Probing the Future

The art and science of prediction

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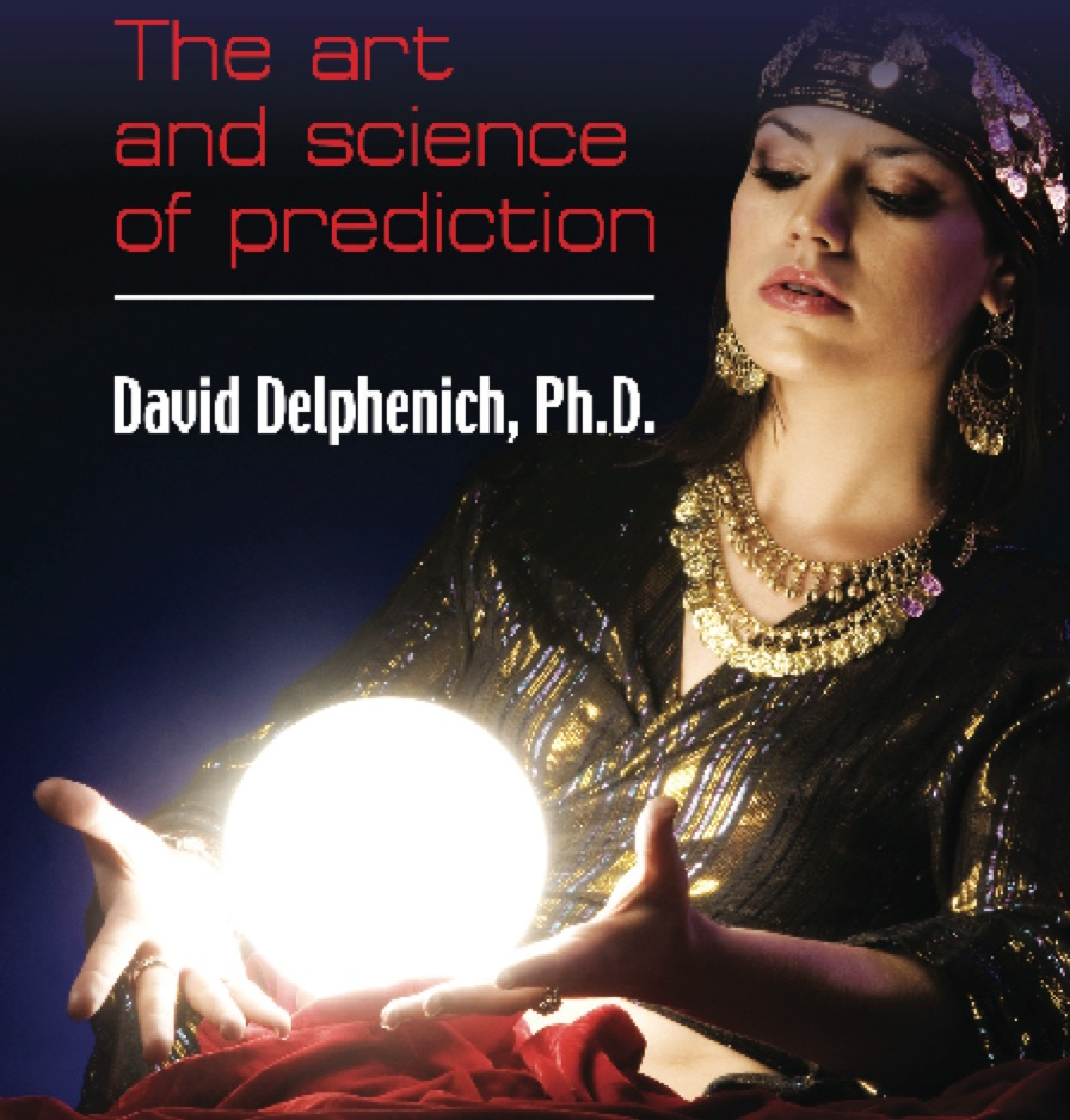

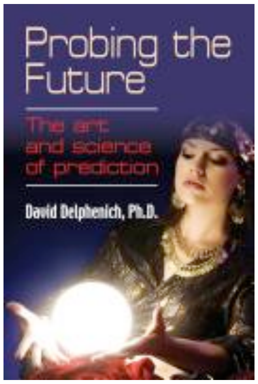

The book consists of two parts. The first is a historical survey of some of mankind's attempts to predict the future since antiquity, including the visions of philosophers, scientists, inventors, writers, and filmmakers, as well as some famously bad predictions by distinguished people. The second part consists of a casual (non-mathematical) discussion of the modeling of dynamical systems and the issues that relate to predicting the future states of such systems.

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Chapter Four

Futurism in popular culture

It is interesting that, even in the face of the incommensurable advances to technology – especially information technology – and advances towards establishing the fundamental form that the Laws of Nature might take, nonetheless, there is still a residual culture amongst popular modern society that clings to the otherwise discredited archaisms that we discussed previously.

For instance, psychics continue to attract attention with their predictions, although often the predictions are not made public until after the fact that was being predicted came to pass.Some Twentieth-Century psychics, such as Jeanne Dixon and Edgar Cayce, developed an enduring cult following, and although astrology has long since morphed into astronomy, astrophysics, and cosmology in the eyes of mainstream science, nevertheless, horoscopes regularly appear in most newspapers along with the comics. Similarly, apocalyptic Doomsday cults, as well as utopian communes, continue to propagate from generation to generation.

Doomsday cults

If one classifies predicted scenarios for humanity as mostly utopian, dystopian (including Apocalyptic), or stagnant then it is probably the Apocalyptic, or Doomsday, cults that seem to give the best examples of faulty prediction. The fact that such cults have existed since Biblical times suggests that they represent a well-defined universal potentiality of the human mind, a “universal archetype of the collective unconscious,” as Carl Jung would have called it. The fact that many of them, such as the Millerites, have predicted the end times of Revelations and seen those dates pass uneventfully is both comical and a relief to those who may have still harbored some willingness to follow the arguments in favor of such a cataclysm. However, some of these cults have reverted to more psychotic forms of group behavior, and we mention the erstwhile Solar Temple and Heaven's Gate cults as chilling counterexamples to the assumption that Doomsday cults are always harmless denizens of the lunatic fringe.

The Order of the Solar Temple – or simply The Solar Temple, – which was also known as the International Chivalric Organization of the Solar Tradition, was a secret society that was founded in Geneva, Switzerland in 1984 by Joseph Di Mambro and Luc Jouret as l'Ordre International Chevaleresque de Tradition Solaire and later renamed Ordre du Temple Solaire. It was that was based upon the mythical assumption of the continuing existence of the Knights Templar, and had been inspired, to some extent, by the British occultist Aleister Crowley, who had headed the Order of Oriental Templars from 1923 until his death in 1947. It was also influenced by the teachings of the Hermetic Order of the Golden Dawn, a Nineteenth-century Rosicrucian Order that Crowley had also briefly belonged to.

According to "Peronnik" (a pseudonym for Solar temple member Robert Chabrier), whose 1975 book called "Pourquoi la Résurgence de l'Ordre du Temple? Tome Premier: Le Corps" (Why a Revival of the Order of the Solar Temple? v. 1: The Body) described the beliefs and structure of the cult, the aims of the Order of the Solar Temple included:

1. The establishment of "correct notions of authority and power in the world."
2. Affirmation of the primacy of the spiritual over the temporal.
3. Assisting humanity through a great "transition."
4. Preparing for the Second Coming of Jesus as a solar god-king.
5. Contributing to the unification of all Christian churches and Islam.

In October, 1994, at the group's center in Morin Heights, Quebec, the three-month-old son of Solar Temple member Emmanuel (Tony) Dutoit was killed by being stabbed repeatedly with a wooden stake. It is believed that cult leader Di Mambro had ordered the murder on the grounds that he was the Anti-Christ, and had been born into the order to obstruct Di Mambro's spiritual objective.

Several days later, apparent mass suicides and murders occurred at Morin Heights and two villages in Switzerland. 15 inner circle members died by poison, 30 were shot or smothered, and 8 others were killed in other ways. As with the Jonestown massacre in Guyana, there was some question regarding whether all of the cult members had cooperated willingly, since many of the bodies were found to have been drugged. Timer devices then initiated incendiary devices that set fire to the buildings, which was purportedly a symbol of purification.

Records seized by the Quebec police during the investigation showed that some of the cult members had personally donated over $1 million to Joseph Di Mambro.

In Western Switzerland, 48 members of another sect that was either affiliated with the Solar Temple or heavily influenced by it died in another apparent mass murder-suicide that included a mayor, a journalist, a civil servant, and a sales manager. The tragedy was discovered when firefighters initially responded to fires that had resulted from remote-control incendiary devices, and there was evidence that many of the victims in Switzerland had also been drugged before being shot.

Other reasons to assume that the event was related to the Solar Temple were:

1. Many of the victims were found in a secret underground chapel that was lined with mirrors and other items of Templar symbolism.
2. The bodies wore the same ceremonial robes as Temple members.
3. They had all been shot in the head.
4. They were arranged in a circle with their feet together and heads directed outward, and most of them had plastic bags tied over their heads.

The use of plastic bags may have represented a symbol of the presumed ecological disaster that would occur after the members moved on to the star Sirius.

Years later, on the morning of March 23, 1997, five of the remaining members of the Solar Temple in Saint-Casimir, Quebec killed themselves in a small house, which then exploded into flames. Three teenagers were discovered alive in a shed behind the house, although they, too, had apparently been heavily drugged.

The fact that all of the suicide/murders and attempts had occurred near the dates of equinoxes and solstices was assumed to be related to the cult's beliefs in some way.

Three days after the tragedy in Quebec, another notorious Doomsday cult made world-wide news in the form of the Heaven's Gate cult. They were based in a sprawling estate outside of San Diego, California and were led by Marshall Applewhite (1931–1997) and Bonnie Nettles (1927–1985), who also had used various aliases over the years, such as "Bo and Peep" and "Do and Ti."

In the 1979 book *Messengers of Deception* by Jacques Vallée, the Heaven's Gate cult had its roots in the early 1970's when Applewhite was recovering from a heart attack. At one point, he had a near-death experience that led him to conclude that he and Nettles, who had been his nurse at the time, were "the Two," which was an allusion to the two witnesses that were mentioned in Revelations 11:3.

They then formed an essentially New Age cult that combined Christian doctrine – mostly the notions of salvation and the coming Apocalypse – with more scientific concepts, such as the evolutionary advancement, as well as pseudo-scientific ones concerned with travel to other worlds and dimensions, and elements of outright science fiction.

Some of these beliefs included:

1. The planet Earth was about to be recycled (i.e., scourged and then renewed).

2. The only chance of surviving this cataclysm was to leave the Earth immediately.
3. There are several paths for a person to leave the Earth, one of which was to hate this world strongly enough:

> "It is also possible that part of our test of faith is our hating this world, even our flesh body, to the extent to be willing to leave it without any proof of the Next Level's existence."

4. Their "human" bodies were only vessels meant to help them on their journey to the Next Level.

They also believed in the virtue of an ascetic lifestyle. In fact, seven of the male group members, including Applewhite himself, had undergone voluntary castration in Mexico in order to maintain that lifestyle.

