Physics and Leadership: Managing Chaos

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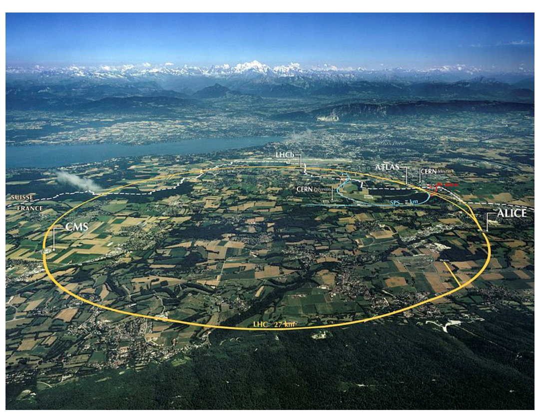
Abstract

The principles of physics have been applied to social settings for generations. Many organization's structure and behavior are patterned after the deterministic models based on Newtonian physics. These mechanistic models work well when leading teams that build mechanistic products. But in physics, the deterministic models of Newton have given way to the less deterministic disciplines of Chaos theory and Quantum Mechanics. This paper addresses the application of non-deterministic physics ideas in the area of leadership. An increased emphasis on relationships as opposed to rigid job functions and a need for constant feedback in the organization are found to be the results of applying current physical understanding to leadership. A model of leading with constant feedback, much like a forecast model in weather prediction, is suggested.

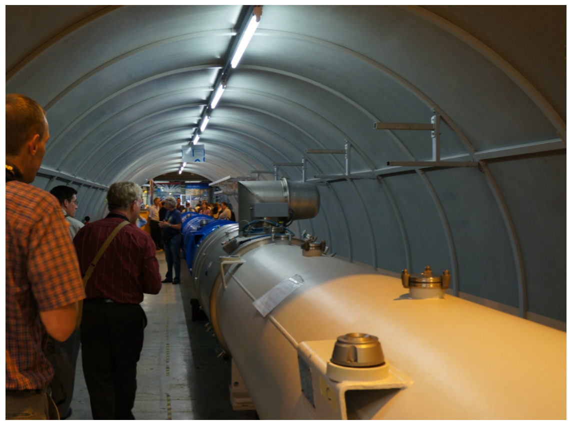
1 Physics

In the country side of Europe, straddling the Franco-Swiss boarder near Lake Geneva lies an engineering and scientific marvel that rivals the Great Pyramids.



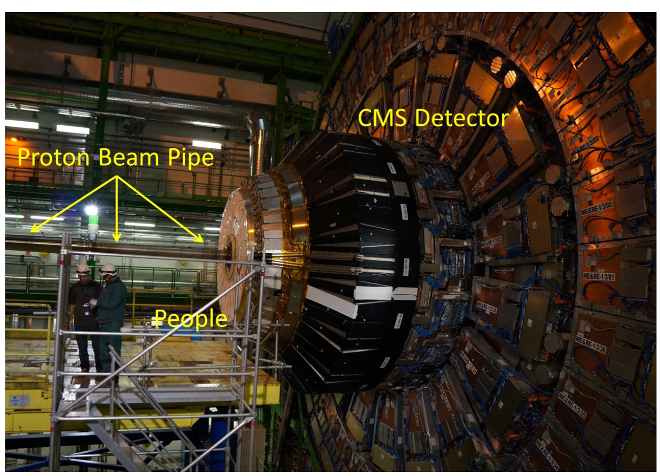
CERN Large Hadron Collider location (https://cds.cern.ch/record/1295244)

It consists of a 27 km (16.8 mi) circular ring dug 100 m below the surface along the underlying bedrock (about the length of a football field down into the ground). This is the Large Hadron Collider(LHC) at CERN.



Inside this tunnel, there are 1232 superconducting electromagnets, each about 15 yards long. These magnets are kept at $-271.25\,^{\circ}\mathrm{C}$ or just 1.9 degrees above absolute zero. The magnets line the circular tunnel, and through the center of this giant magnetic ring, protons are accelerated to very near the speed of light. The protons meet with a similar group of protons that were accelerated the opposite direction. The resulting collisions form small regions of space with very high energy densities.

In this dense region of energy, new particles are formed. The designated meeting place for the two sets of speeding proton is a two story tall detector. The detectors also contain superconducting magnets kept at $-270\,^{\circ}\mathrm{C}$.



The detectors can follow the tiny particles that result from the collisions. All of this, thought, equipment, and effort is designed to answer a simple question, "What is mass?"

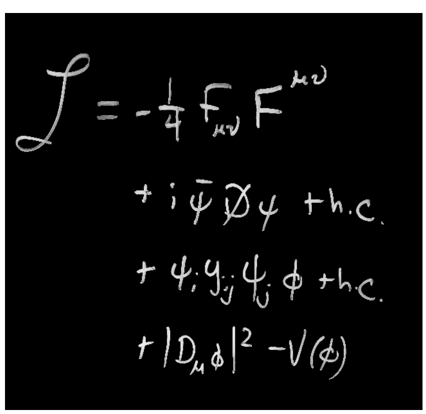
You are probably familiar with the idea of mass. It is how much material there is in an object. If we give you a $10lb$ bag of sugar and a $50lb$ bag of sugar, you would notice that there is more sugar in the $50lb$ bag. We would say that the $50lb$ bag has more mass. So mass does not seem too mysterious.

