My TEDx Talk at IIT, Dhanbad on October 8, 2014

On

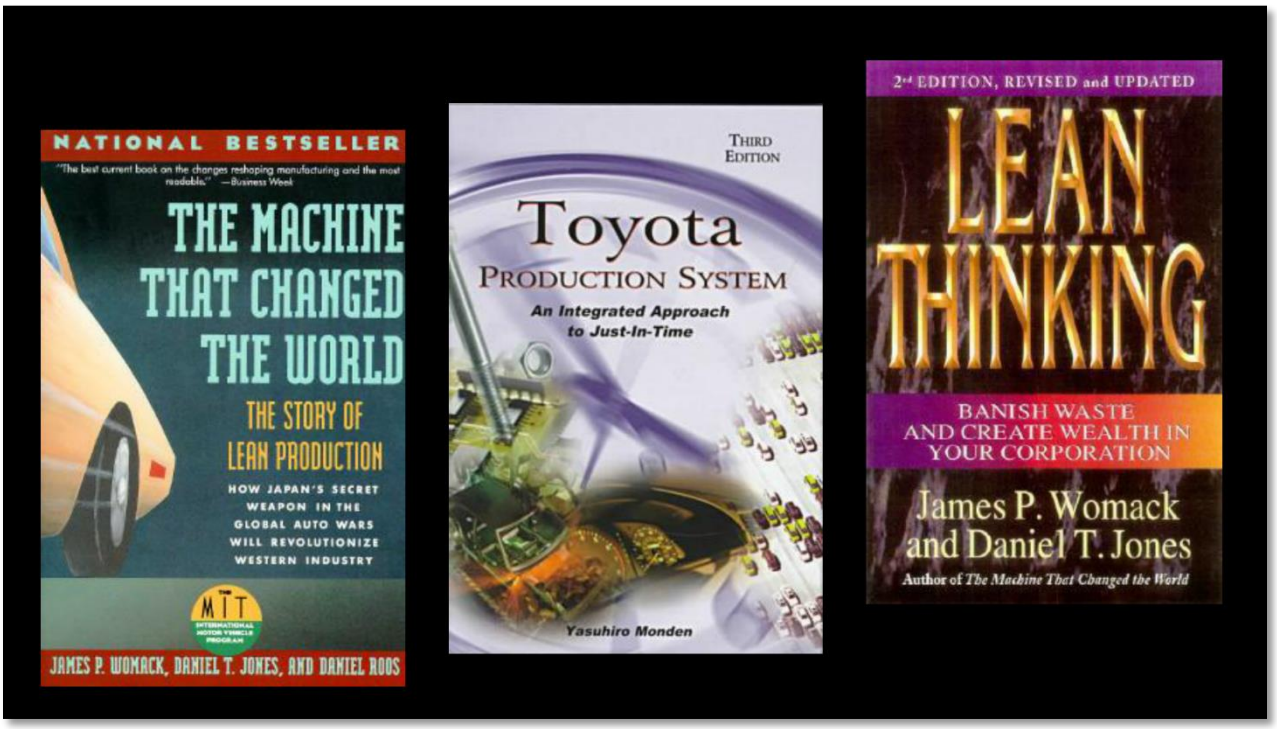
"Lean Processes in Nature"

By

Pratap Sriram Sundar, PhD

Pratap Sundar delivering his talk at TEDxISMDhanbad on October 8, 2014

The Talk



For the last 30 years I have studied, got trained and implemented lean processes in many companies.

Lean was pioneered by the Japanese companies, and especially by Toyota Motors. In the initial years, sometime in the late 1970s and early 80s, it was called by various names such as JIT (Just-in-time), CFM (Continuous Flow Manufacturing), SOMO (Sell One, Make One), MAN (Material As Needed), synchronous manufacturing, and so on.

In 1987 the word 'lean' was coined by John Krafcik, a young research scholar at MIT (Massachusetts Institute of Technology) working in the IMVP (International Motor Vehicle Program). Some of the characteristics of lean are:

- Needs less human effort to design, make, and service products
- Requires less investment for a given amount of production capacity
- Creates products with fewer delivered defects and fewer in-process turn-backs
- Utilizes fewer suppliers with higher skills
- Goes from concept-to-launch, order-to-delivery, and problem-to-repair in less time with less human effort
- Produce products cost-effectively in lower volume with wider variety to sustain pricing in the market while growing share
- Needs less inventory at every step from order to delivery and in the service system
- Causes fewer employee injuries, etc.

In a word, lean needs less of everything to create a given amount of value.

This is Innovation Sports, an orthotics company at Foothill Ranch, CA, USA where I worked as Director of Manufacturing. This is one of the U-lines I have created as a part of lean implementation. We took about six months to implement lean. The results were astounding:

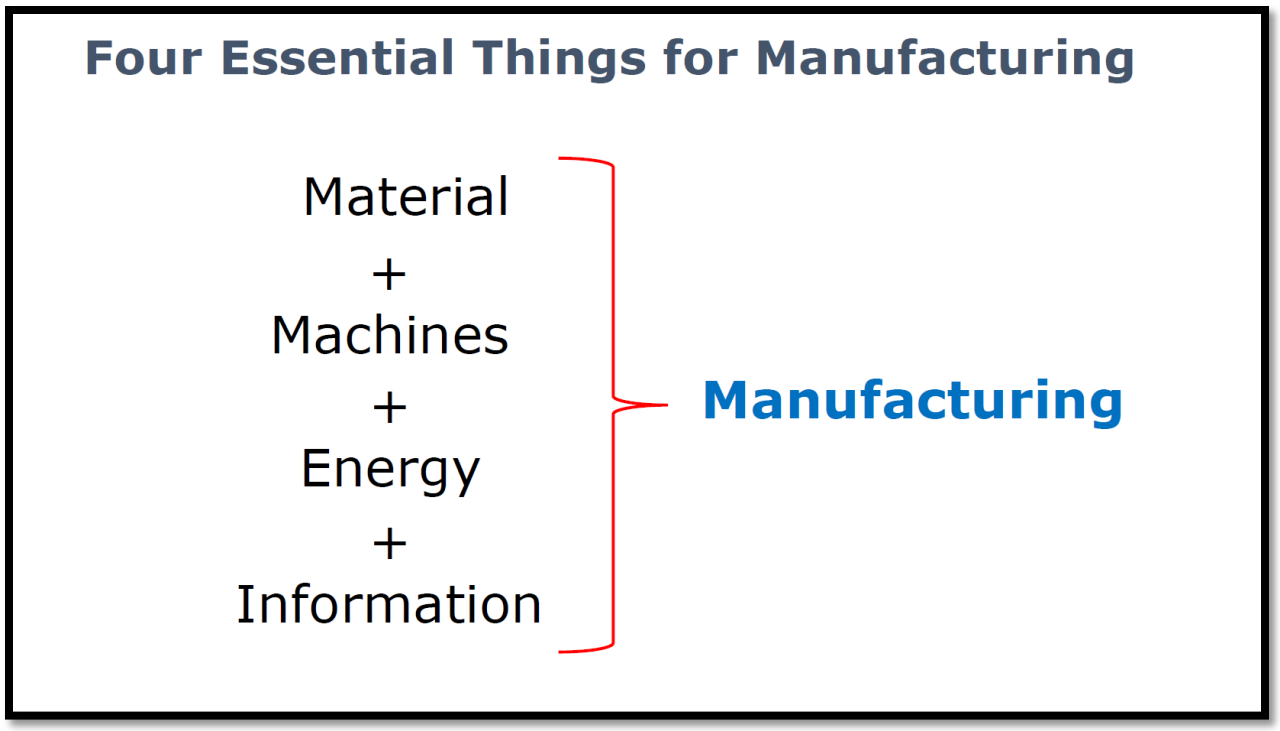
- Our inventory turns went up, from 8 to 22
- Labor productivity went up by 40%
- We eliminated second shift
- We minimization of overtime (OT)
- We saved more than 7000 Sq Ft of floor space
- Our quality costs was brought under 6% of sales revenue
- We divided factory into six channels (mini factories, or factories within a factory) and gave ownership to channel supervisors
- Communication was streamlined (among channels, and with other departments: Sales, Marketing, R&D, HR, Accounts & Finance)
- We defined clear performance metrics for channel supervisors (Metrics: OTIF, Back Orders, Inventory, Productivity, OT, Safety, Kaizen)
- Streamlined new product introductions (channel supervisors work ahead with marketing and R&D)
- I saved lot of my time, and my discretionary time was improved much. Because decision-making was almost automated and firefighting was reduced to a minimum.