Although the group formally opposed the practice of suicide, nevertheless, that was only by using their own definition of the word "suicide," namely: "to turn against the Next Level when it is being offered," and on March 26, 1997, the San Diego police discovered the bodies of 38 cult members at the compound. All of them had apparently committed suicide using Phenobarbital dissolved in vodka to induce unconsciousness combined and placing plastic bags over their heads to induce asphyxia. They were all found lying neatly in their own bunk beds, with their faces and torsos each covered by a square, purple cloth. All were dressed in identical black shirts and sweat pants that held a five dollar bill and three quarters in the pockets, as well as brand-new black-and-white Nike Windrunner athletic shoes, and all wore armband patches that read "Heaven's Gate Away Team."

Two former members of Heaven's Gate, Wayne Cooke and Charlie Humphreys, later committed suicide in a manner that was similar to that of the group.

The mass suicide was planned to be coincident with the appearance of Comet Hale-Bopp, which they believed was being followed by an extraterrestrial "mother ship" of alien hosts that would welcome them into the Next Level. One should note that the association of comets with cosmic messengers of imminent Doom seems to be a recurring phenomenon in history, as similar prophecies were made regarding the comet Kohoutek in 1973 and Halley's comet when it passed by the Earth in 1986. Not only did neither comet conclude with the dawn of Armageddon, both of them were tremendous disappointments to the naked eye as astronomical phenomena.

The cultural theorist Paul Virilio described Heaven's Gate as a "cyber-sect," since they relied quite crucially on the Internet not only as a mode of communication prior to their suicide, but also as a source of income, in the form a website design service that they offered to the online community. Indeed, the cult's Internet website is still being maintained, and has not been altered since the suicides.

Magazines

Predictions always make good copy for newspapers and magazines, so it is entertaining to look at some of the predictions that were made in such publications years after their date of publication. To be fair, in most cases, the predictions were not the product of the editorial staff, but were due to more authoritative specialists, and the journals were simply passing these speculations on to their readers. In retrospect, one sees that the character of the predictions is a key indicator of the spirit of the times – optimistic, pessimistic, or indifferent – towards the future. Hence, once concludes that, except for a certain amount of Post-War insecurity about whether the Cold War would lead America back into a state of national mobilization in the same way that World War Two had, the Fifties had a basically optimistic view of the world.

Many of the most optimistic visions of the future came from Popular Science, so we present a sampling of some of the articles that they ran in the Fifties.

June, 1950: "Will We Drive a Turbo Car?"

This article examined the possibility that there might someday be cars and trucks powered by Boeing gas turbine engines, based on a prototype tested by Rover Company, Ltd., of Birmingham, England. For all of its drawbacks, such as noise and the heat of the exhaust, the best that it could for performance was to go from 0 to 60 in 14 seconds, and reach a top speed of 90 mph at 36,000 rpm, although it was suggested that it could have reached 100 mph. Its main prediction was: "The car and truck may bring about a complete revolution in automotive power and design in the next five years or less."

July, 1950: "Home Atom Labs Are Coming"

This article was mostly a promotional spot for the "Atomic Energy Lab," that would be sold by the A. C. Gilbert Company. It contained a Geiger counter, spectroscope, electroscope, Wilson cloud chamber, spinthariscope, radioactive standards and ore specimens, materials for building atomic models, and sold for $42.50, which was a lot of money in 1950. Popular Science sold for 25 cents a copy then, as opposed to a newsstand price of $4.90 nowadays, so the kit might go for more on the order of $800 now, if the radioactive materials it contained were still allowed on the market by the Nuclear Regulatory Commission. There was also pamphlet on "Prospecting for Uranium" included in the kit.

December, 1950: "The Shape of Wings to Come"

This would be an example of a correct prediction. The triangular wing prototypes that were being tested at Moffett Field (Ames Research Center) by the then NACA (now NASA) did eventually become crucial innovations for the Stealth bomber and fighter.

March, 1951: "How to Build a Family Foxhole"

A common obsession during the Cold War was whether everyone should have a "fallout shelter" in the name of civil defense. This article included the "Popular Handbook for Survival," in which they discussed what to do in the event of a nuclear attack.

One also finds the advertisement: "Want to Save Gas? Be Prepared if Rationing Returns…Burn water in your car!" This was a recurring theme of Popular Science advertizing for years to come: inexpensive devices that would enhance the performance of your car engine in various ways.

October, 1951: “The First Atomic Airplane”

Among the forgettable auguries made by the aerospace expert being profiled were “First flight possible by 1960,” and “Atomic jets forecast for 1980.”

November, 1951: “How We’ll Fly to Venus”

Here, we find a discussion of a proposal by John M. Wuerth, an aerospace engineer at North American Aviation in Downey, CA, which later became Rockwell International’s Space Division, which was primarily concerned with Space Shuttle. It includes an artist’s rendering of Venusians that would look like grasshoppers, but includes the caveat that at that point in time the Venusian cloud cover made observations of the surface impossible. Actually, it is now known from measurements taken by various space probes that the selfsame Venusian cloud cover led to a runaway greenhouse effect that left Venus with an atmosphere that is composed mostly of carbon dioxide, with clouds of sulfuric acid, and having a temperature of 467°C and a pressure at the planetary surface of roughly 93 Earth atmospheres. For the record, the first of these probes was the Soviet Venera 1 probe in 1961.

February, 1955: “Rocket Liner Would Skirt Space to Speed Air Travel”

This article was based on a design proposal of the aforementioned Walter Dornberger, who was then at Bell Aerospace, detailing the possibility that passenger rockets could go to 200,000 feet and reach a top speed of Mach 24 in order to go from New York to Los Angeles or Europe in one and a half hours. It did not, however, specify a time frame for that possibility.

March, 1955: “Passengers Get Separate Domes in Double-Bubble Lincoln”

This article took the form of another Popular Science staple: Cars of the future, at least as envisioned by designers for the major car companies. It described one such prototype called the Lincoln Futura, an experimental car with a windowless double-dome canopy and a microphone to pick up ambient sounds outside the vehicle.

It has been observed that the real reason for presenting futuristic visions of technology and lifestyles at trade shows and sales conventions has more to do with making the people attending them feel that the actual products being introduced on the market by the same company are not as radical as they could have been by essentially “shocking” the public with a possible future in which life looks very different from the present.

May, 1955:“Tomorrows plane, say designers in France, will be a flying engine with a wing wrapped around it”

Although the title sounds bizarre, the article actually discusses a proposal by French aerospace researchers for a vertical take-off jet, a technology that later became an accepted concept in the form of the British Harrier jets that were used in the Falklands.

December, 1955:“Ford Designs a Body for a Gas Turbine”

The irony of this article was in the fact that in retrospect it is clear that the Ford Motor Company ever had any real ambition to make its reciprocating piston gas guzzlers obsolete. The prototype car, which they called the “Mystere,” was to be powered by a gas turbine engine – which was yet-to-be-specified – and would have a pushbutton ignition switch that worked like a combination lock.

Famously bad predictions

Having examined some of the more enduring observations of history's visionaries, it is amusing to also observe how many times people of superior intellect or high positions of decision-making in their fields could also be appallingly lacking in foresight, at least in retrospect.

Scientists and inventors

Particular mention should be made of Lee de Forest, the inventor of the vacuum tube, who was a humble man that not only saw fit to dub himself "The Father of Radio," by way of his autobiography, but also suggested to his wife that she write her own memoirs and call them "I Married a Genius!" (Could this have been the inspiration for the fictional character Lynn Belvedere?)

Charles Darwin

"I see no reasons why the views given in this volume should shock the religious sensibilities of anyone."

Foreword to "The Origin of Species," 1869

Sir William Thompson, Lord Kelvin:

"X-rays will prove to be a hoax."(1883)

"Heavier-than-air flight is impossible."(1895)

"Radio has no future."(1897)

> "The book of physics is pretty much written. All of the problems that can be solved have been solved. The only future to physics seems to be refining the numerical agreement between theory and experiment…There do seem to be two disturbing storm

clouds on the horizon." (Which turned into relativity and quantum physics)

Thomas Edison

"The phonograph has no commercial value at all."(1880's)

"Fooling around with alternating current is just a waste of time. Nobody will use it, ever."(1889)

"It is apparent to me that the possibilities of the aeroplane, which two or three years ago were thought to hold the solution to the [flying machine] problem, have been exhausted, and that we must turn elsewhere." (1895)

Lee de Forest

"While theoretically and technically television may be feasible, commercially and financially it is an impossibility, a development of which we need waste little time dreaming." (1926)

"To place a man in a multi-stage rocket and project him into the controlling gravitational field of the moon where the passengers can make scientific observations, perhaps land alive, and then return to Earth – all that constitutes a wild dream worthy of Jules Verne. I am bold enough to say that such a man-made voyage will never occur regardless of future advances." (1926)

Albert Einstein:

"There is not the slightest indication that nuclear energy will ever be obtainable. It would have to mean that the atom would have to be shattered at will."(1932)

Technology, by category

Here are some other less-than-prophetic observations, which have been organized by the technology that they pertained to.

Computers:

"The electronic digital computer is mathematically impossible, since with all of its vacuum tubes, the mean time to failure for them would be less than the time it takes to find the failed tube."

IBM mathematician, in pre-ENIAC days

"I think that there is a world market for maybe five computers."

Thomas Watson in 1943
Chairman of IBM

"Where a Calculator on the ENIAC is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and weigh only 1.5 tons."

Popular Mechanics, 1949

"[By 1985], machines will be capable of doing any work Man can do."

Herbert A. Simon in 1965
Carnegie Mellon University
(considered by many to be a
founder of artificial intelligence)

"But what…is it good for?"

IBM executive Robert Lloyd in 1968
(Commenting on the microprocessor)

“There is no reason that anyone would want a computer in their home.”

Ken Olsen in 1977
President, chairman, and founder
Digital Equipment Corporation

“This anti-trust thing will blow over.”

Bill Gates, 1995

Telephone:

“This ‘telephone’ has too many shortcomings to be seriously considered as a means of communication.”

Western Union internal memo, 1876

“The Americans have need of the telephone, but we do not. We have plenty of messenger boys.”

Sir William Preece, Chief engineer,
British Post Office, 1876

“It’s a great invention, but who would want to use it anyway.”

President Rutherford B. Hayes, 1876
(After witnessing a demonstration)

Radio, television:

“The wireless music box has no imaginable commercial value. Who would pay for a message sent to nobody in particular?”

David Sarnoff’s associates, in response to his
urgings that they invest in radio in the 1920’s

"Television won't last because people will soon get tired of staring at a plywood box every night."

Daryl F. Zanuck, 1946

"It will be gone by June."

Variety, 1955, in reference to rock and roll

"We don't like their sound, and guitar music is on the way out."

Decca Recording Co., 1962,
upon rejecting the Beatles

<u>Planes, trains, and automobiles</u>:

"Rail travel at high speed is not possible because passengers, unable to breathe, would die of asphyxia."

Dr. Dionysys Larder (1793-1859)
Professor of Natural Philosophy and
Astronomy, University College, London

"What can be more palpably absurd than the prospect held out of locomotives traveling twice as fast as stagecoaches?"

The Quarterly Review, March, 1825

"The automobile will have an important place in the future, but will not seriously affect the sale of vehicles."

The Spokesman, 1905

"What has been observed at recent automobile shows leads to the supposition that finality in motor car chassis design has at last been reached."

Cycle and Automobile Trade Journal, 1908

"If I had my way, I would make it a crime to use automobiles on the public highways, because no one has a right to use a vehicle…that is dangerous…Perhaps the time will come when horses will…not be afraid of automobiles, but I doubt that, for I have not seen the time yet that *I* was not afraid of them."

Joseph W. Bailey,
U.S. Senator from Texas, 1909.

