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Systems Theory in Design Feedforward

Hugh Dubberly **Dubberly Design Office**

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.



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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'.



Variety in Disturbance

Example: C

Variety in Response



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



Variety in Disturbance

Example: C

Variety in Response



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 $68^{\circ}F = 20^{\circ}C = 293.15^{\circ}K$ 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.

 \rightarrow Cold air outside e.g. 60°

... In this example there is only one exterior wall; and all other walls are considered to have perfect insulation

What defines the input and output of the system?



Resolution

[how controllable the output is] 50 watt increments

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.



3/3 seconds

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 = $k^{*}(T_{in} - T_{out})^{*}$ (wall area)/(wall thickness)

At what Temperature does the space heater fail?

Using the equation above we find that T_{aut} = 283.1K or 50°Fwhen the outside temperature falls below 50°F, the space heater will no longer be able to maintain the room at 68°F.

10'

 \rightarrow Cold air outside e.g. 60°

... In this example there is only one exterior wall; and all other walls are considered to have perfect insulation

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



San Francisco, California 2004

ct	Nov	Dec

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

Los Angeles Lakers Coached by: Del Harris 10 yrs. Coaching 53% Wining average	San Antonio Spurs Coached by: Bob Hill 5 yrs. Coaching 53% Wining average	
1995 Starting line-up & r	elated salary	
Los Angeles Lakers		San Antonio Spurs
\$0 Nick Van Exel \$1,900,000	\$20 Million	\$0 Avery Johnson \$650,000
Elden Campbell \$2,100,000		Dennis Rodman \$2,500,000
Vlade Divac \$3,333,300		David Robinson \$7,300,000
Eddie Jones \$1,300,000		Sean Elliott \$1,350,000
Cedric Ceballos \$1,750,000		J.R. Reid \$2,215,000
\$0 \$20 Million		\$0

Starting Line-up Salary Totals \$10,383,300 (26% below the Spurs)

\$14,015,000

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

Los Angeles Lakers		San Antonio Spurs	Los Angeles Lakers
Coached by: Del Harris		Coached by: Bob Hill	Coached by: Phil Jackson
10 yrs. Coaching		5 yrs. Coaching	10 yrs. Coaching
53% Wining average		53% Wining average	75% Wining Average
1995 Starting line-up & rel	lated salary		2000 Starting line-up & related salary
Los Angeles Lakers		San Antonio Spurs	Los Angeles Lakers
Nick Van Exel \$1,900,000	\$20 Million	\$0 Avery Johnson \$650,000	\$0 \$20 Millio Kobe Bryant \$9,000,000
Elden Campbell		Dennis Rodman	Robert Horry
\$2,100,000		\$2,500,000	\$4,800,000
/lade Divac		David Robinson	Shaquille O'Neal
33,333,300		\$7,300,000	\$17,142,858
Eddie Jones		Sean Elliott	Glen Rice
\$1,300,000		\$1,350,000	\$7,000,000
Cedric Ceballos		J.R. Reid	Derek Fisher
\$1,750,000		\$2,215,000	\$3,000,000
	\$20 Million	\$0	\$0 \$20 Millio

Starting Line-up Salary Totals \$10,383,300 (26% below the Spurs)

\$14,015,000

3 yrs. Coaching 69% Wining Average Indiana Pacers Jalen Rose \$2,437,500 Dale Davis \$4,490,000 **Rik Smits** \$12,250,000 **Reggie Miller** \$9,031,850 Mark Jackson \$4,000,000 \$0 **Starting Line-up Salary Totals** \$40,942,858 (23% above the Pacers)

\$32,209,350

Indiana Pacers

Coached by: Larry Bird

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



New reported cases by day in the United States

Note: The seven-day average is the average of a day and the previous six days of data.

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

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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?



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Feedforward

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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

outside, see it's cold, and grab a jacket.

You have acted to avoid a potential problem.

Feedforward is when you look

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



outside temperature



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



Flocculant (acid) doses

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





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



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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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hugh@dubberly.com

Presentation posted at systems.dubberly.com/feedforward_20200915.pdf