But to physicists it is very mysterious. Mass has the property of resisting motion. If you try to throw the $50lb$ bag of sugar, it is harder to move than the $10lb$ bag; but why? What makes things with mass hard to move? And if we understood this, could we more easily move objects? This is the sort of question that physics tackles. The current idea is that there is something in space, itself, that interacts with objects that have mass. That something makes it hard for massive objects to move through space. That something is named the Higgs field. The great Brian Greene says it this way,

> Mass is the resistance an object offers to having its speed changed.
>
> You take a baseball. When you throw it, your arm feels resistance. A shotput, you feel that resistance. The same way for particles. Where does the resistance come from? And the theory was put forward that perhaps space was filled with an invisible "stuff," an invisible molasses-like "stuff," and when the particles try to move through the molasses, they feel a resistance, a stickiness. It's that stickiness which is where their mass comes from.... That creates the mass[1]

But is this Higgs field really there? And does it really make mass hard to move? To invent potential new devices based on the ideas of the Higgs field, we first have to show that such a field exists. But how can you know if a Higgs field is there?

You must find a testable action that directly relates to the existence of the Higgs field. In physics this means forming an equation that predicts an outcome, then testing to see if that outcome happens.

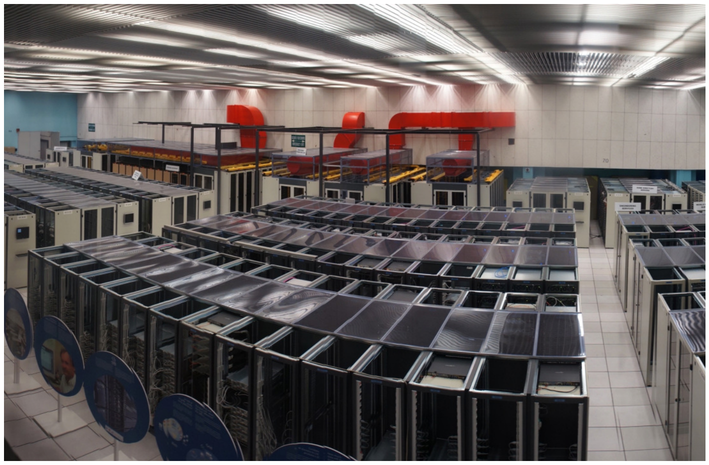


The equation for the Higgs field is complicated and understanding the details is not important for our consideration of physics and leadership. What we should understand is that this equation, like any other equation in physics, predicts an outcome that can be tested. In the case of the Higgs field, the equation predicts that if the energy density in a collision is high enough, occasionally a small particle will form. This particle is called the “Higgs boson.” If this particle exists, then there is very likely a Higgs field, and we can verify our ideal of what mass is. Of course, the experiment to see if the Higgs boson exists is the experiment for which the LHC was built. It is an extremely difficult experiment to perform. The collisions happen so quickly that it takes rooms of computers to monitor and record what happens.

CERN CMS Detector Computer Analysis System.

After all the effort, on July 4 of 2012, the Higgs boson was discovered. And this means that our idea of how mass works may have merit!

What will we build with this new discovery? It is hard to predict. But in the past, engineers using the ideas tested by physics have built marvelous things. Even now we have the people at CERN to thank for the World Wide Web—an invention created to help the thousands of scientists and engineers communicate and share the experimental data from all over the world to build and operate the LHC at CERN.



CERN Processing Facality, the birth place of the World Wide Web

But over the past few hundred years the ideas of physics have been building ever more clever devices that make our life more interesting, from microwave ovens, to cell phones, to computer systems, to Teflon coated pans.

Physics Spin-offs

The idea that became physics has done marvelous things. But how did this all get started?

2 The Big Idea: Find Truth by Testing Actions Distilled from Theory

Let's go back to a time before physics, to the time of the ancient greek philosophers. Plato and Aristotle.

The study of how things move and interact was called "Natural Philosophy" and was practiced by thinking about how things ought to work. For example, if two objects fell, the one with the most mass ought to fall faster. That was the opinion of Aristotle. And that opinion held for hundreds of years. If you wanted to know how the universe worked, you picked up a copy of Aristotle, and read his opinions.

Figure 1: Plato and Aristole

The ancient philosophers did advance human knowledge. But their ideas remained untested. The ideas were accepted at truth, but without any verification.

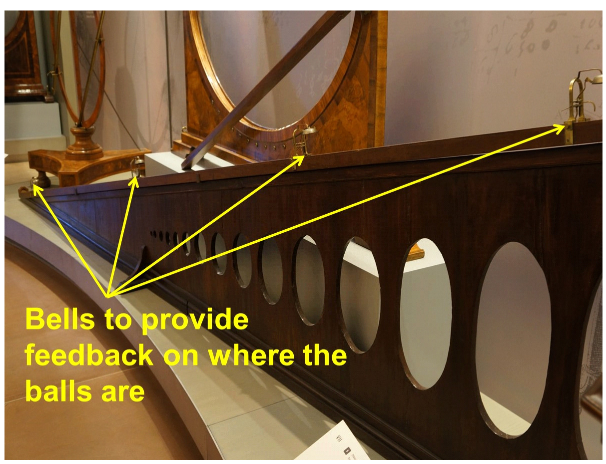
2.1 Galileo

Bust of Galileo from the Galileo Museum, Florence Italy

Galileo Galilei (1564-1642) is credited with first popularizing the idea of testing the ideas about how the universe works. To see how this works, suppose we have two objects, one twice as massive as the other. And further suppose we drop both objects. Would the more massive object fall twice as fast as the less massive object? Aristotle said the larger mass would move faster. But surely you could test Aristotle's thinking by actually making two balls, one twice as massive, and dropping them to see! This is what Galileo did. You are probably familiar with his most famous version of this experiment, dropping objects from the leaning tower of Pisa.

