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Systems Theory in Design
Feedforward

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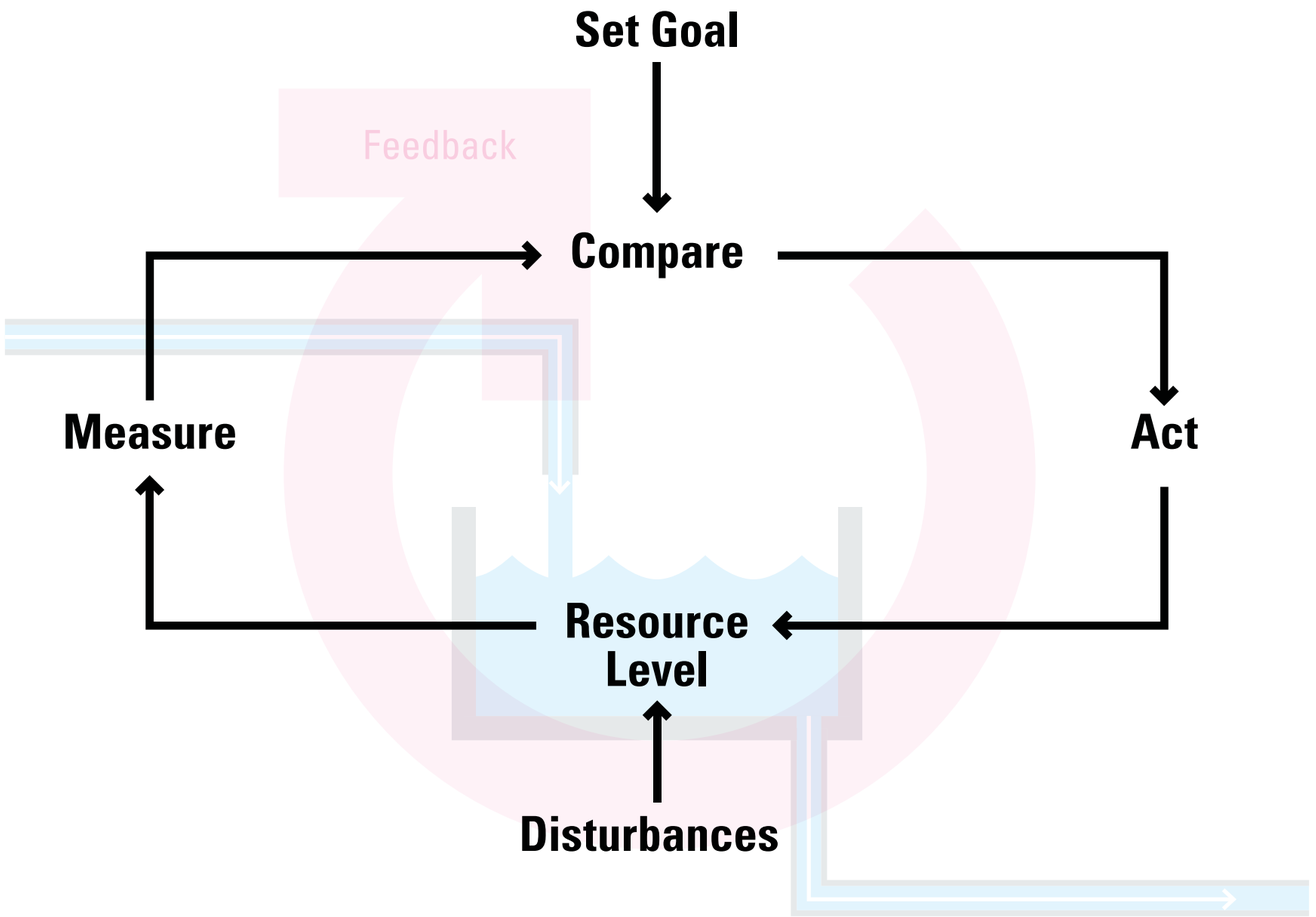
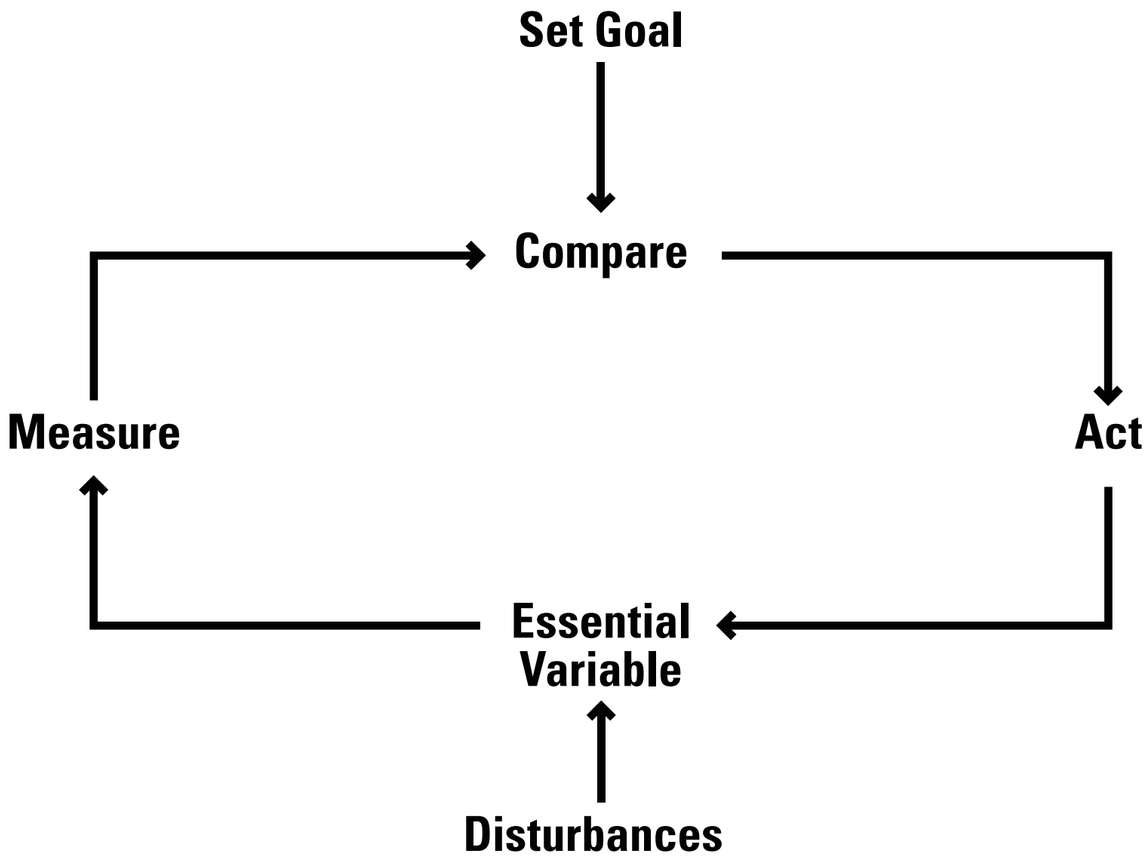
Reviewing Variety and Requisite Variety

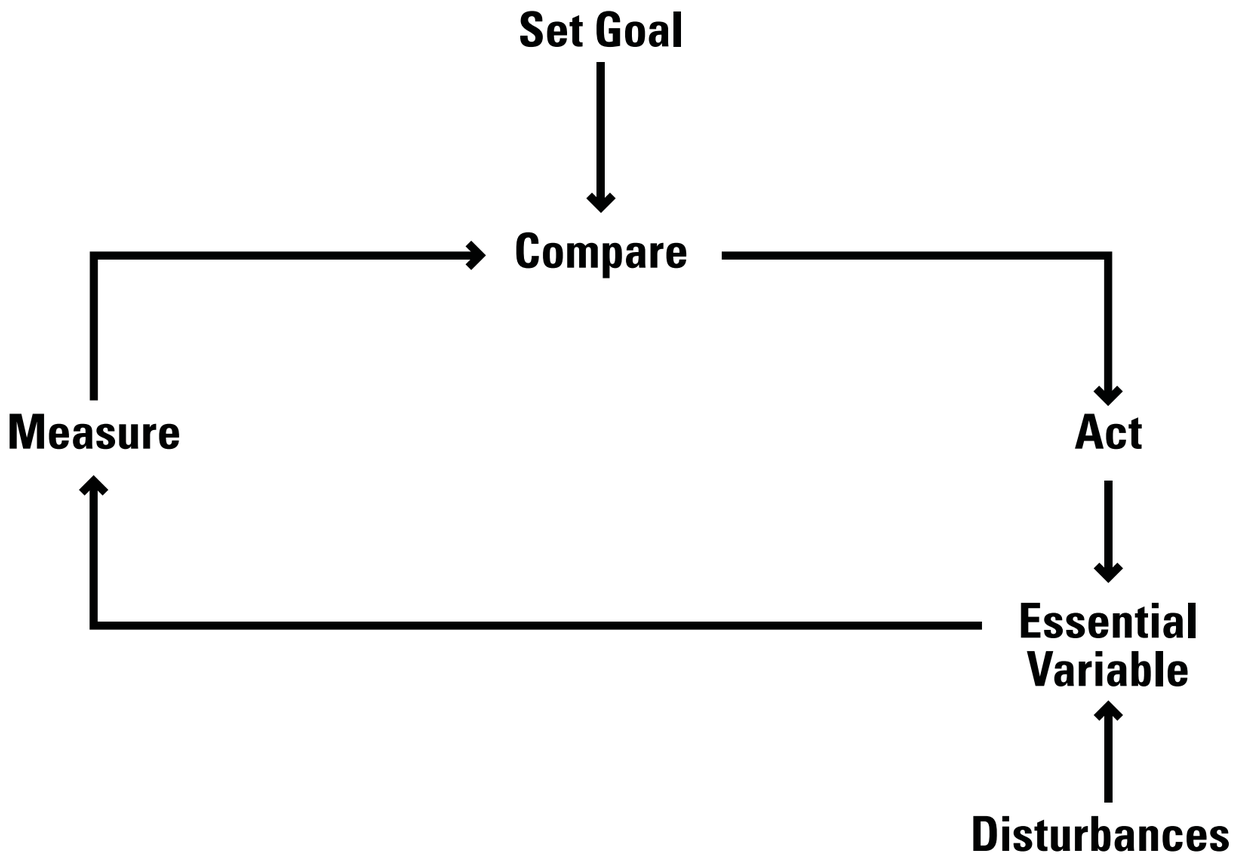
Let's return to our classic feedback loop diagram. A system uses feedback to maintain the level of a stock.



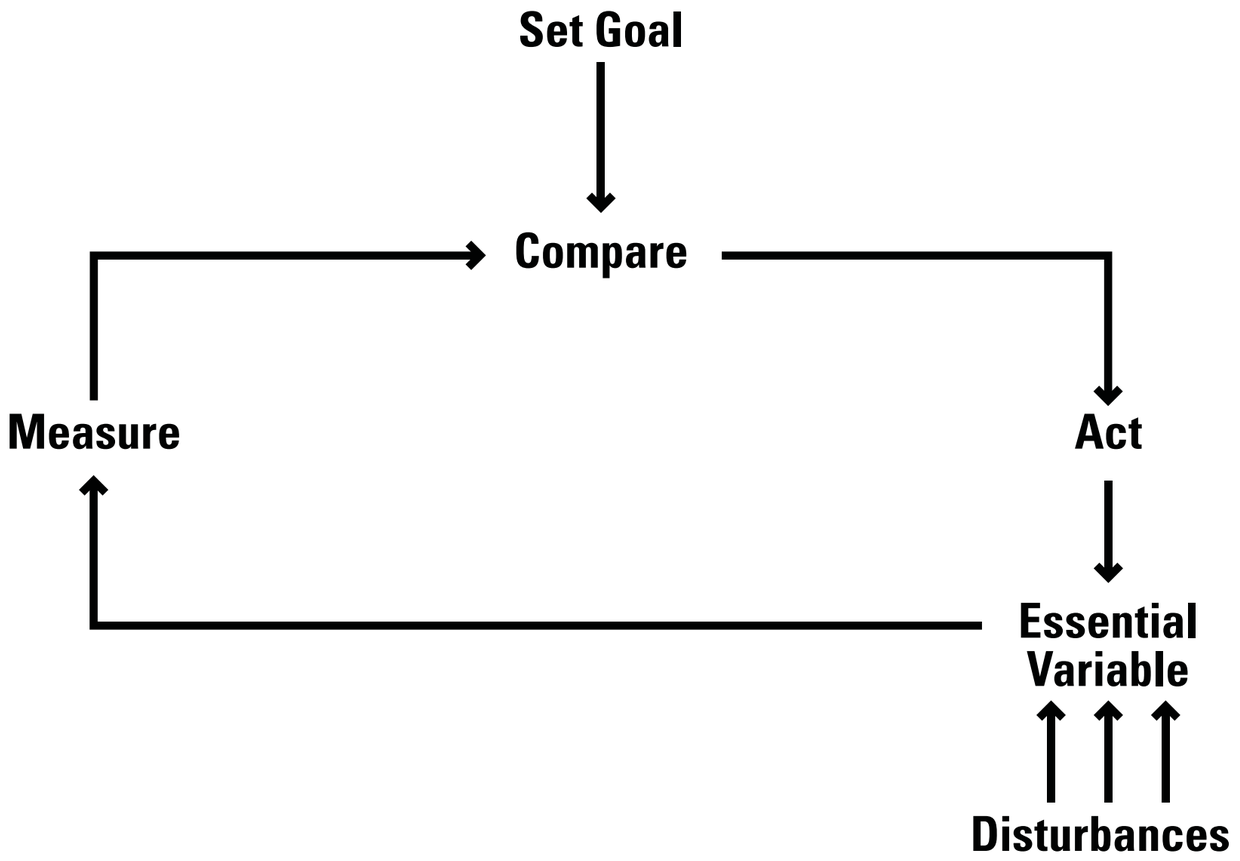
We might generalize ‘Resource Level’ as ‘Essential Variable’.



