Accenture / Fjord   Dublin (via teleconference)   28 July 2020

Systems Theory in Design

Feedback, control, and cybernetics

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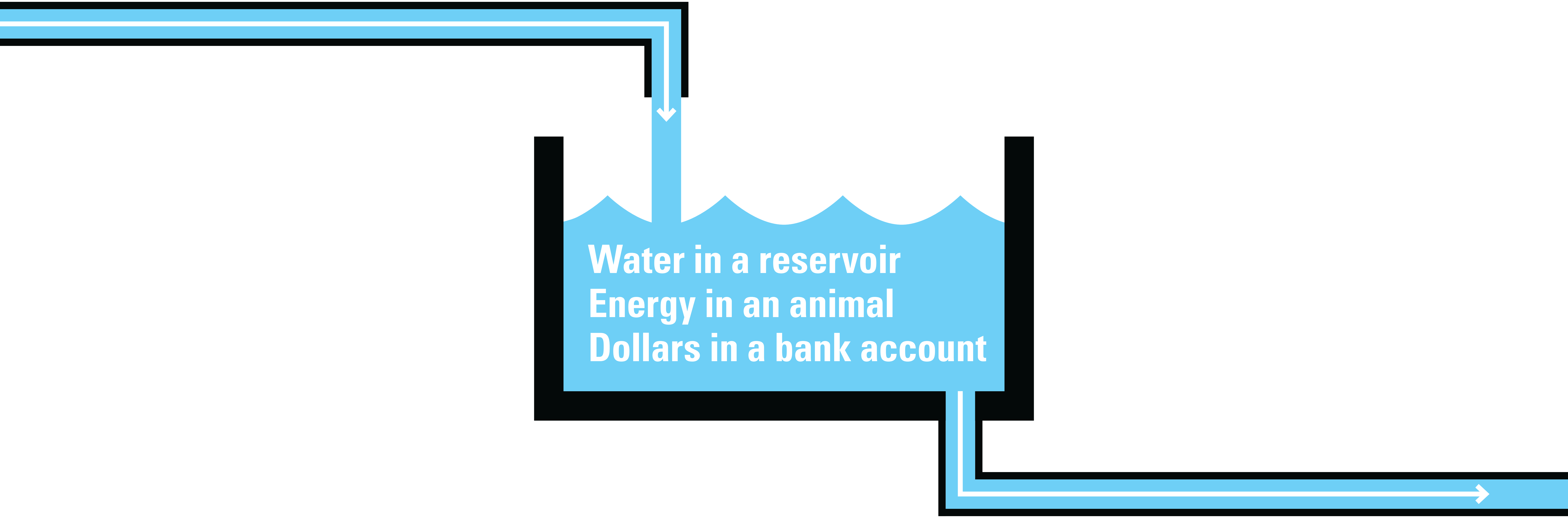
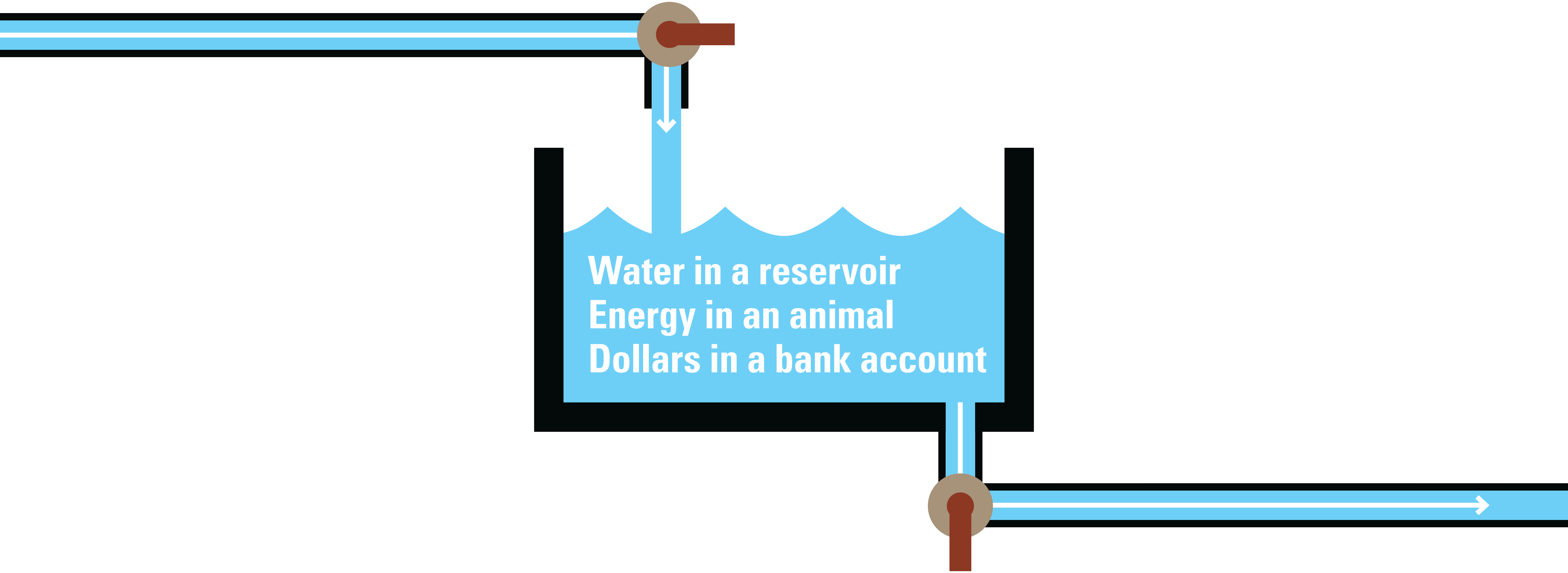
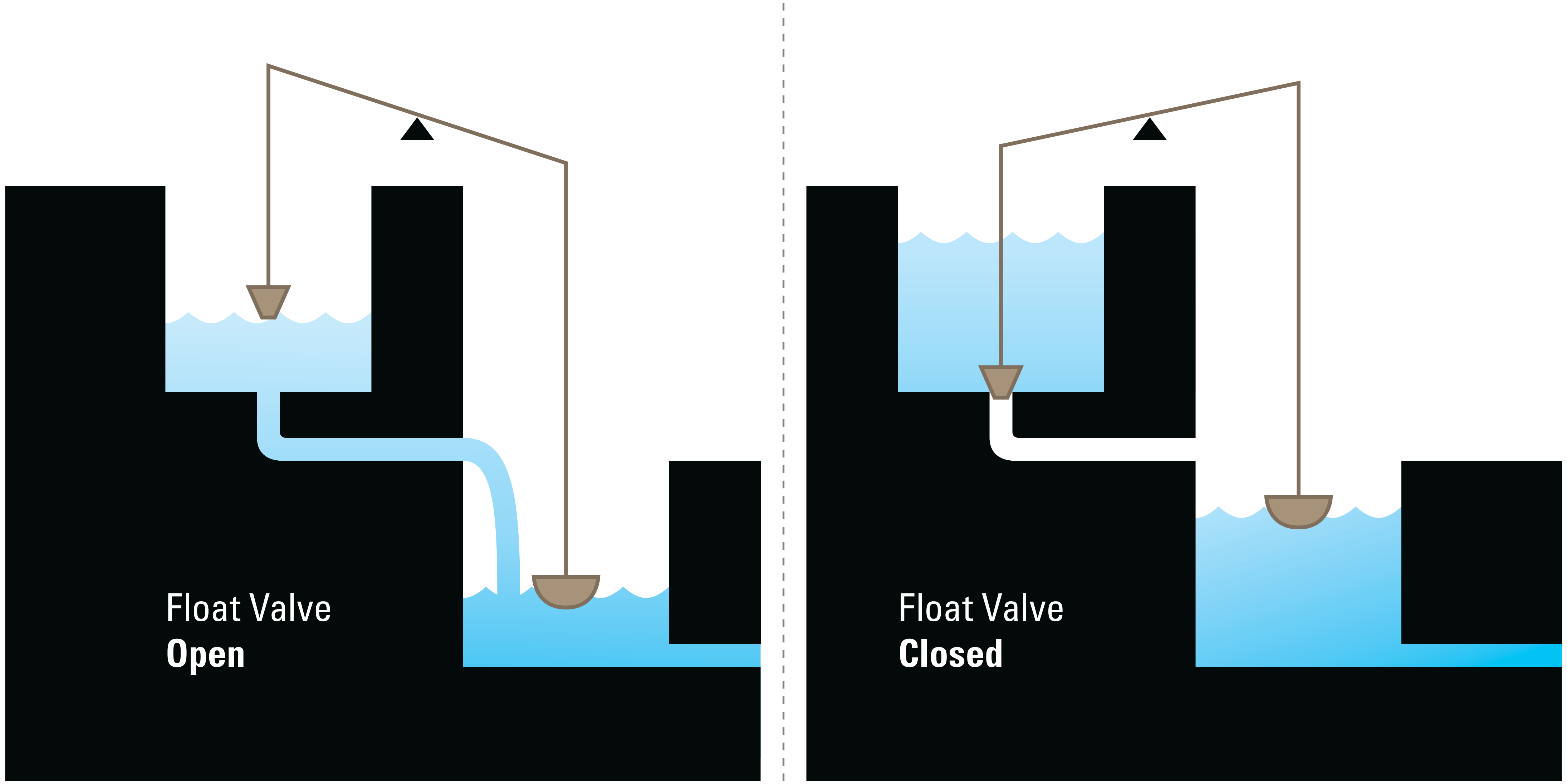
Dynamic equilibrium is a state of balance—
a resource that stays at the same level
even as it flows through a system.



In order to maintain dynamic equilibrium, ‘feedback’ from the stock must regulate inflow or outflow.



For more than 2,000 years, float valves have provided feedback to automatically reduce or shut-off flow.

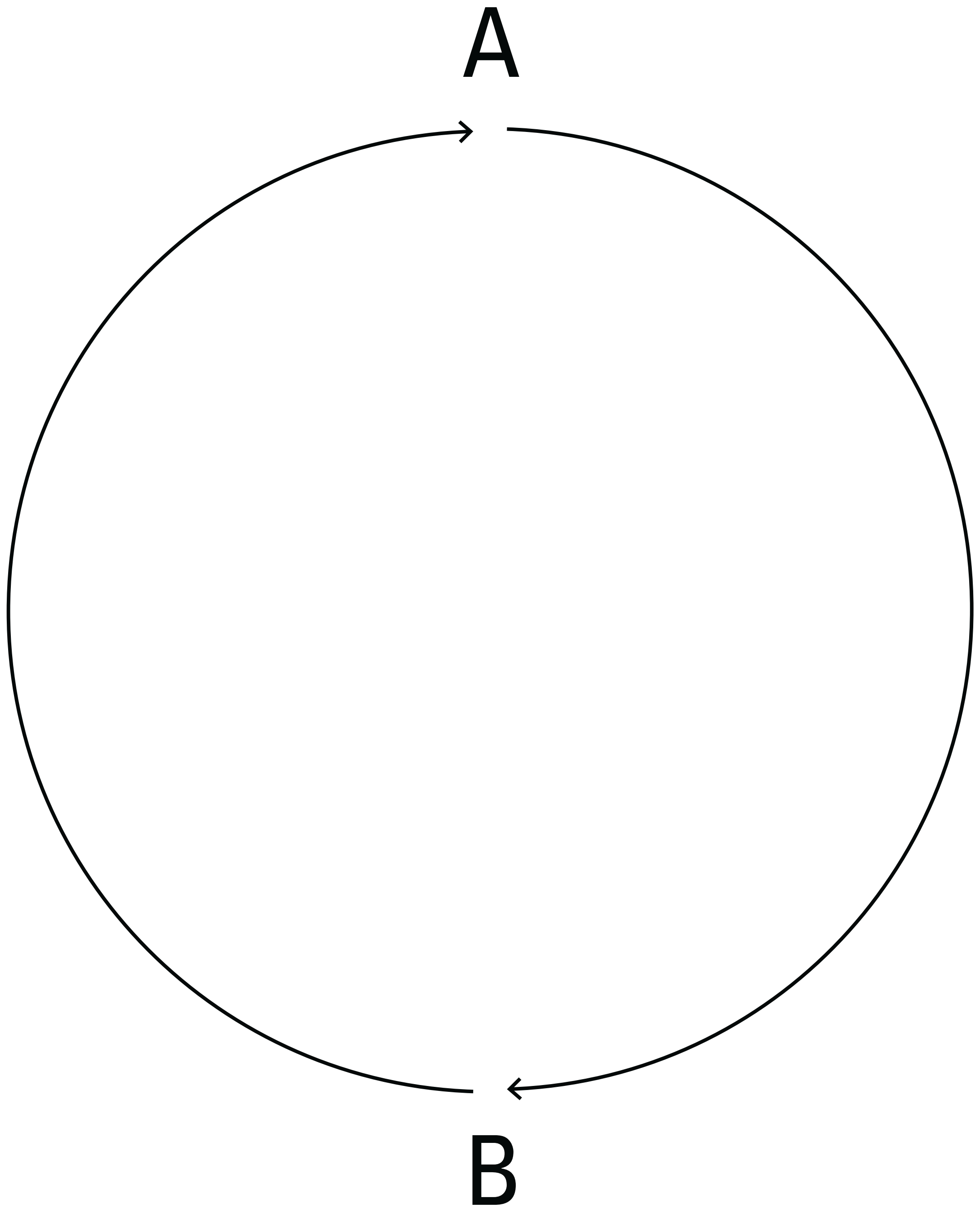


Float valves are part of modern toilets, automatically controlling the water flowing into the storage tank.

“Systems of information-feedback control are fundamental to all life and human endeavor, from the slow pace of biological evolution to the launching of the latest space satellite. . . . Everything we do as individuals, as an industry, or as a society is done in the context of an information-feedback system.”

– Jay W. Forrester

Feedback is: A causes B, and B causes A.

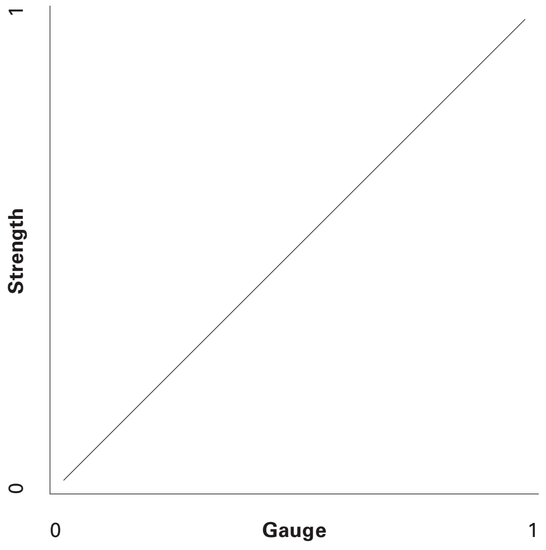


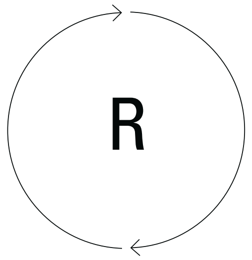
Feedback can be ‘positive’... or ‘negative’.

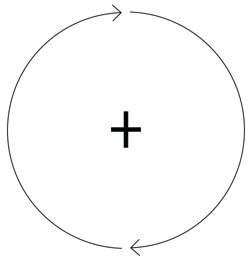
Positive Feedback (+) — a reinforcing loop (R) —
A increases B, and B increases A.

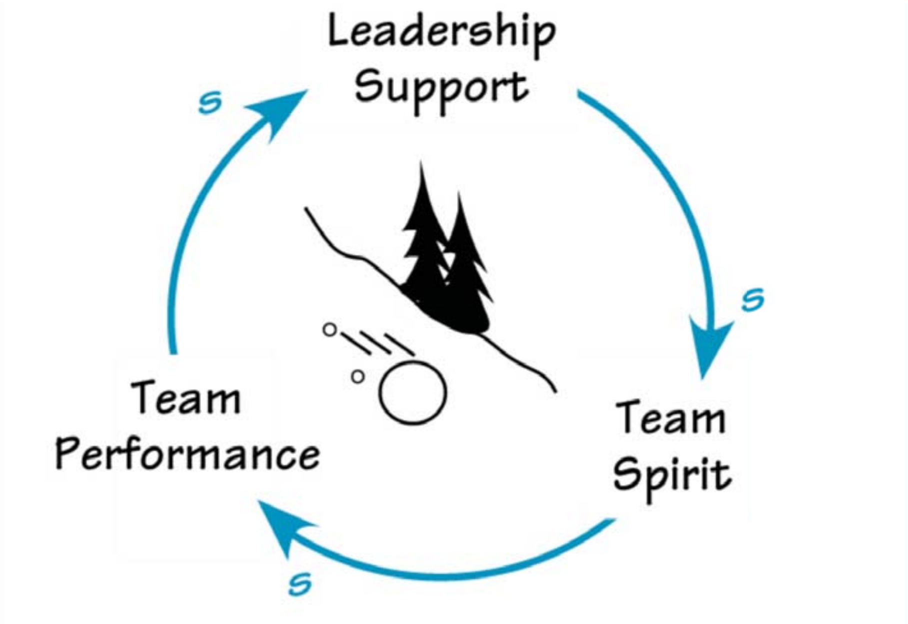
Proportional Relationships

For example, needle strength is proportional to Gauge. Thin needles are weaker than thick ones.





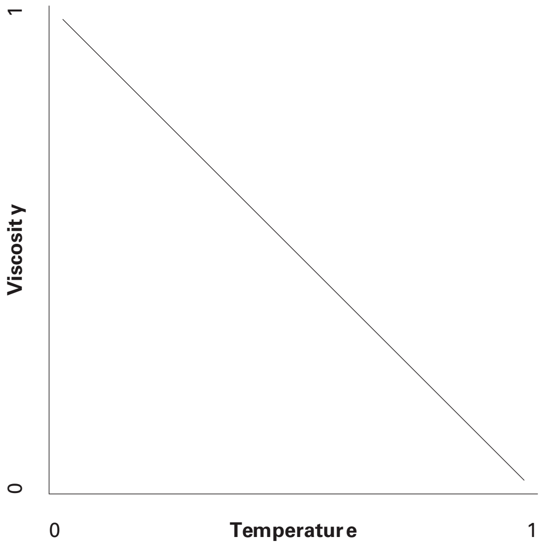


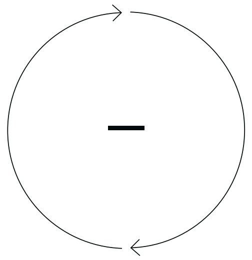


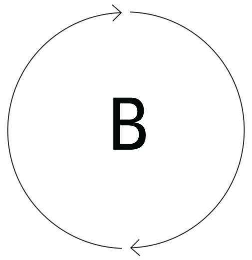
Negative Feedback (-) — a balancing loop (B) —
A increases B, and B decreases A.

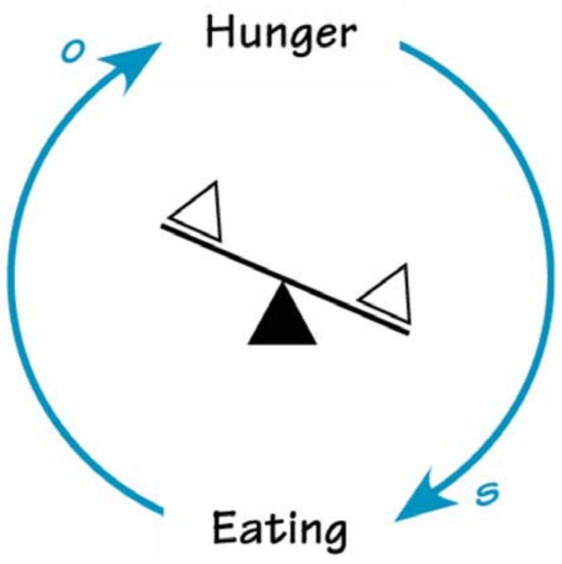
Inverse Relationships

For example, the viscosity of a compound is inversely proportional to temperature. Cold compounds are thicker and more viscous then warm ones.