The mathematical 'zero' is a gift of India to the world. Credit goes to Bhamhagupta and Baskara II of ancient India, who for the first time, defined its mathematical properties. The credit for applying the concept of zero to operations goes to Japanese, notably to Toyota. The philosophy of lean revolves around zero: Zero inventories, zero setup times, zero defects, zero breakdown, zero search time, zero discrepancies, zero paperwork and so on. The implications of 'zero' to operations are deep and vast. A few typical questions related to operations are answered by lean this way:

- What's the best planning? (Answer: Zero mismatch between sales and production)
- What's the best operation? (Answer: Zero operation is the best operation)
- What's the best machine? (Answer: Zero machine is the best)
- What's the best tool? (Answer: Zero tool is the best)
- What's the best changeover? (Answer: Zero changeover is the best changeover)
- What's the best transportation? (Answer: Zero transportation is the best transportation)
- What's the best material handling? (Answer: Zero handling is the best handling)
- What's the best delay? (Answer: Zero delays are the best delays)
- What's the best storage? (Answer: Zero storage is the best storage)
- What's the best downtime? (Answer: Zero downtime is the best downtime)
- What's the best energy-use? (Answer: Zero energy-use is the best)
- What's the quality control? (Answer: Zero quality control is the best quality control)
- What's the best paperwork? (Answer: Zero paperwork is the best paperwork)
- What's the best alignment? (Answer: Zero misalignment of employees with strategy is the best)
- What's the best service? (Answer: Zero service is the best service)

Reaching the goal of ‘zero’ everywhere in operations may not be possible every time. But, that is the lofty goal companies have strived for in implementing lean. While the concept of lean in factory operations is a recent phenomenon, nature has been using only lean principles from day one of her creations which began about 3.5 billion years ago. I would like to illustrate nature's lean products and processes with a few examples.

Besides studying and implementing lean, I have a great passion for nature. I have been studying nature for over thirty years. And I deliver lectures on nature to my friends at Hyderabad. This is one of the group photos of my friends who attended a lecture on *“Heart: The Seat of Love”* on September 8, 2013. It was an eight hour lecture. So far, I delivered about thirty lectures on various topics such as five senses (engineering of the human ear, eye, nose, tongue and skin), brain and its capabilities, science of beauty, ants, honeybees, Moon, information, leaf, egg, nanotechnology, animal architects and so on. You can see more details on these topics on my website: www.naturaconsultancy.com



We need four things to create something, or anything. Firstly, we need materials, the substances that go into the thing that is created. Secondly, we need machines to convert them in the shapes we desire. In this conversion, basically the geometry and the properties of the materials are changed by the machines. Thirdly, we need energy to run the machines that are engaged in the conversion process. And also, we need people and information to carry out all the activities. The information may be in the form of a design document, material properties, a set of process parameters, a production schedule, or logistics data. Some examples:

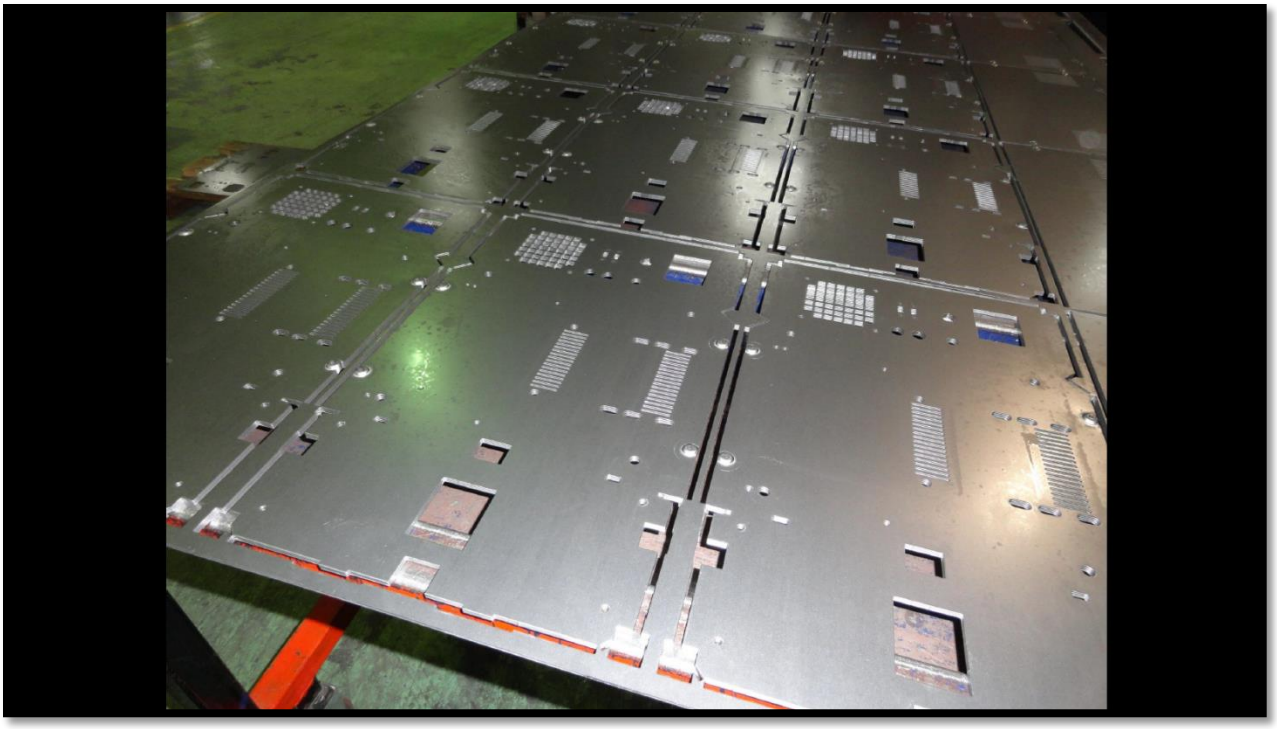
Materials: Steel, Copper, Aluminum, Titanium, Chromium, Mercury, Glass, Rubber, etc.

Machines: Furnaces, Presses, CNC Machines, Electroplating Stations, Powder Coating Booths, Injection Molding Machines, Die-casting Machines, Press Brakes, etc.

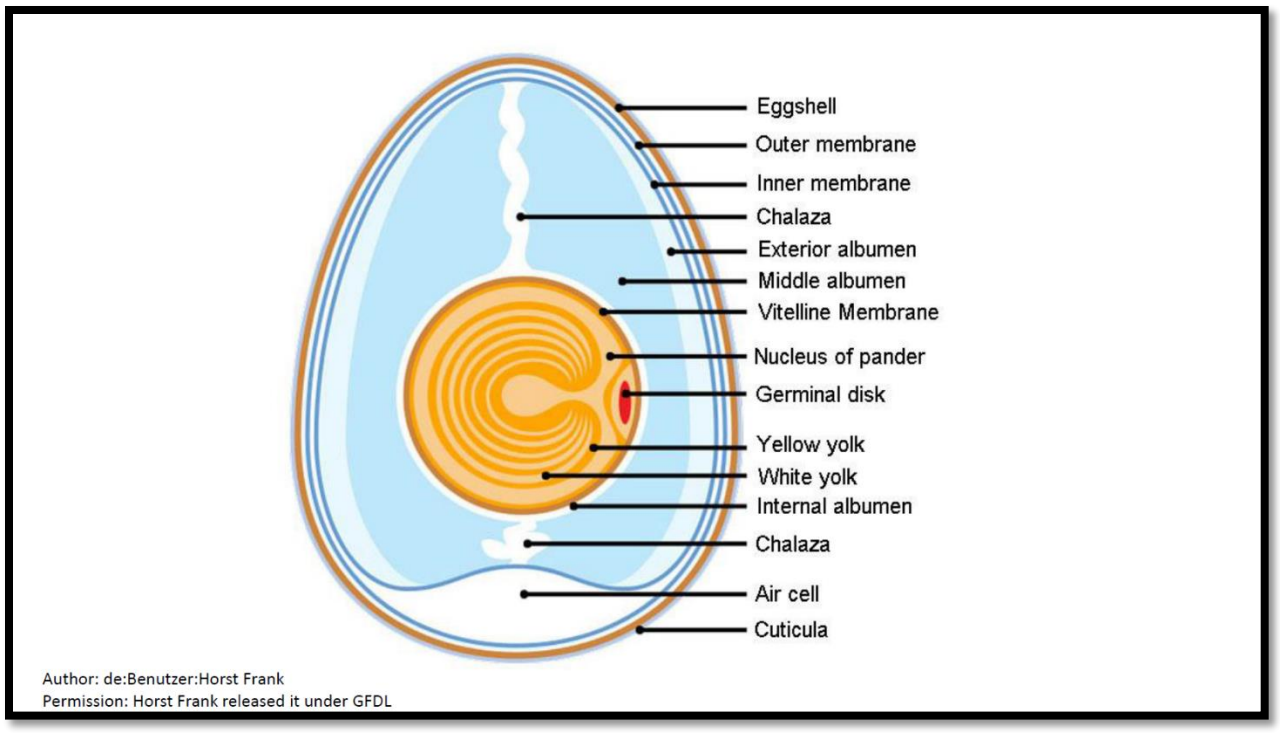
Tooling: Cutting Tools, Molding Tools, Bending Tools, Forging Tools, etc.

Process Parameters: Pressures, Temperatures, Speeds, Vibration, Utilities (Water, Electricity, Compressed Air, Vacuum Lines, AC, Lighting, etc.)

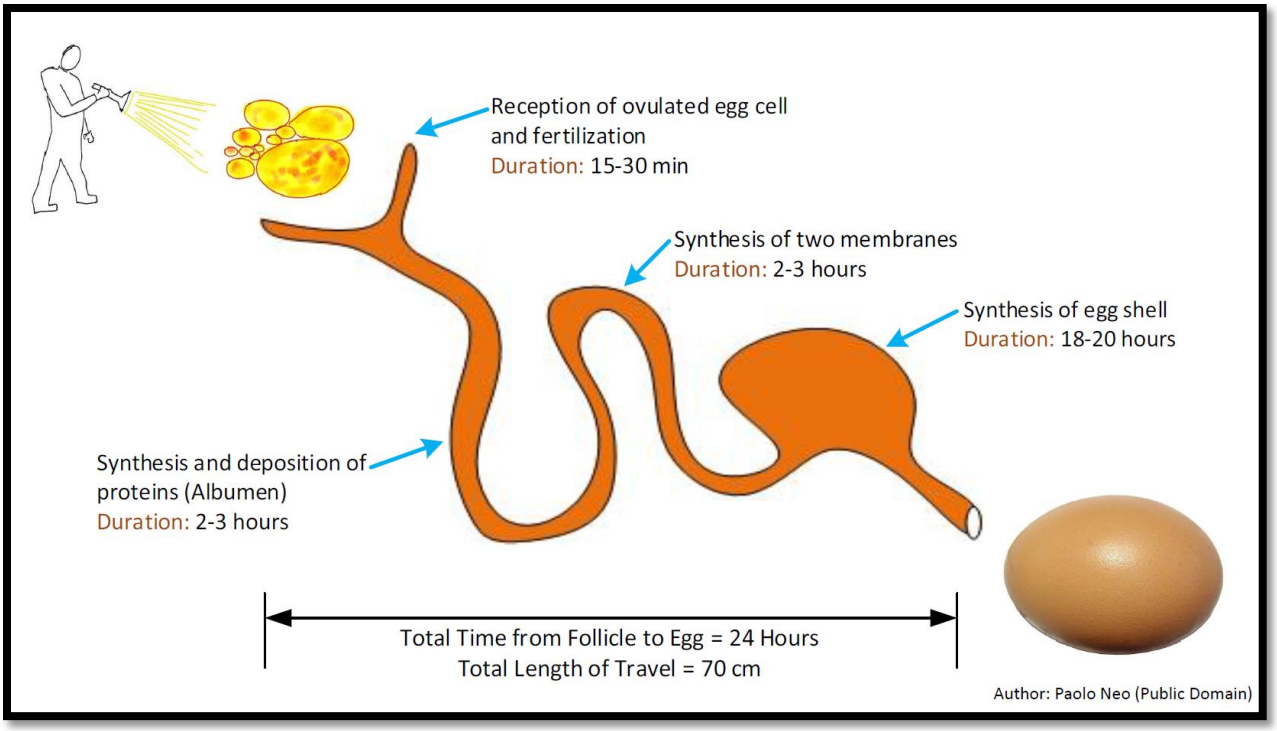
In our manufacturing we use costly and less abundant materials. We are rampant is consuming non-renewable resources. We need elaborate lighting in our factories. And finally there are many after effects of our manufacturing methods: Poisons polluting land, water, and air; dust, noise, greenhouse gases, landfills, increasing rates of cancer and other diseases, recycling problems, etc.



Look at this picture. This is a product in the making. Steel sheet of a couple of millimeters thick is modified by a machine. The forces involved to shear, punch, nibble, bend are too high. High temperatures and caustic chemicals are used to treat the sheet metal. Let us watch a short video clip on how this is done. More or less, all our manufacturing involves, what Janine Banyus, the author of the book *'Biomimicry'* calls *"heat-beat-treat"* methods.



Consider a chicken egg manufactured by nature, in the oviduct of a chicken. An egg has various parts, and each part has one or more functions to fulfil. The egg is surely one of the Nature's most remarkable and versatile inventions. It is a compact, self-contained capsule containing everything necessary for the creation of new life—be it a moth, a frog, a fish, an ostrich, or a human being. For millions of years the egg has carried life from one generation to the next.



Consider the example of chicken's oviduct. How a chicken makes an egg, and how an egg becomes a chicken is a deep intriguing mystery. Developmental biology has understood and explained some bits and pieces of this process. We cannot create an egg from a handful of grain, but a chicken does it all the time. All birds do it, including some mammals (Echidna, Platypus, and Spiny Anteater). The extraordinary intelligence of this process is embedded in their bodies by nature. Ten thousand Nobel laureates can neither explain nor duplicate this process—*a handful of grain becoming an egg*—in their labs.

First a hen eats, let us say, a handful of grain. This grain sustains the chicken and also, some portion of it is converted into follicles in its ovary. These tiny follicles travel through the oviduct, which is about 70 cm in length. An egg is manufactured inside the chicken's oviduct, one egg every twenty-four hours is released during the breeding seasons. The frequency and number of eggs per clutch vary with the species.

For a moment treat a chicken's oviduct as a factory that produces eggs. Imagine that you become a tiny observer of few hundred nanometers in size with a still smaller flashlight in hand and enter the oviduct of a chicken. Let us assume that your presence with a flashlight in your hand does not disturb the manufacturing process inside the oviduct. As you watch the few finite steps in this manufacturing process, you will be filled with amazement and wonder. First, an egg (still unfertilized) is made in the ovary, and as it moves through the oviduct by a small distance, it may be fertilized (life is created) and compacted into a spherical shape. Once it attains predetermined size and shape, the growth of yolk stops. This process takes about 30 min. Then, as it moves a little more distance to the next stage, the egg-white (albumen) and chalazae (to hold the yolk in the center of the egg, against the forces of gravity) are added, which takes about another 2 hours. Then, traveling a little farther, two egg membranes made of keratin, are wrapped around the albumen to keep it in an ovoid shape. Then the synthesis of egg-shell takes place, which takes about 20 hours. Egg shell is not a solid wall, but porous with about 7000 to 17000 holes. (These pores allow exchange of gases during the development stage). Then, the egg is ejected out into a wider world. By now, you have traveled about 70 cm through a muscular-tube called oviduct, observing

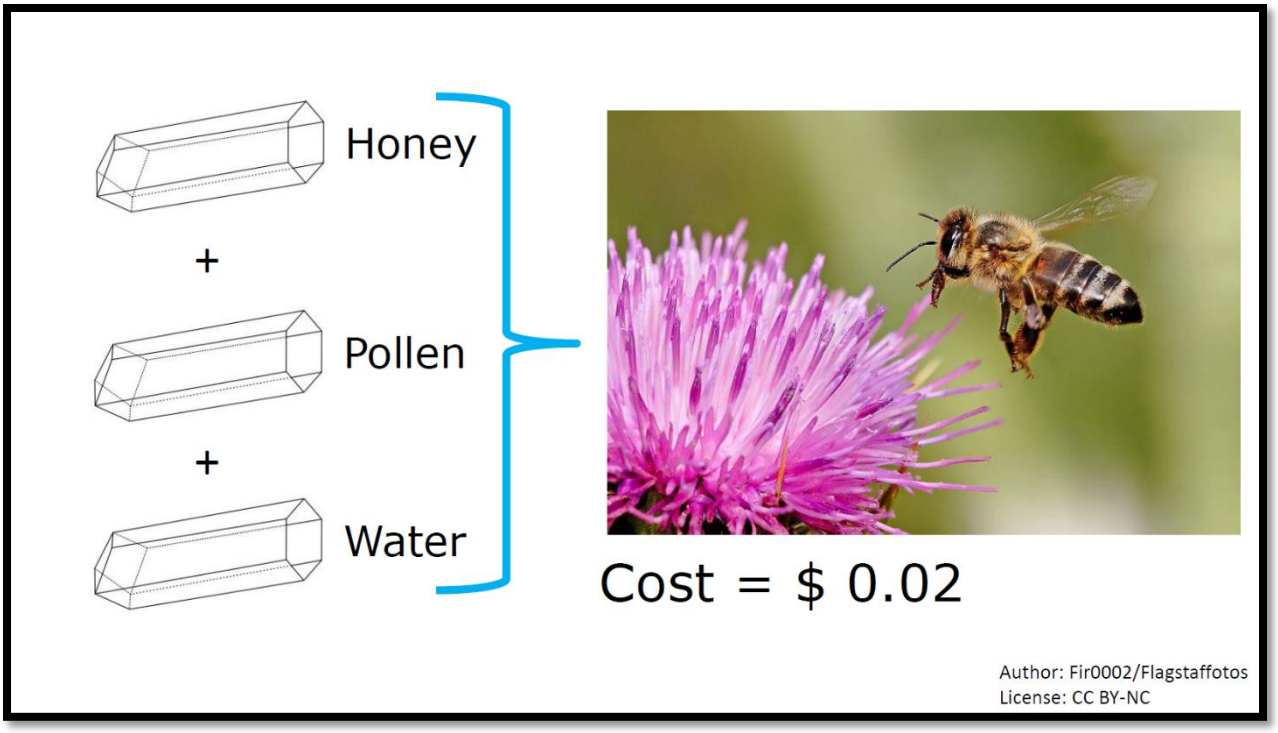
this process for 24 hours. You exit this factory filled with a sense of wonder that words cannot describe. The chief features of this Nature's remarkable factory, the oviduct, are:

