Introduction to Cybernetics and the Design of Systems

Collected Models
January 2010

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Not for re-distribution

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a. goal of models

This book of collected models is intended to serve as an archive and (if not now, then soon) a practicum.

b. description

The collection is an archive in that it comprises the basic models from the discipline of cybernetics, a science of goals, interaction, and feedback. The collection had been developed for a university course where these models were used to frame 'design'. Coursework required students to name and simulate the cybernetic elements of the systems they wished to design, whether software, design process, or organization.
This is the sense in which we speak of the collection of a *practicum*.

c. components and processes

There are 4 broad areas of the collection:

i. Cybernetic Loop—what a cybernetic system is, and what it does, and how feedback is involved.
ii. Requisite Variety—what a particular cybernetic system can't do, yet how it might be changed to do so.
iii. Second-order Goals—when and how systems learn because of interaction.
iv. Conversation—if worlds are co-created, sharing is possible, but conversation is necessary.

As a means of further explaining our intentions, we include an introduction adopted from a paper on the nature of service craft, which adds 3 additional models: bio-cost, autopoiesis, and evolution. We intend to enhance this collection with those additional models in the near future.

We wish to thank our students, for whom and through whom we have evolved the work.

Hugh Dubberly & Paul Pangaro
January 2010

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- **Autopoiesis**
- **Evolution** (in Terms of Requisite Variety)

Cybernetics

"Cybernetics" comes from the Greek: "the art of steering".

In short, cybernetics is a discipline for understanding how actions may lead to achieving goals.

Knowing whether you have reached your goal (or at least are getting closer to it) requires "feedback", a concept that comes from cybernetics.

"Cybernetics" evolved into Latin as "governor".

"Cybernetics saves the souls, bodies, and material possessions from the gravest dangers."
—*Socrates according to Plato, c. 400 B.C.E.*

"The future science of government should be called 'la cybernetique.' "
—*André-Marie Ampere, 1843*

"The science of control and communication in animal and machine."
—*Norbert Wiener, 1948*

"Until recently, there was no existing word for this complex of ideas and…
I felt constrained to invent one...."
—*Norbert Wiener, 1954*

"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 defensible metaphors."
—*Gordon Pask*

"A way of thinking."
—*Ernst Von Glasersfeld*

"First-order cybernetics is the science of observed systems;
Second-order cybernetics is the science of observing systems."
—*Heinz Foerster, 1974*

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

Open-loop Models

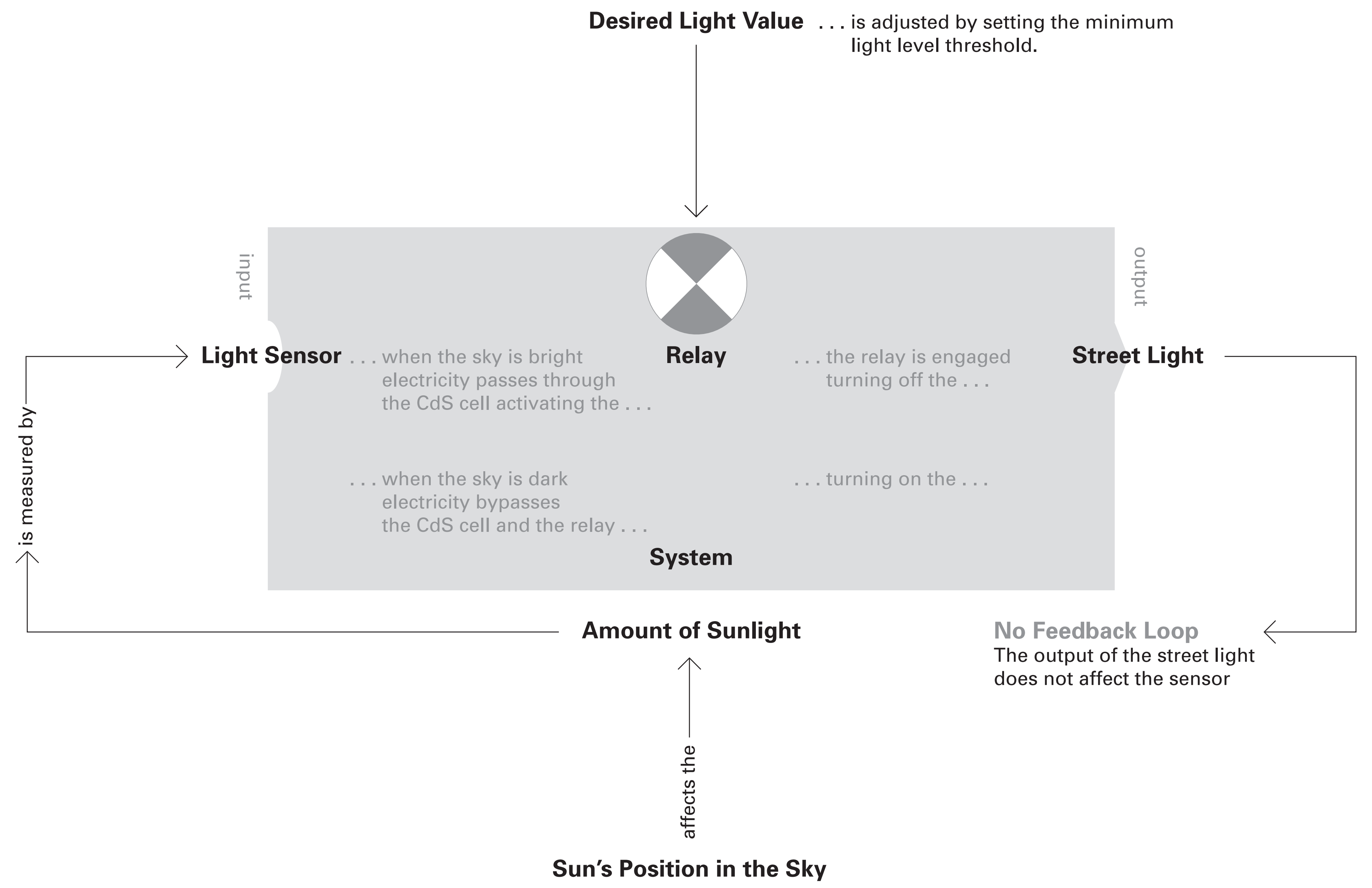
Open-Loop: Mechanical Example

Street light auto-on-off

In the open-loop system shown, the output of the street light does not affect the system—it is not measured by the sensor, thus the loop is “open”, rather than “closed”.

Thus there is no feedback from the action taken, in this case, the turning on of the light.

Open-loop
Street light does not affect the light sensor



Desired Light Value . . . is adjusted by setting the minimum light level threshold.

input

output

Light Sensor . . . when the sky is bright electricity passes through the CdS cell activating the . . .

Relay

. . . the relay is engaged turning off the . . .

Street Light

. . . when the sky is dark electricity bypasses the CdS cell and the relay . . .

. . . turning on the . . .

System

is measured by

Amount of Sunlight

No Feedback Loop
The output of the street light does not affect the sensor

affects the

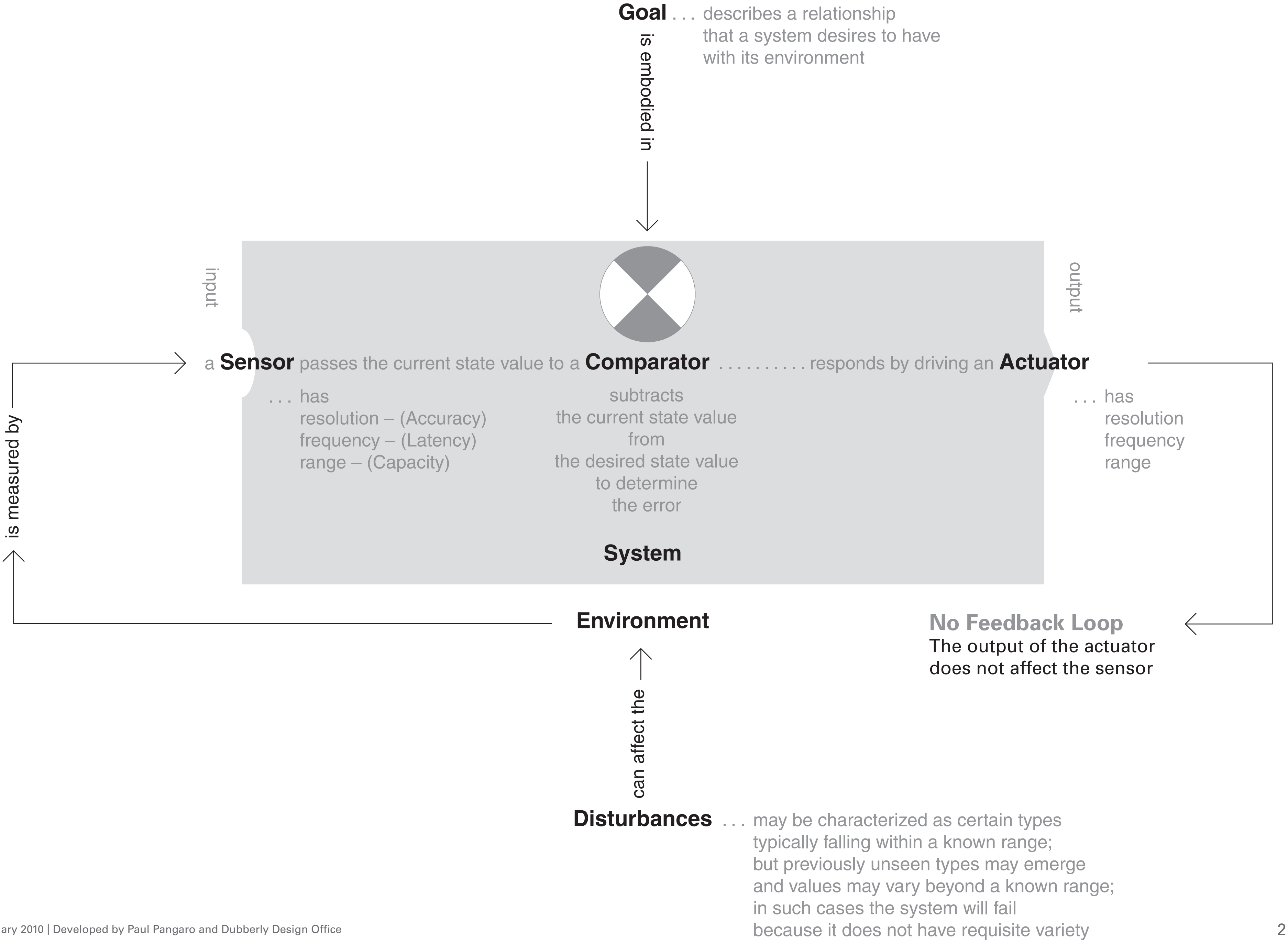
Sun's Position in the Sky

Open-Loop: Canonical Form
First-order System

Many systems have many or even all of the components of a first-order system even without a closed feedback loop.

A “closed system” means that the actions of the system have an impact on the Environment, that can in turn be detected by the sensors, and that has impact, in turn, on subsequent actions of the system.

Open-Loop
Actuator has no effect on Environment—no feedback



Goal . . . describes a relationship
that a system desires to have
with its environment

is embodied in

input

output

a **Sensor** passes the current state value to a **Comparator** . . . . responds by driving an **Actuator**

. . . has
resolution – (Accuracy)
frequency – (Latency)
range – (Capacity)

subtracts
the current state value
from
the desired state value
to determine
the error

. . . has
resolution
frequency
range

System

is measured by

Environment

No Feedback Loop
The output of the actuator
does not affect the sensor

can affect the

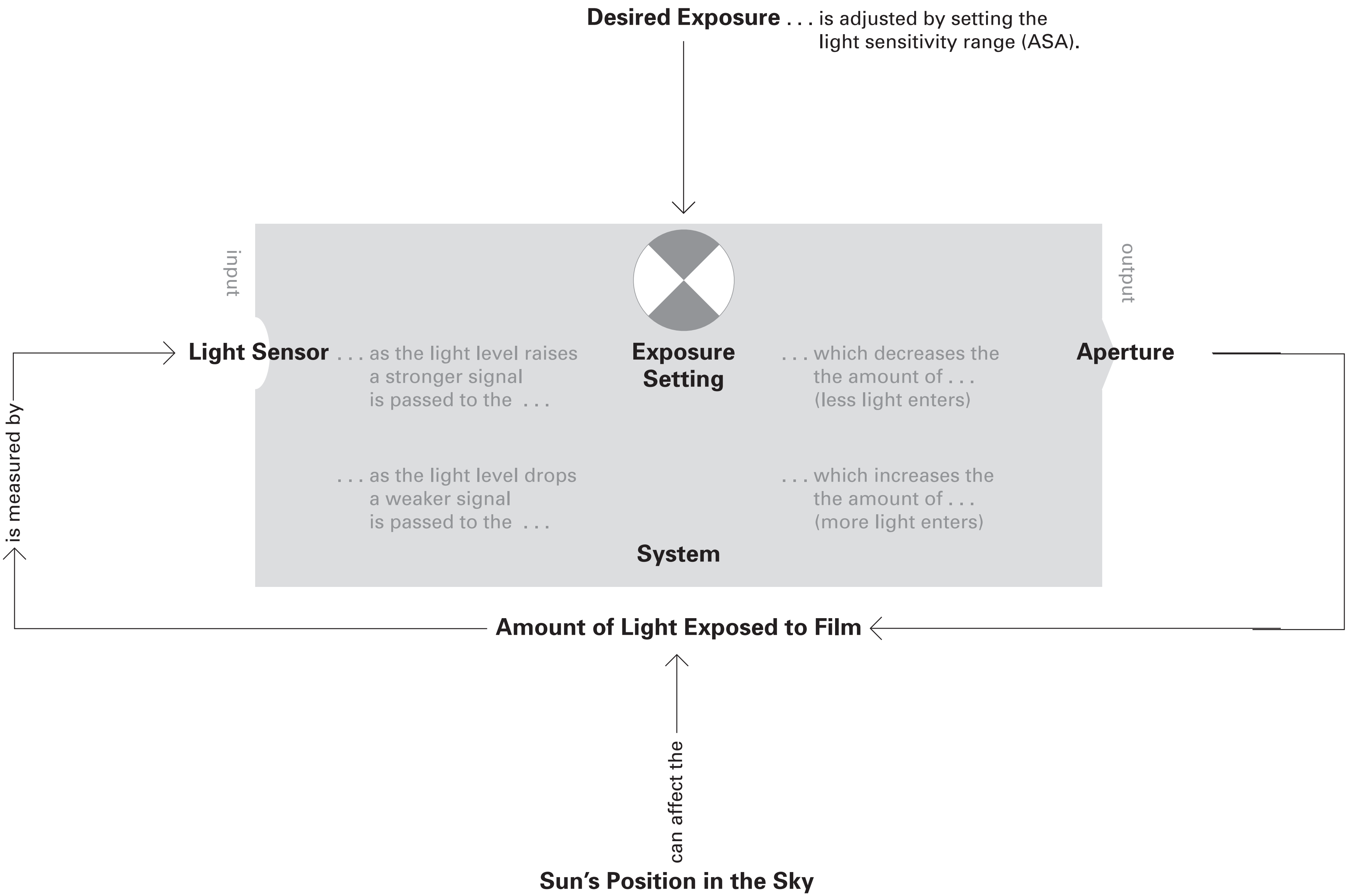
Disturbances . . . may be characterized as certain types
typically falling within a known range;
but previously unseen types may emerge
and values may vary beyond a known range;
in such cases the system will fail
because it does not have requisite variety

Closed-Loop: Mechanical Example
Camera auto-exposure (shutter priority)

In this closed-loop system, a light-sensitive photocell measures the amount of light passing through the camera lens—in real-time while also exposing the film—and automatically adjusts the camera's aperture based on the desired exposure setting.

(In this example the shutter speed is fixed and only the aperture is adjusted in order to achieve the proper film exposure.)

Closed-loop: Control of Aperture changes light impinging on sensor, adjusting the aperture in real-time to expose the film as desired.



Desired Exposure . . . is adjusted by setting the light sensitivity range (ASA).

input

output

Light Sensor . . . as the light level raises a stronger signal is passed to the . . .

Exposure Setting

. . . which decreases the the amount of . . . (less light enters)

Aperture

. . . as the light level drops a weaker signal is passed to the . . .

. . . which increases the the amount of . . . (more light enters)

System

is measured by

Amount of Light Exposed to Film

can affect the

Sun's Position in the Sky

The concept of "feed-back" came into common usage from the origins of the discipline of cybernetics, in the 1940s. It has since lost its hyphen but not its meaning. Here Is a careful definition that preserves the rigor of the original concept:

Feedback (noun): information returned to a system that causes change in subsequent actions of the system, such that those actions become the means whereby the system achieves its goal.

Feedback forms a circular process that moves from intention to action, to sensing the outcome of action, to comparison of outcome to intention, to adjustment of further action. This circularity is the essence of all cybernetic systems, that is, systems that seek goals.

As diagrams of this section show, the thermostat is an excellent example of a circular, cybernetic system that uses feedback to achieve a goal. In response to current temperature in a room, the action of the thermostat causes a heater to start, heating the air in the room that, in turn, gives feedback to the thermostat that the set-point—the desired temperature of the room, the goal—has been reached.

Without feedback, systems are blind and dumb to the affects of their actions. Without feedback, system behavior becomes more like guessing—trying an action and hoping it achieves the goal. With feedback, system behavior can effectively and efficiently reach convergence on a desired state from a current state.

In the 1940s Norbert Wiener and Arturo Rosenblueth developed foundational concepts from which a mathematics was developed for describing electro-mechanical systems that self-correct. Wiener wrote a book called *Cybernetics*, implying the origin of the field was due to him. But in parallel a wide variety of experts were engaged in a series of yearly conferences called the Macy Meetings, where they sought common ground among the fields of anthropology, linguistics, mathematics, computation, sociology, psychiatry, psychology, neurology, biology—and there are some disciplines still left out.

In all of these domains of application for the concepts of cybernetics—summarized as "in the animal and the machine", to give Wiener's book's subtitle its due—the common core is the role of feedback in the circular operation of systems seeking goals in changing environments. Recognition of this core marked the rise of cybernetics in the 20th century.

Every day we hear the phrase, "let me give you some feedback" about some action of ours and its consequences, intended or unintended. The term has come to loosely mean **any information** coming into a system; technically, however, feedback is **information that is used** by the system to change its action in the course of aiming toward its goal.

The concept of feedback is so widely accepted today that it is impossible to re-live its impact on the hard and soft sciences alike. Science prior to cybernetics succeeded only by breaking observations into simple, linear, causal chains that appeared to describe the world (as von Foerster reminded us as often as opportunity allowed, "science" has the same root as "schism"). For cybernetics to "close the loop" with feedback, and to thereby make causality circular, was a foundational shift—for how can a scientist remain objective if observation causes feedback that affects the observer? This was one reason that cybernetics received great resistance in many academic communities.

However, the necessity of feedback in any process that involves iterative refinement is un-contestable. During the processes of design, feedback guides every aspect and every level for those who participate in crafting something. In usage scenarios for the products and services that are being designed, modeling the feedback mechanisms between user and device is, in turn, key feedback to the processes of design.

This section will present a somewhat rigorous view of basic feedback systems, also called first-order systems. In practice, while most design processes do not require so quantitative a view, this rigor provides a foundation from which the designer can judge the degree of specificity required for a particular process.

First-order Feedback Systems

PA systems can produce unpleasant feedback

a. goal of model
This model illustrates the cause of what is probably the most memorable experience of positive feedback.

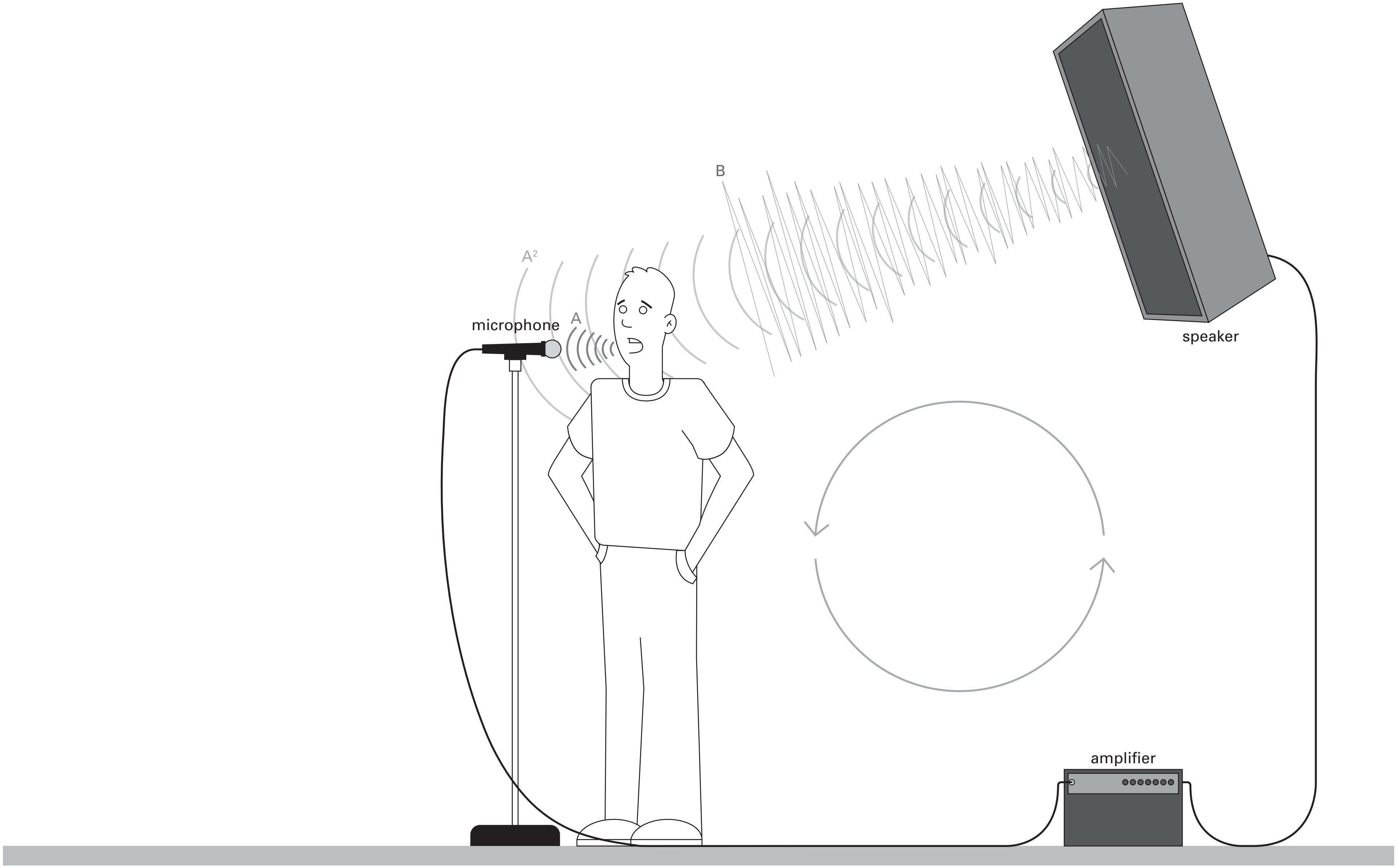
b. description
A “public address system”, whose intention is to amplify sound detected at a microphone, instead produces a high-pitched, ear-splitting scream. This is referred to as “feed-back” because of the mechanism that causes it, explained below.

c. components and processes
The source of sound (for example, a human) speaks into the microphone [A] that converts the acoustic voice into electrical signals that travel via wires to the amplifier. The amplifier’s circuits boost the level of the signals, which are carried to the speaker, which in turn produces an amplified acoustic reproduction of the original sound.

The sound is now louder than the original human voice; it, in turn, enters the microphone where, continuing in the loop just described, it is amplified yet further. This on-goign loop and amplification at every stage continues and so the sound quickly becomes a VERY LOUD, high pitched screech.

The specific frequency of the feedback sound is determined by the characteristics of the circuit and the environment through which the sound travels. The maximum volume reached is determined by the power output of the amplifier itself; otherwise it would increase without bound.

PA systems can produce unpleasant feedback



A = original sound
A^2 = original sound amplified
B = amplified sound, re-amplified
(feedback)

Feedback Graphs

origins

a. individuals
James Clerk Maxwell

b. era/dates
1868

c. references for model, context, author(s), concepts
James Clerk Maxwell, ``On Governors,” Proceedings of the Royal Society, no. 100 (1868); or, slightly easier of access, in The Scientific Papers of James Clerk Maxwell, vol. II, pp. 105--120.

d. examples
Positive feedback: PA system acoustic feedback (previous page), growth in a ecological population with unlimited food, political conflicts that escalate from rhetoric into war

Negative feedback: thermostats (see later pages), homeostatic systems in the human body, self-limiting populations where growth of population causes depletion of food that in turn limits population, governing systems such as the checks-and-balances of the US government (see models in this volume).

a. goal of model
A series of graphs present a precise, quantified series of models of feedback of two types, positive and negative.

b. description
Positive feedback means that each response by a system to a specific variable in the environment tends to push that variable’s value further in a given direction (positive or negative). As the process continues, the variable’s value is pushed to a limit.

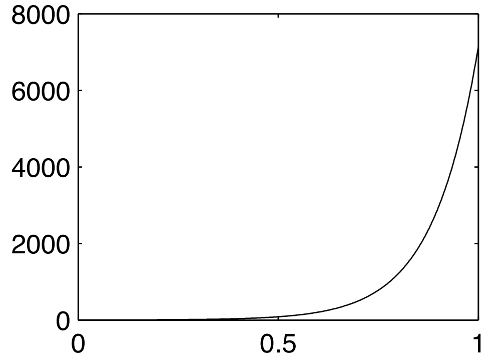
Negative feedback means that a variables movement in a given direction (positive or negative) causes the system to respond in a manner that causes the variable to move in the opposite (or ‘negative’) direction. As the process continues, the variable’s value converges to a stable value.

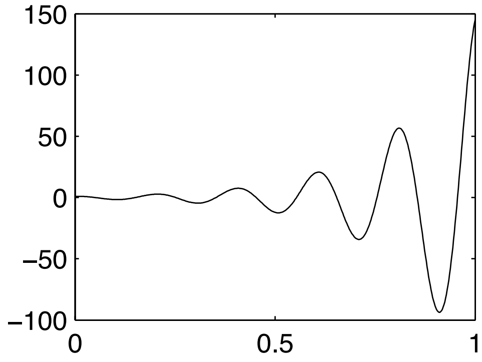
c. components and processes
The upper graphs show the change in a variable as positive feedback ‘pegs’ the value at an extreme. The left graph shows the more common form, such as the PA example on the previous page. The right graph shows a less common but equally important case, where the latency of the response causes oscillation of the variable of wider and wider scope, until, once again, the system becomes unstable.

