sonar

Simulation Stories

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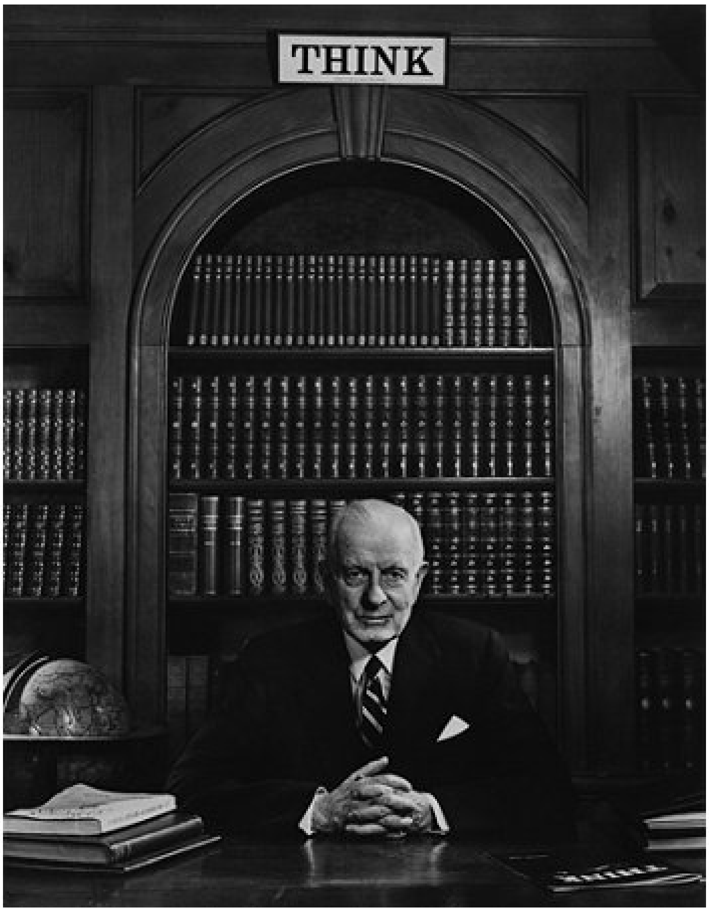


Thomas J. Watson, IBM

There was a time when the term 'computer' was synonymous with 'IBM' and vice versa. People spoke of so-called electronic brains or thinking machines, i.e. devices of which no one really knew how they functioned.

Content

Early experiments with simulations

As early as the 1920s, a certain Lewis Fry Richardson described in his book ’Weather Predictions by Numerical Processes’ an arrangement for using finite difference methods to calculate weather forecasts. He envisioned a spherical hollow space which was divided into a grid of cells. The room was a replica of the earth's surface. In each grid cell sat a human "computer", which covered an area of the earth's surface. Each computer calculated the physical values for the next point in time in its cell based on various physical quantities such as pressure and temperature in the vicinity of its nearest neighbors. In the center of the sphere was a conductor, which provided for the synchronization of the computers. Modern computer programs for weather forecasting and climate calculations work in principle (purely computationally) in exactly the same way. However, we know today that the individual human computers of Mr. Richardson, even if they had calculated around the clock, would have been several orders of magnitude too slow to deliver a useful result in a reasonable time.

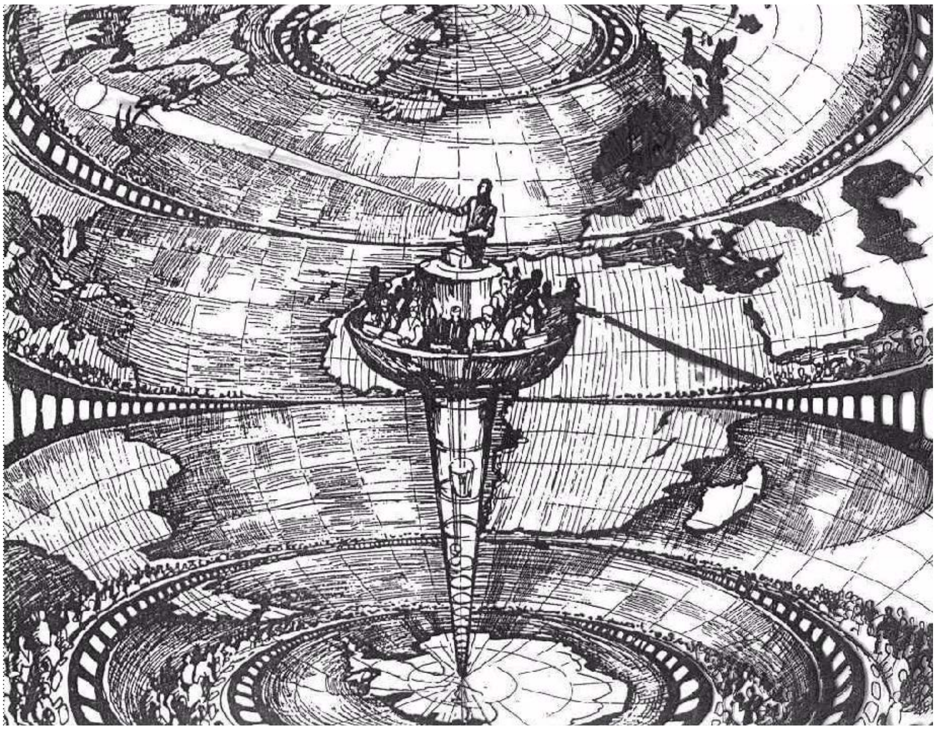


FIGURE 1. Weather forecast according to the ideas of Lewis Fry Richardson

SIN code

The so-called SIN-code is one of the oldest computer programs written for the simulation of shock waves in connection with metals and explosives. Like so many computer programs of this kind, it originated in a military-scientific research institute in the USA. Developed in the 50's of the previous century, it has been in use since about 1960 until today. The SIN-code is spatially a 1-dimensional program and can be used consequently only for purely planar and spherically symmetrical problems.

The name 'SIN' was given to the program by the first users because the calculations on the computers of that time took days or weeks. It was considered as a violation of divine laws to carry out such complex and time-consuming calculations to question with it the divine creation of physical processes. At that time one could not imagine that the computing time of simulations shrank on minutes by the progress in the computer hardware already in the 70's and that today they might take a few seconds or less on a modern personal computer.

FIGURE 2. IBM 7090 at the Ames Research Center of NASA 1961

The first versions of this code were still written in pure machine language and used on IBM-7090 and 7030 computers. Later in the 60's the program was rewritten to the first scientific computer language FORTRAN. L&G Software implemented the SIN-code during the dawn of the personal computer era in the early 80's using the programming language 'Pascal' on an Apple-2 computer and performed the first scientific finite difference calculations of detonics problems on PCs.

The butterfly effect

As scientists learned to use simulation programs, it became obvious that the initial conditions of a simulation play an important role in the accuracy of the results. By initial conditions we mean the exact physical values before the start of the simulation. These include, among many others, the mass, center of gravity, geometry, velocity, etc. of each individual part participating in the simulation. The listed quantities are not yet very problematic in this respect. It becomes more difficult when physical boundary phenomena such as friction or damping effects during impacts come into play, effects that have always been difficult to estimate in engineering.

Initial conditions play a particularly important, not to say central, role in chaotic phenomena. We are now talking about the weather forecast. It's a fact that a very small change in the initial conditions can, or rather will, cause the weather to change in a completely different direction after some time, first locally and later globally. That this happens is not dependent on the absolute magnitude of that change. If the change is made smaller, then the weather change is simply delayed, but it comes.

If now, to give an example, a weather forecast is made on the computer with given initial conditions, then one will find, for example, that the forecast agrees quite accurately with reality for about three days, tends to remain correct for two more days, and then changes to a different direction. In retrospect, one can now examine more closely where the causes of these errors lie. One can manipulate the initial conditions until one finally achieves that the weather with slightly different initial conditions would have matched reality up to seven or eight days. So a small change leads to a different weather after a few days.

We want to refine the said now with the following thought experiment. Let us now consider only the simulation program for the weather forecast alone, uncoupled from the real weather. With given initial conditions we let the program make a hypothetical forecast for the next 180 days.

Now we get to the point and do the following. We change the initial wind speed locally, at a single location by an infinitesimally small value, or by the smallest possible value that the computer can just handle. This is a blast of air produced by a butterfly flapping its wings. All the rest of the initial conditions are taken over identically. If we now start the simulation again, we will observe that e.g. four or five months later suddenly visible deviations build up somewhere which lead to the fact that after six months the weather develops differently over a large area and a hurricane is formed over the Atlantic which did not develop during the first simulation.

Of course, this butterfly effect cannot be verified or reproduced in reality. But on the computer you can see it. This effect has nothing to do with the equations used or with the mathematical model of weather physics. It also has nothing to do with a problem that exists only on the computer. Rather, it has something to do with the behavior and functioning of nature itself. A butterfly influences the weather...

Now is this reality or rather a philosophical problem?

Chaos theorists tell us that it's true. Every living being that stirs or moves somewhere in this world thus contributes its own part to the weather development. Not Saint Peter makes the weather - everybody and everything makes it.

NASA's Saturn rockets

The Saturn-V rocket, which took the American astronauts to the moon, was the first major project to be calculated using the finite element method. The first ideas for the development of FE software emerged around 1960. During the first half of the 1960s, a consortium was formed to develop software called NASTRAN (NAsa STRuctural ANalysis). The designers of the Saturn rocket were aware that vibration and oscillation problems were becoming more dangerous and increasingly difficult to control as the rocket structure expanded. A visionary scientist (Tom Butler) at the Goddard Space Center had the idea to perform these vibration tests on the computer instead of building a huge vibration test system that would have to vibrate the entire real rocket. Thus was born the NASTRAN software and a new way to solve engineering problems.

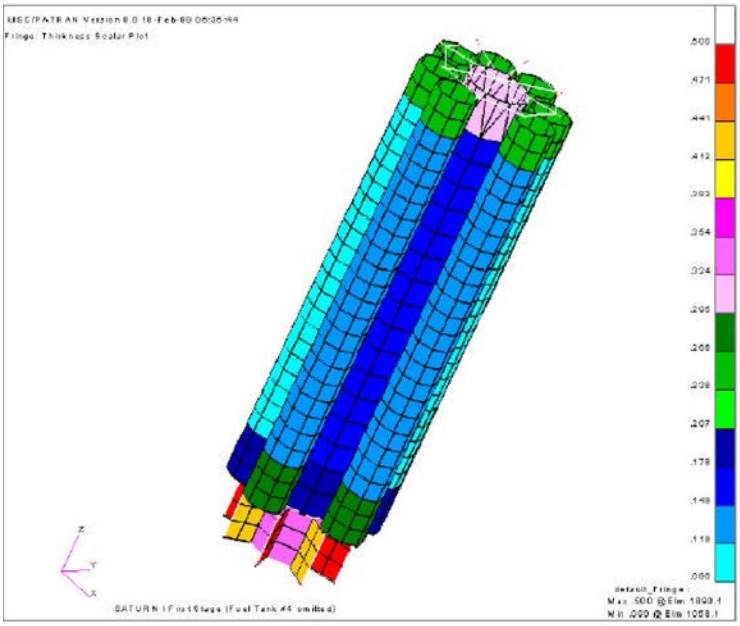


FIGURE 3. Figure from: SPACECRAFT STRUCTURAL ANALYSIS TODAY AND YESTERDAY by Charles R. Gamblin, P. E. Senior Lead Engineer – Structures Group, Teledyne Brown Engineering, Huntsville, Alabama. NASTRAN is a registered trademark of NASA. MSC/NASTRAN is an enhanced, proprietary version developed and maintained by MacNeal-Schwendler Corporation.

The resolution of the rocket structure into elements is almost amusing by today's standards. However, one must keep in mind the limits and the performance of the computers of that time, which already reached their limits with these problems. The figure shows a calculation on the first stage of the Saturn-1B rocket from 1962, a predecessor version of the subsequent actual moon rocket Saturn-V. The calculations of the load on the structure have to be repeated for many states of the rocket, because the mass of the propellant decreases continuously during the flight

The name 'NASTRAN' should still be familiar to every engineer who deals with the finite element method.

The towers of Hanoi

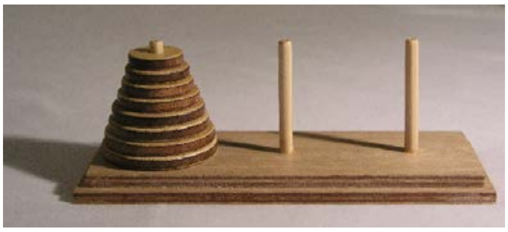


FIGURE 4. The tower of Hanoi game

It is a game with the rule to move a tower from the stack on the left to the one on the right with the restriction that only one disc is moved at a time and never a larger disc may come to rest on a smaller one. The origin of the game is not clear. If you believe the story, the French mathematician Édouard Lucas invented it in 1883 and also offered an exciting story about it:

Indian monks in the temple at Benares had, probably by a divine inspiration, received the task to solve the problem for 64 disks. If they will come to an end with the solution, then the end of the world would have come.

