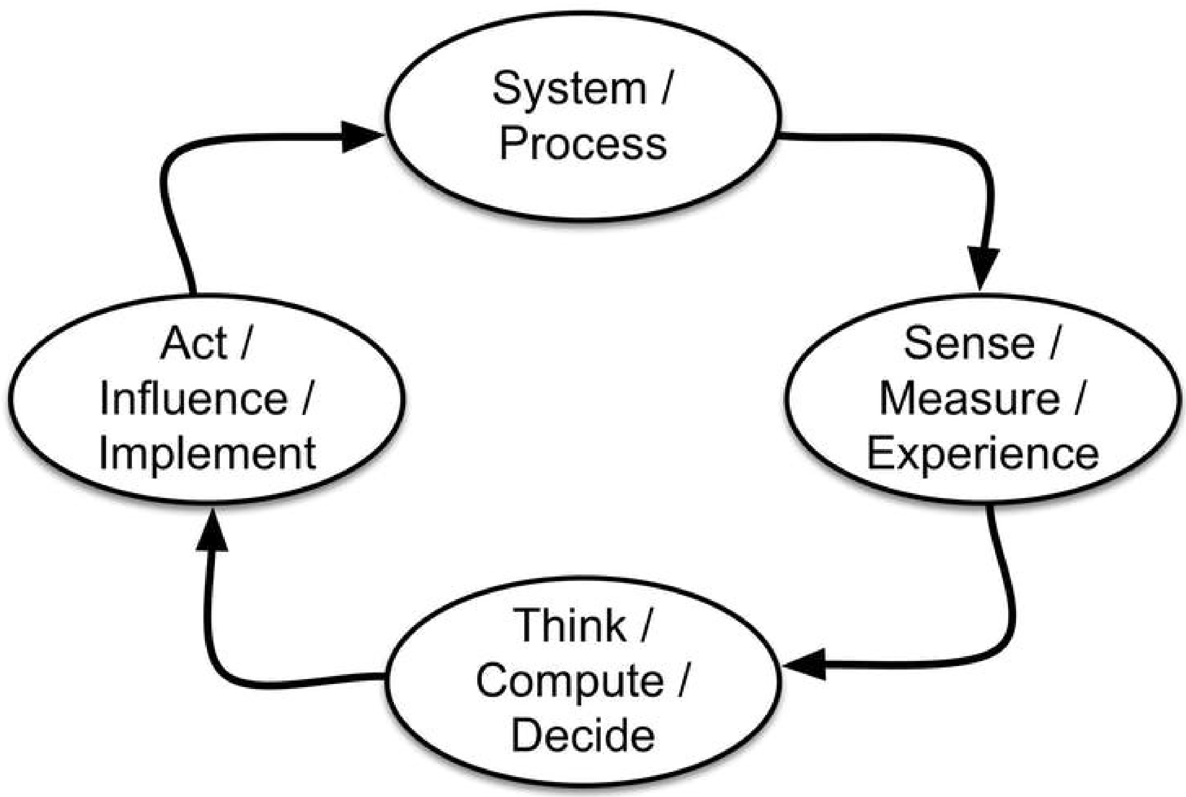
The principle that governs everything from rocket landings to interest rates

February 8 2018, by Christopher M Kellett



Automatic feedback control loop.

The successful first test flight of the SpaceX Falcon Heavy launch vehicle Wednesday morning was an amazing technological feat – and fantastic theatre.

The Falcon Heavy is the second most powerful rocket ever launched, just behind the Saturn V rockets that sent humans to the moon, and is the most powerful rocket currently in operation. It is also notable that this rocket was designed and launched by a private company – Elon Musk's SpaceX. While NASA has a similar launch vehicle in development, some estimates of its launch costs are over ten times those of the Falcon Heavy.

Some of these cost savings are tied to one of the most visually spectacular elements of the test flight: the simultaneous upright landing of the two side boosters.

> Those two SpaceX boosters autonomously landing perfectly in unison was one of the most amazing things I've seen in a long time. Sometimes it really does feel like we live in the future. pic.twitter.com/6miWqKeUWl
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> — Mike Murphy (@mcwm) February 6, 2018

Standard practice has been to jettison such boosters into the ocean, but SpaceX safely lands these boosters and can then reuse them on subsequent flights. The underlying principle that makes the landing possible is "feedback control" or, in fact, automatic feedback control.

Feedback control is everywhere

Feedback control is common and widespread. In fact, so common and widespread that it frequently goes unnoticed. However, this "hidden technology" drives most, if not all, of our technology – and even describes the fundamentals of how humans and animals behave.