Leaning Tower of Pisa where tradition has it Galileo demonstrated his experiment to his colleagues.

But really this was a demonstration for his colleagues at the university of what Galileo had discovered by hours of careful measurement of objects moving down ramps with little bells on them to provide feedback on the ball's progress.



Galileo's Apparatus for testing Aristotle's ideas of mass and motions.

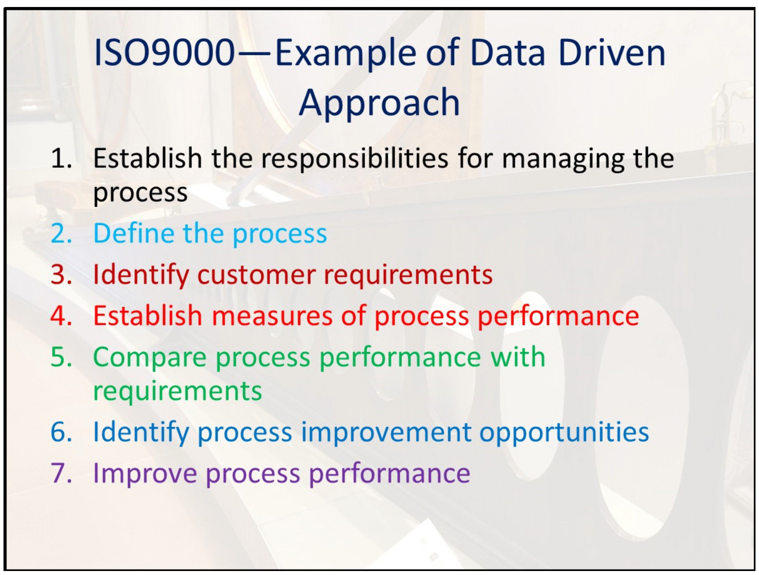
Aristotle's idea was proven wrong by trying the idea on real objects. The idea predicted an outcome, and the outcome did not happen when tested. Science (and physics) was born!

2.2 The Big Idea from Physics used in Leadership

It is only natural that a big idea that worked so well in one area should find itself in another. Testing a theory by collecting evidence is an approach to decision making that is used in leadership today. If you are trained in management you might remember the words "Management by Evidence," or you might have observed the current trend towards "big data efforts." The idea behind both is constant feedback to see if things are working as predicted. Although many have written on this topic, we will give only one comment, from an article by Jeffrey Pfeffer and Robert I. Sutton:

> Evidence-based management – the notion that real knowledge in the form of empirical analysis of results is the shortest path to the best business decisions... From our research, we are convinced that when companies base decisions on evidence, they enjoy a competitive advantage. [2]

From the engineering world, the ISO9000 standards incorporate the big idea in standard practices.[3]



Notice the emphasis on feedback and testing. Objectives are defined up front (3, and 4) and tested (5). Where the objectives are not met, the ideas (the processes) are changed based on the outcome of the test.

2.3 Not just any data

Back in the 80's "Management by Fact" was a popular attempt to bring the principals of science into leadership. But its implementation was often fundamentally flawed. The "facts" were often "metrics" designed to make leaders look good. When one of us was at Eastman Kodak, we implemented Management by Fact in our IT department. The IT leadership picked a metric—the number of closed tickets. A "ticket" was created every time an employee called the IT department to report a computer problem. Tragically, closing tickets was not the actual objective of the IT department. The goal was to fix computer problems. You can guess what happened. Soon the IT personnel were closing tickets no matter what happened. Your hard drive crashed, they replaced it and closed the ticket. But they did not recover the data that was on the defunct hard drive, data that was necessary for the business to function.. Your internet service stopped working. They logged the complaint, then closed the ticket. The actual work of the company was adversely affected, at times terribly so, because few computer problems were actually solved. Lost data and logged problems don't make a business run. A true implementation of the ideas of science would mean distilling leadership ideas into a series of actions with predicted outcomes that further the goals of the organization. Then the desired outcomes must be compared to the actual outcomes, not artificial metrics, to determine if the leadership ideas have been successful. One of the key characteristics of physics is that prediction is nearly everything, explaining past behavior is only part of the program. In leadership, this predictive skill is essential as well. In fact, hindsight is not really 20/20 unless the insight gained from looking back leads to new ideas that better predict outcomes. And the key to this improvement is feedback. It is the feedback that makes physics, physics.

Over the past century a youth organization known as the The Boy Scouts of America was in the business of teaching leadership. The Boy Scouts had a saying "feedback is a gift." The Boy Scouts seemd to be an example of implementing this big idea from physics.

