# A Little Book of Insights

By @PeterLodewijk
Sixth edition

# Table of contents

# Youtube presentations

The following presentations touch on some of the topics of this little book:

- **The Stewart Mackenzie Indaba #27**
  A three-hour interview in which I give my thoughts on many topics (Sep. 8, 2021)
  https://youtu.be/M_UwOVn4O08
- **A History of the Oz Multiparadigm Language**
  Seif Haridi and I explain the history and main concepts of Oz at HOPL IV (June 20, 2021)
  https://youtu.be/7f797AWIQLo
- **Why Time is Evil in Distributed Systems**
  Keynote talk given at CodeBEAM STO 2019 (May 16, 2019)
  https://youtu.be/NBJ5SiwCNmU
- **Little Things and Big Things: Lessons for Building Large Systems**
  Keynote talk given at CodeBEAM Lite Stockholm 2023 (May 12, 2023)
  https://youtu.be/h8sE3Ai8Dsk
- **Reflections on Scalability and Consistency**
  Keynote talk given at WPSDS workshop colocated with SRDS 2019 (Oct. 1, 2019)
  https://youtu.be/kJix0nMmpeU

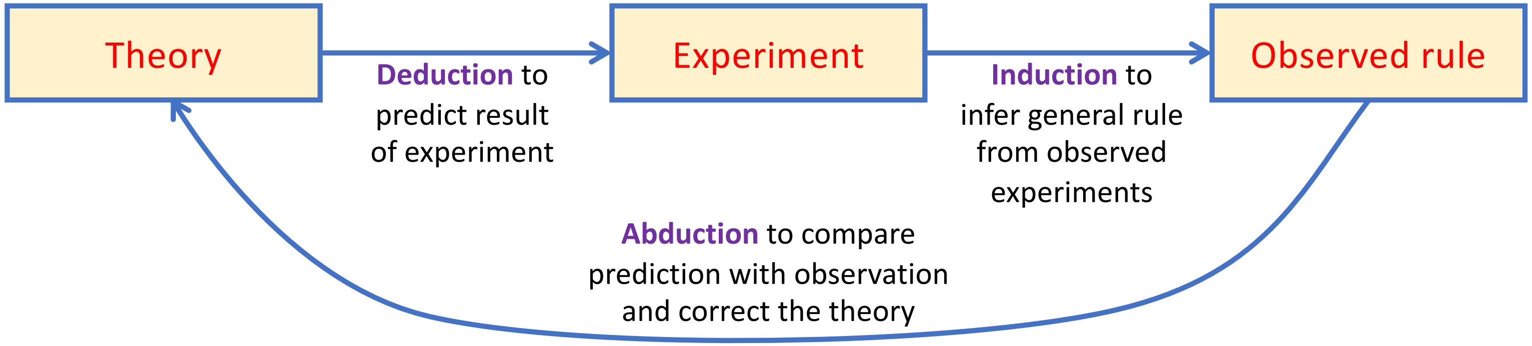
# Chapter 1

# Science

# The scientific method

# The scientific method

- The scientific method is an iterative process to improve theories of natural phenomena
  - A theory is a set of formal rules that allows predicting the observed results of experiments
  - The iterative process can disprove a theory but cannot prove a theory is completely correct




- The scientific method uses three kinds of logical reasoning in a continuous loop:
  - **Deduction**: infer a certain conclusion from a set of assumed premises by applying formal rules
  - **Induction**: infer a probable rule by generalizing from a set of observed events
  - **Abduction**: infer a possible explanation of an event ("educated guess" a cause of the event)
- Example: improving a theory to explain planetary motions in the solar system
  - **Deduction**: Compute the expected planetary motions from the theory
  - **Induction**: Observe the planets and use regression to best estimate the real planetary motions
  - **Abduction**: Compare expected with real planetary motions and correct the theory if necessary

It is believed, but it has not been proved, that *deduction*, *induction*, and *abduction* are the only possible forms of logical reasoning

# Limits of the scientific method

# Science is timid

- Science always greatly underestimates the richness of the world
- For example, we have as yet no strong proof that extraterrestrial life exists
  - Yet there are many plausibility arguments for extraterrestrial life
  - Official science however remains skeptical and continues to gather evidence:
    - Wikipedia lists 61 “potentially habitable” exoplanets that have been discovered (end 2022)
    - For our solar system, Wikipedia lists 7 liquid water oceans and 11 “possible” liquid water oceans outside of Earth (end 2022). Liquid water is known to be highly favorable for life.
    - Life exists on Earth in extreme environments. “Black smokers” on the bottom of the ocean teem with life and organisms that feed on gamma radiation have been found at Chernobyl.
  - Despite the skepticism, it is almost certain that life is abundant in the universe
- Skepticism is needed since science must protect itself against pseudoscience
  - However, it would be a good idea to have an explicit second tier of “likely science”
    - A billion-year-old water ocean would be assumed to have life in the second tier

# Science lacks imagination

- Many common ideas imagining extraterrestrial life assume that alien civilizations are organized in similar fashion to modern human society
  - Dyson sphere: assumes that future societies will be organized around energy consumption and that capturing all the energy production of a star is useful
  - Kardashev scale: assumes that future societies will be organized around mastery of the natural world and its energy sources, and that the depth of this mastery is measured by its size
  - Fermi paradox: assumes that aliens resemble us, namely that they are organic life exploring physical territories, using the electromagnetic spectrum, and poses the question why we have not seen such aliens
  - Drake equation: approximates the number of alien civilizations that resemble us, but says nothing about other kinds of civilization
- All these examples lack imagination
  - *"On a cosmic scale, all modern physics teaches us that only the fantastic is likely to be true."*
    *– Pierre Teilhard de Chardin*
  - *"My own suspicion is that the universe is not only stranger than we suppose, but stranger than we **can** suppose."*
    *– J. B. S. Haldane*

# Other limits of the scientific method

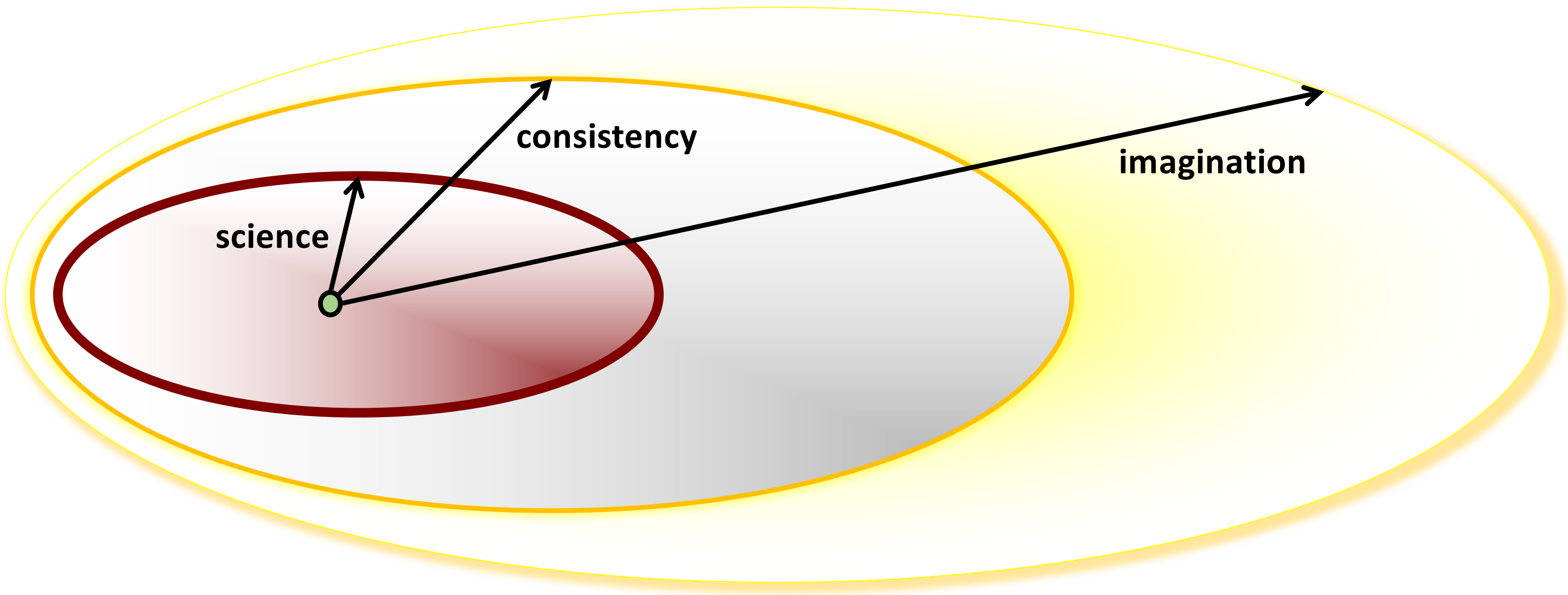
- A scientific theory can never be proved correct
  - A theory can be falsified, when an observation contradicts it, but never proved correct
- A scientific theory does not explain causes but only their effects
  - A theory only explains what can be measured, which means it only explains observations
- A scientific theory cannot explain events that occur only once ("miracles")
  - A theory is based on experiments that must be consistently repeatable and testable
- A scientific theory is a finite structure
  - There are mathematical limits to what a finite structure can explain
  - An unbounded set of historical accidents may be needed for an explanation of reality
- The scientific method is blind if the wrong questions are asked
  - Much progress depends crucially on figuring out what are the right questions
  - The main limitation of scientific progress is lack of imagination

# Beyond the scientific method

# Beyond the scientific method

- The scientific method makes rapid progress when it is applicable
  - This progress has led to modern technological civilization
  - But how can we understand areas where the scientific method does not apply?
    - Why does the universe exist? What is consciousness? What is behind appearances?
- There are three approaches to understand reality:
  - Science (the scientific method): it gives rapid progress for explaining observable events that can be measured repeatedly in controlled conditions
  - Consistency (mathematical reasoning): the consistence of a mathematical theory is by that very fact telling us something about the universe
  - Imagination (e.g., religion, literature, fantasy): an imagined world, even if not consistent, is telling us something about the universe because we ourselves are part of the universe
- It is often believed that progress comes from science, but this is wrong
  - It comes from all three approaches: mathematics and imagination are the motors of scientific progress and their inputs are what inspires scientists to ask the right questions

# Three ways to understand reality




- Science progresses through the scientific method
- Consistency progresses through mathematical proof
- Imagination progresses through internal coherence and richness

# Knowledge and the growth of humanity

- New knowledge starts as *imagination*, becomes *consistency* as it is better understood, and finally can be tested by the *scientific method*
- Ideas that today are religion or philosophy will eventually solidify through observational tests
  - Through the ages, pieces of philosophy have broken off and become sciences
- Through this long process, humanity grows up
  - We are still young as a species, barely beyond the newborn stage, but we are starting to recognize our place in existence
  - We still have many demons to slay on the way to adolescence

