Part XXIII

Future of Informatics - Chapter 2

EVOLUTION

FROM BIOLOGICAL to NON-BIOLOGICAL

and

TO THEIR MERGE

CONTENTS

WISDOMS I

- The futher backward you look, the further forward you can see.

  Winston Churchill (1874-1965)

- Our sole responsibility is to produce something smarter than we are; any problems beyond that are not *ours* to solve.
- There are no hard problems, only problems that are hard to a certain level of intelligence.
  Move the smallest bit upwards [in the level of intelligence] and some problem move suddenly from "impossible' to "obvious". Move a substantial degree upwards, and all of them become obvious.

  Eliezer S. Yudkowsky (1979-)

WISDOMS II

- In the game of life and evolution there are three players at the table:human beings, nature and machines.

  I am firmly on the side of nature.

  But nature, I suspect,is on the side of machines.

  George Dyson

BASIC STANDPOINTS

- Basic assumption 1: Methods of storing and processing information are driving forces of evolution.
- Basic assumption 2: Patternism: Patterns of information are fundamental reality.(Example: particles composing our brain and body parts keep changing within weeks - their patterns remain and they actually create brain and other parts of our body.)
- Basic assumption 3: Evolution can be seen as creating patterns of increasing order and complexity.

SIX EPOCHS of EVOLUTION

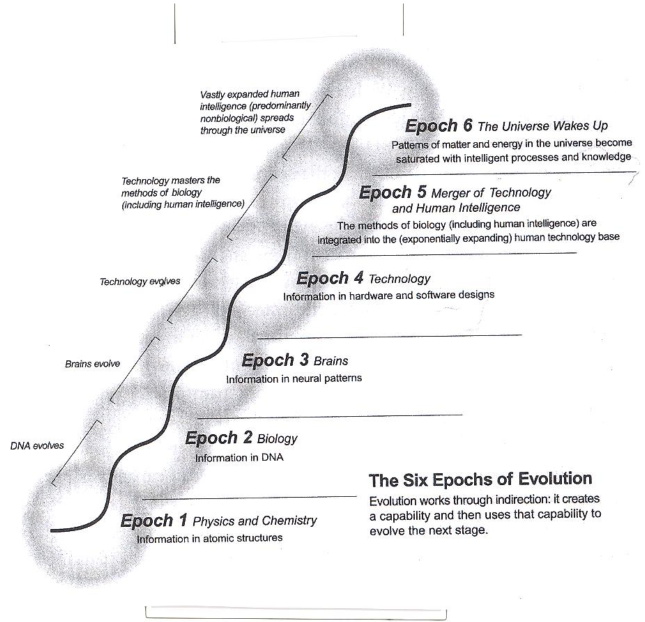
Basic observation: Each epoch creates a capability to use information-processing tools of the previous epoch to create the basis of the next epoch.

- Epoch 1: Information is stored in the basic physical and chemical structures.
- Epoch 2: Information is stored in DNA - the basis of biological evolution - and proteins are basic tools to use this information to create and guide development of living beings.
- Epoch 3: Information is in neural patterns and brains develop as qualitatively new tools to store and process information.
- Epoch 4. Brain is used to develop intelligence and that in turn is used to develop better technologies to store and process information.
- Epoch 5: Biological intelligence develops non-biological intelligence and a merge of biological and non-biological intelligence follows.
- Epoch 6: The Universe gets saturated with knowledge, non-biological intelligence and its processing systems.

- Summary: Evolution works through indictection: it creates a capability and tools and then uses them to evolve the next stage.
- Wisdom: First we build the tools,then they build us.

