THE WILSON'S INTRIGUE

STEM Issue 6: July 2021

COMPUTING

Microprocessors

ENGINEERING

Circular Runways

MATHS

Optimal Stopping

PHYSICS

Rising Entropy

Introduction

Throughout the summer, the Intrigue team has been engaging with new STEM concepts, spanning starships to tetrations. This issue is particularly special given that many of the articles received high praise from the Sydenham STEM 700 words challenge.

The winners of the Wilson's Intrigue STEM Competition will be published in the next issue (Issue 7).

The team of writers and editors is very proud to welcome you to the sixth issue of the Wilson's Intrigue STEM, written for students by students.

Our Mission

- Expand your knowledge
- Contribute to the Wilson's community
- Make complicated parts of science more accessible
- Popularise science and make it more interesting
- Inspire creativity through wider research

Acknowledgements

The magazine is the sum of many parts, each wonderful thanks to the relentless efforts of the writers and editors, navigating deadlines, exams and lockdowns. Their intrigue for STEM and enthusiasm to share their research are the fundamental pillars of the magazine. A massive thank you to all students involved for their contributions!

A special thanks must go to Mr Benn, Mr Carew-Robinson, Dr Cooper, Mr Jackson, Mr Lissimore, Miss Roberts and Dr Whiting for once again proofreading and verifying the accuracy of our articles and the magazine as a whole.

If you would like to write in the seventh issue of the STEM magazine to indulge in researching and sharing a STEM curiosity, please email me (Divy) at *DAYALD@wilsonsschool.sutton.sch.uk* for more information.

Founded by Devanandh Murugesan and his team of editors in September 2019

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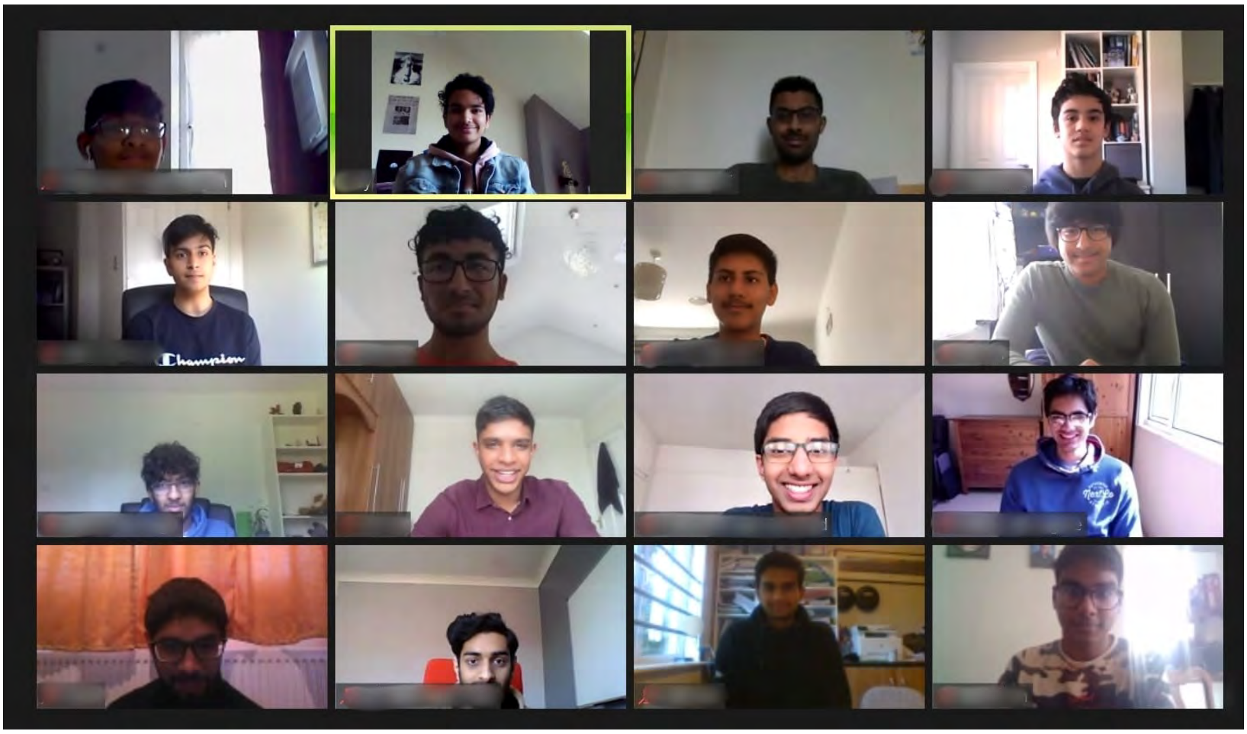
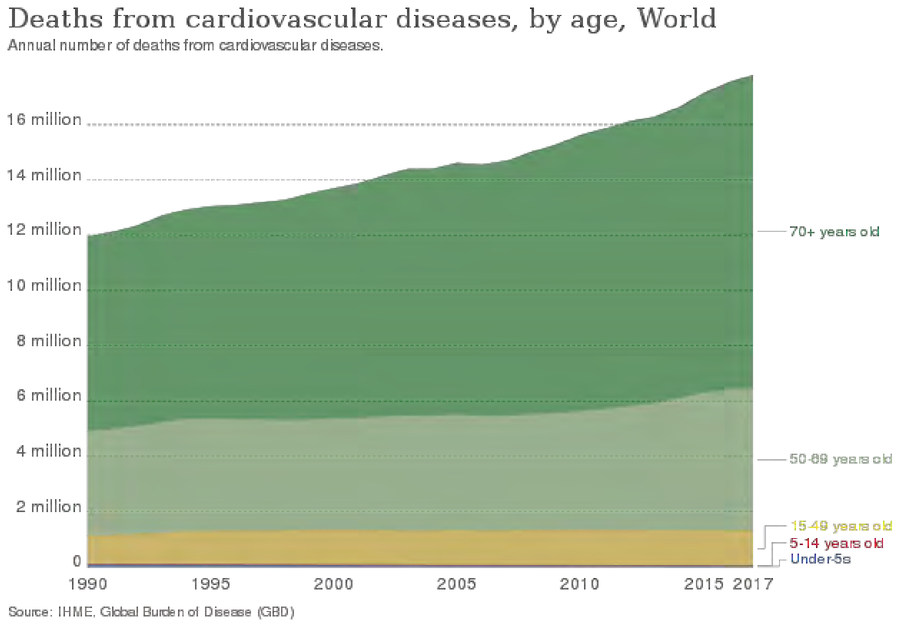


Contents

If you are viewing this digitally, you can click on the titles of the articles or sections.

DID YOU KNOW?

Tomatoes are rich in lycopene. This antioxidant is effective against certain cancers and maintains a healthy heart. Biologically speaking, they are also berries than vegetables, answering the long standing question of whether tomatoes are fruit or veg.



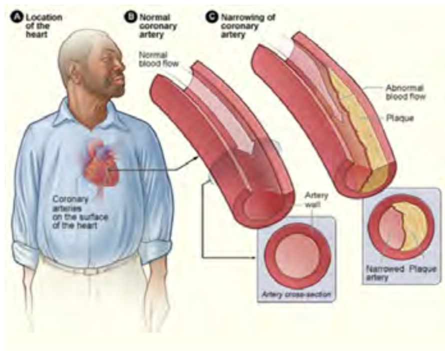
Left: Deaths from Cardiovascular Disease

The Link Between Oral Health and Cardiovascular Disease

By Junaid Ali (Y12)

In 2019, ischaemic heart disease was the number one cause of death at a global level, according to the World Health Organisation [1]. With cardiovascular diseases becoming more and more prevalent, many organisations are looking into the potential factors that may increase the risk of developing cardiovascular diseases. In recent years, there has been increasing evidence to suggest that there is a link between oral health and cardiovascular disease, with poor oral health being associated with higher rates of complications such as heart attacks or strokes. However, the exact pathological relationship between oral health and cardiovascular disease is unknown and there is evidence for and against the potential link.

The British Heart Foundation has been researching how gum disease – also known as periodontal disease – can increase the risk of developing heart or circulatory complications. They believe that in people with periodontal disease, gaps can form between the teeth; this allows bacteria from the mouth to enter the bloodstream. From there, dental bacteria can travel to other parts of the body and trigger an inflammatory response in the blood vessels [2]. Inflammation can lead to the formation of blood clots, which can result in heart attacks or strokes. If dental bacteria travel to the heart and cause inflammation in the coronary arteries this can lead to coronary heart disease.



Atherosclerosis and Coronary Heart Disease

Another complication that can be caused by dental bacteria is endocarditis. Endocarditis occurs when bacteria in the mouth enter the bloodstream, travel to the innermost layer of tissue lining the heart – called the endocardium – and cause inflammation. The bacteria are often able to enter the bloodstream because of dental procedures that break the gingiva (gums) but this can also happen during tooth brushing or flossing. Once in the heart, the bacteria can form clumps on the valves, which make it harder for the valves to ensure sufficient blood flow through to the lungs and the rest of the body. Those with heart defects or an artificial replacement heart valve are particularly at risk as it is easier for bacteria to bypass the immune system due to the presence of immunosuppressant drugs. Common symptoms of endocarditis include joint and muscle pains, headaches and high temperatures. Although endocarditis is a rare condition and the symptoms are not always severe, it can be a potentially fatal infection [3].

Despite the evidence that poor oral health may contribute to cardiovascular diseases, some people believe that there is no causational link between the two but rather there is a common risk factor for both conditions. A study carried out in 2011 on a sample of the Iranian population determined that some established cardiovascular disease risk factors were linked with an increased risk of oral health complications – these risk factors included age, tobacco use and systemic conditions such as diabetes. This suggests that oral and cardiovascular diseases share several risk factors, which means a direct link cannot be concluded [4].

When assessing whether poor oral health can increase the risk of developing cardiovascular disease, it is worth considering the socioeconomic backgrounds of those in question. One might assume that those with multiple risk factors that are characteristic of cardiovascular disease are less likely to take appropriate care of their overall health; hence they would be more likely to have poor oral health and develop oral disease. Additionally, in less developed countries there is little education on the importance of maintaining good oral and overall health, and oral hygiene is typically of low priority as people are forced to spend their money on more immediate needs. Cardiovascular disease is also becoming more frequent in less developed countries as lifespans are increasing and lifestyle factors are changing [5]. These factors include increased inactivity, increased access to westernized diets and increased tobacco usage.

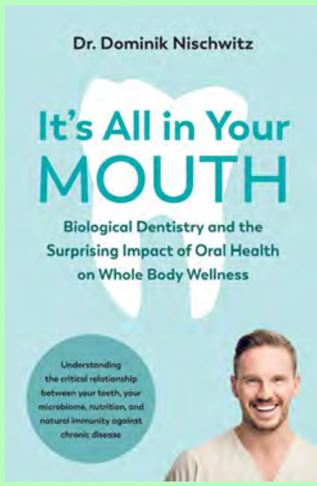
This suggests that a lower socioeconomic status increases the risk of both oral and cardiovascular disease, without any direct link between the two.

It is clear that further research is required to fully understand whether the link between oral health and cardiovascular disease is direct or indirect. A thorough understanding of the factors that increase the risk of developing cardiovascular disease could have big implications in the future of preventative healthcare and reduce the number of deaths from heart disease and other cardiovascular diseases. Whether or not a direct link does exist, what we do know is that dental and oral hygiene is very important for preventing tooth decay and gum disease, which is enough reason to encourage everyone to brush their teeth twice a day with fluoride toothpaste and floss daily between their teeth.

Edited by Aditya Chougule

IT'S ALL IN YOUR MOUTH by Dr Dominik Nischwitz

For many years, biological and holistic dentistry have been viewed as two discrete approaches to maintaining a good oral health. However Dr Nischwitz's "It's All in Your Mouth" presents a new perspective on the significance of oral health in preserving a good overall health. Through the use of thorough and detailed explanations, as well as evidence from recent scientific studies, Nischwitz demonstrates the relevance of the bacteria in our mouth in causing several chronic illnesses such as heart and cardiovascular disease, stroke and obesity. This book contests the traditional belief that your teeth should be treated separately from the rest of the body and Nischwitz describes his ideal future where medicine and dentistry is more closely linked to integrate our understanding of our body as a whole. By including analogies and diagrams that are easy to understand, along with recommendations on how to improve your own oral and overall health which anyone can incorporate into their own lives, this book is suitable for any reader who is interested in improving their well being.



The Science of Ageing

By Ishan Makkar (Y11)

The Oxford English Dictionary defines age as "the number of years that a person has lived or a thing has existed". For many, the concept of age is just a number – a numerical value given to determine how old you are or how long you've lived. But what is ageing really?

A different type of ageing

This conventional definition of age (our chronological age) is not the only way to determine our age. Biological age focuses on the concept of cells gradually accumulating damage over time and thereby becoming less functional. This is dependent on a variety of factors such as genetics, lifestyle and nutrition, making it more complex and therefore, more difficult to determine than chronological age.

Why do we age?

Earlier theories suggested that ageing was caused by a degradation of genetic information in DNA. However, scientists now believe that ageing can be described as a loss of information in the epigenome – "a record of the chemical changes to DNA and histone proteins of an organism" [1]. The name derives from the Greek word 'epi' meaning above the genome. The primary function of the epigenome is to control gene expression – how cell differentiation produces specialised cell types. A system of proteins called histones (which serve the function of maintaining the DNA structure) and the process of methylation carefully manage the non-coding and coding regions of DNA to ensure that, during the processes of transcription and translation, the correct proteins are formed. Histones are ever-present proteins that DNA is wrapped around in order to efficiently pack the DNA within the nucleus; methylation is the process of adding methyl groups to the base cytosine in the DNA in order to repress gene transcription.

Our DNA is constantly being bombarded with environmental missiles such as UV radiation and cosmic rays, which can cause cell damage by creating mutations in the genome. Fortunately, this damage is often not permanent or severe and so our body is able to repair itself: proteins unwrap and replace the mutated bases, leading to a correction in the sequence of bases in an attempt to 'reset' the epigenome (i.e. restore the original sequence of DNA). However, this renewal process is not 100% accurate; histones are rearranged (causing DNA to be packaged differently) and DNA methylation occurs where it shouldn't. As we grow older, our exposure to these factors accumulates and as a result, each time this damage is repaired, there are slight inaccuracies that cause the structures of proteins formed to be altered and therefore, cells no longer perform their specialised functions as effectively.

As we age, certain hallmarks in cellular and molecular processes become present (as shown by the diagram), helping scientists create an 'epigenetic clock' that can be used to accurately determine our biological age.

Slowing the ageing process

Slowing the ageing process is possible by exploiting the evolutionary traits that our bodies have developed to help us survive. Professor David Sinclair – a leading expert on ageing – describes this as the activation of 'longevity genes' [2]. For example, when put under undue stress our bodies focus their resources on repairing and protecting cells, which is often done by creating enzymes that can help maintain the epigenome. Some lifestyle changes can help trigger the same responses, leading to a healthier and longer life; these include activities such as fasting or intensive exercise.

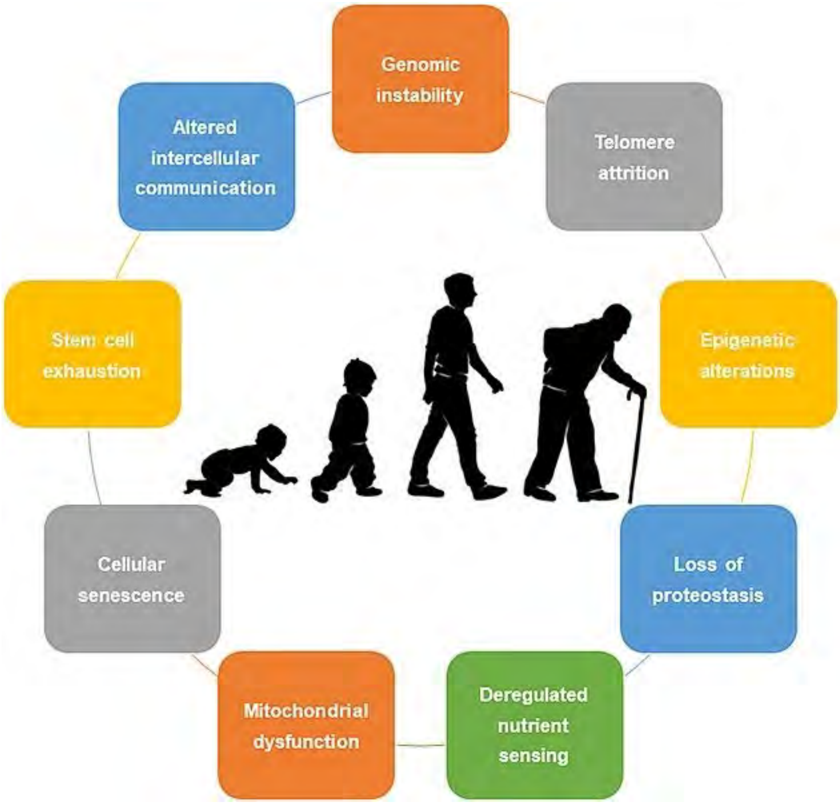
Reversing the ageing process?

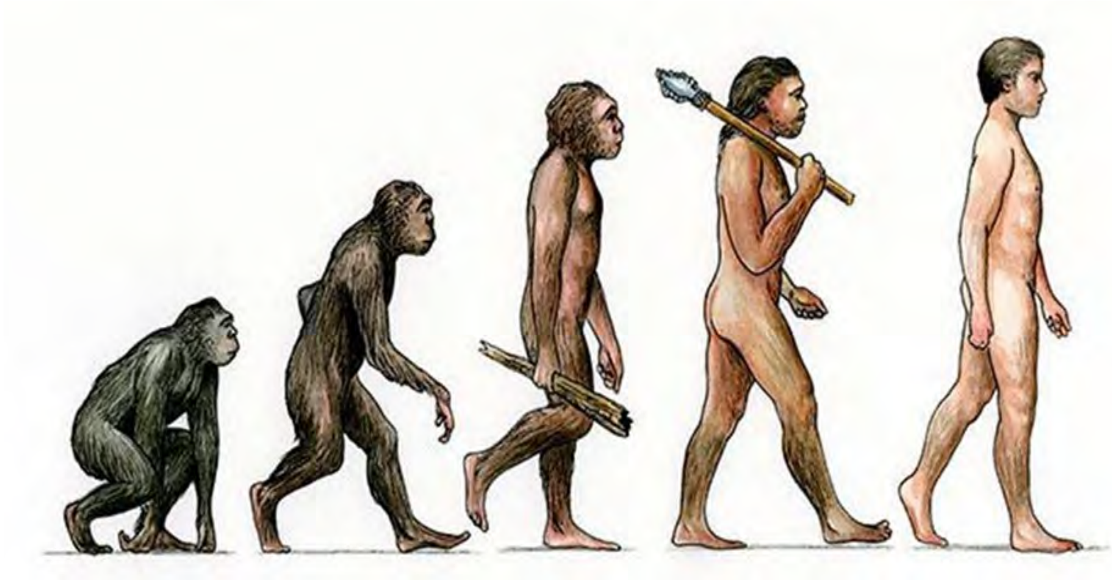
Professor Sinclair and his team at Harvard Medical School have found ways to reverse the ageing process in mice. One of

their projects involved reversing ageing effects on the retinal tissues, an especially difficult challenge given that they start ageing soon after birth [3]. This requires an epigenetic reset: restoring the epigenome to a previous healthier state. The method that the team used involved Yamanaka factors – discovered by Nobel Prize winner Shinya Yamanaka in 2012 – which allowed adult cells to be reverted into pluripotent stem cells. Their experiment was done in vivo (i.e. taking place within a living organism), as the mice were injected with a harmless virus carrying the genes for these reprogramming factors. Sinclair's team used all 4 factors at first, yet quickly found that tumours would develop. This was due to one of the factors (*c-Myc*) being an oncogene and causing cells to rapidly divide. After removing this gene from their experiment they were successfully able to reverse vision loss in older mice.

This is an extremely new and advanced field of research and as such, it may take decades to transfer these effects into the human body. Of course, there are the obvious benefits but the possibilities that this study creates are limitless. In his video on this topic the Youtuber Veritasium showed the results of a Twitter poll, which suggested that many people encouraged further research [4]. However, he also discussed potential issues that could arise, e.g. overpopulation and increased inequality. These are problems that we will have to consider as the prospect of a longer human lifespan gets one step closer to becoming a reality.

Edited by Aditya Chougule



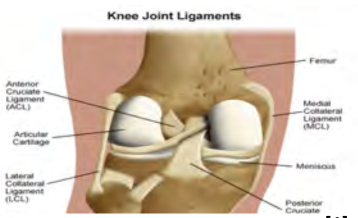


Aging and Evolution: An Intertwined Process

Total Joint Replacements: The Bare Bones

By Aditya Chougule (Y12)

In anatomy, a joint is defined as the point where the ends of two or more bones meet. The human body accommodates a wide variety of joints, from hinge joints (e.g. the knee) to ball and socket joints (e.g. the shoulder). My focus in this article will be the knee joint, composed primarily of the femur and tibia, with articular cartilage present at the bottom of the femur and shock-absorbing menisci cushioning the top of the tibia. The femur and the tibia are connected by two separate pairs of ligaments: the anterior and posterior cruciate (or criss-crossing) ligaments, and the medial and lateral collateral ligaments (on either side of the knee joint).



