Feedback

You're in an auditorium. Someone steps up to the microphone on stage and begins to speak. An increasingly loud sound emerges from the loudspeakers. The person on stage covers the microphone while the sound engineer adjusts the volume control of the amplifier downward. The person tries again and now you can hear their amplified voice, not overwhelmed by the sound you heard at first.

This is feedback. The sound system in the auditorium picks up the person's voice in the microphone, turns the sound into an electrical signal, sends it to an amplifier, which increases the strength of the signal, which then drives loudspeakers. The loudspeakers turn the amplified electrical signal into sound, so the audience can hear the amplified voice.

But there's a bit more to it. The sound picked up by the microphone includes not only the voice of the person speaking, but also the sound emitted by the loudspeakers, that is, their amplified voice. This causes the sound coming out of the loudspeakers to become louder, which results in a louder sound being picked up by the microphone, which causes the loudspeakers to produce an even louder sound, which results in an even louder sound being picked up by the microphone, which causes… The system spins out of control.

You can think of this in terms of a system with an input and an output. The input is the sound received by the microphone. The output is the sound coming out of the loudspeakers. Imagine that the loudspeakers were in another room that was far away from the room with the microphone. The sound coming from the loudspeakers would not be picked up by the microphone no matter how loud. But when the microphone and loudspeakers are in the same room. The output of the system becomes part of the input. The output is fed back into the system. If the total input – the person's voice plus the amplified voice – is limited, the system can work as intended. But too much feedback overwhelms the system.

This kind of feedback is called positive feedback, or reinforcing feedback. It can be useful if kept under control. Some early radio receivers used positive feedback to strengthen weak signals being received. The signal would be amplified, and part of the output of the amplifier would be fed back into it as input. Like the auditorium system, if too much of the signal is fed back as input, is whistles out of control. But if limited, the feedback results in an output that is stronger than it would be without feedback.

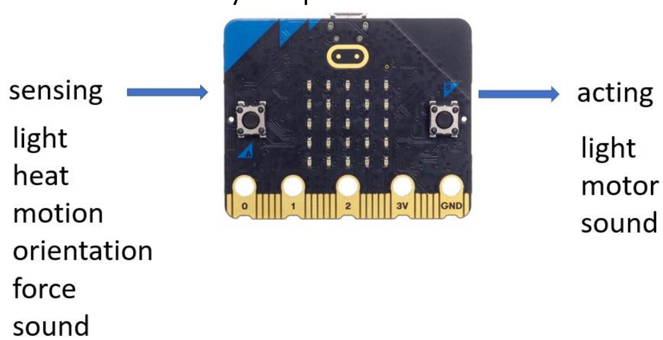
A problematic example of positive feedback is the melting of the Arctic sea ice. During summer, increased sunshine causes some of the ice to melt. In winter, with less sunlight. More ice forms. With a warming world, more ice has been melting in summer and not as much forming in winter. Where does feedback enter the picture? Some of the sun's energy that reaches the earth is absorbed while some is reflected back into space. Ice reflects more sunlight than open water. With more open water and less ice, the Artic Ocean overall is absorbing more of the sun's energy and warming more than it would if it had more ice cover. This increase in open water causes an increase in water temperature, which causes more ice to melt and therefore, more open water, which causes more energy to be absorbed, which causes more ice to melt, resulting in more open water, which causes more energy to be absorbed, which causes…

Think about a home heating system with a thermostat. The system turns on and off maintaining a pretty constant temperature. The thermostat has a heat sensor. When it senses the temperature has risen to a preset high point, the system turns off. Since it's cold outside and heat gradually escapes the room, the temperature starts to drop. When the sensor senses that the temperature has dropped to a preset low point, the system turns on the heat and the temperature starts to rise. In a while, the high point is reached, and the system turns off the heat, and so on. In practice, you set a desired temperature on the thermostat and the system determine the low and high points close to the temperature you set.

This is an example of negative feedback. As in the case of positive feedback, the output of the system becomes an input. But with negative feedback, increasing the input decreases the output. When the temperature rises, heat is reduced. When the temperature drops, heat is increased.

Another example of a useful application of negative feedback is an automatic irrigation system. A moisture sensor in the soil is connected to a system that turns a water pump on and off. When the ground is dry, the water is turned on. When it is moist, the water is tuned off.

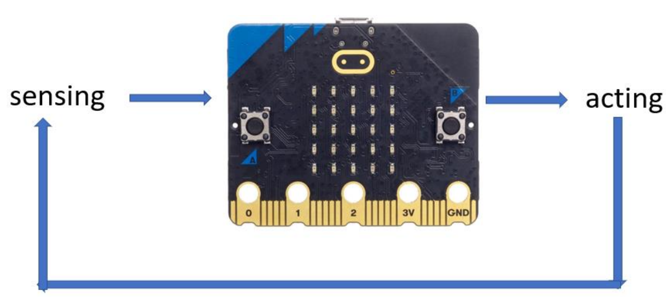
Using Microcontrollers to Build Feedback Microworlds
A microcontroller such as an Arduino or micro:bit, along with sensors and output devices can be used to create programmable devices to explore the Powerful Idea of Feedback. In general, a microcontroller can receive a variety of inputs and activate various devices.



For example, you could build a motorized vehicle with a microcontroller that can turn the motors on. It also could have a sound sensor that detects loud sounds. You could program it so that the motors turn on when you shout at the vehicle.