2.4 Alma and the Big Idea

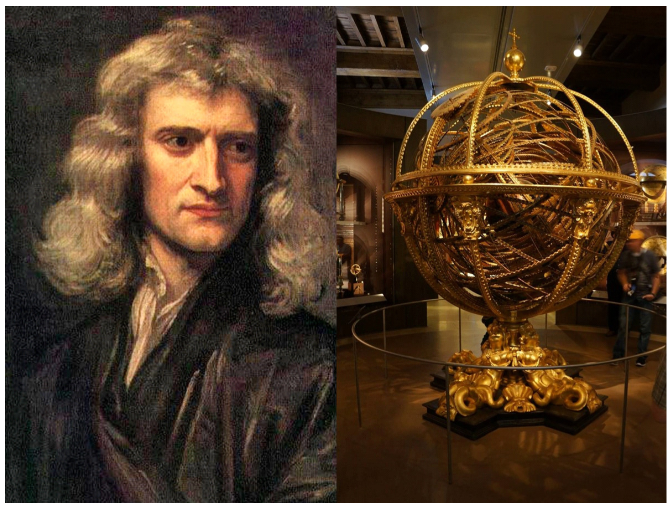
It is interesting that we see this big idea in the Book of Mormon. Alma tells us:

> Now, if ye give place, that a seed may be planted in your heart. . . it will begin to swell within your breasts; and when you feel these swelling motions, ye will begin to say within yourselves–It must needs be that this is a good seed. . . But behold, as the seed swelleth, and sprouteth, and beginneth to grow, then you must needs say that the seed is good; for behold it swelleth, and sprouteth, and beginneth to grow. And now, behold, will not this strengthen your faith?

The process of gaining a testimony seems to involve this same need for feedback and evaluation.

3 Predictable Unpredictably

A year after Galileo died, Isaac Newton was born. Newton used the method developed by Galileo to do great work in furthering our understanding of the universe. Newton viewed the universe as a big machine. He thought that to understand the whole universe you should start by examining and understanding its parts. This idea is now called "reductionism." For Newton the universe was like a clockwork. It was predictable. If you understood each cog and fly wheel, you understood the whole clock.



Sir Issac Newton and an implementation of a "clockwork" universe model.

This reductionist viewpoint has provided great success. By reducing complex systems to parts, and using the big idea to test our understanding, we put man on the moon! The industrial revolution was fueled by this idea. For example, Model-T Ford cars could be built quickly and cheaply by structuring the manufacturing organization around the collection of parts of the car. The reductionist ideas of Newton were bound to make their way into leadership. Our traditional management structure is based on this approach. It is characterized by

- Rigid structure
- Tightly defined roles
- Many levels of leadership (like engineered systems and subsystems)
- Thinking of people as part of the organizational "machine"

This reductionist view point is also at the heart of the deterministic model in organizational psychology. Despite this great success of reductionism there were some physics problems that did not seem to lend themselves easily to this approach. But generally these “outliers” could be ignored. So much progress was being made that these special cases could be ignored. But in 1944, one of these special problems, weather prediction, was about to become important.

3.1 Transition to Chaos

Scientists and engineers were enamored with the regularity of the Newtonian reductionist universe, and who can blame them? The approach gave us space flight, air flight, Microwave ovens, etc. So we ignored and avoided cases where predictable behavior was not possible. The result was that everything seemed predictable, since we only paid attention to the predictable part of the world.

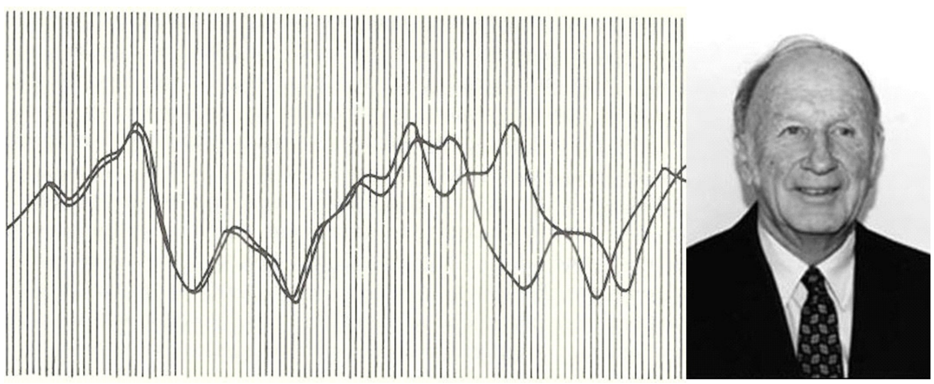
Weather prediction was one of these unpredictable cases. The agriculture industry had an interest in being able to predict the weather, but weather had not proven solvable with a reductionist view point. But most scientists weren’t farmers, so this case was ignored for areas that showed more easy promise. But in 1944, the middle of World War II, the Pacific Fleet was caught unaware by Typhoon Cobra

USS Cowpens (CVL-25) During Typhoon Cobra

Seven hundred and ninety officers and sailors lost their lives in the storm. The USS Hull, USS Monaghan, USS Spence all sank. 146 Aircraft were lost, and all other vessels were damaged, some severely.[4] Admiral Nimitz was directing the fleet when the typhoon struck. The Admiral demanded we never be caught blind by weather events again. He wanted this difficult, non-predictable problem solved. This was the beginning of the National Weather Service. But weather is a non-Newtoninan system. We could not ignore the non-predictable part of the universe any more!

3.2 Chaos, a new way to look at things

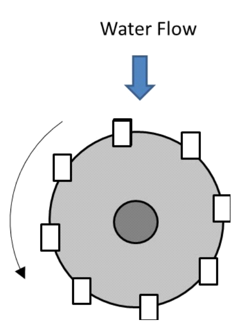
Edward Lorenz took up the challenge of predicting the weather. He noticed that in his calculations, he could do exactly the same calculation with exactly the same inputs, but the computer would give different results every time.