"With over fifty foreign cars already on sale, the Japanese auto industry isn't likely to carve out a big slice of the U. S. market."

Business Week, August 2, 1968

"Man will not fly for 50 years."

Wilbur Wright, to Orville in 1901,
after an unsuccessful experiment

"Airplanes are interesting toys, but of no military value."

Marechal Ferdinand Foch, 1904
Professor of Strategy,
École Superieure de Guerre

There will never be a bigger plane built."

Boeing engineer, commenting on the first flight of the 247, a twin-engine plane that held ten people

Movies

"Who the hell wants to hear actors talk?"

H. M. Warner, Warner Brothers, 1927

"I'm just glad it'll be Clark Gable who's falling on his face and not Gary Cooper."

Gary Cooper, upon turning down the role of
Rhett Butler in "Gone With the Wind."

"The cinema is little more than a fad. It's canned drama. What audiences really want to see is flesh and blood on the stage."

Charlie Chaplin, 1916

Invasion of Iraq

"It's hard to conceive that it would take more forces to provide stability in post-Saddam Iraq than it would take to conduct the war itself and to secure the surrender of Saddam's security forces and his army. Hard to imagine."

Deputy Defense Secretary Paul Wolfowitz,
testifying before the House Budget Committee prior
to the Iraq war, Feb. 27, 2003

"Oh, no, we're not going to have any casualties."

President George W. Bush,
in a discussion with Christian broadcaster Pat Robertson, after Robertson told him he should prepare the American people for casualties

March, 2003

“My belief is we will, in fact, be greeted as liberators.”

Vice President Dick Cheney,
“Meet the Press,” March 16, 2003

“Major combat operations in Iraq have ended. In the battle of Iraq, the United States and our allies have prevailed.”

President George W. Bush,
on the aircraft carrier USS Lincoln,
May 2, 2003

“Had we to do it over again, we would look at the consequences of catastrophic success, being so successful so fast that an enemy that should have surrendered or been done in escaped and lived to fight another day.”

President George W. Bush (on the Iraqi resistance),
Time magazine, Aug. 2004

“I think they’re in the last throes, if you will, of the insurgency.”

Vice President Dick Cheney (on the Iraq insurgency)
CNN’s “Larry King Live,” June 20, 2005

Perhaps the most short-sighted prophecy of all was made in 1864 during the Battle of Spotsylvania (which is in Virginia, near Fredricksburg) by the Union General John Sedgwick, as he looked at the advancing Confederate forces:

“They couldn’t hit an elephant at this dist…”

Having casually browsed some of the fantastic visions of the futurists of history, literature, film, and popular culture, we now turn to the more prosaic scientific basis for the prediction of the future evolution of states in more specific dynamical systems.

<u>Part II</u>

The Science of Prediction

Chapter Eight

Dynamical Principles

If one desires to predict the future state of a system then it is not enough to merely model the space of states of a system and describe the nature of time as it relates to the particular problem. One also needs to specify some guiding principle for the evolution that will single it out from the potentially infinite set of possibilities. That is what distinguishes a *dynamical* model from a *kinematical* one; a kinematical model describes the states of the system, while a dynamical model attempts to also *explain* the time evolution. This is essentially what Alfred Lotka was emphasizing in his book *Elements of Mathematical Biology* as the difference between *change* and *evolution*; viz., in order to have true evolution there must be some way of distinguishing "desirable" changes from the "undesirable" ones, which amounts to a dynamical principle.

Cause and effect

One of the most elementary – and perhaps the most fundamental – dynamical principles for any natural system is that of logical cause and effect. Indeed, such a relationship is always implicit in any natural system, simply because one instinctively feels that the existence of so many recurring patterns in natural phenomena suggests that there is a fundamental natural order at the root of them. In fact, there would be no hope for the development of science if such a fundamental order of things were absent. Ultimately, one expects that the natural order manifests itself in a basic set of logical propositions of the form "*A* implies *B*;" that is, the phenomenon *A causes* the phenomenon *B* to happen.

One of the key issues in such a set of relationships is always that of uniqueness in the outcome, since it is more commonplace that the phenomenon *A* sets in motion several independent or interleaving chains of causality. For instance, if the phenomenon *A* takes the form of "a bee stings you" then the effects that ensue might be "you feel pain," "your skin swells around the stinger," and, depending upon other factors that collectively contribute to that moment in your life as a state in a system, it might also imply "you cry hysterically" (because you're three years old or maybe just timorous), "you die from anaphylactic shock" (because you have a severe allergy to bee stings).

This example points to the key issue regarding uniqueness in the state evolution that follows an initial event: Often, non-uniqueness in the outcome can be resolved by expanding the state space to include properties and parameters that distinguish the possible outcomes at a finer level of description. In the previous example, the state that determined your response to a bee sting would then have to include factors such as age, upbringing, and the state of your immune system. One can also often resolve the non-uniqueness by defining the multiple outcomes to be the components of an abstract vector, especially if some outcomes are usually associated with each other, such as pain and swelling from a bee sting.

Then again, in many cases, this is not possible, or at least not practical. One is then dealing with the realm of random – or *stochastic* – systems. Because the issue of determinism is so fundamental, we shall suspend our discussion here and return to it in a separate chapter dedicated to the topic.

We will say, at this point, that causal relationships can often be depicted in the form of a graph, just like any other system. For instance, one might be dealing with relationships of the form:

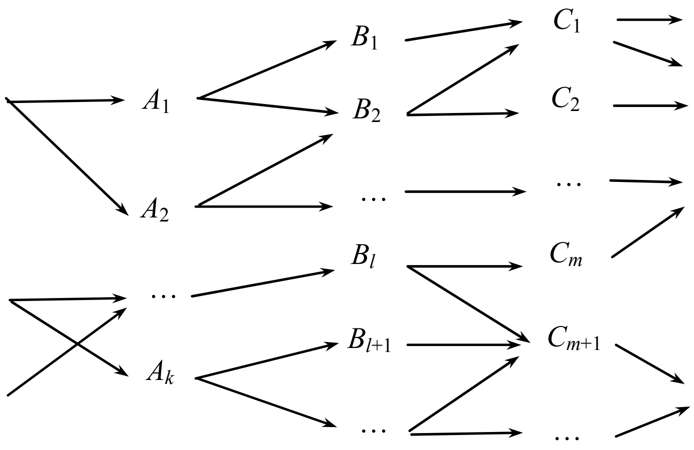

Figure 28. The graph of a possible set of causal relationships.

In essence, we are saying that logical systems are still a type of system, in the sense that we defined the term in Chapter 6. Of course, they are probably the most esoteric of all systems, and the modeling of such systems can be quite abstract, so in the present discussion we shall regard them as more of a source of inspiration for the dynamics of natural law than a basis for it.

As with any graph, one can even have causal loops (e.g., vicious cycles). An example of a double loop in Nature that was given by Alfred Lotka in his book *Elements of Physical Biology* concerned the way that economic hardship can lead to malnutrition, which leads to physical incapacitation, which reinforces the economic hardship through continued unemployment, but malnutrition also can weaken the immune system, possibly leading to a tuberculosis infection, which decreases appetite and reinforces the malnutrition. We summarize this in the following diagram:

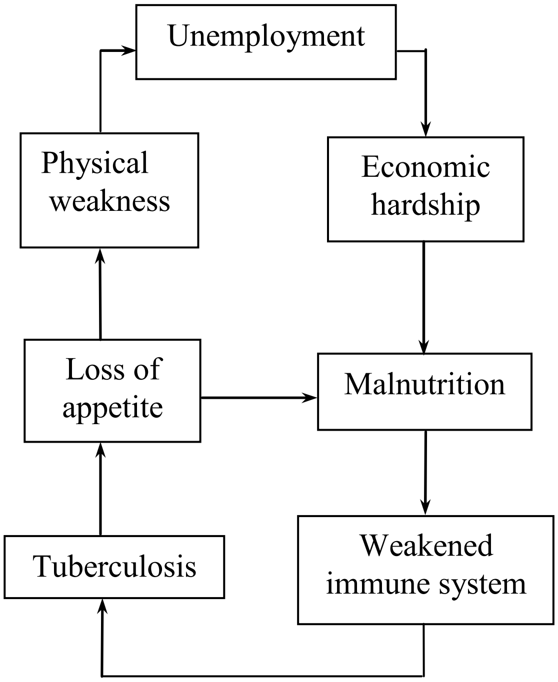

Figure 29. Double causal loop of natural origin.

Actually, whether cycles are "vicious" or not has a lot to do with whether they have a destabilizing effect on the dynamics.

Balance principles and conservation laws

The first principles that govern natural systems usually take forms that are so general as to appear to be tautologies. (That is, statements whose truth follows immediately from basic principles of logic, such as "A implies A.") However, that is because they often involve other concepts that are so vague in scope that before one applies the first principle one must first clarify the meaning of the terms involved, at which point the tautologies take on much deeper significance.

A prime example of this situation is given the concept of a "balance principle." As its name implies, it is a sort of accounting principle for some specified property of a system as its state evolves. Closely related to balance principles are "conservation laws." The essential difference is that when one is dealing with an open system – i.e., one that interacts with its external environment – a balance principle accounts for the *time rates* at which the specified property is flowing into or out of the system, while a conservation law requires that the *amount* itself must stay constant throughout the evolution of the systems state. Hence, conservation laws are usually applied to closed systems, and thus represent a reduction in scope of their applicability.

A simple example of a balance principle is given by a kitchen sink with water flowing into it from a faucet as it also flows out through the drain. The balance principle that governs the volume of water in the sink is then the statement that the time rate of change of the volume of water in the sink equals the rate at which water comes in from the faucet minus the rate at which it flows out the drain. What this balance principle then represents is a "first-order differential equation" whose solution for a given initial volume of water in the sink is going to be the volume of water as a function of time that follows past that initial time point.

The conservation law for volume that would follow by making the system a closed system is that when no water is flowing into or out of the sink the volume of water inside it must remain constant in time. This is distinct from the steady-state condition that when the rate at which water flows in equals the rate at which it flows out the volume must remain constant.

One can see that since water (at constant temperature) will have the same mass density everywhere in the sink, the balance of volume principle will be equivalent to the balance of mass principle: The rate at which the mass of water in the sink is changing in time equals the rate at which mass is flowing in minus the rate at which it is flowing out. The conservation of mass then says that when no mass is flowing in or out the total in the sink must remain constant.

When the rates at which something going in equal the rates at which it is going out, one says that the system is in a *steady state.* As a consequence, the total amount of the quantity in the system is constant in time, and the balance principle becomes a *conservation law.* Closely related to the concept of steady state is that of *equilibrium state,* which we introduced in Chapter 6. The difference is that one only speaks of equilibrium in the context of *closed* systems, for which the rates in and out are also individually zero, and not just collectively zero. Actually, the word "equilibrium" itself refers to the vanishing of the total external *forces* acting on a mechanical system, but, as we shall see, this also implies the constancy of its total linear momentum, so, in a sense, forces refer to the time rates of change of linear momentum.

Stability of equilibrium

Something that has been emerging from the study of complex natural systems, such as living organisms, is that it is not enough to merely specify the equilibrium state – or steady state – of a natural system. One must also specify the way that the system responds to perturbations of that state. Thus, one must address the issue of the stability of equilibrium, as well as the nature of the equilibrium state.

