Introduction to Cybernetics and the Design of Systems

Collected Models
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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.

Introduction to Cybernetics
and the Design of Systems

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]

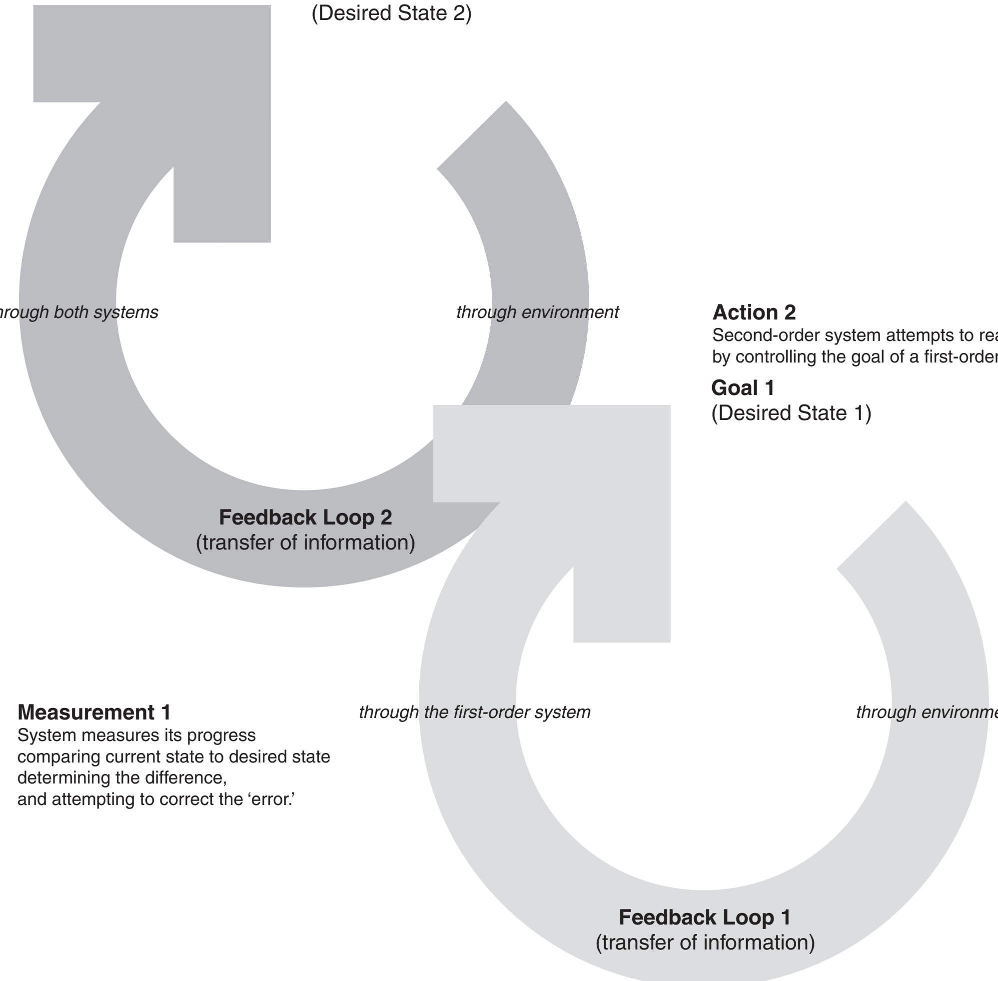
a. goal of model
Building on the feedback loop of first-order systems, the addition of a higher-order loop—one that changes the goal of the first loop—formulates another foundational cybernetic model: second-order feedback.

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



Second-order Feedback: Formal Mechanism

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.