# Why we need faith

- Faith is “firm and unquestioning belief in something for which there is no proof” (Merriam-Webster’s Unabridged Dictionary)
    - Despite the absence of proof there can be reasons for this belief, plausibility arguments pointing the way forward
    - The belief is not fixed, it is unquestioned but still it may change as we learn new things
- Faith is important for all three approaches
    - Science requires faith: that the universe exists and obeys laws that can be discovered by human beings
    - Mathematics requires faith: that the axioms one uses are self-consistent and that they describe a meaningful mathematical world independent of humans (Platonicism)
    - Religious faith (including faith in imaginary worlds) goes beyond this: that what one believes is somehow connected to the universe and important for human morality and ethics
- Faith is an essential part of understanding the universe
    - The universe has many ways of speaking to us and faith is one way to listen to the universe

# How science changed in 1965

# How science changed in 1965

- Around 1965, scientific research made a radical break with the past
- Since then and up to the present, science has changed in two ways:
  - It makes no more fundamental discoveries, but only deepens existing ones
    - Discoveries before 1965: thermodynamics, statistical mechanics, quantum mechanics, Bell's theorem, quantum electrodynamics (QED), general relativity, Big Bang model, evolutionary biology, DNA double helix, catastrophe theory, dynamical systems (chaos theory)
    - The last major discovery, quantum chromodynamics, was made in 1973
    - Inventions before 1965: heavier-than-air flight, rocketry, plastic, atomic energy, electronics, lasers, programmable computers, Turing machine, λ calculus and Lisp, transistors, ICs
  - It no longer studies spirit, but becomes purely materialistic
    - Study of non-materialistic topics becomes marginal and is ridiculed ("New Age")
    - There are no more serious studies of consciousness; post-1965 work is all materialistic
- Development of the Internet required no new fundamental science
  - The Internet is arguably the most important technology of the last 50 years

# Some important works studying spirit

- We give a partial list of important pre-1965 works that study spirit:
  - John G. Bennett, *The Dramatic Universe*, Volume 1-4, 1956-1965.
  - Pierre Teilhard de Chardin, *The Phenomenon of Man*, 1955.
  - John B. Priestley, *Man and Time*, 1964.
  - John W. Dunne, *An Experiment with Time*, 1927.
  - Walter Y. Evans-Wentz, *The Fairy Faith in Celtic Countries*, 1911.
  - Frederic W. H. Myers, *Human Personality and its Survival of Bodily Death*, 1903.
  - Rudolf Steiner, *The Boundaries of Natural Science (selected writings)*, 1925.
  - Marvin Meyer (ed.), *The Nag Hammadi Scriptures: The Revised and Updated Translation of Sacred Gnostic Texts*, 2009.
- All these works study spirit and consciousness with a scientific mindset
  - I am still learning about matter and spirit; this list will be updated as my understanding improves
  - Despite the difficulties to make a scientific study of spirit, all these works make worthwhile contributions and provide a solid foundation for continuing the scientific study of spirit
  - In my experience, works on spirit from after 1965 are all limited to materialistic explanations

# Kelvin and Haldane

# J.B.S. Haldane

- Biologist J.B.S. Haldane has stated:

  "My own suspicion is that the universe is not only stranger than we suppose, but stranger than we *can* suppose"

- Does this mean that we are powerless to understand the universe?
- We can turn the quote around:

  "Since we are part of the universe, everything we can think of, the universe can think of too!"

- This is also a truth.  We are part of the universe, so all our wildest thoughts and speculations are relevant to exploring and understanding the universe.
- Given the enormous size and creativity of the universe, our wildest imaginary creations may be true somewhere in some form.

# Lord Kelvin

- Physicist William Thomson (Lord Kelvin) has stated:

  "When you can measure what you are speaking about, and express it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."

- The opposite is also true:

  "When we can measure something, it means we are imprisoned inside a box limited to perceive what can be expressed by a numeric value."

- When we can measure something and express it in numbers, it means that we have limited our horizon. We always need to break free to explore new concepts that we cannot yet measure by numbers.

# A theory of time

# A theory of time

- This theory is a major contribution of the pre-1965 study of spirit
  - The theory is consistent with modern physics and with free will
    - Formulated by J. G. Bennett [1] as part of his comprehensive theory of reality in *The Dramatic Universe*
  - The theory is supported by considerable observational evidence
    - Gathered by J. W. Dunne [2] and J. B. Priestley [3] from many human volunteers
- Time is three dimensional
  - Physical time axis (numerical time as measured by physics)
  - Potentialities axis (at each physical time instant, there is a set of potentialities)
  - Volition axis (a free choice made in one instant affects future potentialities)

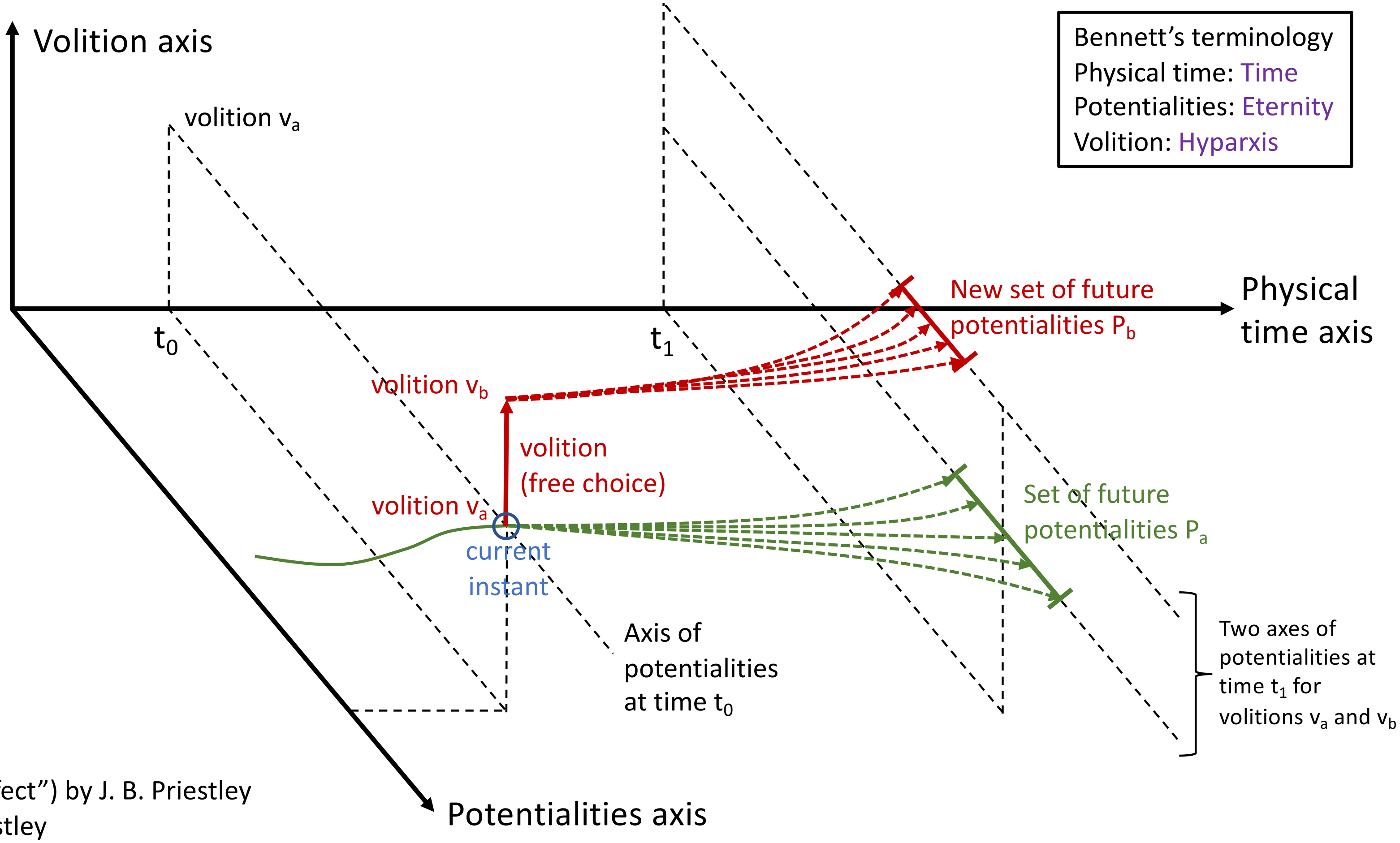
Two extra dimensions needed for free will

- Some consequences of the theory
  - Information can sometimes travel into the past, but physical objects cannot
  - The universe is both deterministic (obeys physical law) and uncertain (allows free will)
    - There is no conflict because volition (each free choice) changes the set of future potentialities
  - Free will is considered to originate outside of the universe, it is not random nor deterministic
    - The theory assumes free will exists but does not explain its origin

[1] John G. Bennett, *The Dramatic Universe*, Volume 1-4, 1956-1965
[2] John W. Dunne, *An Experiment with Time*, 1927
[3] John B. Priestley, *Man and Time*, 1964

# Visual explanation of the theory

- Advancing physical time traces the green curve in 3D time space
- At current instant $t_0$ there is a set of potentialities $P_a$ (green interval) for the future time $t_1$
- When time advances to $t_1$, one potentiality is actualized from $P_a$
- A free choice made at $t_0$ (volition $v_a \rightarrow v_b$) creates a new set of potentialities $P_b$ (red interval) at $t_1$
- Knowledge of potentialities at time $t_1$ can sometimes be perceived at time $t_0$, which influences the free choice [(1)]. The subsequent change in potentialities can give a fixpoint behavior [(2)] that has actually been observed.
- The theory preserves causality because choices only influence the future, never the past