Some time ago I came across a more elaborate story about this problem. This told that the monks, after they had already spend a lot of time with the problem, realized that they did not really make progress with the solution. In fact, it can be calculated that the solution with 64 disks takes about 500 billion years at a speed of one move per second. From this point of view, the claim that the end of the world can be expected if the problem is solved is not so far-fetched, because the universe has an age of about 14 billion years at the moment. To speed up the matter, the monks turned to IBM in the 60's of the previous century. This company promised to be able to accelerate the thing purely computationally with the purchase of a computer of the newest generation . So it happened that the monks were busy with the simulated solution of the problem after the installation of the computer in their temple, while the IBM technicians probably urged to start the journey home, in order not to have to experience the 'disappointment' of the not occurring end of the world.

se non è vero, è ben trovato
(even if it is not true, it is a nice story).

The first 'Bug'

FIGURE 5. Harvard Mark I Computer (Photo: IBM Archives)

In 1943, Howard H. Aiken realized the Harvard Mark-1 computer together with IBM. The switching elements were 'relays' with a calculation performance of three operations per second. In 1945, the operator of the Harvard Mark-2 system, looking for a malfunction, found a moth between the leaf springs of a relay. She pasted this 'bug' next to the explanations in the computer's logbook. From then on, computer and software errors were called 'bugs' until today.

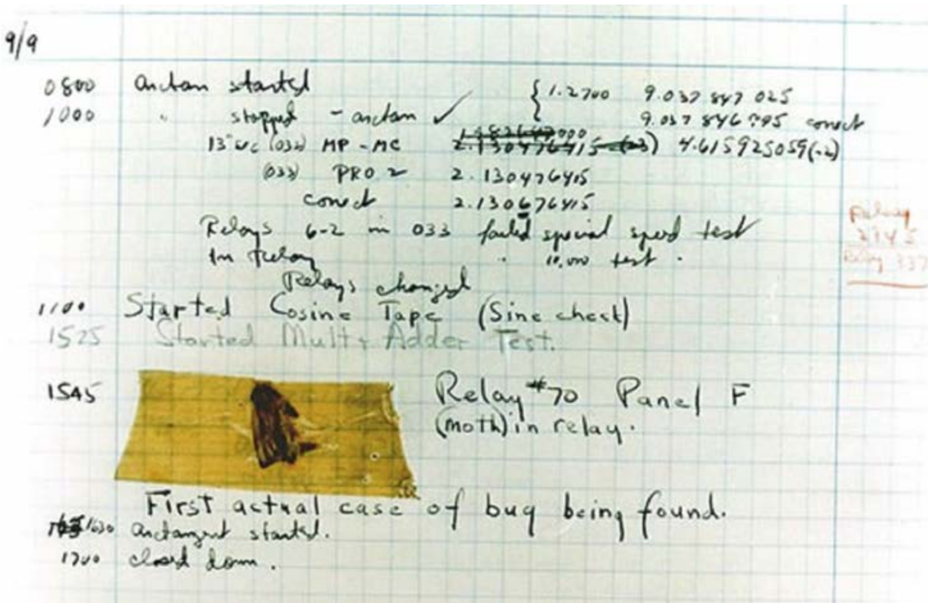


FIGURE 6. The entry in the logbook with pasted moth and the explanation: First actual case of bug being found.

Faster clippers

The participants in the America's Cup, the sailing competition with large sailing ships over long distances, spared no expense to get the last out of their ships. With relatively complex hydro- and aerodynamic simulations, the hull and the sail were optimized and the weight was minimized by means of finite element programs. In particular, the weight reduction was also extended to the sail fabrics. These are, by the way, 3-dimensional surfaces which were shape-optimized with simulations. An improvement of just one percent results in a lead of ten meters over a distance of one kilometer. That may not seem like much, but over a thousand kilometers of race track, that's already a ten-kilometer lead. Legendary are the races with the 'Alinghi', a Swiss boat which was the first European ship to win the America's Cup.

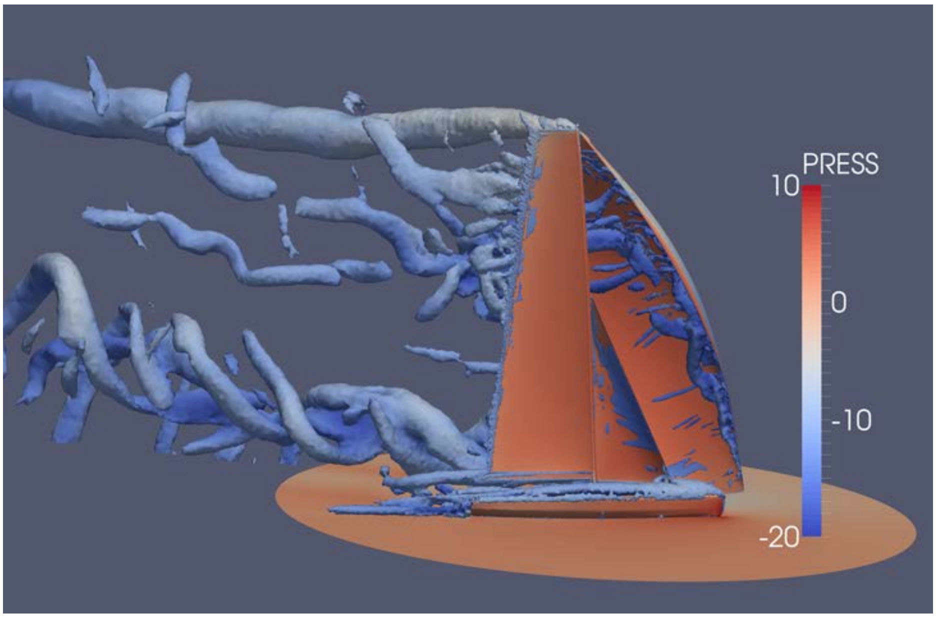
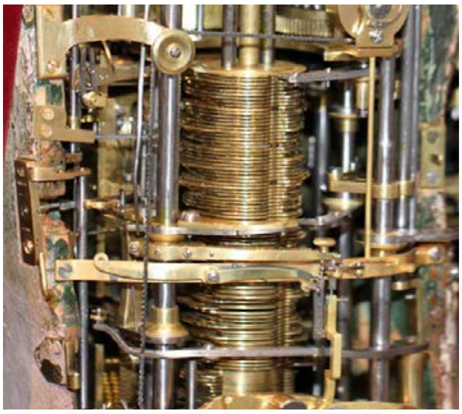


FIGURE 7. wind flow calculation

Incidentally, the simulation and optimization of hulls and sails is a prime example of how important simulation technology is in such a field of knowledge. It is simply not affordable and impossible in terms of time to build and test a hundred variants of improvements. Even if one were to build such variants, then it is almost impossible to measure these effects in isolation and put a number on the advantage, simply because environmental conditions are never constant. This is completely different in a simulation. This has the great advantage that one can simulate, measure and optimize the smallest changes of any kind in an absolutely targeted manner under otherwise identical conditions. This is a strong side of simulation technology. The same is true, for example, in aerodynamics when optimizing the wings of passenger aircraft.

Simulated humans, androids



The idea of creating artificial humans is not new. In addition to the many authors who took up this subject in literature, there were already engineers who created mechanical humans early on. The Swiss watchmaker Jacques Droz (1721-1790) created in the 18th century a whole series of ingenious devices, which amazed not only his contemporaries but also us today. To give just one example, there is the android shown here, which contains a programmable mechanical unit in its body that allows it to independently write any text given to it on a piece of paper. The mechanics is constructed in such a way that for each letter of the alphabet cam disks are run off, which control all movements of the body, the arm and the hand over numerousness levers and axes automatically in such a way that a natural total movement of the artificial human being results. The automaton is able to write down all given or pre-programmed letters in a continuous text with automatic line switching on a piece of paper. It does this with a real pen and with real ink, which, by the way, it regularly fetches itself from an inkwell. A selection of J. Droz's androids can be seen in the 'Musée d'art et d'histoire' in Neuchâtel, Switzerland.

Simulators in surgery

FIGURE 8. Obstetrics simulator from Säcken, France from 1758

As the first figure shows, medical simulators are not a novelty from the computer age. Nowadays, however, there are both hardware and software simulators for practically every surgical procedure, which are available to the trainee physician or surgeon as training objects.

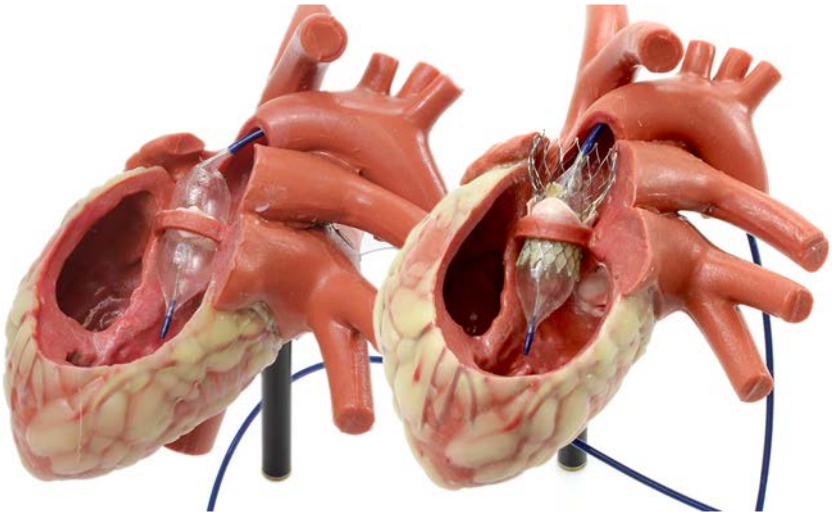


FIGURE 9. Heart bypass simulation. Image ReHaGe International

Stealth Fighter

FIGURE 10. F-117 Nighthawk

The American fighter and bomber F-117 Nighthawk was developed in the 70's of the last century as the first aircraft specifically as a flying object invisible to radar. An airplane which is to possess these abilities must have first of all certain forms of the surface. In addition, further measures are taken, such as special microwave-absorbing materials, coatings, painting, etc. However, these refinements only carry value if they are applied on the basis of a special surface shape.

The shape of the aircraft gives an idea of the shaping characteristics involved. The aircraft shown is characterized by the fact that it consists of a few equally inclined surfaces, which also run as parallel as possible. These surfaces are all arranged in such a way that the radar beams never return to their point of origin or direction of origin, even in the case of multiple reflections on the surface, regardless of the direction from which they come and wherever they strike the surface. In order to answer this relatively complex question and optimize the shape of the aircraft to do so, a given surface must calculate the beam path of the microwaves for each spot on the surface and for each angle of incidence on that spot, similar to a 'ray tracing' image processing technique. In the 70's, this overall simulation was only possible for very simple rudimentary shapes with the available supercomputers of the time (Cray-1). The result of this effort was an unusually ugly airplane that, despite many aerodynamic concessions, met the requirements and was still flyable.

Later generations of stealth aircraft already had aerodynamically nicer shapes. Apparently, it was also possible to fit rounded surface parts that could still meet the original requirements of reflective behavior.

Nuclear weapons development/maintenance

The development history of supercomputers is closely linked to the numerical simulation of nuclear weapons. Already the first supercomputer of the type Cray-1 was put into operation by Los Alamos National Laboratory in 1976 and used in the simulation of components of nuclear weapons. With increasing computing power, computers in general became more and more important in this field of development. This was accompanied by the development of simulation programs to perform the corresponding calculations. Today, a so-called key program exists for each subarea of nuclear weapons development, which covers a specific area of development like a mosaic stone. One such key program is, for example, a variant of the DYNA2D and its successor, the DYNA3D code. From some of these programs also commercial descendants developed with the time which were further developed with emphasis in another direction and do not contain the functions for the simulation of explosives, neutrons, etc. any more. One such derivative is the so-called LS-DYNA-code. The actual DYNA-3D software was further developed by the Lawrence Livermore Laboratories to the PARADYN code, which runs on massively parallel supercomputers of the newest generation.

FIGURE 11. Above Ground Nuclear Weapons Test

After the nuclear weapons test ban and the corresponding treaties between the superpowers prohibiting all nuclear weapons tests, numerical simulation has become a basic technology for the development of these weapons. For this reason, this treaty was not implemented until it was ensured that all core competencies in nuclear technology could be simulated realistically on the computer. Since then, supercomputer development in the USA has been closely linked to the national research laboratories Los Alamos, Lawrence Livermore and Sandia Laboratories. These are the places that always top the Top_500 list of the fastest computers in the world. These research laboratories are not only the technology carriers of nuclear weapons development, but today they must also ensure that the existing nuclear arsenal remains operational. Simulation also plays a decisive role today in the field of maintenance and, in particular, the aging of individual components of nuclear weapons. In France, with a certain time lag and at a lower level in terms of effort, a completely analogous development to that in the USA has taken place with regard to nuclear weapon simulation.

Space Shuttle Software

When the space shuttle lifted off from the launch pad, four identical computers aboard each spacecraft were in command. They were the ones who decided whether or not to fire the solid fuel boosters. Thousands of sensors provided a state of the system at each moment, and the four computers constantly checked with each other to see if they were of the same opinion about what to do at each moment. The software had to be relied upon 100.0% of the time. Errors were not an option. Nothing was allowed to happen that had not been thought of beforehand, and no situation was allowed to occur in the program code at any moment for which a clearly programmed solution had not already been prepared in advance. In no moment a variable value was allowed to flow into any program line, which could lead to a problem in the computation of the formula concerned.

How to write a large software without errors? Every professional software developer knows that above a certain size and complexity of a software it is no longer possible to write a computer program without bugs using the normal development tools. Microsoft was reported by beta testers after the release of the first Windows 7 system software from all over the world about 2000 different bugs. How many remain undiscovered over the years or are never reported for other reasons is unknown.