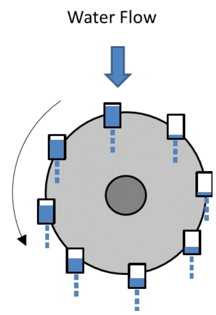
Lorenz and his Weather Prediction Calculations (from Lorentz's 1961 printouts)

The problem got worse as he tried to predict farther into the future. What he discovered was that the weather patterns depended on even slight differences in the starting point for the calculations. The calculations were so sensitive, that it was impossible to ever repeat the same prediction twice. This startling realization meant that long-term weather prediction was impossible—not what the Admiral wanted to hear! The problem being that conditions today depend on conditions in the past week, month, year, decade, etc. And the dependency is so intricate, that tiny, imperceptible changes would radically change the outcome in the future. These initial conditions are unknowable. So the system is not deterministic—we can't accurately predict what will happen.

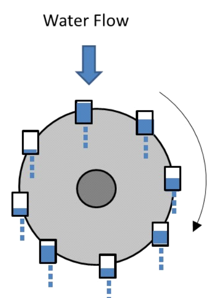
Lorenz and others decided to study simpler systems that had the same sort of non-predictable behavior. One that was known was the chaotic water wheel. It looks like this



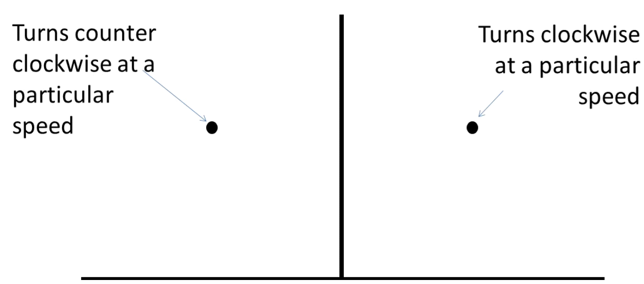
A wheel has buckets attached to it. Water falls from above and the wheel turns as the buckets fill.



But the buckets are leaky. Because the buckets are heavy with water, the wheel turns. But each bucket loses water, until it is empty when it gets to the top. In this way, the wheel turns only one direction. But if the water is forced downward, say, through a nozzle, the buckets are pushed away by the fast moving water before they are full. The buckets can lose water too quickly because they were never full. If the buckets are empty before they reach the bottom, the wheel might reverse direction.

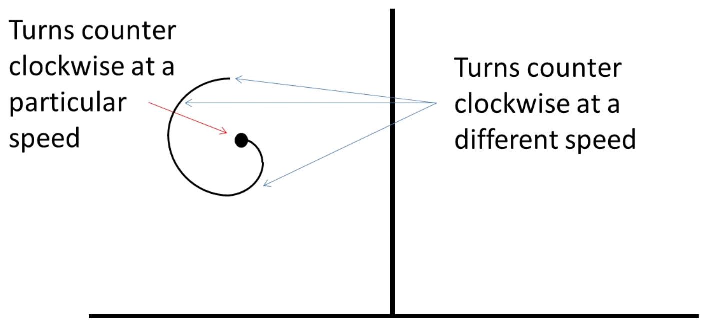


As the water flow rate increases, the reversals happen more often. The Newtoninan prediction for the slow water case could be represented in a graph like this.

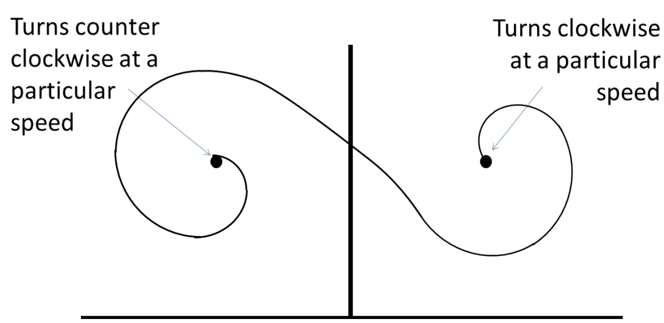


The graph collects all the characteristics of how the wheel turns into a single point. In our case, we would predict, based on the water flow rate, that the wheel would either turn to the right or to the left, and it would turn at a particular speed based on the water flow rate. The idea “turns left at a particular speed” is represented by a point on the left.

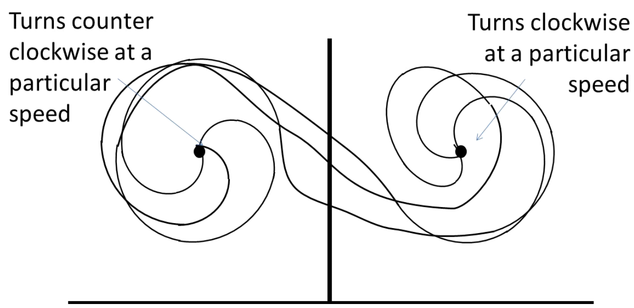
Now you could envision disturbing the wheel. You might grab the side and slow it down temporarily, but a small disturbance will be short lived, and the wheel will tend to return to it’s particular speed and direction. In physics, we say that the preferred speed and direction point is an “attractor” for the system.



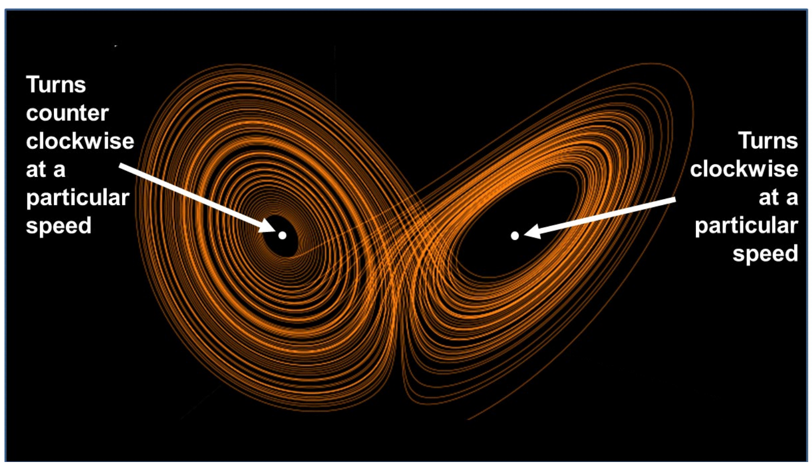
As the water speed increases, the wheel will change direction at times. It would slow down, stop and turn around the other way. We could represent this as shown in the next figure.



Notice that we picked up an additional attractor. As the flow rate increases even more, the wheel will change directions more often.



But what Lorenz and his colleagues found was that above a particular flow rate, the behavior of the wheel was no longer predictable.

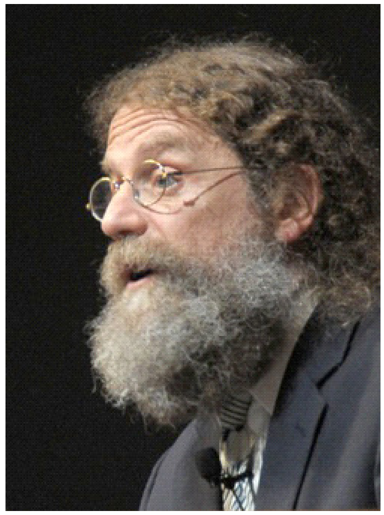


The wheel still turned around, so it was not completely unpredictable. But for any given time, they could not predict what direction the wheel would go, nor could they predict the exact speed. This was like the weather problem!

Notice that in our graph, the wheel never turns with our predicted attractor speed and direction. The path never reaches the Newtonian points. But it is also never all that far away from these two points.

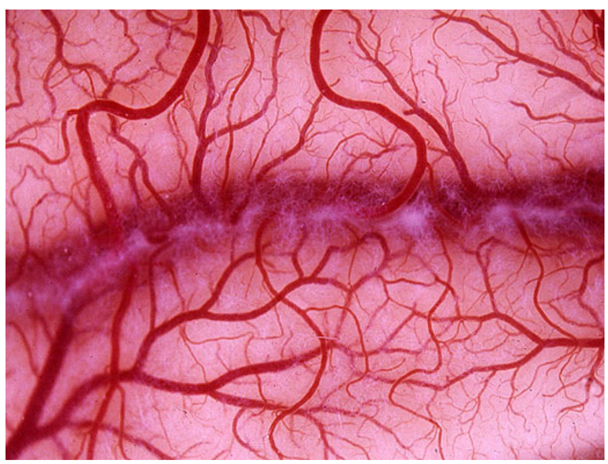
3.3 Human Chaos

At this point, you may be thinking, "Great! But I am a leader, not a weather man!" But it turns out that humans are made more like stormes than clocks.[5]



Robert Sapolski

Robert Sapolsky, one of the leading neurobiologists of our time, tells us we are non-Newtonian systems, very like weather or chaotic wheels. And there is a good reason for this. Our design engineer was very frugal. For example, think of blood flow. From the Aorta, our vessels must split to make smaller vessels. This splitting happens over and over again until we have capillaries that can feed our cells.



Blood Vessel Bifurcation

If our bodies needed instruction on exactly how far to go before each vessel splits into two, it would take millions more genes than we have to encode the process. To be efficient, our design engineer gave up exact Newtonian specifications. Instead we encode the pattern: Grow, then split. And we repeat this pattern at every level down to capillaries. This is more efficient for encoding instructions. But it means the exact specification of each vessel is not known. But in the end, all that matters is that blood flow happens and that all the parts of the body are nourished.[5]

Neurons in our brain follow the same pattern. Our brains are inherently not Newtonian systems. The science developed by Lorenz and others is called the science of Deterministic chaos. It says that things are sometimes not predictable, but in predictable ways (we won't know which way the wheel goes at any given time, but we know it turns some way).

Other physicists have done work in the realm of small particles that give similar results. You may have heard of Heisenberg's uncertainty principle. This principal states that there is a fundamental limit in what can be known.

Werner Karl Heisenberg

Which of course, means there is a fundamental limit on what can be predicted. Rodger Penrose, a coauthor with Stephen Hawking, theorizes that the brain is such a predictably unpredictable system.[6] And if the brain is unpredictable, behavior will be unpredictable.