- Design blueprint: DNA, few nanometers in size
- Shape: Long tube, with flexible diameter, and with several bends to reduce overall space
- Tube length: 60 to 70 cm
- No lighting (Dark Inside; Lights-out factory)
- No workers, operators, supervisors
- No planners, schedulers, material suppliers
- No tools, molds, machines, furnaces, containers
- No high pressures, temperatures, or caustic chemicals used in the manufacturing process
- No sound, no noise
- No scrap, no rework
- No quality control experts
- Material transforms while moving through the tubular factory with minimum energy requirements in the conversion process
- Technology: Nanotechnology (Self-assembly; Hierarchy, Massive parallelism, Bottom-up strategy)

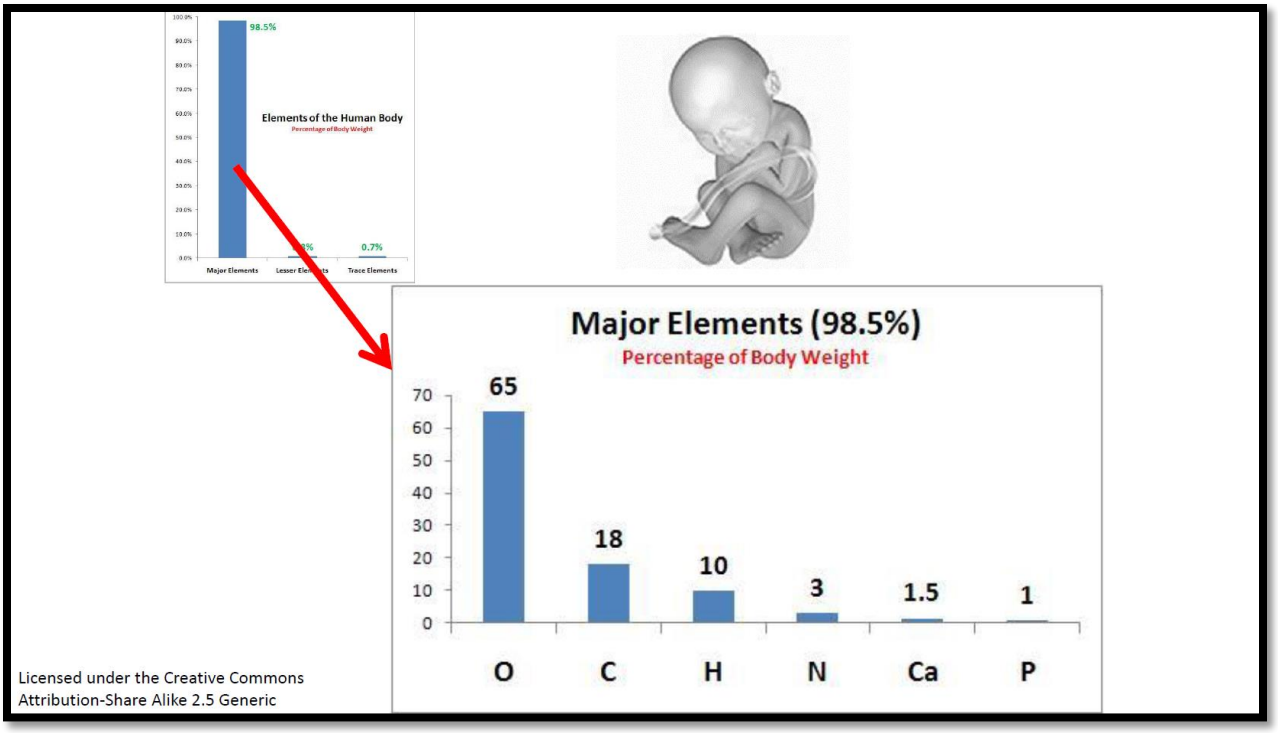
The oviduct is like a moving workshop, silent and lights out factory, where an egg is manufactured, at the rate of one egg every 24 hours. What comes out of the oviduct is a miracle. And further, there are:

- No customer complaints or product recalls
- Zero pollution, 100% recycling (all the parts of chicken and egg are fully recycled by Nature)
- Closed-loop system: Egg hatches into a new factory (chicken) that can produce more eggs, with blueprint (DNA) embedded within.

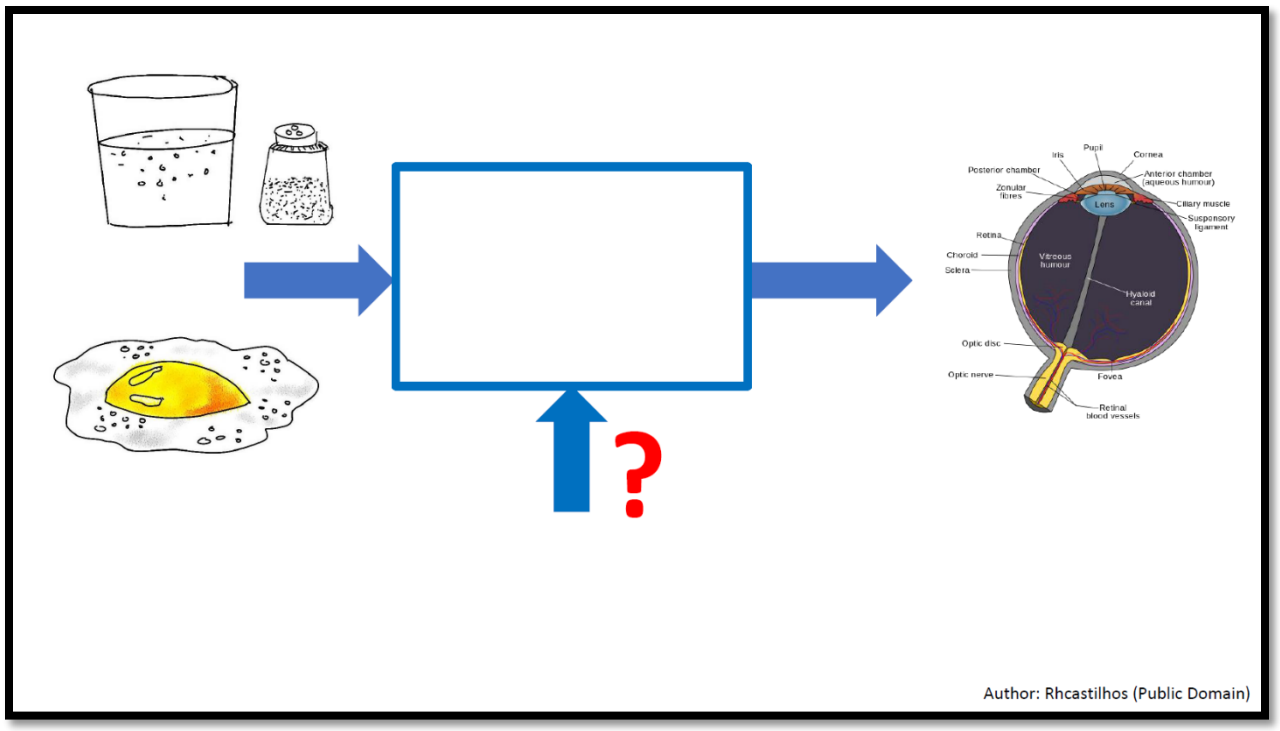
Are these not characteristics of lean manufacturing? Yes, we must admit and be very humble before nature. If you have a lights-out factory, no workers, no supervisors, no machines, no tools, no IT experts, and you are still able to produce products … that is surely an amazing lean factory! Let us apply the list of questions on page 4 of this document to the oviduct. The answers confirm that the oviduct-factory is either 'absolutely lean' or 'very close to lean.' From the moment the first single-celled organism was born, about 3.5 billion years ago, nature has been using only lean principles in her creation. The key to her 'lean' processes is in nanotechnology. Nature's lean is a million times more frugal than the best factories in our industrial world, be it Toyota, GE, Dell or Apple. And also, her products also are a million times more efficiently designed.



