Homeostasis

Home

Of Pools, Balance, Equilibria, and Homeostasis:

Physiology is the study of life's processes. Indeed, life is **not** just structure (even if you **have** been immersed in anatomy and histology for the past few months!).

- Remember, the body's anatomy is identical in life and just after death. It is the **process** that is missing.

Learning physiology is therefore different than learning structure. One must build an understanding of the elements and interactions that give the body its process.

These introductory pages on homeostasis are designed to help you become familiar with learning process. They use simple, dynamic examples to build up systems that are representative of real physiologic processes.

Learning Physiology

Physiology does not just consist of studying one big system. Rather, the body has an almost infinite number of interlinked processes, some simple, some very complex. One strategy for learning physiology is to separate out these processes one system at a time, and learn them individually.

- This physiology course uses a systems approach to accomplish this aim.

Unfortunately, many of the processes that one needs to learn are complex, with many interacting parts, like a fancy old Swiss watch. It would be impossible to memorize all the different gear movements of such a watch, to know what each gear does when the seconds tick, the hour is struck, or the date changes.

A different skill aids you in physiology. One must learn to build an understanding of process from that basic knowledge of the parts and of their interrelationships.

- The study of process is aided by building models, and by making analogies to processes you already understand.
- These models and analogies help you to remember the process.
- They also help to teach you aspects of behavior that would be very difficult to study in living systems.
- Using such a skill, on can construct the details of behavior when needed.

Design Patterns of Life:

Even though there are a large number of physiological processes that are critical to life, learning physiology does not require starting from scratch for each of the body's systems.

Luckily, many of the body's diverse processes use similar **patterns of behavior"**.

These fundamental types of behavior, the "**Design Patterns of Life**" are repeated, like architectural motifs, through each of our subjects.

The processes of **Balance, Equilibria, and Homeostasis** are some of the most important of these design patterns.

The goal of these lectures is to start to examine these design patterns as dynamic processes. By "playing" with these basic example systems, you should get a "feel" for process, which you can then apply throughout this course.

Pool, a functional definition:

The "pool" is a functional term that is used implicitly in most physiological processes. If process can be taken as the action verb of a sentence, the pool is simply the subject.

This "subject" is often literally a pool, as in the total quantity of body water. However, the pool can also take on many other forms:

- Salt Content of extracellular fluids
- The body's total mass
- The number of muscle cells in a tissue
- The blood pressure
- The body temperature

As we'll see in the next section, the pool is usually the subject of one or more actions that have the effect of increasing or decreasing that pool. The simplest of these actions is balance, where the size of the pool depends on the quantity of inflow and outflow.

Balance:

If you think of a pool literally as a big container of water in someone's backyard, you can start to visualize how the level of that pool depends on how much water is put into it (rainfall, garden hose, condensation), and how much leaves (evaporation, leaks, splashes, etc.).

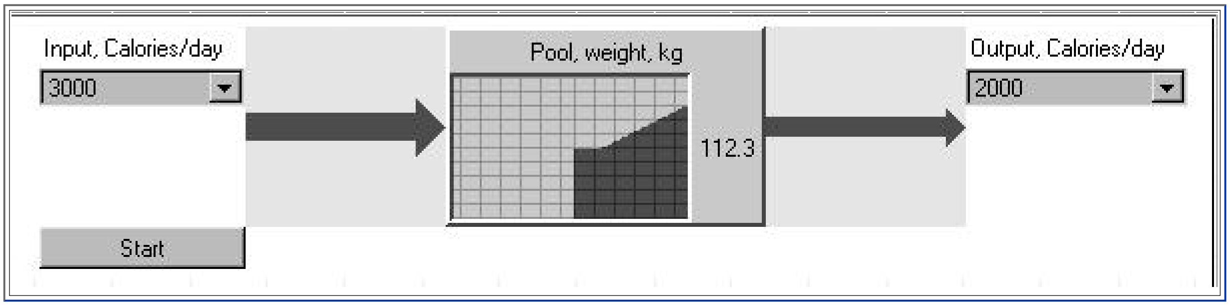
The pool of water reflects a **balance** between its input and its output. Within reasonable limits, the level in the pool will climb if input exceeds output, and fall if the output exceeds the input. When input and output are equal to one another, the level will stay the same.

The same kind of balance is found within the body as well. Fluid exchange between capillaries and the interstitium is one example of such a balance. The total body weight is another example.

Lets examine a simplified caloric balance to see this process in action. The pool here is the body weight, as shown in the simulation below by the moving strip chart recorder. Each day there is an input of calories from food, and an output based on the number of calories burned.