In order to meet the enormously high requirements of the Space Shuttle software, not only extremely extensive and detailed tests had to be provided, but above all new ways had to be found how the software had to be written in principle. It was the opposite of the free, chaotic code generation that all programmers love so much. It was an almost infinitely detailed planning that prescribed down to each line of code what it had to do and what requirements each variable in that line had to meet, and in terms of what ways that line of code had to be checked and tested, and so on.

In the end, it was also new test software developments that put the entire shuttle software under the magnifying glass, varying and permuting all possible input data in billions of test runs. Systematically complete test runs and a large number of random variations of the incoming sensor data were never allowed to result in an error. It was the most comprehensive software simulation performed in the world up to that time. As we know today, the software worked very reliably until the end of the Shuttle era. It were other errors in the end that led to the space shuttle disasters..

FIGURE 12. Space Shuttle cockpit

Space Shuttle Columbia Accident

The cause of the crash of the Space Shuttle Columbia during re-entry into Earth's atmosphere was a defective wing leading edge, caused by the impact of a detached piece of insulating foam a week earlier during ascent into space. Events of the type that foam pieces could detach from the shuttle's tank during launch had been known for some time. But it was not thought possible that lightweight fragments of polyurethane foam could ever pose a threat to the wing leading edge structures, which were reinforced with carbon fiber.

When both experimental tests and numerical simulations of these processes were carried out after the accident, it was very surprising to see the effect these lightweight pieces could have at high speeds. When it was noted how these parts literally smashed the leading edge of the shuttle in the simulations, it was clear to anyone with a technical sense what must have been happening in the skies over Texas at that time.

The following figure shows an experimental simulation of the impact of a foam part on the leading edge of the wing:

FIGURE 13. from: A Summary of the Space Shuttle Columbia Tragedy and the Use of LS Dyna in the Accident Investigation and Return to Flight Efforts by Matthew Melis and Kelly Carney NASA Glenn Research Center Cleveland, OH, Jonathan Gabrys Boeing Philadelphia, PA Edwin L. Fasanella US Army Research Laboratory/VTD Karen H. Lyle NASA Langley Research Center Hampton, VA

Simulations cracked the code

The ENIGMA was the standard cipher machine of the German Army and Navy during World War II. It was considered absolutely secure and unbreakable by the Germans. The breakthrough to decryption was achieved by the English in Bletchley Park near London with the help of the so-called 'bomb'. It is ultimately a technical simulation of the real cipher machine. The inner mechanism of the original machine was transferred to an electromechanical device, which 'de facto' did the same as the original Enigma, just much faster.

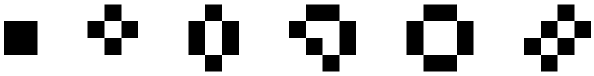
The ciphering in the original machine was done in the so-called drums, of which there are four in the figure of the ENIGMA. In each drum, a letter is converted into another letter by appropriate internal electrical wiring. The electrical signal, starting from the keyboard, passes through all the drums forth and back and at the end lights up a letter lamp. After each keystroke, the drums are advanced one position like the odometer in old cars. Consequently, the Enigma is rewired after each keystroke. The whole thing was complicated by additional measures like a plug-in board with manual swapping of letters and a secret code book with daily settings of the starting position of the drums. Finally, a 'random' code was transmitted by Enigma before each data transmission, which caused a further shift of the settings of the actual message.

FIGURE 14. Enigma bomb

The daily settings were known through hijacked code books. A large number of so-called 'bombs' searched for a readable text in the intercepted radio message by systematically trying all drum positions. The search was for so-called 'cribs', i.e. suspected words or word combinations such as 'Heil Hitler' or 'Stab General Jodl', etc. Over time, these cribs could be relatively reliably assigned to the respective sender.

Simulations with cellular automata

The mathematician John Horton Conway developed the Game of Life in 1970. It is, with the modern terminology paraphrased, an EXCEL table which is populated with randomly distributed virtual living beings. In each step of the game, which by the way runs by itself on the computer, the living being in an EXCEL cell can either die, continue to live or reproduce, depending on how many and what living beings are present in its neighboring cells at the moment and in which state they are. Of course, the rules can be changed arbitrarily and lead to different gameplays. With the standard game rules, as suggested by Conway, several stable groups of cells (multicellular organisms) result which dynamically migrate through the matrix, eat other living beings, perhaps with different rules, die of overpopulation, and so on.



All aspects of an evolutionary 'life' arise automatically in a miraculous way in Front of the observers eye. There is a constant up and down of developments which, as in real life, punish deviations from the equilibrium and promote overpopulation where no opponents restrict expansion.

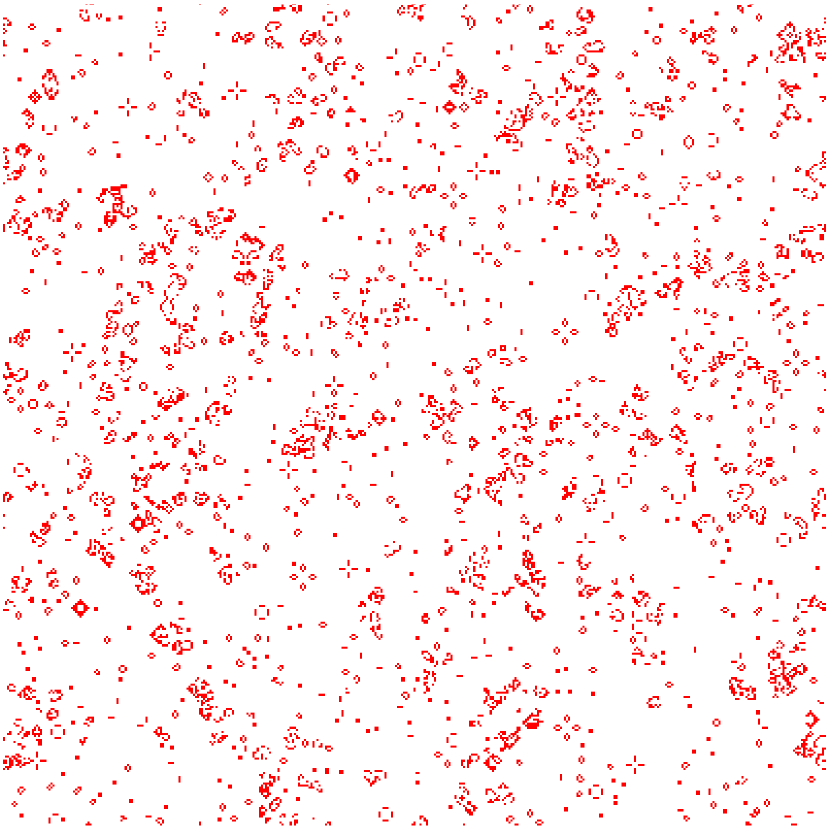


FIGURE 15. an accidental state in the game of life

http://www.zahl-art.de/game-of-life/
http://www.galaxygoo.org/blogs/2006/07/conways_game_of_life.htm

Simulation --> dark matter

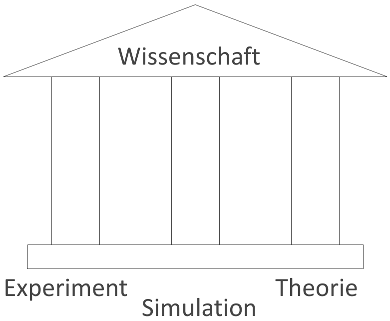
With simulation programs like sonar one is able to dynamically simulate the motion of a whole galaxy using a large number of mass points and to observe how the spiral arms rotate around the common center of gravity. To observe the rotation of a real galaxy is not possible for purely temporal reasons. One rotation takes on average several hundred million years.

If we carry out the movement of a galaxy however simulation-technically, we come to an astonishing result. Actually, the galaxies should not look like they do. Because the effect of gravitational force decreases strongly in direction of the outer arms - due to the 1/square(r) law - these would have to move much slower in the outer area, otherwise the galaxy flies radially apart. Conversely, the galaxy arms would be stretched infinitely with the time, if the orbital velocity is calculated radially as expected according to Newton. We expect that the galaxy arms 'smear' by the time to a homogeneously distributed mass disk, similarly the Saturn ring, as we observe it from the earth.

The observation disproves the common Newtonian physics, independent of how large the mass in the center of the Galaxy is assumed to be. Only if the entire galaxy disk is supplemented with a hypothetical, equally distributed but stationary mass, i.e. a mass that acts statically on the visible mass but does not move dynamically, only then do the computer simulations produce the same images as we observe. From this the astrophysicists conclude that there must be a 'dark' matter. But the essential thing about this fact is that it is not a 'mass' that we simply haven't seen yet. This dark matter obviously does not work according to Newton's laws. That is the essential. It is something new.

Simulation = 3rd pillar of science

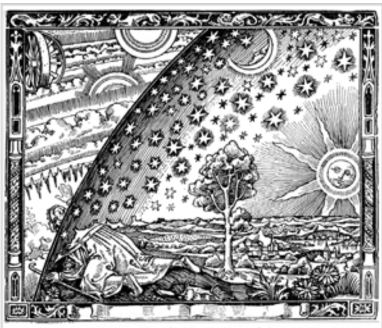
For a long time, science consisted of the direct interaction between experiment and theory. Since the advent of computers, a third pillar has been added to these two. Simulation acts as a mediator between these two pillars.



Numerical simulation extends the theoretical calculation possibilities of the engineer and scientist in a way that would never be possible with analytical calculation methods. Conversely, virtual experiments are possible today with simulations, which would be impossible to pay for with purely experimental methods in this range and depth of variation. Simulations can also be used to try out the impossible, the experimentally impracticable, the dangerous, the forbidden, or the never-before-seen. Simulation is an extension of the brain. All that we could previously only think or imagine, we can now perform virtually. And not just with the power of our imagination in our heads, but virtually for real.

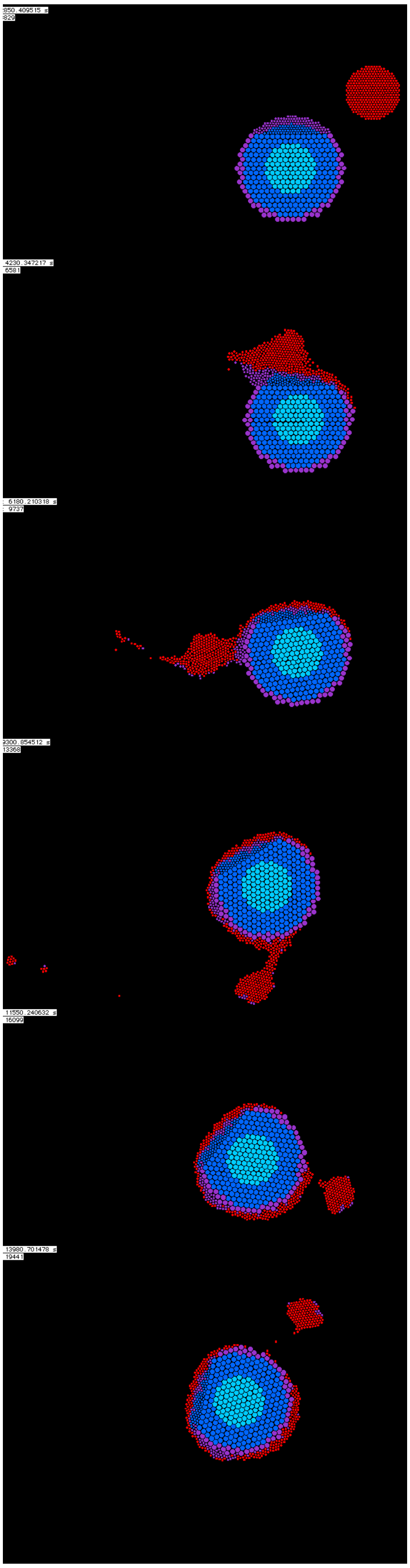
Today, we are only at the immediate beginning of this development. It is simply impossible to imagine what possibilities will be opened up to us in the future. What is certain is that simulation will develop in the following directions, among others:

- more and more powerful, complex simulations with increasingly higher resolution and level of detail.
- the software is becoming easier to use
- virtually closer and closer to reality
- three-dimensional holographic walk-through simulations (3D glasses)
- people will be able to immerse themselves in the simulation, in the end to such an extent that they will no longer be able to distinguish the virtual world from reality
- all senses are addressed



Un missionnaire du moyen âge raconte qu'il avait trouvé le point où le ciel et la Terre se touchent...

The formation of the moon



Our moon originated, so the scientific assumption, in the early time of the solar system by the collision of a planet of the size of Mars with the earth. The collision partner was completely destroyed during this process and produced our moon from the debris. Already with the older simulation software SILUX, which the author of the sonar software wrote in the 90's, the actual collision process and the formation of the lunar core in the course of the first Earth revolution could be simulated with the help of a 2.5-dimensional simulation. Simulations of this kind show impressively how processes can be reproduced with simulations which would be impossible to calculate analytically.

Interesting in this sequence of images from a simulation film is the celestial-mechanical formation of a nucleus which, after completing the first orbit of the Earth, orbits the Earth on a very narrow path without colliding with it again. This happens by constantly 'pulling' material from the debris core during its first orbit of the Earth, and as a result it is permanently pulled towards the Earth. One could call this a kind of 'rubber band effect'. So the nucleus does not fly along an elliptical path but experiences a continuous bending of the trajectory. Therefore, it does not collide with the Earth again at the end.