The lower graphs show the change in a variable as a negative feedback process causes convergence to a stable value (here shown as 0, but other values are possible). The left graph shows the simple attenuation of a value. The right graph shows the damping of an oscillation in a system variable until a stable value is reached.

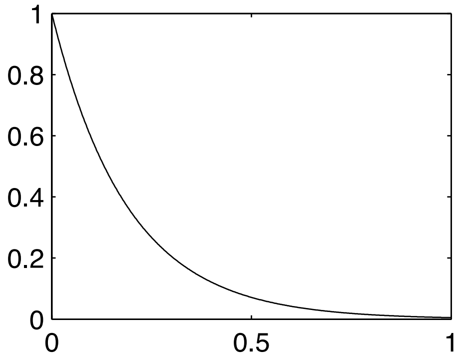
Feedback Graphs
after Maxwell

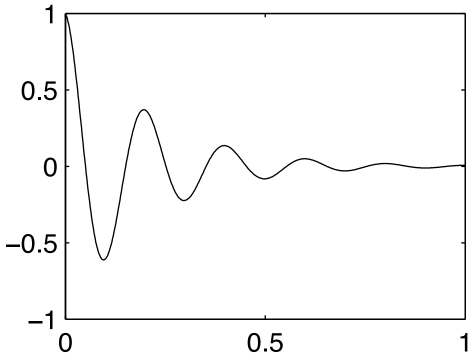
Positive Feedback throws systems out of balance.





Negative Feedback can maintain a system in balance.





Cybernetics as Steering

origins

a. individuals
Terminology for the discipline of cybernetics was developed in the 1940s, and led to the resurgence of the term from obscurity, by Norbert Wiener, Arturo Rosenblueth, and Julian Bigelow.

b. era/dates
1940s, when Wiener declares that the term is newly coined. He later learned that both the concept and the word goes back to Plato (400 B.C.E.) and is used by André-Marie Ampere in 1843 to describe 'the science of government.'

c. references for model, context, author(s), concepts
Norbert Wiener (1948), Cybernetics or Control and Communication in the Animal and the Machine, MIT Press, Cambridge, MA.

a. goal of model
The model explicates the relationship between the modern term 'cybernetics' and its fundamental meaning as 'the science of goal-directed systems'.

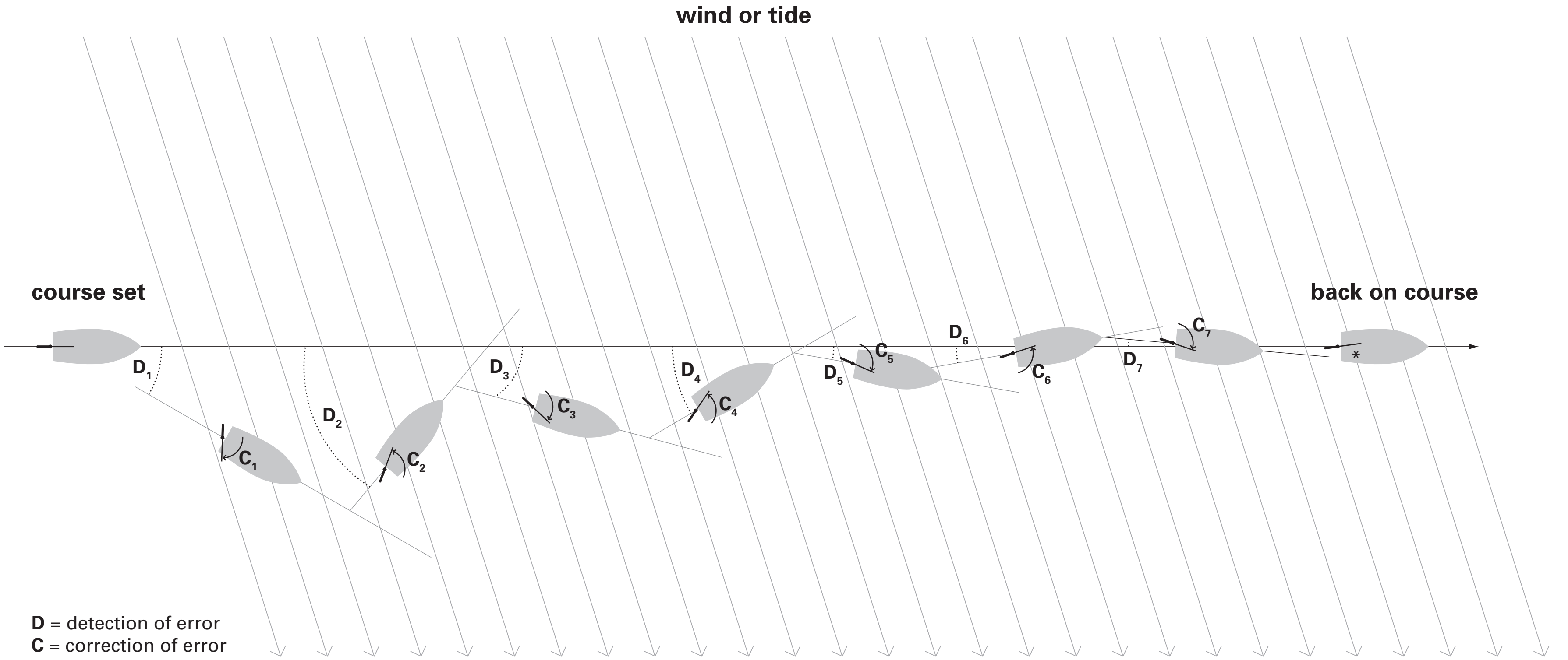
b. description
The term 'cybernetics' is derived from the Greek word 'kubernetes', usually translated as 'steersmanship', meaning the understanding and skills required to successfully steer a ship to its desired destination.

More than a metaphor, the process of steering a vessel (or system) from a present location or current state through to a destination (or, more generally, a goal) is an accurate description of cybernetics as the science of goal-directed systems.

c. components and processes
Beginning from a current position, the system sets a course and actions are taken toward the goal—in this case, the pilot adjusts the rudder and hence the direction of the ship. The environment presents disturbances to the system, making the present action insufficient to meet the goal. This discrepancy—the difference between intention and situation, or between current state and desired state—is called the 'error'. Adjustment to the current course is required, using the details of the error—its magnitude and direction—as a guide to the next action. This process repeats in a loop: actions followed by disturbances followed by correction followed by actions.

If the system has enough control over its course despite disturbances from the environment, it can achieve its goal. The pilot may be a human captain or technology only.

Pilots rely on negative feedback to steer a system toward a goal



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

origins

a. individuals
Heinz von Foerster and other participants of the Macy Meetings on Cybernetics

b. era/dates
1940s

c. references for model, context, author(s), concepts
Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems, Transactions of the Sixth Conference. New York, N.Y., Heinz von Foerster, Editor. Josiah Macy, Jr. Foundation, 1950-1955

F. L. Lewis, Chapter 1: Introduction to Modern Control Theory, from *Applied Optimal Control and Estimation*, Prentice-Hall, 1992. Available at http://arri.uta.edu/acs/history.htm.

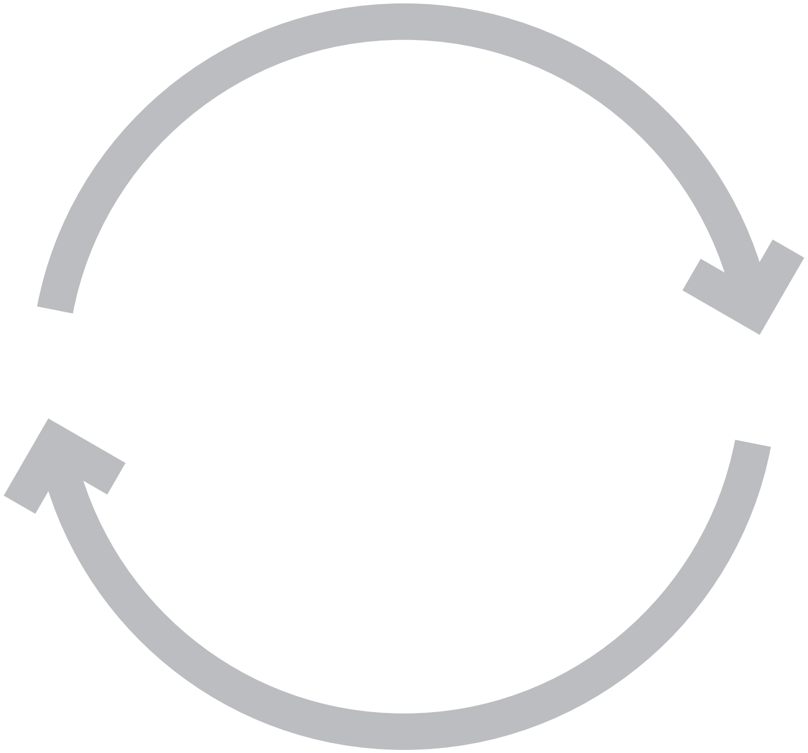
a. goal of model
The model is one possible representation of the fundamental elements of cybernetic loops, here comprising the detection and correction of errors.

b. description
Steering is shown as an on-going loop, from detection of error to correction of error. This is the purest expression of a cybernetic system, the topology of a cybernetic action as a loop.

c. components and processes
Starting from [D], the current heading (as of a ship) is compared to the desired heading. The difference between current and desired heading is the ‘error’. This difference is used at [C] to attempt to correct the error via adjustment of the rudder. Equally important is the continuation of the system around the loop and recursive action that continues at [D]—detection of the new error, and new actions to respond.

d. important aspects of model/breakthrough
The topology of the model, that of a loop, is the first occurrence in a scientific frame and is called ‘circular causality’—detection of error causes the system to correct its actions, which leads to an outcome, which in turn is reacted to via detection and correction, etc. This can be characterized as ‘A causes B causes A causes B…’

Steering as a feedback loop



D = detection of error
compares current heading
with desired heading

C = correction of error
adjusts rudder
to correct heading

Goal of Regulator or Governor

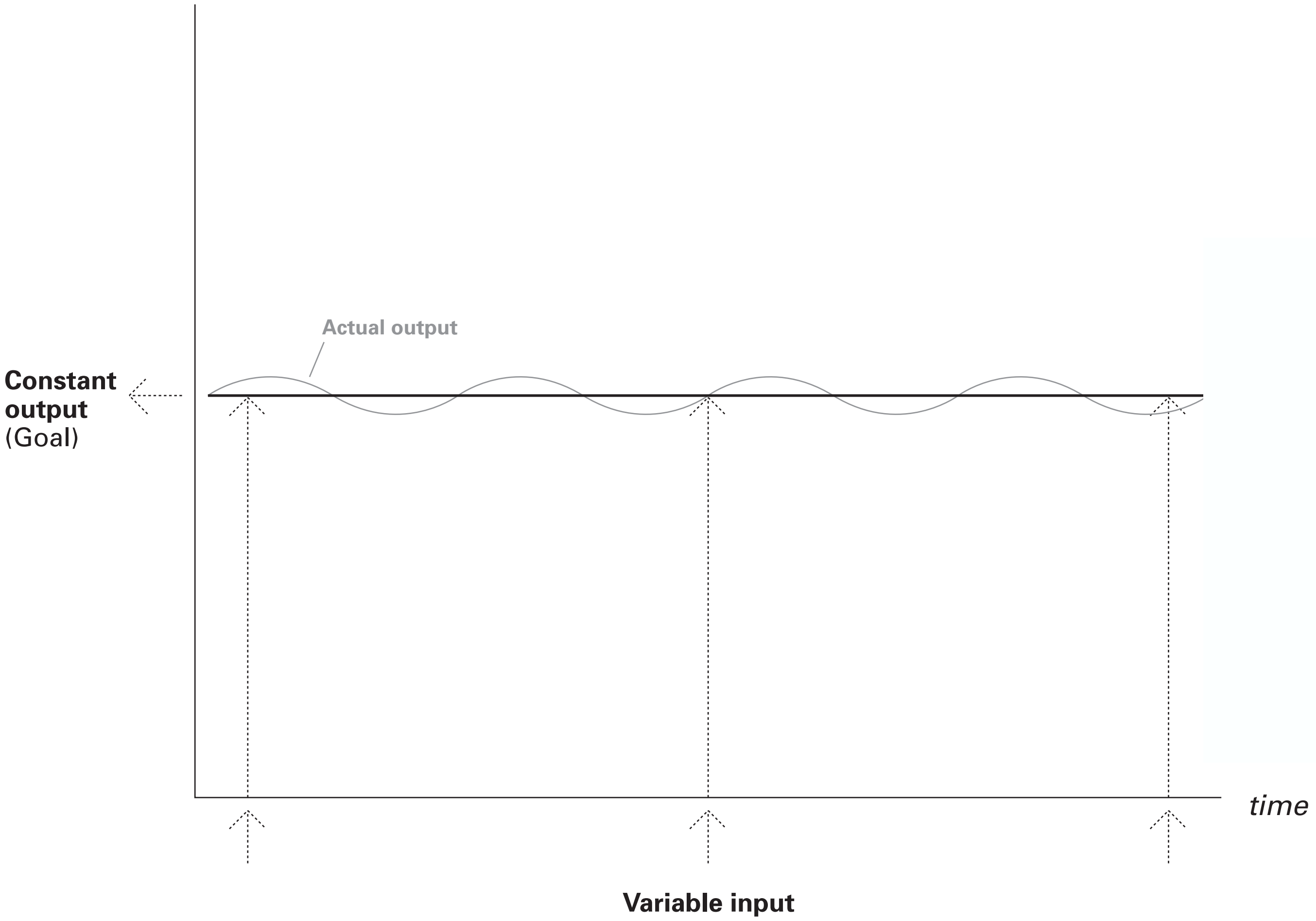
a. goal of model
The model shows how the response of a system may cause oscillation of a variable around a desired goal.

b. description
While the goal of a system may be to maintain a variable at a specific value, in practice a system is constrained by latencies of sensing and responding, as well as characteristics of physical systems that force a delay between action and the effect of that action on the variable.

c. components and processes
The line labelled ‘Constant output (goal)’ is the ideal value for the variable that the system attempts to maintain. As input to the system varies over time, the action of the system tends to bring the value of the variable back to that ideal value.