In the starting condition, the person's weight is 70 kg, and both the caloric input and output are 2000 calories per day.

Use the selector boxes at the right or left to alter the input and output. As long as they stay in balance, the weight remains constant. If they differ, the weight starts to increase or decrease correspondingly.



Input, Calories/day: 3000

Pool, weight, kg: 112.3

Output, Calories/day: 2000

This simulation is obviously overly simplistic. If you "diet" long enough, the weight shown here will become negative. Similarly, overeating for too long increases the weight to improbable proportions. Nevertheless, within these limits this simple simulation reflects all too well our daily dilemma: If you eat more than you burn, you get fat!

Indeed, try to loose weight in the simulation above when your daily caloric output is very low (500/day). The weight comes off very slowly, even on a starvation diet. This illustrates another of those little facts we might like to forget. Exercise is critical to weight loss.

Note that there is nothing in this balance simulation that causes the level of the pool to stay at any particular level. It could be anything.

In many physiological processes, the output reflects the size of the pool itself. In such a case, the pool will reach a new equilibrium for each different level of input. Go to the next simulation to see this in action.

Equilibria:

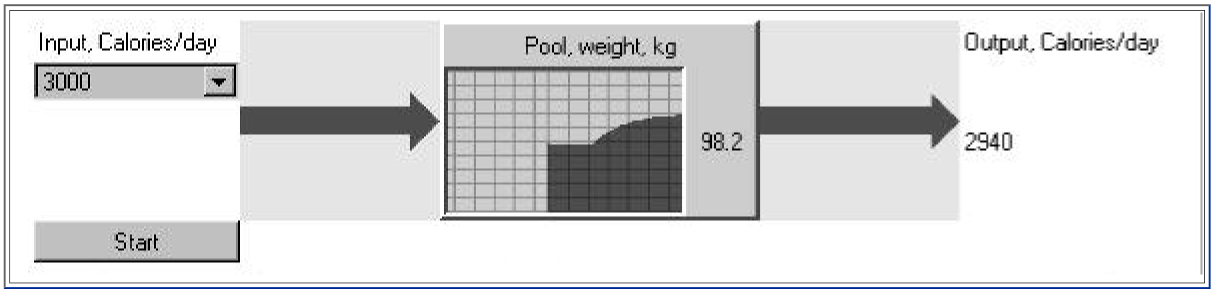
An equilibrium is reached when the size of the pool helps to determine the magnitude of its input, output, or both. In such a case, the pool will settle into certain preferred levels.

This is illustrated in the simulation below, which is just an extension of our caloric balance simulation. In real life, the number of calories we burn is not just determined by exercise, but also by the size of our bodies themselves.

In this simulation, adjustments to the output have been dropped. Instead, the output is proportional to the weight. At first, the caloric input is 2000 calories/day, and the body weight is 70 kg. This weight causes 2000 calories to be burned each day, so the system stays in balance at this weight.

Change the caloric input. Watch what happens to the weight. If the calories are reduced to 1000/day, the weight starts to drop, but now it does not continue to decline. It slows and levels out at a new steady weight. This new weight reflects the newly established equilibrium between input and output.

Note also the shape of the weight curve as it changes between the two steady levels. The curve has an "exponential" shape (it would be a straight line on a semi-log plot). This shape often appears in physiological processes. Where it does, it usually reflects a balance where the pool size helps adjust either the input or output to that pool.



Input, Calories/day: 3000

Pool, weight, kg: 98.2

Output, Calories/day: 2940

Even though this system tends to reach steady values for its pool size, there really isn't much discrimination about what those values are. Weight can still vary over a large range of possible values.

For many physiological processes, it is critical that the pool size be kept within very tight limits. Body water, salt concentrations, blood pressure, hormone levels are all examples of "pools" that require very close regulation in order to support life. Such close regulation requires something more than simple equilibria. They require a system that can adjust it's input and output to maintain a constant level in the pool. Go on the the next page to examine simple feedback systems.