Anatomy of the knee [1]

Degenerative diseases and trauma are the two main causes of joint damage in the knee. Arthritis is a degenerative condition which causes pain and inflammation in joints and affects more than ten million people in the UK [2]; there are more than 100 different types of arthritis, the most common being osteoarthritis and rheumatoid arthritis. The former is characterised by breakdown of the protective cartilage that lines the joints brought about through wear and tear as the joints are continuously subjected to many forces and loads during everyday activities. This process continues gradually until it reaches a point where the cartilage disappears completely, causing the bones of the joint to grind against each other; this is not only very painful but can also severely hinder the mobility of the affected individual. Rheumatoid arthritis, meanwhile, is an autoimmune condition which occurs when the body's own immune system attacks the cartilage in joints and destroys it (along with ligaments and tendons). Scientists are still uncertain as to its exact underlying cause, although studies have shown that both genetic and environmental factors are likely to contribute to the disease's progression [3]. In addition to deteriorating, joints can become injured through trauma, which is when the joint is subjected to a sudden impact or shock (as often happens in car accidents, for example).

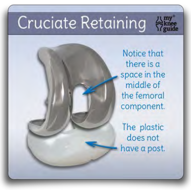
The first total knee arthroplasty – any surgery that improves the function of a damaged joint – was performed in 1968 and is now recognised as one of the most important surgical advances of the 20th century. Over time, the procedure has increased in effectiveness by virtue of the gradual improvements made to surgical material and technique [5]. According to the National Joint Registry, 90,000 primary total knee replacement procedures were carried out in the UK alone in 2018 [6]. The operation itself lasts around one to three hours and begins with the surgeon creating a cut down the front of the knee to expose the kneecap. Once this is complete, the skin and muscles are moved to the side so that the surgeon can access the knee joint behind it. The damaged ends of the femur and the tibia are cut away using special surgical tools, a process known as resurfacing; this stage is necessary in revealing healthier bone underneath, which provides an ideal surface for the artificial joint to attach to. The ends are then accurately measured and shaped to fit the appropriately sized artificial joint. A dummy joint is temporarily placed to test that the joint is working properly and adjustments are made to ensure the best fit possible, after which the bone ends are cleaned and the final artificial joint is fitted. The end of the femur is replaced by a curved piece of metal and a flat metal plate replaces the end of the tibia. These can be fixed using a glue-like substance known as bone cement (polymethyl methacrylate) or alternatively, the metal can be chemically treated to provide a rough surface and thereby encourage the bone to attach to the components – a process known as osteointegration. For example, a surface might be treated to add a hydroxyapatite coating, which comprises mostly calcium and phosphate and encourages bone growth. Whether or not bone cement is used is entirely up to the surgeon's preference and often will depend on which method they are more skilled at. Having fixed the metal plates, a plastic spacer is now placed between the pieces and acts like cartilage to reduce friction in the joint. The back of the kneecap can also be resurfaced with a plastic button if the surgeon deems this necessary to reduce pain for the patient. Finally, the wound is closed with either stitches or clips and a dressing is applied [7].

Delving deeper, total knee arthroplasties are available in two different designs: posterior

Knee with total knee prosthesis [4]

stabilised and cruciate retaining. The difference between these surgeries relates to the posterior cruciate ligament (PCL). In knee joints affected by osteoarthritis and rheumatoid arthritis, the cruciate ligament that lies in front (the anterior cruciate ligament) is usually damaged by the disease process and rendered non-functional. The surgeon would therefore routinely remove this ligament during the operation as a total knee prosthesis functions well even without it. This leaves the back (posterior) cruciate ligament. In order to understand the challenge that surgeons face in deciding whether to remove or preserve the PCL, we must first understand its role in assisting the kinematics of the knee.

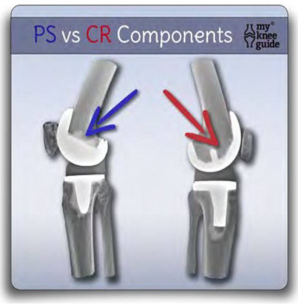
Posterior stabilised total knee prosthesis [8]



Cruciate retaining total knee prosthesis

When the normal knee joint bends, the PCL pulls the upper part of the knee joint (the femoral condyles– a part of the femur) backwards in a motion referred to as 'rollback'. When the PCL is damaged, the femoral condyles glide forwards unrestricted during bending and this uncontrolled action causes severe instability to the knee joint. Therefore, a different method for total knee replacement is required if the PCL can no longer be retained due to deterioration. The stabilisation of the total knee joint in this case is achieved by equipping the prosthetic components with a 'cam and post' mechanism, which replaces the function of the PCL. This system involves an adapted tibial plate with a polyethylene post placed in the middle of it; the post sticks through an opening in the femoral component, known as the cam. As the knee bends, the hinge created by this 'cam and post' interaction prevents the forward glide of the femoral component, instead allowing the knee prosthesis to rotate around the hinge, mimicking natural movement. In this way, the posterior stabilised total knee replaces the function of the PCL. In a cruciate retaining total knee arthroplasty, the anterior cruciate ligament is removed but the posterior cruciate ligament is kept; the retained PCL therefore 'rolls' the femoral component back when the knee bends, allowing for a stable total knee joint. The tibial plate does not have a post for this surgery, but instead leaves space for the PCL [1].

In conclusion, it is evident from the number of total knee arthroplasties completed each year that the procedure is popular and indeed rather successful, with studies showing survival rates above 90% at follow-up times for ten to 20 years [9]. Out of the 90,000 primary total knee replacements carried out in 2018, only 430 reported untoward intra-operative events such as fracture and ligament injury [6]. However, it still remains unclear as to which knee design is more effective. In a study of 45 patients who received a posterior stabilised total knee replacement, the average range of motion at final follow-up was 118°, whereas this value increased to 125° in the cruciate retaining patient group [9]. Reasons for this are associated with the preservation of bone (see Figure 7) and femoral rollback on the tibia during flexion thanks to the preservation of the PCL (which allows for greater stabilisation of the prosthesis). Although the study did not find a conclusive demonstration as to whether one method was superior over the other, it did suggest that the choice of implant should be "based on surgeon preference and existing pathology of the posterior cruciate ligament" [9]. I would personally argue that a



A "box" shape is required to enable the PS knee to function correctly so more

cruciate retaining total knee prosthesis is more effective, with the exception of when the ligament has lost functionality, since the polyethylene tibial post in a posterior stabilised design can wear off severely (as was found in around 30% of all posterior stabilised total knees). This can result in joint failure as femoral rollback is no longer achieved – a risk easily mitigated by retaining the PCL [1]. Any surgery comes with its associated risks but with total joint replacements, this is kept fairly minimal as the surgery can be completed in a mere 1-3 hours, reducing the likelihood of adverse events from general anaesthesia as well as risk of infection. Overall, the huge boost to quality of life that the procedure offers makes it profoundly effective in treating degenerative diseases or trauma affecting the knee.

Edited by Nabeel Abdul Rasheed

Stem Cells

By Moksh Sachdeva (Y12)

What breakthroughs have we seen so far with stem cell research?

- In 1998, the first human embryonic stem cells were grown in a laboratory dish, laying the foundation for our current understanding of how cells function and divide.

- In 2001, stem cells were used to successfully create beating heart cells outside of the body for the first time. This made developing treatments for diseased hearts easier and allowed us to understand the disease process in greater detail.

- 2003 marked the discovery of cardiac stem cells and the starting point for intensive studies into the potential for stem cells to regenerate damaged heart tissue. This would help patients avoid the need for a potential heart transplant in the future [1,2].

How can stem cells be modified?

- The major limitation with cell replacement therapy is that a great proportion of the cells die when transplanted. Regardless of whether the cells are autologous (from oneself) or from a syngeneic (genetically similar) population, a loss of cells is almost guaranteed.

- Through stem cell modification, cell survival during transplantation can be drastically increased, particularly when inserting the new cells into a hostile environment.

- Modification occurs by a gene cassette being constructed and loaded into a vector for entry into the cell. Once inside the cell, the gene construct can express specific genes. The inserted gene expression can be controlled by a gene switch, which effectively makes the cell 'intelligent' by forcing it to respond to a physiological stimulus before the transplant of the tissue.

Stem cell modification for cardiac regeneration

The clinical impact of stem-cell modification for cardiac regeneration is still in its early stages and clinical trials are yet to move onto phase three.

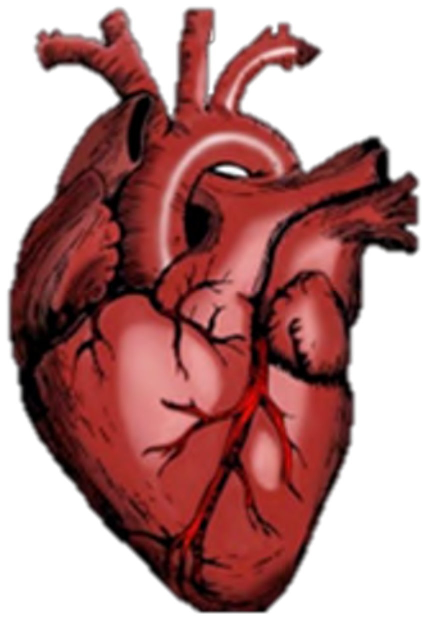
In a randomized trial of 66 patients who had stem cells injected into the site of infarction, a significant reduction was noted in the size of the infarct using MRI imaging [2].

The main issue currently preventing cardiac regeneration from being a successful treatment method is inefficient cell delivery which currently involves the use of four methods to the site of the infarction, as well as low cell retention which could be the result of rejection by the immune system or even failure to adhere to the organ's scaffolding and limited effectiveness of the remaining stem cells.

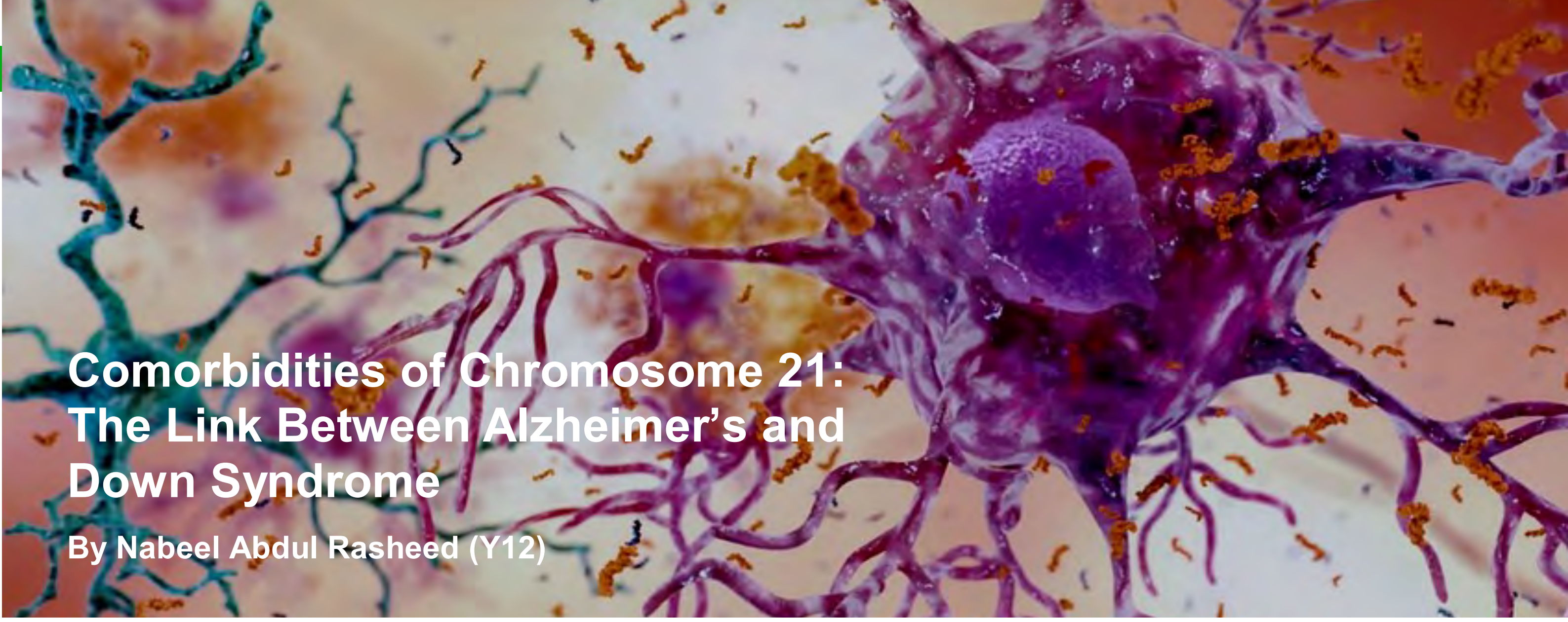
Various studies have shown that embryonic stem cells provide the most promising results for cardiac regeneration, along with second-generation stem cells that have been produced by researchers. These second -generation cells possess an improved regenerative capacity compared to the stem cells produced by the body since they are more long lived[4].

Overall, this highlights the considerable potential of stem cells but also the current challenges we face with making effective use of them such as the ethical issues involved with the extraction of embryonic stem cells. With evolving treatment and research methods, we may not be far from finding a treatment for infarctions or an alternative for regenerating damaged tissues.

Edited by Nabeel Abdul-Rasheed



"Stem-cell modification for cardiac regeneration is still in its early stages and clinical trials are yet to move onto phase three"



Comorbidities of Chromosome 21: The Link Between Alzheimer's and Down Syndrome

By Nabeel Abdul Rasheed (Y12)

In 1866, British physician John Langdon Down described an uncanny resemblance between a group of his psychiatric patients, noting that their comparably slanted eyes and flat faces made it 'difficult to believe that [they] are not children of the same parents' [1]. Forty years later, German psychiatrist Alois Alzheimer reported equally 'peculiar' findings from the case of Auguste Deter, long suffering from memory loss, language difficulty and erratic mood shifts [2].These signs are now considered characteristic of Alzheimer's disease, in the same way that Down's observations typify the syndrome bearing his name. Yet to the layman, any hint of a connection between the two may raise an eyebrow. Having a younger brother with Down syndrome, I find it particularly disconcerting that at least half of all those who share his condition will develop Alzheimer's by the age of 60 [3,4]. To put this into perspective, only 11.3% of the general American population over the age of 65 have the disease (although this may be somewhat skewed due to ethnic differences) [18].

On a closer level, the pathophysiology of Alzheimer's revolves entirely around the brain which comprises billions of neurones, each containing an integral membrane protein known as amyloid precursor protein (APP) [5]. Normally, APP is sectioned by a- and g-secretases to produce soluble peptides which can be recycled by the body. Sometimes, a third enzyme (b-secretase) replaces a-secretase and cuts the APP further along its length. This produces larger, insoluble fragments known as b-amyloid which aggregate around the neurones and form senile plaques [5,6]. Here, they disrupt impulse transmission and potentially stimulate an inflammatory immune response, bringing about damage to the neural network. When coupled with formation of neurofibrillary tangles (caused by detachment of insoluble stabilising proteins known as tau from the neuronal skeleton), this results in cerebral atrophy and progressive cognitive impairment which can eventually prove fatal [5,7].

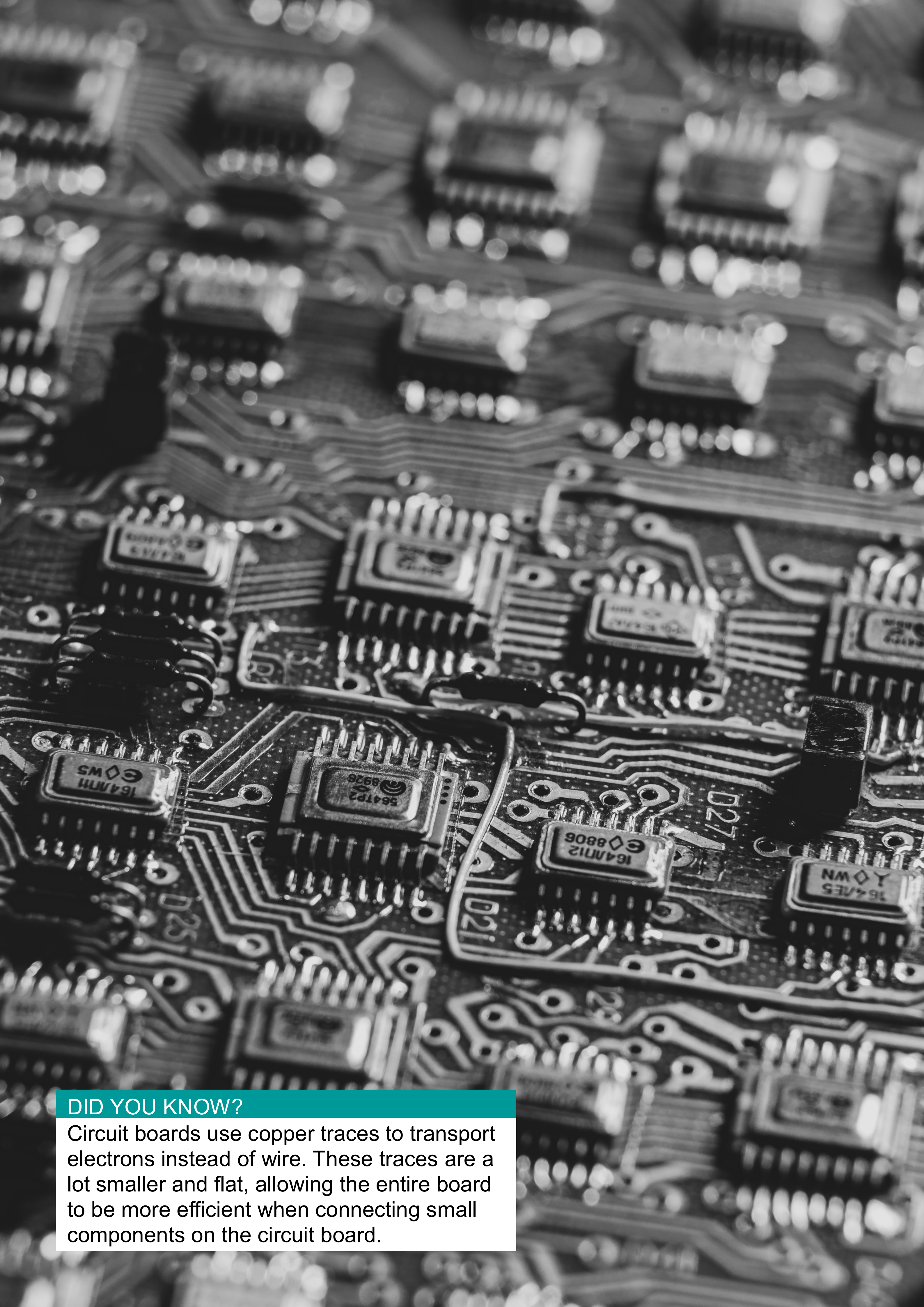
In contrast, the pathophysiology of Down syndrome is not limited to any one organ. Instead, it is defined by the presence of a third copy of chromosome 21, which also happens to contain the APP-encoding gene responsible for plaque formation in Alzheimer's [8]. This overexpression is believed to increase the likelihood of excess b-amyloid build-up in the brain, and is supported by evidence suggesting that partial trisomy of chromosome 21 (which excludes APP gene triplication) does not lead to pathological signs of Alzheimer's [9]. More recent studies have also highlighted the potential role of genes that control ageing in accelerating the onset of dementia for those with trisomy 21 [10].

Importantly, genetic predisposition is not the only bridge between these two conditions: sleep deprivation can be an equally potent contributor. During deep sleep, cerebrospinal fluid is spread throughout the brain by the pumping action of glial cells (a type of non-neural cell found in the CNS), clearing out metabolic waste and toxic substances including b-amyloid [11,12]. In more than half of those with Down syndrome, this period is regularly disrupted by obstructive sleep apnoea (during which the relaxed throat muscles fall back and block the airways) [13,14]. The true extent of this disruption only becomes clearer to me with each time I check on my brother in the middle of the night after another bout of coughing and spluttering.

While there is no known cure for Alzheimer's disease, scientists believe that mentally stimulating activities can play a key preventative role by boosting cognitive reserve and establishing stronger neuronal connections through neuroplasticity [11]. In an effort to maximise this protective benefit, I have started teaching my brother the basics of chess on a daily basis, testing his recall and perception of pieces, board layout and simple tactics. Ambitious as it may be, the structured cognitive exercise this provides will certainly make a difference and serve as motivation for anyone else in my position. If the relative they are caring for is anything like my brother, they will welcome the challenge with open arms.

It is easy to forget that just a century ago life expectancy for someone with Down syndrome was as low as nine years, with adulthood often a sliver of hope [15]. Nevertheless, it is in human nature to strive for further improvement in every aspect of life. Conquering Alzheimer's disease is no exception. If not through championing research or spreading awareness, the least we can do for those like my brother is fulfil our duties as family, friends and carers. Even if our efforts extend their lifespan by just one more year, this year will prove to be the most invaluable to loved ones.