Goal of Regulator or Governor

Maintain constant output in the face of varying input



Goal-Directed System—
Behavioral View

origins

a. individuals
Control theorists or practitioners in mechanical or electrical engineering.

b. era/dates
Feedback systems were first documented in the form of a float regulator to keep constant the level of oil in a lamp (circa 250 BCE).

c. references for model
Gregory Bateson, Mind and Nature—a Necessary Unity, 1979. On the limits of traditional logic for modeling causality in biological systems.

d. example
Thermostats, autopilots.
Homeostatic systems in the body.
Ecological balance across animal and food populations.

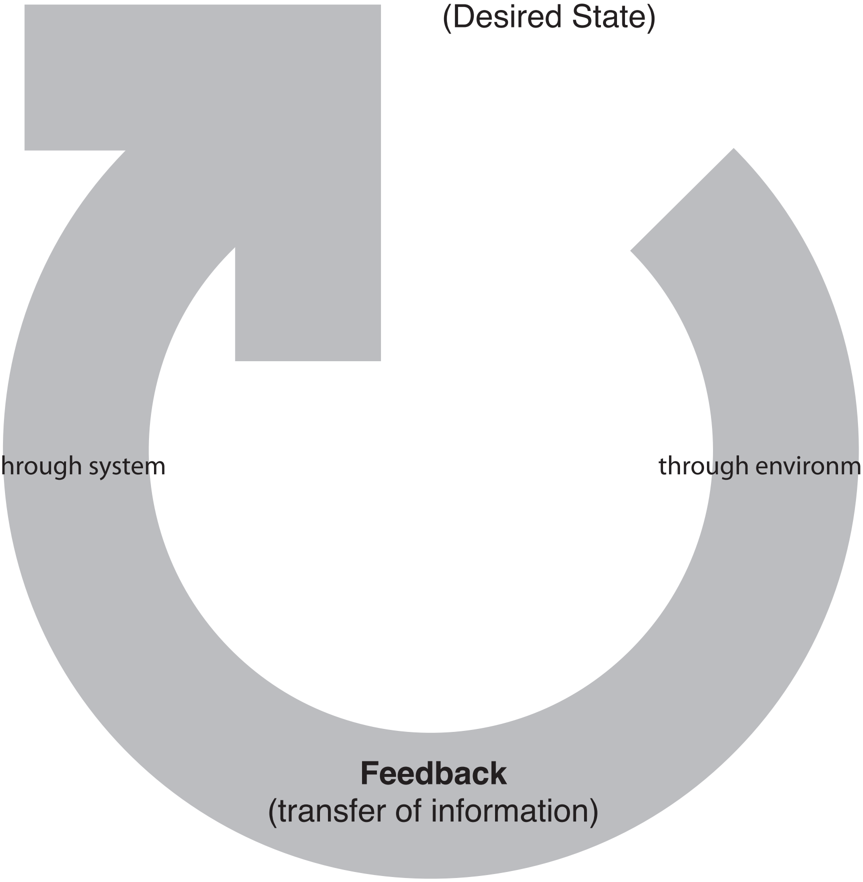
a. goal of model
This model describes the nature of the cybernetic loop at the level of a system's observed behavior. The model treats the system as a black box whose internal functions and specifics are not shown.

b. description
The fundamental model of cybernetics is the loop. Actions cause changes that in turn impact actions in a closed, circular relationship, all in service of the system acting to achieve its goal.

c. components and processes
An action taken by a goal-directed system may have some effect on the environment. The effect is measured by an information flow from the environment that comes into the system, called 'feedback'. The system compares its measure of the current state to its goal, and then attempts through a new action, if necessary, to reach its goal. This circular process repeats so long as the system seeks its goal. This is the fundamental process of cybernetic systems.

d. important aspects of model/breakthrough
Cybernetics was the first science to embrace circular causal relationships, of the form 'A causes B causes….
A (see example below). This contrasts to conventional science that focuses on linear causality (A causes B: this ball hits the bowling pin and knocks it over; sunlight makes ocean water hot; etc.). Before the era of cybernetics, loops were explicitly excluded from science because of complexities introduced by them, and the desire of science to reduce complex problems to simple, linear-causal chains in order to describe them.

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.’

through system

through environment

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

Feedback
(transfer of information)

Effect
(Current State)

Feedback: Formal Mechanism

a. goal of model
The model shows the necessary organization of a cybernetic system, that is, the individual elements and processes required.

b. description
Replacing the ‘black box’ model of the simple loop of the previous model, the formal mechanism of a cybernetic system must show enough details to explain its behavior or to reproduce it.

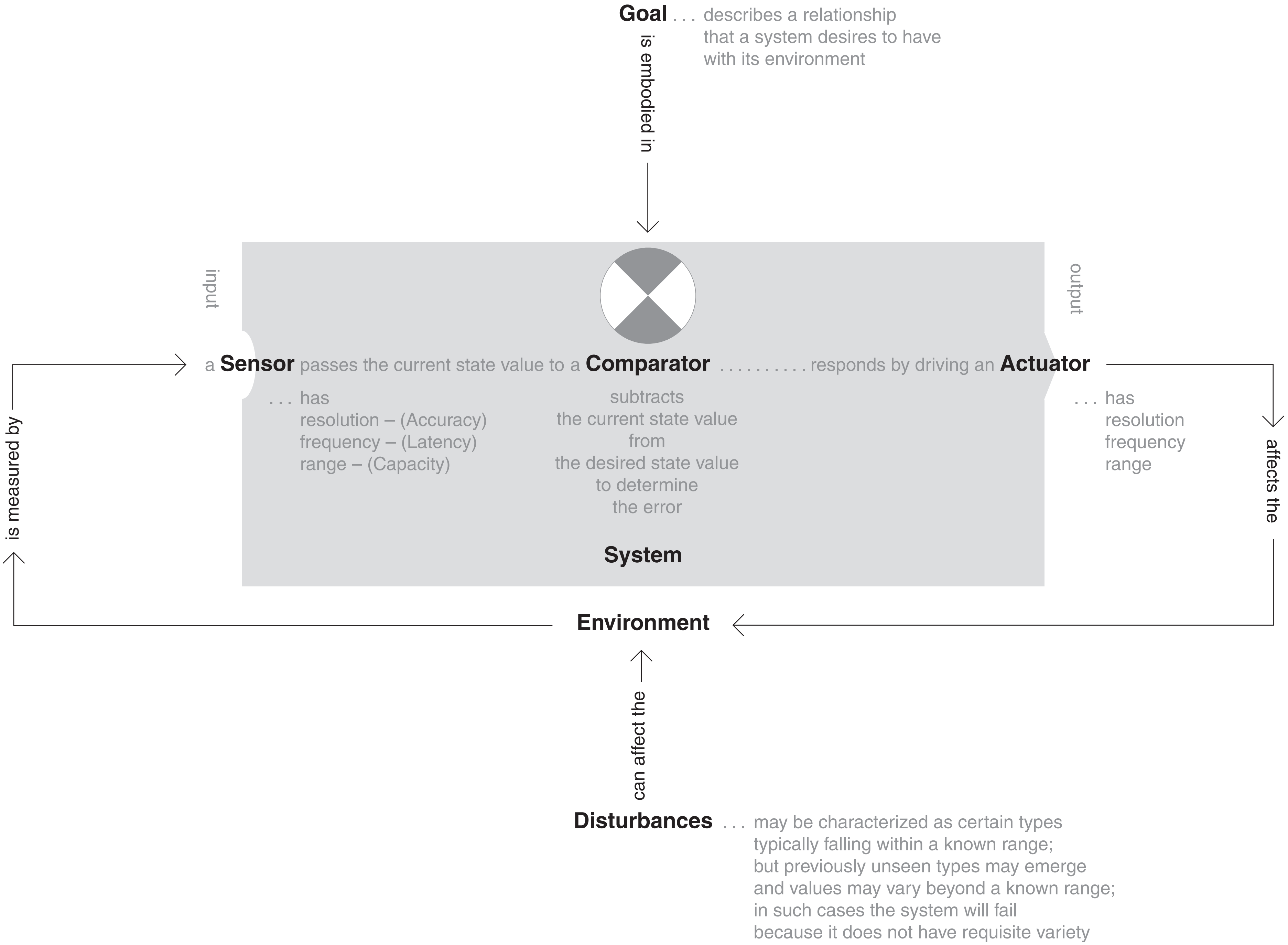
c. components and processes
The system is shown as the shaded box; all other areas are the system’s environment. The goal is reified by the specifics of the system’s construction:

The comparator takes input from the sensor and computes an error. This results in a specific response by the actuator acting upon the environment in an attempt to correct the error, that is, reduce it to zero. Whatever changes occur in the environment—whether due to correction by the system or other disturbances—are reflected in the sensor measurement, which is again passed to the comparator, closing the loop.

Sensors and actuators are limited by their resolution, frequency (or speed), and range, which has impact on the ability of the system to achieve its goal.

c. important aspects of model/breakthrough
The model begins to characterize dimensions of sensing, comparing, and acting such that the potential effectiveness of a given system in the context of a range of environmental disturbances can be considered.

Feedback: Formal Mechanism



Goal . . . describes a relationship
that a system desires to have
with its environment

is embodied in

input

output

a **Sensor** passes the current state value to a **Comparator** . . . . responds by driving an **Actuator**

. . . has
resolution – (Accuracy)
frequency – (Latency)
range – (Capacity)

subtracts
the current state value
from
the desired state value
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affects the

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Disturbances . . . may be characterized as certain types
typically falling within a known range;
but previously unseen types may emerge
and values may vary beyond a known range;
in such cases the system will fail
because it does not have requisite variety

Feedback: Classic Example

a. goal of model
This model results from the application of the previous formal model of a cybernetic system to a room thermostat.

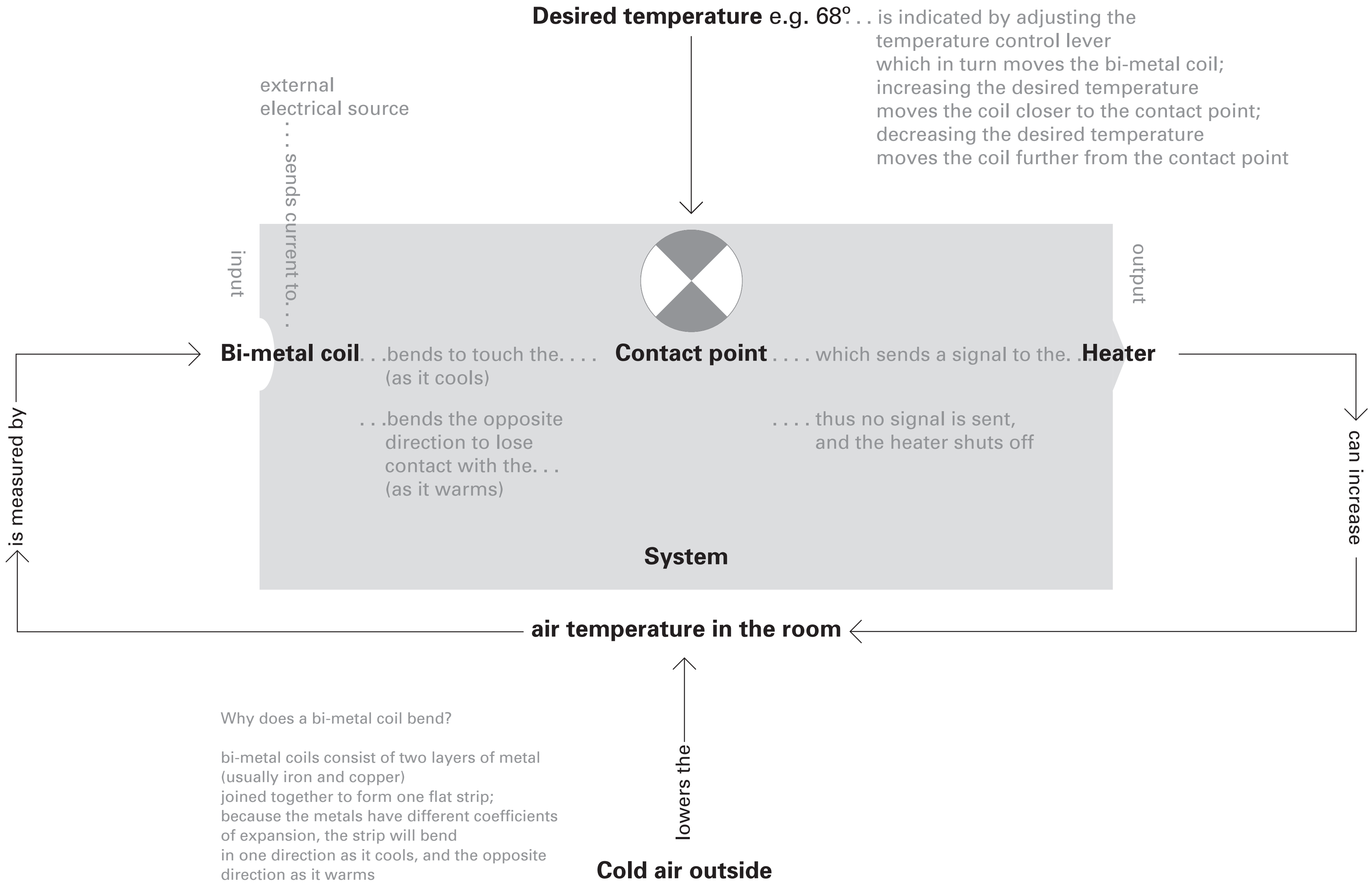
b. description
Each element of the cybernetic organization is mapped to the components of the thermostat.

c. components and processes
The goal of a Desired temperature of 68F is set by the human. This enables a comparator function, in the form of the relationship between the Contact point and the Bi-metal coil which reflects the current temperature of the air in the room. (The next model gives an example of exactly how the comparator might work.) If the Contact point closes a circuit, indicating that the temperature of the room is too low compared to the Desired temperature, the Heater is turned on. Over time this should raise the air temperature in the room, which will be sensed by the Bi-metal coil, in turn causing movement of the Contact point such that the circuit is opened and the heater turned off.