Simple Feedback Systems:

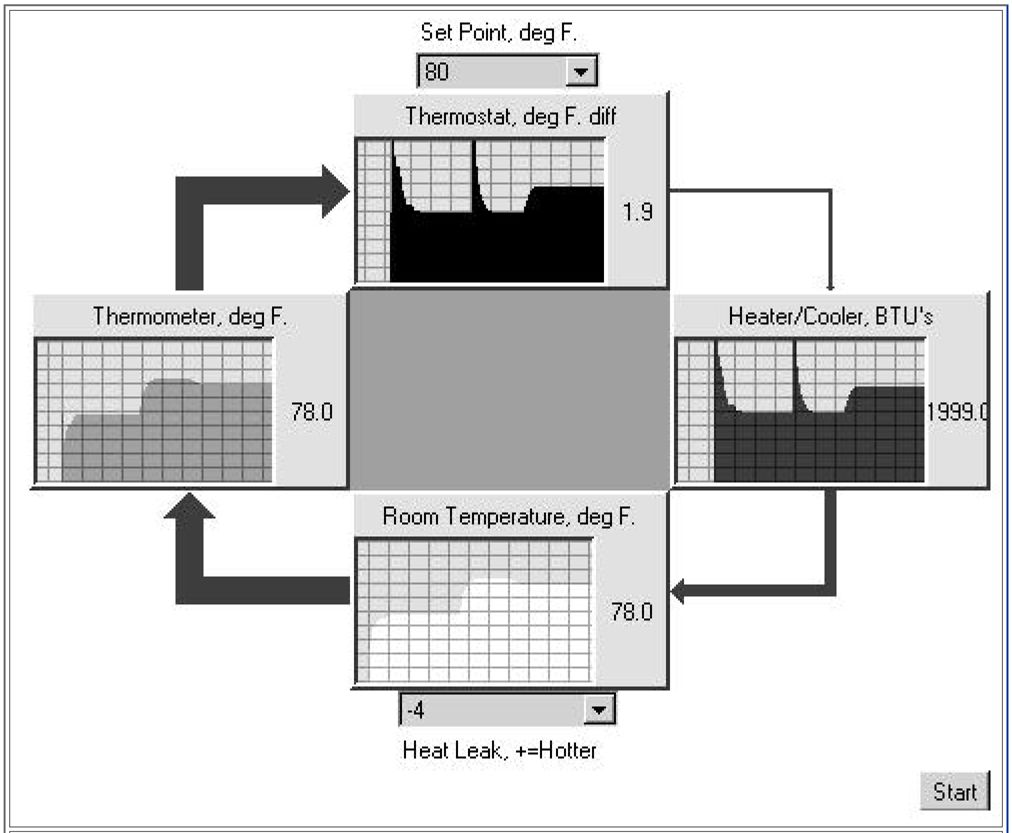
The close control of pool size, as required for many of life's processes, is no accident. Instead it depends on active and continual adjustments on the part of the body. This process cannot rely simply on static inputs and outputs. As we have seen, even simple equilibria don't have the needed precision. Special systems must be developed to accomplish this aim.

The process of actively maintaining constancy, even in the face of changing input and output, is called **homeostasis** (the term itself comes from Claude Bernard, a pioneer physiologist). A homeostatic system needs a special set of elements. These include:

- The pool itself.
- A system for measuring the size of the pool.
- A foreknowledge of the desired level for the pool (the **setpoint**).
- A system for comparing the pool size with the setpoint.
- A system for adjusting the pool should it differ from the setpoint.

These elements make a loop -- changes in the pool are sensed, and an adjustment is made to that pool to bring it back to the set point. Such a loop is called a **feedback loop**. In particular it is an example of "negative feedback", since pool changes are corrected in the opposite direction.

Lets look at these elements in action in a simple feedback system, as shown below. Here strip chart recorders represent each of the major elements described above. The arrows show the connections between each system (with the color and width of the arrow showing relative intensity). The system is modeled to represent a heating system, which is an everyday example of a negative feedback loop.



Set Point, deg F.: 80

Heat Leak, +=Hotter: -4

The simulation above represents the feedback loop of a climate control system. The strip chart at the bottom is the room temperature. The left chart is the thermometer temperature. The top chart is the difference between the thermometer and the set point. The chart at right is the climate control output.

When running (you can start and stop the simulation with the button at bottom), the system uses negative feedback to keep the room temperature close to the set point. Use the pull-down menu centered at the top to change the set point.

Also, use the pull-down menu centered at the bottom to change the climate conditions of the room: Add positive heat (light a fire in the woodstove), or negative heat (open a window) to alter the work the system must do.

This feedback loop models a climate control system, but with little change it could also be showing physiological systems for control of body water and salt, for controlling blood pressure, or for maintaining steady levels of blood sugar.