Edited by Aditya Chougule

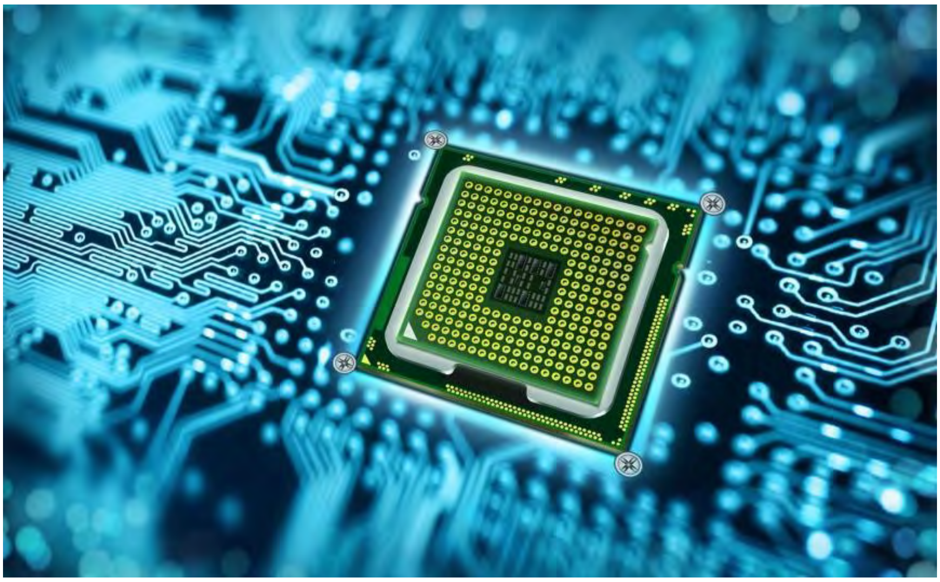


DID YOU KNOW?

Circuit boards use copper traces to transport electrons instead of wire. These traces are a lot smaller and flat, allowing the entire board to be more efficient when connecting small components on the circuit board.

"Computing is not about computers any more. It is about living"

- **James Dyson**



The Microprocessor: Design and Smartphone Integration

What causes your smartphone to function so fast?

By Adam Ali (Y12)

Central processing units (a microprocessor) are at the beating heart in almost all of the world's technology, whether that is from your handheld smartphone, to your kitchen microwave, or even in satellites thousands of kilometres above the earth's surface; microprocessors are at the centre of it all.

In fact, you might like to think of the CPU as a nucleus of the phone. It is a component (that works with other components like the graphics accelerator) to form a SoC, or a system on a chip. This SoC is what controls everything going on in your smartphone and ensures it functions correctly. Indeed every action performed on your smartphone goes straight to the processor, which is then registered, translated, and executed before finally appearing as a visible change on your screen [1].

A processor consists of multiple cores. One core has a maximum number of instructions it can process within a certain amount of time, and so if you are performing a lot of actions, a queue will start to form. If this queue gets too long, it will overload onto the next core, allowing your smartphone to continue functioning smoothly [1]. The CPU can come in Dual core, Quad core, and more recently, Hexa and Octa core. For something like a 3D game, four cores are required and so in general, a large number of cores not only expands the functionality of the system but also increases the speed of task execution. Mobile chipsets designed by companies like Apple, Samsung, Intel etc., all contain several types of cores called Cortex-A*x*, which are supplied by the company ARM Ltd. The higher the "*x*" value, the higher the performance of the core. This has allowed a new type of technology in which the SoC uses two different types of cores; top and economical. For example, in standby mode, when high performance is not required, more energy efficient ones are utilised, and if a resource-intensive application starts up, then more productive ones are connected [2].

We compare the performance of cores using something called the clock rate. The clock rate of a CPU is normally determined by the frequency of the oscillating crystal which creates electrical signals. Nowadays, smartphones can have clock speeds of around a few billion instructions per second the units of which are in gigahertz (GHz) [1, 3].

It is important to note that modern microprocessors are actually made up of transistors, which act as a logic gate, either allowing or preventing current to flow through. These transistor "building blocks" are on the scale of nanometres in order to pack billions of them into a single microprocessor. This requires the use of incredibly high precision machinery, 20 to 40 engineers, and more complex processes to manufacture them – a single speck of dust on the silicon semiconductors could cost thousands of dollars. The down-scaling of transistors, which roughly follows Moore's Law (that the number of transistors on a microprocessor doubles every two years, though the cost of computers is halved) has actually caused a problem known as quantum tunnelling. Transistors are designed to stop the flow of electricity when they are in the off state, but at thicknesses of a couple of nanometres, they are becoming so small that electrons can flow right through them [4]!

Apple's current generation iOS devices are equipped with Apple's most recent SoC, the A14 Bionic chip. It is the fastest and most powerful chip on the market right now,

Apple's A14 Bionic Chip [7]

featuring in the iPhone 12 and iPad Air 2020 models and is divided into two performance cores and four power efficiency cores, packed with 11.8 billion transistors. Apple claims the CPU performs up to 40% faster than the A12 and the new chip also includes a 16-core neural engine, enabling it to perform eleven trillion operations per second [5].

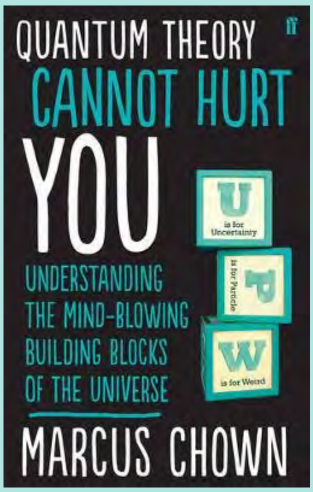
And so you see, microprocessors are the real heroes behind the power of smartphones. It is the extraordinary electrical engineering that has allowed them to evolve into a living piece of machinery, directing electrical signals along atomic mazes. They are what allow your phone to run at the speeds it does, to manage the apps you use…

…and to do it all in a split second!

Edited by Atharva Narkhede

QUANTUM THEORY CANNOT HURT YOU by Marcus Chown

Quantum theory is a fundamental scientific study and is only really ever touched upon in A level Physics due to its complexity, yet in his book, Marcus Chown illuminates and breaks down the quantum world with vivid, understandable imagery. In the book, Chown describes topics including the "Telepathic Universe", "The Death of Space and Time" and "Dark Energy". The most interesting topics were learning about quantum Physics; potentially most exciting opportunity – quantum computing. This involved the explanation behind "qubits" and the reason for faster speeds than the conventional computers today. The book is a quick and intriguing read and something that anyone with some Physics interest would enjoy, especially to bridge the gap between GCSE and A level. I would thoroughly recommend this book – it is something that will leave you invested in the science for years to come…



What are distributed systems, and why should we care?

By Jonathan Peter Rajan (Y11)

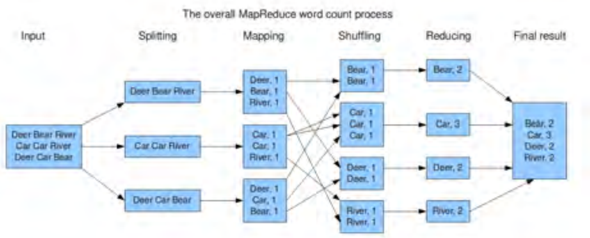
Have you ever wondered how Google handles billions of requests per day, the magic behind cloud computing, and what even made a decentralized currency possible? The technology behind these wonders is distributed systems. The computer scientist Andrew Tannenbaum defines it as "a collection of independent computers that appear to its users as one computer" [1]. To elaborate, a distributed system is a collection of independent hardware/software components, called nodes, that are networked to work together coherently to fulfil one end goal. If you are still confused, just as many people may work together on a single problem, in a distributed system, many computers work together usually to solve a computationally difficult problem, simulating a single massive computer.

How it works

To make a distributed system, you need multiple nodes, some resources, and middleware to tie it up altogether [3]. A node can be either hardware or software which has a memory. An example is an internet, a giant open group of nodes (host computers identified by an IP address). Homogeneity is not required for these nodes, which means that they can have different operating systems and technologies. Furthermore, there should not be a shared clock or memory. Finally, these nodes should work concurrently, meaning that multiple tasks/computations happen simultaneously. A resource can be anything - it is simply an asset that the nodes can access and take advantage of. The middleware is the backbone of a distributed system since it provides a logical layer that connects the nodes, making them appear as a single computer. It is often imagined being like plumbing because it connects all the nodes, allowing data to be passed between them. Applications are built on top of the middleware.

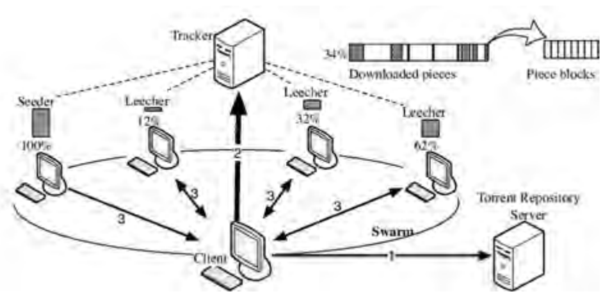
Examples of implementations

A notable example, which was developed and initially used by Google for its search engine, is a framework called MapReduce which effectively divides up a task across numerous machines. MapReduce breaks down what you are trying to do into three stages: map, shuffle and reduce. A famous example to explain how it works is counting the number of occurrences of words appearing in very large documents [2]. Let us say that we have got two computers and 16 documents. We would start by distributing the documents between the computers (so eight documents for each computer). Now what each computer is going to do is count the number of times each word appears. So, for example, computer one would compute many keys and values from the documents it was assigned (such as happy:15 and learn:10), and computer two would do the same and produce (happy:123 and learn:5). At this stage, there is no communication between these machines. Instead, keys are grouped based on their key and then processed onto the reduce stage at the shuffle stage. For example, the two computers will communicate and shuffle/aggregate their results to duplicate the keys together. Finally, all the results are taken from the map stage and combined to get a finalized result at the reduce stage. So, in this case, at the reduced stage, we would get a result that "happy" appears 138 times (happy:15 + happy:123) and "learn" appears 15 times (learn:10 + learn:5). Thus, this is a way in which a single computation is distributed among many machines.



Another example of distributed systems that we interact with daily is DNS (Domain Name System) [4]. A DNS is simply a directory of names (specifically website URLs) that are matched with IP addresses - imagine a phone book/contacts list. This domain name service is maintained and operated by many independent organizations (such as ICANN) and a network of thousands of servers that interact with each other so that the requested website is served on our browser.

The final example is BitTorrent, a peer-to-peer file-sharing system used to distribute large amounts of data over the internet. Rather than downloading a file from a single source server, the BitTorrent protocol allows users to join a "swarm" of hosts to download and upload from each other simultaneously. The first step in this process is the user downloading a torrent file that contains information about the files to be shared and a list of the trackers, which are a server that tells you where to contact other computers that are also downloading this file. When the user opens this torrent file with a BitTorrent client, the client will know what it should download, and it will then contact the tracker and download a list of peers attempting to connect to them. Then in the "initial seeding" phase, a small chunk of data would be uploaded to each peer. These peers will then become seeders and will start uploading their chunks to others while at the same time downloading other chunks from other peers. This results in the user having many pieces that make up the file they want, which the BitTorrent client will sort so that the user gets all the data in a usable and appropriate way at the end. This peer-to-peer architecture is much faster and more convenient when sharing a file with large groups of people than on a client-server.



To exemplify how significant and ubiquitous distributed systems are, revolutionary technology such as cloud computing and blockchain would not exist today without them.

Types of Distributed Architecture

Cluster computing (centralized, closely connected identical computers. This used for high-performance and minimum downtime. An example is one of the world's most powerful supercomputers, IBM's Sequoia [5].)

Grid Computing (computers that are placed in many locations worldwide, not necessarily close to each other. This is often used for large data repositories and high computing power requirements. An example is BOINC - developed by UC Berkeley - which lets you contribute computing power on your home PC to projects researching many scientific areas.)

Advantages

The most obvious advantage of using a distributed system is that it improves reliability since instead of relying on a single powerful computer that can stop working due to individual components malfunctioning or a power outage. On the other hand, even if one computer/server fails in a distributed system, the other computers/servers will not be affected, and the program will continue to run - this is called fault tolerance. Furthermore, distributed systems are usually favoured because they effectively scale horizontally. For example, when scaling vertically, there is a hard limit to the extent to which you can upgrade your machine; however, when scaling horizontally, there is no such cap to how much you can scale since all you have to do is add another node the demand is high. This also proves to be more cost-effective. In addition, an often-overlooked feature of distributed systems is the ability to reach a consensus which is vital for online payments and blockchain. Consensus, in essence, is getting all the nodes to agree on a value that is important to improve fault tolerance and trust (which is mandatory in online payments). Finally, distributed systems are particularly advantageous when used in resource-sharing applications, as shown in the BitTorrent example above.

Disadvantages

Like all things in the world, distributed systems are not without their flaws. Notably, there are several security issues due to its open nature, so it is difficult to provide adequate security to all nodes and connections. Furthermore, since this system is built upon the ability of the nodes to communicate with each other, overloading may occur in the network if all the nodes try to send data at once. Finally, the management of tens if not thousands of nodes is challenging as it also means that it is often easy to detect failures or optimize any performance bottlenecks.

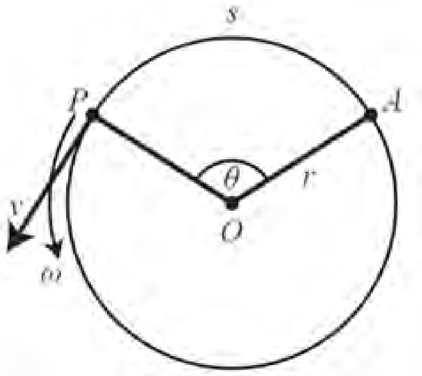
Edited by Mann Patira

DID YOU KNOW?

The term horsepower was used to quantify the mechanical output of steam engines, asking how many horses an engine would replace. Interestingly, the peak power of an actual horse has actually been measured at 14.9 horsepower.

(Left) An artists' depiction of a circular "endless runway" airport

(Below) Angular Velocity is the rate of change of the angle of an object, typi-



$$\omega_{average} = \frac{d\theta}{dt} = \frac{\frac{1}{3}\pi}{40} = \frac{1}{120}\pi\ rad\ s^{-1}$$

$$\omega_{final} = 2 \times \omega_{av} = 2 \times \frac{1}{120}\pi\ rad\ s^{-1} = \frac{1}{60}\pi\ rads^{-1}$$

$$V_{LOF} = r\omega_{final} = 1750 \times \frac{1}{60}\pi\ rads^{-1} = 91.6\ m\ s^{-1}\ (3\ s.f.)$$

Are Circular Runways a Plausible Replacement for Existing Runways?

By Atharva Narkhede (Y12)

Another step towards innovation in aviation – a circular runway! This concept (which is not yet an idea) may revolutionise the aviation sector and the way humans take to the sky in the 21st century. The proposal came from Dutch researcher, Henk Hesselink and his team at the Netherlands Aerospace Centre and they suggested that it should have a diameter of 3500 km; this means it will have a circumference of 11 km useable tarmac [1]. However, if need be, in the rarest of situations, this can be exceeded since this is an endless runway due to its shape. This makes it possible to place the airport terminal buildings and Air Traffic Control (ATC) tower in the middle.

Hesselink claims according to his computer-generated calculations, an average aircraft will take approximately one-quarter of the runway during take-off and landing (although, it can be anticipated that take-off will require more runway). Let us test whether this claim is valid – for this to be valid, the aircraft will have to be capable of reaching its lift-off speed (V_{LOF}) in only 2.75 km [2]. This is easily achieved on conventional runways. To test this claim let us use the theory of circular motion and estimated measurements:

The aircraft will turn through 60° which is equal to *π/3* radians and the radius is 1750 m. The time for take-off roll will increase by ten seconds because the aircraft is turning and so cannot reach higher velocities as quickly; as a result, take-off roll will now last for 40 seconds. The angular velocity, ω, can now be calculated and is given as the rate of change of the angle, θ, concerning time. Using this, the linear speed, which will be V_{LOF}, can be calculated as a product of the radius and angular velocity:

Therefore, the claim is reasonably valid since the average V_{LOF} for commercial aircraft is 80 ms^{-1}. However, this does hold the assumption that all future circular runways will be built with consistent dimensions.

Circular runways entice airport operators because they can handle multiple take-offs and landings simultaneously. This will boost airport capacity as it is statistically calculated by Hesselink and his team that one circular runway is capable of handling the traffic of four conventional (straight) runways combined [1,4]! Avoiding crosswind landings is also a significant benefit, if not the most significant since it is due to the problem pilots face during crosswind landings that this concept was conceived! The idea is the aircraft can choose the optimal position for touchdown or lift-off dependent on wind direction and ATC guidance. Since an aircraft takes off and lands in the wind, an optimal headwind can be flown into, potentially increasing operator safety. The same can also be said for avoiding tailwinds – they sure are helpful during the cruise phase but are no pilot's friend when it comes to descent and landing! Furthermore, since aircraft can land from a desirable direction, they do not need to constantly fly over residential areas, thus reducing noise pollution too. This is of utmost importance to surrounding residents as noise from jet engines is an ongoing complaint. Airlines will also be able to save a lot more fuel because an optimal landing zone reduces the need for as many aircraft holding stacks above the airport before proceeding to land by ATC [5].

However, the constraints are prominent. Most pilots fly what is known as auto-landing – this uses the Instrument Landing System (ILS) to guide the aircraft to the touchdown zone on the runway using two radio signals (one being the localiser and the other being the glideslope) [6]. These are usually located at the ends of runways and aid the aircraft in its lateral and longitudinal axes. Though, the obvious problem here is that there *is* no end to the runway! The use of ILS is impossible in this case because the landing zone will constantly be changing according to wind and weather demands. This certainly does not make it any easier for pilots trying to land in near-zero visibility, when the runway is contaminated (with precipitation) or at night [7].

Additionally, Hesselink also mentioned the runway to be slightly banked; the angle with which he did not specify [1]. The centripetal force will cause the aircraft to accelerate towards the centre of the circle. This, itself, poses a risk of damage to the aircraft due to a decreased wingtip clearance, and the outer engines of a jumbo jet (Boeing 747) and super jumbo jet (Airbus A380) may scrape the ground. This will inevitably be problematic when landing the aircraft as there will be a very minor scope for error. Further safety concerns about the turning of the aircraft have been raised since this results in a slower speed and may cause the aircraft to stall. The problem of not having an auto-landing system can be solved using the Airbus' ATTOL project in which the aircraft makes use of ground mapping or terrain recognition instead of an ILS, however, given that the runway is banked, the software will need to be taught to account for the required angular velocity, ω, and banking angle [8].

A350 modelled using "image recognition technology" [8].

There is one final major aspect that these fascinating runways leave unaccounted for – the emergency go-around [7]! These are very difficult to perform given the variable aircraft directions, especially during microbursts. The same goes to say for aborted take-offs; these would be dangerous since it would not be long after the aircraft applies its brakes that it encroaches upon another aircraft on the runway for reasons less apparent than a collision – wake turbulence! The following aircraft could swerve (this would likely be a roll in the air and yaw on the ground) on entering the wake turbulence of the aircraft in front. An engine failure, caused by a bird strike, would be the worst possible scenario on a circular runway, especially if the outer engine were to fail, as the aircraft would turn towards the dead engine making it even more difficult for the pilot to control [5]!

Despite the many cons of a circular runway, it is still an exceptional concept since it attempts to improve the capacity of the aviation sector. It may not be a good fit for existing commercial aircraft, however, it may be for futuristic aircraft with compatible structures. One such example would be the Flying-V as this has high wingtips and engines mounted on the wings, which eliminates the possibility of damage from scraping. Maybe a 2017-abandoned concept could be considered in the future, who knows?

Edited by Mann Patira

A380 modelled taking off from a banked runway [4].

How One Letter Could Be Changing The Future

By Ishaan Choudhary (Y11)

With the exponential improvement in technology that humanity has witnessed over the past 30 years, it has become ever more pertinent that already existing machinery is developed to become more refined and streamlined. Whilst new technologies are constantly being invented, the true progression (and even conservation) of man relies upon our ability to continually modernise our existing technology and make it more efficient. A prime example of this is the fairly recent conception and utilisation of the lithium iron phosphate battery.

For years, the conventional lithium-ion battery has been used in a multitude of daily-use equipment including mobile phones, laptops, and electric vehicles due to their rechargeable capabilities. This list of examples is in no way exhaustive, and it is clear that the lithium-ion battery plays a crucial part in every single one of our lives despite, perhaps, its existence being lesser known to the wider public. Perhaps even lesser known are the extreme dangers that these batteries pose to the machinery they are used in and the great disadvantages that were endured when these batteries had no alternative.