(1) Called FIP ("future-influencing-present effect") by J. B. Priestley

(2) Called "double-mirror effect" by J. B. Priestley

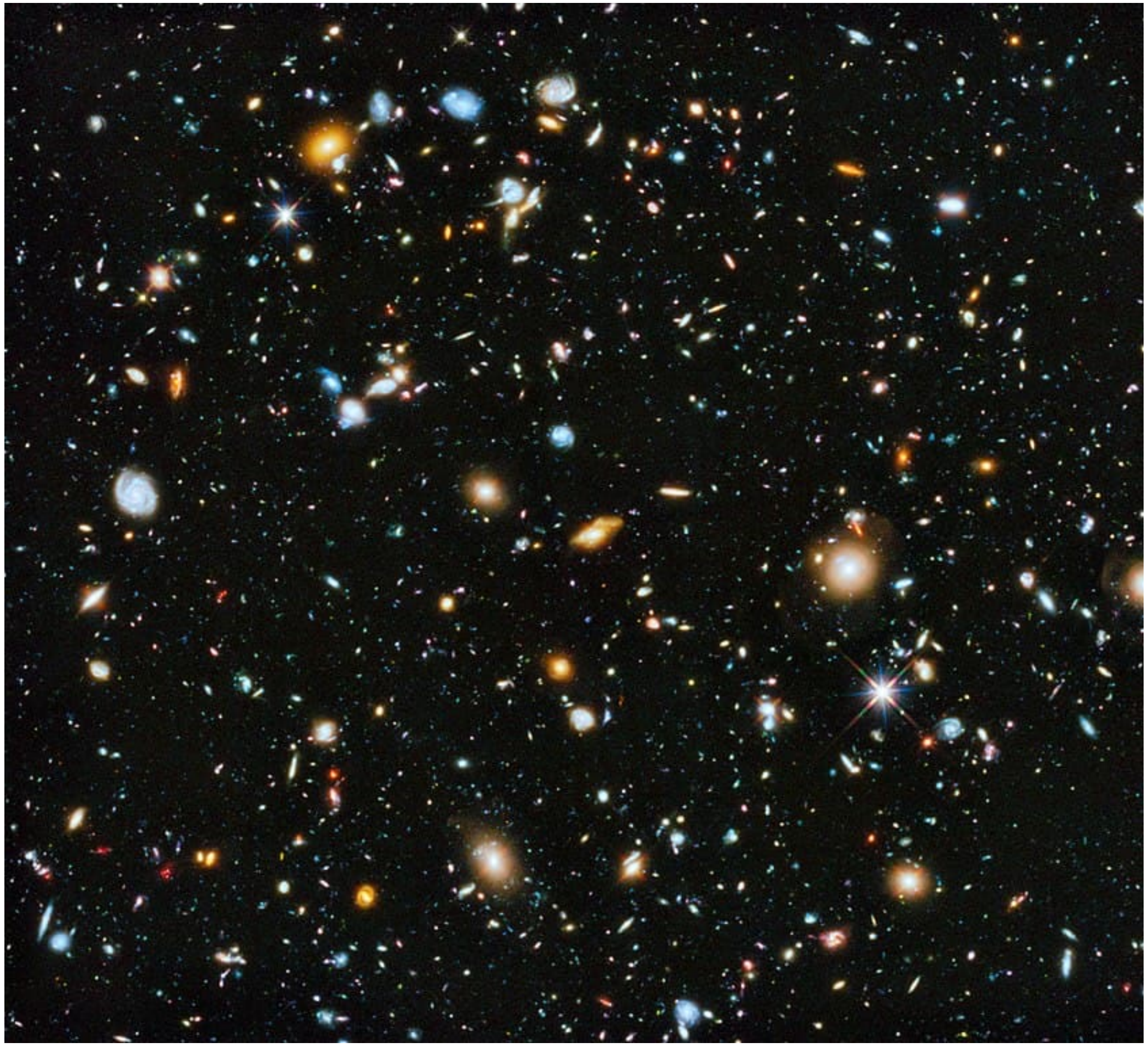
We know almost nothing

# We know almost nothing of the Earth

- We have explored almost nothing of the Earth
  - Consider exploring 1 $km^2$ over 100 years as one Exploration Unit (Ex). Simple calculation gives $2.3 \times 10^{16}$ Ex for the Earth over its history.
    - To a good approximation, we have explored zero so far
    - Remember that the Earth has *always* been highly active!
- Australia, Canada, Russia, and Antarctica have total area 48.4 million $km^2$
  - Most of this area is unpopulated and largely unexplored
- The ocean floor and the Earth's interior are almost unknown
  - The ocean's area is 361 million $km^2$ and its floor is 5000m deep and hard to reach
  - The Earth's radius is 6371km and the deepest borehole is only 12.2km deep

# We know almost nothing of the universe

- We know much less about the universe than about the Earth
  - We have just recently discovered liquid water oceans in the Solar System outside of the Earth
- Physicists affirm that black holes will evaporate through Hawking radiation and they compute its lifetime
  - Do they really believe a recent theory is the final word about what will happen in $10^{10}$ years?
  - In 1863, Lord Kelvin computed the Earth's age at around $100 \times 10^6$ years old; radioactivity was discovered in 1896
- Quantum theory is highly successful, but it is strange to our intuition
  - It is a recent theory, so it is likely much more strangeness awaits to be discovered
- Cosmology studies the universe at large scale and its origin
  - Cosmological theories have changed radically since the cosmic background radiation was first detected in 1964, so it is likely that today's theories are wrong



# Extreme events

# Extreme events


- Meteors (rocks from the sky) and ball lightning were long denied
- The existence of rogue waves was long denied by oceanographers
  - They dismissed and even ridiculed all eyewitness reports (“they were drunk!”)
  - Until satellites eventually proved that rogue waves of 30m exist
- Humans know almost nothing of rare events
  - A Carrington event can destroy the Internet and happens every couple of centuries (one happened in 1859); a Miyake event can destroy all electrical infrastructure and happens around every thousand years (one happened in 774)
  - Supervolcano explosions happen around every 50 thousand years
    - The Krakatoa eruption of 1883 ejected 20km$^3$ of rock and ruptured eardrums at 100km
    - Supervolcanoes eject more than 1000km$^3$; Yellowstone would cover continental US in 1m of ash
- Extreme events much greater than these will happen if you wait long enough
  - If you wait 1 million years, much can happen! Asteroid impacts, earthquakes, etc.

# Anomalies

# Anomalies

- Observation of nature turns up surprisingly many phenomena not explained by science
  - Anomalies are usually ignored or explained away and their proponents ridiculed. Occasionally it happens that the evidence becomes overwhelming and the anomalies are accepted. Meteors (rocks from the sky) and ball lightning are now accepted after centuries of denial. We know that birds are the descendants of dinosaurs. But many anomalies are still unexplained.
- Archeology and paleontology
  - Today's standard theory of the evolution of Homo sapiens has been laboriously created since the 19th century. But this theory reposes on very little hard evidence. According to Richard Leakey, all bone fragments can be displayed on a couple of large tables. It is generally believed that the theory is probably true. However, there are many anomalous discoveries that were either ignored or actively suppressed. They are not mentioned in textbooks so they are simply forgotten.
  - Many strange discoveries exist such as rocks in mines with live toads inside them or apparently artificial objects found in geologic layers that are estimated to be hundreds of millions of years old. Science simply ignores them.
- UFOs (Unidentified Flying Objects)
  - There are thousands of credible eyewitness reports of unexplained phenomena in the sky and of landings with occupants. Documents show that these phenomena have existed for centuries. Since the phenomena are created by intelligent beings, studying them is difficult. Studies by serious researchers have given a few conclusions, but much remains unknown.
- Cryptids (animals claimed but not proved to exist)
  - There is a mass of evidence for the existence of animals that are not generally recognized by zoology. Some of these animals have since been discovered, but many remain elusive. There may be deliberate reasons why they are so elusive.

# Some serious works on anomalies

A short list of serious books on different kinds of anomalies:

- Charles Fort, *The Complete Books of Charles Fort*. Dover Publications, 1974.
- William R. Corliss, *The Unexplained: A Sourcebook of Strange Phenomena*. Bantam Books, 1976.
- Michael A. Cremo and Richard L. Thompson, *Forbidden Archeology: The Hidden History of the Human Race*. Torchlight Publishing, 1998.
- J. Allen Hynek, *The Hynek UFO Report*. Souvenir Press, 1998.
- Edward J. Ruppelt, *The Report on Unidentified Flying Objects*. Doubleday & Company, 1956.
- Aimé Michel, *The Truth About Flying Saucers*. Pyramid Books, 1967.
- Bernard Heuvelmans, *On the Track of Unknown Animals*. Kegan Paul International Limited, 1995.
- Ivan T. Sanderson, *Abominable Snowmen: Legend Come to Life*. Adventures Unlimited Press, 1961.
- Bob Skinner, *Toad in the Hole: Source Material on the Entombed Toad Phenomenon*. Fortean Times, 1985.

# The intelligence of birds

# The intelligence of birds

- Crows have 1.5 billion neurons and parrots up to 3 billion, despite their small brains
  - Dogs have around 500 million and cats have around 250 million
- Birds show many attributes of intelligence
  - They can count at least up to seven
  - They succeed in the detour test, achieving a goal by first going away from it
  - They succeed in the mirror test, being conscious of themselves
  - They are capable of using tools
  - They recognize humans and others and remember their previous actions
  - They fully comprehend the concept of object permanence
- Since birds are the descendants of dinosaurs, how intelligent were dinosaurs?
  - Until recently, the idea that birds are dinosaurs was ridiculed, so what ridiculous idea of today will eventually be found to be true?

Evolution is just a mechanism

# Evolution is just a mechanism

- Evolution by natural selection is a mechanism that creates order from randomness
  - It combines a source of random variations (mutations) and a filter that favors fitness (survival)
  - The precise characteristics of the order depends on the historical accidents of the randomness
  - Evolution is successful because the universe allows the existence of complex systems and is stable enough that the complex systems can endure
- Is there an intentionality in nature?
  - Because evolution is based on random mutations, it is widely believed that it cannot be goal-driven. This is wrong. A goal-driven agency (natural or human) can use evolution as a mechanism. Humans use evolution to breed horses. Nobody knows what an intentionality in nature could do.
  - Therefore the existence of evolution is not an argument against intentionality in nature
- The question of intentionality in nature remains open, but it is likely
  - There are plausibility arguments in favor of intentionality
  - The main argument in favor is the existence of humans, organisms with volition that are part of the universe and who use evolution to mold nature according to their desires. If humans exist at such a small scale, it is likely that much intentionality and volition exists elsewhere in the universe.

# Real numbers are not real

# Real numbers are not real

- A mathematical real number embodies an actual infinity
  - It has infinite precision and is defined formally as a limit (Cauchy sequence)
- But we observe no actual infinities in nature
  - Nature only has potential infinities, i.e., values that increase without bounds
  - We conclude that real numbers do not exist in reality!
- Theories of physics use real numbers
  - Physics uses real numbers because of the powerful mathematics built on top of them
  - But physics predicts singularities, like the Big Bang or a black hole, which are actual infinities
  - And quantum computations need special techniques to avoid diverging (renormalization)
- It is likely that real numbers are the wrong abstraction for physics
  - Physics will have to be recast in a mathematics without actual infinities
  - Intuitionistic mathematics allows potential infinities but rejects actual infinities
  - This may be the path to successfully unifying quantum theory with relativity

# The oneness of reality

# The oneness of reality

- According to quantum physics, there is only one kind of substance
  - Matter (particles) can transform into energy and energy can transform into matter
  - A particle is an energy concentration that endures in time
- According to quantum physics, all substance is interconnected
  - There is a single quantum wave function for the whole universe
    - Studying an isolated system is always an approximation
    - Even single atoms are infinitely complex because they are linked to the whole universe
  - Turning an object by 360° inverses the sign of its wave function
    - Two turns are needed to get back the original wave function
    - This shows that the object is always connected to the rest of the universe
      - It is like a glass held in the hand that returns to its initial state when turned twice, without spilling any water
  - Measurement statistics of entangled particles correlate independent of distance (nonlocality)
    - This is consistent with relativity since no information can be transferred (Bell's Theorem)
- According to relativity, all objects always travel at the invariant speed
  - The invariant speed c is the speed of light in a vacuum
  - Overall speed combines space speed and time speed: more of one means less of the other
    - Space speed of 0 m/s means a time speed of 1 s/s; space speed of c means a time speed of 0 s/s

# Chapter 2

# Human Society

# Evolution of humanity

# Exteriorisation of function

- Hypothesis: humans evolved by successive exteriorisation of function
  - Abilities done by the human body were moved outside of the body
  - This greatly increases the possibilities of the function that is exteriorised
    - Realizing these possibilities requires intelligence, i.e., a more powerful brain
    - Exteriorisations are guided by conscious efforts of humankind
  - Exteriorised functions often outperform the functions they replace (including intellectual ones)
- A few examples (there are many others)
  - From having fur to a naked body covered by clothing
  - From claws and fangs for defense to weapons
  - From direct physical effort to harnessing animals and machines
  - From digesting food directly to cooking it to broaden acceptable foodstuffs
  - From doing by instinct to doing by learning from others (language and culture)
  - From oral transmission through memorization to transmission by writing
  - From direct reasoning to using computers for part of the reasoning
- We can make predictions
  - What abilities that we now do directly can be exteriorised in the future?
  - What is the ultimate limit of exteriorisation?