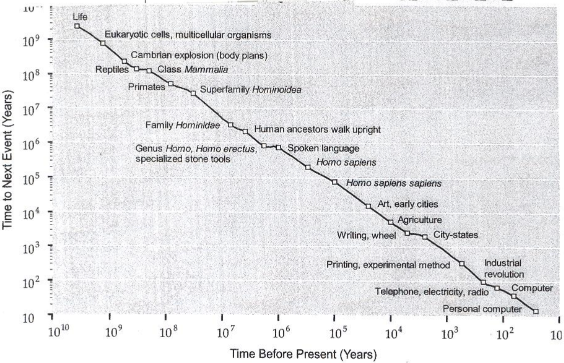
Marshal McLuhan

VISUALISATION of SIX EPOCHS



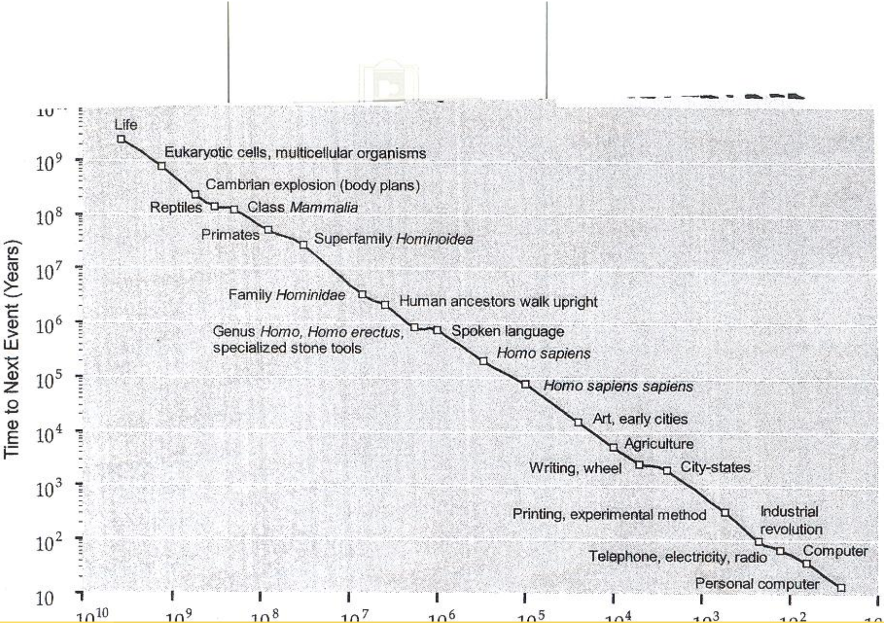
COUNTDOWN to SINGULARITY I

Logarithmic plot in the following picture shows continual acceleration of biological and technological evolution (two billion years from the origin of life to cells; 14 years from PC to the World Wide Web).



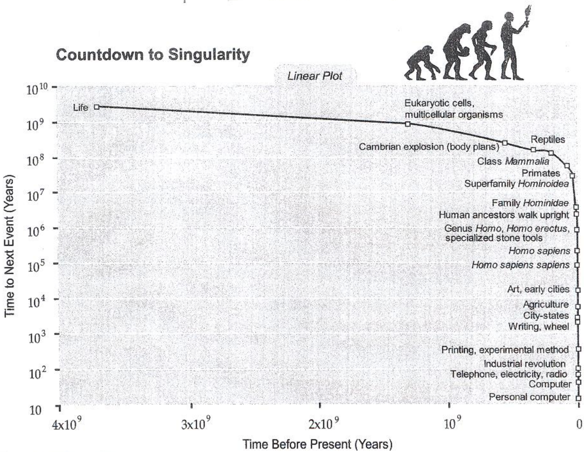
Countdown to Singularity: Biological evolution and human technology both show continual acceleration, indicated by the shorter time to the next event (two billion years from the origin of life to cells; fourteen years from the PC to the World Wide Web).

COUNTDOWN to SINGULARITY Ia



COUNTDOWN to SINGULARITY II

This time continual acceleration of biological and technological evolution is shown in a linear plot (two billion years from the origin of life to cells; 14 years from PC to the World Wide Web).

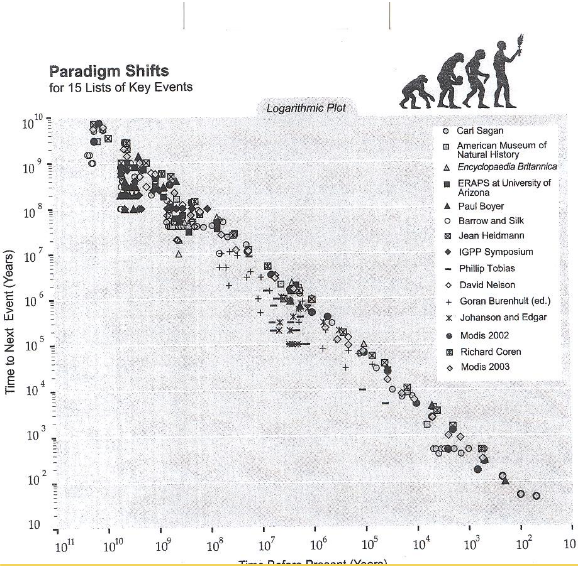


PARADIGMS and SUPERPARDIGMS

- The clock, steam engine and computer have all inspired metaphorical frameworks for science that can be called super-paradigms.
- A paradigm can be viewed as a framework of thought within which researchers in a given field practice "normal science".
- Each new paradigm leads to a different way of understanding of nature; offers new insights to old things; as well as suggesting new avenues of investigation that lead to new discoveries.
- A superparadigm is a point of view about what's ultimately fundamental in determining what happens in the world.

PARADIGMS SHIFTS

The following picture shows major paradigm shifts in the history of the world as seen by 15 different lists of key events of history.