We can see that the material of the colliding planet is scattered all around the earth and the moon consists almost exclusively of material of the foreign planet. The earth gets an additional momentum and spin. What is not yet considered in this very simplified simulation is the formation of a widely scattered debris field of small material in the near-Earth region, which will be collected by the new moon in its further orbits. The initially low orbit of the moon may subsequently grow due to tidal effects, as is happening to this day.

Later the same calculations were made in 3D.
-> see: www.sonarsimulation.com

The 9th planet

After the former planet Pluto left the list of real planets and was demoted to a so-called dwarf planet, the current solar system consists of only 8 planets. Outside of the last planet Neptune, however, hundreds of other celestial bodies are known, most of them, however, smaller than Pluto. The orbits of these bodies run completely outside the orbit of Neptune and their orbital period around the sun is some thousand to some ten thousand years. Based on orbital perturbations of 6 observable of these celestial bodies, shown in purple in the figure, astronomers concluded that a large mass must be responsible for the strong orbital inclination and periodic perturbations of the trajectory of these bodies.

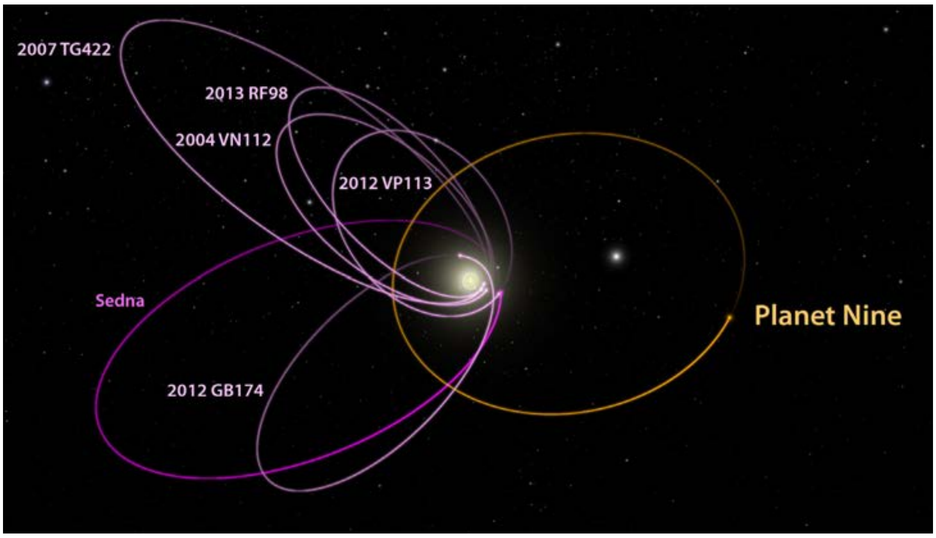


FIGURE 16. Six known celestial bodies (purple) and one hypothetical planet (yellow). The bright white spot in the center represents the entire solar system, including all planets and with Neptune's orbit at the outer edge of the white spot. Image: Caltech/R. Hurt, IPAC

Computer simulations were subsequently performed to determine the mass and trajectory that a hypothetical 9th planet would need to have in order to understand the orbits of the other bodies. With a large number of simulations with constant changes of the orbital parameters, it was finally concluded that a planet with about 10 Earth masses on a far out orbit could explain the observations. The closest point to the Sun of this hypothetical 9th planet and its current position on this orbit would therefore be so far outside the orbit of Neptune that a direct observation of the reflected light would be very difficult. However, some astronomers believe that this planet will be discovered in the next 10 years (as of 2016).

FIGURE 17. from: www.presagis.com

In the not too distant future, we'll be able to take a walk through ancient Rome of the imperial era. We will be immersed in a three-dimensional all-around simulation, in which we will be able to turn our heads in any direction. We will walk through the Roman Forum and meet the Romans who are also walking around. These Romans not only look photo-realistically real, they also move just as real and avoid us when we are on a collision course with them. We will be able to speak to a Roman, if we know Latin, and ask for directions to the 'Circus Maximus'. We will perceive the world around us with all our senses, all the spoken words of the people, the sounds, breathe in the smell of the ancient city with our nose, feel the cool stone bench with our fingers and feel the breeze of the wind on the skin of our face. It is the 'holodeck' with a total experience.

Today there are modest approaches that go in this direction. They are three-dimensional models which try to recreate and resurrect Rome. But they are still relatively modest, sterile, clinically clean, unpopulated, static and spatially confined models. On the other hand, all the core technologies for a full-scale experience are already in place, at least in the rudiments. The games industry is playing a significant pioneering role here. and may also become the first market segment to dive into this future.

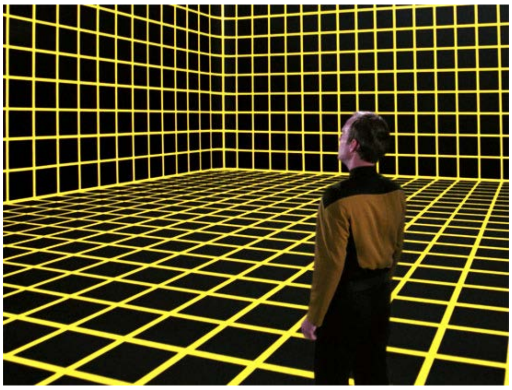


FIGURE 18. from: www.startrek.com

Simulate autonomous driving

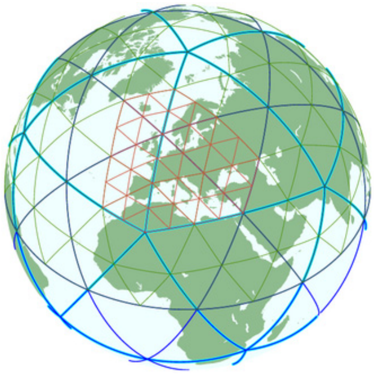
FIGURE 19. Image from Volkswagen Germany

The technology of autonomous driving has made almost unbelievable progress in the last 10 or 15 years. At the beginning of this century, the U.S. research institution DARPA (Defense Advanced Research Projects Agency) announced competitions for autonomous driving in which many universities and technical research institutions participated. The objective was to develop an autonomous vehicle that could drive as far as possible from a fixed starting point in a desert in the USA along a predefined route. While the first cars were eliminated a few meters after the start because they drove around the enclosure of the starting area, the best ones reached a distance of a few kilometers before they ended up in a ditch somewhere.

Today, when cars are already capable of driving autonomously in the heaviest traffic through cities or half of Europe with a high degree of safety, the task of carmakers is increasingly to put the finishing touches to the systems. Before autonomous cars can even be legally approved as fully-fledged road users, the automotive industry must prove that its cars are capable of covering a very large number of kilometers without causing an accident. At this point, the following technologies come together: the simulation, the supercomputer, the graphics card manufacturer (keywords: NVIDIA, GPU) and the gaming industry. All the control software of the autonomous cars is made on a supercomputer to virtually drive over stored, photorealistically recreated landscapes. For example, graphics card manufacturer NVIDIA has developed a simulation solution that is capable of traveling 90,000 kilometers in one hour. In this sense, the car drives more than twice around the earth per hour. Thus, a supercomputer is allegedly able to drive the entire road network of the USA in a few days and deliver the same results as a real car would do.

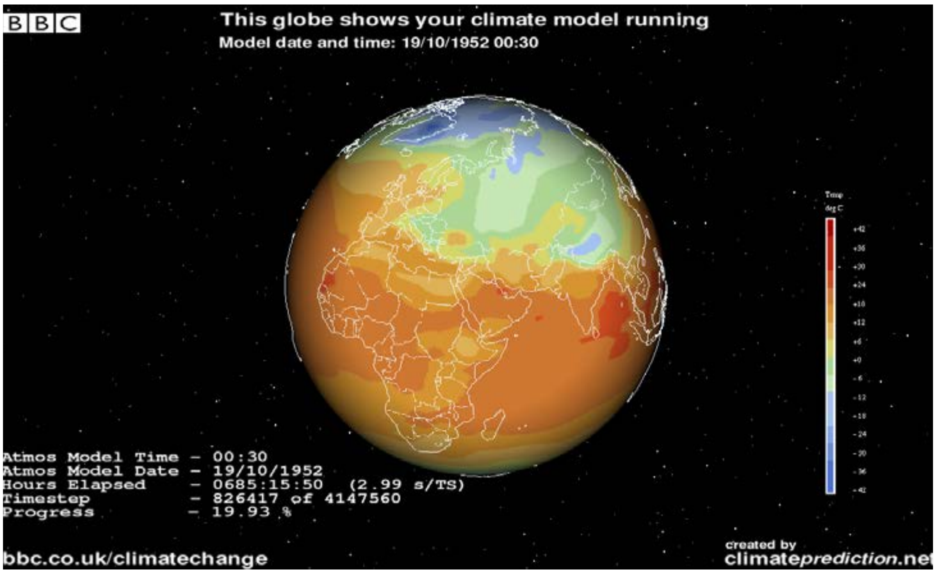
Simulating the weather and climate

Weather forecasting today is largely based on numerical simulation. The simulation model usually consists of a heterogeneous three-dimensional grid structure covering the globe surface horizontally and vertically. At locations of particular interest, i.e. where the forecast has its target audience or where weather phenomena may change significantly in a small area, the mesh structure is successively refined up to a mesh size of one kilometer. The adjacent figure shows this procedure schematically.



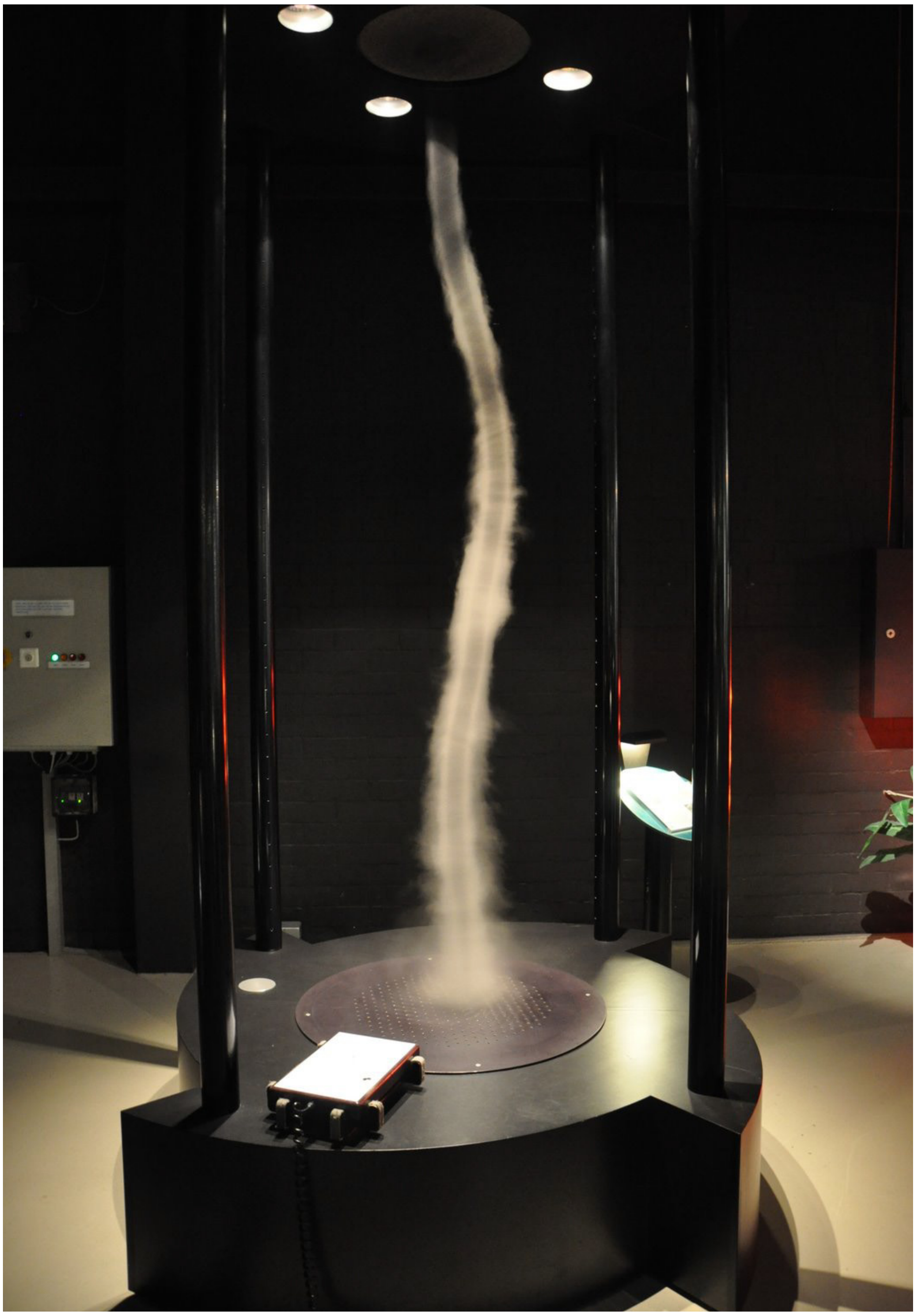
aus: www.mpinet.mpg.de

Using the 'Navier-Stokes' equations, the formation and transport of physical quantities such as air pressure, temperature, humidity, etc. from each cell to its neighboring cells is then calculated in small time steps. This process is constantly repeated iteratively, moving forward in the time scale and providing a forecast of the state of the weather over the next few days. Since weather is physically a chaotic process, knowing the initial conditions at a given time is extremely important. Thus, the weather models must be calibrated daily against the real observed weather. The accuracy of these initial values is subsequently an important criterion for how long the calculated weather forecast will be valid.