# Limits of exteriorisation

- Humans exteriorise not just physical functions but also intellectual ones
  - Transmission of information by speaking and writing (culture and science)
  - Using machines to do intellectual activities (computers)
- What are the limits of intellectual exteriorisation?
  - The human brain contains thousands of organs for reasoning
    - Language, planning, judgement, social skills, physical skills, etc.
    - Many forms of abstract thought: social thought, technical thought, imagination, etc.
  - Some have already been exteriorised and many more will be so in the future
    - The salient example in 2023 is ChatGPT: the ability to generate useful text according to complex queries, by using large deep neural networks that have assimilated existing text
    - ChatGPT was a surprise: even experts in the field did not expect that their large language models would perform so well. Quantitative increase led to unexpected qualitative increase.
- Probably all human intellectual functions will eventually be exteriorised
  - They will greatly augment human abilities in all areas and lead to independent intelligent beings (“AIs”)

# Human genetic improvement

- Exteriorisation goes hand in hand with the improvement of humans
  - Since paleontological past, hominins have always been improving genetically
  - This process will accelerate as humans understand better their own genetics
  - It is important to note that evolution is a mechanism that has been and will continue to be used by humans to improve themselves and other organisms
- What will the far future bring?
  - It will bring major changes in humans and their exteriorised companions
  - It is not possible to predict what will happen in the long term, except to say that intelligent life on Earth will be very different from what it is today
    - Ancient hominins could not predict modern humans
    - By definition, the future cannot be predicted: anything that is predicted correctly has already arrived!

# Genetic improvements to expect soon…

- Curing genetic diseases (this is already being done today)
  - CRISPR is being used today to cure genetic diseases in humans
- Rejuvenation therapy with CRISPR
  - CRISPR is a technique to do search and replace in genes of living organisms
  - CRISPR could rejuvenate living organisms by removing accumulated errors
  - A limited rejuvenation of 10-20 years should have little or no side effects
  - I hope it appears before I am too old!
- Increasing intelligence
  - We now know that brain areas encode concepts in single neurons
  - Increasing the size and connectivity of these areas will increase intelligence

# Increase in schizophrenia

# Increase in schizophrenia

- An abnormal increase in the occurrence of schizophrenia may be enabling dysfunction in society
  - Around 30% of Americans have symptoms of schizophrenia. Is this just cultural or are they really schizophrenic?
  - Compared to 30 years ago, there is much increased belief in conspiracy theories and feelings of persecution: covid denial, election denial, anti-vaxxers, climate change denial, deep state paranoia, Qanon, and so forth
- What is schizophrenia? A mental disorder where the patient is detached from reality.
  - The patient has paranoia and irrational beliefs that change daily, and often believes that TV talks to them personally
  - The patient can be intelligent and even be reasoned with, but continues to believe in their private reality
- What may have caused the increase in its occurrence? (information taken from Wikipedia)
  - The main cause is the proliferation of artificial chemicals in the environment
  - Leaded gasoline, banned in 1996, has reduced the IQ of half of the population (–6 points if born before 1970)
  - Endocrine disruptors cause birth defects, development disorders, and cancer
    - Bisphenol A (widely used in food containers), parabens (widely used in cosmetics), DDT (widely used as insecticide until ban in 1972), PCB (widely used in consumer products until ban in 1979), and many others
  - Food additives, dozens of chemicals considered “harmless” but much is unknown about them
  - Hormones and antibiotics, widely used in food production, also affect humans
  - Byproducts of various industries (chemical, refining, manufacturing) often affect humans
- The horrible consequences if this were true means it must be studied urgently

# The empty singularity

# The empty singularity

- The predicted singularity is the moment artificial intelligence surpasses human intelligence
- The singularity we are actually experiencing is quite different
  - It is a singularity of infinite brainless cleverness
    - More and more computation is used to do less and less useful work
    - Eventually, it seems that infinite computing power will be used to do nothing at all
  - Each time you load a Web page, hundreds of complex auctions are organized to determine which advertisements will be placed and how much they cost
    - The auctions are themselves based on an enormous amount of computation to analyze your preferences
  - Systems such as the ChatGPT text generator and the Youtube recommendation algorithm amplify both true and false information to create a neverending flood of plausible babble
- The Internet has become an enormous lotus-eater machine
  - We are constantly being fed by tidal waves of seductive conspiracies and exciting entertainment
  - How can we possibly escape?

# Experiencing infinity

# Experiencing infinity

- Infinity is hard to understand intuitively
  - We give some examples where you as a human can experience infinity
- The Earth's surface connects two infinities, sky and ground
  - The discontinuity between sky and ground divides your universe into two parts, yet you can touch it with your bare hands
  - Space is much bigger than the Earth, but from a human perspective both are infinite
- A beach connects three infinities, sky, ground, and ocean
  - Wading into the water, you feel all three infinities at the same time
  - The third infinity, the ocean, starts small and grows indefinitely into the distance
  - This may be one reason why the beach has an almost mystic attraction to humans

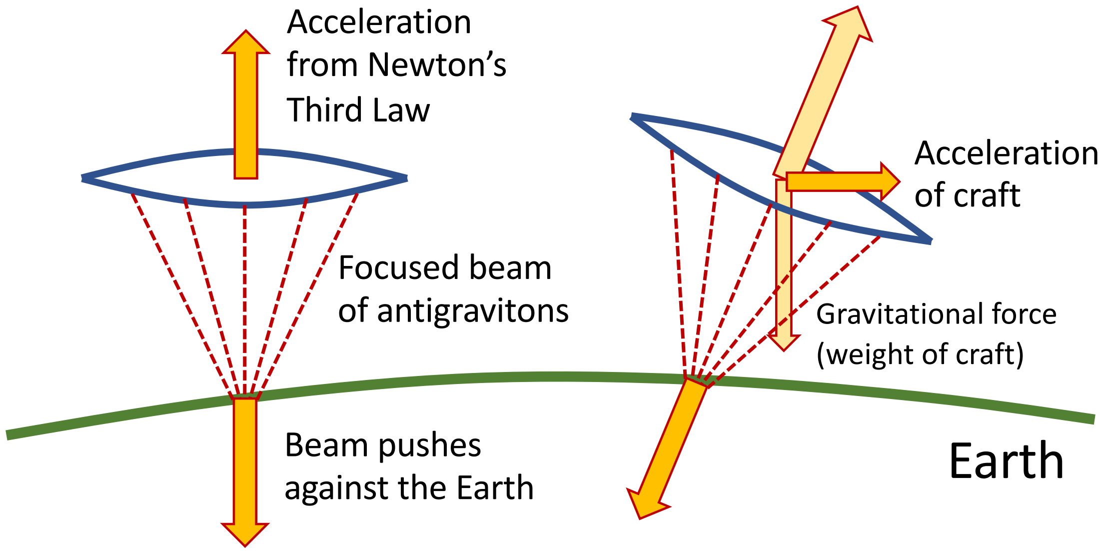
# A theory of UFO propulsion

# UFO phenomena

- As far as we know, UFO phenomena have existed for centuries
  - They cannot be studied as natural phenomena, because they are guided by intelligence. They must be studied by techniques of psychological warfare.
    - The intelligence behind the phenomena uses techniques of active deception and has technology beyond our own such as the ability to affect perception
  - There are many reliable eyewitness reports, including landings and occupants
    - The phenomena are clearly real and the reports give much useful information
  - The occupants' behavior is often absurd from a human viewpoint
    - It may be like cats observing humans. A cat does not understand why a human puts flea powder on its back. The cat sees humans as both rational and absurd.
- Reliable eyewitness reports should be believed
  - It is easy to separate honest witnesses from hoaxers who seek media attention
  - This is true for all areas, not just for UFO phenomena
  - Current science has many gaps and we should expect events that are inexplicable

# A theory of UFO propulsion

- NASA scientist Paul Hill [1] has studied the reliable reports and proposed a theory for their propulsion consistent with the reports
  - UFO propulsion could use a focused beam of gravitons or antigravitons
  - This beam could push against a massive object such as the Earth or the Sun, giving a reaction force (Newton's Third Law)
  - Craft acceleration of 100g to 1000g has been observed by eyewitness reports
  - If the beam envelops the craft, its occupants would not feel the acceleration and there would be no "boom" effect in the atmosphere
  - UFO researcher Aimé Michel [2] proposed a similar but less detailed theory in 1956
- We have no idea how to generate such a beam with current technology
  - But it would not break known laws of physics




[1] Paul Hill, *Unconventional Flying Objects: A Former NASA Scientist Explains How UFOs Really Work*, 2014

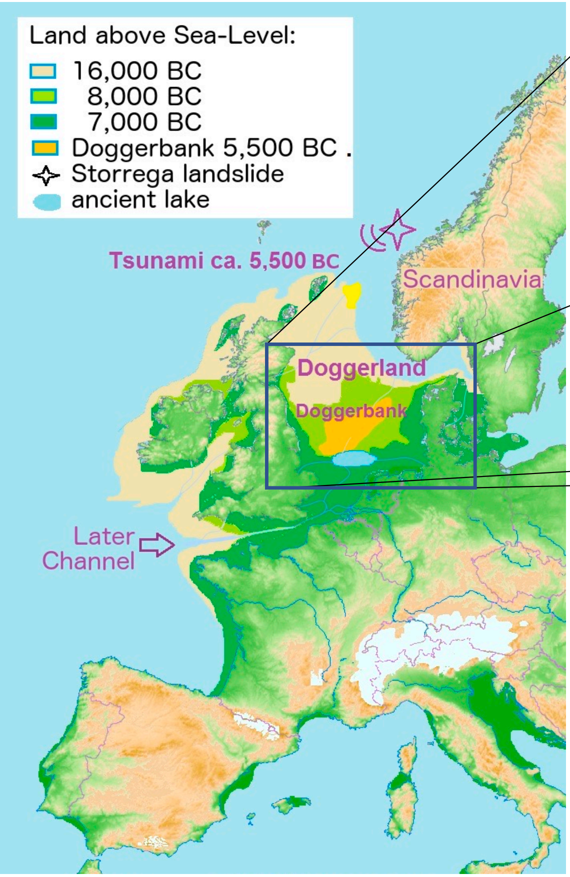
[2] Aimé Michel, *The Truth About Flying Saucers*, 1956