When an equilibrium state is stable, there are still two basic responses to a perturbation of the equilibrium state: the return of the perturbed state to equilibrium and the displacement of the equilibrium state to a new equilibrium state. In general, the former dynamical principle is called *self-regulation*, while the latter one is called *displacement of equilibrium* or *adaptation.*

Self-regulation is the soul of homeostasis in living organisms, but it also manifests itself in simpler natural systems. For instance, the popular wisdom that water "seeks" its own level simply says that when a volume of water is acted on by gravity the equilibrium state of the volume involves the presence of a surface at the top that is planar for small volumes, such as coffee cups, or spherical for larger ones, such as oceans. Because that equilibrium state is stable, any perturbed state of the water will eventually return to the equilibrium, if one includes the presence of viscous damping. Notice that once again, there is a limit on the magnitude of perturbation for which this is true. For instance, one could perturb the coffee in a cup so much that it would slosh over the edge and form a new volume in equilibrium, such as a puddle on the table.

When a system is in a stable equilibrium state, the response of that system to a perturbation away from that state also depends upon whether the perturbation is essentially impulsive, in the sense of being applied at a single a point in time, or permanent, in the sense that it persists for an indefinite time interval. When the perturbation is impulsive, stability implies a return to equilibrium, or at least a bounded motion about it. However, when the perturbation is permanent the response is usually a displacement of the equilibrium state to a new equilibrium state.

In the case of the pendulum, applying an impulsive force to the bob that makes it oscillate until its oscillation damps out, while applying a permanent force to the bob makes it remain still at a new equilibrium position that involves a non-zero angle with the vertical. One then sees that the state space must be enlarged in order to accommodate the applied force as an internal component, not an external one.

Displacement of equilibrium can take on more complex forms when one recognizes that it really describes a process of adaptation. Thus, one can think of the changes in a natural habitat as being like those perturbations to the state of equilibrium in its ecosystems and the long-term responses to the changes as possibly taking the form of a displacement of the equilibrium state. Similarly, living organisms regularly adapt to long-term changes in the environment, such as changes in climate, with changes in the body fat or water content.

Physics

Because the branch of science called physics is fundamentally concerned with the motion of matter, its dynamical principles are some of the most established principles in the sciences. This has led to the present situation in which many scientists prefer to believe that the laws of physical systems are fundamental to all other natural systems. However, one often finds that in natural systems that are more complex than the kind that can be described by basic physical models the applicability of even the first principles of physics can be limited.

Newton's Laws. The prime example of this situation is given by Newton's laws of motion for physical systems. One can phrase them in their original form that was sufficiently vague in its terms as to be widely applicable:

1. A body in a state of motion will remain in that state unless acted on by an external force.
2. The mass times the acceleration of a body will equal the sum of all the external forces that act on it.
3. To every action there is an equal and opposite reaction.

The vagueness in the first law is in the concept of the "state of motion" of a body. Suppose one interprets that phrase to mean its "total linear momentum," (linear momentum being mass times velocity). One finds that the second law can be rephrased as:

2′.The time rate of change of linear momentum equals the sum of the external forces of compression acting on the body minus the sum of the external forces of tension.

This statement represents a balance law for linear momentum in which the "rate in" is represented by the forces of compression and the "rate out," by the forces of tension. Hence, when these rates vanish the time rate of change of total linear momentum must be zero, which makes the total linear momentum constant in the absence of external forces. This, of course, makes the first law a corollary to the second law, and not an independent principle.

The steady-state condition for the balance of linear momentum is that the sum of the forces of compression must equal the sum of the forces of tension. Actually, in most books on engineering statics this is the definition of the equilibrium condition for forces, but since we need to clearly distinguish between open and closed systems, we shall reserve the word "equilibrium" for the case of a closed system.

One finds that similar remarks can be made when the state of motion of the body is given by total angular momentum, such as when one is concerned with a mass that rotates around an axis. The "rates in and out" then take the form of torques that act on the body in opposite senses of rotation, although that distinction makes more sense in the case of fixed-axis rotations, which are appropriate to wheels on axles, than it does in the case of spatial rotations, as one might consider for the aerial maneuvers of fighter jets. The steady-state condition then says that the sum of all the torques that act on the body must be zero, which is also usually regarded as rotational equilibrium in engineering statics.

The Newtonian law of motion that is easiest to misapply is probably the third law, since the concepts of "action" and "reaction" are quite open-ended in it. There are two common applications of the law in physics: One can interpret the actions and reactions as forces or as momenta, whether linear or angular.

In the former case, one says, for instance, that when one is standing on the floor in the presence of gravity the force of gravity that pulls one down is precisely contradicted by an equal and opposite "normal" force that the floor exerts as a reaction. As a result, one's vertical state of motion is one of rest. If a trap door were to open beneath one's feet then there would be no normal force to contradict gravity and the vertical state of motion would be one of acceleration.

In the case where one interprets action and reaction as momenta one can account for the forces of recoil and jet propulsion in a concise way. When you put a rifle up to your shoulder to fire it, it starts out with a total linear momentum of zero. Since the only force that comes about when the rifle is fired is internal to the firing chamber the only way that the bullet can acquire such a high linear momentum towards the muzzle is if the gun itself acquires an equal and opposite linear momentum into your shoulder. Incidentally, this is an easy way of proving to yourself that the Hollywood action movies in which being shot by a gun is depicted as being capable of lifting someone up and throwing them a significant distance are exaggerating in their design of that stunt, since the only way that a bullet or shotgun load could carry enough momentum to pick the target up and throw them is if the recoil also picked up the shooter and threw them backward, as well. (…Then again, it's only a movie.)

An elementary case of physical motion in which action and reaction can be misapplied is when a mass is falling though a viscous fluid. (For instance, there was once a shampoo commercial in which a pearl fell through the liquid in the bottle.) If the "action" is interpreted to mean "force of gravity" and the "reaction" is taken to mean "force of viscous drag" then the reaction would not generally be precisely equal to the action unless one included the "inertial force" of mass times acceleration in the reaction. Of course, the inertial force will be in the same direction as the force of gravity, not opposite to it, just as it would in the previous example of a trap door opening under your feet.

It is when Newton's laws get applied to non-physical systems, such as human emotions or crowd behavior that it becomes more obvious that actions in the most general sense do not always provoke equal and opposite reactions. Indeed, the same action might very provoke completely unrelated emotional responses in different people, due the difference in their individual mental states, especially their states of emotional stability.

One can see that in more system-theoretic terms, Newton's three laws of motion might be restated as two laws, the first of which is a balance principle for the system state and the second of which is a principle of feedback:

1.The time rate of change of the system state equals the total rates of increase minus the total rates of decrease.

2.In every natural system, a change in the state of the system will produce feedback in one form or another.

Hamilton's principle. A more precise usage of the word "action" is the basis for Hamilton's principle of least action, which says that the time evolution of the state of a physical system will follow the path of least action (suitably defined). Once again, the precise definition of "action" is somewhat open-ended, but a simple example of its application might be the (curvilinear) length of the path that connects the starting point with the ending point. The preferred path between them becomes the path of least *distance*, which sometimes called a *geodesic.* In common Euclidian spaces this path will be a straight line, but on a curved surface, such as the surface of the Earth, this does not have to be true. The reason that airline routes from the United States to Europe always look like they are taking the long way from point A to point B is simply that when the course is plotted on a globe, instead of a flat map, one sees that the path is an arc of a "great circle" between the two paths, which is the path of shortest distance on the surface of a sphere. Note that in the case of flying from any point to its diametrical opposite point there will an infinitude of these paths of least distance.

The general concept that one associates with a path is that of a "performance index," in the language of optimization theory. The same basic problem might very well admit several relevant performance indices, which can then produce distinct path of least action. For instance, in the case of spacecraft orbits there is generally going to be more than one way of changing from one orbit to another depending upon whether one is trying to minimize the time, distance, or fuel expended in the process.

Often the first principles of a dynamical model in physics are phrased as either balance laws or conservation laws for some fundamental set of quantities. We have already seen how Newton's first and second laws of motion can be construed as conservation laws and balance principles for linear or angular momentum. In the case of continuum mechanics, one usually adds the balance of mass for the system, as well. When the mass density is constant, this reverts to the balance of volume, and when the volume of an object remains constant during all of its deformations one calls the material *incompressible*. Most liquids and elastic materials are approximately incompressible, although the fact that sound waves propagate through them with a finite speed shows that they are not perfectly incompressible, since that would make the speed of sound infinite.

A very powerful concept in physics that gets yet another balance law or conservation law is that of *energy*. Energy is expressed by a number and can take many forms in physical systems, such the kinetic energy of motion, the potential energy of something's position in the presence of certain forces (namely, conservative ones), the heat that it contains, and the photons that it radiates, to name a few. Ultimately, one finds that the two fundamental forms are potential energy and kinetic energy, while the other ones are usually the forms that these kinds of energy take on in complex systems with many components, such as the molecules of a gas or the atoms of a crystal. For instance, the temperature of a material represents the average kinetic energy of the atoms or molecules that comprise it. However, it is usually more convenient to simply deal with these "collective modes" directly than it is to repeatedly revert to their formulation in terms of "microstates."

It is essential to understand that an appropriate notion of energy cannot always be defined for every physical system. In particular, not all forces are conservative forces that would lead to a definition of potential energy. A key issue is whether the work done by the force when going from point *A* to point *B* depends upon the path taken. For a force like friction, it is clear that pushing a box across a concrete floor will take more work for longer paths than it does for shorter ones.

Thus, in order to use conservation of energy as a first principle for the dynamics of a physical system, one must be dealing with the kind of situation in which energy is well-defined. However, one can sometimes weaken the constraints slightly by posing the balance of energy for an open system, rather than the conservation of energy for a closed one. Whereas the conservation of energy requires that the total energy in a closed system remain constant in time, the balance of energy for an open system requires only that the time rate of change of the total energy in the system [1] must equal the total rate going in minus the total rate going out. Consequently, one can still define the power dissipated by friction even though the force of friction does not admit a potential energy function.

Despite its limitations, energy is nonetheless widely used as the fundamental quantity for describing the states of physical systems. Indeed, the states of the systems treated by quantum mechanics are basically energy states and the dynamics of such states is closely related to using the conservation of energy as the dynamical first principle.

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[1] The time rate of change of energy is also referred to as the *power* that is either exerted on, exerted by, or dissipated by the system, such as the time rate of change of doing work on it.

Thermodynamics. When one is concerned with energetic systems of sufficient complexity, it becomes impractical, if not impossible, to account for all of the dimensions of the state space directly; for instance, the state of each molecule of air in a room at a chosen time point cannot be effectively measured. One then finds that the state space associated with the possible measurements one can make is quite distinct from, and generally much lower in dimension than, the state space of the system being measured. One refers to the states of the system being measured as *microstates,* while the states of the measuring devices are called *macrostates*. It then becomes clear that the modeling of the space of microstates is a purely theoretical exercise when compared to the modeling of the space of macrostates.

The laws governing the macrostates can also be quite different from those of the microstates. Of particular interest is the law of conservation of energy, which is also referred to as the *first law of thermodynamics*, which goes back to the work of the English scientist James Prescott Joule (1818–1889). Had one the luxury of completely accounting for all of the motions and forces of interactions of all of the air molecules in a room, the total energy of the system would simply involve a very large sum of kinetic and potential energies over all of the molecules, which would then be assumed to remain constant in time as long as no energy was coming into or going out of the room. In such a case, one says that the system is (energetically) *closed*.