EPOCH 1 - CREATION of PHYSICS and CHEMISTRY ELEMENTS

- We can trace our origins to an era where information was represented in the basic structures of universe - in patterns of matter and energy.
- A few thousands years after Big Bang, atoms began to be formed, as electrons became trapped in orbits around nuclei consisting of protons and neutrons.
- Chemistry elements were borned few million years later as atoms came together to create relatively stable structures called molecules.
- Of all the element, the carbon proved to be the most versatile - it is able to form bonds in four directions.

BRIEF STORY OF UNIVERSE

- The universe began a little less than 14 billion years ago in a huge explosion called Big Bang.
- As universe expanded and cooled down, various forms of matter condensed out of the cosmic soap.
- Three minutes after the Big Bang, the building blocks for simple atoms such as hydrogen had formed.
- These building blocks clumped together under the influence of gravity to form the first stars and galaxies 200 million years after the Big Bang.
- Our own sun and solar system were formed 5 millions years ago.
- Life on earth was up a little over a billion years later.

- How could something - Big Bang- came out of nothing?
- Were time and space before the Big Bang?

INFORMATION STORY of UNIVERSE

- After the Big Bang the universe was simple - it required few bits to describe it.
- The early universe remained simple, for a very short time.It could be described by just a few bits of information.The energy that was created was so called free energy.
- As universe expanded, it pulled more and more energy out of the underlying fabric of time and space.
- After a billionth of a second the universe was of an order of 10^{50} bits.
- After that billionth of a second the universe performed 10^{67} elementary operations on its bits;there was very little of free energy, order, at that time.
- Protons and neutrons, particles that make up the nuclei of atoms, condense out a little more than one millionth of second after Big Bang.
- After 3 minutes the nuclei of the lightweight atoms - hydrogen,... - had condensed;
- 380 000 years after the Big Bang stable atoms were formed.

FROM MATTER, ENERGY and ENTROPY

to

INFORMATION

STRUCTURE of ATOMS - BASIC FACTS I.

- Atoms are typically a few billions of a metre across spheres held together by electricity.
- An atom of a compact nuclei (100 000 times smaller) consists of (positively charged) protons and (without charge) neutrons;
- A nucleus is surrounded by a cloud of electrons whose masses are a couple of thousands times smaller that those of protons and neutrons;
- Electrons are negatively charged and there are so many neutrons as protons and therefore each atom as the whole is electrically neutral.
- Each electron has a wave associated with its position and velocity. The places where wave is big are places where electrons are likely to be found. The shorter the length of the wave, the faster electron is moving.

STRUCTURE of ATOMS - BASIC FACTS II

- The rate at which the wave wiggles up and down is proportional to electron's energy.
- Suppose we want to fit electron's wave around an atom's nuclei. The simplest wave that can fit around a nucleus is a sphere;the next simplest way has one peak, then two and so on.Each of these types of waves corresponds to an electron in a definite energy state.The more peaks in an electron's wave, more energy it has.
- When an electron jumps from a higher energy state to a lower energy state it emits a photon whose energy equals to the energy difference of two states.Similarly, an atom can absorb a photon and jump from one energy level to a higher energy level. Any atoms refuses to absorb a photon whose energy is not exactly the difference of some energy levels.
- Emitting or absorbing a photon takes some time.
- Usually we take ground state (corresponding to lowest energy level) as representing the basis state $|0\rangle$ of quantum bit and the next exciting state as representing the another basis quantum bit state $|1\rangle$.
- Alaser pulse takes an atom from the state $|0\rangle$ to $|1\rangle$ and vice verse.

ENERGY

- Energy is ability to do work. Energy makes physical systems to do work.
- Since by the first law of thermodynamics energy cannot increase it seems to be puzzling where energy came from.
- Quantum mechanics describes energy in terms of quantum fields - a kind of underlying fabric of universe, whose weave makes up elementary particles.
- The energy we see around us, in the form of Earth, stars, light, heat, was drawn out of underlying quantum fields by expansion of our universe.
- As universe expands, gravity (a force that pulls things together) sucks energy out of quantum fields.
- The energy in quantum fields is almost always positive, and its almost exactly balanced by negative energy of gravitational attraction.
- As the expansion proceeds, more and more positive energy is available, in the form of matter and light.