Climate models basically work in the same way. In these forecasts for the next decades, however, homogeneous network structures are used which include the entire globe and also take into account influencing variables which will have an effect in the long term, such as the concentration of 'harmful' gases in the atmosphere, the melting of ice masses, etc.

Simulation of tornadoes



At Technorama, a technology museum in Winterthur, Switzerland, there is a hands-on tornado simulator. The effect of precisely controlled external air movements on the floor, on the ceiling and in the vertical bars creates an air turbulence in the central and smoke-enriched air column that mimics a tornado. In principle, these external effects correspond to the large-scale air movements in the vicinity of a real tornado. So this model shows quite nicely how a tornado is formed in principle.

The flight simulator

As early as the First World War, the need to accelerate and optimize training on the aircraft arose with the large number of pilots to be trained. The first "flight simulators" made it possible for pilot trainees to experience and learn the basics of aircraft control and the consequences of control stick movements while still on the ground.

FIGURE 20. an unknown flight training device from World War 1.

Before, during and after the Second World War, entire generations of pilots were trained on the so-called LINK Trainer. This simulator was not intended to teach pilots how to control an aircraft, but to practice blind flying. The pilot had the blind flight instruments in front of him in a closed cabin simulating night flight, which actually calculated the current position in the background and displayed the direction of direction finders on the instrument panel. The device was able to continuously mechanically add the flight direction and speed to the current position of the aircraft. As a rule, this trainer was used to practice approaching airfields in blind flight. On a chart table located in the same room, an x-y recorder was used to continuously record the aircraft's position on a chart. The flight instructor and his student were thus able to make an assessment of the flight path and approach to the airport after the virtual flight.

Modern flight simulators offer a flight experience which, at least visually, hardly differs from reality. Most of the pilot training on airliners today is done on simulators. The real flights complete the training at the end.

FIGURE 21. LINK Trainer

The simulated wind tunnel

FIGURE 22. Wind Tunnel

The Wright brothers, who performed the first hand-controlled powered flight in the sand dunes of Kitty Hawk, USA, in 1903, had already constructed a simple wind tunnel during the development of their flying machine 'Flyer' in order to carry out measurements of the lift on small flying models.

Before the computer age, the wind tunnel was the only way to accomplish flow studies on new aircraft that had not yet been developed. The goal was to optimize the shape of an aircraft's outer hull, taking into account all flap positions and lift aids. In such measurements, the lift and drag coefficients were ultimately measured at different angles of attack of the aircraft relative to the airflow. Although the actual wind tunnel cannot be dispensed with to this day, more and more tasks are being taken over by so-called CFD simulations (Computational Fluid Dynamics).

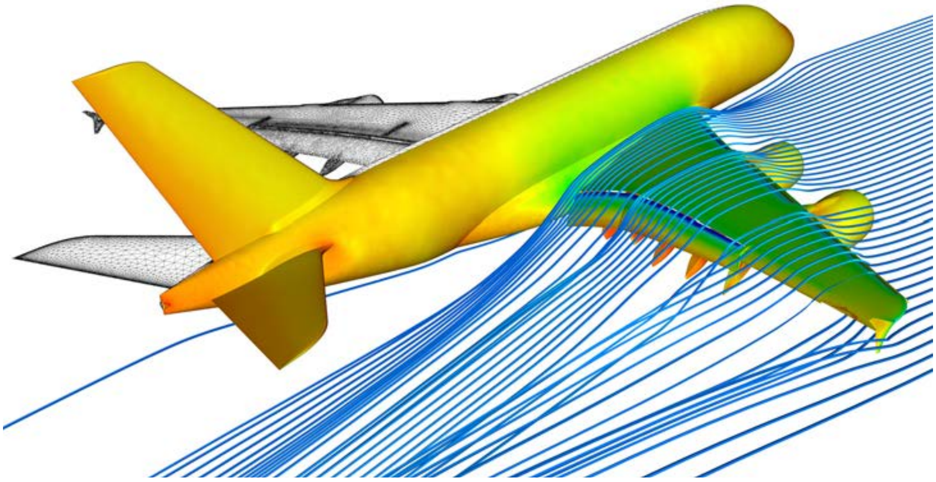


FIGURE 23. Airbus A380 simulation. Source: German Aerospace Center DLR.

In a CFD simulation, an outer aircraft hull, represented by a complex grid structure, is subjected to a calculated flow, which is also carried by a 3-dimensional spatial grid and completely flows around the aircraft. Both grid structures are spatially fixed and the virtual air is then moved through the outer grid structure purely computationally using so-called transport equations. During this process, the air flow is simulated very realistically. The entire pressure distribution on the aircraft hull as a function of velocity can also be determined during these calculations. The figure shows both the flow path of individual air particles (blue) and the pressure distribution on the surface of the entire aircraft (yellow, green, red). Today, the CFD method is also used for many other simulation tasks, such as the air flow around cars, skyscrapers and entire city districts, the cooling of electronic circuits and the flow in turbines, etc.

Simulating breaking load

FIGURE 24. Load test on a Boeing 787 Dreamliner wing

During the development of a new aircraft, the maximum load capacity of the individual components, including the wings, is calculated in detail using suitable simulation programs for structural analysis. The real wing is finally subjected to appropriate load tests. In the first test, the wing is loaded until it actually breaks. As a rule, twice the load value of the maximum conceivable deflection or the maximum bending load to be expected for which the wing was designed mathematically is aimed for. The second load test is an endurance test with alternating loads as they are to be expected in the later use of the aircraft. Here, the wing is continuously exposed to alternating loads over months and years in order to induce fatigue fractures at parts that are particularly endangered in this respect. If these tests are successfully completed, the aircraft usually achieves several times its intended service life.

Today, these tests are standard. However, this was not always the case. In 1953 and 1954, the first mass-produced passenger jet aircraft, the 'De Havilland Comet-1', experienced several unexplained crashes. The aircraft broke up during operations at high altitudes. Intensive investigations on the ground using alternating loads of the cabin pressure finally led to a reconstruction of the incidents. A 'too angular' shape of the cabin windows resulted in unexpectedly high peak loads in the corners of the windows, which after a certain loading time led to cracks and finally ended with the fuselage breaking apart.

FIGURE 25. De Havilland Comet-1

Recognize faces

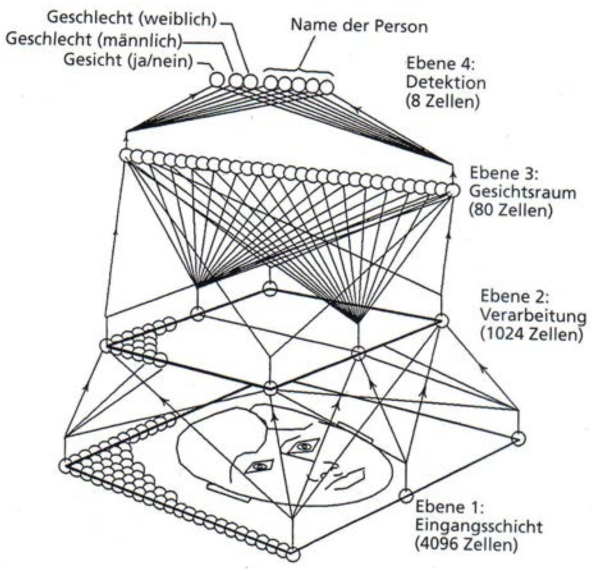


FIGURE 26. from: The Soul Machine, a Philosophical Journey into the Brain by Paul M. Churchland

With the help of so-called neural networks, it is possible to transcend the limits of pure digital data processing with its yes-no logic. However, neural networks can be simulated on digital computers. The adjacent figure shows schematically the structure of a neural network for face recognition. Neural networks consist of at least three, often four or even more layers. Each layer consists of a two-dimensional array of neurons. A neuron is a logical unit which can take not only the values 0 or 1, but also all values in between. The first layer or the input layer in our example is the image of a face. The layer consists of e.g. 64 * 64 pixels or neurons, where each pixel can take a brightness value between 0 and 1. Each neuron in turn passes a signal to the wired neurons in the next layer if its activation exceeds a fixed value between 0 and 1. However, these settings at the neurons are not fixed. One can imagine that there is a kind of 'potentiometer' or ’regulator’ at each neuron, which can change the sensitivity of the neuron. Further, the sum of all settings at the neurons can be automatically changed by the system with appropriate functions by training the apparatus with concrete solutions. It is a peculiarity of neural networks that they only function properly after they have gone through a training phase. In the end, a neural network can only recognize with certainty the faces it has already been trained for.

Interesting is the way the neural networks work in practice. In the network shown here, one output neuron is provided for each person. If face no. 'k' is shown to the apparatus, then lamp no. 'k' lights up at the end if the network has already been trained well. However, neural networks always give an answer. They are like little children. The only question is whether the answer is right or wrong. This depends on how well the neural network has already been trained. If we show the network a new face, which the network has never seen before, then it will tell us as an answer that this is face no. 'j'. Probably because face number 'j' is the closest to the face shown. And this is also an interesting answer, of which a pure binary thought process would not be capable without further ado. For this reason, the network can correctly recognize the face it knows even if we show it a photo of the face from a slightly different direction.

Also interesting is the reading out of the content of an intermediate layer. In the book cited above, this is done at individual positions and the content is shown pictorially. In the actual sense, these are frightening, ghostly faces. Probably there are also such intermediate forms of faces in the hidden intermediate layers of our brain, which serve us to store faces efficiently and space-saving. Humans cannot store faces as whole units, this would be much too memory intensive. For this reason, we cannot even sketch faces that are very familiar to us, such as that of our mother or our own wife, in an approximately recognizable way on a sheet of paper, unless one is a true artist. Probably evolution has optimized the process of recognizing faces to a large extent, in that humans has memorized an average face and stores the differences to this central original face with every new person he gets to know. Perhaps there is also a group of faces stored in our brain, one for each type of person? It is also possible that only single parts of the face are stored in the way of a modular system? These original faces do not necessarily have to be beautiful, smooth and handsome shapes. These faces may well be a difficult to describe abstract variant of a face, which can be combined well and optimally when thinking about it. They may well be ghostly facial shapes. It is equally possible for these normally hidden memory forms of faces to surface when the body temperature is high.

Blue Brain Project

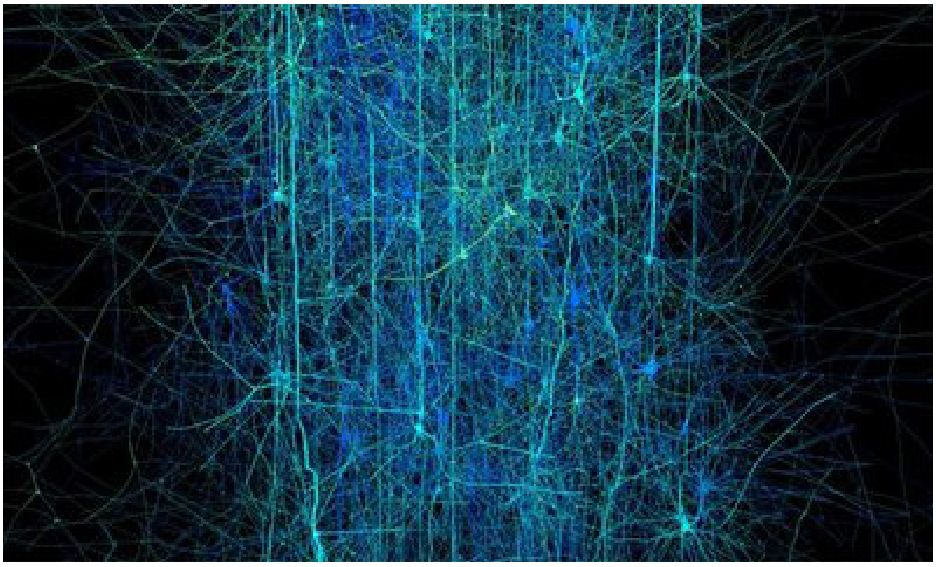


FIGURE 27. http://bluebrain.epfl.ch/

The so-called Blue Brain project under the direction of Prof. Makram at the EPFL in Lausanne, Switzerland attempts nothing less than to simulate the human brain on a computer. The aim of this project is to recreate a brain piece by piece. After some preliminary work, the collaboration with IBM began in 2005. IBM provided the project with a supercomputer of the type 'Blue Gene'. For a project with the demands set, the computing power is absolutely critical and decisive for success. In the following years, the scientists successfully analyzed a single neuronal column from the neocortex of a rat and transferred the 'circuit diagram' analogously to the computer. In the rat, the outer cortex consists of about 100,000 such columns, each with about 10,000 neurons. In humans, the order of magnitude for both numbers is at least a factor of 10 higher. The results are expected to be of great use not only in medicine and biology, but especially in sciences such as computer technology, informatics and mathematics. Especially in software technology, new impulses are likely to be gained by understanding the inner wiring and functioning of large to very large neural network structures.