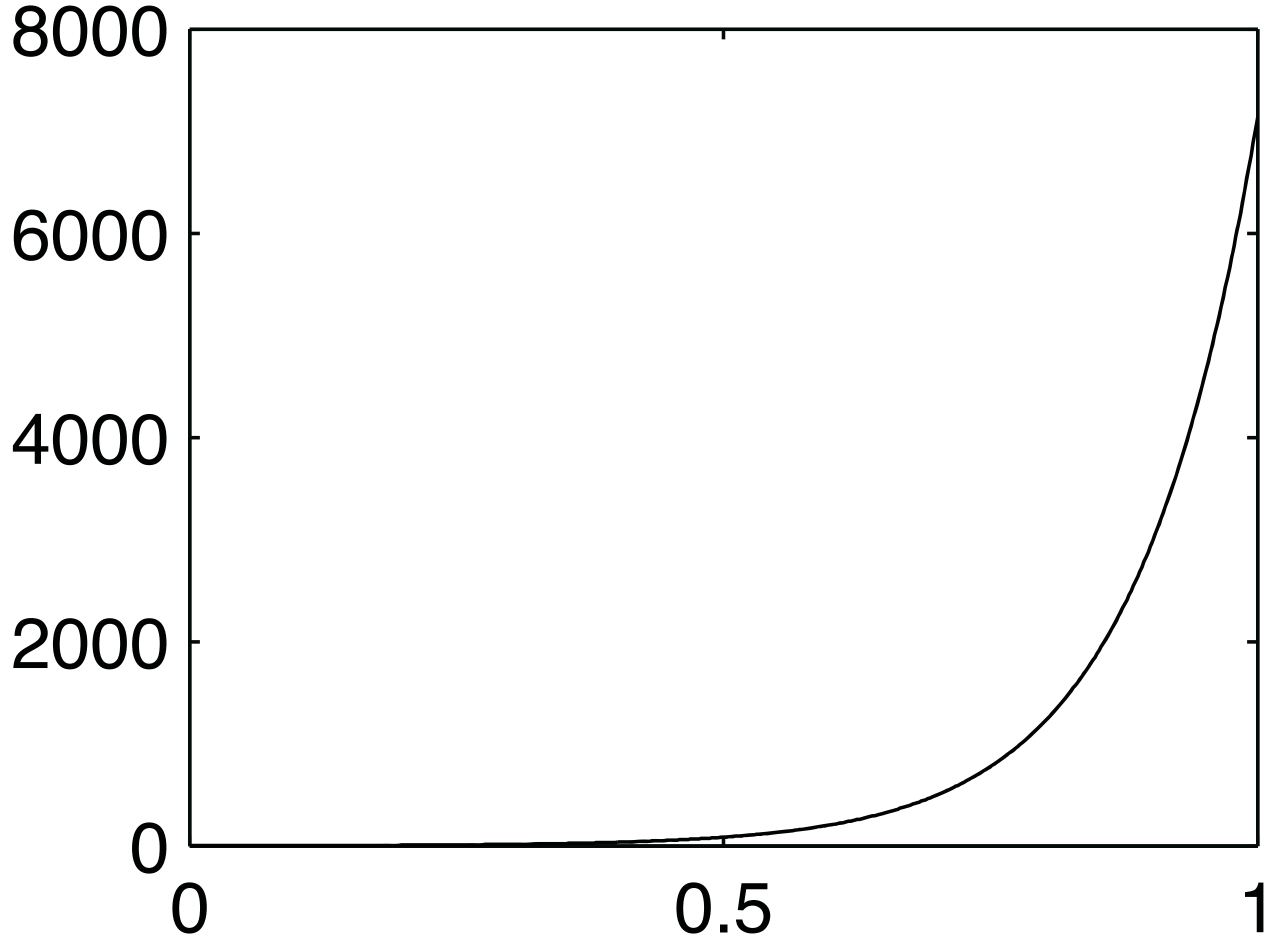


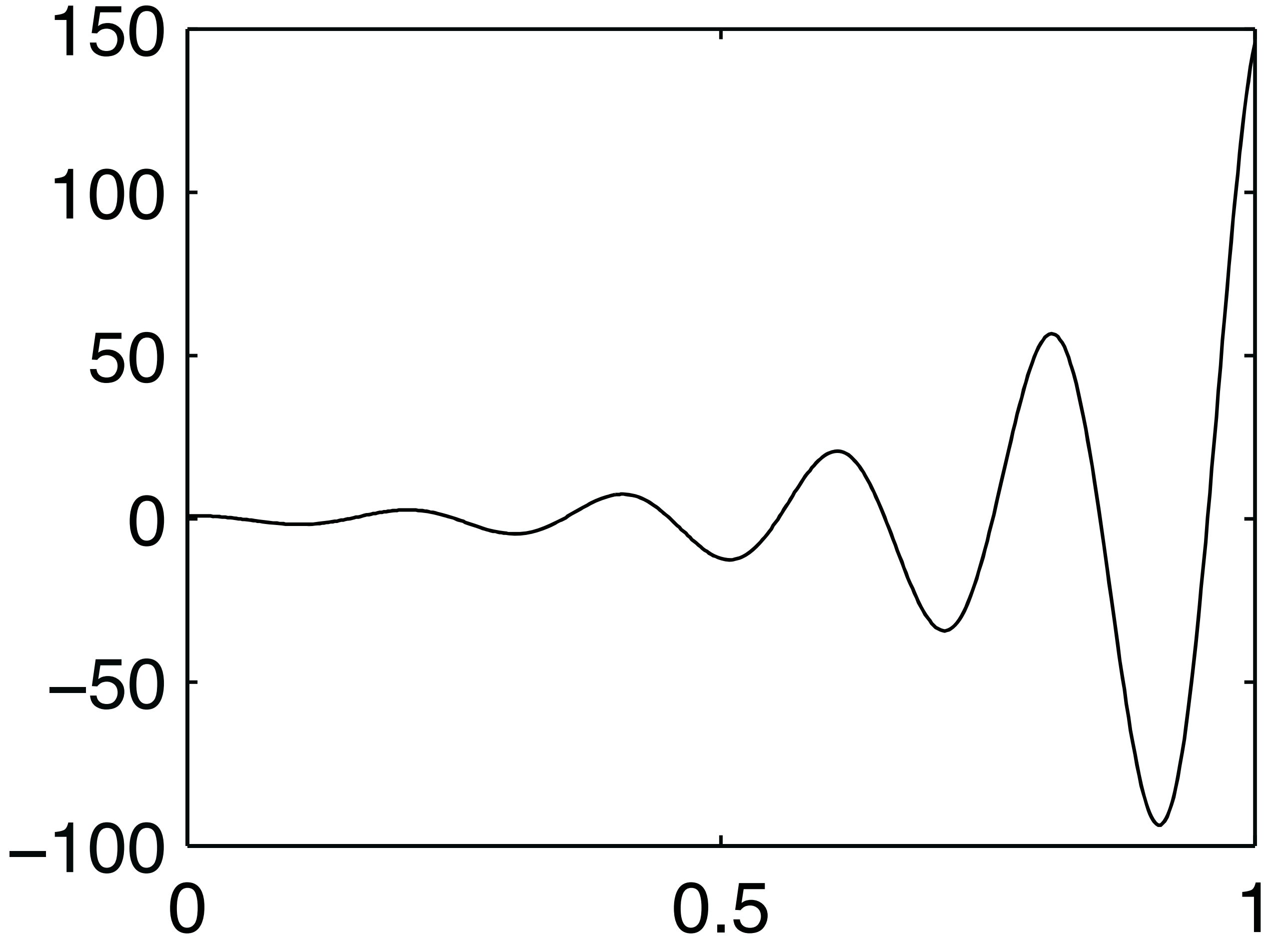




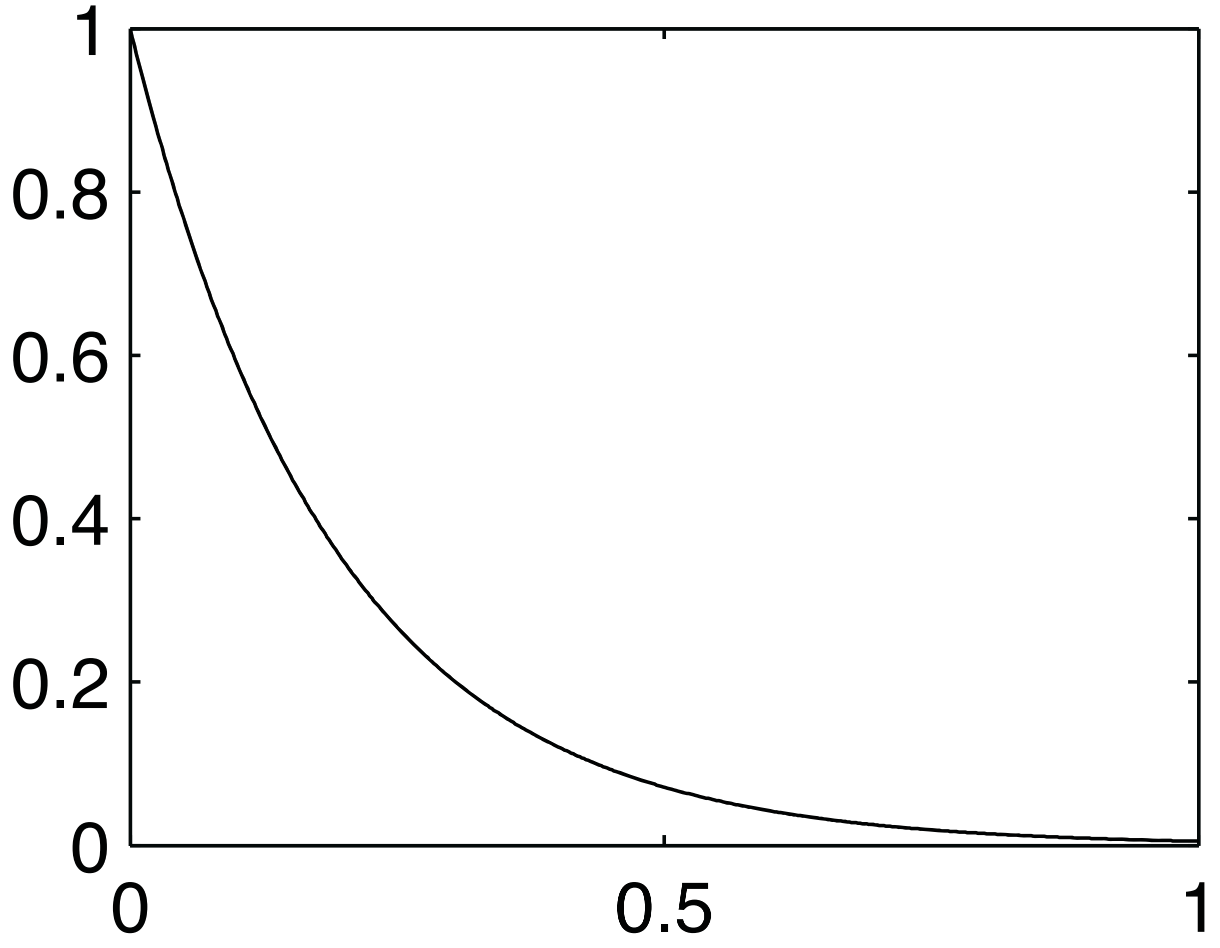


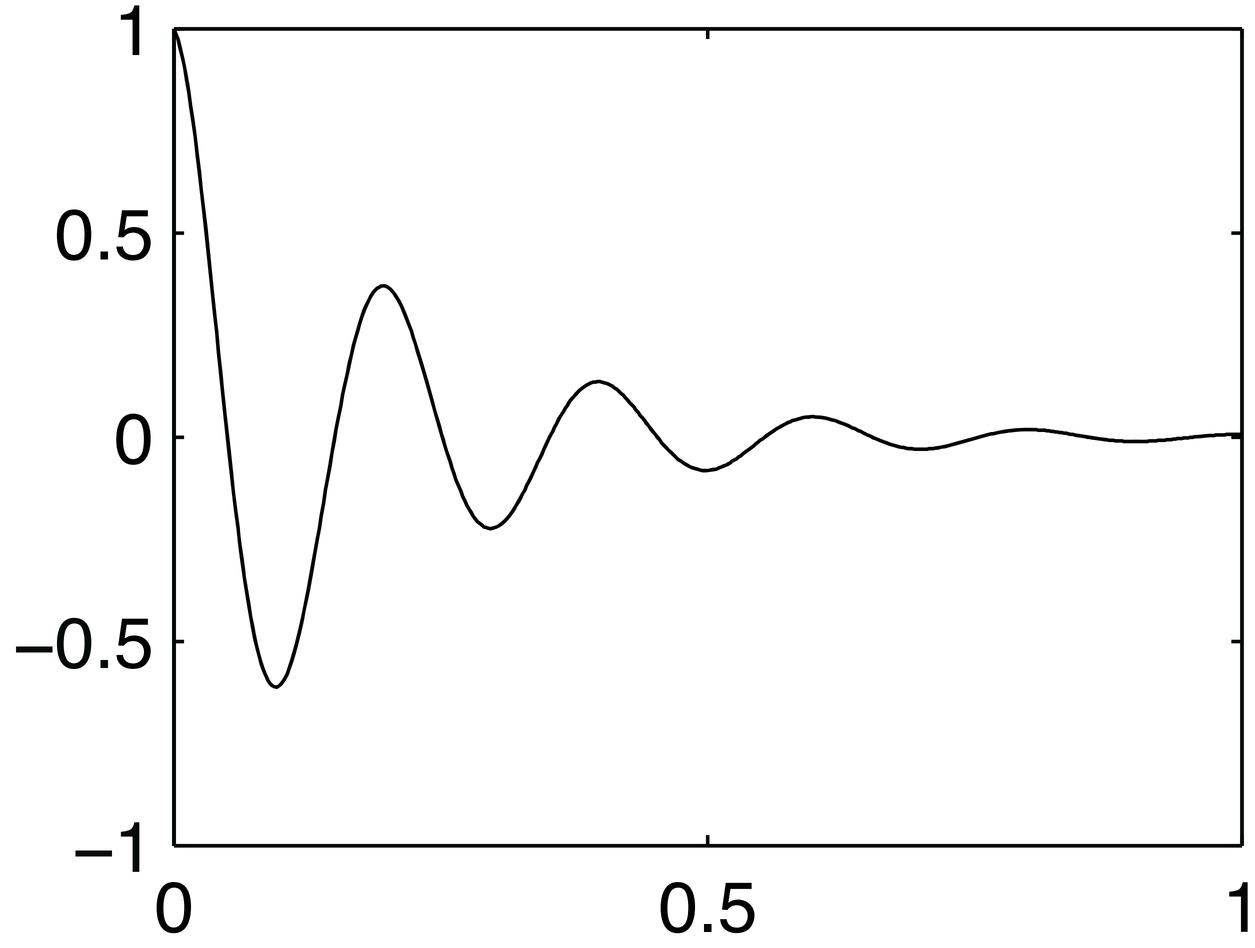
Positive feedback throws systems out of balance.



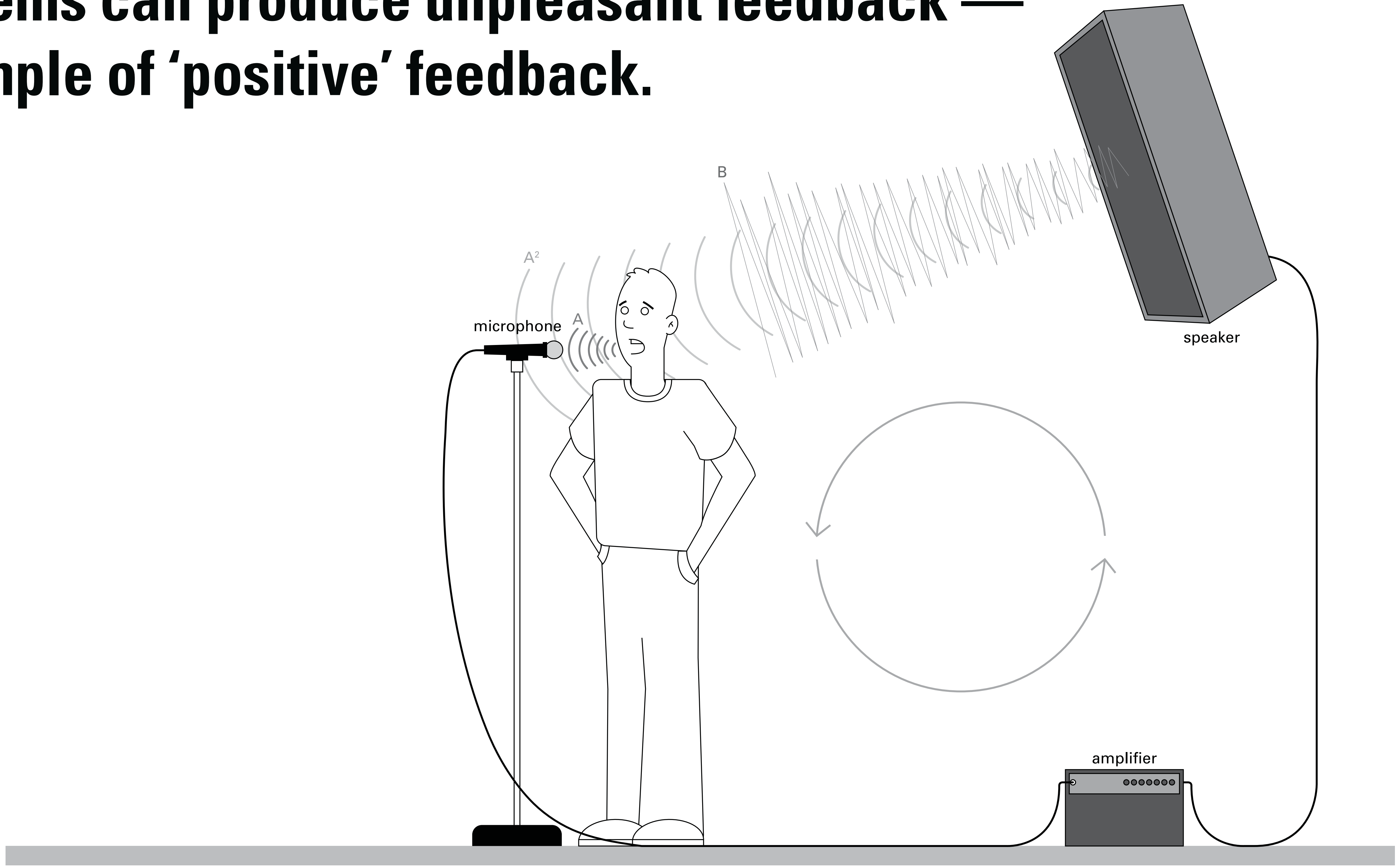


Negative feedback can maintain a system in balance.





PA systems can produce unpleasant feedback — an example of ‘positive’ feedback.



A = original sound
A² = original sound amplified
B = amplified sound, re-amplified (feedback)

The classic reinforcing loop is an eye for an eye; a tooth for a tooth — for example, the feud between Hatfields and McCoys —

If a Hatfield kills a McCoy, then a McCoy kills a Hatfield.
Likewise, if a McCoy kills a Hatfield, then a Hatfield kills a McCoy.

The situation goes from bad to worse in a vicious cycle.

A situation that goes from good to better is a virtuous cycle.

Both vicious cycles and virtuous cycles are positive feedback loops.

The classic example of a balancing loop, negative feedback, is foxes and rabbits (or wolves and elk):

If foxes increase, rabbits decline.
If rabbits decline, foxes decline (increase more slowly).

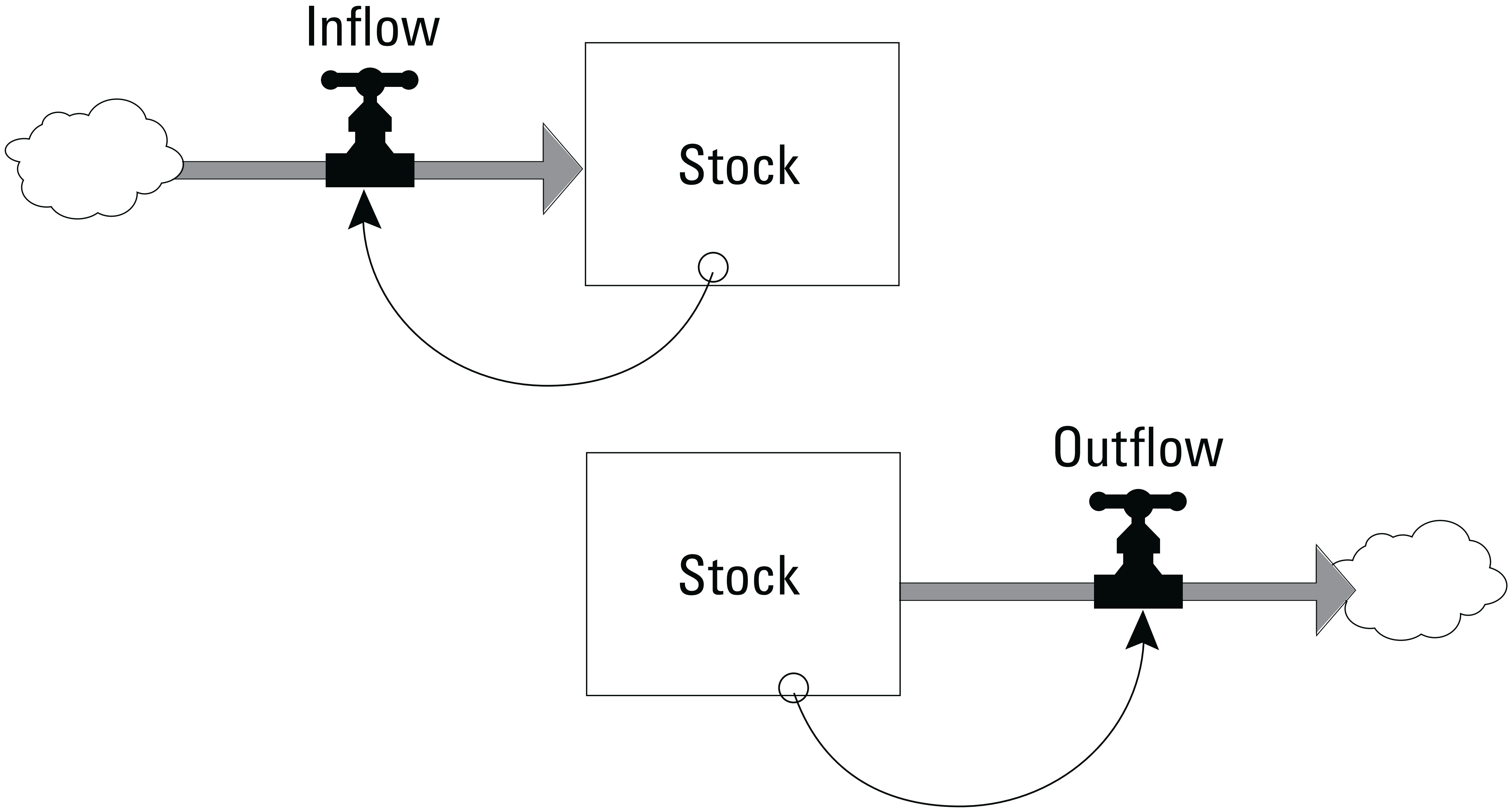
If foxes decline, rabbits increase.
If rabbits increase, foxes increase (more quickly).

But what about a thermostats / AC + temperature?

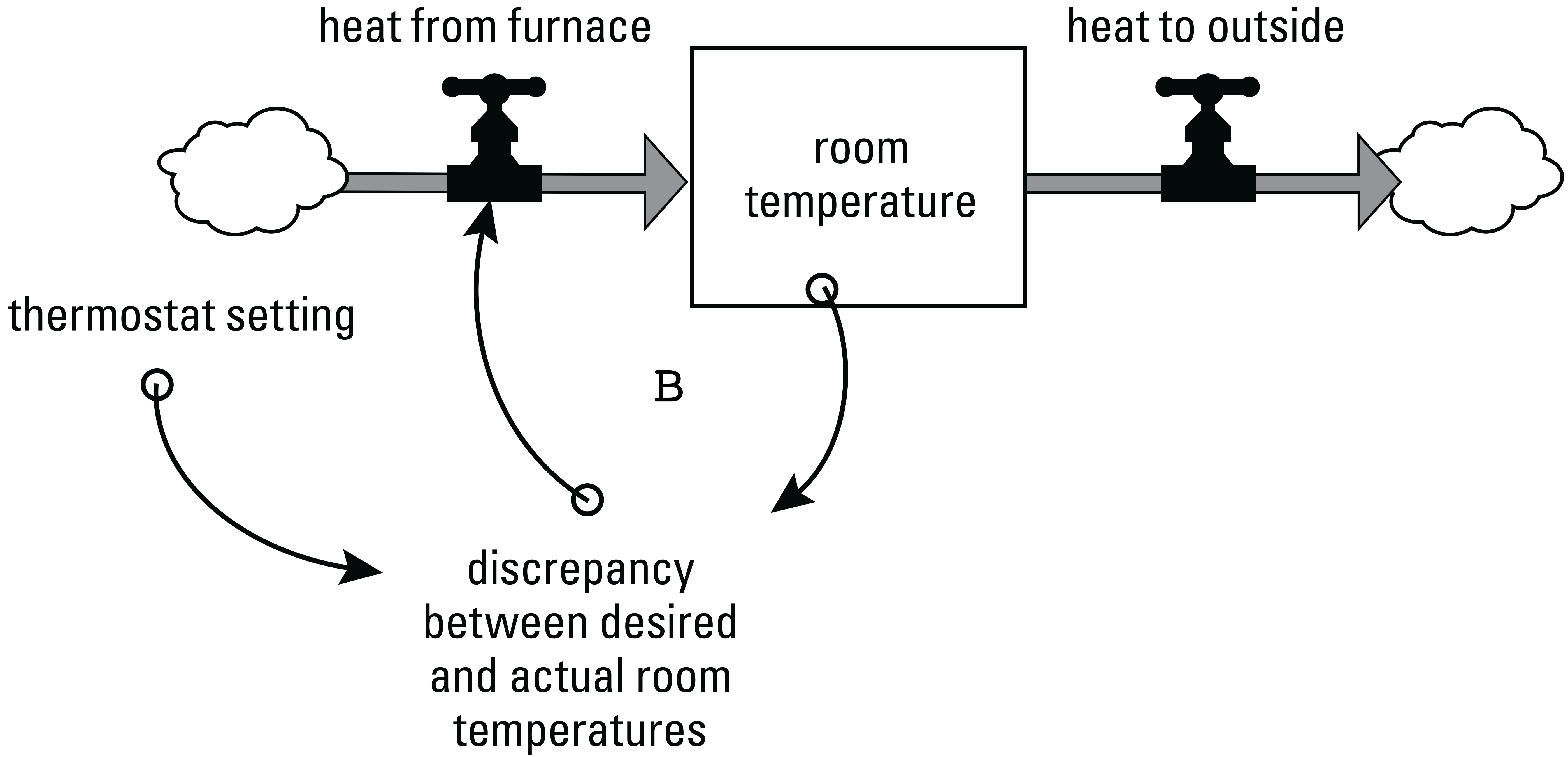
If AC increases, temp declines.
If temp declines, AC declines (goes off at the set point).

If AC declines, temp increases.
If temp increases, AC increases (goes on at the set point).

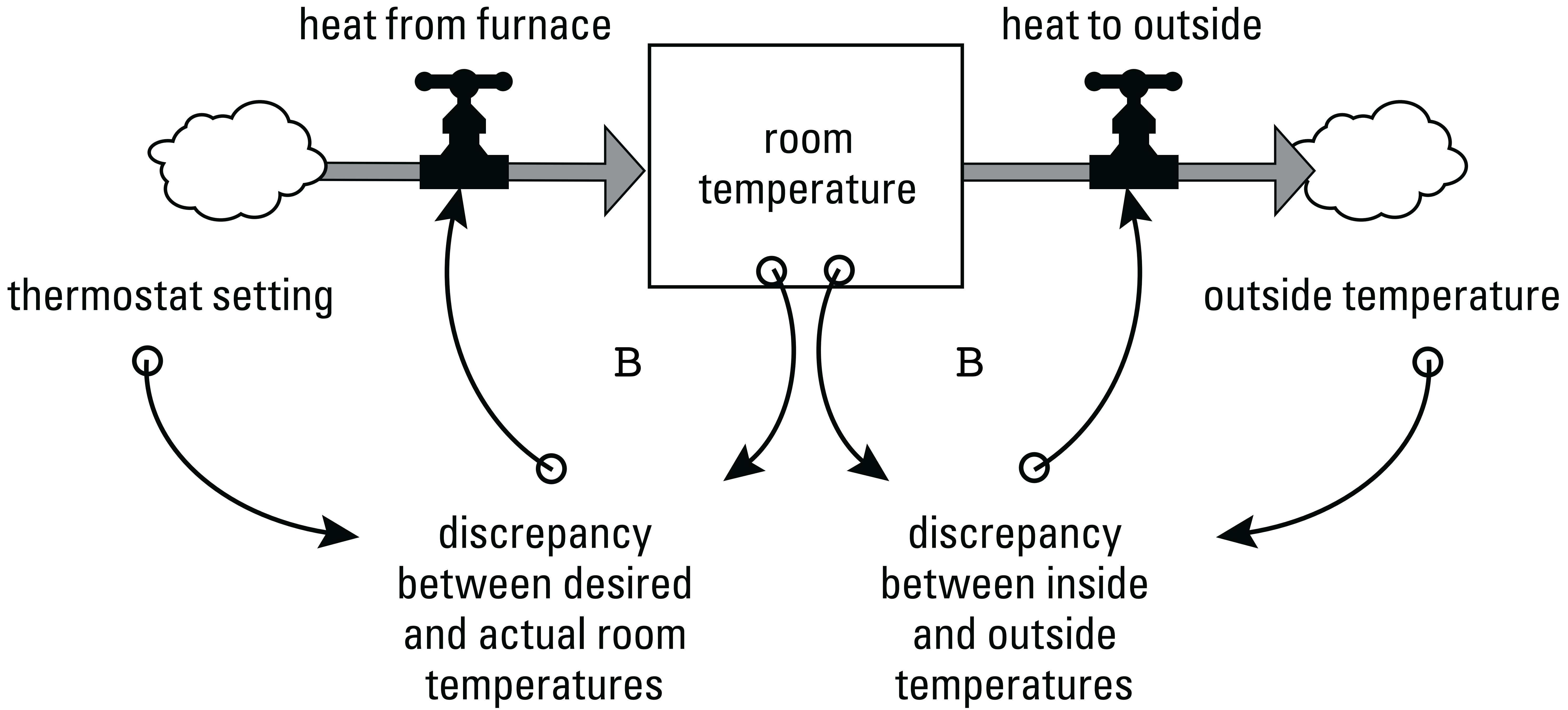
In Meadow's view, **"A feedback loop is formed when changes in a stock affect the flows into or out of that same stock."**



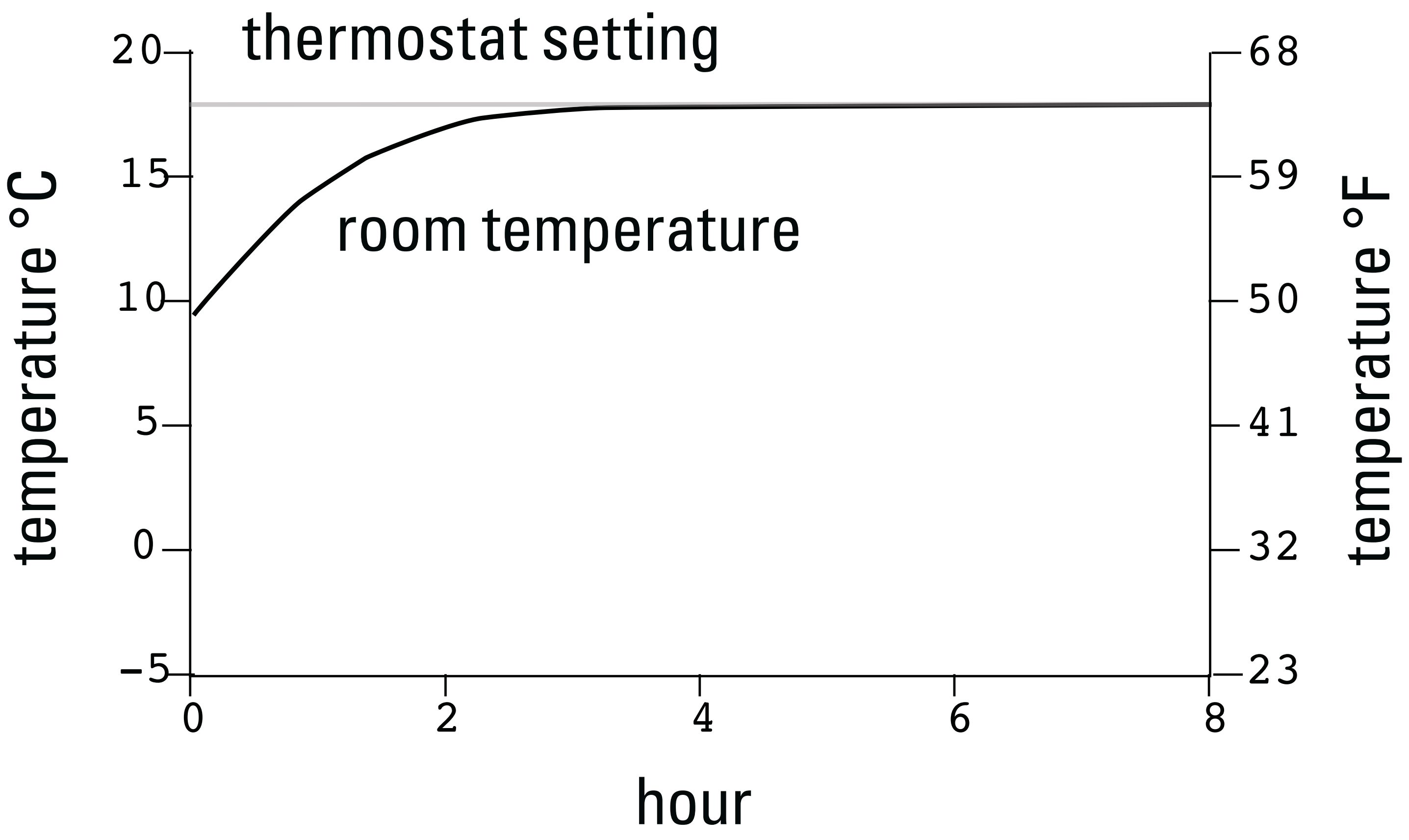
Meadows: **“Room temperature regulated by a thermostat and furnace.”**