Consider another example. A honeybee is an engineering marvel. It is a miniature flying machine that is capable of understanding the world around it, and thrive. A honeybee hive has thousands of cells made of wax to store pollen, honey, water and also it's young. Each honeybee is manufactured by nature from the contents of three cells (one cell of honey, one cell of pollen, and one cell of water). All this costs only about 2 cents. If you watch the modern technology of drones, you will know that it costs millions of dollars to design them, and our robotic drones cannot come anywhere near this type of tiny self-supporting flying machine of nature.



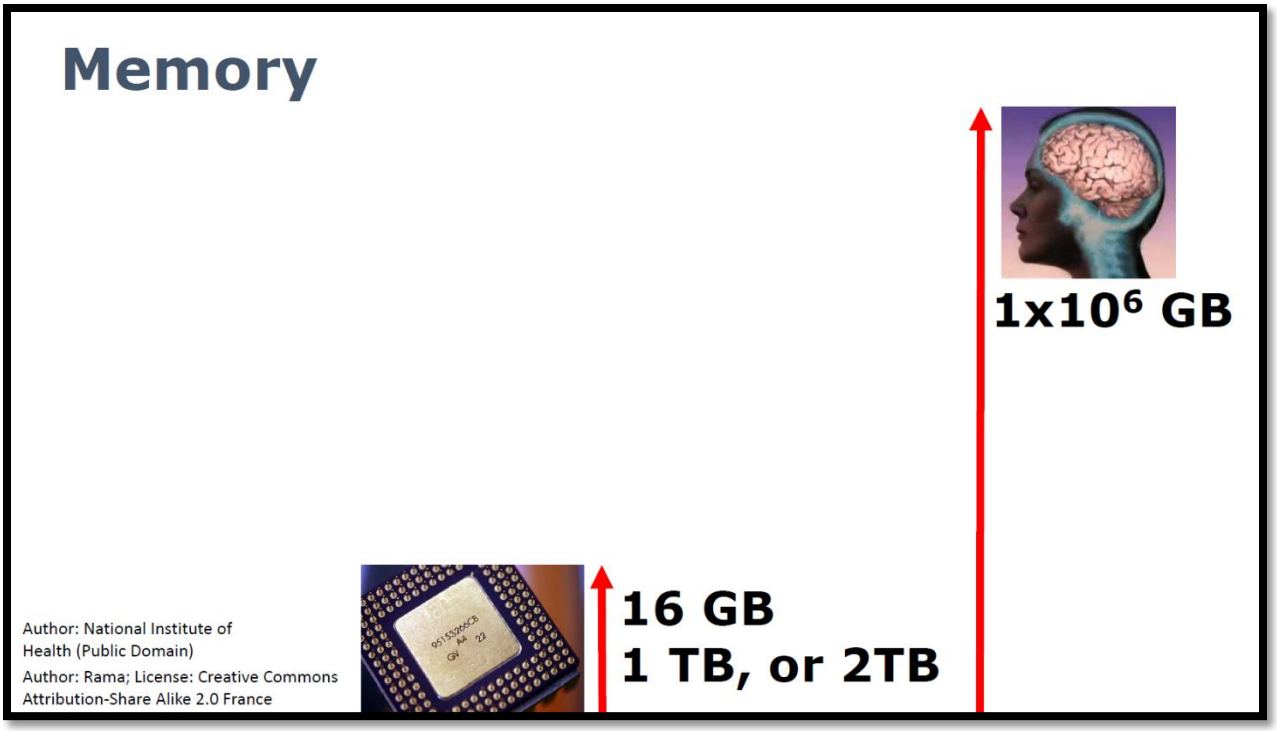
Consider your own body. 98.5% of it are made of abundant materials: Oxygen, Carbon, Hydrogen, Nitrogen, Calcium, and Prosperous. The material cost of a human body is only Rupees 400, or about $7.



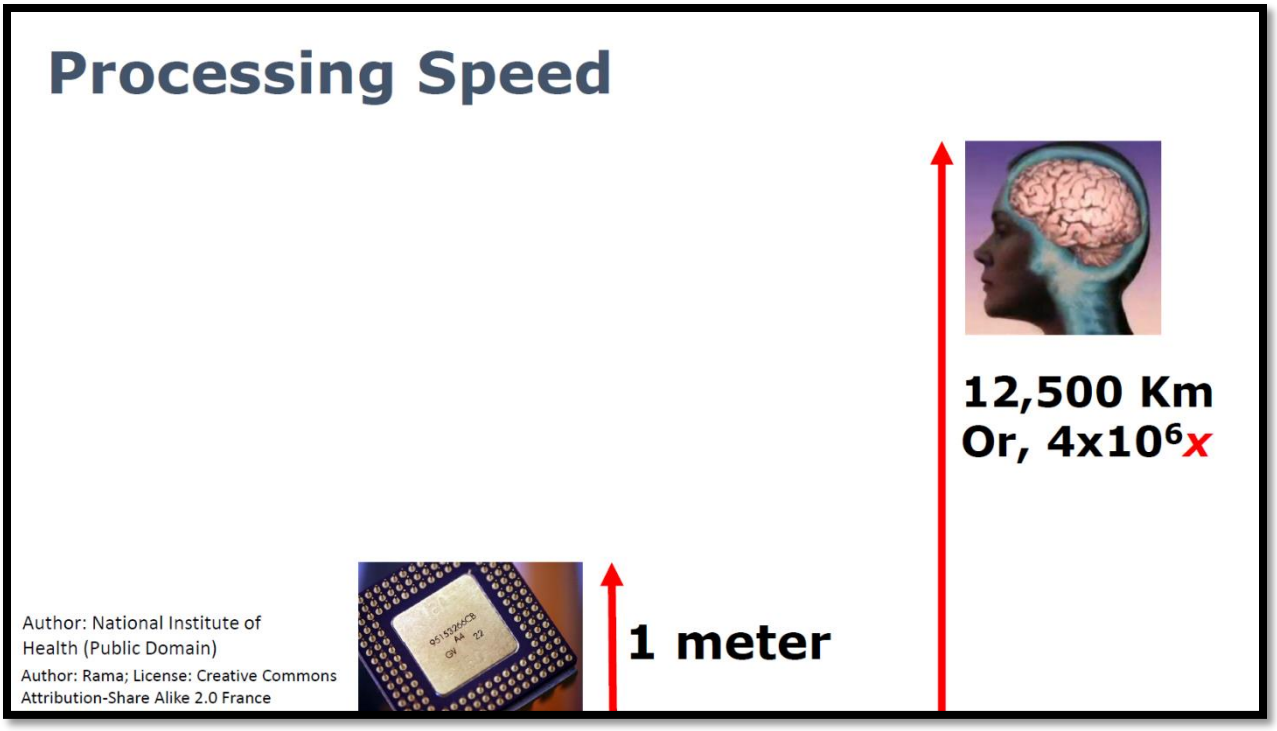
Consider an organ, the eye, in the human body. Two human eyes put together are equivalent to 576 megapixels (estimates vary). Both are mounted on automatic tripods, controlled by a set of six muscles for each eye. They can see, focus, move, lock on to a moving object, and filter data. Though the eye has structural similarities with a digital camera, the working mechanisms may be completely different. Long ago, I read a book by Dr. Charles Sherrington, Nobel laureate for medicine or physiology in 1932, on the *'Eye'*. That was a really an eye opener to me. Nature creates an eye from a glass of water, albumen (egg white), a bit of salt, and some other negligible amounts of trace materials. The material cost of this 288 megapixel camera is only Rupees 10, or a quarter dollar. If a craftsman, such as Thomas Edison is given these materials, and asked to produce a camera, he wouldn't even know how to go about it. But, nature does this all the time. Billions of eyes are created every day. Longtime ago, I was working with lens manufacturers at Bharath Electronics Ltd, and Opto-electronics factory at Dehradun. I know the lens manufacturing process. It is costly, time-consuming, and creates lot of pollutants. But the manufacturing method of lenses for the eyes of animals by nature is completely a different story. Most of Her technologies are executed at ambient temperatures and pressures, without the use of harsh chemicals, and are efficient (require least energy), non-polluting and eco-friendly.