When one formulates the law of conservation of energy in terms of macrostates, though, it has a very different character. The most common macrostate variables for air in a room in thermodynamics are its pressure, density, and temperature, as well as perhaps its mass when one includes the possible flow of air molecules into and out of the room. In the thermal equilibrium state, the macrostate variables are all constant in time and space, while in the more realistic non-equilibrium state they become functions of space and time. The macrostate formulation of the conservation of energy then takes the form of saying that the work done on the system (which is usually due to a change in volume caused by a pressure or force) equals the change in the internal energy of the system and the change in the total heat contained in it.

One then sees that, in one sense, the very definition of heat comes about as a kind of accounting device that one introduces in order to make conservation of energy truly meaningful. Basically, the concept of total internal energy is flawed in that when some of the work done on a system also gets dissipated due to friction, viscosity, or what-have-you, the total internal energy is not a complete accounting of all "internal energy." Rather than abandoning conservation of energy for non-conservative forces, one then simply defines the change in total heat to represent the degree of non-conservation.

One way of refining the energy accounting further is to introduce the concept of *entropy*. In its earliest form, it was introduced in the theory of heat engines – namely, mechanical devices that convert heat into mechanical work and vice versa. The prototype of such a device was defined by the French scientist Nicolas Léonard Sadi Carnot (1796–1832) in 1824. One of the key results of his research was the idea that the efficiency of this conversion process depends upon the temperature difference between an engine and its environment.

Joule's work on the conservation of energy then inspired the German scientist Rudolf Gottlieb Clausius (1822–1888) to formulate the second law of thermodynamics during 1850 in the form of proposing that heat does not flow *spontaneously* from cold to hot bodies; i.e., heat flows "downhill." He then showed how this accounted for Carnot's principle, which then led to his definition of entropy (1865) as something that explained the spontaneous tendency of heat to flow one way and not the other.

The next major advance in the definition of entropy came from the Austrian physicist Ludwig Eduard Boltzmann (1844–1906), who gave it a more statistical definition, and thus laid the foundations for what are now called statistical mechanics and statistical thermodynamics. Basically, he regarded the key concept as the number of "complexions" in the system – that is, the number of energy microstates that could sum up to the given energy macrostate. The entropy of the system then became proportional to the logarithm of this number, and the constant of proportionality was eventually dubbed Boltzmann's constant. Hence, the higher the entropy in the system, the more microstates could equivalently represent the pressure, temperature, and density at the level of laboratory experiments. One also sees that the higher the total energy, the higher the entropy in the system. Incidentally, Boltzmann was one of the most ardent advocates of the atomic theory of matter in an age when that scientific model was still highly controversial.

The formulation of the second law of thermodynamics in terms of entropy amounts to further refining the definition of the change of total heat in the system to an expression that depends upon temperature and entropy. It implies that in an energetically closed system the entropy will always increase to a maximum value that one finds when the system is in thermal equilibrium. Otherwise stated, the thermal equilibrium state is also the state of maximum entropy.

Another mechanical form of the second law was defined by Lord Kelvin and Max Planck in the Nineteenth Century, and takes the form: "It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work." They then showed that this statement was equivalent to the formulation given by Clausius.

Another form of the second law is that there are no "perpetual motion machines," which would then be essentially closed, cyclic heat engines that could convert heat into work. (Although a steam engine converts heat into work, it is not a *closed*, cyclic heat engine, but an open one.)

Although there is also a "Zeroth" law of thermodynamics, as well as a third one, we shall not elaborate here, since they are not as crucial to the discussion that follows as are the laws that pertain to balance principles and the equilibrium state.

Chemistry

We have previously discussed the role of Le Chatelier's principle in the dynamics of chemical reactions. In addition to Le Chatelier's principle, chemical systems are also assumed to be driven by the second law of thermodynamics, which then gets expressed in other forms that are tailored to the nature of chemical systems, instead of mechanical ones.

In chemical reactions, it is not usually necessary to account for the details of the reaction at the level of individual atoms. Rather, one is primarily concerned with total amounts and concentrations of the reactants involved in a chemical reaction, as well as the total heat that is produced or absorbed in the process. Thus, to some chemists entropy becomes a way of explaining why it is that for a given initial temperature sometimes the reaction will only happen in one direction and not the other. For instance, it is possible to combine hydrogen and oxygen (explosively, at times) to form water, as well as to ionize water molecules into hydrogen and oxygen. However, at low enough temperatures, no ionization will come about, while at high enough temperatures, no molecular bonds can form. At lower temperatures, one then accounts for the one-sidedness of the reaction by saying that there is more entropy in the water vapor than there would be in the mixture of ionized gases.

Another way of characterizing the direction of increasing entropy is by saying that a reaction in which the entropy increases is *irreversible*, while one in which it remains the same is *reversible*. In particular, one sees that when the system remains in its equilibrium state of maximal entropy, the reaction will be reversible. Hence, equilibrium thermodynamics is solely concerned with reversible processes, while non-equilibrium thermodynamics involves irreversible ones, as well.

Homeostasis

Basically, homeostasis represents the tendency of a system, which can be either open or closed, to regulate its internal environment in such a way as to maintain a stable equilibrium state. One finds that there are two basic system processes at work: the self-regulation of a steady state and the displacement of that steady state to a new value.

The concept of homeostasis first took the form of the "milieu interieur" in the works of the French physiologist Claude Bernard (1813–1878). He wrote, "La fixité du milieu intérieur est la condition d'une vie libre et indépendante" (*"The constancy of the internal environment is the condition for a free and independent life"*).

Later, the American physiologist Walter Bradford Cannon (1871–1945) coined the actual word "homeostasis," and popularized it in his book *The Wisdom of the Body* (1932). (Incidentally, he also introduced the still-used concept of "fight-or-flight" in animal behavior. (*Bodily Changes in Pain, Hunger, Fear and Rage: An Account of Recent Researches into the Function of Emotional Excitement*, Appleton, New York, 1915)) He described the general features of homeostasis by means of four tentative propositions:

1. Steady-state conditions require that any tendency toward change automatically implies factors that resist change.
2. Maintaining constancy in an open system, such as our bodies represent, requires *mechanisms* that act to maintain this constancy.
3. The regulating system that determines the homeostatic state consists of a number of cooperating mechanisms that act either simultaneously or in succession.
4. Homeostasis does not occur by chance, but is the result of organized self-government.

It is not surprising that some of the earliest inspirations for the founding of a "general systems theory" came from physiology. As mentioned before, von Bertalanffy was originally trained as a biologist, so much of the impetus to look further into the realm of natural and man-made systems for examples of analogous processes came from the recognition that self-regulating processes in living organisms implies that there are naturally occurring "servo systems" in their structure whose function is to maintain some "set-point" for a physiological parameter.

One common example in which the closed-loop nature of self-regulation occurs in the human body is its process for maintaining a constant body temperature, much like a glorified thermostat that actuates a furnace or air conditioner, a process that is referred to as *thermoregulation*. The decision-making component for the feedback loop is the hypothalamus of the brain, which works to maintain the temperature set-point. That this process is necessary is evidenced by the fact that the core body temperature must remain within a narrow window in order for healthy bodily processes to occur.

There are two basic sources of heat generation or flow in the human body: internal sources, which mostly amount to the heat generated by the flexing of muscles, and external sources, which mostly means the difference between the body temperature at its surface and the ambient temperature of the environment (which is usually air or water). From elementary thermodynamics, when the skin temperature is greater than the ambient temperature of the environment, heat will flow out of the body and the core temperature will go down. Up to a point, this is necessary in order to dissipate the excess body heat that is being generated, which is why an outside air temperature of 98 degrees Fahrenheit does not actually feel comfortable, even though it is close to a state of thermal equilibrium between the body and the air. When that temperature reaches a set-point on the low side, the brain signals the muscles to begin contracting periodically (i.e., shivering) in order to generate more internal heat. When the ambient temperature is greater than the skin temperature by a certain margin, the brain signals the sweat glands to begin secreting sweat onto the skin surface so that evaporation will cool the surface. Incidentally, this explains why an increasing layer of body fat under the skin surface tends to increase the amount of sweating one does: Fat is basically a thermal insulator, which undermines the efficiency of the surface cooling to also cool the underlying muscles and blood vessels. It is also why one should wear clothing that is close to the skin in cold weather and loose on the skin in hot weather.

It is essential to understand that evaporation only occurs in a gaseous environment, such as air. This why one can tolerate desert temperatures, which can be over 120 degrees Fahrenheit, despite the fact that one usually becomes comatose and experiences irreversible brain damage, if not death itself, when the body temperature goes above about 103 or so. By contrast, when one is submerged in hot water, such as a hot tub or Jacuzzi, no evaporation can take place and it is inevitable that as long as the water temperature is above the maximum tolerable body temperature, that body temperature will eventually rise to the ambient temperature. Not only is the lethargy and sleepiness one feels in hot water consistent with a low-grade fever, but there have been documented cases of people who fell asleep in Jacuzzis and eventually died when the ambient temperature was only around 115 degrees Fahrenheit. There have also been fatalities associated with exposure to 230 degrees Fahrenheit in a Finnish sauna, since the humidity of the air in a sauna reduces the rate of evaporation of sweat on the skin. However, in the 1950's a U.S. Air Force test subject endured 450 degrees Fahrenheit for over twenty minutes in a test chamber, along with a pan of chocolate-chip cookies. His comment on the feat was that he was glad that he had more water to lose than the cookies did. Of course, the air in the oven would have to be quite dry in order to be survivable for that period of time.

One also finds that in addition to processes in which perturbations from equilibrium are compensated for by a return to equilibrium, one also has examples of the displacement of that equilibrium state. A popular example of this in the human body is given by the relationship of one's body mass to one's metabolic rate, in the sense of the rate at which metabolism is generating energy, which also means the rate at which it is converting the chemical energy that is stored in the food that one ingests into mechanical energy. When the rate at which the body is ingesting food exceeds the rate at which it is metabolizing it, the body mass increases. However, since it will take more mechanical work to move a more massive body around, one also experiences a corresponding increase in the metabolic rate, as well. Eventually, the original equilibrium state of mass and metabolic rate gets shifted to a new mass and metabolic rate that is consistent with the demands of maintaining that mass. Conversely, when the rate of food intake is less than the metabolic demands of the body the body mass begins to drop accordingly until a new equilibrium between the rate of food intake and the rate of metabolism is attained. This is sometimes referred to as the "set-point" theory of body mass, although one can see that the set-point is being shifted to a new value in this case.

Yet another important example of homeostasis is given by the way that the body regulates an acceptable level of oxygen and carbon dioxide in the blood stream, a mechanism that was first established experimentally in 1905 by the Cambridge biologists John Burdon Sanderson Haldane, F.R.S. (1892–1964) and J. G. Priestly. The "misalignment receptors" that define the error signal for the servo loop are the "peripheral" receptors in the arterial walls of the neck and they respond to reductions of the blood oxygen level, as well as increases in the carbon dioxide level. The "central" receptors are in the medulla of the lower brain and they respond to only an increase in the level of carbon dioxide. When the error signal grows unacceptable, the brain increases the rate of respiration by increasing both the frequency and volume of breathing until the proper concentrations of the two gases in the blood are restored. Of course, respiration is not a purely unconscious process, and one can "manually override" the autonomic signals by conscious control of one's breathing by holding – or at least slowing – one's breath or hyperventilation.

One of von Bertalanffy's more celebrated contributions to mathematical biology was his *allometric equation*, which represented a simple semi-empirical differential equation for relating the metabolism of an organism to its mass in a way that also accounted for the increase and decrease in that mass. Not surprisingly, at the root of it was a balance principle that expressed the total time rate of change in the body mass as a difference between the rate at which mass was accumulating in the basic tissues and the rate at which it was being destroyed.