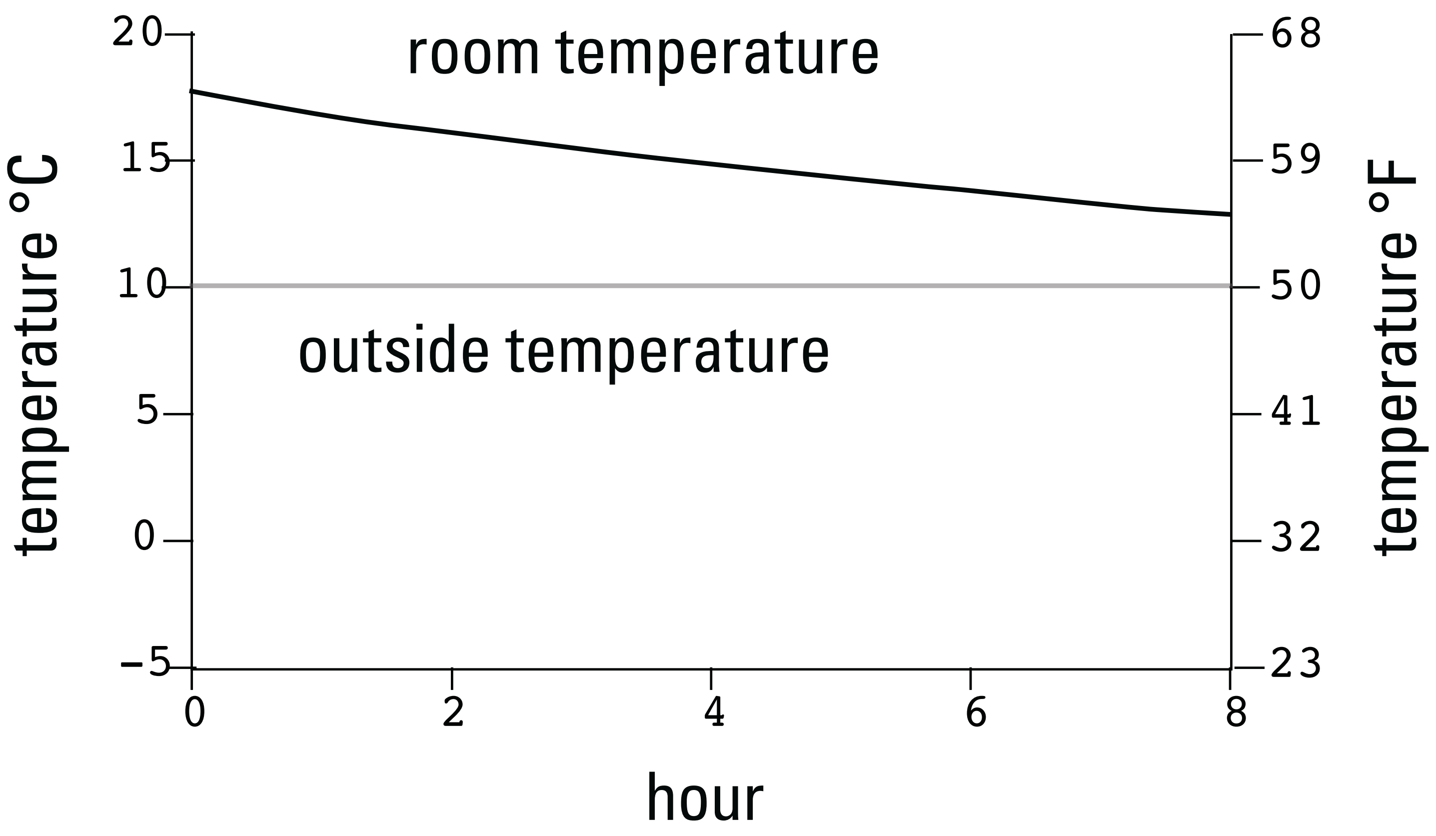
Meadows: **“Room temperature is *also* regulated by outside temperature.”**



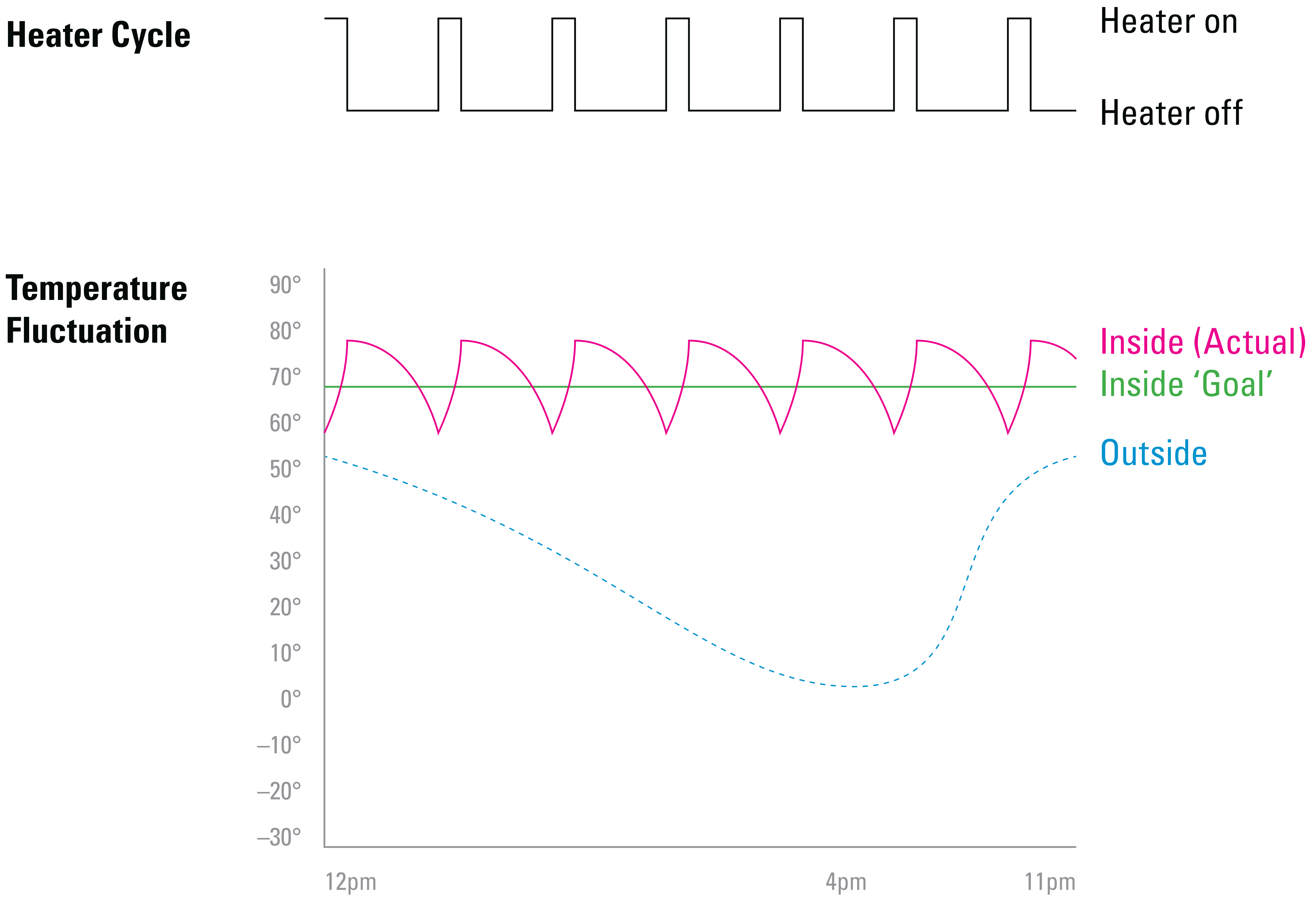
A cold room warms quickly to the thermostat setting.



A warm room cools slowly to the outside temperature of 10° C.



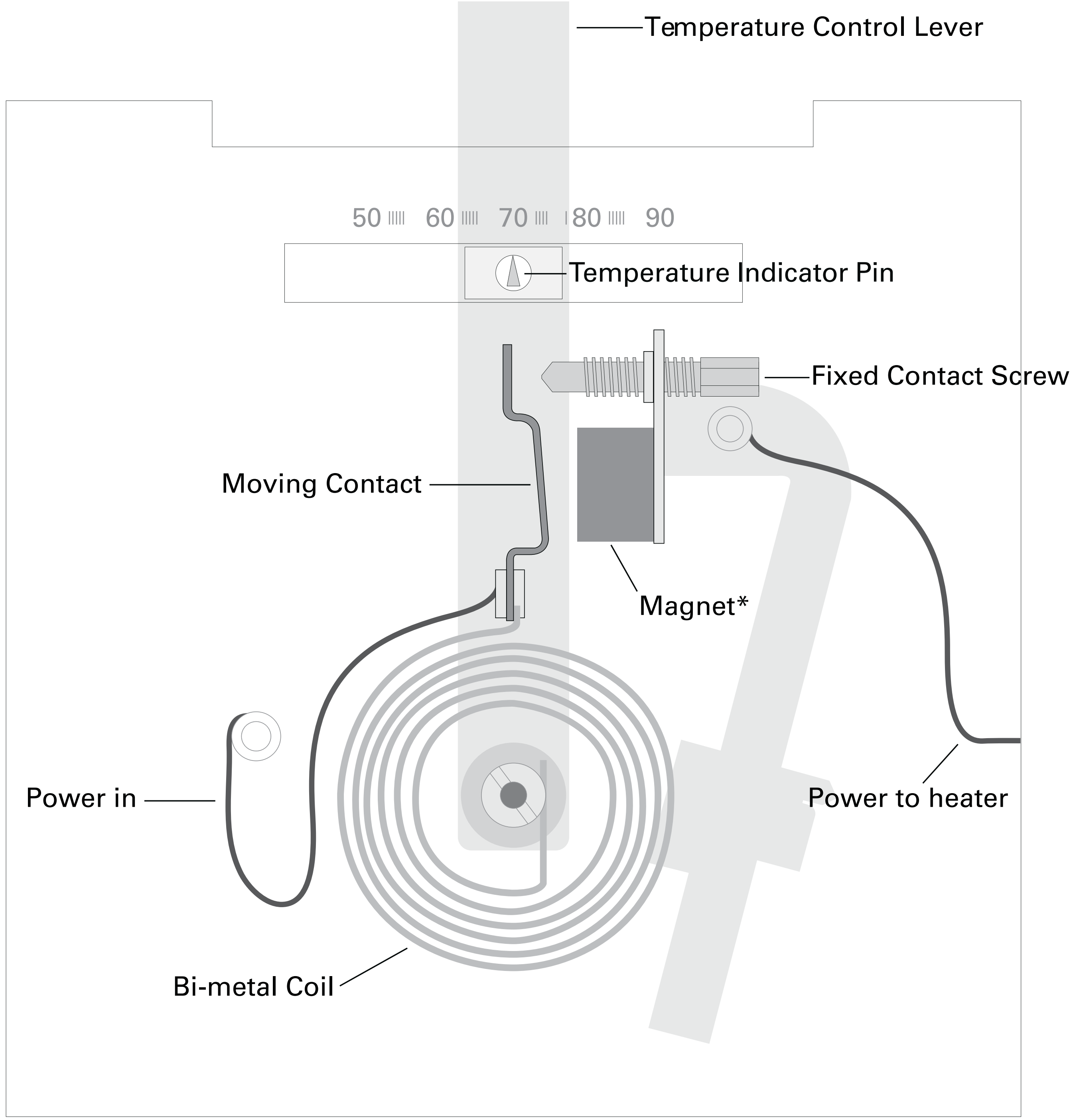
A thermostat maintains a constant temperature.



How a Thermostat Works

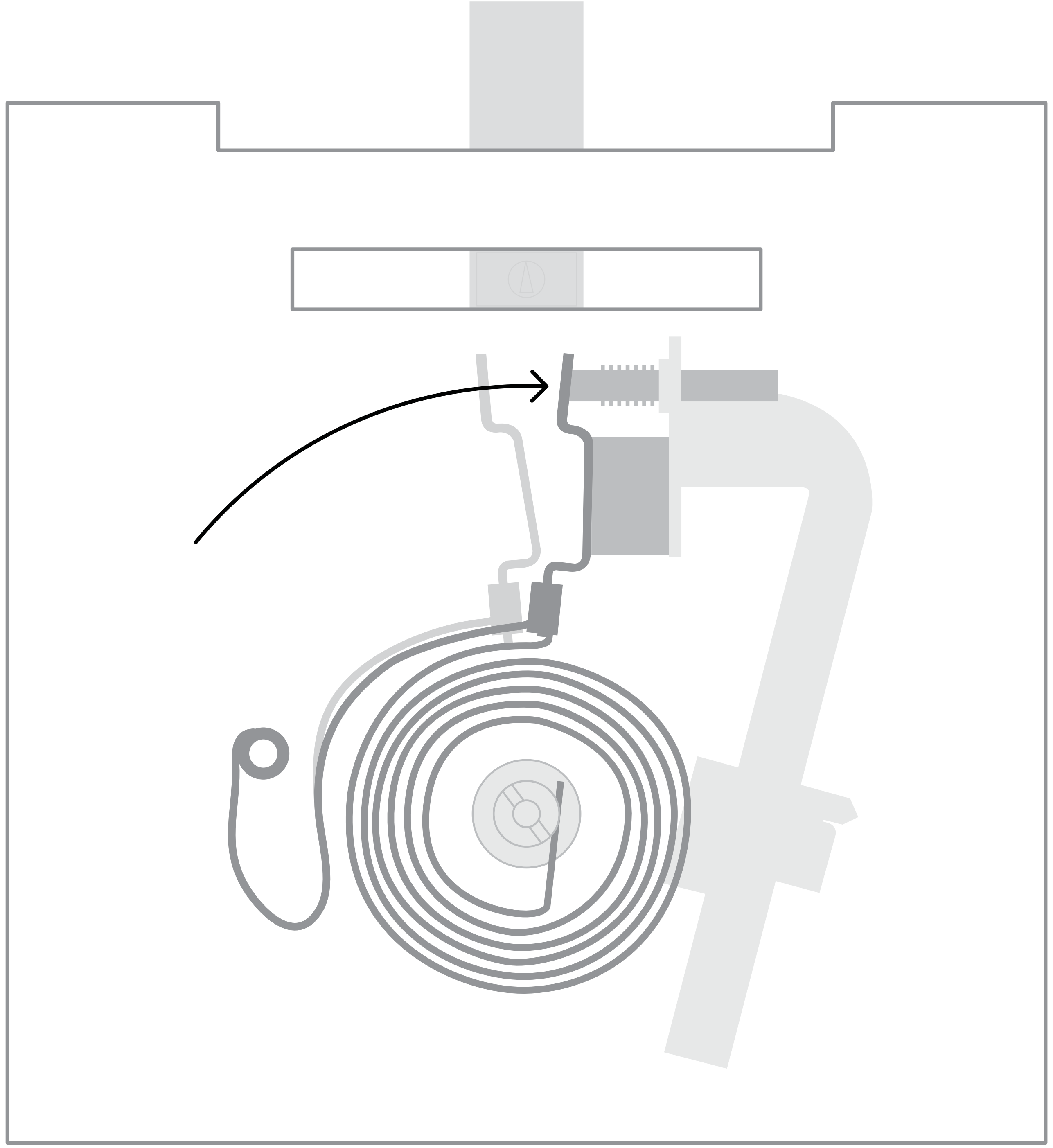
The bi-metal coil is connected to the temperature control lever.

* The magnet insures a good contact and prevents erratic on/off signals to the heater in the event that the air temperature within the room fluctuates to quickly.



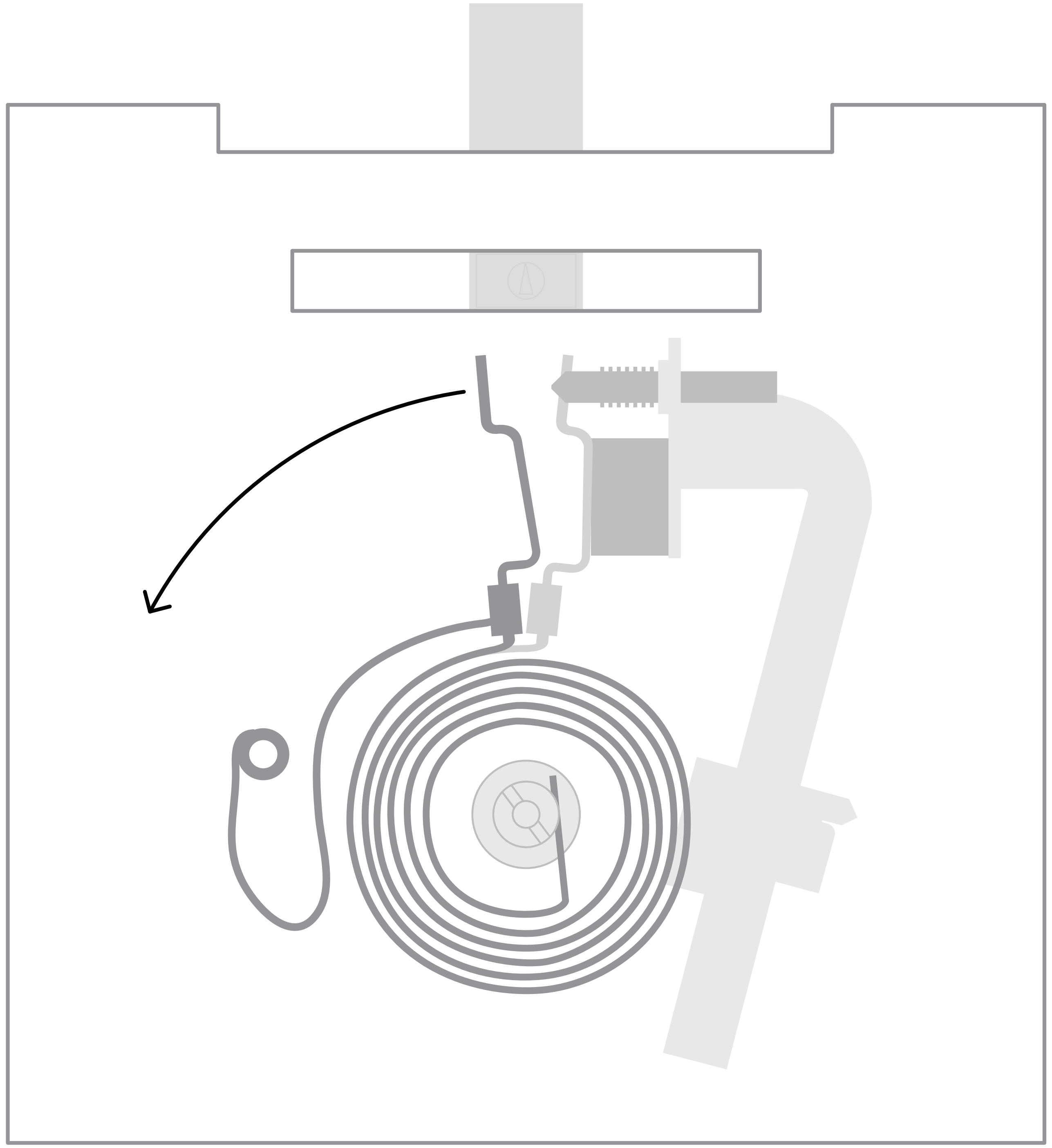
As the room cools, a bi-metal coil contracts closing a circuit.

The bi-metal coil bends towards the contact screw as it cools.

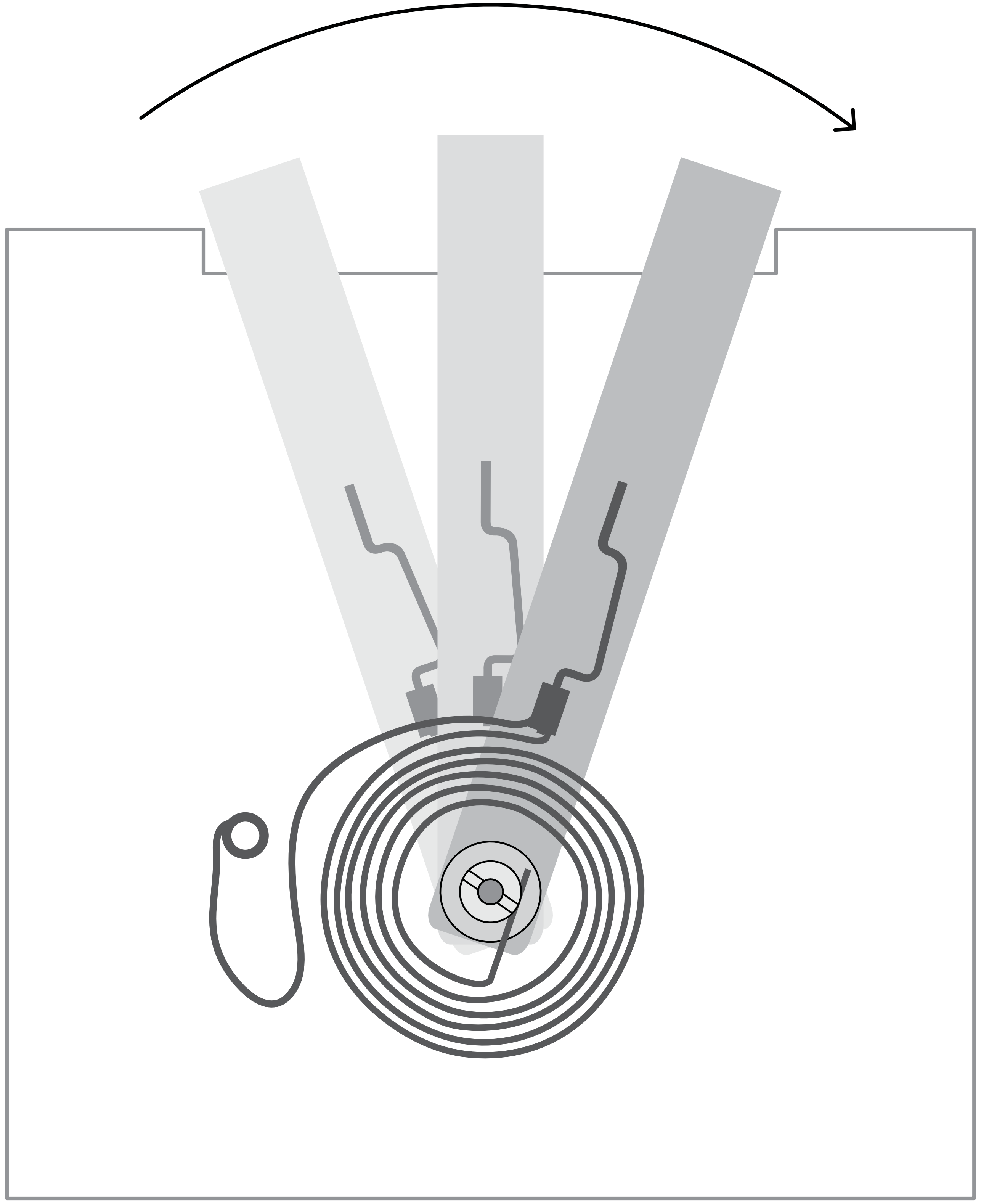


As the room heats, the coil expands breaking the circuit.

The bi-metal coil bends away from the contact screw as it warms.



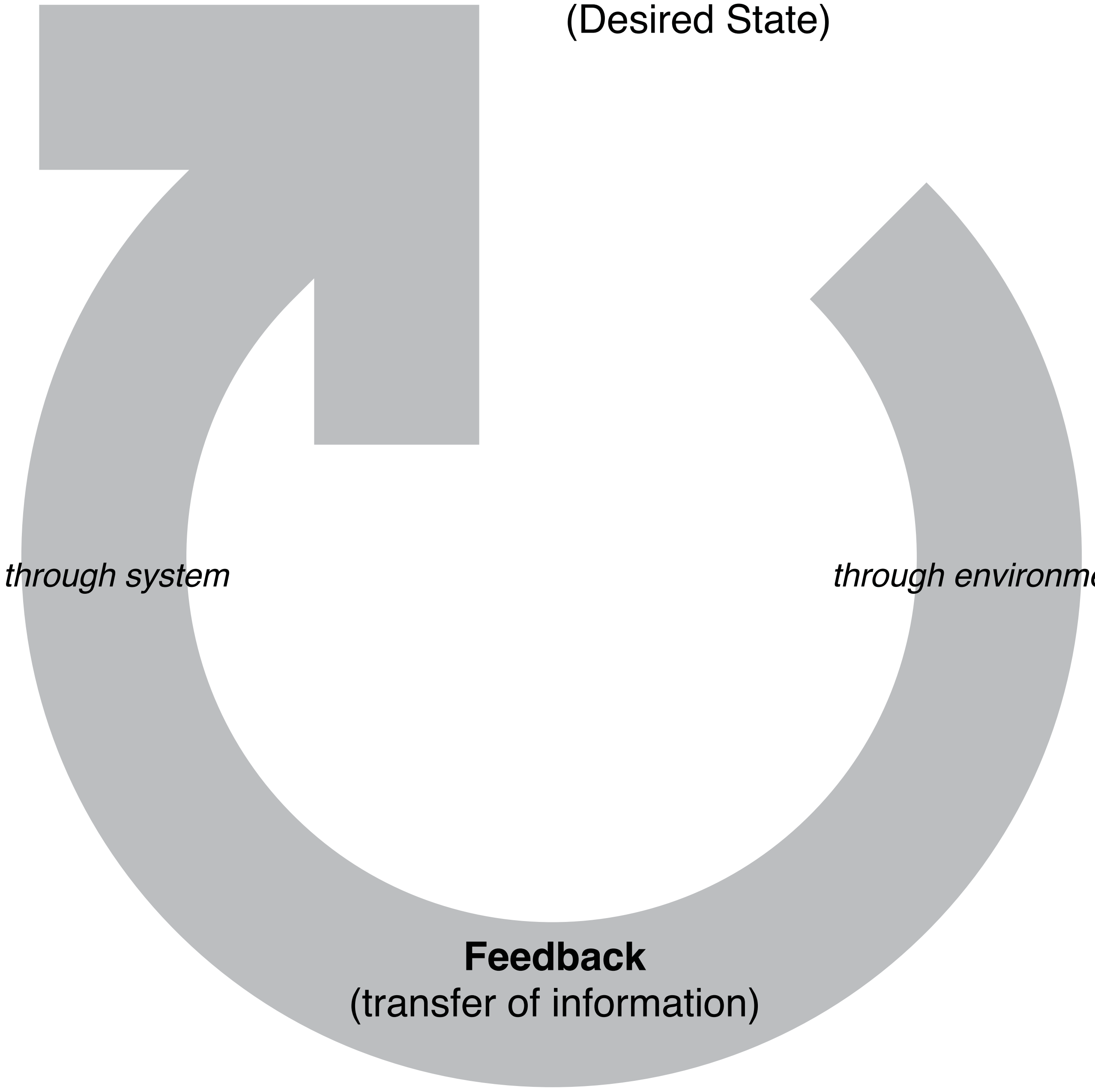
Moving the temperature control lever moves the bi-metal coil.



Modeling Feedback

Feedback: Basics

Goal
(Desired State)

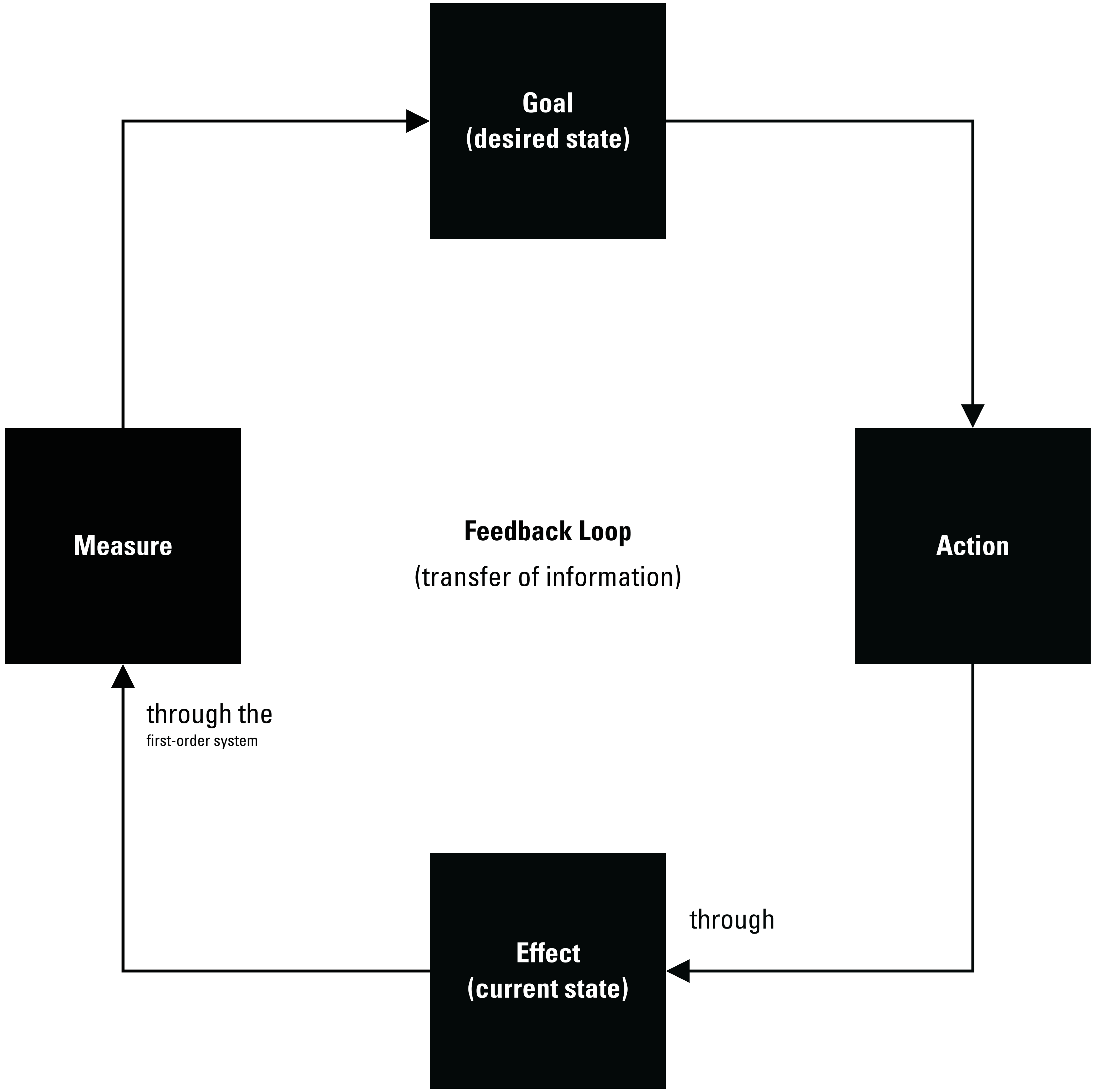


Measurement
System measures its progress
comparing current state to desired state
determining the difference,
and attempting to correct the ‘error.’