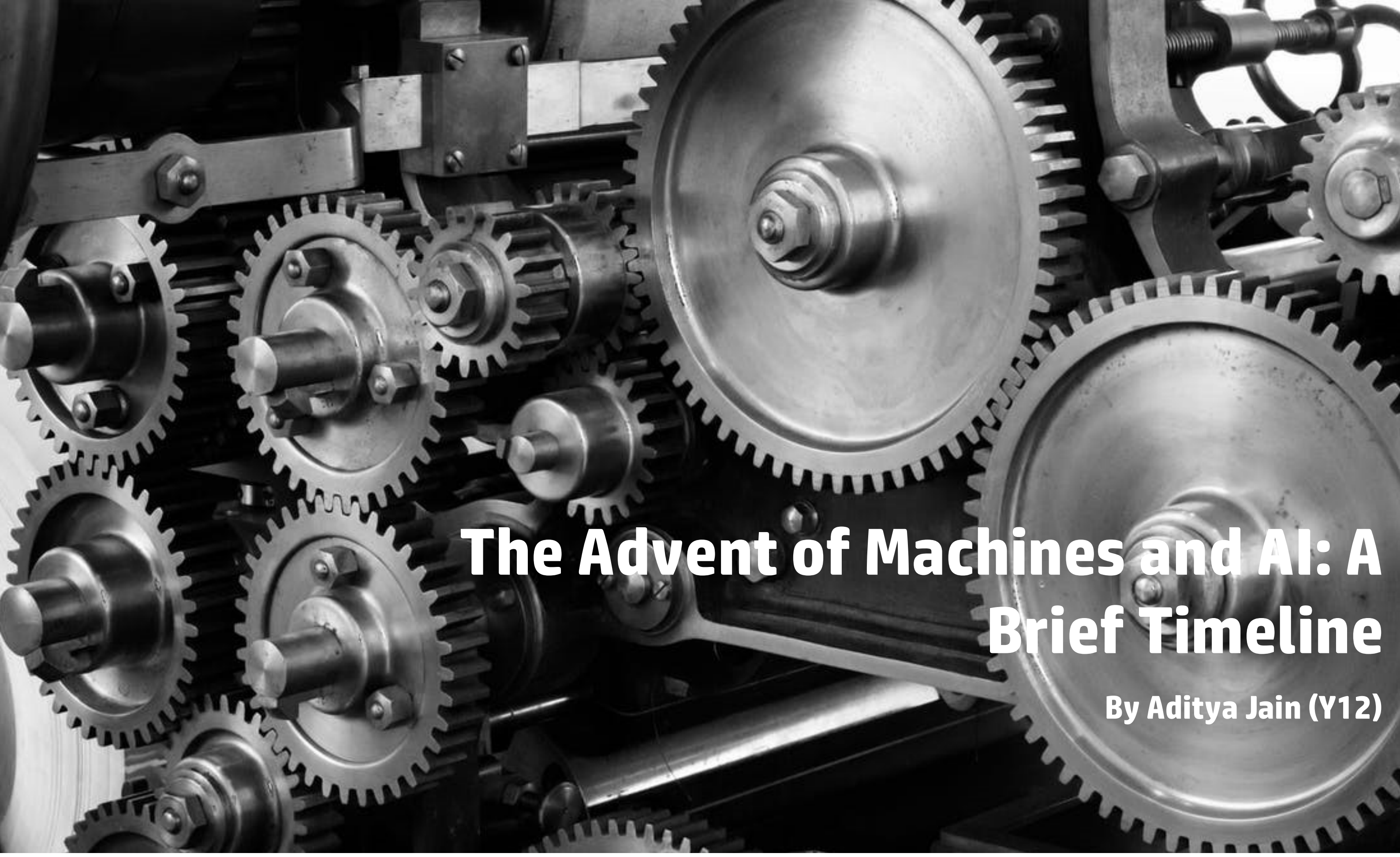
One such problem that often occurred was self-combustion should overheating occur in the traditional lithium-ion battery. Essentially, inside the chemical cell the liquid electrolyte could dry up and, following the failure of an insulating microporous separator layer, cause a short circuit between the electrodes leading to an explosion or fire [1]. Furthermore, the conventional cathode material of the lithium-ion battery is lithium cobalt dioxide ($LiCoO_2$), which is extremely susceptible to thermal runaway. This is where the increased temperature also increases current, causing a further rise in temperature in a somewhat uncontrolled positive feedback system, which is clearly hazardous and can occur regardless of ambient temperature. This has led to multiple disastrous accidents in the past; the most devastating of which transpire on aircraft carrying high quantities of the battery. Several accidents are the result of this now almost ancient technology: in September 2010 a UPS cargo plane with over 80,000 batteries on board caught fire and crashed, killing two pilots in the process [2]. Whilst safety is integral and obviously should be manufacturers' number one priority, socioeconomic factors of the lithium-ion battery are similarly disheartening. The use of cobalt in the cathode of a lithium-ion battery adds massively to the high cost of its manufacturing; its mining in conflict areas such as the Congo is also ethically questionable and obtaining it has become geopolitically complex and thus alternatives have been sought after [3].

The frontrunner in alternative technology is the development of the lithium iron battery. The addition of the letter 'r' in the battery's name is accompanied with a whole host of benefits, hence this article's name. More commonly known as LFP cells, the cathode used in these batteries are lithium iron phosphate ($LiFePO_4$). Low toxicity, low cost and long-term stability are a few of the qualities that are increasing the battery's prominence in certain machinery [4]. $LiFePO_4$ is intrinsically safer than its cobalt-comprised counterpart as it omits its negative temperature coefficient that leaves the conventional lithium-ion battery liable to thermal runaway. Additionally, LFP cells can withstand short circuit conditions and higher temperatures to a much greater extent, which means that they are incombustible in the event of mishandling – differing completely to the traditional lithium-ion batteries [5]. Even more surprisingly, the composition requires no cobalt and is revolutionarily cheap. It could be rightfully questioned why companies aren't making the switch to safer, more durable and cost-effective batteries.

Well, simply put, they are. Tesla – the embodiment of recent innovation – confirmed that, in tandem with the Chinese government, a new version of the Model 3 will hit the market with cheaper lithium iron phosphate batteries [6]. Forbes deemed the inauguration of LFP "Tesla's most important move yet" with its capability to push past the $100 per kWh barrier by 2023, which may result in electric vehicles finally becoming cheaper for consumers than their internal combustion engine equivalents. The threshold may be further annihilated as the predicted price is just $61 per kWh in 2030 proving just how truly revolutionary this development is and its capacity to be a catalyst for a more sustainable future [7].

Whilst the intricacies of lithium battery technology are somewhat less important, the message that these evolutionary developments represent are paramount. It clearly demonstrates a humanitarian urge to guard against complacency and to never be fully satisfied, continuing to improve and enhance inventions as problems arise. This small improvement to a somewhat antiquated technology shows to us that simply being satisfactory is not enough and this must continue to be the case in all walks of life, should humanity continue to prosper.

Edited By Mann Patira



The Advent of Machines and AI: A Brief Timeline

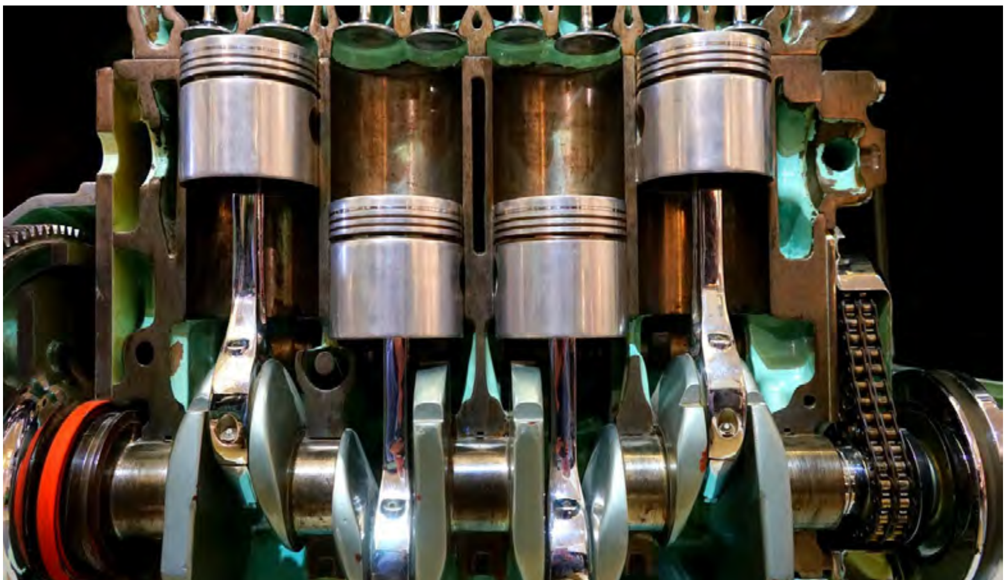
By Aditya Jain (Y12)

Human Powered Machines

Ever since their conception millions of years ago, machines have come a tremendously long way in easing the burden on the human race and expanding our scope beyond the limits of our innate capabilities. The very first machines were those of the early hominids *Homo habilis* (meaning 'handy man'), who used stone tools to scrape and butcher meat from animal carcasses. Whilst crude, these instruments fulfilled their main purpose: to maximise the nutritional value gained from a single meal and thereby increase chances of survival.

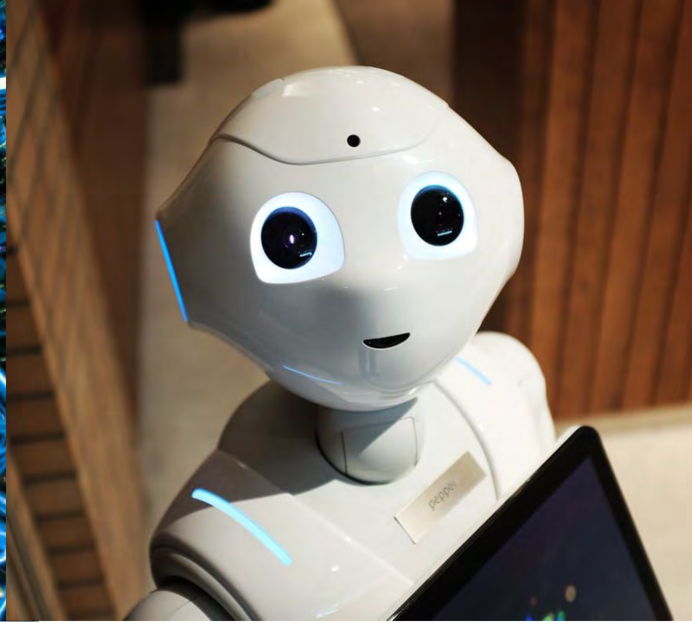
> **"Machine intelligence is the last invention that humanity will ever need to make"**
>
> **By Nick Bostrom**

In a similar fashion, the invention of spears, wheels and needles helped us to hunt prey, move equipment and work much more efficiently and effectively than before [1]. However, these simple devices were limited in that they all relied on human muscle power and could not provide any of the computational prowess that we see in today's machines.



Steam Power and the First Computational Machines

The first recorded calculating device is believed to have found in Babylonia (now Iraq) over 5,000 years ago [2]. This was an abacus and could conduct basic operations with a marginally higher accuracy and speed than humans. The next iteration of the calculator came with the more familiar mechanical calculator in 1632 AD [3]. By the 18^{th} century, the steam engine had kickstarted the industrial revolution. Machines could now harness heat from steam almost magically to drive pistons back and forth and power up heavy trains, turbines and factories. The output of factories



skyrocketed through this constant, steady supply of electricity; people could now be transported across the planet in huge steam-powered ships such as the Titanic; merchandise and troops could be transported anywhere across the globe in a matter of months if not weeks.

'Dumb' Machines with Astounding Computational Power

The next big leap came from the invention of the electronic computer in the 1930s by American physicist John Vincent Atanasoff. Through binary mathematics (using different permutations of '0's or '1's to denote any finite number) and Boolean logic (using "true" or "false" as the value of the variables), the Atanasoff–Berry Computer (ABC) was able to solve up to 29 linear simultaneous equations with 100% accuracy [4]! Although such early computers were exceptionally fast and becoming even faster year on year, they had one major limitation: they needed to be programmed by humans. In other words, they could perform programmed, repeated operations at lightning speed but introducing a new function would require time-consuming reprogramming.

Smart Thinking Machines

The question "Can machines think?" was first proposed by Alan Turing in his paper '*Computing Machinery and Intelligence'* in 1950 [5,6]. Since then, the rise of artificial intelligence means that computers can now be trained to solve new unknown problems without the need for reprogramming. Today's AI machines can recognise a face, flower or dog breed from a completely new picture. AI-based chatbots are now used by most major company websites to solve customer queries and provide prompt assistance without human intervention. AI now pervades all aspects of life from mobile phones, smart homes, gaming, voice recognition software to even suggesting movies, music or news to customers [7].

Training 'Dumb' Machines to become Smart through Machine Learning

Machine learning is a sub-branch of artificial intelligence which can be categorised as supervised machine learning and unsupervised machine learning [8,9]. In supervised machine learning, training is carried out using statistical models to predict the desired result. The data is either categorised or regressed to solve an equation. For example, a machine can be trained using statistical models to identify a face or type of flower using millions of test images [10]. Using different set of images, the model is then tested for accuracy. If the model is able to predict the results from test images with reasonable accuracy it can then be used to identify the object from new unseen images in the real world. Unsupervised machine learning, meanwhile, involves predicting outcomes from unlabelled and uncategorised data. Use cases for unsupervised learning include customer segmentation, genetics and card fraud detection, to name just a few [11].

The Future of Machine Learning

As computers become more powerful and models more accurate, we will see even smarter machines implemented almost everywhere. We can soon expect to see safer self-driving cars, caring robots and enhanced healthcare with accurate and bespoke medicines [12]. Smart machines will be used to identify solutions to complex research, projects in all sectors and dangerous assignments. The future is bright, not just for smart machines but also for humankind.

Edited by Nabeel Abdul Rasheed

How will cities develop to become more sustainable as the population continues to rise?

By Matteo Cascini (Y11)

Sustainable cities. Affordable and clean energy. Urgent climate action. These are just three of the 17 Sustainable Development Goals which the United Nations set out in 2015 to be achieved by 2030 for the "peace and prosperity for people and the planet, now and into the future" [1]. Notably, many countries, including the UK, are targeting net-zero carbon emissions by the year 2050. Therefore, how must these countries gradually transition so that we all live in more environmentally-friendly, sustainable cities?

Greener Cities

The city of Copenhagen in Denmark is one of the most sustainable and energy efficient cities across the globe. All as part of Copenhagen's goal to be the first carbon-neutral city, they have made large technological advancements as well as much simpler but still effective ones. As simple as just the national consensus to use bicycles for commutes rather than drive polluting cars across the city. However, much more innovative solutions such as the £610 million Amager Bakke Waste-to-Energy Plant Project which burns waste collected from 500,000 to 700,000 inhabitants and 46,000 companies in and around Copenhagen, have also helped the city to a great extent. Whilst providing in excess of 150,000 Danish homes energy throughout the year, the plant also acts as a social and cultural hub with activities such as the CopenHill artificial ski slope, an 80m-high rock-climbing wall and a running track [2].

All of the city's impactful efforts have consequently accumulated to Copenhagen winning the European Green Capital Award back in 2014 and striding towards the finish line to be the first carbon-neutral city in the world.

Clean Energy

Today, approximately 26% of the world's energy is derived from renewable sources but as fossil fuel supplies dwindle and energy consumption increases, affordable and clean energy is augmenting in importance. One striking example is Kenya where over 70% of their energy is renewable after over US $1.3 billion was spent in 2010 alone to construct infrastructure technologies utilising the energy in wind, geothermal, small-scale hydro and biofuel stores [3]. These sustainable developments are crucial to supply electricity with the nation's energy demand raising by 6-8% per annum as well as providing approximately 260,000 jobs. The United Kingdom, on the other hand, has relied on 41.2% fossil fuels and only 25.4% renewable energy on average over the last year[4]. Will the UK be able to sustainably generate the extra 263GW required by 2050 whilst still meeting their goal of being carbon-neutral by then?

Electric Vehicle Infrastructure

With the looming ban of selling petrol and diesel cars in 2030, it is increasingly important for countries to prepare for this transition by redeveloping our transport infrastructure with more efficient public transport systems, increased bicycle lanes and more electric vehicles stations. Where is your nearest electric car charging point? Indeed, whilst some may even have one already installed in their driveway, others may not be able to locate one within a 5 mile radius from their home. In the UK, currently there are over 35,000 charging points across 13,000 locations [5]. In contrast, there are reportedly 8,385 petrol stations operational in the UK, so taking the average of 12 fuel pumps per station, that equates to over 100,000 fuelling points [6]. Furthermore, other countries across the globe have much less infrastructure, Singapore having almost no electric vehicle infrastructure.

On the other hand, Norway is a key example of a country which has successfully taken on board the electric vehicle revolution. In 2020, 54.2% of all car sales were of electric vehicles - the first time such cars have comprised more than 50% of new car sales in a country across a full year [7]. This parallels the rapid development of charging infrastructure with over 16,000 points available for a population of only 5.3 million. Moreover, Norway plans by 2025 to have at least two fast-charging stations per every 50km of road, in addition to plans to introduce wireless charging under main roads in the capital of Oslo [8]. Should the UK's government follow Norway's lead for a more sustainable future?

Therefore, as our population continues to rise, how will cities continue to develop in a sustainable manner? Whether it be through large, innovative projects such as Copenhagen's Amager Bakke Project, cleaner sources of energy or even the implementation of more efficient EV infrastructure, countries must work together in this crucial fight towards carbon net-zero by the year 2050.

Edited by Aditya Jain

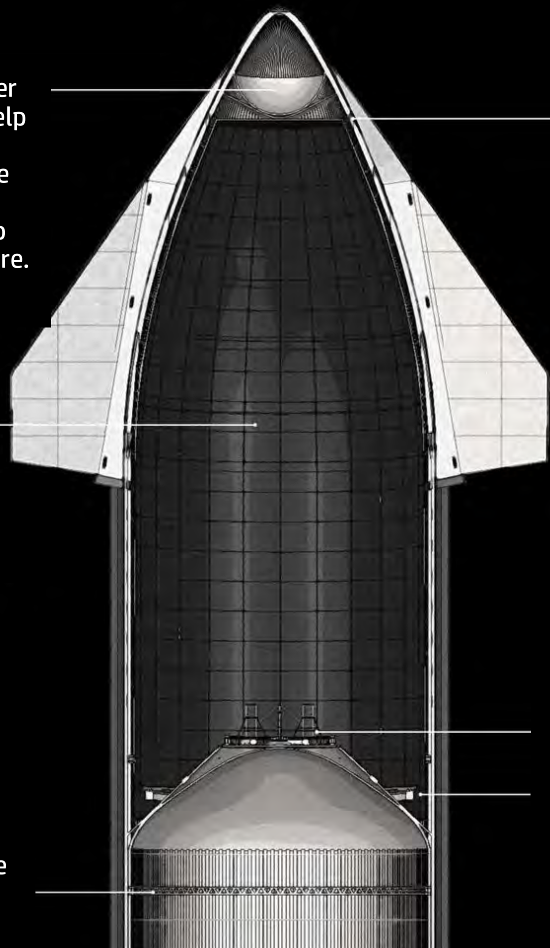
The Race to Space — SpaceX's Starship

By Sanuka Gunawardena (Y12)

Render of a future Starship base on Mars,

Ever since NASA's Apollo programme in the 1960s ignited a race to space, both countries and private organisations have invested billions into designing and building machines like rockets and sate llites, capable of surviving the harsh conditions needed for humanities' multiplanetary expansion! Most notably, Elon Musk's SpaceX, now a household name, has pioneered rocket design. SpaceX has not only proved the efficiency of reusable rockets but provided inspiration and hope that our dream of exploring the stars is not simply a lost vision from science fiction!

Starship in flight [2]



SpaceX has designed the LOX header tank (liquid oxygen) at the top to help move the rocket's centre of mass further upwards, counter-acting the weight of the engines. This helps during the de-orbit burn as Starship enters belly first into the atmosphere.

Starship will have the largest payload volume of any launch rocket in use or development (1100 m^3). This space can be configured to carry cargo such as satellites, equipment or crew. SpaceX has designed Starship with a maximum capacity of 100 people [5].

A retaining ring is used to attach the fuel tank to the rocket body.

The forward RCS (Reaction Control System) thruster outlet is used to provide a small amount of thrust in any direction [4]. It is used to provide a torque to rotate the rocket, especially to allow more accurate manoeuvring, docking and to ensure the rocket is vertical when landing.

A payload adapter is used to attach any payloads or cargo to the rocket using a clamp. Springs are used to release the cargo into orbit.

SpaceX plans to use a Tesla model S power pack to control on board equipment such as key flight control sensors and the rocket's fins [6].

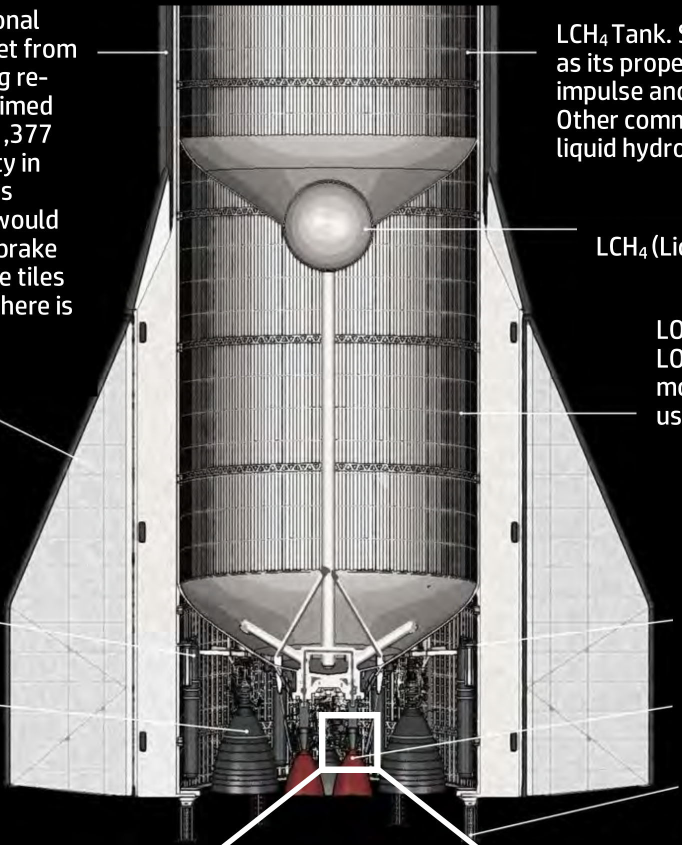
The Starship is a dual-stage rocket, meaning that the main thrusters detach, usually on leaving Earth's atmosphere, once their fuel has been used. This reduces weight. The first stage contains the payload space and additional thrusters to propel the rocket to its destination, whether that is the Moon, Mars, or another planet. SpaceX has perfected their design to this dual-stage as reduced stages means greater ease of use and manufacture and overall, cheaper rockets! In comparison, most rockets such as NASA's Saturn V and SpaceX's own 'Falcon 9' are triple-stage rockets. The second stage is commonly referred to as "Super Heavy". Since the rocket's inception in 2016, the rocket has undergone many design and name changes, with previous versions called BFR (Big Falcon Rocket) and BFS (Big Falcon Ship). Starship is a staggering 120 metres tall and nine metres in diameter with "Super Heavy" being 70 m tall and able to carry 3,400 tonnes of fuel for launch [3].