To the physiologist, good health is synonymous with the steady state condition on all of the body's subsystems, while the perturbations away from it represent morbid situations, such as fevers, diabetic comas, high blood pressure, obesity, and malnutrition. One also sees that when the organism ceases to be an open system energetically, such as when it is deprived of food or oxygen, the metabolic processes can cease altogether and the body temperature eventually converges to the ambient temperature, which is to say, it dies, and the body tissues further converge to a state of maximal entropy by decomposition, in which the maximal entropy attainable will depend upon the ambient temperature. That is, dead tissues decompose faster in a warm environment than they do in a cold one, which is why refrigerators and freezers are so useful for the storage of food and cadavers (or is it food and *other* cadavers?).

Ecological Imperatives

Undoubtedly, the most fundamental imperative of all life in the universe is the will to exist in this world in the first place. Certainly, all of the higher functions performed by any living organism are contingent upon that existential fact.

In order to address this survival instinct, one must then address the nature of one's surrounding environment, especially as it concerns the availability of air that is not too noxious, potable water, food, and a survivable weather and climate. When the immediate environs proves to be survivable it is the nature of most living things to remain in place as long as that condition prevails; when the environment proves not to be survivable, they migrate to a different locale. Of course, some life forms, such as plants, are unavoidable static objects, except insofar as their seeds might be carried to other places by the wind, while others, such as the fish in a lake or pond, are mobile, but only within geographical limits. Furthermore, the migration of most birds, whales, salmon, and the like can follow a periodic cycle that is driven by the periodic changes in the climate or the cycle of reproduction. There are also basically nomadic species are in a continual state of migration, although often that too is bounded by some larger geographical limits.

The geographical region that falls within these geographical limits is essentially the *territory* of the organism in question. More to the point, one can imagine that at a primitive level most animals have some degree of confidence in their probability of survival at each point of the Earth's surface, as well as for some interval of time into the future. One can then think of the territory for that animal as being defined by the set of all geographical locations at which the animal feels at least some minimal degree of confidence in its survival at that point. Furthermore, the degree of confidence is generally strongly correlated with the animal's prior experiences at that point. Thus, most of the Earth's surface, being not-yet-explored by the animal, becomes a realm of probable threat – i.e., low confidence in one's probability of survival.

The influences that can drive the migration of a mobile species include, in addition to the aforementioned cyclic changes, the exhaustion of a food or water source (which can be permanent or just temporary), or the presence of competition for the territorial resources, either from competing members of one's own species or from other species that feed upon the same resources. Since competition really falls with the scope of an interaction between sub-systems or system components, we shall return to this topic in a later chapter that will be devoted to the nature of interactions.

It is important to note that it is not only individual organisms that have a will to survive, but also their species itself. This is why all living things are driven to eventually reproduce. Thus, territorial resources must not only sustain the existence of the individual within their confines, but also provide the means for that individual to reproduce, as well.

The main concern of mathematical ecology is to construct mathematical models for the dynamics of interacting populations of living organisms. Thus, the main state variables usually take the form of population counts for each species under scrutiny, or really, population densities. Generally these variables will be functions of both time and geographical location, but in the first approximation one usually neglects migration so they become merely functions of time. Furthermore, the basic dynamical model is often traceable to the logistic equation, which is the nonlinear extension of the exponential growth model that includes the unavoidable saturation of a population density at some maximum possible limit. Thus, the Malthusian assumption of unbounded exponential growth in any population becomes less definitive.

One sees that it can be just as crucial to have a model for the growth curve of an individual organism in order to more precisely account for the growth of the population it belongs to. This is because the demands of the individual for food and water will generally vary over the course of its lifespan. Of course, as a first approximation, one can simply take the mean demand over a typical lifespan, as well as over the population itself.

The Evolution of Species

The idea that a biological species itself can change over time, as well as its individual members and populations, had already been discussed by the natural philosophers of ancient Greece, Rome, China, and the Islamic world. However, until the 18th century Western natural philosophy was dominated by the doctrine of *essentialism*, namely, the belief that every species has essential characteristics that cannot be changed.

In the early 19th century, Jean-Baptiste Pierre Antoine de Monet, Chevalier de la Marck (1744-1829) proposed his theory of the *transmutation of species*. For Lamarck, the evolution of species was mostly due to two first principles:

1. The complexifying force (*le pouvoir de la vie*).

2. The adaptation of organisms to their environment.

The first principle posits that organisms were created in their simplest forms via spontaneous generation and are then driven by a natural tendency for organisms to become more complex.

The second principle could move organisms upward from the ladder of progress into new and distinct forms with local adaptations, or drive them into evolutionary blind alleys, where no further change could occur. Lamarck felt that the interaction of organisms with their environment would lead to the *inheritance of acquired characteristics* through the use and disuse of certain characteristics. This inheritance of acquired characteristics is also called the theory of adaptation or *soft inheritance*.

Charles Robert Darwin, F.R.S. (1809 –1882) was an English naturalist who was born in Shrewsbury, Shropshire, England. His university education began at the University of Edinburgh Medical School in 1825, but he found that discipline unstimulating, although he did engage in debates concerning the theory of Lamarck. Eventually his father sent him to Christ's College at Cambridge University in the hopes of turning him into an Anglican parson. There, he became a close friend and follower of botany professor John Stevens Henslow and graduated with a Bachelor of Arts in 1931, although he remained at the university for some additional months.

When he returned home, he found a letter from Henslow in which his former mentor had proposed Darwin to captain Robert FitzRoy for a place on the HMS *Beagle* as a self-funded gentleman naturalist who would contribute to an expedition to chart the coastline of South America. The voyage of the *Beagle* lasted from December, 1831 to October, 1836, and Darwin spent most of that time on land investigating geology and making natural history collections, while the *Beagle* surveyed and charted coasts. On the return voyage, Darwin wrote in his notes that if his growing suspicions about the mockingbirds, tortoises, and Falkland Islands Foxes were correct then "such facts undermine the stability of Species," but then cautiously added the word "would" before "undermine." He later wrote that such facts "seemed to me to throw some light on the origin of species." Since Henslow had given selected naturalists a pamphlet of Darwin's geological letters in December 1835, by the time the *Beagle* reached Falmouth in Cornwall, Darwin was already something of a celebrity in scientific circles.

After documenting his observations from the trip in less controversial tomes on natural history, Darwin then went on to write his conclusions regarding the evolution of species in his defining work *On the Origin of Species*. When it went on sale in November of 1859, it proved to be unexpectedly popular, and, in fact the entire first printing of 1,250 copies was already oversubscribed as of its release.

The essence of Darwin's theory is simply stated in the introduction to his classic work:

> "As many more individuals of each species are born than can possibly survive, and as, consequently, there is a frequently

> recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be *naturally selected*. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form."

In addition to natural selection, the other fundamental principle of Darwinian evolution is the idea that species tend to mutate over many generations, although the precise mechanism of mutation was treated as essentially a random forcing function. The process of natural selection then becomes a sort of environmental "filter" for each mutation, and ultimately the only issues in the eyes of nature are whether the mutation is an inheritable trait, and whether the mutant organism survives to reproduce its mutation in a new generation. This is actually a type of feedback loop between the mutations and the probability of surviving to reproduce, in which positive reinforcement produces dominant traits, while negative reinforcement produces recessive ones.

Natural selection is often referred to by the misleading phrase "survival of the fittest," although that phraseology is often used as a justification for a basically selfish, aggressive approach to survival that does not really represent a consistent pattern in nature. As we will discuss later, although a predator that preys upon another animal (usually an herbivore) is clearly the more aggressive of the two when it comes to lifestyles, nonetheless, the fact that there are still so many rabbits, mice, and what have you after millions of years of predation indicates that the less aggressive animals have there own way of surviving from one generation to the next, even in the face of being preyed upon. The key is in the fact that their rate of reproduction is usually much higher than that of the predator; i.e., they breed like rabbits.

The phrase "survival of the fittest" itself was coined by Herbert Spencer (1820–1903), who was an English philosopher, sociologist, and prominent classical liberal political theorist. He introduced the expression in his textbook *Principles of Biology* (1864) in response to reading Darwin's theory. Although nowadays the term strongly suggests that it has a basis in natural selection, nevertheless, Spencer himself actually cleaved to Lamarckism.

The next major step in establishing Darwinian evolution was taken by Gregor Johann Mendel (1822–1884), an Augustinian priest and scientist who had studied physics at the University of Vienna under Christian Doppler. In 1853, Mendel returned to teach at the school he had attended as a youth, the Augustinian Abbey of St. Thomas in Brno (which was then a part of the Austrian Empire, but is now in the Czech Republic), where he mostly taught physics. The abbot there at the time was C. F. Napp, who had sponsored Mendel's studies in Vienna.

Despite his training as a physicist, between 1856 and 1863 Mendel cultivated and tested some 29,000 pea plants. This study showed that one in four pea plants had purebred recessive alleles [1], two out of four were hybrid, and one out of four was purebred dominant.

His experiments led him to make two generalizations, which later became known as Mendel's Laws of Inheritance:

1. Law of Segregation: when any individual produces gametes [2], the copies of a gene separate so that each gamete receives only one copy. A gamete will receive one allele or the other.
2. Law of Independent Assortment: alleles of different genes assort independently of one another during gamete formation.

This research produced a paper "Experiments on Plant Hybridization," that Mendel presented at two meetings of the Natural History Society of Brno in Moravia in 1865. That paper was then published in 1866 in the Proceedings of the Natural History Society of Brno, although it attracted little interest at the time. In fact, it was cited about three times over the next thirty-five years, and according to Jacob

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[1] An *allele* is one of two or more forms of the DNA sequence of a particular gene. Each gene can have different alleles. Sometimes, different alleles can result in different traits, such as eye color, but sometimes, different alleles will have the same result in the expression of a gene.

[2] A *gamete* is a cell that fuses with another gamete during fertilization (conception) in organisms that reproduce sexually. For instance, the sperm and the ovum are gametes.

Bronowski, in his book *The Ascent of Man,* even Charles Darwin was unaware of Mendel's paper in the early states of his own work on the origin of species. The true significance of work seems to have been first recognized in 1900, after Mendel had long since left this world, with the independent duplication of his work by Hugo de Vries and Carl Correns, both of whom acknowledged Mendel as having historical priority.

By 1867, Mendel had replaced Napp as abbot of the monastery, and he found that his ecclesiastical responsibilities gave him less and less time in which to pursue his genetic experiments.

Mendel’s laws were eventually integrated with the chromosome theory of inheritance that was due to the American embryologist Thomas Hunt Morgan (1866–1945), and they then defined the core of classical genetics. Morgan was awarded the 1933 Nobel Prize in Physiology or Medicine for this work.

The next fundamental advance in establishing the genetic foundations of evolution was made in 1953 by James D. Watson and Francis Crick while working at the Cavendish Laboratory of the University of Cambridge. On the basis of x-ray diffraction data that had been collected by Rosalind Franklin they proposed the now-accepted *double helix* structure for the DNA molecule, which made of the chromosomes that were the basis for genetics. Together with Maurice Wilkins, they were awarded the Nobel Prize in Physiology or Medicine in 1962.

The refinement of Darwinian evolution that emerged was that one was ultimately looking at the evolution of information encoded into the structure of the DNA molecule from one generation to the next. Thus, the fundamental level at which mutation is taking place is at the level of this information itself, although the exact mechanism of mutation is not entirely clear. The environment in which the organism lives, with its selection processes, especially as it concerns the selection of mates in the cause of reproduction, then becomes a sort of gantlet for the information to run in order to reproduce itself in the next generation.