# A plausible theory of Atlantis

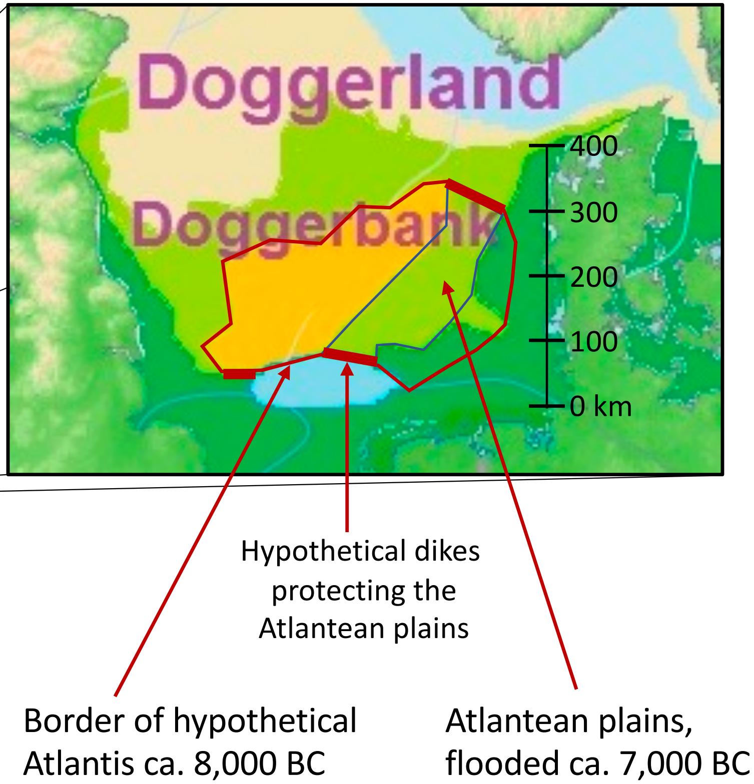
# A plausible theory of Atlantis

- Ever since Plato wrote the story of Atlantis, there has been much speculation on whether this story has a historical foundation
  - Most of these speculations are pure fantasy and almost surely wrong
- There is one plausible historical scenario for the Atlantis legend (diagram on next slide)
  - Atlantis was a Mesolithic civilization that thrived on the fertile plains between Doggerland and the Netherlands. At that time, sea level was much lower than today because of glaciers, and the plains were above sea level. These plains are several hundred km long, consistent with Plato's size estimation, and protected from the sea along their northwest flank by the Doggerland heights.
  - Over several thousand years, sea level gradually rose. The Doggerland heights remained an island, but the plains were threatened with flooding and the Atlanteans built dikes on the east and west to protect the plains.
    - There is precedent for this: in modern times, the Netherlands builds dikes to protect land below sea level
  - At some point, when the dikes were several meters high, there was a sudden breach that could not be repaired (possibly due to a tsunami) and the plains were flooded rapidly, "in a day and a night" as Plato stated
  - Sea level continued to rise for several millennia, and today Doggerland is known as the Dogger Bank
  - For more information see the book by Jean Deruelle, *L'Atlantide des Mégalithes*, France Empire, 1999
- The history of Doggerland is well-documented, for example on Wikipedia
  - The early Holocene sea level rise (EHSLR) was an increase in 60 m between 12,000 BP and 7,000 BP

# Hypothetical flooding of Atlantis




Wikipedia, Early Holocene sea level rise




- Figure taken from Wikipedia, Early Holocene sea level rise
- Between 8,000 BC and 7,000 BC, sea level gradually rose above the Atlantean plains
- To protect the plains, the Atlanteans built dikes on the northeast and southwest
  - The work was spread over several centuries, as the sea level gradually rose
  - The south dike may have been west of a lake below sea level
- The Atlantean plains that were flooded was approximately rectangular, 100 km x 300 km
  - Doggerbank remained an island for several thousand years after the flooding event

# Old books

# Old books

- The Internet contains everything, right? Wrong!
  - Many important books, magazines, and documents are not on the Internet
- Old books are obsolete and not worth looking at, right? Wrong!
  - They are treasure chests of information that can’t be found elsewhere
  - Out-of-print books can be found on eBay and AbeBooks for reasonable prices
- A few examples from my personal experience
  - Books on nomography, an old technique that deserves to come back, from early 1900s
  - Magazine “Planète” from the 1960s has not been surpassed for predicting the future
  - Science magazine “La Nature” from 1873 to 1914 is chock full of interesting articles
  - Archeology papers from early 1900s describe anomalies that should not be forgotten
  - Books on high-voltage engineering, radar technology, and electronics since 1900
  - Books that present scientific studies of non-materialistic topics from 1800s and later

# Three principles of clear writing

# Three principles of clear writing

- Writing clearly about technical topics is difficult
- These three principles have successfully guided my writing
  - I used them when writing the textbook *Concepts, Techniques, and Models of Computer Programming (2004).* This book has 929 pages and took four years to write. It is widely considered to be highly readable and is still sold in 2022.

1. If you cannot explain something simply, then you do not understand it
   - I have never seen an exception to this rule
2. Always say the truth and never say half-truths, even when summarizing
   - The truth has the immense advantage over any half-truth that it stays correct forever. You don't have to forget it as you understand better.
3. The beginning of each part should clearly summarize the whole
   - A part can be a paragraph, section, chapter, or book
   - This allows the reader to skim profitably to the relevant part

# Three fables
# for grown-up children

# Fable 1: Why the universe has three forces

- God first created gravity so stuff would come together
  - All the lumpy stuff, planets and stars and galaxies
- He then created the strong force so stuff would have variety
  - All the different elements and their isotopes
- Finally, He created electromagnetism to do all the work
  - All the hard workers like mechanics, chemistry, and biology

- Remember this kids for your own universe!

# Fable 2: Why $\pi$ and e are so small

- Why are these two numbers so small?
  - There are so many possibilities to be large, why are they so close to 1?
  - The reason is they both convert a discrete move to 2 into a continuous move to 2
  - That is why they are both just a little bit bigger than 2

- e is the “forward” number
  - Move from 1 to 2 in one step
  - Stepping continuously during the move ends up at e instead of 2

- $\pi$ is the “forward and back” number
  - Move from 1 to 2 in one step and back to 1
  - Changing direction continuously during the move gives distance $\pi$ instead of 2

# Fable 3: Why we don’t see sentient aliens

- This fable answers the Fermi question: where are the aliens?

- Humanity is young like a newborn baby
  - Aliens are old like parents
  - Does a newborn recognize its parents?
  - No, it has to grow up and learn to recognize them

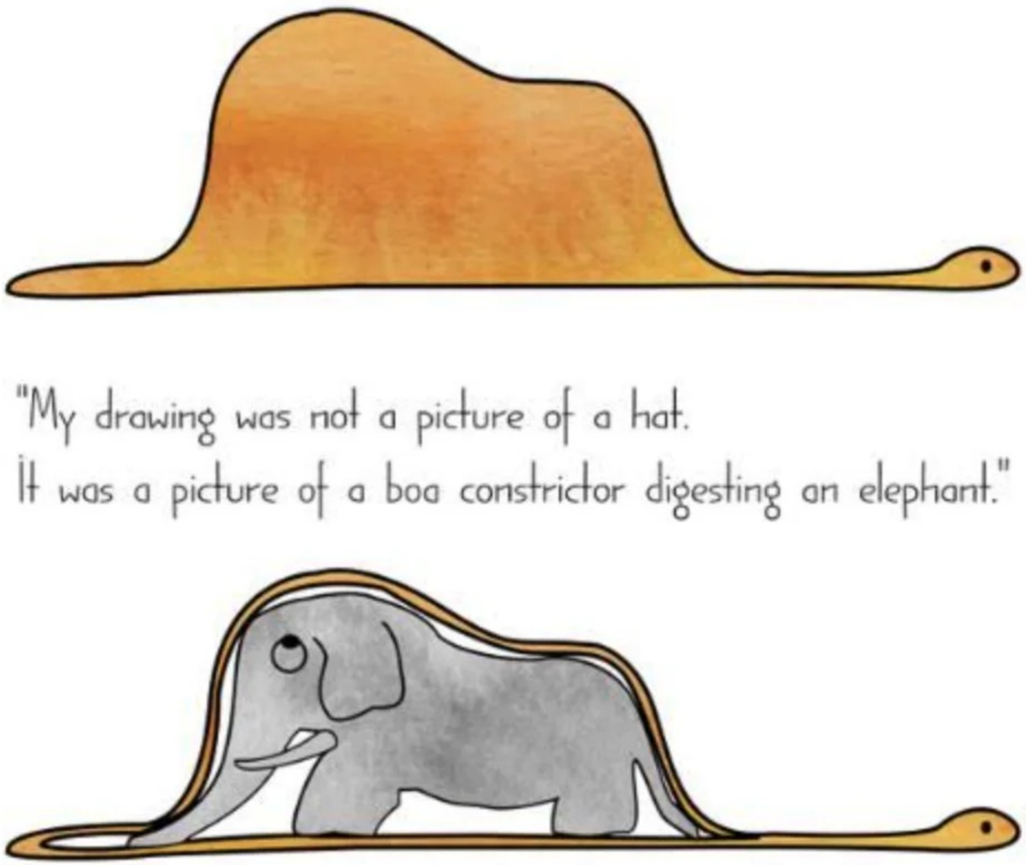
- Likewise, humanity does not recognize sentience in the universe
  - We are growing up and we will learn to recognize them

# Chapter 3

# Computers and Systems

# Programming languages

# Syntax is just the surface …



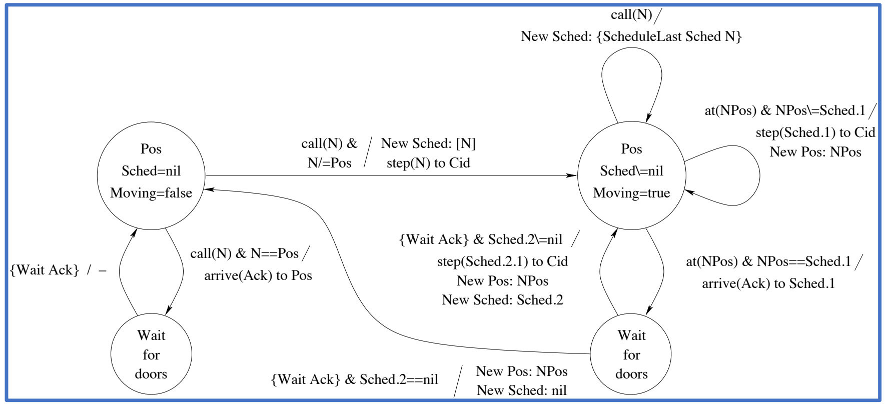

*“It is only with the heart that one can see rightly; what is essential is invisible to the eye.”*

*“On ne voit bien qu’avec le cœur. L’essentiel est invisible pour les yeux.”*

*– The Little Prince, Antoine de Saint-Éxupéry*

# … semantics is the ultimate language

Semantics of lift control system (state diagram)
(from CTM book)