The system's actions directly oppose the disturbance.

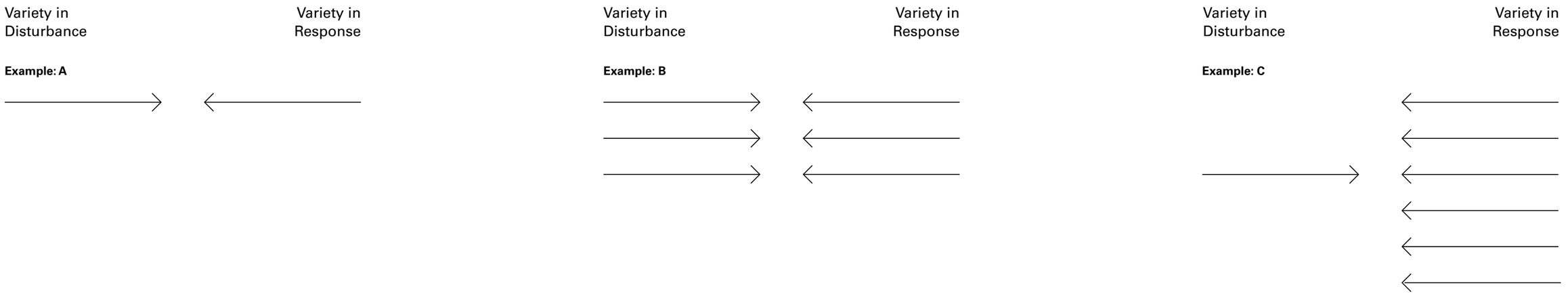


The system can maintain itself as long as it can ‘defeat’ disturbances, but if the disturbances are large enough, they can overwhelm the system.



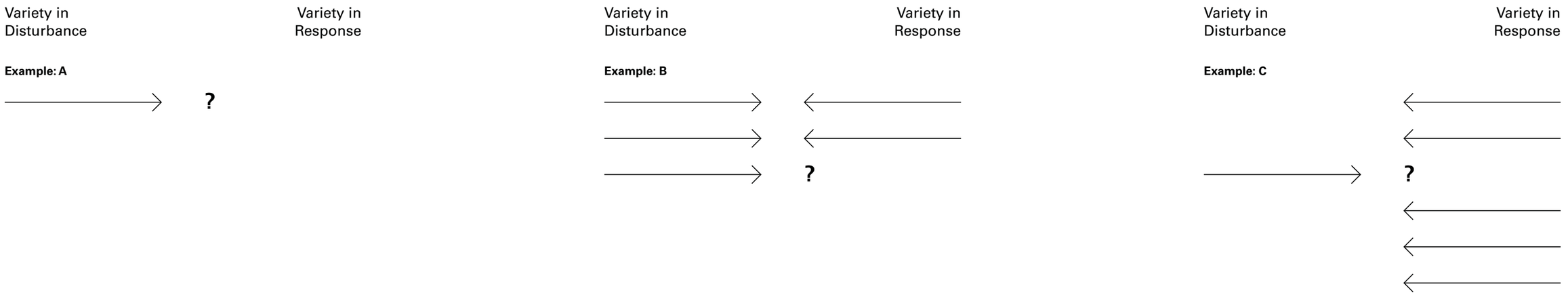
A regulator defends an essential variable against a set of disturbances. ‘Variety’ in the regulator must be = or > the ‘variety’ in the disturbances. If so, we say the system has ‘requisite variety’.

Result = EV Preserved
(system succeeds—“lives”)

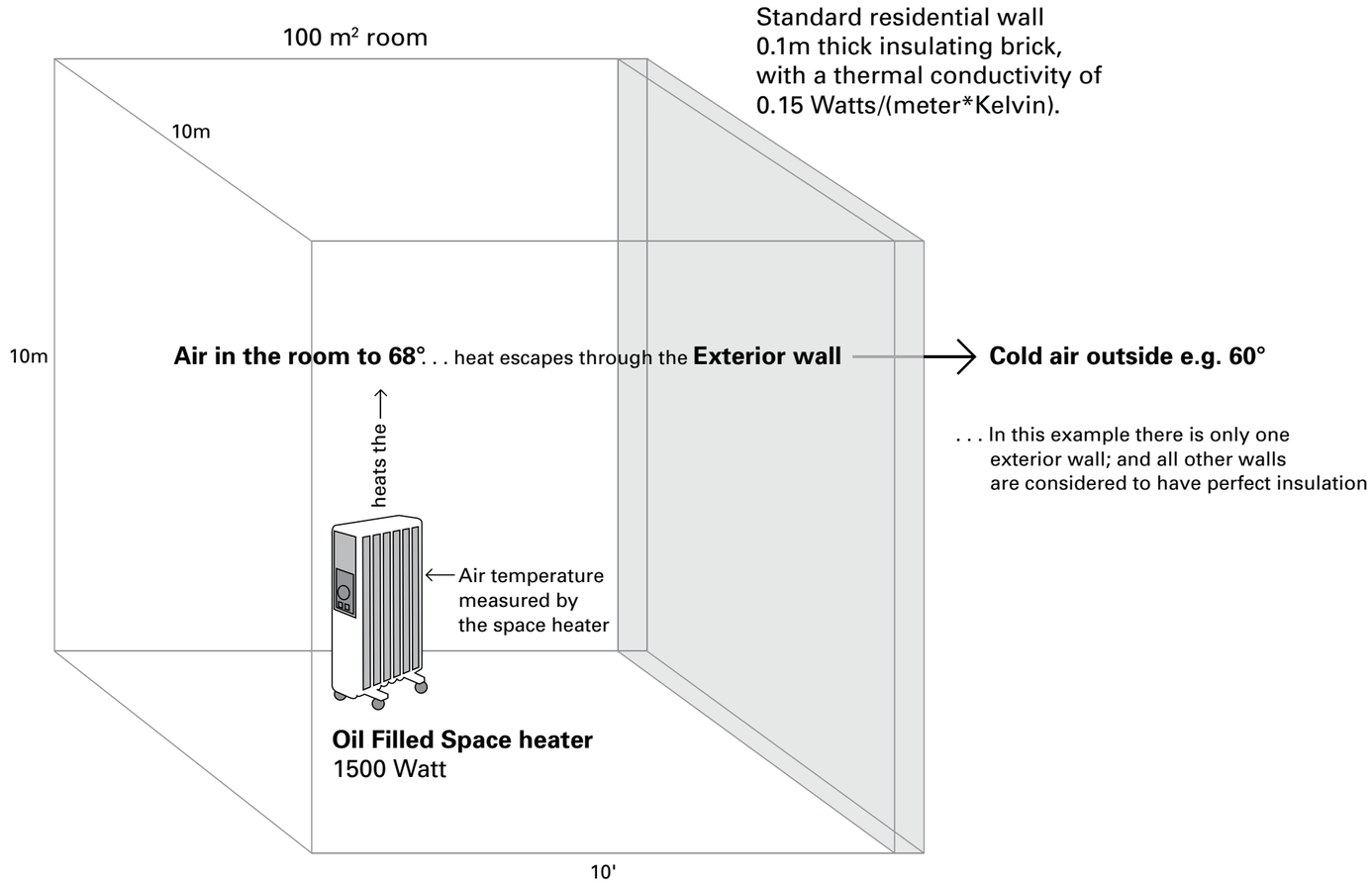


But if the ‘variety’ in the regulator < the ‘variety’ in the disturbances, then the system fails to preserve the essential variable — ‘variety destroys variety’.

Result = EV Destroyed
(system fails—“dies”)



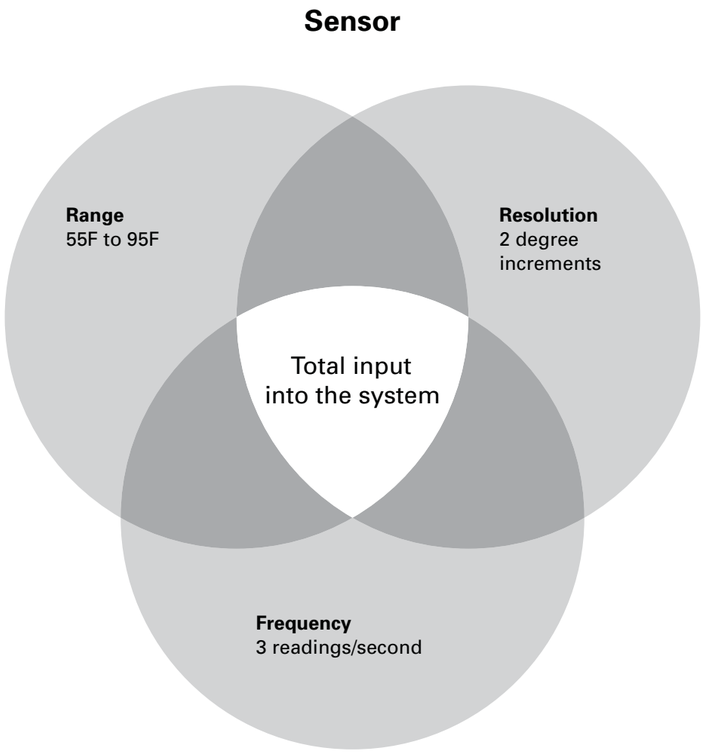
Consider a space heater in a 10m cubed room, with one exterior wall; how much variety does it have?

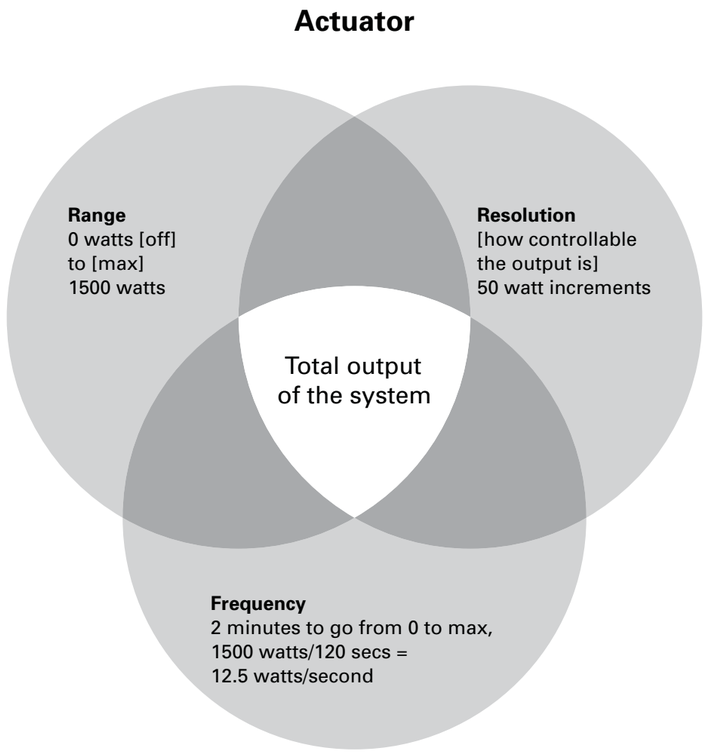


Elements within the Current Situation:
Space heater output = 1500 Watt (5120 BTU/hr)
Wall area = 100 m^2
Wall thickness = 0.1 m
68°F = 20°C = 293.15°K
Thermal conductivity for k (insulating brick) = 0.15 Watts/(meter*Kelvin).