Henri-Louis Bergson (1859–1941) was a French natural philosopher who had been influenced by the writings of Herbert Spencer in his early studies. His refinement of Darwinian evolution was set down in his 1907 book *L'Evolution créatrice (Creative Evolution)*.

He essentially applied the eternal debate between predestination and free will to the way that science conceives of time itself. The dominant view up to that point in time was the Cartesian-Newtonian "clockwork universe" paradigm that regarded all processes as deterministic at some sufficiently universal scale of understanding and that the future state of that system was dependent only upon the current state. In effect, one was dealing with a reversible system without memory, like the collision of billiard balls on a frictionless table.

Bergson took a more "thermodynamic" view of causality in Nature: that the future evolution of any complex natural system depended upon its history, and not just the current state. That is, complex natural systems usually have "memory," which he incorporated into his concept of *duration* as an essential part of natural causality. Consequently, such systems are not generally reversible, as their (internal) entropy is usually increasing.

Perhaps the most-discussed philosophical principle that Bergson introduced was what is now referred to as *Vitalism*. The origin of that word, in turn, is his use of the term *élan vital* (vital impetus) to describe an otherwise-enigmatic dynamical principle in Nature that represented a fundamental creative principle. Being universal in its scope, this principle affected not only the evolution of the basic molecular structures of life but the ultimate evolution of consciousness in the human mind. Although one can still regard the *élan vital* as a sort of "X factor" in the dynamics of Nature – that is, a random forcing function – nevertheless, to some extent it further refined the concept of mutation as a driving force, especially when given an interpretation in terms of the information stored in the DNA molecules.

The English evolutionary biologist, humanist and internationalist Sir Julian Sorell Huxley F.R.S (1887–1975) used the term *élan vital* in a more jocose metaphorical sense in one of his lectures:

> "When I was just last in New York, I went for a walk, leaving Fifth Avenue and the Business section behind me, into the crowded streets near the Bowery. And while I was there, I had a sudden feeling of relief and confidence. There was Bergson's *élan vital* – there was assimilation causing life to exert as much pressure, though embodied here in the shape of men, as it has ever done in the earliest year of evolution: there was the driving force of progress"
>
> lecture 1, n. p., J. Huxley papers

A distant precursor to Bergson can be found in the work of the pre-Christian Greek Stoic philosopher Posidonius "of Apameia (Syria)" or "of Rhodes" (ca. 135–51 BCE). He postulated that a "vital force" emanated by the sun to all living creatures on the Earth's surface. The concept of *élan vital* is also similar to Schopenhauer's concept of the will-to-live.

Bergson was awarded the Nobel Prize in Literature in 1927.

Pierre Teilhard de Chardin (1881–1955) was a French philosopher and Jesuit priest who was originally trained as a paleontologist and geologist, and took part in an expedition to China that resulted in the discovery of "Peking Man." His most-cited book, *Le Phénomène Humain (The Phenomenon of Man),* had to be published posthumously in 1955, since in that book, he had abandoned the traditional Christian interpretations of creation that were given in the Book of Genesis in favor of a less strict interpretation, which predictably displeased certain officials of the Catholic Church, to which the Jesuits are subordinate. However, in 2009 Pope Benedict XVI praised Teilhard's idea of the universe as indicating the presence of a "living host."

In his book, Teilhard gives natural evolution a more cosmic context. To him, the material cosmos evolves from primordial matter into a geosphere, a biosphere, into (human) consciousness, the "noosphere," and finally to his vision of the Omega Point, which represented a state of supreme consciousness that "pulls" all creation towards it.

The concept of a noosphere (from the Greek "nous," meaning mind) refers to the collective consciousness of humanity, and encompasses the networks of thought and emotion in which all humanity is immersed. The term was first coined by the Ukrainian minerologist and geochemist Vladimir Vernadsky (1863-1945).

Teilhard was a leading proponent of "orthogenesis," which is the idea that evolution occurs in a directional, goal driven way, and argued in terms that are now referred to as *convergent evolution*. As far as biology was concerned, he argued in Darwinian terms, but he advocated more Lamarckian ideas for the development of culture, which primarily came about through education. He observed:

> "Our century is probably more religious than any other. How could it fail to be, with such problems to be solved? The only trouble is that it has not yet found a God it can adore."

Teilhard also states that "evolution is an ascent toward consciousness," and gave encephalization – i.e., the emergence of brains – as an example of one of its early stages. This led Julian Huxley to characterize Teilhard's philosophy by saying that it described humanity as "evolution becoming conscious of itself."

The Scottish biologist, mathematician, and classics scholar Sir D'Arcy Wentworth Thompson C.B., F.R.S., F.R.S.E. (1860-1948) is mainly remembered as having been the author of the monumental (1116 pages!) 1917 book, *On Growth and Form*, in which his central theme was that biologists of his era were placing too much emphasis on Darwinian evolution as the fundamental determinant of the form and structure of living organisms, while placing too little emphasis on the role played by the laws of physical mechanics. In particular, he devoted considerable attention to the role played by symmetry and the least action principle in determining the shapes of things, such as minimal surfaces [1].

The book *on Growth and Form* was later cited by the French mathematician René Thom (1923–2002) in his 1972 book *Stabilité Structurelle et Morphogenèse (Structural Stability and Morphogenesis)*. Actually, Thom had spent the early part of his career as a mathematician who primarily worked in topology and received the 1958 Fields Medal. It was his later work in the classification of "catastrophes" – i.e., spaces that undergo drastic changes in their topological nature at some point in their evolution – that eventually led to his interest in how catastrophes and the qualitative theory of dynamical systems, which went back to the far-reaching work of Poincaré on celestial mechanics, might suggest more definitive foundations for the biological process of morphogenesis. This represents the emergence of recurring shapes and patterns in the evolution of species. In his much-cited work on the subject, he even went on to suggest its applications to psychology and the evolution of languages.

Psychodynamics

The dynamics of one's mental state – however one chooses to represent it – are usually though to be due to one's *emotional* state. Just as one's mental state can be primarily due to lower-brain, mid-brain, or upper-brain processes, similarly, there are emotions that correspond to each level of the brain, as well.

The lower brain is governed by primitive emotions, such as laziness, fear, and hunger, which are mostly associated with the maintenance of one's very survival in the world. The production of adrenalin in response to the demands of the amygdalla seems to play a

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[1] Dynamically, a minimal surface comes about as a shape in which the internal stresses are a minimum, such as the figures formed by soap bubbles spanned by sets of wires. Geometrically, this often takes the form of the surface of minimal area that is spanned by the same wires.

key role in the emotional state of the lower brain. These primitive animal emotions then become somewhat rationalized into more civilized one's, such as aggression, curiosity, and the pleasure principle, which says that people are often driven by the need to maximize their pleasure or minimize their pain. In particular, the "fight-or-flight" decision is a response to the perception of threat that says one must choose between facing an immediate conflict or evading it. Eventually, one is dealing with the emotions that pertain to the states that are primarily cerebral, such as faith, joy, bliss, inspiration, and the unconscious incremental processes of association that lead up to those inspirations.

Although in most situations, emotions are responses to situations in one's immediate environment, nevertheless, there is still the question of what drives the evolution of the human mind in the absence of stimuli. In general, such an intrinsic driving force for psychodynamics is referred to as a *will*, in one form or another.

For the German philosopher Arnold Schopenhauer's (1788 –1860), the dynamical principle for human life was what he called the "will to live," which he presented in his best-known work *The World as Will and Representation* (*Die Welt als Wille und Vorstellung;* published in December 1818). According to Schopenhauer, the entire world is the representation of a single Will, of which our individual wills are phenomena.

The Austrian existential philosopher Friedrich Wilhelm Nietzsche (1844 –1900) was strongly influenced by the Greek thinker Heraclitus, as well as to Schopenhauer. In his treatise on moral philosophy *Beyond Good and Evil* (published 1886), Nietzsche refined Schopenhauer's will to live into an actual will to *power*.

Since one often hears the popular Nietzsche quote: "That which does not destroy us will only make us stronger," it is interesting to consider the eventual fate of its author.

On January 3, 1889, Nietzsche suffered a mental collapse in the streets of Turin and was arrested after he caused a public disturbance. The precise nature of the incident remains unknown, but one popular version states that Nietzsche had witnessed the whipping of a horse at the other end of the Piazza Carlo Alberto, ran to the horse, threw his arms up around its neck to protect the horse, and then collapsed to the ground. In the following days, Nietzsche sent short letters to a number of friends that included Cosima Wagner and Jacob Burckhardt. In the letter to Burckhardt, he wrote: "I have had Caiaphas put in fetters. Also, last year I was crucified by the German doctors in a very drawn-out manner. Wilhelm, Bismarck, and all anti-Semites must be abolished." In addition, he commanded the German emperor to go to Rome to be shot, and summoned the European powers to take military action against Germany.

In the remaining years of his life, he was in an out of mental hospitals, when he was not being cared for at home by his sister.

Sigmund Freud, born Sigismund Schlomo Freud (1856–1939), was an Austrian who was originally trained as a neurologist, and later went on to found the psychoanalytic school of psychiatry. He is best known for his theories of the unconscious mind and the defense mechanism of repression, and for creating psychoanalysis as the clinical practice of treating psychopathology through a dialogue between the patient and a psychoanalyst, a therapy that was often referred to as "the talking cure.". He believed that sexual desire was the primary motivational energy of human life. It then formed the basis for his therapeutic techniques, which included free association, and the interpretation of dreams as a window into one's unconscious desires, as well as his theory of transference in the therapeutic relationship.

The concept of id impulses comes from Sigmund Freud's structural model of id, ego, and superego. According to this theory, id impulses are based on the pleasure principle: it demands the instant gratification of one's desires and needs. To Freud, the id represented primitive, instinctual, biological impulses, such as aggression and sexuality, which also related to the conflicting demands of the "life wish" and the "death wish." The superego represented the feedback of the higher brain, such as the conscience that one evolves from upbringing, education, and experience. Meanwhile, the function of the ego is to coordinate the demands of the two. When the impulses of the id conflict with the superego this produces feelings of anxiety, which then become conscious emotions. In order to reduce these negative feelings, the ego might use conscious or unconscious defense mechanisms in order to block them. Freud also believed that conflicts between these two structures resulted in conflicts associated with psychosexual stages of development.

Anna Freud (1895–1982) was the sixth and last child of Sigmund and Martha Freud. Her main contribution to psychology was to further elaborate on the concept of ego defense mechanisms, which she discussed in her book *The Ego and the Mechanisms of Defence* (published in 1937). Later, the American psychiatrist George Eman Vaillant (born 1934), in his 1977 book *Adaptation to Life*, categorized ego defenses into four levels of defenses:

I. Pathological:psychotic denial, delusional projection,
II. Immature:fantasy, projection, passive aggression, acting out,
III. Neurotic:intellectualization, reaction formation, dissociation, displacement, repression,
IV. Mature:humor, sublimation, suppression, altruism, anticipation.

The American psychologist Robert Plutchik (1928(?)-2006) viewed defenses as being derived from basic emotions [1]. The defense mechanisms that he recognized were: reaction formation, denial, repression, regression, compensation, projection, displacement, and intellectualization.

