

Feedback: When Output Returns as Input

IDE-010 · Fundamental Ideas

Concept essays for *The Universe and Its Observers*

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Article Abstract

Feedback exists when a process changes a quantity that later acts back on the same process. Closing that loop does not merely adjust a value; it changes the system's dynamics, which is why a feedback system can do things none of its parts can do alone. Maxwell analysed the steam governor in these terms in 1868, and the same analysis now covers amplifiers, physiology, ecosystems and climate.[1] The article sets out what determines a loop's behaviour: the sign of the return path, the gain, the delay and the nonlinearities that eventually bound it. It argues that a sign alone predicts almost nothing, that regulation is not the same as holding a set point, and that a loop diagram is a causal claim which has to be earned rather than drawn.

In 60 Seconds

A loop is closed when the output of a process is returned to its own input. Negative feedback returns a correction that opposes the departure; positive feedback returns one that reinforces it. The signs are the easy part. What decides behaviour is the loop gain, how much of the output comes back, and the delay, how long it takes to come back.[3,6] Negative feedback with high gain and enough phase lag does not stabilize; it oscillates, which is why Black had to give amplifier design a stability criterion and not just a correction sign.[2,3] In nonlinear feedback models, bounded positive feedback can settle to fixed points; bistability and hysteresis depend on the existence and stability of multiple branches.[5] Regulation is not a thermostat holding a number: physiological homeostasis keeps variables inside ranges through several interacting loops with different speeds.[4] And a loop drawn on a diagram is an assertion about direction and timing. Without those, an apparent loop can dissolve into a shared driver.

Why This Question Matters

Feedback is one of the few ideas that genuinely crosses engineering, biology, economics and climate science, and that reach makes it easy to use as decoration. Saying a system has negative feedback sounds like saying it is stable, and it is not: delay and gain decide that, and a corrective loop with the wrong values is an oscillator. Saying a system has positive feedback sounds like predicting runaway, and

usually it predicts a threshold instead. Getting this right matters wherever the stakes are in the dynamics rather than the direction, which includes every argument about how fast a regulated system responds to being pushed.

1. What Closing a Loop Does

A centrifugal governor on a steam engine lets the engine's own speed adjust the steam supply: run fast, and the flyweights rise and close the valve. Maxwell's contribution was not the device, which was already in use, but the analysis. He wrote the equations of the machine together with its governor and studied the roots that determine whether a disturbance decays or grows.[1]

That move is the whole subject in miniature. Before the loop is closed, the engine's speed is a consequence of the steam supply. After it is closed, the two are mutually determined, and the quantity to solve for is no longer a value but the behaviour of a system whose equations now contain their own output. Loops therefore change the order and the character of the dynamics, adding modes that neither the plant nor the controller has by itself.[6]

This is why feedback buys properties that open-loop design cannot. An amplifier whose gain depends on temperature and on the particular valve fitted can be made to have a gain set almost entirely by a passive divider in the return path, because the loop drives the error towards zero rather than trusting the forward path.[2] Precision is bought from structure rather than from components.

Where That Leaves Us

Closing a loop makes a system's output part of its own cause, which changes the equations rather than just the numbers they produce. That is what lets feedback deliver accuracy from inaccurate parts. But it also introduces dynamics that were not there before, and whether those dynamics settle or grow depends on quantities the sign of the loop does not contain.

2. Sign Is Not Enough: Gain, Delay and Phase

Negative feedback opposes a departure from the operating point. It does not follow that it damps it. The correction arrives after a delay, and by the time it arrives the system has moved on. If the delay is long enough that the correction pushes in the same direction as the disturbance by the time it lands, the loop reinforces what it was built to oppose.[3,6]

Bode gave the classical way of stating this. Follow the loop's response frequency by frequency; where the signal returns having been inverted by accumulated phase lag, ask whether the loop gain there is greater or less than unity. If it exceeds unity at that frequency the system will not settle, and the margins by which it avoids that condition are the standard measures of how much delay or gain variation a design can tolerate.[3,6]

The engineering statement generalizes, but not to every loop. Closed-loop instability and sustained oscillation depend on gain and phase conditions.[3,6]

Where That Leaves Us

A negative loop is stabilizing only for some combinations of gain and delay, and the same loop becomes an oscillator outside them. Closed-loop instability and sustained oscillation depend on gain and phase

conditions. Positive feedback is often introduced as the opposite case, but its usual behaviour is not the opposite of stability either.

3. Positive Feedback, Thresholds and Saturation

Positive feedback returns a correction that adds to the departure, so small differences grow. Growth at a rate proportional to the current value is exponential, and if nothing intervened the variable would diverge. In nonlinear feedback models, bounded positive feedback can settle to fixed points; bistability and hysteresis depend on the existence and stability of multiple branches. [5] That is what makes positive feedback useful in a cell that has to commit to a decision.

Where That Leaves Us

Bistability and hysteresis depend on the existence and stability of multiple branches.[5] This distinction also clarifies what regulated systems hold steady.

4. Regulation Is Not a Set Point

Cannon coined homeostasis for the physiological maintenance of internal conditions and was careful about the word. He chose a term meaning a similar condition rather than a fixed one, because what physiology maintains is a range within which the organism functions, held by several loops with different speeds and different effectors.[4]

A domestic thermostat is a poor model of this. It compares a measured temperature with a number and switches a heater, and the number is imposed from outside the loop. Body temperature is defended by sweating, shivering, vasomotor changes and behaviour, each with its own threshold, and the defended range itself shifts with time of day, with activity and with illness. There is no single stored target being tracked.[4]

The distinction matters beyond physiology. Describing a regulated system as having a set point invites the question of where the number is stored, and for most natural regulation there is no answer because there is no number. What exists is a structure of loops whose combined action has a stable region, and that region is a property of the whole system rather than a value held in one part of it.

Where That Leaves Us

Regulation usually means a stable region maintained by several loops, not a stored target tracked by one. Homeostasis was named for a similar condition rather than a fixed one, and the defended range itself moves. That leaves the question of how anyone establishes that a given loop is really there, which is where feedback diagrams have to be earned.

5. A Loop Diagram Is a Causal Claim

Drawing an arrow from A to B and another from B back to A asserts two directed influences and an order in time. Neither is delivered by observing that A and B move together. Two variables driven by a common third will correlate, and their correlation can look like a loop when plotted, without either acting on the other at all.

Establishing a loop therefore requires the same evidence any causal claim requires: intervention where it is possible, or explicit structural assumptions where it is not, plus timing that distinguishes the paths. Control engineering usually has the easy version, because the loop can be opened deliberately and the system studied with the return path disconnected. Fields that cannot open the loop have to work much harder, and that problem belongs to IDE-004.

The honest version of a feedback claim therefore names the loop variable, the sign, the gain, the response time and the bound on growth, and says how the direction was established. A diagram with arrows and no numbers is a hypothesis drawn in a suggestive shape.

Where That Leaves Us

A loop diagram asserts direction and timing, and neither follows from correlation, so a feedback claim has to be earned by intervention or by stated structural assumptions. Naming the variable, the sign, the gain, the delay and the saturating bound is what turns the diagram into a model. IDE-011 takes up a process that closes a loop of its own kind, where differential persistence alters what comes next.

What We Know, and How

- Closing a loop changes a system's dynamics rather than only its output values, which is why feedback can produce accuracy that does not depend on the precision of the forward path.[1,2]
- Whether a negative loop stabilizes depends on gain and delay, and the frequency-domain criterion for the boundary is standard design practice rather than an approximation.[3,6]
- Physiological regulation maintains a range through multiple loops with different speeds and effectors, and the defended range itself varies, so it is not a stored set point being tracked.[4]

What We Still Don't Know

- How to identify loop structure reliably in systems that cannot be experimentally opened and where the candidate loops operate on similar timescales.
- How much of the apparent robustness of large biological and ecological regulatory networks comes from loop architecture and how much from redundancy in the components themselves.
- Which quantitative measures of feedback strength transfer usefully between engineered systems, where the loop gain is designed, and natural systems, where it must be inferred.

What Could Change Our Minds

- A physical control system that maintained stability with loop gain above unity at the frequency where accumulated phase lag inverts the returned signal, with all delays and dynamics accounted for, would overturn the standard stability criterion.[3,6]
- A demonstration that a defended physiological variable is tracked against a single stored numerical target, identified as a physical quantity in a specific structure rather than inferred from behaviour, would replace the multiple-loop account of homeostasis.[4]
- A well-characterized system with positive feedback whose measured steady-state input-output relation intersects the balance condition at more than one stable value, so that the fitted model predicts a threshold and a hysteresis loop of a stated width, that nonetheless showed a single

stable state with neither, under slow forward and reverse sweeps of its driving parameter, would break the standard account of why positive loops give thresholds.[5]

If You Remember Only One Thing

Feedback makes a system's output part of its own cause; the sign tells you almost nothing, and the gain, the delay and what stops the growth tell you the rest.

Related Articles

- IDE-011 — Selection
- IDE-004 — Causality
- IDE-017 — Uncertainty

References

- [1] James Clerk Maxwell. On Governors. Proceedings of the Royal Society of London 16, 270-283 (1868). DOI 10.1098/rspl.1867.0055.
- [2] Harold S. Black. Stabilized Feedback Amplifiers. Bell System Technical Journal 13(1), 1-18 (1934). DOI 10.1002/j.1538-7305.1934.tb00652.x.
- [3] Hendrik W. Bode. Network Analysis and Feedback Amplifier Design. Van Nostrand (1945).
- [4] Walter B. Cannon. Organization for Physiological Homeostasis. Physiological Reviews 9(3), 399-431 (1929). DOI 10.1152/physrev.1929.9.3.399.
- [5] Steven H. Strogatz. Nonlinear Dynamics and Chaos, 2nd ed. CRC Press (2015), chapters 3 and 8.
- [6] Karl Johan Åström; Richard M. Murray. Feedback Systems: An Introduction for Scientists and Engineers, 2nd ed. Princeton University Press (2021).