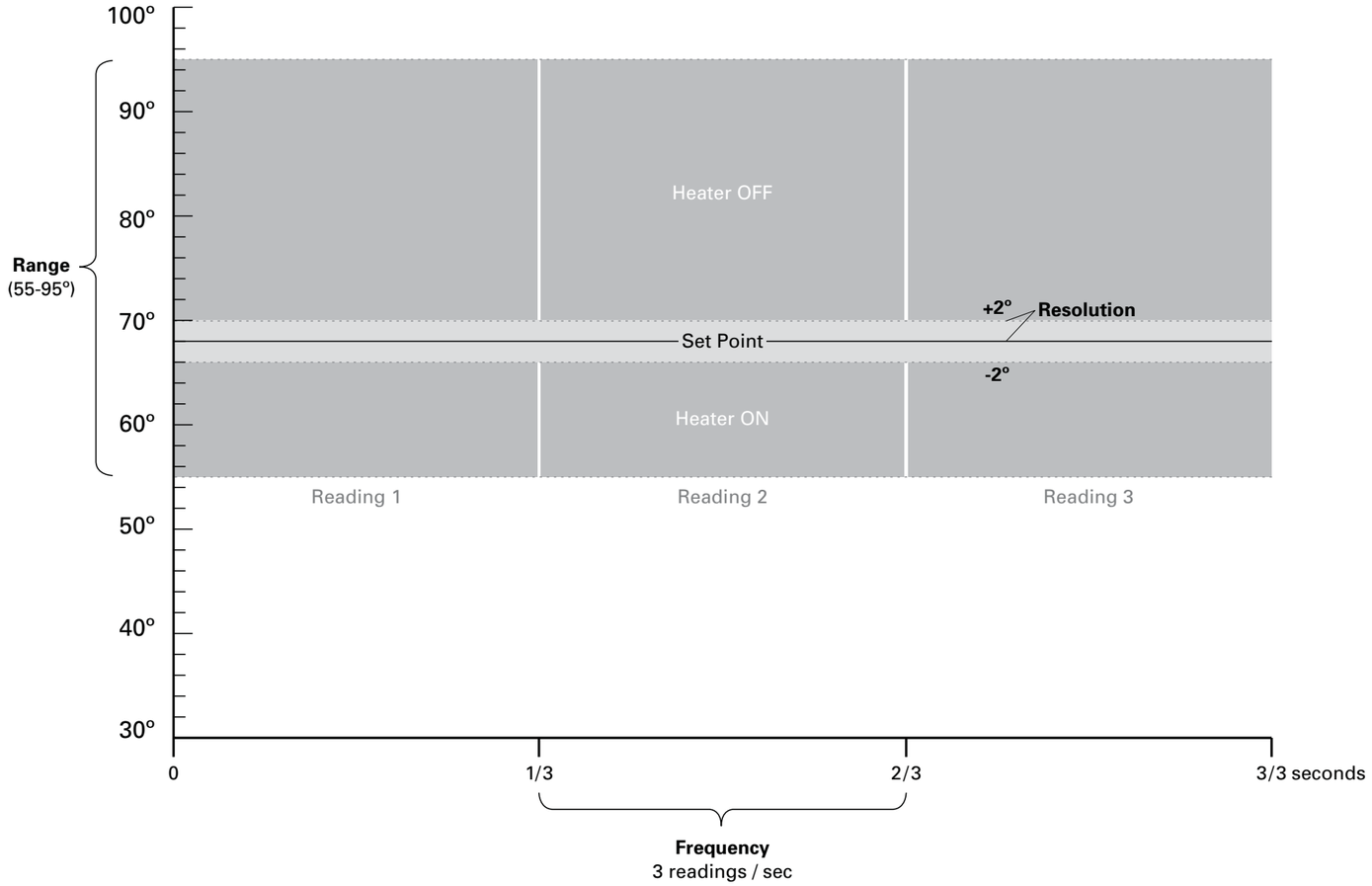
Using the equation above , we find that T_{out} equals 283.15°K (50°F).
Keep in mind that this result is for a 10 centimeter thick wall of insulating brick.

What defines the input and output of the system?



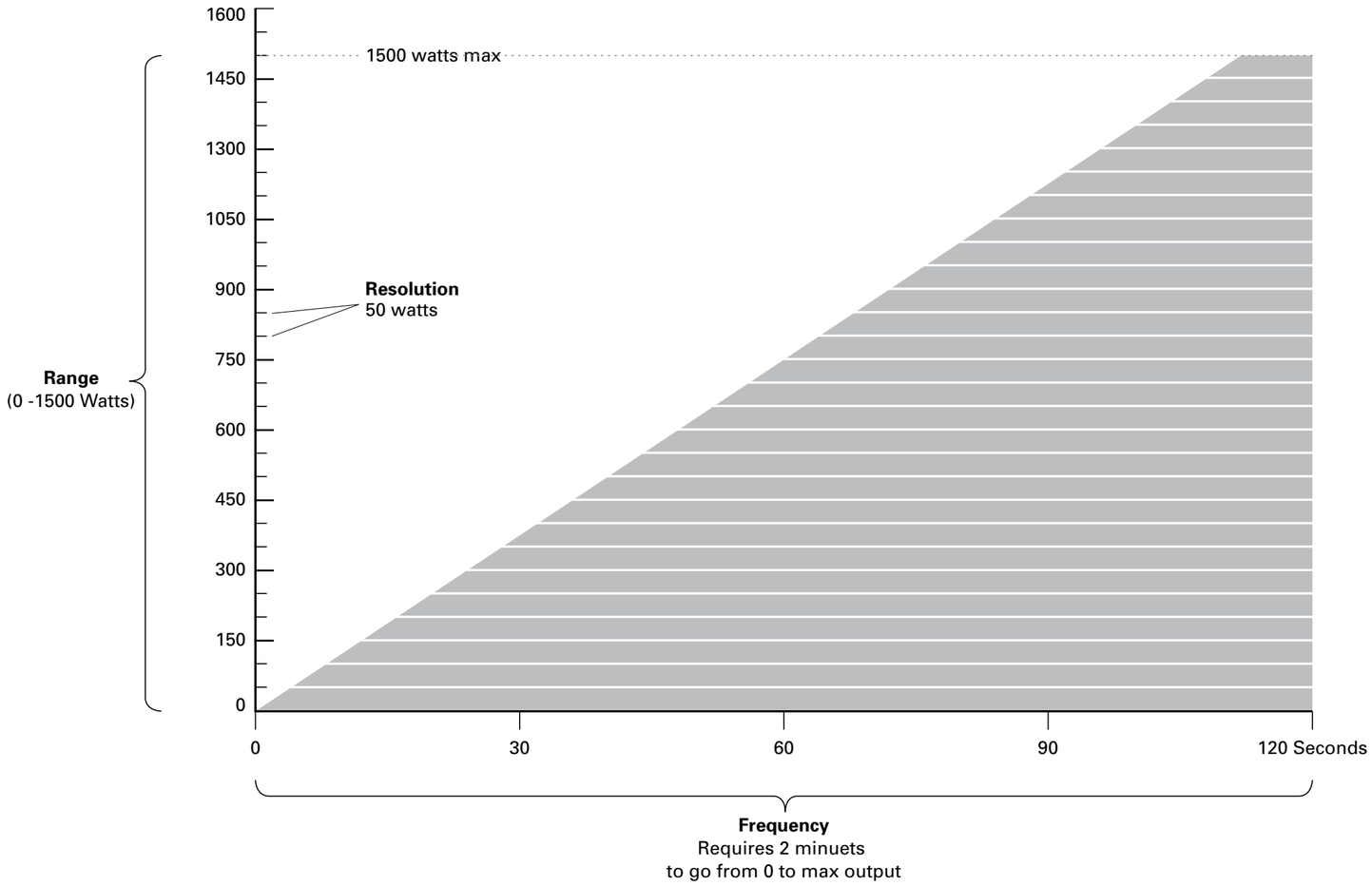


The sensor has a range of 55-95°F (13-35°C), a resolution of 2°F, and a frequency of 3 readings per second.

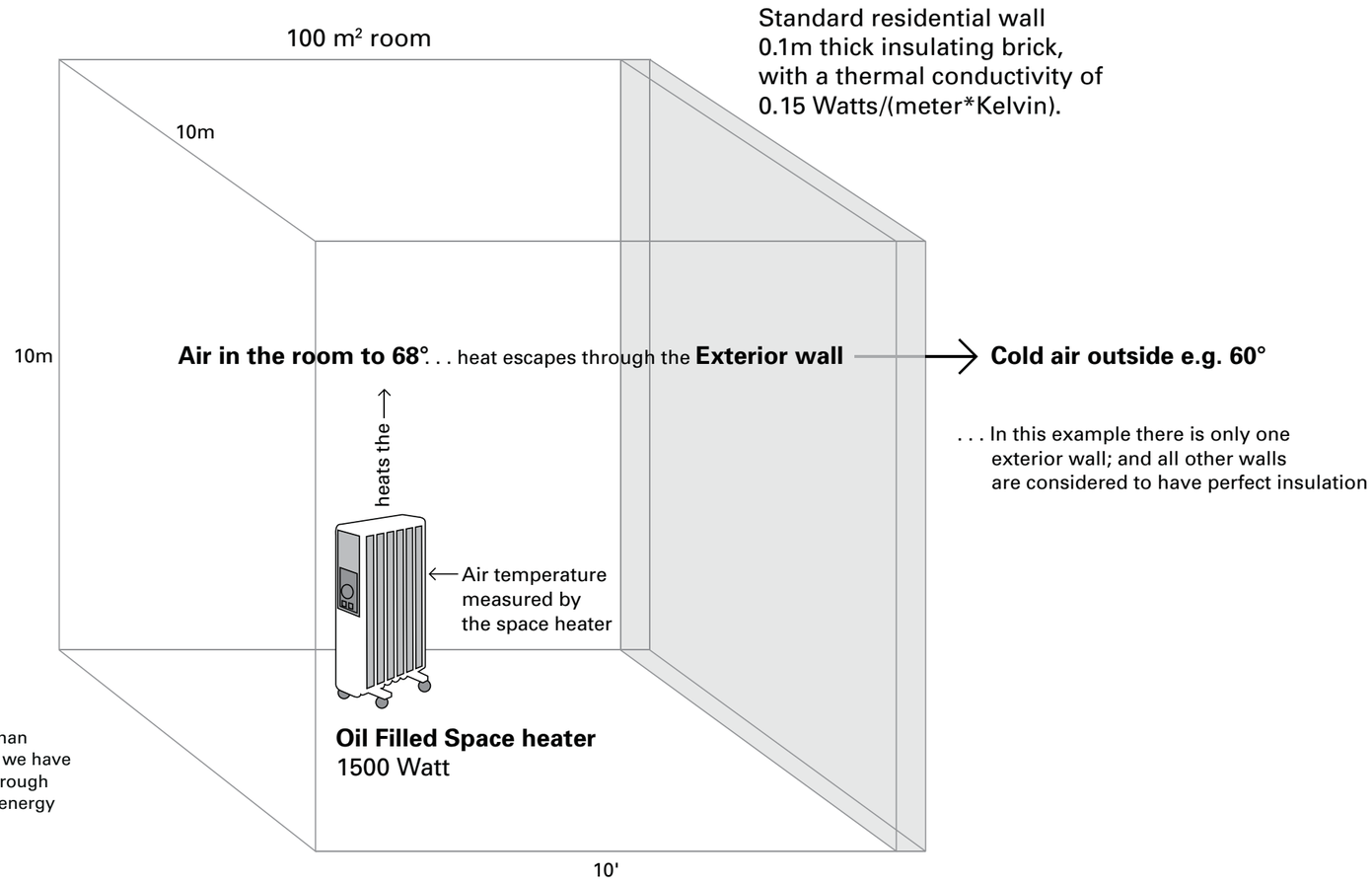


The actuator has a range of 0-1500 Watts, a resolution of 50 Watts, and requires 2 minutes to go from 0 to maximum output.

(Cooling also takes time.)



This system will ‘fail’ when the outside temperature drops below 50°F — outside air will draw out heat faster than the space heater can replace it.