Starship is equipped with hexagonal heat tiles which protect the rocket from the extreme temperatures during re-entry. During tests, Musk has claimed that these tiles have withstood 1,377 °C. Whilst designed with durability in mind, SpaceX claims that the tiles would wear out after reuse and would need to be replaced just like car brake pads. The hexagonal shape of the tiles means that, according to Musk, there is "no straight path for hot gas to accelerate through the gaps" [7].

AFT actuated fins are used during atmospheric entry. AFT simply refers to being at the rear end of the rocket.

Pressure vessels are used to store fluids at a high pressure.

The three vacuum raptor engines are reusable and provide more than double the thrust of the Merlin engines used in the 'Falcon 9' rocket [8]! The vacuum engines have a larger nozzle diameter than their sea-level counterparts to increase efficiency in space. Each can produce 220 tonnes of thrust [9].



LCH_4 Tank. Starship uses liquid methane as its propellant due to its high specific impulse and relatively easy storage. Other common propellants include liquid hydrogen and kerosene.

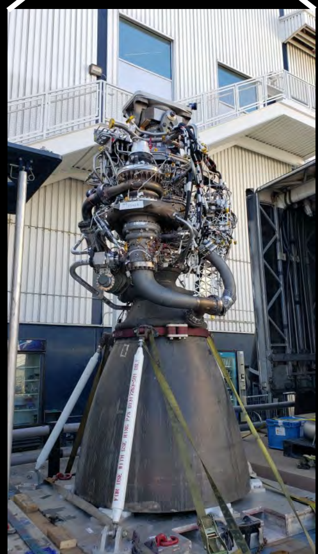
LCH_4 (Liquid methane) Header tank.

LOX (Liquid oxygen) tank. LOX is the liquid form of molecular oxygen and is used as an oxidiser.

The AFT RCS thruster outlet serves the same purpose as its 'forward' counterpart but is used to control the rear end of the rocket.

Rocket engine nozzles and their size are vital for efficiently generating thrust.

Starship has six retractable landing legs to allow it to touch down on other planets and on Earth, allowing it to be reused.



Raptor sea-level engine [11]

As well as the three vacuum engines, Starship will utilise three sea-level raptor engines too. These share the same technology as their vacuum counterparts but have a smaller nozzle diameter. As the name suggests, these engines will be used for take-off from the surface, whether that is Earth's or Mars'. Each engine is 1.3 m in diameter, 3.1 m in height and produces 200 tonnes of thrust [10].

SpaceX's rival firm Virgin Galactic is also providing space tourism with its new spacecraft range

SpaceX is still early in the development of its Starship, with the rocket estimated to cost around $216 million (which is four times as much as its 'Falcon 9') [12]! As of 31st March 2021, there have been eight Starship tests, with many ending in magnificent explosions. However, SpaceX has proven that a private organisation can beat even NASA, when it comes to innovation and technology and Starship is a brilliant example of that. Science fiction portrays enormous rockets, carrying thousands to distant solar systems, travelling at unimaginable speeds. Starship may act as a catalyst to revolutionise the commercial space industry and finally make trips to space very much a reality!

Edited by Atharva Narkhede

No One Knows How Planes Fly

By Sanuka Gunawardena (Y12)

Tourism, transport, war. Today, planes are all around us. We have so much confidence in them that many of us, despite our lives depending on them, have never really questioned how planes generate lift. What if I told you that we do not have a complete understanding of how planes generate lift? Although, to reassure you, engineers know what conditions are needed for flight, thankfully, but knowledge is different from understanding. In this article, I will explain the main misconception of how lift is created and the two most popular correct explanations: Bernoulli's principle and Newton's Third Law.

Firstly, it is vital to mention that the 'equal transit time' theory outlining that the velocity of airflow over the cambered aerofoil is greater due to it having to travel a greater distance (due to the aerofoil's convex shape) in the same time period, in order for airflow across the top and bottom of the wing to reach the trailing edge at the same time is incorrect [2]. There is no law or theory stating that airflow above and below must have an equal transit time.

A380 banking [1]

Explanation 1 – Bernoulli's Principle:

An aerofoil's leading edge splits incoming airflow into two separate flows at the stagnation point – one travels across the top of the wing and the other across the bottom. Due to an aerofoil's asymmetrical shape and streamtube pinching, the cross-sectional area that the flow of air above the aerofoil takes, is much smaller than that of the air flow below the aerofoil.

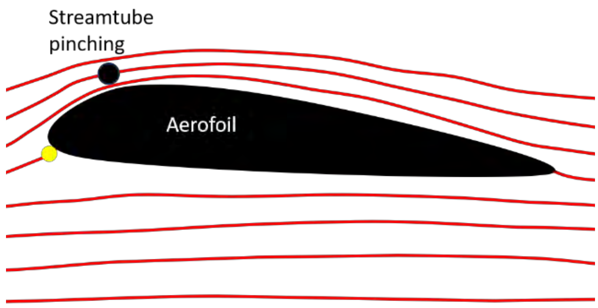
Therefore, as shown by the continuity equation (above) for steady state flow, as area decreases, velocity must increase to maintain a constant flow

$$PA_1V_1 = PA_2V_2$$

P = Pressure

A = Cross Sectional area of flow

V = Velocity of airflow



Airflow around cambered aerofoil showing streamtube pinching where cross-sectional area of flow is less than below the aerofoil. Yellow dot is the stagnation point.

rate needed for the continuity equation and conservation of mass [3]. Bernoulli's equation (below) shows that as the velocity of the airflow increases, the pressure of the air jet must decrease to compensate and satisfy the law of conservation of energy [4].

$$P_1 + \tfrac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \tfrac{1}{2}\rho V_2^2 + \rho g h_2$$

P = Pressure of fluid

ρ = Density of fluid

g = Gravitational acceleration

V = Velocity of fluid

h = Height (Elevation) of fluid

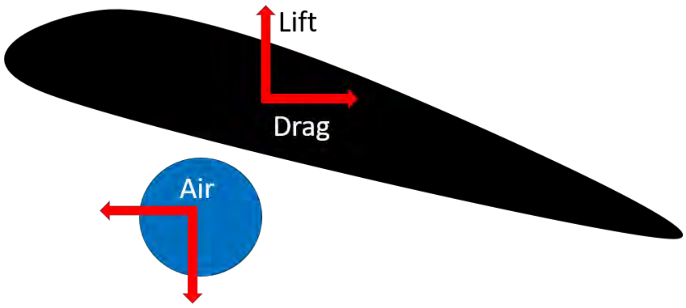
A decreased pressure means a decreased force as pressure equals force divided by area. (Area remains constant), generating lift.

Despite Bernoulli's theory being fully correct, this explanation fails to explain why streamtube pinching above the aerofoil is created, how paper aeroplanes generate lift since their wings are flat or how planes can fly inverted (upside down).

Explanation 2 – Newton's Third Law:

Newton's Third Law states that if object A exerts a force on object B, object B will exert an equal (magnitude) and opposite (directional) force on A. Most aerofoils are cambered, pushing incoming air down. As shown by Newton's Law, when the wing exerts a downwards force on air particles, the air particles will exert a force of the same magnitude upwards on the wings, generating lift.

Take a paper aeroplane. Some can travel almost one hundred metres with wings that are perfectly flat. How is this possible? Despite a paper aeroplane's flat wings, Newton's Third Law can still be used to explain their flight. Here the angle of attack is key. A positive angle of attack still means that air is being deflected downwards by the wings. Therefore, Newton's Third Law still offers a correct explanation, even if the wings are not cambered. This explanation still applies for all types of aerofoil, including the 'flat bottom design'. This is due to the Coandă effect which describes how the



Cambered (convex) aerofoil at a positive angle of attack deflecting air. Wing is 'deflected' in opposite direction, due to Newton's Third Law, generating lift.

air jet remains attached to the convex upper surface of the aerofoil, which bends away from the initial flow, and is deflected downwards, generating lift upwards [5]. However, cambered wings are advantageous due to their ability to generate lift at a 0^{o} angle of attack [6].

This explanation is also correct. It explains why aerofoils can be optimised to generate lift and how the action-reaction pair of the air and wing generates lift, but it cannot explain the lower pressure above the aerofoil, thus, falling short of a universal theory.

Our understanding of aerodynamics has come a long way since the inception of aircraft. Thousands of physicists and engineers in research institutions are currently exploring new concepts such as Doug McLean who believes that a complete answer rests in taking conservation of mass, momentum and energy into account together. He, through CFD (Computational Fluid Dynamics) modelling, devised 'the co-dependency of lift's four elements' as an alternate theory of lift [7]. Could this be the complete explanation of lift we have been waiting a century for?

Edited by Atharva Narkhede

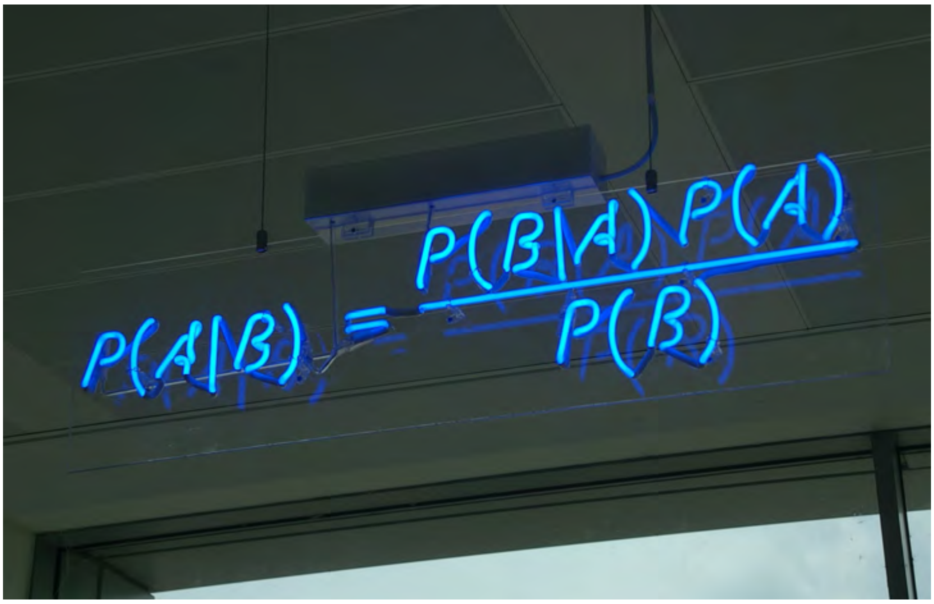
A new generation of Soviet Aircraft have experimented with backward aerofoil, claiming it provides greater manoeuvrability, such as on this SU-47

STRUCTURES OR WHY THINGS DON'T FALL DOWN by J. E. Gordon

'Structures or why things don't fall down' by J.E. Gordon immediately caught my attention as it promised an overview of materials science, a topic which is briefly covered in A level Physics. Whilst reading, it became extremely clear that Gordon not only met what he had set out to do but managed to link his explanations creatively and relevantly to examples that further aided understanding. He not only covers man-made objects, forces experienced by them and different joints but explores the natural world. The best example of this is his use of the Pterodactyl to demonstrate the efficiency and aerodynamic gains of membrane surfaces and, later, feathers and how this knowledge can be used to design improved sails. Another topic I found particularly interesting was on pressure vessels and the properties and calculations involved with their different shapes, a topic directly linking to fuel storage from the article above. I discovered this book on Cambridge Engineering Reading List and strongly recommend to anyone interested in materials or planning to study any form of engineering.

DID YOU KNOW?

An interesting theory is that the 52 cards show the weeks of the year, the colours (two: red and black) reflect day and night. The 13 cards in a suit match the number of lunar cycles and the twelve court cards represent the months of the year. The sum of all the symbols is also 365 - the number of days in a year.



Bayes' Theorem

By Divy Dayal (Y12)

$$P(H|E) = \frac{P(E|H) \times P(H)}{P(E)}$$

$$P(E) = P(H) \times P(E|H) + P(\neg H) \times P(E|\neg H)$$

$$P(H|E) = \frac{P(H) \times P(E|H)}{P(H) \times P(E|H) + P(\neg H) \times P(E|\neg H)}$$

Suppose you have just done a Maths practice paper and want to find out the probability that you will get an A* in the A level, given that you have got an A* in this practice paper. For you to find a numerical answer for the probability that you will get an A* in the real exam, you need Bayes' theorem [1].

Bayes' theorem is rather intuitive (even if the formula does not convince you), so much so that Thomas Bayes thought it was "common sense" and not worthy of publication. Bayes abandoned the project for a decade and only after his death was it published [2]. It is so influential today that Cass Business School is being renamed after Bayes, and statisticians are using Bayes' theorem to estimate R values in the pandemic.

Why it works?

It is important to know why this formula works before we even address its applications. We are familiar with the concept that getting two consecutive tails is the probability of getting one tail times the probability of a second tail. Therefore, for a fair coin, *P(A) X P(B)* where A and B are coin flips is $^1/_4$. What we have found is the *P(A and B)* and multiplying the independent probabilities is appropriate. This is because the outcome of A does not affect the outcome of B – the definition of independent events [3].

For something like exam grades, your past performance is likely to influence your future grades. More practice is undoubtedly going to improve your mathematical abilities, and thus the outcome of the practice paper affects the outcome of the real exam [4]. Here, to find the *P(A and B)* you cannot multiply the probabilities *P(A)* and *P (B)*, since they are not independent. Instead, to work this out, you would need to know how many people succeeded in getting the best grade having revised and attained an A* in the practice paper, divided by all the people who got an A* in the practice paper (regardless of whether they got A* in the real exam).

Here the hypothesis you are testing is whether you will get an A* in the A -Level, and the proportion of students historically proving the hypothesis true is *P(H)* – this is also known as the prior. The *P(E|H)* is the probability of the event (proportion of students attaining an A* in the practice paper) given that you have met the hypothesis. This means the proportion of people who got the top grade in the practice paper out of those who later on got A* in the real exam, and it is known as the likelihood. The notation of ¬ simply means *"the event not occurring"* and so *P(E|¬H)* simply means the proportion of students meeting the event (A* in practice paper) out of those that did not meet the hypothesis (attaining A* at A level). Thus the bottom fraction can also be written as *P(E),* i.e. the total probability of doing well in the practice paper.

Numerical Example

Suppose that in your year of 72 people, 24 ended up getting an A* in the real exam. Out of these 24, only $^1/_2$ got an A* in the practice paper a month ago. $^1/_6$ of the people who did not get an A* in the real exam got an A* in the practice paper.

Therefore, *P(H)* = $^{24}/_{72}$ since this is the proportion of people who got an A*. The proportion of students who got A* in both papers is $^{24}/_{72} \times {}^{1}/_{2} = {}^{24}/_{144} = 0.166$. This is the numerator of the Bayes' theorem calculated.

To find the total number of people who got an A* in the practice paper, this would be the probability of those that got an A* in the real exam and in the practice paper (*P(H) × P(E|H)* which we calculated as *0.166*) as well as people who did not get an A* in the real exam but did in the practice paper.

This is the *P(¬H) × P(E|¬H)*. Remember that the *¬H* is due to them not meeting the hypothesis. This can be calculated as $^{48}/_{72}$ (the number of students who did not get A*) multiplied by $^{1}/_{6}$ (the number of students out of those that did not get A* in the real exam but did in the practice paper). This leads to the probability *P(¬H) × P(E|H)* being $^{48}/_{72} \times {}^{1}/_{6} = {}^{1}/_{9} = 0.111$. Hence, the denominator of Bayes' theorem sums to 0.2777.

With the current prior, there is a 60% chance that you will get an A* in the A level given that you just got an A* in the practice paper.

$$P(H|E) = \frac{\frac{24}{72} \times \frac{1}{2}}{\left(\frac{24}{72} \times \frac{1}{2}\right) + \left(\frac{48}{72} \times \frac{1}{6}\right)} = \frac{\frac{1}{6}}{\frac{1}{6} + \frac{1}{9}} = \frac{3}{5} = 60\%$$

This may seem disappointingly low, but this is the benefit of Bayes' theorem – it can be updated. The prior ($^{24}/_{72}$) you used in this equation was simply the historical average, however, now you can update this with the new probability. If you do another practice paper and get an A*, you can replace the prior with *0.6,* as this is the most recent probability you have about your chances of getting an A*.

$$P(H|E) = \frac{\frac{2}{3} \times \frac{1}{2}}{\left(\frac{2}{3} \times \frac{1}{2}\right) + \left(\frac{48}{72} \times \frac{1}{6}\right)} = \frac{\frac{1}{3}}{\frac{1}{3} + \frac{1}{9}} = \frac{3}{4} = 75\%$$

This makes sense. With more and more A* grades in practice papers, there is a greater likelihood that you will get an A* in the exam, because the P(A* in practice paper) and P(A* in exam) are not independent and the outcome of one *does* affect the other [5].

Bayes Search Tactics

Bayes' theorem is incredibly useful in search missions, most notably used for the location of sunken USS Scorpion. Bayesian search tactics were also used to locate a ship carrying $700 million worth of gold by a man called Tommy Thompson on 11th September 1988 [6].

The process works by first using all the data currently available to hypothesise possible locations, and then plot a probability density function for each [7]. A path that targets high density areas is created and all the probabilities are revised constantly as the search takes place. For example, if there is an unsuccessful search, the probability density is revised and all the other areas' probability densities are marginally increased.

Moreover, the formula can be adapted when the numbers are easier to calculate, and the left and right hand sides can be rearranged to calculate *P(H|E)* and *P(E|H)* [8].

Conclusion

Bayes' theorem is a fundamental equation that allows for beliefs to be updated. Imagine a person lived their entire life in a cave, and when they came out saw the sun rise. They are marvelled by the event and wonder whether it happens every day. The next morning, they see the sun rise again and they update their beliefs, and with every sunrise they become more and more confident that the sun rises every day [9]. Bayes' theorem is meant to be used multiple times, updated each time as new information is revealed. It is of such importance that Sir Harold Jeffreys said that Bayes' theorem is "to the theory of probability what the Pythagorean theorem is to geometry [10]."

Edited by Atharva Narkhede

$$\frac{P(H) \times P(E|H)}{P(H|E) \times [P(H) \times P(E|H) + P(\neg H) \times P(E|\neg H)]}$$

$$= P(H \text{ and } E)$$

$$= \frac{P(E) \times P(H|E)}{P(E|H) \times [P(E) \times P(H|E) + P(\neg E) \times P(H|\neg E)]}$$

Golden Ratio: Applications in Design and Nature

Shanjeev Mathialagan (Y11)

Why is this one of the most interesting numbers in human history? Despite being an irrational number with an infinite number of digits after the decimal point, it is frequently applied to art and design. This "golden" number is represented by the Greek letter Phi Φ and is more famously known as 'The Golden Ratio' (1:1.61803...).

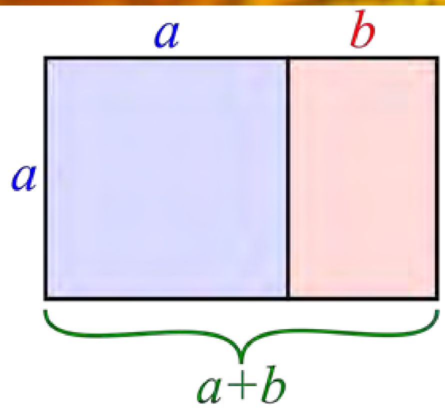
Mathematics

It was first studied by Ancient Greek mathematicians, because it regularly appeared in geometry. Euclid, regarded as the 'father of geometry', called it "the division in extreme and mean ratio".

Simply, the Golden Ratio is when the ratio of two quantities is equal to the ratio of their sum to the larger quantity (with *a* being the larger quantity here):

$$\frac{a+b}{a} = \frac{a}{b}$$

In geometry, a golden rectangle is a rectangle which has its dimensions



"[The Golden Proportion] is a scale of proportions which makes the bad difficult [to produce] and the good easy"

- Albert Einstein

in the Golden Ratio. A golden rectangle that has long side *a* and short side *b* produces a similar golden rectangle when adjacent to a square with sides of length *a*. The larger golden rectangle now has the long side *a* + *b* and short side *a* [1]. This helps us to visualise the relationship between two quantities which are in the Golden Ratio.

Fibonacci Numbers:

There is a relationship between the Golden Ratio and the Fibonacci sequence (a sequence where each number is the sum of the two numbers in front of it). The ratio between any two consecutive Fibonacci numbers is very close to the Golden Ratio. For example, the ratio between 144 and 233 is 1.618056.