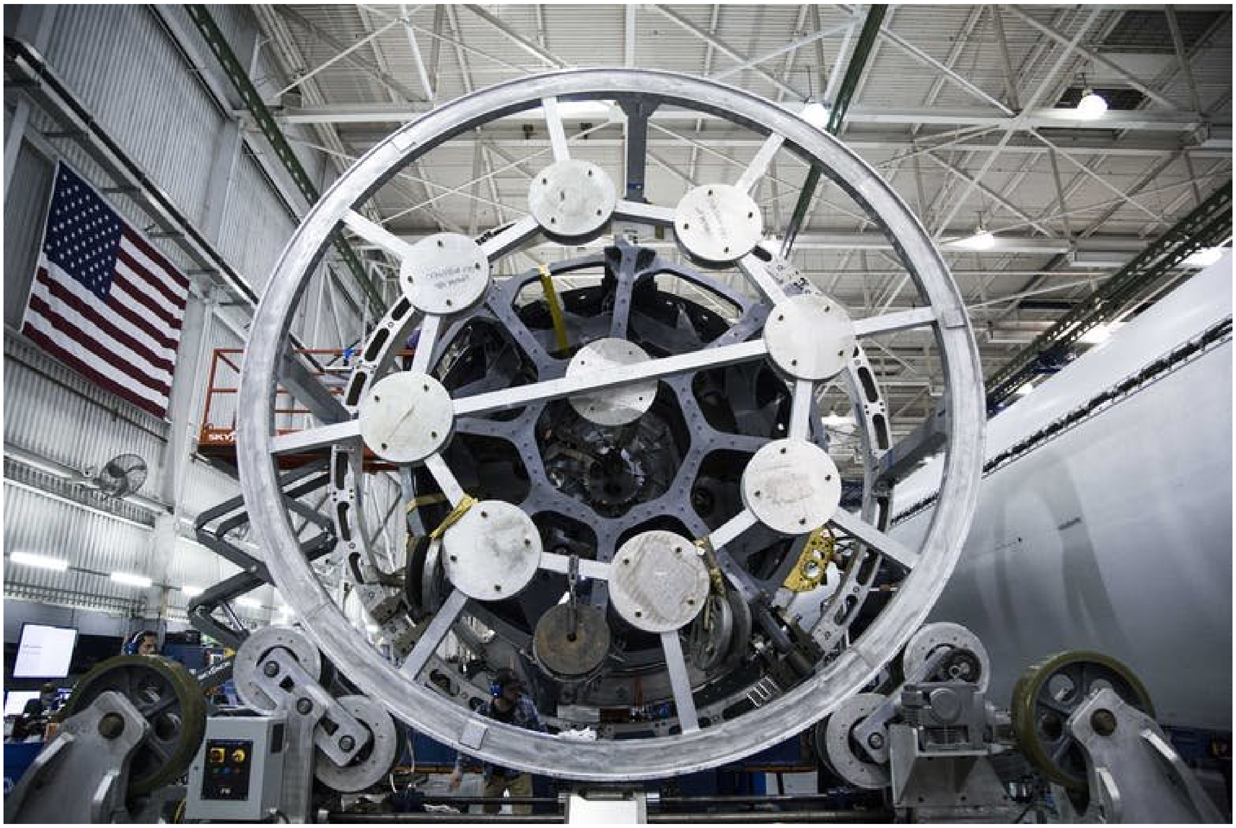
The basic idea is one of sense, think, act as shown in the figure below.

Well-designed feedback control provides robust, reliable, and efficient systems by choosing corrective actions based on collecting available data.

Consider a cruise control on a car that does not use feedback control, but only holds the accelerator in a fixed position. The speed increases if we are headed downhill, or decreases if we are headed uphill. Correcting this with feedback control is easy. Measure the speed of the car (sense), decide if the car is travelling faster or slower than desired (think), and then change the accelerator appropriately (act).

Automatic feedback control is also key to keeping the lights on. Electricity grids are designed to work at a frequency of either 50 or 60 Hertz. The actual frequency changes over time depending on the load, which is then compensated by reactive changes in generation, such as spinning generators faster or slower. In other words, we measure the frequency (sense), compute an appropriate corrective action (think), and then implement that action (act).

The same principle is at work in the human body and can be mimicked by artificial organs, such as the artificial pancreas under development at the University of Newcastle by a team led by Professor Graham Goodwin. The pancreas plays a key role in the regulation of blood glucose levels, and a malfunctioning pancreas leads to diabetes. An artificial pancreas would again follow the sense, think, act paradigm by measuring blood glucose levels (sense), using a clinical model of the patient to compute an insulin dose (think), and then deliver the computed dose (act).



The octaweb engine configuration of a Falcon Heavy booster. Credit: SpaceX

It even extends to financial institutions, such as the Reserve Bank of Australia. One of the Reserve Bank's goals is ensuring stability of the Australian dollar. The main tool used to achieve this goal is the setting of interest rates. Here again, we see the use of the feedback control idea. The Reserve Bank collects data on a variety of economic indicators, such as employment levels and inflation rate (sense), analyses the data to determine an interest rate (think), and then sets the interest rate (act).

Balancing the Falcon Heavy boosters

Coming back to the landing of the Falcon Heavy boosters, there are a range of similar and familiar balancing problems: the Segway, balancing offshore drilling platforms over a wellhead, or even walking on two legs. A circus-inspired analogy is trying to balance a broom handle on your fingertips.

Each Falcon Heavy booster accomplishes this balancing trick by having nine engines, each of which can be aimed. Watching the landing video closely, it is possible to see the different engines firing at different times and at different intensities.

It is also possible to see the central engine changing its direction. In the broom handle analogy, changing the intensity and orientation of the engines corresponds to moving your hand to keep the broom handle upright. In both cases, it is possible to measure the orientation of the rocket/broom (sense), decide how to fire the engines or move your hand (think), and then implement those decisions (act).

While the examples discussed above come from very different domains, they share the common attribute of key quantities or variables changing over time. In other words, they are dynamic systems.

For each of these examples we can construct mathematical models that frequently turn out to be similar despite coming from very different applications. The rich mathematical field of feedback control theory sometimes provides a ready-to-use algorithm for the calculations comprising the "think" part of the feedback control loop.

However, for many imagined applications, such as driverless cars, smart electricity networks, or optimal carbon pricing, these algorithms are still the subject of active research.

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