Code of lift control system (in Oz)

```
declare
fun {ScheduleLast L N}
   if L\=nil andthen {List.last L} == N then L
   else {Append L [N]} end
end

fun {Lift Num Init Cid Floors}
   {NewPortObject Init
    fun {$ state(Pos Sched Moving) Msg}
       case Msg
       of call(N) then
          if N==Pos andthen {Not Moving} then
             {Wait {Send Floors.Pos arrive($)}}
             state(Pos Sched false)
          else Sched2 in
             Sched2={ScheduleLast Sched N}
             if {Not Moving} then
                {Send Cid step(N)} end
             state(Pos Sched2 true)
          end
       [] 'at'(NewPos) then
          case Sched
          of S|Sched2 then
             if NewPos==S then
                {Wait {Send Floors.S arrive($)}}
                if Sched2==nil then
                   state(NewPos nil false)
                else
                   {Send Cid step(Sched2.1)}
                   state(NewPos Sched2 true)
                end
             else
                {Send Cid step(S)}
                state(NewPos Sched Moving)
             end
          end
       end
    end}
end
```

- Programming languages are just smoke and mirrors obscuring the ultimate reality of programming, which is semantics
  - To design a system, first design its semantics
  - Coding it in a language is easy, if the language stays out of the way!
- Most programmers are too attached to syntax
  - They rarely leave the comfort zone of their favorite syntax
  - But syntax is just the surface; what really happens is underneath
  - Programmers should be polyglot: they should go beyond syntax into semantics

# λ calculus is the foundation of computing

- λ calculus
  - The single concept of function suffices to define a Turing complete language
- Higher-order programming
  - The ability to program with function values gives enormous flexibility
- Data abstraction
  - All data abstractions are defined with higher-order programming
- Large software built by teams
  - It is possible to build software too large to be understood by one person
- Information technology in society
  - The proliferation of software has enabled information technology to pervade society

# Language design is a science of nature

- Modern programming languages have evolved over more than seven decades of experience in constructing solutions to complex, real-world problems
  - Modern programs can be quite complex, with sizes measured in millions of lines of code, written by large teams of human programmers over many years
- Languages that successfully scale to this level of complexity are not just arbitrary constructions of the human mind
  - Since computers are real-world artifacts, designing languages is studying nature
  - Successful languages model essential aspects of how to build complex systems
- We would therefore like to understand languages in a scientific way, i.e., by explaining them in terms of a simple underlying model
  - Designing languages for solving complex problems is doing scientific exploration

# The golden decade of computing

# The golden decade of computing

Many concepts in computing were invented during the golden decade 1964-1974

- Data abstraction
  - Object-oriented programming (Simula-67, 1967)
  - ADT programming (CLU, 1974)
- Declarative programming
  - Functional programming (SECD machine, Landin 1965)
  - Logic programming (Absys 1965, Prolog 1972)
- Relational databases (Codd's relational model 1970)
- Software engineering (Brooks' mythical man-month 1974)
- Backtracking (Floyd 1967)
- Capability security (Dennis and Van Horn 1965)
- Semantics
  - Axiomatic semantics (Hoare 1969)
  - Denotational semantics (Scott & Strachey 1971)
  - NP completeness and the P=NP question (Cook & Levin 1971)
- TCP/IP and Internet (ARPANET 1970)
- Human-computer interfaces
  - Graphical user interfaces and mouse (Engelbart 1968)
  - Alto personal computer and WIMP (Xerox PARC 1973)
- Concurrency
  - Declarative concurrency (Kahn 1974, laziness, Kahn and MacQueen 1977)
  - Message-passing concurrency (actor model, Hewitt 1973)
  - Shared-state concurrency (monitors, Hoare 1974)
- Architecture and operating systems
  - Virtual memory (B5000 1961, Atlas 1962): before 1964!
  - Out-of-order execution (IBM 360/91, 1964)
  - Superscalar (CDC6600, 1964)
  - Timesharing operating systems (Multics 1965, Unix 1970)
  - Cache memory (IBM 360/85, 1968)
  - Pipelining (CDC7600, 1969)

# Beyond the golden decade

- Progress did not stop after the golden decade
  - The golden decade was like a dambreak: when computing technology arrived at a certain level, this enabled many latent scientific ideas to develop quickly
- New concepts continued to appear afterwards, but at a slower pace
  - Distributed computing
  - Machine learning
  - Constraint programming
  - Theoretical computer science
  - Quantum computing
- All these concepts are built on Turing equivalent computations
  - They are enabled by the enormous increase in computing power due to technological progress
  - It is possible we will eventually go beyond this, for example, as computers become embedded in the physical environment then this environment will effectively become part of the computer
    - It can be argued that human society plus computers is already beyond the abilities of Turing equivalence

# Focus on distributed computing…

- Research on distributed computing started in the 1980s
  - PODC (Symposium on Principles of Distributed Computing) started 1985
  - FLP result (impossibility of consensus in unreliable asynchronous systems) in 1985 (Fischer, Lynch, Paterson)
  - Paxos (consensus in unreliable partially synchronous systems) in 1989 (Lamport)
- Things started getting organized in the 1990s
  - *Introduction to Distributed Algorithms* by Gerard Tel 1994
  - *Distributed Algorithms* by Nancy Lynch 1996
  - Failure detectors introduced in 1996 by Chandra & Toueg
  - CAP theorem (conjecture by Brewer in 2000, proof by Gilbert&Lynch in 2002)
  - Structured peer-to-peer networks (Chord, in 2001)
  - Algorithmic understanding advanced, but programming remained hard!
- Progress in distributed ***programming*** came much later, in the 2000s
  - *Introduction to Reliable Distributed Programming* by Guerraoui & Rodrigues 2006
  - Layered decomposition of many important distributed algorithms
  - Layered concurrent component model with actor-like semantics

# Magic in computing

# Magic in computing

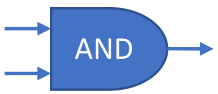
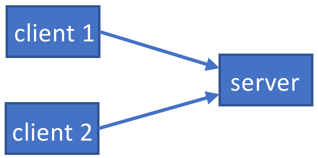
- In my research I have found three computing disciplines so good they can be described as "magical"
- Deep learning
  - Deep learning creates multilayer neural networks where the hidden nodes correspond to new concepts. The hidden nodes are trained by using derivatives of nonlinear continuous functions with the chain rule. This is creative: it can discover original concepts and new algorithms. Variations and extensions such as generative adversarial networks and large language models increase even more the abilities of deep learning.
- Constraint programming
  - Constraint programming solves complex combinatorial problems. It uses search to achieve completeness combined with sophisticated algorithms from operations research to achieve efficiency. Search is creative: it can find completely original answers. We have a project to use constraint programming as a foundation for computer-aided music composition [(1)].
- Kalman filters
  - Kalman filters are used for sensor fusion to merge sensor data to give a unified view of the environment. They combine a computed trajectory together with sensor input to predict future trajectories. Intersecting the two uncertainties narrows down the possible futures. We have developed a system for sensor fusion written in Erlang on the GRiSP platform that executes directly on the edge [(2)], that does navigation in real time and that tolerates arbitrary board and sensor failures.
- Other magic?
  - Probably many more "magical" techniques exist! What kinds of magic have you experienced? Tell me what magical techniques you have used in your own projects.

[(1)] Damien Sprockeels, Thibault Wafflard, Peter Van Roy, and Karim Haddad. *A Constraint Formalization of Fux's Counterpoint*, Journées d'Informatique Musicale (JIM 2023), May 24-26, 2023 (to appear).
[(2)] Sébastien Kalbuch, Vincent Verpoten, and Peter Van Roy. *The Hera framework for fault-tolerant sensor fusion with Erlang and GRiSP on an IoT network*, 20th ACM SIGPLAN Erlang Workshop, Aug. 26, 2021.

# Programming paradigms and nondeterminism

# Programming paradigms and nondeterminism

An executing program is nondeterministic when it makes choices that are not determined by the programmer but that are imposed from outside the program. Managing nondeterminism is one of the most difficult tasks of a programmer. Writing a program in a suitable paradigm, such as functional dataflow, greatly simplifies managing nondeterminism.

| | *Example scenario* | *Paradigm* | *Programmer advice* |
|---|---|---|---|
| Determinism | Logic gate<br><br>*The gate computes an output signal when it receives one signal on each input* | Functional dataflow<br>• Functional programming with threads and dataflow variables<br>• Deterministic: results always same ("no observable nondeterminism")<br>• Race conditions are impossible<br>• Lazy evaluation is allowed | "Concurrency for Dummies"<br>• This paradigm can be used when the program makes no choices<br>• You can **add threads at will** without affecting correctness<br>• By far the easiest and best way to write concurrent programs |
| Nondeterminism | Client/server<br><br>*The external world decides which client sends first; the server must accept the first message that arrives* | General concurrency<br>• General programming with threads and mutable state (Java, Erlang)<br>• Nondeterministic: results depend on choices made<br>• Race conditions are possible<br>• Exists in two paradigms:<br>- Message-passing (multi-agent, actor)<br>- Shared-state (monitors, transactions) | "Abandon all hope ye who enter here"<br>• This paradigm is needed when the external world makes choices that the program must accept<br>• It is hard to program and debug<br>• Unfortunately, it is heavily used in legacy code<br>• Avoid it as the pest unless you are forced to use it |

**Design guidelines**

- Write as much as possible in functional dataflow
- Only add choices if they are imposed by external world interactions
- Practice shows that most programs can be largely deterministic so that few choices are needed
- Making choices cannot be completely eliminated if the program interacts with the external world

Peter Van Roy, *LINFO1104: Concepts, Paradigms, and Semantics of Programming Languages*.
Course slides, Université catholique de Louvain, 2022. See: [www.info.ucl.ac.be/~pvr/linfo1104-handouts.pdf](www.info.ucl.ac.be/~pvr/linfo1104-handouts.pdf)

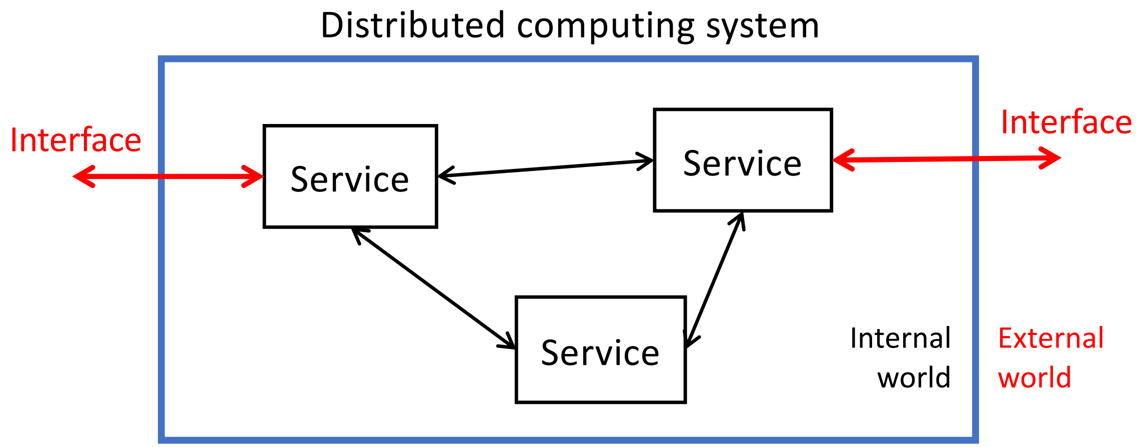
# Parable of the car

# Parable of the car


- In a car, friction is both desirable and undesirable
- The car's tires need friction to grip the road
  - Tires are the car's interface to the external world
- The car's motor avoids friction, since it causes heating and wearing out
  - The motor is inside the car