Consider the lens manufacturing. Engineers create them chiefly from glass (Silica) for use in eyewear, cameras, microscopes, telescopes, and such devices. Glass is melted in a furnace, purified, poured into molds, cooled, ground, polished, tested and dispatched for assembly. The quantity of lenses manufactured by humans may not exceed a few million per day. Nature also creates lenses, trillions of them every second. Consider these numbers: 15,000 children are born every day. They need 30,000 lenses (2 per head). Millions of creatures—butterflies to buffaloes, mice to elephants, dogs to deer, snails to snakes, spiders to eagles—are born every day. They all need lenses, 2 per head (spider needs 8). Perhaps, a million dragon flies are born during the season in a patch of forest land. Each dragon fly needs 64,000 lenses (32,000 per eye). A million flies would need 64 billion lenses. A mosquito or a fruit fly needs similar

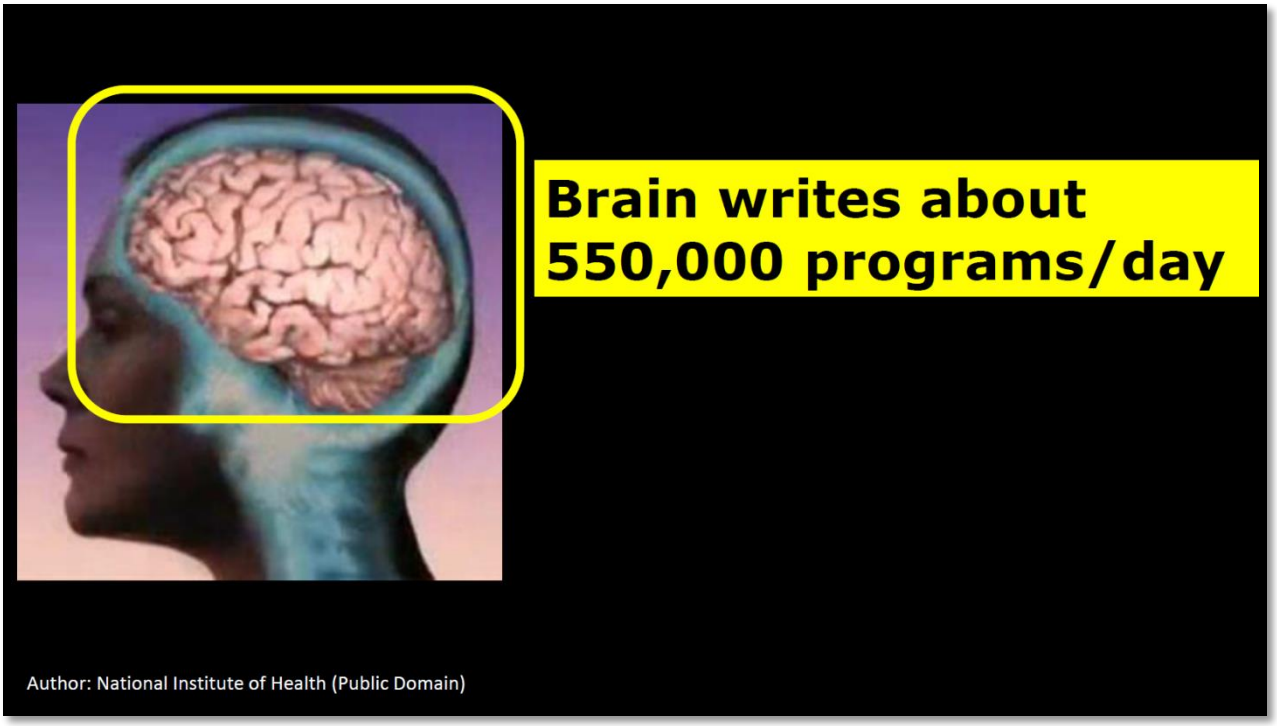
quantity of lenses for its vision, navigation and protection. How many anchovy, krill, fishes and crustaceans are born in one cubic kilometer of a sea? Trillions! They all need eyes (some 2 each, some 4 each, some 40 each). A crude estimate will lead us to a quantity of atleast a billion trillion (10^{18}) lenses per day. In the process of manufacturing these many lenses, nature's choice materials, designs, manufacturing methods, technologies to achieve high reliability, maintainability, recyclability etc, far exceed the human imagination and intelligence. Even the best-in-the class designs that human engineers have created so far, are at best dim and dull before Nature's designs.



Consider another organ: Human brain. The human brain is the nature's masterpiece. It is the most complex organ in the entire universe. It is about 1.5 kg in weight, like an oversized walnut, a bundle of nerves, flesh, and fluid. It has 100 billion neurons and 40 quadrillion synapses. The brain is like the CPU of a computer, and it processes the data sent by five senses—Ears, eyes, tongue, nose, and skin, which are like peripheral devices of a computer system. It also processes many signals received from internal organs. The brain is 80% water, 12% fat, 8% protein, and has trace amounts of ions. The material cost of the brain is only about Rupees 40 or less than one US dollar, and it works on just 10 Watts of power, and has no moving parts. It is the seat of our pains and pleasures and of our dreams. It is also the center of our memory, imagination and creativity. It is your private computer without a password and yet nobody can download its contents. It wakes us up in the morning (clock in the brain), conducts the day's activities until sleep. Between waking and sleep it enables us to write, type, work, dance, eat, drive, drink, talk, sing, joke, laugh, walk, trust someone, be angry, shed a tear drop, dream, plan our future, and so on. It is jam-packed with functions, programs, connections, and interconnections that overlap with each other. Though the body sleeps at night, the brain itself doesn't, and its uptime is 100% over 70 years of average life (not 99% or even 99.99% that we use to measure the uptime of our computer servers; Nature choose either 0% or 100% for the uptime; 0% means death, and 100% means life; if the brain is down, we are dead). We have learned more about brain in the last 50 years than in the last 5000 years. In the last 110 years, more than 35 Nobel prizes were awarded to neuroscientists who unlocked a tiny fraction of its mysteries. The detailed workings of the brain is the last great mystery of the human body to be explored and discovered. We owe not only our existence and survival to its capabilities, but also for the infinite joys that we derive by its powers of creativity. That's why it is a masterpiece of Nature. From among its infinite capabilities, let us consider just three features: (1) It's memory capacity, (2) It's processing power, and (3) It's programming capability. The brain has a memory capacity of 10^6 GB, or, one million gigabytes. That's why it can store all important data of a life time, without any need for upgrades.

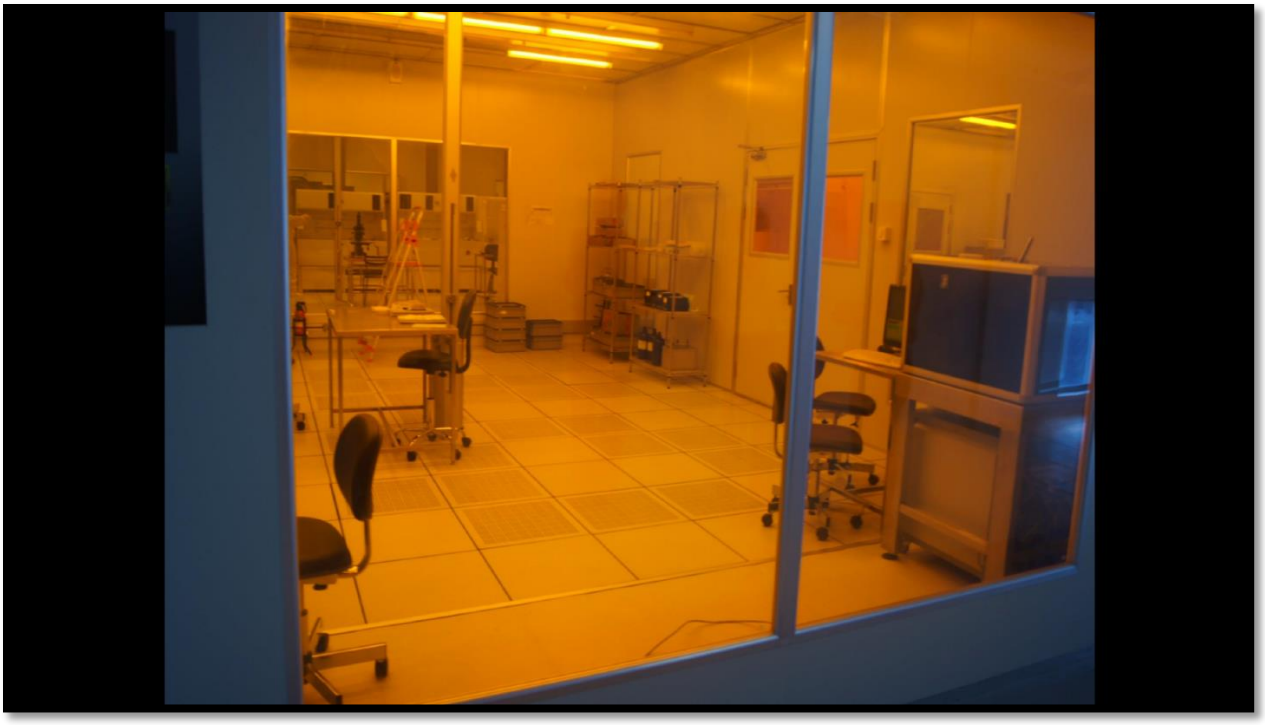


Signal rate from the senses and internal bodily processes may be about 100 GHz. But, the processing speed of the brain is much more, about 12.5×10^6 GHz. While driving through a busy street, the eyes and the brain process about 20 GB per second. Thanks to this colossal processing power, we could reach our homes or offices or other destinations safely. (Note: These numbers of memory size and processing power are just estimates. Scientists' estimates of human brain's processing speed and memory vary, and there is no definite answer until now).

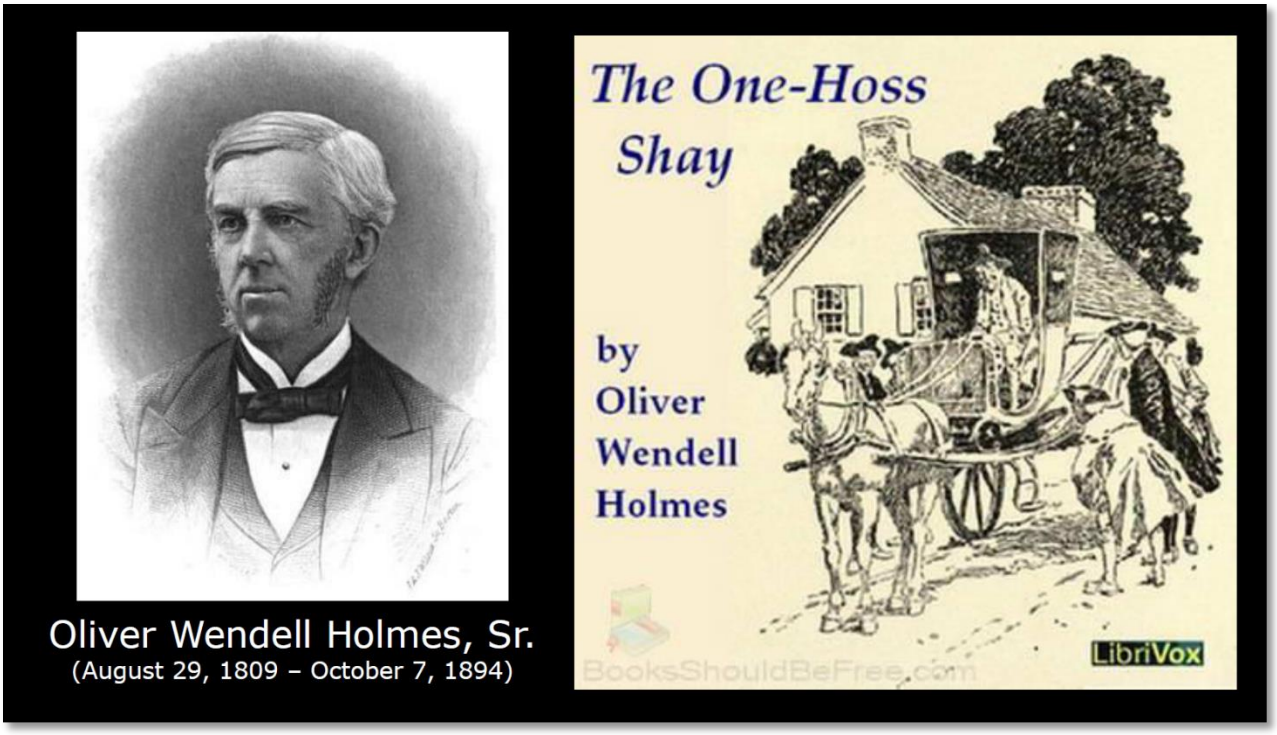


The human brain makes about 20,000 decisions and writes about 550,000 programs to execute our actions each day. It guides the body through the motions of intricacy and delicacy, ranging from the most gross to the most subtle movements, emotions, thoughts. I worked for a company Paraform in Silicon Valley, CA about 14 years ago. There were developers, whose work must go thru testing & quality control department, before being released into the market. Debugging and re-testing are common activities in all software companies. I have seen robots whose limb-movements and body-motions are executed by complex programs embedded within. Watch Honda's ASIMO. They are damn slow! When I look at these 550,000 programs (in a mix of analog and digital modes) written by the brain, and executed in millionths of seconds, I was wondering where is testing & quality control department. Are all these 550,000 programs are defect free, i.e., without any bugs? Yes, it must be so! Is there a testing & quality control department. No! Is this truly lean! Yes! Because the goal of lean is to eliminate. Zero quality control is the best quality control.

In 2009 I attended a workshop on nano-sensors at the NEU (Northeastern University) Boston. I also made a visit to nanotechnology center at IISc (Indian Institute of Science), Bangalore. I saw STMs, AFMs, Raman Spectroscopes. Recently I visited James Watt Nano-fabrication center at Glasgow University, Scotland. There I was with my friend Dr. Srinivas Velugotla (above photo). There I saw dry etch rooms, photolithography (cleaning, developing and etching), metallization room (metal deposition, thermal evaporation, sputtering), spinner room (photo resisters, baking), mark aligner room (UV exposure), SEMs (scanning electron microscopy), EBL (electron beam lithography, capable of 10 nm), dry etching machine, and so on. These machines are complex and costly. They are used to create many things imitating nature such as a small cell-phone size device that could sniff out explosives.



This is one of the clean rooms in one of the nanotechnology centers I visited.



We are poor designers, compared to nature. Consider a design axiom: *"If a system is designed so that all its constituent parts fail at the same time, we don't need maintenance professionals, and upkeep technologies."*

If all parts of a car breakdown at the same time, we will throw that car away and buy a new one. If nature can reuse all the materials that have gone into a car, in a few days of time, then that would be a very efficient design. If all our organs—the heart, lungs, liver, kidneys, pancreas, stomach, brain, teeth, nose, brain, ears, tongue etc.—fail at the same time, we don't need doctors. Entire medical profession would be eliminated. (Of course, I am assuming that there won't be accidents and people won't lose their limbs, and people don't need cosmetic surgeries to beautify themselves.) To illustrate this axiom, one has to read the poem One-Hoss Shay (one-horse-drawn chaise or carriage) by Oliver Wendell Holmes (1809-1894), a professor at Harvard Medical College**.** Holmes commented, prefacing an illustrated edition of his book, "'*The Wonderful One-Hoss Shay*' that the carriage is a perfectly intelligible conception, whatever material difficulties it presents. It is conceivable that a being of an order superior to humanity should so understand the conditions of matter that he could construct a machine which should go to pieces, if not into its constituent atoms, at a given moment of the future. The mind may take a certain pleasure in this picture of the impossible. The event follows as a logical consequence of the presupposed condition of things. There is a practical lesson to be got out of the story. Observation shows us in what point any particular mechanism is most likely to give way. In a wagon, for instance, the weak point is where the axle enters the hub or nave. When the wagon breaks down, three times out of four, I think, it is at this point that the accident occurs. The workman should see to it that this part should never give way; then find the next vulnerable place, and so on, until he arrives logically at the perfect result attained by the deacon."

Products may have many components. For example, a ballpoint pen has four parts— tip, ink-lead, barrel, and the cap. A bit more complex pen may have up to 20 parts. A scissors has between 4-8 parts; a spectacles has 10-15 components; a wrist watch has 15-50 components (if it is electronic), 60-300 (if it is

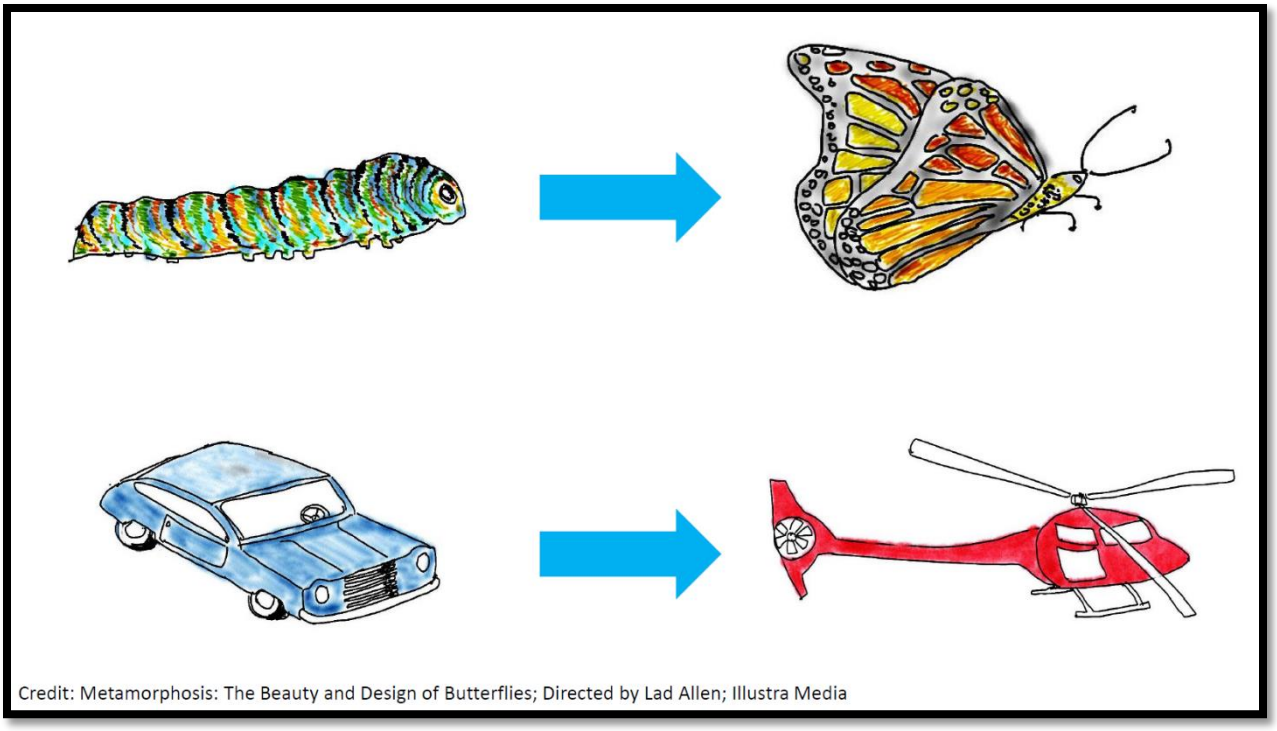
mechanical). A desktop computer may have 200-400; a typewriter 200-1000; a car 5000-10,000, a truck 10,000-15,000. An army tank such as the America's Abrams has about 40,000 components. The amazing Boeing 777 aircraft has about 4 million components, if we count every bolt, nut, latch, washer, rivet, and resistor, strip of wire or length of insulation that go into its body. An engineering challenge would be that all parts should fail at the same time, and all parts should disintegrate into nature as quickly as possible, like what happens in nature all the time. The material choices, manufacturing methods, recycling strategies are all related to design, in the first place.

Here are some of the nature's recycling principles:

- Nature recycles everything
- Waste equals food (Waste = Food)
- Nature's "Cradle-to-cradle" Vs. Humans' "Cradle-to-grave"
- Nature uses local resources, and materials that are abundant
- Nature does not create monstrous hybrids (Ex: Landfills)
- There is no confusion of flows in nature
- Nature respects diversity
- World of two metabolisms (Technical and biological metabolism)

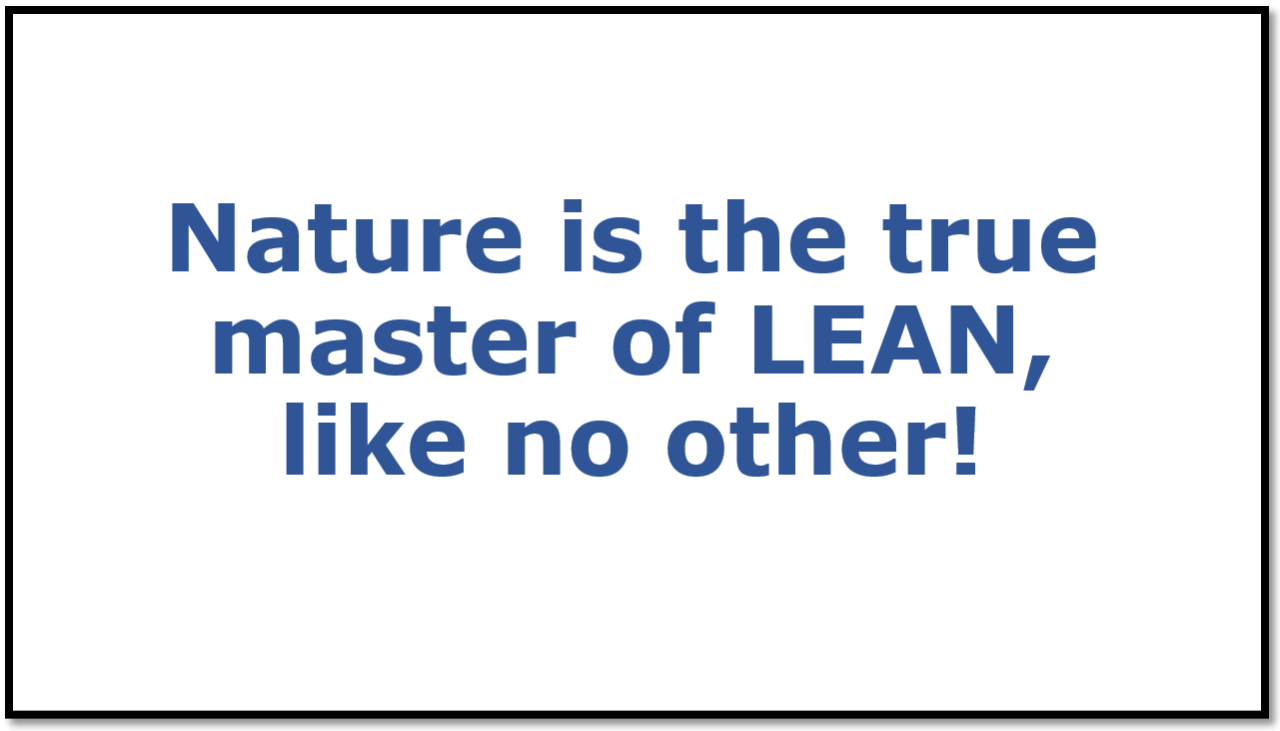
All life on earth runs by Sunlight. Plants are primary food producers. Without plants engaged in the job of photosynthesis, all animals would die. By leaves we live. All flesh is grass. Leaf is the inspiration for the solar cell. A leaf manufactures another leaf, while a solar cell cannot make another solar cell. We have factories that run on fossil fuels (not on solar energy) to make solar cells. Once a solar cell is discarded after its useful life, which is about 25 years, it becomes a problem of pollution. It spoils our water and soil. On the other hand, a dead leaf becomes nutrient to other newly budding leaves. A perfect harmony that nature devised.

Consider another example. Batteries run all most all the devices we use today—our laptops, ipads, cell phones, cars, toys and so on. But, batteries are notoriously inefficient, takes lot of time to recharge, and they are made of harmful materials such as lead, lead alloys, sulfuric acid, etc. In nature, there are living batteries. For example this electric eel that lives in the shallow muddy waters of amazon. It has both slow discharge (2-3 volts) and also can bolt with a high discharge (500-800 volts DC). It can recharge in a couple of seconds. And this living battery is made of organic stuff, and some traces of potassium, sodium, calcium and chlorine. This electric eel is a battery that you can eat (may not be very tasty like salmon or tuna!) and when this living-battery dies, it becomes a part of nature without any harmful polluting consequences to the environment.



These is a miracle in nature that happens millions of times every second. This miracle is metamorphosis. A caterpillar, which is a mud-crawler, becomes an elegant flying machine. Consider this analogy. I give you an old car, and out this, I want a helicopter. I will not give any extra materials, tools or energy, and I will keep you in a dark lights-out workshop or a factory shed. You have to convert this old car into a helicopter. Can we? We can't. But it happens all the time in nature. We can learn tons of things about *"reduce-reuse-recycle-remanufacture"* from nature.

When a person dies, his or her body becomes a part of nature within a couple of weeks. The 576 megapixel cameras (eyes), the super computer (brain), the motor-pump set (heart) that worked non-stop for 70 years, … and all other organs which are complex engineering devices disintegrate and merge in nature quickly. Out of these broken-down materials (atoms and molecules) nature builds many other things—a leaf, an ant, a plant, a honeybee, and so on. With nature's designs, life renews itself fast. When you discard an obsolete digital camera into your environment, we don't know yet, it may take thousands of years before nature can reuse those materials to build something else. Same argument goes for our computers, cell phones, fabrics, eyewear, footwear, toys, and all that we create, make, use and discard.



All the characteristics of lean are present in nature all through the 3.5 billion years story of life. After studying lean and nature deeply for about thirty years, this is what I concluded: *"Nature is the true master of LEAN, like no other!"* In the years to come, when nano-materials, nanotechnology and nanofabrication and such human scientific endeavors advance well, by imitating nature and learning from her, we will be able to create our products the way nature does. And then, then only, we will have a healthier and a better planet. Lean processes are essential in saving not only our inefficient factories and supply chains, but also our planet.

Thank you!

[End of the Document]