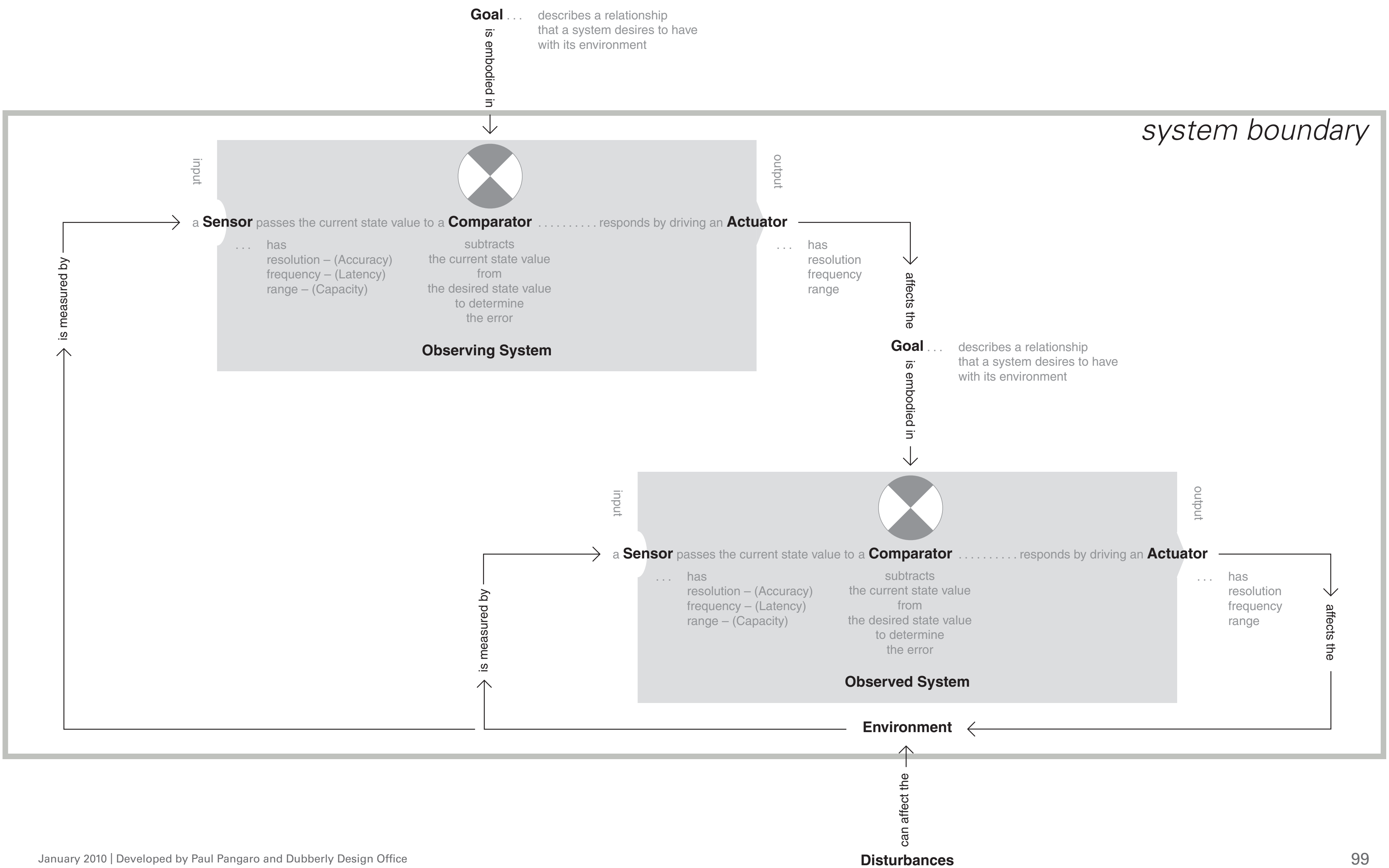
b. description
The nested quality of the two sub-systems is shown in their exact relationship. All the elements of each sub-system are as before.