See the next model for an example of the mechanisms of a thermostat.

Feedback: Classic Example

Thermostat regulating room temperature (via a heater)



Desired temperature e.g. 68°. . . is indicated by adjusting the
temperature control lever
which in turn moves the bi-metal coil;
increasing the desired temperature
moves the coil closer to the contact point;
decreasing the desired temperature
moves the coil further from the contact point

external
electrical source
. . . sends current to. . .

input

output

Bi-metal coil. . .bends to touch the. . . . **Contact point** . . . . which sends a signal to the. . .**Heater**
(as it cools)

. . .bends the opposite
direction to lose
contact with the. . .
(as it warms)

. . . . thus no signal is sent,
and the heater shuts off

System

can increase

air temperature in the room

is measured by

lowers the

Cold air outside

Why does a bi-metal coil bend?

bi-metal coils consist of two layers of metal
(usually iron and copper)
joined together to form one flat strip;
because the metals have different coefficients
of expansion, the strip will bend
in one direction as it cools, and the opposite
direction as it warms

How a Thermostat Works

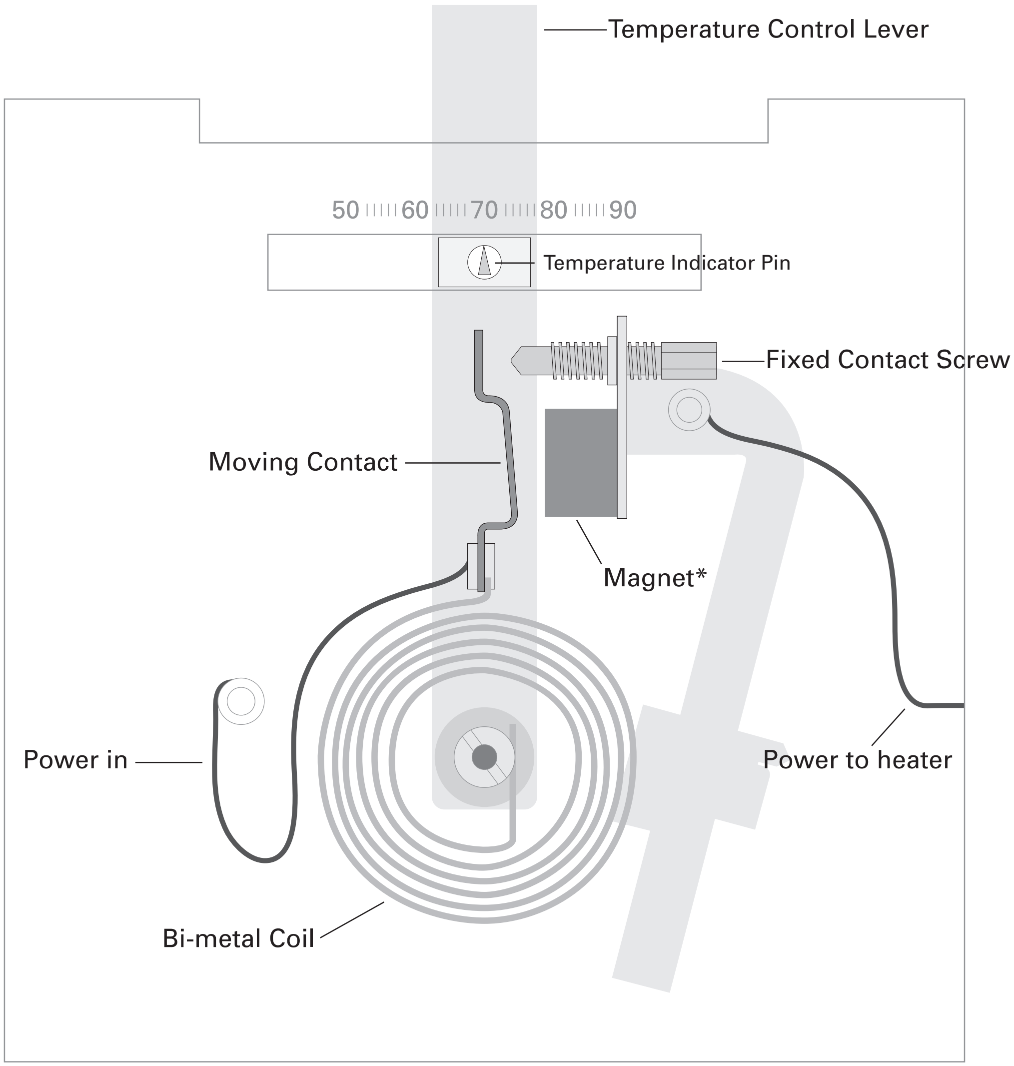
a. goal of model
This diagram shows a specific example of an electro-mechanical room thermostat, used in the previous model.

b. description
This thermostat design was common for decades, due to its simplicity, reliability, and intuitive human interface for setting the goal of desired room temperature.

c. components and processes
The Temperature Control Lever does not directly control the temperature of the room; rather it controls the setpoint goal of the system. If the temperature of the room drops below the desired temperature, the expansion/contraction characteristics of the Bi-metal Coil cause the Moving Contact to touch the Fixed Contact Screw. This closes the electrical circuit that powers the heater, causing it to heat the air in the room. As the temperature of the air rises, the Bi-metal Coil responds and at some point breaks the contact, turning off the heater. The process repeats.

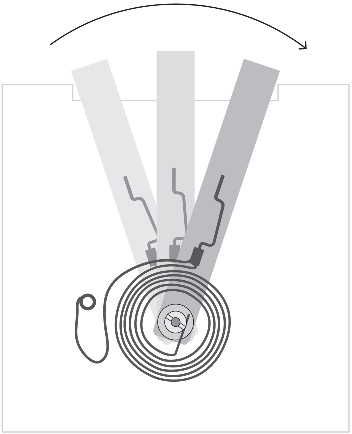
d. important aspects of model/breakthrough
The diagram displays an embodiment of the individual elements of a cybernetic system, namely, a sensor (Bi-metal Coil), comparator (relationship of the Moving Contact to the Fixed Contact), and actuator (closing of the circuit to turn on the heater when contact is made).

How a Thermostat Works

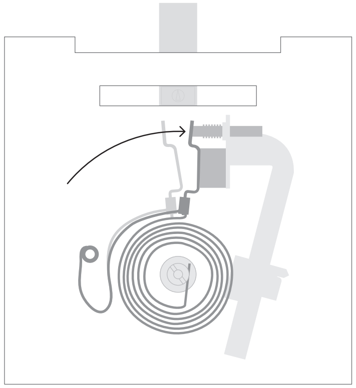


The bi-metal coil is connected
to the temperature control lever.

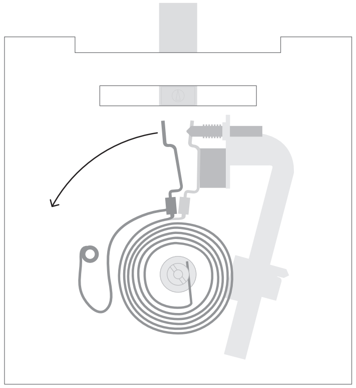
*The magnet insures a good contact
and prevents erratic on/off signals
to the heater in the event that the
air temperature within the room fluctuates
to quickly.



Moving the temperature control lever
moves the bi-metal coil



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



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

Heating System Behavior

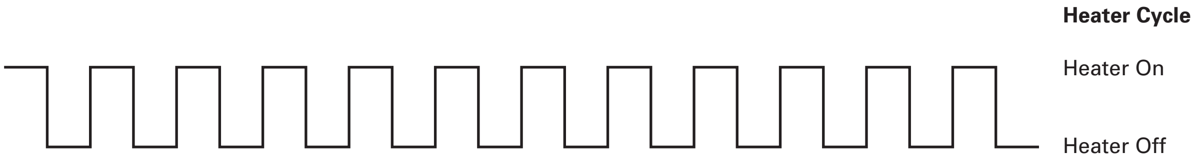
a. goal of model
This diagram compares the results of a regulated system to that of an unregulated one.

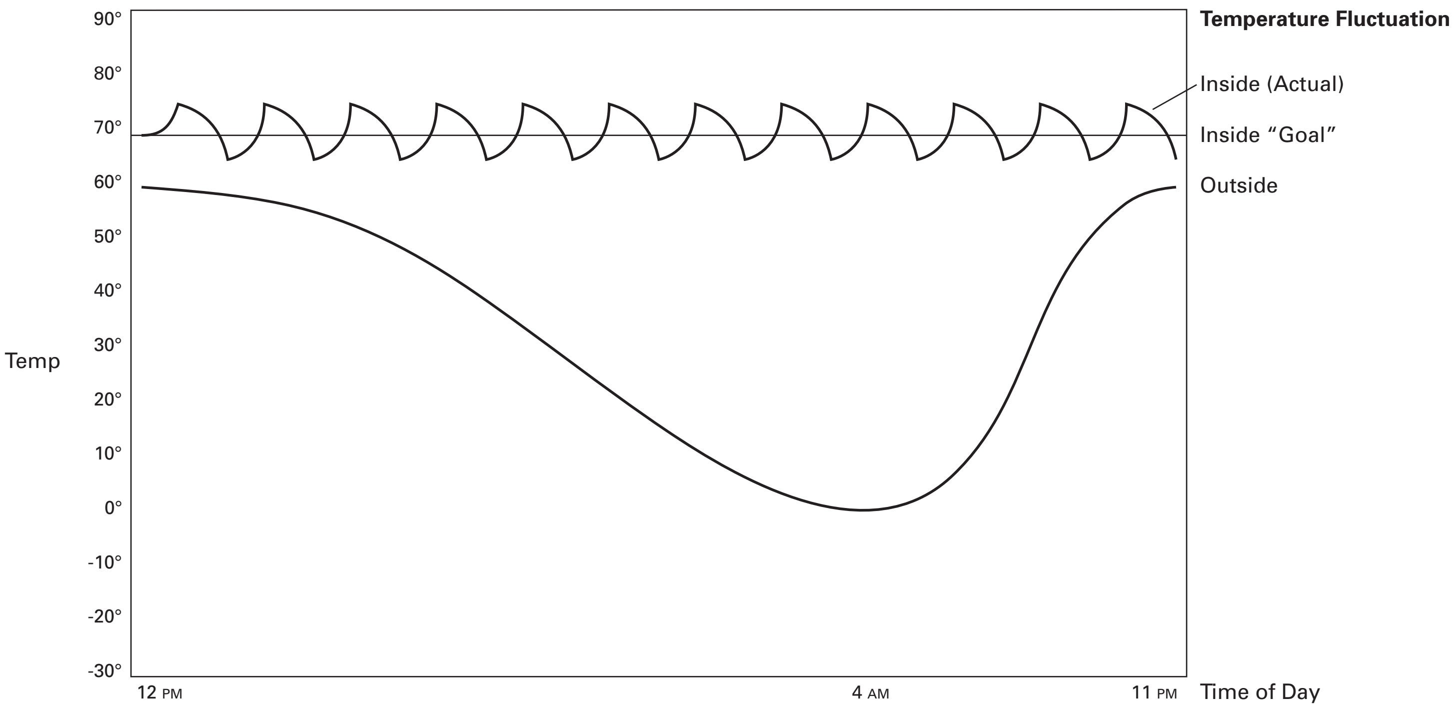
b. description
This diagram shows fluctuation of outside temperature vs. inside temperature being successfully regulated by a thermostatically-controlled heating system.

c. components and processes
The x-axis shows time of day. The curve labelled “Outside” shows how it gets colder at night reaching minimum temperature around 4 AM, and reaching maximum temperature around noon.

The y-axis compares the Outside temp to both the “Inside (Goal)”—the setpoint of the thermostat—and the “Inside (Actual)” temperature. This curve is oversimplified, as the oscillations of the air temperature may not be uniform throughout the outside temperature cycle.

Heating System Behavior





These diagrams are only intended as theoretical examples.

Feedback: Mechanical Example

a. goal of model
This diagram shows the specific example of a purely mechanical regulator used in steam engines.

b. description
Components of the flyball governor are mapped to the cybernetic loop.