Action
System attempts to reach a goal;
based on feedback,
it modifies its actions.
(System acts both within itself
and on its environment.)

Effect
(Current State)

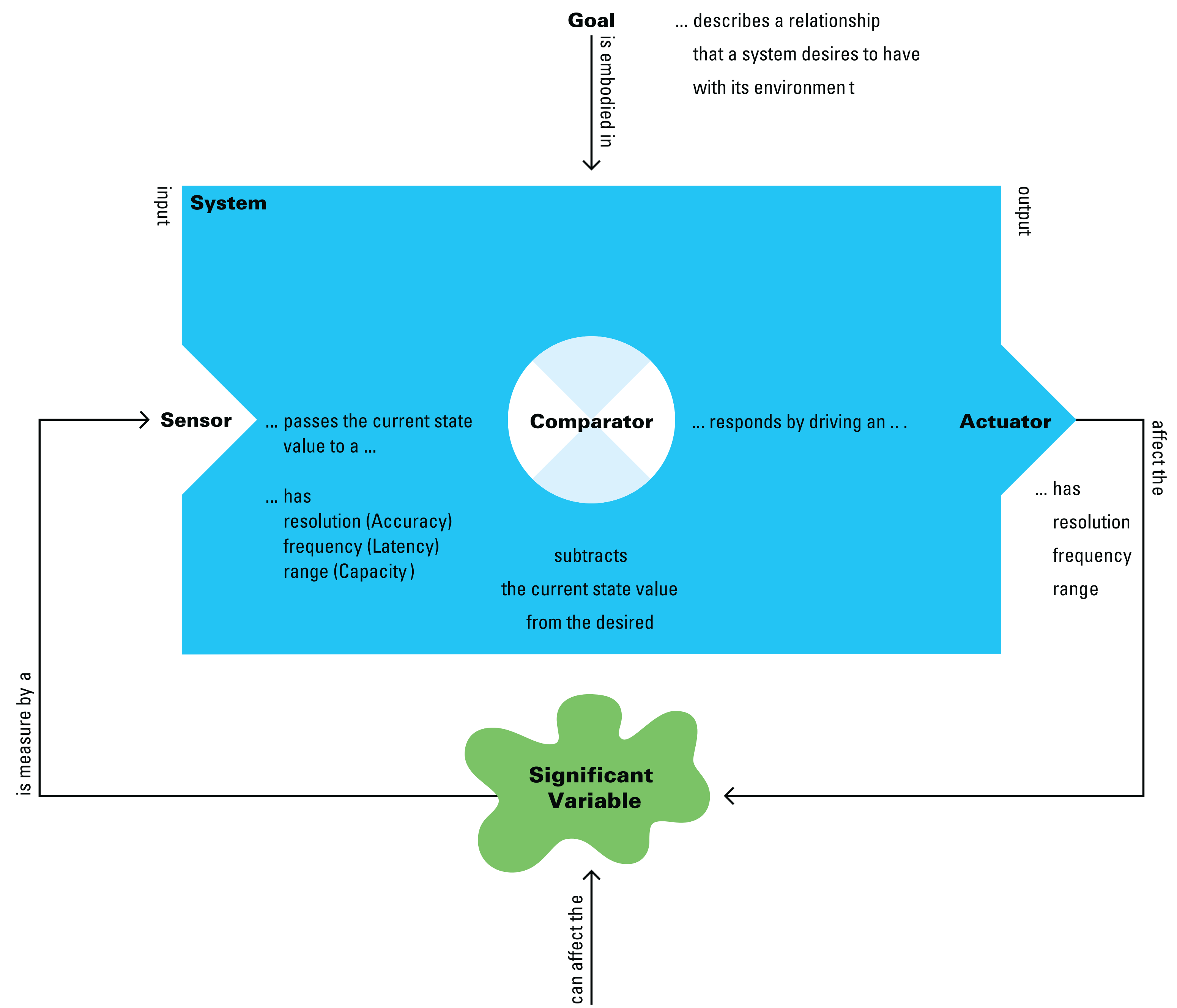
Feedback: Basics



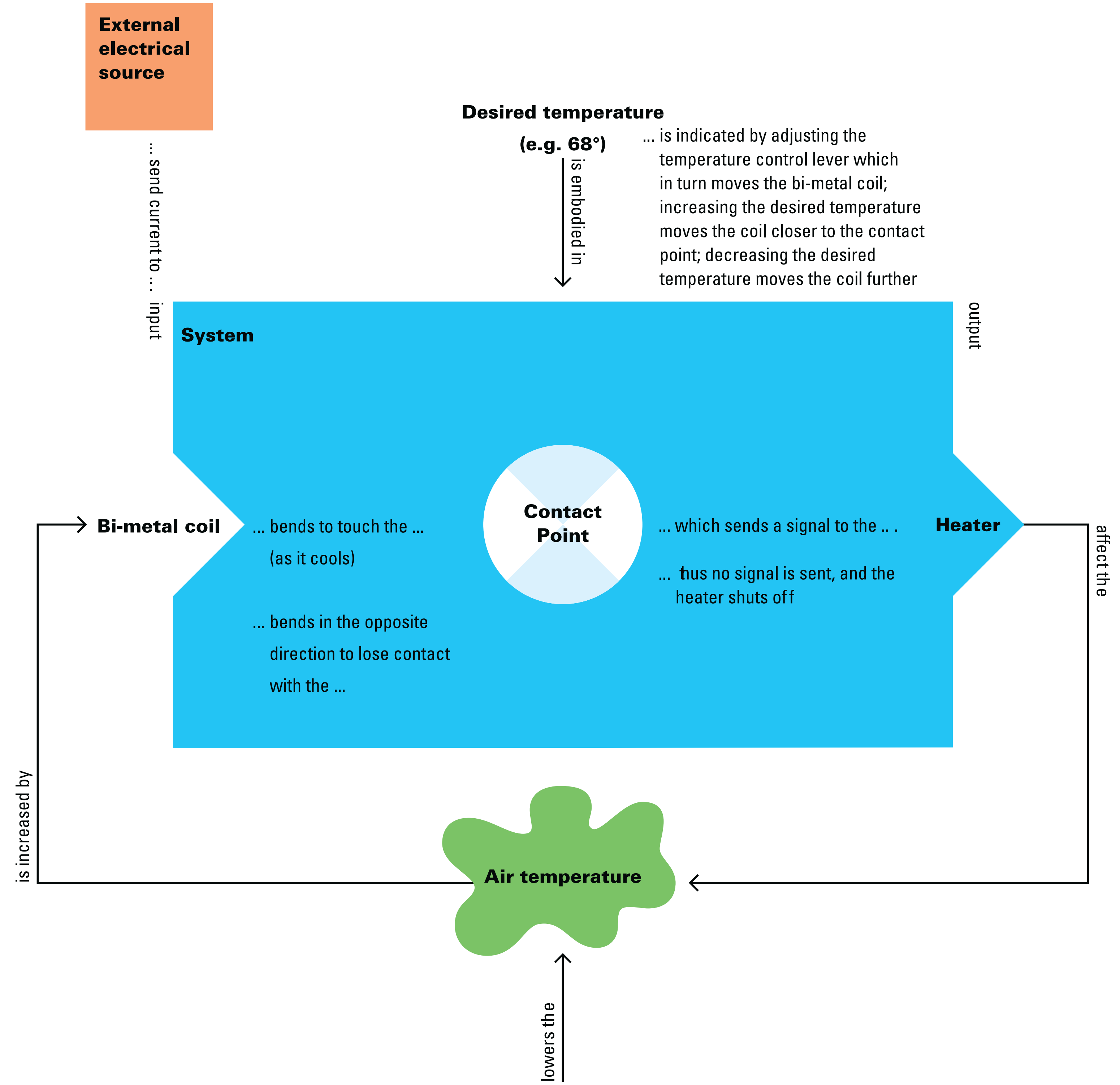
System measures its progress comparing current state to desired state determining the difference, and attempting to correct the 'error.'

First-order system attempts to reach a goal; based on feedback, it modifies its actions. (The first-order system acts both within itself and on its environment.)

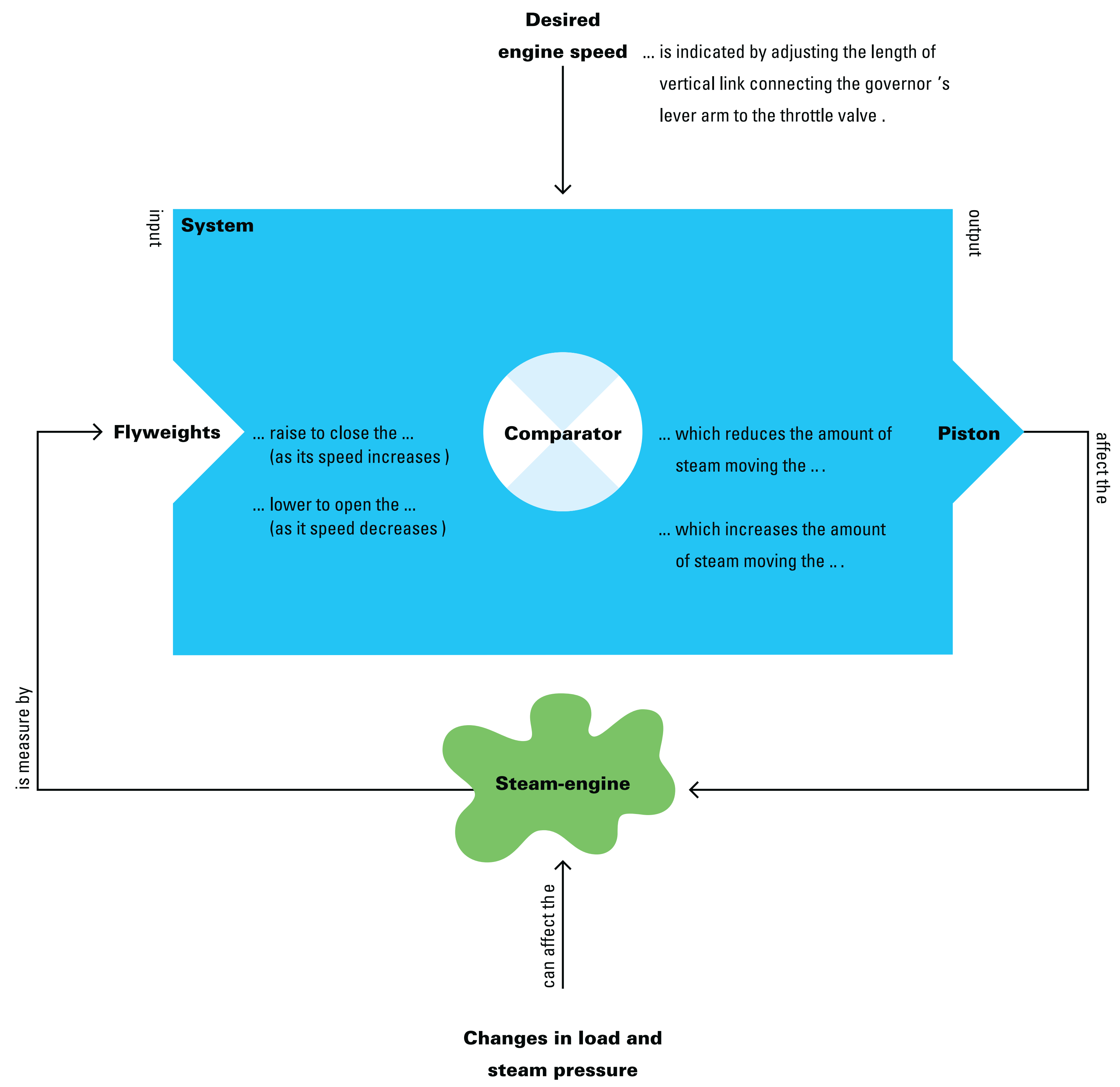
Feedback: Formal Mechanism



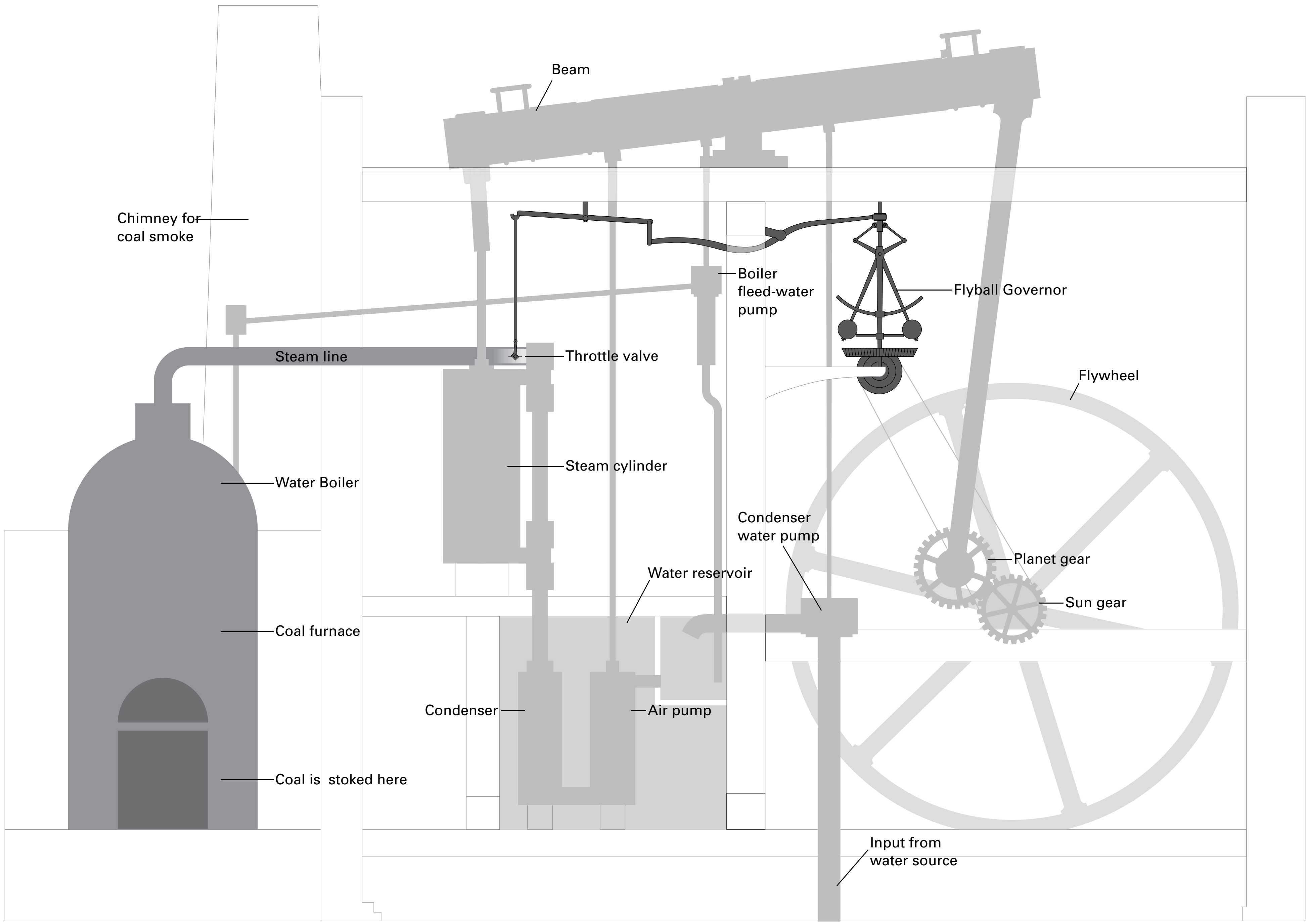
Feedback: Classic Example



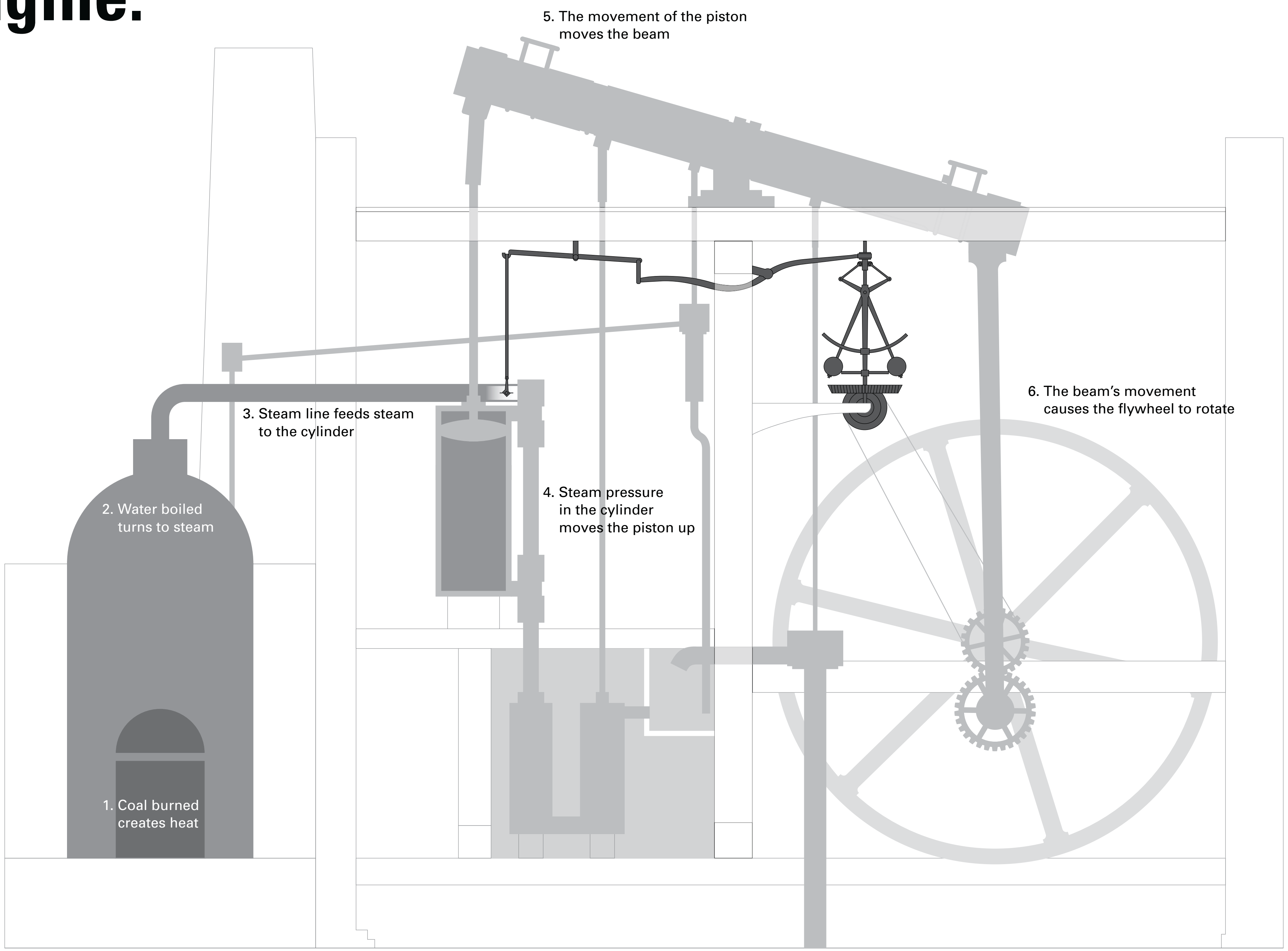
Feedback: Mechanical Example



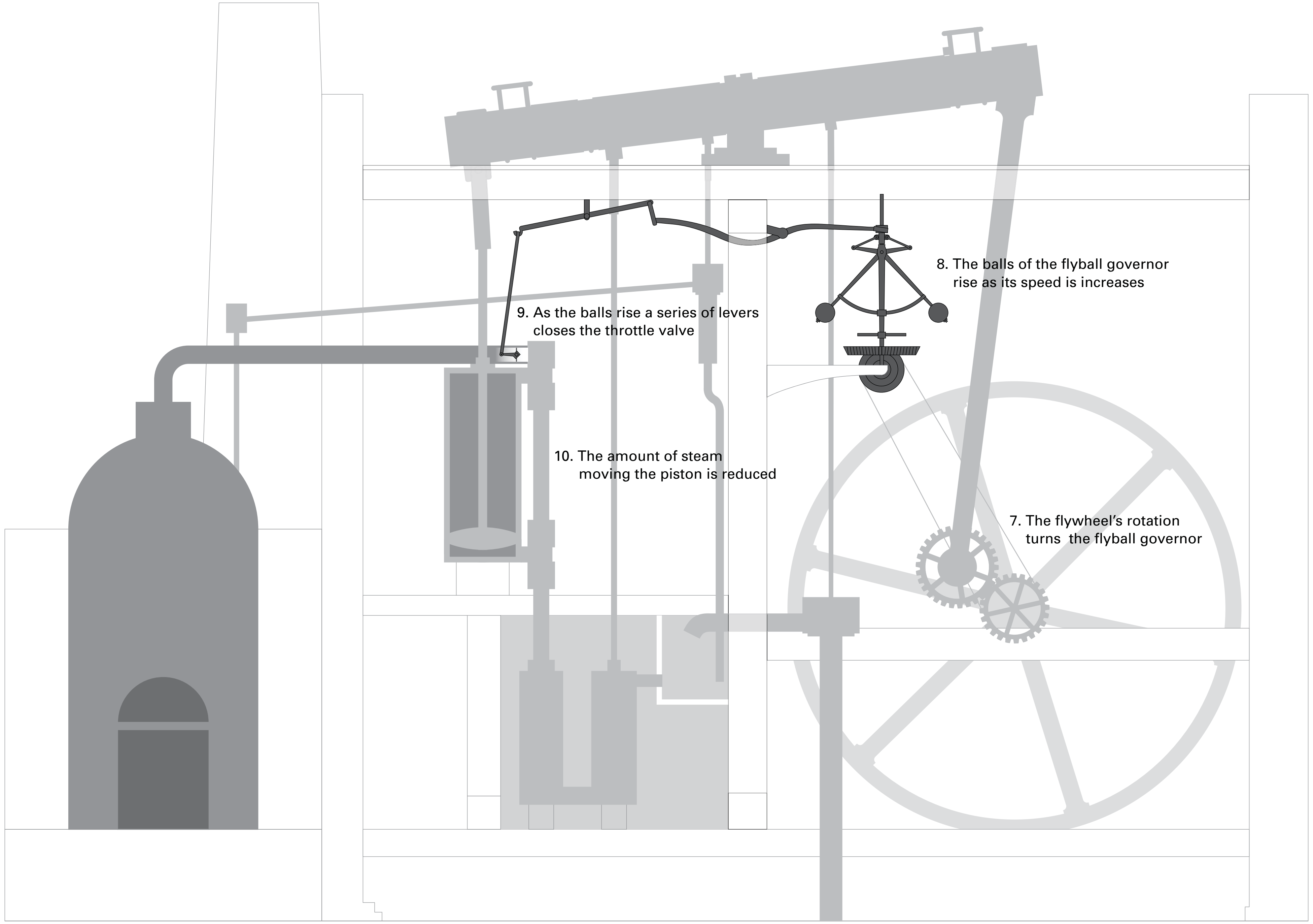
Watt steam engine with flyball governor



A flyball governor maintains constant pressure in a steam engine.



At high speed the throttle valve closes



Increasing speed closes a valve; decreasing speed opens the valve.

0 Through a system of gears and pulleys the speed of the steam engine is transferred to the gear at the base of the flyball governor—causing it to rotate.

1.1 At low speed, the flyweights remain close to the spinning central axis

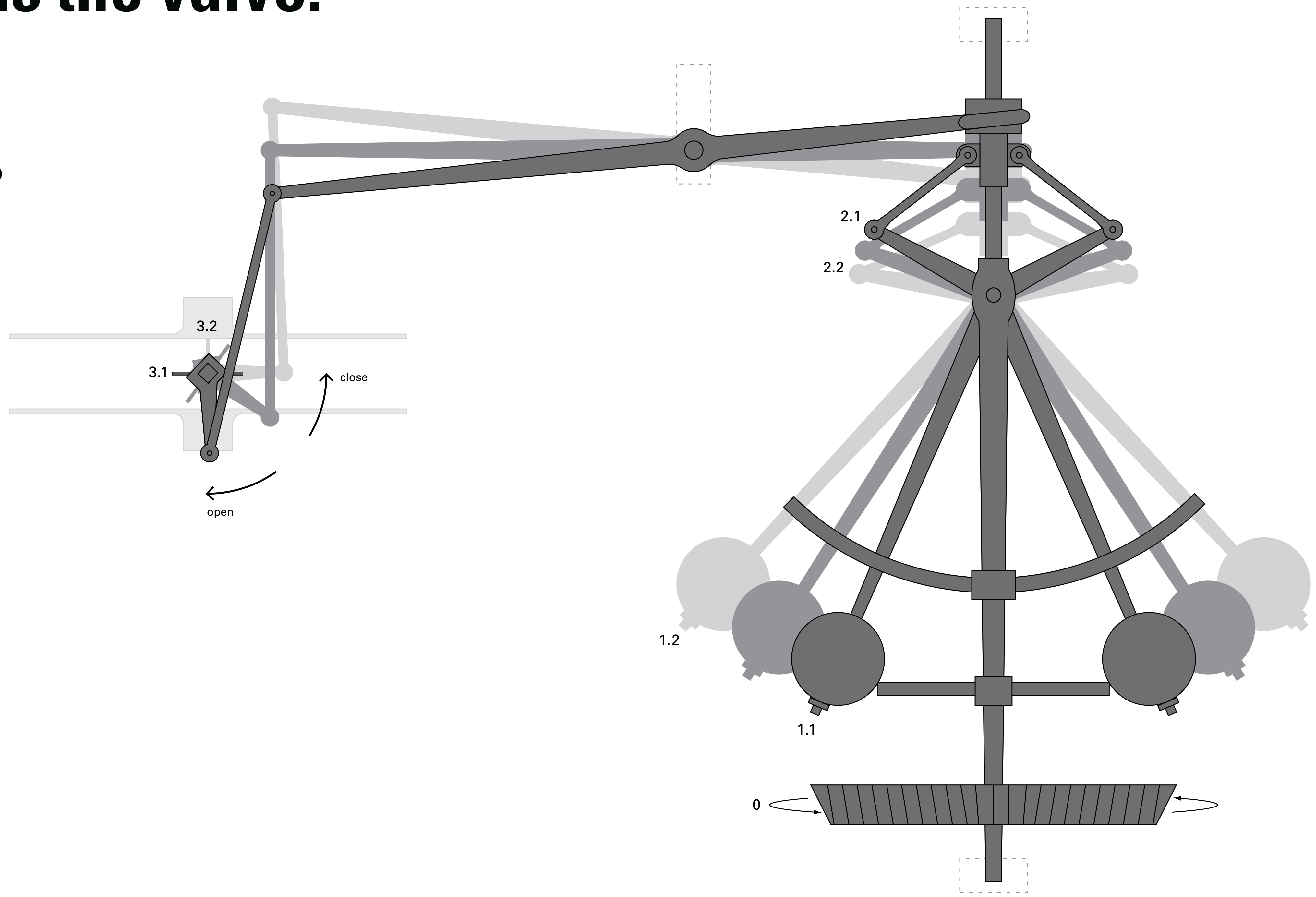
1.2 As speed increases, the flyweights swing outward, and upward.

2.1 At low speed, the scissor mechanism pushes the lever arm up

2.2 At high speed the scissor mechanism pulls the lever arm down

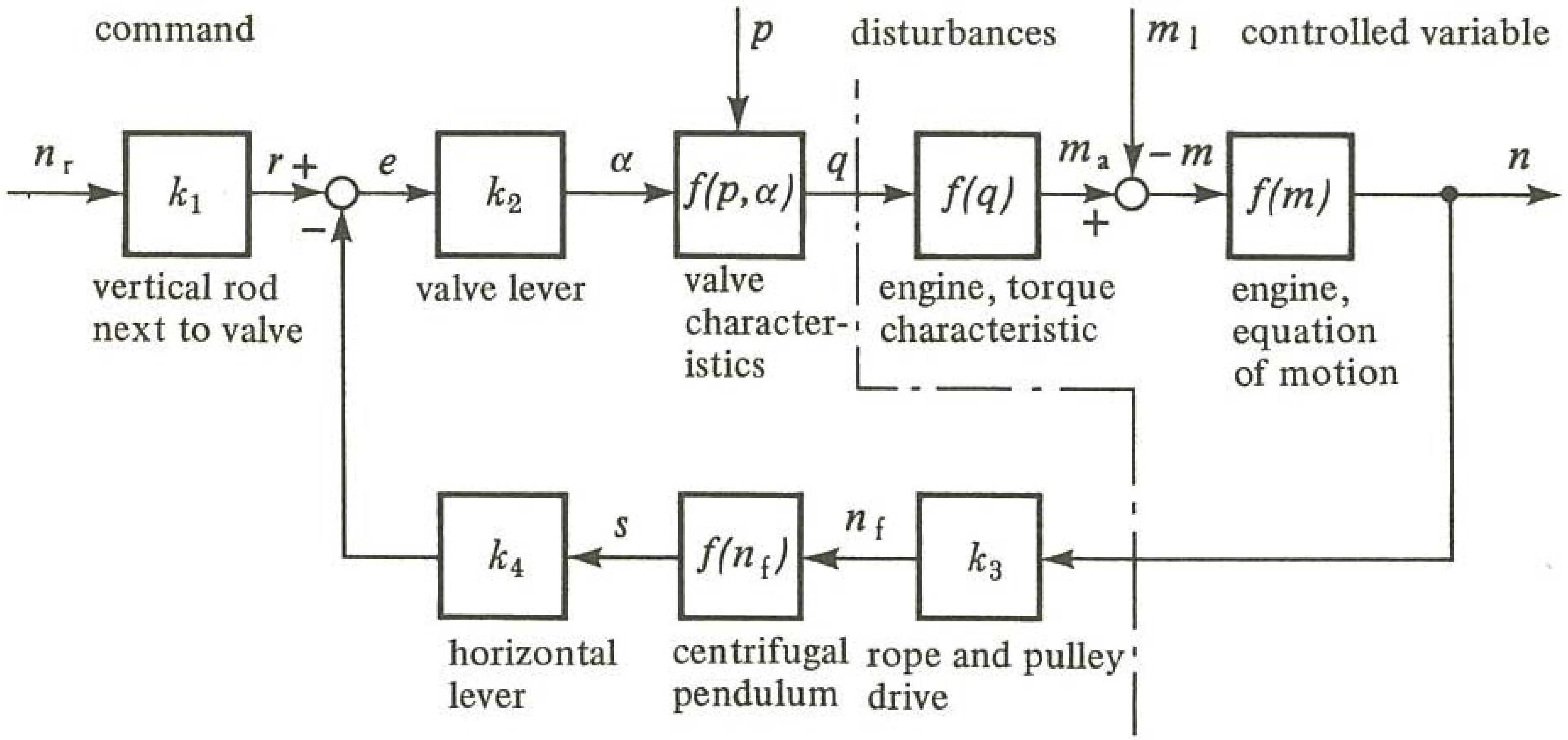
3.1 At low speed, the lever arm pushes the throttle valve open; increasing the flow of steam

3.2 At high speed, the lever arm pulls the throttle valve closed; reducing the flow of steam



Dashed lines indicate the points at which the flyball governor is mounted to the wooden framework of the Watt steam-engine.

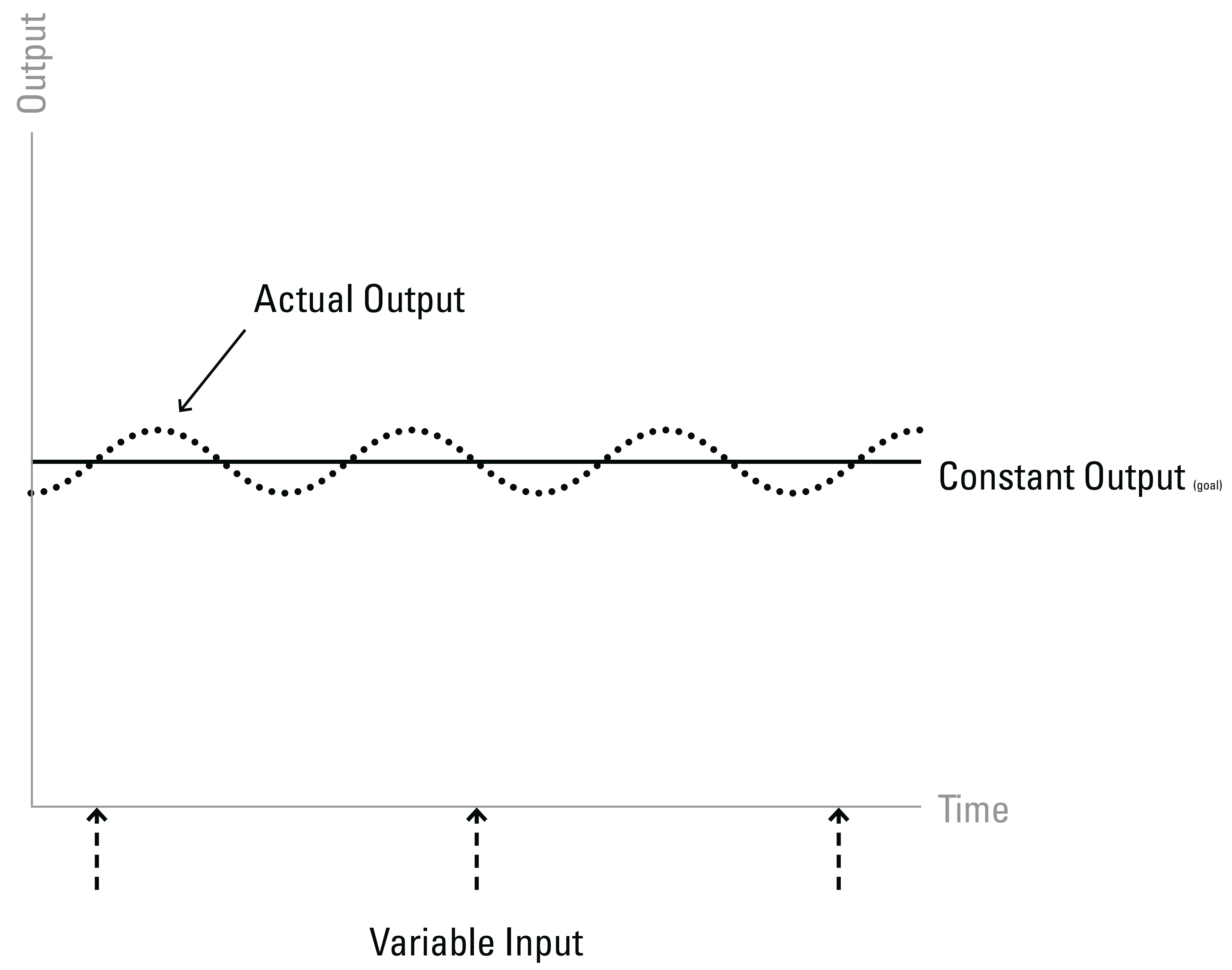
Otto Mayr's block diagram of the centrifugal governor.



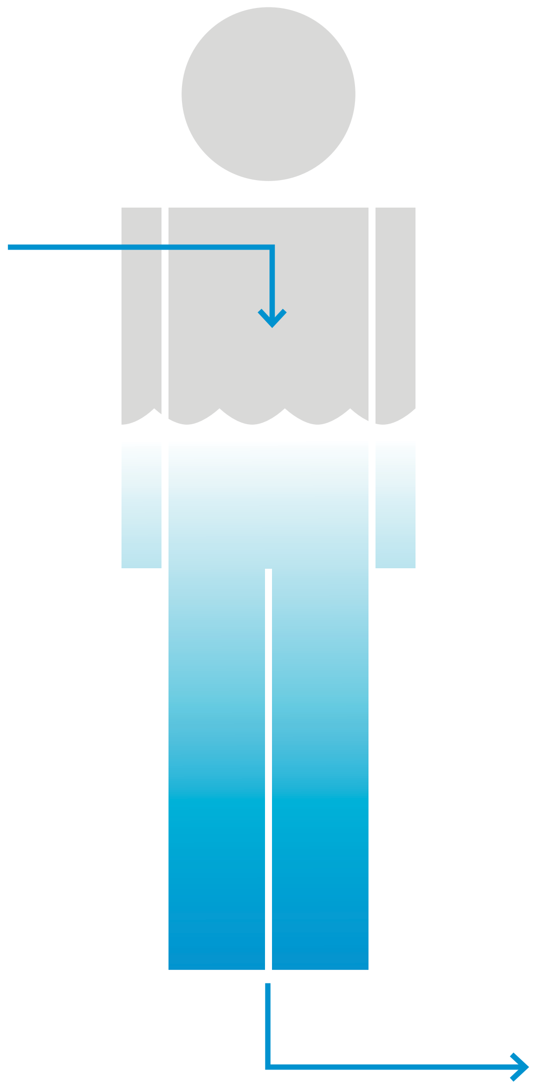
n = desired speed
r = position of vertical valve rod
b = position of the right end of horizontal lever
α = $r - b$
a = angular position of valve lever
p = steam pressure
q = steam flow rate

m_a = driving torque
m_l = load torque
m = $m_a - m_l$
n = actual speed
n_f = speed of governor
s = position of governor sleeve

Goal of Regulator or Governor

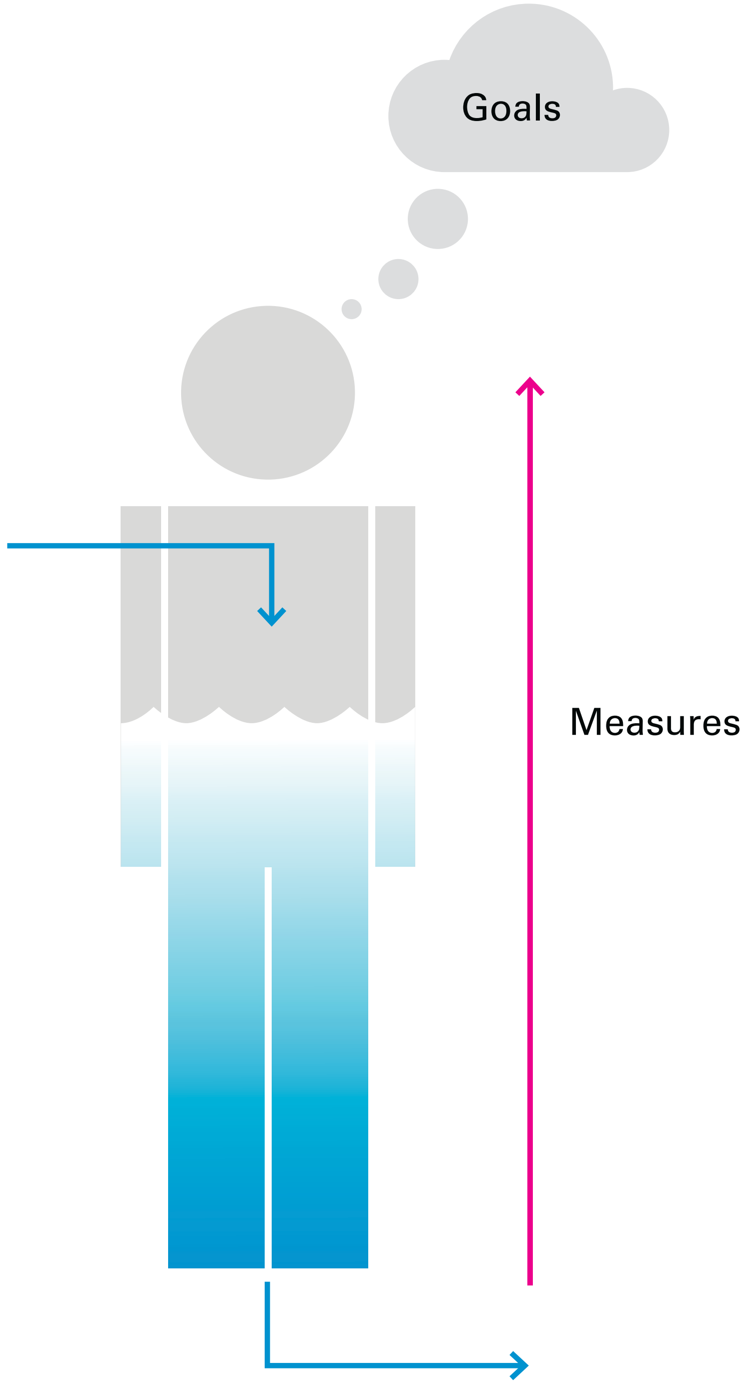


Living systems must maintain dynamic equilibrium (homeostasis) to survive.

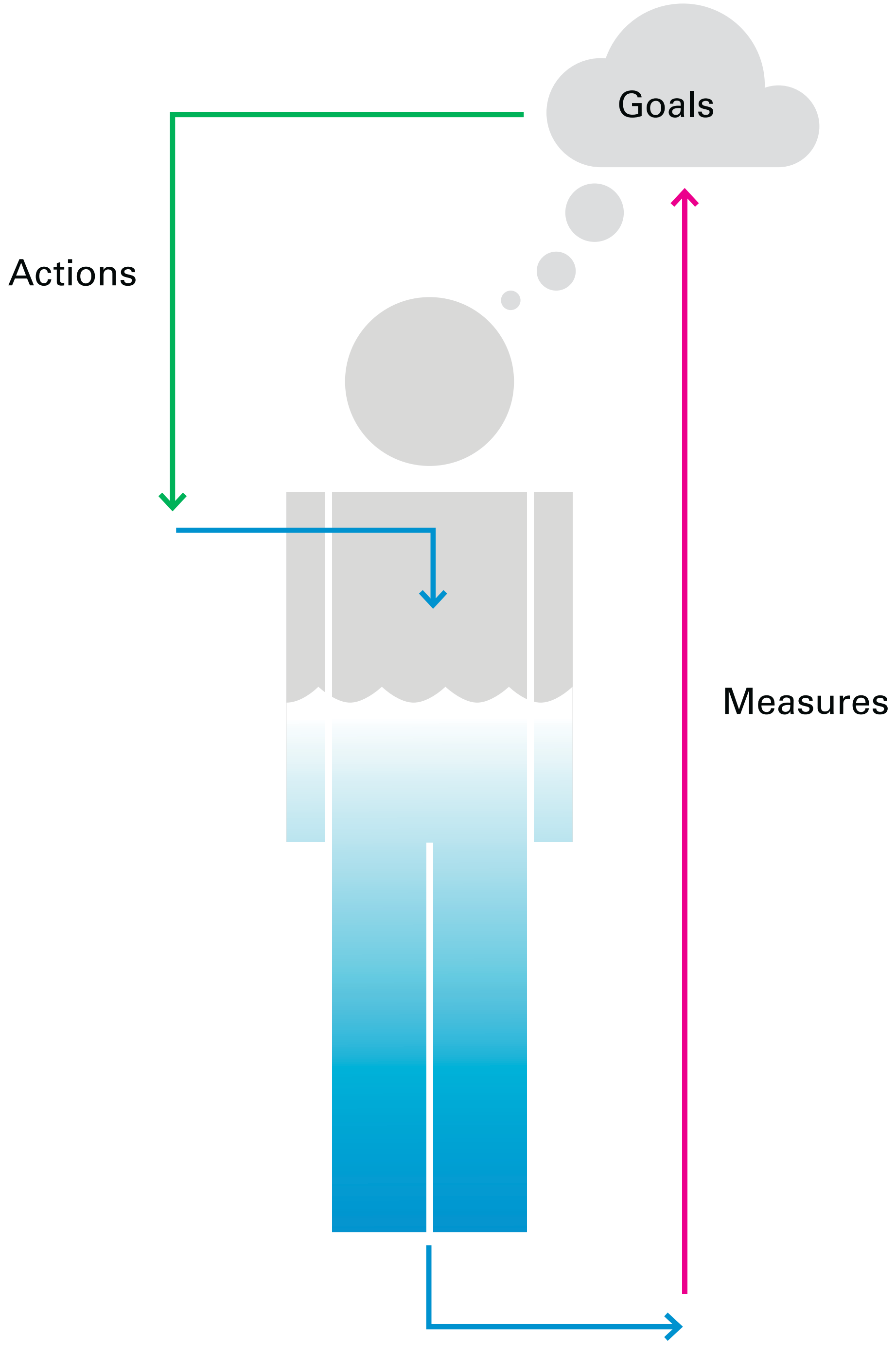


A patient's vital signs measure important elements of homeostasis.

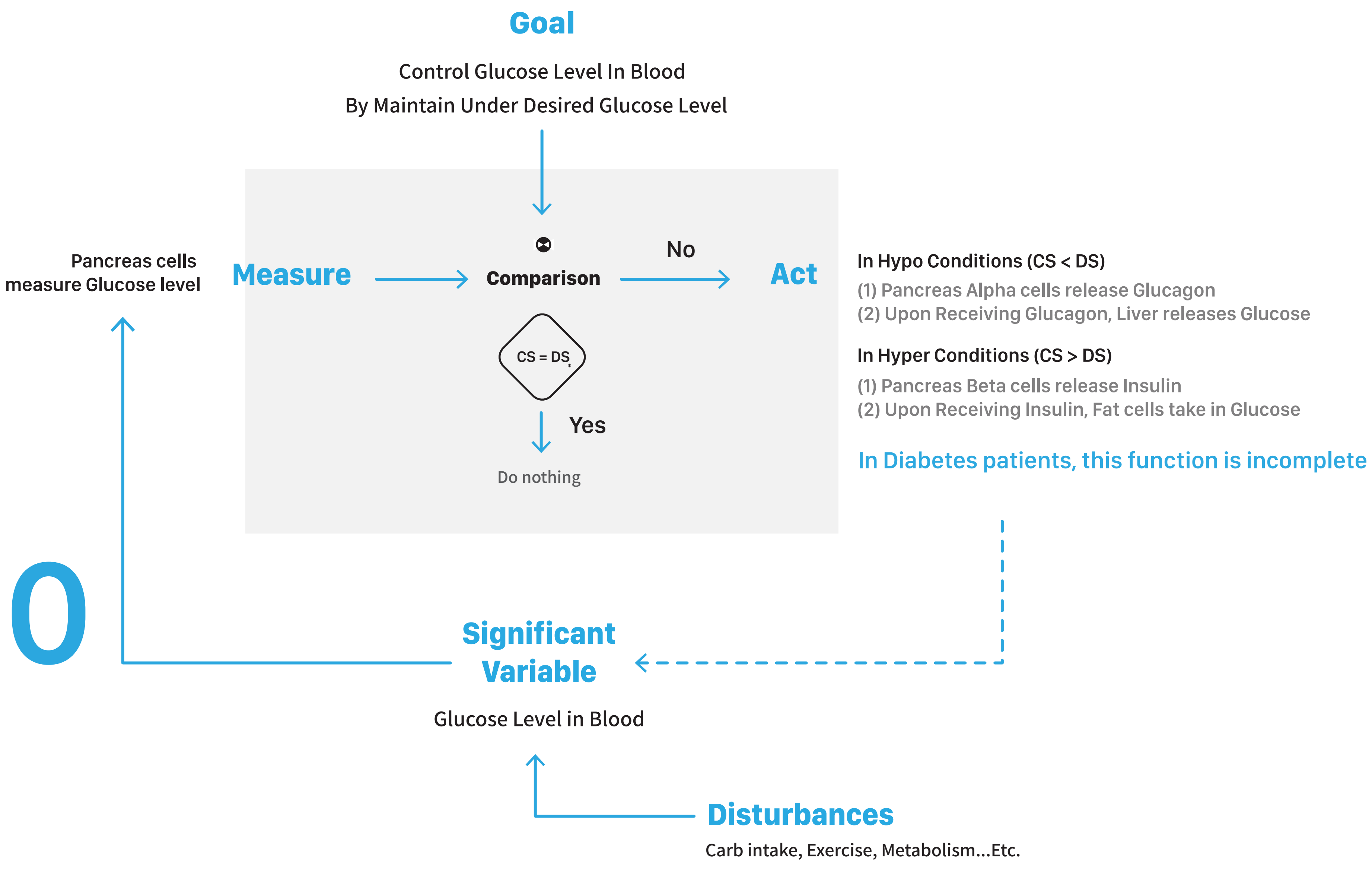
Variable	Goal range
Body temperature	97.25°F – 99.5°F
Heart rate	60 – 80 bpm
Blood pressure	< 120 / < 80 mm Hg
Respiratory rate	10 – 14 bpm



Maintaining homeostasis requires ‘closing the loop’ on many variables simultaneously.

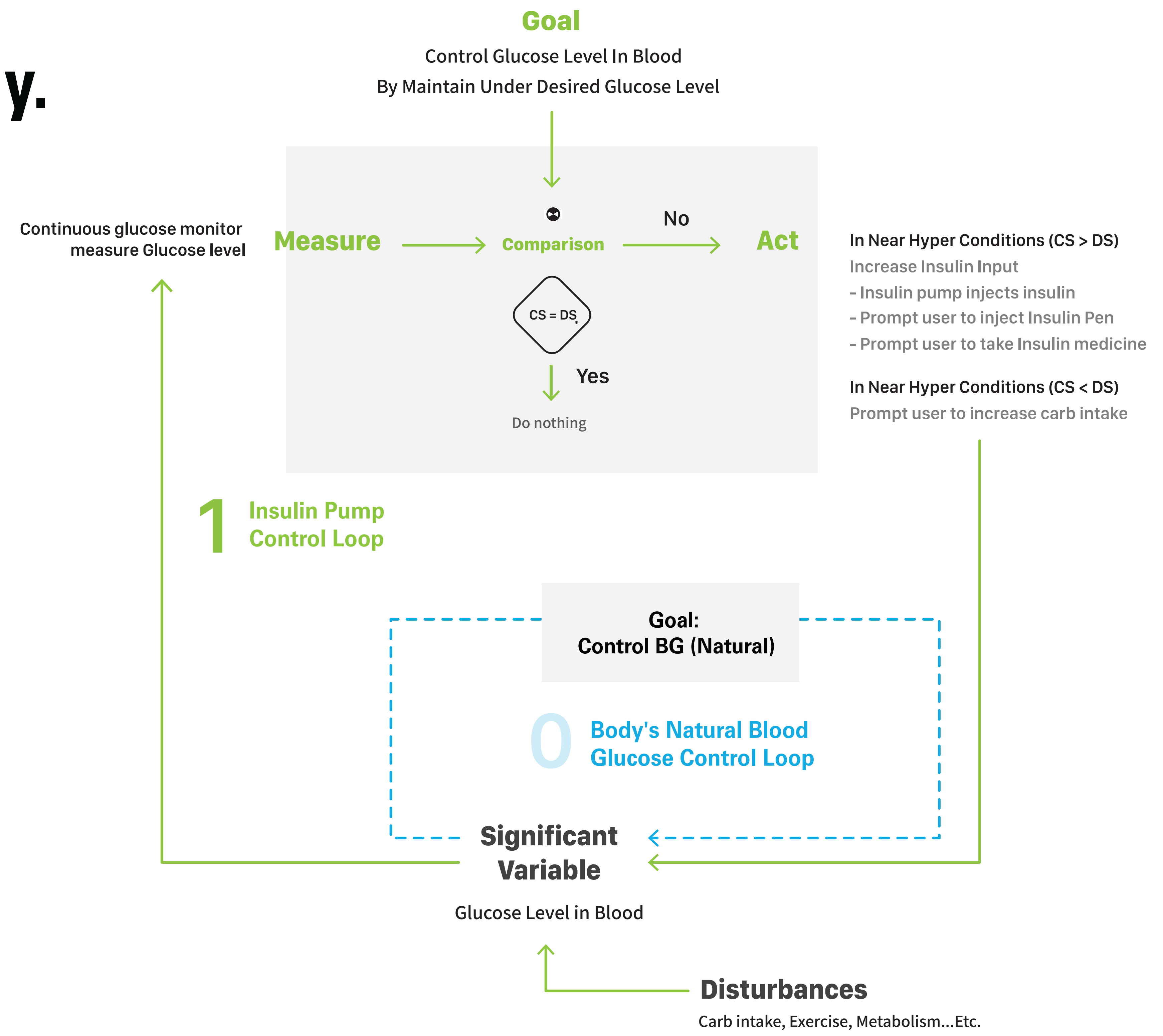


The body’s natural blood-glucose control loop



Diabetes is when a body does not make enough insulin or react to it quickly.