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

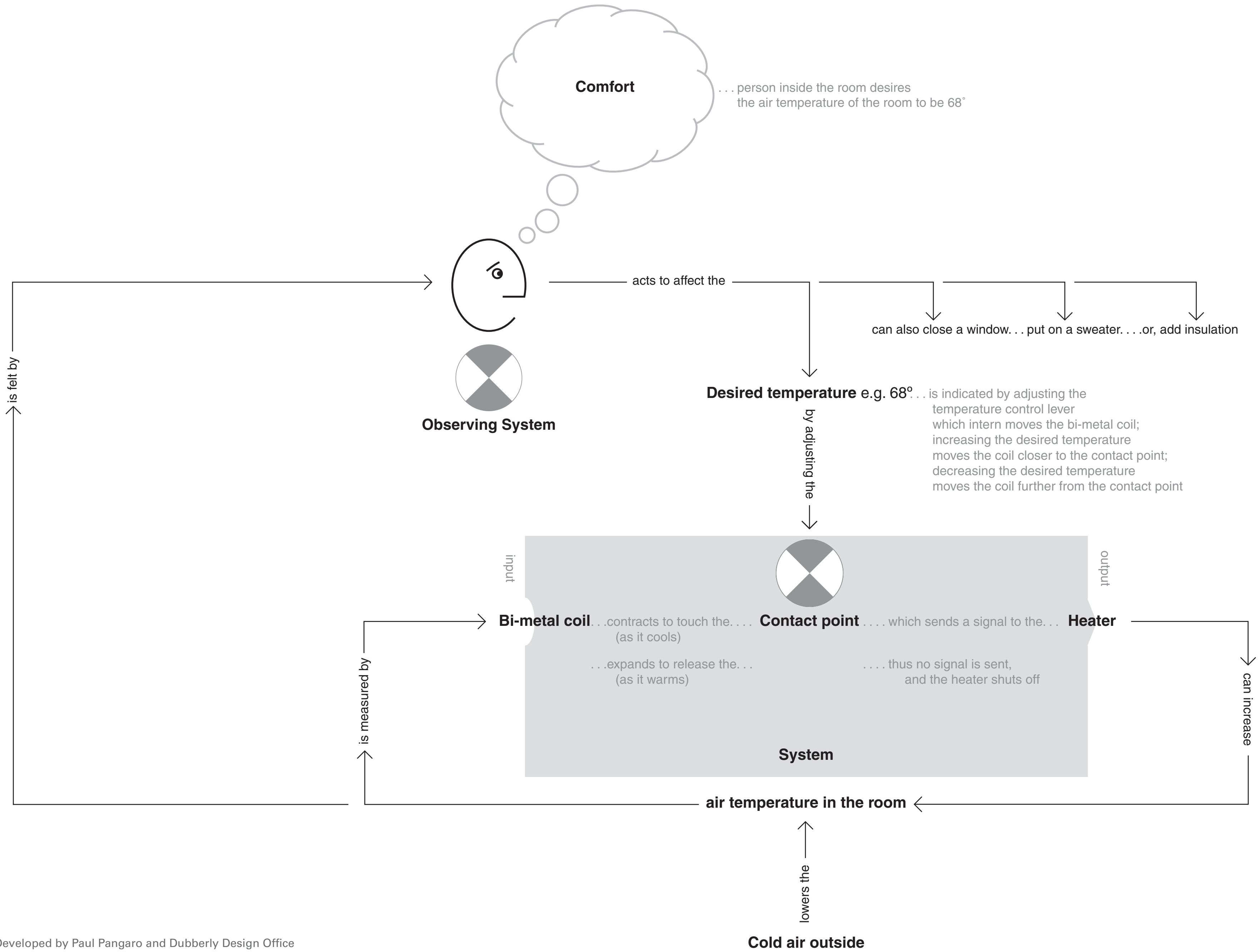
a. goal of model
The model places a person in the role of the second-order feedback system, setting the goal of the first-order system.

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.

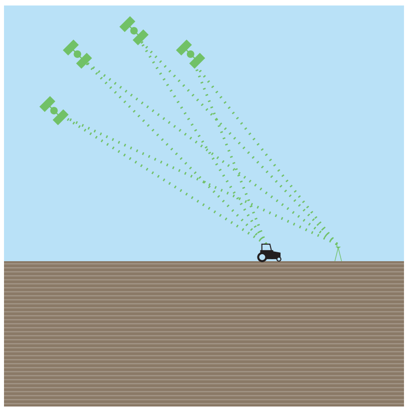
Second-order Feedback: Classic Example
Person controlling a thermostat (regulating a regulator)



How the AutoSteer system works: Overview

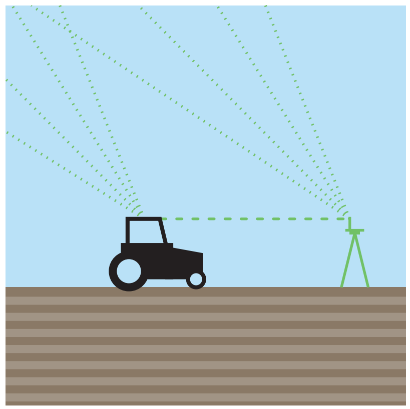
The AutoSteer system enables farm equipment to accurately steer a path and then—a minute later or a year later—come back and steer the same path. Being able to steer the same path means farmers know where their plants will be and can precisely position tools for prepping, planting, spraying, cultivating,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

