

If there are no elements of the model selected on the canvas the parameter tab will be similar to Figure 10 and contain the model description, tags, and parameter sliders used to set parameter values just before running the model.

If there is a single element selected on the canvas then the parameter tab will present the list of parameters that can be set for that element. Figure 11 shows the parameters for the stuff element of the model. This is where I set the stuff in to 50 before running the model. Please don't be overwhelmed by this long list of parameters. We'll cover them one at a time as they are actually used in a model.

You should note in Figure 11 under the User Interface section it indicates that there should be a slider for stuff and it can be set for values from 0 to 100. Each element has some of the same parameters and some unique to it. Click one of the flows and see what its parameters are.

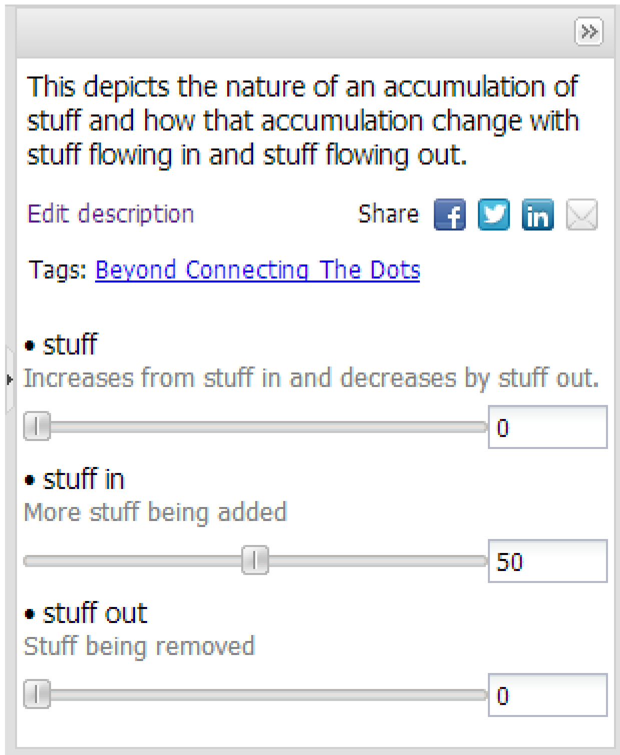

Figure 10. Configuration Panel

Just a couple more pieces and you can go interact with the model some more and get away from this boring description.

Time Settings

In Figure 8 I talked about the swimming pool filling for 24 hours. It's the Time Settings tool that allows you to define this for the model. Figure 12 shows the elements you can set before running a model.

This is where I told the model to start at Time = 0 and runs for 24 time units. It steps one unit at a time and the unit is in Hours. Don't worry about Time Step for now. We'll get into that later.

Simulation Results

When you click the Run button the model is stepped through the defined time period and produces a display of the results. There are various options for the type of display and which elements are displayed as in Figure 13.

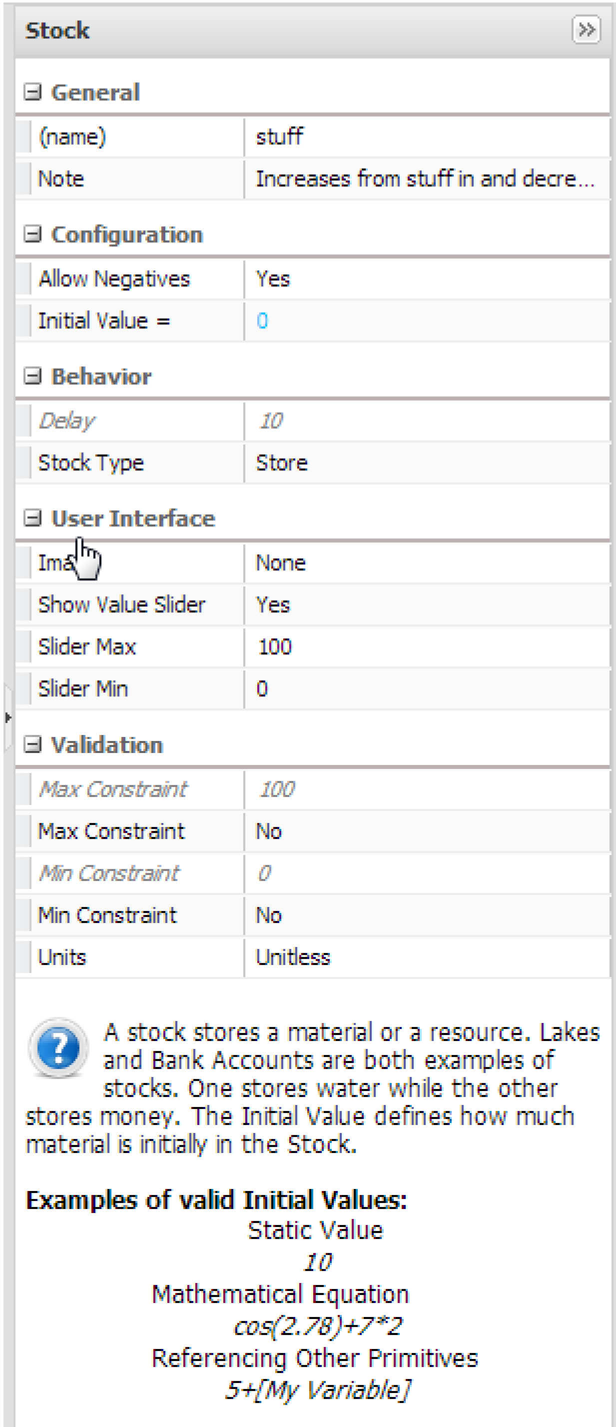

Figure 11. Element Parameters

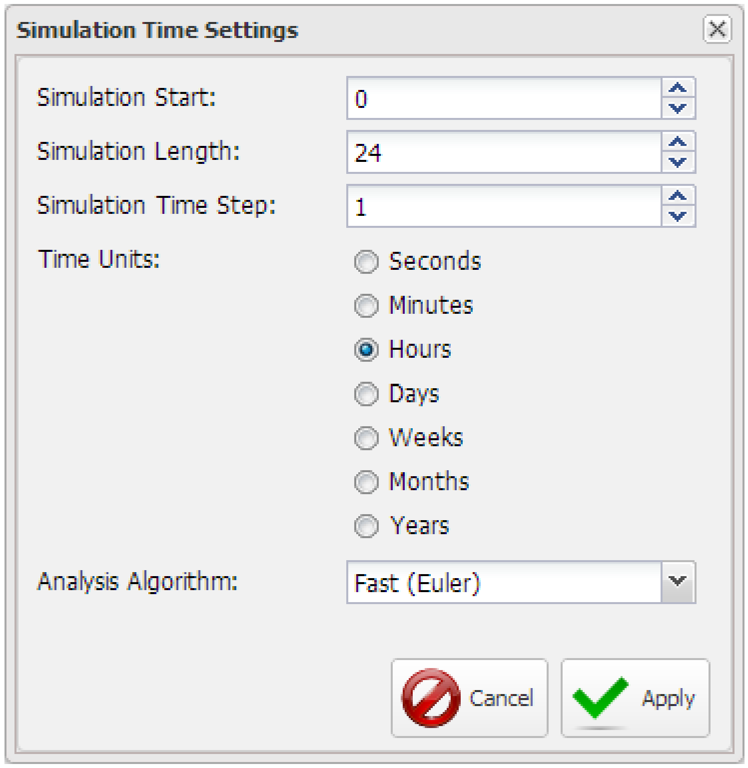

Figure 12. Time Settings

Configure Simulation Results

A default configuration is put together when the model is constructed on the canvas. If you click the Configure button in the upper right corner of the Simulation Results window the Chart/Table Configuration window will open. It is in this window you indicate what type of display you want and which items of the model are to be displayed. The only part you need to be concerned about at the moment is the Y-Axis Label field. That's where I indicated that the items displayed were in Gallons. You will need to change this shortly in the next exercise.

Note that if you change items in the configuration they will be immediately reflected in the Simulation Results window when you click Apply. You don't need to run the model over again to see a different configuration of the data. This makes it very convenient when when you decide you need another display for one or two of the items.

I hope you haven't found this short introduction to the modeling environment too overwhelming. As I said I will try to introduce different parts of the environment just as you need them to interact with the models presented.

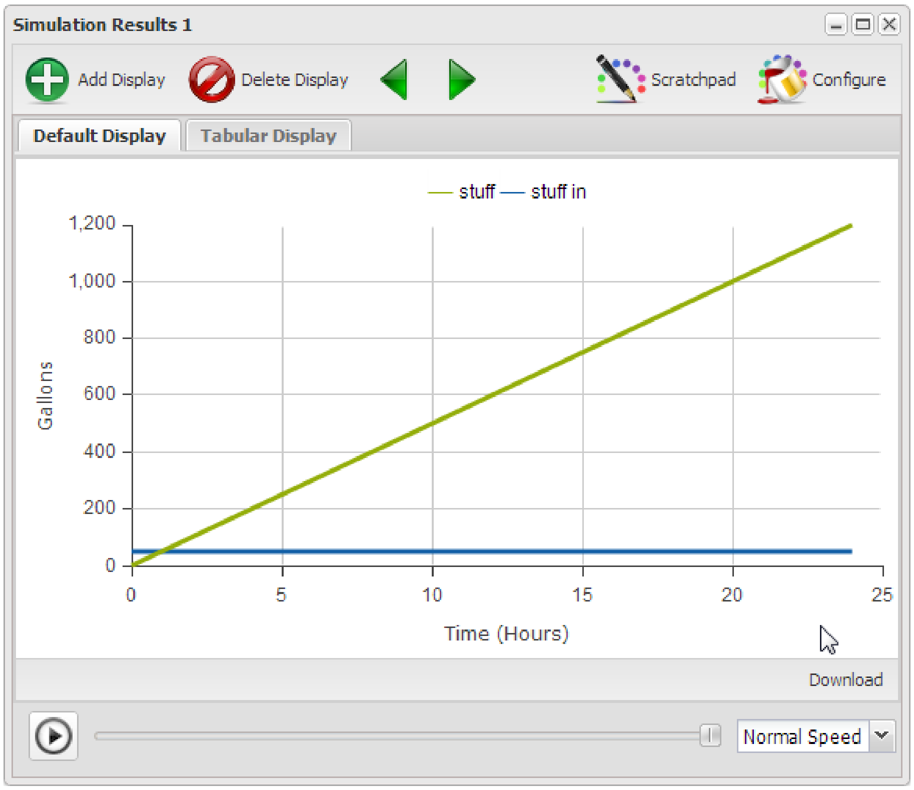

Figure 13. Simulation Results

Too much explaining and not enough hands on interaction gets to be real boring in a hurry. I encourage you to actually do the exercises presented. By interacting with the various aspects of the modeling environment you will develop a level of comfort and expertise which will serve you well throughout the rest of the book.

Exercise

Go back and consider the various pictures in Figure 5. Pick a couple of them to model. The only parts you need to set up are the Time Settings, how long will it run and the Time Units. You can also set the values for stuff, stuff in and stuff out on the Configuration Panel. After you run the model open the Chart/Table configuration window and set the Y-Axis Label appropriate for

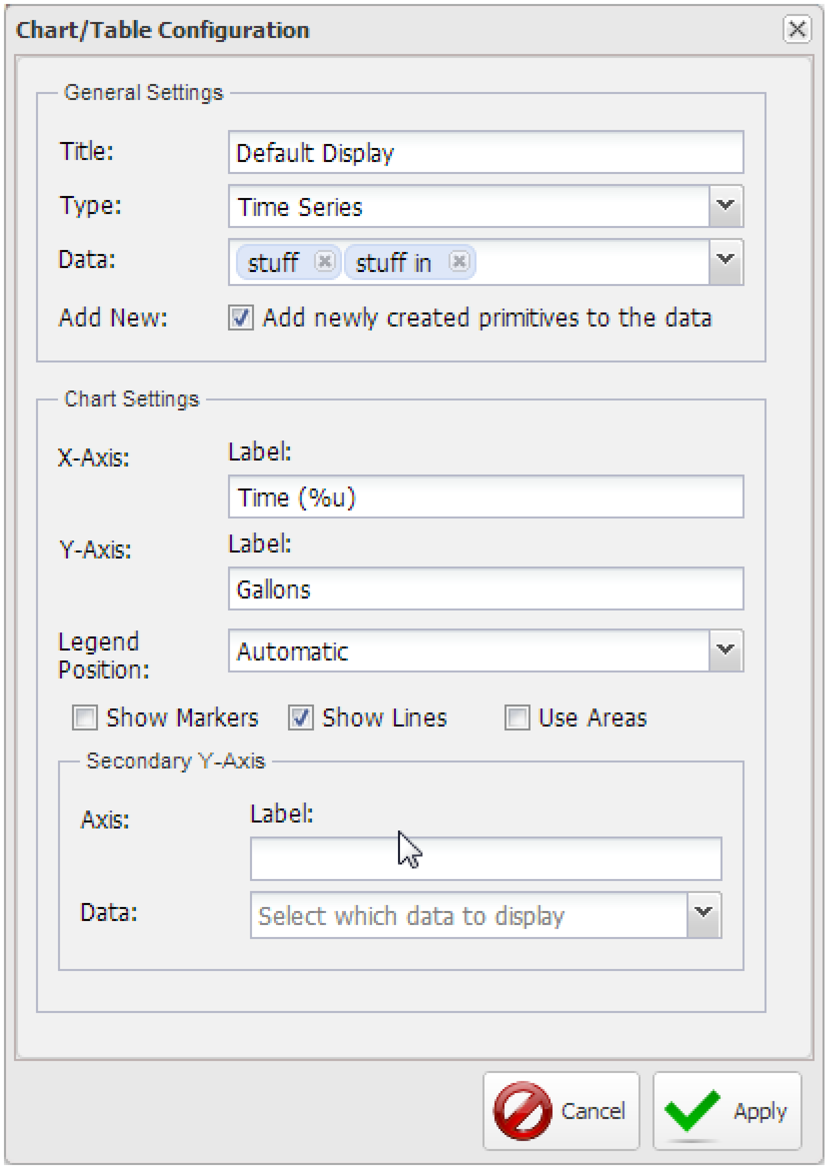

Figure 13. Chart/Table Configuration

what you're modeling. I encourage you to be adventurous. Make new Displays, Table Displays, etc. You can't brake anything, it's just an opportunity to become comfortable with the environment and learn.

Now that you've become intimately familiar with almost the simplest model possible lets go back and look at a couple of the pictures in Figure 5 and think about how the accumulations change in a bit more detail.

Rabbit Population Growth

If you modeled the accumulation of rabbits you may have already realized that the model of Figure 7 is missing something. Yes, if you add rabbits to rabbits you get even more rabbits. Though if you have more rabbits don't they create even more rabbits? Figure 14 is a model that reflects the the notion that rabbits create more rabbits.

Modeling Notes

I've stuck a couple new pieces in here and it's probably a good idea if I explain the pieces before talking about how it works. The previous model had a stock, something that accumulates, and flows, the movement of stuff into or out of a stock. And the real important thing to remember is that accumulations take time to change. Stocks only change in the blink of an eye if you blink for a very long time.

Variable

A constant or equation used to influence some part of the model. Remember that a variable and a stock are different. A stock is an accumulation that changes over time as a result of one or more flows. A variable may change though it doesn't represent an accumulation. Rabbit Birth Rate is a variable, and in this model a constant value.

Link

A link is used to communicate a value of one element to another. The link doesn't actually represent something moving like a flow does.

= & i

If you mouse over the elements of the model you'll notice an = and an i appear. The i indicates there is additional info available so if you click it a note window will open with a description of the element. This is because the info was entered when the model was created. The = indicates there is a value or equation associated with the element. If you click on the = it will open the *Equation Editor* window. We'll talk more about this when you start building a model.

Based on the previous modeling notes the model depicted in Figure 14 indicates that if you start with some population of Rabbits and each time period the current number of Rabbits times the Rabbit Birth Rate will result in a number of Births. This number of Births will then be added to the accumulation of Rabbis and figure into the calculation for the next period. If you mouse over the elements of the model and click on the = sign you can look at the definitions for the elements.

The Time Settings for the model were set up to run from 0 to 12 months. If you click the Run button you you might be surprised when the model produces the graph in image in Figure 15.

Figure 15 really shouldn't be a surprise. If you look at the Configuration Panel you'll see that it indicates 0 Rabbits and 0 Rabbit Birth Rate. If there are no Rabbits how could anything happen? And if we had some Rabbits with the Rabbit Birth Rate was 0 what would you expect the result to be?

Suppose we start with 10 Rabbits, half of which are male and half of which are female. My research indicates that a female rabbit can give birth to between 18 and 26 Rabbits a year. I'll average this out (18 + 24) / 2 = 22 and then I'll round this up to 24 just because it will make the math easier. If a female Rabbit can produce 24 Rabbits in a year, that's 2 per months, though it actually takes two Rabbits. With all these assumptions we get about 1 new Rabbit per month for each Rabbit. If you plug Rabbits = 10 and Rabbit Birth Rate = 1 into the model and run it you should get Figure 16.

Forty thousand Rabbits in a year? That seems a bit bizarre doesn't it? This result actually points out the real value of modeling, which is learning. You build a model based on what you think you understand. You then populate it with assumptions about the values and you run it. The result then either seems to make sense or seems really bizarre. In that case what the model is telling you is that either the structure is wrong, the assumptions are wrong, or both, because the world can't possibly be this bizarre. As a result you investigate the model and your assumptions and as you understand better the model gets better. At some point the model finally serves its purpose, to be a simplification of some aspect of the world which leads to a better understanding. I hope you

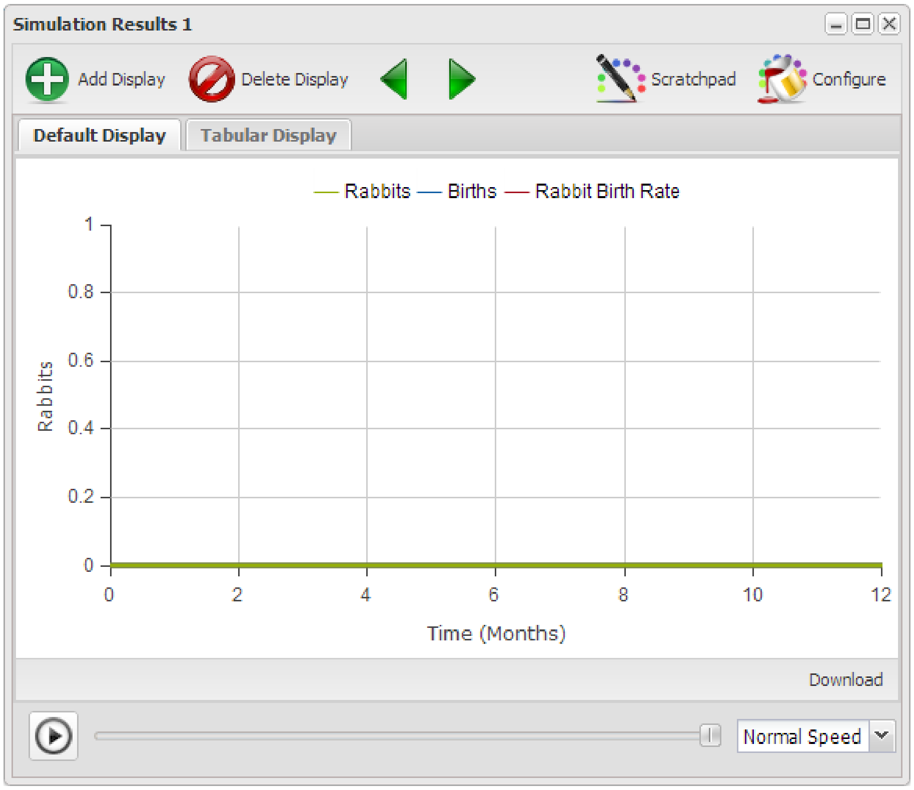

Figure 15. Rabbit Population Growth with No Rabbits

come to find, as I have, that going round and round with a model can be a delightful learning process.

After that sidetrack lets get back to our 40,000 Rabbits that can't possibly exist after a year. I'm pretty sure I can be certain how many Rabbits I started with at the beginning. And when I check my formula for Births = Rabbits * Rabbit Birth Rate it seems to be in order. This sort of means my assumption for Rabbit Birth Rate must be too big. And if you think about what the model is doing it's probably not too difficult to figure out that the model assumes that a Rabbit can be born this month and then give birth to another Rabbit next month. If a Rabbit has to mature for six months before it gives birth to Rabbits then the Rabbit Birth Rate might be something more like 20%. Using this estimate for Rabbit Birth Rate the model produces Figure 17.

Is this right? A good thing to remember at this point is that's actually the wrong question. A better question might be, "What have I learned, and is there more I can learn?" The graph in Figure 17 sure seems more reasonable than what the model presented in Figure 16 though I don't think we have a high degree of confidence in the current Rabbit Birth Rate. And there are a number

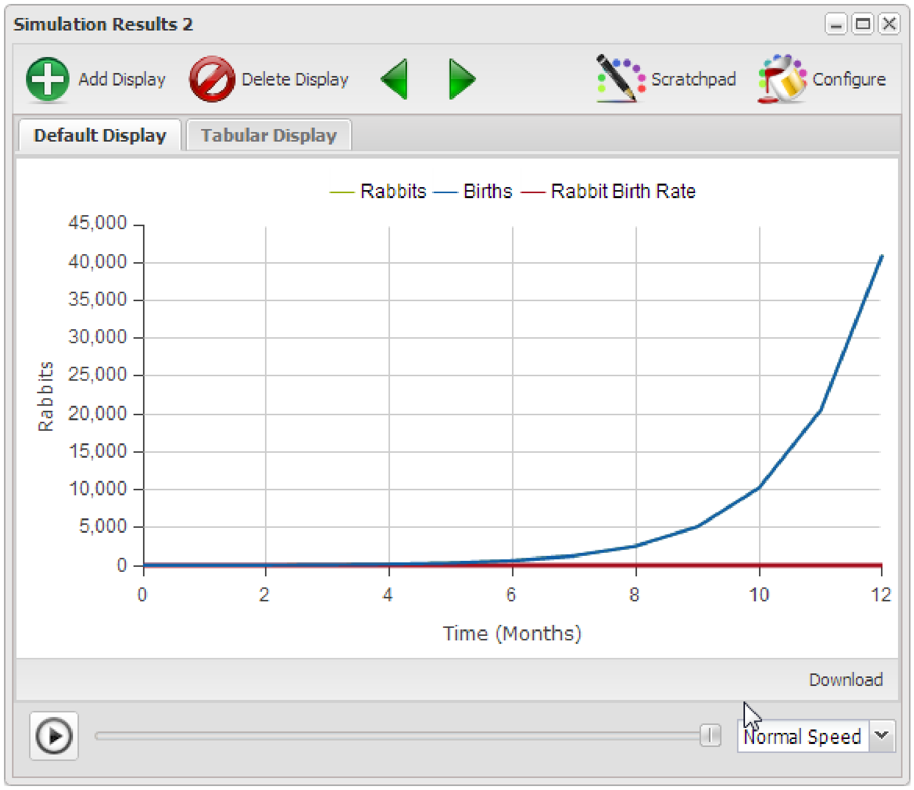

Figure 16. Rabbit Population Growth with 10 Rabbits

of other questions we could ask about our Rabbits. What is the Rabbit Death Rate? Do they have enough food to eat? Are they living out in the open where Coyotes and Foxes can get at them? Does their owner have a passion for Rabbit Stew? These might each be a basis for building a better model, though at this point we're going to leave the Rabbits alone and move on to something else.

The most important learning I hope you take away from this model is that when what flows into the accumulation increases as the accumulation increases the accumulation can get real big in a hurry. This is actually called exponential grown and we'll talk in more detail about this in due quite soon.

Filling A Swimming Pool

Long long ago, meaning back in Figure 7 and Figure 8 I was talking about filling a swimming pool with a hose and how much water was in the pool after a period of time. A more useful question might be, If the pool holds 20,000 gallons of water and the hose fills the pool at 50 gallons per hour, how long will it take to fill the pool. I know, you can do the math faster than it will take to

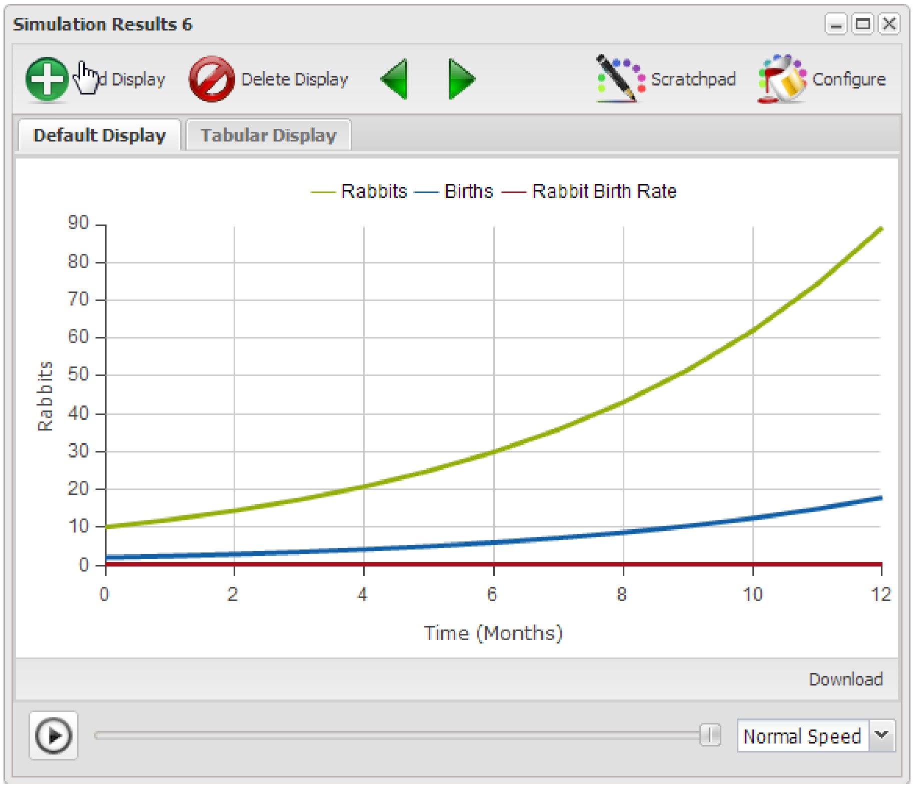

Figure 17. Rabbit Population Growth with 10 Rabbits and 20% Birth Rate

build the model. Please bear with me a bit as there's another aspect of models right around the corner you will find very useful on an ongoing basis.

I begin with a Swimming Pool that needs to be filled with a hose. I know how many gallows of water it takes to fill the pool and I don't want to put too much water in the pool. I create a model where I compare the amount of the water in the Swimming Pool with the the Full Level and use that to decide whether water is flowing in the hose or not. If you mouse over Hose and click the = sign you'll see the following equation.

```
IfThenElse([Swimmng Pool] < [Full Level], [Full Level]-[Swimmng Pool]), 0)
```

This says that if the Swimming Pool isn't full then I need to add enough water to fill the pool. And if the Swimming Pool is full then I add 0.

Modeling Note

Isn't it curious that the structure of this model looks just like the one for the Rabbit Population growth in Figure 14. I'll talk about this after we figure out how long it's going to take to fill the Swimming Pool.

With the Time Settings set for the model to run for 24 hours. Set the Swimming Pool to 0, meaning empty, and the Full Level to 20,000, on the Configuration go ahead and click the Run button. You should end up with the graph as shown in Figure 18.

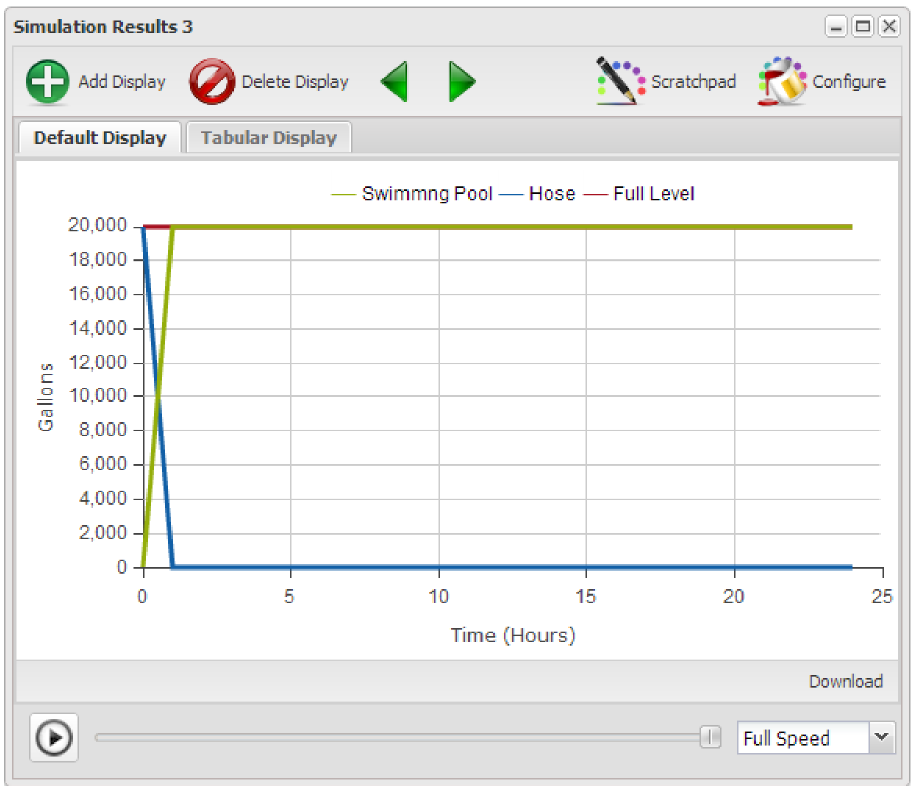

Figure 19. How long to fill the pool

This is really great. I can fill the Swimming Pool in just 1 day, or can I? Either it's a really really big hose or I've done something wrong because I don't think I can really fill the Swimming Pool with a Hose in one day if it takes 20,000 gallons.

Modeling Note

I sincerely hope you come to understand that when your models don't do what you expect them to do it's not a problem – it's opportunity for learning. This is the real reason why we do modeling. Just think of it as, the more things don't go the way you expect them too, the more opportunities you have to learn.

As I look back at the formula I put in for the Hose I notice I didn't take into account my initial statement that the Hose could only deliver 50 gallons per hour. And, might it be useful if I could see what happened with different Hose capacities?

Figure 20 is a revised version of the model with Hose Capacity as a variable so you can set the capacity of the hose before you run the model.

The new formula for Hose takes into account both the current amount of water in the Swimming Pool, Full Level and Hose Capacity

```
IfThenElse([Swimmng Pool] < [Full Level], min([Full Level]-[Swimmng Pool],[Hose Capacity]), 0)
```

With Hose Capacity = 50 if you run the model it should produce Figure 21.

Was this what you expected? Probably not. Over a period of 24 hours we've not even come close to filling the Swimming Pool.

Open the Time Settings and set the Simulation Length to 600 hours and Run the model again. Your run should produce the an equivalent of Figure 22.

Figure 22 indicates we need to wait 400 hours to fill the pool. That's a little over 16.5 days. I think we need a bigger hose.

While there are a number of things we could do to improve the model at this point I think we've gone far enough with this one.

Exercise

Do a number of runs for the model in Figure 20 with different values for Full Level and Hose Capacity.

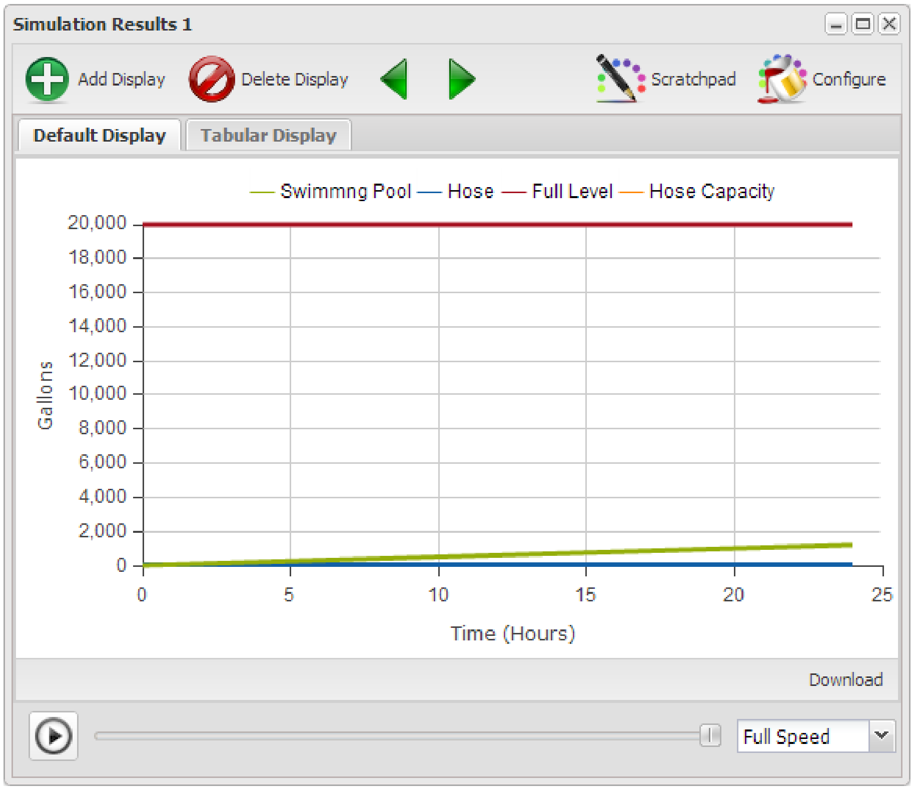

Figure 21. How long to fill the pool at 50 gallons per hour

Similar Structures / Different Behavior

If you compare Figure 14 and Figure 20 you should find the two of them to be quite similar. And yet the behavior of the two models are distinctly different.

In Figure 23 I've redrawn the Rabbits model so it's easier to see how similar they are. The Swimming Pool and Rabbits both represent accumulations. Hose and Births both represent flows into the stock. Hose Capacity and Rabbit Birth Rate are both factors which govern he rate of flow. Full Level is a target value which the Rabbits model doesn't have. The difference that makes a difference is what happens in the connection between the accumulation, or stock, and the flow.

The link between the stock and the flow provides information from one point to the other and is generally referred to as feedback, mostly probably because the information travels in the opposite direction as the flow.

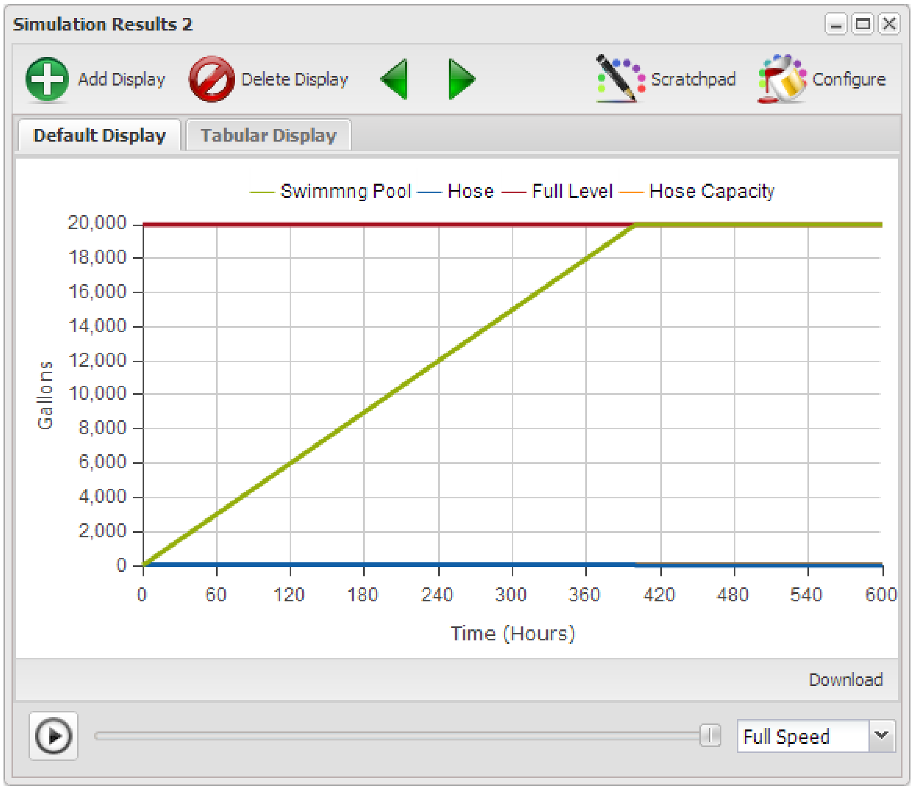

Figure 22. Filling the pool takes how long?

Balancing

In the Swimming Pool model the Hose flow depends on the difference between the value of Swimming Pool and Full Level. This difference influences the Hose flow to increase the Swimming Pool until it reached Full Level. The structure tries to bring about a balance between Swimming Pool and Full Level so the difference is zero, and then there's no more Hose flow.

Reinforcing

In the Rabbits model Births depends on the value of Rabbits. The number of Rabbits influences Births to increase the number of Rabbits which increases the Births. One might consider a Reinforcing structure to be a Balancing structure that's out of control.

Would you believe that no matter how complicated a model may look it's really only some number of these two structures connected together? In the next chapter you will begin actually building some models and investigating the implications of the Balancing and Reinforcing structures.

Exercise

I put some values in the Figure 23 model elements so when you run the model it will produce the graph in Figure 24. Can you figure out why the values assigned are responsible for the curves produced?

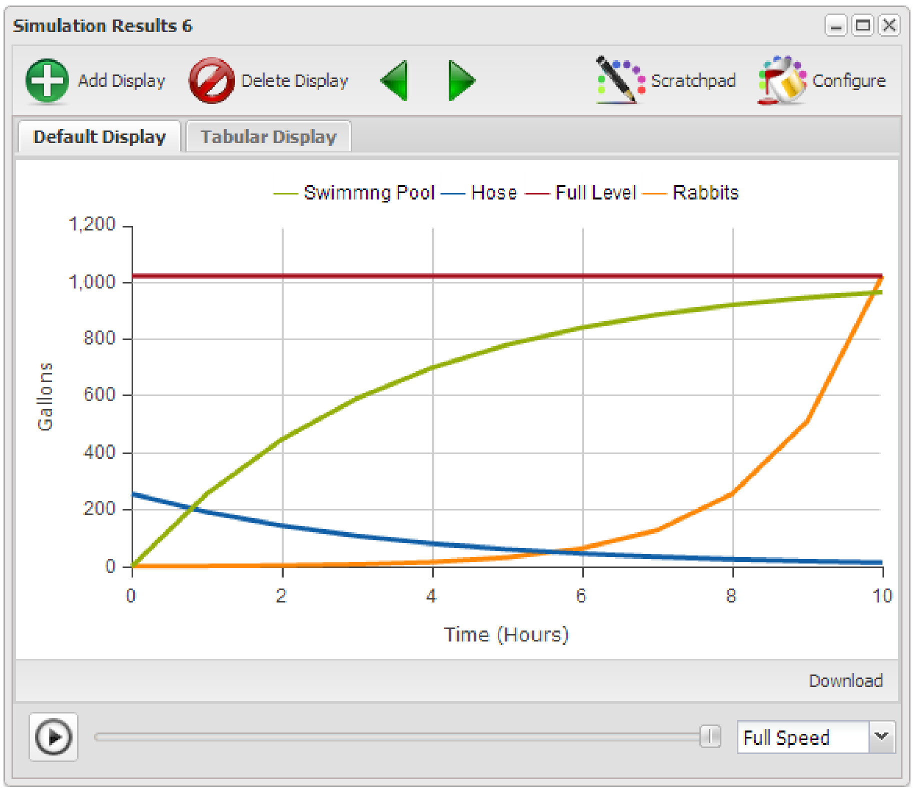

Figure 24. Balancing and Reinforcing Results

Summary

- Models are simplified versions of the world around us.
- We build models to help us understand.

- We build simple models and add to them as we learn with them.
- Reinforcing and Balancing structures are the basic building blocks for all models.
- These building blocks can aid understanding aspects of our interactions with the world around us.

Chapter 3

Chapter 2 - Dynamic Lego Blocks

Notes to Reviewers

This chapter is intended to provide the reader with enough experience with the basic elements of the modeling environment such that they can construct simple balancing and reinforcing loops. Supporting aspects of the environment necessary to run these models will also be described. This will build on the elements presented in the previous chapters and is intended to be an introduction, not an exhaustive dissertation on modeling and simulation theory. The intent is to encourage the reader to develop and play with models, not chase them from the room screaming in fear never to return again.

The Blank Canvas

Some might look on the blank canvas and hesitate not knowing where to start. You will be far better off if you look on the blank canvas as a gift of freedom which allows you to start anywhere. You will come to understand that if you approach modeling appropriately it won't matter where you start, you'll still end up with a meaningful model.

In the next few segments you will learn how to create on this canvas the two basic structures from which all models are constructed.

Notice in Figure 1 that similar tools are grouped on the *Toolbar* in Figure 1. Also only a portion of the *Toolbar* is displayed though it's enough for what will be covered in this section.

To use a tool you click on it on the *Toolbar* to select it, then you click on the canvas where you want it located, or used. For each tool there are a set of allowed uses. Once you place the item on the canvas it is named for what it is with that name selected so you can type in the name you want. Labels can be anything except braces "{}", brackets "[]", parentheses (), and quotes '. If the label is no selected you can double-click on it to select the label and then enter a new one, or you can enter the label in the *Configuration Panel* though we'll address that in a bit more detail later.

Exercise 2-1

Practice placing *Stock* and *Variable Primitives* on the blank canvas in Figure 1 and naming them. You can remove a *Primitive* by selecting it and pressing the *Delete* key or clicking the *Delete* button in the *Actions* section of the *Toolbar*. Note that the *Save* option is disabled so you won't be able to save what you create. Note: This is only for the review copy. In the final copy you will be able to save what you create.

Stocks, Flows, Variables and Links

Stocks and *Variables* are connected using *Flows* and *Links* and there are very explicit rules associated with these connections. The allowed connections are depicted in Figure 2.

If *Use Links* or *Use Flows* is selected in the *Connections* segment of the *Toolbar* then when you mouse over an element of a model a little right pointing arrow shows up at the center of the element. You always draw a *Link* or a *flow* from one element to another and the arrow on the element points in the direction you draw the connection. If neither *Use Links* or *Use Flows* is selected then thee will be no right pointing arrow when you mouse over the element.

Exercise 2-2

Click on the Set Up button on Figure 2, answer OK to both questions, and then repeatedly click Display to walk though a description of the valid connections between Stocks and Variables.

Hopefully the rules associated with the connections were easy to understand. Just remember that Flows represent the movement of stuff while Links only communicate the value of something from one location to another.

Valid Primitive Connections

The valid primitive connections of Figure 2 are described as follows.

Flow

A Flow adds stuff to a Stock, subtracts stuff from a Stock, or moves stuff from one Stock to another. The only way to change the quantity of stuff in a Stock is with a Flow.

- A flow out of a stock decreases it. If where the flow goes isn't relevant to the model then it just flows from the stock to the canvas. Select Flow from the toolbar and then click on the arrow that appears on the stock when you mouse over it and drag onto the canvas and release.
- A flow into a stock will increase it. If you don't care where the Flow is coming from then you first have to draw the Flow from the Stock to the canvas and click the Reverse button in the Connections section to get the Flow to come into the Stock from nowhere. It's just a quirk of the web implementation.
- A flow from one stock to another decreases the source and increases the destination. The get a flow between two Stocks draw the Stocks first and then draw the Flow from one Stock to the other.
- Flows can be bidirectional.

Link

A Link is used to communicate a value from one element to another. There is no flow of stuff through the link itself. The communication is considered to be instantaneous.

- You can use a Link from a Stock to a Variable to communicate the value of the Stock to be used in an equation. This does not change the Stock.
- You can use a Link to communicate the value of a Stock to a Flow to be used in the equation determining the value of the Flow in the next iteration. The Link does not change the value of the Stock.
- You can use a Link to communicate the value of a Flow to a Variable to be used in an equation. This does not change the value of the flow.
- You can use a Link to communicate the value of a Variable to a Flow to be used in the equation that defines the flow. This does not change the value of the Variable.

- You can use a Link to communicate the value of a Variable to another Variable so that value can be used in an equation in the destination variable. The link does not change the value of the source Variable.
- You can use a Link to communicate the value of a Variable to a Stock to be used as it's Initial Value when the simulation begins. The value of the Variable is computed and assigned to the Stock as the simulation begins and it has no influence on the Stock during the simulation.

When you draw a link from one element to another it is created as a straight line. There are times when you would prefer that the connection be other than a straight line to make the diagram easier to understand. You can turn a straight line into a multiple segment line as follows.

- Click on the line to select it.
- Hold down the shift key and click somewhere in the middle of the line then release. This puts a little node on the line.
- Click on the node and move it as you wish to create a two segment line.
- You can create as many segments as you need, simply repeat the second step above.
- If you wish to remove the segments select the head of the link, move it off the element it's connected to and then reconnected it. It will now be a straight line.

Exercise 2-3

Go back to Figure 1 and recreate Figure 2 for yourself. Actually making the connections helps develop a level of familiarity which will serve you well in the long run.

To this point you've learned how to develop a static picture of a model. It actually is a model and provides a sense of the relationships between the various elements of the model. What it doesn't give you a sense of is the dynamic nature of these interactions over time. What are the implications of the relationships? In the next few sections you'll learn how to bring your model to life.

Common Property # 1

Look at the pictures in Figure 3 and ask yourself what it is that these pictures have in common. The pictures all represent very different kinds of things, some

Figure 3. Common Property # 1

living, some not, though there is a characteristics they all have in common. Have you figured it out?

Maybe you notice the rabbits from the previous chapter? The things depicted in the various images all grow in one way or another, and some faster than others.

Constructing a Growth Structure

Lets use Figure 4 to construct a basic growth structure and in the process you'll learn about several of the parameters associated with the different elements of a model.

- Place a Stock on the canvas and label it Stuff.
- Now make sure the Stock is selected and take a look at the Configuration Panel on the right.
- For each Primitive and Connection there are a set of parameters you can assign.
- There are some in common across all elements of a model and there are some unique to various elements as they server different purposes.
- If you scroll down you'll notice there is a description of the element along with examples at the bottom of the panel.

- For this exercise you don't actually have to set any of the parameters though you could take a min to read thogh them. We'll discuss each parameter the first time it's used in a model.
- Click on Use Flows to select that element.
- Mouse over the stock and click when the arrow appears at the center and drag onto the canvas somewhere outside the stock. Which direction doesn't make a difference though make sure you're a couple inches outside the stock before you release the mouse button.
- While the flow is still selected click on Reverse so you have a flow into the stock.
- Notice that the parameters in the Configuration Panel are different from those for the Stock.
- Click in the field to the right of Flow Rate = and change the zero to a 1.
- Click the Run Simulation button and you've successfully created and run your first model. Admittedly it may not be very exciting though it is the first one, and one of many.

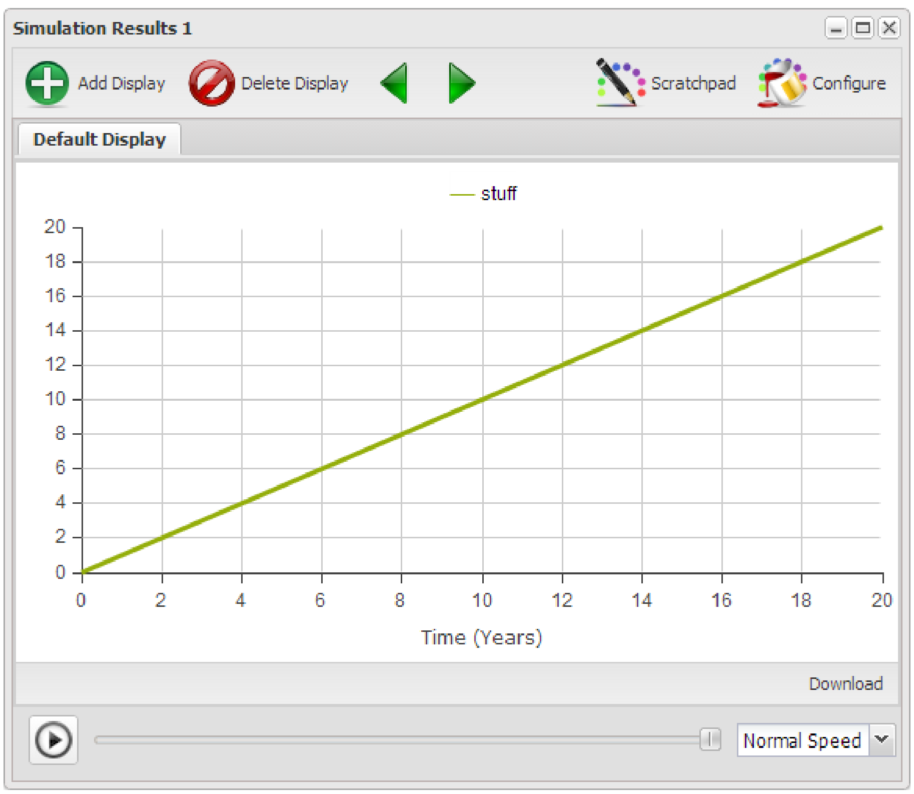

Figure 5. Your First Model Output

Notice that the model ran for 20 years. That's because we used the default Time Settings.

Chapter 4

Models and Truth

All models are wrong, but some are useful – George E.P. Box

In discussing the relationship between models and truth, it is useful to first take a step back and discuss the different types of models. Modeling is a wide-ranging field and there are many distinctions that modelers and mathematicians make when discussing models. Some distinctions – such as Bayesian versus Frequentist statistical models[1]– have been the subject of century's old philosophical arguments between mathematicians which continue to this very day.

Such arguments are of little interest to us – we will present our own classification scheme that once completed will really clarify the core dichotomy that is at the heart of modeling – but it can be useful to briefly discuss the distinctions that are commonly made in order to obtain a deeper understanding of the choices underlying the development of a model.

Deterministic versus Stochastic Models

There are two views of the world. One view says the fate of the universe is governed by strict predictable laws. The universe is in effect a giant machine and, given its current state, its future states through the rest of time are predetermined. Another view, is that the universe is ruled by chance and randomness. Random quantum mechanical fluctuations merge and amplify each other leading to an infinite range of diverging possibilities. Which is the truth? We certainly do not know and it is possible that this will be one of the questions that physicists will never cease exploring. Albert Einstein had a particular viewpoint though. He was a strong partisan in favor of the deterministic view, famously remarking that "God doesn't play dice with the world."

[1] Briefly, this debate refers to two divides within the statistical community that hinge on how probability is interpreted. A Frequentist claims that probability derives from the relative frequency of outcomes of numerous events. Bayesians take probability as a subjective degree of belief. Frequentist statistics are what are generally taught in introductory statistic courses and receive the most use in practice today.

When creating a model of a process, we must make a similar choice about chance. Do we build our model in deterministic way such that each time we run it we get the same results? Or do we conversely incorporate elements of uncertainty so that each time the model is run we may obtain a different trajectory of outcomes?

Mechanistic versus Statistical Models

When beginning to model of a system, there are many questions that you should ask yourself. Two of them are:

1. Do I know (or have a hypothesis of) the mechanisms that drive the system?
2. Do I have data which describes the observed behavior of the system?

If the first question is answered in the affirmative, then you can build a mechanistic model that replicates your understanding (or hypothesis of) the true mechanisms in the system system. If the second question is answered in the affirmative, you can use statistical algorithms, such as linear regression, to create a model of the system based purely on the data.

If neither question is answered affirmatively, well in that case, there isn't much of anything you can build.

Aggregated versus Disaggregated

When building a model, the question of scale becomes very important. Imagine we are concerned about the affects of Global Climate Change on water resources. We may wish to examine the question of whether there will be sufficient water supplies given a rise in temperatures in the future.

At what resolution do we build this model? There scale is wide:

- At the most aggregate, we could simply estimate total Worldwide water demands and supplies into the future.
- Maybe that is too coarse a scale; clearly having excess water in Norway has little impact on the situation in Egypt. We could instead create a finer resolution model that separately looked at the water demand and consumption in each country.
- Maybe even that is still too coarse, maybe we should make our model even more granular to look at a specific cities and population clusters around the globe
- At the extreme disaggregated level, we might even want to model individual people: all 7 billion of them.

Clearly, there is no simple answer to this question and the best choice is highly context sensitive and depends on the needs of the specific model and application.

Prediction, Inference and Narrative

The three distinctions presented above can be used to classify models. We can even use them to classify the models we have discussed in this book. Most of our models would be classified as deterministic (random chance is generally not explicitly incorporated in the models), mechanistic (we generally assume mechanisms rather than estimating relationships from data), and highly aggregated (the agent based models are an exception to this).

Outside of modelers, however, these distinctions are of little importance. Let's take off our modeler hats for a moment, and instead look at modeling from the perspective of a client. As clients, we would hire a modeler to build a model to fulfill some specific purpose. The choices the modeler make (aggregated versus disaggregated, stochastic versus deterministic, what software they use, etc.) are all really secondary to the success of the model in fulfilling that purpose. Let's look back at Box's quote at the beginning of this chapter. We know all models are wrong, what we should really care about is there applicability to a specific task: how useful they are.

So instead of using these classifications to classify models, we can use the purpose of a model. There are three main purposes for models: prediction, inference and narrative.

Prediction : Models used for prediction are the most straightforward. They attempt to forecast some outcome given information about variables that may influence that outcome. A weather forecast is an example of a model being used prediction. Likewise, when you apply for a credit card at a bank, they run a predictive model to determine your risk of default. When you apply for life-insurance, similarly, the company has an actuarial model to predict how much they should charge you for a given payout. All these models take in data (the weather yesterday, the amount of money in your bank account, or your age) and use that data to generate a prediction of the outcome.

Inference : Models used for inference are the most common in academic research. Often, academic research questions boil down to the simple template: "Does X affect Y?" These are inferential type questions. As an example, a researcher may make a hypothesis statement such as, "The wealthier a high-school student's family is, the higher the student's test scores will be." They may then build a model to test the validity of this hypothesis and the model's results will generally be phrased in terms of a p value indicating the significance of the evidence in support or against the hypothesis.

Narrative : Models are often used to tell a persuasive story. When the Obama administration wanted to persuade law makers and the public to support there proposed stimulus, they famously published the graph shown in Figure 2. A lot of complex modeling and mathematics surely went into constructing this figure, however its sole purpose is to tell a story: things are going to be bad, but the recovery plan will make them less bad. We will return to this figure later on.

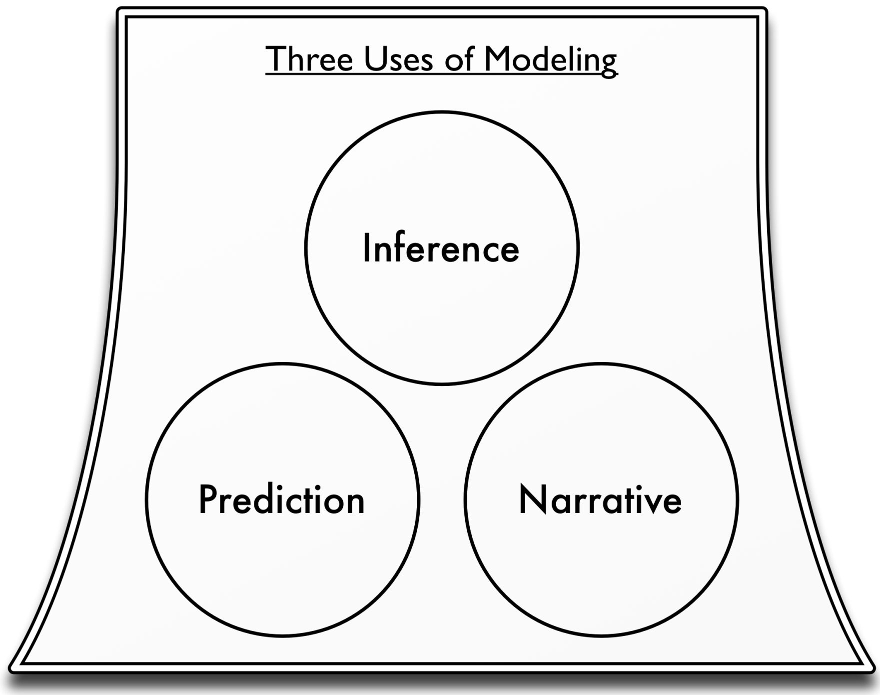

Figure 1. Three Usages of Models

All models can be classified in terms of these three primary usages and it can be useful to discuss modeling projects in terms of them. There is an even simpler classification system we can use, however, that once we complete it will clarify the core dichotomy that is at the heart of modeling.

The Strange Case of Inference

To help us get at this reduced classification scheme, let's first talk for a moment about the process of inference. Take our earlier example of finding whether wealth results in increased high-school test scores. We phrased this hypothesis in a specific way: that increased wealth will always increase test scores. This illustrative statement, however, actually differs from what is often done in practice. In general, researchers simply asks the question "Does X affect Y?" rather than "Does X increase Y?" This is a more flexible question that allows

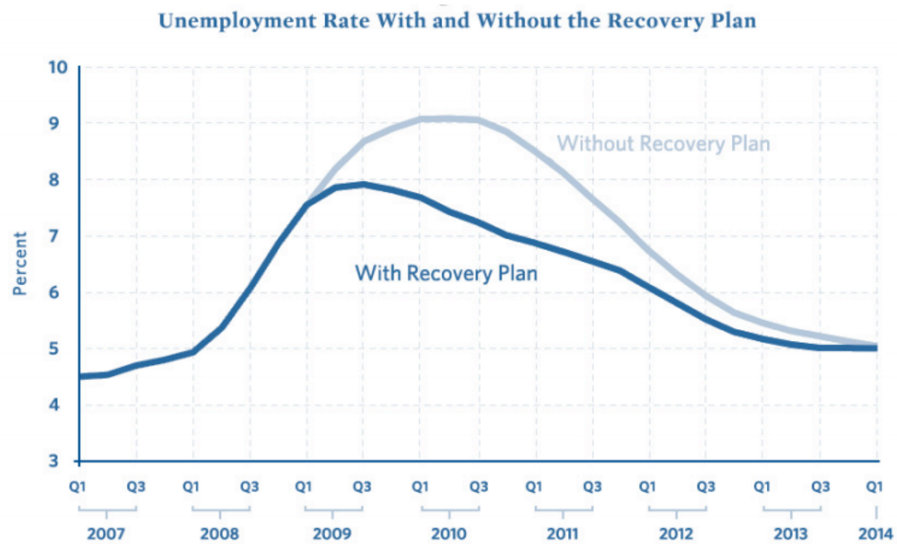

Figure 2. The Obama Administration's Predictions for the Effects of the Recovery Plan [@Romer:2009tx]

for many forms of relationships. Using this more general terminology, we would ask the question "Does wealth affect tests scores?"

The gold-standard to answering questions like this is the controlled experiment. For our wealth case, we could imagine an experiment where we took a sample of a thousand families from a school district. When the families' children enter high-school we randomly select have to be in a "poor" category and the other half to be in a "rich" category. Families in the rich category are given grants of $500,000 a year to spend how they wish while the parents in the poor category are fired from their jobs and have their savings frozen for the duration of the experiment. Once the students have graduated from high-school, we simply compare the average scores for the students in the poor and rich categories.

This is the ideal approach to answering inferential questions like these. For many types of questions, controlled experiments can be done (for instance does treatment with a novel drug help control a disease), but in general complex social questions are simply impossible to answer with them. We can construct the procedure we just imagined, but it would be impossible (and deeply unethical) to implement in a community.

Traditional Model Based Inference

Given this inability to do controlled experiments in many cases, how do we approach inferential questions? The standard way is to collect data and then construct a model enabling us to measure the statistical significance of the hypothesis given the data. The model of choice due to history and simplicity is the linear model:

$$Y = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 ...$$

For the education example we could simple collect data on a number of students. We could measure their families' wealth (X_1 in the equation above) and on their test scores (Y). We could then run the linear regression to determine the coefficient values (β_0 – the intercept – and β_1 – the effect of wealth on test scores). If we thought there were other factors that affected test scores, we could measure them and include them as addition X's in the regression.

In addition to obtaining the values of these coefficients, we also obtain as a result from the regression the statistical significances or "p values" of these coefficients. Although p values are commonly used in statistics, they are ubiquitously misunderstood[2] so it would be useful to briefly review them.

In short a p value measures the probability of seeing the measured data (or more extreme data) assuming the null hypothesis is true. When looking at the significance of coefficients, a p value means the probability of seeing that magnitude of coefficient (or one even further from 0), given that the (unknown) truth is that the coefficient actually has a value of 0. In other words, it is the probability of seeing the observed non-zero value, assuming that the true value is in fact 0. Generally probabilities of 10%, 5% or 1% or smaller are taken as indicating statistical significance. These low values indicate that the coefficient value is so far from 0, and the probability of this occurring by chance so small, that we can accept the fact that the coefficient is not 0.

This is what a p value is. Now let's specifically mention what a p is not, as this is often misunderstood. p values do not represent the following commonly used interpretations:

- The probability that the null hypothesis is true (that the coefficient is 0)
- One minus the probability that the alternative hypothesis is true (that the coefficient is not 0)
- Any sort of "proof" that the null or alternative hypotheses are correct or incorrect
- The probability that you are making the correct or incorrect decision if you accept or reject the null or alternative hypothesis

Using the p we can do inference by using the statistical significance of the coefficients. If the probability of β_1 (the coefficient for wealth) occurring due to chance (given it is false in reality) is less than, say 5%, we can claim with

[2] These misunderstandings are not only made by on-the-ground practitioners and analysts, they are frequently shared, and propagated, by university-level statistics instructors; see, for instance, @Haller:2002vo.

reasonable strength that wealth does in fact affect test scores. This is the standard approach researchers take to model-based inference.

A Sea of Assumptions

However, let's stop for a second and consider what we have done here. In carrying out these logical steps, we have had to make one very large assumption: that the relationship between test scores and wealth is linear. Our equation above assumes that for every increase in one unit of wealth (X_1), test scores (Y) will increase on average by the amount of the coefficient (β_1). What if this were not in fact true? For instance, we could easily imagine the case where wealth initially helped test scores by providing students more resources and opportunities to learn. However, after a certain point, wealth could theoretically negatively impact scores as very wealthy students might lack the pressure or motivation to work hard.

If we thought this was the case, we could change are regression formula to contain quadratic terms which could replicate this type of relationship:

$$Y = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_1^2$$

If our assumptions about the quadratic relationship are correct, then this models will yield accurate inferences. However, if they are wrong, are inferences will also be wrong.

What are we really doing when we assume regression forms like this? Now it might not be immediately obvious, but what we are in fact doing is telling a story. Using our first equation, we are telling the story that as wealth increases, test scores will always increase. Bill Gate's children will preform amazingly well! Using the second equation we are telling a different story: that as wealth increases test scores initially do as well but after a certain point increased wealth will hurt test scores. That picture isn't so rosy for Bill Gates!

And so we arrive at a very interesting conclusion. By telling these stories, our inferences are in fact based on narrative modeling approaches. Yes, these inferences build upon numerous calculations and very advanced theoretical underpinnings, but ultimately what governs our conclusions and inferences are the stories or narratives we tell about them. These are choices that we as the storyteller make, they not determined by an objective truth or reality.

Predictive Inference

Is there an alternative approach to inference? Can we accomplish it without using narrative techniques? The answer is yes. An alternative prediction-based approach to inference is available. In this approach, rather than calculating statistical significances as a function of an assumed model, we calculate significances as a function of the simple question: "Does knowing X help us to predict Y?" This question is effectively identical to our earlier question – "Does X affect Y?" – but it is structured in an explicitly predictive manner. If the answer to the question is true, then we can say that there is a relationship between X and Y.

The techniques to accomplish prediction-based inference are much newer than classic techniques as linear regression as they rely upon ample computing power and would not be possible with out. One of these approaches is the A3 method (XXX Citation) which uses resampling based algorithms to obtain estimates of predictive accuracy and statistical significance. They focus purely on predictive accuracy to determine whether a variable is significant and often require the automatic exploration of hundreds or thousands of competing models to find the one that best describes the data.

Predictive versus Narrative Modeling

As we can see, inferential techniques can be split into two categories: those based on narrative modeling methods and those based on predictive modeling methods. So from our original three categories of model purposes – prediction, inference, and narrative – we are left with just two fundamental types of modeling: predictive modeling and narrative modeling.

This terminology is not a traditional one, but it is at the heart of modeling. Understanding the distinction between these two types of modeling will prove to be much more valuable than mastering fine technical details. The choice of whether to build a predictive or a narrative model is fundamental one that shapes every aspect of a model and determines its ultimate utility for a specific purpose.

Predictive Models

How do we define a predictive model? The obvious answer is that predictive model is one that makes predictions. If a model generates predictions for a future outcome or a given scenario, than it must be a predictive model. By this definition, a weather forecast is a predictive model as were the Obama administration's unemployment predictions we saw earlier.

Unfortunately, this straightforward definition is useless. Worse than being useless, it is actually quite dangerous.

Let us propose a model for next year's unemployment figures in the United States:

> Generate a random number from 0 to 1. If the number is less than 0.1, unemployment will be 20%. If the number is greater than or equal to 0.1, unemployment will be 0%.

There, we have just constructed a model of unemployment. Furthermore, our model creates predictions. With just a few calculations we can forecast unemployment for the coming year. Isn't that convenient?

Of course this model is a joke. It is clearly a horrible tool to use to predict unemployment. However, using the naive definition of what it means to a predictive model, it would be classified as one. What makes this simple model, such a poor model for prediction purposes?

There are several answers to this. We might start by saying it is too *simple*. Clearly if we are trying to predict unemployment we should include the current economic state and trends into our model. If the economy is improving, unemployment will probably drop and vice versa. This is a valid point. Let's address it by proposing an "improved" model:

> Generate a random number from 0 to 1. If the number is less than the percentage change in GDP over the past year, unemployment will be 20% plus the current unemployment rate. If the number is greater than or equal to 0.1, unemployment will be the net change in the consumer price index over the past 8 years.

Is this a better model? Clearly, it is more complex than the previous one and it incorporates some relevant economic data and indicators. Equally as clear, however, it is also a joke no one should treat this as a real predictive model.

So what defines a predictive model? These toy economic models show that just generating predictions is not a rigorous enough criterion. Instead a predictive model must fulfill two additional criteria. A predictive model is one that:

1. creates predictions,
2. has an accurate estimate of prediction error,
3. and has the lowest prediction error of a reasonable set of other models.

If these three criteria are true, then you have a predictive model. Our two proposed models to estimate unemployment are clearly not predictive as we do not have any estimate of predictive error. We can also apply this definition to Obama's employment predictions we saw earlier. When we first presented the model, we called it a narrative model which was probably slightly confusing as the model did generate predictions. However, using these three criteria we can see also that it is in fact not a predictive model. The model contains no estimate of prediction error (and one is not available in the original report) so it simply cannot be consider to be predictive.

If an accurate estimate of prediction error are available, you can proceed to criteria 3 and directly compare the prediction errors between different models to find the one with the lowest error. For instance, we could estimate prediction errors for the two simple models proposed here along with Obama's model to find the one with the lowest error. We would hope that the one Obama presented to congress would be the most accurate, however, before we test it we must not make the error of blindly accepting a model to be right based on who presented it to us or its complexity.

Why do we so rarely hear about the predictive accuracy of models. There are a number of reasons but they all boil down to three basic issues:

1. Assessing prediction error accurately is quite difficult.
2. Sharing prediction error may perversely decrease subjective belief in a model.
3. Most models people use for prediction are actually narrative models and their predictive error is irrelevant.

Let's look at each of these points in detail. First the issue of the difficulty of assessing prediction error. In general, obtaining an accurate assessment of prediction error is much more difficult that developing the predictions themselves. Most commonly used approaches (for instance the standard R^2 from linear regression) have significant flaws. There are both theoretical and numerical methods that can be used to more accurate prediction errors in many cases (this will be discussed further in the section the Cost of Complexity; see also @FortmannRoe:2012tf). When dealing with time series models, however, like most of those explored in this book, it is almost impossible to truly manage to accurately assess model prediction error. In the past ten years, theoretical technique to approach these issues have just begun to be developed (e.g. @He:2009jp or @King:2008jq) but they are still impractical to apply in most cases.

If the challenge of measuring prediction error is overcome, there is an even more insidious barrier to its being provided with the model. There is a perverse phenomena that the act of reporting prediction error will often *decrease* the credence an audience gives a model. An anecdote was relayed to us by a member of a team working on a model of disease spread. His team was sharing the predictions from the model with a group of policy makers. Everything was going well until the audience saw the error bars of the predictions. Where his audience had been content with the raw predictions, they were quite unhappy with the predictions given the accurately estimated uncertainty. Why was this? Was the team's model particularly bad and these policy makers had a more predictive model at their disposal? Unfortunately, not. In a world where policy makers and clients are constantly shown models (like Obama's unemployment figures) with no measure of uncertainty (or even worse, poorly calculated, artificially low uncertainty), they come to have unrealistic expectations and turn away good science in favor of magical guesstimates.

Finally, probably the most likely reason supposedly predictive models do not include prediction error is that they simply are not predictive. Generally models developed for a purportedly predictive purpose are actually narrative models in disguise. Why is this? Well lets look at the reason for most modeling project. It is very rare that models are being funded solely for the purpose of generating an accurate prediction. More often, the models are part of some political process within an organization or between organizations. Ultimately, the people funding the model expect it to prove a point to their benefit. In environments like these, it is to be expected that even the most purportedly predictive modeling efforts will become side tracked by political concerns and make significant compromises to placate these concerns.

We can see the results of such influences in the predictions generated for unemployment presented earlier. Figure 3 shows the projections for the unemployment rates with and without the stimulus plan just as in Figure 2. Overlaid on this, however, are the true values of unemployment. As is readily evident, the original modeling and predictions were way off the mark. Not only are they worse than the projections assuming the stimulus was enacted (which it was) they are much worse than the projections for the economy assuming the stimulus had never been enacted! This is just a small example – one that is sadly replicated over and over again in business and policy making – of mistakenly treating a narrative model as a predictive one.

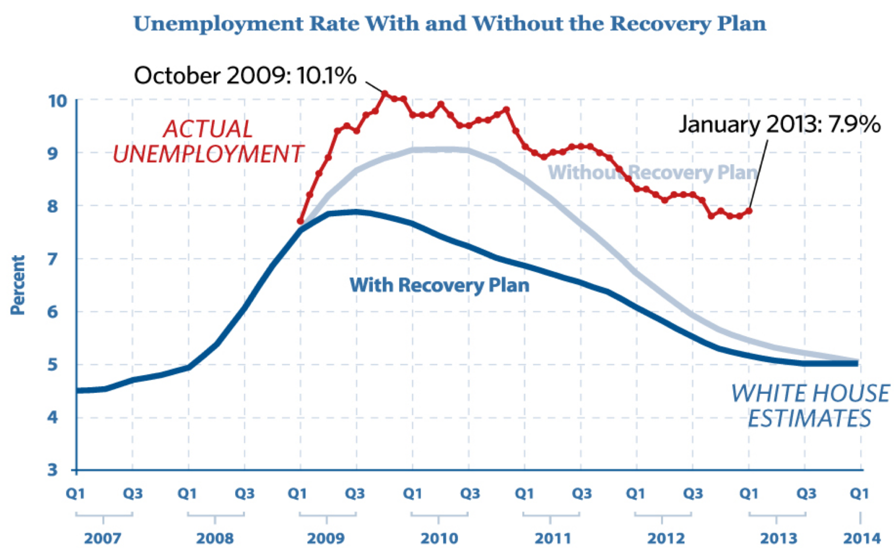

Figure 3. Unemployment projections versus reality [@TheHeritageFoundation:2013vu]

Narrative Models

In contrast to predictive models, a narrative model is one built to tell a story. When most people first hear the "narrative" terminology, they often have an instinctive negative reaction. We find this strange as narratives are the fundamental human form of communication. We tell narratives to our friends and relatives. Politicians communicate their policies to us using narratives. Of course the vast majority of our entertainment is focused on narratives[3]. Business leaders and managers attempt to describe their strategies to us using narratives; and business books are in generally dominated by narrative anecdotes.

Generally we humans do not view the world as a collection of numbers and probabilities, instead we see reason and meaning. In short, narratives are how we see the world.

One critique of the term narrative is that it implies a lack of numbers or mathematics. This could not be further off the mark. There are many ways to construct narratives. Words are one, pictures are another, music is a third. Numbers and mathematics are just a fourth way of constructing a story.

In fact, most statistical and mathematical models are in fact narrative models. We looked earlier at the case of linear regression as a tool to predict test scores given wealth. Again the mathematical equation for this simple model is:

$$Score = \beta_0 + \beta_1 \times Wealth$$

This equation defines tells narrative. Translating this narrative into words, we would say:

> Test scores are only determined by a student's family's wealth. A child's whose family is broke, will have a test score, on average, of β_0. For every dollar of wealth a child's family accumulates, the child will score, on average, better on tests by β_1.

You might or might not agree with this narrative (in our view it is a nonsensical and reductionist view of child achievement) but it shows the strict equivalence between this mathematical narrative and narrative prose. This process can be applied all mathematical models. The mathematical definition of the model can be converted directly, with more or less lucidity, into a story describing how the system operates. The same can also be done in the reverse: we can take a descriptive narrative of a system and convert it into a mathematical description. As we have seen (will see? XXX) this is what tools like reference modes and pattern matching are all about: eliciting a narrative from a subject in a way which can be formulated quantitatively.

[3] Even sports, a form of entertainment that innately contains no narrative, becomes wrapped in narrative the announcers and commentators attempt to create for it to engage us.

With predictive models, we can compare competing models based primarily on prediction accuracy[4]. But how do we evaluate and compare the quality of narrative models?

The basic criterion to assess a narrative model is that it should be *persuasive*. Although persuasion is not a purely objective measure like prediction accuracy, there are two key goals of a persuasive model. A persuasive model is one that is both highly believable and one which effectively communicates its results.

When building a narrative it is very important to use tools that are well suited to these tasks. Again, as with most modeling work, statistical models like the wealth linear regression example are the most commonly used tools for the construction of narrative models. Unfortunately, they are quite poorly suited to them many ways. Most statistical models depend on numerous unrealistic and highly technical assumptions about the data. If these assumptions are enumerated in plain english, they will often conflict with people's understanding of a system discrediting the model. The alternative is to leave these assumptions hidden creating a black box model. This is often the road taken and in our view, it is a shame. Narrative models should never be given any credence if the model operations is not transparent. There is a reason for the saying, "there are lies, damned lies, and statistics."

The modeling techniques presented in this book, on the other hand, are well suited for narrative modeling. The techniques we present are "clear box" modeling where the workings of the model are transparently evident and clear. The models in the book have their structure explicitly described using a very accessible modeling diagram showing the interactions between the different components in the model. The equations governing the evolution of a model are clear and readily accessible for each part of the model. Furthermore, these modeling techniques make it straightforward to generate animated illustrations and displays to communicate model results.

In total this combines to make them these models powerful persuasive tool. As with any model, however, there are concerns and questions people will raise about them that could cause them to doubt the work. There are a number of techniques that can be used to help build an audience's confidence in these models.

Confidence Building Steps

. . .

@Forrester:1978vy

[4]Other criteria include ease of use, cost of fulfilling data requirements, and computational requirements. But all those are secondary to prediction accuracy.

Sensitivity Testing

There are four key distributions that are quite useful for specifying the uncertainty in a variable:

Uniform Distribution : The uniform distribution is defined by two parameters: a minimum and a maximum. Each number within these two boundaries as an equal probability of being sampled. The uniform distribution is useful when you know the boundaries on the values a variable can take on, but you do not have any information on the likelihood of the different values within this region. The uniform distribution can be used in Insight Maker using the function *Rand(Minimum, Maximum)*, the two parameters are optional and will default to 0 and 1 if *Rand()* is called without them.

Triangular Distribution : The triangular distribution is defined by three parameters: the minimum, the maximum, and the peak. Like the uniform distribution, the triangular distribution will only generate numbers between the minimum and maximum. Unlike the uniform distribution, the triangular distribution will not sample all numbers between these boundaries with equal likelihood. The value specified by the peak will have the most likelihood of being sampled with the likelihood falling off as you move away from the peak towards either the minimum or maximum boundary. The triangular distribution is useful when you know the both the most likely value for a variable and you also know boundaries for the values a variable can take on. The triangular distribution can be used in Insight Maker using the function *RandTriangular(Minimum, Maximum, Peak)*.

Normal Distribution : The normal distribution is defined by two parameter: the mean of the distribution (generally denoted μ) and the standard deviation of the distribution (generally denoted σ[ˆ This is where the term six-sigma of the Quality Control methodology comes from.]). The most likely value be sampled from the normal distribution is the mean. As you move away from the mean (in either a positive or negative direction), the likelihood of a number being sample decreases. The standard deviation controls how fast this likelihood falls as you move away from the mean. Small standard deviations results is steep declines in the likelihood while large standard deviations result in more gradual declines. The normal distribution is useful when you do not have boundaries on the values for a variable but you do know what the most likely value for the variable should be (the mean). The normal distribution can be used in Insight Maker using the function *RandNormal(Mean, Standard Deviation)*.

Log-normal Distribution : The log-normal distribution is closely related to the normal distribution. In fact the logarithm of the values samples from a normal distribution will be log-normally distributed. Like the normal distribution, the log-normal distribution is defined by two parameters: the mean and standard deviation. Where the log-normal distribution differs from the normal distribution, is that negative values will never be generated by the log-normal distribution. Thus is is useful when you have a variable which you know cannot be negative, but for which you do not have an upper bound. The log-normal distribution can be used in Insight Maker using the function *RandLogNormal(Mean, Standard Deviation)*.

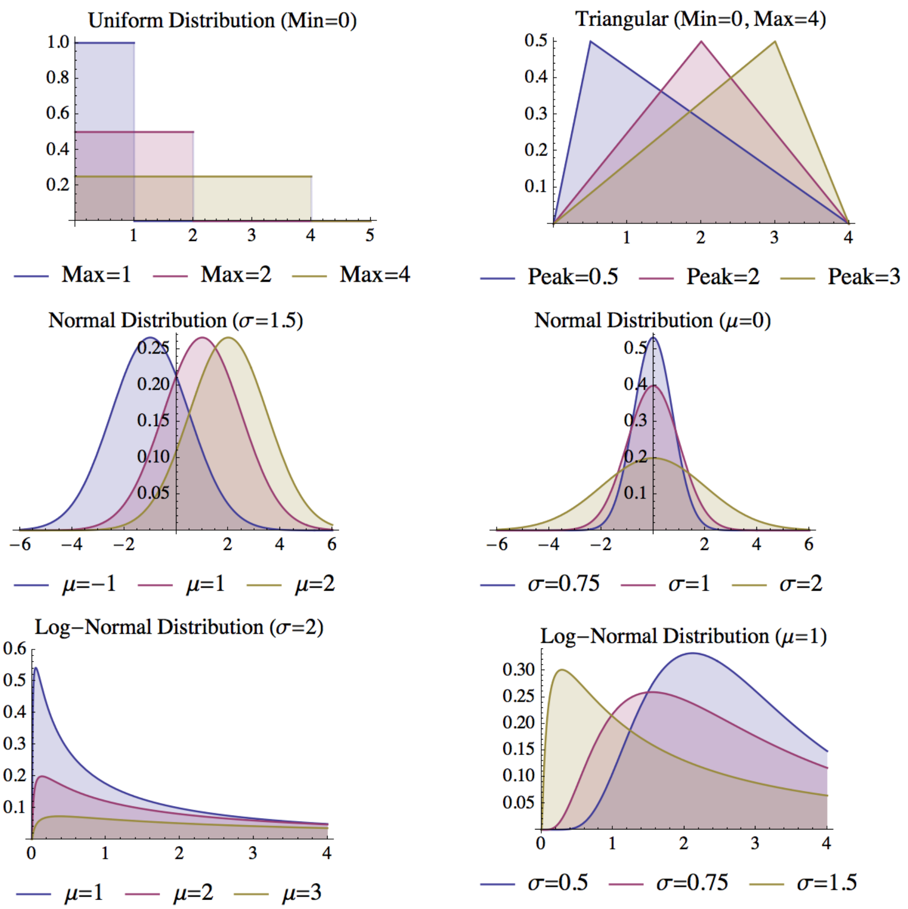

Figure 4. Common Distributions for Sensitivity Testing with Sample Parameter Values

There are many other forms of probability distributions. Some notable ones are the Binomial Distribution (*RandBinomial(Count, Probability)*), the Negative Binomial Distribution (*RandNegativeBinomial(Successes, Probability)*), the Poisson Distribution (*RandPoisson(Lambda)*), the Exponential Distribution (*RandExp(Lambda)*) and the Gamma Distribution (*RandGamma(Alpha, Beta)*). These distributions can be used to address very specific modeling usage cases and needs (for instance, the Poisson distribution can be used to model the number of arrivals), however, the four distributions described in detail above should generally be sufficient for most sensitivity testing needs.

The astute reader will notice that our discussion up to this has failed to address an important point: how do we know the uncertainty of a variable? It is very easy to say that we do not know the precise value of a variable, but it is much harder to define the uncertainty of it. One case where can precisely define uncertainty is when you take a random sample of measurements. For instance, suppose our model included the height of the average american man as a variable. We could randomly select a hundred men and measure their heights. In this our uncertainty would be normally distributed with a mean equal to the mean of our sample of one hundred men and a standard deviation equal to the standard error of our sample of one hundred men[ˆ Please note that this contradicts slightly what we said earlier. Clearly, a person cannot have a negative height while the normal distribution will sometimes generate negative values. So wouldn't a log-normal distribution be better than a normal distribution? Mechanistically, it would, however statistical we can show that due to the Central Limit Theorem the normal distribution does asymptotically precisely model our uncertainty. Given a large enough sample size, the standard deviations for heights will be so small that the chances of seeing a negative number (or even one far from the mean) are effectively none.]. For any random sample of n values from a population, the same should hold true: you will be able to model your uncertainty using a normal distribution with:

$$\mu = \frac{Value_1 + Value_2 + Value_3 + ... + Value_n}{n}$$

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Value_i - \mu)^2}$$

However, in most applied cases you will not be able to apply this normality assumption. Generally you will not have a nice random sample, or you might have no data at all and instead have some abstract variable you need to specify a value for. In theses cases, it is up to you to make a judgement call on the uncertainty. Choose one of the four distributions detailed above and use whatever expert knowledge available to you to place an estimate on the parameterization of uncertainty. One rule of thumb, however, is that it is better to overestimate uncertainty than underestimate it. It is better to err on the side of overestimating you lack of knowledge than it is to obtain undue confidence in model results due to an underestimation of uncertainty.

Extreme Value Tests

Forecasting

Units

Chapter 5

Model Testing

This is some **Markdown**.

fjdshkfjds

fdshfjsd

Model: Test Model

{“create”: “Stock,”geometry“:{”x“:400,”y“:140,”width“:100,”height“:40},”name“:”Healthy"}

{“create”: “Stock,”geometry“:{”x“:400,”y“:280,”width“:100,”height“:40},”name“:”Infected"}

{“target”: “Infected,”geometry“:{”x“:400,”y“:280,”width“:100,”height":40}}

DIAGRAM

{“create”: “Flow,”geometry“:{”x“:0,”y“:0,”width“:100,”height“:100},”alpha“:”Healthy, “omega”: “Infected,”name“:”Infection"}

DIAGRAM

The basic model structure has been laid-out, we can start to define parameter values and equations. We’ll start with a very simple model containing a population of 100 people and where 2 people becoming sick each year.

{“attribute”: “InitialValue,”target“:”Healthy, “value”: “100”}

{“attribute”: “FlowRate,”target“:”Infection, “value”: “2”}

RESULTS

The results are as we would expect. However this is not a model of an infectious disease as the infection rate does not depend on the presence of infected individuals. Let’s change the infection rate so it depends on the contact rates between sick and healthy people.

{“attribute”: “FlowRate,”target“:”Infection, “value”: “0.006*[Healthy]*[Infected]”}

RESULTS

That’s strange. No one ever gets sick. Why is that? It turns out it is because we start the simulation with no infected people in the model. Since we’re modeling an infectious disease, this means there is no one to start the epidemic! Let’s change that we’ll add a single infected person to get the epidemic started.

{“attribute”: “InitialValue,”target“:”Infected, “value”: “1”}

RESULTS

That looks about right. Before moving on, let’s spend a moment to improve our model structure. Right now if we wanted to edit the infection rate, we would have to dig down in the equations to find the right number. Let’s make our model more modular, without changing any results, by separating the infection rate into its own variable.

{“create”: “Variable,”geometry“:{”x“:230,”y“:145,”width“:120,”height“:50},”name“:”Infection Rate"}

{“create”: “Link,”geometry“:{”x“:0,”y“:0,”width“:100,”height“:100},”alpha“:”Infection Rate, “omega”: “Infection”}

DIAGRAM

{“attribute”: “Equation,”target“:”Infection Rate, “value”: “0.006”}

{“attribute”: “FlowRate,”target“:”Infection, “value”: “[Infection Rate]*[Healthy]*[Infected]”}

RESULTS

We can hide the display of the infection rate by configuring the display.

{“attribute”: “Primitives,”target“:”DISPLAY, “value”:[“Healthy”, “Infected”]}

RESULTS

Now that we have our basic model working, let’s extend it by adding the phenomena of people recovering from the disease. We’ll model something like the Chicken Pox where people become immune to the disease after they recover.

{“create”: “Stock,”geometry“:{”x“:400,”y“:400,”width“:100,”height“:40},”name“:”Immune"}

{“target”: “Immune,”geometry“:{”x“:400,”y“:400,”width“:100,”height":40}}

{“create”: “Flow,”geometry“:{”x“:0,”y“:0,”width“:100,”height“:100},”alpha“:”Infected, “omega”: “Immune,”name“:”Recovery"}

{“create”: “Variable,”geometry“:{”x“:610,”y“:290,”width“:120,”height“:50},”name“:”Recovery Rate"}

{“create”: “Link,”geometry“:{”x“:0,”y“:0,”width“:100,”height“:100},”alpha“:”Recovery Rate, “omega”: “Recovery”}

DIAGRAM

{“attribute”: “Equation,”target“:”Recovery Rate, “value”: “0.1”}

{“attribute”: “FlowRate,”target“:”Recovery, “value”: “[Recovery Rate]*[Infected]”}

{“attribute”: “Equation,”target“:”Infection Rate, “value”: “0.008”}

{“attribute”: “Primitives,”target“:”DISPLAY, “value”:[“Healthy”, “Infected”, “Immune”]}

RESULTS

Fantastic! Now we have a working disease simulation. You can experiment with different population sizes, infection rates and recovery rates to see how they change the results.

This is what is known as the *SIR Model* (Susceptible-Infected-Recovered) in the modeling community.

Chapter 6

End Model

Some more text...

convert_latex_modelThis is the end of the chapter. # References