FREE ENERGY

- Free energy is energy in highly ordered form associated with relatively low amount of energy.
- The relatively small amount of information required to describe this energy makes it available for use - that is why it is called free.
- For example, energy in chemical bonds is free. (Every gram of glucose contains a few kilo-calories of free energy.)
- While one runs the free energy in the sugar is converted into motion by our muscles; after finishing running we are hot. Free energy in sugar was converted into the heat and work.
- To convert energy in the heat (which has a lot of

ENTROPY I

- Thermodynamics is governed by two main laws.
- First law of thermodynamics says that total amount of energy never changes.
- Second law of thermodynamics says that entropy - the amount of an un-useful energy, or of disorder - always increases.
- In other words, the second law of thermodynamics states that each physical system contains a certain number of bits of information - both invisible information (entropy) and visible information - and that the physical dynamics that process and transforms such information never decreases that total number of bits.
- Two laws of thermodynamics are statistical - they do not have to hold any time, they are only very likely to held.

ENTROPY II.

- The two laws of thermodynamics guide the interplay between two main actors of universe: energy and information.
- It is this interplay between energy and information that makes universe to compute.
- In 1948 Claude Shannon introduced mathematical theory of information and a measure of information - entropy.
- It has been slowly realised that these two concepts of entropy are deeply related, that they are two sides of a coin.
- Entropy is information required to specify the random motion of atoms and molecules.
- Entropy is information contained in physical systems invisible to us.
- Example: to describe an 8×6 inches color photo with 1000 pixels requires 10^9 bits; to describe all underlying atoms requires 10^{24} bits (of invisible information).

STORY of ENTROPY

- Entropy was first defined in 1865 by R, Clausius as a mysterious thermodynamic quantity that limits the power of steam engines.
- Originally entropy and heat were seen as special features of matter.
- Entropy was first seen as a measure of how much disorder or randomness is present in any (hot) system.
- At the end of 19th century Maxwell, Boltzmann (especially) and Gibbs realised that entropy was a form of information - a measure of the number of bits of unavailable information registered by atoms and molecules.
- Another view: Heat is just the energy in the jiggling of atoms. To describe the motion of atoms requires a lot of bits of information - entropy is then proportional to the number of bits required to describe the way atoms are jiggling.
- Consequence: the faster the atoms jiggle, more information is needed to describe their jiggling and therefore more entropy they posses.
- The physical quantity known as entropy came to be seen as a measure of information registered by individual atoms that make up the matter.

HOW ORDER ARISED from CHAOS?

- At the beginning the universe contained very little of information - it was features and uniform.
- One of fundamental questions is how could then such structures as suns, planets, solar systems, galaxies be created.
- Creation of order from chaos is due to randomized nature of quantum mechanical laws.
- In the process of creating such large structures gravity also created free energy that lining things require to survive.
- Every galaxy, star and planet owes its mass and position to some quantum accidents of early universe (and its butterfly effects).
- Chance and Randomness are crucial elements of Nature.

BLACK HOLES

- A black hole is a place where gravity is so strong that the velocity required to escape from it is greater than the speed of light.
- A black hole has a gravitation field as planets or stars.
- By Wheeler black holes keep records of information they absorb.
- A black hole can consume anything that exists and still be described in terms of how much information it has digested.
- In other words, the black hole converts all sorts of real things into information.
- Black holes are systems that can be described using laws of thermodynamics.
- An important open question: What is nature of information trapped in a black hole?
- A black hole has entropy that is proportional to the area of its horizon and measures the amount of information trapped beyond her horizon.
- Dozens of candidate black holes have been discovered.
- Most of galaxies, including our own, seem to have an enormous black hole in the centre - with a mass million times of that of sun.
- A black hole with the mass of Mount Everest would be no longer than a single atomic nucleus, but it would glow with a temperature greater than the centre of a star.
- A black hole is actually a very simple object. Once formed, it is featureless. From the outside one can measure only a few of its properties: mass, electric charge and angular momentum.

BLACK HOLES PARADOX

- It is known that black holes evaporate.
- It is known that information that gets into black holes cannot get out.
- All that means that information can disappear. However, quantum mechanics says that information cannot be lost.
- Quantum gravity theory therefore says that information can get lost - quantum mechanics that it cannot. Both theories turned out as excellent in describing universe or microworld.
- The above information paradox of black holes was a first example when concept of information played key role in the mainstream of physics.
- Evaporation of black holes is slow. It would take black hole the mass of the Sun about 10^{57} times the present age of universe to evaporate.

BASIC POINTS Of VIEW - A SUMMARY

- The universe is made of bits.
- Every molecule, atom and particle register bits of information.
- Every interaction between those pieces of universe processes that information by altering those bits.
- Therefore universe computes and since it is governed by the laws of quantum mechanics, it computes in intrinsically quantum fashion - its bits are qubits.
- The history of universe is therefore, in effect, a huge and ongoing quantum computation.
- What universe computes? - Itself - its own behaviour!
- As soon as universe began, it began computing. At first it produced simple patterns. Later more complicated.
- Life, human beings, language and ... all owe their existence to the intrinsic ability of matter and energy to process information.
- The computational capability of universe can also explain one of the great mysteries of nature: how such complex systems as living creatures could arise from fundamentally simple physical laws.
- The digital revolution, that is under way today, is merely the last in a long line of information processing revolutions stretching back to the beginning of universe itself - to the Big Bang.