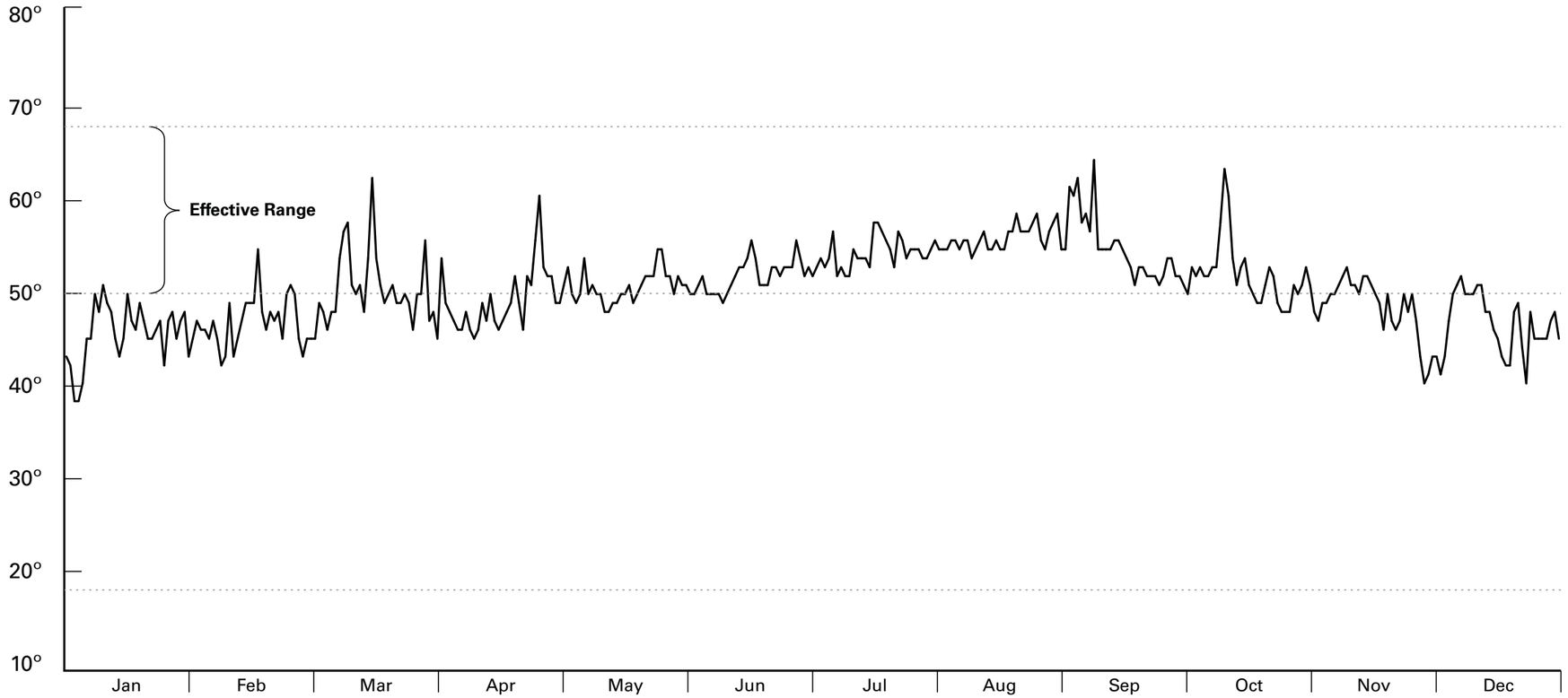


Determining the Effective Range
The heater can maintain the room at 68° when the outside temperature is less than or equal to 68°, and greater than or equal to some minimum temperature T that we have to find. This T is characterized by the fact that it causes the rate of energy loss through the wall 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 = $k*(T_{in} - T_{out})*(\text{wall area})/(\text{wall thickness})$

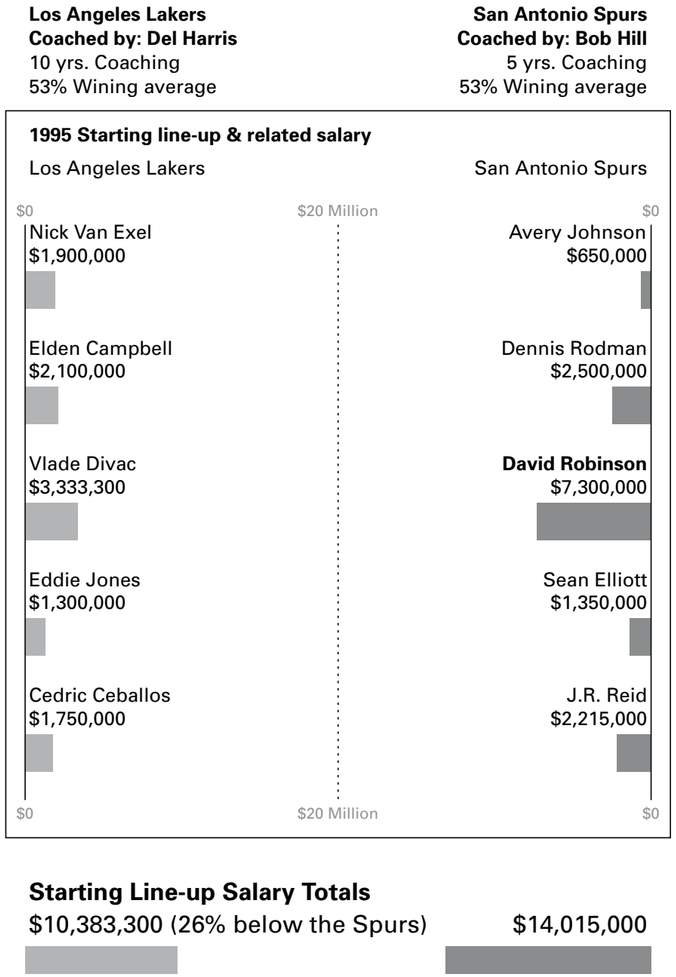
At what Temperature does the space heater fail?
Using the equation above we find that T_{out} **= 283.1K** or **50°F**— when the outside temperature falls below 50°F, the space heater will no longer be able to maintain the room at 68°F.

In San Francisco, the system would lack ‘requisite variety’ about half the year.

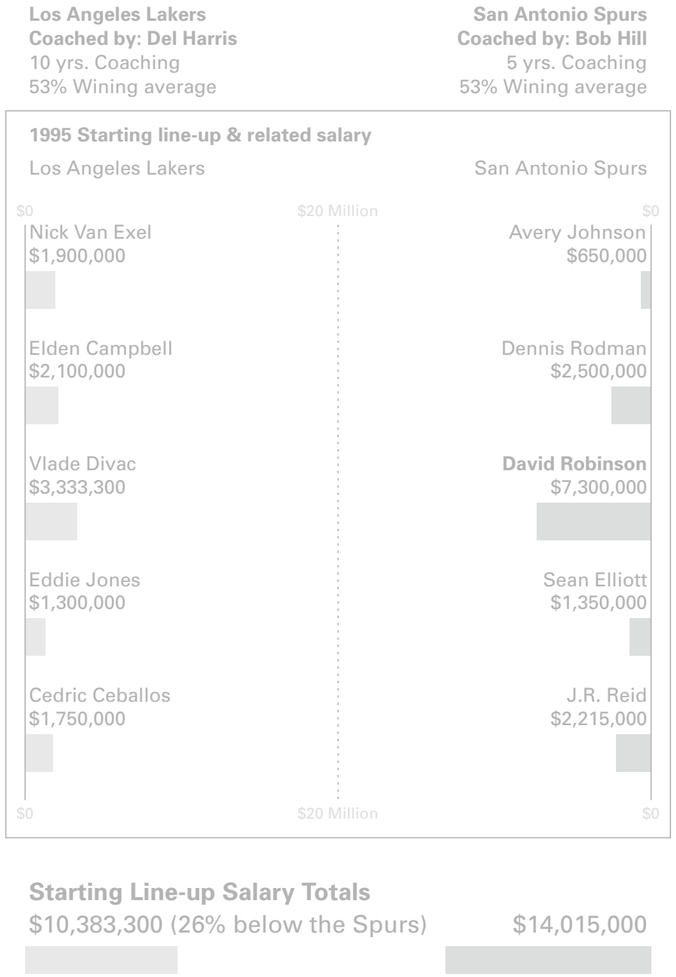


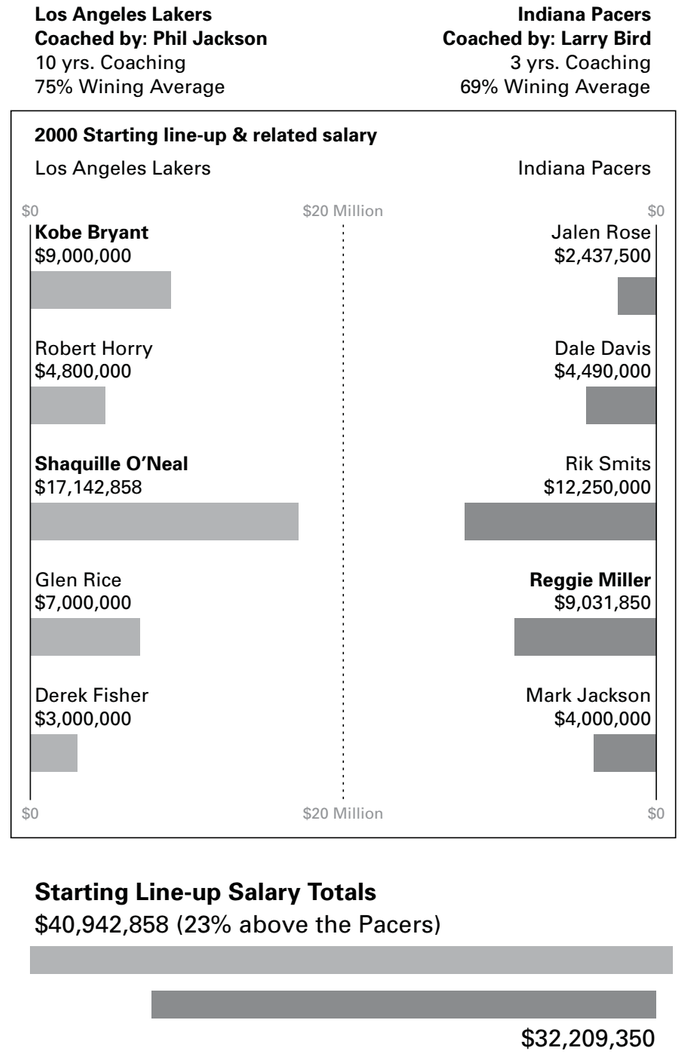
Daily Low Temperature
San Francisco, California 2004

Consider sports teams; money may be a proxy for player performance. In 1995, the Lakers did poorly, losing their conference semi-finals.

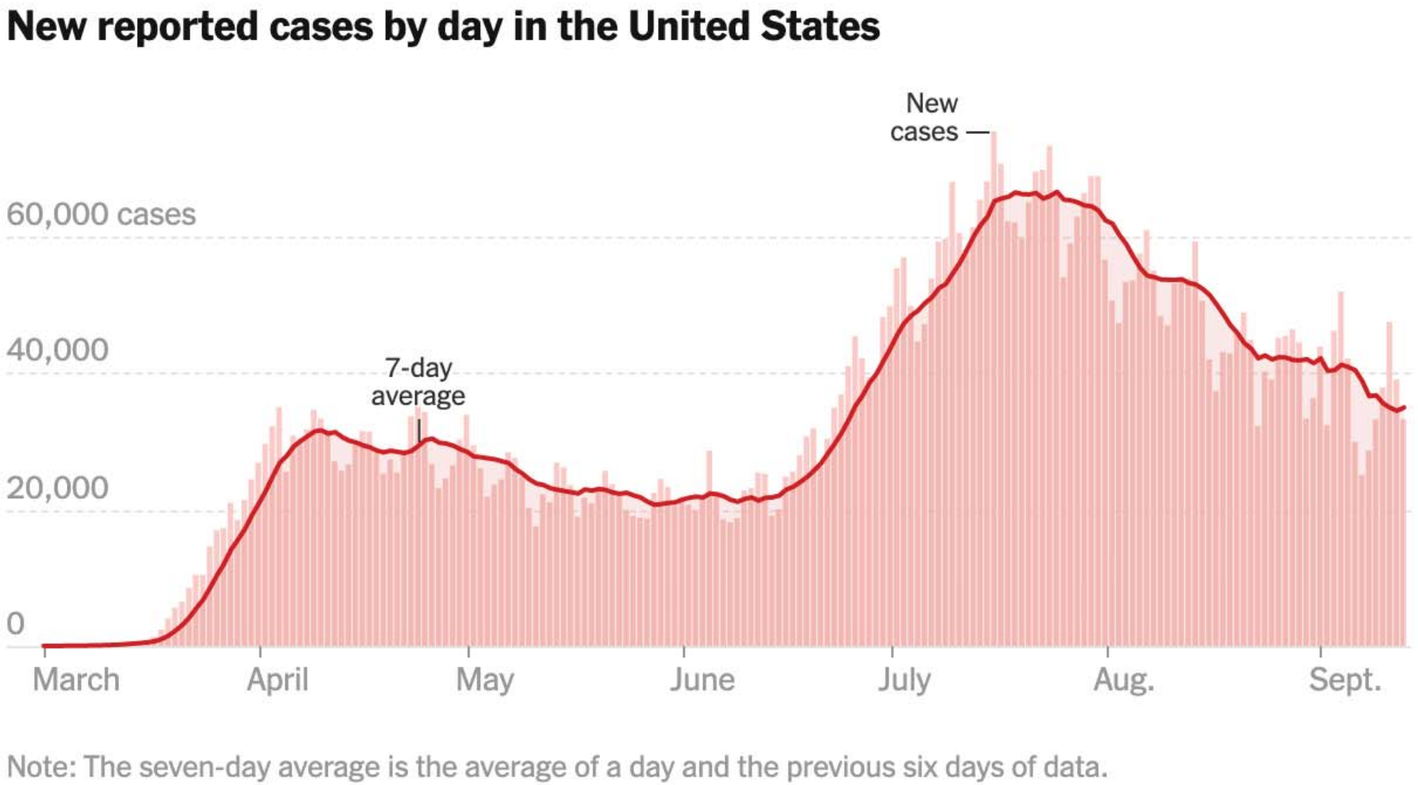


The Lakers went on a spending spree, increasing their ‘variety’ and winning the NBA championship in 2000.