Nature

The Golden Ratio is even called the "divine proportion", because of its frequency in the natural world.

The number of petals in flowers follows the Fibonacci sequence and the Golden Ratio. For example, lilies have three petals and buttercups have five

petals; both three and five are numbers in the Fibonacci sequence. Phi also plays a significant role in the arrangement of petals. It has been found that each petal is placed at 0.61803 per turn (out of a 360° circle) in order to maximise the exposure to sunlight to maximise the rate of photosynthesis, which is the process that produces food for the plant [2]. 0.61803 is the reciprocal of Phi (1/1.61803...) to five decimal places.

Curiously, it is claimed that Phi appears throughout the human form with many proportions of the body having a link to the Golden Ratio, such as in the face, body, and fingers. For example, the ratio of the forearm to hand is the Golden Ratio. Furthermore, DNA molecules, which carry the genetic code that programs our bodies, are based on 'The Divine Proportion'. A DNA molecule measures 34 angstroms long by 21 angstroms wide (1 angstrom is a unit of length equal to 1 x 10^{-10} metre) for each full cycle of its double helix spiral. Naturally, 21 and 34 are successive numbers in the Fibonacci sequence and their ratio, 1.6190476 closely approximates Phi, 1.6180339.

Architecture

Throughout history, the ratio has been used by designers to create magnificent structures. Some well-known examples include the Great Pyramids of Giza in Egypt, the Parthenon in Greece and the Taj Mahal in India. The proportions of these constructions show that the architects deliberately applied the golden ratio to their designs, since it was believed to be more aesthetically pleasing. So is it really a coincidence that the named examples above are all Wonders of the World?

In his 1919 book Ad Quadratum, Frederik Macody Lund, a historian who studied the geometry of several Gothic structures, claims that the Notre-Dame of Laon has golden proportions - shown by the superimposed regulator lines on the illustration [3].

More modern applications of the Golden Ratio can be seen in the design of Toronto's CN Tower. For example, the ratio of the observation deck at 342 meters to its total height of 553.33 is 0.618, the reciprocal of Phi.

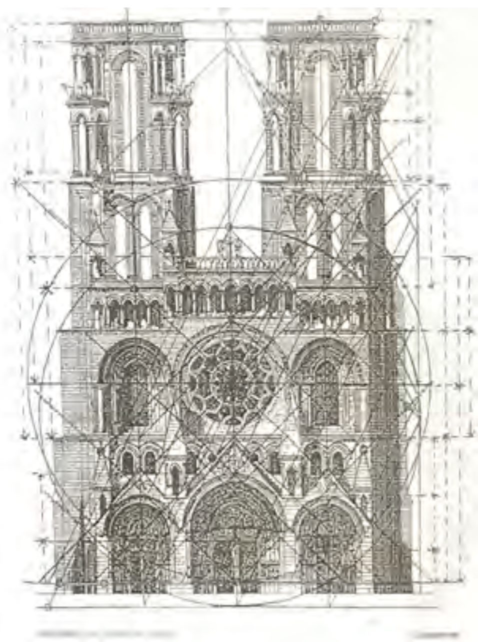
So why do architects keep using the principles of the golden rectangle? When applied to design, it is not only visually attractive but it is also one of the simplest ways to impart a sense of balance to a structure. An architect can easily make the structure larger or smaller to satisfy their clients; by following the principles of the Golden Ratio, they can correctly alter a building's proportions with just a few simple calculations.

Art

"Without mathematics there is no art," said Luca Pacioli, an Italian mathematician in the 15th Century, who collaborated with Leonardo da Vinci.

The Golden Ratio is not just found in the design and beauty of nature; it is also present in art. Artists used the Golden Ratio in their work because it was thought to be attractive.

Leonardo da Vinci has used it elegantly to create visual harmony



The mesmerising spirals in Romanesco Cauliflowers is based on the Golden Ratio

within his paintings. One famous example is "The Last Supper": the key dimensions of the room and table were based on the Golden Ratio, which was known as 'The Divine Proportion' in the Renaissance period [4].

Overall, the Golden Ratio is a mathematical ratio that can be found all around us from nature to architecture to art, which are just a few examples. Although we will never find one size that suits all the needs in design and nature, there is a tangible, mathematical approach that will always help us create impressive designs and view them in nature: the Golden Ratio.

Edited by Aditya Jain

Is there Sufficient Statistical Evidence that the Stock Market can be Beaten?

By Karun Kirubananthan (Y12)

Currently, the stock market is increasing in value at a high rate, despite the COVID-19 pandemic, with the S&P 500 Index (a collection of the 500 largest U.S. publicly traded companies) rising by a formidable 16.26% [1]. If we extrapolate this growth (which is generally not a good idea for the stock market), we find that anyone holding money in this index would double their money within approximately five years, which is a high pay-off for doing relatively little work other than depositing money into an index:

$$1.1626^x = 2$$

$$\ln(1.1626^x) = \ln(2)$$

$$x\ln(1.1626) = \ln(2)$$

$$\therefore\ x = \frac{\ln(2)}{\ln(1.1626)} \approx 4.6\ years$$

This highlights that index growth may be unsustainable at the moment. However, hedge funds (which charge fees) have recently been underperforming. The S&P 500 index has been returning 13.6% per year on average in the last ten years, but hedge funds are not able to keep up with this growth because of the fees they charge [2].

Currently, "the average hedge funds portfolio is close to a multi-generational or all-time low. When measured by a rolling five-year return, hedge funds have reached a low of 0.8% annualised five-year return as of October 2012" [3]. To test whether the market can be beaten, we will use the S&P 500 to model the entire market and find out whether any hedge funds are able to consistently beat the market rate of 13.6%. This is a major oversimplification but will help us estimate the odds of being able to find extraordinary success in the market. We will also take hedge fund fees into account by taking fees to be approximately 18% of profits [4].

Let *'s'* be the initial amount.

Expected value after one year from S&P 500 = *1.136s*

Hedge funds must, therefore, end up with a value of better than *1.136s*, when fees are considered.

Let *'r'* be the expected growth percentage of a hedge fund portfolio, for example, 10% growth per year —> 0.1 expected growth percentage.

$$Value\ of\ hedge\ fund\ portfolio\ after\ 1\ year - fee\ on\ profit \geq Value\ of\ S\&P\ 500\ portfolio\ after\ 1\ year$$

Let us conduct a hypothesis test at the 2% significance level. Assuming returns follow a normal distribution above or below the mean of

$$X \sim N(0.136, 0.1348^2) \text{ where } X \text{ is the random variable denoting annual return rate}$$

$$H_0: \mu = 0.166$$

$$H_a: \mu > 0.166$$

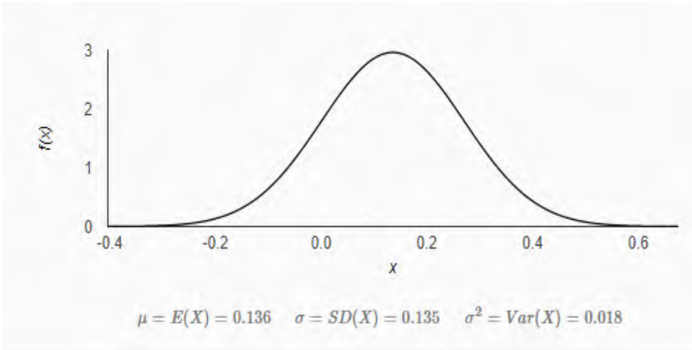
$$s + sr - 0.18(sr) > 1.136s$$
$$1 + r - 0.18r > 1.136$$
$$0.82r > 0.136$$
$$= 1 - 0.588 = 0.412$$
$$P(X > 0.166) = 1 - P(X \leq 0.166)$$
$$r > 0.166 \text{ i.e. hedge funds must return } 16.6\%$$

13.6%, with a standard deviation of 13.48% we can say where μ is an expected hedge fund's return [5]:

We will let our significance level be 2%, i.e. a false positive has a 2% chance of occurring – we will not reject the null hypothesis (that the market can be beaten) until we have sufficient statistical evidence that $P(H_a) < 0.02$

This means that there is a 41.2% chance of achieving greater than 16.6% returns in a given year, assuming the mean return is 14.6%, the standard deviation of returns is 13.48% and returns follow a normal distribution. Our significance level is 2% so *0.0412 > 0.02*.

Therefore, we have sufficient evidence to reject the null hypothesis that *μ = 0.166* and can say that while *P(higher returns than S&P 500)* is less than 0.5 (i.e. the average investor is likely to be better off investing in the S&P 500), some hedge funds are reasonably likely to be able to beat the



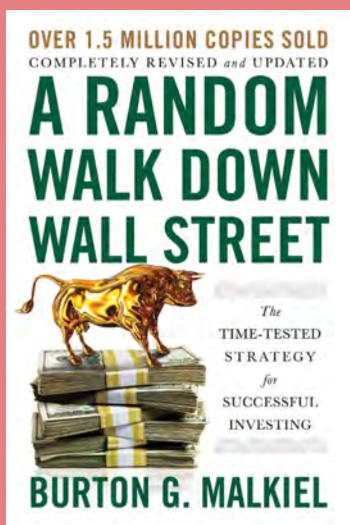
Returns of the stock market modelled by a normal distribution: *X~N (0.136,*

market.

Edited by Atharva Narkhede

A RANDOM WALK DOWN WALL STREET by Burton G. Malkiel

Today's equity and asset trading markets seem as appealing as ever to the average retail investor, with returns as high as 10,000% in only a couple of months, yet also potentially carrying the most volatility and risk that investors have ever faced. What should the average investor do? "A Random Walk Down Wall Street: The Time-Tested Strategy for Successful Investing" was originally written in 1973 by American economist Burton Malkiel, and popularised the random walk hypothesis – the financial theory that stock market prices evolve according to a "random walk" and thus cannot be predicted. Despite its relatively old age, the book continually gets updated revisions and remains the major face of the efficient-market hypothesis. The book uses academic papers and historical examples to suggest that it is statistically unlikely that an average investor will be able to outperform their benchmark index over the long term, so the average investor should invest into an index fund and brave any market downturns that occur. Anyone who has read "A Random Walk Down Wall Street" is bound to pick up a lifetime interest in the stock market, so this book is one that is definitely recommended to all!



The Natural Number Game

By Syed Shah (Y12)

Peano's Axioms and the Definition of Addition

As human beings we have become accustomed to the idea that *2 + 2 = 4*, but how can we prove it? Our experiences tell us that if we have two stones in our right hand and two more in our left then we have four altogether, but is that really a proof? While it may be in the eyes of a human, this is certainly not the case for the so-called "theorem prover" Lean.

Theorem provers are very pedantic by nature – they require an exact definition of a "number" – but once all the obvious statements have been fed in, they become very powerful tools for checking large, complicated proofs.

In this article, I will introduce the definition of a natural number and go on to present the basic syntax of Lean.

Inductive Mynat — The definition of a number

Our goal when defining the natural numbers is to minimise the number of assumptions we make as much as possible. For example, if we are able to avoid the assumption that *a + b = b + a* then we must do so.

In 1889, Guiseppe Peano proposed the following definition [1] for
S is known as the "successor" function; *S(n)* is defined to be the number after *n*, where *n* is an element of the set of natural number.

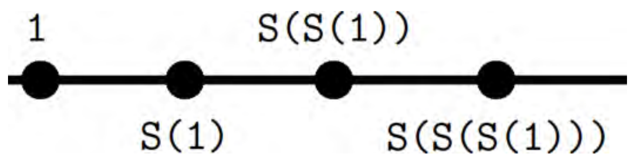
$Eq.1 \quad 1 \in \mathbb{N}$ "1 is a member of the set of natural numbers"

$Eq.2 \quad S(n) \in \mathbb{N}$ "S(n) is also a member of the set of natural numbers"

Statement 2 means that if we have some natural number *n*, then the number after *n*, *"S(n)"*, is also a natural number. We therefore have the following number line [5]:

In the online Natural Number Game [2], this definition is written in Lean code as:

```
inductive mynat
| zero : mynat
| succ (n : mynat) : mynat
```



Note that in Lean, 0 is used as the starting point for $\mathbb{N}$ instead of 1. While this simplifies our definition of addition later on, it is somewhat unconventional. So far, we can count and if needed we could arbitrarily define "one" as *S(0)* and "two" as *S(1)*. However, at this point neither Lean nor we know what *"1 + 2"* means because we have not yet defined addition.

$\mathbb{N}$

add — The definition of addition

In the Natural Number Game this is written as:

```
definition add : mynat -> mynat -> mynat
| a zero := a
| a (succ b) := succ (add a b)
```

Addition is a *recursive function*, which means that it refers to itself in its definition. For example, Lean does not know immediately what *0 + S(0)* is, but we can rewrite it as *S(0 + 0)* because of equation 4. Again, Lean does not know the value of *S(0 + 0)*, but we can rewrite it as *S(0)* because of equation 3.

$$(3)\ a + 0 = a$$
$$(4)\ a + S(b) = S(a + b)$$

We are now able to prove rigorously that *2 + 2 = 4*.

zero_add — 0 + n = n

Equipped with our two rules *a + 0 = a* and *a + S(b) = S(a + b)* – named ***add_zero*** and ***add_succ*** in the Natural Number Game – let us prove that *0 + n = n* for any natural number *n*.

This method of proof is called induction. First, we prove that there is some number *d* such that *0 + d = d* (***zero_add***) is true — this is called the base case. Afterwards, we show that if the statement is true for any number *d*, then it is also true for *S(d)*.

If ***zero_add*** is true for *S(d)* then it is also true for S(*S(d))* and likewise for S(S(*S(d)))*, S(S(S(*S(d))))* and so on. If we have *d = 0*, we have therefore proved ***zero_add*** for all the numbers on the natural number line.

rw is short for ***rewrite***. When we want to apply an assumption or theorem onto some numbers *a* and *b*, we do so by writing ***rw theorem_name a b***. Notice the way in which the progress of our proof changes as we use ***rw*** to rewrite the left-hand side (*0 + n*) until it is the same as the right-hand side (*n*). Please note that the information provided after each use of the symbol '**--**' does not represent code but are rather comments that show our progress:

```
theorem zero_add (n : mynat) : 0 + n = n :=
begin
  induction n with d hd, -- Introducing the base case:
                  --    0 + d = d, with d = 0
                  -- <=> 0 + 0 = 0
  rw add_zero 0,        -- =>     0 = 0
  refl,                 -- refl just tells Lean that x = x is always true.
                  -- Now the inductive step:
                  --    0 + S(d) = S(d)
  rw add_succ 0 d,      -- => S(0 + d) = S(d)
  rw hd d,              -- =>     S(d) = S(d),
                  -- using the truth of zero_add for d
  refl,                 -- Proof finished!
end
```

As an exercise for the reader, can you prove that *a + b = b + a* using what you have learned about ***zero_add*** and induction?

http://wwwf.imperial.ac.uk/~buzzard/xena/natural_number_game/

Automation

The proofs above are examples of a theorem prover being used to *formalise* mathematics by checking every statement very rigorously and forcing us as humans to define everything carefully [3]. There is, however, an active effort by computer scientists to use machine learning as a way of prompting systems like Lean to *generate* proofs entirely on their own [4]. Precise and unaffected by confusion and human error as they are, will computers one day mechanise pure mathematics?

Edited by Nabeel Abdul Rasheed

Tartaglia and the Truth behind Pascal's Triangle

By William Lu (Y12)

What is Pascal's Triangle?

Pascal's triangle has many applications within mathematics. These include finding binomial coefficients, combinatorics, generating sequences and calculating probabilities. The triangle itself is constructed by starting with a '1' followed by two '1's in a row next to each other on the row below. We then add these together to get '2', which we place in between the '1's on the row below. The initial '1's can be thought of as having a '0' either side of them; just as before, we can add the neighbouring '1's and '0's to give a '1' on either side of the '2' on the second row. Likewise, the addition of the terms in the second row leads to the terms in the third row, and so on (see *Figure 1*).

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1
1 6 15 20 15 6 1
1 7 21 35 35 21 7 1
1 8 28 56 70 56 28 8 1
1 9 36 84 126 126 84 36 9 1
1 10 45 120 210 252 210 120 45 10 1

The first ten rows of Pascals' Triangle

Who discovered the triangle?

You would be forgiven for thinking that as the triangle is an eponym of French mathematician Blaise Pascal, it must have been he who discovered it. In reality, this is not quite the case. Although Pascal did write a paper on the 'Arithmetical triangle' in 1654 (entitled *Traité du triangle arithmétique*), Italian mathematician Niccolò Fontana (also known as Tartaglia) described the triangle almost one hundred years earlier in his 1556 work *General Trattato di Numeri et Misure*. Interestingly, Fontana got the nickname 'Tartaglia', meaning 'stutterer', after he received face and mouth wounds when the French attacked Brescia in 1512. In Italy, the arithmetical triangle is known as Tartaglia's triangle.

Ironically, Tartaglia wasn't even the first to discover the arithmetical triangle! The triangle of coefficients was studied by Chinese mathematician Jia Xian and Persian astronomer Omar Khayyam both in the tenth century. The triangle was popularised in China in the 1300s by Yang Hui and so it is also known as the Yang Hui triangle. In other words, 'Pascal's triangle' was really discovered over 500 years before Pascal himself acknowledged its existence!

Cardano-Tartaglia Formula

Sadly, the arithmetical triangle was not the only instance where Tartaglia's deserved recognition was whisked away by a fellow mathematician. At GCSE, we learn that the quadratic formula is

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

where $a \neq 0$. Similarly, there are various forms of cubic formulas, designed to solve a

$$\sqrt[3]{-\frac{q}{2}+\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}+\sqrt[3]{-\frac{q}{2}-\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}$$

Depressed cubic formula

variety of cubic equations. Tartaglia is most famous for discovering a cubic formula for 'depressed' cubic equations (those of the form $ax^3 + bx^2 + d = 0$). Tartaglia kept the formula a secret but fellow Italian mathematician Gerolamo Cardano begged Tartaglia to reveal the solution to him. Eventually, on March 29th 1539, Tartaglia told Cardano his secret but made Cardano swear an oath that he would never publish his formula.

The agreement didn't last long as Cardano soon discovered that a different Italian mathematician (Scipione del Ferro) had found a solution to the depressed cubic equation before Tartaglia. Thus, Cardano was no longer bound by his oath and so in 1545, he published *'Ars Magna'* (Great Arts), in which he attributed the depressed cubic solution to Del Ferro rather than Tartaglia. Initially, it was named after neither Del Ferro or Tartaglia, instead being dubbed 'the Cardano Formula' after its publisher. Nowadays, many mathematicians call it the Cardano-Tartaglia formula to credit the latter with his important work in solving depressed cubic equations.

History is Written by the Victors

Tartaglia's life and relatively underwhelming legacy serves as an example that not everyone in history receives the credit they deserve when it comes to mathematical and scientific discoveries. With myriad mathematical formulas, each with myriad more applications, it is not rare for two different mathematicians to come across solutions to problems independently of one other. It can at times be very difficult to know whom to commend and attribute discoveries after, as is so clearly demonstrated in the arithmetic triangle and cubic formula.

Blaise Pascal, the "winner" of this intellectual property

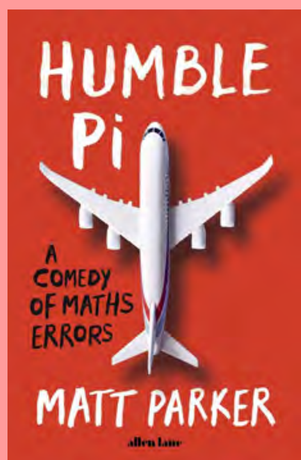
Edited by Nabeel Abdul Rasheed (Y12)

HUMBLE PI by Matt Parker

When researching my article on the challenges of learning Mathematics, it was no coincidence that I was gravitated towards a book based on Mathematical mistakes made throughout history. Humble Pi is a humorous yet informative anthology of mathematical mistakes, which reinforce the ever-growing role mathematics has in key fields: ranging from biological gene sequencing, to Engineering disasters, to predicting financial market growth.

I found it fascinating how Parker managed to demonstrate the complicated maths behind something as innocuous as 'how humanity kept track of time throughout history.' Yet still his well written and detailed explanations make the book really accessible to everyone - even those who aren't very familiar with more technical mathematical concepts, such as permutations, hexadecimal numbers, and even the Euler characteristic of a shape.

What Parker really excels at is demonstrating how poorly we understand mathematics through intuition alone. One of my favourite chapters in Humble Pi, would be 'Does not compute,' where Paker explores how the well-meant intentions of programmers often clash with the strictly logically nature of computers and having to store information in binary. This can lead to roll-over errors, which can be as serious as making level 256 of Pacman bugged, to giving patients lethal doses of radiation from x-ray scans.



Thus, we need to be wary of how we use Mathematics, given how it can often be used to misinform or even cause preventable deaths.

Significance of Zero

By Krish Agarwal (Y10)

The term mathematics is derived from the Greek word for 'knowledge' and all knowledge that has existed about the world and universe began with its quantification. Maths officially began in the 6th century BC with the Pythagoreans who began to study mathematics as a subject in their rights. Since then, many interesting theories have been developed which have further helped in understanding the world and everything around us. One interesting theory is that of zero. Join me as I explore it in this article.