EPOCH 2 - CREATION of LIFE and DNA

- Several billions years ago carbon-based compounds became more and more intricate until complex aggregation of molecules formed self-replicating mechanisms.and this way life originated.
- Step by step biological systems evolved a digital mechanism, DNA, to store information describing a large systems/mechanisms of molecules.
- Molecules and their supporting machinery of codons and ribosomes enabled keeping of records of the evolutionary experiments of this epoch.

OBSERVATION of CARL SAGAN

- Two billion years ago, our ancestors were microbes;
- A half-billion years ago they were something like mice;
- Ten millions years ago, they were arboreal-aps;
- A million years ago they were proto-humans puzzling out the taming of fire.

Our evolutionary ancestry is marked by mystery of change.

In our time, the pace is quickening.

LIFE AS AN INFORMATION PROCESSING PROCESS

- Science's understanding of life is is based on Darwinian evolution by natural selection, and selection is, in essence, information processing.
- Virtually all forms of life, including humans, are descendants from their ancestors, by the transmission of DNA.
- DNA information storage function alone is reason enough to regard life, as being in essence an information processing process.
- In a deep biological sense, computing is as much a part of life as eating and breathing.

HOW HUMANS FIT into the COMPUTATIONAL UNIVERSE? - I.

- The information-precessing capacity of universe, at the most fundamental level, gives rise to all possible forms of information processing.
- After the Big Bang, as different pieces of universe tried out all possible ways of producing information, sooner or later, some of them, seeded by quantum accidents, some pieces of universe succeeded to develop an algorithm to reproduce itself - such an accident led to the origin of life.
- Life evolved by processing genetic information to try new strategies for survival and reproduction.
- After trying billions of strategies, some living organism discovered sex - a technique that much increases the rate at which new evolutionary strategies and algorithms can be explored (because it speeds up the rate of genetic information processing).
- After billions of years of sex - living creatures had evolved various tools of getting and processing information - eyes, ears, brains and so on.
- During the last 100 000 years humans developed language that allowed distributed information processing, what in turned allowed cooperation, association.
- It is the richness of our tools for mining, processing and communication of information that brought human beings so far.

CELLS and INFORMATION PROCESSING

- Cell's do not need humans to perform computations. They are full of computational tricks of their own.
- Cells are actually tiny chemical calculators.
- Compared to even the best of human computers, the living cell is an information processor extraordinaire.
- However, cells are much more than computers. They make proteins needed for all life's purposes.
- Cells need to to copy DNA's genetic information for two reasons; one is to make proteins, the other is to pass important life information to new generations.
- The DNA in a cell contains enough information not only to make human (animal) body, but also to operate it for lifetime.
- Molecules within certain cells of living humans contain fruitful information about the history of human species.
- A cell's computational skills allow simple life forms to respond to their environment successfully - bacteria have no brain, yet they somehow figure out how to swim toward food and away from poison.
- Cells guide life not merely by exchange of energy among molecules - that is, simple chemistry -but by the sophisticated processing of information.
- By understanding cellular information processing, medical researchers can come up with better strategies.

SEX and information precessing

- Getting a new organism is a complicated process, requiring the formation of sex cells by so called meiosis.
- After a cell is divided by meiosis, each new cell contains only half the normal supply of genes.
- This is followed by fertilization, the merging of male and female sex cells to restore a full supply of genetic material.
- In this process of meiosis and fertilisation, DNA from two parents is cut up and recombined, giving the offspring's cells a set of DNA information that contains many similarities while still differing from both parents.
- To make kids is just a complicated information processing process.

DNA AND INFORMATION PROCESSING

- Genetic information is encoded along DNA strands using four kind of "bases" (molecular fragments that connect the two DNA strands). The basis are known/denoted by their initial letterers: adenine, thymine, guanine and cytosine.
- DNA strands stick together in a special way: A is always opposite to T and G with C.
- When it is time for DNA to divide and reproduce, the two strands split and the master enzyme comes along to build to each strand a new partner.
- When Watson and Crick discovered DNA, in 1953, they immediately realized that the secret of transmitting genetic information had been exposed.
- A gram of dried-out DNA stores as much information as maybe a trillion CD-ROM discs.
- DNA origin is believed to be close to the origin of life itself.

POTENTIAL of DNA for INFORMATION PROCESSING

- DNA in each cell contains 3 to 5 millions of base pairs;
- It can be seen as 2m long and 2nm thick and with 750 MegaBytes;
- In a human body we have 3 billions of cells, DNA as 5×10^9 km long and with 7.5 OctaBytes.
- Nature uses DNA in certain ways, mainly using proteins.
- However, there is no reason not to assume that we can try to use DNA/RNA in different ways than nature and to build nano-devises including nano-computers. Indeed,
- DNA computing has been developed already for quite a while as a form of computing that uses DNA, biochemistry and molecular biology to do computation.

- The blueprint for any given protein is called a gene and DNA is the stuff that genes are made of.
- A gene holds the instructions for producing a protein.

- Biology and informatics - life and information processing - are related. I am confident that at their interfaces great discoveries await those who seek them.

Leonard Adleman in "Computing with DNA"

- Biology had become the science how cells use information contained in genes.
- In a way, thanks to DNA and genetic code, information processing superparadigm entered life sciences sooner than computers brought it to the physical sciences.

EPOCH 3 - BRAINS ARE COMING

- DNA-guided evolution produces organisms that could detect information with their own sensory organs as well as store and process this information in their own brains and nervous systems.
- These outcomes were made possible by second epoch mechanisms (DNA and epigenic information of proteins and RNA fragments that control gene expressions), which (indirectly) created main third epoch information processing mechanisms - brains and nervous systems of organisms.
- The epoch started with evolution of organisms with ability to recognize patterns - which still accounts for the vast majority of activities in our brains.
- This epoch first culminated with species with an ability to create abstract mental models of the world they experienced and to contemplate the rational implications of these models.
- The epoch culminated with an evolution of humans with the ability to redesign the world in our minds and to put these ideas into actions.

MAIN PROBLEMS of SPECIES of the BIOLOGICAL EVOLUTION

- In early stage of biological evolution the main problem and objective of its species was to survive - to find food and to camouflage themselves from predators.
- In the later stage, when humanoids appeared, the objective evolved to the ability to out-think adversaries and to manipulate environment accordingly.

BRAIN AND INFORMATION PROCESSING

- There are little doubts that brain performs sophisticated information processing and that main progress in understanding the brain came recently from the researcher that view the brain as an information processing system.
- There is a lot of controversy whether brain is a computer in the usual (Turing machine) sense - or it is just “a dynamical systems” where a lot of information processing interactions go on.
- von Neumann was perhaps the first to explore these issues in a scientific depth.
- Computer and computer models are nowadays mail tools to get in depth into brain information processing processes.
- It seems getting clear that brain has to be seen as a computer with ever evolving hardware and with special (no) distinction between hardware and software.

COMPUTATIONAL NEUROSCIENCE

- Information precessing ideas clearly help scientists to understand how the brain's nerve cells conspire to create thoughts and behaviour.
- Design of computational functional models of brain activities is currently seen as a very important way to study brain behaviour and mind.
- The main current idea is that an understanding of brains will result in an iterative combination of bottom-up and top-down approach
- The basis of the bottom-up approach is to scan of the brain biological components and their activities and from that to derive their functionality.
  The basis of the top-down approach is to design functional and predictive models of brain elements and regions and through their simulation to determine properties of biological elements that cannot be observed directly using available scanning methods.

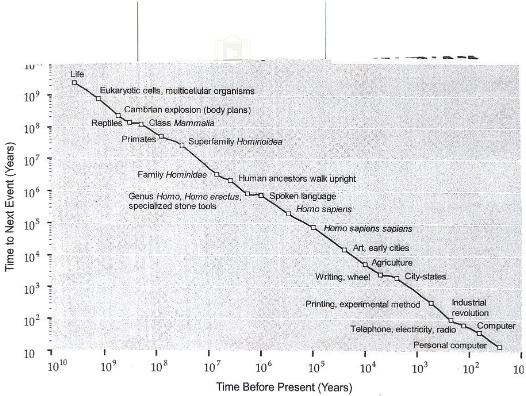
EPOCH 4 - TECHNOLOGY REVOLUTION

- Developments of brain, better and better rational and abstract thoughts as well as the development of more and more easy to use hands and legs and sensory organs, initiated development of human designed technology.
- Technology evolution started with the design of very primitive tools and developed subsequently to the design of automated mechanical machines.
- This resulted to the development of sophisticated devises for sensoring, storing, processing and communication technology capable to process sophisticated patterns of information.

To compare the rate of progress of the biological evolution to that of technology evolution, consider that the most advanced mammals have added about one cubic inch of brain matter every hundred thousands years, whereas we are roughly doubling the computational capacity of computers every 1-2 years.