Discussion topic:
Did the United States have the ‘requisite variety’ to handle COVID-19? Why or why not?



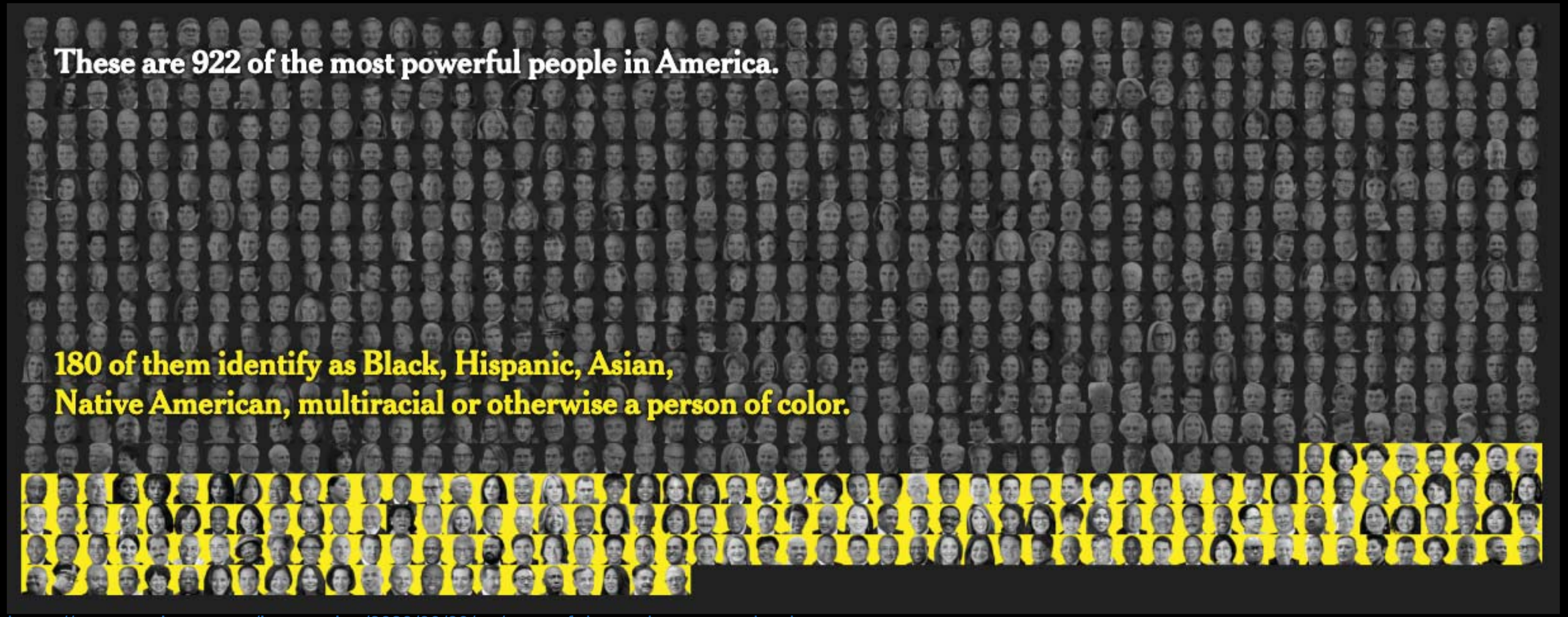
https://www.nytimes.com/interactive/2020/us/coronavirus-us-cases.html

Discussion topic:

In manufacturing supply chains, just-in-time delivery creates efficiency and reduces costs.
What happens when demand spikes?

How can supply chains be made more ‘resilient’?

Discussion topic:
Is homogeneity dangerous?
And why is ‘diversity’ more than a nice idea?



https://www.nytimes.com/interactive/2020/09/09/us/powerful-people-race-us.html

Feedforward

Comparing feedback and feedforward.

Feedback is when you feel hot
and turn on the air conditioner.

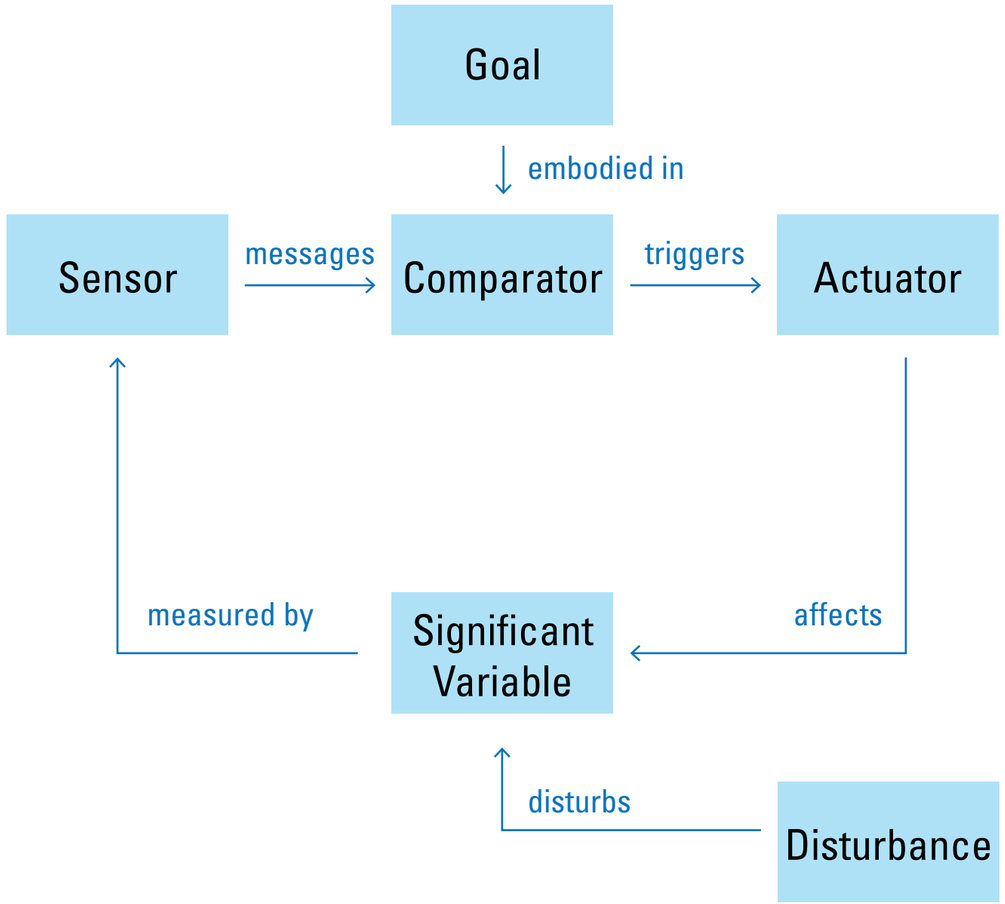
Or when you feel cold
and turn on the furnace.

You have acted to change
an existing condition

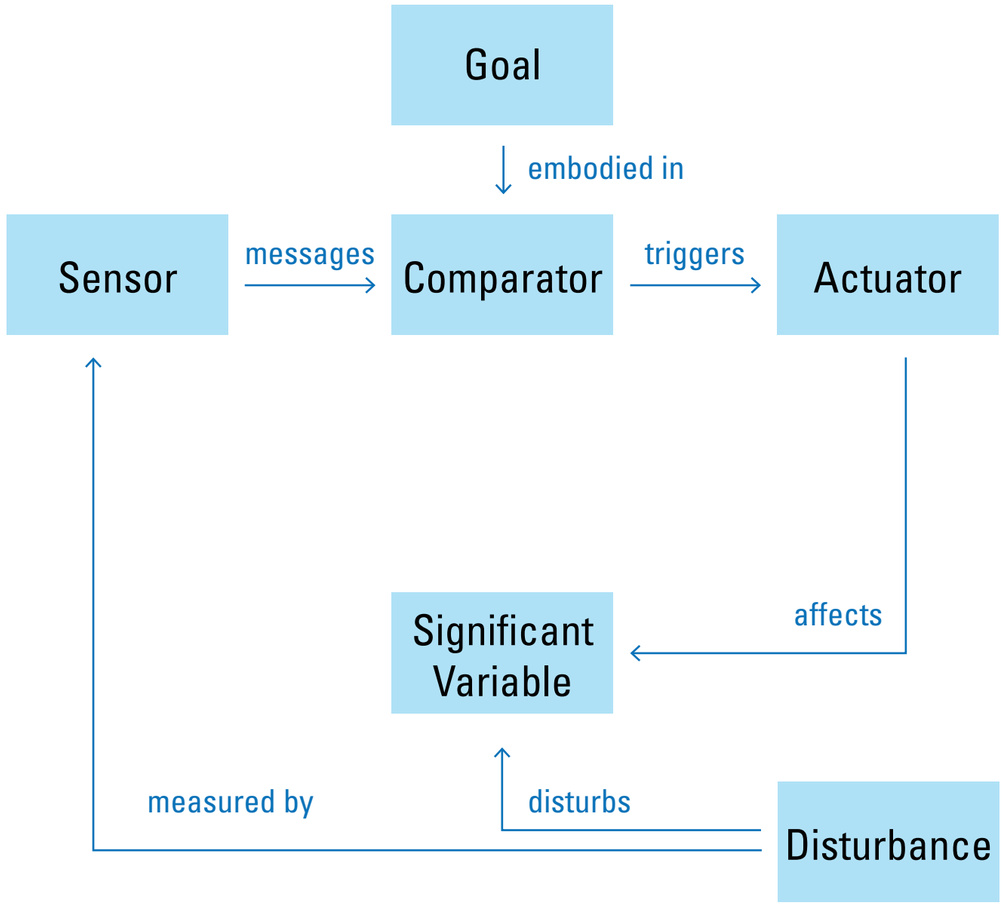
Feedforward is when you look
outside, see it's cold,
and grab a jacket.

You have acted to avoid
a potential problem.

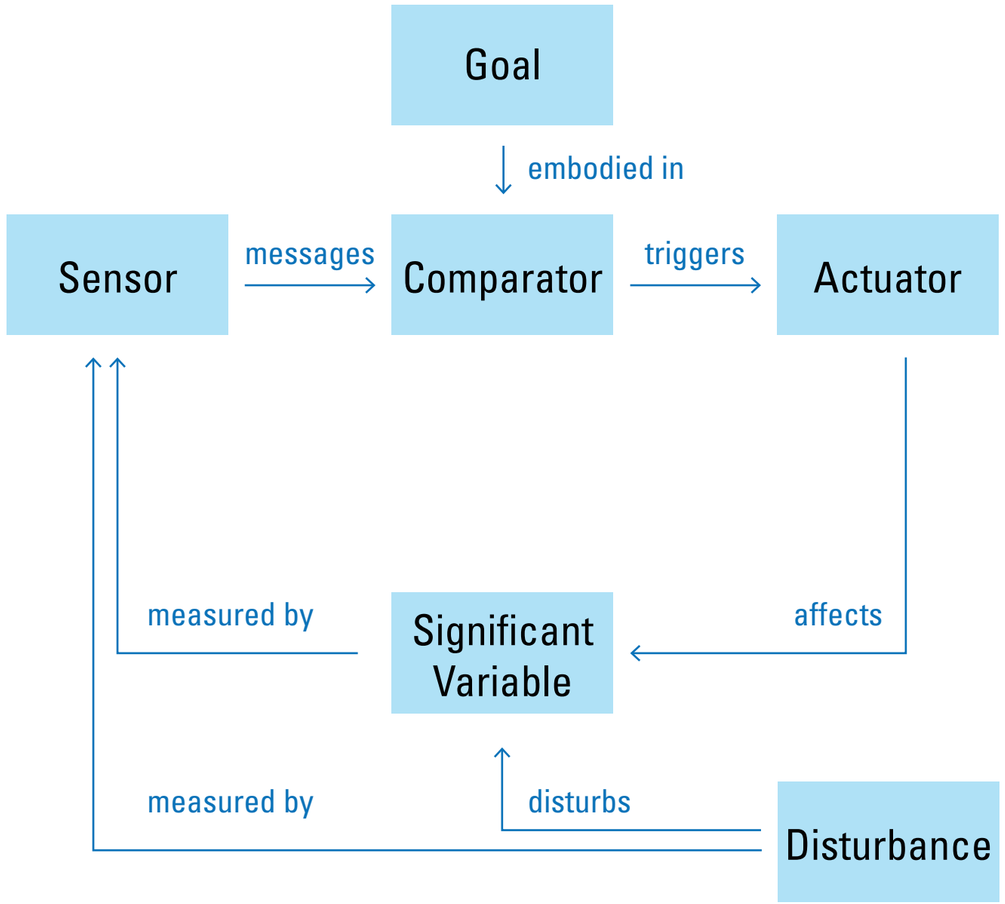
Meadow's tells us maintaining dynamic equilibrium requires 'Feedback': sensing the level of a stock and using that information to control in-flow (or out-flow).



But, if we know the in-flow rate, we could also use that information to control the out-flow rate — without ever measuring the stock level. That's 'Feedforward'.