The history and concept of zero

When anyone thinks of one hundred, two hundred, or nine thousand the image in his or her mind is of a digit followed by a few zeros. Zero acts as a placeholder so nine and then three zeros denote nine thousand as opposed to nine hundred. One zero can dramatically affect the value of a number. Just imagine one zero being removed from your salary! Though it may seem insignificant in one scenario, it can be one of the most important numbers in another scenario.

The Sumarians were the first to develop a counting system to keep track of goods such as cows, horses, sheep, donkeys, etc. They developed the idea of positions and that a number's value is dependent on its position with the other numbers.

This system was then passed down to the Babylonians in 2000BC. They devised a system of marking to show that a number was absent. For example, the zero in 2021 shows that there are no hundreds present. It was a good starting point for the evolution of zero.

Then came the Indians. They began to think of zero not as just a number or a mark but as an idea. A man by the name Aryabhatta was born in 476 AD and would go down in history as a legend. He gave the world the digit zero by being the one who designed it to be an oval. Brahmagupta in 650 AD was the first to develop arithmetic using zero. He used dots to represent zero and wrote the basic addition and subtraction using and achieving zero. He developed the idea that any number multiplied by zero is equal to zero as there is no value associated with zero. However, he did not account for division by zero; a problem that so many of us still cannot understand.

Fast forward to the 9th century to a man called Mohammed ibn-Musa al-Khowarizmi. He developed equations that equal zero which is more commonly known as algebra. He also developed quick methods for multiplying and dividing numbers known as algorithms. Al-Khowarizmi called zero 'sifr', from which our cipher is derived. By 879 AD, zero was written almost as we now know it, an oval but in this case, it was smaller than the other numbers.

In 1202, the Italian mathematician called Leonardo of Pisa (more commonly known as Fibonacci) started to build on Mohammed ibn-Musa al-Khowarizmi's work. Fibonacci's work gained notice by Italian merchants and German bankers, especially the use of zero. Accountants knew their books were balanced when the positive and negative amounts of their assets and liabilities equaled zero. But governments were still suspicious of Arabic numerals because of the ease in which it was possible to change one symbol into another. From this, merchants continued to use zero in encrypted messages, thus the derivation of the word cipher, meaning code.

Adding, subtracting, and multiplying by zero are relatively simple operations. But division by zero has confused even great minds. How many times does zero go into ten? This is where zero and calculus enter the picture. In the 1600s, Newton and Leibniz solved this problem independently and opened the world to tremendous possibilities. By working with numbers as they approach zero, calculus was born.

Conclusion

The discovery of it is one of the most useful things that has happened to the world of mathematics. In the twenty-first century, zero is so familiar that to talk about it seems like much ado about nothing. But it is precisely understanding and working with this nothing that has allowed civilization to progress. Though it signifies nothing, it paved the way for a variety of different topics and ideas. The development of zero across continents, centuries, and minds have made it one of the greatest accomplishments of human society.

Edited by Mann Patira

Introduction to Tetrations: The Fourth Hyperoperation

By Arya Narang (Y11)

In Mathematics, hyperoperations are a sequence of operations which increase by completing the previous hyperoperation a certain number of times. More simply put, the first hyperoperation is addition. Repeated addition is more commonly known as multiplication – this is the second hyperoperation. Repeated multiplication is exponentiation (multiplying a number by itself a set number of times). As you may have guessed, the fourth hyperoperation is repeated exponentiation. Repeated exponentiation is raising a number to the power of itself a certain number of times – these are known as tetrations. Similar to any previous hyperoperation, tetrations provide fascinating possibilities with their own set of laws and are much more complex compared to exponentials [1].

Firstly, it is important that we read notation correctly as many people interpret tetrations incorrectly. Let's look at 2 to the fourth tetration (2^2^2^2) - it can also be written as 2^^4 or $^{4}2$ (pronounced 2 to the superpower of 4) – many would evaluate this expression as follows:

2^2^2^2 = 4^2^2 = 16^2 = 256

This is incorrect, however, and instead, we evaluate tetrations in the 'opposite direction' [2]:

2^2^2^2 = 2^2^4 = 2^16 = 65536

As a result, tetrations give us extremely large numbers very quickly such that not even the most powerful computers today would be able to calculate 3^^5. Here is a table displaying tetrations of small integers so that we can start to grasp how large tetrations can become:

One of their main properties is the recursive rule which states: a^^(k + 1) = a^(a^^k). This is pretty self-explanatory as it is essentially saying that raising a number to the next tetration is raising the base by the answer to the previous tetration (e.g. 3^3^3 = 3^27 = 7,625,597,484,987). Using the recursive rule, we can solve the answer to negative heights (where the superpower is below 0) such as a^^-1 [2]:

a^^-1 can be written as $\log_a {}^0a$ because if we apply the recursive rule, a^^k = $\log_a$ a^^(k + 1) since we subtract 1 from k when we find the log of the expression.

$\text{Log}_a {}^0a$ is the same as $\log_a 1$ which equals 0 so a^^-1 is equal to 0 [2].

Another interesting property of the negative heights of tetrations is that in the expression ^{n}a, n must always be greater than -2. This is because a^^-2 is equal to negative infinity and we can prove this by using the recursive rule again:

a^^-2 can be written as $\log_a$a^^-1 because a^^k = $\log_a$a^^(k + 1) (recursive rule).

In addition, we have just proven that a^^-1 = 0 so if we substitute in 0, we get a^^-2 = $\log_a 0$ and as we know from the laws of logarithms, this is equivalent to negative infinity thus we have proven that n must always be greater than -2 in the expression ^{n}a [2].

On top of these properties, there are 2 simple rules – the first one is the addition rule which states: (a + b)^^2 = $(a + b)^a (a + b)^b$ [3]. This is quite simple to prove because we know that (a + b)^^2 can be rewritten as (a + b)^(a + b). Furthermore, using the

Integer (a)	a^^1	a^^2	a^^3	a^^4
1	1	1	1	1
2	2	4	16	65536
3	3	27	7,625,597,484,987	3^7,625,597,484,987
4	4	256	4^256	Extremely large
5	5	3125	5^3125	Extremely large

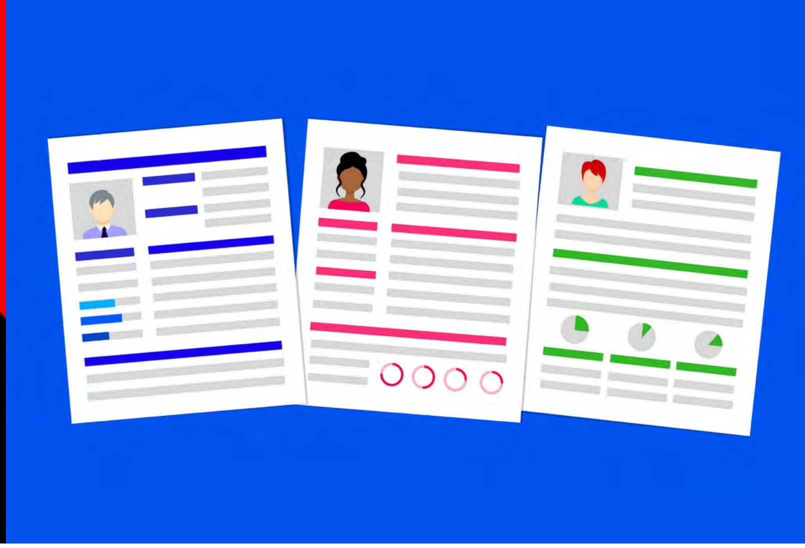
multiplication rule of indices ($a^m \cdot a^n = a^{m+n}$), $(a + b)^a (a + b)^b$ can also be rewritten as $(a + b)^{(a + b)}$ thus we have proven the addition rule of tetrations.

The second rule is the multiplication rule of tetrations which states: $(a\text{^^}2)^b \cdot (b\text{^^}2)^a = (ab)\text{^^}2$ [3]. In order to prove this, we can rewrite the left hand side of the equation as $(a^a)^b \cdot (b^b)^a$ and using the laws of indices, this is equivalent to $a^{ab} \cdot b^{ab}$. Now we must prove that this is equal to (ab)^^2 or in other words, $(ab)^{ab}$. This can again be demonstrated by the laws of indices: $a^{ab} \cdot b^{ab}$ essentially means we are multiplying the variable *a* by itself an *ab* number of times and we are multiplying *b* by itself an *ab* number of times. Likewise, with the expression $(ab)^{ab}$, we get *ab* x *ab* x *ab* . . . an *ab* number of times so the amount of times we multiply *a* by itself and *b* by itself is the same on both sides of the equation, thus we have proven the multiplication rule of tetrations [4].

We can take this even further by looking at hyperoperations even greater than tetrations. These can help us visualise one of the largest numbers constructively used: Graham's Number. We know that 3^^3 is approximately 7.6 trillion – this is a colossal number! But even that is minuscule compared to Graham's number; we need even higher hyperoperations to envision this number and we can start off with 3^^^3. This is known as g_1 and is unimaginably large, yet this is also tiny compared to Graham's number. What if we had a number 3^^....^^3 with a g_1 number of arrows? No computer can store this value due to how large it is but it is referred to as g_2 - again we are not anywhere close to the actual value of Graham's number. If we had an integer 3^^....^^3 with a g_2 number of arrows, we would get the number g_3. We can repeat this iteration until we reach g_{64}, also known as Graham's number. Interestingly, this number would be so large that we would need a memory card greater than the size of the observable universe to store it in binary [5]!

In conclusion, tetrations are an extremely complex concept to wrap your head around and can appear to be quite perplexing. Nonetheless, they have intriguing properties and even have inverse operations known as the super square root and super logarithms which make use of Euler's number and the Lambert W function [2]. They have not been fully explored yet and more research is being undergone related to this branch of Mathematics but tetrations could provide us with captivating, new possibilities yet to be discovered.

Edited by Aditya Jain



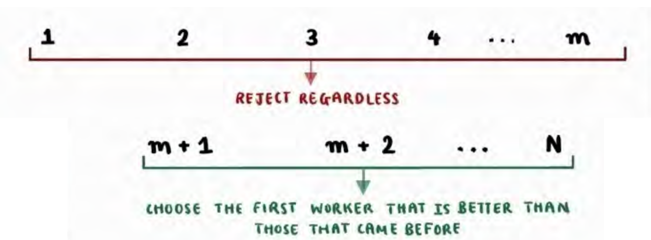
The 37% Rule — Where is the Logic?

By Kinshuk Jain (Y12)

Suppose you own a construction firm and you are looking to hire a new builder. There are *'N'* candidates and each one is called for an assessment on their bricklaying skills. After each assessment, you must make a final decision: hire or reject? The 37% rule is that you should reject the first 37% of applicants unconditionally (in this case, 37% is known as the stopping point). Then, from the remaining candidates, you should hire the first person that is better than all the people you have assessed already [1]. Like with many similar "rules", you may be wondering – where is the logic? Well, it turns out that there is strong logic to this, and it is *very* mathematical.

Let the probability of choosing the best worker be *P(m)*, where *'m'* is the stopping point. We are trying to find out the best possible value of *'m'*. We can define *P(m)* as follows:

P(m) = ∑ [P(the best worker is in position n) × P(you choose that worker)]



Considering workers one to *'m'*:

P(best worker is in a position from 1 to 'm') = 1/N

As you reject all workers from one to *'m'*, if the best worker is in that range, the probability of picking them is zero.

P(a worker from 1 to m is chosen given that they are the best) = 0

Considering worker *'m + 1'*:

P(the best worker is in position 'm + 1') = 1/N

If the best worker is in position *'m + 1'*, then they will be better than all the preceding workers, so they will be hired. Therefore, the probability of picking them is one.

P('m + 1' is chosen given that they are the best) = 1

Considering worker *'m + 2'*:

P(the best worker is in position 'm + 2') = *1/N*

If the best worker is in position *'m + 2'*, there is only one scenario in which they are not chosen – the worker in position *'m + 1'* needs to be better than all workers from one to *'m'* (but still not as good as worker *'m + 2'*). The probability of worker *'m + 1'* being the best out of all the workers from one to *'m + 1'* is *1/(m+1)*, therefore, the probability of choosing the best worker when they are in position *'m + 2'* is

$$1-\frac{1}{m+1}=\frac{m}{m+1}$$

P('m + 2' is chosen given that they are the best) = $\frac{m}{m+1}$

We can obtain similar probabilities for workers *'m + 3'*, and even *'N'*:

P(the best worker is in position 'm + 3') = $\frac{1}{N}$

and *P('m + 3' is chosen)* = $\frac{m}{m+2}$

P(the best worker is in position N) = $\frac{1}{N}$ and

P(N is chosen) = $\frac{m}{N-1}$

Therefore, using the equation for *P(m)*, we can obtain the following calculation:

$$P(m) = m\left[\frac{1}{N}(1)\right] + \frac{1}{N}(2) + \frac{1}{N}\left(\frac{m}{m+1}\right) + \frac{1}{N}\left(\frac{m}{m+2}\right) + \cdots + \frac{1}{N}\left(\frac{m}{N-1}\right)$$
$$= \frac{m}{N}\left(\frac{1}{m} + \frac{1}{m+1} + \frac{1}{m+2} + \cdots + \frac{1}{N-1}\right)$$

$\left(\frac{1}{m} + \frac{1}{m+1} + \frac{1}{m+2} + \cdots + \frac{1}{N-1}\right)$ is an approximation for the area under the graph *y=1/x* [3], so:

$$\left(\frac{1}{m} + \frac{1}{m+1} + \frac{1}{m+2} + \cdots + \frac{1}{N-1}\right) = \int_m^N \frac{1}{x}\,dx = [\ln(x)]_m^N = \ln(N) - \ln(m) = \ln\left(\frac{N}{m}\right)$$

Therefore, $P(m) = \frac{m}{N}\ln\left(\frac{N}{m}\right)$.

If we now make the substitution *x=m/N*, then:

$$P(x) = x\ln(x^{-1}) = -x\ln(x)$$

For the final part of the working, we need to find the optimum value of *'m'*. If the stopping point is one (*'m = 1'*), and we simply hire the first worker we interview, then the likelihood of that worker being the best is small. If, instead, *'m + 1'*, the likelihood of picking the best worker increases (although it is still small). If we continue this pattern and increase the stopping point, the probability will increase until we reach an "optimum" value – after this, it will decrease (because, after this point, it is likely that the best worker is out of those you have rejected regardless). This can be shown on the curve on the right.

In order to find the optimum value of *'m'*, we can find the maximum point of the graph above using differentiation:

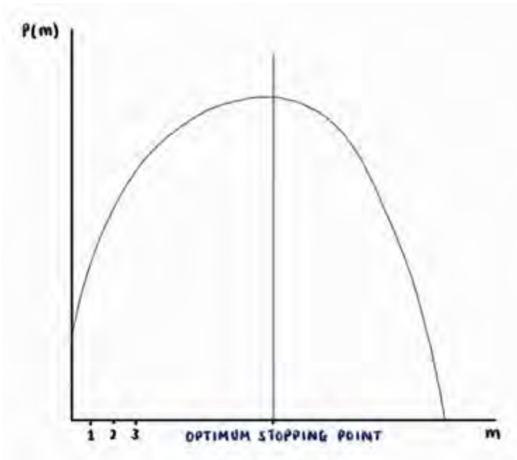
$$P(x) = -x\ln(x)$$
$$P'(x) = -\ln(x) - x\left(\frac{1}{x}\right)$$
$$P'(x) = -\ln(x) - 1 = 0$$
$$\ln(x) = -1$$
$$x = e^{-1} = 0.368 \approx 37\%$$
$$\frac{m}{N} = 37\%$$

Therefore, the optimal value for *'m'* is 37% of *'N'* [2].

The 37% rule has been applied in many other scenarios, ranging from choosing a toilet at a music festival to dating (and apparently, 26 is the ideal age to get married [1, 4, 5]!). However, many have questioned its effectiveness given the number of assumptions it makes, many of which are used in the (somewhat strange) hypothetical situation used above. There are also questions about its morality – leading on the first 37% of applicants when they will be rejected anyway – but we'll leave that discussion for another day and another magazine!

Whether or not it is sensible to follow, the 37% rule definitely provides a very interesting mathematical proof!

Edited by Atharva Narkhede



DID YOU KNOW?

Suspension bridges are those with cables supporting the roadway. They typically span longer distances but are also among the most expensive to construct. Due to the stresses faced, the suspension cables are bundled and twisted to reduce strain.

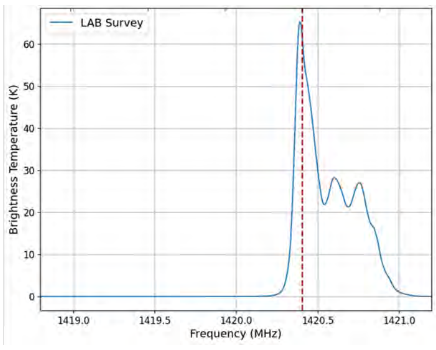
Mapping our Galaxy with Radio Astronomy

How could you map 400 billion stars?

By Leo Kavanagh (Y11)

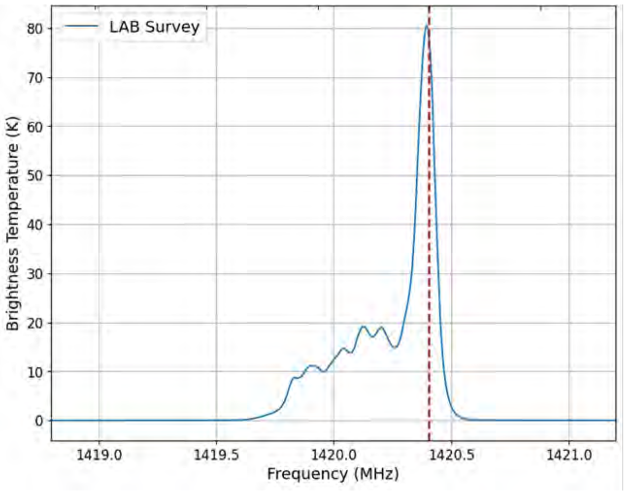
It has been known since 1925 (when Edwin Hubble measured the distance to the Andromeda Galaxy) that the matter in our universe is not evenly distributed – rather, it is clustered up in huge structures called galaxies. Bright and nearby galaxies have been observed by astronomers for hundreds of years, with some such as Andromeda and M33 being visible to the naked eye, and classified according to structure – some have formed into spiral shapes as they spin in space, others are elliptical disks, and some are chaotic balls of stars and gas. As telescopes became more and more powerful, we have been able to observe more and more of these distant objects, and see those we already know about in greater and greater clarity and resolution. However, there remains one galaxy that we cannot directly see, no matter how large or advanced our telescopes become – our own galaxy, the Milky Way.

In dark, rural areas, on a clear night it is possible to see a band of the Milky Way, stretching overhead, but this is only a cross sectional view from within it – we cannot see the structure of the Milky Way unless we leave it (which is far beyond what is possible with our current space travel technology) – that is, until Karl G Jansky, an employee of Bell Telephone Laboratories made an interesting discovery. He had built a radio receiver to detect radio waves at the frequencies around 20.5Mhz, in order to research the different types of radio static that might affect communications technology. He noticed that there was a rise and fall in static every 23 hours and 56 minutes – the length of time it takes for the Earth to rotate once, meaning that the signal had to be coming from space, getting stronger as the Earth turned towards the source, and weaker as it turned away. After experimenting, Jansky realised that the source was brightest in the direction of the Milky Way's centre. What Jansky was observing was the radiation emitted by the Hydrogen atoms spread out throughout the Milky Way. Hydrogen atoms will occasionally produce radiation at a frequency of 1420 MHz, and although an individual atom will do this very rarely, the vast quantities of Hydrogen gas present in the Milky Way means that it is constantly emitting a steam of radiation at the frequency of 1420 MHz. Jansky was detecting the radiation coming from the concentrated band of the milky way as it passed overhead, as there is more hydrogen located within the milky way, meaning that it emitted more radiation.



After Jansky made his discovery, many astronomers were keen to study this radiation, and they made an interesting discovery – the Milky Way wasn't just emitting radiation at 1420 MHz, but was also emitting radiation at surrounding frequencies, sometimes in a pattern of several distinct bumps. These astronomers soon realised that these bumps had to be coming from large bands of Hydrogen gas travelling at different speeds – the radio emissions coming from the Hydrogen gas had been subjected to a Doppler Shift, the same effect that makes approaching cars sound higher pitched. Radiation from Hydrogen gas coming towards the earth was getting shifted to a higher frequency (with more shifted frequencies corresponding to higher speeds), and Hydrogen gas moving away getting Doppler shifted to lower frequencies. Astronomers found that in one half of the galaxy, the signals from Hydrogen were getting Doppler shifted up – as you can see in this modern data, when looking at radiation from the galactic longitude of 90 degrees, all the bumps are at a higher frequency than the 1420 MHz reference line.

However, when we look at Hydrogen emissions from the opposite side of the galaxy at a longitude of 270 degrees, the bumps are all on the other side:



This means that one half of the galaxy is moving in a different direction to the other - it was rotating. The bumps in the signal were due to separate arms of the galaxy, moving at different speeds depending on how far away from the galactic centre they were. This meant that for the first-time astronomers were able to deduce that the Milky Way is in fact a spiral galaxy – a spinning galaxy with spiral arms - like our neighbour Andromeda. In fact, astronomers could go further and use this data to calculate exactly where the different parts of the spiral arms were in relation to the galactic centre by using something called a rotation curve – this is a curve that can be calculated to show how fast objects will travel a certain distance from the centre of a galaxy (all objects a given distance away from the galactic centre travel at roughly the same speed). This way, radio astronomers were able to look at the radio signals coming from a certain point on the Milky Way, and then use the Doppler shift to work out how fast the source was travelling. They were then able to use this speed to calculate their distance from the galactic centre, and then combine this information with the direction that they had looked in to work out where in the Milky Way all the radio emitting points, they had observed, were. They were then able to repeat this process for lots of different points on the Milky Way, and thereby create some of the first ever maps of the Milky Way, such as this one [1]:

In conclusion, radio astronomy has helped us to see something that we are otherwise unable to see and helped us discover fundamental that we would otherwise not be able to know – the structure of our home galaxy.