A



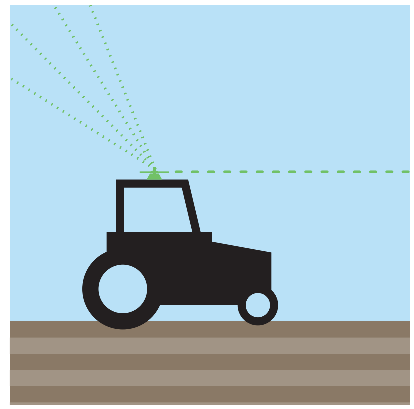
The AutoSteer system begins with GPS satellite signals

B



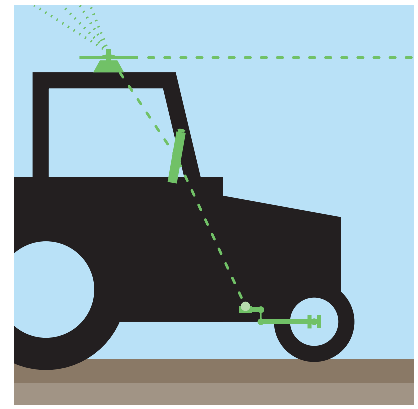
The base station provides correcting signals

C



Multiple antennas measure position and orientation (heading)