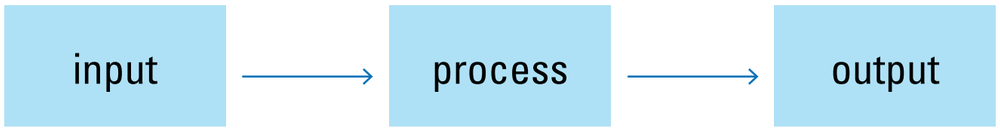
In practice, we may want both Feedback and Feedforward controls — Feedforward to anticipate large changes; Feedback to account for errors.



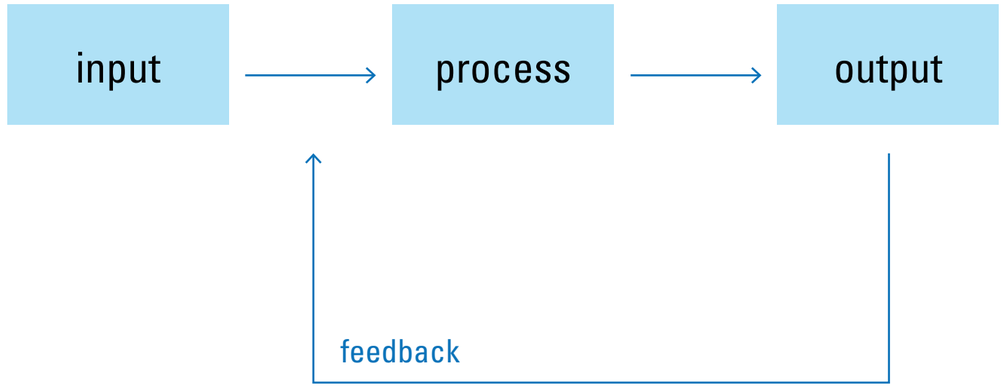
Let’s compare four arrangements of a system:

1. Open loop
2. Closed loop (feedback)
3. Feedforward
4. Feedback + feedforward

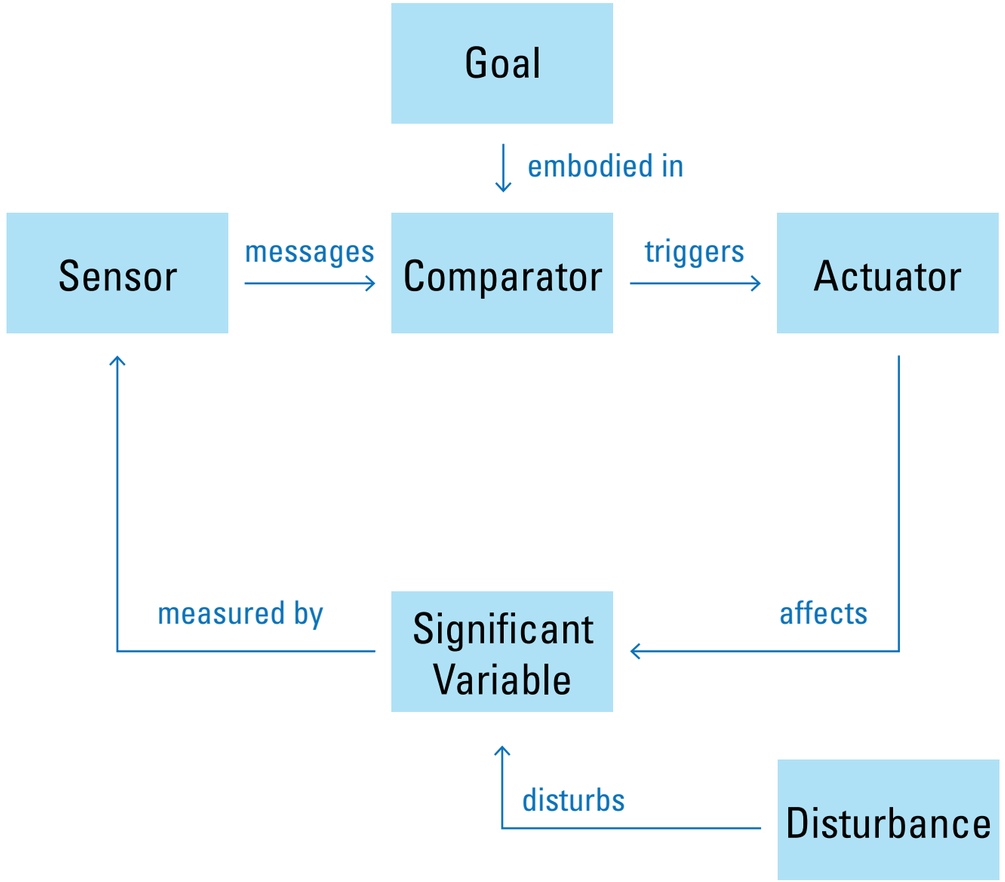
Open Loop



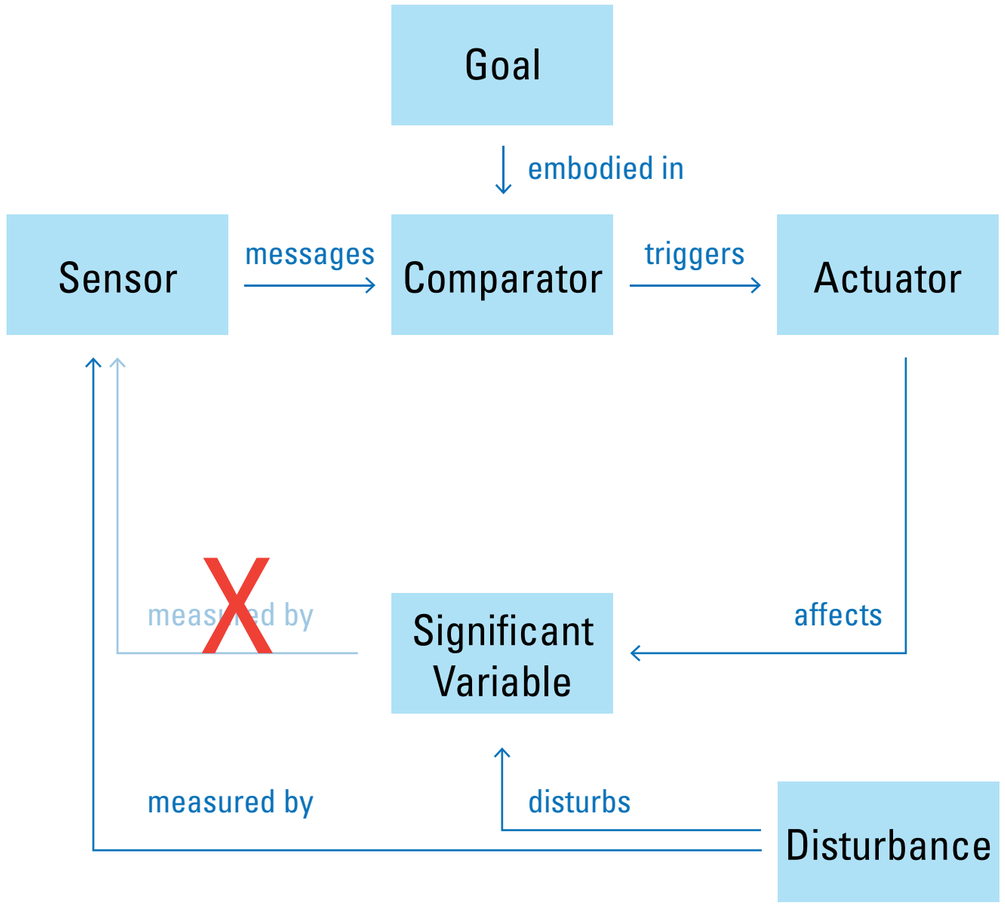
Closed Loop



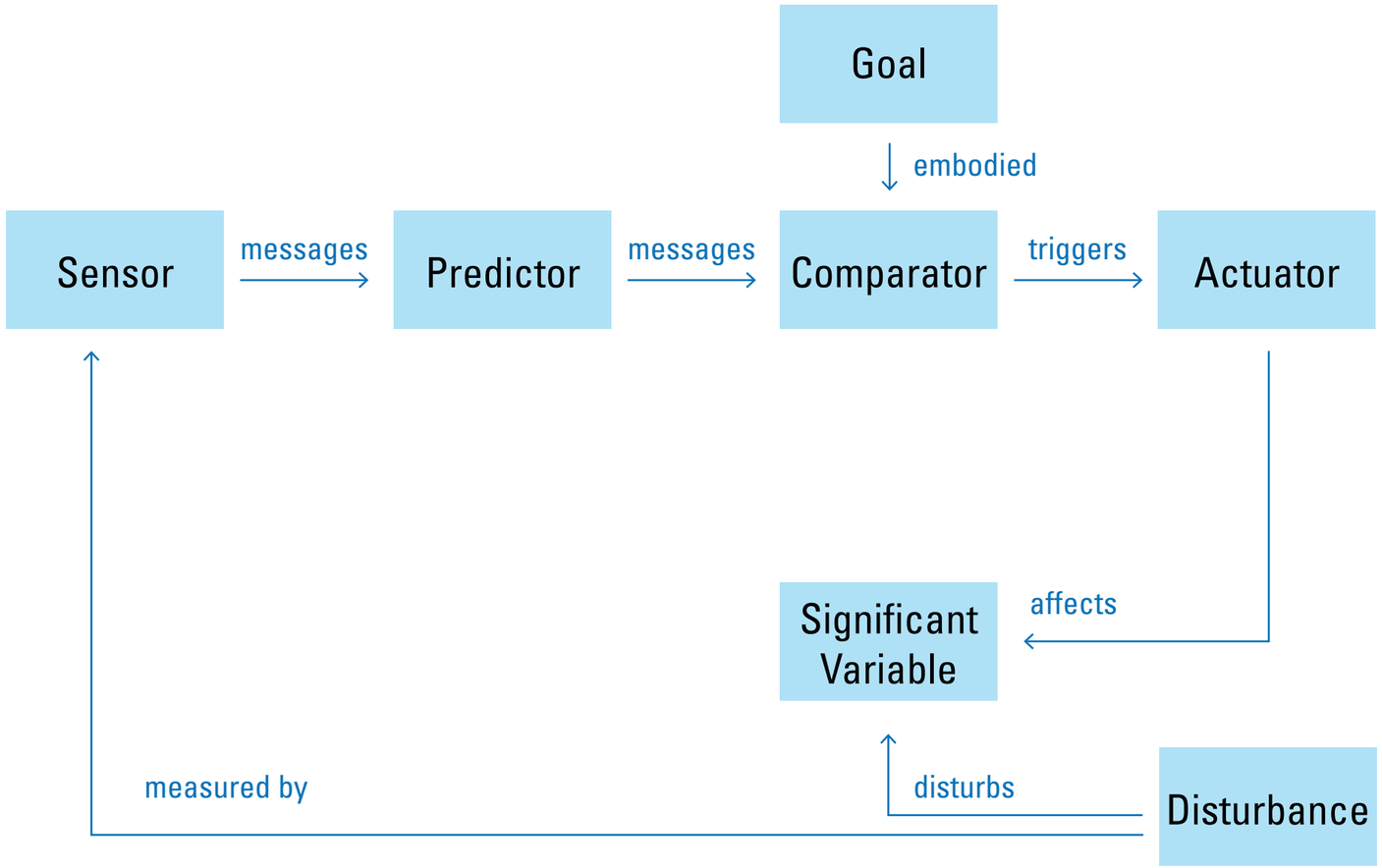
Closed Loop: Formalized as a Feedback loop model
The system measures the significant variable and acts to correct it