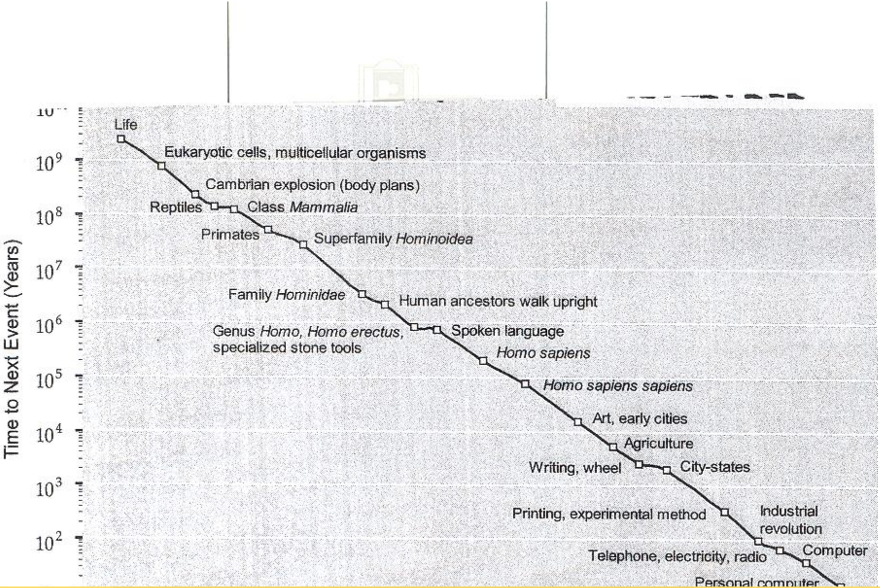
LOGARITHMIC PLOTTING of the DEVELPMENT of the BIOLOGICAL and TECHNOLOGICAL EVOLUTIONS I

If we place key milestones of both biological evolution and human technological developments on a single graph plotting both the x-axis (number of years ago) and y-axis (the paradigm shift time) on logarithmic scale , we find a reasonably straight line with biological evolution leading directly to human-directed developments.



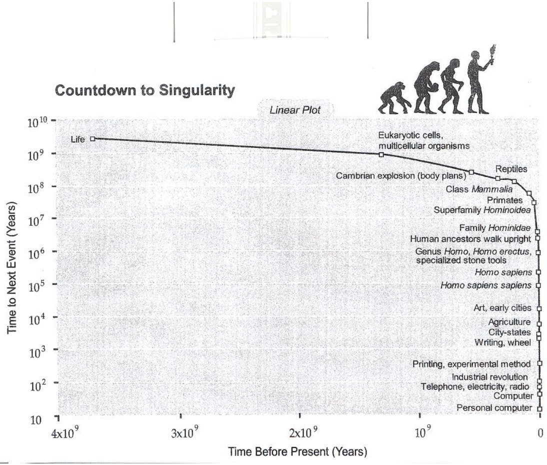
Countdown to Singularity: Biological evolution and human technology both show continual acceleration, indicated by the shorter time to the next event (two billion years from the origin of life to cells; fourteen years from the PC to the World Wide Web).

LOGARITHMIC PLOTTING of the DEVELOPMENT of BIOLOGICAL and NON-BIOLOGICAL EVOLUTIONS Ia



LINEAR PLOTTING NEAR PLOTTING of the DEVELOPMENT BIOLOGICAL and TECHNOLOGICAL EVOLUTIONS

The following figure shows the same data as the preceding figure, but with a linear scale for time present. Exponential acceleration is more visible, but details are not and from such a linear perspective most of the key events have just happened recently.



OBSERVATIONS

- The attributes that are growing exponentially in previous plots are order and complexity.
- The accelerations presented match our commonsense observations.
- A billion years ago not much happened even the course of one million year.
- A quarter-million years ago epochal events such as the evolution of our species occurred in time frames of just one hundred thousand years.
- Fifty thousands years ago not much happened even over one-thousand years period.
- Recently in World Wide Web it took a decade from inception to mass adoption (meaning that it was used by a quarter of population in advanced countries)

The term *singularity* and refers to the state of mankind after non-biological intelligence overcomes biological one.

Singularity is the future period during which the speed of technological progress will be so rapid and its impact so deep that human life will be irreversibly transformed.

EPOCH 5 - MERGE of HUMAN INTELLIGENCE and TECHNOLOGY

- It is the epoch that begins with singularity stage of society.
- Singularity will result from the merge of the vast amount of knowledge in our brains with vastly greater capacity, speed and knowledge sharing ability of our technology.
- This epoch will enable our human-machine civilization to transcend humans brains limitations of a mere hundred trillion extremely slow connections.
- **Singularity will enable us to overcome many ages-old human problems and vastly amplify human creativity.**
- Humans will be able to preserve and enhance biological intelligence that evolution has bestowed on us and at the same time to overcome many of the profound limitations of biological evolution.
- However, one has to admit that Singularity may also amplify our destructive inclinations - this has not been explored so far.

EPOCH 6 - POST SINGULARITY DEVELPMENTS - THE UNIVERSE WAKES UP

- Expectation of the developments in the aftermath of the Singularity are all on a very speculative level.
- It can be expected that intelligence, derived from its biological origin in human brains and its technological origin in human ingenuity will start to saturate matter and energy in its midst.
- This will be achieved by reorganizing matter and energy to provide an optimal level of computation to spread out from its origin on earth.
- Whether our civilisation infuses the rest of the universe with its intelligence and creativity quickly or slowly depends on its immutability.
- In any case, we can expect that the "dumb" matter and mechanisms of the universe will be transformed into exquisitely subLine forms of intelligence, which will constitute the six epoch in the evolution of patterns of information.

APPENDIX

DNA

- Deoxyribonucleic acid (DNA) is nuclei acid found in the nuclei of cells. It is the principal constituent of chromosomes, the structures that contain encodings of the genetic instructions used in the development and functioning of all known living organisms.
- The amount of DNA is constant for all typical cells of any given species of lant or animal.
- Each DNA molecul is a long, two-stranded chain made up of subunits, called nucleotides, containing a sugar, a phospate group, and one of the four nitrogenous bases: adenine (A), guanine (G), thymine (T), cytosine (C).
- DNA can be replicated, i.e. the identical copies can be made in order to transmit genetic information to the enxt generation.

PARADIGMS and SUPER-PARADIGMS

BASIC CONCEPTS and OBSERVATIONS

- The clock, steam engine and computer have all inspired metaphorical frameworks for science that can be called super-paradigms.
- A paradigm can be viewed as a framework of thought within which researchers in a given field practice "normal science".
- Each new paradigm leads to a different way of understanding of nature; offers new insights to old things; as well as suggesting new avenues of investigation that lead to new discoveries.
- A superparadigm is a point of view about what's ultimately fundamental in determining what happens in the world.

- Example: Newton's superparadigm described the universe in terms of the motion governed by force, the way the moving parts of a clockwork mechanism were driven by the pull of weight attached to ropes.
- The basic mechanistic view provided a convenient picture for understanding why things happen and how things change.
- The basic idea of force thus formed a foundation on which other science could be built in the Newton spirit.

MAIN MACHINE SUPER-PARDIGMS

Clock
- Dominant tool in the society in the medieval time.
- Tool and metaphor for science leading to new science of Newtonian mechanics.
- Metaphor for scientific world view based on force.

Steam engine
- Dominant tool in the society during the first industrial revolution
- Object of scientific study leading to new science of thermodynamics.
- Metaphor for scientific world view based on energy.

Computer
- Dominant tool in the society in the information era.
- Tool for science and object of scientific study leading to new science of quantum information processing.
- Metaphor for scientific world view based on information.

CLOCK-DRIVEN SUPERPARADIGM

- History of clocks is very old, but only after weight-driven mechanical clocks were invented the clockwork metaphor of universe started to catch on.
- Clocks were hot commodities already around 1320; around that time communal clocks began to appear in most of towns of any significant size.
- Soon some of them started to depict movements of sun, moon and some of planets - for example in the cathedral in Strasbourg in 1354.
- Nicole Oresme was first, in 14th century, who explicitly formulated a clock-like vision of universe.
- In his famous *Principia* of 1687 Newton transformed the metaphor of clockwork into something more tangible - called *force*.
- Newton's force prevailed as the central concept of physics for a century and a half.

STEAM ENGINE DRIVEN SUPER-PARADIGM

- The steam engine story started in 1698 when Thomas Savery in Britain patented a steam device for pumping water out of coal mines.
- A key improvement was done by James Watt in 1765 and soon Watt-style steam engines became a driving force of the industrial Britain.
- For a long time there was a very little scientific understanding of steam engines. This has changed in 1824 when Sadi Carnot formulated physical principles underlying the workings of steam engine and in doing so he identify general principles that constrained operations of any heat engine.
- Carnat's work gave rise to thermodynamics and its laws and thermodynamics description of nature led to establishment a new central concept of science - energy.
- Carnat's work gave rise to thermodynamics and its laws and thermodynamics description of nature led to establishment a new central concept of science - energy.
- The ideas that temperature is a measure of energy in random motion and entropy is a measure of information underlie what is called statistical formulation of thermodynamics.

- Pascall-Leibnitz calculators.
- Babbage's Difference engine and Analytical Engine.
- Turing machines
- From Zuse, through Collosus to ENIAC.
- From Benioff through Bennett to Feynman - quantum computer
- From Deutsch through Simon to Shor - quantum computation.