Alfred Adler (1870–1937) was an Austrian medical doctor, psychologist and founder of the school of individual psychology. In collaboration with Sigmund Freud and a small group of Freud’s colleagues, Adler was among the co-founders of the psychoanalytic

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[1] Plutchik, R., Kellerman, H., & Conte, H. R. (1979). “A structural theory of ego defenses and emotions.” In C. E. Izard (Ed.), *Emotions in personality and psychopathology*. New York: Plenum Press, pp. 229–257.

movement and was as a core member of the Vienna Psychoanalytic Society. He was the first major figure to break away from psychoanalysis to form an independent school of psychotherapy and personality theory.

He also differed from Freud in rejecting the sexual drive as the most fundamental of human drives in favor of what he regarded as a will to attain a state of divinity or ideal perfection, which was rooted in the philosophy of Nietzsche. This produced his most famous concept in the form of the *inferiority complex*, which comes about when the expectations and ambitions of the individual are too unrealistic to not produce conflict with their experiences.

Adler maintained that human psychology is psychodynamic in a goal-oriented sense, so one can characterize it as a *teleological* model. Constructivist Adlerians view these teleological goals as largely unconscious and *fictitious*, and usually there is a fictional final goal which can be resolved into innumerable sub-goals. For example, in anorexia nervosa the fictive final goal is to “be perfectly thin” and is then overcompensated by the weight-loss behavior of the sufferer, since the idealized self-image that they are using as the equilibrium state is unreachable compared to the delusion self-image that they currently possess.

Another motivation for human behavior comes from *peer pressure*, which has more to do with the interaction of the individual with groups of people. Although we shall have more to say about interactions in a later chapter, for now, we point out that if one thinks of the group as having one template for one’s personality and social behavior, while the individual has another then the resulting inconsistency will generally represent a conflict in both the individual and the group. Like any other conflict, it will generate negative emotions that demand compensation. Unlike the internal psychological conflicts, though, it primarily relates to social feedback mechanisms.

One clearly sees that the conception of the human mind by the early theorists of psychodynamics kept returning to some basic system concepts. The work of Pavlov and Skinner established the validity of the system model by examining how the state of the mind would affect its behavioral response to external stimuli. The work of Freud and Adler further refined the dynamics of the mental state by introducing the notions of goals, drives, internal conflicts, and responses to those internal conflicts. One could view one function of the ego then as that of maintaining a state of "psychostasis," i.e., the absence of negative emotions. The mechanism of ego defense then begins to emerge as a form of self-regulating feedback with the mind. If the equilibrium state is one of psychostasis then the negative emotions would represent perturbations of that equilibrium, and the resulting conflict would represent the "error signal" in the servo loop. The ego defenses can then be further subdivided into the ones that simply restore the previous equilibrium and the ones that represent a displacement of the equilibrium state to a new value. Clearly displacement, which amounts to substituting a different source for the negative emotions, would represent such a process, as well as sublimation, in which one converts the socially undesirable behavior that the id demands into something more socially acceptable. For instance, it is common for sexually-obsessed adolescent males to sublimate that drive into athletic competition or delinquent behavior.

Later attempts to introduce general systems concepts into psychology viewed the Pavlov-Skinner "automaton model" of the human mind as being limited by its status an essentially a closed system, through its lack of independent ambition or adaptation, in form of learning to optimize its responses. The view of von Bertalanffy, Allport, Menninger, and others was to regard the human mind as an open system in which psychostasis represented a steady state, rather than a static equilibrium. These theories became increasingly based in the theories of personality that were evolving, as well.

Economic systems

To this day, if there is a catchphrase of economics that merits the term of "mantra," it would be the phrase "supply and demand." Indeed, when the American comedian Father Guido Sarducci (a.k.a. Don

Novello) was describing the curriculum offered at his "Ten-Minute University," in which they teach you in ten minutes everything that you will remember from your college education ten years after graduation, that ubiquitous slogan was all he deemed necessary for a course in economics.

The phrase "supply and demand" was first used by James Denham-Steuart in his *Inquiry into the Principles of Political Economy*, which was published in 1767. The principle basically asserts that in a free, but competitive, economic market the price of any good or service will be directly correlated with the demand for it and negatively correlated with its supply. Consequently, its price will rise if the supply remains constant while the demand increases, or if the demand remains constant and the supply decreases.

Of course, one must always remember that the principle is an idealization that also seems to assume that people will make the best decisions in any case, which is clearly quite weak, especially when money is involved. Thus, one can still find conspicuous counter-examples of commodities on the market that have high prices despite the low-to-non-existent demand by simply browsing an Internet search engine for used books. There are innumerable cases of ex-library books that are selling for hundreds of dollars when the fact that they were *ex*--library books already suggests that the demand for them was so non-existent that they were retired from circulation. In most cases, the library would sell you the same book for less than a dollar or give it away for free, since the alternative was usually to have them destroyed, or at least recycled.

The first drawing of supply and demand curves was in the 1870 essay "On the Graphical Representation of Supply and Demand" by Fleeming Jenkin, which also included a discussion of comparative statics as it related to a shift of supply or demand, as well as an application to the labor market. The model was further developed by Alfred Marshall in his textbook *Principles of Economics* (1890).

The importance of the principle of supply and demand was also reiterated by the Scottish moral philosopher Adam Smith (1723 –1790), who was a true pioneer of political economics. In his widely-cited landmark treatise *An Inquiry into the Nature and Causes of the Wealth of Nations* (published in 1776), Smith defined another enduring first principle of the dynamics of economic systems in the form of his "invisible hand," which he described as follows: "By pursuing his own interest, [the individual] frequently promotes that of the society more effectually than when he intends to promote it."

He illustrates this by way of the example:

> "It is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to their own self-interest. We address ourselves, not to their humanity but to their self-love, and never talk to them of our own necessities but of their advantages."

Another phrasing of the invisible hand principle was given by a more modern economic pundit:

"Greed…is good."
Gordon Gecko, in *Wall Street* (1987)

Thus, to Adam Smith self-interest plays essentially the same role in economics that entropy does in thermodynamics. Not surprisingly, many of the best-established dynamical principles in economics that emerged later were in a sense "learned borrowings" from thermodynamics more generally. In particular, there was considerable focus on the formulation of a suitable notion of equilibrium that could explain the dynamics of economic systems.

By all accounts, Smith's basic personality and lifestyle were strongly reminiscent of the men who inhabited Swift's floating city of Laputa. Smith talked to himself incessantly, had occasional spells of imaginary illness, and his study had books and papers placed in tall stacks about it. Some of the anecdotes concerning his absent-mindedness were truly bizarre windows into the machinations of his mind. Once, while taking Charles Townshend on a tour of a tanning factory, during a discussion of free trade with him, Smith walked into a huge tanning pit, and required assistance to get back out. He also once put bread and butter into a teapot, and upon drinking the resulting brew declared that it to be the worst cup of tea he had ever drunk. He had also been known to go out walking and daydreaming in his nightgown, until he was 15 miles outside town before the nearby church bells brought him back to reality.

In economics, *general equilibrium theory* studies a given economy by using the assumption of equilibrium pricing, and seeks to determine the circumstances under which the assumptions necessary for general equilibrium will hold. Its objective is to explain the behavior of supply, demand, and prices in a whole economy, which might be decomposable into several or even many markets, by attempting to prove that not only do equilibrium prices for goods exist, but that all prices are at their equilibrium values. This state is called *general* equilibrium, in contrast to *partial* equilibrium, which only applies to a specific market.

In general equilibrium theory, one must distinguish economic equilibrium from market equilibrium. *Economic equilibrium* is simply a state of the world where the economic forces all balance out and in the absence of external influences the (equilibrium) values of economic variables do not change. In such a state, the quantity demanded of something equals the quantity supplied. *Market equilibrium* refers to a condition where a market price is established through competition such that the amount of goods or services sought by buyers is equal to the amount of goods or services produced by sellers. This price is often called the *equilibrium price* or “market clearing price” and will tend not to change unless demand or supply changes.

The theory of general equilibrium mostly goes back to the work of the French economist Marie-Esprit-Léon Walras (1834-1910), who first published it in 1874 in his classic treatise *Éléments d'économie politique pure, ou théorie de la richesse sociale (Elements of Pure Economics, or the theory of social wealth, transl. W. Jaffé)*. The basic principle at work in general equilibrium theory is *Walras’s Law:* Considering any particular market, if all other markets in an economy are in equilibrium then that specific market must also be in equilibrium.

The modern conception of general equilibrium theory came about in the 1950's, as a result of a model that was developed jointly by Kenneth Arrow, Gerard Debreu, and Lionel W. McKenzie. Gerard Debreu presented this model axiomatically in *Theory of Value* (1959).

The notion of displacement of equilibrium was also applied by the American economist Paul Samuelson (1915–2009), who was also the first American to win the Nobel Prize in Economics. As a graduate student at Harvard, he had studied under Edwin Bidwell Wilson, who had himself been a student of that giant of statistical mechanics Josiah Willard Gibbs. The inspiration for Samulelson's economic theory came from reading the 1876 paper by Gibbs "On the Equilibrium of Heterogeneous Substances," which eventually produced Samuelson's 1947 landmark treatise *Foundations of Economic Analysis*. In it, he used Le Chatelier's principle to establish the method of *comparative statics* in economics, which has since has proven to be a very powerful tool and found widespread use in modern economics.

Whereas Henri Bergson envisioned creative evolution as a driving principle for Nature, Joseph Schumpeter introduced a notion of "creative destruction" into the dynamics of economic models. Like the Bergsonian analogue, the presence of creative destruction was a form of spontaneity in the system that drove innovation and progress, like the phoenix rising from the ashes.

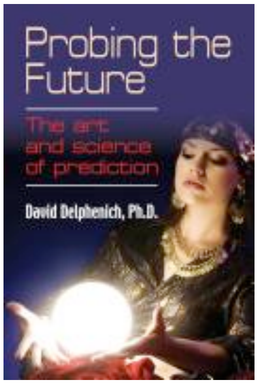
The concept had been previously introduced by the German sociologist Werner Sombart in 1913, who wrote:

> "Again, however, *from destruction a new spirit of creation arises;* the scarcity of wood and the needs of everyday life... forced the discovery or invention of substitutes for wood, forced the use of coal for heating, forced the invention of coke for the production of iron."

In *Capitalism, Socialism and Democracy*, Schumpeter then elaborated on the term in describing the sequence of transformations that are associated with radical innovations. In his vision of capitalism, it was the introduction of innovation by entrepreneurs that represented the force behind long-term economic growth, even though the innovations destroyed the previously-established way of doing business-as-usual.

Summary of some dynamical principles throughout history

Genesis:The Will of God
EmpedoclesLove and Strife
Heraclitus:Universal flux
Aristotle:Logical cause-and-effect
Descartes-Newton:A Clockwork Universe
Hamilton:Least action
Boltzmann-Gibbs:Increasing entropy
Le Chatelier:Displacement of equilibrium
Smith:Invisible hand of self-interest
Schopenhauer:Will to live
Nietszsche:Will to power
Freud:Will to pleasure (Sexual drive, libido)
Adler:Will to a state of divine perfection
Teilhard de Chardin:Will to a supreme state of consciousness (Omega Point)
La Marckcomplexifying force
Darwin:Mutation and natural selection
Bergson:Creative evolution (élan vital)
Schumpeter:Creative destruction
D'Arcy Thompson:Biology must answer to physics



The book consists of two parts. The first is a historical survey of some of mankind's attempts to predict the future since antiquity, including the visions of philosophers, scientists, inventors, writers, and filmmakers, as well as some famously bad predictions by distinguished people. The second part consists of a casual (non-mathematical) discussion of the modeling of dynamical systems and the issues that relate to predicting the future states of such systems.

Probing the Future
The Art and Science of Prediction