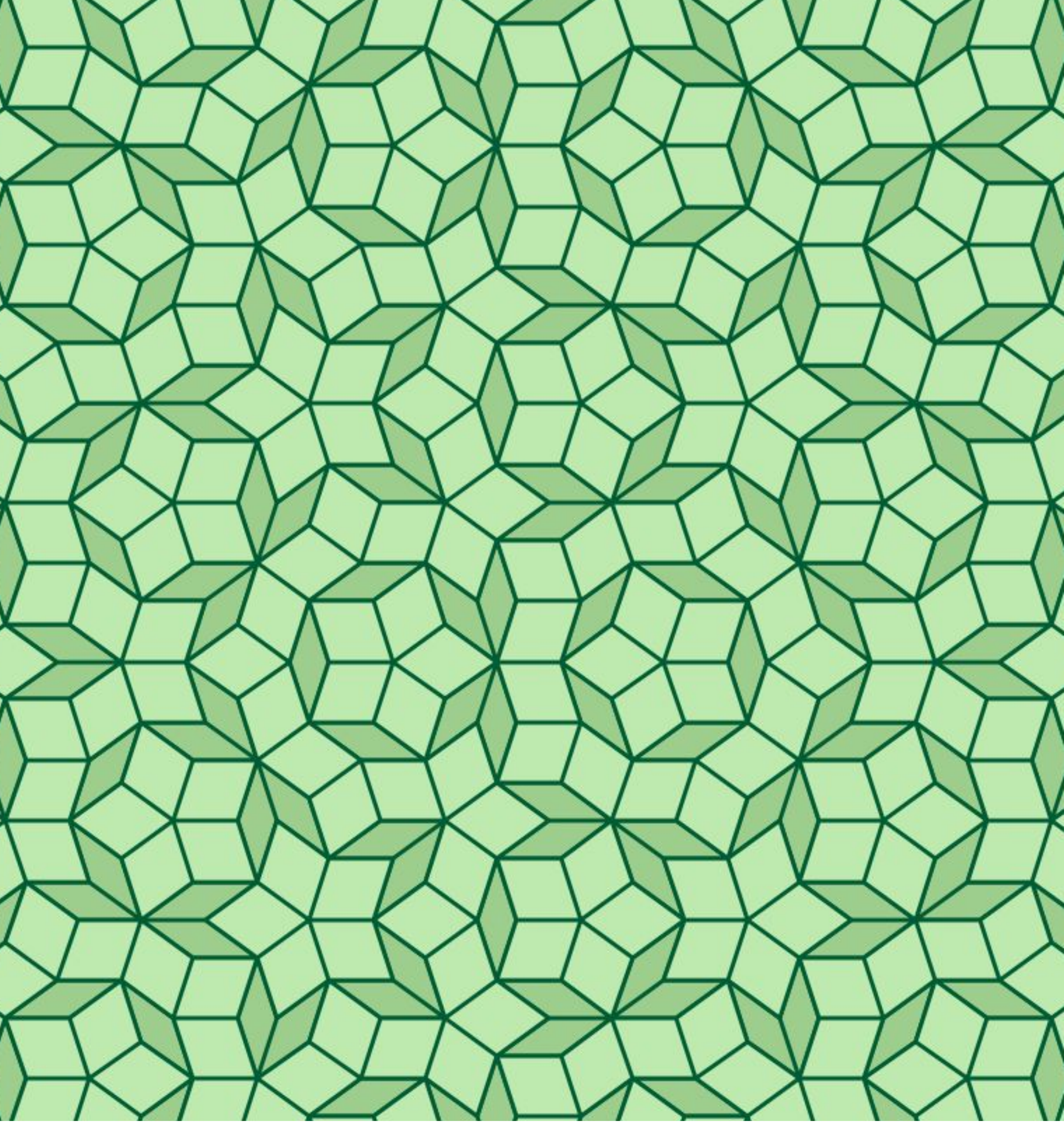

THE PENROSE MAGAZINE

Science, Technology, Engineering, Math

Issue 4, 17 Jul 2025

Welcome to the fourth Issue of the Penrose Magazine!

Penrose is our Computer Science, Engineering and Physics magazine where we hope to establish a community of young people who are passionate about STEM and want to share with their peers and further their knowledge beyond their curriculum. This installment of the magazine centers around the theme 'Everyday STEM', featuring topics from the dangers of speculative execution to the life cycle of stars. We hope to continue fostering an environment where people are encouraged to push themselves to create meaningful work.

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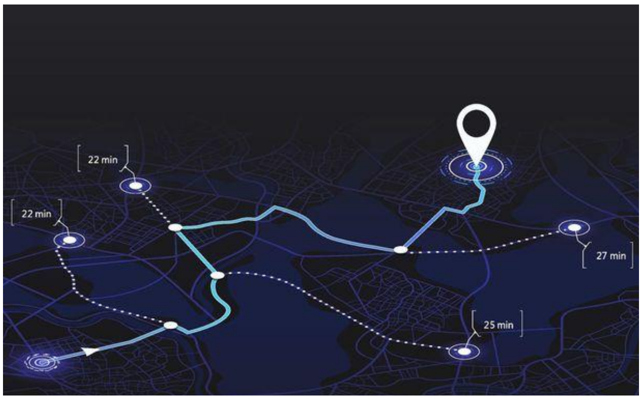
How GPS Tracks Location

Whenever we get lost, the first thing that we reach for is our phones; it contains the one thing that can help us find a way home – mapping apps. We are all aware of the existence of GPS tracking, with approximately 4 billion users daily, but the mechanics behind it appear almost impossible. [1] Despite the fact that it is seemingly invisible, it is a piece of technology that none of us can live without.

This technology was first discovered by accident during the Russian-American race to the stars during the cold war. On the 4th of October 1957, the USSR commenced the Space Age after launching the first artificial satellite, which was named Sputnik. It orbited the Earth every 90 minutes while continuously sending out radio waves. Due to this and the use of the Doppler effect – the changing wavelengths of the waves – scientists on Earth were able to track Sputnik's location. [2] This discovery was soon expanded; if the distance of a satellite from a location on Earth could be tracked, the scientists realized that a location on Earth could be tracked by a satellite. The Advanced Research Projects Agency (ARPA) mused on this idea to develop Transit just a year later. This was the first global satellite system, with its first satellite being launched in 1960. This technology became available to all users, for commercial, martial, and industrial uses. By 1968, 36 fully functional satellites were providing navigation for commercial and military users within tens of metres. [3] This technology operated under the name "Transit" until 1996 when it was replaced by GPS (Global Positioning System). [4]

However, during this period, others were already trying to advance this technology even further. Throughout the 1960s, The Aerospace Corporation planned to diminish the costs of these satellites to make this technology more available to the public. This was done via the changing of the structure of satellites. Instead of having high-accuracy clocks in the receivers, each satellite would be equipped with its own clocks. These clocks are what allow the satellites to be tracked much more easily and to a greater degree of accuracy. The distance of the satellites would be determined using the time taken for the radio wave signals to reach a certain point on the Earth. The time would be kept using the clocks and the use of the speed of the radio waves (the speed of light). [5] The first satellite equipped with the atomic clock was launched in 1974, which was the third of the TIMATION satellites. These satellites were produced by the US Naval Research Laboratory (NRL) and experimented with the clocks and found that the satellites that ran at rubidium atomic frequencies (launched in 1974) and caesium atomic frequencies (launched in 1977) were the most efficient. [6]

Without the need of these atomic clocks on the ground, developers found that the receivers could be shrunk down, which would end up being small enough to fit in our mobile phones. By the end of the 1980s Magellan Corporation had released their Magellan NAV 1000, which was the first handheld GPS device to hit the market. It was the first of its kind, weighing around 0.68 kilograms (1.5 pounds) and costing $3,000.[7] Despite its shorter battery life of only a few hours, the device was still very accurate for its time, giving civilians a location accuracy from 300 to 20 metres.[8] This device then paved the way for smaller and more accurate devices to be constructed – GPS found itself on our mobile phones just 10 years after NAV 1000's release. In 1999, Benefon announced the release of Benefon Esc! which was the first mobile phone with any kind of mapping applications. It included the average GPS mapping system along with the navigation for applications like “Friend Find” and downloadable maps, including nautical, city, and graphical ones. [9] The Benefon Esc! revolutionized civilian technology in the 2000s, and was a hugely significant moment in technological history, allowing this kind of technology to be easily and readily available to the public.



Astronomers used to look at stars to find out their location; however GPS takes a different approach. Around 31 satellites orbit our Earth, which, along with ground stations and receivers, make up the GPS system. [10] The satellites are the equivalent of stars – we know their precise locations; the ground stations use this information and Radio Detection and Ranging (radar) to check whether the satellites are where they are meant to be. The receivers, which are in all our devices that have any kind of navigation or location tracking systems, listen for the signals from the satellites which the ground stations send. The receivers use the time taken for the signal to reach it to calculate the positioning of the device. [11] To determine this, the satellites still carry the same atomic clocks that US NRL had launched; the time information that these clocks carry would be broadcast by the satellite and the receivers use the data to determine the locations of the satellites. This calculation is done with at least 4 different satellites, which together calculate the latitude, longitude, altitude, and time of the signal and the device. [12]

GPS has undoubtedly made a mark on our society, going from a discovery made by mistake to something that everyone relies on every day for the weather, finding directions home, or finding out when buses will arrive after a long day at work. It has been able to develop at astonishing speeds in the span of half a century. Now, the average GPS service to date would have an accuracy of approximately 7 metres 95% of the time, anywhere close to the Earth's surface. [12] The impact and development of space-based navigation technology remains and will continue to do so in the future. For example, reports estimate that, since the release of GPS systems to society, they have aided in nearly $1.4 trillion in economic benefits, especially since the data we get from the navigation systems are necessary when running data and financial systems. Furthermore, it has been shown that between 2007 and 2017, GPS guidance apps have helped Americans save 52 billion gallons of fuel due to the ease of travel that these navigation systems bring. [3]

Today, GPS and navigation systems aid society in ways that we could never have dreamed of, and, in some cases, ways that we still do not realise in our day to day. Through this accidental discovery in the

1970s, we can understand the Earth in ways that we would not have been able to do prior. For example, we can now use satellites to study earthquakes and other natural phenomena, while also being able to aid with construction and farming by tracking the vehicles and other devices which would be used in these areas of work. When checking the weather or using any mapping application, the great innovations of NASA and NRL are what aided the app's navigation.

By Rosalia Bialek 27'

References:

[1] The central place of GPS in our lives [online]

[2] 65 Years Ago: Sputnik Ushers in the Space Age [online]

[3] A Brief History of GPS [online]

[4] Nuclear Transit: nuclear-powered navigation satellites in the early 1960s [online]

[5] What Is an Atomic Clock? [online]

[6] NRL Launched First Time-Based Navigation Satellite in 1967 [online]

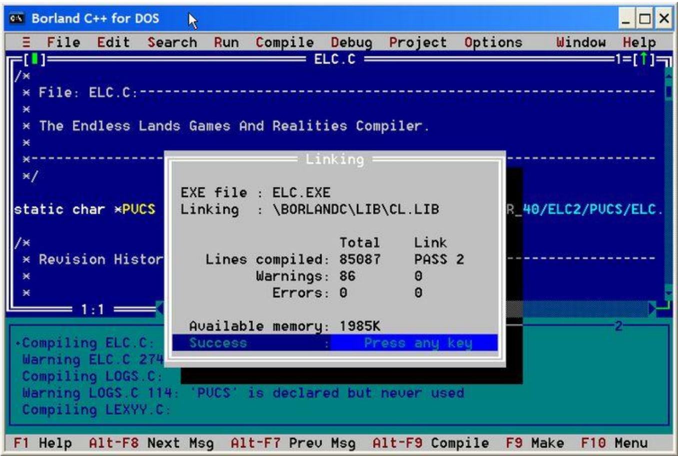
[7] My Garmin GPS 45 was amazing in 1994, and it still works [online]

[8] Magellan NAV 1000 [online]

[9] Benefon [online]

[10] Satellite Navigation - GPS - How It Works [online]

[11] How Does GPS Work?[online]



The Evolution Of Compiler Optimization Techniques

Modern technology has introduced a new demand for enhanced programming tools. This has most importantly led to improvements in programming translators. Compilers are a type of translator that converts the code a programmer writes, known as source code, into code understandable by a computer, known as object code. Compilers are often favored by programmers due to their ability to optimize code, making them a large part of everyday life. However, when compilers were first created, they were slow, repetitive and inefficient. The research done by Frances Allen was able to overcome this and transform compilers into what they are today.

Frances Allen was a computer scientist and mathematician born in 1932 in Peru, New York. In 1954, Allen obtained her bachelor's degree in mathematics from University at Albany before teaching at a local high school. After teaching for two years, Allen returned to school, obtaining a master's degree in mathematics from the University of Michigan. Subsequently, Allen began working at IBM (International Business Machines Corporation) in hopes to pay off her student debt [1]. It was her work here that revolutionized the ability of compilers and the state of programming as a whole.

```
def A(num1, num2):
    return num1 + num2

def B(num1, num2, num3):
    return A(num1,num2) - num3
```

Early compilers faced significant timing delays in several areas, especially when processing linked subroutines. Specifically, four states can be considered when optimizing linked subroutines: closed, semi-closed, semi-open, and open. Closed linkage subroutines prevent the compiler from accessing the entirety of the code while it translates a single part. Therefore when a subroutine within a different subroutine is called, the encompassing subroutine would not know the parameters and variables from the encompassed subroutine. This results in registers constantly needing to save and restore information and certain subroutines being assigned specific registers [2].

```
def A(num1, num2):
    return num1 + num2

#Open Linkage
def B(num1, num2, num3):
    return num1 + num2 - num3
```

Comparatively, open linkage subroutines combine the code from the encompassed subroutine into the encompassing subroutine. This allows both subroutines to be optimized at once, considering all parameters and understanding the complete context of the code. However, this method can often result in programs becoming too large with repeated code, leading to inefficient compiling [2].

Semi-open and semi-closed linkages reflect several similarities of open and closed linkages. