A Simple Introduction to Systems Modeling: Tell a Good Story, Build a Good Model

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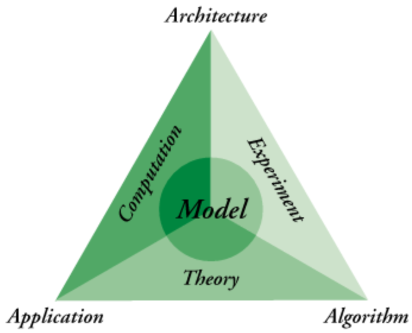


All models are wrong; some models are useful. – G. E. P. Box (English Statistician)

The purpose of computing is insight, not numbers. – R. W. Hamming (Computer Scientist)

If you can't trust the numbers, you won't get much insight. – R. M. Panoff (Physicist)

A little math can model the world! - Holly Hirst (Mathematician)

This exercise has three motivations:

- To explore the mental space of expectation, observation, and reflection in science;
- To build a simple model in Vensim starting with a good story and a simple 'picture';
- To realize how much of Nature could have similar, and simple, generating rules.

Even though it may look like a specific recipe for a specific model (how the flu spreads), the steps here are really generally applicable: Thinking, observing, conjecturing, observing, and back to thinking.

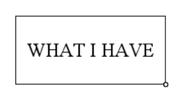
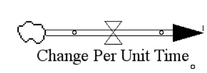
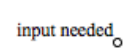
Expectation, Observation and Reflection: The process of science comes down to these three basic and very active steps: *expectation, observation, and reflection*. Vensim offers a wonderful way to explore science in a variety of ways, offering a chance to learn how to model from limited input information, to explore emergent phenomena, and to interpret the qualitative and quantitative aspects of a dynamic, visual, interactive model.

Not everything that we will do is written in this handout. That's because I have no idea what each of you will suggest along the way, and I suppose that it would be more fun to do what you think of as interesting and fun, than for me to try to get you to do something I might think is fun.

Part of the motivation of this exploration is to change the "sound" of science from, "*What is the answer to this question?*" to "*How many different ways could we explain what we observe, and what does that tell us about the world*?"

SYSTEM DYNAMICS: Our starting point is the **collective** or a **property of the collective** (also called the **system**, the **aggregate**). This approach takes a **global** view of the world. We need to state the initial conditions of the system and how it changes. Our model can include as much information or conjecture as we want to build in.

Almost every systems modeling environment includes the four basic components listed below. They may look slightly different and be called different things depending on the software. The images and the bold terms below are those used in the Vensim software.

what you have	a quantity represented with a **box** or container shape, sometimes called a stock or reservoir.	
how something changes per unit of time	a **rate** of change represented with a pipe flowing into or out of a box, sometimes called a flow or pipe. Notice the valve image in the middle, which indicates that the actual number flowing through this pipe can be set.	
what you know	a **variable** or constant input to the model represented with a circle or text.	
what depends on what	A dependency **arrow** or connector from one component to another that can be read as, "I need to know ______ in order to calculate what I am pointing to."	

Our Story: How Disease Spreads

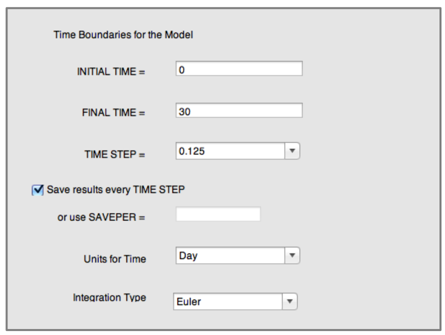
Applying the systems approach to a specific situation of modeling the spread of a disease, let's start with the simplest case, that is, that a healthy person catches a disease from contact with a sick person, and that –once infected– this person doesn't get the infection again. For now we can even ignore the prospect that the sick people get better as a first approximation.

Main Model Ideas:

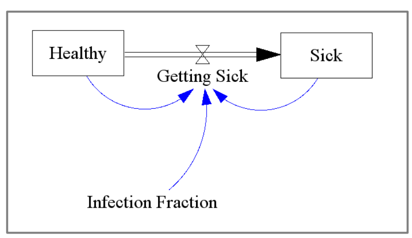
- We have some number of healthy people, H, and some number of sick people, S, who are interacting with each other.
- If the healthy people can come in contact with the sick people, then $H \times S$ is the total number of possible contacts
- some fraction of these contacts moves a person out of the healthy "stock" into the sick "stock," that is, if f is the infections per time per contact, then $f \times (H \times S)$ is the number of people that get sick per unit time.

Let's build this model in Vensim. Start Vensim. Before starting on the diagram, we need to introduce the concept of ***Time*** into the model, and we do this in Vensim by the **Model / Settings** menu item (note that in some versions of Vensim, this settings dialog box may pop up automatically.

We need to think about what the appropriate units are for this model. For a disease-spreading model, ***days*** is perhaps the best mental model to work with. Let's look at how the disease spreads in the first 30 days, with the time step set to a fraction of a day.

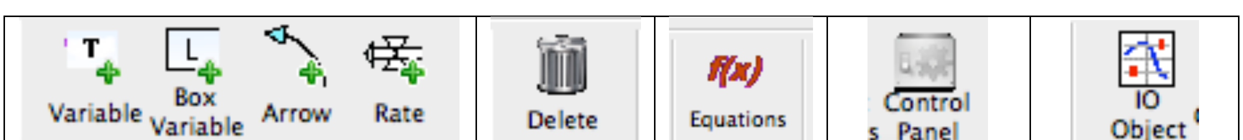


Now that we have our mental model of time worked out, we can construct a visual representation of our mental model of the disease itself. This "spread of infection" model can be pictured this way, as a kind of *concept map* or *pathway diagram*:



In each box you have a certain number of people, and the people, for the most part, start out healthy, and a fraction of these become sick when in contact with a sick person. The rate arrow represents the change from a healthy person to a sick person, and the blue arrows show what information you need to know in order to compute the rate "getting sick."

To create this diagram, select each component from the tool bar and place it in the model by clicking. The most commonly used tools are pictured below – take a moment to locate them in the Vensim toolbar.



standard components of the model	delete pointer	equation builder	set up graphs and tables	placement of graphs and tables

Once the component is set you will be asked to name the component. If you need to erase one of the objects, select the delete trash can and click on the item you want to erase. Placing the rate and arrow components will take some practice, because you want to be sure they are connected correctly.

- Getting Sick **Rate** Pipe: In this model the rate component is attached to the healthy box and flows into the sick box. Select the rate then click *inside* the healthy box once. Move the mouse over to the *inside* of the sick box and click again. You should see the image above when done. If you see a cloud on one or the other of the ends of your rate component, you will need to delete it and try again!
- Infection Fraction Dependency **Arrow**: Once you place the infection fraction variable you can show that the getting sick rate depends on it. Select the arrow component and click *once* on the infection fraction text. Then click once inside the hour-glass-shaped valve on the rate pipe to make the connection. If you want the arrow to bend as in the image above, click 3 times: once on the infection fraction, once outside of all the components, and once on the rate pipe valve. The same process works for the other dependency arrows.

Once the diagram is complete, the next step is to define each component. Select the **Equations** icon from the tool bar, and everything needing a definition will turn black. To define each item, double click on the object and answer the dialogue. Let's assume the following values:

- In the healthy box, initial healthy: 1000
- In the sick box, initial sick: 1
- In the Infection fraction variable, equations: 0.001
- getting sick rate pipe, equations: Infection_fraction*HEALTHY*SICK

To run the model, select **Simulate** from the tool bar. To run the model and vary the model as you run, select **SyntheSim**. You can examine various graphs and look at the output to see how the infection proceeds.

Graphs and Tables

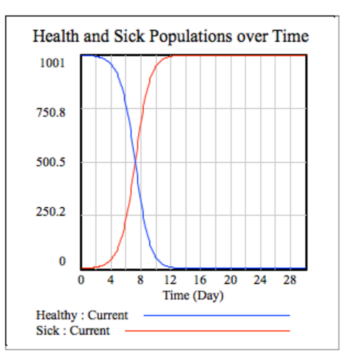
Notice that you can click on any item in the diagram and then choose the graph or table from the left sidebar to see a representation of the data generated by the model. To get a graph that is permanently displayed, including one that can include multiple quantities:

1) Run the model at least once first!
2) Choose **Control Panel** from the tool bar at the top of the window, and click the **Graph** tab. Then **New Graph.**
3) Use the select (**Sel**) button to choose the x-axis variable – usually time – specifying a range for the axis if desired.
4) Use the select button(s) to choose one or more y-axis variables to plot, again specifying a range if desired.

Note: If you choose more than one y-axis variable, without specifying a range, you will find that each variable is overlaid on the graph with different ranges. This can be confusing for students. To have the y-variables all use the same range of values, check the box in front of the y-variable names as shown below.

Scale	Variable		Dataset	Label	LineW	Units	Y-min	Y-max
☑	Healthy	Sel					0	1001
☐	Sick	Sel						

Once you OK the changes in the Control Panel, choose **IO Object** from the tool bar, and click on the screen to place the object. In the dialog box that opens, choose **Output Custom Graph** and select the graph or table you created out of the picklist at the bottom of the dialog box. Run the model again, and you should see the graph:



Note that if you wish to have a table instead, the process is similar.

1) Run the model at least once first!
2) Choose **Control Panel** from the tool bar at the top of the window, and click the **Graph** tab.
3) In the top right corner of the dialog box, choose **As Table.**
4) Use the **Variable** button to choose a variable to put in the table and then use the **Add** button; note that by default time will be in the table.
5) The default setting for the table is to run horizontally; you can change that by clicking **Running Down.**

Place the table in the same way as the graph sing the **IO Object** tool.

There are many "bells and whistles" in most system modeling tools, including Vensim. The goal is to make the model as appealing, transparent, robust, and applicable as possible. The Vensim help feature and the Vensim website both have help pages (http://www.vensim.com/documentation/). There is a full tutorial with bells and whistles at http://www.shodor.org/tutorials

Extensions to Try as Home Work, if not addressed in class:

1. Allow sick persons to get better. Are they immune or can they get sick again? How would your models differ? How do you estimate the rate of getting better?

2. Introduce other factors to getting sick or getting better. How would you model 'staying home/quarantine'? What effect(s) does it have on the rates of new infections?

3. How could birth and death be taken into account? What effect could it have on new infections? What about scale?

4. What other physical processes can you imagine "spread" in a way that would be similar to how a disease like a cold spreads? Make at least one equivalent or "analogous to" model that is different from the simple spread of disease.

   NOTE: come to LAB NEXT WEEK prepared to share your analogous model with the class. Put your model somewhere that you can get to it from the lab (your H drive, on a thumb drive, etc.).

Getting your own copy of VENSIM: Google "free download Vensim"

Notes: