Introduction to Cybernetics and the Design of Systems

Collected Models
January 2010

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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
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Contents

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*

Cybernetics: Language for Design

Adopted from an article published in Kybernetes

A history of connections between cybernetics and design

The influence of cybernetics on design thinking goes back 50 years. [1] Yet today, cybernetics remains almost unknown among practicing designers and unmentioned in design education or discussions of design theory.

Designers' early interest in cybernetics accompanied cybernetics' brief time in the spotlight of popular culture. First-generation thinking on cybernetics influenced first-generation thinking on design methods. [2] And second-generation design methods [3] has many parallels in second-order cybernetics [4], where the field applied its methodology of focusing on goals, action s, and feedbacks to itself.

Both cybernetics and the design-methods movement failed to sustain wide interest. One reason is that initially both had limited practical application; in some sense, they were ahead of their times and the prevailing technologies. That may be changing. Particularly in the world of design, cybernetics is newly relevant.

Ross Ashby lists as the "peculiar virtues of cybernetics" its treatment of behavior and complexity. (Ashby 1957) Both topics increasingly concern designers, especially those designing "soft" products, those engaged in interface design, interaction design, experience design, or service design. In these areas, where designers are concerned with "ways of behaving"—with what a thing does as much as what it is or how it looks—here, cybernetics can help designers.

Cybernetics as a source for new language in design

Learning a new language increases our repertoire. New words may enable us to think about new ideas. New language may also lead to new ways of "seeing" or to uncovering new relationships between and among elements of a system.

More words may enable us to make finer distinctions. Our thinking and communicating become more precise—we become more efficient. We can work at deeper levels and take on more complex tasks—we become more effective. Our view of our work and ourselves takes on greater coherence—we become more integrated.

Forty years ago, in Notes on the Synthesis of Form, Christopher Alexander described the growing role of modeling in design practice. (Alexander 1964) In the last 10 years, much of design practice has come to rely on modeling. Designers have begun to develop language for discussing behavior—ways of understanding dynamic systems and visualizing patterns of information flows through systems.

Today, most models found in design practice are highly specific to the situation at hand. Designers rarely view the situation they are modeling as an example of a larger class and thus rarely draw on broader frameworks as a basis for their modeling. To be sure, designers have developed some conventions for modeling, e.g., site maps, application flow diagrams, and service blueprints. But for the most part, conventions for modeling are still not widely shared or well-defined within design practice.

In design discourse, most frameworks have been "cherry-picked" from the social sciences and semiotics. For the most part, designers have not established a firm foundation or organized systems for their modeling. Richard Buchanan's formulation of design within frameworks of rhetoric—"design as rhetoric"—is a notable exception. (Buchanan 2001)

The authors propose cybernetics as another rich source of frameworks for design practice, similar to the social sciences, semiotics, and rhetoric. We also propose cybernetics as a language—a self-reinforcing system, a system of systems or framework of frameworks for enriching design thinking.

The idea that cybernetics is a language is not new. Many have pointed out its value as a sort of lingua franca enabling members of different disciplines to communicate. (Ashby 1957) (Pask 1961) (Mead 1968) What may be new is the idea that cybernetics is a language of design. The authors agree with the claim that "the homomorphism between the two is such that . . . cybernetics is the theory of design and design is the action of cybernetics." (Glanville 2007)

Cybernetic frameworks for modeling what we design

Much of design practice comes down to two models: a model of the current situation and a model of the preferred situation. Alexander points out the need to abstract the essence of the existing situation from the complexity of its concrete manifestation. Abstracting the situation makes it easier for us to consider meaningful changes, to find alternatives we might prefer. He also underscores the need to make models visible, to provide representations for ourselves and others to analyze and discuss. (Alexander 1964)

Cybernetics offers conceptual frameworks for understanding and improving the things we design.

At the heart of cybernetics is a series of frameworks for describing dynamic systems. Individually these frameworks provide useful models for anyone seeking to understand, manage, or build dynamic systems. Together, these frameworks offer much of the new language design needs as it moves from hand-craft to service-craft.

In their teaching and practice, the authors have found seven cybernetic frameworks to be especially useful.

1) First-order cybernetic system
A first-order cybernetic system detects and corrects error; it compares a current state to a desired state, acts to achieve the desired state, and measures progress toward the goal. A thermostat-heater system serves as a canonical example of a first-order cybernetic system, maintaining temperature at a set-point that is the system's goal.

A first-order cybernetic system provides a framework for describing simple interaction. It introduces and defines feedback. It frames interaction as information flowing in a continuous loop through a system and its environment. It frames control in terms of a system maintaining a relationship with its environment. It forms a coherence in which goal, activity, measure, and disturbance each implies the others.

This framework is useful for designers thinking about interfaces. It provides a template for modeling basic human interaction with tools, machines, and computers. It also provides a template for modeling machine-to-machine interaction or the interaction of processes running on computer networks.

[Diagram 1, First-order cybernetic system]

2) Requisite variety
Ross Ashby's definition of requisite variety provides a framework for describing the limits of a system—the conditions under which it survives and those under which it fails. (Ashby 1957) For example, humans have variety sufficient to regulate their body temperature within a fairly narrow range; if we get too cold or too hot, we will die quickly.

This framework is useful because it forces designers to be specific when describing systems. It suggests crisp definition of range, resolution, and frequency for measures related to goals, actuators, and sensors. The framework also enables discussion of the validity of goals. What is the range of disturbances we should design the system to withstand? Is the cost of additional variety in the system warranted by the probability of additional variety in disturbances?

[Diagram 2, Requisite variety]

3) Second-Order cybernetic System
A second-order cybernetic system nests a first-order cybernetic system within another. The outer or higher-level system controls the inner or lower-level system. The action of the controlling system sets the goal of the controlled system. Addition of more levels (or "orders") repeats the nesting process.

A second-order cybernetic system provides a framework for describing the more complex interactions of nested systems. This framework provides a more sophisticated model of human-device interactions. A person with a goal acts to set that goal for a self-regulating device such as a cruise-control system or a thermostat.

This framework is useful for modeling complex control systems such as a GPS-guided automatic steering system. It is also useful for modeling ecologies or organizational or social control systems such as the relationship between insurer, disease management organization, and patient. This framework provides a way of modeling the hierarchy of goals often at play in discussions of "user motivation", which take place during design of software and service systems.

[Diagram 3, Second-order cybernetic systems]

4) Conversation, collaboration, and learning (participatory system)
Gordon Pask defined a conversation as interaction between two second-order systems. (Pask 1975) This framework distinguishes between discussions about goals and discussions about methods, and it provides a basis for modeling their mutual coordination—or what Humberto Maturana called "the consensual coordination of consensual coordination of behavior." (Maturana 1997) It also distinguishes between it-directed (control in the cybernetic sense of regulation) and I/you-directed (conversation). Pask also used the framework in discussions of collaboration and learning. Michael Geoghegan wryly observed, "The mouse teaches the cat. . . Of course, . . . the cat also teaches the mouse." (Geoghegan and Esmonde 2002)

This framework is useful for modeling the larger service systems in which many of the products of interaction design are situated. It provides a basis for beginning to model communities, exchanges, and markets, and interactions such as negotiation, cooperation, and collaboration.

The conversation framework suggests a sort of ideal: two second-order systems collaborating. Comparing this model of human-human interaction with typical human-computer interaction suggests many opportunities for improvement. Today, the typical framework for human-computer interaction might best be described as a second-order system (a person) interacting with a first-order system (a device). Designing second-order software systems to understand user goals and aid goal formation suggests a new way for people to work with computers. (Pangaro 2000)

[Take in Diagram 4, Conversation]

5) Bio-cost
The notion of bio-cost grows out of conversations between the authors and Michael Geoghegan. We define bio-cost as the effort a system expends to achieve a goal. (Geoghegan and Esmonde 2002)

This framework is useful for evaluating and comparing existing and proposed interaction methods. It may be possible to measure bio-cost and thus make notions of "ease-of-use" more concrete. We speculate that the bio-cost framework may be useful in developing key-performance indicator (KPI) systems for evaluating software usability and service quality.

[Diagram 5, Bio-cost]

6) Autopoiesis
Francisco Varela, Humberto Maturana, and Ricardo Uribe introduced the idea of autopoiesis or "self-making" to describe processes by which a system achieves autonomy and maintains itself. (Varela, Maturana, and Uribe 1974)

This framework is useful for discussing organizations and communities—how they form and how they maintain themselves. It holds promise for organizational design, which is often a critical component of service design. [The authors are aware of the disagreement as to whether the original, rigorous biological meaning holds for social organizations; we find autopoiesis a unique and powerful metaphor for application to design in any case.]

[Diagram 6, Autopoiesis]

7) Evolution
Geoghegan points out that "all evolution is co-evolution." (Geoghegan and Esmonde 2002) A population changes in response to changes (disturbances) in its environment. In turn, the new population, behaving in new ways, may provoke changes in its environment. Of course, the idea of evolution by natural selection (or natural destruction) precedes the origin of cybernetics as a science, but framing evolution in cybernetic terms expands the scope and value of the earlier frameworks; for example, requisite variety can be seen as a mechanism of evolution and mutations as changes in variety. In addition, framing evolution in cybernetic terms strengthens the set of cybernetic frameworks, giving the whole a sort of completeness.

This framework is useful for discussing the evolution of services and businesses—and the process of innovation. It casts markets as shaping organizations and companies, ideas and products, by evolutionary means. Speciation occurs as new ideas are put forth; selection occurs as they are adopted (or ignored).

[Diagram 7, Evolution]

Value of cybernetic frameworks

These seven frameworks are useful in a variety of ways, for example: analyzing existing systems; comparing systems which may at first appear very different; discerning and organizing patterns of interaction; and evaluating the way a proposed design fits its context. These frameworks apply at several scales: simple interaction between human and device; interaction among component sub-systems; interactions among people through devices or services; interactions between people and businesses (in the coinage of internet business models, "consumer to business" or "C2B") and between businesses ("B2B"); and interactions within markets.

These frameworks also provide a way to look forward in design and suggest the kinds of research from which design practice—and development of software applications and services—may benefit. Of particular interest for design research are systems that model user's goals, systems that help users model and clarify their own goals, systems that facilitate participation, self-organizing systems, and systems that evolve.

Cybernetic frameworks for modeling how we design

The previous section described the application of cybernetic frameworks to design practice. It emphasized using the frameworks to model existing situations and imagine preferred situations. It focused on using cybernetic frameworks to model what we design. This section focuses on using cybernetic frameworks to model how we design—to model the design process itself. Another way to approach this subject is to think of designing the design process; that is, adapting the design process to its context. Here again, the authors have found cybernetic frameworks to be useful.

Cybernetics offers conceptual frameworks for understanding and improving design processes and thus their outcomes.

The seven frameworks we described in the previous section can also model the design process:

1) First-order cybernetic system
Design is a cybernetic process. It relies on a simple feedback loop: think, make, test —in Walter Shewhart's words, "plan, do, check." (Shewhart

1923) It requires iteration through the loop. It seeks to improve things, to converge on a goal, by creating prototypes of increasing fidelity.

In Herbert Simon's words, "Design is devising courses of action aimed at turning existing situations into preferred ones." (Simon 1969) Alan Cooper has called this process "goal directed." (Cooper 1999) When we design, we try to achieve goals, often by imagining the goals of people we hope will use our products.

A model of design as a feedback process applies equally well to design in the traditional hand-craft mode or in the new service-craft mode. In both cases, the designer relies on feedback. What differs is the nature of their prototypes and the degree to which they articulate their goals separately from their product.

2) Requisite variety
Design teams, product development teams, or whole companies (as well as individual designers) have variety; that is, they have a set of skills and experience which they may bring to a project. We can evaluate the fitness of a team or even individuals for a task in terms of the variety they bring. Does the team have the variety required to be successful in this task? Of course, to answer the question, we must understand the goals of the task and possible disturbances.

3) Second-order cybernetic system
Douglas Engelbart has described a process he calls "bootstrapping", which involves three nested cybernetic systems. Level 1 is "a basic process". Level 2 is "a process for improving 'basic processes' ". And level 3 is a process for improving "the process of improving 'basic processes'". (Engelbart 1992)

Here's an example. John's team is responsible for producing a new widget—a level 1 process. John begins holding weekly meetings (Friday afternoon beer busts) at which his team discusses problems—a level 2 process. Implementing ideas from their meetings lowers the widget defect rate. Management asks John to share his improvement and decides to mandate Friday afternoon beer busts for the entire company—a level 3 process.

John Rheinfrank pointed out the need for three-level systems in creating sustained quality management and building true learning organizations. [6]

4) Conversation
Design is conversation, between designer and client, between designer and user, between the designer and himself or herself. Design involves the consensual coordination of goals and methods.

Framing design in terms of conversation has broad implications, challenging the designer's role as expert and casting him or her instead as facilitator—more about these ideas in the next section, A constructivist view—design as politics.

5) Bio-cost
Robert Pirsig has written eloquently about "gumption traps", ways in which people loose the energy necessary to sustain quality work. (Pirsig 1974) A gumption trap is a source of bio-cost in the design process. Minimizing gumption traps and other bio-costs in the design process is a critical component of design management.

6) Autopoiesis
One of the great challenges facing the design profession is how it can create sustained learning about design practice. In recent years, several universities have begun to grant PhDs in design, but design research is still young and relatively unformed. The feedback systems necessary to sustain it are not yet in place. Designers need a self-sustaining, learning system whose components make and re-make itself: the curricula must contain "the practice" while also capturing processes that learn while also sustaining those that already exist. Inherent in the seven cybernetic frameworks are mechanisms to make such activities explicit for the design community and for the institutions (schools, consulting studios, and corporate design offices) that support it.

7) Evolution
The design process is also a process of evolution—artificial evolution, perhaps. Generating new ideas or variations is a form of speciation; the designer's ideas compete for selection and for the chance to reproduce as a new set of variations in the next cycle of iteration. One of the values of design is its ability to speed up the evolutionary process, which might otherwise have to take place within the market, at some greater risk or higher cost.

A few leading design thinkers such as John Rheinfrank and Austin Henderson have begun to discuss designing for emergent behavior and designing for evolution. (Henderson 2003) Still new is the idea that the product of design practice is not fixed, but rather something that will evolve as others use it and themselves design with it. This change may shift designers' attention from making to what Shelley Evenson calls "the making of making." (Rheinfrank and Evenson 2004) We believe this idea will grow in importance and become a major trend in design. If that happens, frameworks for modeling evolution will be critical.

Designers also lack tools for evolving their tools and processes. Progress is slow; innovation is infrequent. Globalization may put pressure on the current environment and force more rapid change.

A constructivist view—design as politics

The design process is more than a feedback loop, more than a bootstrapping process, more even than a "simple" conversation. An approach to design that considers second-order cybernetics must root design firmly in politics. It views design as co-construction, as agreeing not just on solutions but also on problems. It recognizes what Horst Rittel called "the symmetry of ignorance" between designer and constituents of a project and argues both share the same level of expertise or ignorance. (Rittel 1972) It views design as facilitation—as managing conversations about issues.

For Rittel, the main thing in design was managing the myriad issues involved in defining what a team is designing. His view led to early work in creating issues-based information systems (IBIS), which provided a foundation for more recent research in design rationale, which is still an on-going area of inquiry. (Rittel 1970)

Heinz von Foerster pointed out the limitations of defining systems in objective terms. Von Foerster asked, "What is the role of the observer?" (von Foerster 1981)

Horst Rittel pointed out the limitations of defining design in objective terms. Designers often describe their work as problem solving, but Rittel asked, "Whose problem is it?" He showed that the framing of the problem is a key part of the process. He posited agreement on definition of the problem as a political question. And he noted that some ("wicked-hard") problems defy agreement, for example, in modern times, bringing peace to Palestine or creating universal health care. (Rittel and Weber 1969)

How remarkable that both von Foerster and Rittel reacted to their milieus in the same way, debunking the notion of objective, detached observation, recognizing the subjective and involved nature of our work. Here, second-order cybernetics and second-generation design methods converge (perhaps by coincidence, for we cannot establish explicit links as with the original cybernetics movement which clearly affected first-generation design methods).

Rittel also noted that if design is political, then argumentation is a key design skill. Here is a design theorist with a background in physics and operations research, influenced by cybernetics, concluding design is not objective but instead political and thus rooted in rhetoric. He comes to the same conclusion as Richard Buchanan, who has a background in the humanities. This link is extraordinary. It is an important connection between two different ways of understanding design. It suggests a foundation for moving forward within design practice and design education.

A call for curriculum change

Our culture is undergoing a change as profound as the industrial revolution, which gave birth to the design profession. The ongoing shift to a knowledge-service economy and the continuing growth of information-communication technology will profoundly change the practice of design.

Design educators need to respond to these changes.

Cybernetics can help designers make sense of the complex new world they face. Cybernetics can inform design on at least three levels:
1) modeling interaction—human-human, human-machine, or machine-machine,
2) modeling the larger service systems in which much interaction takes place, and
3) modeling the design process itself.

As the founders of cybernetics and the founders of the design methods movement pass away[7], the risk increases that much of what they learned will be lost to future generations. That would be a tragedy.

We urge design educators to radically alter the current approach to design education and to adopt a systems view incorporating in their teaching the language of cybernetics—and rhetoric.

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Notes

[1] Nortbert Wiener lectured at the Hochschule für Gestaltung Ulm (HfG Ulm). Ulm required students to take a course in cybernetics. Herbert Simon noted the relationship of cybernetics to design in Sciences of the Artificial. Stewart Brand recommended books on cybernetics right alongside those on design theory in his Whole Earth Catalog.

[2] Two founders of the design methods movement, Bruce Archer and Horst Rittel, explicitly mention cybernetics in their writing on design. Rittel incorporated cybernetics in his courses on design methods at UC Berkeley.

[3] In 1972, Horst Rittel proposed a second generation of design methods in "On the Planning Crisis: Systems Analysis of the 'First and Second Generations'". He stressed the difficulty of maintaining an objective view of design, and he presented the second-generation approach as an expert-less argumentative process that is inherently collaborative and political.

[4] In a 1972 lecture, Heinz von Foerster proposed second-order cybernetics. He noted the role of the observer in describing systems, and he too stressed the difficulty of maintaining an objective view.

[5] While design has many similarities to architecture, architectural practice has a separate history, which we will not cover here.

[6] Personal discussion, which took place at CMU School of Design in 2004.

[7] Gordon Pask died in 1996; Heinz von Foerster in 2002; Horst Rittel in 1990, and Bruce Archer in 2005.

Introduction to Cybernetics
a basis for modeling interfaces and the design process

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January 2010

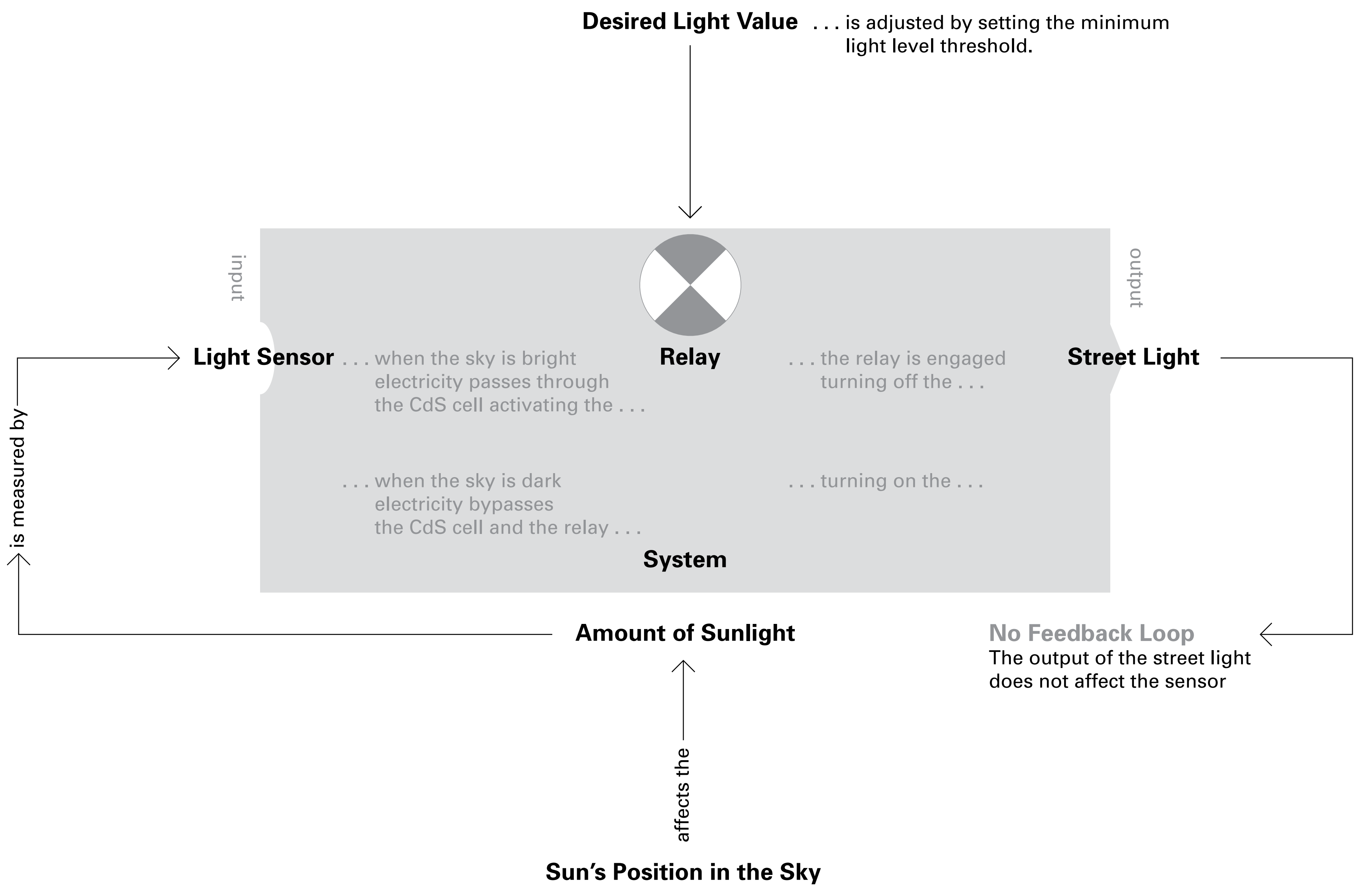
Open-loop Models

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

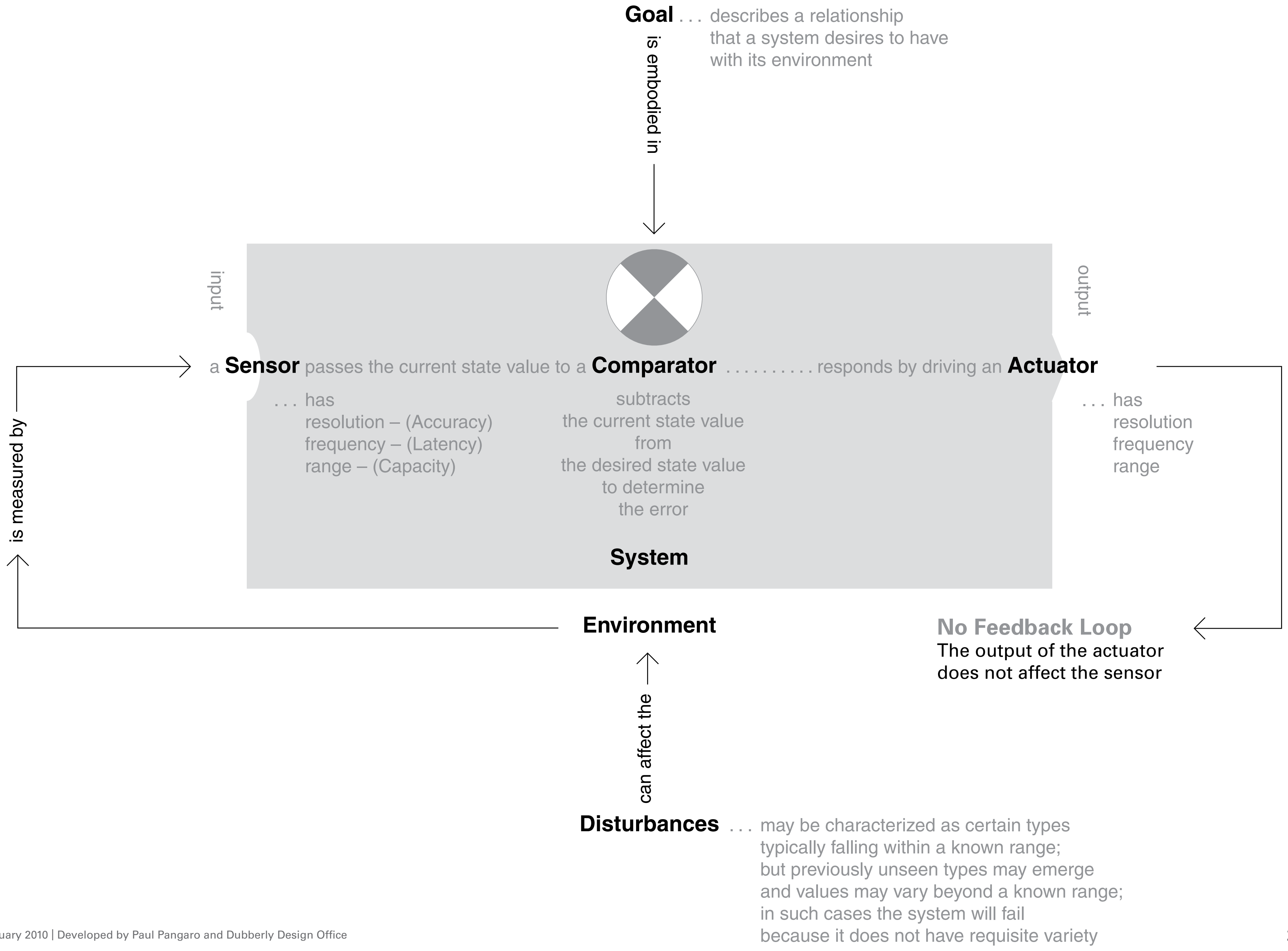


Open-Loop: Canonical Form
First-order System

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

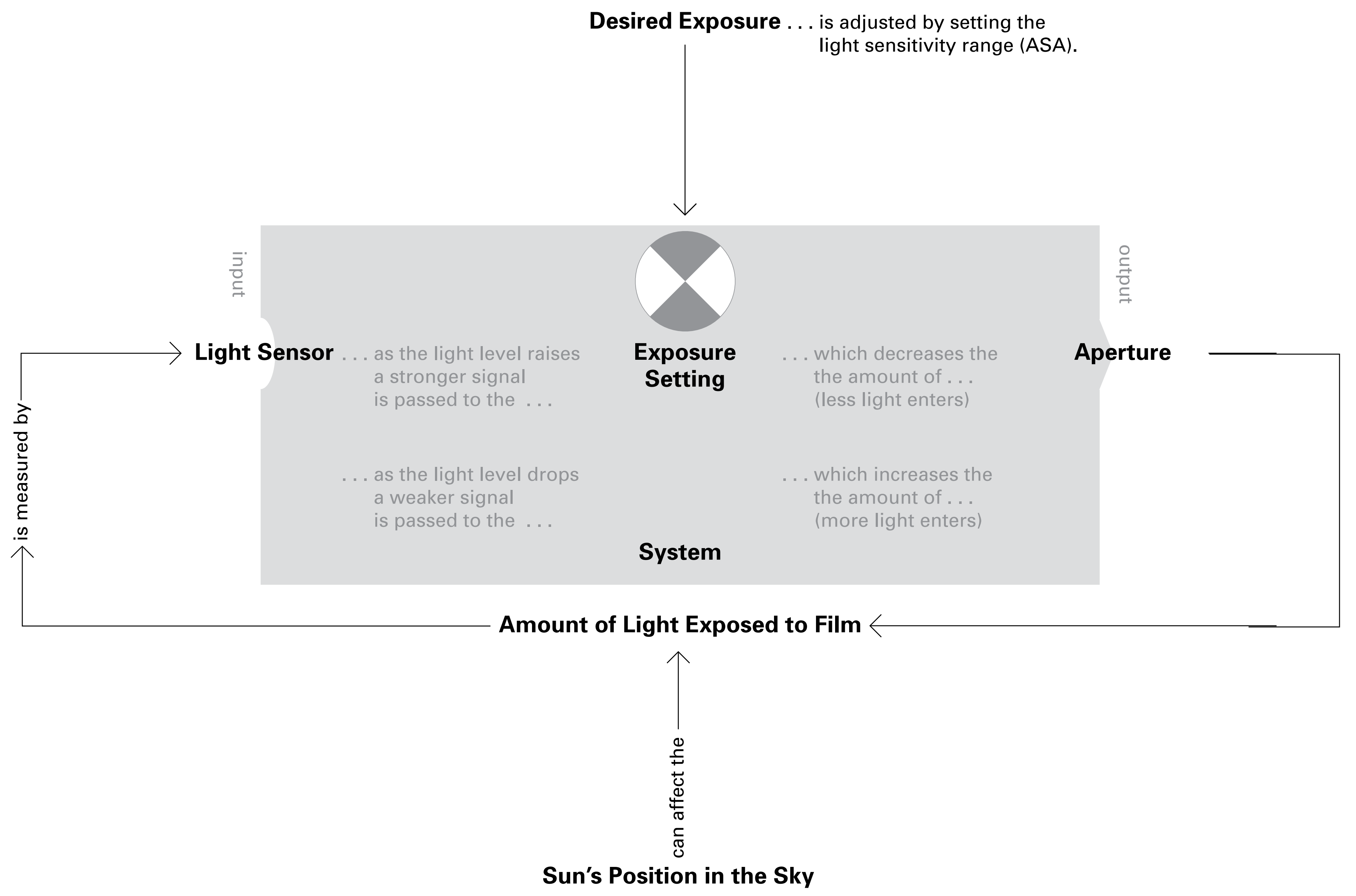


Closed-Loop: Mechanical Example
Camera auto-exposure (shutter priority)

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.



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.

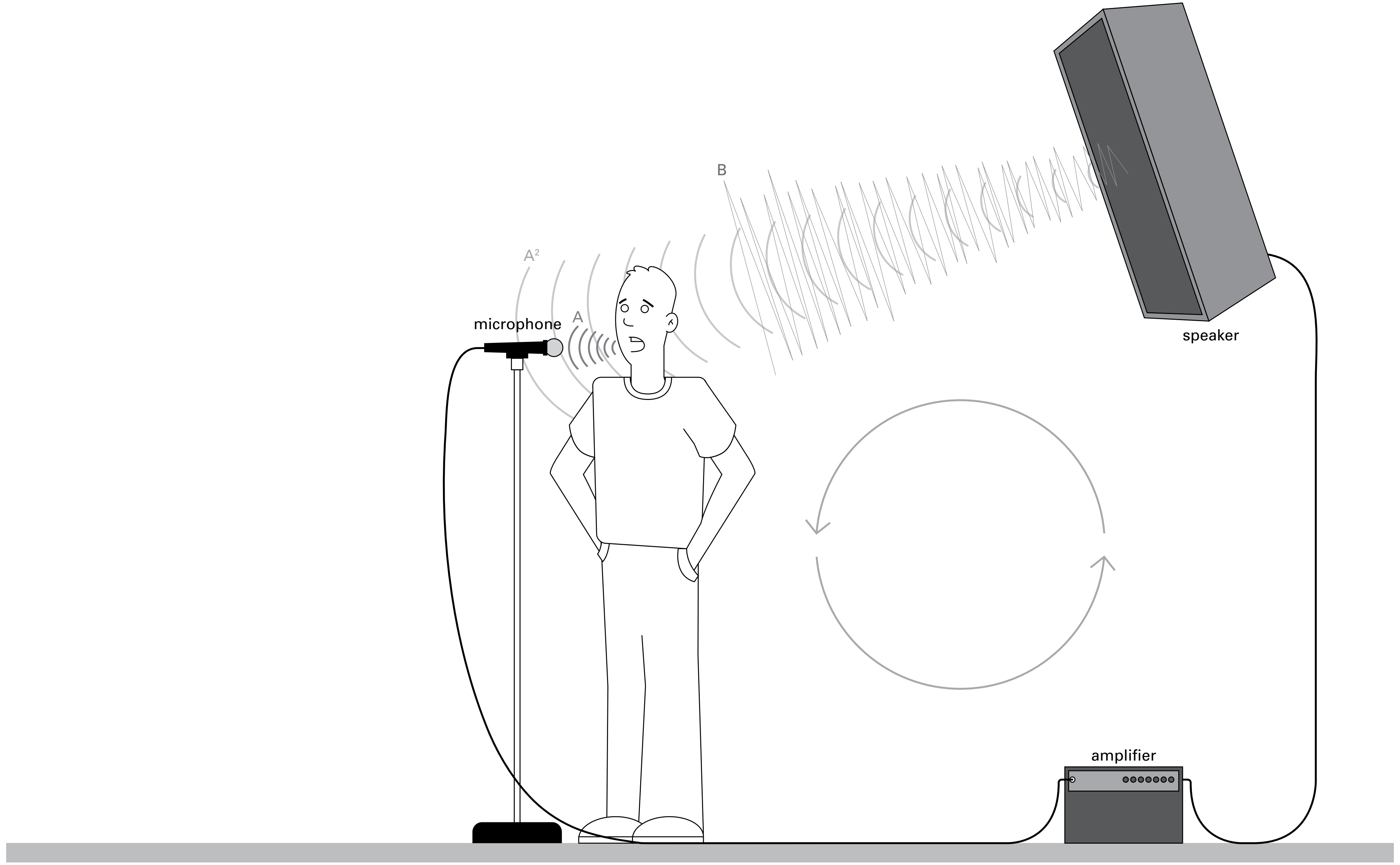
b. description
A "public address system", whose intention is to amplify sound detected at a microphone, instead produces a high-pitched, ear-splitting scream. This is referred to as "feed-back" because of the mechanism that causes it, explained below.

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.

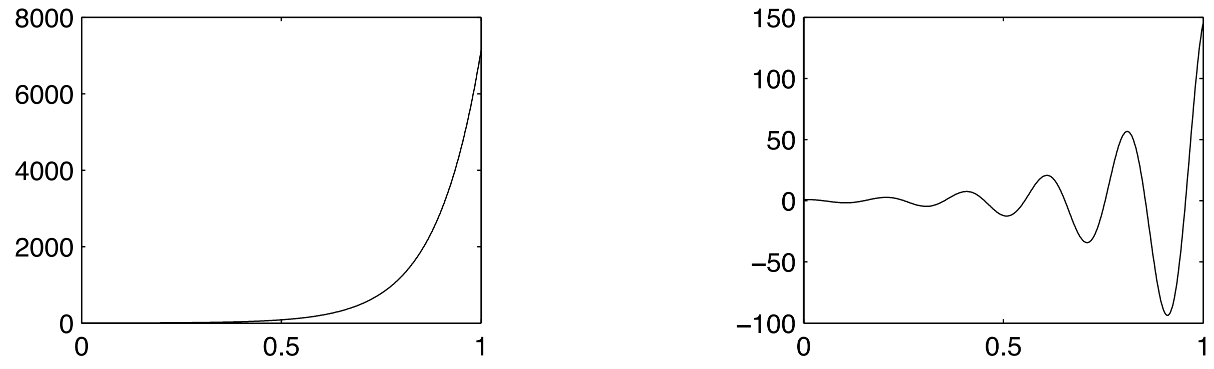
Negative feedback means that a variables movement in a given direction (positive or negative) causes the system to respond in a manner that causes the variable to move in the opposite (or 'negative') direction. As the process continues, the variable's value converges to a stable value.

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.

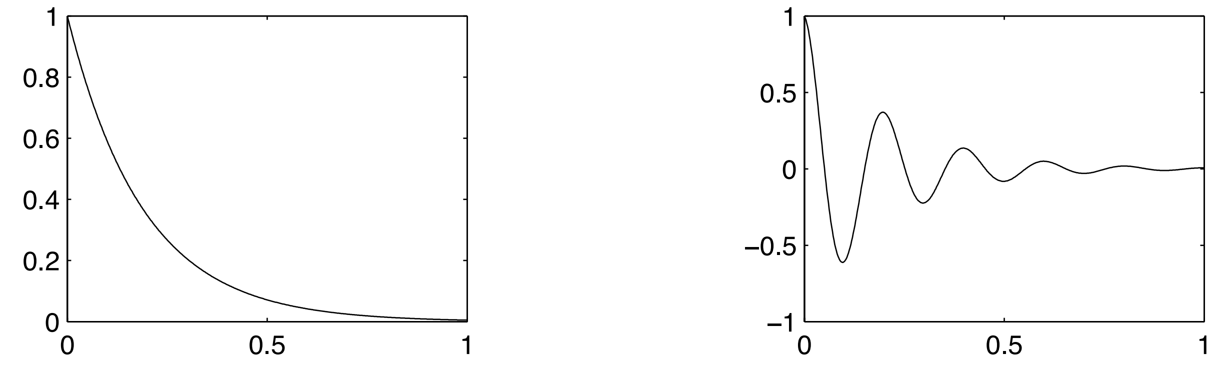
The lower graphs show the change in a variable as a negative feedback process causes convergence to a stable value (here shown as 0, but other values are possible). The left graph shows the simple attenuation of a value. The right graph shows the damping of an oscillation in a system variable until a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

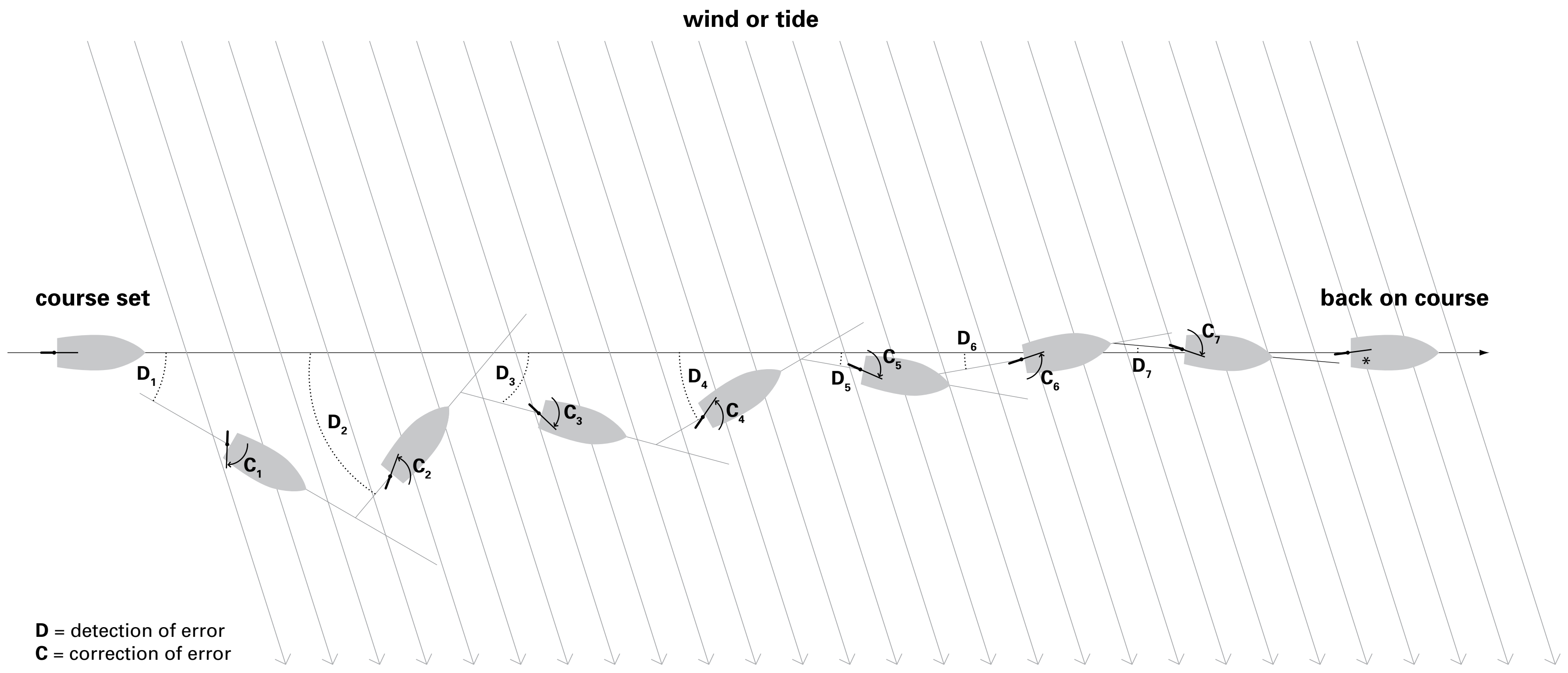
b. description
The term 'cybernetics' is derived from the Greek word 'kubernetes', usually translated as 'steersmanship', meaning the understanding and skills required to successfully steer a ship to its desired destination.

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.

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

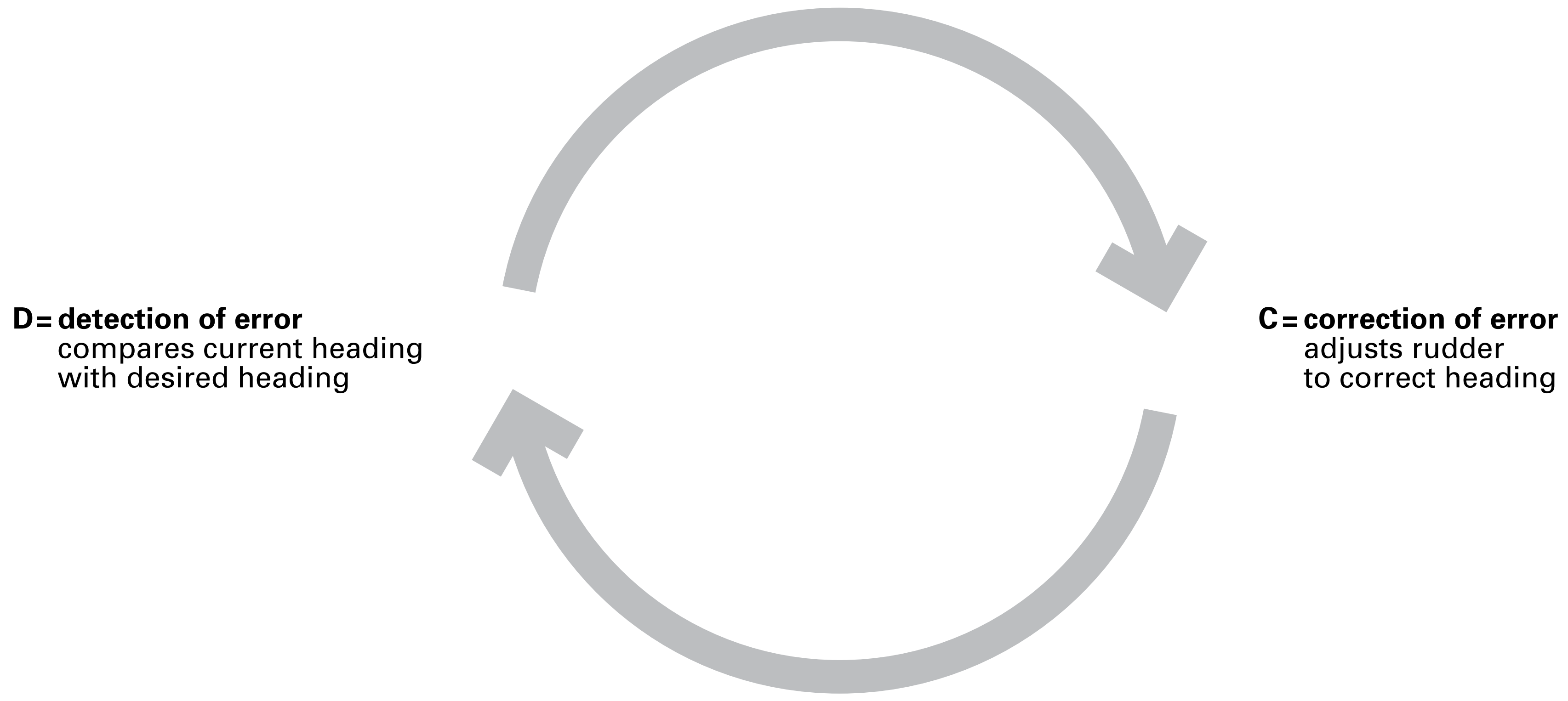
F. L. Lewis, Chapter 1: Introduction to Modern Control Theory, from *Applied Optimal Control and Estimation*, Prentice-Hall, 1992. Available at http://arri.uta.edu/acs/history.htm.

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…'



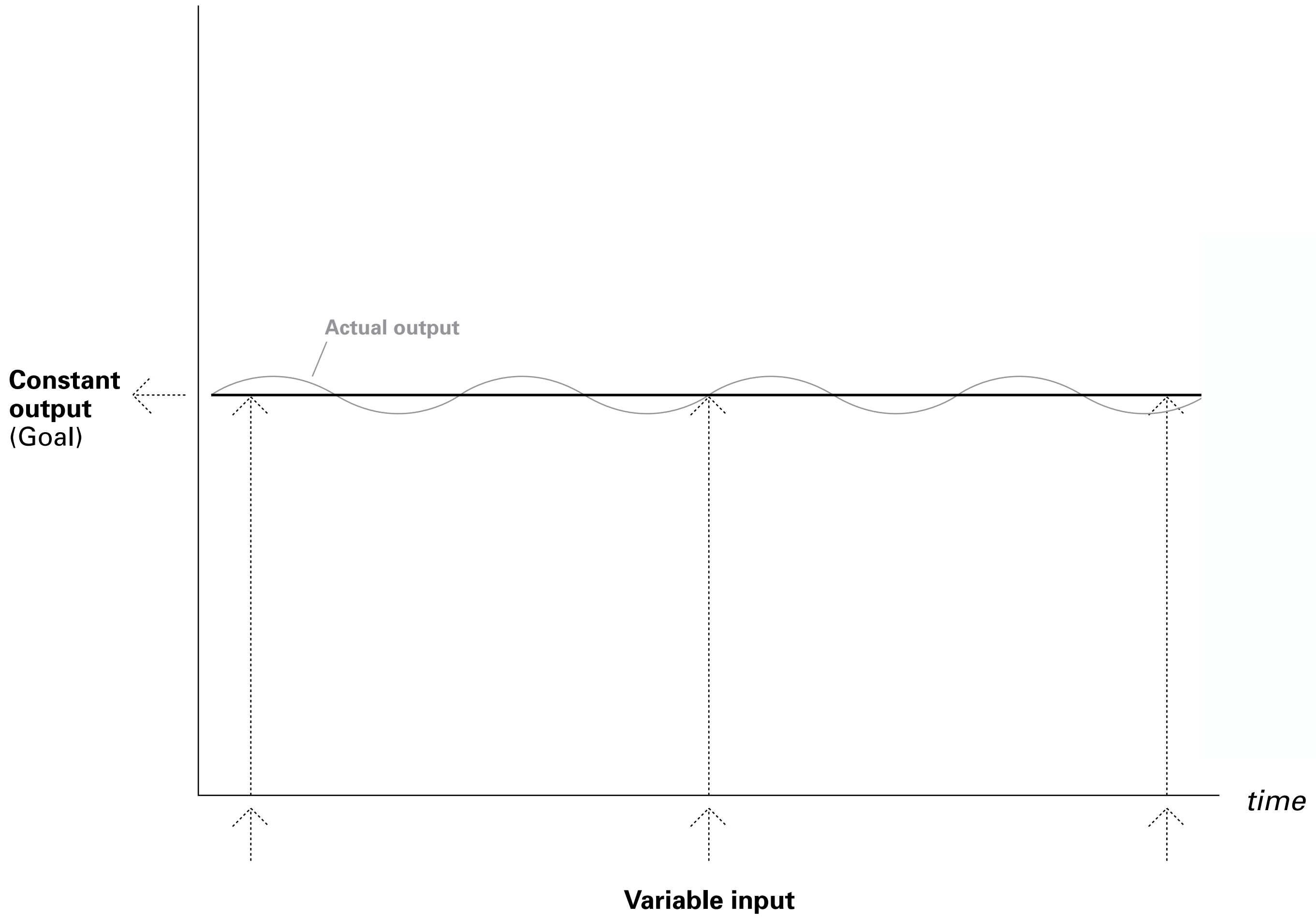
Goal of Regulator or Governor

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.

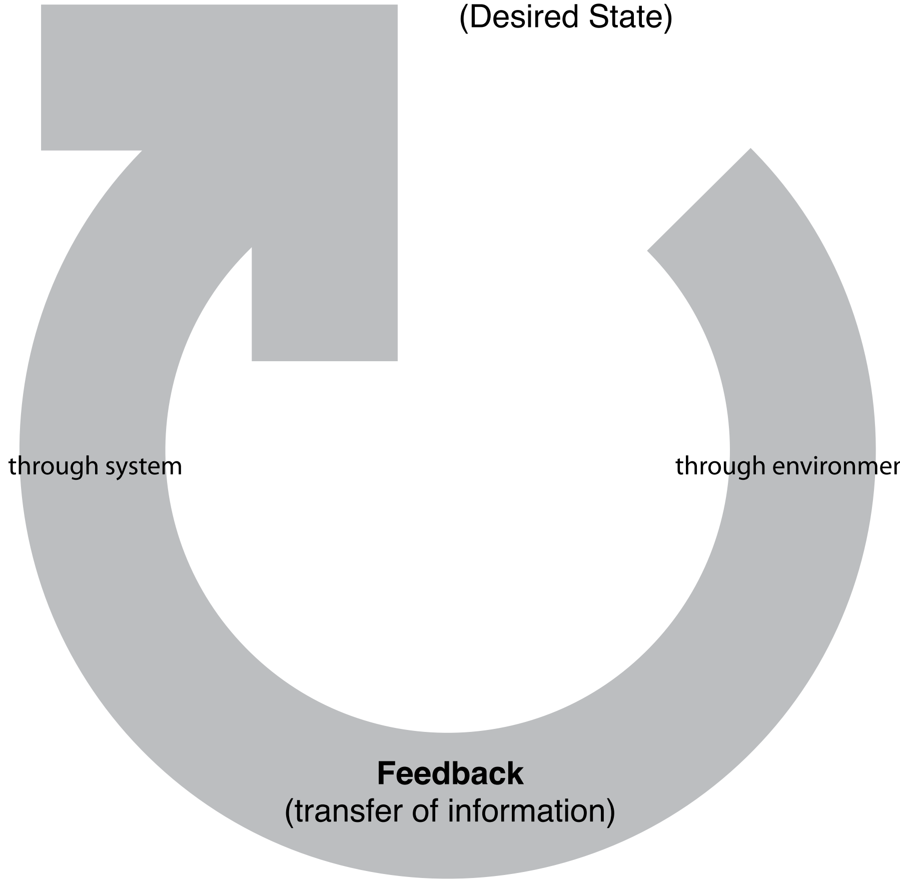
a. goal of model
This model describes the nature of the cybernetic loop at the level of a system's observed behavior. The model treats the system as a black box whose internal functions and specifics are not shown.

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



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.

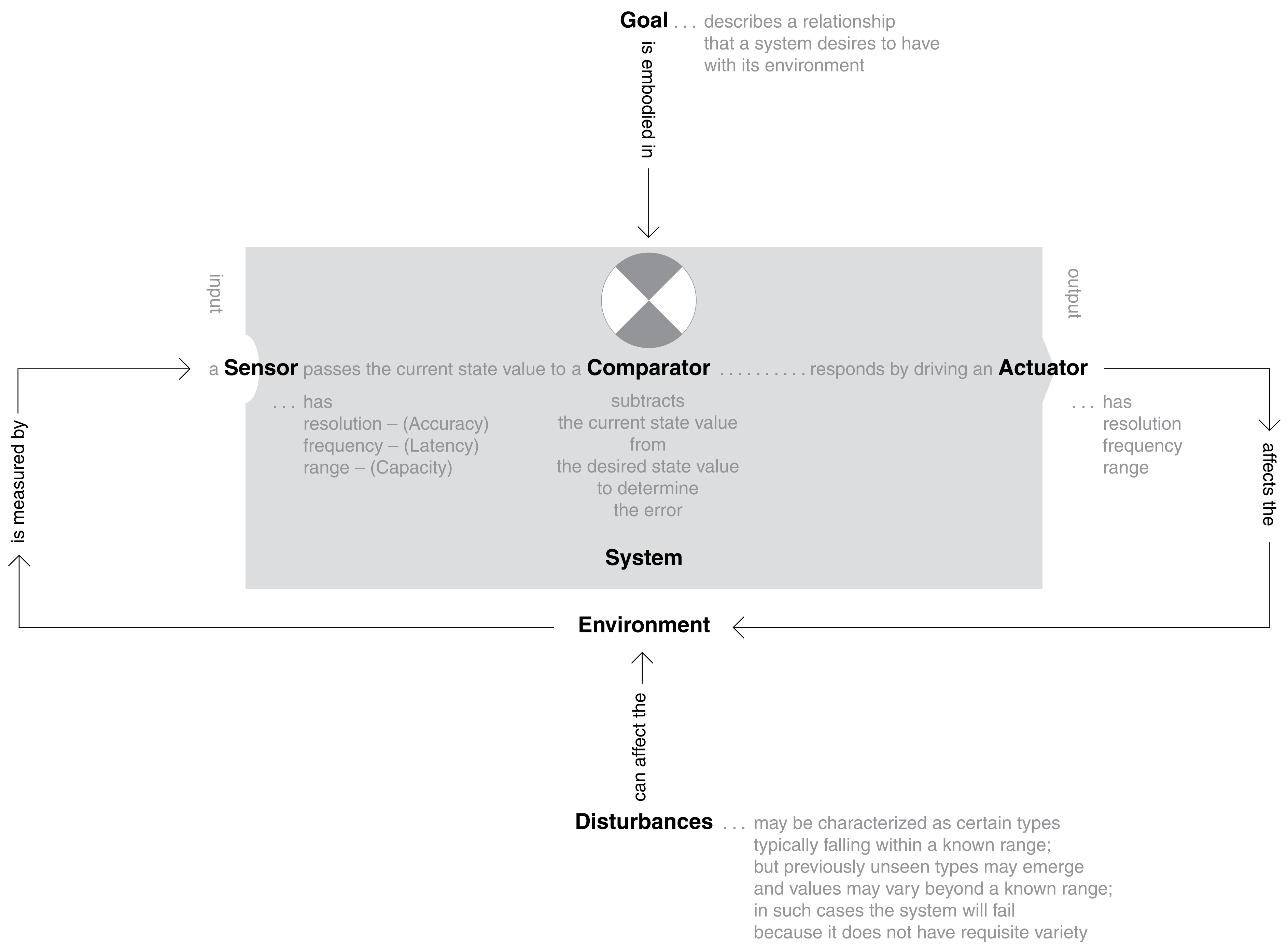
c. components and processes
The system is shown as the shaded box; all other areas are the system's environment. The goal is reified by the specifics of the system's construction:

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



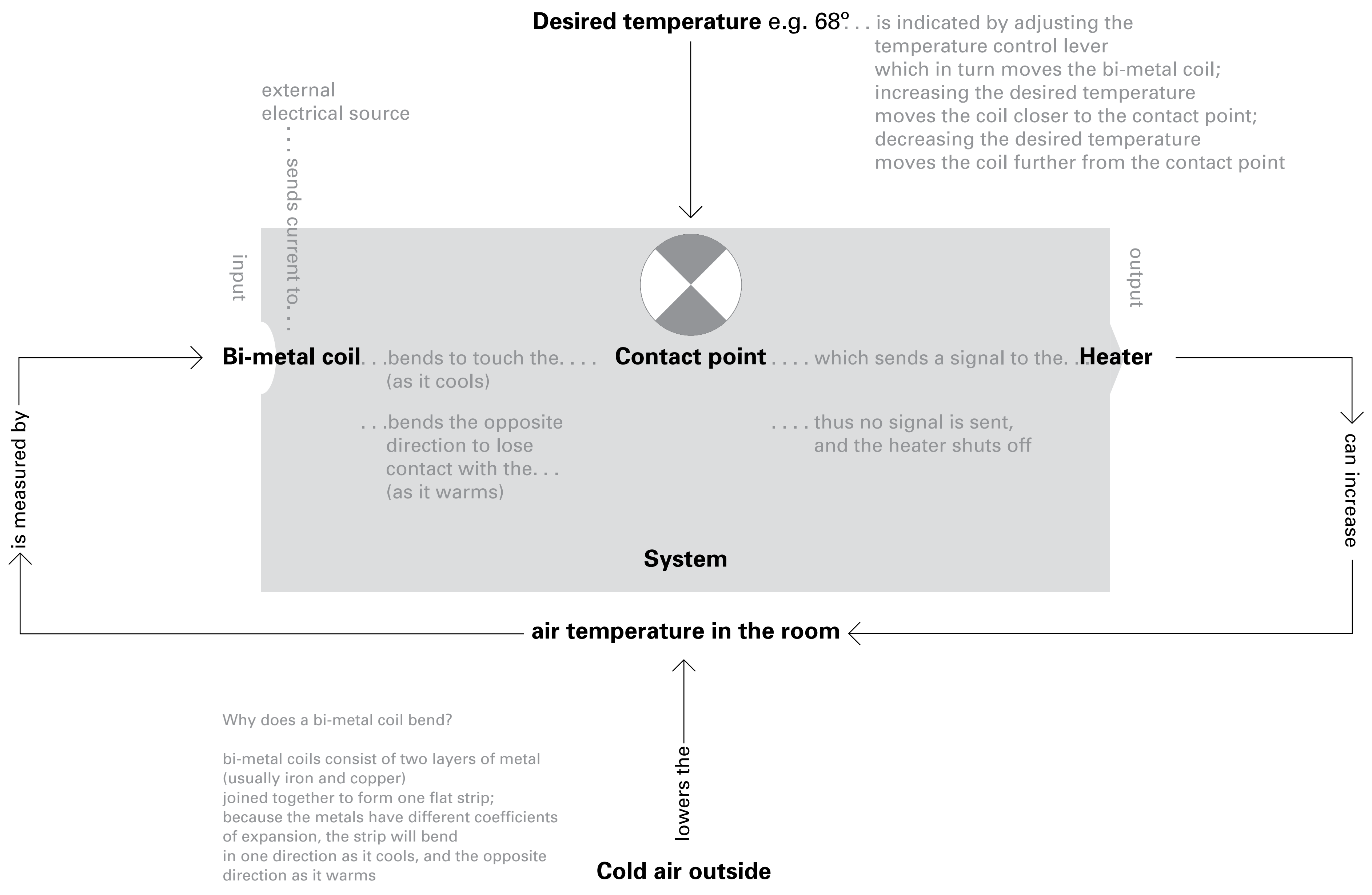
a. goal of model
This model results from the application of the previous formal model of a cybernetic system to a room thermostat.

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)



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

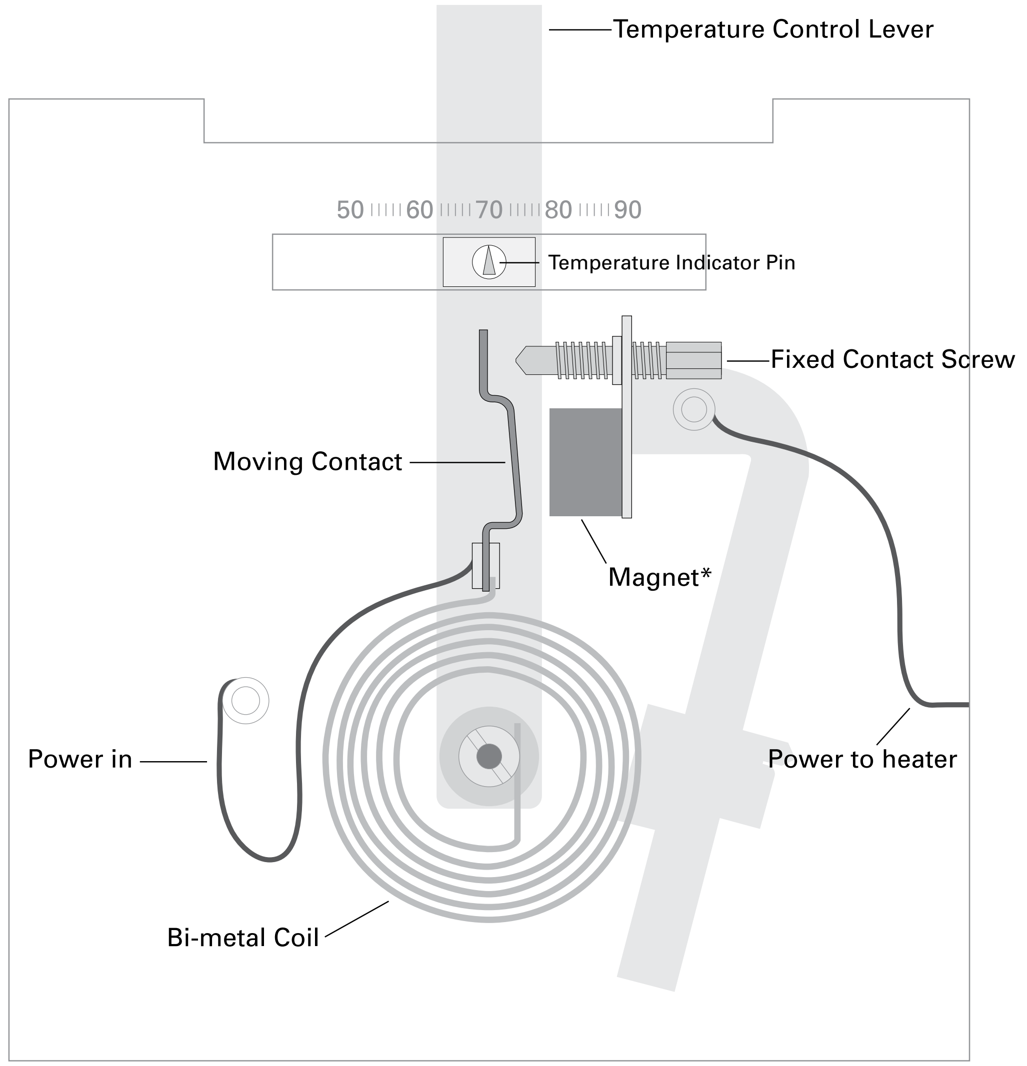
a. goal of model
This diagram shows a specific example of an electro-mechanical room thermostat, used in the previous model.

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.

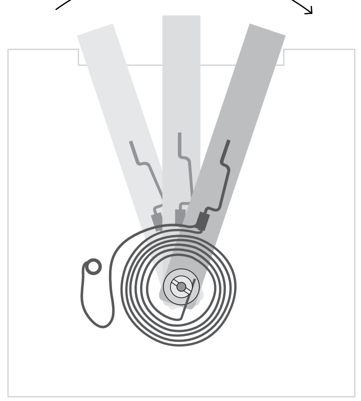
d. important aspects of model/breakthrough
The diagram displays an embodiment of the individual elements of a cybernetic system, namely, a sensor (Bi-metal Coil), comparator (relationship of the Moving Contact to the Fixed Contact), and actuator (closing of the circuit to turn on the heater when contact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

How a Thermostat Works

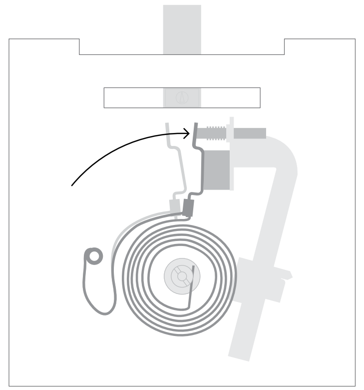


The bi-metal coil is connected
to the temperature control lever.

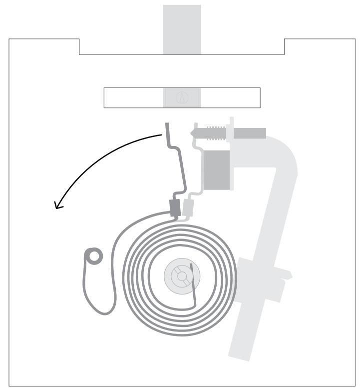
*The magnet insures a good contact
and prevents erratic on/off signals
to the heater in the event that the
air temperature within the room fluctuates
to quickly.



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

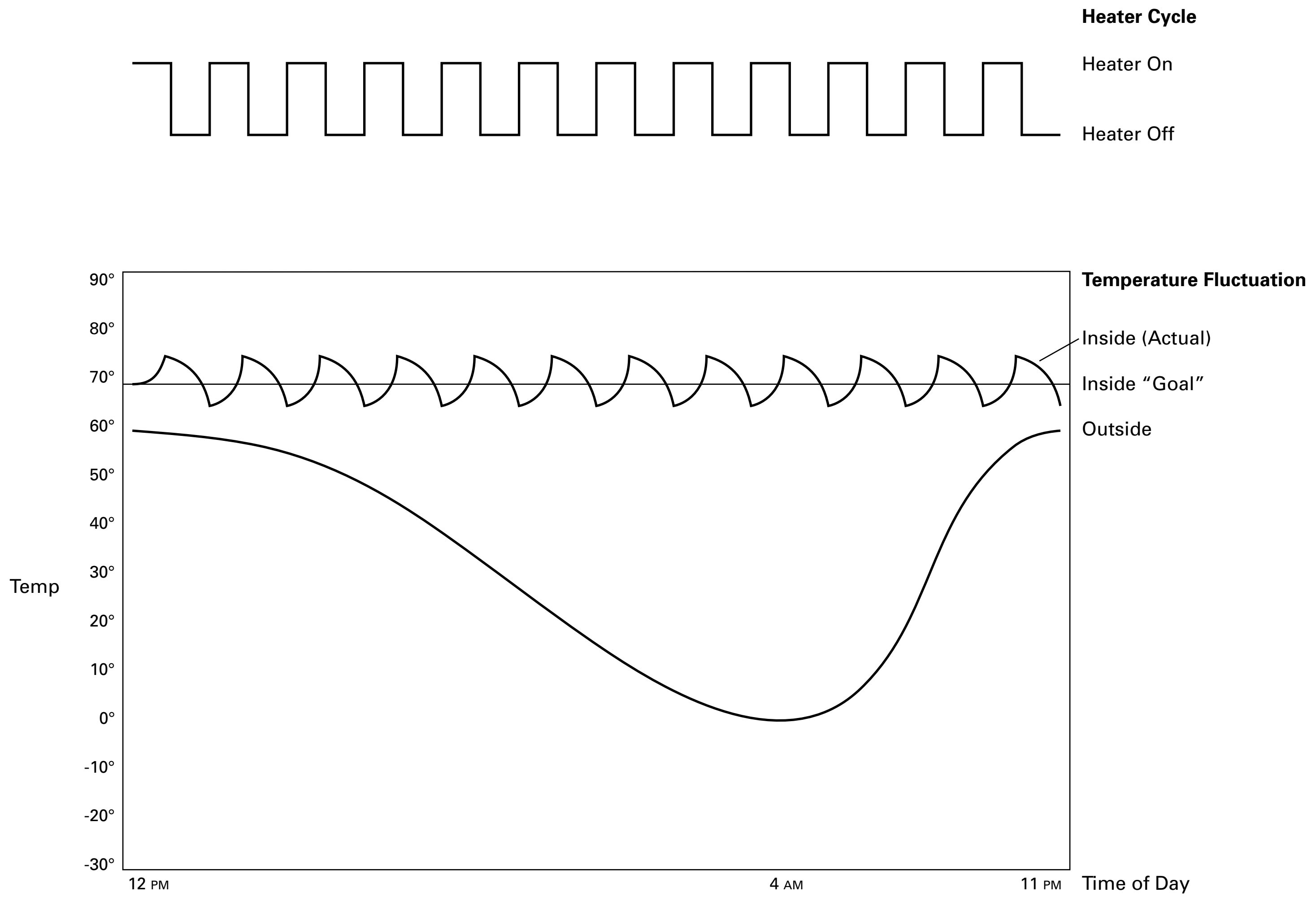
a. goal of model
This diagram compares the results of a regulated system to that of an unregulated one.

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.

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

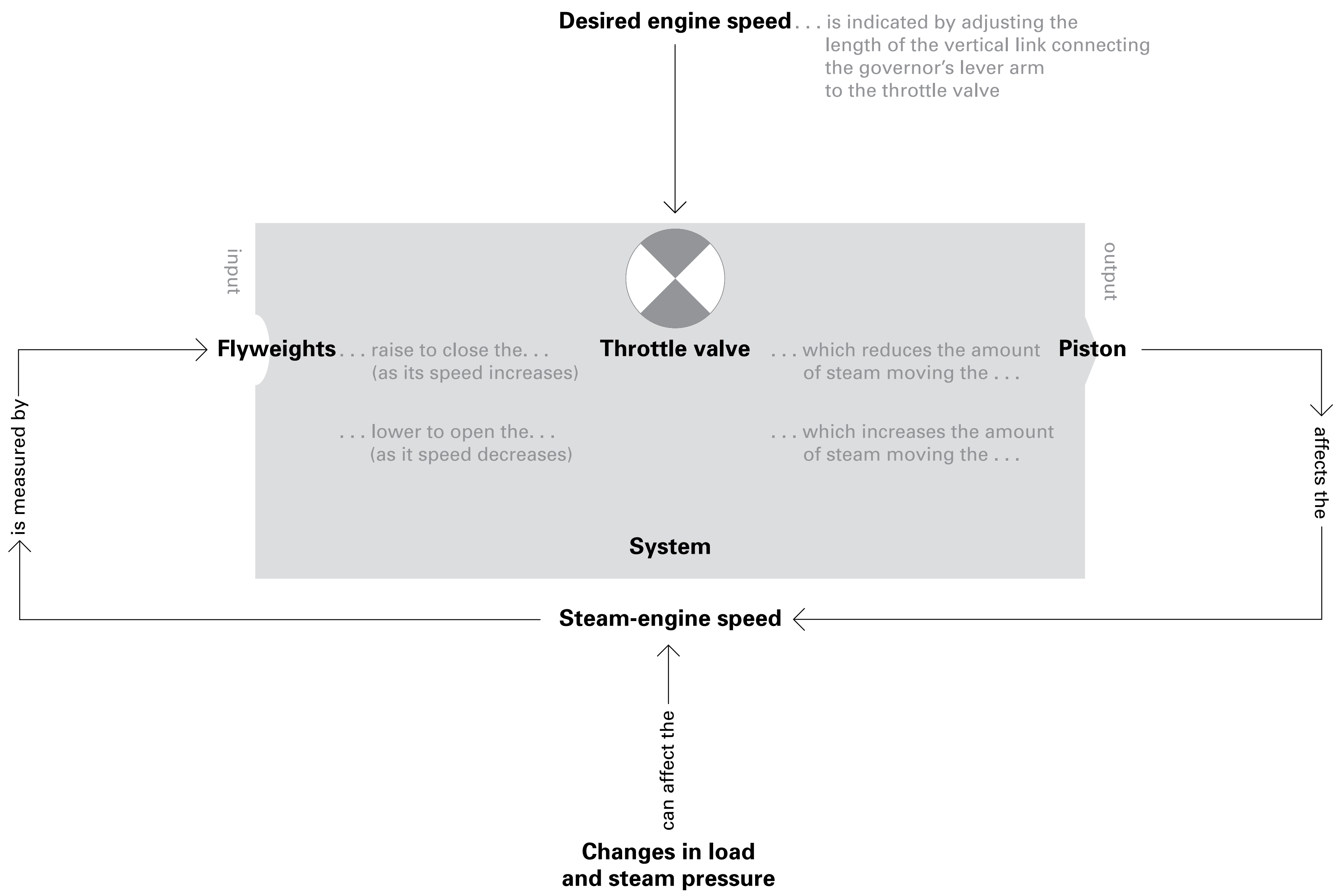
b. description
Components of the flyball governor are mapped to the cybernetic loop.

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

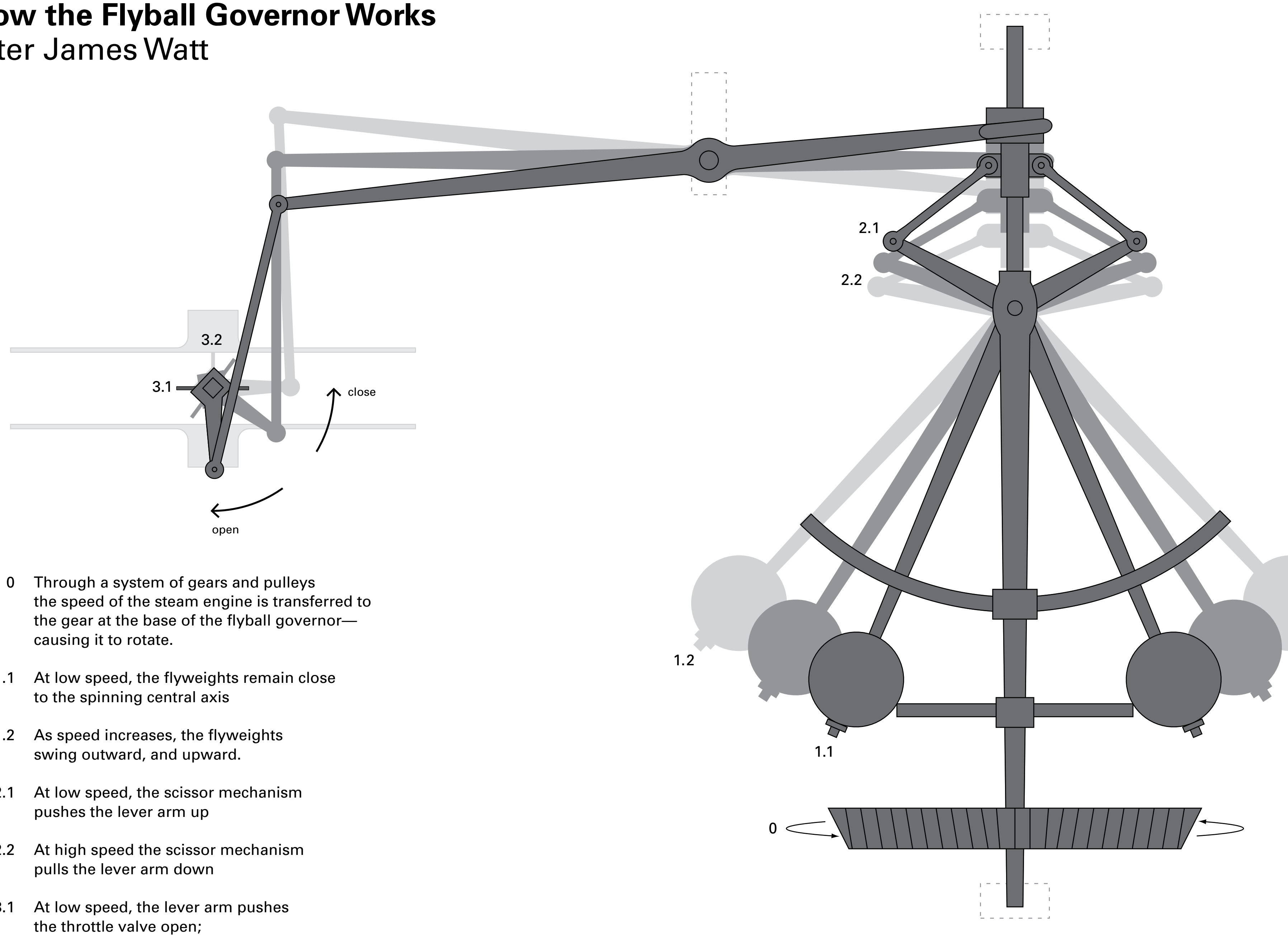


How the Flyball Governor Works
after James Watt

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

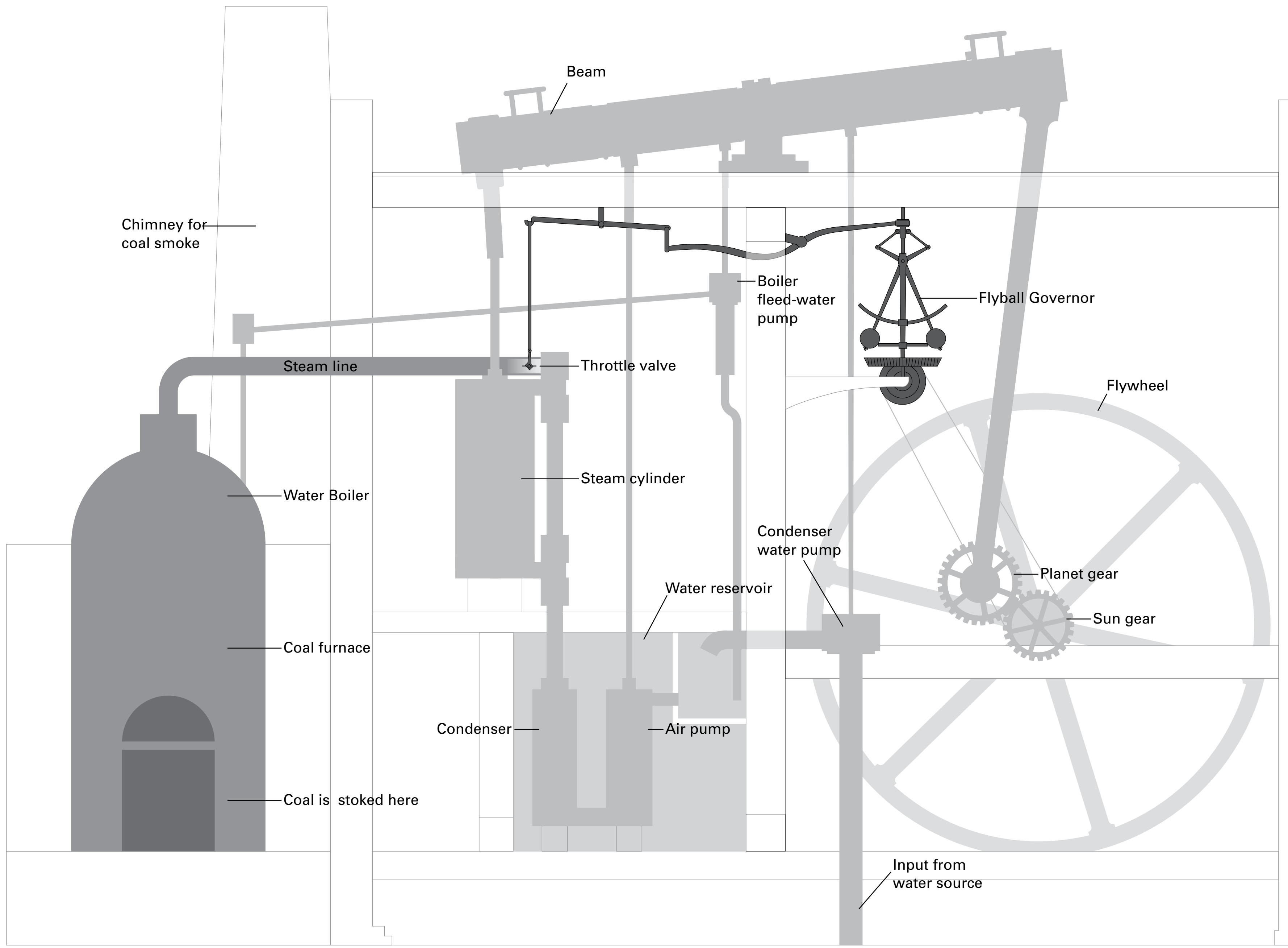
3.1 At low speed, the lever arm pushes the throttle valve open; increasing the flow of steam

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.