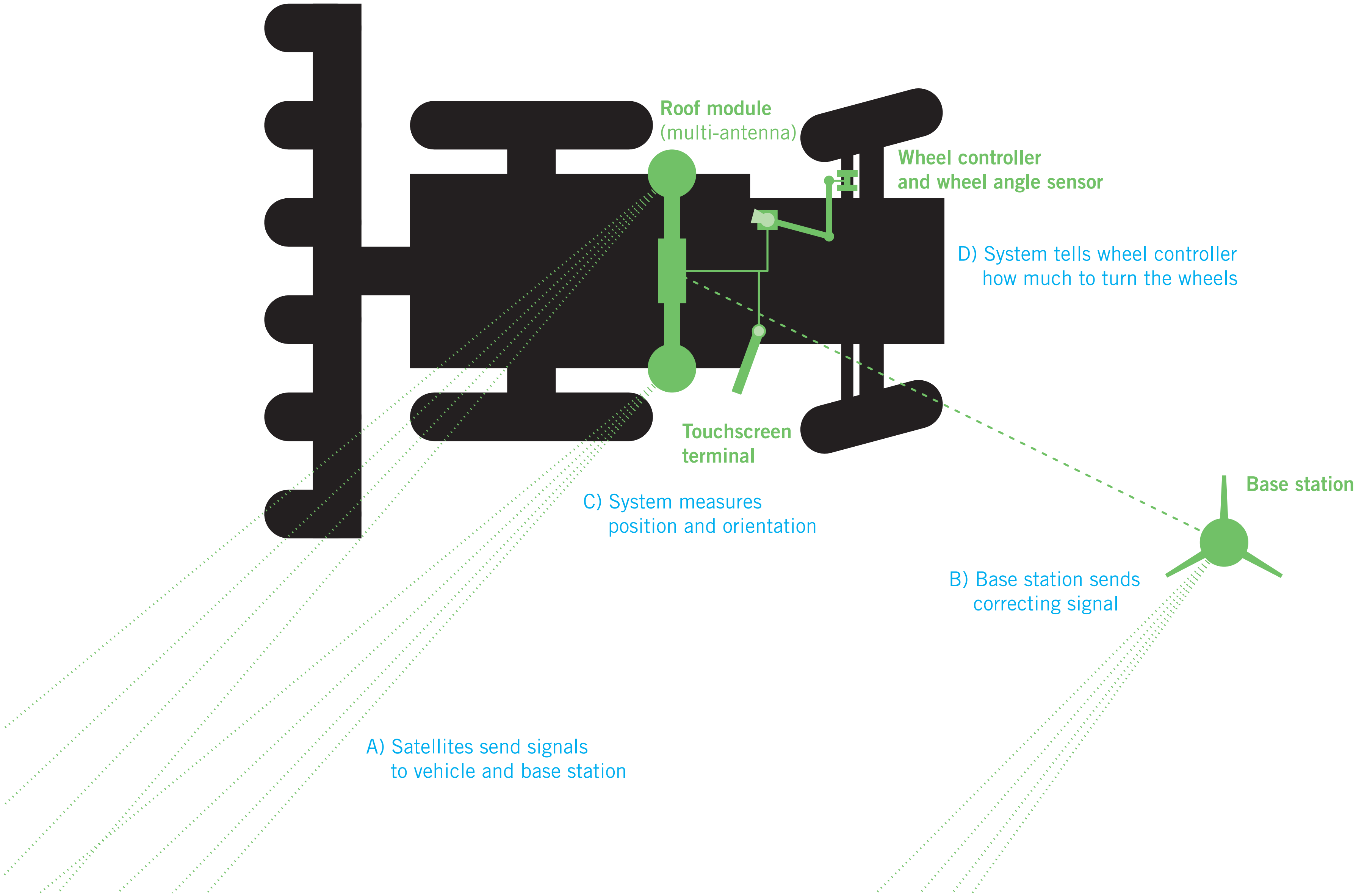
D



The wheel angle controller and sensor insure precise steering

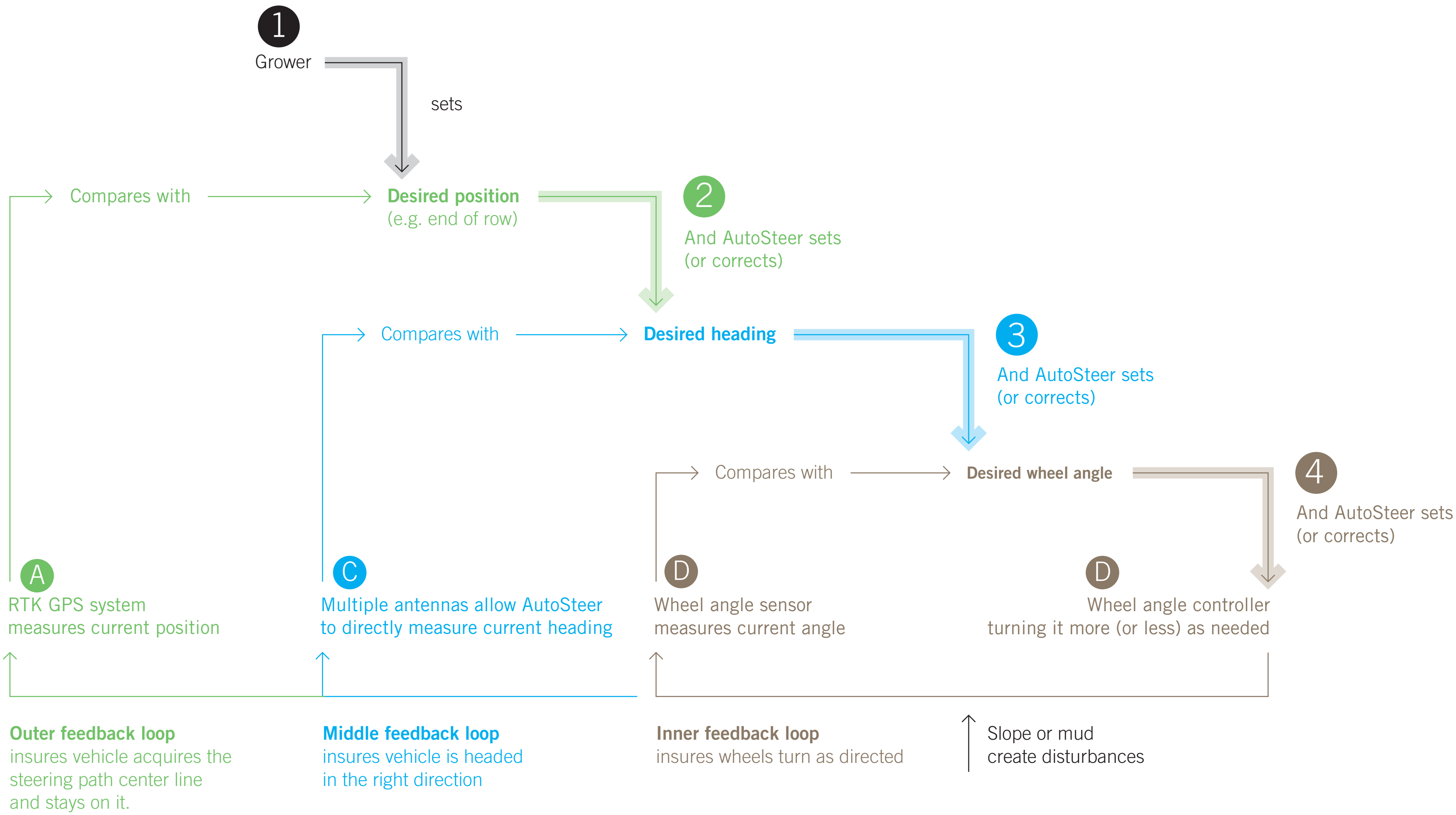
How the AutoSteer system works: Tractor Detail