Edited by Aditya Jain

The Discovery of the Higgs Boson?

By Aadin Patel (Y11)

Nine years ago, the discovery of the Higgs boson thrilled the scientific world. Its implications in particle physics had significant consequences and years later we still see how its discovery has furthered our knowledge of the world. So how was the Higgs boson discovered?

Before we delve into the perplexing particle physics, we need some familiarity with the standard model (as shown below). This model represents all the particles that we know make up the universe but it is unfinished and recently has been the focus of a new discovery - the muon g-2, but let's save that for another time. One thing it does show is that the proton can be broken down even further into an up quark and two down quarks interacting with a gluon field to create a proton.

First, we need to go back to 2012, to the Large Hadron Collider (LHC), a particle accelerator, in Geneva, Switzerland. Here scientists concluded their discovery of the Higgs Boson and its how it can affect particles to give them a vital property - mass.

So what is a particle accelerator? It is a large machine used to speed up particles to speeds very close to the speed of light and collide them in a chamber to create detectable outcomes which can later be analysed. It consists of incredibly long vacuum tubes, to ensure that there is no interaction with other real particles, that contain strong magnets which help to direct and accelerate the particles before collision.

We might have heard of Einstein's famous equation.

$$E = mc^2$$

Using this we know that any object with a mass will have energy proportional to the speed of light squared. When an object is thrown up into the air, it transfers kinetic energy to gravitational potential energy before transferring it back to kinetic energy when it returns to its original position. Similar to this, when particles such as protons collide with each other, they can transfer their kinetic energy into mass and cause the formation of other particles, such as bosons, leptons and quarks. Quantum theory tells us that a collision has many different outcomes, with varying probabilities and that ultimately the result is random and unpredictable.

However due to the many collisions per second, it is likely that one Higgs boson is produced every second. However, the boson itself lasts for a few microseconds before decaying into other particles. This makes it impossible to detect naturally.

The Higgs boson has many decay modes - different ways the boson can decay. One possible outcome of the Higgs decay is into a virtual charged particle and antiparticle pair such as a *W* boson and $\underline{W}$ boson (the antimatter equivalent). This then annihilates into a pair of photons, moving in opposite directions, which can be easily detected.

However, observing two photons does not mean that the Higgs boson has been produced but we can determine the origin of these photons based on their energy and momenta. We can tell that the total energy of the combined photons will be equal to the sum of their kinetic energies represented as

$E_{total} = E_{K1} + E_{K2}$. We also know that, due to conservation of momentum, the two kinetic energies of the photons must be equal

$$E_{K1} = E_{K2}$$

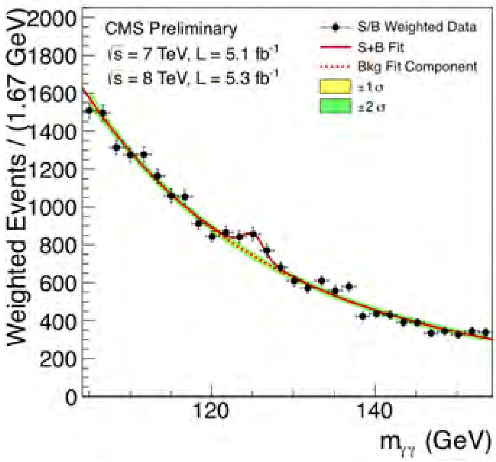
This must mean that both photons will have energy equal to half of the mass of the Higgs boson. This is the principle we can use to correctly detect the boson. We need to remember that after the collision, the Higgs boson will be moving and has momentum, which means we must use the formula

$$E^2 = (mc^2)^2 + (pc)^2$$

factoring in momentum. This can be rearranged to give us

$$mc^2 = \sqrt{E^2 - (pc)^2}$$

and gives us the invariant mass - the unchanging mass of the entire system, even when the parent particle decays into other particles. So, this means we can calculate the invariant mass of the system, when two photons are detected, and if they equal the mass of the Higgs boson particle, then we have successfully discovered it.



Probability distribution of the invariant masses after collision

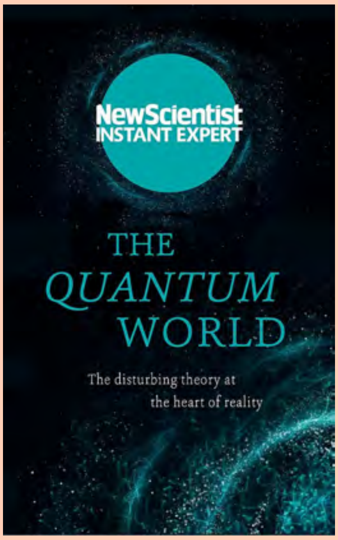
You must be thinking, how do we know what the actual mass of the Higgs boson is? Well after repeating the collision many, many times, scientists saw that a certain mass (see above) was occurring often and it matched with a theorised value of the Higgs boson. Note, that results of collisions have certain probabilities and you could expect to detect certain particles more than others. This is the case here but when a particle is detected significantly more than it should (over thousands of tests) and it is concluded that it was not by chance, then we know that there is a gap that needs filling in our knowledge.

Finally, now we move on to the implications of this discovery. The Higgs boson ties directly with the masses of subatomic particles, but it neither gives nor is the reason for the masses of particles. You might wonder what is it then? It is a real particle that represents how subatomic particles interact with a Higgs field, best summed up by Michael Schirber, Corresponding Editor for *Physics*. Lyon: "The Higgs boson does not technically give other particles mass. More precisely, the particle is a quantized manifestation of a field (the Higgs field) that generates mass through its interaction with other particles."

To conclude, the Higgs boson and the Higgs field have had a crucial impact on the future of particle physics and have paved the way for future discoveries, expanding our insight on the fundamental physics of the world, from the smallest to the biggest scale.

Edited by Aditya Jain

THE QUANTUM WORLD by New Scientist Instant Expert



For those with a consuming passion for physics and an overpowering desire to grow their knowledge, New Scientist's 'The Quantum World' provides a digestible answer to an increasingly more important question - "What is quantum mechanics?" As an avid non-fiction addict, reaching for any eye-catching physics book on a library shelf, 'The Quantum World' was a page turner for me from page one. It delves into the more interesting content almost immediately without pocketing any of the challenging material behind the concepts, however, the presentation and layout makes it incredibly simple to understand. Throughout, the barrage of knowledge continues - the book enjoys throwing a range of intriguing theories at you, spanning from physics to philosophy. For me, 'The Quantum World' might just be the best title I have walked out of the library with this year.

Entropy, the Director of the Universe ?

By Tathushan Subenthiran (Y12)

Why does ice melt at 0°C, but not any temperature colder? Why does sodium chloride dissolve in water, while silver chloride is insoluble? Why can an egg be boiled, but not un-boiled? These sorts of fundamental, seemingly mundane questions are ones that plagued the minds of both physicists and chemists alike – many theories were proposed, but it wasn't long until someone poked holes in them. One strong argument was that the determinant was enthalpy – if a process generally releases energy to the environment (it is exothermic) then its products were taken to be 'more stable', as is seen with combustion for instance. However, this explanation failed to account for endothermic reactions, where the energy of a system increases, as is observed with thermal decomposition (the endothermic breakdown of a molecule) of any substance: such reactions are still possible.

So, what is it? Many scientists, including physicists Nicholas Leonard Sadi Carnot, Rudolf Clausius, William Thompson, and mathematician Constantin Caratheodory proposed the second law of thermodynamics. In a spontaneous process, the 'entropy' of the universe always increases, where the universe can be divided into two parts: the system being observed and the surroundings.

But what is entropy?

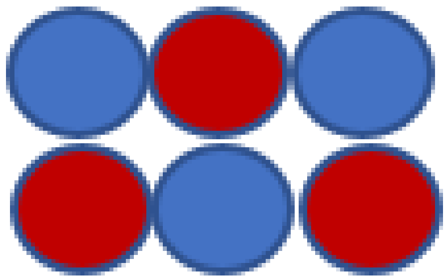
Entropy is a quantitative measure of disorder, where high entropy corresponds to high disorder and low entropy corresponds to low disorder. This idea can be understood if we consider a pack of cards – if a pack of 52 cards is sorted such that each suit is ordered from Ace to King, and the suits are in the order Hearts, Diamonds, Clubs and then Spades, there is only one way the pack can be ordered: if the deck was ordered in any other way, you could instantly tell. Thus, there is only one 'microstate' (order of deck) that the system (the pack of cards) can take given the macroscopic quantities we know about the system (the way it should be ordered) and the system has high order – it has no entropy. Let's say that a particularly aggressive passer-by yanks the pack of cards out of my hands and chucks it into the air, stalking off as the cards slowly cascade down from the sky. As you pick the cards up, you find that the cards are all jumbled up – this is the macroscopic quantity you are aware of. If that same passer-by were to return and then chuck the cards into the air again, upon picking them up, you are likely to find that the cards are still jumbled up, but will you be able to tell if it is any more or less jumbled up than the last time your cards were assaulted? No. These two microstates would be indistinguishable, and all other innumerable jumbled up orders of the pack of cards would too – as there would be many indistinguishable microstates, it can be said that disorder is high, as there are many ways to jumble a deck up. When a deck of cards is chucked in the air, you will pick the cards up and find them jumbled up many more times than in order, as there are many more ways for it to be jumbled up – it is more likely.

Ludwig Boltzmann came up with the statistical Boltzmann equation – a formula so influential that it is carved on his gravestone:

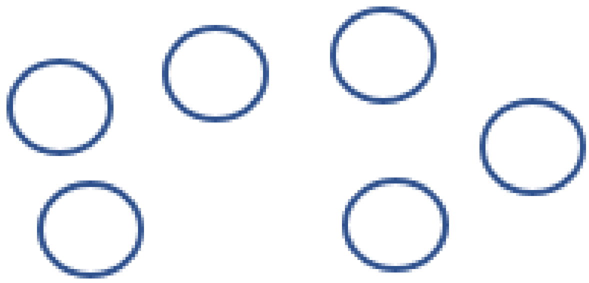
$S = k_B \ln(W)$

S denotes the entropy of an ideal gas; k_B denotes the Boltzmann constant (around 1.38×10^{-23} JK^{-1}) and W denotes the number of possible (indistinguishable) microstates for a given set of macroscopic quantities. Gaseous particles have greater freedom of motion than solid ones in a lattice, and so have a greater entropy as a gaseous arrangement of particles can be rearranged many ways without the system is noticeably changed. Similarly, a hotter substance will have greater entropy than a cooler one as its particles will vibrate more. As ln (1) = 0, when there is only one possible microstate, W=1 and S = 0 so there is no entropy, and as W increases, entropy increases and the probability of the system having the corresponding macroscopic characteristics increases, as the number of ways to do so does too. This is why the entropy of the universe is observed to increase: it is statistically more probable for a system and the surroundings to have high entropy.

Solid:



Gas:



For a process to occur, $\Delta S_{universe} > 0$, where $\Delta S_{universe}$ = the change in the entropy of the universe = $\Delta S_{system} + \Delta S_{surroundings}$ (the change in the entropy of the system and the surroundings respectively.) For exothermic reactions, energy is given off to the environment so the system itself cools and its molecules slow, so $\Delta S_{system} < 0$ but the environment warms up slightly so $\Delta S_{surroundings} > 0$. If $|\Delta S_{surroundings}| > |\Delta S_{system}|$, $\Delta S_{universe} > 0$ and the process occur. The opposite applies to endothermic processes.

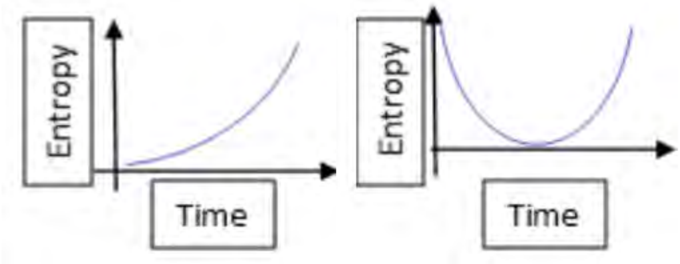
But why is it that processes like state changes are restricted by temperature? What forces water to only boil when it reaches 100°C? $\Delta S_{surroundings} = \Delta H_{surroundings} \div T_{surroundings}$ for constant pressure, where ΔH and T correspond to enthalpy change and temperature respectively. Processes will have an absolute entropy change value for a system (analogous to how there is the standard enthalpy of combustion values for different compounds) but the change in entropy of the surroundings is variable. As the energy that the surroundings will gain or lose is equal to the energy that the system will lose or gain respectively, it can be said that $\Delta H_{surroundings} = -\Delta H_{system}$. Water must be cooler than its melting point to freeze, as freezing slows its molecules, so the entropy of the system decreases while the entropy of the surroundings increases. 0°C is the particular temperature at which the denominator of the $\Delta S_{surroundings}$ equation (temperature) is low enough that the increase of the entropy of the surroundings is greater in magnitude than the decrease of entropy of the system so that the entropy of the universe increases. A similar line of thinking applies to boiling – when water boils, its molecules become gaseous so the entropy of the system increases: the decrease in the entropy of the surroundings (energy is taken in from the surroundings and its temperature decreases) must be low enough that entropy increases overall, and this is only possible at or above water's boiling point. Solubility in water can also be considered concerning entropy, as a solution in water requires an overall increase in entropy too.

While it seems useful that we can theoretically statistically predict the events of any moment in the future and determine the characteristics of a system at any point in the past if given knowledge of the state of every constituent of the universe, I would argue that this classical view of the physical universe is deeply troubling: I found the idea that every process and event in my life could be exactly predicted to be unsettling as it leaves no room for free will. If entropy always rises, what role does sentience and free will play in one's life beyond allowing for thoughts and mental reactions to events – to what extent would our mental actions be voluntary? Luckily, this deterministic image of the universe imposed by classical physics and chemistry was dispelled by the quantum revolution of the last century, which brought into light the inherent randomness and probabilistic nature of life and the universe – a relief to me, as it meant I had some say in my fate.

The second law of thermodynamics was revolutionary not only in its ability to accurately predict which reactions occur but also because of its implications for the field of Big Bang cosmology. Since pre-modern, Newtonian physics has no built -in temporal orientation, all of the reasoning used to argue that systems will tend to evolve from a lower state of entropy to a higher one as we look to the future apply when arguing that entropy increases when looking to the past too, as the statistical reasoning behind the second law of thermodynamics relies on the laws of physics. There is thus an implication that the entropic arrow of time is double-headed: this directly contradicts our experiential arrow of time, which is singly headed and points to the future. If we were to see a block of ice melting in a cup of coke sitting on a table, based on experience, we would say that the partially melted block was a fully solid block of ice 10 minutes ago. However, according to the second law of thermodynamics, this partially melted block of ice would have been water (higher entropy) 10 minutes ago (or at least more melted) as this likelihood is greater than the likelihood that entropy was even lower 10 minutes ago than it is now. Remember that entropy is a measure of disorder, and disorder is statistically far more likely than order, so Boltzmann argued that the likelihood that any order we observe in the universe is the product of a statistical fluctuation that began at what we take to be the beginning of the universe such that entropy, by chance, dropped from a state of higher entropy to one of lower entropy is greater than the likelihood that the early universe was of an even lesser entropy than it is observed to be now. This idea directly contradicted Big Bang Cosmology, which argued that the Big Bang produced nearly uniform hot gas.

While on a sub-cosmic scale, gases are of a higher entropy than solids, on a cosmic scale, gases are of a high order as gravity is much more influential and so gases will tend to clump together – as there are many different ways they can clump up and still be observably the same, gases are considered to be of low entropy when gravity matters. Therefore, the Big Bang argues that the universe began with low entropy.

The left graph shows the experiential arrow of time (it increases as time goes on) and the right graph shows the paradoxical entropic arrow of time implied by the second law of thermodynamics.



But should we simply relinquish this model of cosmology on the basis that statistics indicate we should? Further examination may shed more light on the situation: if the universe is a statistical fluke in the way Boltzmann proposed, how can we trust any of the laws of physics, historical records, and memories that are intrinsic to the understanding of the universe and ourselves? Our experiences and records contradict this idea, so are these also wrong? Furthermore, surely this approach is paradoxical as, if the laws of physics are false and the second law of thermodynamics relies on them, how can we trust the second law – how can anything be trusted? It is important to note that, while the second law of thermodynamics applies when looking to the past, it is only probabilistic – there is still the likelihood that the universe began with a substantial level of order, such that it initiated a drive towards higher entropy as it allowed for clumps to form (clumps that evolved into planets, stars, etc.) when on a cosmic scale. While this explanation is highly unlikely, it is the only one that makes sense, as the alternative would imply that nothing can be trusted, and is paradoxical. There is a direction to time that is implied: time has an arrow that points to the future, in the direction of increasing entropy.

Thus, entropy is the true director of the universe not only in that it determines what processes take place on a smaller scale but also that it indicates what order all the events of the universe, from its conception, occur in.

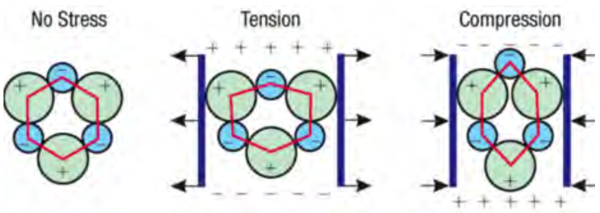
Edited by Mann Patira

This will take you 207 seconds to read

By Boyu Xiang (Y12)

Essentially every metric of time is centred around the second. If you have a watch on your person or a clock nearby, take a second to glance at it – watch the long thin stick twitch forward and abruptly come to a stop. Congratulations… you wasted a second.

Even with the emergence of digital watches the majority of them still use quartz to regulate the ticking process. Quartz demonstrates piezoelectricity, which means that if you apply stress to the material it can generate a voltage. This characteristic primarily appears in asymmetrically charged crystals: originally, they are distributed evenly with a net neutral charge, but when applying pressure positive and negative ions can gather together creating an electrically charged dipole. Quartz is chemically known as silicon dioxide, possessing a similar structure to diamond, but with partially positive silicon and negative oxygen, which – when undergoing deformation –



unbalances these charges. This effect can be applied in the generation of electricity, such as in shoes that generate electricity as you walk [1],[2]

Piezoelectricity is a reversible effect. Applying a voltage to quartz causes the positive and negative charges to organise themselves; passing electricity through it causes a very exact frequency of vibration as the charges organise and disorganise themselves – exactly 32,768 times every second – and so the watch or clock knows a second has passed if the quartz contained inside it has vibrated 32,768 times [3]. Quartz is almost ideal for this purpose: the material itself is extremely common with roughly 20% of the crust being made of it (although it does need refining); its frequency of 32kHz is just above the frequency humans can detect, sparing everyone of a high-pitched whistle every time they approach a clock; and is extremely consistent in its vibration.

However, quartz is not the most accurate material, especially for measuring a more extended time period. Most quartz watches lose 15 seconds every month and even the most expensive ones lose around 10 seconds every year [4]. Of course, the fact that they can be inaccurate at all implies the existence of a more accurate system to measure it against.

'Second' is the SI unit of time and all SI units have some platonic measurement that every other in the world is based upon and is a pale imitation of. For the kilogram, all 1kg weights used to be replicas of the original platinum-based weight (hidden away in Paris), although this has recently been changed. For the second, all clocks around the world are based on and judged against caesium.

Caesium (specifically caesium-133) is, like every other element, identical to every other caesium-133 atom in the universe and also, like every other element, has electron energy levels. When irradiated with a range of microwave radiation the $6s^1$ electron jumps to a higher energy level and, upon returning to the ground state, re-emits the radiation corresponding to the difference in energy between the two shells – exactly 9,192,631,770 Hz of EM radiation [5]. Since being adopted in 1960, the SI unit for a second has been defined by the time taken for radiation emitted from caesium-133 to oscillate 9,192,631,770 times and, missing only one second in 100 million years, it crushes the accuracy of quartz or using the Earth's orbit around the sun [6].

These atomic clocks are so accurate they have been able to measure and prove predictions of kinematic time dilation by special relativity and gravitational time dilation by general relativity, with each having only a few hundred nanoseconds of difference; since the speed of light is always constant, regardless of how far an object is moving it always perceives light to travel at the same speed and therefore, time and space must change in its stead [7].

Much like the kilogram, the second might be having another upheaval, though not as major. Boulder Atomic Clock Optical Network (BACON) Collaboration recently created atomic clocks using different materials – combinations of aluminium ions, ytterbium lattice and strontium – said to be a hundred times more accurate than the caesium-based second, meaning with more testing we might see another change in the SI system [8].

Since you began reading, the quartz in your watch has vibrated 6798049.28 times and the radiation emitted by the caesium in the clock has oscillated 1907103387004 times. As the title says, this has been 207.46 seconds in an attempt to explain one.

Edited by Mann Patira

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