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



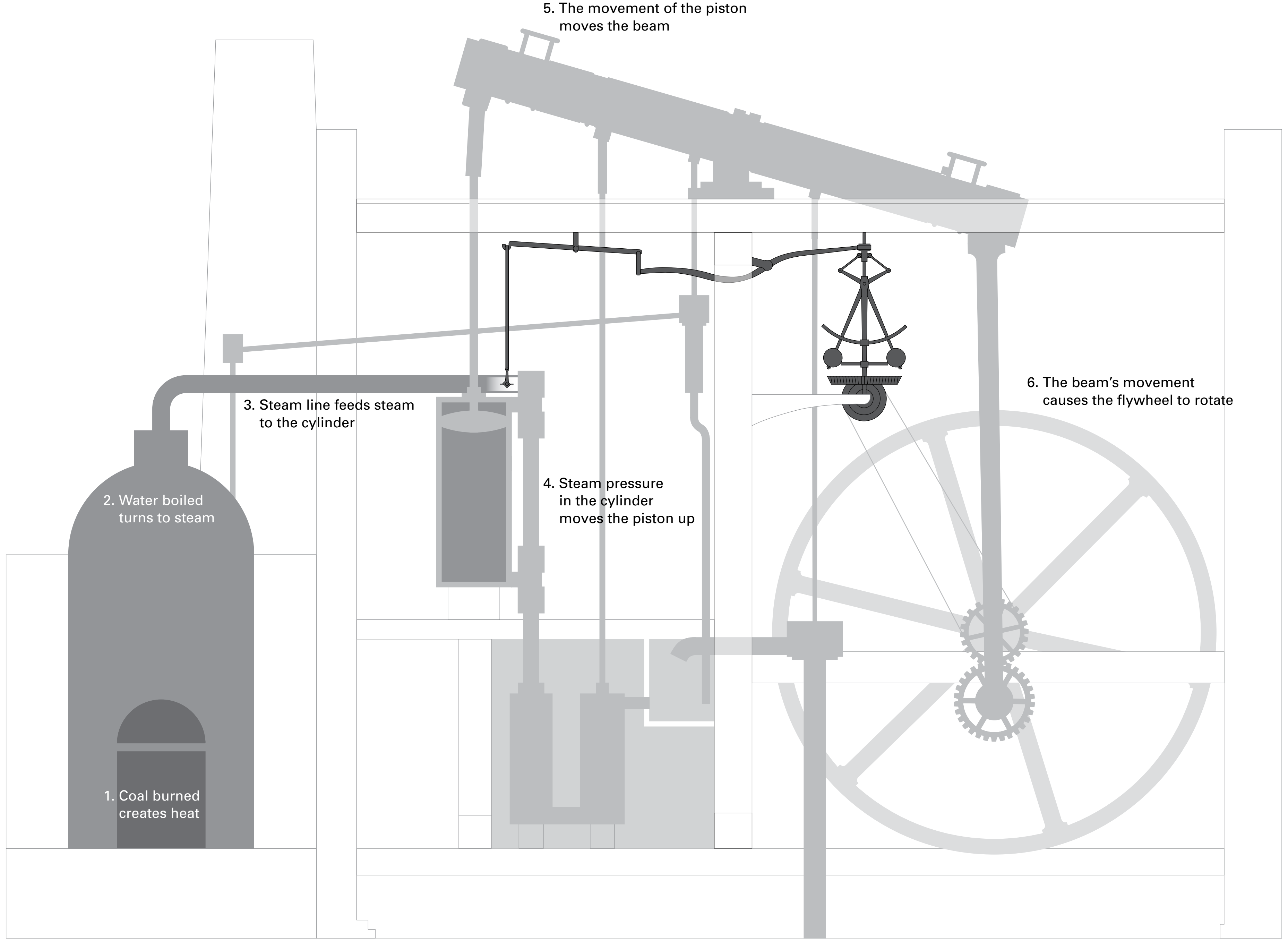
At low speed the throttle valve opens

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

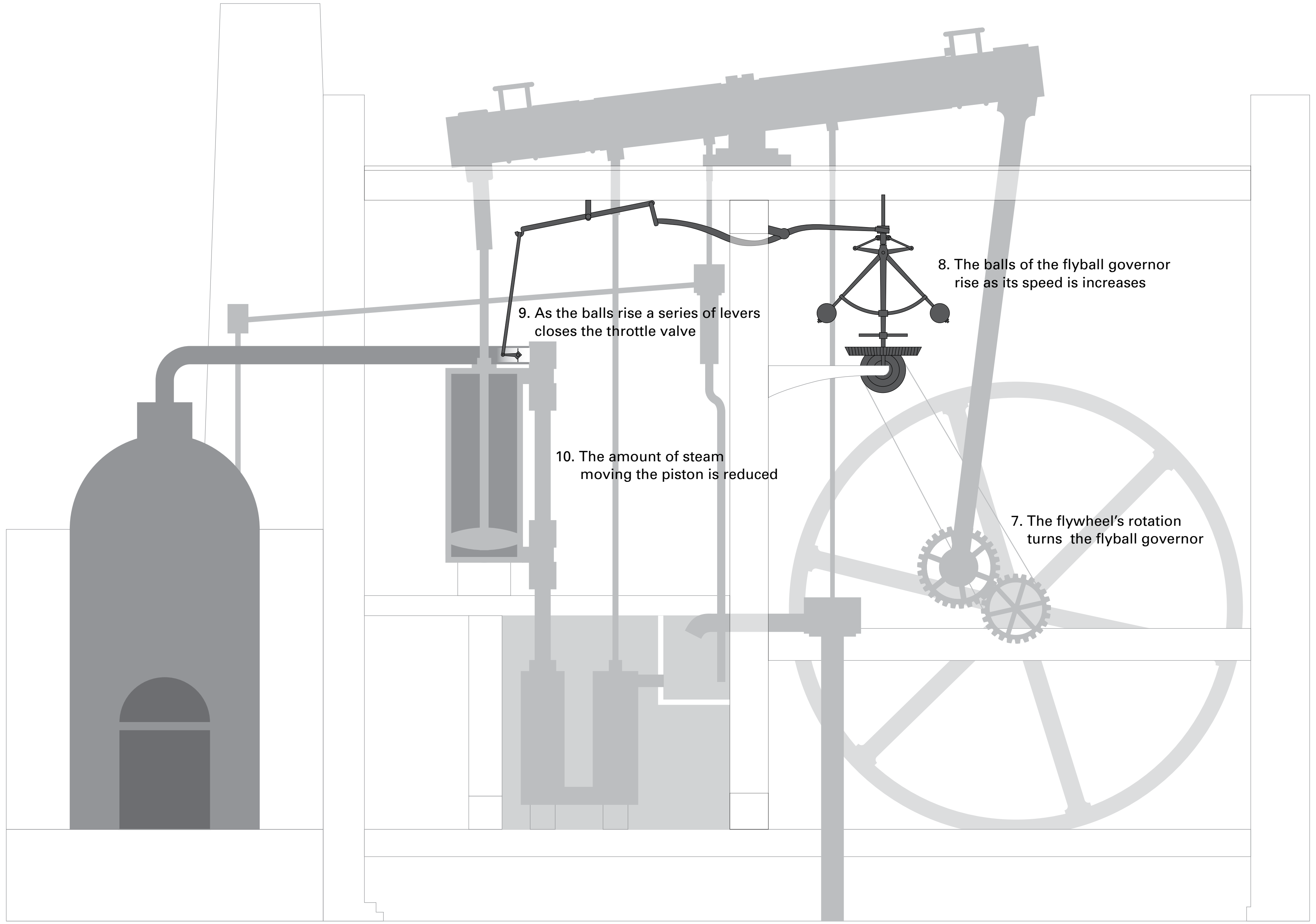


a. goal of model
The configuration of the system when the engine is turning at high speed is shown.

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

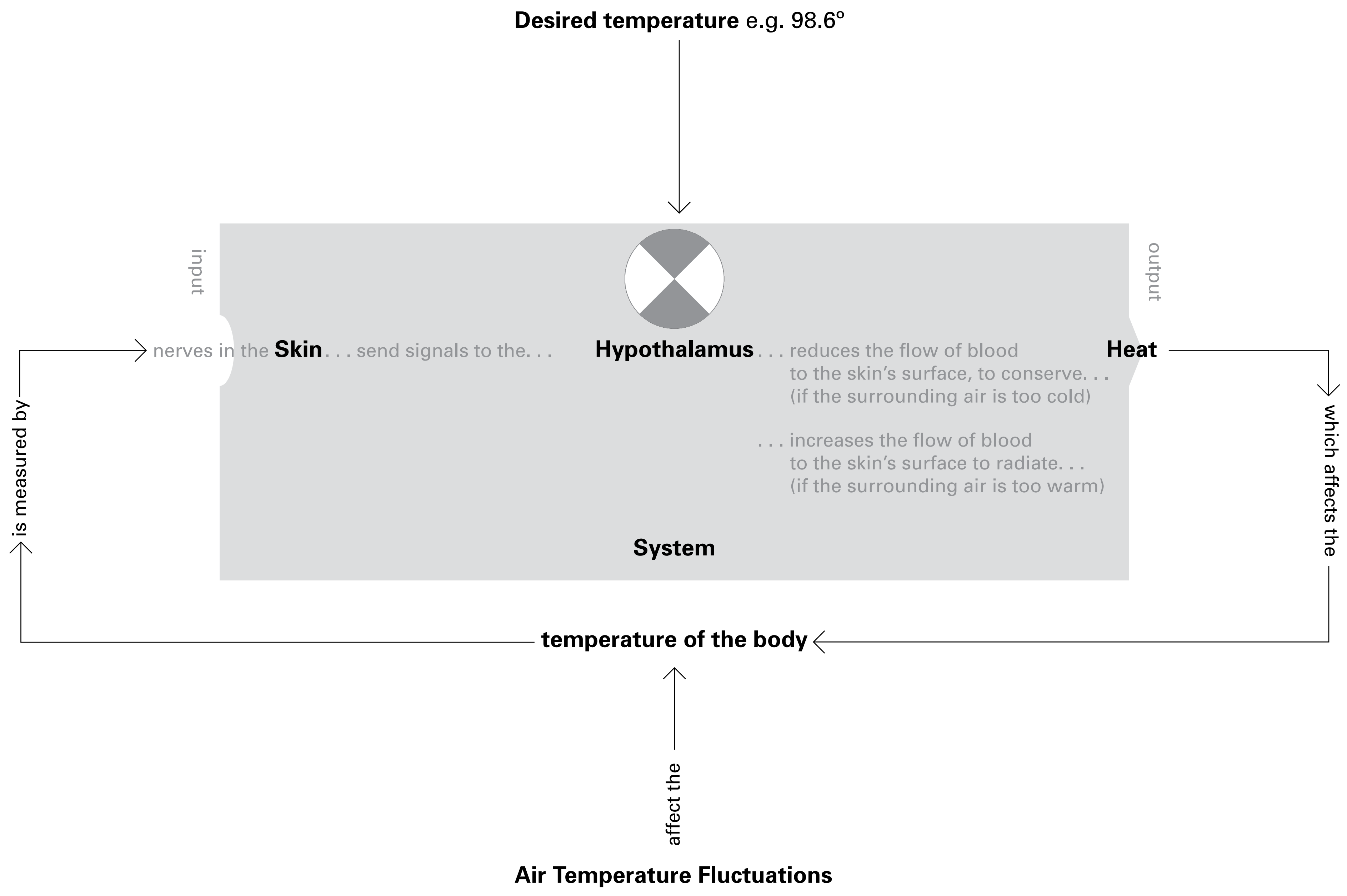


Feedback: Biological Example

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



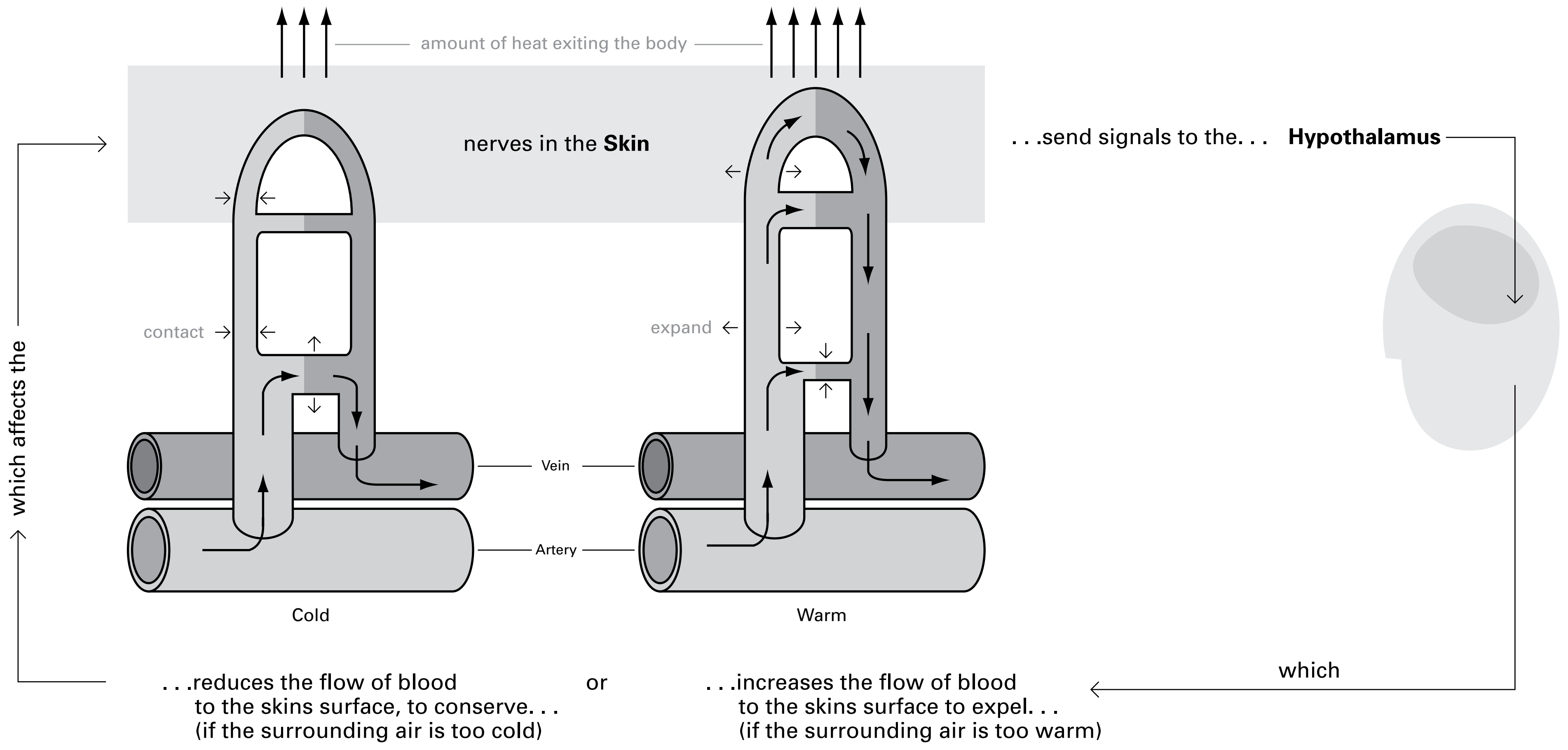
How the Regulation of Body Temperature Works

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



First-order Feedback and Modeling Interfaces

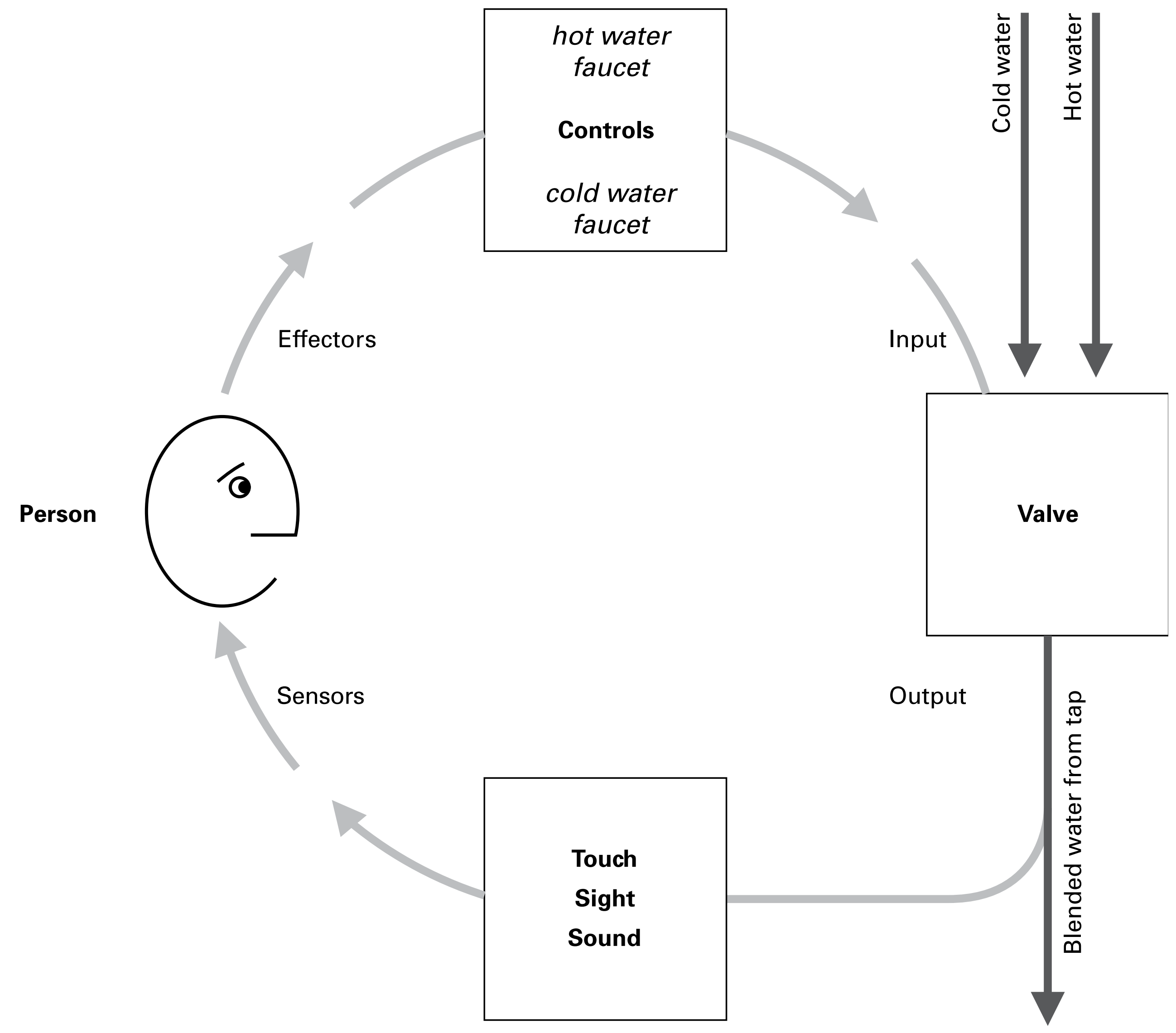
a. goal of model
The diagram shows how a human can complete a cybernetic loop.

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



First-order Feedback and the Design Process

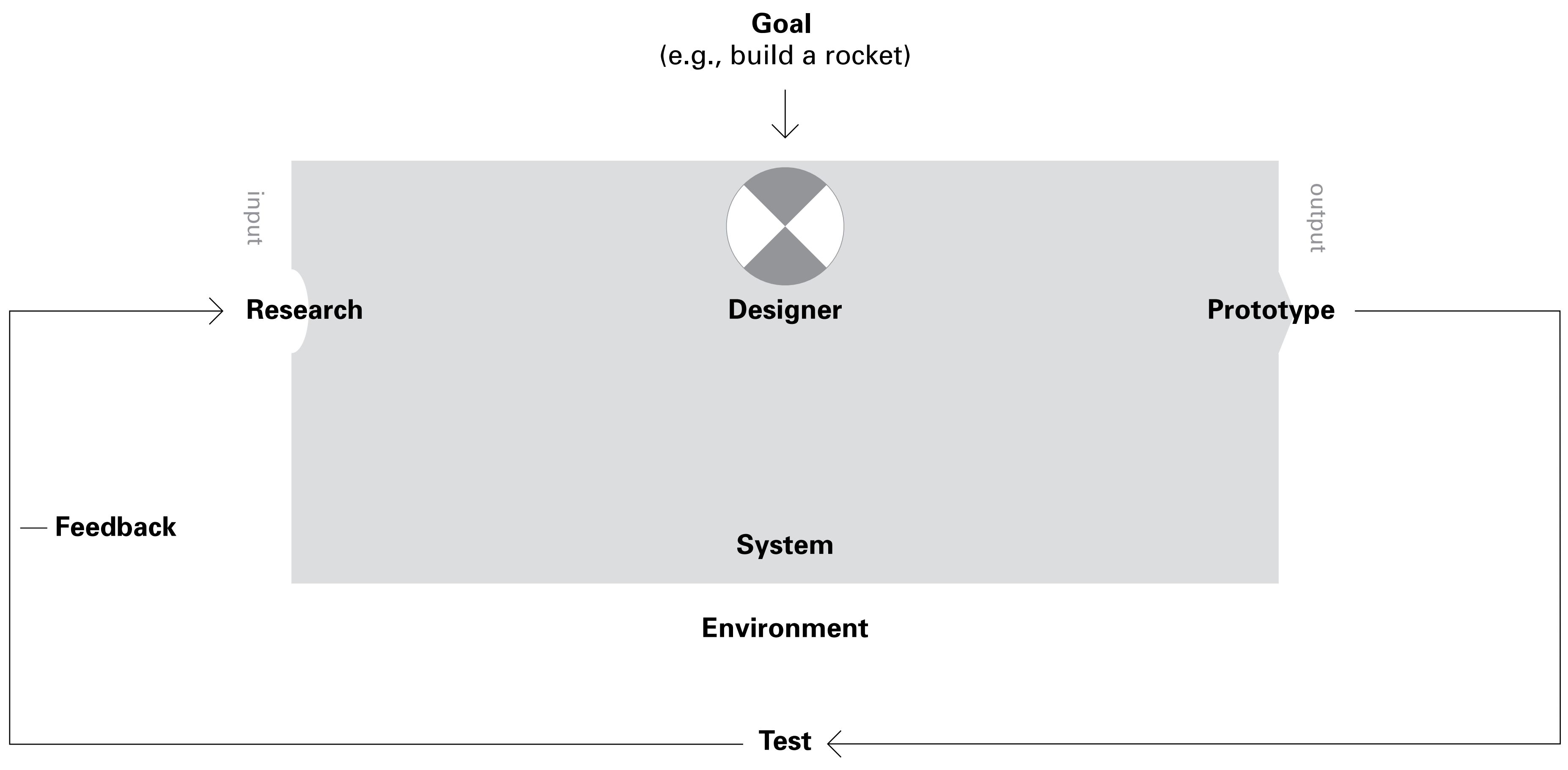
a. goal of model
The model maps an iterative process of design to the cybernetic framework. A designer is considered a cybernetic system, in the process of creating a rocket.

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



As observers, we say that certain systems are organized to act effectively in their environment in order to achieve a goal. To do so, a system must be able to sense its environment, compare what it senses (current state) to a model of its goal (desired state), and to act in a manner that moves closer to its goal.

In general terms, a system experiences disturbances from its environment that move it away from its goal. The system must be able to respond so that it can achieve its goal despite the disturbance.

Essential variables are those parameters of a system's operation that must be kept within strict limits for the system to achieve its goal. The alternative is a system that is ineffective at achieving its goal, or even dying or being destroyed.

In the case of a thermostat, the essential variable is the temperature of the room; if kept close to the setpoint of, say, 70° F, we say the system has maintained its essential variable.

The capabilities and capacities of a system to overcome disturbances and to achieve its goal must be measurable, if design is to be explicit. Of course, it is always possible to try more-or-less random changes until something works. This wastes resources by "just trying things" instead of converging efficiently and purposefully. In addition, such random attempts increase the risk of system failure between now and (possibly never-attained) success.

One way to measure a system's capabilities is in terms of the number of different possible responses that the system, because of its make-up, can have to what it senses in the environment. In the case of a simple thermostat, the system has 2 possible responses: turning the heater on or turning it off.

Using a number to reflect range of capabilities of a system is particularly mechanistic and or quantitative, but valuable as a starting point.

We call the range of possible responses embodied in a system its variety. In the course of many design tasks—software or service design, for example—a simple numeric measure of the total number of responses may seem too simplistic. But there is great value in thinking about—and explicitly designing for—the variety of the systems we create and then evolve. Just as the scope of cybernetics extends from mechanical to biological to social systems, so does the concept of variety.

If a system possesses enough variety to achieve its goal, we say the system has requisite variety (RV), that is, it has the variety required to succeed in achieving its goal.

For a system to have requisite variety, the system must possess at least as much variety as the environment that is the source of the disturbances. This is called Ashby's Law of Requisite Variety

RV is always a relationship between a system and a proposed environment. While the system's variety changes only when the system is changed, RV is judged to be present or not depending on a comparison between a measure of system variety and a measure of the variety of an expected environment.

It is incorrect to refer to "adding to a system's requisite variety" or "giving the system more requisite variety". Either the system has RV or doesn't; it is a binary relationship between system and environment, not a quantity.

Requisite Variety

Requisite Variety

origins

a. individuals
W. Ross Ashby

b. era/dates
Early 1950s

c. references for model, context, author(s), concepts
Design for a Brain (1952) and Introduction to Cybernetics (1956),

Introduction to Cybernetics is available for download at http://pespmc1.vub.ac.be/ASHBBOOK.html.

See also Geoghegan and Pangaro, "Design for a Self-Regenerating Organization", that applies Requisite Variety to social organizations, available for download at http://pangaro.com/ashby.

d. examples
A pilot + ship's ability to withstand a storm. A heating system's ability to keep the internal temperature above 70° F during a cold snap. A corporation's ability to avoid bankruptcy during a market downturn.

a. goal of model
"Variety" is the measure of a range of behaviors, whether the system's or the environment's. Ashby rigorously explicates the limits of a system's ability to achieve its goals with his concept of "Requisite Variety".

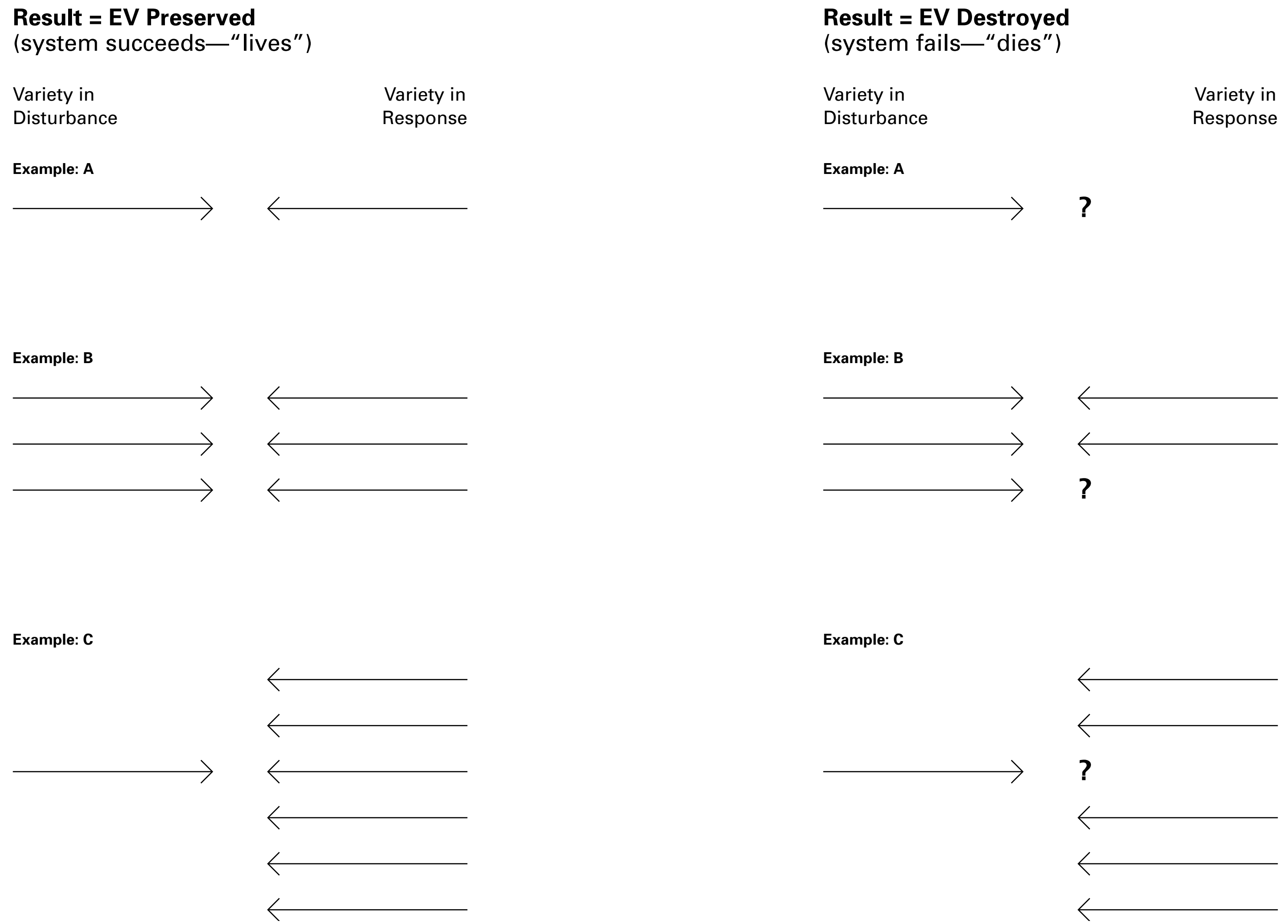
b. description
The term "control" applied to a system's relationship to its environment is potentially confusing: while some systems can, in practice, dominate their environment (for example, a human's relationship to a pencil), it is almost inevitable that disturbances (whether predictable or unforeseen) arise to confound the system. What can be done? Designers can calculate variety in the system and the environment, and decide on trade-offs of viability and cost.

c. components and processes
Ashby coined the term "Essential Variables" to refer to those aspects of a system that must be maintained within a specified range in order for the system to be viable, that is, to continue to exist as the system in question. Text at right explains the relationship among these terms. The diagram under "Result = EV Preserved" shows metaphorically that the system's variety in all cases meets the variety of the environment, and so persists. Under "Result = EV Destroyed", the system cannot respond to particular disturbances in the environment—as indicated by "?"—and so cannot persist.

d. important aspects of model/breakthrough
For the first time, Ashby provides a tool for determining viability of a given system design.

Requisite Variety

A regulator achieves a goal (preserves an essential variable) against a set of disturbances. To succeed, variety in the regulator must be equal to or greater than the variety of disturbances threatening the system. If this is so, then we say the system has requisite variety.



Requisite Variety is a Function of the System's Goal

a. goal of model
The diagram contrasts the probability of a disturbance occurring with the cost of constructing a system that will successfully regulate against that disturbance. It also shows variety as a quantity, rather than a discrete conditions that are present or not-present, as in prior diagrams.

b. description
Extending the range of a system's viability is not without a price: in general, the more extreme a disturbance, the greater the effort required to counter it. In turn, more resources are required to construct, comprise, or operate the system under those extreme conditions; and, in turn again, the greater the cost of handling those extremes.

c. components and processes
Looking bottom to top, the left-hand figure shows the value of an essential variable (e.g., temperature) from cold to hot (shown bottom to top). The curve shows that the probability of extreme cold is low (bottom); the probability of middle-level temperatures is greater; and the probability is again low for the extreme hot (top).

The right-hand figure shows, for the same range of temperatures bottom to top, that the cost of attaining the goal goes from high, at the extremes, to low in the middle values. The size of the area to the right of the curve is a rough indication of the cost of constructing and/or operating a system to handle the range of disturbances.

d. important aspects of model/breakthrough
Although not quantitatively precise, the diagram displays the consequences of design decisions in terms of variety versus cost.

Requisite Variety is a Function of the System's Goal

Determining appropriate goals involves balancing probability of disturbances against cost of meeting them.

The greater the range of disturbances met—that is the greater the variety of the system—the more it costs.

Comparing the Cost of Adding Variety to the Probability of a Disturbance

a. goal of model
The graph provides another view of the relationship between variety and cost (can be compared to previous model).

b. description
Designers must be aware of the implication of the range of their design; specifically, that handling less-probable cases can increase costs significantly.

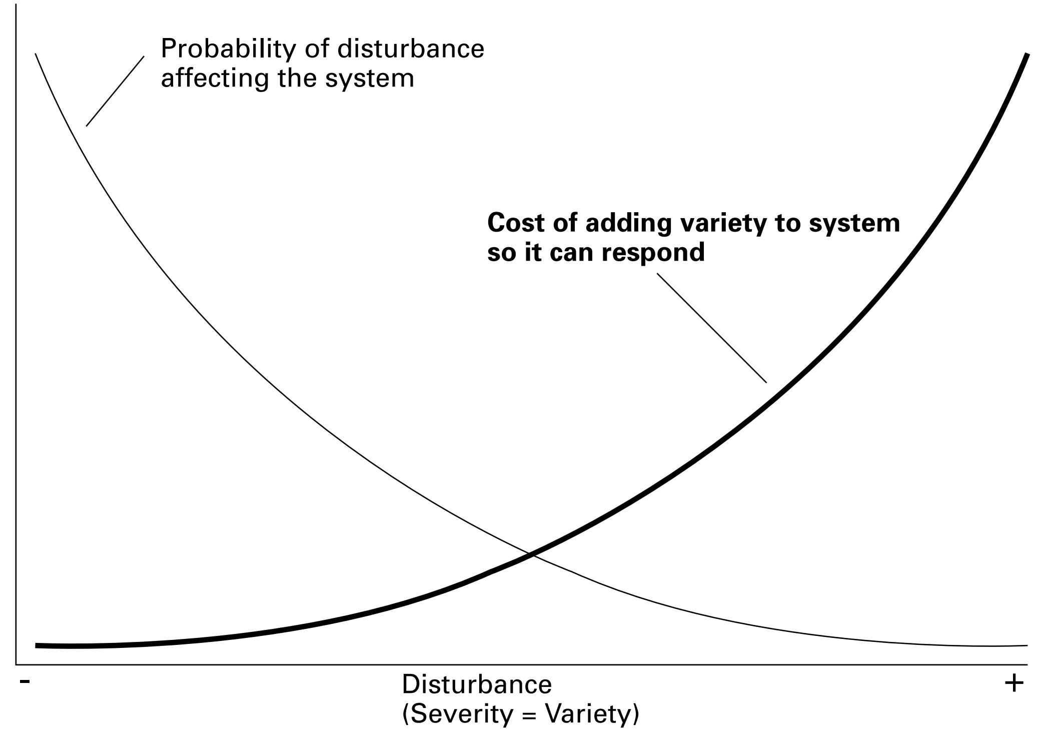
c. components and processes
The horizontal axis shows amount of Disturbance, with increasing disturbance from left to right. The amount of Disturbance, or its Severity, is another name for the Variety presented by the environment.

The vertical axis shows the probability of an environment exhibiting a particular degree of Disturbance.

The lighter curve shows that, as the Disturbance (Variety) increases, the probability of it occurring is reduced. The darker curve shows that, even as the probability of the severity of the Disturbance is reduced, the cost of handling it increases.

d. important aspects of model/breakthrough
There are always trade-offs in incorporating additional system complexity in service of system variety and the concomitant cost to achieve more system variety. This trade-off is one of the most difficult design issues in complex systems, and design outcomes may be improved by close examination involving multiple views and calculations

Comparing the Cost of Adding Variety to the Probability of a Disturbance



a. goal of model
The diagram formalizes the required actions of the system to achieve requisite variety.

b. description
The diagram places the functioning of Requisite Variety in the frame of the formal model of a cybernetic system, as well as the Shannon model of a communication channel. Disturbances correspond to noise in Ashby, and Essential Variables correspond to messages in Shannon.

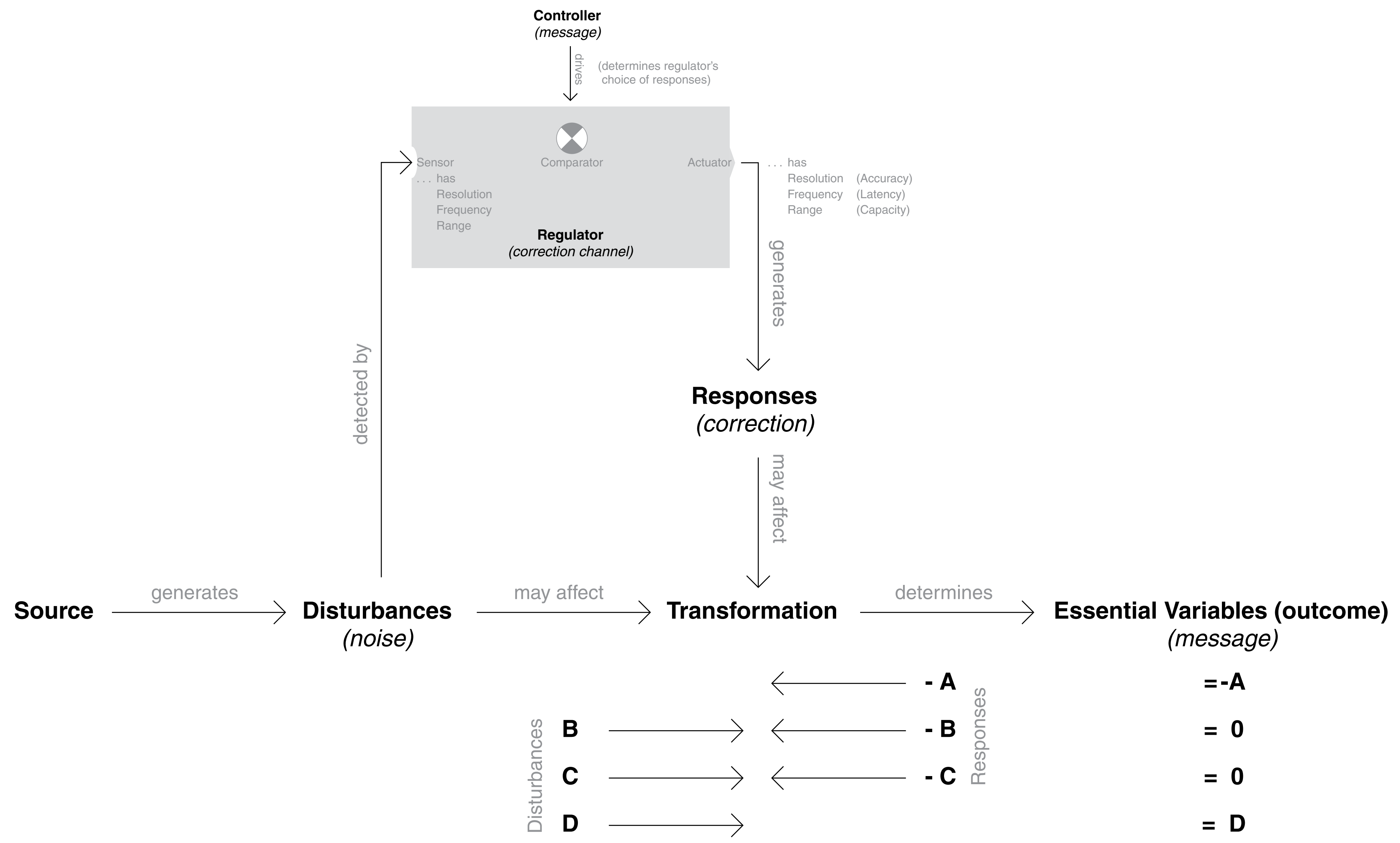
c. components and processes
Grey System Box: sensor, comparator and actuator operate as before. Note annotation of Resolution, Frequency, and Range as parameters on input and output; these become part of the design considerations in calculating Requisite Variety.

Channel Line: Source, Disturbances, and Transformation mirror Shannon's transmission channel, used by Ashby to bridge the two models.

Lower Section: Arrows that show Disturbances meeting Responses, and calculation of Essential variables as per previous models.

d. important aspects of model/breakthrough
The diagram shows correspondences between Ashby's and Shannon's formulations.

Requisite Variety: Formal Mechanism



If variety of disturbances ≤ the variety of responses, then the system remains stable (first 3 cases).
If variety of disturbances > the variety of responses, then the system becomes unstable (last case).

a. goal of model
This model results from the application of the previous model, the formal mechanism of requisite variety, to a space heater.

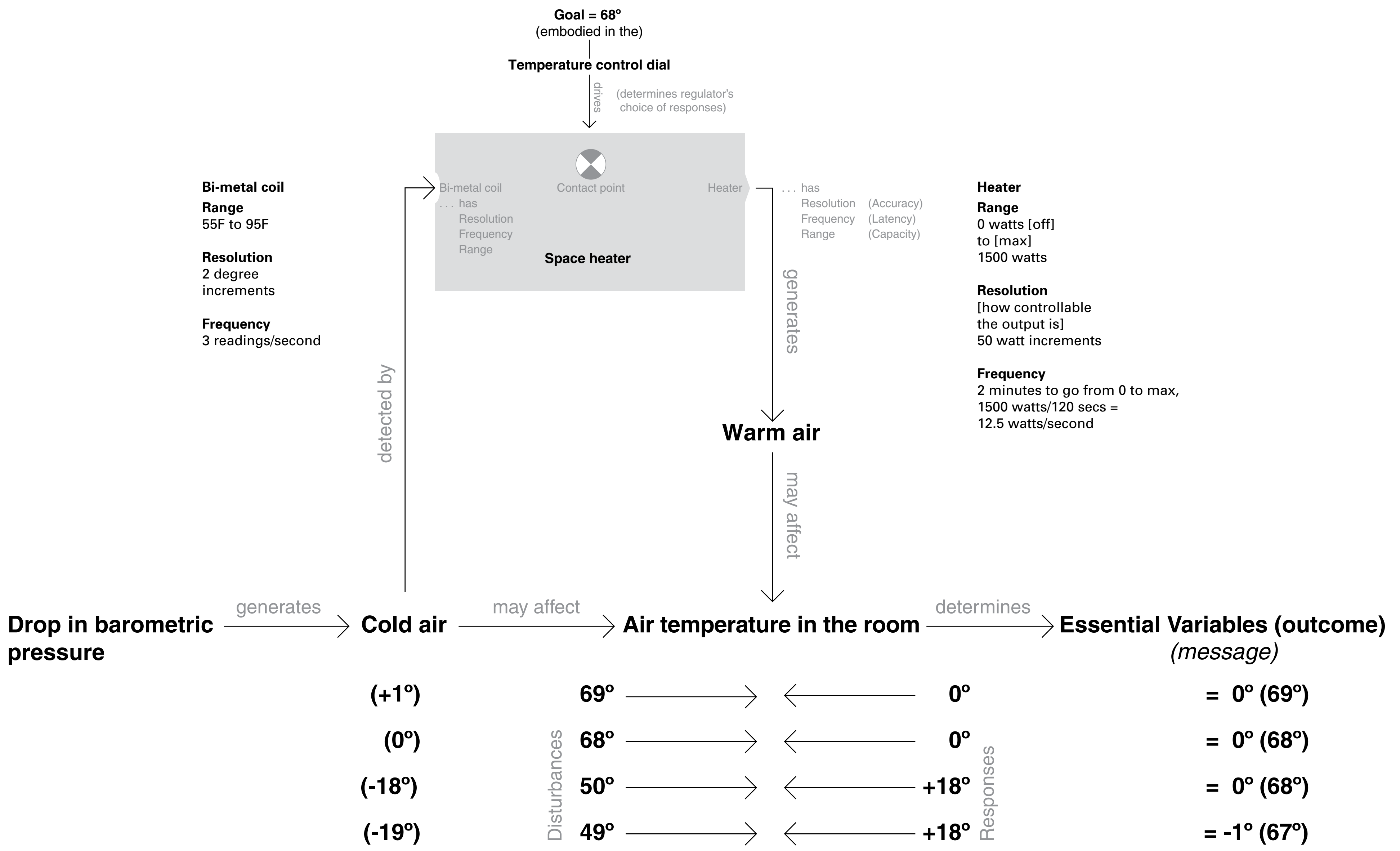
b. description
Each element of the model of requisite variety is mapped to the components of the system of a space heater.

c. components and processes
Components and processes as per previous model. Specific values for variety of sensor and actuator are given. This enables a quantitative calculation of conditions for which the system is capable of maintaining the desired goal of 68° Farenheit. Note that 18° F is the maximum temperature shift possible with the current system design.

As shown in the arrowed-figure at bottom right, the system loses its ability to achieve its goal when the air temperature in the room goes from 50° to 49°. This is indicated by the Essential Variable moving to -1°.

d. important aspects of model/breakthrough
Not all variables under system control are necessarily, strictly 'Essential Variables' (EVs), that is, conditions required for the system to persist. Ross Ashby coined the term to refer to living systems, for which loss of control of EVs would mean, in the case of an organism, death.

Very often, as in the case of a space heater, subjecting the system to temperatures down to 40° will probably not damage it, even while it can't achieve its goal. However, subjecting the system to -20° probably would damage it.



If variety of disturbances ≤ the variety of responses, then the system remains stable (first 3 cases).
If variety of disturbances > the variety of responses, then the system becomes unstable (last case).

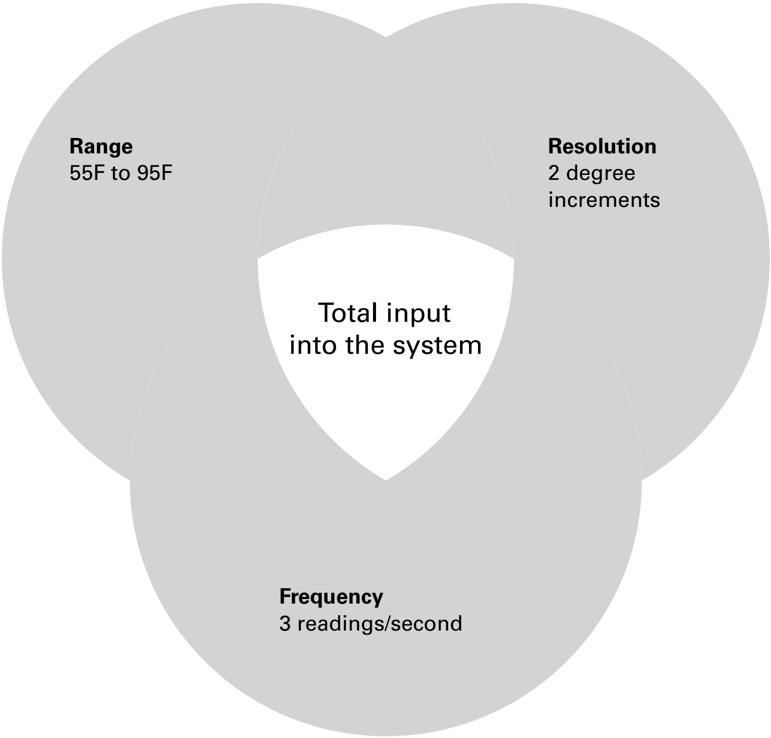
What defines the input and the output of a System?

a. goal of model
The figure presents the parameters of the sensor and actuator in a specific case. These parameters have direct bearing on the variety of the system. The use of the Venn diagram is metaphorical only.

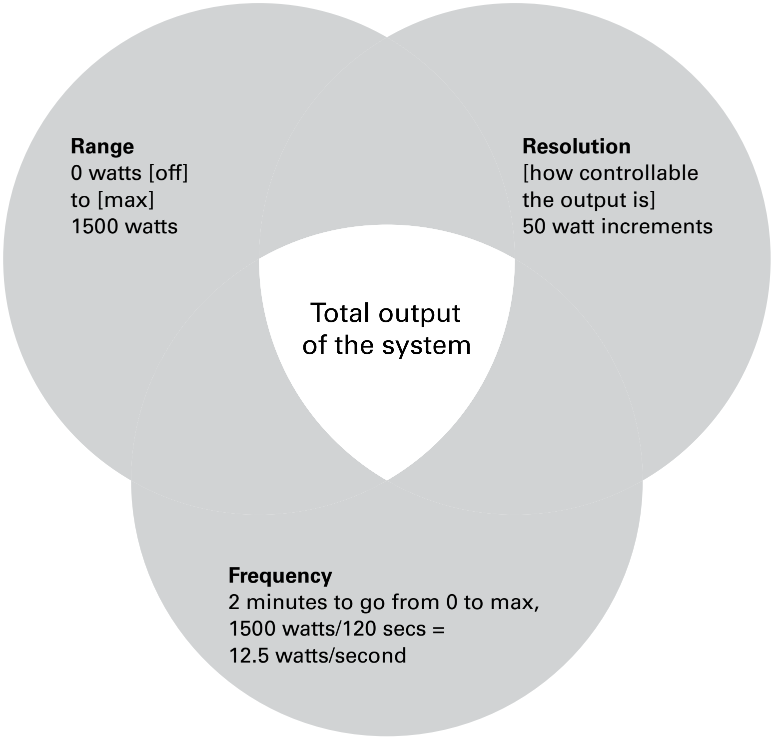
b. description
Range, Resolution, and Frequency (latency) are parameters for both the sensor and actuator of any system. For the specific case of a space heater, the breakdown of these parameters is shown.

What defines the input and the output of a System?
Example: Space Heater

Sensor



Actuator



Defining resolution, frequency, and range within an sensor

a. goal of model
The graph quantifies the parameters of the operation of the temperature sensor of a space heater.

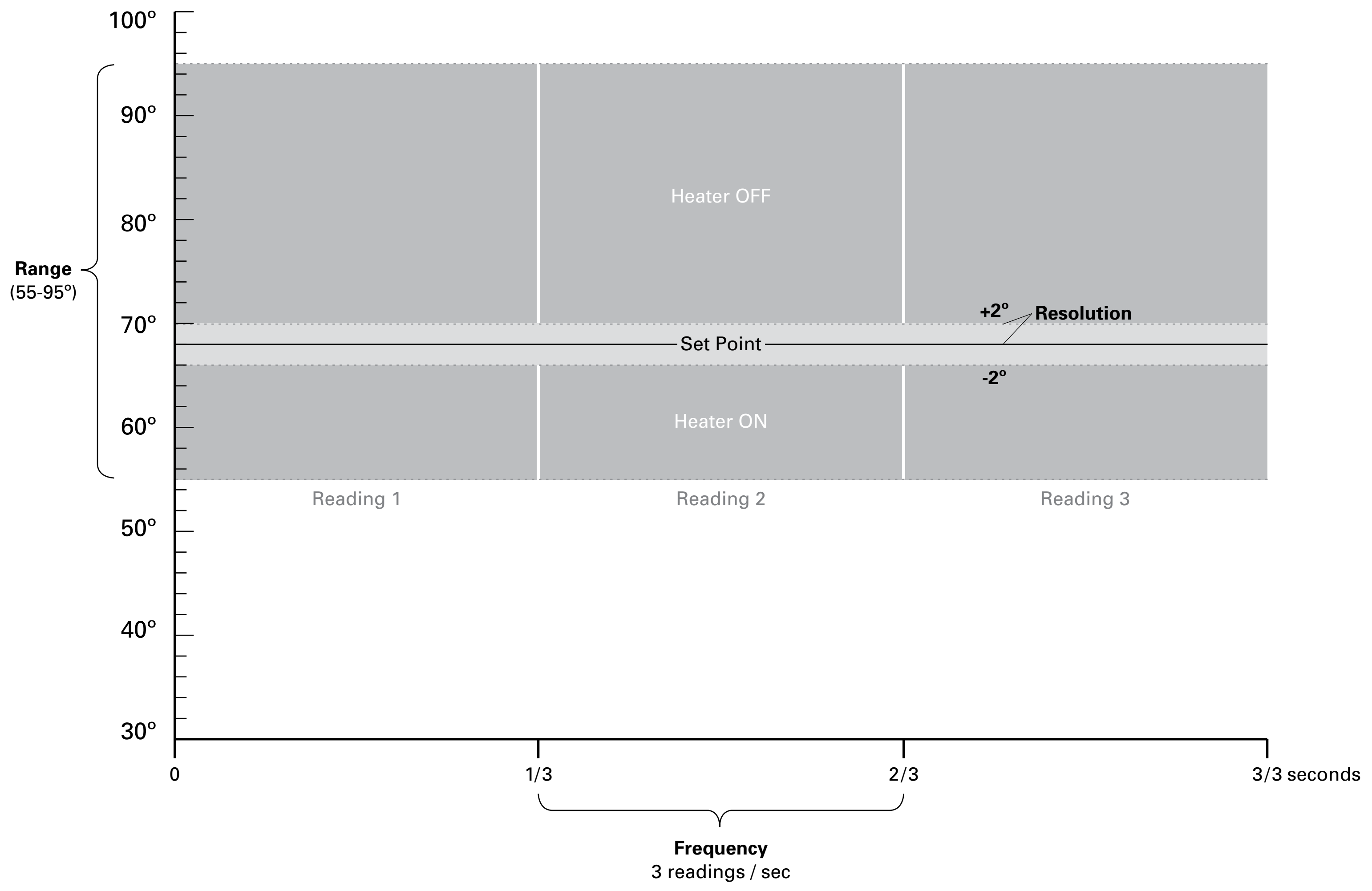
b. description
The temperatures at which the sensor changes its output, and how frequently the sensor takes a reading, are shown.

c. components and processes
The horizontal axis shows the frequency of (or latency between) readings by the sensor of the temperature, that of 3 times per second.

The vertical axis shows the range of readings in which the sensor maintains the value of its other parameters, namely, its resolution and frequency. This range is 55° to 95°.

The horizontal, lightly-shaded area of the graph shows the accuracy of its readings, which occur within 2° of a given value.

Defining resolution, frequency, and range within an sensor
Example: Space Heater



Defining resolution, frequency, and range within an actuator

a. goal of model
The graph quantifies the parameters of the actuator of a space heater.

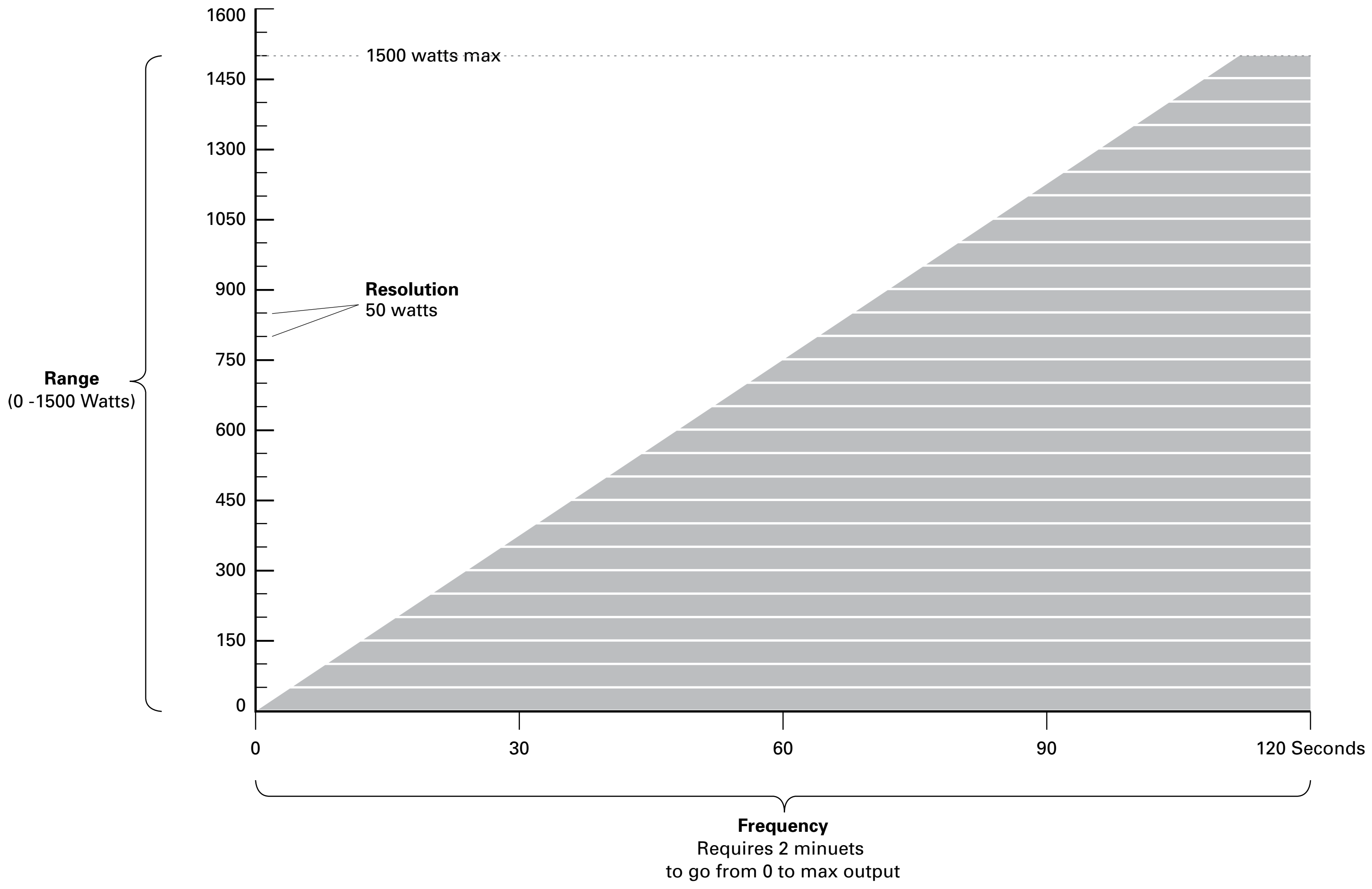
b. description
The heat output of the actuator, and the rate at which it produces heat, are shown.

c. components and processes
The horizontal axis shows the time in seconds that the heater takes to go from completely off to completely on (maximum heat output). The graphs shows this process to take 120 seconds. This parameter is called frequency (or latency) because it describes the time required for the heater to act.

The vertical axis shows the range of potential heat output for the space heater. The span of potential output is from 0 watts (off) to 1500 watts (completely on and warmed up). This is called the range of the actuator. Control of the heat output has a resolution of 50 watts, that is, the finest grain of control of the actuator is in roughly 50-watt increments.

The shaded area of the graph shows the relationship of time to heat output, assuming the heater is turned on full and the environmental disturbance is unchanged. The linear increase of output is an ideal case, while real-world heaters are likely to have non-linear heat-up times, but this is not material to most designs.

Defining resolution, frequency, and range within an actuator
Example: Space Heater



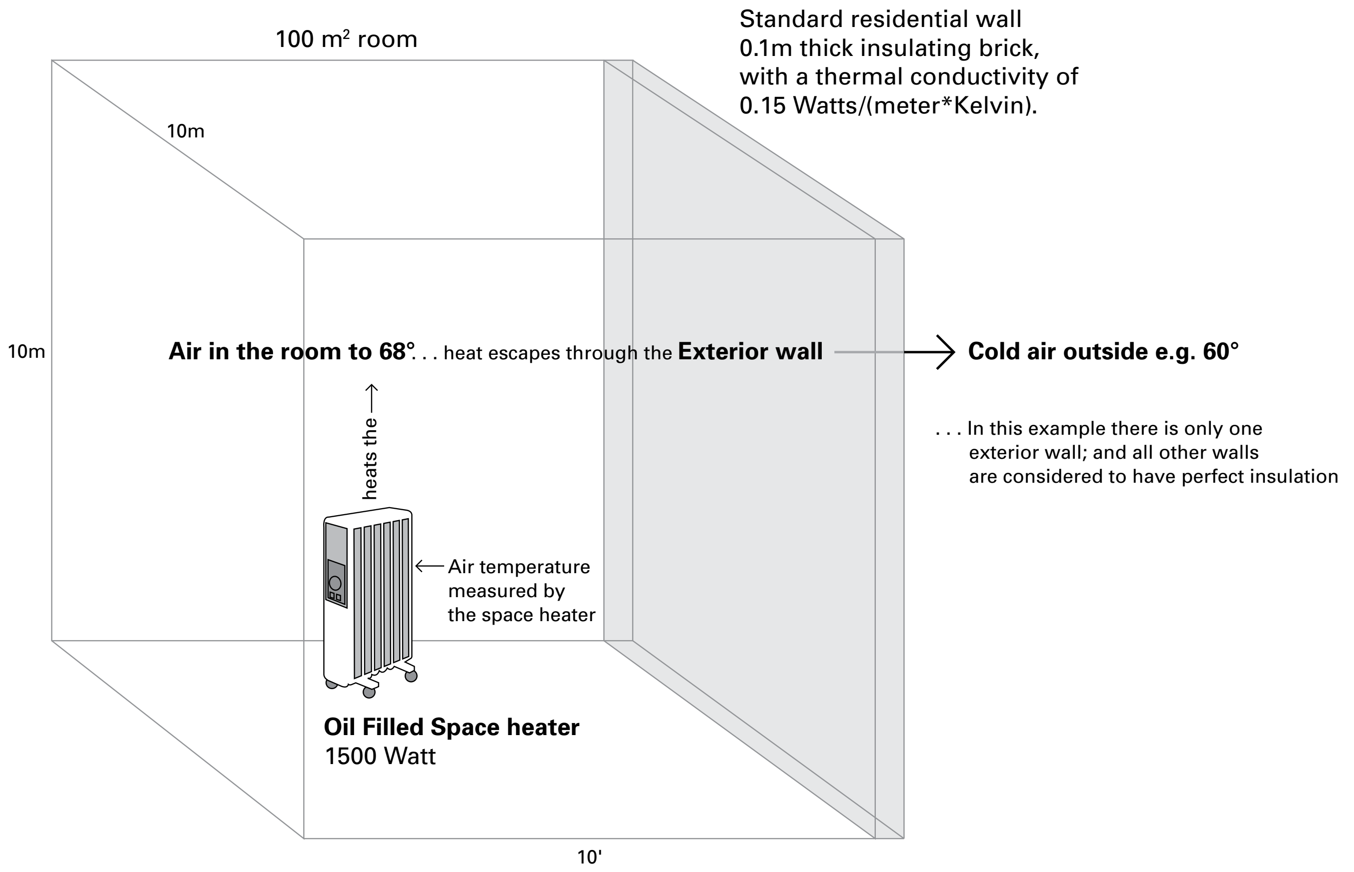
Determining the effective range of a space heater

a. goal of model
The model and graphs on subsequent pages provides a detailed and quantitative analysis of the variety of a room space heater.

b. description
Specifications of a space heater, the heat transmission qualities of a room, and outside conditions are used to define a specific case for computing the variety of a system.

Effectiveness of the heating system could be improved by adding insulation to the wall or increasing the heat output capacity of the heater.

Determining the effective range of a space heater
(How much variety does it have?)



Determining the Effective Range
The heater can maintain the room at 68° when the outside temperature is less than or equal to 68°, and greater than or equal to some minimum temperature T that we have to find. This T is characterized by the fact that it causes the rate of energy loss through the wall to be exactly equal to the maximum rate at which the heater can bring energy into the room.

An equation describing this is:
rate of energy transfer = k*(T_{in} - T_{out})*(wall area)/(wall thickness)

At what Temperature does the space heater fail?
Using the equation above we find that T_{out} **= 283.1K** or **50ºF**—when the outside temperature falls below 50ºF, the space heater will no longer be able to maintain the room at 68ºF.

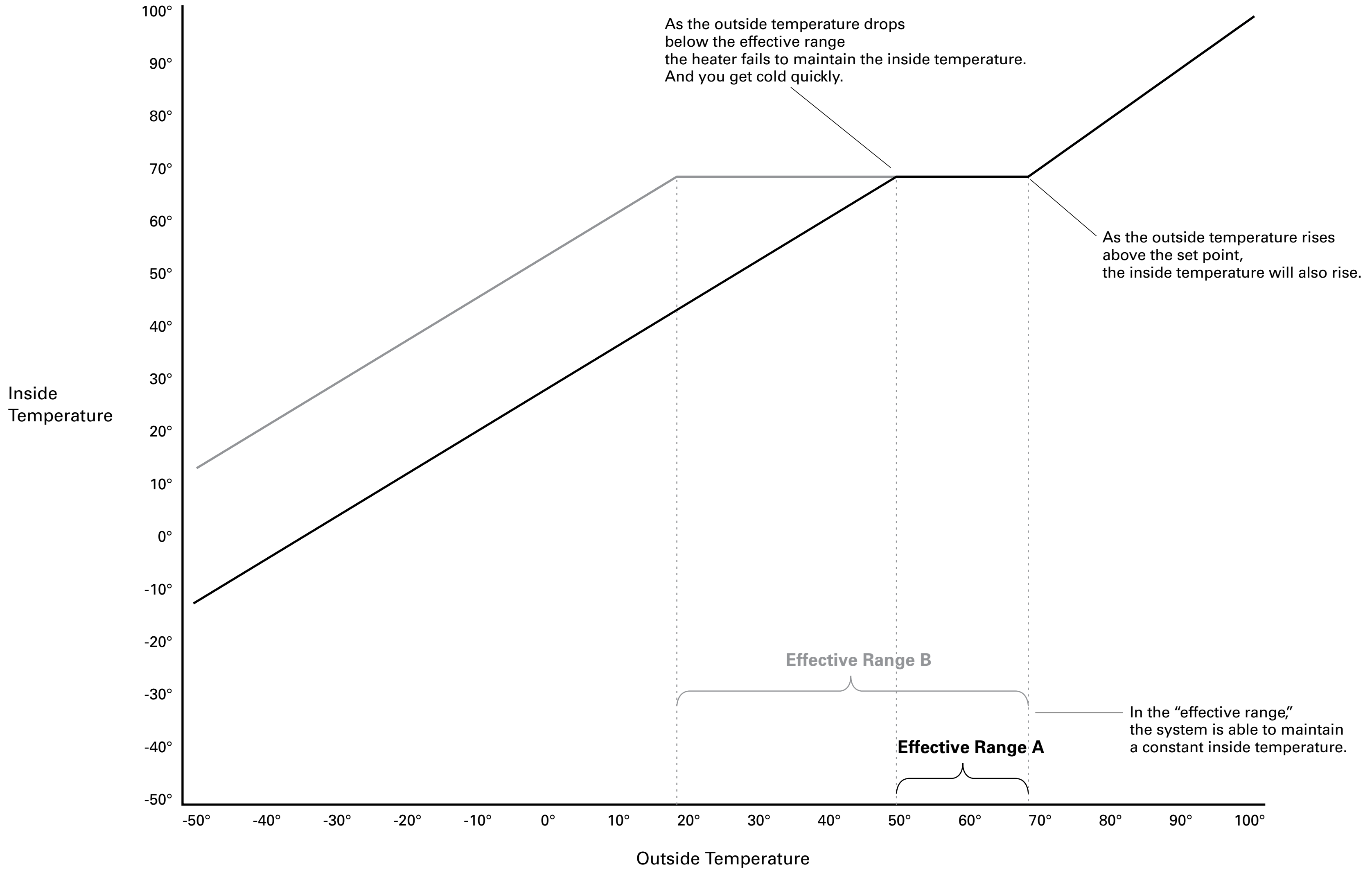
Elements within the Current Situation:
Space heater output = 1500 Watt (5120 BTU/hr)
Wall area = 100 m²
Wall thickness = 0.1 m
68ºF = 20ºC = 293.15ºK
Thermal conductivity for k (insulating brick) = 0.15 Watts/(meter*Kelvin).

Using the equation above , we find that T_{out} equals 283.15ºK (50ºF).
Keep in mind that this result is for a 10 centimeter thick wall of insulating brick.

Graphing the effective range of a space heater

a. goal of model
The graph shows the effective range—the conditions under which the system achieves requisite variety—for a specific system and environment.

Graphing the effective range of a space heater



These figures are only intended as a theoretical example.

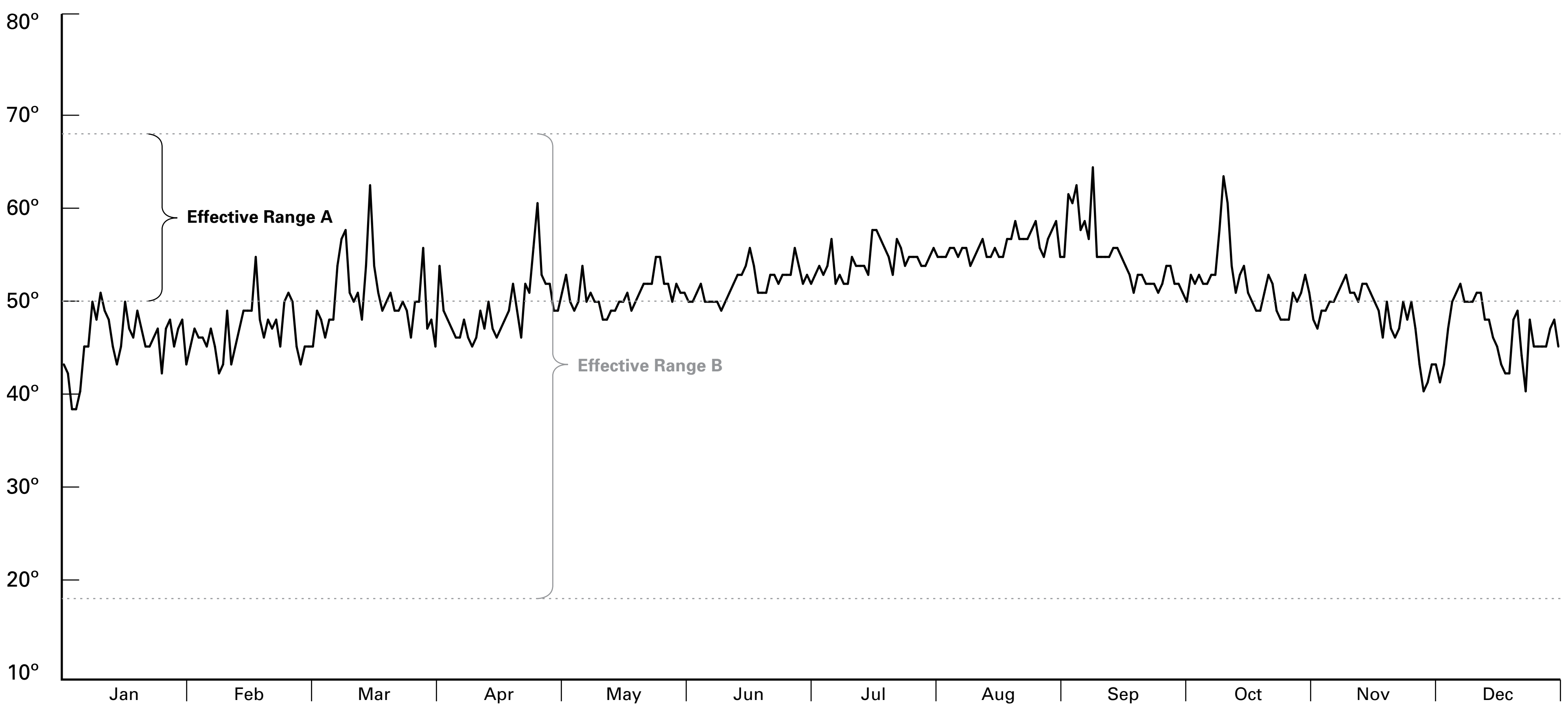
In the previous example, the effective range of the space heater is relatively narrow, due to the amount of heat lost to the cold air outside. Above we can see the effective range from the previous example (**Effective Range A)**, in comparison to a room of equal proportions, but with improved insulation (**Effective Range B**).

Effective Range A
Insulating brick R-Value = 3.8 (0.15 Watts/meter*Kelvin).

Effective Range B
2"× 4" construction & standard insulation R-Value = 10.5

a. goal of model
The graph plots actual temperature for a city against the effective ranges of space heater described in previous pages.

b. description
By contrasting the two ranges, Effective Range A and Effective Range B, the graph highlights the implications of careful calculation of the variety of the system versus the variety of the environment. In this case, a system designed for Effective Range A would achieve its goal for mid-June through mid-October, only. The more expensive system designed for Effective Range B, however, achieves its goal for the entire year—at least, for the specific enivironmental conditions of the year shown.



Daily Low Temperature
San Francisco, California 2004

Requisite Variety: Social Example Los Angeles Lakers

a. goal of model
The diagram shows the application of the concept of variety to a social example, that of analyzing the capabilities of a basketball team in terms of the quality (variety) of its individual players.

b. description
The diagram shows the five starting players for each team with their salaries. Variety of an individual player is derived from his salary; the higher the pay, the "better" the player which, in the game of basketball, is interpreted to mean his capacity to respond in real-time to conditions of play; that is, the variety of the player versus the variety of the environment, that of the game itself.

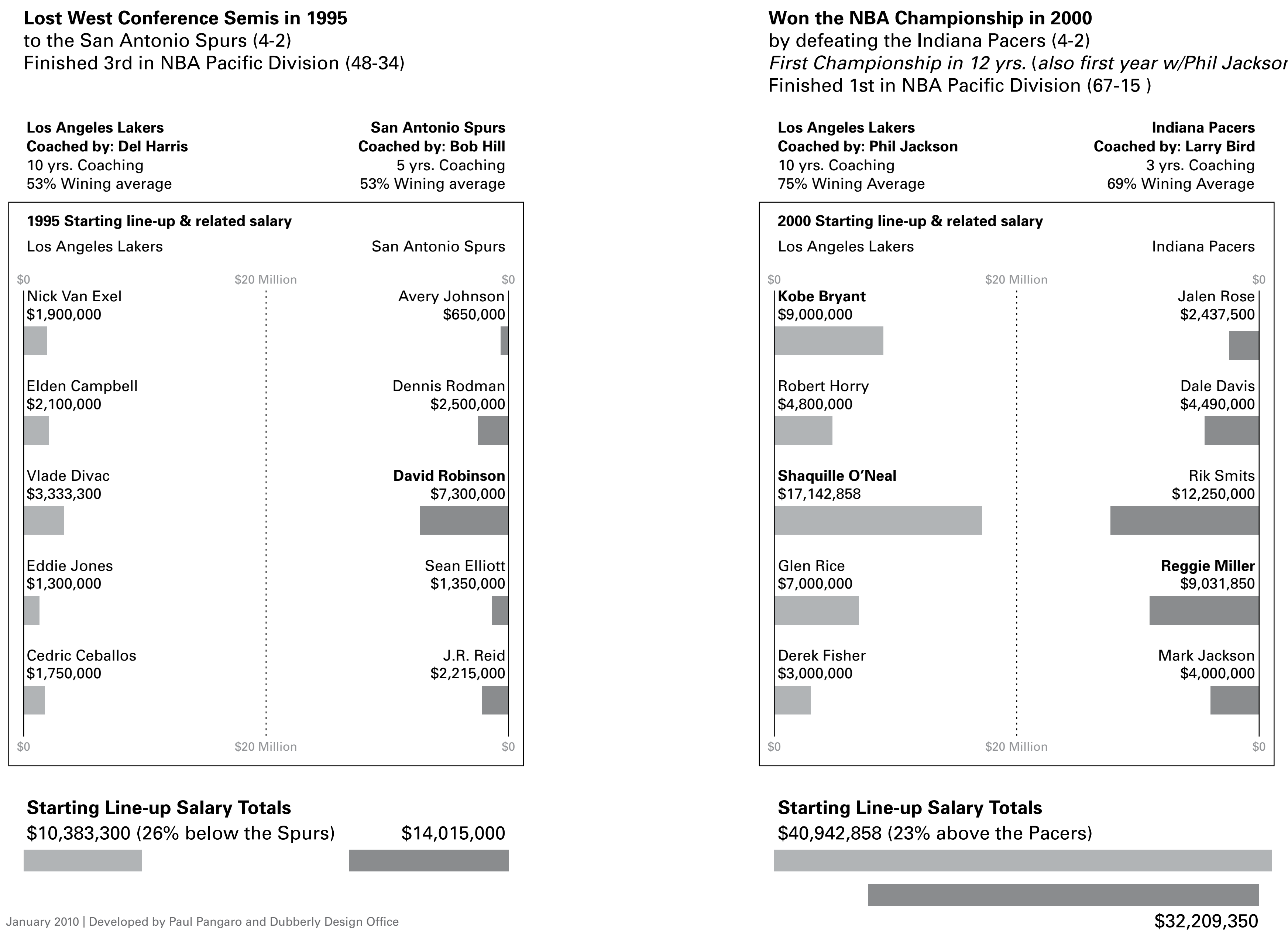
c. components and processes
On the left side is shown a comparison of players of the losing team, the Los Angeles Lakers, and the winning team in the Semifinals of the 1995 West Conference. The sum of the salaries is shown at the bottom, implying that the variety of the Lakers fell short of that of their opponents in this game.

In contrast, when the Lakers played in the NBA championship 5 years later, the team was completely different and had the advantage over their opponents in salary and, therefore, in variety. This time they won.

d. important aspects of model/breakthrough
While not strictly precise, the use of salary as proxy for variety, and the understanding that comes from the ensuing analysis, are valid examples of applying the concept of variety to systems that are social and involve human components.

Requisite Variety: Social Example—Los Angeles Lakers

Money is a proxy for player performance.
In this case increased Laker spending seems to have increased variety.



Page Headline

origins

a. individuals
Side bar infomation text size

b. era/dates
Side bar infomation text size

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

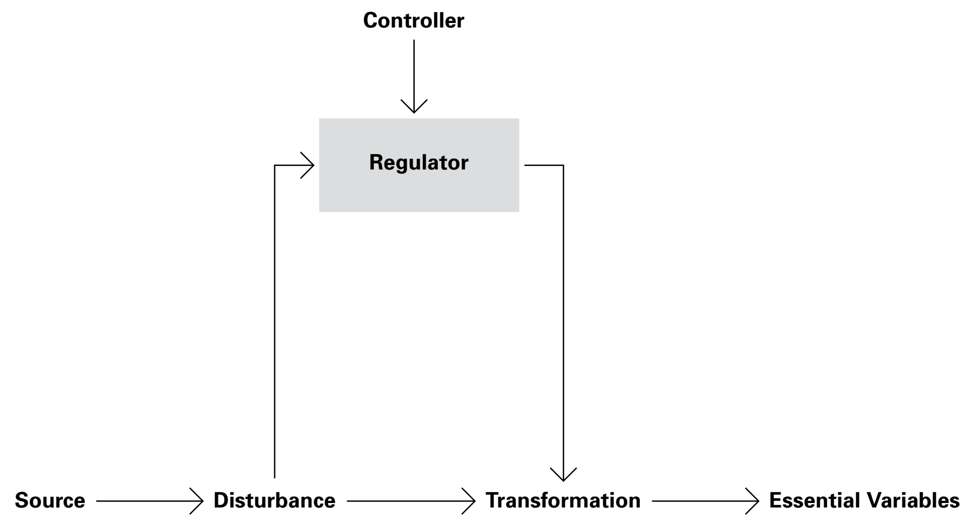
d. examples
Side bar infomation text size

a. goal of model
[do we want to keep this in the book? might need it to bridge the ashby readings --- if so, annotation needs changing, refers to ‘previous page’]

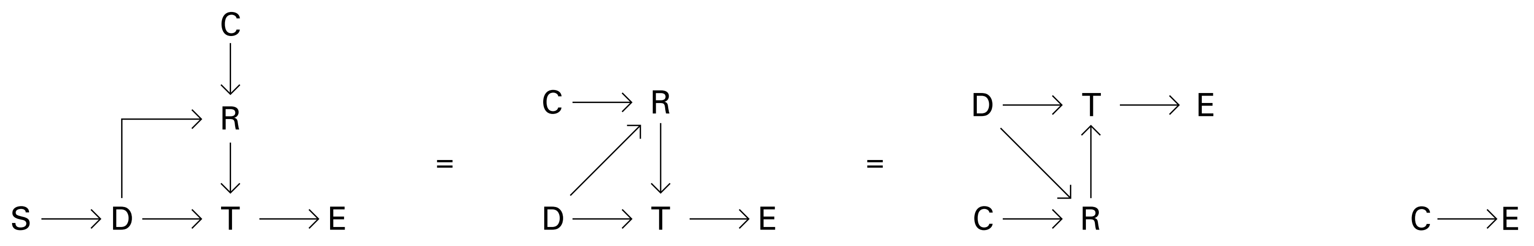
b. description
Main Text Area

c. components and processes
Main Text Area

Mapping the Feedback: Formal Mechanism to Ashby’s Communications Model



Our formal feedback mechanism from the previous page—
itself a slight transformation of the Feedback: Formal Mechanism—
may be translated into single-letter shorthand.



As above

Rearranging to align inputs C & D

Flipping on the horizontal axis
to yield Ashby’s model

C can completely control outcome E
when R is a perfect regulator,
i.e., when R has requisite variety;
only then are we assured a constant
or noise-free signal.

Mapping Ashby’s Model to Shannon’s

origins

a. individuals
Side bar infomation text size

b. era/dates
Side bar infomation text size

c. references for model, context, author(s), concepts
[ashby and Shannon as before, OK to repeat here probably]

d. examples
Side bar infomation text size

a. goal of model
[Again not sure about keeping this; seems like more than the students need, esp. Given culling of content from reader]

b. description
Main Text Area

c. components and processes
Main Text Area

Mapping Ashby’s Model to Shannon’s

Consider R as a transmitter.
The law of Requisite Variety says that
R’s capacity as a regulator cannot exceed
R’s capacity as a channel of communications.

Disturbance	Regulator	Transformation
D →	**R** →	**T**
Noise	Correction Channel	Message

Shannon’s Theorem 10 says that
if noise appears in a message,
the amount of noise that can be removed by the correction channel
is limited to the amount of information that can be carried by that channel.

Thus the use of a regulator to achieve homeostasis
and the use of a correction channel to suppress noise
are homologous.

Second-order feedback systems comprise two first-order loops in a particular relationship: the actions of the outer loop regulate the goal of the inner loop.

This offers a major advantage over single-loop systems: a capacity to learn.

A first-order system cannot learn. Given what the sensors "see" in the environment, the comparator chooses an action. If there the system possesses requisite variety, the system has an appropriate response and the system's goal is achieved, no matter what the environmental condition. If not, the system simply fails. But either way the relationship between the sensing and acting never changes, because nothing inside the system changes.

A second order system has additional structure—the higher-order, or outer loop—which can "see" the results of the actions of the first-order loop, "in its own terms". By comparing results to its own (second-order) goal, the outer loop can modify the goal of the first-order loop, and then sense whether its goals are met. If so, the outer loop can remember which goal-setting of the first-order loop was successful under which conditions. The function of remembering is performed by the comparator of the outer loop.

This is the simplest possible form of learning—that is, depending on its experience, the system changes its future behavior.

Per Ashby, the simplest strategy for learning is a random change of goal followed by the memorization of a successful change of goal versus a particular environmental condition.

In practice, a system often has a more efficient mechanism than random trials; for example, it might have built-in strategies—that is, pre-programmed learning—for determining what to try in relation to a specific condition of the environment. However, this requires additional complexity and is no longer the simplest case.

Second-Order Feedback

Second-order Feedback: Basics

origins

a. individuals
Gregory Bateson
Margaret Mead
Donald Schön & Chris Argyris
Heinz von Foerster

b. era/dates
seeds from the 1940s
development 1960s and after

c. references for model, context, author(s), concepts
Gregory Bateson and the concept of deutero-learning.
Donald Schön & Chris Argyris and the concept of double-loop learning.
Heinz von Foerster and the concept of second-order cybernetics ["Ethics and Second-order Cybernetics, Stanford Humanities Review]

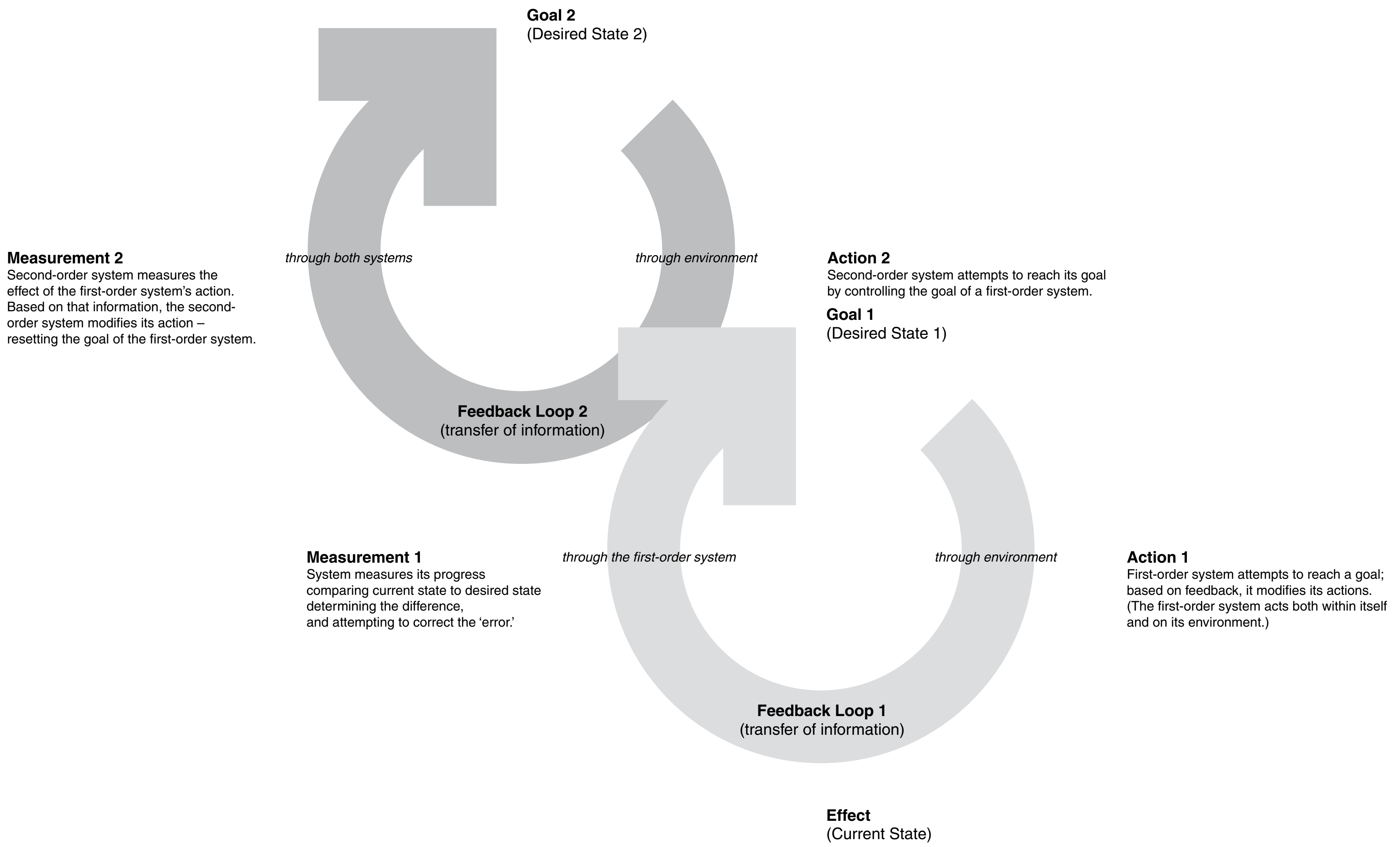
a. goal of model
Building on the feedback loop of first-order systems, the addition of a higher-order loop—one that changes the goal of the first loop—formulates another foundational cybernetic model: second-order feedback.

b. description
The elements of each loop are the same as first-order systems. The manner in which the two systems are coupled—the second-order loop changing the goal of the first-order loop—is a requirement for second-order feedback systems.

c. components and processes
See description in the diagram.

d. important aspects of model/breakthrough
Only systems that are second-order can learn, that is, can modify their goals based on experience. Without the outer loop regulating the goal of the inner loop, there is no mechanism *within* the system of changing goals at all. A first-order loop has a fixed goal, which means that it has the same response to the environment whether it has just started or anytime in the future. By definition, a system that learns is one which changes its behavior based on experience. In order words, it learns when to change its first-order goal, the better to achieve its second-order goal.

Second-order Feedback: Basics



a. goal of model
The model shows the necessary organization of a second-order cybernetic system, that is, the individual elements and processes required for a system that is capable of learning.

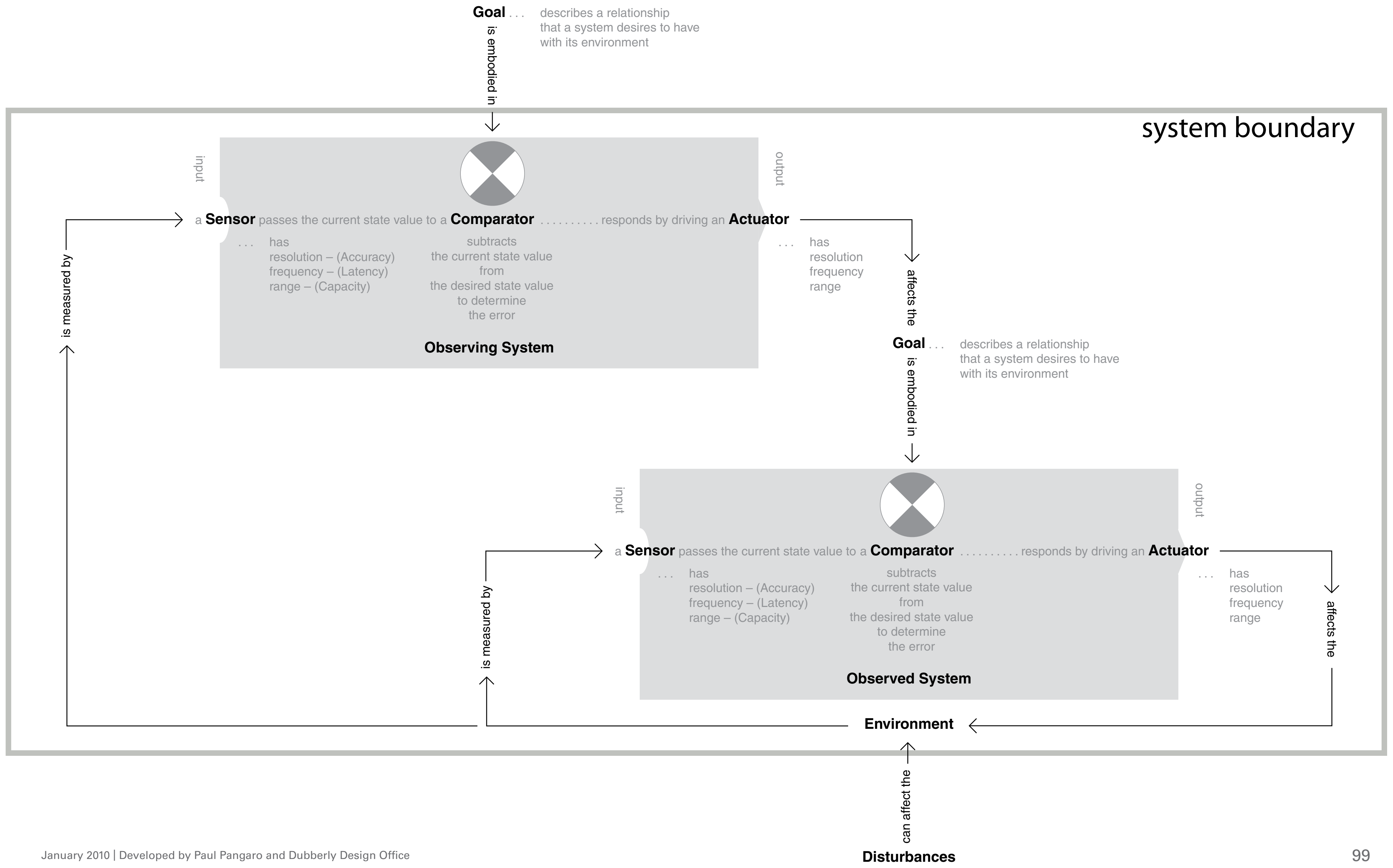
b. description
The nested quality of the two sub-systems is shown in their exact relationship. All the elements of each sub-system are as before.

c. components and processes
See description on right-hand page.

d. important aspects of model/breakthrough
The exact relationship of actuator, goals, and feedback is shown, providing a template for confirming or designing second-order feedback systems.

Second-order Feedback: Formal Mechanism

An automatic feedback system (first-order) is controlled by another automatic feedback system (second-order). The first system is 'nested' inside the second.



Second-order Feedback: Classic Example

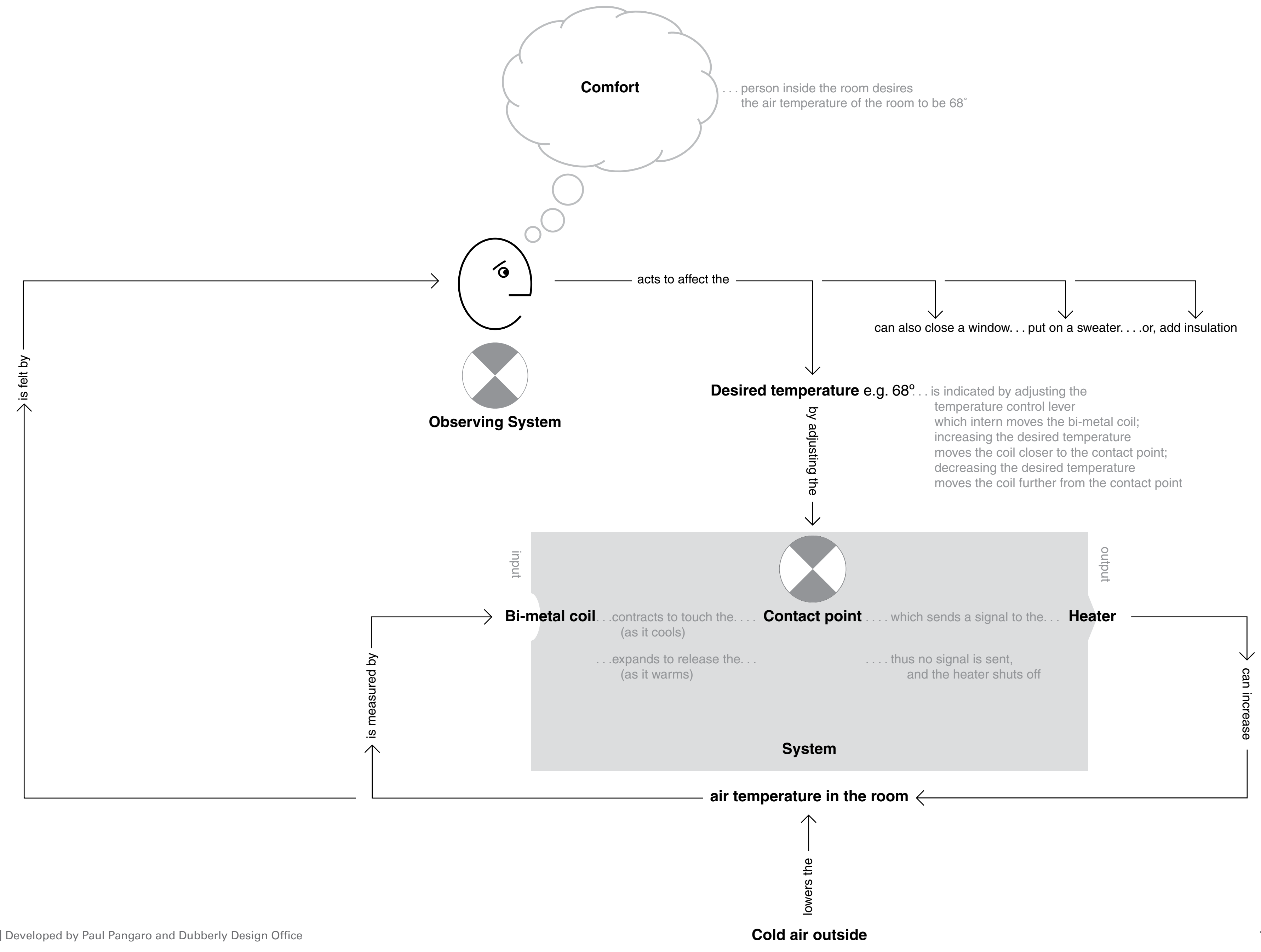
a. goal of model
The model places a person in the role of the second-order feedback system, setting the goal of the first-order system.

b. description
The model combines the first-order thermostat model with a person who uses feedback from the environment to determine if the goal has been achieved.

c. components and processes
Feedback from the environment (air temperature in the room) is used by the second-order system (person) to determine if the goal (comfort) has been achieved. If not, the second-order system (person) may modify the first-order goal (the setpoint of 68 degrees), in an attempt to achieve the goal. Or, the person may decide to regulate a different system, such as removing a disturbance of cold air by closing an open window, putting on a sweater, etc.

d7. important aspects of model/breakthrough
The second-order loop introduces the term "Observing system", that observes the outcomes from the first-order loop and determines if regulation of the first-order goal is required.

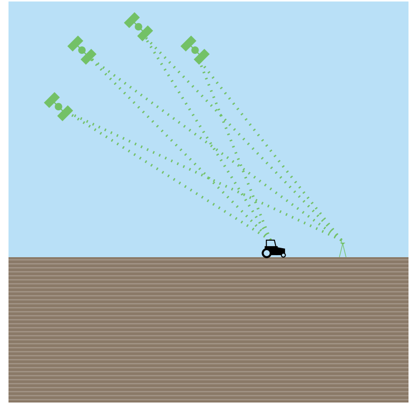
Second-order Feedback: Classic Example
Person controlling a thermostat (regulating a regulator)



How the AutoSteer system works: Overview

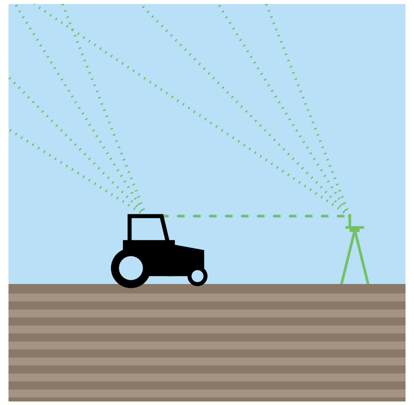
The AutoSteer system enables farm equipment to accurately steer a path and then—a minute later or a year later—come back and steer the same path. Being able to steer the same path means farmers know where their plants will be and can precisely position tools for prepping, planting, spraying, cultivating, and harvesting. And with accurate, repeatable steering, farmers can increase yields, reduce chemical use, and decrease costs.

A



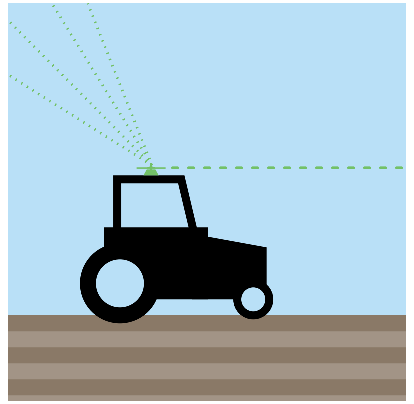
The AutoSteer system begins with GPS satellite signals

B



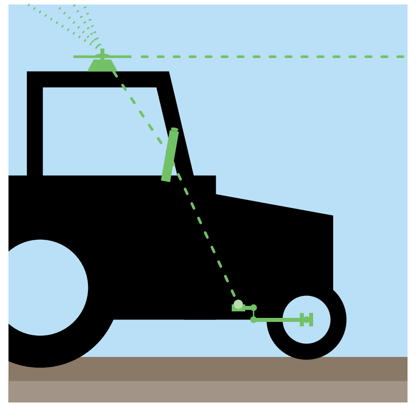
The base station provides correcting signals

C



Multiple antennas measure position and orientation (heading)

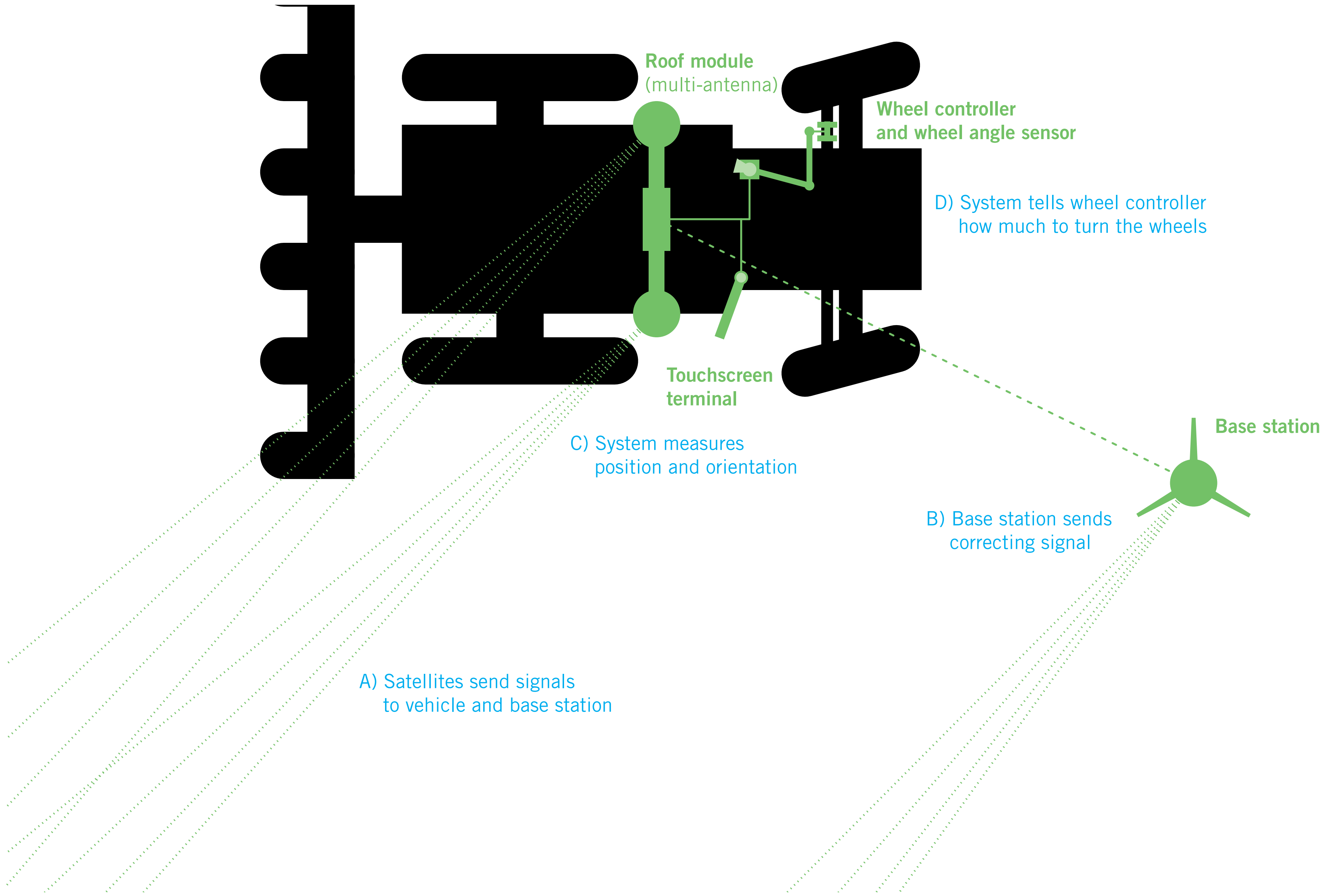
D



The wheel angle controller and sensor insure precise steering

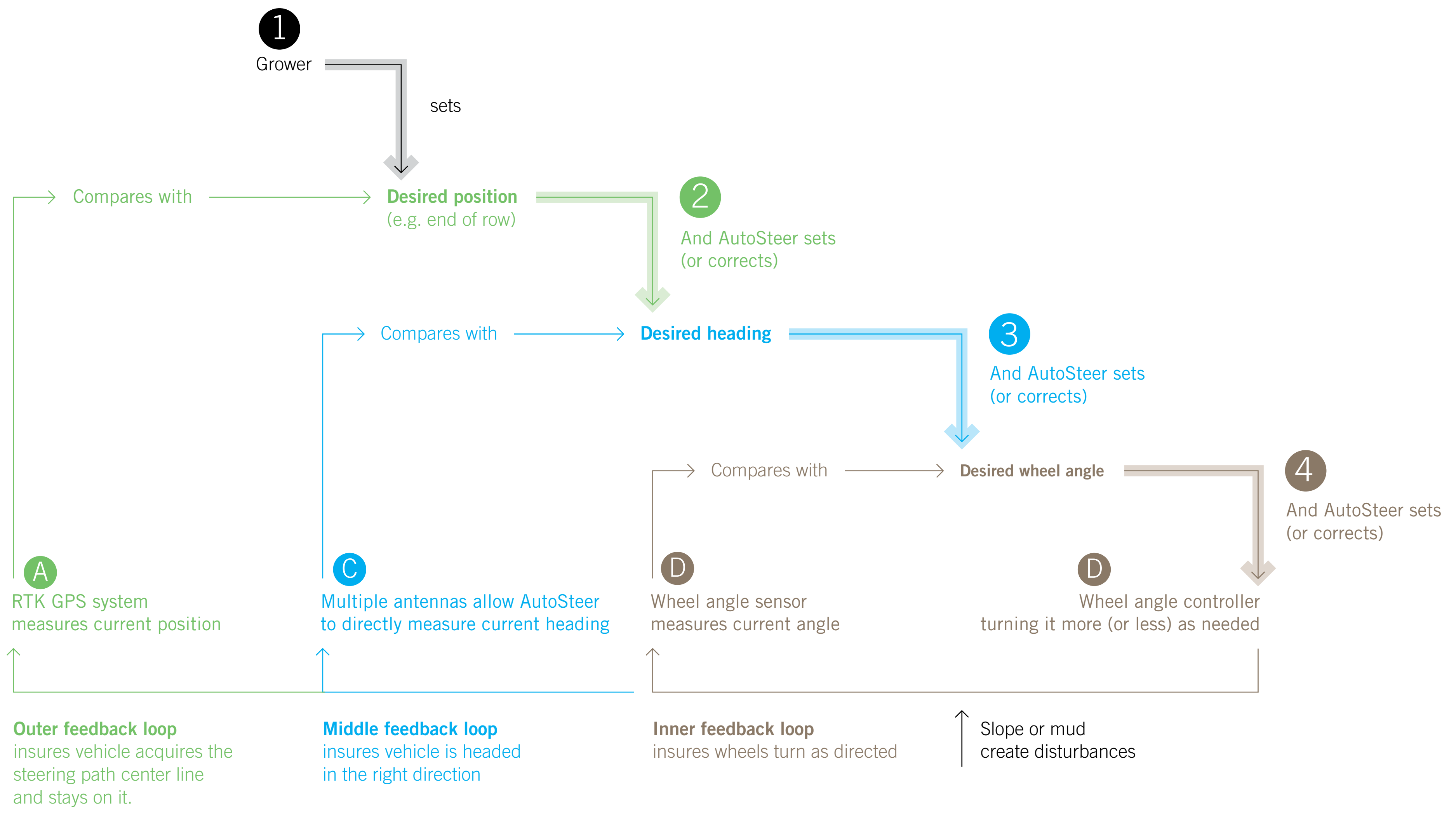
How the AutoSteer system works: Tractor Detail

The AutoSteer system relies on feedback to insure the components work together



Second-order Feedback: Electro-mechanical Example: Precision Farming

The AutoSteer system uses three nested feedback loops
to automatically steer farm equipment, positioning it to an accuracy of +/- 2 cm
with repeatability assured year-round.



Second-order Feedback: Biological Example

a. goal of model
The model applies second-order feedback models to a complex biological example.

b. description
Based on a real-world example, the model shows the nested relationships and influences on many levels.

c. components and processes
See description on right-hand page.

d. important to notice
Even without any quantitative details, the model is instructive in showing the complexity and interdependencies of the nested systems.

Second-order Feedback: Biological Example
The Role of Wolves in Regulating the Yellowstone Ecosystem

Decreasing the wolf population seemed to increase erosion (and created a more desert-like environment).

Conversely, restoring wolves seemed to reduce erosion (and restored much of the environment's diversity).

Increasing Erosion

As the number of wolves drops,
the level of elk grazing around streams
(and the nearby willows) rises
(an unexpected outcome).

As more elk graze near the streams,
they destroy more and more willows—
eventually (over many years)
destroying nearly all of the willow.

As the willow population declines,
the beaver population declines.

As the beaver population declines,
the number of damns decrease.

As the number of the dams decrease,
the number of the ponds decrease.

As the number of the ponds decrease,
the speed and extent of erosion increase.

Decreasing Erosion

As the number of wolves increases
(after reintroduction),
the level of elk grazing around streams
(and the nearby willows) drops—
presumably because the elk "sense"
the increased danger in these areas
where wolves can more easily trap them.

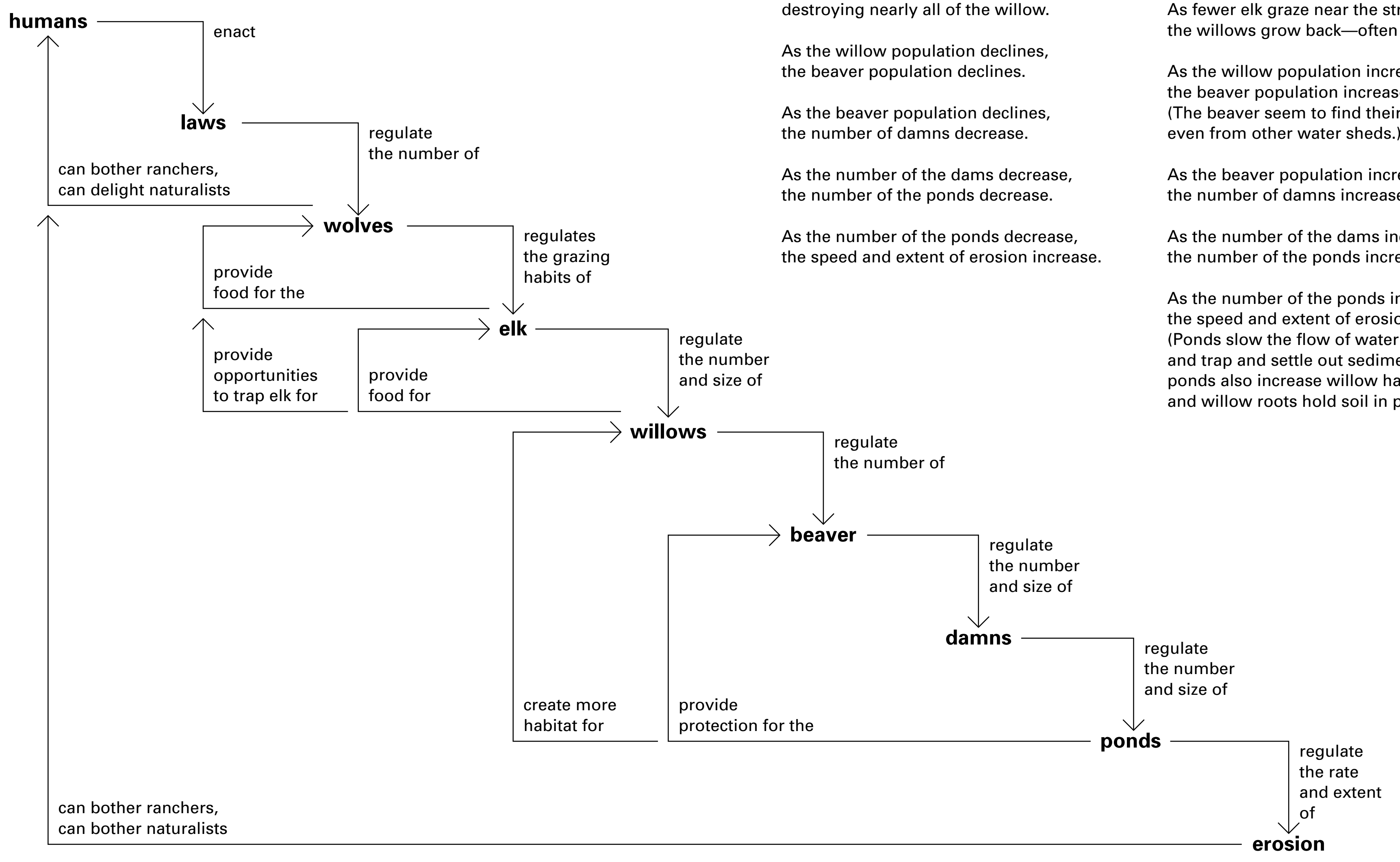
As fewer elk graze near the streams,
the willows grow back—often quite rapidly.

As the willow population increases,
the beaver population increases.
(The beaver seem to find their way back
even from other water sheds.)

As the beaver population increases,
the number of damns increase.

As the number of the dams increase,
the number of the ponds increase.

As the number of the ponds increase,
the speed and extent of erosion decrease.
(Ponds slow the flow of water
and trap and settle out sediment;
ponds also increase willow habitat;
and willow roots hold soil in place.)



Second-order Feedback: Social Example
after Douglas Englebart

a. goal of model
The model explains Englebart's second-order perspective on organizational regulation.

b. description
Characterizing the cybernetic loops of an organization in relation to its own learning requires multiple, nested systems.

c. components and processes
The lowest-level system (lower-right) shows a typical manufacturing process, involving input (raw material), some product-making processes, and output (finished product). The role of feedback is to ensure that a given level of quality of the finished product is maintained. Sensors may detect variations in quality and cause a modification of production processes to return to the desired level of quality.

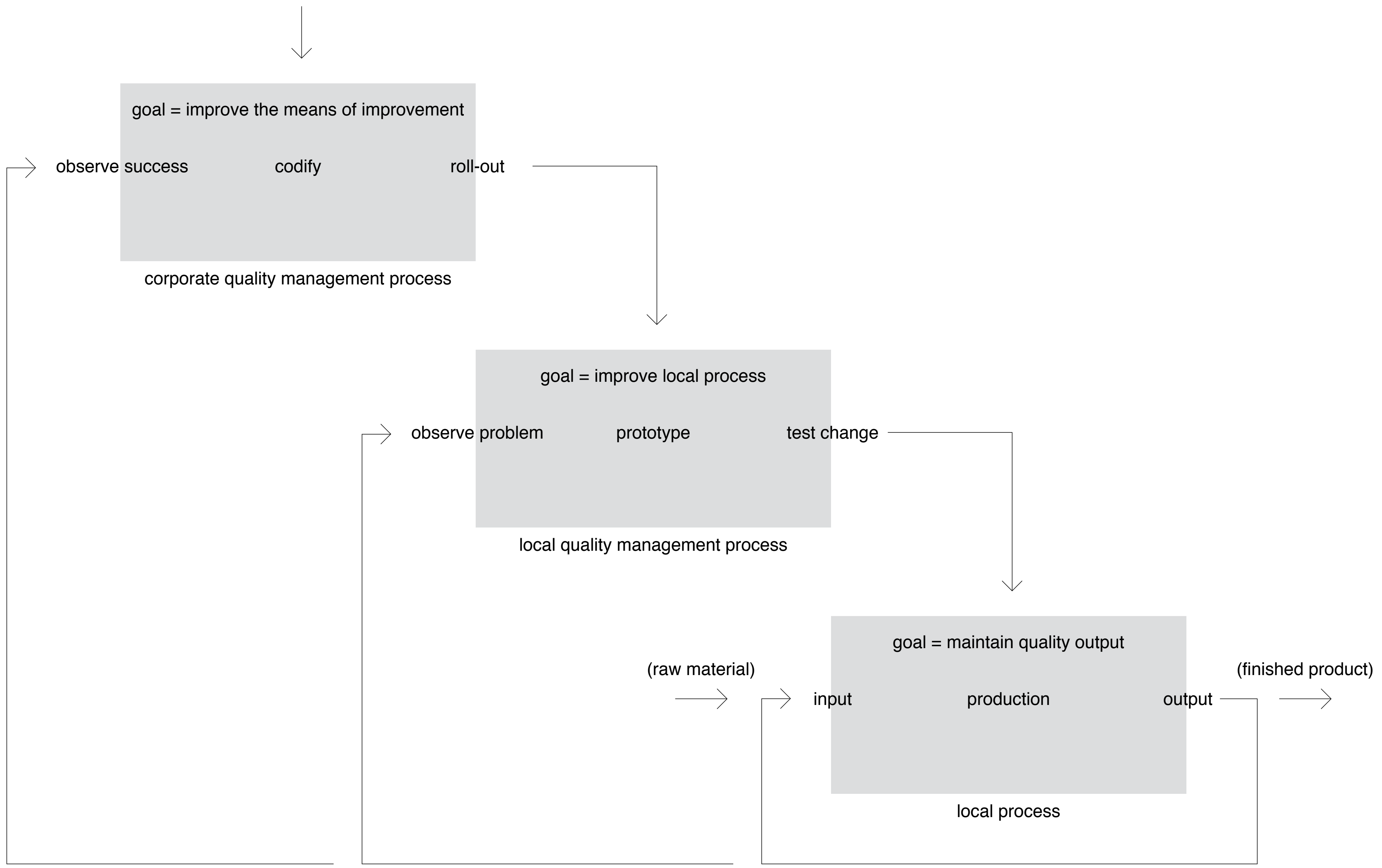
The above system is nested in a second-order relationship with a localized quality-management system (center) whose responsibility is to sense whether the lower-order system is achieving its goals for quality. If not, the quality management system may test changes to the goals of the lower order system. Status of quality is monitored (by both systems) and adjustments made if needed; successful tests cause changes to be installed in the lower-order system.

A further second-order relationship is maintained with the corporate quality management system (upper-left). This system also senses the overall quality of output and will act, if needed, by roll-out of changes to the localized quality-management system.

Englebart's model makes explicit the need for multiple nestings to achieve robust and efficient organizational design.

Second-order Feedback: Social Example
after Douglas Englebart

Organizational 'boot-strapping' process relies on nested feedback loops.



Second-order Feedback: Social Example
Levels of feedback in design processes

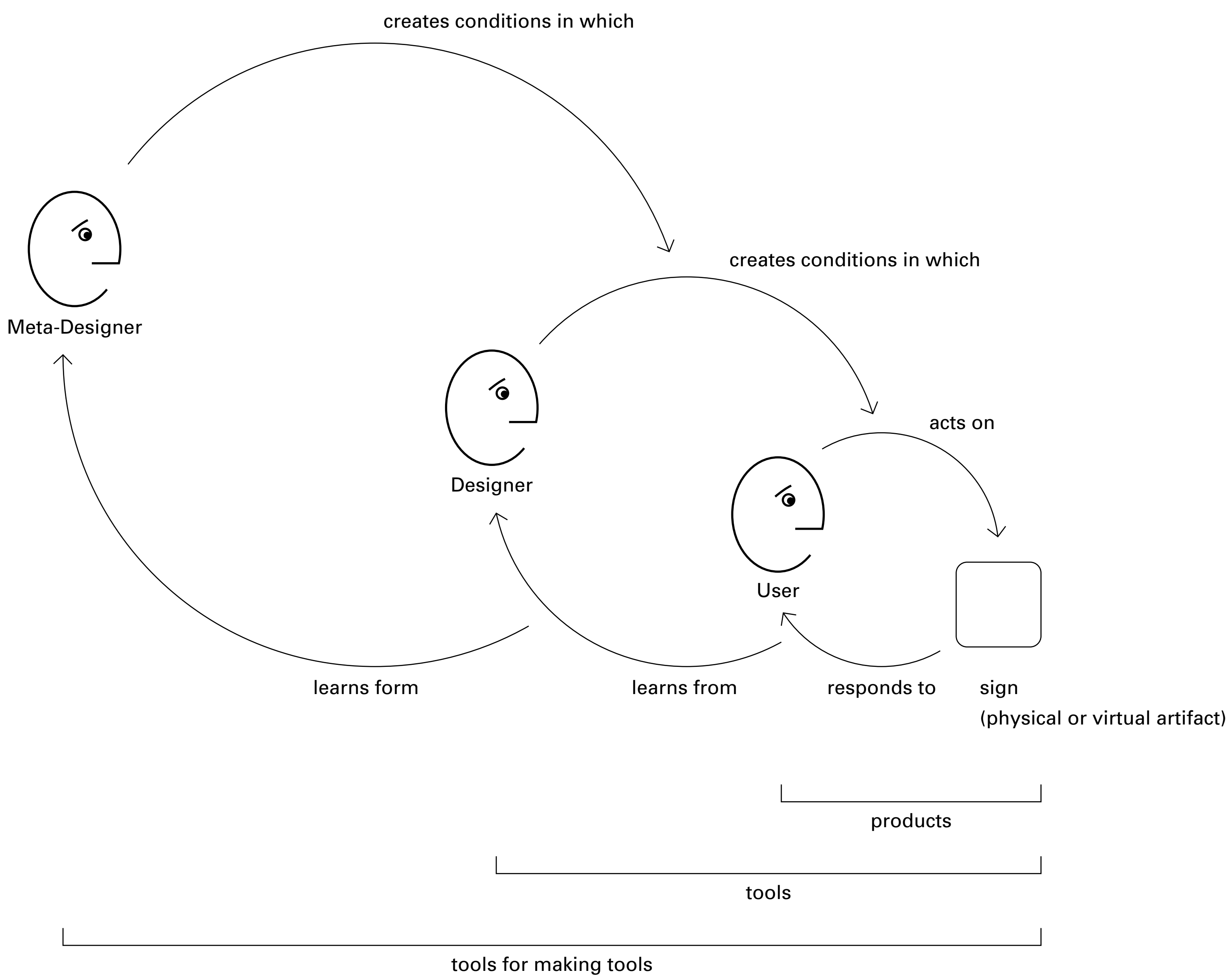
a. goal of model
The model applies second-order feedback to the social example of "design", showing nested systems.

b. description
Distinctions are made between the User of a product, the Designer of that product, and the Meta-Designer, that is, the system or role that sets the goals for the Designer. Depending on circumstances, the roles of User, Designer, and Meta-Designer may be taken by the same individual.

c. components and processes
Working from the far right of the model, the sign is some physical or virtual (software or even imagined) artifact that the User acts on to achieve a goal. This first-order system is nested inside a system that serves as its regulator, that of the Designer, who creates conditions in which the first-order system (User and artifact) can operate. The Designer learns from outcomes of the User loop system and may change conditions for the first-order system. Furthermore, these systems are nested inside an enclosing system enacted by the Meta-Designer, who creates conditions for the Designer loop, analogously to the Designer loop in relation to the User loop.

One way to characterize the two higher-order loops is that of making tools, and making tools for making tools. However, "tools" should be construed in broad terms to include any physical or virtual artifacts that aid the creation of products, or tools for creating products or services.

Second-order Feedback: Social Example
Levels of feedback in design processes



Two First-order Systems Communicating

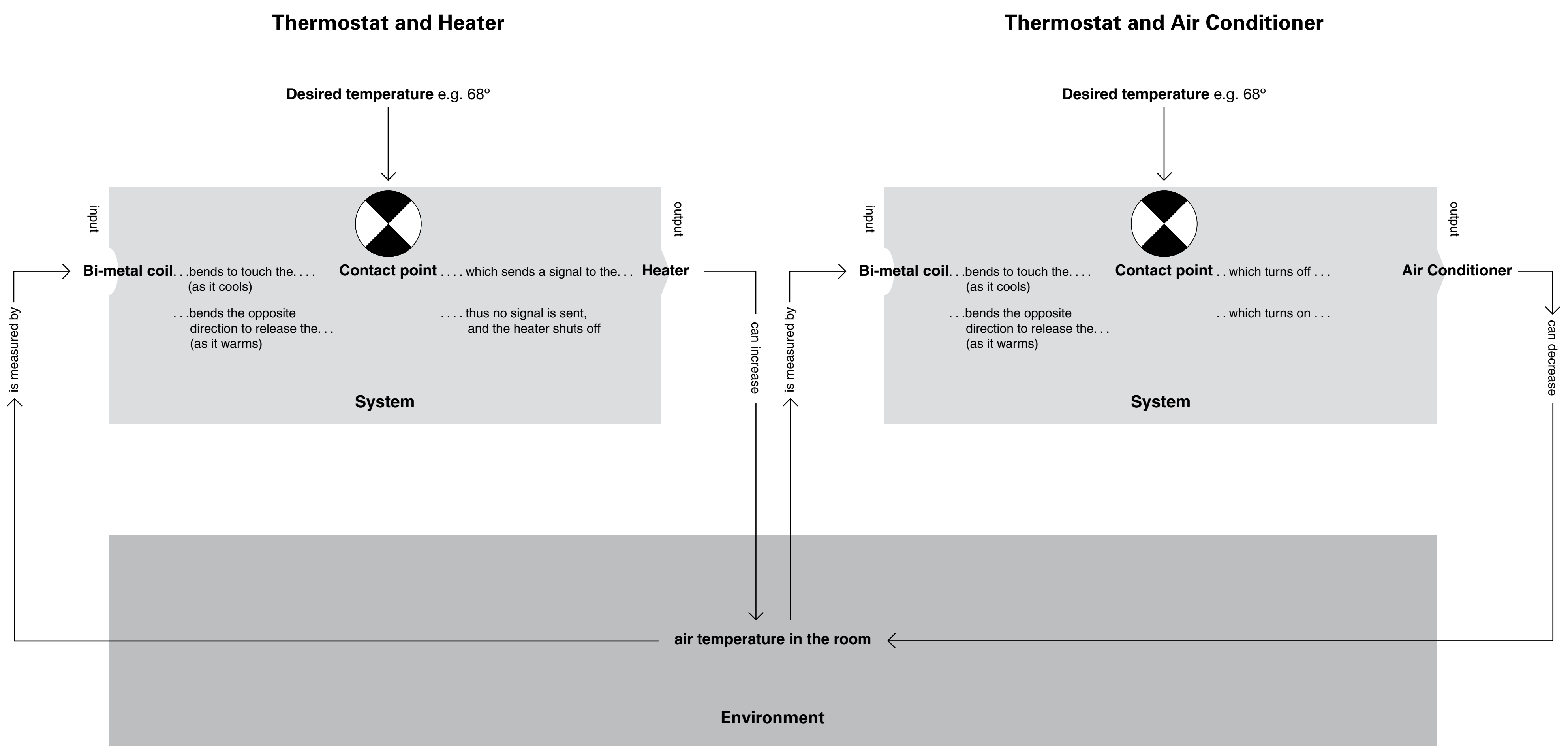
a. goal of model
The diagram shows that two first-order systems may share an environment, and hence influence each other indirectly, but may not be coupled directly such that they constitute a second-order system.

b. description
Consider two systems, one that heats the air in a room and another that cools it.

c. components and processes
Each first-order system depicted as before. Each as influence on the same environment (the air temperature in the room) but neither as direct impact on the other. In practice the settings of each thermostat should prevent contention, that is, actuation of both heating and cooling at once. Single devices that control both heating and cooling functions are usually designed to prevent such a setting from taking place.

Two First-order Systems Communicating
Independent Heating and Cooling Systems

The two systems illustrated below may affect each other,
but neither changes the other's goals.
Thus, they do not form a second order system.



Conversation

Model of Communication
after Shannon & Weaver

origins

a. individuals
Claude Shannon was the primary source for the model. His co-author, Warren Weaver, hoped for a broader scope for the model than Shannon. Weaver claimed extension of the model to explain the transfer of 'meaning', which was never achieved.

b. era/dates
Late 1940s.

c. references for model, context, author(s), concepts
Shannon, Claude E., and Weaver, Warren: The Mathematical Basis of Information, University of Illinois, Urbana, Illinois, 1964.

Note that Ashby's Introduction to Cybernetics includes a mapping of requisite variety to Shannon's channel model.

d. examples
Telephone transmission lines were the original context of the model's development.

a. goal of model
The model distinguishes sources of information from their encoding and transmission. The impact of noise in the communication channel is countered by a quantitative approach to calculating the required redundancy of the channel—additional data that must be inserted into the source's message—in order to achieve a desired accuracy of transmission.

b. description
A hypothetical communication channel is presented and the effectiveness of the channel at transmitting the original information of the source can be computed.

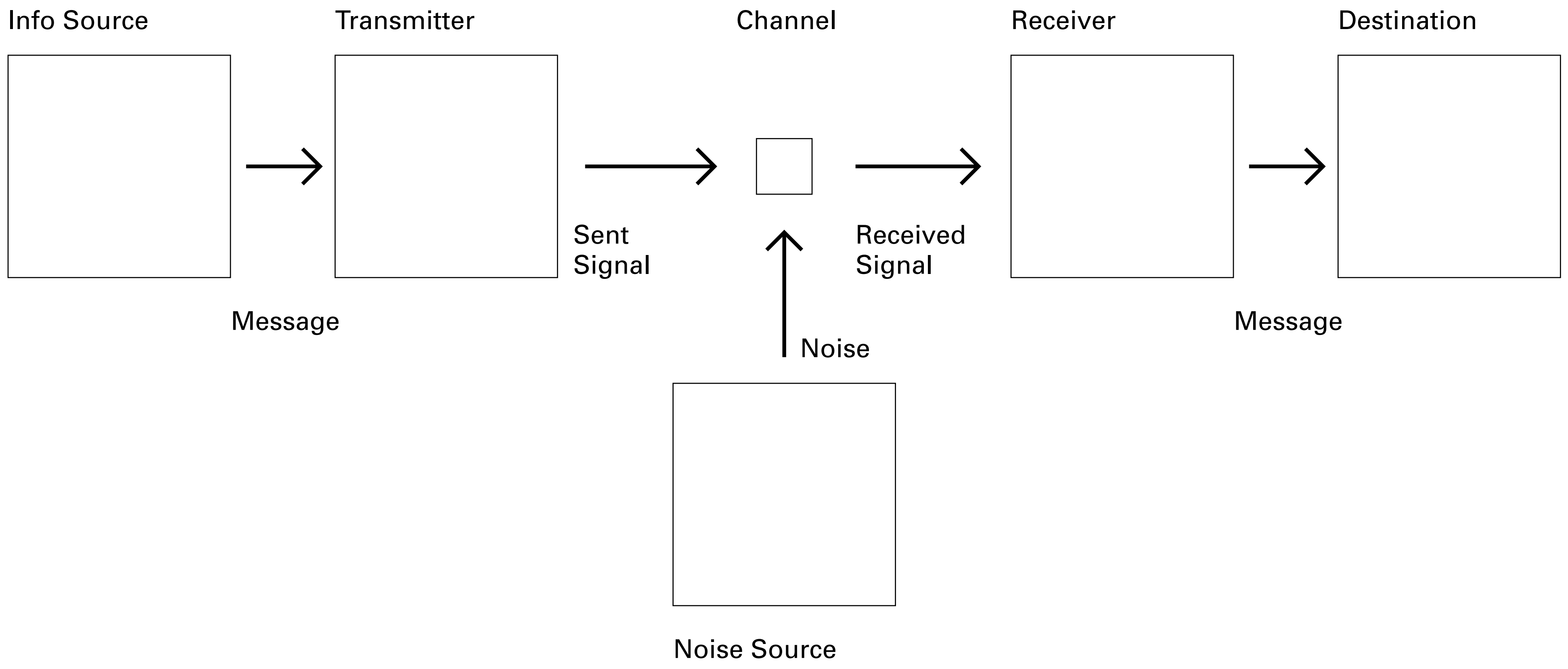
c. components and processes
An information source composes a message in the form of a set sequence of characters from a given alphabet. The transmitter encodes the message into a signal that is sent through a communication channel. At the far end of the channel, the signal is received and decoded by the receiver and turned into a message, which is delivered to the destination.

d. important aspects of model/breakthrough/limitations
Not shown here, the model provides a mathematical basis for designing a channel to guarantee a desired level of accuracy ("goal") against an anticipated level of noise ("disturbance"). Innovations of the model include the measures of "information" based on the number of bits of data required to distinguish distinct characters in the transmitted alphabet; this was an innovation at the time. The limitation of the model is that the alphabet must be pre-agreed by both the transmitter and receiver.

Model of Communication
after Shannon & Weaver

This model describes the process of one telephone communicating with another.

Weaver points out that *The Mathematical Theory of Communication* (and the model below) are primarily applicable to "*technical problems* [which] are concerned with the accuracy of transference from sender to receiver of sets of symbols (written speech), or of a continuously varying signal (telephonic or radio transmission of voice or music), or of a continuously varying two-dimensional pattern (television), etc."



Model of Human Communication

origins

a. individuals

b. era/dates

c. references for model, context, author(s), concepts
Paul Pangaro, "Cybernetics and Conversation", at http://pangaro.com/published/cyb-and-con.html

d. examples
A: I'd like to have hamburgers at home for dinner.
B: [imagines that this will require defrosting]. Are there any left in the freezer?

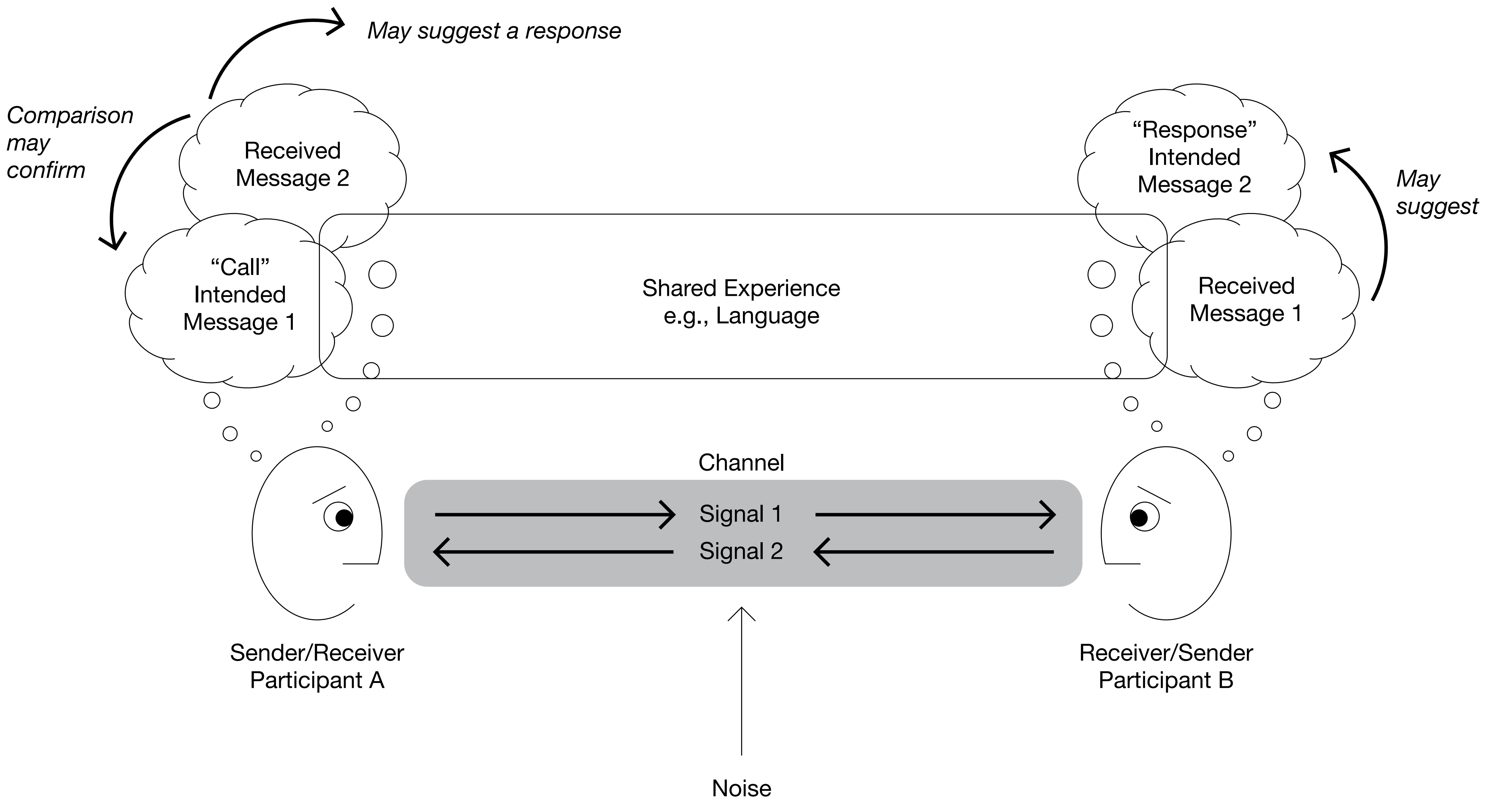
a. goal of model
The model bridges Shannon's Information Theory and Pask's Conversation Theory. It moves from the pure syntactic operation of Shannon's theory ("What character was sent?") to the semantic domain ("What message was meant?").

b. description
The channel of communication is seen as parallel to a context of shared experience that is required for the correct interpretation of the message. Senders and receivers become "participants" who must actively engage in the message in order to interpret it, rather than deterministic processes that merely distinguish among predetermined characters in an alphabet.

c. components and processes
Participant A uses a channel, for example a telephone, to speak a message. Message arrives to Participant B who uses shared experience to interpret the meaning, for example, the context of preparing dinner or achieving some other a shared goal. (Little need be spoken, much is understood.) Participant B may formulate and send a response back along the channel to A, who in turn interprets the message, formulates a meaning, compares that meaning to A's original intention, and may formulate and transmit a response.

d. important aspects of model/breakthrough/limitations
The model should not be interpreted too literally as it involves certain compromises for the sake of making a bridge from the mathematical/syntactic Information Theory to the cybernetic/semantic Conversation Theory. For example, "trigger" is a better label than "signal".

Model of Human Communication
after Pask and Pangaro



Model of Agreement
after Dubberly

a. goal of model
The model informally presents the necessary layers required to "come to agreement" about a particular subject.

b. description
The context of agreement is represented as a relationship among two participants and a subject.

c. components and processes
Participants, represented as "me" and "you" each have a model of a subject, represented here as an abstract cube. I hold a model of the subject "in my mind". I also imagine that you hold a model of the subject "in your mind".

One aspect of agreement is my model of the correspondence between my model and your model of the subject. If they correspond sufficiently, then I believe that we "agree" about the subject. The next aspect of agreement involves my knowing about your model of this first aspect, that is, whether you believe that we agree (how this is achieved is not shown).

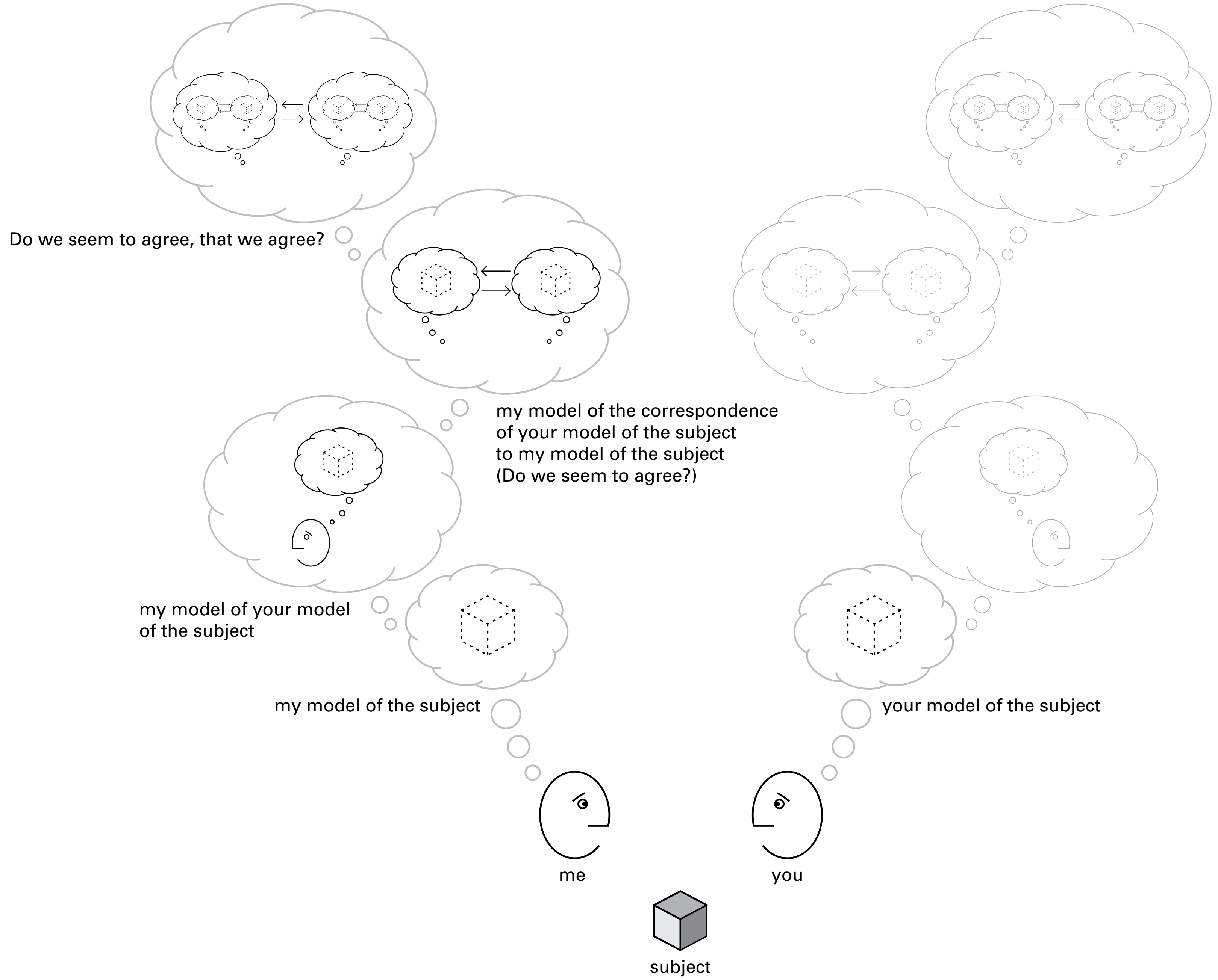
We may agree that we agree about a subject.
However, we may be wrong.

d. important aspects of model/breakthrough/limitations
The model is symmetric, in that all the aspects internal to me must also hold internal to you for agreement to take place.

There is an additional case not shown: where we agree that we do not agree.

Model of Agreement

Human communication relies on agreement.



Who defines the 'system'?

origins

a. individuals
Heinz von Foerster, Godon Pask

b. era/dates
Second-order cybernetics, implicit and discused from the 1940s, becomes "mainstream" in the 1960s though resisted within the community for another 25 years.

c. references for model, context, author(s), concepts

"The meaning of Cybernetics in the Behavioural Sciences". In *Progress of Cybernetics*, Volume 1, Editor, J. Rose. Gordon and Breach, 1970, 15-45. Reprinted in *Cybernetica*, No. 3, 1970, pp 140-159 and in No. 4, 1970, pp 240-250. Reprinted in Artoga Communications, 1971, pp 146-148.

d. examples
The observer observes the system of a thermostat, noting its control of a heater, based on sensing the air in the room, and striving toward the goal of maintaining a set temperature.

a. goal of model
The model is intended to show the dependency of the system on the observer.

b. description
The system arises as a consequence of the observer. The system—its boundaries and features—is delimited by the observer and does not exist as distinct from the environment except insofar as the observer chooses to delimit it.

c. components and processes
A first-order system (a placeholder for a system of any complexity) shown as before. Arrows indicate actions toward and sensing from the system by the observer.

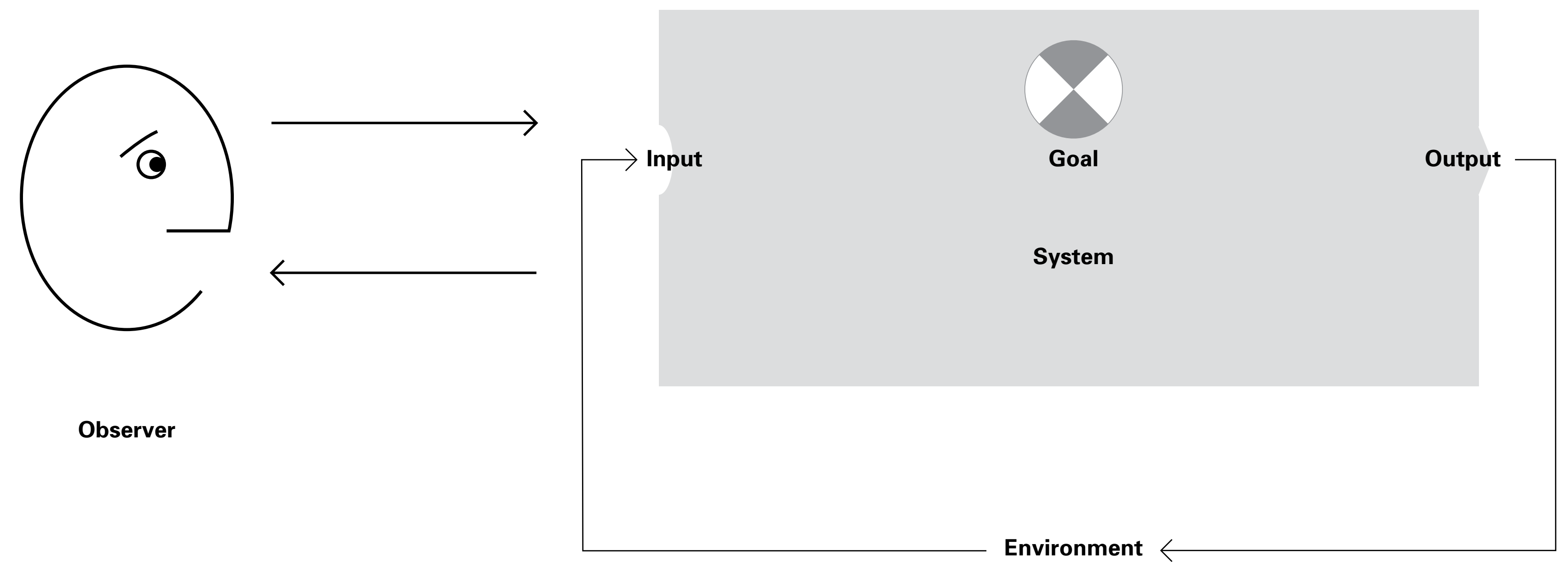
d. important aspects of model/breakthrough
The model supports the constructivist epistemology of cybernetics, that is, the stance that systems do not exist except as boundaries created by observers.

It is appropriate to say that observers *have goals for* the systems they create/observe. Specific systems have specific value to observers, whether for scientific, technological, or social reasons, but cybernetics considers them as artifacts of observation and not independent entities.

A more careful statement would be to say that observer and system co-arise as a consequence of interaction.

Who defines the 'system'?

The system is an observer phenomenon.
Heinz von Foerster: 'Objectivity is the delusion that observations could be made without an observer.'



2nd-Order Cybernetics and the Introduction of Subjectivity

origins

a. individuals
Ernst von Glasersfeld is a primary source of writings of cybernetics as a constructivist epistemology from the perspective of philosophy.

b. era/dates
Second-order cybernetics, 1960s+.

c. references for model, context, author(s), concepts

Ernst von Glasersfeld, "An Exposition of Constructivism: Why Some Like it Radical", available at http://www.oikos.org/constructivism.htm.

d. examples
Choosing what language to use delimits what we see, want, and do. "Problem framing", from design methods, is the process of deciding what to observe.

a. goal of model
The model shows the related scope of first- and second-order cybernetics and that the inclusion of the observer requires recognition of subjectivity in all observation.

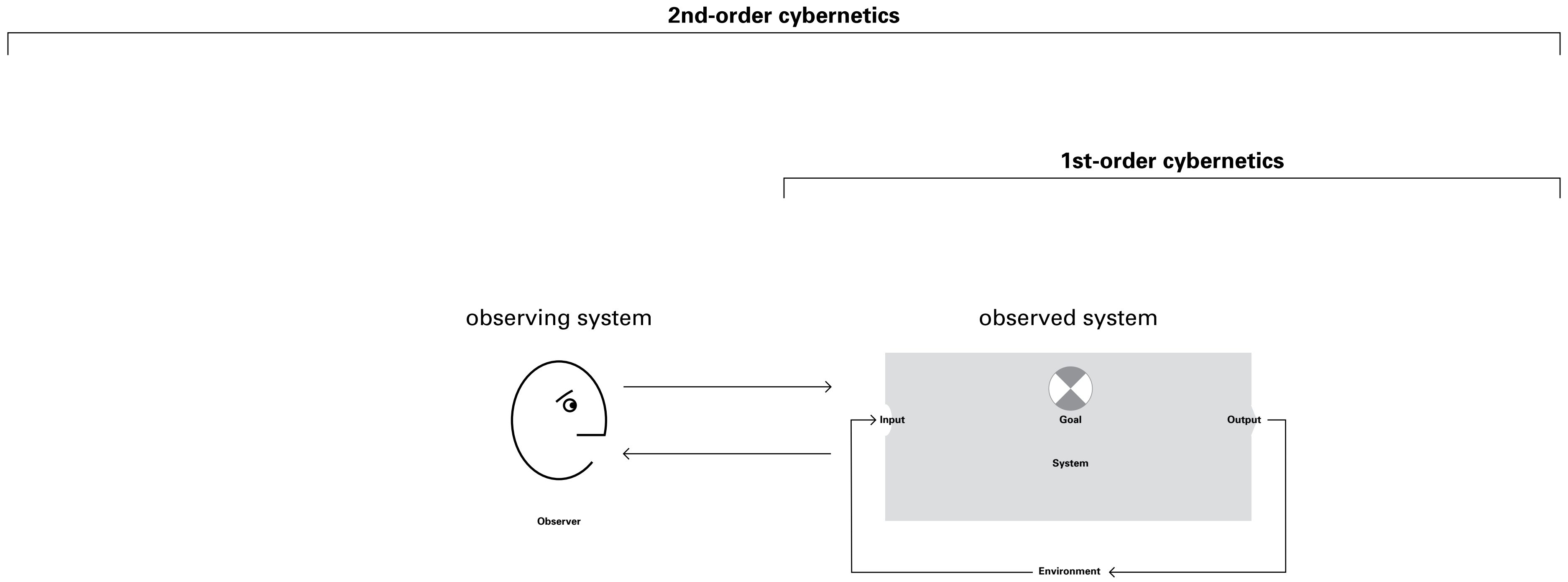
b. description
1st-order cybernetics is concerned with observed systems ('systems that are observed'). 2nd-order cybernetics adds the realization that it is an observer who specifies or creates the observed system, and that the observer is limited by biases of reference frame, perception, preference, values, beliefs. Therefore, systems are necessarily subjective in nature, that is, subject to the biases of the observer.

c. components and processes
First-order system shown as shaded area with loop through environment, as before. Observing system ('system that is observing') interacts with first-order system, as per previous model.

Brackets above show the domains of 1st- and 2nd-order cybernetics.

2nd-Order Cybernetics and the Introduction of Subjectivity

Heinz von Foerster noted:
'First-order cybernetics is "the science of observed systems".
Second-order cybernetics is "the science of observing systems".'



Observing the observing

origins

a. individuals
Heinz von Foerster was a foundational force behind establishing 2nd-order cybernetics as the main discipline.

b. era/dates
Second-order cybernetics, 1960s+.

c. references for model, context, author(s), concepts
von Foerster, Heinz: "On Constructing a Reality".

d. examples
An observer observes the interaction between an observer and a thermostat, where the nested observer is seen to delimit the boundaries and features of the thermostat in terms of its input, output, and goal. In practice, the two observers may be different perspectives in the same person.

a. goal of model
The diagram explicitly adds the further layer, that of the observer of the interaction between the observing and observed system (which was merely implicit in the previous diagram).

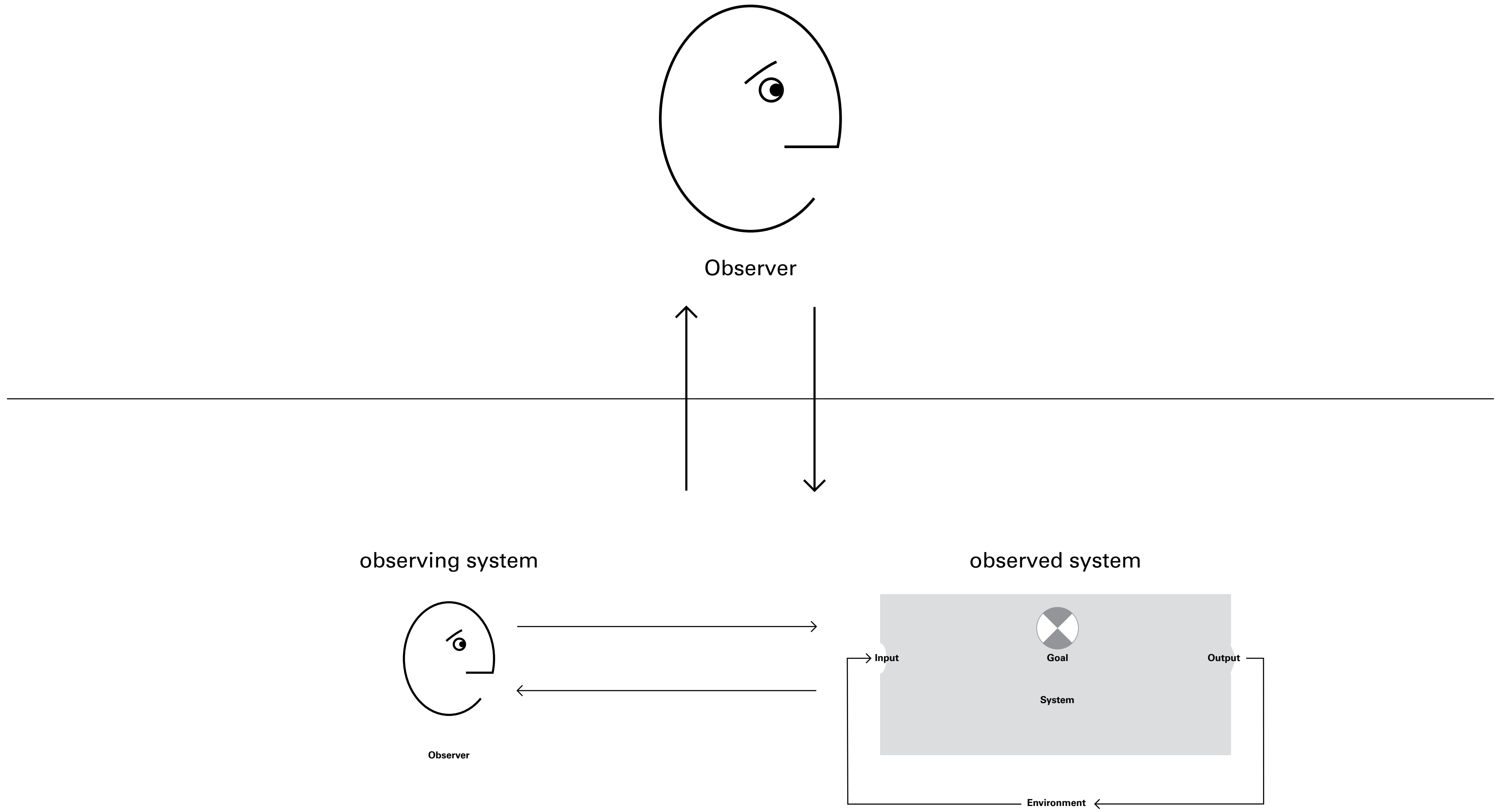
b. description
The upper observer has an interaction with the observing/observed system interaction shown in the lower part.

c. components and processes
Upper-observer interacts with the system of lower-observer-interacting-with-system.

Observing the observing

We can back up still further and observe the observer observing.

Maturana said, "Everything said is said by someone."
And Von Foerster added, "Everything said is said to an observer."



Observing conversations

origins

a. individuals
Gregory Bateson, Margaret Mead, Gordon Pask.

b. era/dates
Side bar infomation text size

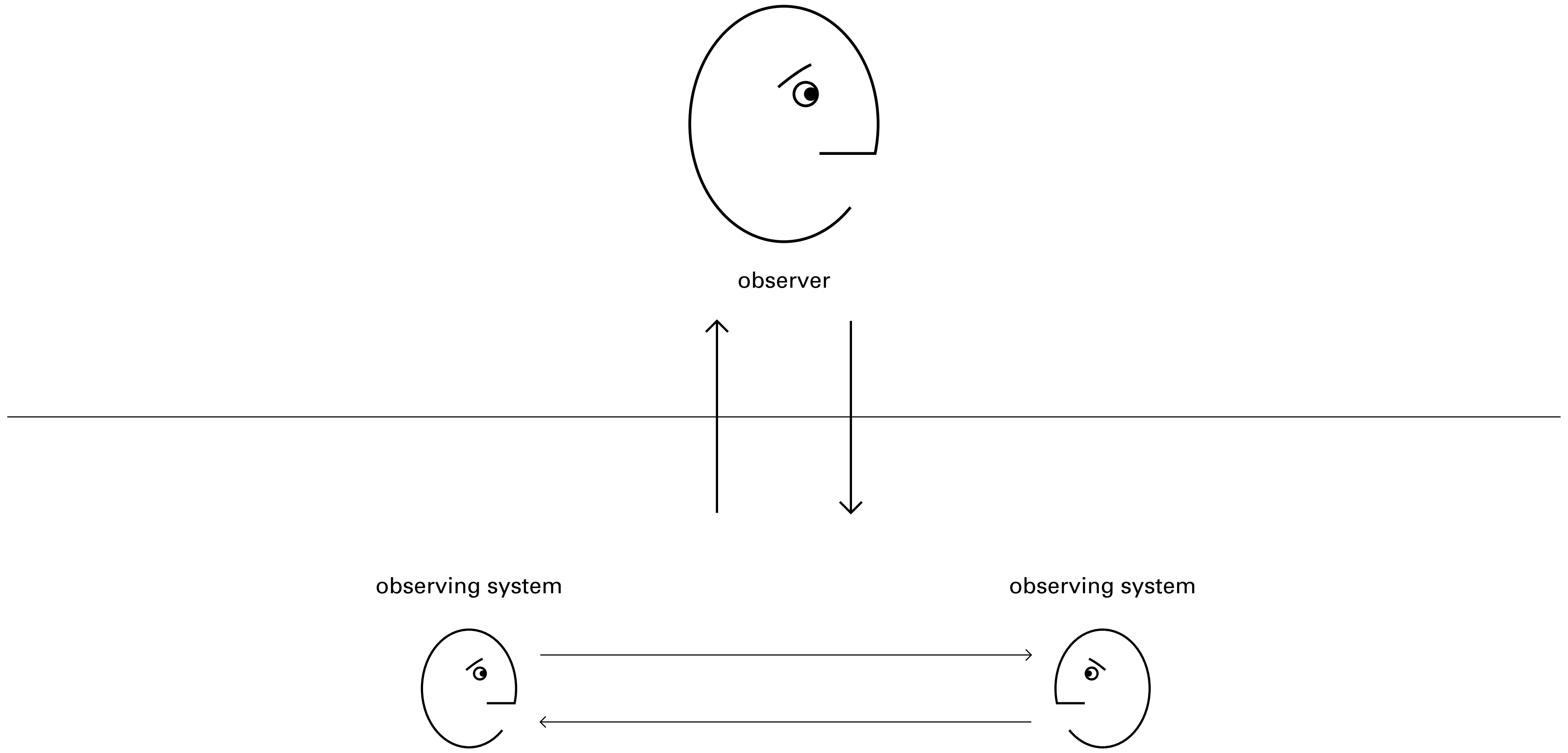
c. references for model, context, author(s), concepts
Gordon Pask, *The Cybernetics of Human Learning and Performance*, London, Hutchinson, 1975.

d. examples
An observer observes the interaction between two participants in a conversation and formulates the viewpoint that the conversation is an argument about politics.

a. goal of model
Continuing to build on prior models, this diagram shows that the observed interaction may be that of conversation.

Observing conversations

The observer in the upper level may observe a pair of observing systems that are interacting in a conversation, shown in the lower level. Under certain circumstances, it is possible for this observer to judge whether the two observed systems are in agreement.



a. goal of model
The diagram shows the relationships among two sets of participants in different conversations, where one conversation is about the other.

b. description
Many conversations are about other conversations

c. components and processes
Lower conversational exchange as above.

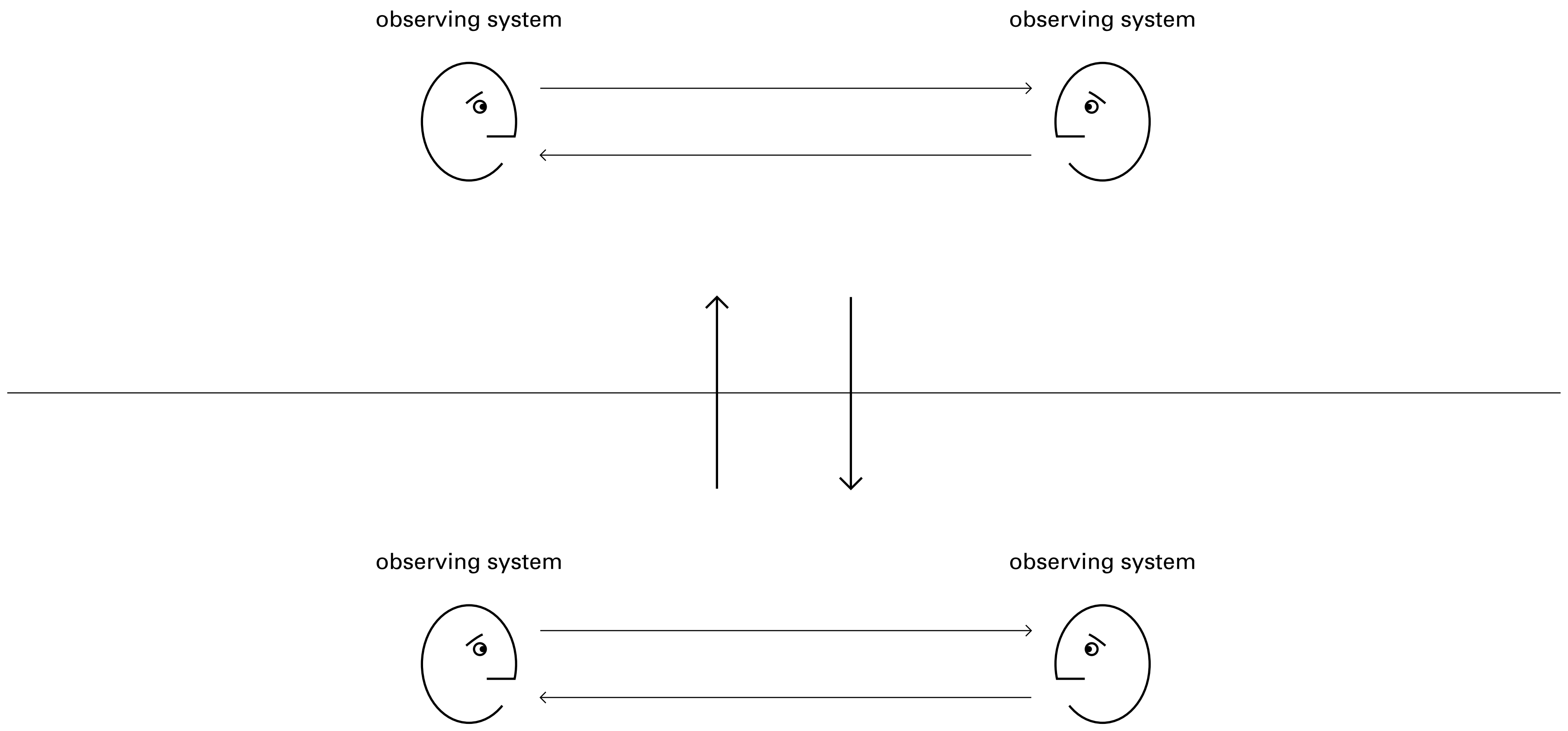
Upper exchange between participants who monitor (a.k.a. sense) and converse about the lower conversation (upward-facing arrow). These participants may choose to intervene (act) by interrupting the lower conversation (downward-facing arrow).

d. important aspects of model/breakthrough
The organization of this model acknowledges that conversations specifically, and interactions in general, take place on multiple levels—at least, according to an observer.

While the model allows for each observer/role to be a separate person, it is equally valid (and perhaps equally common) for multiple roles to be instrumened by the same person.

Conversations about conversations

Observers in the upper level may have a conversation about what they observe in a different conversation, shown here in the lower level. Participants in the upper level may be the same as those in the lower level. For example, one participant might say, 'That conversation we just had was interesting, wasn't it?'



‘Interaction’
after Pask and Pangaro

a. goal of model
The model casts the concept of ‘interaction’ in the framework goals and actions.

b. description
Multiple layers of interaction are shown (horizontal flows) as well as multiple participants (vertical boundaries). The emerging relationship between Participant A’s goals to B’s goals begins to form.

c. components and processes
A’s goals direct A’s actions. B interprets A’s actions and uses them to infer A’s goals. B compares B’s goals to inferred goals for A.

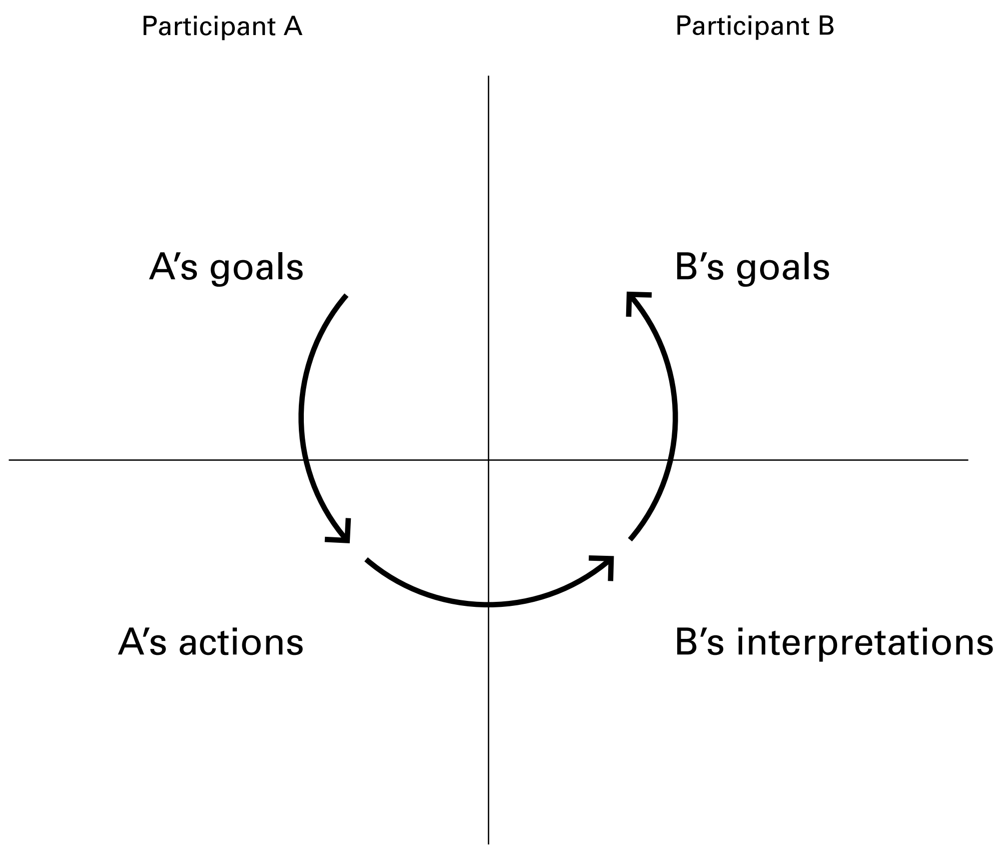
Actions may be physical movements or, as is most common in conversation, speech or writing or other modes of conveying language-based messages.

d. important aspects of model/breakthrough
The model shows how B does not have direct access to A’s goals, but only to A’s actions—actions which could be what A says about A’s goals. A may not be correct or honest—A’s actions may not reflect A’s goals. B’s interpretations may be also incorrect.

‘Interaction’

Participant B attempts to determine if A shares B’s goals.

B compares B’s goals to A’s actions.
(A’s actions may indicate A’s goals)



‘Relationship’

a. goal of model
The model casts the concept of ‘relationship’ in the framework goals and actions.

b. description
The reciprocal relationship between Participant B’s goals and Participant A’s goals builds from interactions that flow in both directions. By adding recursion and therefore history to initial, one-way interactions of the previous model, reliability of each’s models of the other is increased, (Contrast with the addition of redundancy to increase reliability, per Shannon model.)

c. components and processes
Similar to previous model, B’s goals direct B’s actions.
A interprets B’s actions and uses them to infer B’s goals.
A compares A’s goals to inferred goals for B.

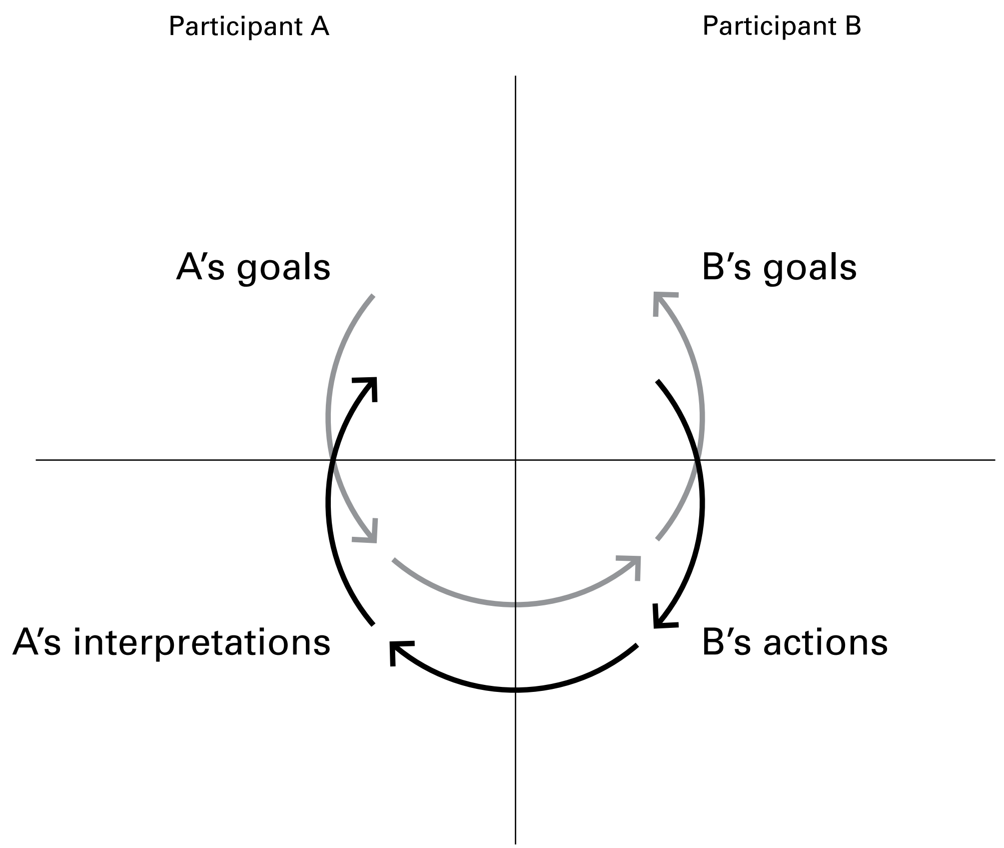
d. important aspects of model/breakthrough
Similar to previous model, this model shows how A does not have direct access to B’s goals, but only to B’s actions.

However, consistency of interactions over time may be sufficient for B to develop a sufficiently correct correct model of A. Should B’s goals be compatible with A’s, B may choose to cooperate or collaborate with A.

One aspect of the relationship may be the development of trust, that is, the judgment of the reliability of a belief about someone else.

‘Relationship’

Participant A develops A’s model of B’s goals.



origins

a. individuals

b. era/dates

c. references for model, context, author(s), concepts
W. Ross Ashby, Design for a Brain, Chapman and Hall, 1960.

d. examples

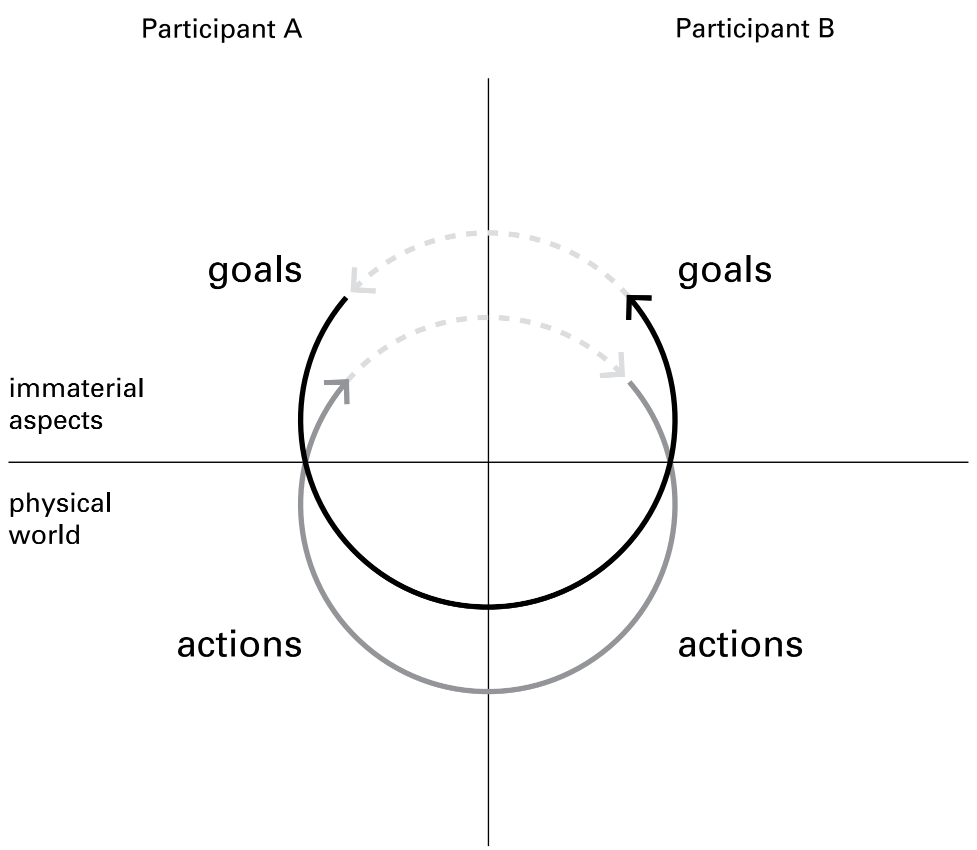
A. goal of model
The model casts the concept of 'conversation' in the framework goals and actions.

b. description
The close-coupled connection between goals and actions is shown to be fundamental to conversation.

c. components and processes
As before, goals lead to actions that result in interpretation and response among participants. Actions take place in the physical world, while goals do not. Goals, the province of cybernetics, are the "immaterial aspects" of interaction [W. Ross Ashby]. The dotted lines indicate that recursions via conversations are as if we are interacting directly at the level of goals, while in practice we are not. The interaction loops are shown as closed because there is coherence or consistency in recursive conversations over time, moving from goals to actions and back to goals. The loops are shown as overlapping yet separate because the participants may strongly agree and yet can never be identical.

d. important aspects of model/breakthrough
The interaction model is shown to bridge both physical actions and the less-intangible, 'immaterial' interactions engaged in by participants that possess language. Because participants are able to build stable models of others' goals as a consequence of their relationship, coöperation and collaboration are possible.

'Conversation'



Conversation: Basics

origins

a. individuals

b. era/dates

c. references for model, context, author(s), concepts
Gordon Pask, "Artificial Intelligence - a Preface and a Theory". Preface to chapter on Machine Intelligence, in *Soft Architecture Machines*, ed., N. Negroponte. MIT Press, 1975.

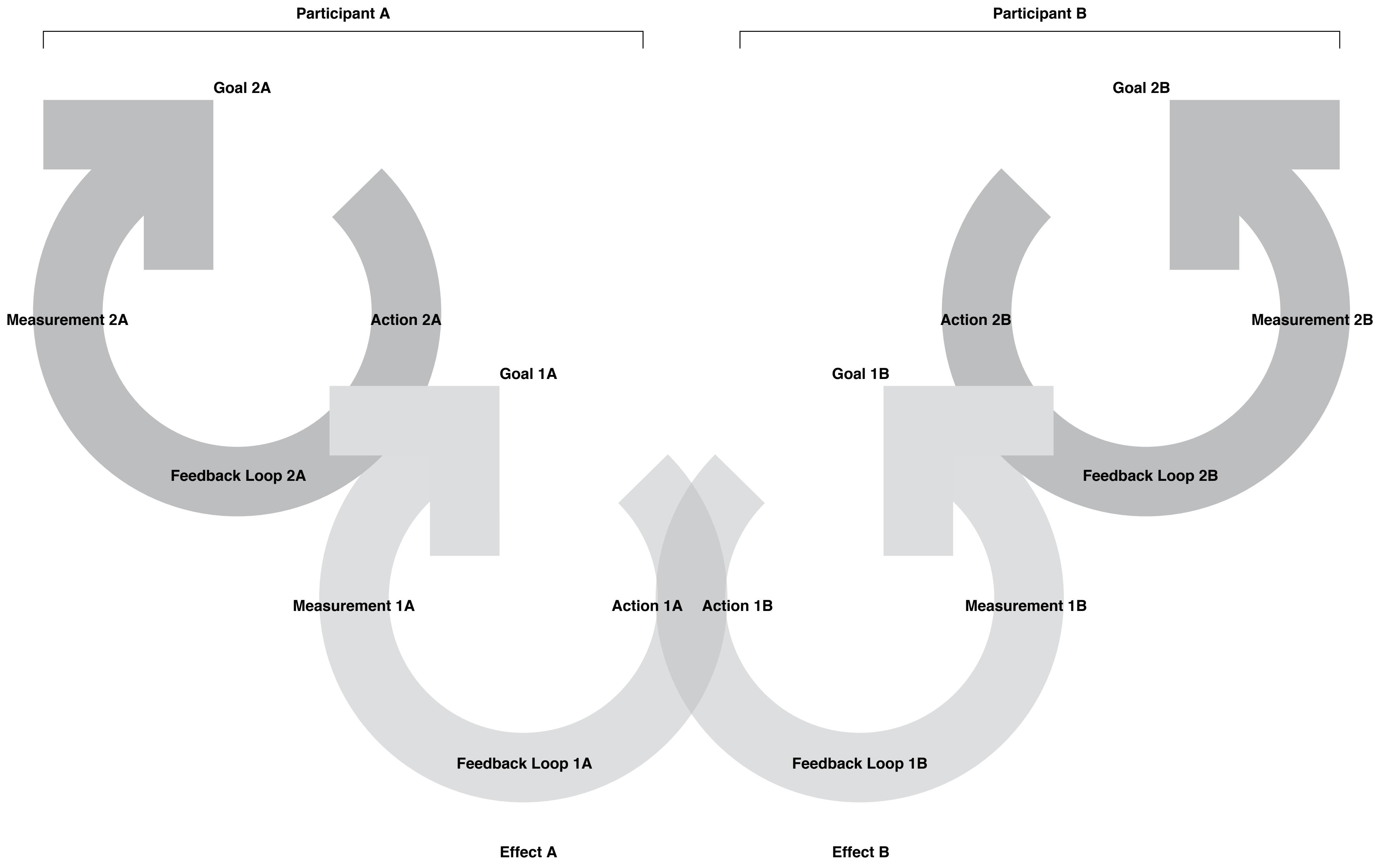
d. examples

a. goal of model
The model brings together the graphical form of the feedback models with the developing architecture of conversations.

b. description
As before, multiple participants interact at multiple layers, with feedback loops operating to build stable relationships and converge to shared goals (see also later models where goals are conflicting).

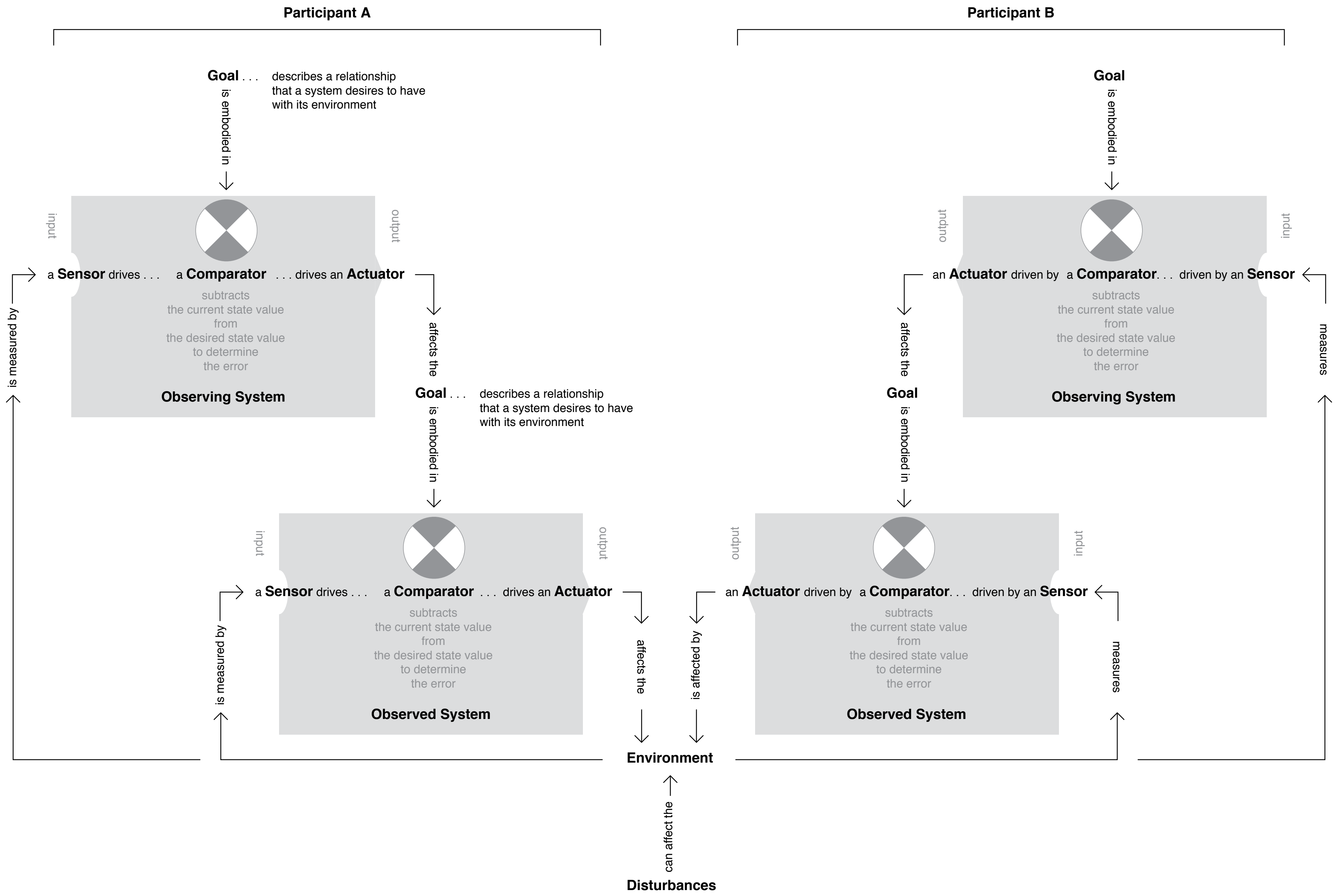
The horizontal layers are not controler/controlling relationships [see below] but may involve physical or linguistic interactions.

Conversation: Basics
after Pask



a. goal of model
As before, the basic cybernetic model is mapped out into the formal mechanisms involved.

Conversation: Formal Mechanism



Conversation: Biological Example

origins

a. individuals

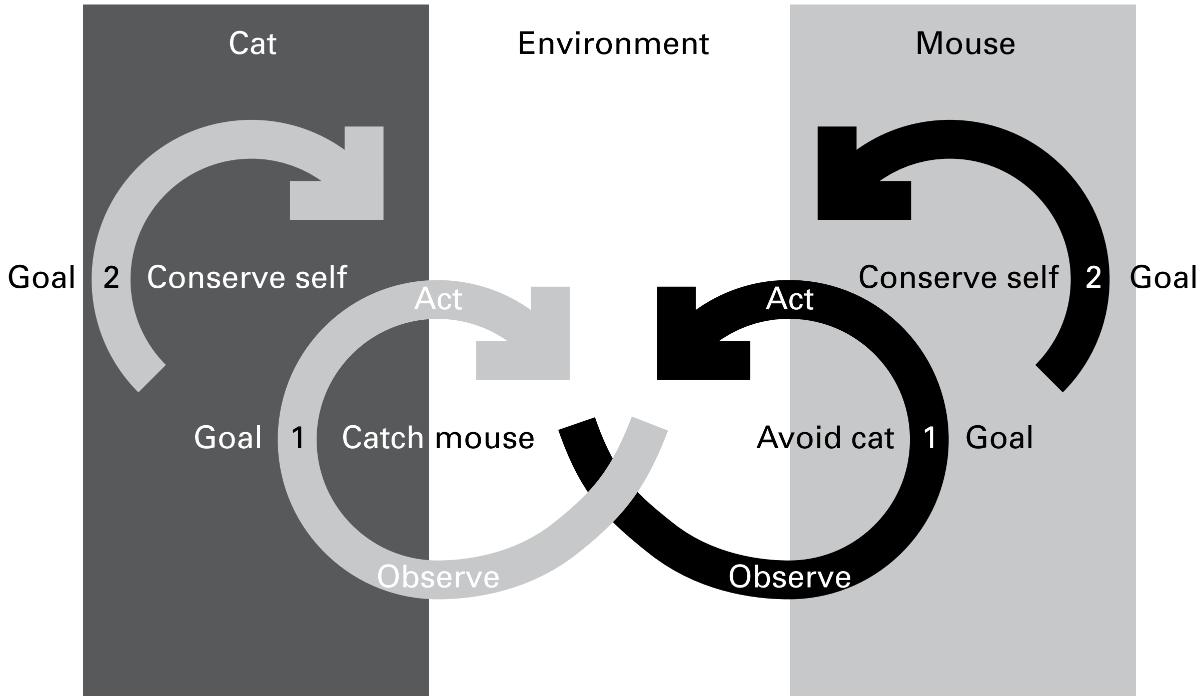
b. era/dates

c. references for model, context, author(s), concepts
Hugh Dubberly, Peter Esmonde, Michael Geoghegan, Paul Pangaro, "Notes on the Role of Leadership and Language in Regenerating Organizations", produced for Sun Microsystems, 2002. Available at http://pangaro.com/littlegreybook.pdf

d. examples

a. goal of model
The relationship between two biological systems, in terms of double-loops of goals and actions, is shown. The model applies the same double-loop, double-layer architecture to non-language interactions.

Conversation: Biological Example



The mouse teaches the cat.

The cat's nervous system
compels it to respond to every small thing that moves.

Trying to catch a mouse,
a cat observes the mouse's actions closely.
The cat actively learns
from the mouse's behaviors,
continually changing its capture strategy
in response.
So: The mouse teaches the cat.

Of course,
the mouse's behavior also changes continually,
in response to the cat's shifting tactics.
So: As the mouse teaches the cat,
the cat also teaches the mouse.

The cat's behavior may be thought of as a double feedback loop:

The first feedback loop defines the cat's catching behaviors.
The second feedback loop dominates the first;
it conserves the cat itself. (For example: The cat may want
to chase the mouse out a window, but its system
of self-preservation will prohibit that behavior.)

The mutual learning process is also
a double feedback loop:

Processing input from the mouse, the cat continually adjusts its capturing behavior, adaptively increasing efficiency and reducing noise in the message (that is, limiting extraneous actions). Conversely, the mouse changes its output based on the cat's input. As a result, the entire system evolves over time.

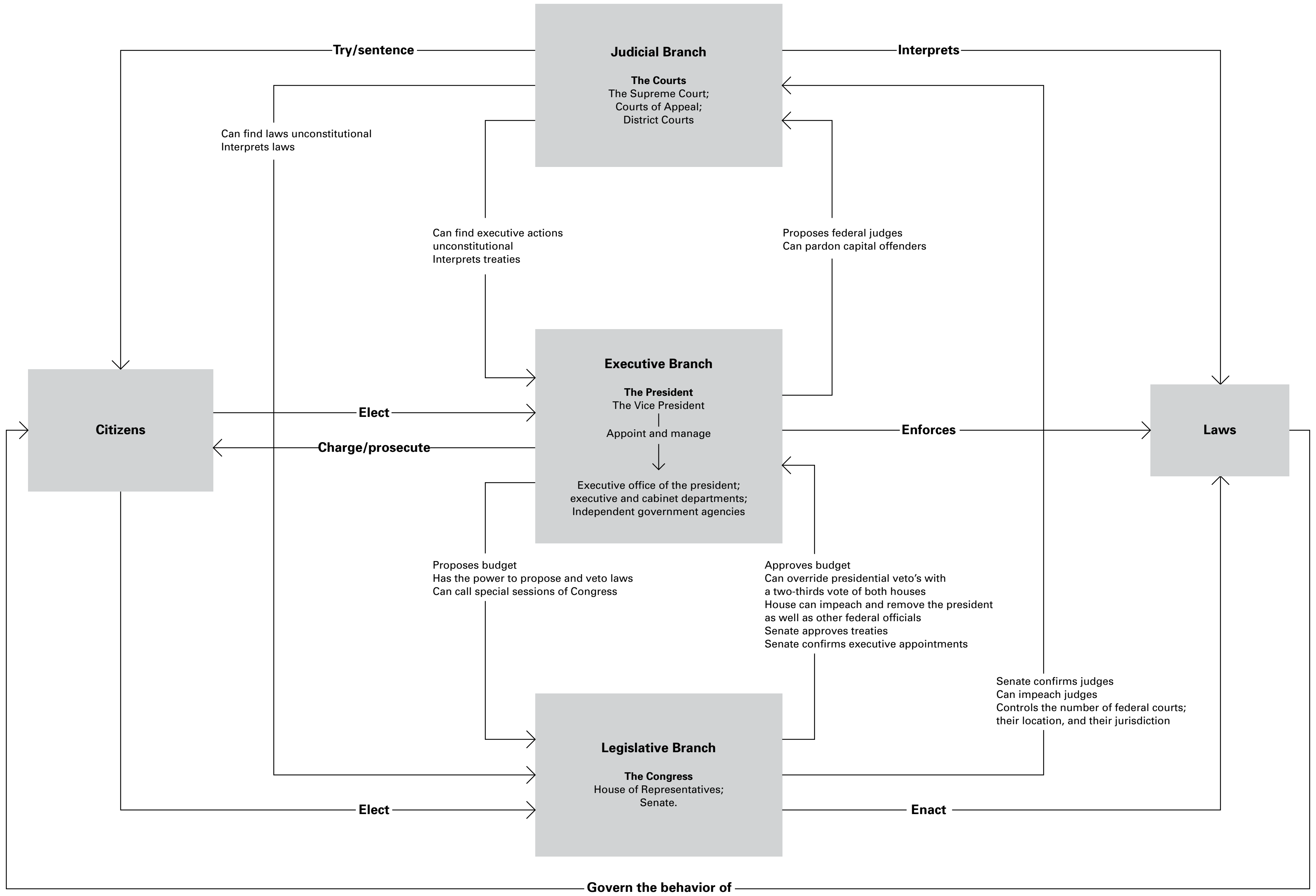
Checks and balances in the U.S. Federal Government

a. goal of model
The three branches of the US Federal Government is modeled as a series of interactions among the components.

b. description
This diagram is a departure from those above and below. Instead of showing the layered relationship in a conversational exchange, arrows indicate interactions among processes.

Checks and balances in the U.S. Federal Government

Feedback systems help each branch of the government balance the others.



Architecture of Conversation
Conversation Theory after Pask

origins

a. individuals
Gordon Pask and his collaborators at System Research, Ltd., England, including Dionysius Kallikourdis and Bernard Scott.

b. era/dates
The comprehensive theory was developed by the early 1970s. Published in 1976 in Nicholas Negroponte's Soft Architecture Machines.

c. references for model, context, author(s), concepts
Gordon Pask, "Aspects of Machine Intelligence", published as introduction to chapter in Soft Architecture Machines, Nicholas Negroponte (Ed.), MIT Press, 1976.

Paul Pangaro, "Architecture of Conversation Theory", at http://pangaro.com/L1L0/index.html.

Paul Pangaro, "A Model Of Entailment Meshes", at http://pangaro.com/ entailments/entailing-v2.htm

a. goal of model
The model explicates the interactions between "participants" in a conversation. Participants may be persons, schools of thought, or distinct viewpoints within a person. Their interactions can be classified by an observer as concerned with goals or methods.

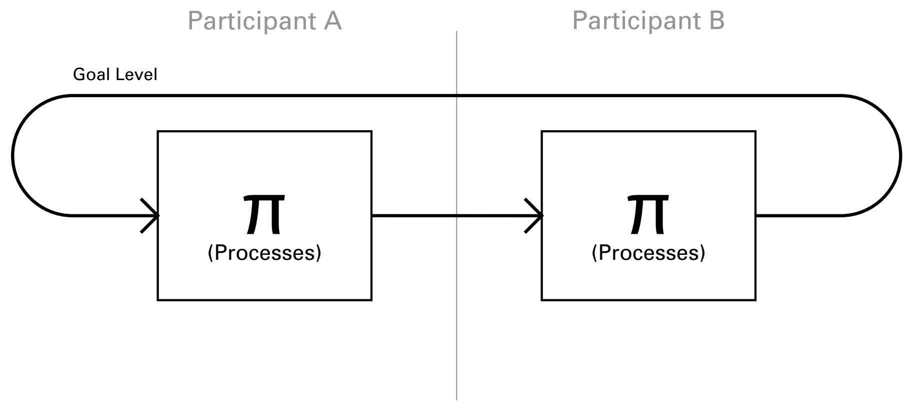
b. description
Conversation may take place between participants, here labeled 'A' and 'B'. The vertical line represents the distinction between the participants. The exchanges in language are shown as arrows that form a loop: A to B to A to B…

c. components and processes
Each quadrant contains a box with the symbol π; or "pi" that stands for "processes", namely, mental activities that manifest as knowing, believing, and acting, including language exchanges.

Each loop—the arrow from A to B and the closing by arrow from B back to A—represents triggers carried by language. The "traffic" of these loops occur in language, interpreted by the listener, for whom entailments are triggered and meaning is (potentially) made.

d. important aspects of model/breakthrough
The model shows how observers may distinguish conversational participants as well as levels of language in their discourse.

Conversation Theory
after Pask



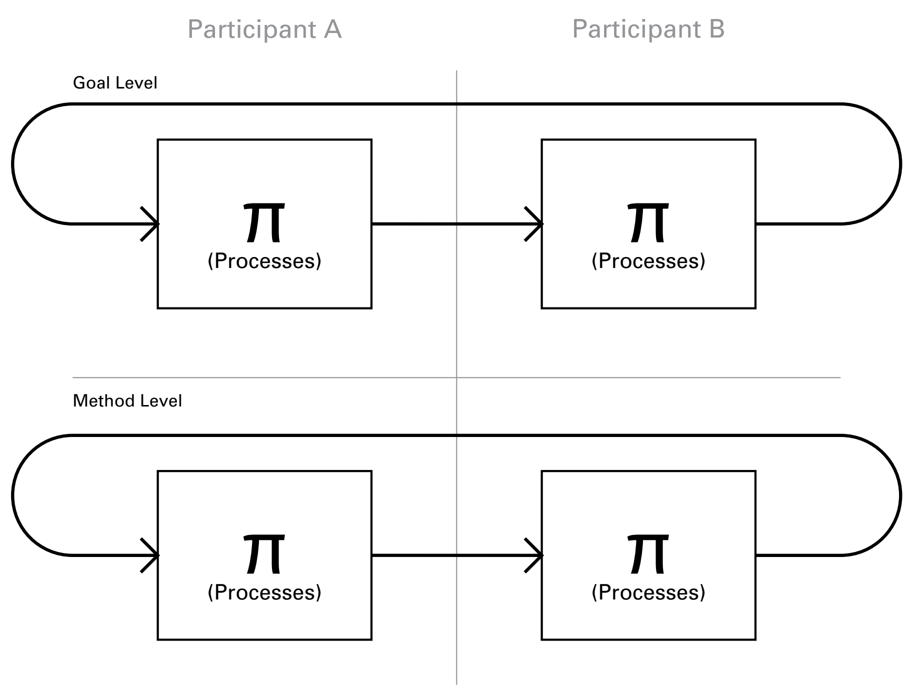
Example:
A: Can I have a hamburger?
B: Sure, you want fries with that?

a. goal of model
Show the multiple levels that may be observed in a conversation.

b. description
An observer may classify conversational exchanges between A and B as about goals or methods.
Goals are desired outcomes. Methods are the ways participants may act to achieve goals. The horizontal line, drawn by the observer, distinguishes the levels.

c. components and processes
Each quadrant contains a box with the symbol π; or "pi" that stands for "processes", namely, mental activities that manifest as knowing, believing, and acting, including language exchanges.

Architecture of Conversation
Distinguishing Goals and Methods



Example:
A: Can I have a hamburger?

B: Sure, you want me to make you one here or get takeout?

Conversation (Objective)
Interactions with 'it'

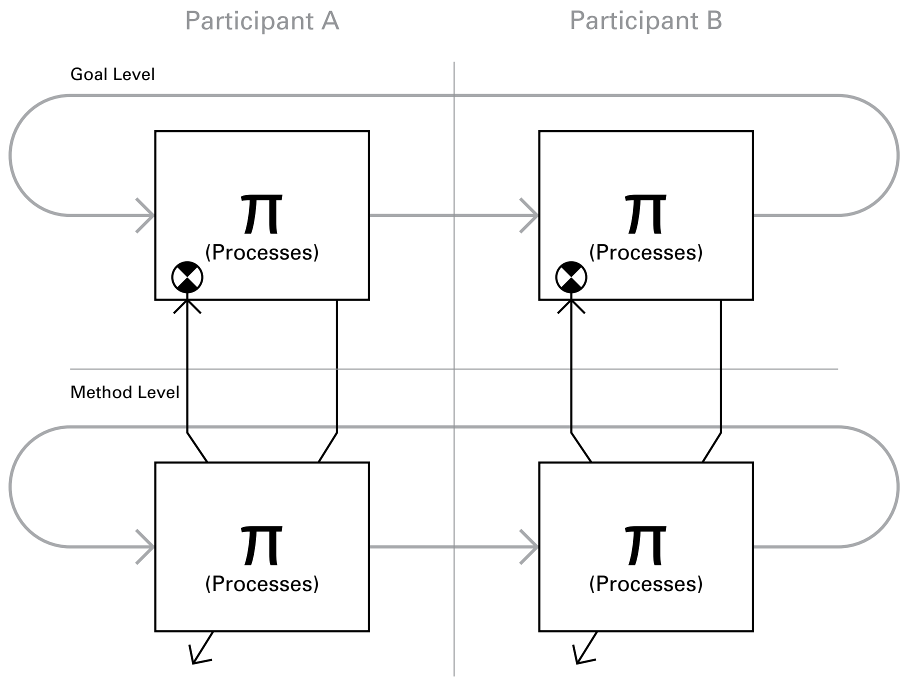
a. goal of model
To model those exchanges within a participant that are "control", or objective, interactions.

b. description
The upper level treats the lower level like an object, that is, like an "it". The lower level has no choice in the interaction; its goals are dictated. The vertical loops show that processes in the upper level control processes in the lower level. The loop is closed from lower to upper level via feedback of outcomes at the lower level.

c. components and processes
The upper process ("goal") selects and initiates ("controls") a lower process as a means to achieve the goal ("method"). The performance of the method yields a result ("current state") that may or may not achieve the goal. Result of performance of the method is returned to the goal level as feedback, where comparison of the current state to the desired state leads to the next response/action of the system.

d. important aspects of model/breakthrough
In this model the relationship between goals and methods is shown as a "control" relationship. Contrast this model with Conversation (Subjective), Interactions between "I" and "you" (next page).

Conversation (Objective)
Interactions with 'it'



Example:

A: (upper) I'd like to have a hamburger for dinner.

B: (upper) I'd like to eat chicken. I'll go get takeout.

A: (lower) [Performs the actions of taking the meat out of the fridge, putting it on the grill, turning the grill on, watching until it's done, etc.]

B: (lower) [Gets coat, leaves the apartment, walks to the takeout place, orders the food, waits until it's done, pays for it, brings it home and then eats it.]

A: (upper) I've cooked the hamburgers and achieved my goal.

B: (upper) I've eaten the chicken and achieved my goal.

Conversation (Subjective)
Interactions that refer to ‘I’ and ‘you’

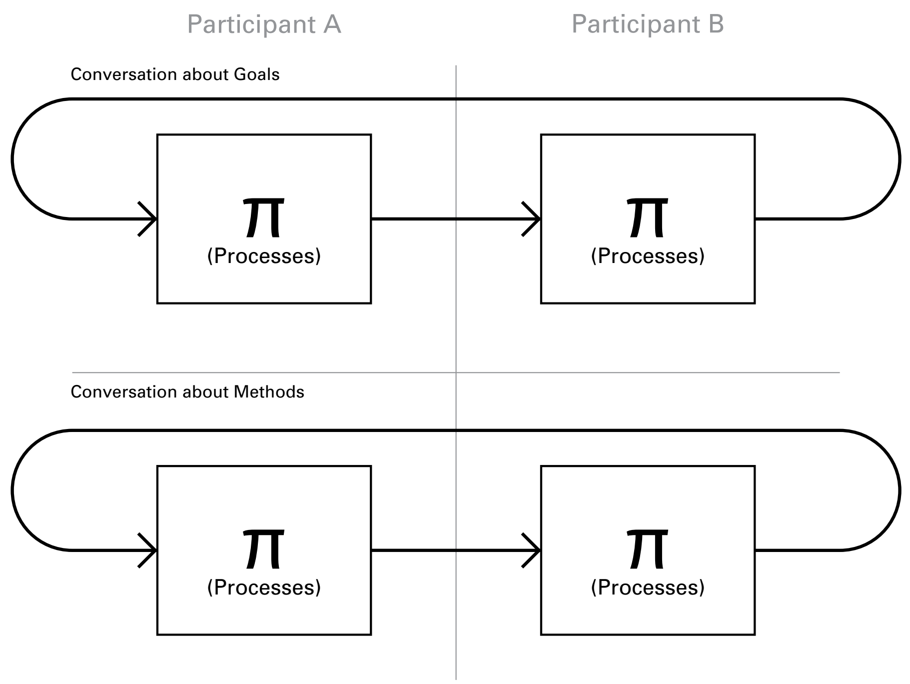
a. goal of model
The model distinguishes those exchanges between participants that take place in language. The experience for participants is subjective, i.e., it is subject to the limitations of language, constrained by individual interpretations, and may include misunderstandings.

b. description
The horizontal loops carry messages. The upper level may comprise exchanges about the whys or the goals of the participants: what they want to achieve and the degree to which they share the same goals. The lower level may represent exchanges about the hows or the methods to achieve the goals: what they might do to achieve goals and who might do it.

c. components and processes
The participants are the “I” and “you” of the title.
By looping around horizontally, the participants can build on previous exchanges and create a history and relationship. The relationship may include agreements to help each other define goals or define and carry out the methods to achieve the goals.

d. important aspects of model/breakthrough
This model shows that participants may choose to cooperate and to engage in conversation, or not. Contrast this model with Conversation (Objective), Interactions with “it” (previous page).

Conversation (Subjective)
Interactions that refer to ‘I’ and ‘you’



Example:
A: (upper) I’m thinking we might want to have hamburgers for dinner.

B: (upper) Well, ok. We had them last night. What about chicken instead?

A: (upper) Chicken is fine too.

B: (lower) We don’t have any chicken defrosted.

A: (lower) You could go to that takeout place and bring it back.

B: (lower) I went last time, so it’s your turn.

A: (lower) I’ve been twice recently.

B: (lower) Yes, ok, I’ll go after I finish reading my email.

A: (lower) Ok.

Conversation for Understanding
Explaining Concepts to others

a. goal of model
The model displays the levels of exchange required to bring about shared understanding among conversational participants.

b. description
Informally, a concept is a set of topics that ‘make sense together’. Participant A wishes to convey a concept to Participant B with some level of confidence. This requires exchanges in language at 2 levels: Why and How.

[upper level] Why—the goal or purpose of the overall concept; this comprises a description of the role that each component or topic plays in the concept.

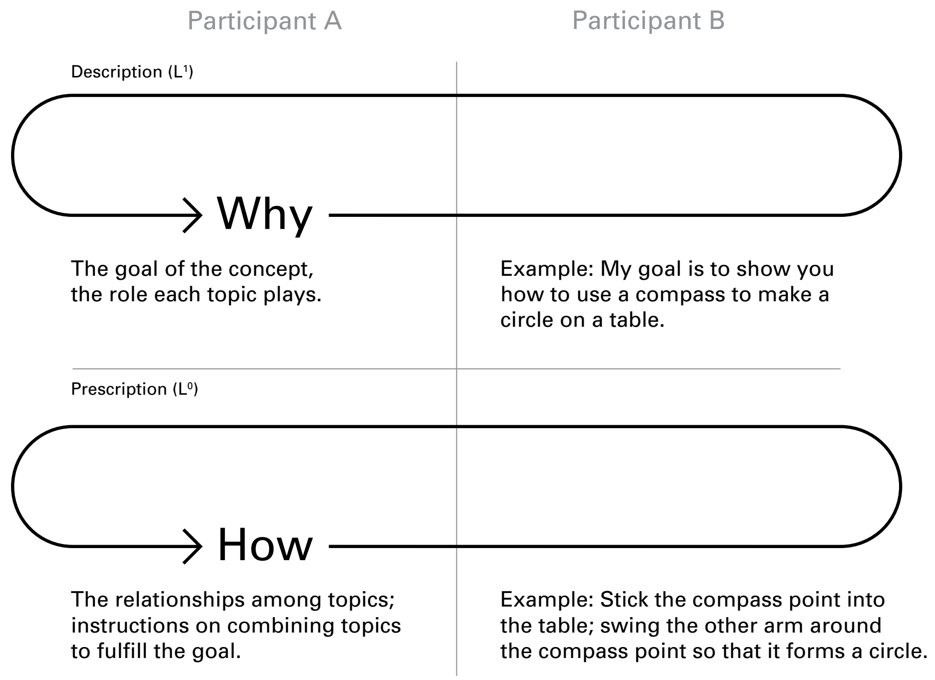
[lower level] How—the specific relationships among the topics; this comprises prescriptions (instructions) for how to combine the topics to fulfill the goal.

c. components and processes
Participant A comprises processes that embody the concept. These processes can be split into two (or more) levels. Processes at each level must be consistent with each other across levels, so that Participant B can, in any order:

i. understand the intention of the Why exchange
ii. situate the How exchange in the context of the Why;
iii. compare the consequences of the How and determine that, in practice, the goal of the Why exchange is achieved by performing the instructions in the How.

d. important aspects of model/breakthrough
The model visualizes the consistency that is required for Participant B to ‘put it all together’, to ‘make sense of’, and hence to ‘understand’ what A intends, based on what A says. Put another way, the exchanges do not carry meaning; rather, meaning is created by Participant B as a consequence of the guidance or triggers afforded by the conversation with A and as structured by the strict relationships among the components of the concept in the complementary aspects of Why and How.

Conversation for Understanding
Explaining Concepts to others



a. goal of model
The model explicates classes of conversational relationships.

b. description
[left] Conversation about goals and methods: Participants converse about goals and about methods to achieve them [see models above].

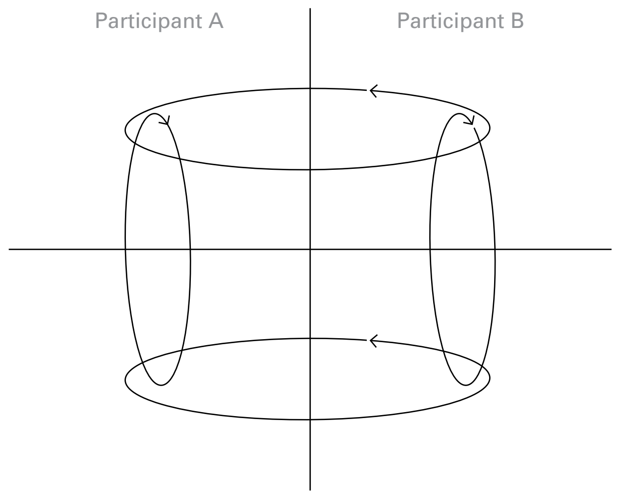
[middle] Cooperation to achieve goals: Participants ask each other to help achieve goals by performing necessary tasks [criss-cross].

[right] Collaboration for common goals: Participants agree to collaborate on the formulation goals and agree on methods to achieve them.

c. components and processes
Horizontal and vertical interactions are as before. Diagonal interactions [middle diagram] are manifest in language but involve a "control" component in the sense that the receiver of the request to take action is not told the reason why the request is being made (the "goal") and does not participate in its formulation. The receiver may infer it, or choose to act anyway, or choose not to act.

d. important aspects of model/breakthrough
The figures constitute a taxonomy of interactive modes, from conversation, to cooperation, to collaboration.

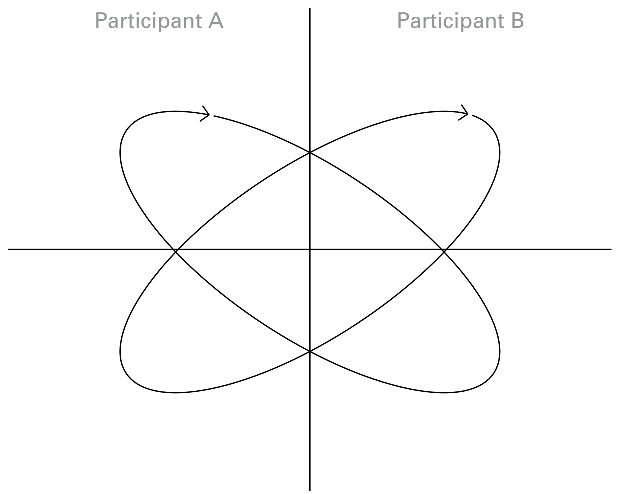
Conversation about goals and methods



Participants converse about goals and about methods to achieve them (horizontal loops). Internally, each participant checks for consistency in the conversation (vertical loops).

Example—A: (Upper horizontal) It's important that I avoid certain food allergies and minimize cholesterol. (Lower horizontal) So I buy the ingredients and prepare nearly all my meals myself.

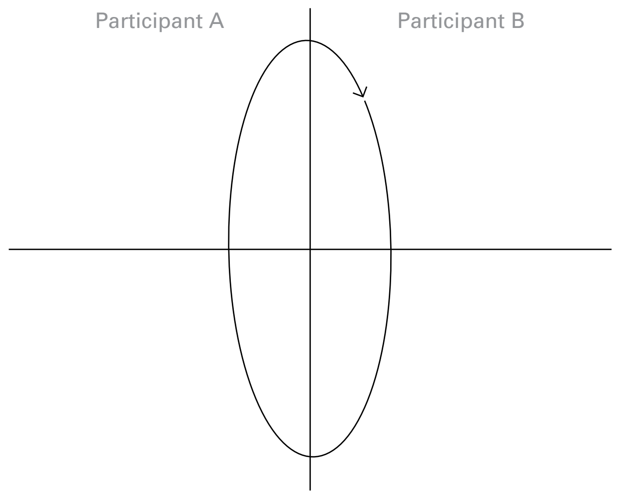
Cooperation to achieve goals



Participants ask each other to help achieve goals by performing necessary tasks (criss-cross). A's goals and B's goals may be different, but each agrees to help with the other's goal.

Example—A: (Upper left to lower right) Would you mind going to the store for me on your way home? I need some organic cabbage.
B: Sure. Think you can pick up my cleaning from downstairs?

Collaboration for common goals



Participants agree to collaborate on the formulation of goals and agree on methods to achieve them. In this sense, they merge to become a single system of goals and actions. In exchange for losing their individuality, they lower their individual biocost.

Example—A/B: Let's decide what to make. Then we can go together to the store to buy whatever ingredients we need.

a. goal of model
First of two diagrams that summarize Pask's architecture of conversation.

b. description
The figure enumerates the necessary interactions for a system to be 'intelligent', that is, to use feedback between upper and lower levels (vertical loop) to achieve its second-order goals. Existing or planned systems can be evaluated for their completeness, that is, to ensure they embody all the necessary components, A through F.

c. components and processes
See figure.

d. important aspects of model/breakthrough
The concept of 'intelligent system' is given a specific definition. Existing or planned systems can be evaluated for their completeness, that is, to ensure they embody all the necessary components, A through F.

A: "Controlling Process (alias goal)"
is, for example, management policy defined at this level ("increase revenue by 4%") but carried out at another (see below). The distinction of levels is made in the course of the modeling process. The precise levels are chosen to display the flows of control and feedback that are of interest.

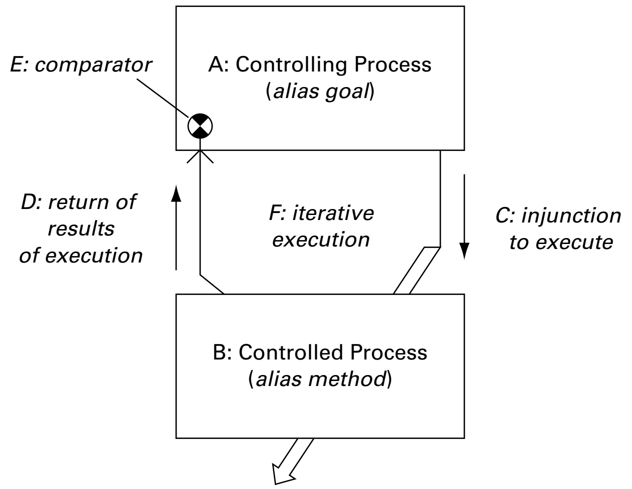
B: "Controlled Process (alias method)"
is, for example, the increase of revenue via hiring more salespersons, as dictated by the level above.

C: "Injunction to execute" is the actual line of control that causes the lower level to respond, for example, the memorandum indicating start of a project or a budget authorization.

D: "Return of results of execution"
is the actual feedback of information to the higher level, as for example a report indicating results of specific manufacturing procedures, or an internal survey.

E: "Comparator"
is the specific mechanism whereby the feedback information is used by comparing the actual result to the desired result, or original goal.

F: "Iterative execution"
of the entire loop takes into account the result from the comparator above, that causes changes in various processes, flows of control and feedback, etc., to make the entire loop more effective.



Closure occurs when comparator confirms execution of controlled processes is coherent with controlling processes
(as when a goal is achieved by executing a successful method)

If all of the above aspects are present, the system of interactions is deemed "intelligent."

It must be emphasized that the two levels shown are only two of (possibly) many vertical levels; modeling by the observer leads to distinguishing multiple vertical layers in the conversation. Hence a box that appears at a "lower level" in one interaction may itself be at the "higher level" relative to a further box that appears below it.

Conversations (Subjective Interactions)
Required Elements for Language-oriented Interactions

a. goal of model
Second of two diagrams that summarize Pask's architecture of conversation.

b. description
The figure enumerates the necessary interactions for a system to achieve a reasonable degree of certainty that it is understood by another system. In practice, this requires interactions at a minimum of two levels in language exchanges (horizontal loops).

c. components and processes
See figure.

d. important aspects of model/breakthrough
It is important to note that references to "goal" or "method" are relative to any pair of vertical boxes; changing level by moving up or down the hierarchy changes the attribution of "goal" or "method" for a given box. These attributions are always relative to a specific neighbor.

Not shown for simplicity in the figure are potential responses, from right to left, to any given communication. In the general case, the entire relationship is completely symmetrical.

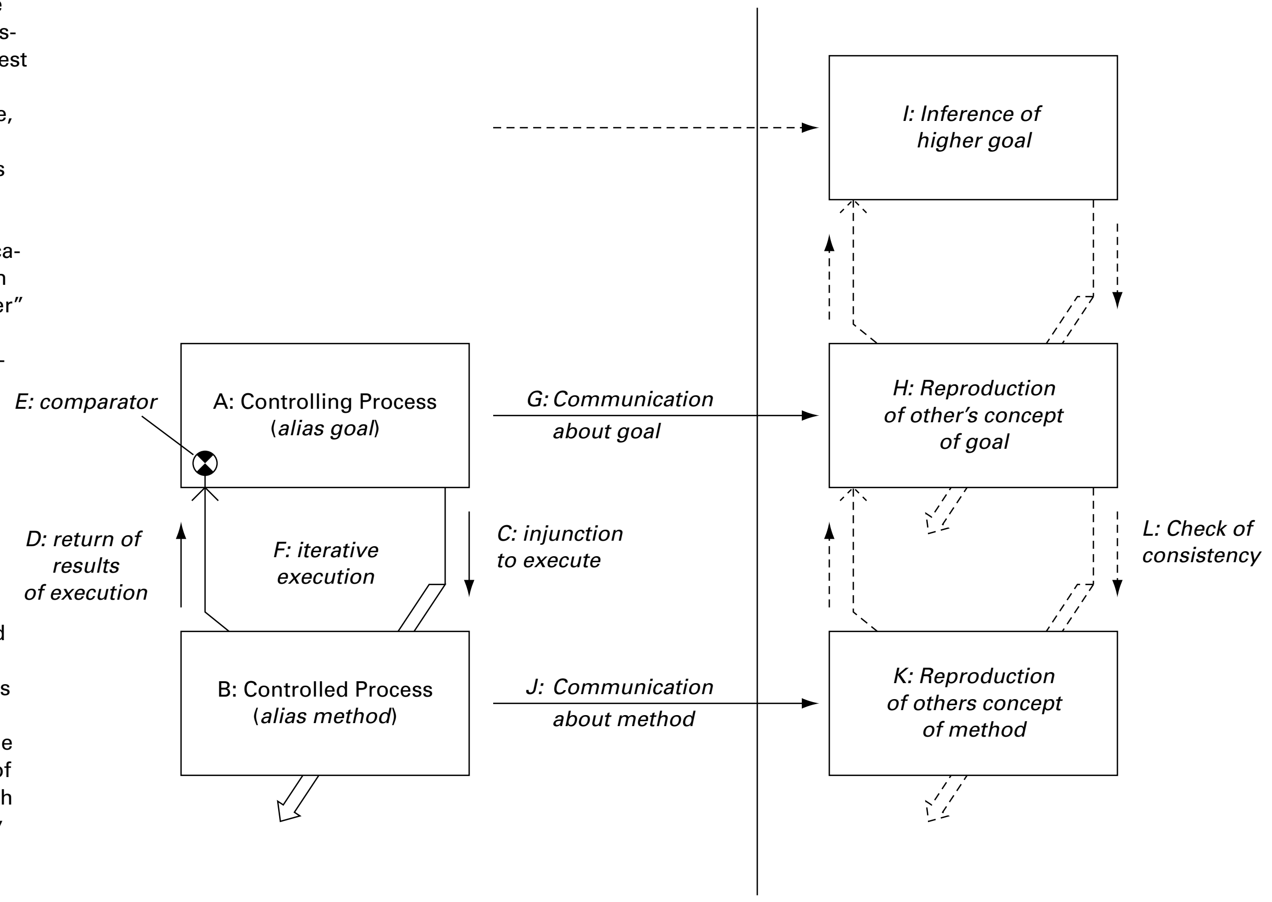
The figure completes the Conversation Theory model that encompasses subjective (horizontal) and objective (vertical) interactions in conversational systems that have second-order goals and use cooperation and/or collaboration to achieve their goals.

Conversation (Subjective Interactions)
Summary of Elements

G: "Communication about goal" is, for example, the communication to a customer that the company's value proposition expressed via its advertising is to provide products with the best cost/benefit ratio, or durability, for a given application; or, to an employee, that the company considers the employee to be an essential asset for its future.

H: The actual result of the communication is different than what came from the "sender." ("Sender" and "receiver" are held in quotations to retain a different meaning from that of information theory.) The "receiver" attempts "Reproduction of other's concept of goal" but this may not be accurately achieved.

I: "Inference of higher goal" is the production of a higher goal for which the previous interaction is consistent and affirming. This is as if the "sender" had actually exchanged something (shown as the upper, dashed arrow) but in fact nothing has actually been "transferred" at this level, up to this point. Quite often, the context or the common experience of the two conversants provides enough for a higher-level goal to be correctly inferred. However, sometimes the "sender" creates a false context to encourage an incorrect inference, as for example when advertisers imply a food product is healthy simply because it uses the word "natural", or when a participant simply states "I have your interests at heart" while not having demonstrated this to be the case.



J: "Communication about method" is, for example, the communication to a customer about the details of a product's capabilities (which should affirm its stated goals, G); or, an exchange with an employee about the details of working conditions and health benefits from the corporation, which should show the method by which that employee is to be considered an asset to the corporation, relative to the goal as communicated in G.

K: "Reproduction of other's concept of method", as in H above, is subject to interpretation and later modification.

L: "Check of consistency" is a reproduction in the "receiver" of the entire vertical loop of the "sender." This may show the consistency across the upper and lower levels, and thereby affirm understanding of the "sender's message." Of course, this can only be (at best) very close and (at worst) only a small fraction of the intended message. Alternatively, the consistency check can expose the inconsistency between communicated goal and method. For example, the loss of retirement pensions or erosion of healthcare coverage would contradict the assertion that the employee is a valued asset to the corporation. The "receiver" can either make queries back to the "sender" about intended meanings in order to clarify understanding (not shown in the diagram); or maintain a model of the perceived inconsistency in the "sender."

Du Pont Goal Structure
Snapshot 1910 to 1940

origins

a. individuals
Developed by Paul Pangaro for Dr. Michael C. Geoghegan, Research Fellow, Du Pont.

b. era/dates
The models were developed in the late 1980s as part of a enquiry funded by Geoghegan to explain the degradation of employee experience from his early employment, in the 1960s, to the time of this modeling exercise.

a. goal of model
The model explicates the goal hierarchy that was implicit in the management philosophy and organizational structure of the Du Pont company between 1910 and 1940.

b. description
After World War I, when Du Pont had again made huge profits by supplying explosive materiel to a major armed conflict, the decision was made to focus on the mission of achieving growth through diversification (top-most process box). All subsequent processes (sub-goals represented by lower-level boxes) were consistent and effective means to carry out that mission. Not shown are the forces that moved the organization toward the new mission: anti-trust pressure plus innovations that were made possible by recent innovations in macromolecular chemistry.

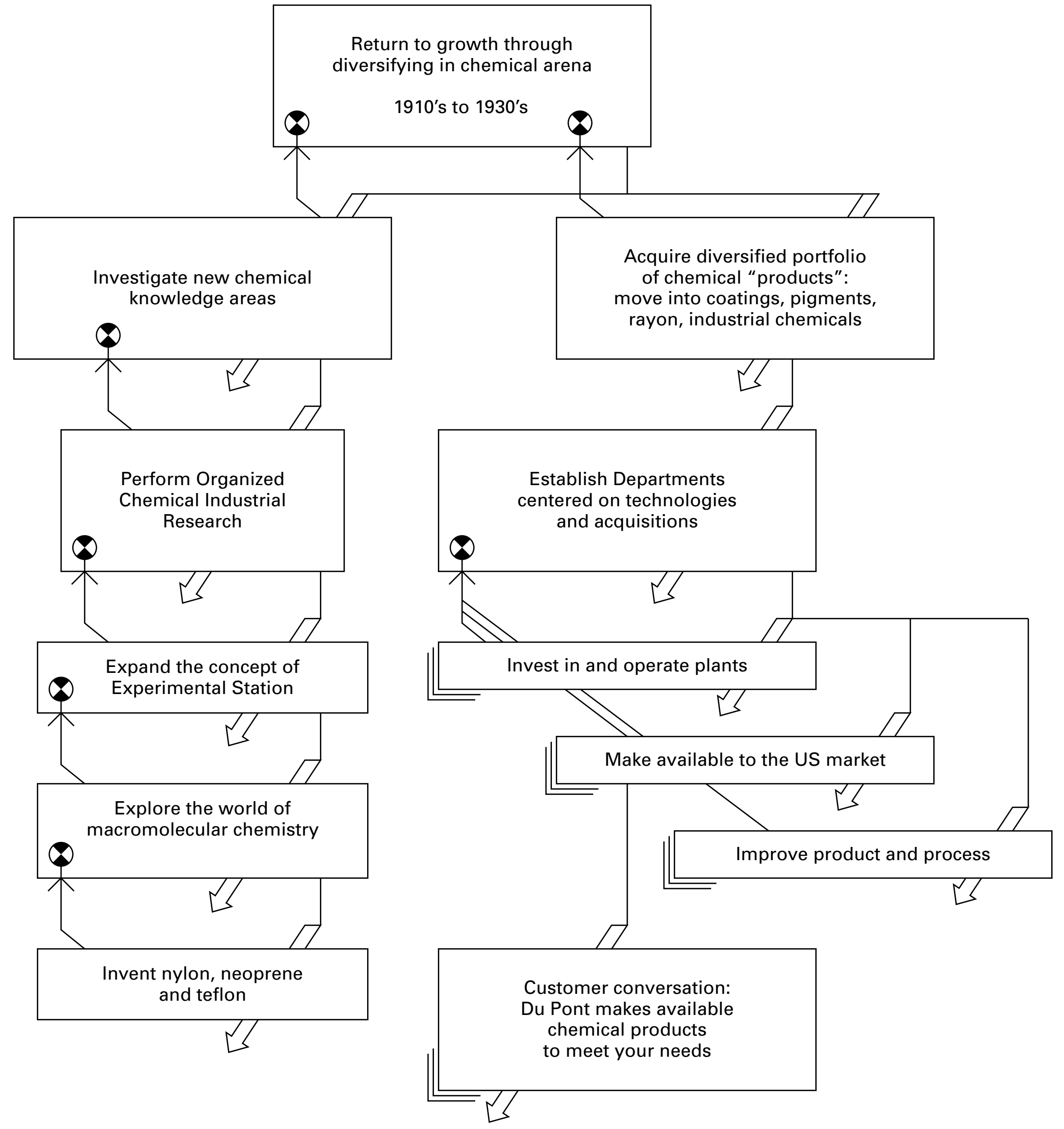
c. components and processes
Each level in the figure controls ('dictates') the processes at levels below it. The result of performing the processes at a given level are returned as feedback to upper levels to steer the processes to achieve their goals.

The organization is fundamentally divided between research (left side) and production (right side).

d. important aspects of model/breakthrough
A rare example of post-hoc examination of organizational evolution, this model offers an explanation as to why Du Pont was successful in this period: because of the consistency of the structure and processes of the organization in relation to its mission.

Du Pont Goal Structure
Snapshot 1910 to 1940

Laid the foundation for a new business—'invention' phase.



Du Pont Goal Structure
Snapshot 1940 to 1975

a. goal of model
The model explicates the goal hierarchy that had evolved in the management philosophy and organizational structure of the Du Pont company between 1940 and 1975.

b. description
Success in research explorations in macromolecular chemistry led to the ability to mimic natural products—cotton, rubber—in the form of synthetic "knock-offs"—nylon, neoprene (central box). The organization shifted in response, developing the mission of "Better Things for Better Living through Chemistry", which was both the company's advertising slogan and a literal mission consistently carried out by the organization. Not shown are post-WWII demand growth of consumerism, creating huge demand for Du Pont's output, which in turn caused increased focus on controlling manufacturing, and the rise of paternal attitudes toward its industrial customers to the effect that "Du Pont provides solutions to your needs."

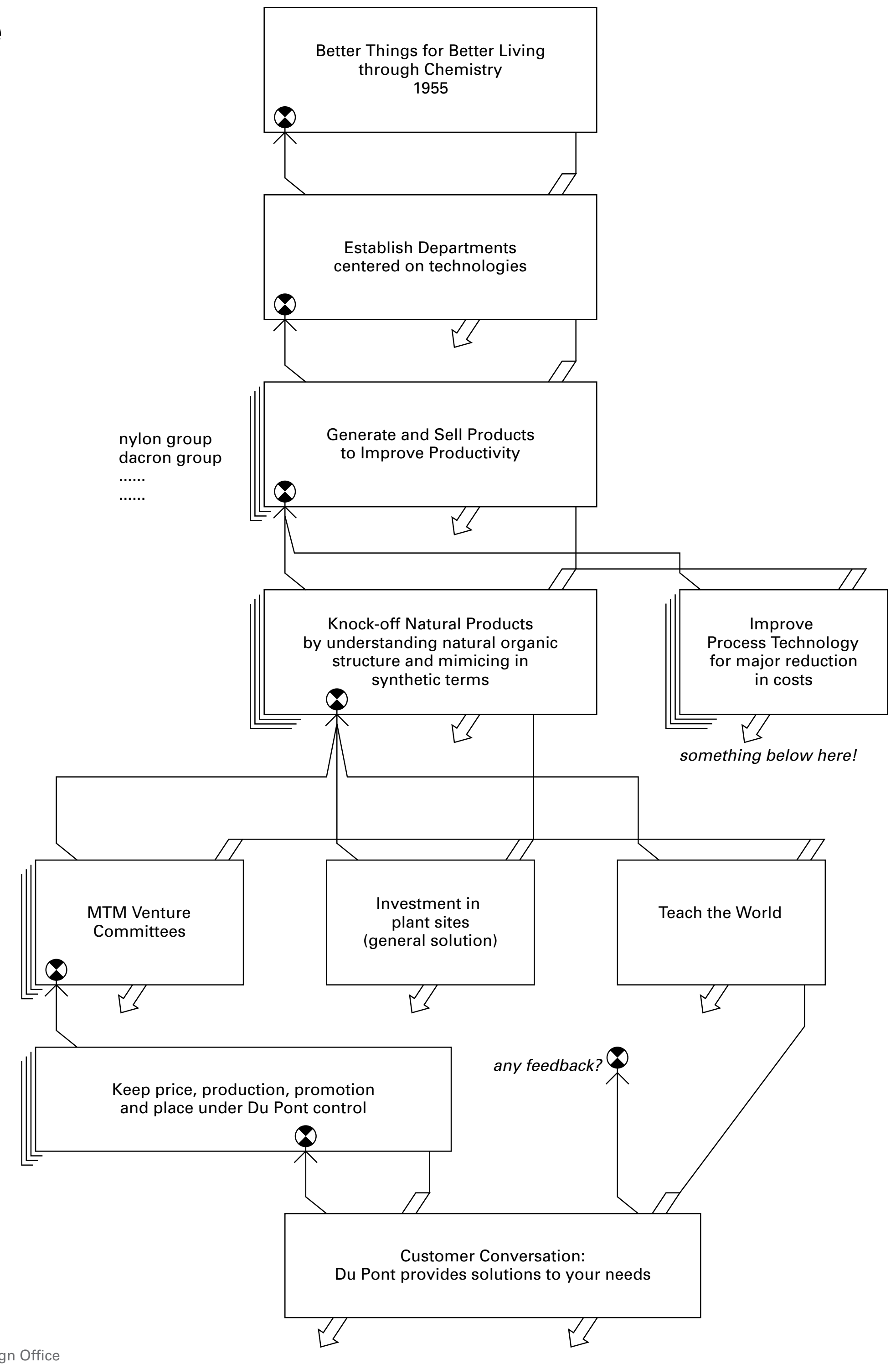
c. components and processes
Model components of control and feedback as before.

Research, though still a significant expenditure, is de-emphasized in this phase. Note the beginning of the unraveling of goal/method consistency as the organization fails to monitor feedback from customer conversations in relation to its paternal stance (bottom process).

d. important aspects of model/breakthrough
The reassignment of focus and resources from the previous phase is relatively smooth. However, in the new structure are sown the seeds of later failure.

Du Pont Goal Structure
Snapshot 1940 to 1975

Built on the foundation—
'discovery' phase.



Du Pont Goal Structure
Snapshot of 1980’s

a. goal of model
The model explicates a major shift in mission for Du Pont, as a direct consequence of previous phases.

b. description
With fewer new products coming from research, the company was forced to focus on earnings as its primary mission in order to maintain viability. This causes another change in structure and priorities, reflected in the progression from mission (top box) to the methods for achieving that mission (subsequent levels below top).

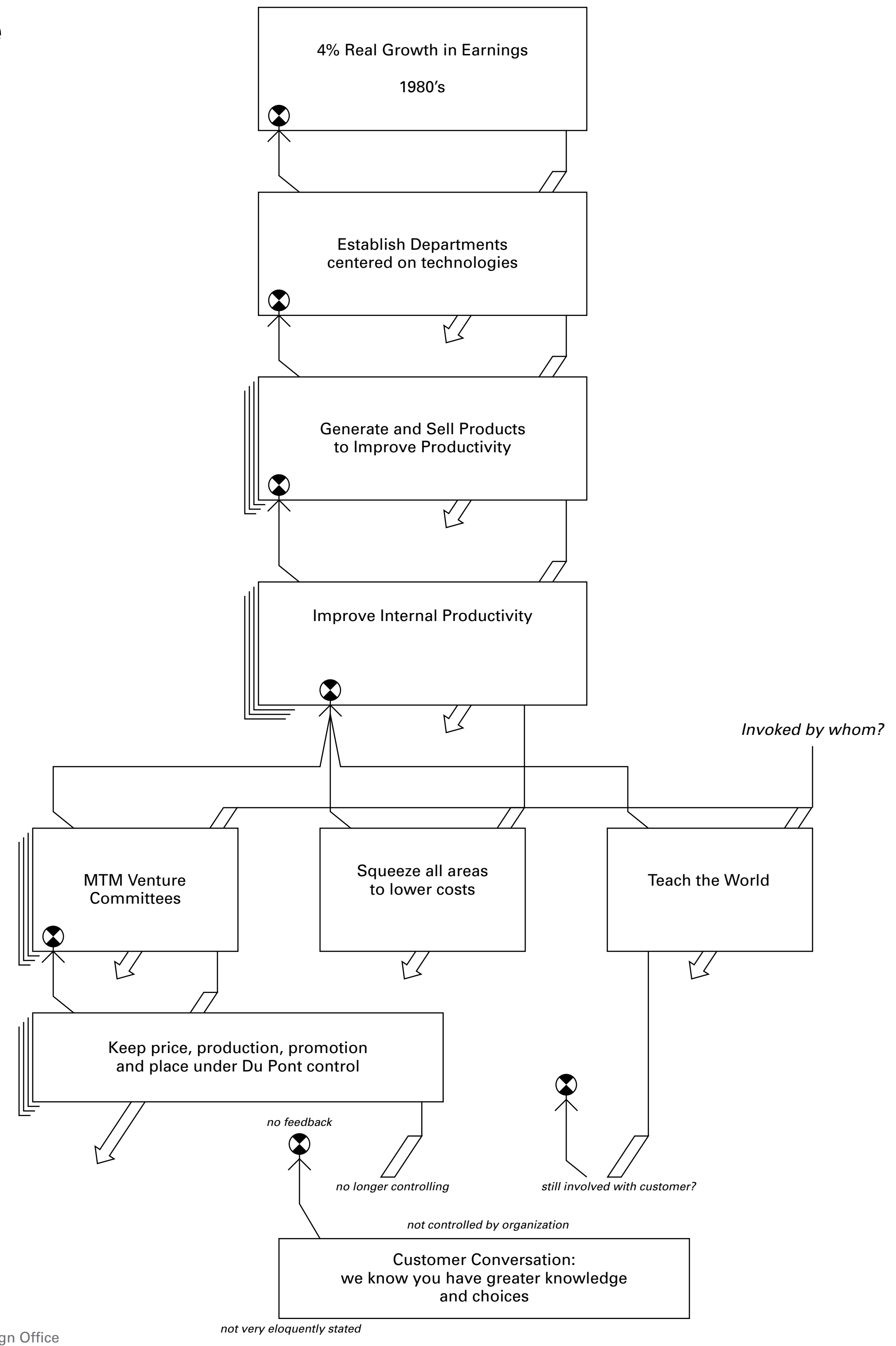
Not shown is a major shift in the philosophy of management promotions: formerly, successful chemists became executives, whereas in this era MBAs and other businessmen [sic] rose to power. Research innovation diminished because of the relative maturity of macromolecular chemistry; that is, little new could come from chaining molecules together because all the possibilities had been explored.

c. components and processes
Model components of control and feedback as before. The earlier dual structure of research & production evolved to a relatively monolithic focus on earnings. Note the continued unraveling of customer relationships as sales processes were immune to hearing of changes in customer needs, and the organization overall would miss new competitive threats and opportunities to collaborate with its customers.

d. important aspects of model/breakthrough
The company is disconnected from the market and loses any ability to understand or respond to continued market pressures. The number of employees shrinks to one-half that of the 1960s, further evidence of loss of preeminence.

Du Pont Goal Structure
Snapshot of 1980’s

Milked the existing structure—
‘efficiency’ phase.



Bio-cost

Page Headline

origins

a. individuals
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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
Main Text Area

b. description
Main Text Area

c. components and processes
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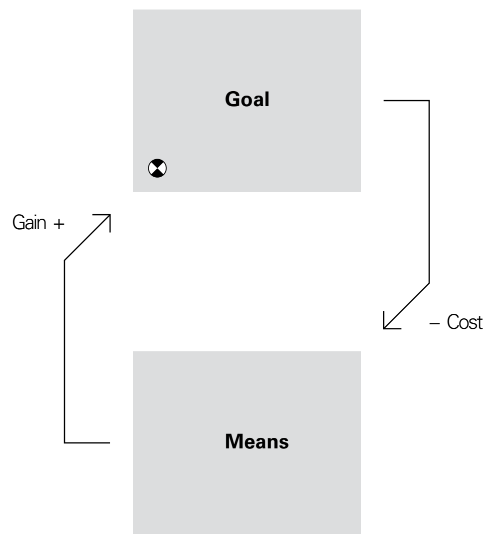
Bio-cost

Bio-cost describes the effort
(in energy, attention, time, stress)
expended by an organism to reach a goal.

Value = Bio-gain - Bio-cost



Autopoiesis

Page Headline

origins

a. individuals
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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
Main Text Area

b. description
Main Text Area

c. components and processes
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Autopoiesis

Maturana writes,
"...living beings are characterized in that, literally, they are continually self-producing."

They contain a set of dynamic transformations that maintain themselves and their boundary. The two arise together, not in sequence.

Evolution

(in Terms of Requisite Variety)

Page Headline

origins

a. individuals
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b. era/dates
Side bar infomation text size

c. references for model, context, author(s), concepts
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d. examples
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a. goal of model
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b. description
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c. components and processes
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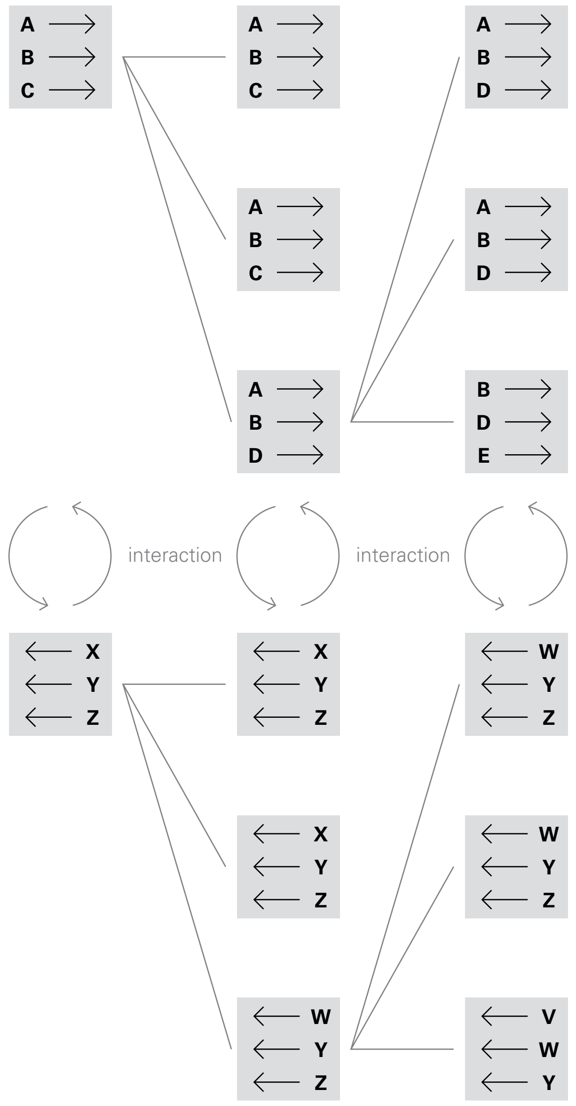
Evolution (in Terms of Requisite Variety)



Organism
An organism requires variety to counter disturbances from its environment. With sufficient variety an organism will survive long enough to reproduce.

Its offspring will be similar, but may exhibit changes in variety—mutations. This new variety may be more (or less) effective countering disturbances from the environment. Organisms that are more effective will survive longer and multiply faster.

Environment
At the same time, the environment may also evolve, changing the variety of disturbances it poses. Both processes affect each other. Changes in variety in the orgamism may affect evolution of its environment, and likewise changes in variety in environmental disturbances will affect evolution of the organism.