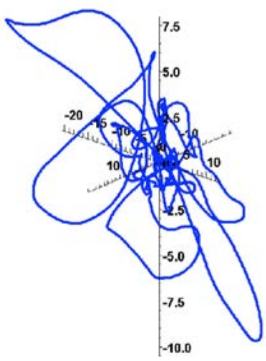
After little or modest advancement in artificial neural network technology in terms of complexity over the past 20 to 30 years, 'Blue Brain' is the first project to attempt a truly dramatic leap into the future. In 2013, the project was awarded approximately $1 billion by the EU Commission and the status of being one of the two most important projects in EU research.

As a result, the project has also generated much ill will and envy across Europe. Critics allege that many other areas in neural research are underplayed by this project and that the project's goals are unrealistically ambitious. However, if the project achieves even 10% of its set goals, then more will probably be gained than if the money were poured out according to the watering can principle. Whoever wants to achieve great things must also dare to advance.

Simulate earthquake

FIGURE 28. Large-scale simulation of a building on an earthquake simulator in Japan

Japan has to live with earthquakes. It is one of the countries on the edge of a large earth plate that is constantly in motion. Earthquake research has a long tradition in Japan, both experimentally and with numerical simulations. The strong earthquake of Kobe in 1995 further stimulated the will for greater efforts. Japan is now the leading country in the world in terms of earthquakes and takes the dangers very seriously like no other country. All new buildings in Japan are subject to strict legal requirements and must provide evidence of high earthquake resistance. This applies to houses as well as to public structures such as bridges, railroads, etc.



3D-progression of the ground displacement of the 1995 Kobe earthquake in [cm]. (Thomas Wenk, Earthquake Engineering and Structural Dynamics GmbH Zurich))

However, the numerical simulation of houses under the influence of vibrations is very challenging. This is due to several reasons. First, the motion signal of the subsurface during an earthquake is not a directional excitation but a more or less chaotic 3-dimensional spatial motion. Even if the amplitudes and the frequencies are approximately known, the exact course of this spatial motion is of course different again for each earthquake. A certain spatial motion can lead to the collapse of a building, while the house next to it survives the oscillation well. If the vibration signal in another earthquake happened to be the same strength but spatially different, then the effect might be different. Second, buildings with load-bearing steel structures are structurally well-defined, while those of pure stone construction are more difficult to model. Concrete, on the other hand, is a building material that has virtually no tensile strength and should always be loaded in compression. When tensile loads are applied, the reinforcements have to take over the forces. However, they can only do so as long as the concrete around the reinforcement remains intact.

The development of computing speed

Computing power is an absolutely central issue for numerical simulation. It is simply always too low. Those who simulate always think "would be nice if this would take seconds instead of days".

We go back to the year 1984. The author of the sonar software had an Apple-II computer at home and developed the simulation program 'ALIEN' in the company Oerlikon Bührle AG in Zurich by means of a VAX-11/780 computer system. The colleagues in Los Alamos (New Mexico, USA), who were engaged in the development of similar programs, were better equipped. They had the legendary CRAY-1 computer, the fastest computer in the world. One could only dream of its phenomenal computer performance and imagine what would be possible if one had such a computing unit (costing around 8 million dollars at that time). In the logbook for the program 'ALIEN' the following measured comparison for the accomplishment of a certain simple simulation task (benchmark program) was entered in 1984:

- 1 man handwork : 3000 years
- MARK-1 computer 1944 : 40 years
- Apple II computer : 2.5 days
- VAX-11/780 computer : 3 hours
- Cray-1 computer : 40.2 seconds

We now leap forward 26 years to the year 2010. What the author of sonar software had under his desk has exceeded all expectations. The computing speed of a workstation has 10'000 times the performance of the VAX-11/780 system from back then. The same simulation task from 1984 now takes exactly 1 second on this workstation. That is 40 times the performance of the Cray-1 computer. After 2010, the development of computing power takes a slightly different path. The number of computing cores now determines the absolute simulation speed of multiprocessing capable software like ‚sonar'. This is another leap in performance compared to 2010. We are staying tuned.

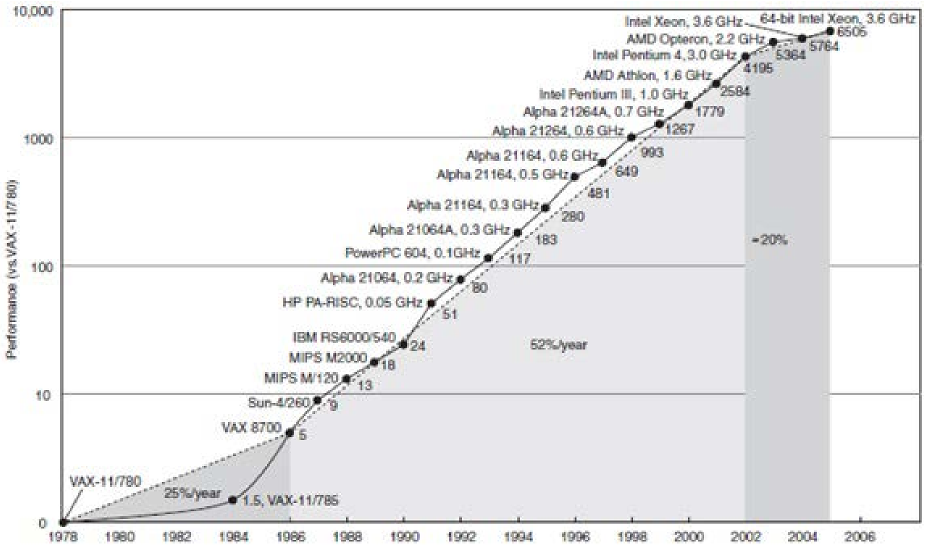


FIGURE 29. Relative computing power of microprocessors to the computer VAX-11/780

Simulate bionically

Bionics is the discipline of looking to nature for ideas and solutions to certain problems and implementing them technically, drawing inspiration from nature to optimize technical designs. A classic task on this topic is to optimize the shape of a mechanical component in terms of form and weight so that the component can withstand the applied loads with minimum weight. Today, there are simulation programs that can perform this task almost automatically by applying a given load to the component in question and, as a result, adding some material wherever the loads are too high and, conversely, removing some material wherever they are low enough. If these algorithms are implemented consistently and iteratively, then structures are created which are familiar to us from the human bone structure. This is not surprising, because nature works in the same way. The problem we still have with these optimized structures is their implementation. Such optimized components are not easy to manufacture. In most cases, a series of constructive compromises were necessary, which again destroyed part of the design. But the latest technical development has a solution for this problem as well: the 3D printer. Together with bionics, these are two technologies that fit together almost ideally.

FIGURE 30. door hinge

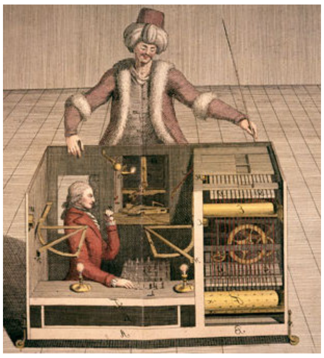
The example shows the prototype of an optimized hinge of a door on an Airbus aircraft, produced by additive sintering of titanium on a 3D printer. This application may not yet be fully convincing in terms of its utility, because there are not that many door hinges on an airplane. But imagine that you could achieve weight savings of just 250 g on an airplane seat thanks to the new technology. In an airplane with 400 passengers, this corresponds to a weight saving of 100kg. This weight can be directly converted into a corresponding fuel saving which, extrapolated over a year, adds up to a large amount of money.

Simulate skyscrapers

In the documentary entitled 'Nice New World' by the Second German Television (ZDF, 2016), Carl Bass of the Autodesk company explains to TV link man Claus Kleber how a skyscraper in the skyline of Shanghai, China, was planned. The curved tower is the result of 100,000 hours of computer simulation, the aim of which was to use as little material as possible to construct a building that would be less susceptible to wind loads and, at the same time, have low aerodynamic vibration due to its twisted edges.

FIGURE 31. The picture shows the building under construction

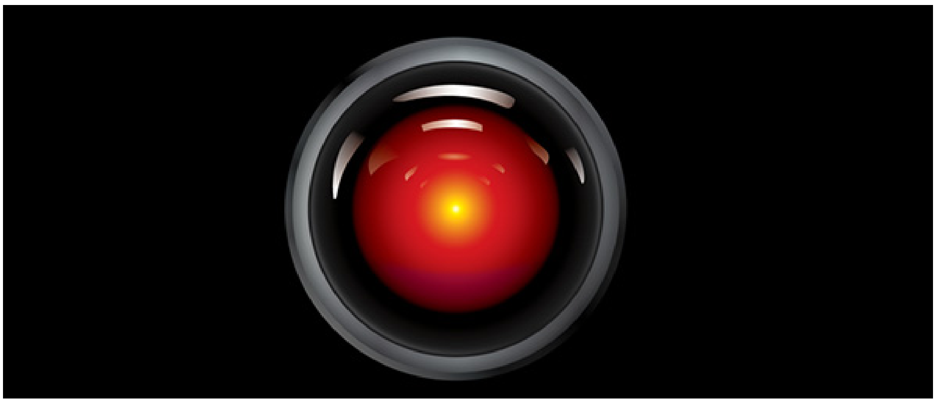
The faked simulator



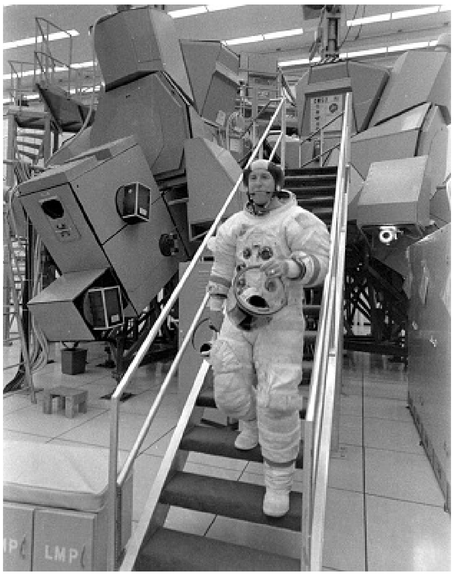
In 1769, the mechanic Wolfang von Kempelen presented a mechanical chess automaton that was supposedly capable of playing chess independently at a high level. The automaton consisted of a chest packed with lever gears, cogwheels and the upper part of a human android, which also operated the pieces on the chess board via lever systems. The android was dressed in a Turkish costume, which is why the whole thing was called the 'Chess Turk'. Because the spectators were successfully made to believe that the whole apparatus worked independently, the device was a real sensation which was demonstrated all over Europe. There were even games at the royal court in Vienna and against king ’Friedrich der Grosse’ in Potsdam, Prussia. Even Napoleon is said to have played against the Turk. Because the owner of the device allowed some people to look into the opened apparatus, it was not obvious that in fact there was a human chess player in the chest. Perhaps because the open areas in the chest intended for the player could be ingeniously obstructed with movable levers, so that no place for a human being was recognizable. The mystery surrounding the Turkish chess player changed hands several times and lasted for almost 70 years until 1838, when the first urgent suspicion arose that there must be a human being inside the apparatus. What remained of this story is the german label 'getürkt', in english ’faked’.

130 years later, when the audience left the Cinerama cinema 'Apollo' in Zurich in 1968 after the screening of '2001 Odyssey in Space', discussions immediately arose about the feasibility of all these predictions which the film impressively presented. One heard sentences like "I can well imagine that everything shown in this film will sooner or later become reality. Only one thing I cannot imagine: That a computer will ever be able to play chess". That was just too far-fetched. Chess was the ultimate measure of human intelligence and creativity. Chess was the highest hurdle of human thinking imaginable at that time. To be able to play chess was, in terms of intellectual ability, to become human.

Twelve or fourteen years later, playing on the Apple II computer against the chess program 'Sargon', unless you were a very good player, you were already struggling to win at the higher difficulty levels. In 1996, the computer developed by IBM with the associated chess program 'Deep Blue' won a chess game conducted under regular competition conditions against the reigning world champion Garri Kasparov. A year later, the program even won an entire chess tournament over six rounds. 'Deep Blue' was thus 'de facto' world chess champion. Kasparov, who assured several times before these historic games that he would never be beaten by software, had to admit that the computer, as he called it, had played like a little god.



Lunar flight simulators



The astronauts prepared for the historic flight to the moon in 1969 with a whole series of special simulators. Appropriate equipment had been constructed for each phase of the flight. One of the most important was the actual descent simulator, which was used to practice the flight from lunar orbit to touchdown. Since the fuel supply was very limited, this simulator was used to control and practice the best possible timing of engine thrust during descent.

With the so-called 'Lunar Landing Research Vehicle', also known as 'flying bedstead', the astronauts practiced the very last phase before the actual landing. The 'LLRV' had the same flight characteristics as the real lunar landing vehicle and automatically simulated the reduced gravitational force of the moon. By the way, Neil Armstrong, the first man on the moon, crashed during a practice flight (out of fuel) with this vehicle a few weeks before the actual lunar flight and had to save himself with the ejection seat.

The effective gravitational force on a human on the Moon is about 1/6 of the gravitational force of the Earth. A particularly imaginative simulator was used to practice walking and hopping on the moon with reduced gravitational force. An astronaut suspended on long ropes with the correct rope angle of approx. 9.5° perfectly simulated the weight with which he stood on the lunar soil. With this simulator even jumps with rollovers were possible.