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.

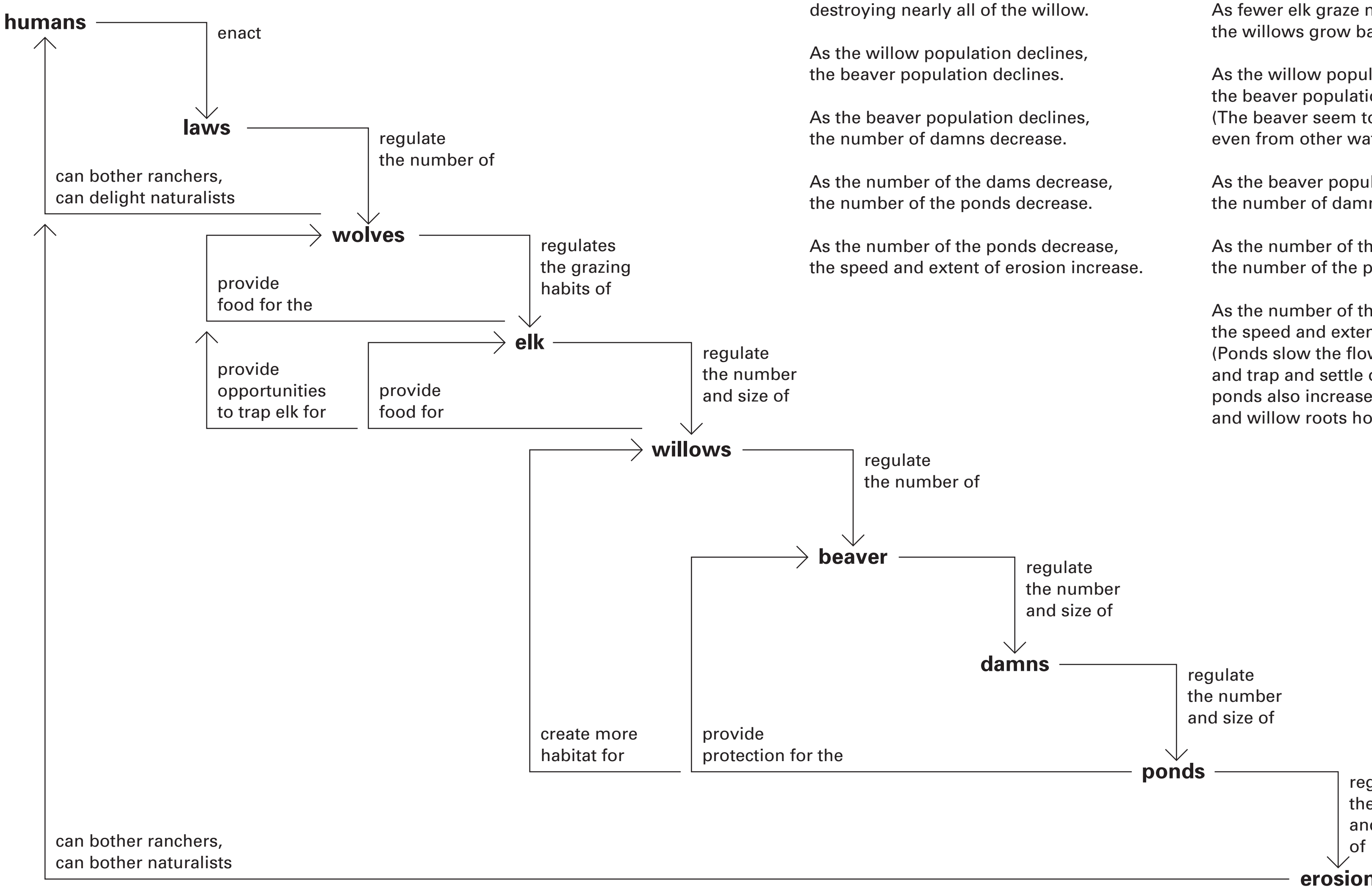
d. important to notice
Even without any quantitative details, the model is instructive in showing the complexity and interdependencies of the nested systems.

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.

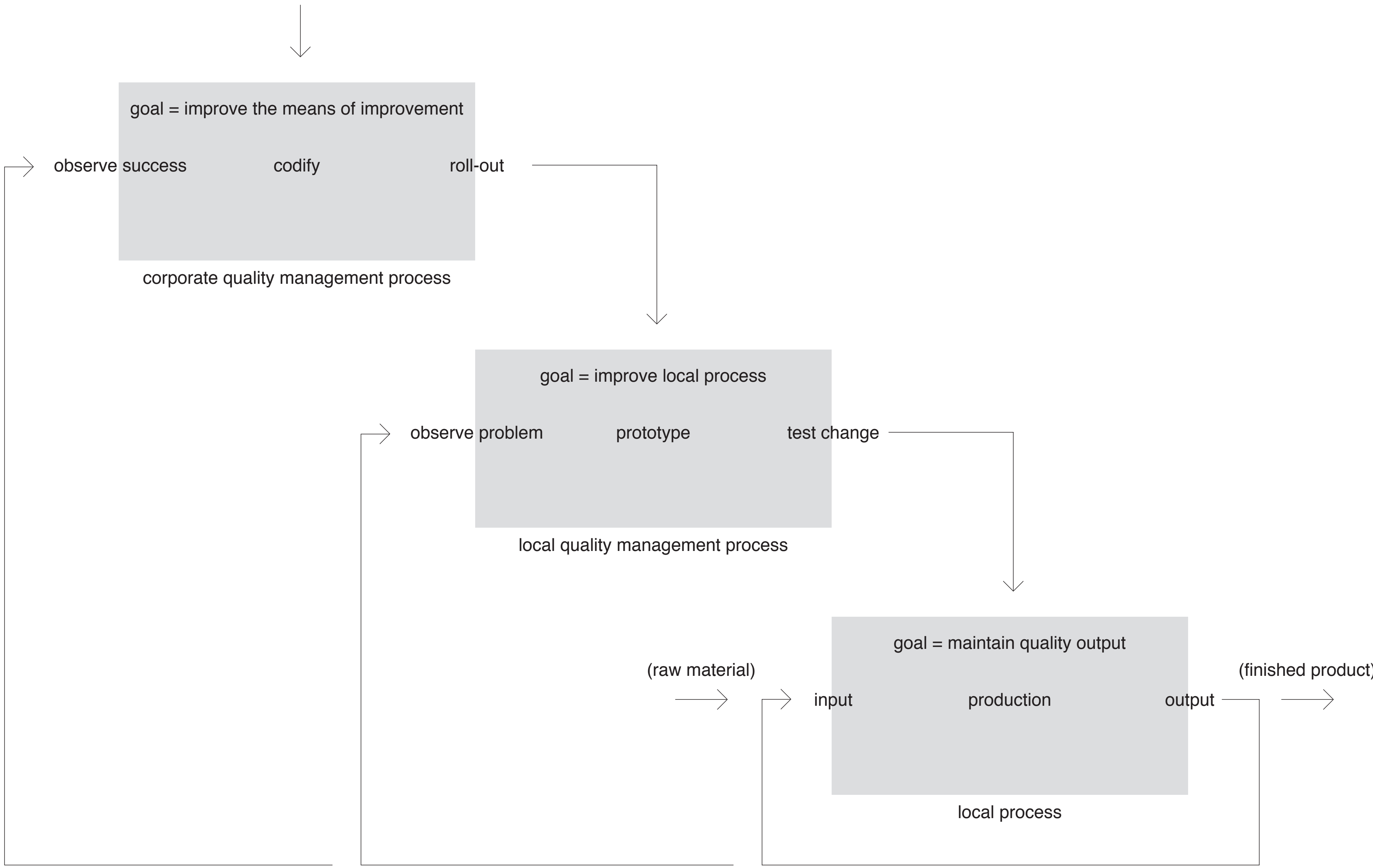
The above system is nested in a second-order relationship with a localized quality-management system (center) whose responsibility is to sense whether the lower-order system is achieving its goals for quality. If not, the quality management system may test changes to the goals of the lower order system. 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

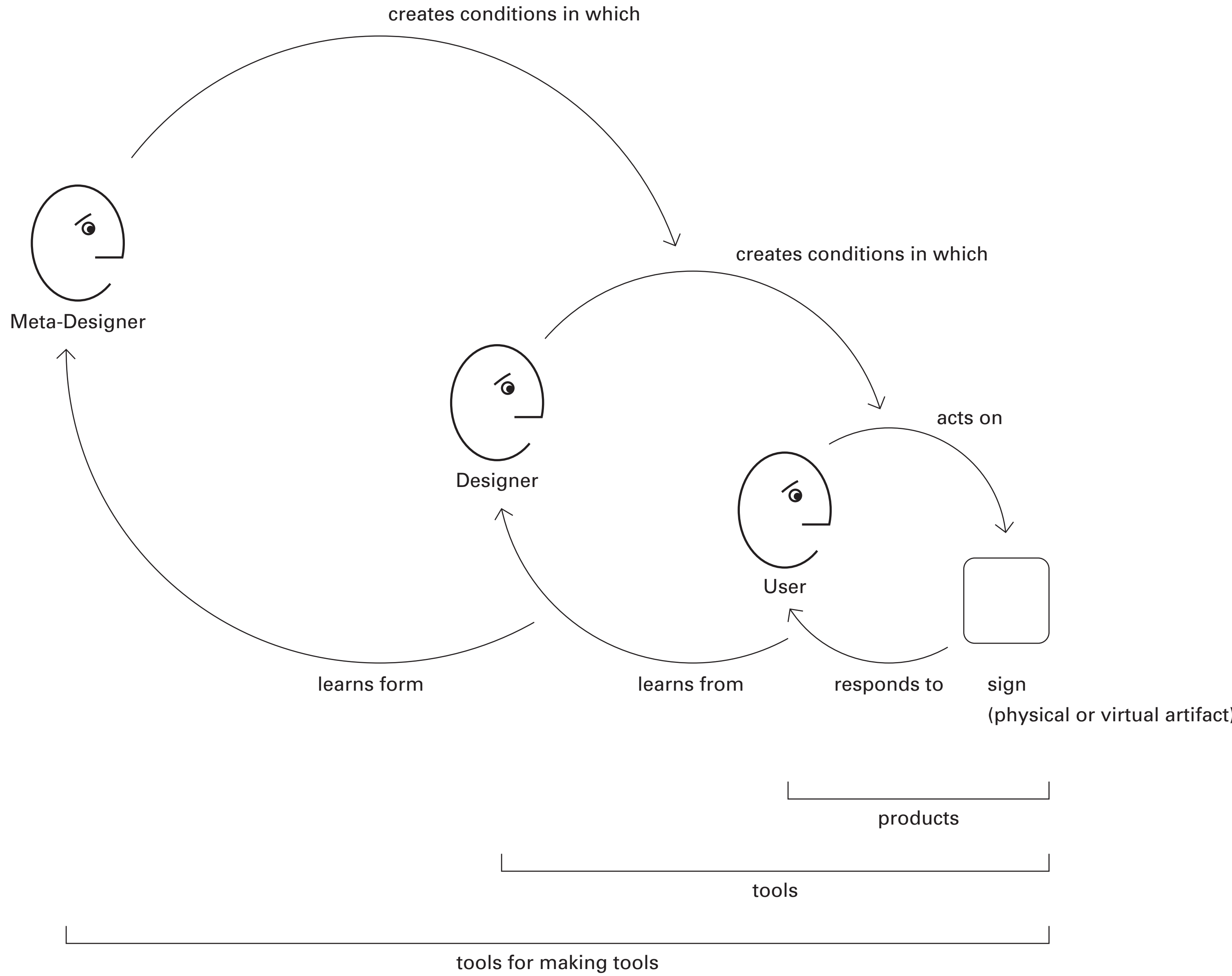
a. goal of model
The model applies second-order feedback to the social example of "design", showing nested systems.

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.