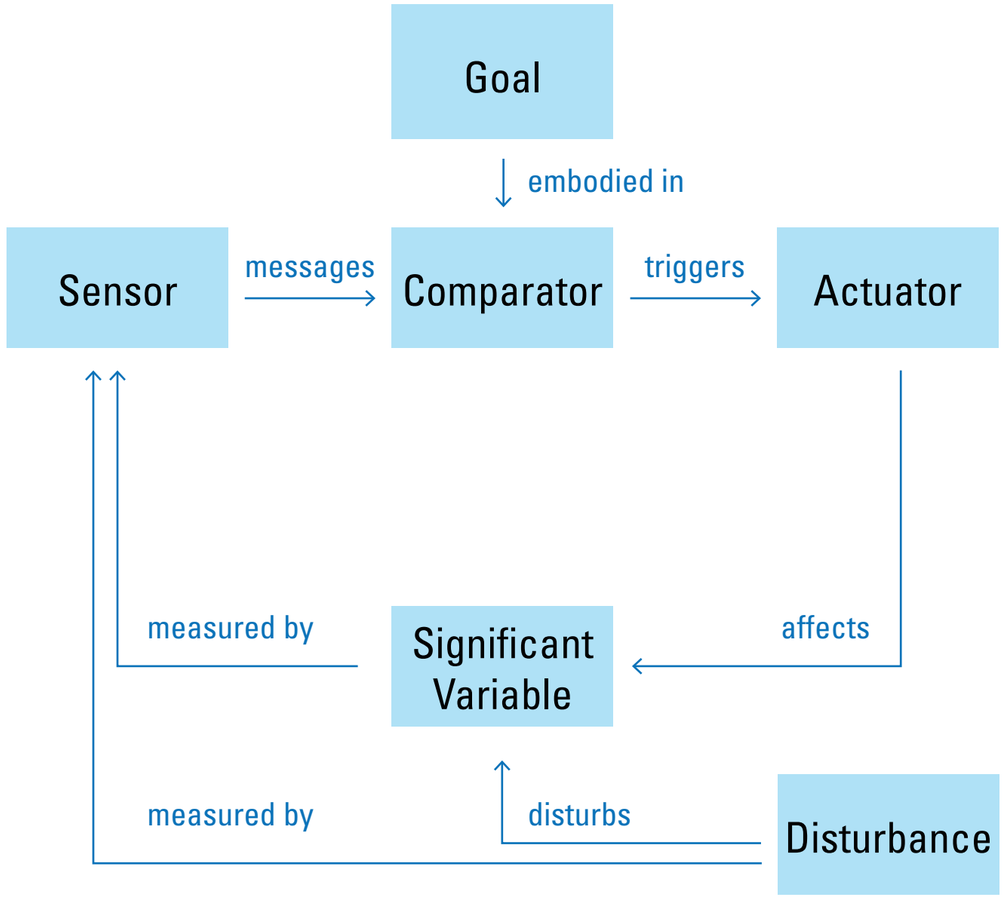
Feedforward (also Open Loop)
The system detects a disturbance before it affects the significant variable



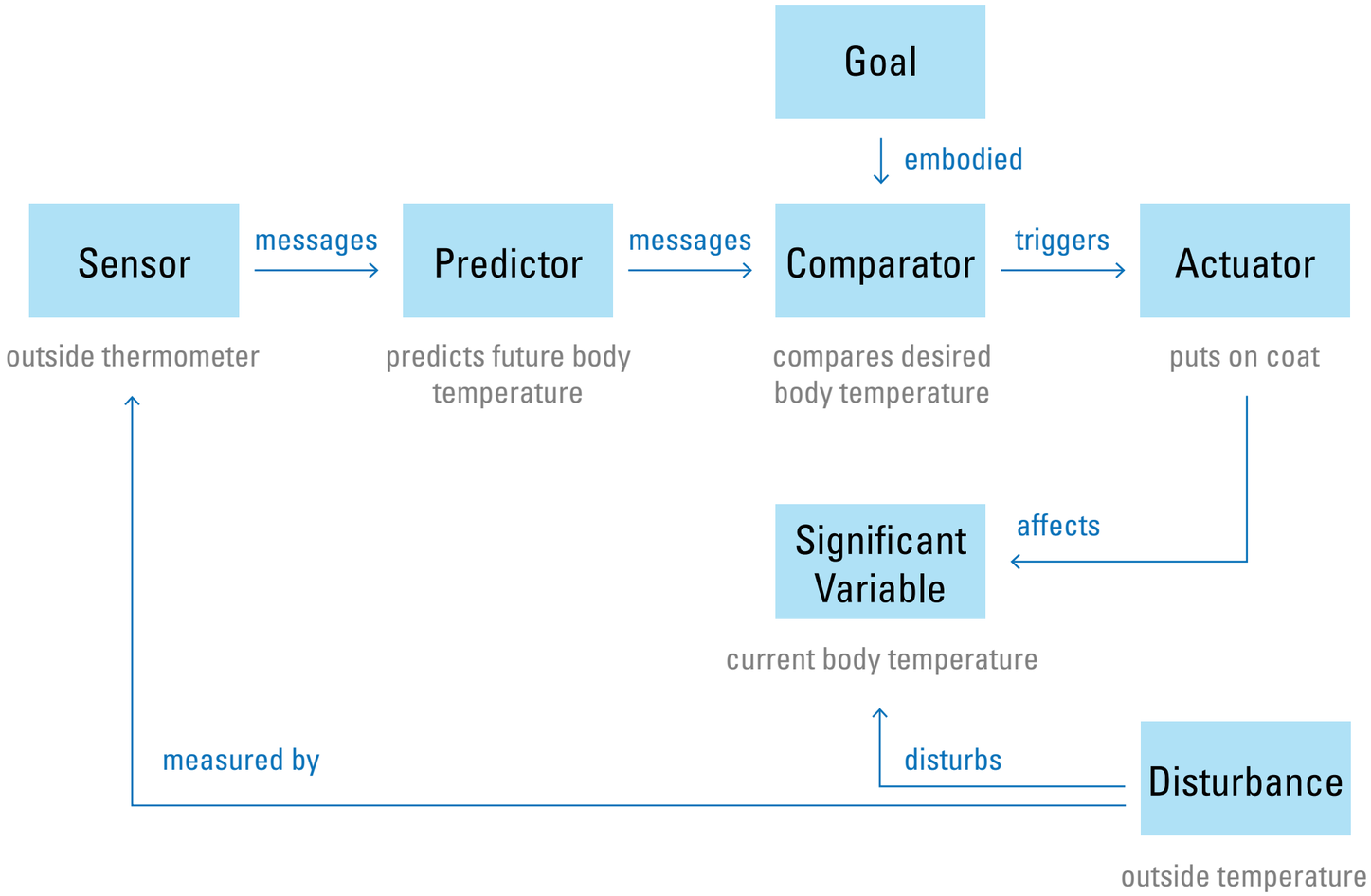
Feedforward
Feedforward can also be based on prediction



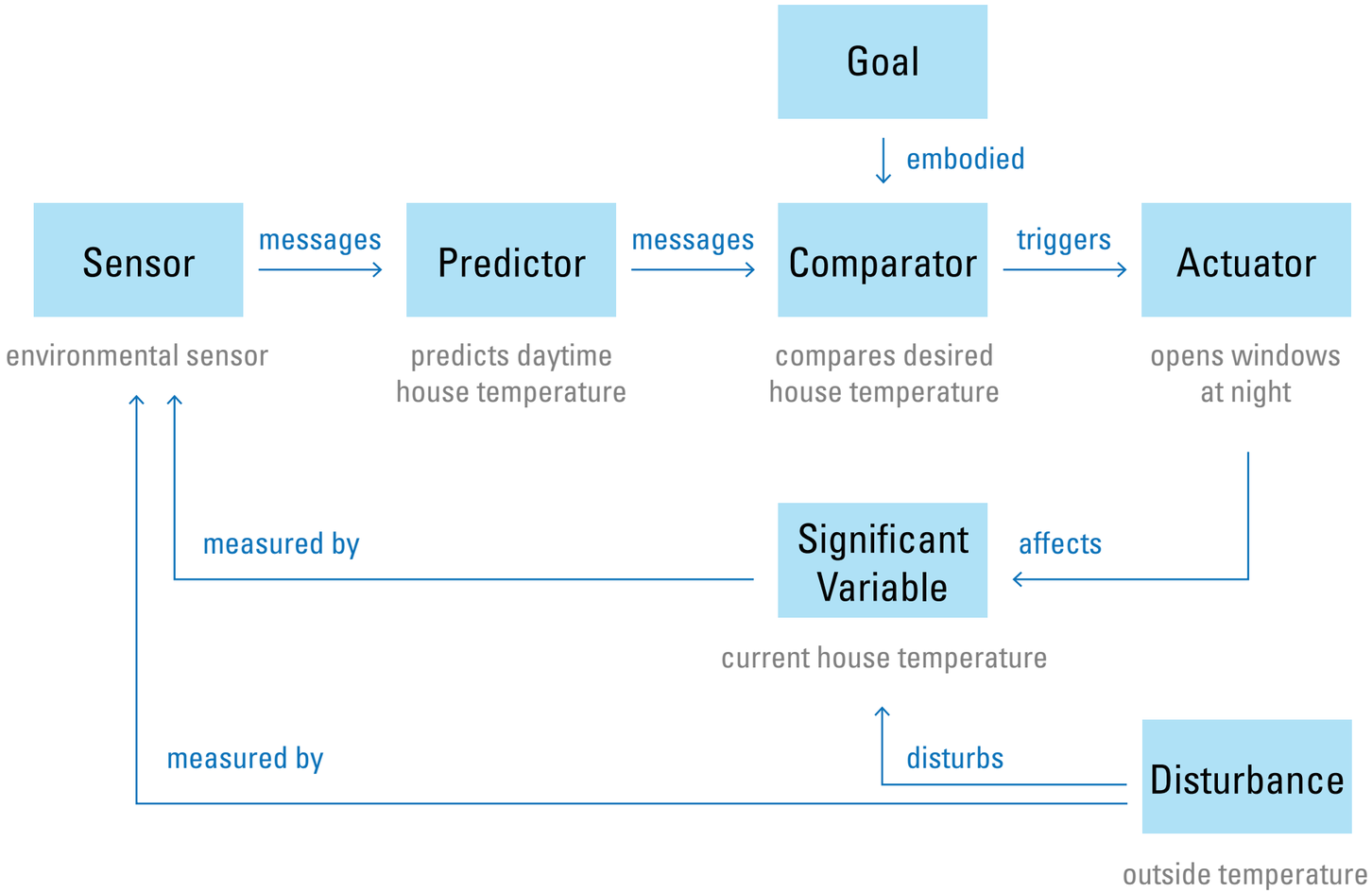
Feedforward + Feedback — sometimes both may be used



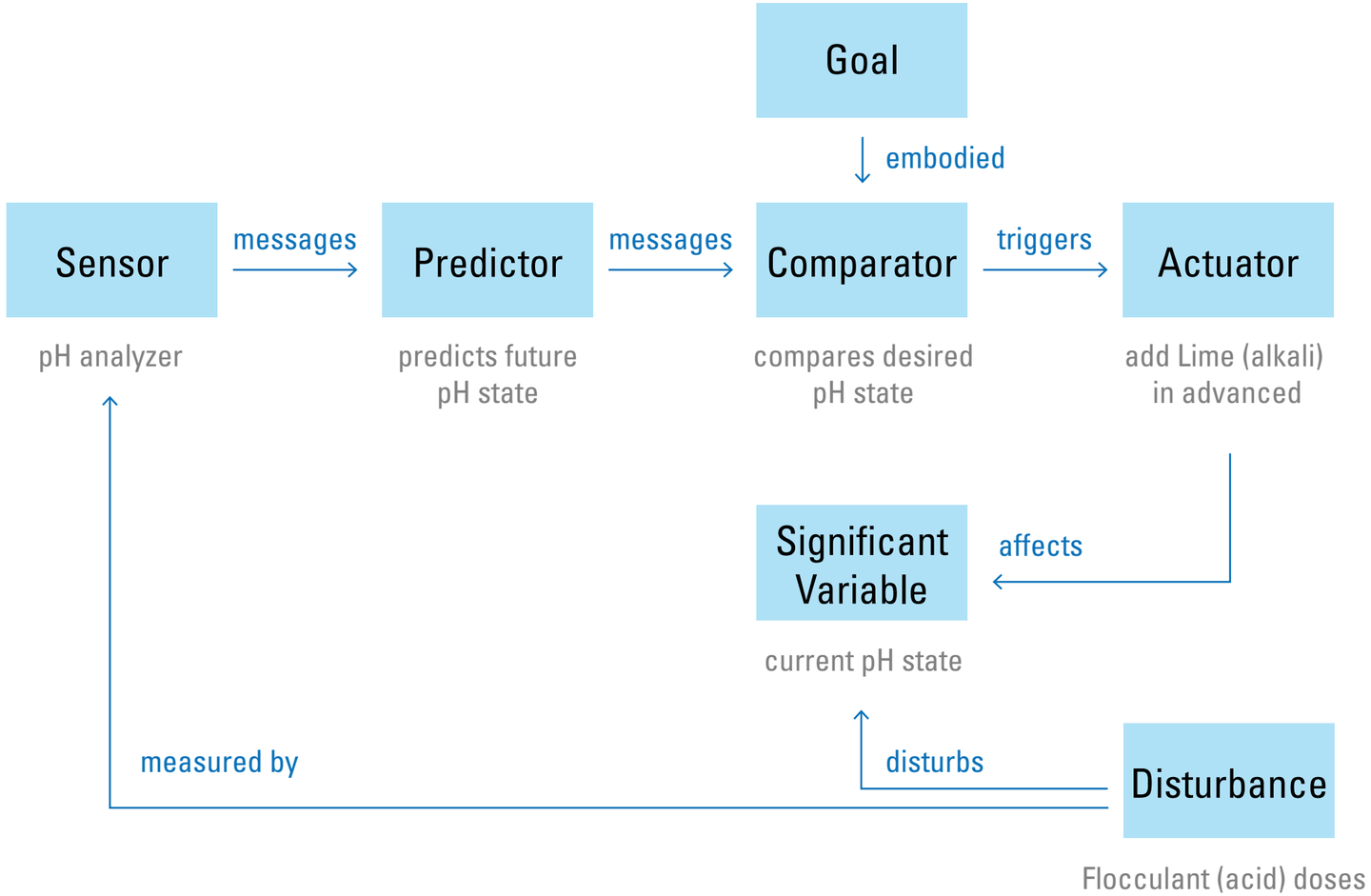
Example of Feedforward:
People put on a coat before they go outside



Example of Feedforward + Feedback:
Smart Home pre-cools the house at night for coming daytime

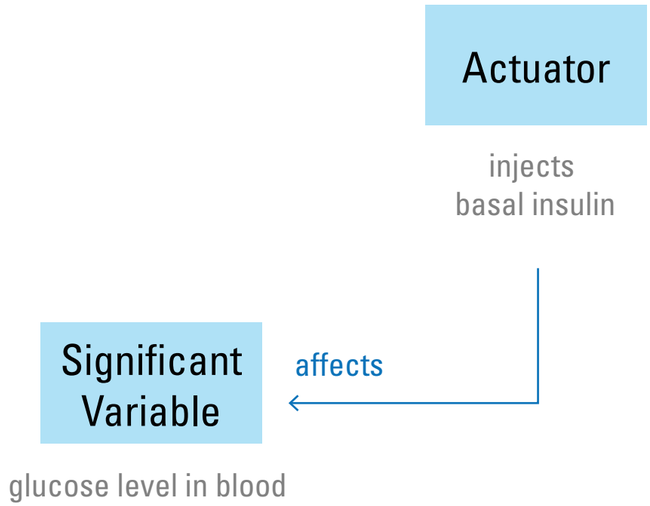


Example of Feedforward:
A water purification system may use Feedforward, anticipating pH changes and acting to avoid them.