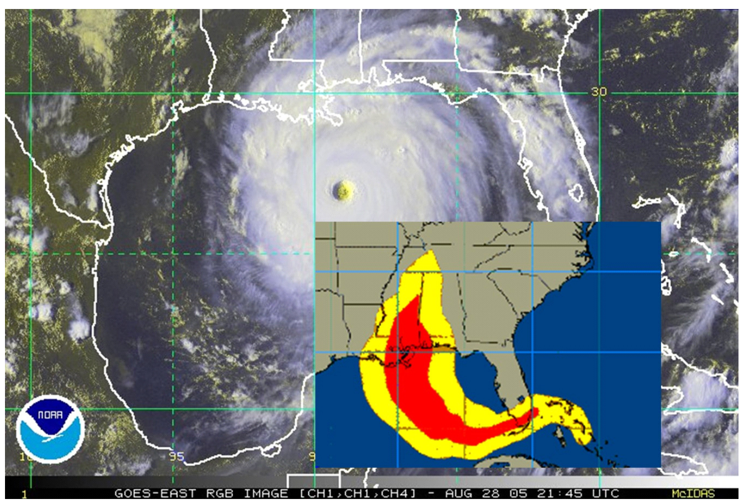
An example of this, given by Sapolsky, is an experiment with territorial fish. If ten of the fish are placed in a tank, they will establish a dominance order. Early researchers theorized that if they put the fish, two at a time, in a tank, and recorded which was dominant, that they could predict the dominance order of all ten once placed in the communal tank. This is a good reductionist prediction. You understand the parts, this time of a society of fish, and you understand the whole.

The experiment was run. Not only was the predicted dominance order wrong, it was terribly wrong. There was no correlation at all between the prediction and the actual outcome. It seems that Sapolsky and Penrose are right. A reductionist model is not so good when applied to living organisms and the societies they build.[5]

Others have come to the conclusion that uncertainty and chaos in human systems need to be addressed.[7][8] The question is, can the science that tries to deal with weather and other chaotic systems be used to deal with living things, in particular, people?

4 Forecasting: How to predict the unpredictable

In 2005, Hurricane Katrina hit land in New Orleans. This time it was no surprise.

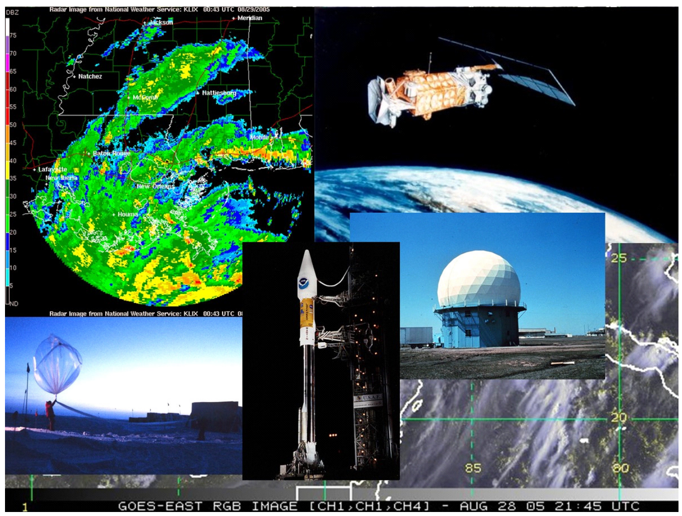


Hurricane Katrina and Karina Forecast.

The NOAA weather service people plotted the course of the storm, and the prediction was fairly accurate. What made the difference?

The answer was the physicist's friend, feedback!

The weather scientists knew the relationships between parts of the weather system. They understood the chaotic nature of the weather. But to do accurate short term predictions then needed constant feedback from the actual weather system. In weather forecasting, this takes the form of receiving new data on how the weather really happened every 6 hours. Current weather scientists use a computer and the knowledge of how weather systems relate to each other to forecast the near future, but they don't try to predict too far. The system is chaotic. We can't make long-term predictions. The scientists had to give up predicting the weather next year, and had to be content to predict what will happen next week. But for the Navy, and commercial shipping, that is good enough! So in the distant future we can tell that there will be some sort of weather (it is not totally chaotic, with no bounds to the behavior), but long term forecasts won't tell us what weather will really happen. We did not find the Newtoninan attractor point, but we did find a solution that met the actual objective, no more surprise storms.



GOES Satellite and imagery, Weather balloon, Defense Meteorological Satellite Program Satellite, Weather Radar.

A business example of this would be the rise of Walmart. Walmart keeps track of what customers buy (feedback that matters to the objective!) Walmart even has an electronic system that tracks purchases and plans deliveries based on what has actually been purchased. As trends change, the Walmart forecast model adjusts to those trends, because it has a constant feed of pertinent data. It won't predict that the world will go crazy to get a new version of the pet rock. But once pet rocks start to sell, Walmart will be ready to ship them. The feedback makes the difference. And Walmart is ready to ship something. So all that is needed is the data to drive the near term forecast of sales. Even then, a chaotic system likely won't bring the exact results the leader may want. So what are we to do?

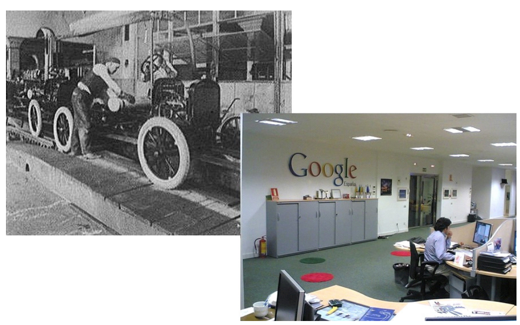
Again, Sapolsky gives a biological example. Suppose we inoculate ten lab rats with a vaccine. Then we watch the reactions of the rats. We might find that three respond better than we thought. Six respond as was expected. But one does not respond at all. If the rats were Newtonian systems, we would take apart the non responsive rat to find which rat part was at fault. But this is like taking apart a cloud to find out why it did not rain. A rat system is not Newtonian, it is not deterministic. So at some point, taking apart the rat won't help. But in the mean time, we have benefited nine rats.[5] And that is the key.

