Homeostasis and Feedback Control
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Homeostasis

The word homeostasis was coined by the physiologist Walter Cannon in about 1920, although the idea can be traced back to Claude Bernad (1860).

Homeostasis is where the internal state of a system is maintained at a relatively constant level even in the face of environmental perturbations.

Homeostasis

Examples:

Glucose levels
Temperature
Water Balance
Calcium Levels
Hunger
ATP levels

Including processes such as:

Target Tracking by the Vision System
Maintaining Balance

etc.

Welcome to Daisyworld

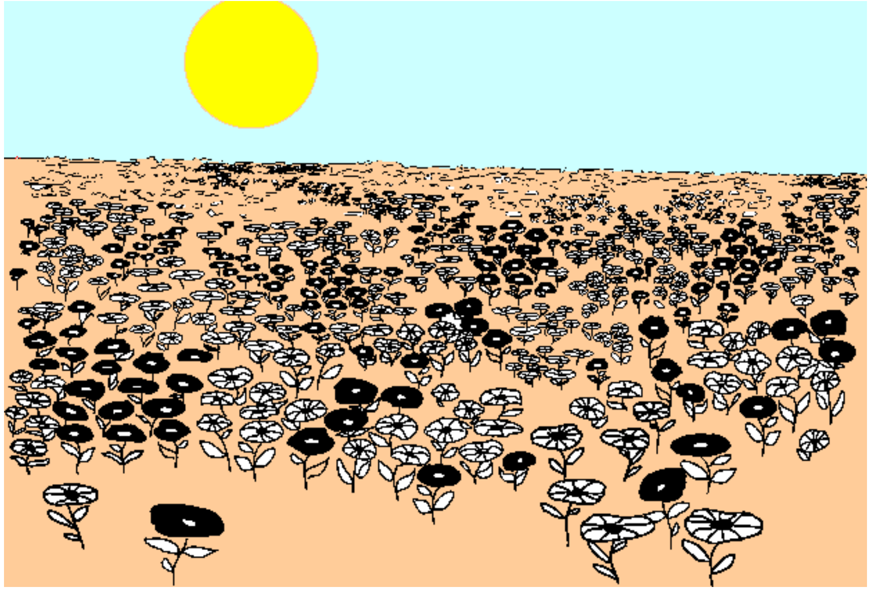
A long time ago in a galaxy far far away….

there was a planet call Daisyworld that orbited a variable star.

Daisyworld is a planet filled with two different kinds of daisies:

Black Ones

White Ones



http://academic.sun.ac.za/medphys/abstract.htm

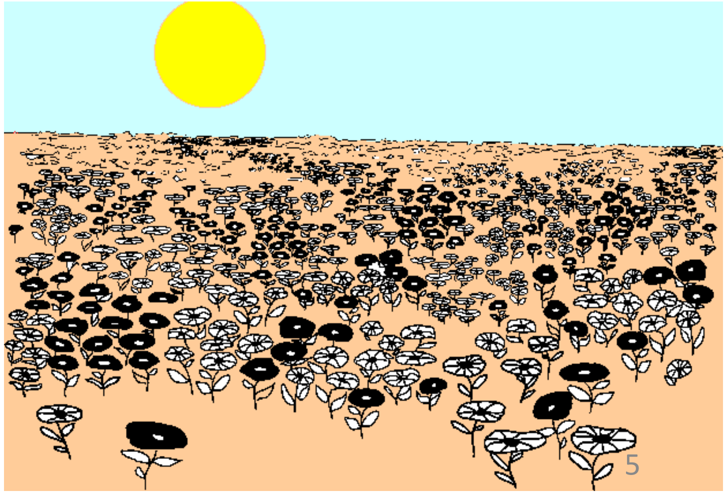
http://www.pbase.com/tracyjo/image/53564724

Watson and Lovelock, 1983

Welcome to Daisyworld

Black daisies absorb light and warm up, thereby warming the planet.

White daisies reflect light and cool the planet.



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Welcome to Daisyworld

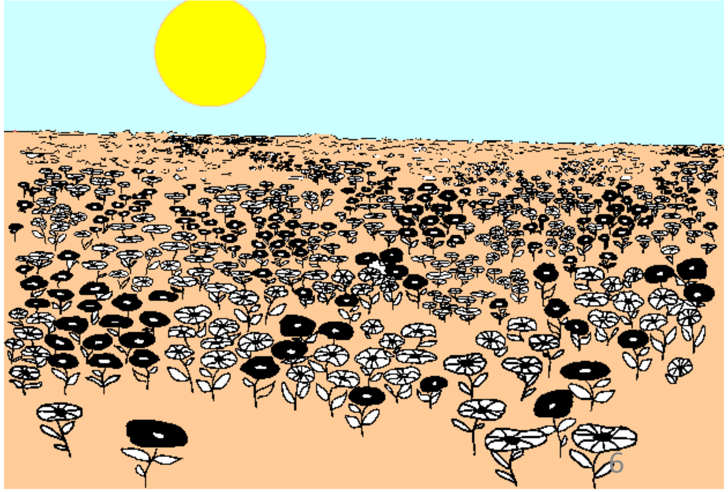
Black daisies absorb light and warm up, thereby warming the planet.

White daisies reflect light and cool the planet.

Lets say we start with an equal number of black and white daises on the planet.

Lets assume that the sun´s output starts to increase. This change will make the black daises warm up even more and many will probably die. However white daises survive better because they can cool the surroundings. If there are enough white daises, the entire planet will begin to cool and restore the original temperature.

Assume now that the sun starts to cool. This means that the white daises will cool so that they begin to die off, however the black daises will survive better because they can keep warm and therefore grow.



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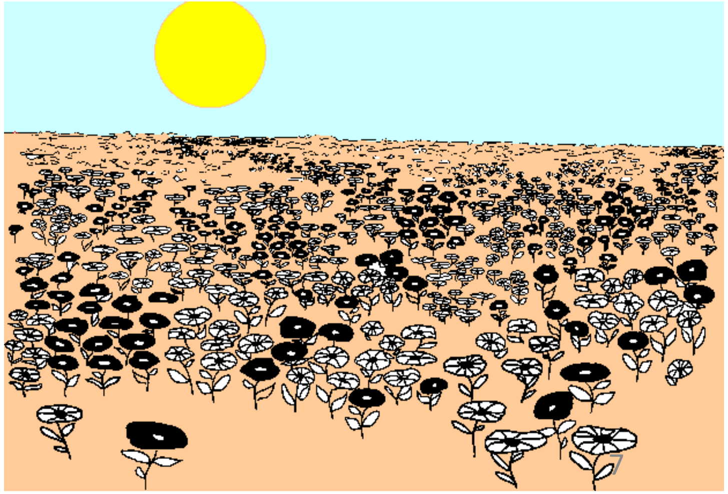
Welcome to Daisyworld

In this way the daises can modify the temperature of the planet by varying the ratio of black to white daises and stabilize the planet's temperature. There is a single temperature where the rate of growth and death of each type of daise is the same.

This idea has been a strong argument in recent years for preserving biodiversity on our own planet and is the basis of the Gaia Hypothesis which states that the planet is a self-regulating system.



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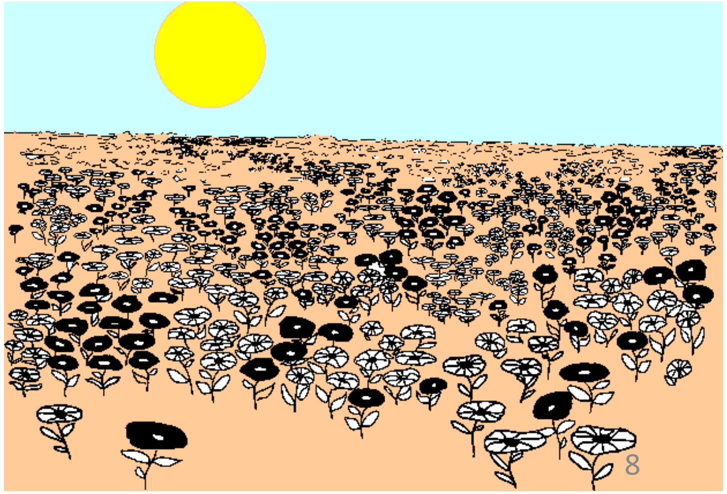
Welcome to Daisyworld

What does Daisyworld remind you of?



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Welcome to Daisyworld

What does Daisyworld remind you of?

Temperature equivalent to Glucose

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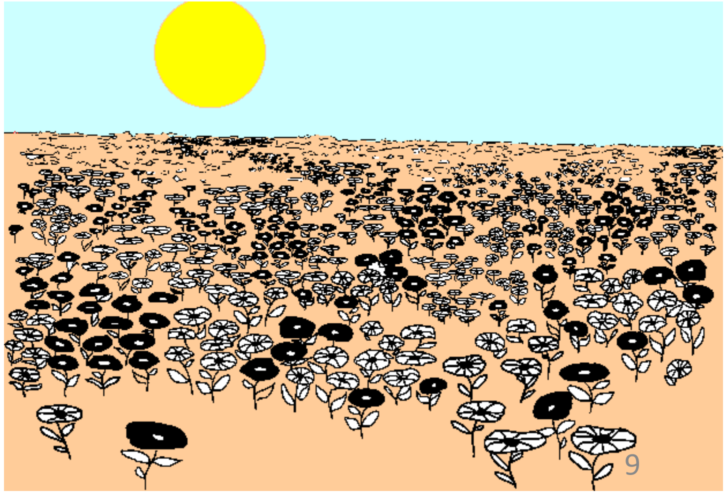

Welcome to Daisyworld

What does Daisyworld remind you of?

Temperature equivalent to Glucose

Black Daisies equivalent to Glucagon

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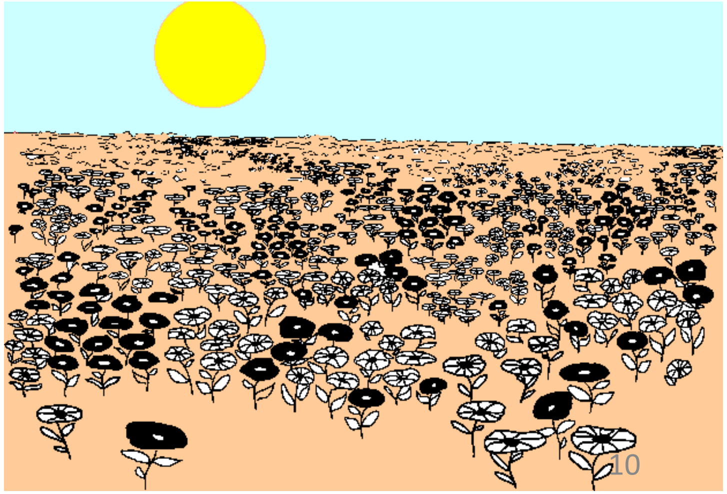


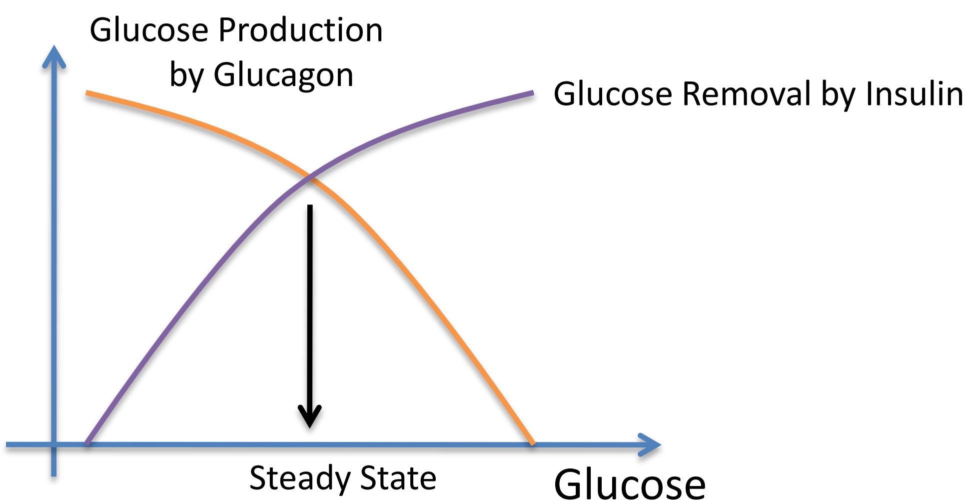
Welcome to Daisyworld

What does Daisyworld remind you of?

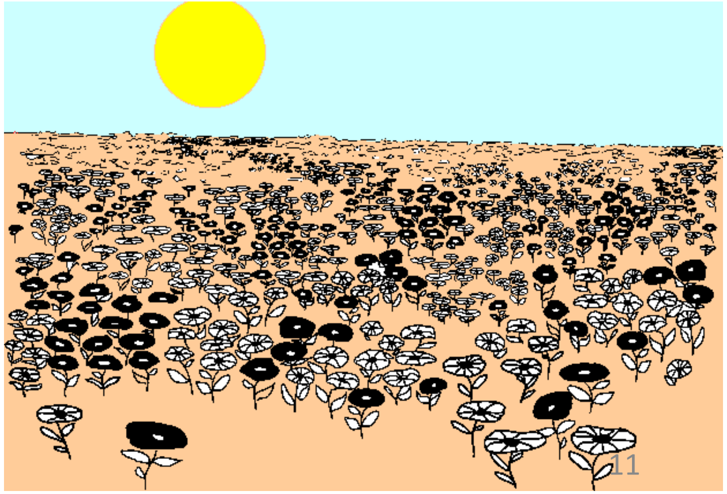
Temperature equivalent to Glucose

Black Daisies equivalent to Glucagon

White Daisies equivalent to Insulin



Integral Rein Control: Antagonistic Hormones



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Homeostasis

All homoestasis is based on some kind of feedback control. Glucose regulation is a fairly sophisticated example. The use of two hormones to control one variable seems overkill but it has disctinct advantages over simpler strategies.

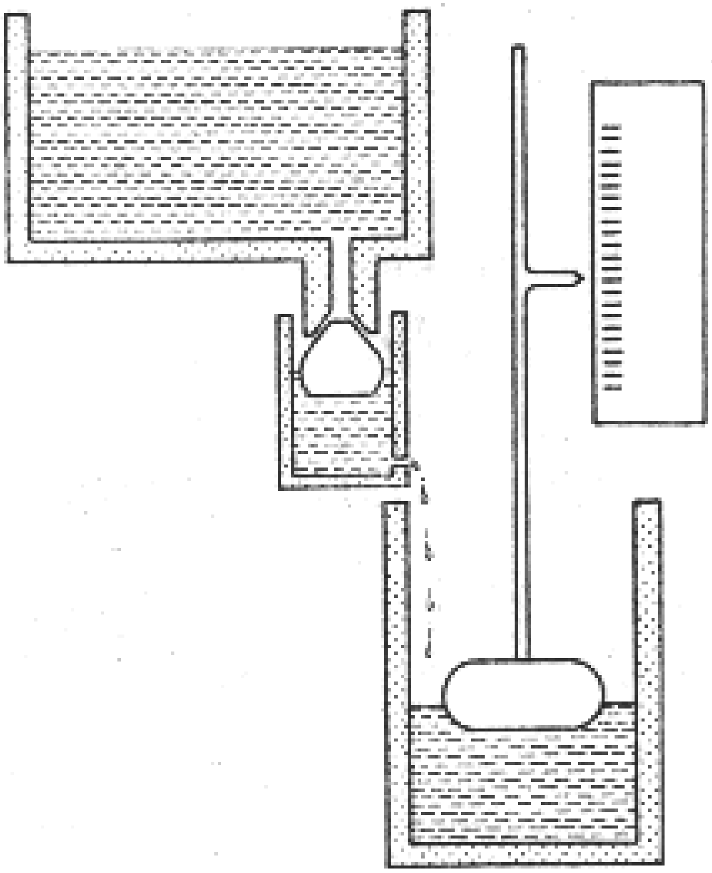
Let us look in detail at one the simplest control systems called:

Proportional feedback control.

Feedback Control: Brief History

Earliest Feedback System

A water clock invented by Ktesibios (Tesibius) in Alexandria (285 to 222 BC)
(Siphon, water organ, hydraulics)



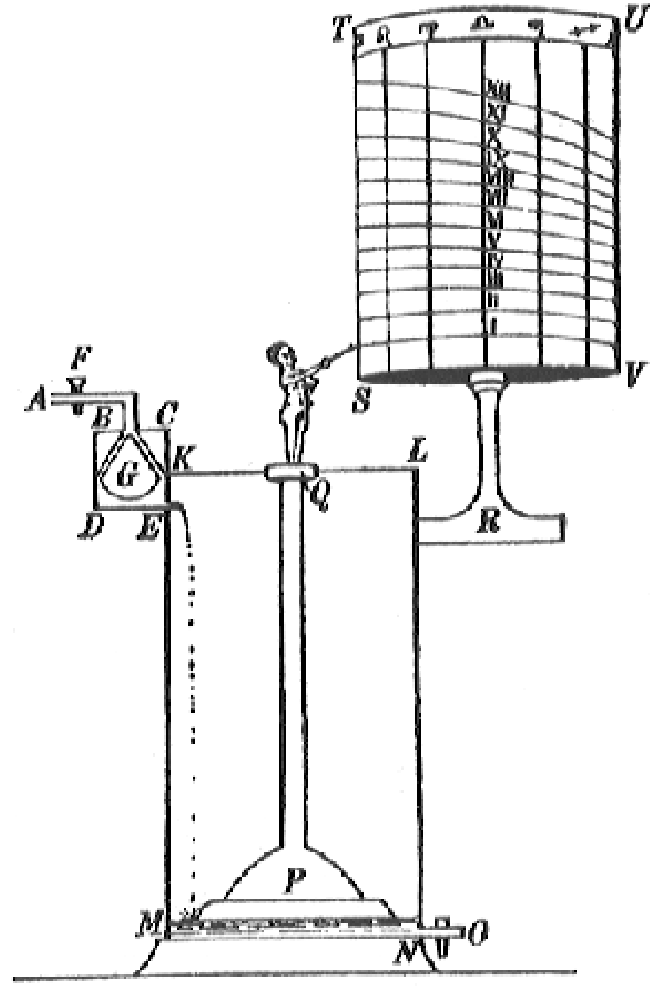
http://www.intermedia.c3.hu/~szmz/comparch/lecture_1/1.html

Feedback Control

A water clock invented by Ktesibios (Tesibius) in Alexandria (285 to 222 BC) (Siphon, water organ, hydraulics)

After about 1200 AD the float value disappeared until 1740 when it reappeared again in England to control the level of water in house water tanks. Together with the siphon, the reemergence of the float valve gave birth to the modern Lavatory Cistern.

Water clocks were replaced with mechanical clocks in the 14^{th} century.



http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol4/ahak/report.html

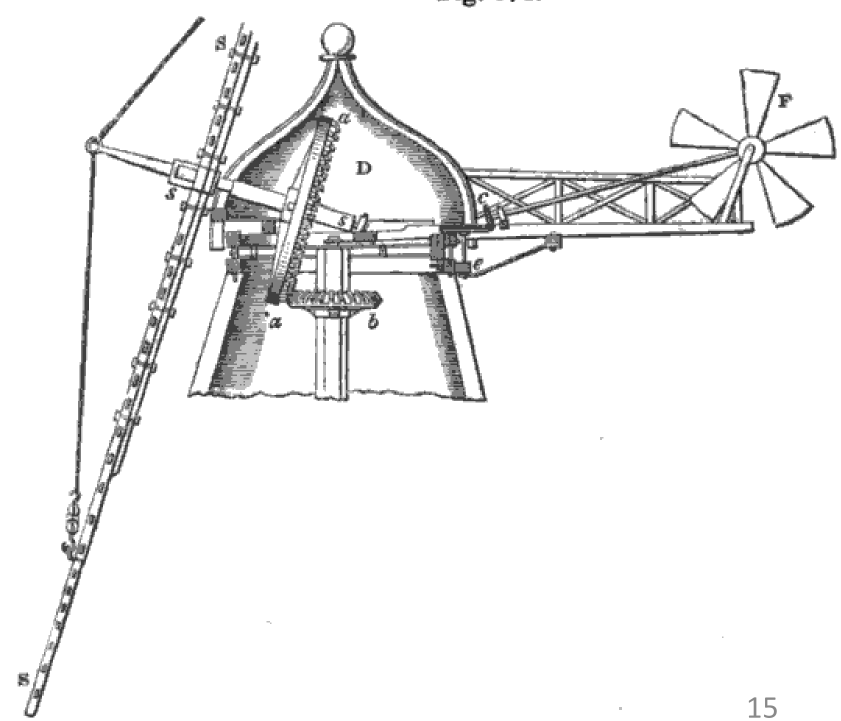
Feedback Control and the Industrial Revolution

The next major phase in the development of feedback control was during the industrial revolution. Many small scale developments including:

1. Furnace temperature regulation
2. Fantail regulation for Windmills that drove flour mills.
3. Regulating the distance between the two mill stones.

The most important development however was undoubtedly the flyball governor for controlling the speed of steam engines.

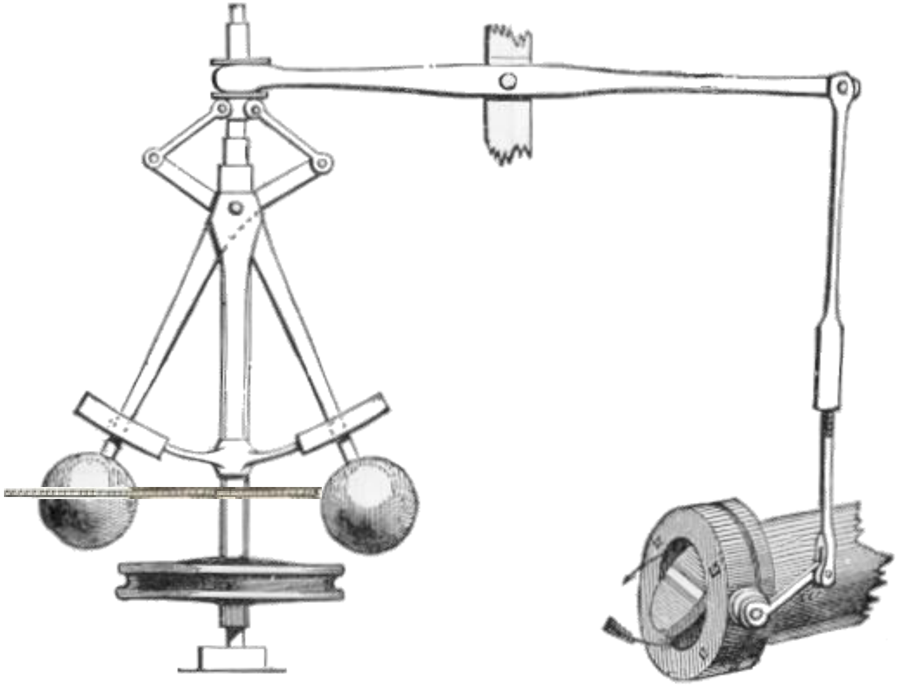
Fig. 174.



Treatise on Mills and Millwork By William Fairbair, 1871

Feedback Control and the Flyball Governor

Early steam engines were uncontrolled, that is the speed at which they ran depended on how much coal or wood was used to stoke the boiler or what load was attached to the engine itself. This problem was quickly solved by James Watt from Glasgow in 1788 (as in Watt power). By 1868 it is estimated that 75,000 governors were in operation in England alone. The Heritage museum in Washington DC has an excellent collection of governors on display.

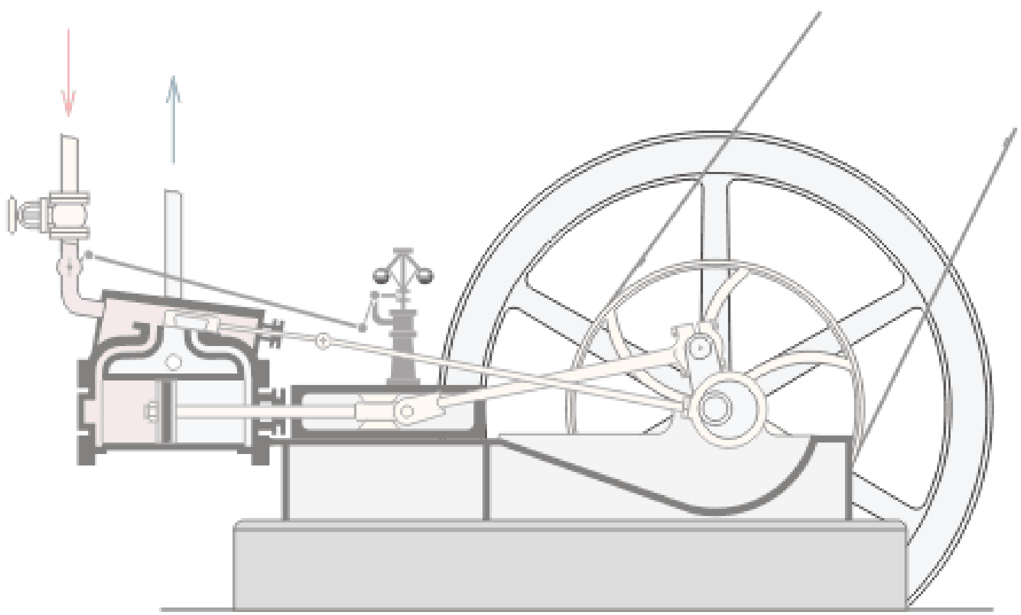


http://flickr.com/photos/51672464@N00/2104596364; http://www.history.rochester.edu/steam/thurston/1878/f29p115.gif

Feedback Control and the Governor

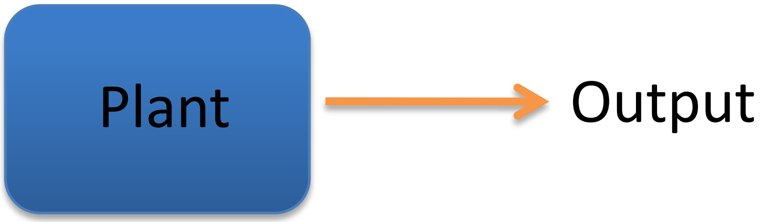
Although governors worked very well, it was found that as machine technology improved and friction between the machine elements was reduced, the governors started to exhibit a strange effect called “hunting ”. That is, they would sometimes oscillate back and forth “hunting” for the homeostatic point.

It was this observation that led to the beginnings of a new field called Control Theory when James Clerk Maxwell wrote a paper "On governors” in 1868. The introduction of the governor also stimulated people like Alfred Wallace to draw an analogy between governors and population dynamics in the animal kingdom.



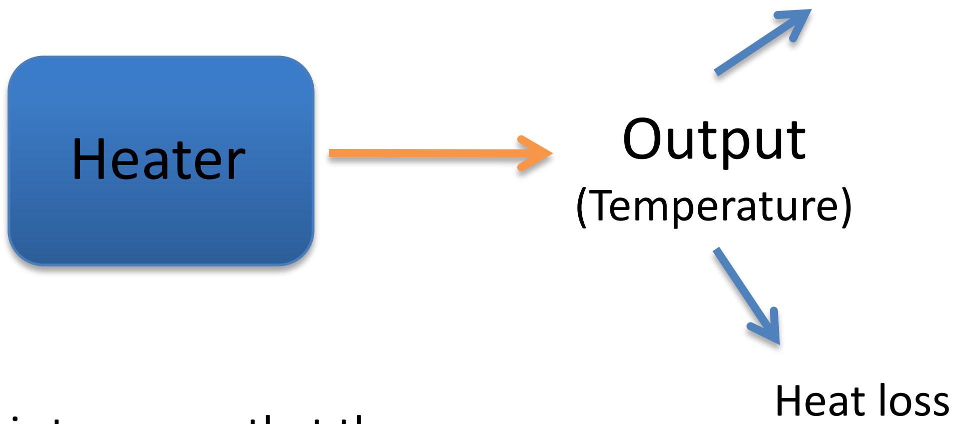
http://content.answers.com/main/content/wp/en-commons/f/f0/Steam_engine_in_action.gif

Classical Feedback Control



The aim of feedback control is to ensure that the value of some important variable remains steady in the face of external disturbances.

Classical Feedback Control



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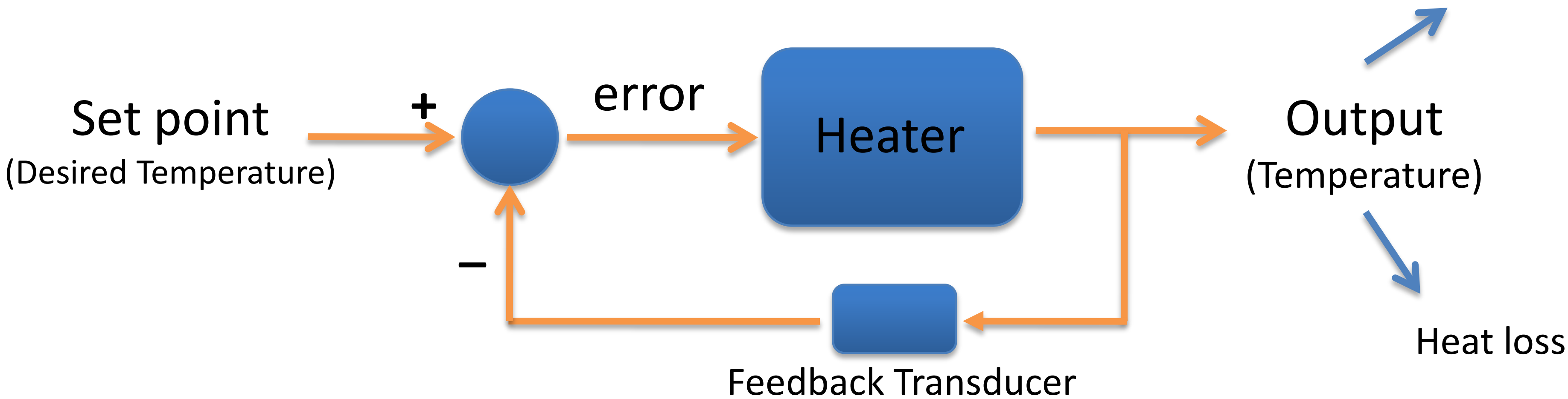
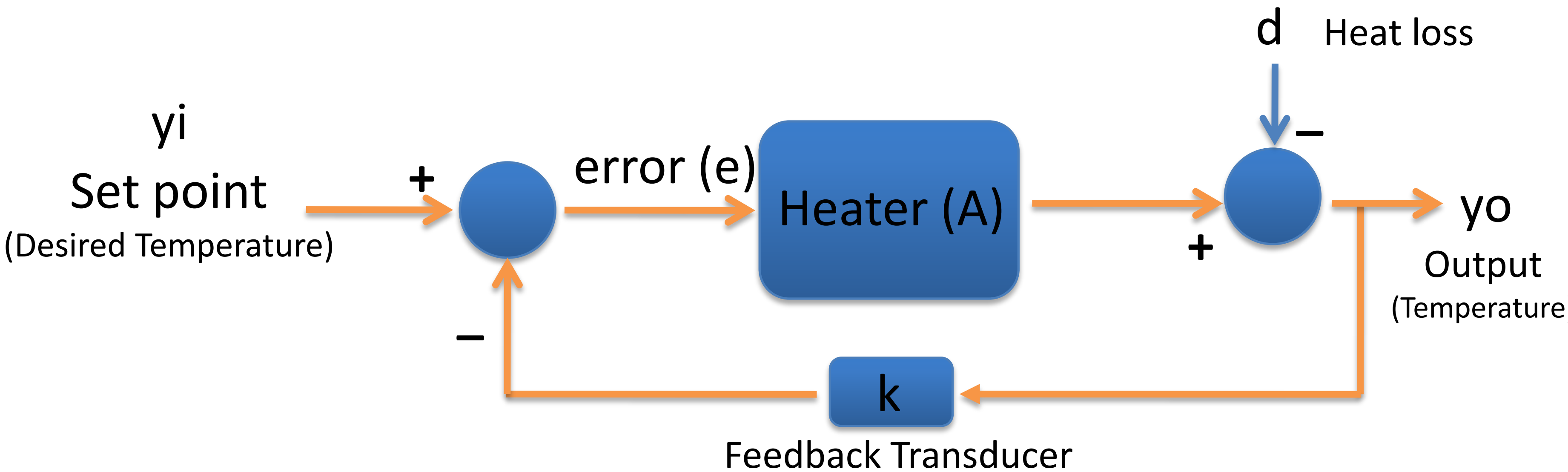
Classical Feedback Control



If the temperature goes below the desired temperature, there will be a positive error signal. This signal will be used to drive the heater. The bigger the error the more the heater will heat.

Classical Feedback Control



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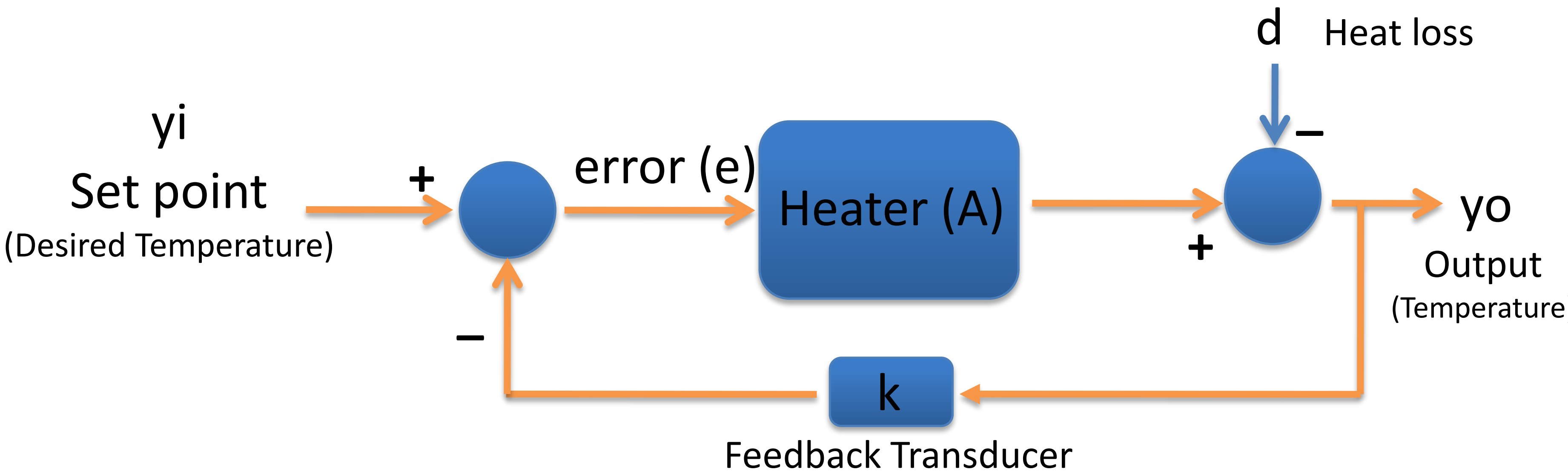
Classical Feedback Control

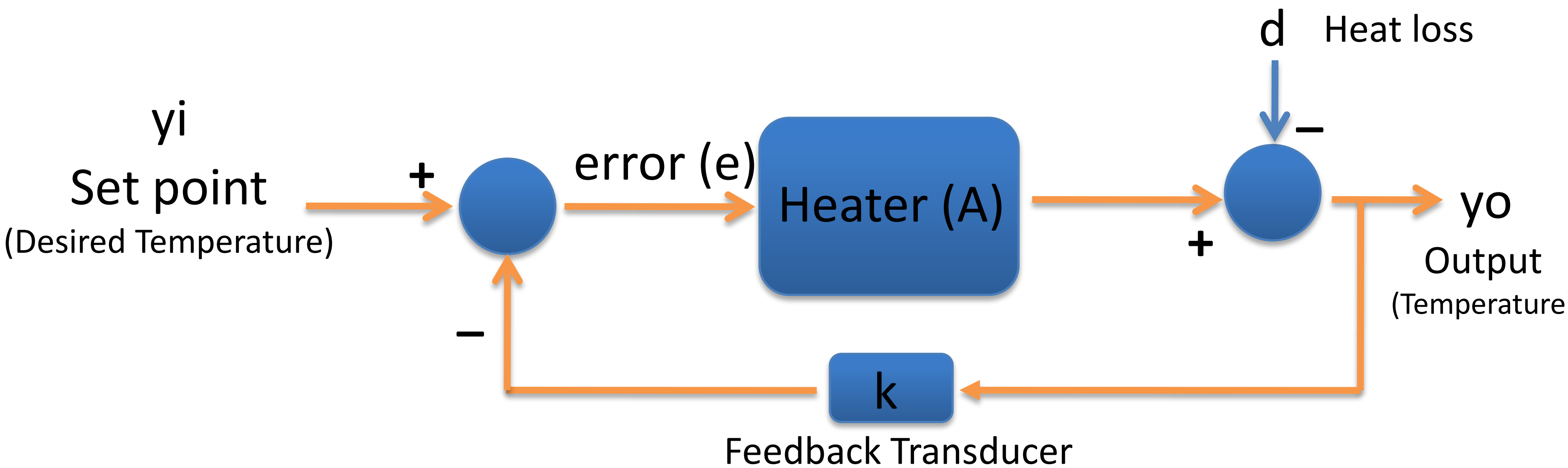


$$e = y_i - k y_o$$

$$y_o = A e - d$$

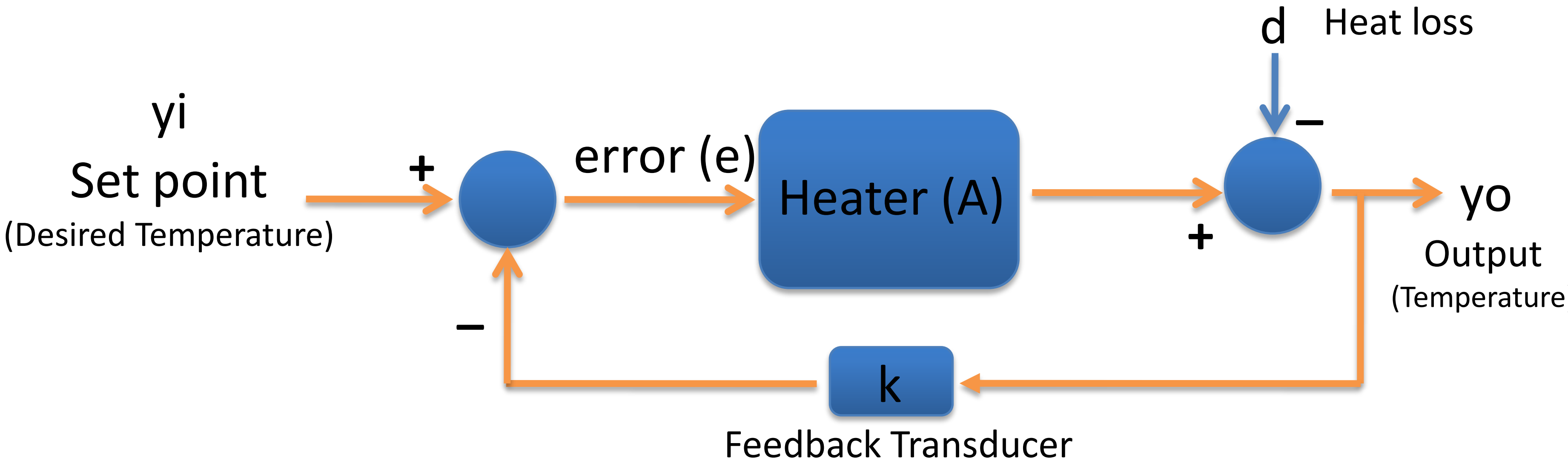
Solve for yo

Classical Feedback Control



$$y_o = \frac{Ay_i - d}{1 + Ak}$$

Classical Feedback Control

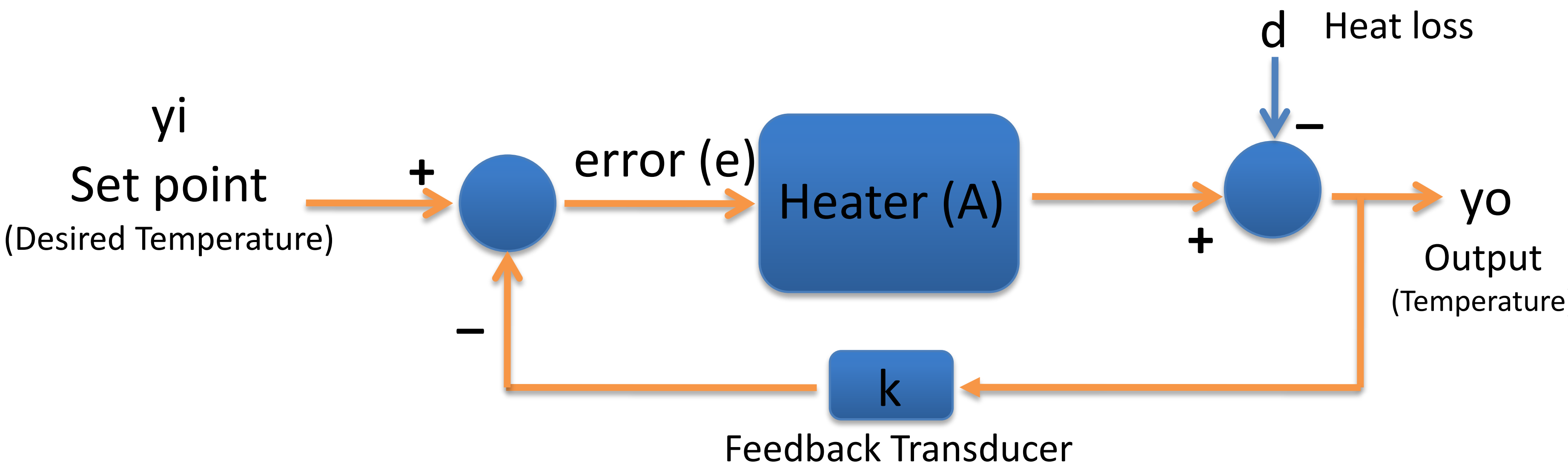


$$y_o = \frac{Ay_i - d}{1 + Ak} = \frac{Ay_i}{1 + Ak} - \frac{d}{1 + Ak}$$

So long as A k >> 1, the effect that d has on the output temperature is minimal.

HOWEVER: yo < yi, that is there will be an offset between the set point and the output

Classical Feedback Control

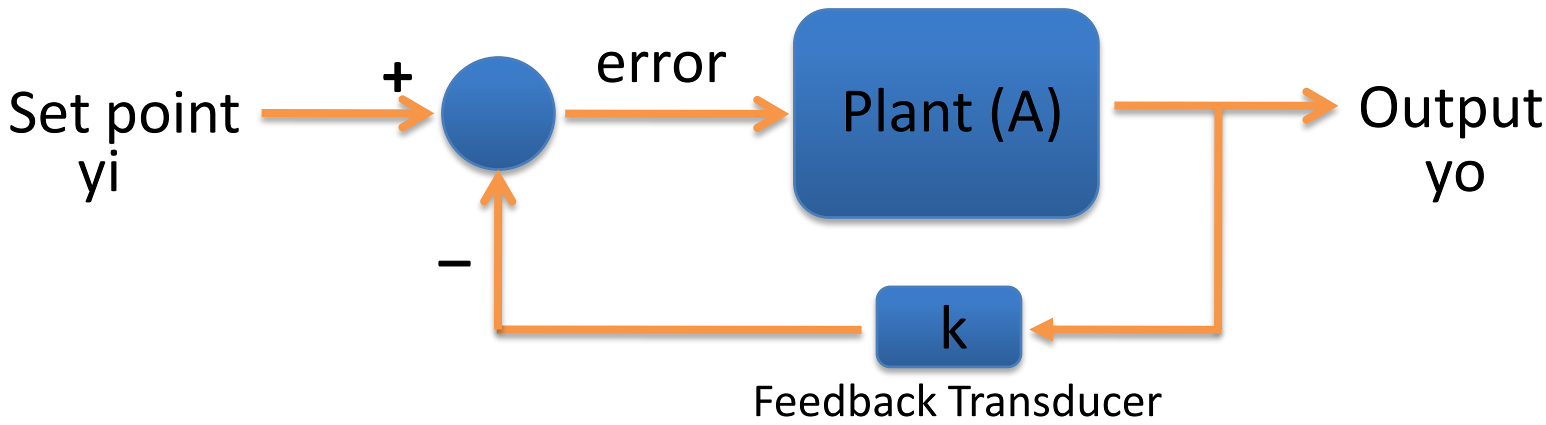


$$y_o = \frac{Ay_i - d}{1 + Ak} = \frac{Ay_i}{1 + Ak} - \frac{d}{1 + Ak}$$

Another problem is that the offset will vary depending on the size of the disturbance.

This means that this type of feedback can not stabilize the temperature exactly where we want it.

Proportional Control



$$e = y_i - k y_o$$

Proportional Control

$$y_o = Ae$$

Classical Feedback Control
Summary of Proportional Control

1. Makes the output resistant to external disturbances.

2. The above also implies that the output will be immune to component variation in the plant.

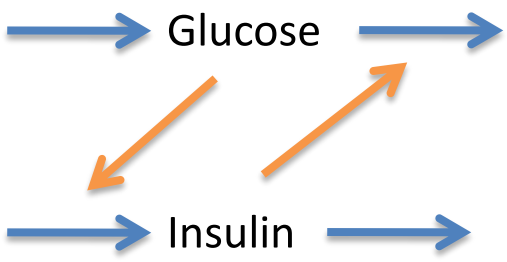
3. There will always be an offset between the set point and the output.

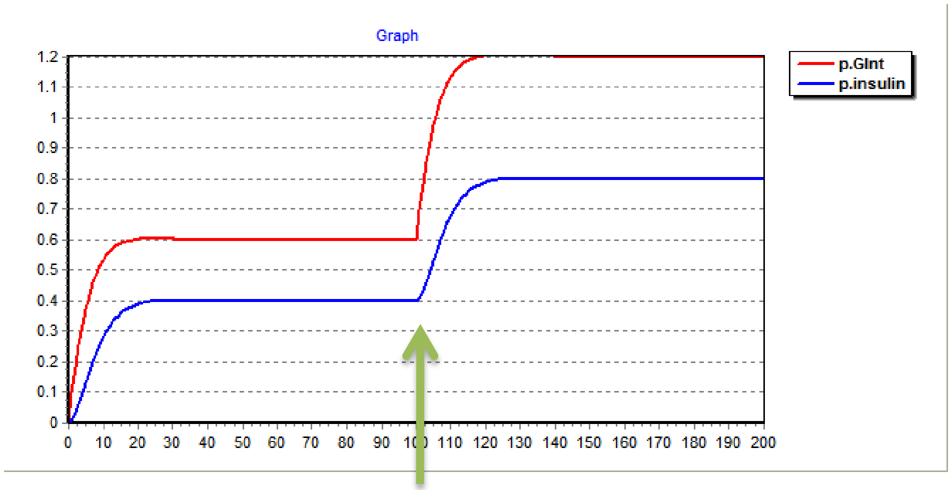
4. This offset will be a function of the magnitude of the external disturbance.

Therefore would you want a proportional controller to manage your glucose levels?

One other thing, you may be thinking, the above doesn't matter, I can just ramp up the strength of the feedback and all will be ok?

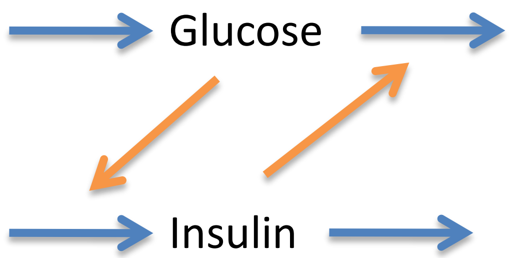
Simple Insulin Model

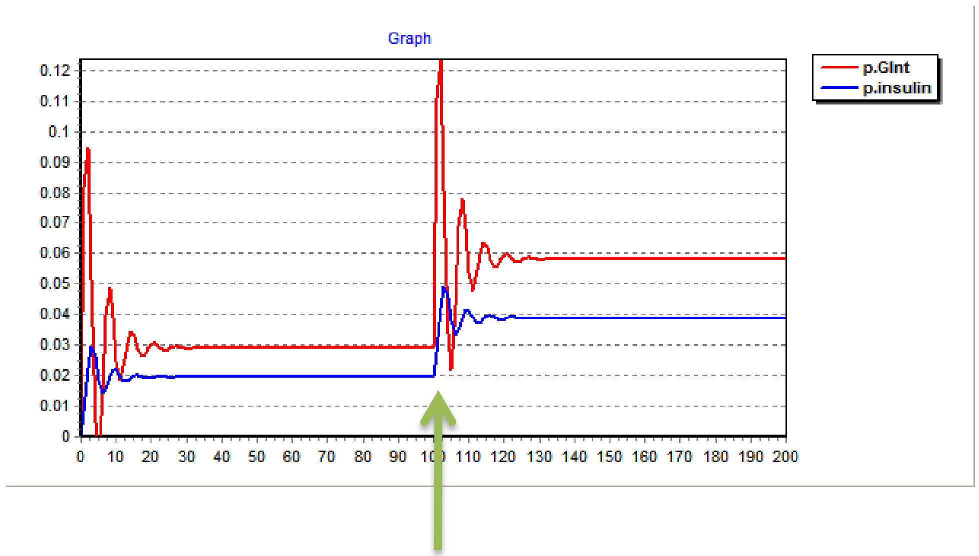




Increase Glucose Input

Simple Insulin Model





Increase Glucose Input

If the feedback strength is too large, a proportional feedback system can become unstable.

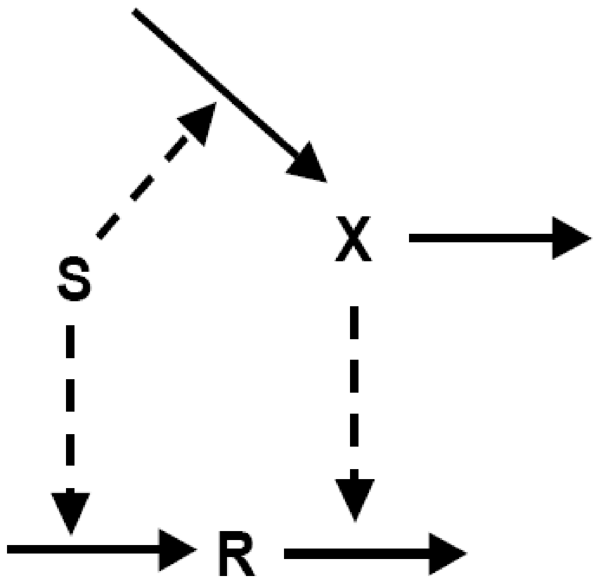
This was the so-called “hunting” that the early steam engine engineers observed.

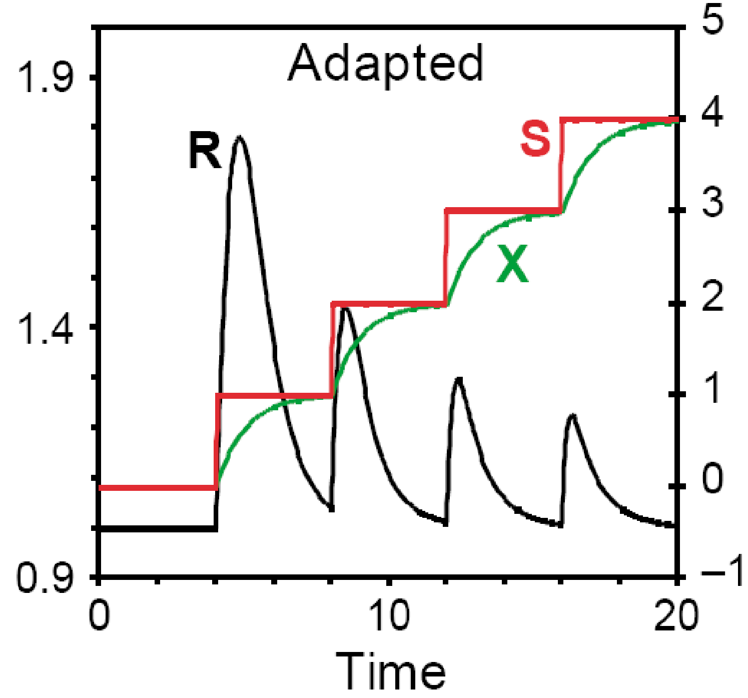
Classical Feedback Control
Summary of Proportional Control

1. Makes the output resistance to external disturbances.
2. The above also implies that the output will be immune to component variation in the plant.
3. There will always be an offset between the set point and the output
4. This offset will be a function of the magnitude of the external disturbance
5. If the feedback is too strong, the system can become unstable but it is fast!

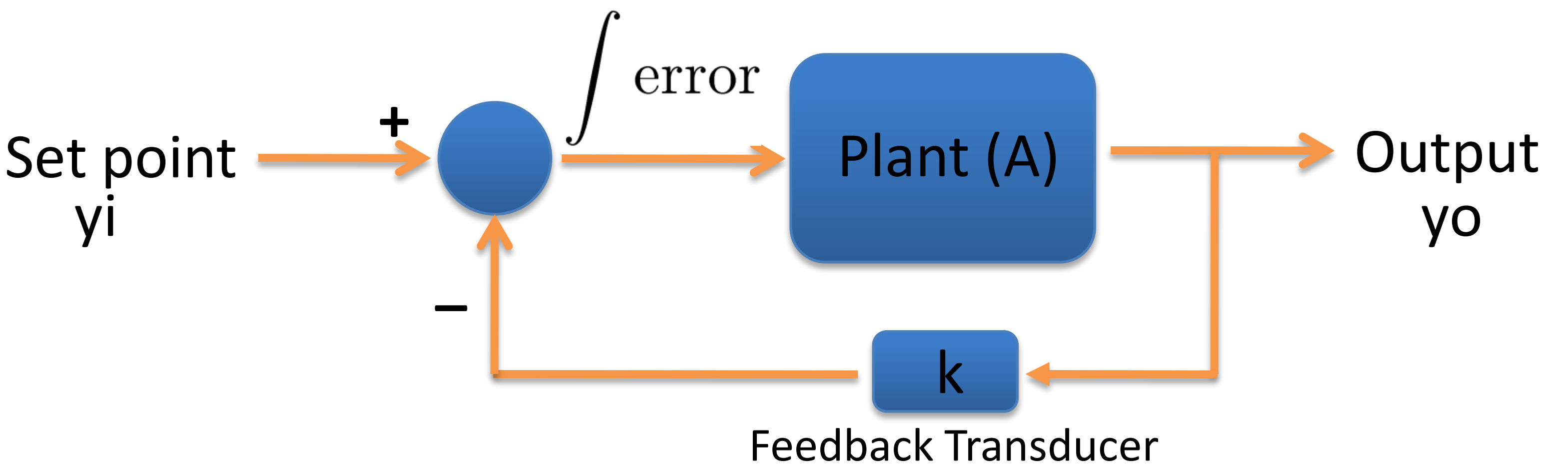
Therefore would you want a proportional controller to manage your glucose levels?

Classical Feedback Control
Removing the Offset





Integral Feedback Control
Removing the Offset

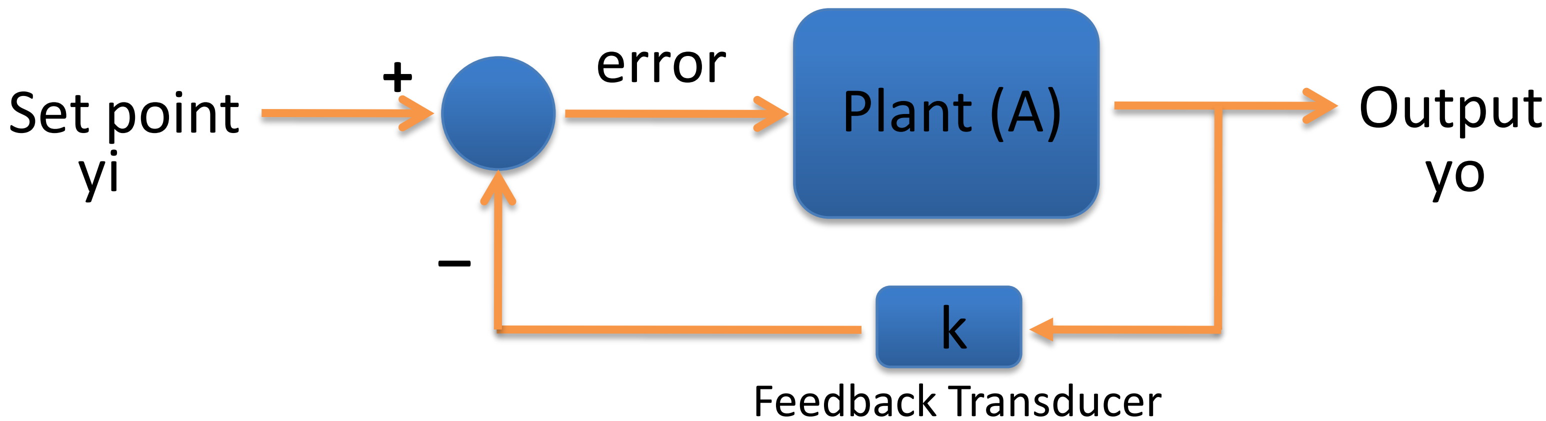


The plant is now controlled not in proportion to the error but by the integral of the error.

PID Control

Feedback Amplifers

Feedback Amplifiers



$$y_o = \frac{Ay_i}{1 + Ak}$$

If $Ak > 1$

$$y_o \approx \frac{y_i}{k}$$

Feedback Amplifiers