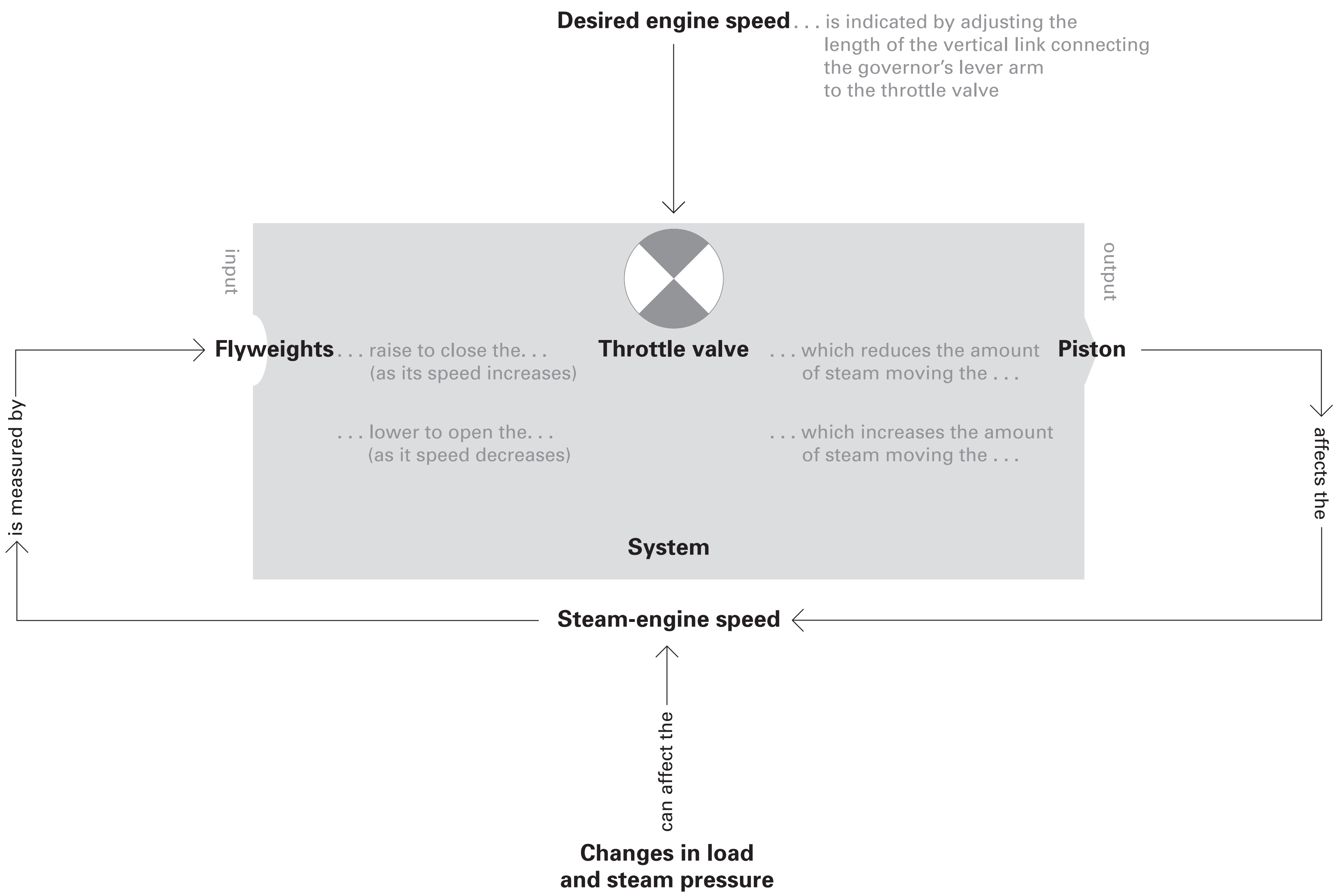
c. components and processes
Elements of the cybernetic loop as before, see diagram to right for details.

d. important aspects of model/breakthrough
When first developed, steam engines would tend to run faster or slower than the desired rate, whether because of variation in load or random variations in the system. Unfortunately this led to unstable conditions, and sometimes an engine would run faster and faster and blow itself up—until the flyball governor was invented.

Without this cybernetic device, the use of steam engines to provide controllable and reliable power would have been impossible, vastly slowing the progress of the industrial age.

Feedback: Mechanical Example

Flyball Governor regulating steam-engine speed



Desired engine speed . . . is indicated by adjusting the length of the vertical link connecting the governor's lever arm to the throttle valve

input

output

Flyweights . . . raise to close the. . . (as its speed increases)

. . . lower to open the. . . (as it speed decreases)

Throttle valve

. . . which reduces the amount of steam moving the . . .

. . . which increases the amount of steam moving the . . .

Piston

System

affects the

Steam-engine speed

is measured by

can affect the

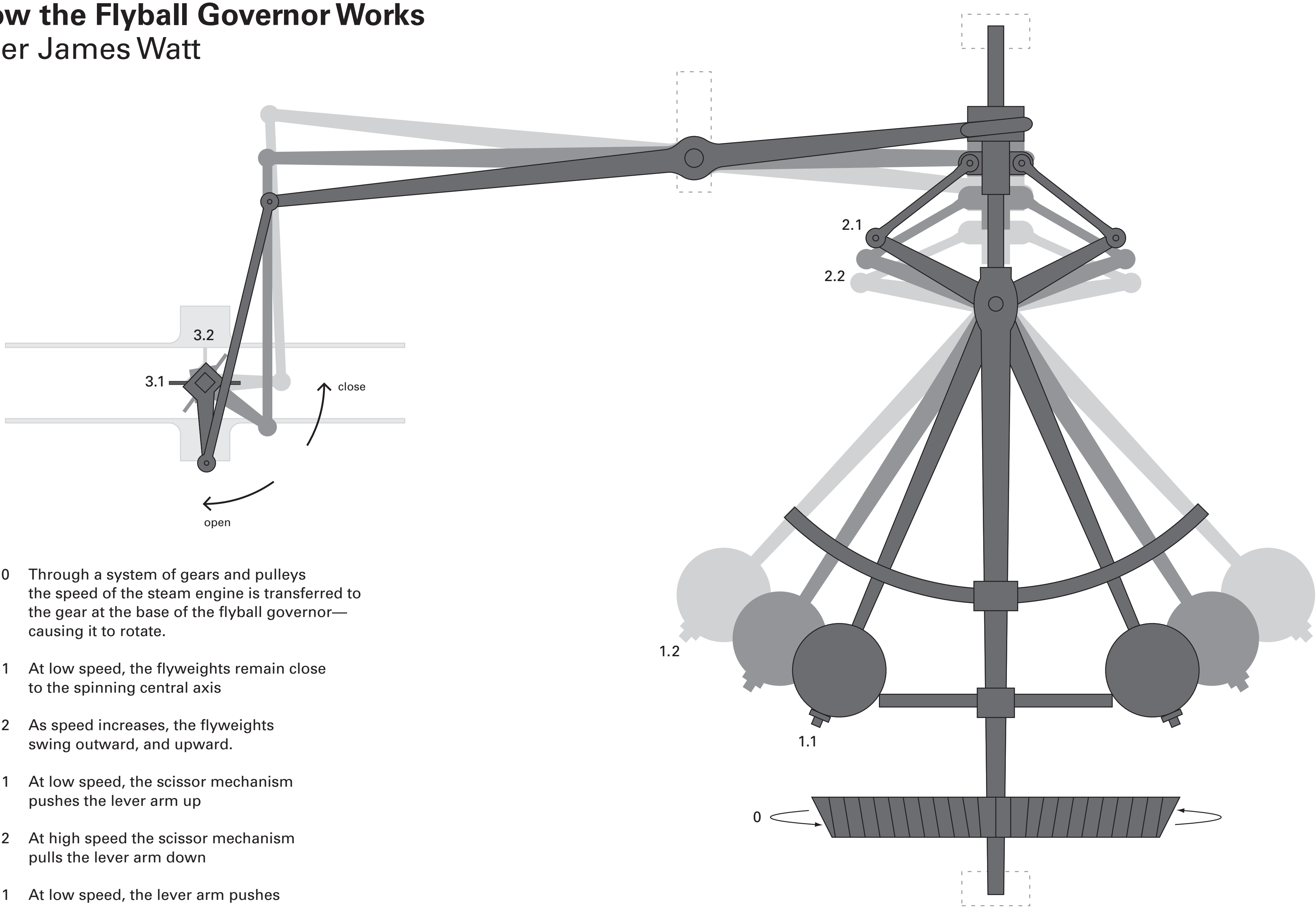
Changes in load and steam pressure

How the Flyball Governor Works
after James Watt

a. goal of model
The schematic shows the mechanical relationships in a flyball governor that embody a cybernetic feedback system.

b. description
Constructed of the same materials as the steam engine that it was designed to control, the elements of the flyball governor implement the elements of every cybernetic system: sensor, comparator, and actuator.

How the Flyball Governor Works
after James Watt



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

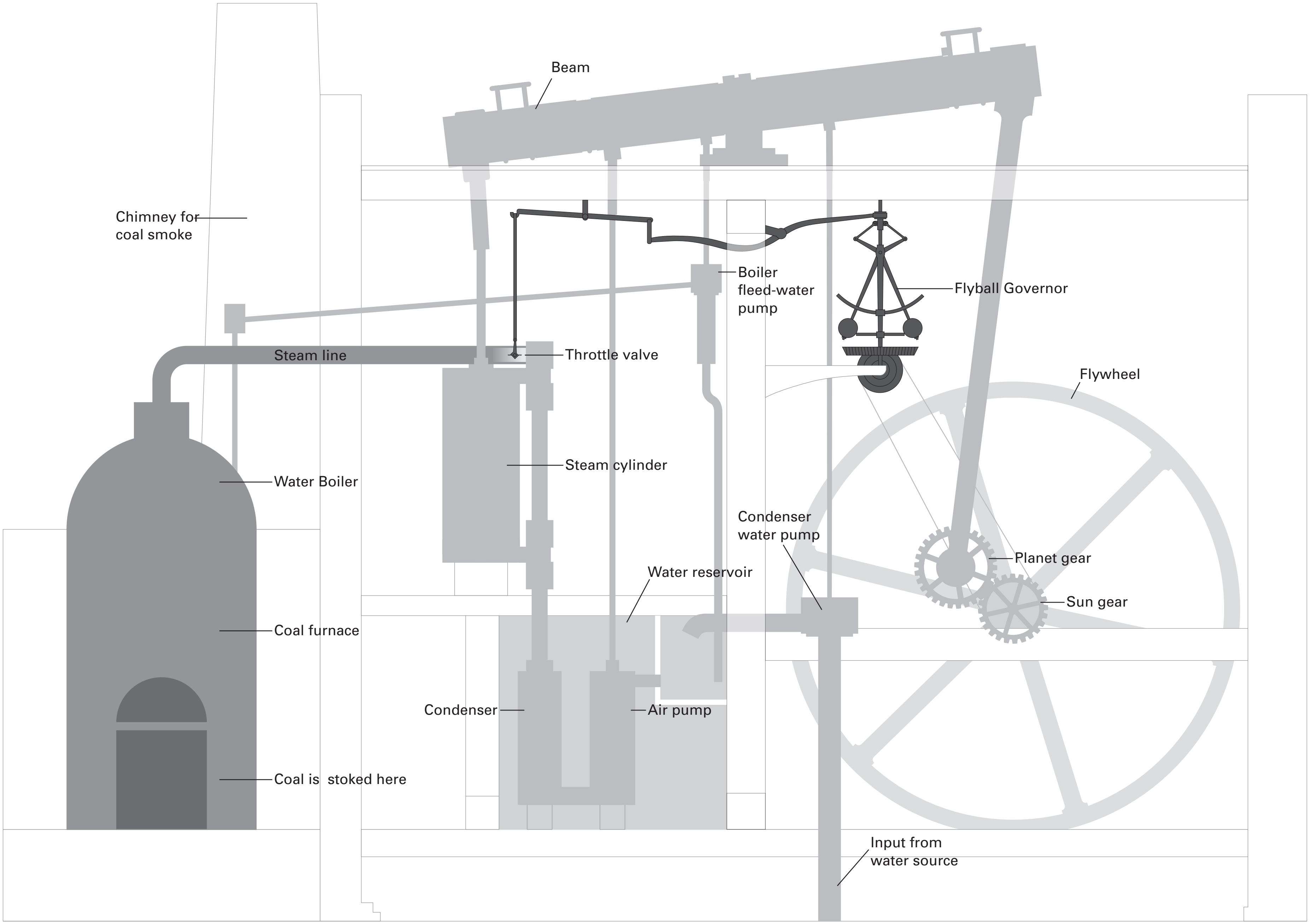
3.2 At high speed, the lever arm pulls the throttle valve closed; reducing the flow of steam

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

Watt steam engine with flyball governor

a. goal of model
The entire system of the steam engine and the role of the flyball governor is shown.

Watt steam engine with flyball governor



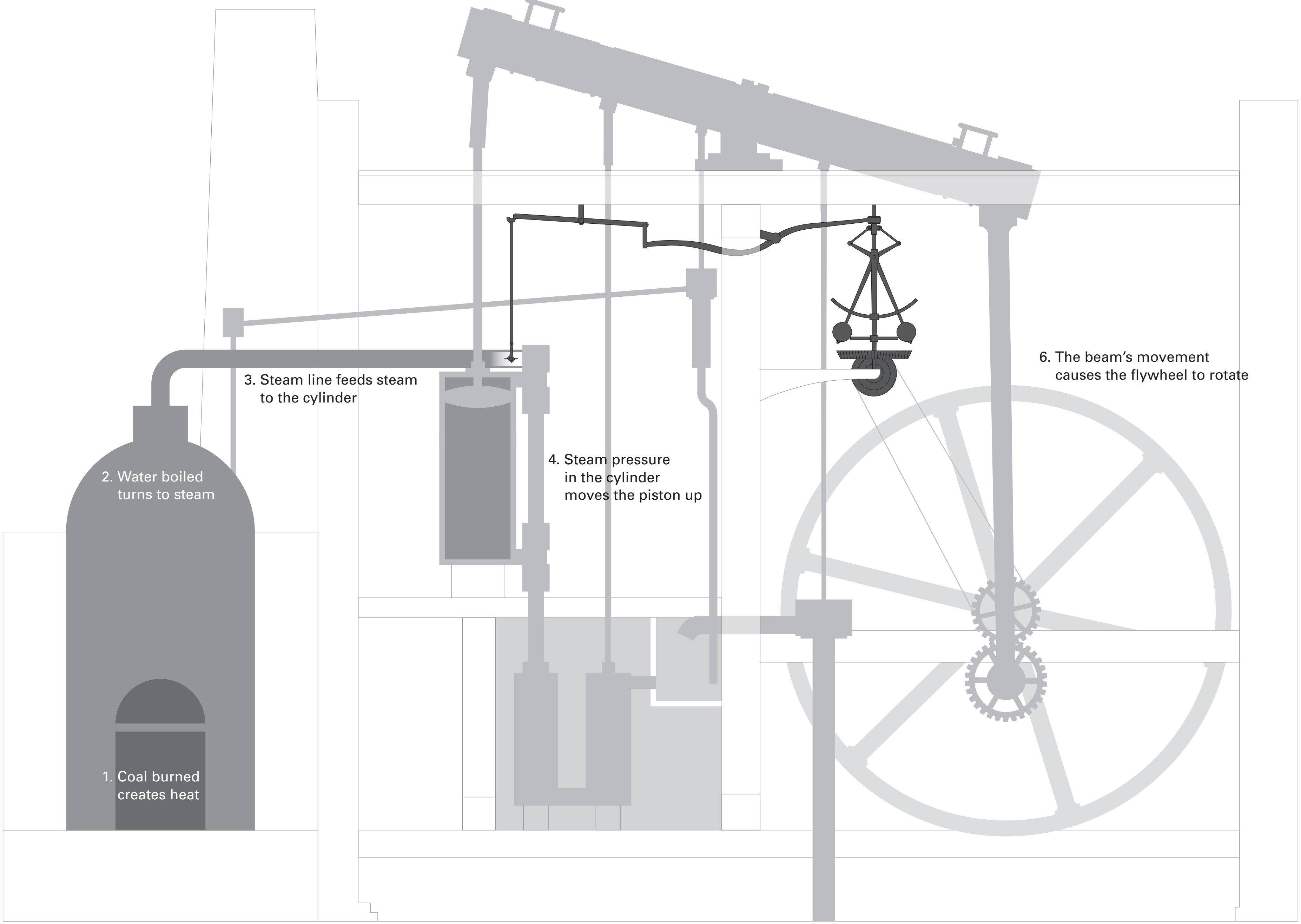
At low speed the throttle valve opens

a. goal of model
The configuration of the system when the engine is turning at low speed is shown.

b. description
The diagram is a detailed view of the linkages and settings when the engine is moving at low speed, matching position 1.1 in the earlier close-up diagram of the flyball governor.

c. components and processes
In feeding from the boiler [2], the steam line [3] carries steam into the pressure cylinder [4], subject to a flow valve that is under the control of the linkages from the flyball governor. Here the valve is shown to be in the full open position, allowing the maximum about of steam to move into the cylinder, moving the piston at increasing speed and thereby increasing the speed of movement of the beam [5] and therefore the rotation of the flywheel [6].

At low speed the throttle valve opens



5. The movement of the piston moves the beam
3. Steam line feeds steam to the cylinder
6. The beam's movement causes the flywheel to rotate
4. Steam pressure in the cylinder moves the piston up
2. Water boiled turns to steam
1. Coal burned creates heat

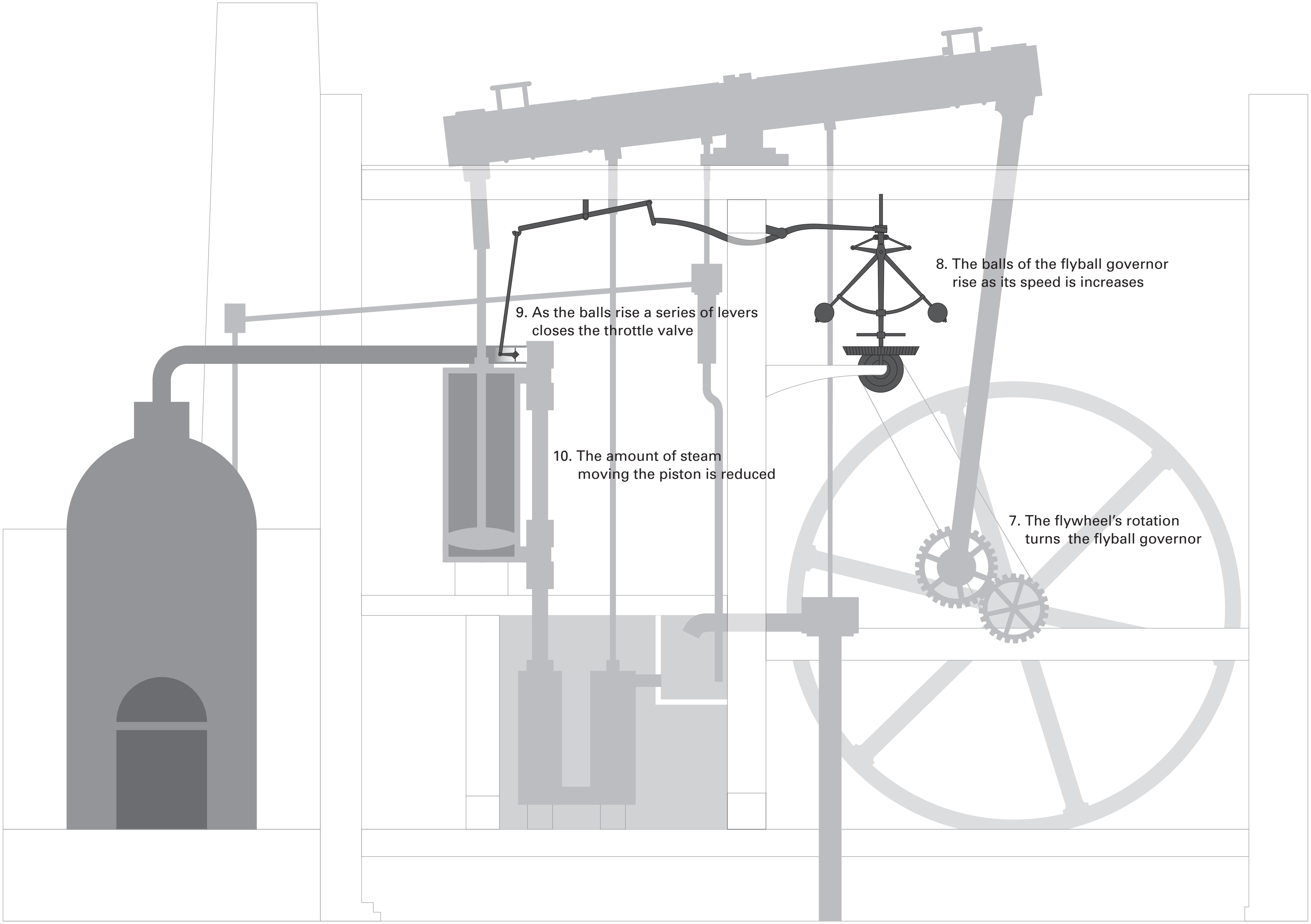
At high speed the throttle valve closes

a. goal of model
The configuration of the system when the engine is turning at high speed is shown.

b. description
The diagram is a detailed view of the linkages and settings when the engine is moving at high speed, matching position 1.2 in the earlier close-up diagram of the flyball governor.

c. components and processes
Because of the increased speed of the engine and therefore the flywheel [7], the pulley from the flywheel to the flyball governor increases the rate of rotation of the flyball governor. This in turn whips the balls at higher speed [8], causing them to raise up and thereby move the connected linkages to close the throttle valve [9], reducing the steam in the piston [10] and slowing the engine.

At high speed the throttle valve closes



8. The balls of the flyball governor rise as its speed is increases

9. As the balls rise a series of levers closes the throttle valve

10. The amount of steam moving the piston is reduced

7. The flywheel's rotation turns the flyball governor

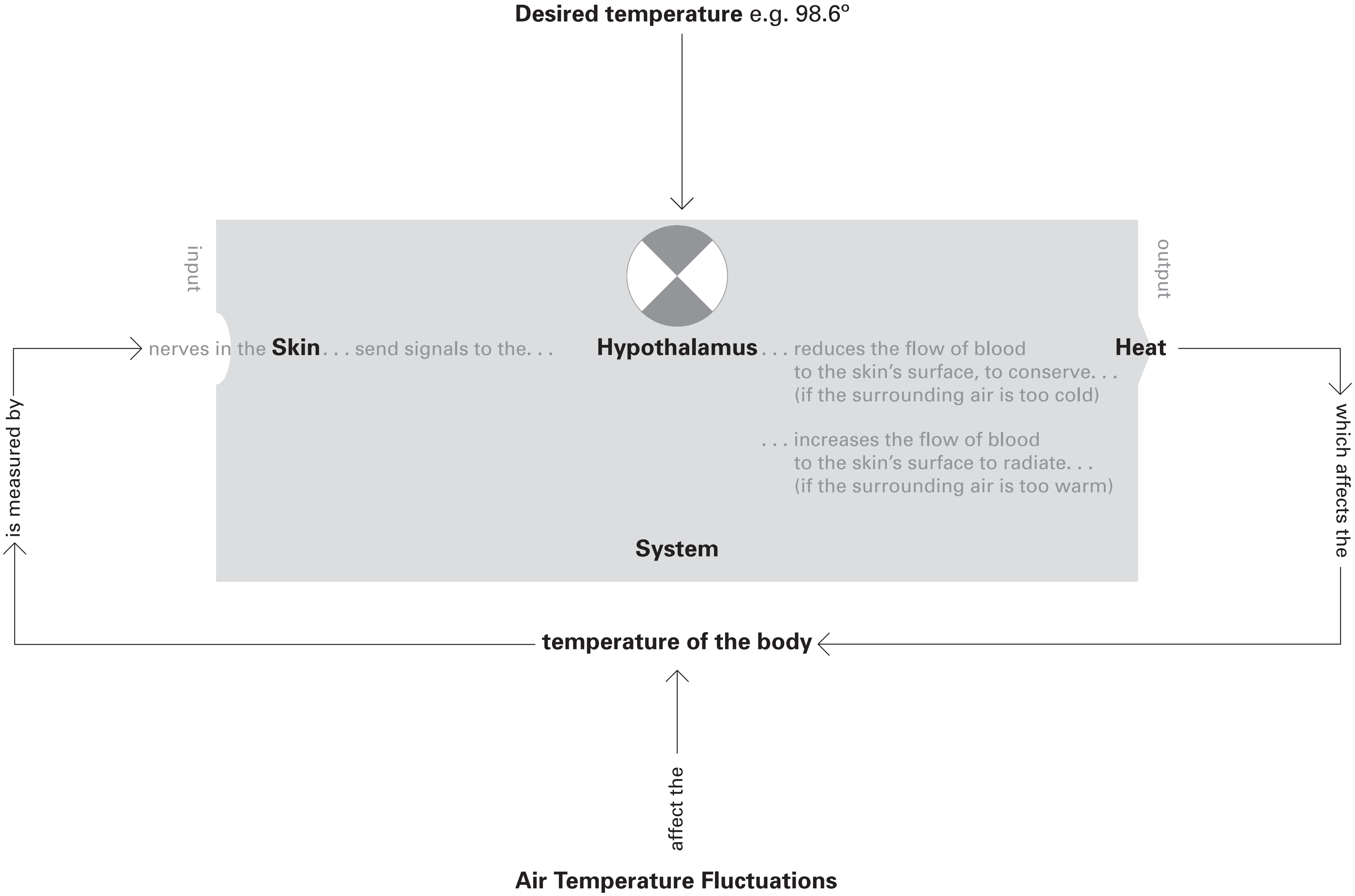
Feedback: Biological Example

a. goal of model
The model shows the relationship of the system of biological regulation of temperature in the human body to the form mechanism of a cybernetic system.

b. description
Each element of the cybernetic organization is mapped to biological components that fulfill those elements.

Feedback: Biological Example

Regulating temperature in the human body



Desired temperature e.g. 98.6º

input

output

nerves in the **Skin**. . . send signals to the. . .