Our Newtonian ideal may never be realized, in fact, not even approached! But as long as leaders can change their thinking to accept a little uncertainty in the outcomes, we can benefit those we lead.

Walmart, and Sapolsky have decided that the exact, deterministic result is not so important. Rather, being in the ballpark, with an idea of what to do next based on feedback may work better than any alternative.

5 Clocks and People: Two different leadership styles

So what does physics tells us about leadership? If you are making machines, a reductionist vision of leadership might be fine. If you are not, then there will be a cost in a reductionist leadership style. Part of that cost will undoubtedly be frustration on the part of the leader because the Newtonian ideal may not be obtainable no matter what you do. Even if you do make machines, the workers are likely to dislike being treated as only parts of an organizational machine, because they are not like cogs. They are deterministically chaotic systems.



Ford Assembly Line and Google Office

As a young leader, one of us was faced with an unproductive employee. At the time, this young leader viewed the world in a reductionist way, so the thought was to replace the "broken cog." It turned out that it cost $10,000 to replace one employee, and then when the "replacement" arrived there was a six month training period before the new employee was productive! Replacing the "cog" was really expensive. Later as a more experience manager, this same leader approached a very similar situation by working with the employee to develop the skills they lacked to keep themselves productive. This proved to be a successful, cost effective, approach. And in a non-Newtonian fashion, it improved the moral of the entire group to see that the leader cared about the individual as well as the business objective.

This managed chaos approach seems to teach us that the relationship is all important. In the weather system, the scientists needed to understand how weather systems interact. Then feedback was useful in determining forecasted behavior. Physicists are fond of saying that "the numbers aren't that important" but "the relationship is everything."

A deterministically chaotic leadership style might include a less rigid structure with less strictly defined roles. Google might be a good example. The young Google organization functioned with teams and less rigid structures. It even experimented with allowing employees to control what they did for a part of their time. They did have to be productive, but there was not a Newtonian type goal. Some of Google's favorite products (e.g. gmail) were produced this way. Incidentally, Google has recently changed their approach to be a little more Newtonian, but such innovation time is still part of the culture. Another example comes from an experience at Hughes Information Technology Systems. A group building a custom ground station to control weather satellites had become badly behind schedule. Another group was asked to step in and catch up to make the schedule. The leaders knew that the group would need to work long hours and make many sacrifices to get the job done on time. They also realized that if you push too hard, like with our chaotic wheel, you may get chaotic results. So they built into their plan constant feedback on how the employees were feeling. They helped them manage and balance their family needs and responsibilities, provided rewards for milestones achieved—not promotions—but meaningful representations of gratitude. By being in touch with what the employees were experiencing and responding to enable the employees, the project was on time, and the customer was very impressed. More work came from this success. And the team as well as the leadership were all happy with the experience.

Some Characteristics of the two Leadership Styles

Newtonian (reductionist) Leadership Approach
- Rigid structure, many levels of leadership
- Tightly defined roles
- People are viewed as "resources"-part of the machine

- **Good for**
  - Long term manufacturing projects
  - Financial systems
- **Characteristics**
  - Rigid control
  - Leader involved in all aspects of operation
  - Results are judged against strict, detailed specifications
  - Promotions are a strong part of the reward system
  - Change adverse
  - Expensive – requires large structure

- **Non-Newtonian Leadership Approach**
  - Flatter organization, broad employee categories
  - Roles shift with project changes
  - Relationships are key, people are viewed as multifunction organisms with many skills, capabilities
- **Good for**
  - Quickly changing organizations
  - Design teams
- **Characteristics**
  - Leaders controls outcome region, but not details of methods
  - Results are judged against desired outcomes region
  - Promotions are not used as rewards
  - Agile
  - Cheaper – groups self organize

Of course, the idea of managed chaos as a leadership style is nothing new. The Mormon Scholar Hugh Nibley attributed our (the Allied) success in World War II to our ability to manage chaos.

US Soldiers at the Battle of the Bulge

The German troops were mechanized, like clock works. But that meant that even when they knew the Normandy invasion was in progress, they would not move forward without orders. The American and British forces had the same goals, to win! But the style of leadership was different. The Americans gave lower ranking officers the authority to get the job done and protect their troops in whatever way seemed best within their unit goal.[9] Nibley observed that this made all the difference.

Mozart and Count Basie, two different styles.

Let's go back to thinking about CERN and remember the rooms full of computers to process the data, the natural feedback from the experiment. The idea of management by feedback is central to modern physics. A colleague of mine, a physicist, listened patiently to me explain this shift in the physics model behind leadership, and summed it up succinctly as "so you want us to play jazz instead of Mozart." Perhaps this description is best. Mozart is predictable, even mathematical. Jazz is improvisational and unpredictable. Both styles have their place! But a jazz ensemble must trust and rely on each other. The relationships are key, the product uncertain, undetermined, and never exactly the same twice, but always good because the musicians listen to and react to applause as well as each other. That is managed chaos.

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