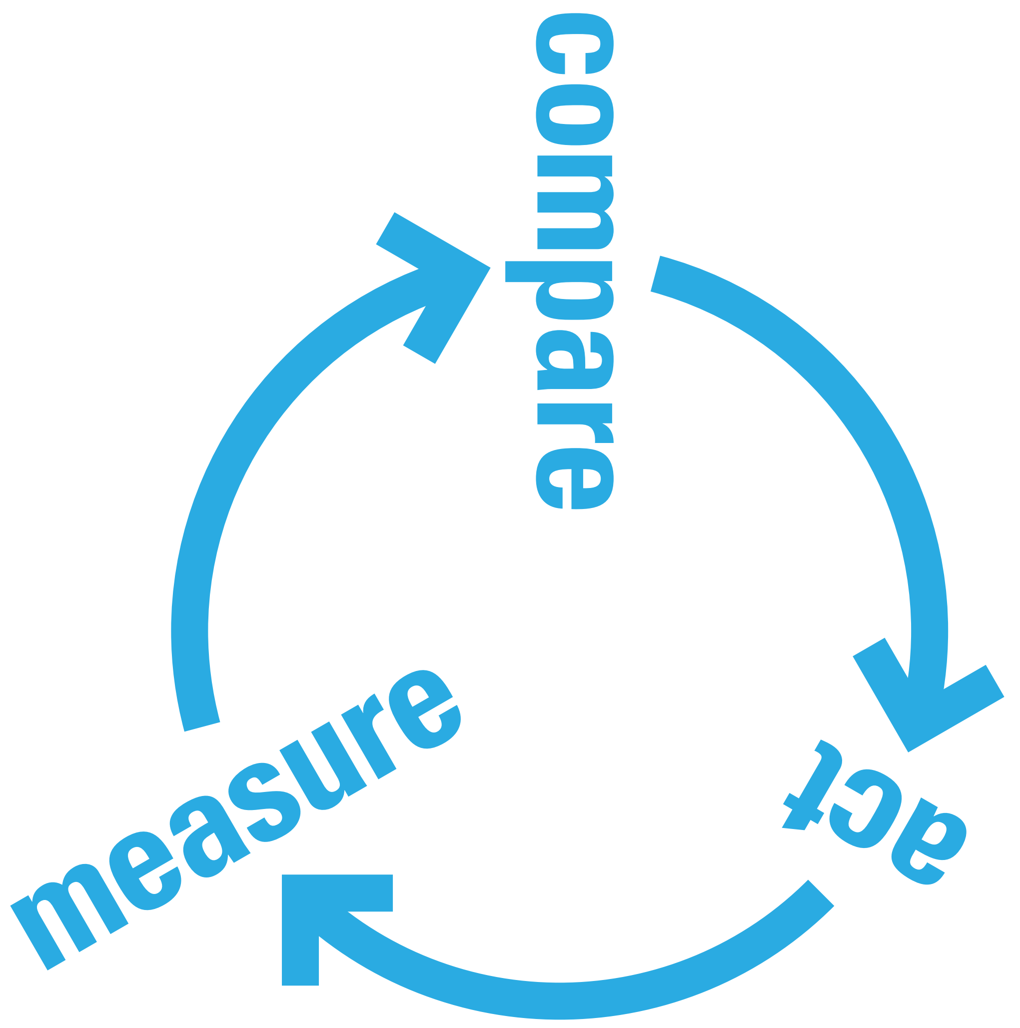
A patient must then create an artificial control loop.



The feedback loop is a structure common to all control mechanisms: act, measure, compare to goal, and act to correct errors.

Self Regulating System

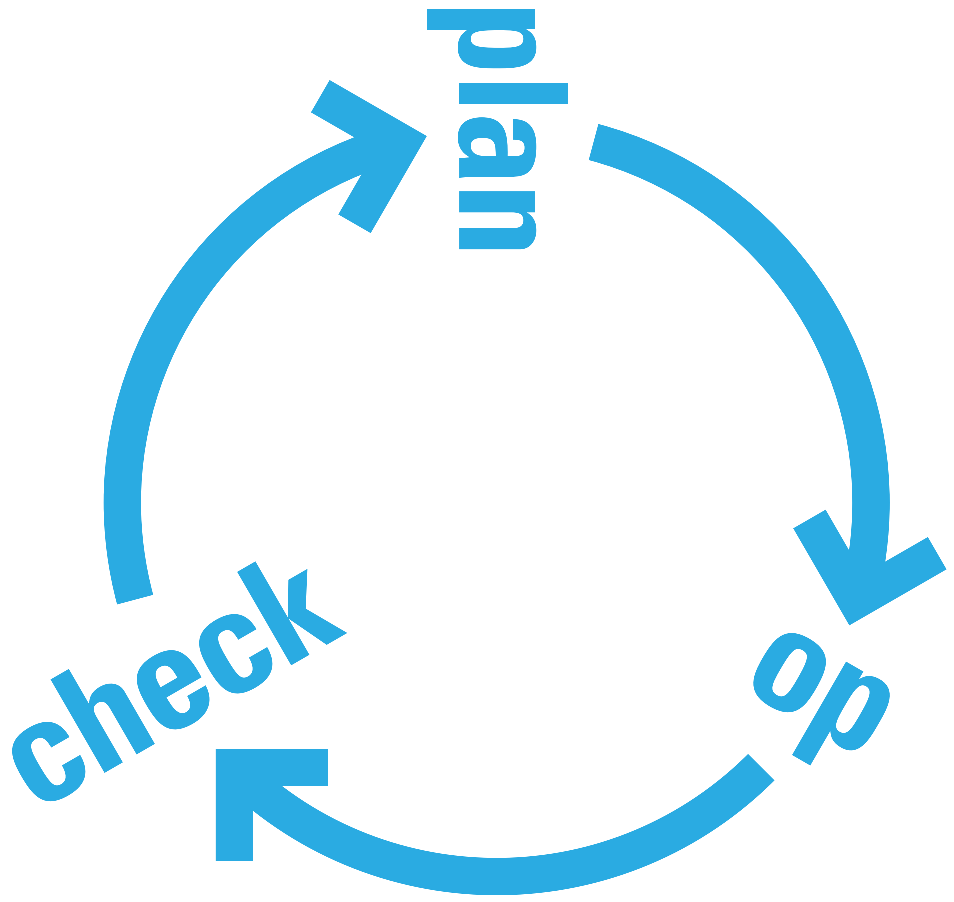
Like a self-regulating system, the creative process is a classic feedback loop. Measure an essential variable; compare it to a goal; and act to eliminate any difference.



The feedback process is inherent in the Shewart-Deming quality cycle, plan-do-check-act* (PDCA).

Quality Cycle

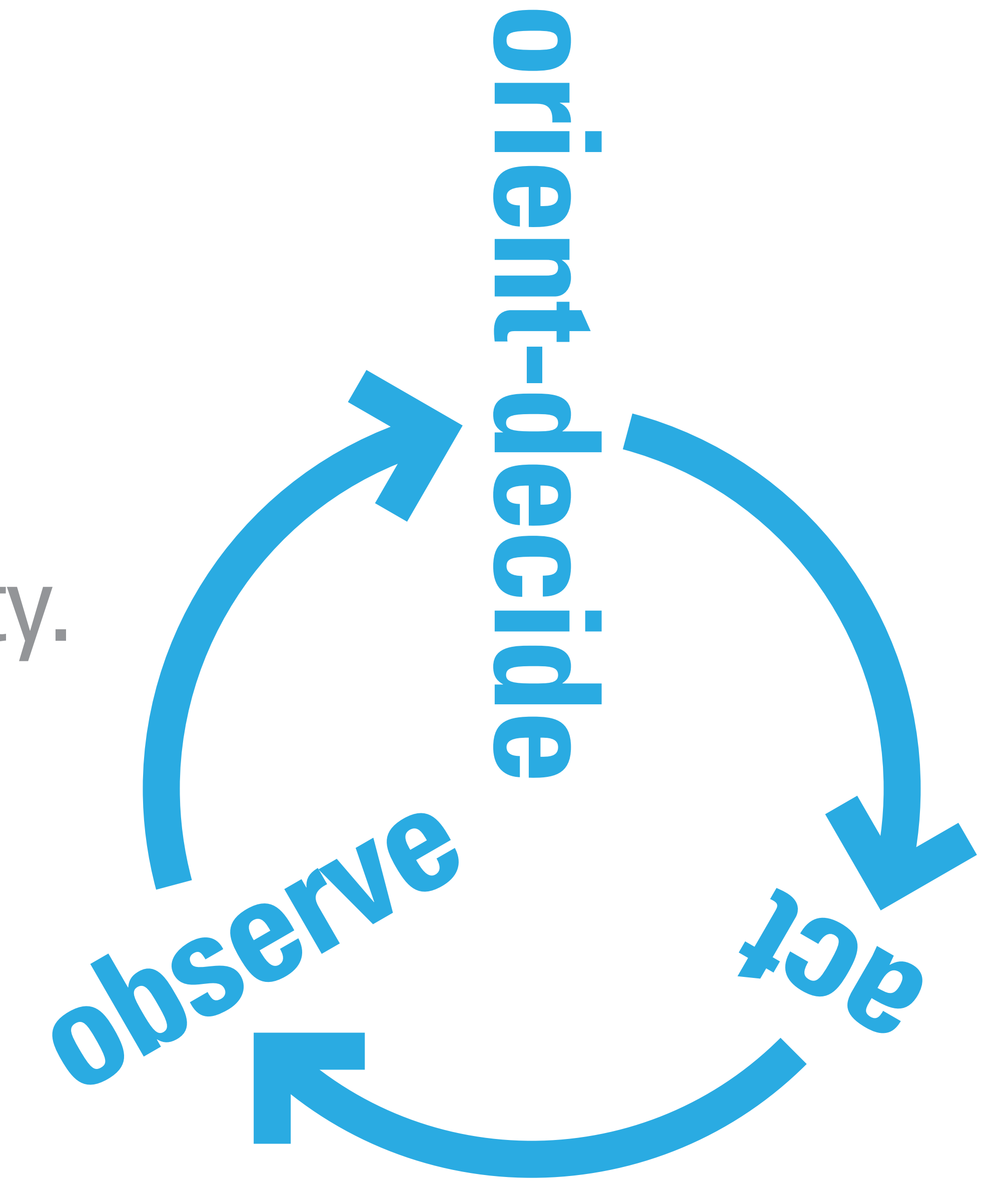
The creative process is startlingly similar to the quality cycle (Shewart, 1939), popularized in business circles by the quality management movement (Deming, 1982).



*The ‘act’ or ‘adjust’ in PDCA refers to a ‘meta’ or ‘second-order’ action, improving the quality process.

John Boyd's OODA loop (1976) is similar.

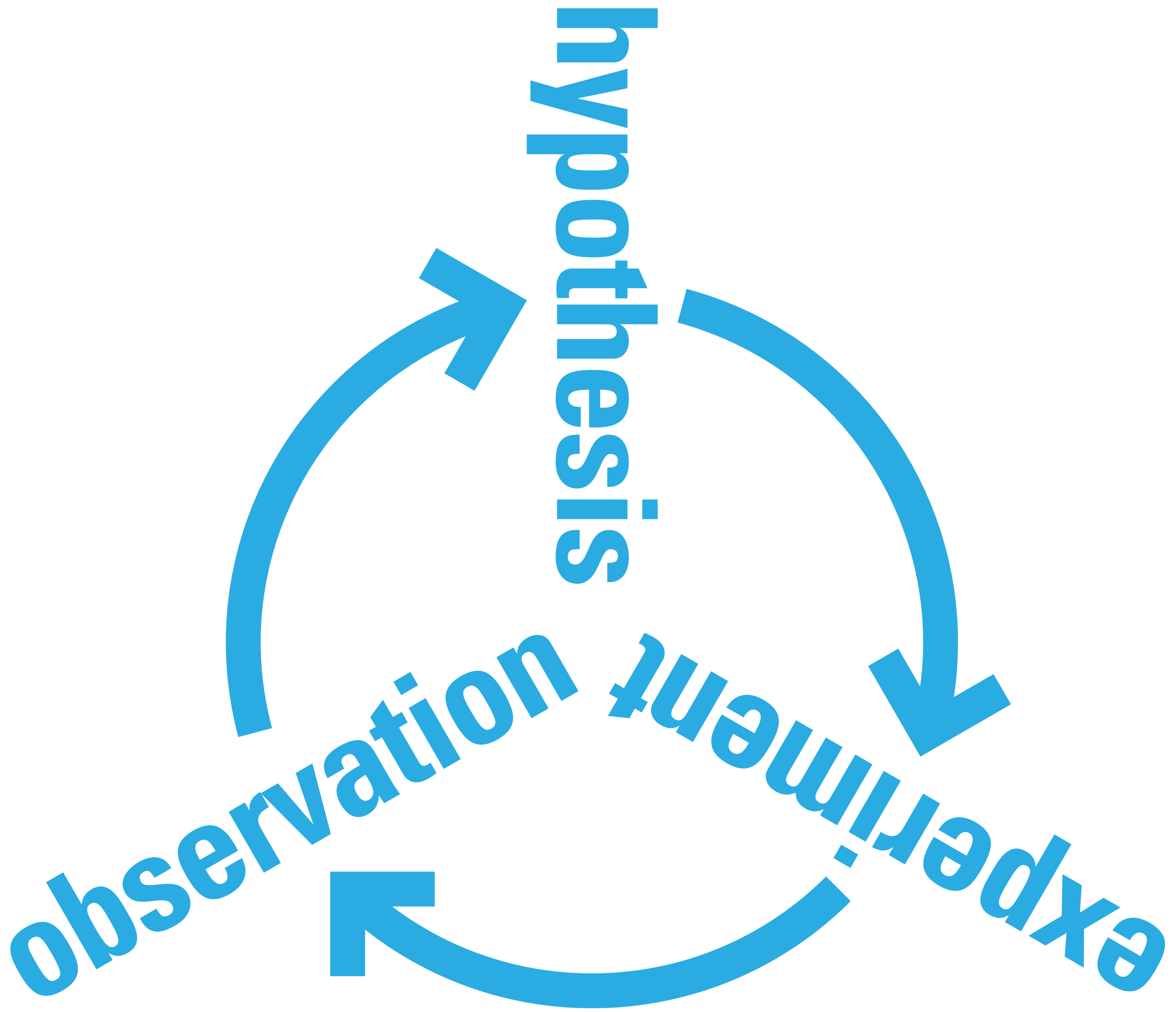
Boyd applies feedback to strategy.
Understand a competitor's goal,
while obscuring your own.
Act more quickly to increase their uncertainty.
Act more quickly to improve your position.



Feedback is also inherent in the scientific method.

Scientific Method

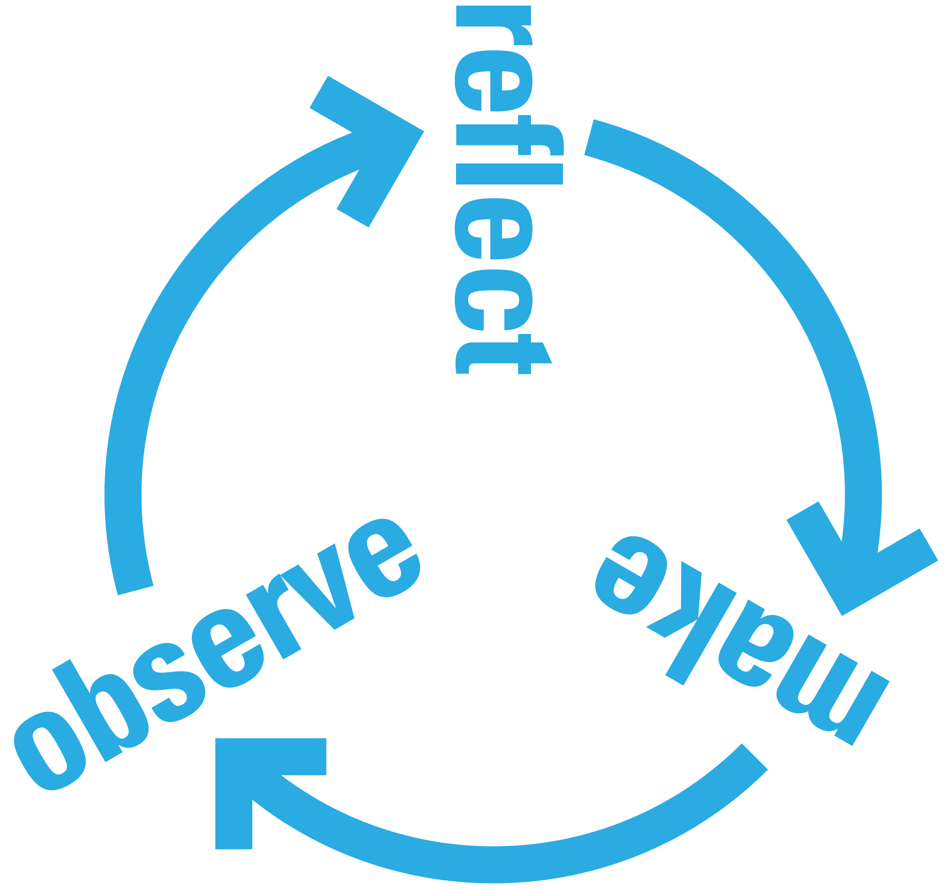
Forming a hypothesis is a special type of creative act. Framing the creative process as “experimenting” shows the tie it has with the domain of science.



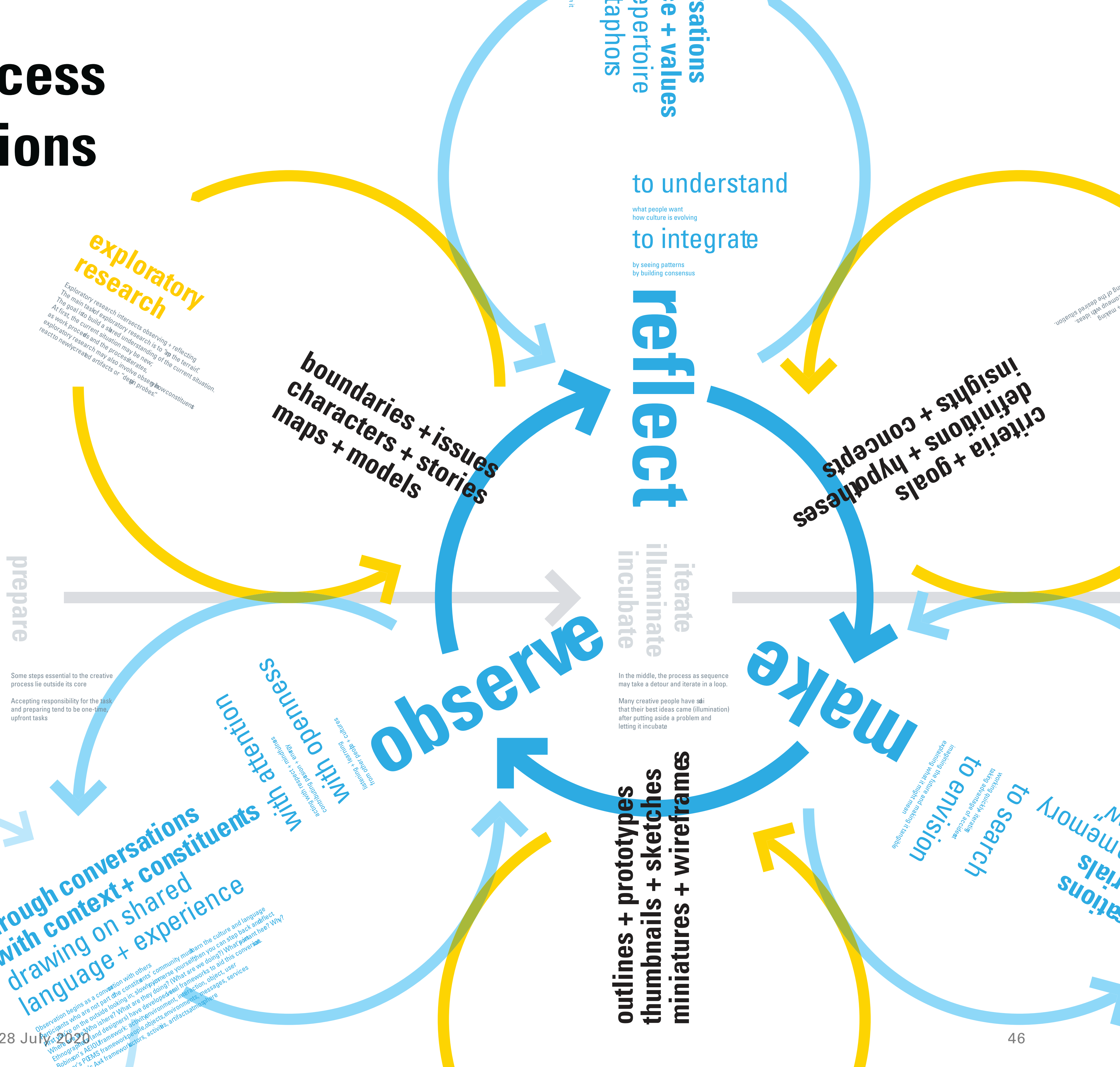
In some ways, the design process is an analog to the scientific method.

Design Process

The design process viewed as "problem solving" (Jones, 1976), "problem seeking" (Peña, 1987) or "turning existing situations into preferred" (Simon, 1969) is a variation on the creative process.



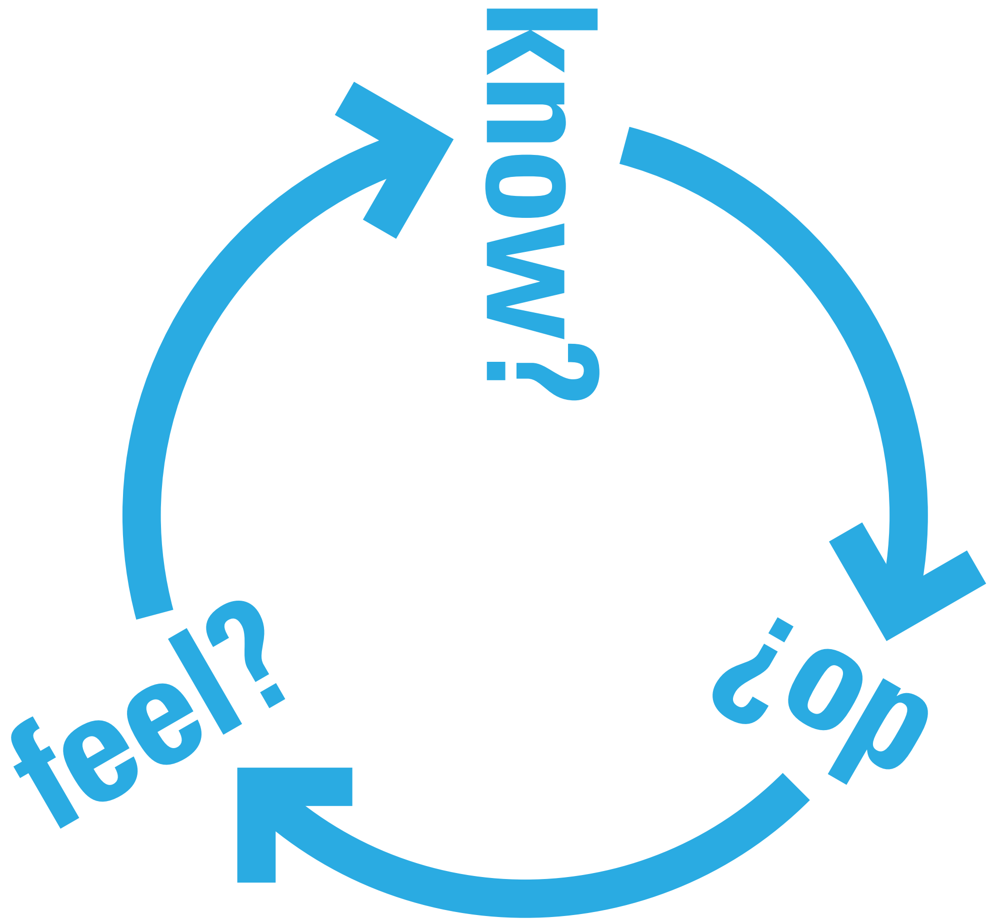
Each step in the creative process may spawn on other interactions



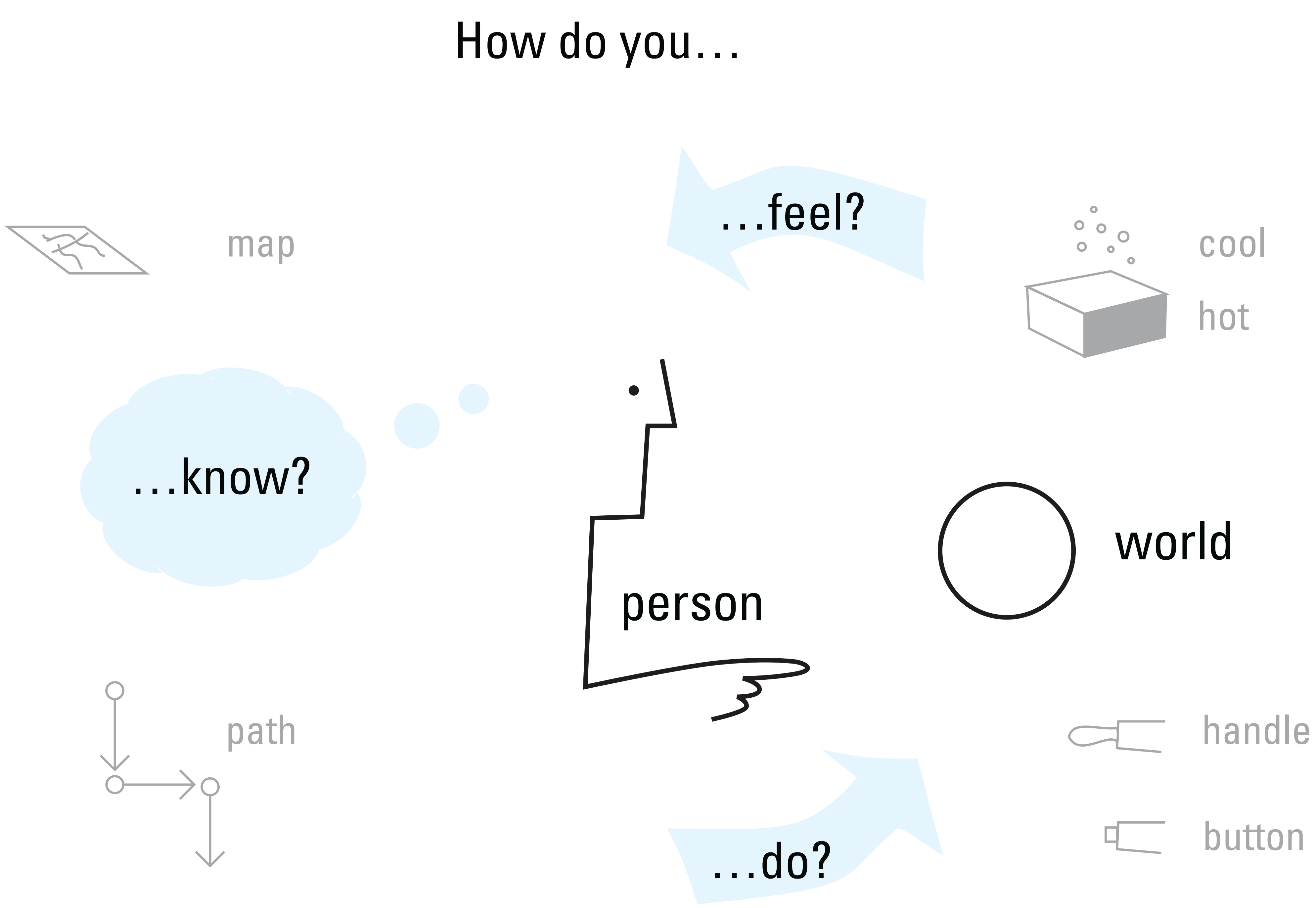
Interaction (as with a computer) requires feedback.

Interaction loop

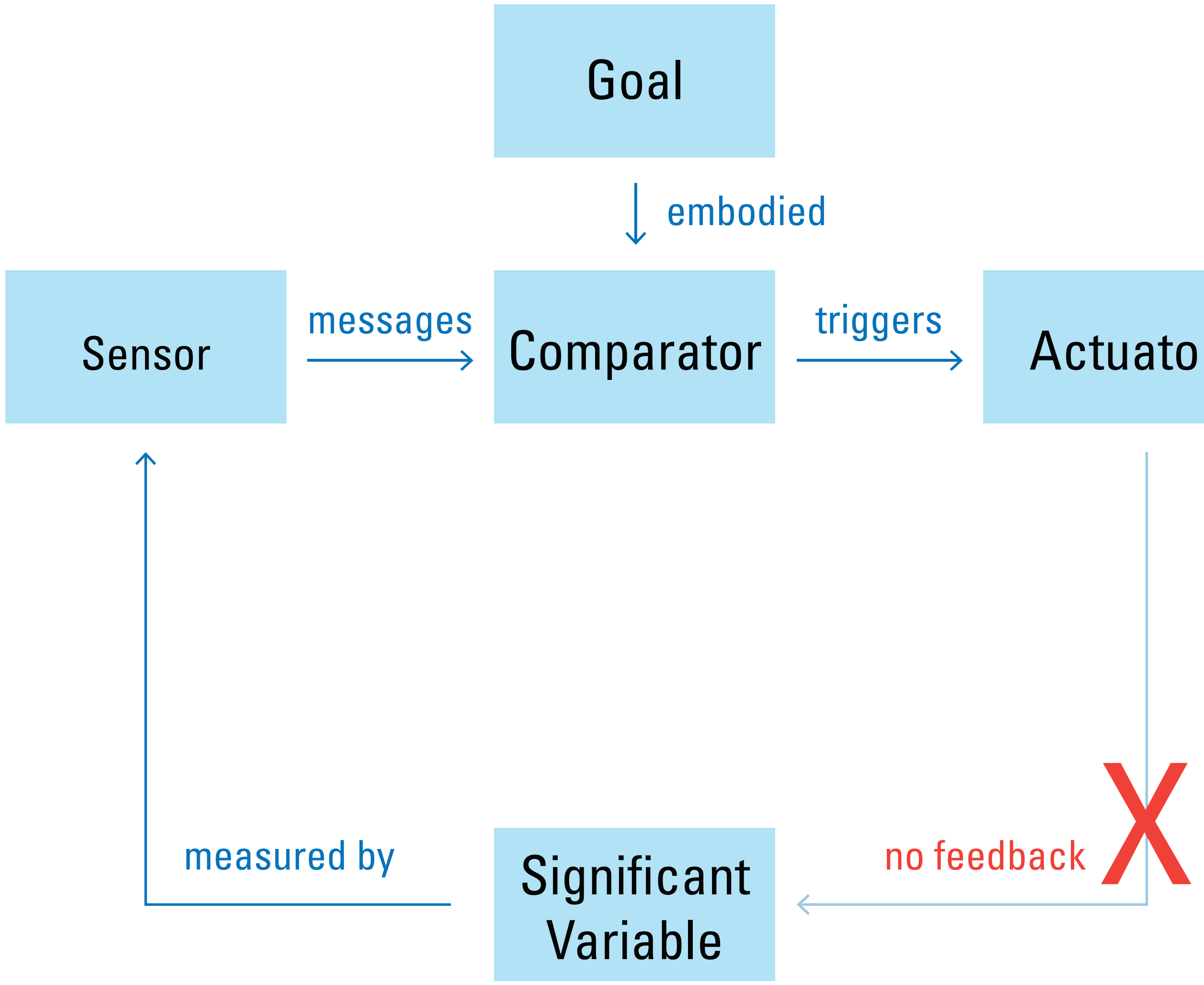
Interaction (with computers or the wider world) answers three questions:
What do you sense? (feel?)
How do you learn + plan? (know?)
How do you change things? (do?)
(Verplank, 2000).



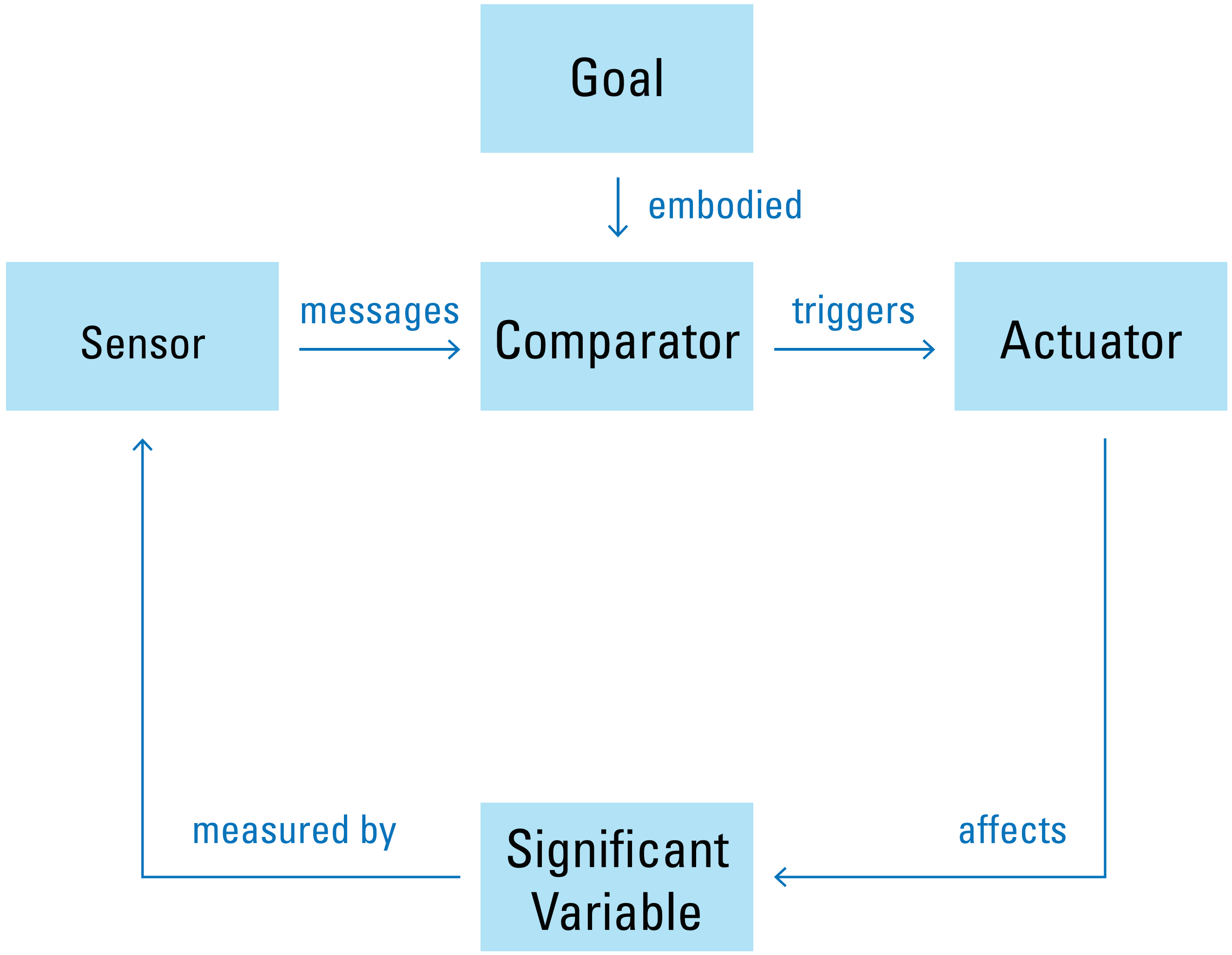
Bill Verplank's model of interaction (2000)



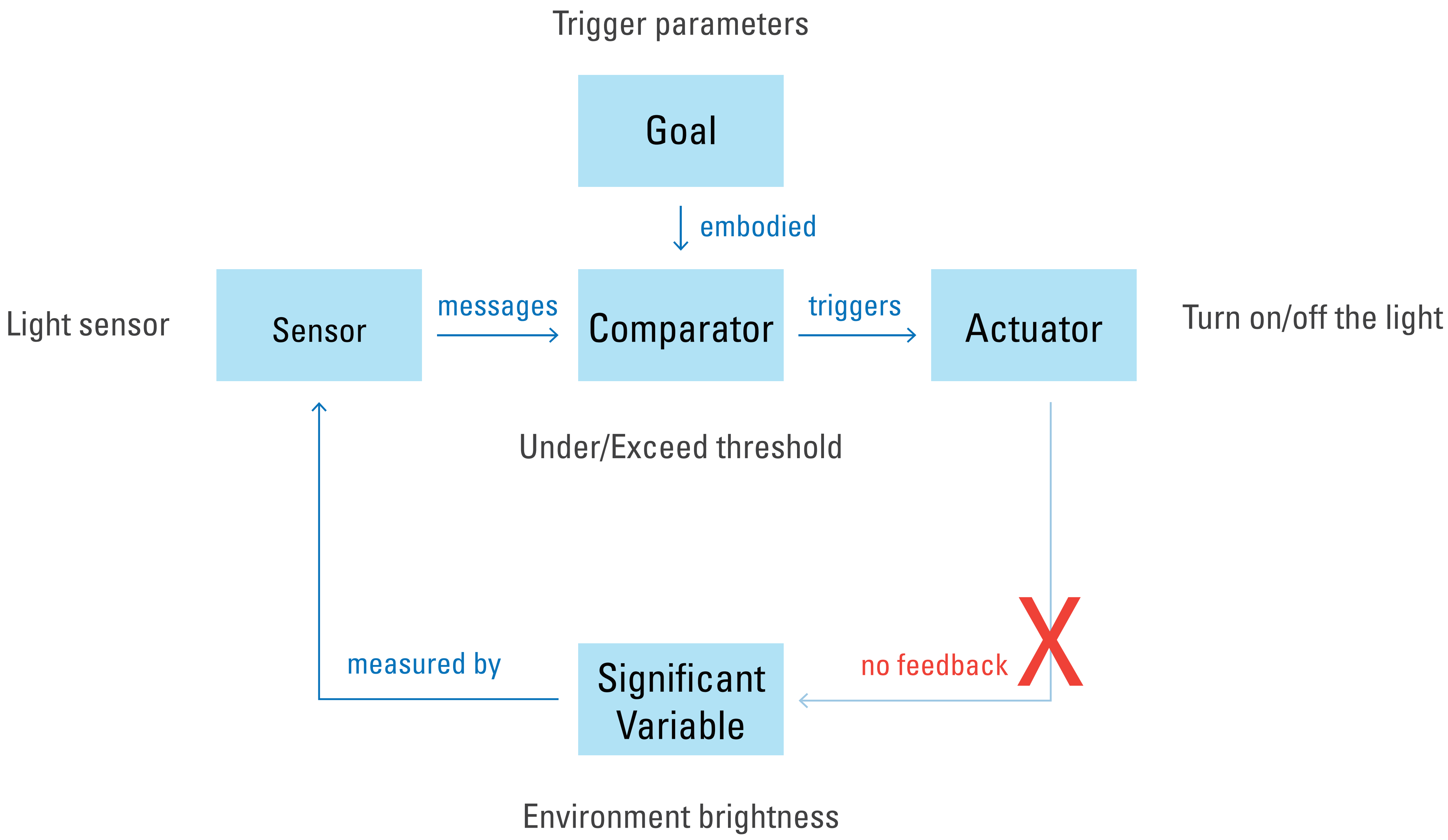
Open Loop



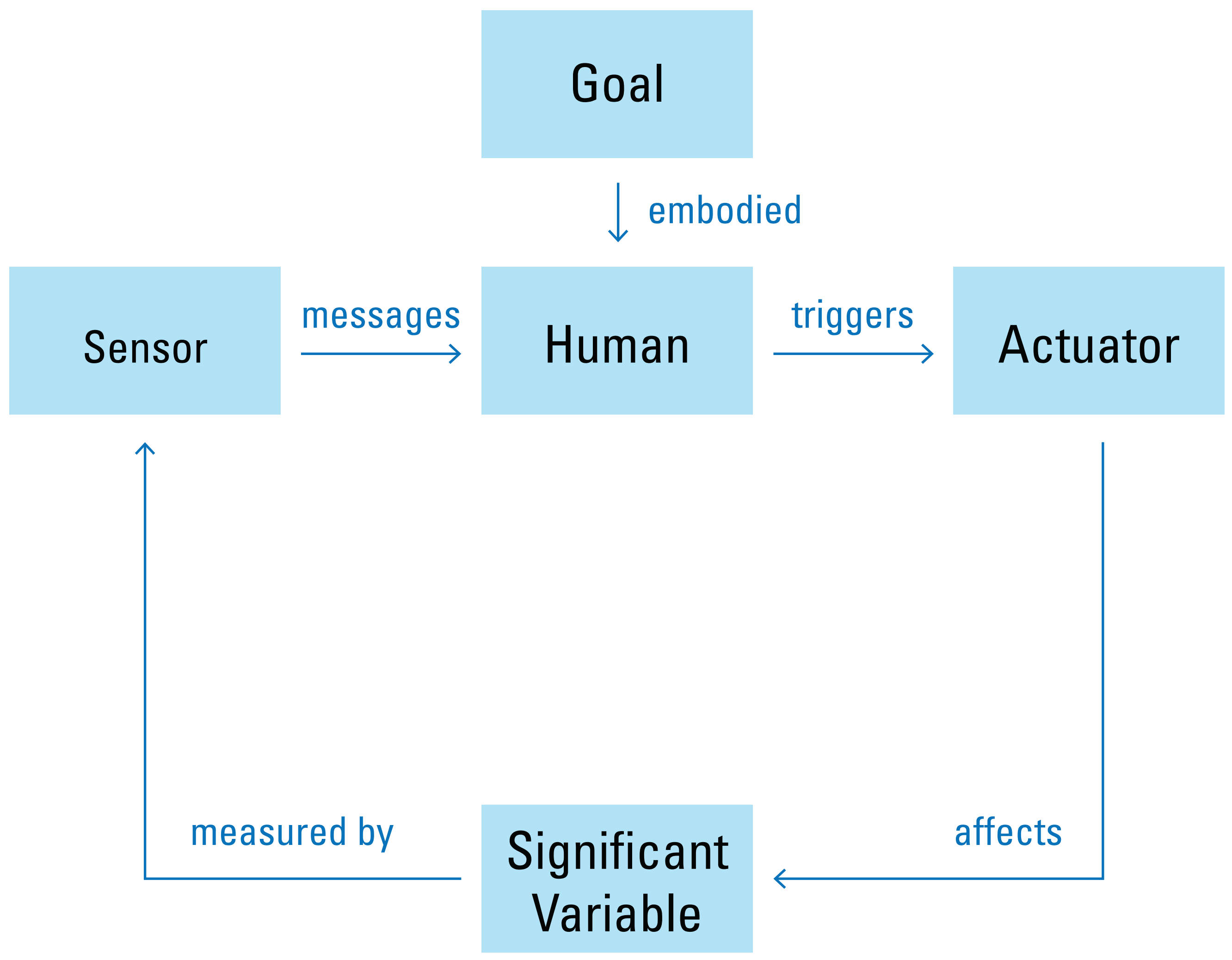
Closed Loop



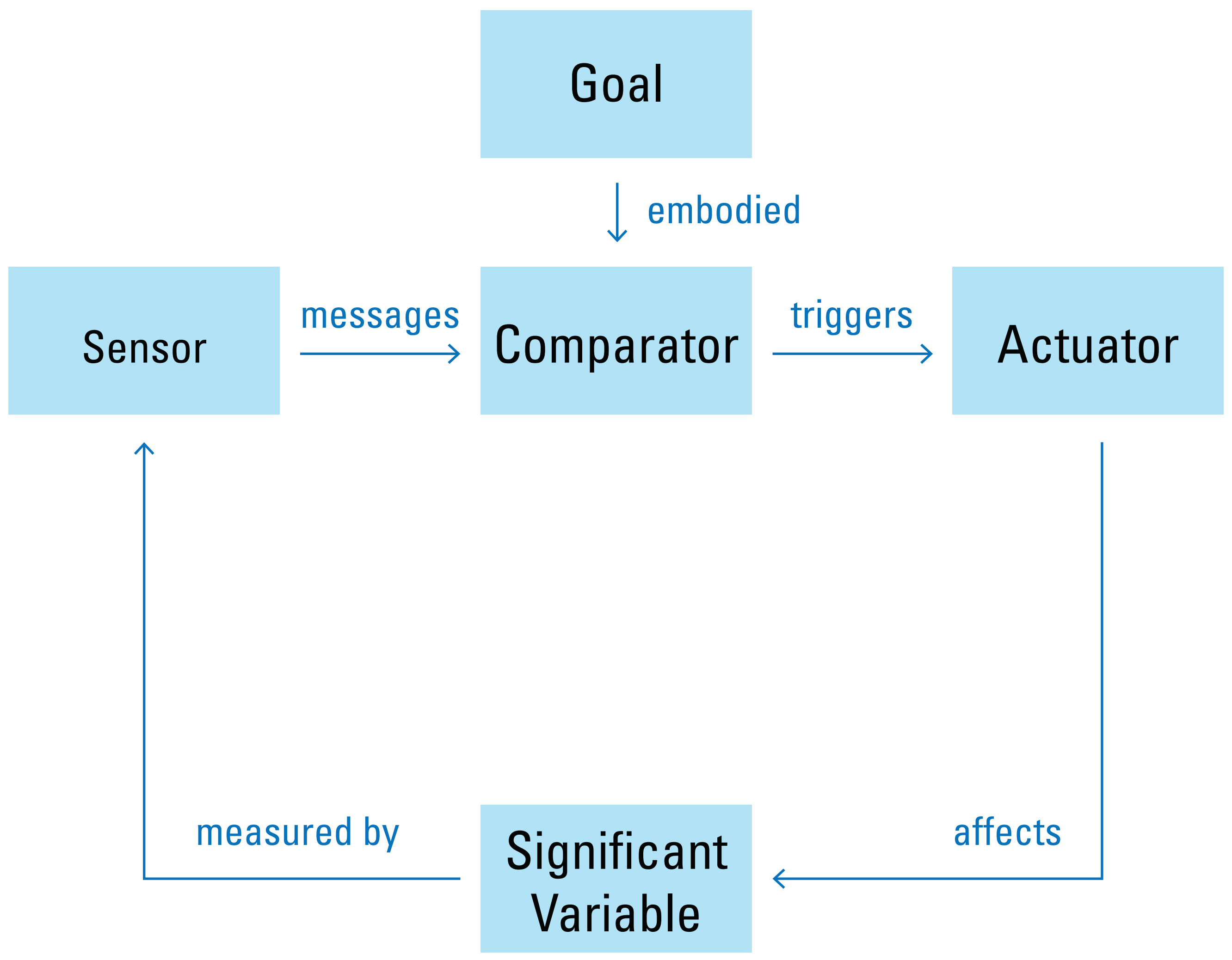
Example of open loop:
Traffic light that comes on at night, using light sensor



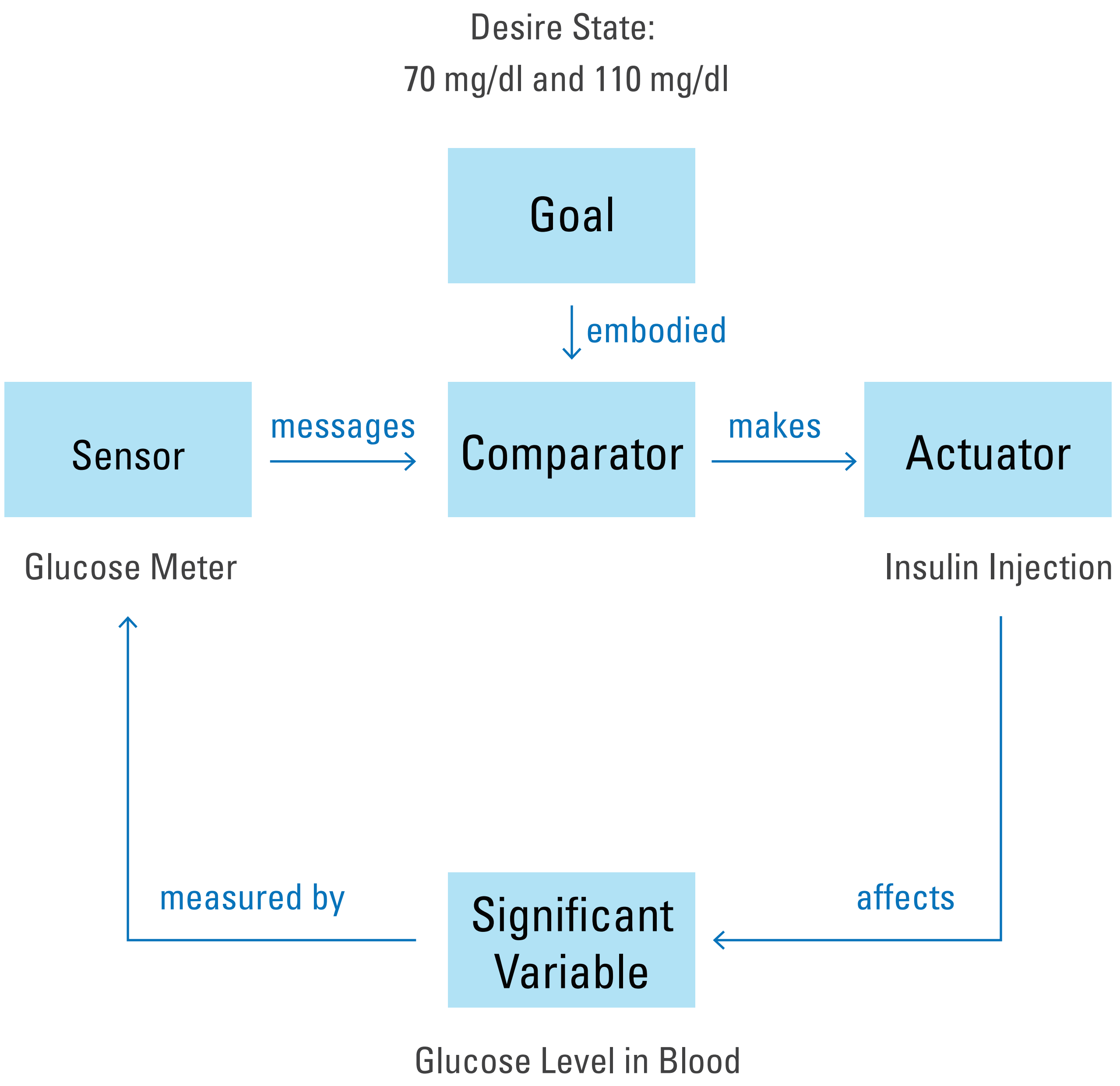
Human-in-the-loop

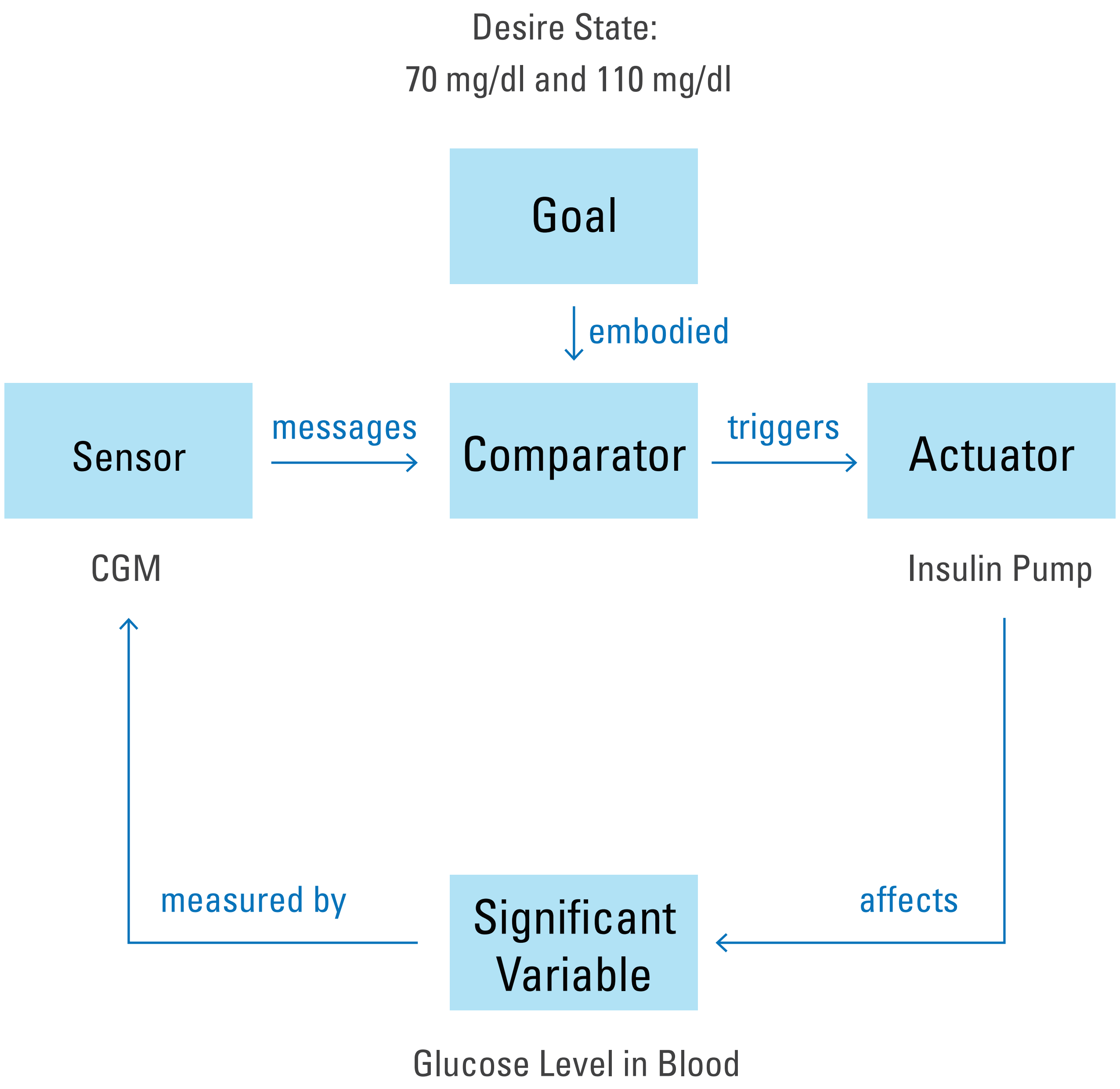


Automated loop



Example of a person with diabetes manually measuring their BG and giving themselves an injection vs a CGM + pump

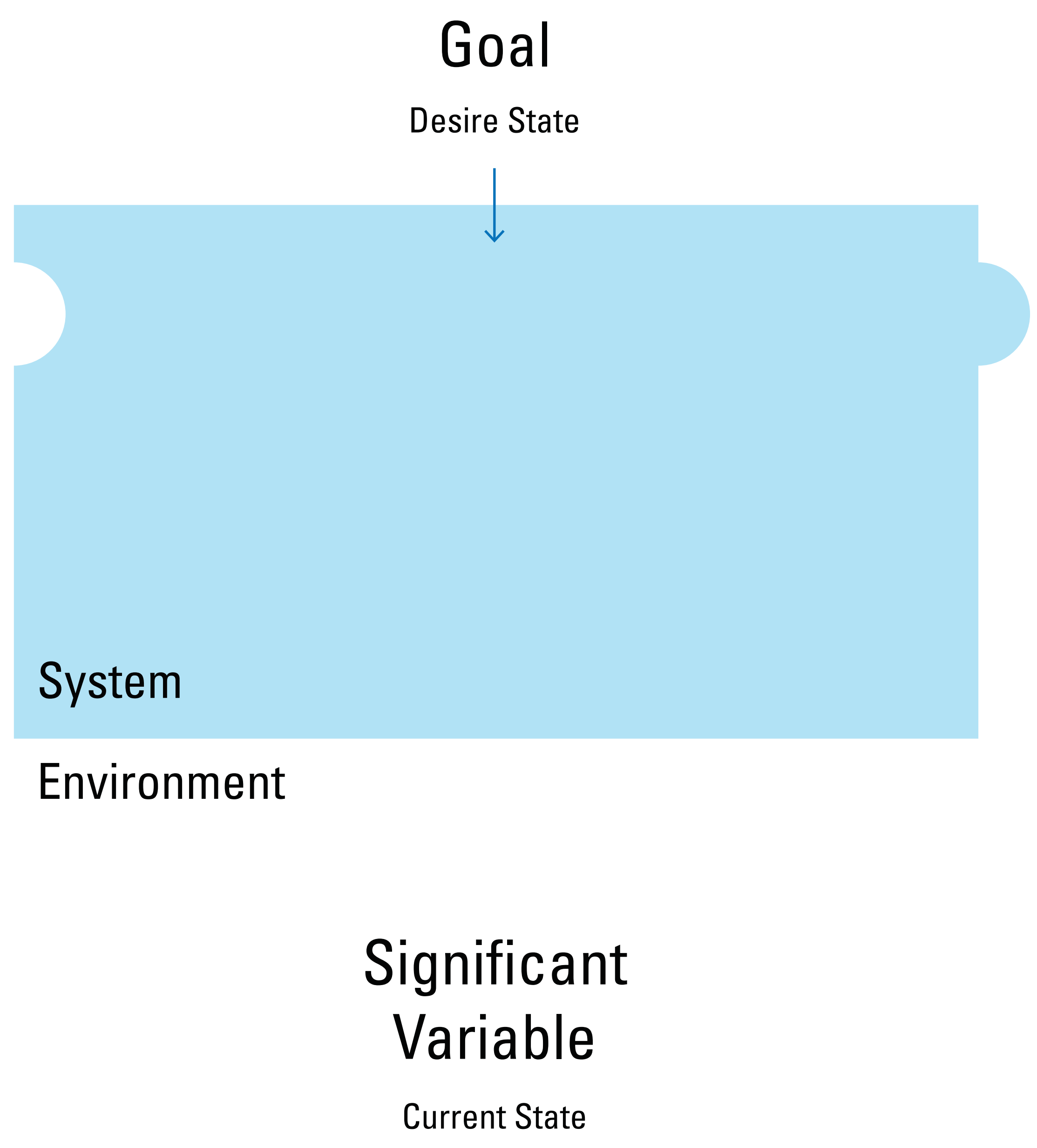




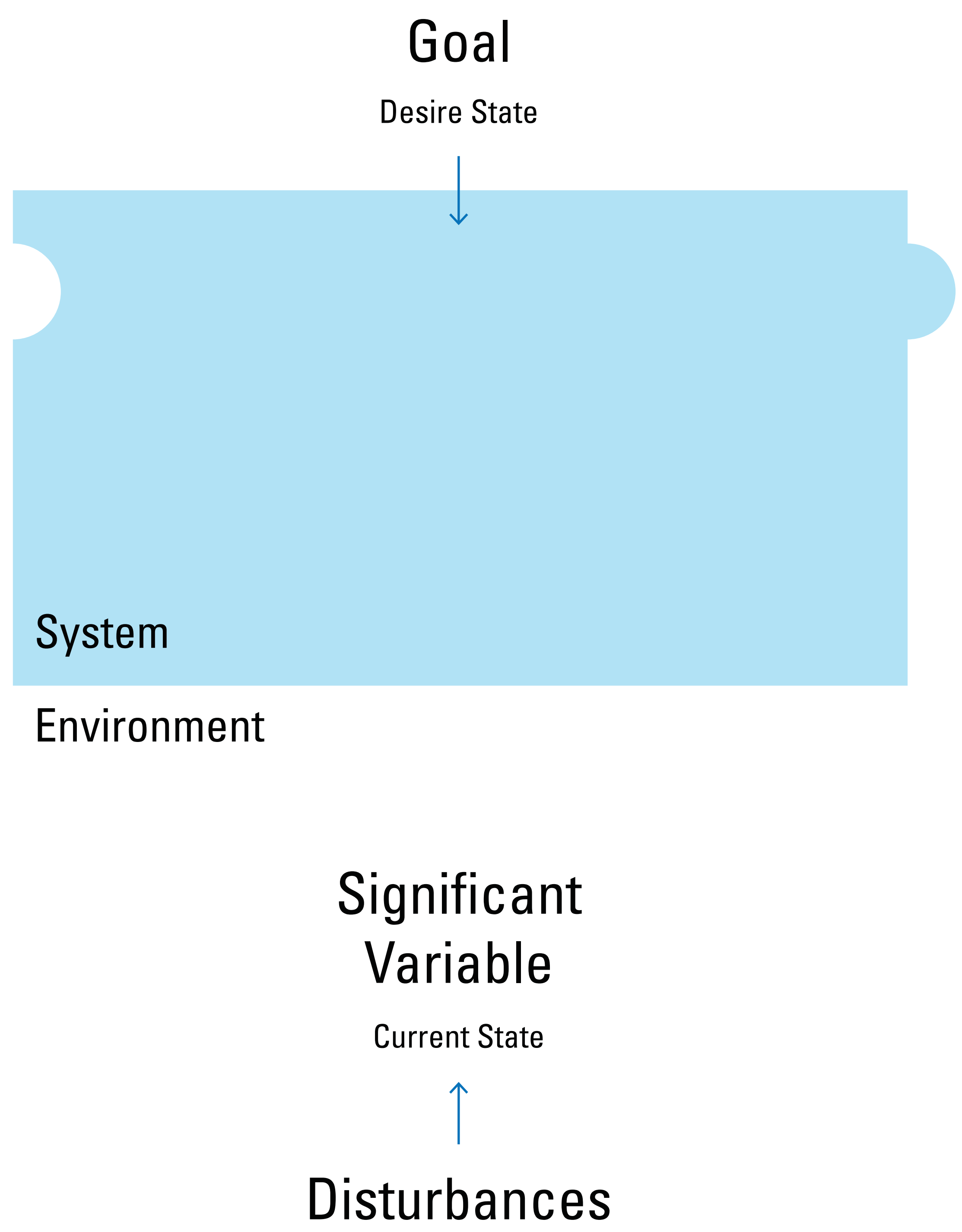
Elements of the framework

Feedback Loop Framework: System and Environment

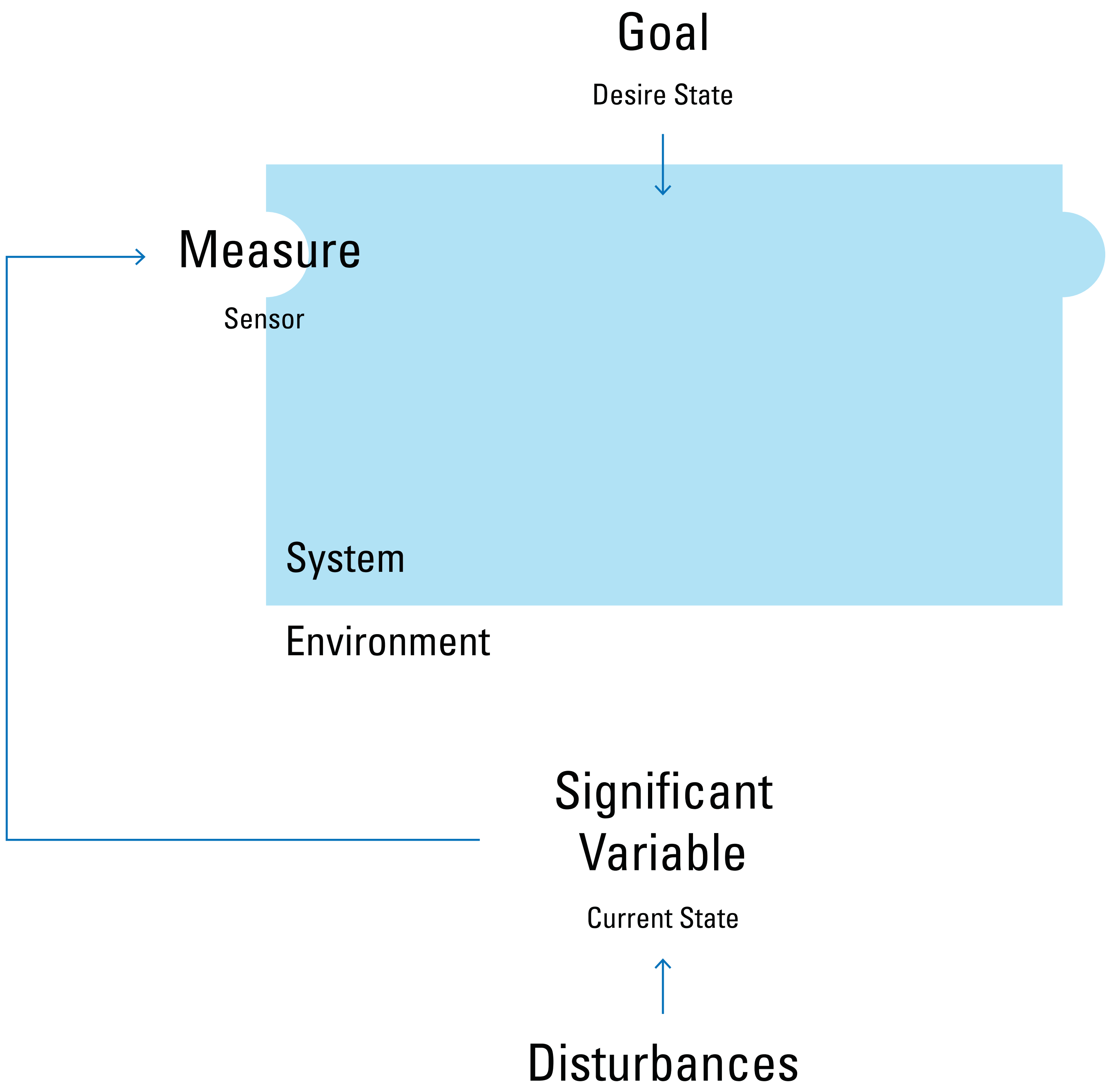
Feedback Loop Framework: Goal and Significant variable



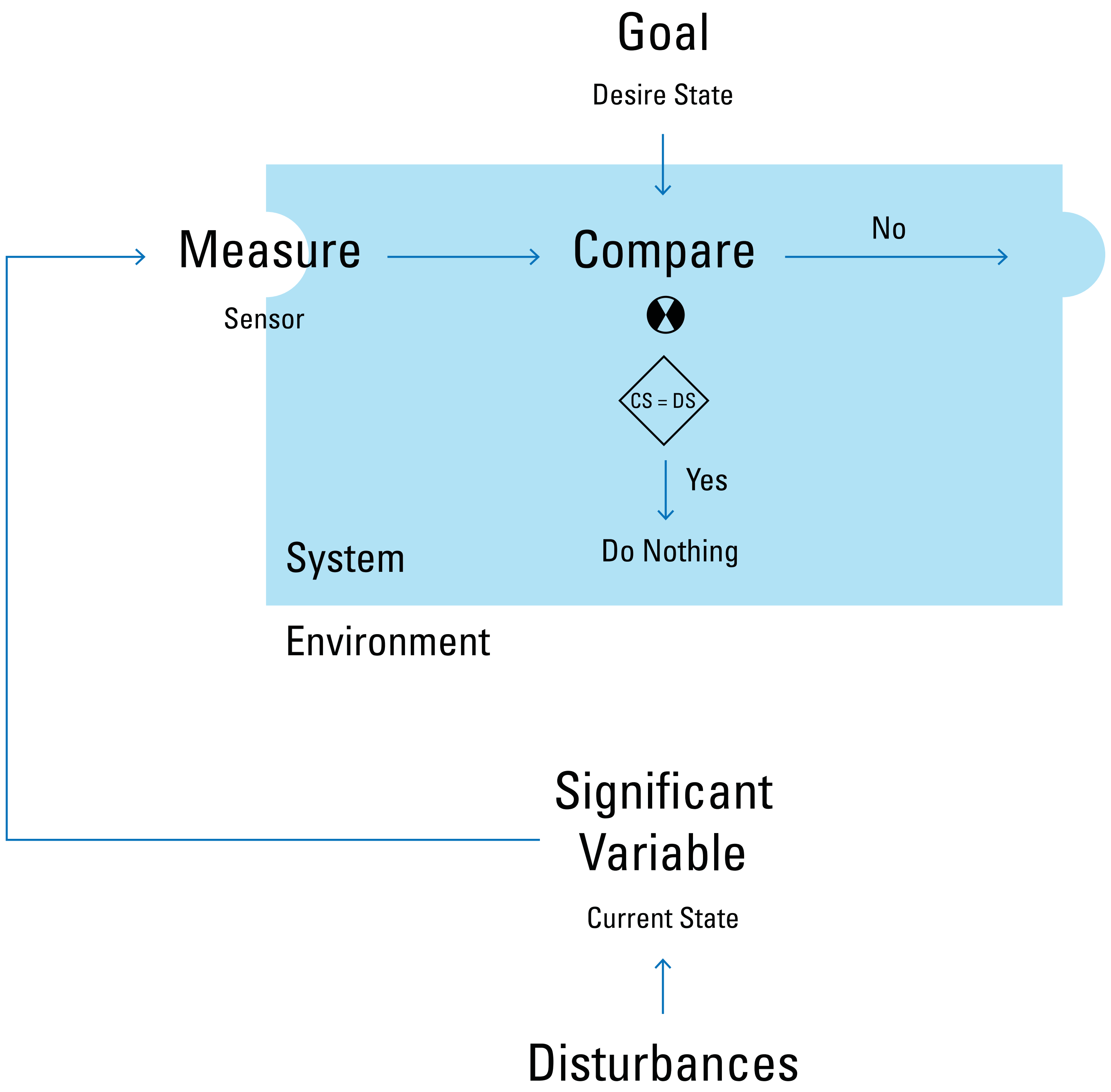
Feedback Loop Framework: Disturbances



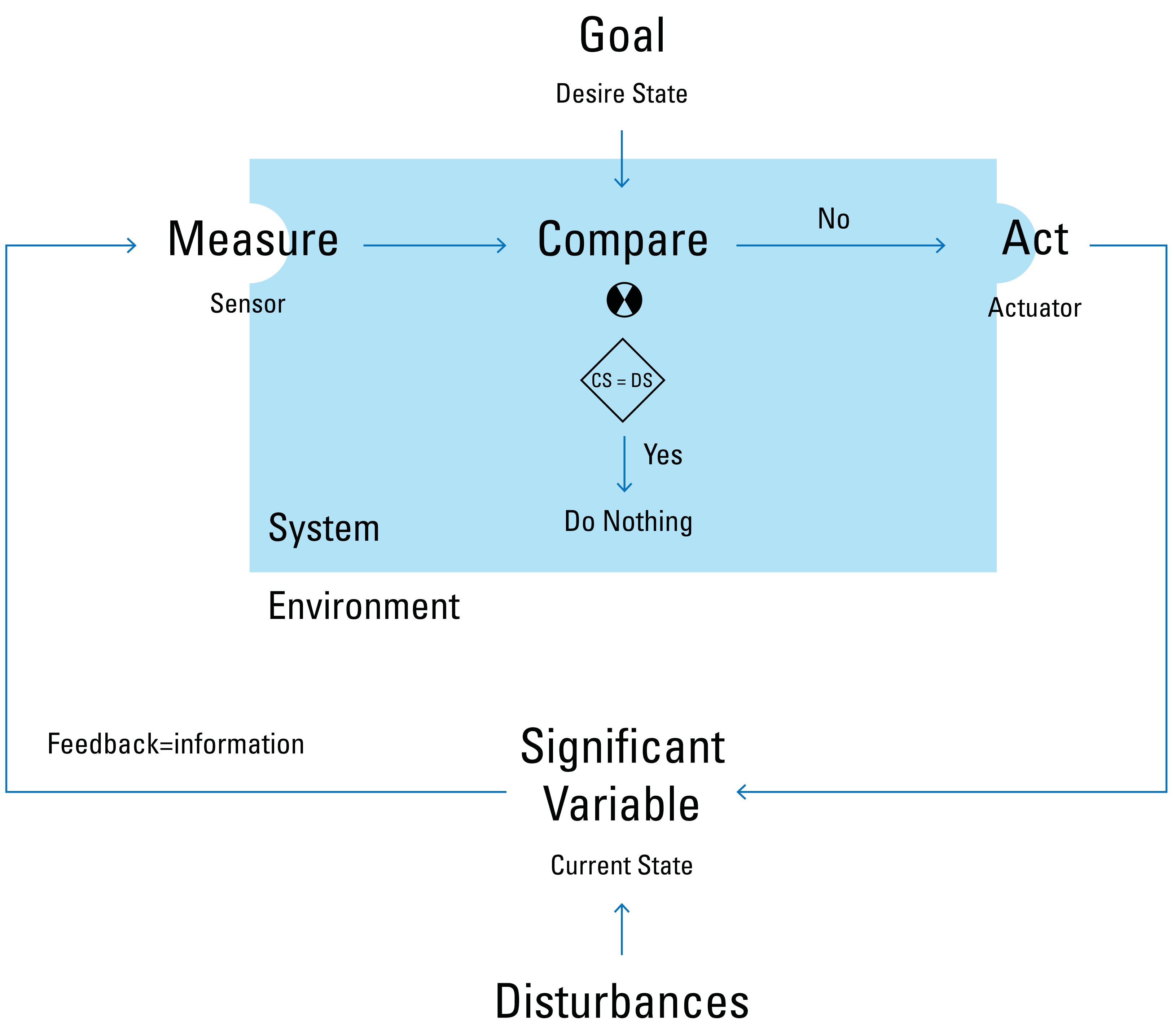
Feedback Loop Framework: Measure



Feedback Loop Framework: Compare



Feedback Loop Framework: Act



Cybernetics

‘Cybernetics’ comes from the ancient Greek word ‘κυβερνήτης’; ’kubernetes’ means ‘steersman, pilot, guide, or navigator’.

Also the word ‘governor’ comes, via Latin, from the word ‘κυβερνήτης’.

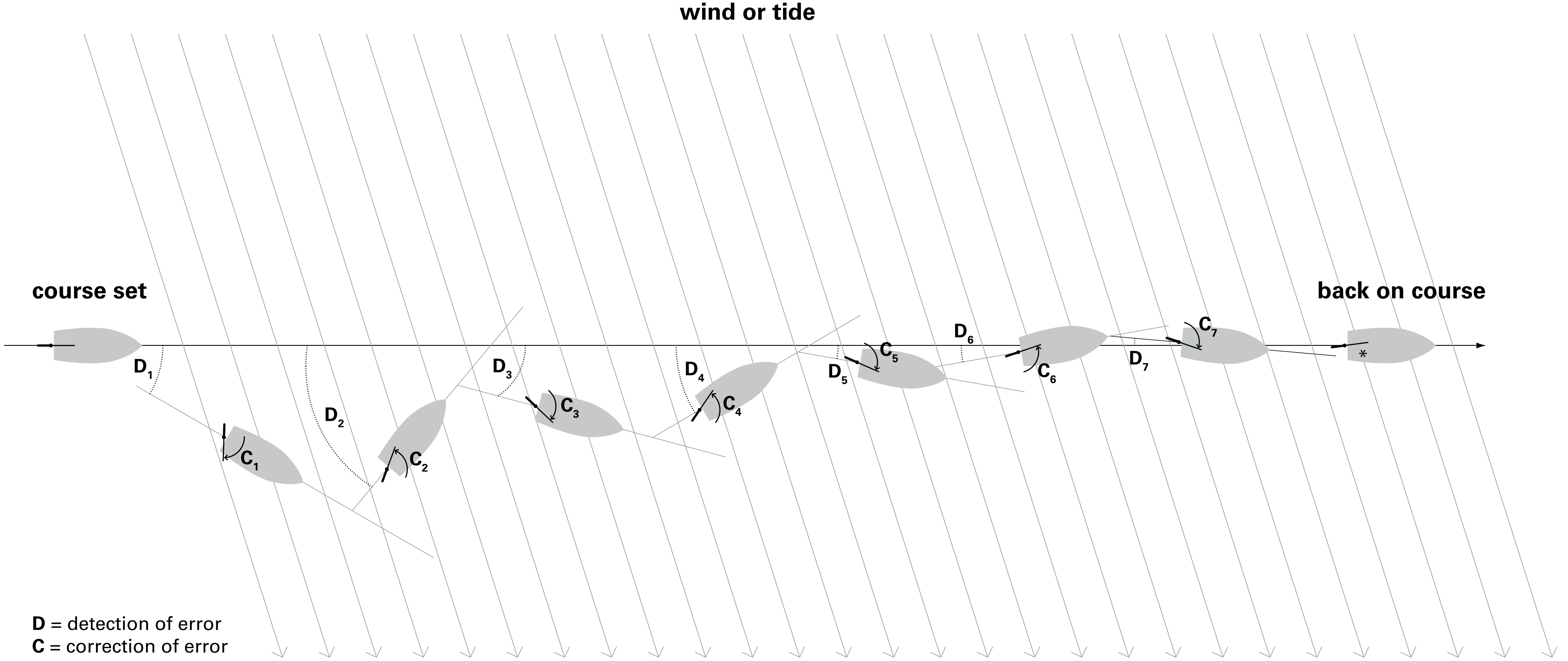
Approximate synonyms are ‘regulator’ and ‘controller’.

Plato used the word ‘kybernetes’ in several dialogs, e.g.:

“… I will tell you of another and greater art,
the art of the pilot,
who not only saves the souls of men,
but also their bodies and properties
from the extremity of danger…”

— Plato, “Gorgias”, c. 400 BCE

Cybernetics as steering — Staying “on course”



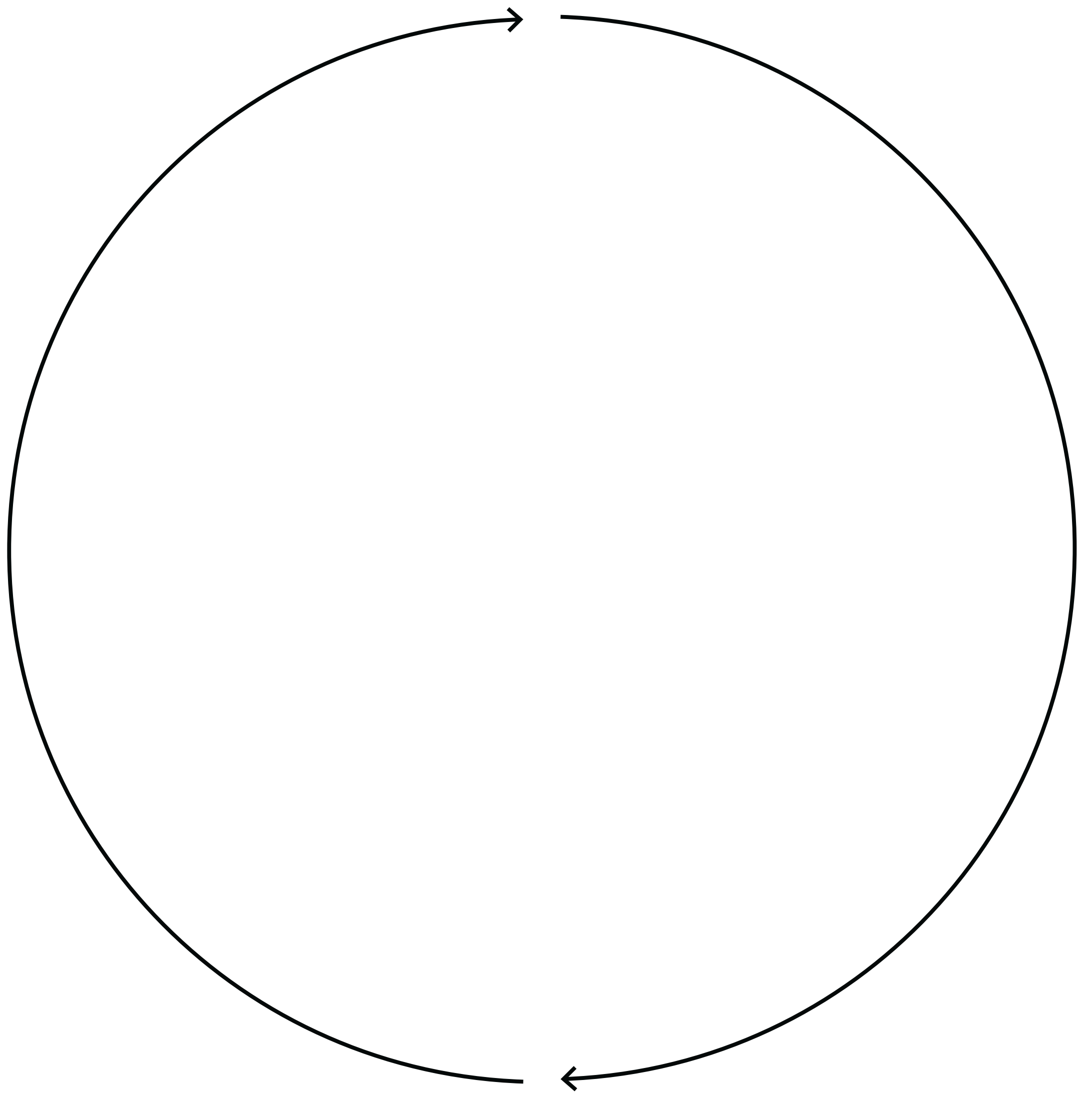
D = detection of error
C = correction of error

*Rudder needs to be maintained at a slight starboard angle (left turn) to compensate for wind and tide.

Steering as a feedback loop

D = Detection of error

compares current heading
with desired heading



C = Correction of error

adjust rudder to correct heading

Ampere used ‘kybernetes’ to describe a broad ‘art of governing’.

“3. Cybernétique.
The relations of people to people, studied in the two preceding sciences, are only the least part of the issues over which a good government must watch; the maintenance of public order, the execution of laws, the fair distribution of taxes, the choice of the men whom it must employ, and all that can contribute to the improvement of the social state, demand every moment its attention.

It constantly has to choose from among various measures the one which is best suited to attaining the goal; and it is only by the in-depth and joint study of the various elements that provides it, for this choice, the knowledge of everything relating to the nation that it governs, to its character, its customs, its opinions, it history, its religion, its means of existence and prosperity, its organization and laws, which it can, make general rules of conduct, which guide it in each particular case.

It is therefore only after all the sciences which deal with these various issues that we must place that which is in question here and which I call cybernetics, from the word κυβερνήτης, which, almost first was used in a narrowed sense, for the art of governing a vessel, among the Greeks even, the meaning, quite otherwise extended, to the art of governing in general.”

— Andre-Marie Ampere, “Essay on the Philosophy of Science,” 1843, page 140.
(Also mentioned in the 1834 edition.)

Norbert Wiener and the Macy Conferences group adopted cybernetics to describe "control + communication".

"…as far back as four years ago [1944], the group of scientists …had already become aware of the essential unity of a set of problems centering about communications, control, and statistical mechanics, whether in the machine or in living tissue. … we were seriously hampered by the lack of unity of the literature concerning these problems, and by the absence of any common terminology, or even of a single name for the field. … We have decided to call the entire field … Cybernetics, which we form from the Greek κυβερνήτης or steersman. In choosing this term, we wish to recognise that the first significant paper on feedback mechanisms is an article governors, which was published by [James] Clerk Maxwell in 1868, … We also wish to refer to the fact that the steering engines of a ship are indeed one of the earliest and best-developed forms of feedback mechanisms. … the term cybernetics does not date further back than the summer of 1947 …"

— Norbert Wiener, "Cybernetics Or Control and Communication in the Animal and the Machine", 1948.

Cybernetics and the scientific method

"Besides electrical engineering theory of the transmission of messages, there is a larger field [cybernetics] which includes not only the study of language but the study of messages as a means of controlling machinery and society, the development of computing machines and other such automata, certain reflections upon psychology and the nervous system, and a tentative new theory of scientific method."
— Wiener

"There is nothing distinctively scientific about the hypothetico-deductive process. It is not even distinctively intellectual. It is merely a scientific context for a much more general stratagem that underlies almost all regulative processes or processes of continuous control, namely feedback, the control of performance by the consequences of the act performed. In the hypothetico-deductive scheme the inferences we draw from a hypothesis are, in a sense, its logical output. If they are true, the hypothesis need not be altered, but correction is obligatory if they are false. The continuous feedback from inference to hypothesis is implicit in Whewell's account of scientific method; he would not have dissented from the view that scientific behaviour can be classified as appropriately under cybernetics as under logic."
— Sir Peter B. Medawar, "Induction and Intuition in Scientific Thought", (1969), 54-5.

Other definitions of cybernetics

"La Cybernetique est l'art d'assurer l'efficacite de l'action."
— Louis Couffignal, 1956

"The science of effective organization."
— Stafford Beer

"The study of the immaterial aspects of systems."
— W. Ross Ashby

"The art of and science of manipulating defensible metaphors."
— Gordon Pask

"A way of thinking."
— Ernst Von Glasersfeld

"The science and art of human understanding."
— Humberto Maturana

On balance...

"The famous balance of nature is the most extraordinary of all cybernetic systems. Left to itself, it is always self-regulated."

— Joseph Wood W, "Saturday Review", 8 June, 1963.

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