# Synchronization is like friction

Consider a distributed computing system made of services connected together and interacting with the external world




- Synchronization is only needed at the system's interface with the external world
- Internally the services should avoid synchronization
- This is the preferred way to build distributed systems

*Friction is only needed externally, so the tires can grip the road*

*Internally, the motor avoids friction*

Distributed systems should be mostly functional

# Asynchronous messages can be functional

- Functional programming is based on λ calculus
  - Its strength comes from confluence, also known as the Church-Rosser property
  - This property states that reductions can be done in any order and the result is the same
- Functional dataflow programming
  - Add dataflow variables: function result binds a variable, function argument reads a variable
  - Add threads: expressions inside a thread are reduced sequentially, threads have a scheduler
  - This is concurrent and still pure
- Distributed functional programming
  - Spread the λ expression over multiple nodes, one node binds a variable and another reads it
  - This is distributed and still pure
- Conclusion
  - Asynchronous message passing can be part of a purely functional computation
  - Message passing is only impure if it is not part of a λ computation, i.e., it has external interactions

Peter Van Roy, *Why Time is Evil in Distributed Systems and What To Do About It*.
Keynote talk, CodeBEAM 2019, Stockholm, Sweden, May 16, 2019. See: [www.info.ucl.ac.be/~pvr/Time-is-evil.pdf](www.info.ucl.ac.be/~pvr/Time-is-evil.pdf)

# Distributed systems should be mostly functional

- Distributed systems today are much too nondeterministic (too many nondeterministic choices are made)
  - Developers spend much of their time debugging race conditions
- Distributed systems should be built with almost no nondeterminism
  - The system is defined internally as a distributed functional program, which is deterministic
    - Execution must be equivalent to a λ computation
    - This allows asynchronous messages between nodes, as explained in the previous slide
  - Nondeterminism is needed only at the system boundaries
    - Where the system interacts with the external world, like clients talking to a server, as in the parable of the car
    - Using mutable state is considered to be interaction with the real world, since mutable state respects real-world time!
  - It is therefore important to define carefully what is the system boundary
    - What is internal is controlled by the developer, what is external is controlled by others
  - It is important to choose carefully what distributed algorithms to use
    - Consensus is implicitly nondeterministic and should be avoided as much as possible
    - Consistent replicated data should be implemented without consensus, e.g., with CRDTs
- When designing a new system, start with a purely deterministic base (i.e., purely functional)
  - Add nondeterminism only where it is truly needed at the boundary, nowhere else
  - Failure handling should be encapsulated to hide the nondeterminism
  - Servers should always have at least one deterministic API that knows where messages come from

# Causal consistency is only needed at the boundary

- The real world respects causal order: causes occur before their effects
  - Causes can be either direct or indirect:
    - An event $e_1$ may directly cause another event $e_2$: $e_1$ causes $e_2$
    - An event $e_1$ may indirectly cause another event $e_2$: $e_1$ causes $e_2$ if $e_1$ causes $e_m$ and $e_m$ causes $e_2$
      This rule is called **transitivity** and is applied recursively.
- A distributed system often needs to respect causal order between its events
  - This is not automatic, because message travel time between nodes can fluctuate. Enforcing causal order requires a distributed algorithm that runs on all the nodes. The algorithm has a large overhead compared to a system that just sends messages between nodes. The overhead comes from enforcing the transitivity rule, because of the huge number of possible intermediate events (for n events there are $n^2$ possible links).
- Enforcing causal order is greatly simplified for distributed functional programming
  - A purely functional distributed program does not need to enforce causality. Because functional programming is confluent, the order of message arrival is unimportant for correctness.
  - Causal consistency needs to be enforced only at the system boundaries, when the system interacts with the external world. Again, it is important to define carefully what is the system boundary.
  - Causal consistency is needed only when interacting with the real world, when the real world needs causality

# The two great frauds

# The two great frauds

- When designing systems, two great frauds must be avoided
- Systems obey inductive reasoning – *false!*
  - Past experience with systems is a bad guide for future systems, especially if the future system is going beyond the past one
- Systems obey probability distributions – *false!*
  - Probability distributions are introduced to simplify analysis, but often do not exist in reality
  - Assuming that a probability distribution exists is a very strong assumption (frequency limit exists) that is very probably wrong
- Black swan: an unexpected event that falsifies induction
  - Large systems must be designed to survive unexpected events
  - These events are often completely obvious in hindsight
  - See Nassim Nicholas Taleb, *The Black Swan*, 2010

Dijkstra's demon

| In a guarded command, any command with a true guard can be chosen. The program must work even if a demon makes the worst possible choice each time. |
| --- |
| The demon does not obey a probability distribution! |

# The first law of scalability

# The first law of scalability

- At each new scale, the situation changes…

Sam Spade: "Ten thousand? We were talking about a lot more money than this."
Kasper Gutman: "Yes, sir, we were, but this is genuine coin of the realm. With a dollar of this, you can buy ten dollars of talk."
*– The Maltese Falcon*

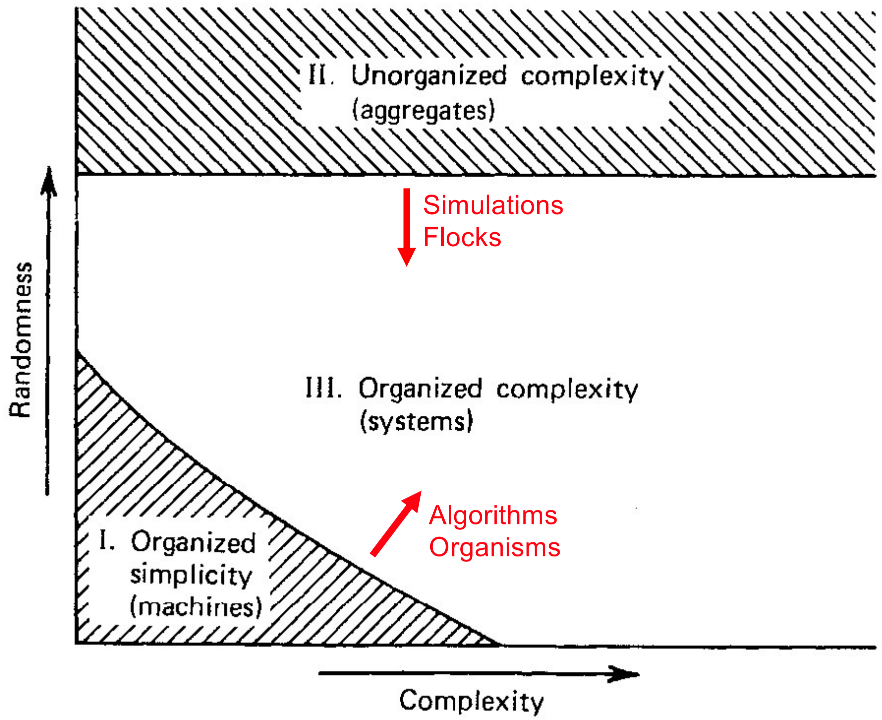
  - **No problem is ever solved for all scales** (despite claims to the contrary)
- This is a basic law of scalability in all areas
  - In large systems, we see this every day
    - Not just computing systems, but any kind of system that can get big, e.g., organizations, skyscrapers, biological organisms, etc., they all introduce new ideas at each level of scale
    - Biological systems take the lead in complexity and the more we look the more complexity we find (e.g., see Gerhard Michal, *Atlas of Biochemical Pathways*, 1999)
    - Computing systems take the lead for man-made systems

# Alps viewed from space

- This amazing sight was never seen by humans until spaceflight was invented
  - Mountaineers are impressed by the beauty of mountains, but they only see them close up
- This sight has always existed!
  - We only noticed it when we arrived there
- New ideas appear at each scale
  - They are often original and beautiful
  - As we climb to higher scales, we discover many new and amazing things
  - Nature obeys the first law of scalability

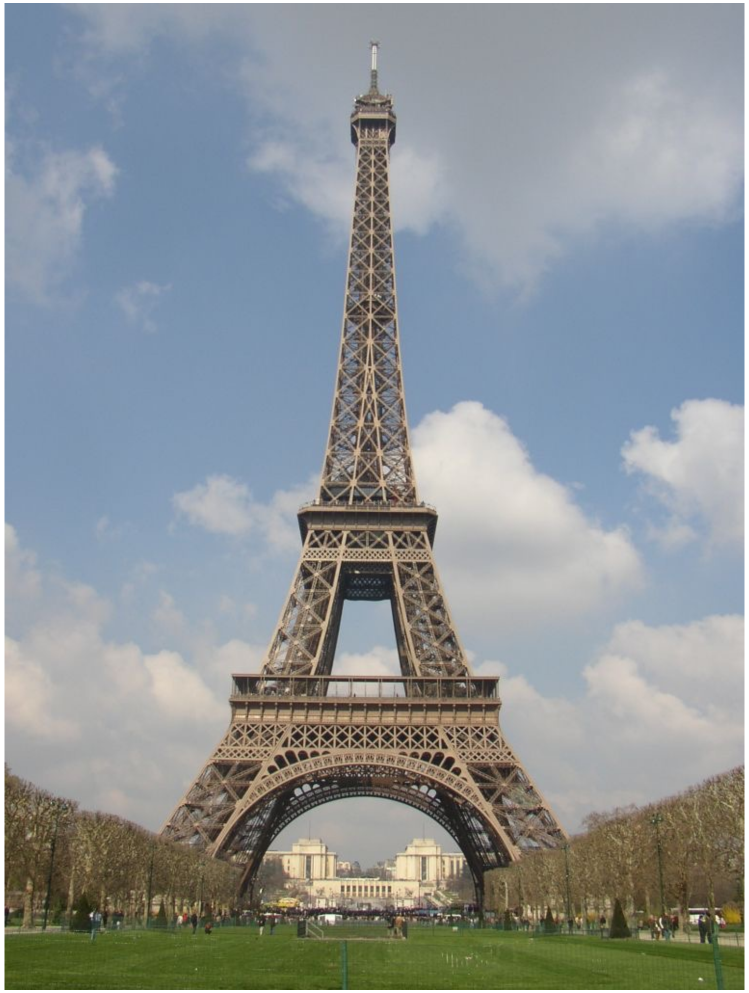
# Understanding systems

# Understanding systems



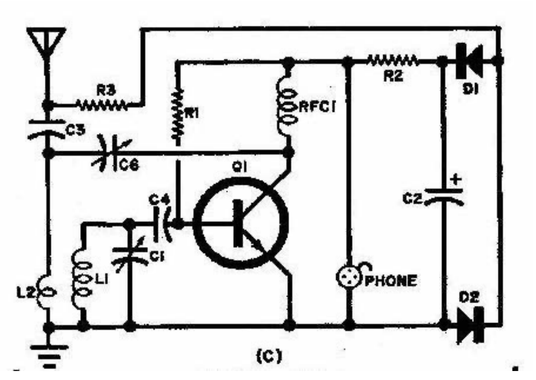

- This diagram is taken from the book *An Introduction to General Systems Thinking* (Weinberg, 1975)
- Science has made progress in understanding the shaded areas (machines and aggregates), but the white area (systems) is poorly understood
  - A system is a set of parts that interact in well-defined ways
  - We are barely starting to explore the amazing phenomena in the white area. For example, a living cell has $10^{14}$ atoms. What other surprising systems could be constructed with $10^{14}$ atoms?
- The disciplines of informatics (the engineering of new complex systems) and biology (the scientific study of existing complex systems) are pushing the boundaries of the two shaded areas inwards
  - The universe seems to be designed to favor the development of highly complex systems, a process that Pierre Teilhard de Chardin calls complexification
  - J. G. Bennett in *The Dramatic Universe* has developed a comprehensive theory of systems called Systematics to explain how the universe works