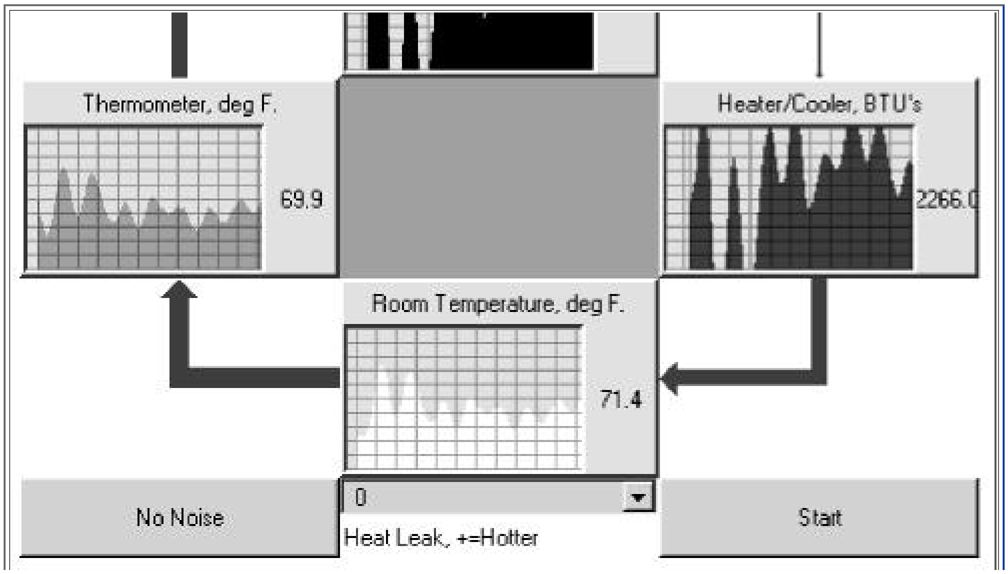
However, this feedback system is quite simple. In particular, the thermometer responds instantaneously to changes in room temperature, and the heating/cooling system is very powerful and quick. Often systems are much more complex than this. Look at the next page for a simulation of a complex feedback system.

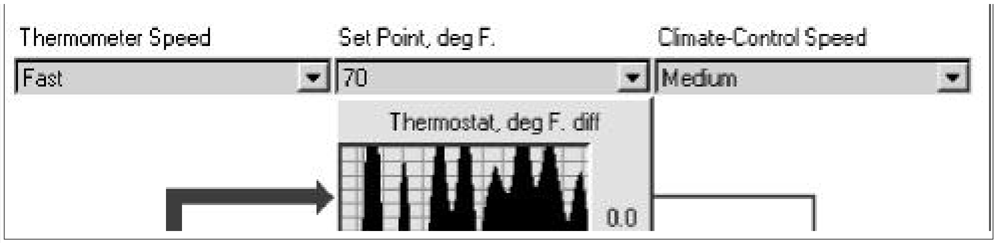
Complex Feedback Systems:

The simple feedback simulation that was shown on the previous page really works too well! It quickly responds to changes in its set point, and the new room temperature settles in smoothly to whatever value is set. Even if it were challenged with complex changes to the room's temperature, it would give the same old boring responses. Too bad the climate control systems in our homes and workplaces don't work this well.

Feedback systems can be quite sensitive. Of particular importance is the relative speed of action for the thermometer, for the climate control unit, and for the temperature change itself. The simulation below adds the possibility for adjusting these parameters to see how feedback performance degrades when the system is not adjusted "just right".

The simulation shown is an extension of the simple feedback system. It uses the same four basic elements, but now permits three new adjustments. First, the speed of response of the thermometer can be adjusted. Second, the speed and inertia of the climate control system can be determined. Finally, fluctuations (noise) in the room temperature can be added or not.





Thermometer Speed
Fast
Set Point, deg F.
70
Climate-Control Speed
Medium

Use the adjustments for the speed of the thermometer and climate control to probe the system's feedback limits. First, make sure that noise is off (press the button at lower left). Next, make the thermostat much slower with the pull-down menu at the upper left. Watch for a while and see if this makes much difference.

If things had been pretty close to steady, not much change might be seen, but change the set point by 10 degrees and you will see the system begin to oscillate between hot and cold.

Return the thermometer to fast and let things settle. Now make the heating response slow. Change the set point again to make the system work, and see what happens.

Finally, add the noise back to see a "real" system try to struggle with complex input.

This simulation doesn't just represent the behavior of poorly designed heating systems. When elements of the body's feedback systems are degraded by disease, those systems too can become unstable.

For example, in diabetes mellitus, the body can no longer produce insulin to control blood sugar. Instead the patient has to measure it, and determine an amount of insulin to inject. With care this manual feedback can be made to work reasonably well, but in some patients the delays in measurement and in the insulin action lead to the same kind of instabilities shown above.

The normally brisk and accurate responses of the body's feedback systems are a monument to the careful "design" that has evolved in these systems.

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For problems or questions regarding this web contact Joe Patlak.
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