Simulate zero gravity

To get away from the influence of the earth's gravity and simulate real weightlessness there are the following possibilities:

- to go into an earth orbit (earth satellite)
- parabolic flight with an airplane
- drop tower
- numerical simulation

In Bremen, Germany, a drop tower has been in place since 1990. It was built for the investigation of short-term experiments with high quality weightlessness. In an evacuated vertical tube, an instrument capsule is dropped from a height of 110m and is non-destructively intercepted at the end in a container filled with styrofoam. The fall time is 4.74 seconds. The experimental facility was later extended with a catapult system so that the capsule is first propelled from the ground into the air. In this case, a weightlessness of more than 9 seconds is achieved.

FIGURE 32. The drop tower in Bremen. Images ZARM (Center for Applied Space Technology and Microgravity.

The research facility in Bremen is used for a wide range of applications. These include experiments from scientific fields such as astrophysics, biology, chemistry, combustion research, fluid mechanics, fundamental physics, materials science, etc. Many scientific experiments can be performed in this way free of external gravitational influences in a more fundamental way, often leading to new discoveries. Furthermore, these drop tests are used to test individual components of satellites for their functionality in weightlessness before they are actually used in space.

Simulate free fall

FIGURE 33. Windwerk Winterthur Switzerland

In Winterthur, Switzerland, we have the opportunity to experience and fly free fall in a vertical wind tunnel. An air flow with a speed of 250 to 300 km/h, as experienced in free fall during a parachute jump, is generated here with a powerful wind machine in a closed channel. In the vertical part of the flow channel is the illustrated glass tube into which the jumper enters through a side access.

Crash Test Dummies

In 1949, the US Air Force developed the first modern dummies for the purpose of testing ejection seats in aircraft. Previously, this task was performed by volunteers who risked their lives with each test. The American John Paul Stapp became famous for his acceleration tests on rocket sleds, researching the maximum possible acceleration a human being can withstand. His face after these tests sometimes had the appearance of a boxer being beaten up over fifteen rounds. In one of his spectacular tests, he allowed himself to decelerate in a rocket sled from a speed of over 1000 km/h to zero in a whopping 1.4 seconds, suffering acceleration of up to 46 g with his face looking ahead in direction of travel.

Modern dummies, as they are often used in crash tests in the automotive industry, are technically advanced apparatuses with sophisticated measuring devices and crammed with sensors and recording devices of all kinds. In simulation programs such as 'sonar', equivalent virtual dummies are used to simulate the same processes and to measure and analyze the influences, accelerations and forces on human bodies and body parts. In this context, dummies of children and infants are also used to test appropriate carrying bags and their fastening possibilities in the car under real conditions.

Simulated 'Car Crash'

As far as the combination of real simulation technology and numerical simulation on the computer is concerned, the automotive industry is one of the most advanced and leading users of this technology. According to reports from Honda, the development of the very detailed virtual model, as shown, took about half a year. However, once in place, this model can be used to simulate any number of different crash scenarios. Even the influence of the variation of individual parts on the overall result can be studied in detail in this way. This is one of the great strengths of numerical simulation. In it, small changes can be investigated very specifically under otherwise 100-percent identical conditions, which is hardly possible in reality. Since real tests are expensive, today one only goes into the real test phase after optimization on the computer has been completed. In the real tests, the findings and results obtained then only have to be confirmed or verified with a few tests at the end.

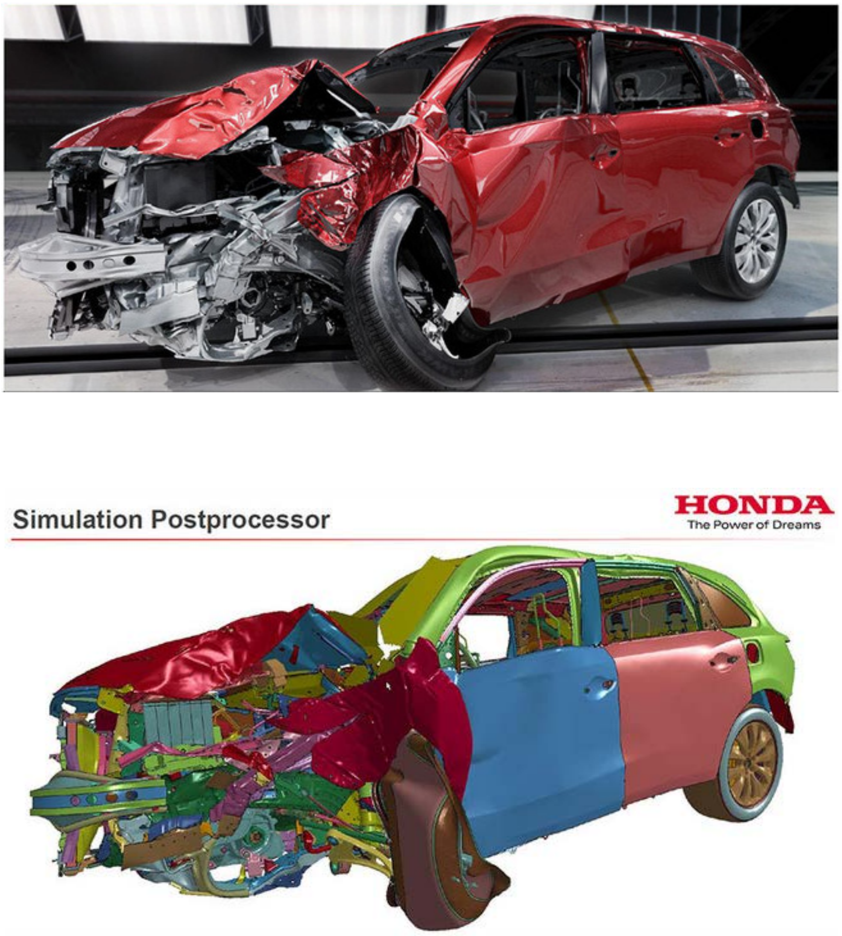


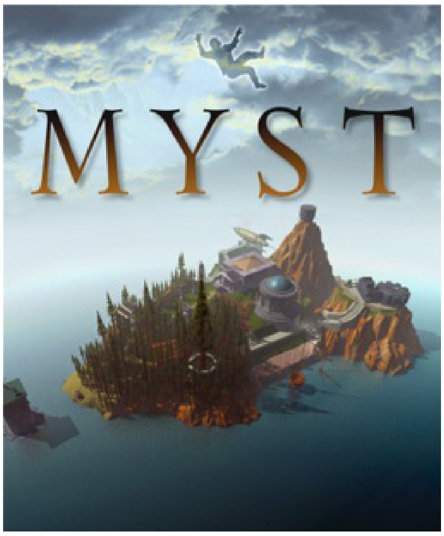
FIGURE 34. Automotive Savety Simulation, Honda R&D Americas, Inc.

Simulation games

Towards the end of the last century, a whole series of computer games appeared under the abbreviation 'Anno', such as 'Anno 1602'. A whole generation of children and young people tried their hand at conquering and settling new worlds. Due to their depth, these games also had a positive learning effect. The appealing graphics and the background music truly transported the player to other worlds and conveyed a lasting sense of experience.

One of the most successful games in this segment was 'SimCity'. The memorable schematic graphics, which were still from the late 80's and, in contrast to the later game Anno 1602, seemed rather technical, directed the focus more to the actual events on the playing field. It was less of an artificial world that the player was immersed in, but more like a board game that the user had in front of him on the table.

In my opinion, one of the best and most sophisticated computer games was 'Myst'. For the time it was developed and for the target computers it was played on at the time, it had an extremely high degree of realism in terms of graphics. No game before it incorporated so much detail-rich artificial photorealistic artifacts. In no other game was such an elaborate literary background included. The entire soundscape is part of the game. Successful musical compositions enhance the experience, just like in a good movie. All this packed with a completely new kind of gameplay, which also demanded something mentally. A masterpiece of game design.



Simulating kinematics as art

The artist Theo Jansen from the Netherlands is engaged in kinetic art. The so-called 'strandbeest', as he calls his mechanisms, are autonomous movement apparatuses that move independently across the beach, driven solely by the wind.

FIGURE 35. "strandbeest" by Theo Jansen

The graceful beauty of these lively-looking movements can hardly be described. You have to see these fascinating apparatuses in action.

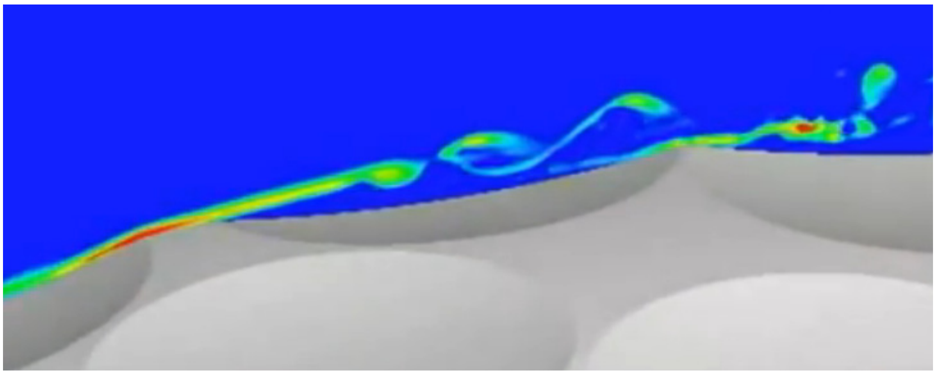
`https://www.youtube.com/watch?v=LewVEF2B_pM`

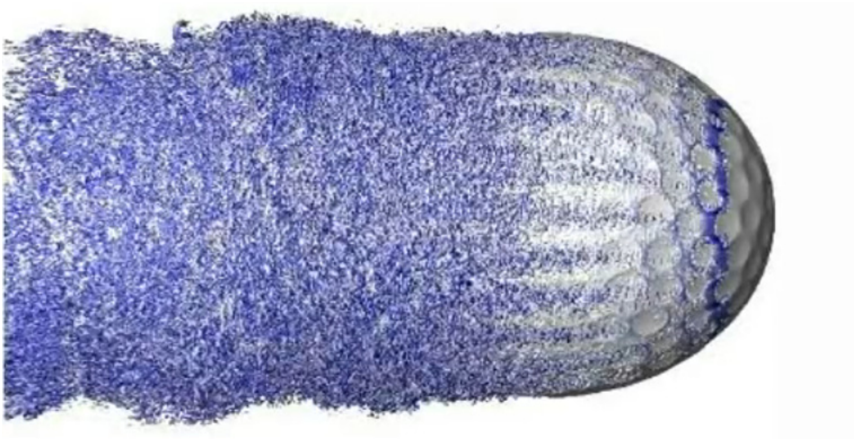
Theo Jansen has succeeded in presenting technical kinematics as beautiful simulation models wrapped in art and in this way demonstrating the beauty of technology in general and of technical movements in particular in a way worth seeing.

The simulated golf ball

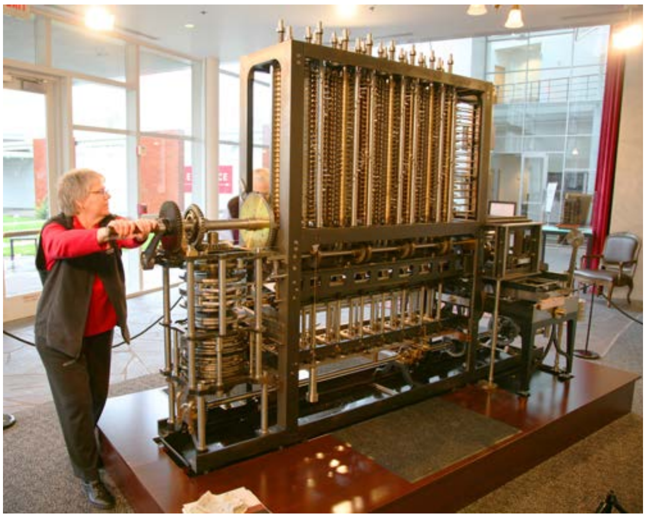
A golf ball has small dents all over its surface which give it its characteristic appearance. Depending on the make, these dents have different shapes such as round or honeycomb depressions. It is not self-evident, but of course it has been known for a long time that these dents reduce air resistance considerably. The dimples apparently ensure that the airflow changes earlier from laminar to turbulent flow, thus preventing early stalling. However, it was not known until today how this happens exactly and in detail. Until now, golf balls were simply optimized empirically or in a wind tunnel.

In 2011, a doctoral student named Clinton E. Smith submitted a thesis to the 'State University of Arizona' in which he, together with the 'University of Maryland' and with the help of a supercomputer, simulated and analyzed the flow around a golf ball in a new quality of resolution. This problem is definitely of general interest in aero-dynamics and the results can sometimes be applied to other fields of application in aeronautics. In this sense, the golf ball is something of an inexpensive and mass-produced experimental vehicle for studying surface structures to reduce and optimize drag. But the manufacturers of golf balls are now also interested in further optimizing their products in this way and staying a little ahead of the competition. They can also sell the advantages of their products in this way in terms of marketing (The golf ball that came out of the supercomputer...).





Mechanical analog computers



After a long tradition in mechanical calculating machines, Charles Babbage had the vision in the 19th century to build an analytical machine, which should be able to solve any mathematical equations numerically. However, it was not until the 20th century that his detailed technical drawings were fully built as a replica by the Science Museum in London and turned into a fully functioning machine.
A satisfaction that he himself did not live to see. Before the actual electronic age dawned after the Second World War, so-called analog computers were built and used on a mechanical basis at various universities and research laboratories. The American Vanevar Bush (1890 - 1974) (see figure below), who not only achieved great things in this field, but who also proposed a kind of apparatus called 'Memex' in 1945 in an essay with the title: "As we may think", on which one could access the entire knowledge of this world and also display it. He thus anticipated the Internet.

An analog computer of the type shown functions by transforming rotations into corresponding other, functionally dependent rotations. For example, one can transform a given rotation into one which corresponds to the sine of the given rotation, and so on. By adding up many such basic mechanical units, relatively complicated systems of equations can be solved mechanically in the end. By the way also relatively fast. The whole thing could be used to solve simpler simulation tasks. The accuracy was probably the biggest problem.

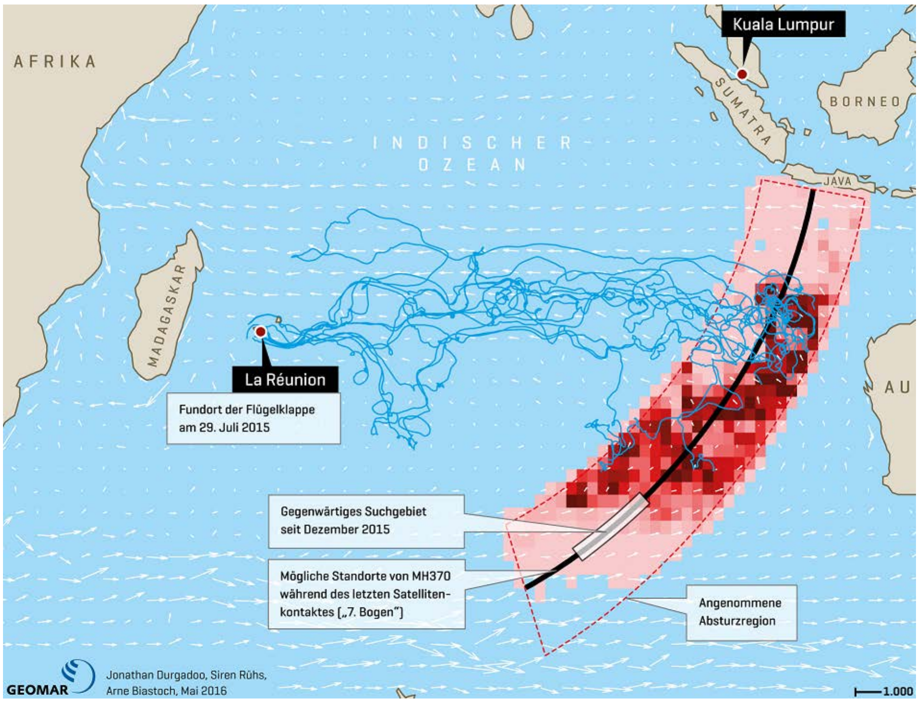


FIGURE 36. Possible crash site of Malaysia Airline MH370 based on a wing flap found on La Reunion. Source: Geomar, Helmholtz Centre for Ocean Research, Kiel, Germany.

With precise knowledge of the ocean currents in the Indian Ocean, the Geomar Institute in Kiel has used so-called Monte Carlo simulations to simulate possible paths of a found wing flap. The wreckage in question was discovered on the island of La Reunion and could be clearly assigned to the missing aircraft. By tracing the ocean drift as a function of time, a large number of scenarios were run with the goal of evaluating the location of origin of the found piece. In particular, the question was asked which current paths would ultimately hit the suspected crash area along the black arc drawn in the figure. This shows the possible position of the aircraft at the last received satellite contact. As can be seen, the actual search area on the arc, in which more than a year of systematic search was conducted, lies below the positions of the accident site found with this analysis.

In a Monte Carlo simulation, a large number of numerical simulations with slightly different initial conditions are run. The time-dependent ocean current model and the arrival time of the find at the target location are varied within a certain range representing the uncertainty of the data. In the end, a probability statement about where the find started is obtained in this way. The figure shows a few typical paths taken by the wreckage during individual simulations. In total about 5 million simulations were run. Dark red fields in the map are therefore possible crash positions with a high probability.

Simulate evolution

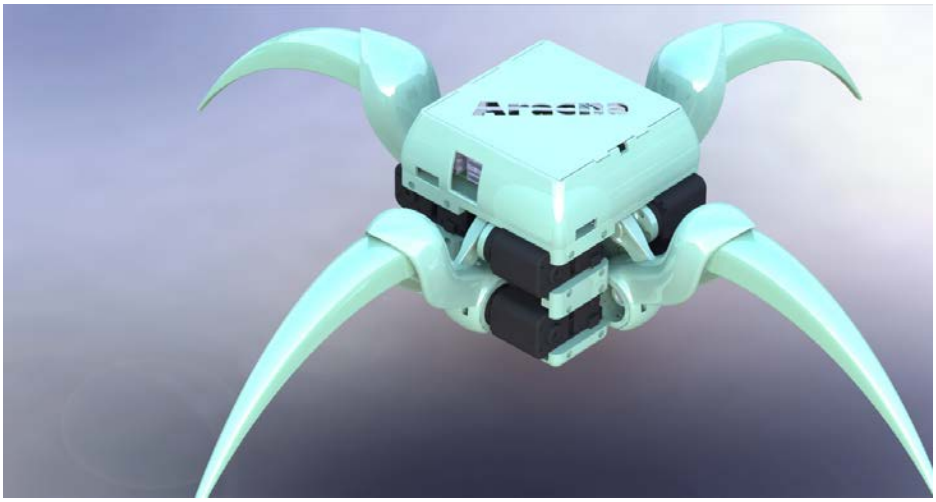


FIGURE 37. The robot 'Aracna' for the simulation of evolutionary behavior

Hod Lipson from Columbia University and Jason Yosinski from Cornell University are two representatives of research groups that deal with the evolutionary development of mechanical movements. Based on a four-legged robot, they try to leave the learning of locomotion to an evolutionary process. At the beginning the robot has movable legs and a "brain" which is able to control the movement of the legs, to program movement sequences and to store empirical values of the applied algorithms and to compare them with other empirical values. However, the robot still has no idea which movements in detail or which combinations of movements of the actuators ultimately lead to walking ahead on the ground.

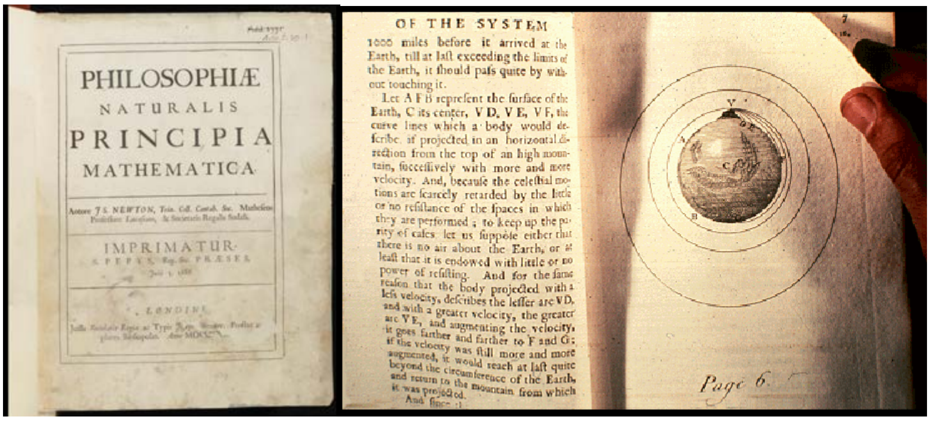
The robot's central controller is now able to run through a learning cycle. The little crawling animal starts from scratch and must painstakingly learn each movement. This begins with attempts to stand up and remain stable without tipping over. Once this has been achieved, the next stage of development comes with the first tentative attempts to walk. Whenever the robot loses its balance or otherwise fails, these negative impressions are recorded and something new is attempted. It is no coincidence that the whole process is reminiscent of an infant hopping around on the floor in the second half of the first year of life and finally making its first attempts to walk at around 12 months of age.

At the very end of the process, perhaps after tens or hundreds of thousands of trial cycles, the robot will crawl across the floor with great confidence and may even have developed movement patterns that we had not thought of. It, the robot, has invented walking itself and has developed the most optimal form of locomotion, which gets the maximum out of its given weight and the mobility of its legs. Finally, it is interesting to note that this entire evolutionary process can also be performed virtually on a computer using multi-body dynamics simulation software such as 'sonar-3D'.

Simulate in the brain / thought experiments

Engineers and physicists partly have the ability to mentally play through physical processes in their brains. This does not mean that they want to predict the movement of a mechanism by applying a known formula, but that a film runs in their heads when they look at an apparatus or even just a drawing of an apparatus, which in principle is nothing other than a numerical simulation. Starting from an imaginary initial situation and the mental application of different forces to different parts of an imaginary mechanism, the mechanism finally starts to move in the mind's eye of the observer. If one now superimposes the temporal change of the forces on such an imagined motion sequence, then an iterative sequence of individual images is ultimately created in the brain which mentally simulates the development of the motion. In this way, the person concerned projects a film onto a virtual projection plane in front of his or her mind's eye.

Isaac Newton also apparently used such thought experiments to fathom the cause and effect of physical forces. In this sense, it is known that Newton imagined a horizontal stone throw and wondered what would ultimately happen if a bullet were fired with an increasingly powerful cannon. The bullet would of course fly further and further and at some point when exceeding a very high velocity the distance of fall per second would just correspond to the curvature of the earth and the bullet would thus fall around the earth. The bullet would become an earth satellite like the moon.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1000 miles before it arrived at the Earth, till at last exceeding the limits of the Earth, it should pass quite by without touching it.

Let A F B represent the surface of the Earth, C its center, V D, V E, V F, the curve lines which a body would describe, if projected in an horizontal direction from the top of an high mountain, successively with more and more velocity. And, because the celestial motions are scarcely retarded by the little or no resistance of the spaces in which they are performed; to keep up the parity of cases let us suppose either that there is no air about the Earth, or at least that it is endowed with little or no power of resisting. And for the same reason that the body projected with a less velocity, describes the lesser arc VD, and with a greater velocity, the greater arc VE, and augmenting the velocity, it goes farther and farther to F and G; if the velocity was still more and more augmented, it would reach at last quite beyond the circumference of the Earth, and return to the mountain from which it was projected.

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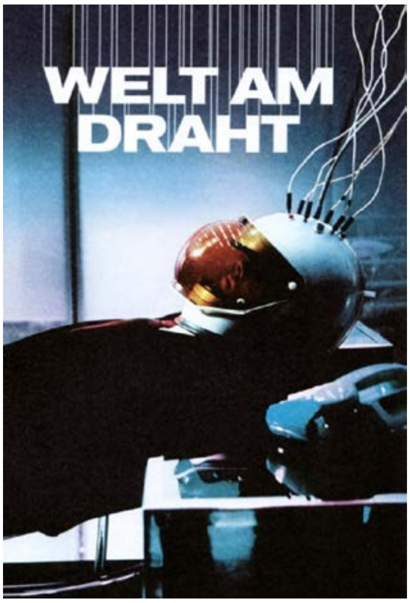
FIGURE 38. University of Cambridge, Digital Library

The necessary speed for an earth orbit depends on the flight altitude. In the near earth range it is about 7.9 km per second. The cannonball then needs about 90 minutes for an orbit around the earth.

Newton's main work entitled "Philosophiæ naturalis principia mathematica" was published in 1687 and is considered one of the most important works in the history of science. It contains the fundamental Newtonian laws of mechanics and thus the foundations of modern physics. In the ranking of the most important and greatest physicists, Newton is still undisputedly in first place. In the book "Who is Who of Science" by John Simmons, Newton even ranks first among all scientists of all disciplines.

Is the whole universe 'just' a simulation?



In 1973, German film director Rainer Werner Fassbinder adapted the 1964 science fiction novel Simulacron-3 by author Daniel F. Galouye and named the film World on a Wire. A computer specialist dealing with simulations of artificial worlds discovered that he and the whole world around him was also just an illusion. He himself and our world was a simulation of an even higher world, just like the world he himself had created on the computer. The movie 'Matrix' revisited this theme decades later.

In 2012, serious scientific articles appeared in professional journals, which addressed this issue. Physicists Silas R. Beane, Zohreh Davoudi and Martin J. Savage wrote a paper titled 'Constraints on the Universe as a Numerical Simulation'. In it, they pondered how and by what one might recognize if our universe is a simulation. Nick Bostrom, an Oxford philosophy professor, initiated this discussion back in 2003 and set in motion a lively exchange of views worldwide.

Even if we have to disappoint the reader at this point, a final answer to the question has not been made until today. However, criteria for the recognition of such a state of facts have been suggested in the above-mentioned scientific article. However, the corresponding physical experiments would devour some money and effort to carry them out. The authors of the article come, simplified formulated, to the conclusion that also our universe would have to have a grid structure (n-th dimension) and that also in this grid structure the transport equations of certain physical processes of astronomical extent could not be isotropic. And this anisotropic behavior of these processes could indicate that we live in a simulation. The fact that in particle physics all elementary processes can ultimately be traced back to the smallest exchange particles could be a further indication that someone is 'calculating' with us.

Already today, we simulate parts of this world on the computer to a limited extent. At some point in the future, we will be able to populate these simulated worlds with artificial avatars that could develop consciousness by virtue of the complexity of their own software brains. We can make sure that these beings with their sensors in their environment perceive purely software-oriented everything that we also experience with our five senses in our world. And all this without existing material 'reality' in a computer. In what way do these virtual beings differ from us in the last consequence? Will they eventually realize that there is still a higher world?