# Organized complexity built by humans



- Successful complex structures built by humans are successful precisely because they obey the essential laws of complexity
- It is therefore worthwhile to try to understand them in a scientific way

# Engineering of organized complexity: electronics




**Free-power radio**

A battery-less receiver that uses regeneration to improve selectivity and sensitivity and is able to receive short-wave as well as conventional AM transmissions.
– Terry L. Lyon, *How to Build « Free-Power Radios »,* Popular Electronics, Oct. 1973.

- Electronics is an applied science concerned with constructing practical devices based on electromagnetism
- Practical electronics, to a first approximation, assumes that electronic components obey simple (often linear) laws and are compositional, so that a circuit's properties can be deduced from its components
  - Typical components include resistors, capacitors, inductors, transistors, etc.
  - Each component behaves according to a known law
    - For example, a resistor follows Ohm's Law (E=IR)
- In reality, each component is enormously (infinitely) complex and the compositionality is approximate.  To build a circuit that pushes the envelope we must model some of this complexity.
  - A resistor has distributed inductance and capacitance and can be nonlinear
  - Simulation tools (e.g., SPICE) use complex models to analyze a circuit
    - For example, transient behavior at high frequency

# Some of the wonders of organized complexity

| Nonlinearity | *Growth, decay, and equilibrium* | *Oscillations* | | *Collective phenomena* | *Waves and patterns* |
|---|---|---|---|---|---|
| Nonlinear | Fixed points<br>Bifurcations<br>Hysteresis | Limit cycles<br>Pendulum<br>Predator-prey<br>Biol. oscillators | Controlled Chaos<br>Chaos<br>Intermittency<br>Strange attractors<br>3-body problem<br>Fractals<br>Digital electronics<br>Analog electronics | Lasers<br>Neural nets<br>Immune system<br>Economics<br>Ecosystems | Solitons<br>Earthquakes<br>Fibrillation<br>Epilepsy<br>Turbulence<br>General relativity<br>Life<br>Consciousness |
| Linear | RC circuit<br>Radioactive Decay | RLC circuit<br>Mass + spring<br>2-body problem | Newton's Laws | Solid-state physics<br>Equilibrium<br>stat. mechanics<br>Molecular dynamics | Maxwell<br>Schrödinger<br>Elasticity<br>Wave equations<br>Diffusion |
| Dimensions | 1 | 2 | ≥3 | >>1 | continuum |

Diagram modified from Steven Strogatz, *Nonlinear Dynamics and Chaos,* 1994.

- This diagram gives a sampling of what we know today about organized complexity
- Many complex systems, such as life, seem to obey simple laws in some situations, but their simplicity disappears when examined closely

# The convergence toolkit

# The convergence toolkit
## for understanding the Internet

This chart gives a (non-exhaustive!) list of convergence effects that occur whenever people interact through networks. Real-world networks are *always converging to a changing equilibrium*. Understanding this is important for organizations using networks.

This chart was compiled by Peter Van Roy from the excellent book *Networks, Crowds, and Markets* by David Easley and Jon Kleinberg (2010). The chart is simplified for brevity. Please refer to the book for explanations.

V0.2 – May 2022

- **Social networks, graphs where nodes are humans (chapter 1-5)**
  - Closure: a social-affiliation network (which has both human nodes and center of interest nodes) tends to add links ("friends of friends become friends")
  - Structural balance: a friend/enemy network evolves toward balance: 2 enemy groups (if strongly balanced) or n enemy groups (if weakly balanced)

- **Games, where players make decisions to get payoff (chapter 6, 8)**
  - Games tend to converge somewhere between two extremes:
    * Nash equilibrium, which models a pure free market
    (which is based on reciprocal best response and indifference principle), and
    * Pareto optimality, which models government regulation

- **Auctions, where a group of players compete for an item (chapter 9)**
  - Traditional ascending-bid (like eBay) are second-price auctions, which tend to converge toward bidding your true value (which is a dominant strategy)

- **Markets, where a group of buyers and sellers interact (chapter 10)**
  - Market prices tend to converge toward market clearing ("supply equals demand"), and prices are a decentralized conflict resolution mechanism

- **Trading networks, adds traders as intermediate nodes (chapter 11)**
  - Economic networks with traders converge in two ways: monopoly maximizes profits to traders and competition maximizes profits to sellers and buyers
  - Increasing the network connectivity increases the overall benefit to society and reduces individual trader profits

- **Negotiation on networks, when nodes bargain (chapter 12)**
  - Negotiation power of a node depends on its position in the network; and negotiation converges according to the following three rules:
  - Stability: convergence tends to remove instabilities
  (instability = ability for a neighbor to sabotage an agreement)
  - Balance: convergence tends to a Nash bargaining solution for all nodes (which is a solution that is considered fair by its participants)
  - Avoiding extremes: humans avoid "all-or-nothing" division of benefits

- **PageRank algorithm, to determine quality of a Web page (chapter 13, 14)**
  - Page importance is modeled as fluid flow on the Web graph; always converging to equilibrium of flow and evaporation (equivalent to random walk with jumps)

- **Cascades, when each decision is based on others (chapter 16, 17, 19)**
  - Information cascades form easily: they form when decisions made sequentially tilt too strongly one way or another, which locks in all future decisions; on the other hand they are easily broken by bringing in new information
  - Direct-benefit cascades ("network effects") get benefits from a large community:
    * Tipping point (unstable equilibrium): below, fraction of users converges to zero, above, it converges to a high value. The goal is to get beyond it.
    * Lowering price: lowering the price can sometimes convert a tipping point into a narrow passageway that converges to a high value
    * Cluster: a tightly-knit community in a network can block network cascades; this can sometimes be avoided by convincing influenceable targets to switch

- **Power law of popularity, when network growth is "organic" (chapter 18)**
  - Preferential attachment: copying earlier decisions (such as links on older Web pages) converges to a power law and gives a significant long tail

# Three Powerhouses

# Three Powerhouses

- A Powerhouse [(*)] is a long-lived energy source that illuminates its surroundings but remains hidden
  - Many Powerhouses exist in different domains. Programming languages based on Powerhouses are successful despite being "under the radar". We give three examples.
  - Even the users of a Powerhouse often don't realize its true power: they live off of the tiny sparks that it emits as it continues to burn brightly. This is especially true for Prolog and Haskell programmers!
- **Logic programming: Prolog**
  - The Powerhouse is based on the **declarative/procedural semantics**: the same program is both a statement of logic and executable on a computer
  - This is so powerful that Prolog thrives despite its limited semantics and nonlogical extensions
- **Functional programming: Haskell**
  - The Powerhouse is based on the **confluence of the λ calculus**: the execution of a program gives the same result for all execution orders
  - This is so powerful that Haskell thrives despite its limited semantics and nonfunctional extensions
- **Multi-agent programming: Erlang**
  - The Powerhouse is based on the **"let it fail" approach**: a program without sharing that fails fast can be made highly robust by adding an independent program that observes it
  - Erlang defines abstractions called *behaviors* that make it easy for programmers to take advantage of the power

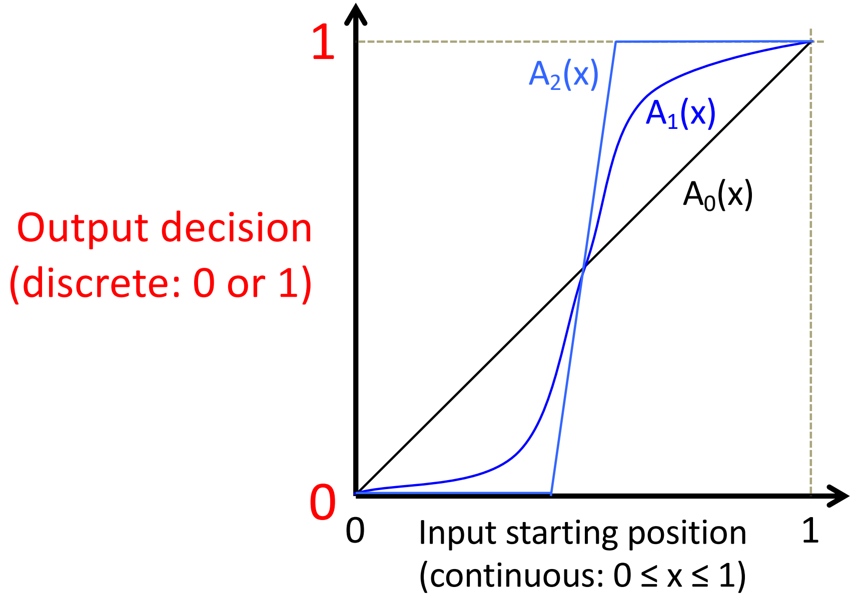
[(*)] Louis Pauwels and Jacques Bergier, *Morning of the Magicians*, 1960.

# Buridan's principle

# Buridan's principle

- Philosopher Jean Buridan stated that an ass placed equidistant between two bales of hay must starve because it has no reason to choose one over the other
  - This has surprising consequences as shown in *Buridan's Principle* (Leslie Lamport, 1984)
- Assume a system has to make a discrete decision from continuous input. Then we can prove the following:
  - A discrete decision based upon an input with a continuous range of values cannot be made within a bounded length of time
- There are many examples of this principle
  - A car at an unguarded railroad crossing, the driver stops at the crossing and proceeds when it is safe. The driver must decide whether to wait for the train or to cross.
  - A jury must decide whether a student passes or fails. As the average gets closer to 50%, the decision becomes harder and harder, because more information must be analyzed.

# Proof of Buridan's principle




Given an input x such that 0 ≤ x ≤ 1, we must decide 0 or 1

- $A_t(x)$ is the position at time t with starting position x
- As t increases with x constant, $A_t(x)$ converges to the decision 0 or 1
- Since $A_t(x)$ is continuous in t & x, there exist x for which t is arbitrarily large