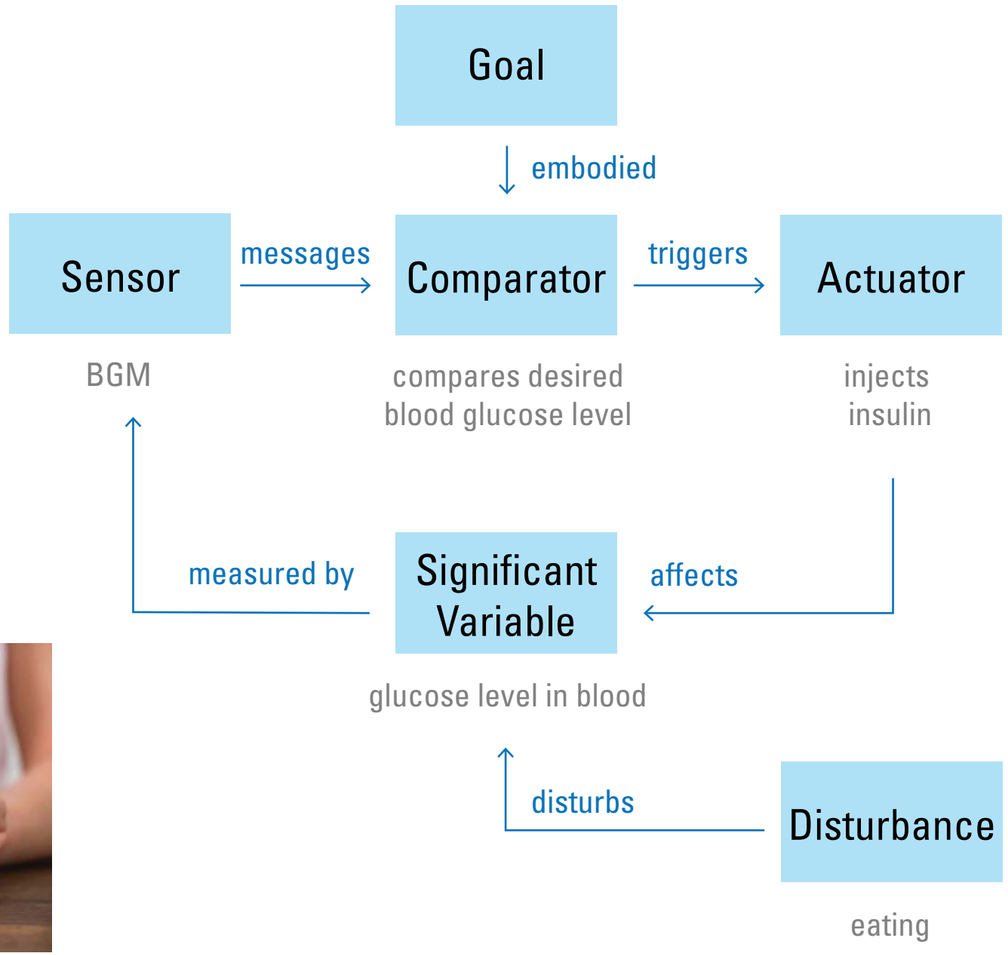


Flocculant is necessary to expedite the removal of impurities from the water, but some flocculation compounds have the unfortunate effect of decreasing the pH value of the water (turning it more acidic). If the water's pH value is too low, the flocculant ironically loses its ability to function.

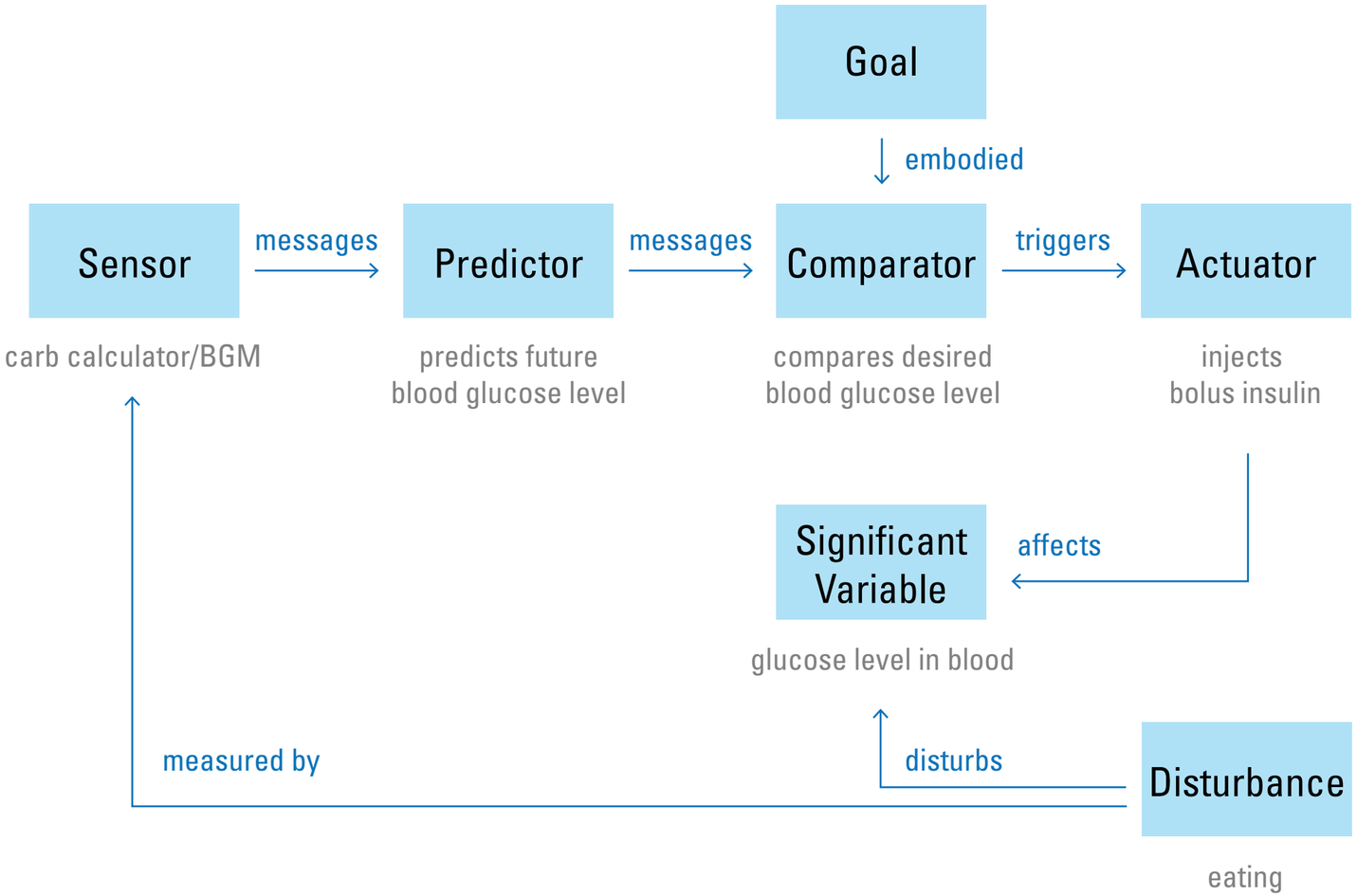
Simple open loop for a constant process:
Human injects Basal Insulin for basic insulin needs for a day



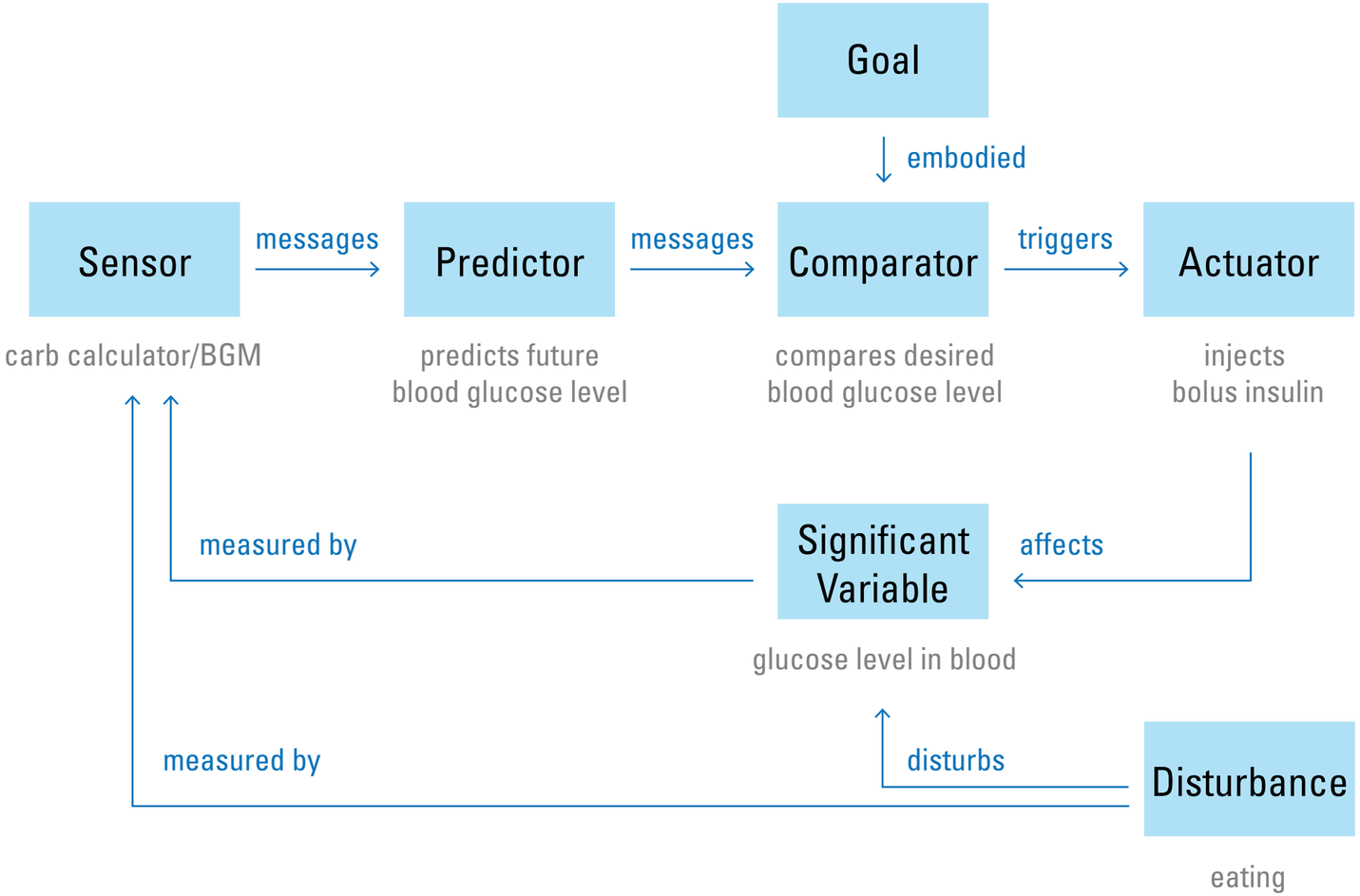
Feedback loop :
A person with diabetes measuring their BG and giving themselves an injection



Feedforward:
Bolus mealtime insulin based on carb-counting



Feedback + Feedforward:
A person uses a BG reading and carb-counting to determine the Bolus



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Jamie Ikeda
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Presentation posted at
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