You could put a microcontroller with an orientation sensor and a sound generator into a stuffed animal. You could program it so that when the animal tips over it lets out a loud sound.

In some cases, the output is sensed as an input.



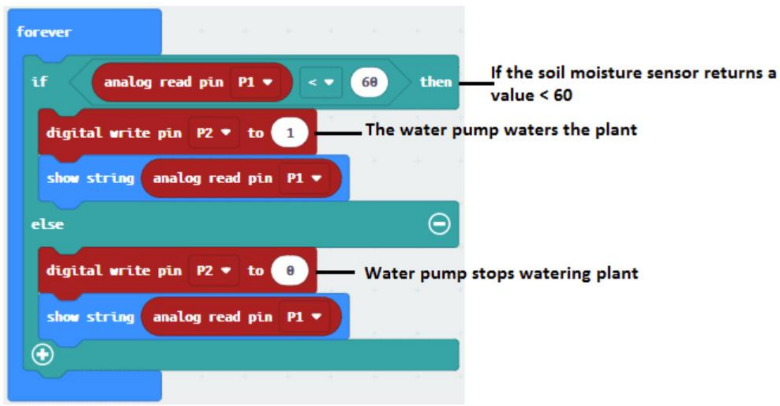
In these cases, we have feedback. Here are some examples:

An automatic irrigation system can be built with readily available materials. In the photo, the moisture sensor is two nails stuck into the soil spaced a few centimeters apart. They are wired to the microcontroller. Moist soil conducts electricity pretty well. Dry soil does not. The microcontroller will detect the difference. The output of the system is a submersible pump, sitting in the glass of water. When it is on, water is drawn from the glass and sent out into the potted plant through a plastic tube.

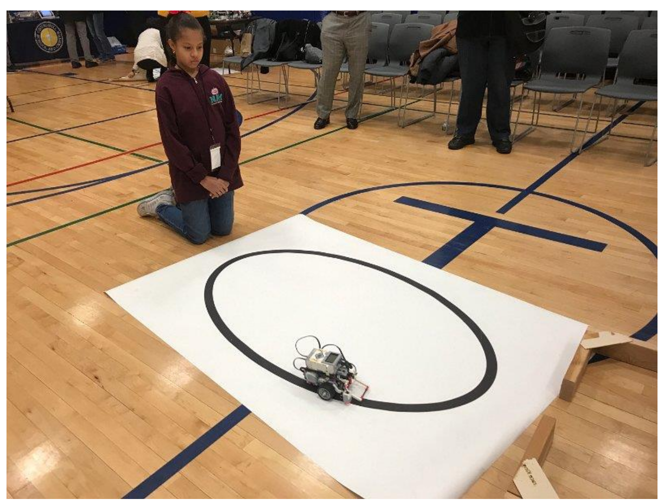
The negative feedback loop is:

- When the soil is dry, turn on the water pump, which makes the soil moist.
- When the soil is moist, turn off the water pump, which, over time, will allow the soil to dry out.

Here's a MakeCode program for the micro:bit that will control the device.



Here's another example of feedback that involves a robotics project to design, build and program a robot that can follow a line. This robot has two wheels, each controlled by its own motor. Each motor can be turned on and off, and the direction of its rotation changed. With both motors turning in the same the direction, the bot moves in a straight line. If one motor is on and the other off, or if they are turning in opposite directions, the bot rotates. In combination, these moves can send the bot anywhere on the surface it is travelling on.



There is a reflective light sensor pointing downward. Since the white paper reflects more light than the black line, the bot can know if it is on or off the line.

The strategy for following the oval line in a counterclockwise direction is:

- If I am on black, move forward a bit.
- If I am on white, back up a bit, rotate slightly to the left and move forward a bit.

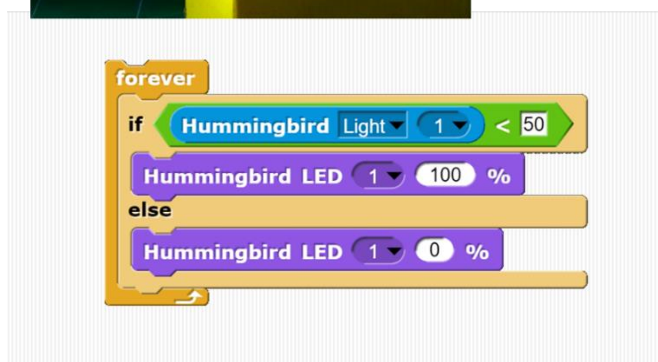
This is repeated until the bot is stopped.

The input to the bot is the sensor value indicating whether it is on white or black. The output is the motion of the bot. The feedback mechanism is that the choice of which of the two output motions occurs depends on the input, and the output determines what the next input will be.

Here's a thought experiment. The cylinder on top of this streetlight contains a light sensor that detects whether it is day or night. The streetlight is automatically turned on at night and off during the day.

There is no feedback loop involved. Since the sensor is detecting light coming from the sun, whether the streetlight is on or off has no effect on what the sensor senses.

This model of such a streetlight is built with a Hummingbird Robotics kit. The LED is turned on or off depending on the value of the light sensor.



Now imagine that we remove the light sensor for the top of the streetlight and put it below the light.

What happens?