Hypothalamus. . . reduces the flow of blood to the skin's surface, to conserve. . . (if the surrounding air is too cold)

. . . increases the flow of blood to the skin's surface to radiate. . . (if the surrounding air is too warm)

Heat

which affects the

System

temperature of the body

is measured by

affect the

Air Temperature Fluctuations

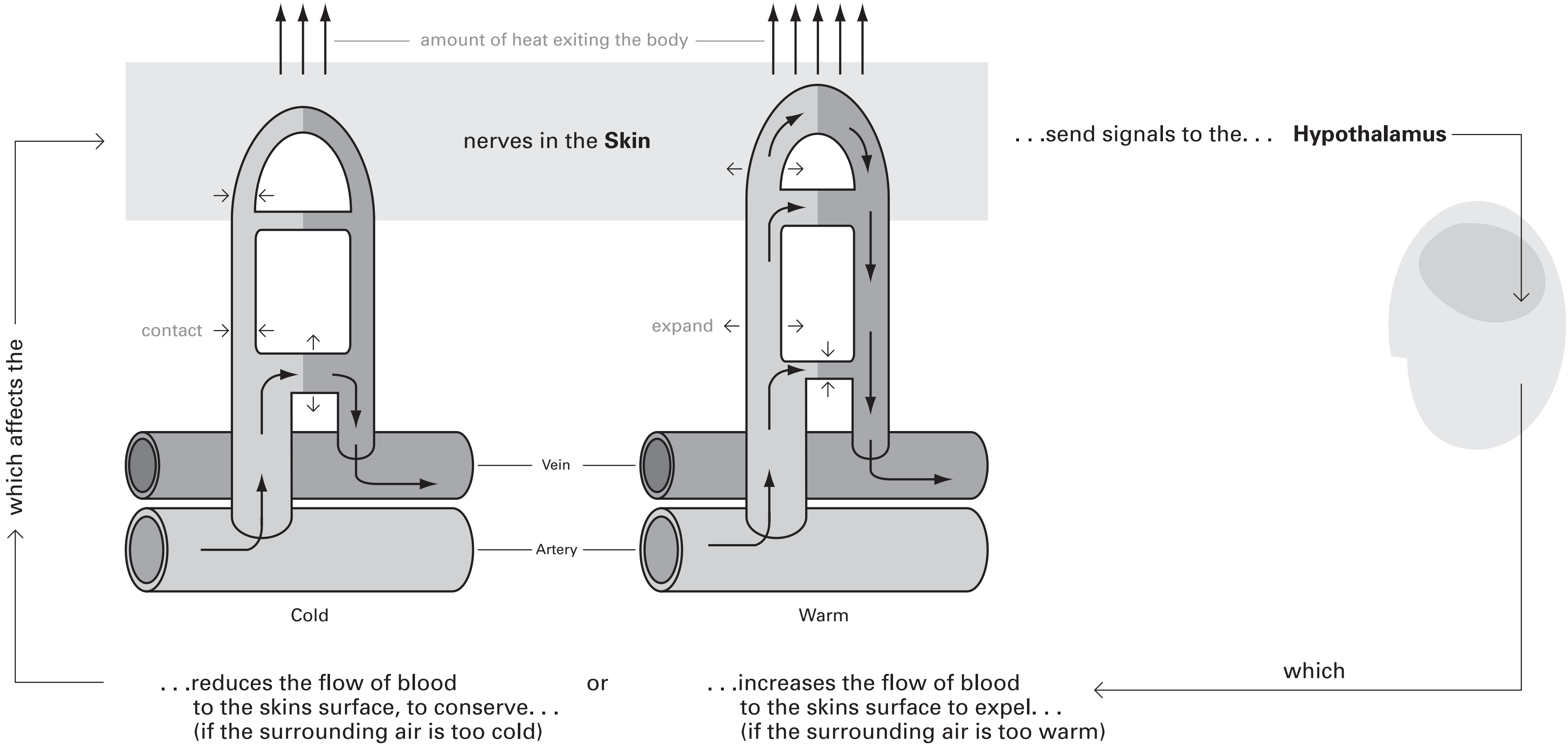
How the Regulation of Body Temperature Works

a. goal of model
The diagram shows the specific physiological functions that implement temperature control in the human body.

b. description
The cybernetic loop is superimposed on the physiological components that implement them.

c. components and processes
Loop as per earlier diagrams. Nerves in the skin send signals to the Hypothalamus which controls an increase or decrease in the flow of blood to the skin, depending on whether the goal is to increase or decrease the heat of the body.

How the Regulation of Body Temperature Works



nerves in the **Skin**

. . .send signals to the. . . **Hypothalamus**

which

. . .reduces the flow of blood
to the skins surface, to conserve. . .
(if the surrounding air is too cold)

or

. . .increases the flow of blood
to the skins surface to expel. . .
(if the surrounding air is too warm)

which affects the

First-order Feedback and Modeling Interfaces

a. goal of model
The diagram shows how a human can complete a cybernetic loop.

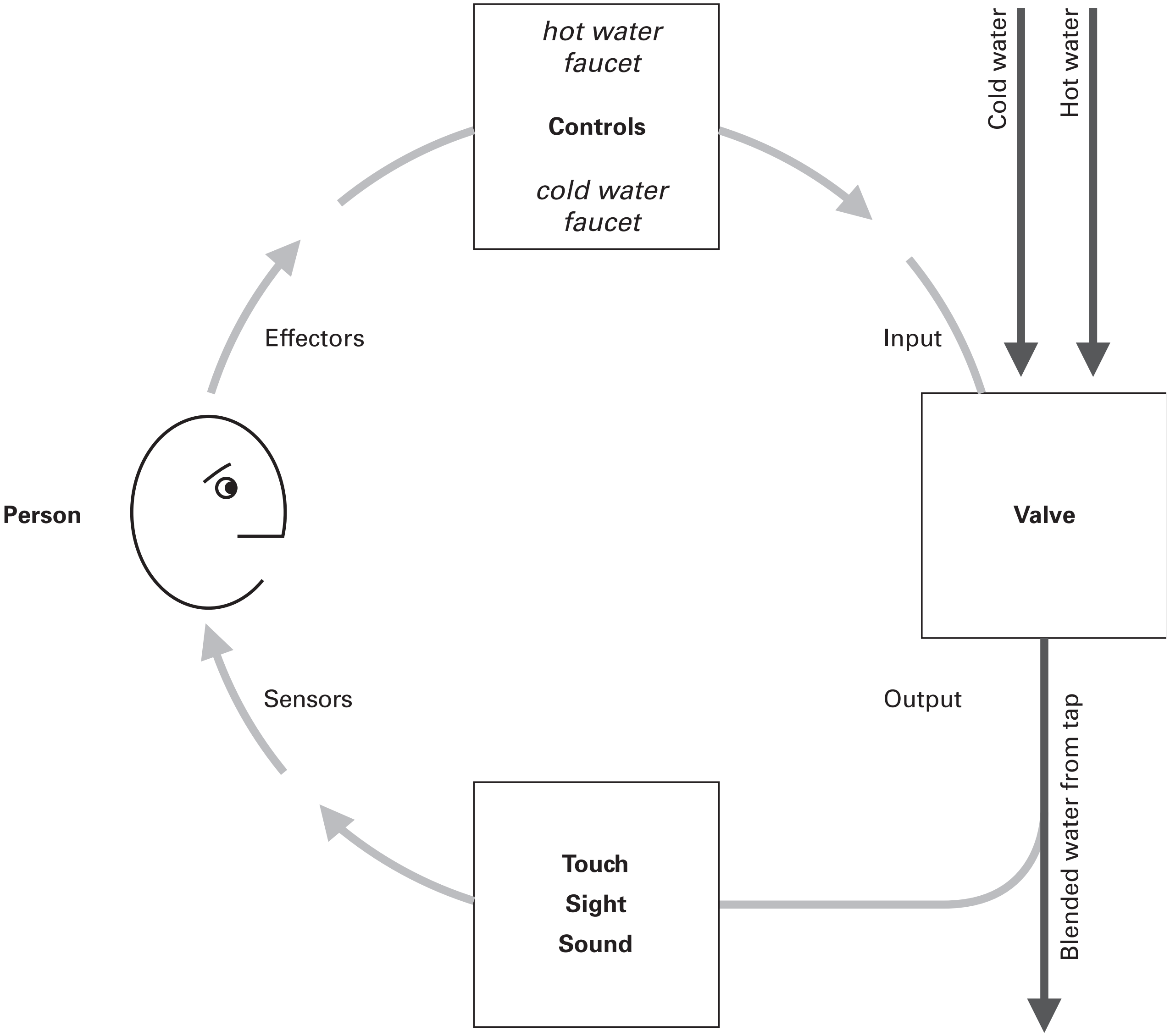
b. description
A person adjusts the flow of hot and cold water in order to obtain the desired temperature and rate of flow.

c. components and processes
Starting from the right side, the Valve controls the water flow, that is, the volume of the Cold water and Hot water. These volumes mix and produce the Output. Via Touch, Sight, and/or Sound—the Person's sensors—the Person can detect the difference between the current an desired state. By deciding on the direction and scale of the error, the Person adjusts the Controls, that is, varies the setting of the Cold and Hot water Valves. This changes the Output, which in turn is sensed by the Person, etc.

d. important aspects of model/breakthrough
Because cybernetics effectively models loops that involve goals, actions, and feedback, cybernetic models can improve a designer's understanding of the role that each component of the system plays: sensors, comparator, and actuators, as well as the feedback channels required to close the loop for the user.

First-order Feedback and Modeling Interfaces

Regulating water temperature



hot water faucet

Controls

cold water faucet

Cold water

Hot water

Effectors

Input

Person

Valve

Sensors

Output

Blended water from tap

Touch

Sight

Sound

First-order Feedback and the Design Process

origins

a. individuals
[when first applied to design? and by whom?]

b. era/dates
Side bar infomation text size

c. references for model, context, author(s), concepts
Side bar infomation text size

d. examples
Side bar infomation text size

a. goal of model
The model maps an iterative process of design to the cybernetic framework. A designer is considered a cybernetic system, in the process of creating a rocket.

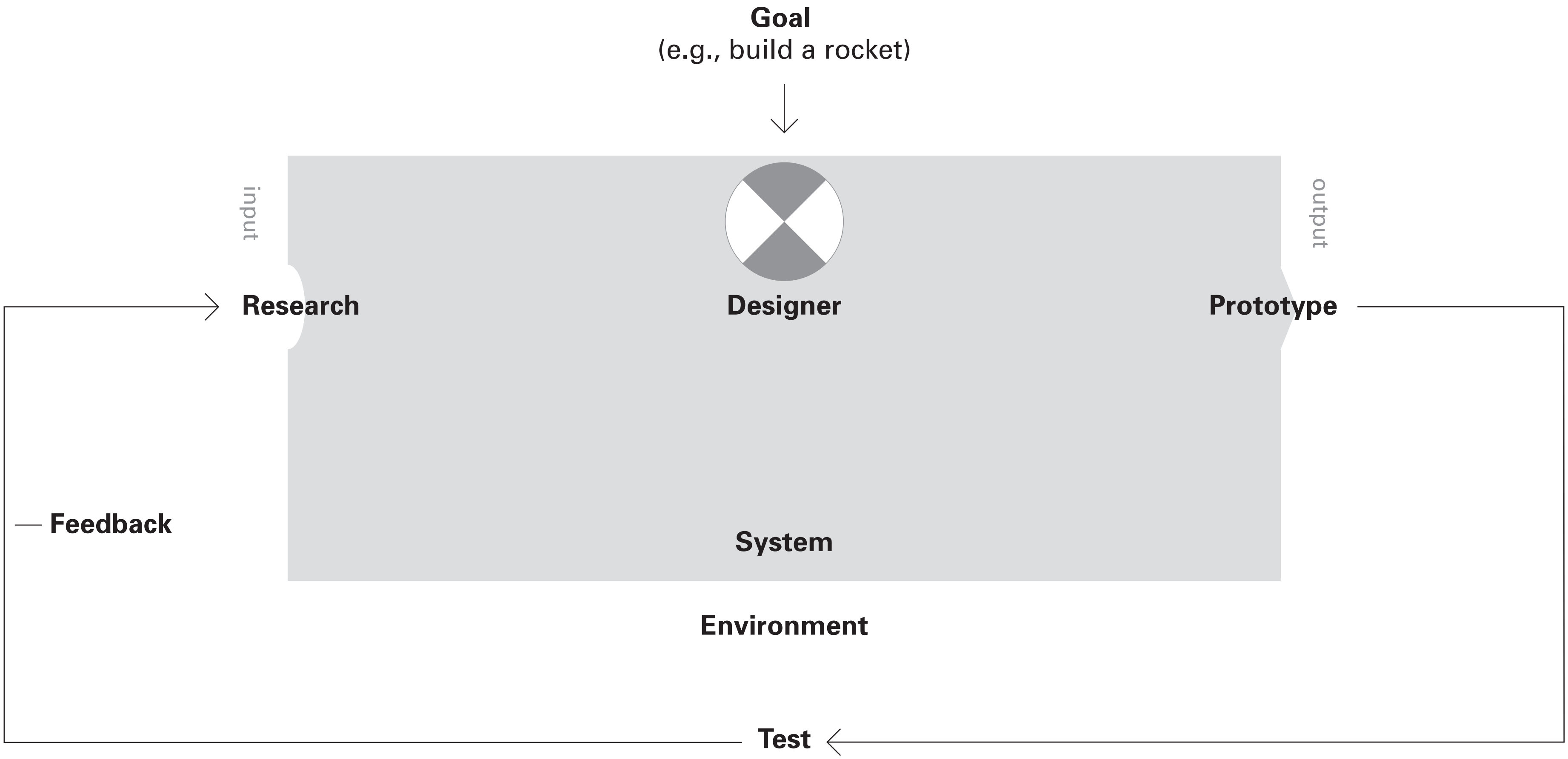
b. description
As usual, the process involves a loop where system actions (building a prototype) have impact on the environment (that which is designed, in this case a rocket). Viability of the built prototype is tested, feedback gathered by the system, and an evaluation made. The process loops and repeats.

c. components and processes
Comparator = Designer
Actuator = Prototyping process
Environment = Prototype being tested
Sensor = Research performed on outcomes of the test

d. important aspects of model/breakthrough
The mapping of design to the cybernetic loop begins the correspondence between cybernetics and design. While design processes have always implied iteration and test of ‘fitness’ of the design to its purpose (the goal of the designer), this model makes the direct correspondence explicit and therefore subject to understanding, improvement, and extension.

First-order Feedback and the Design Process

Prototype-test process



Goal
(e.g., build a rocket)

input

output

Research

Designer

Prototype

— **Feedback**

System

Environment

Test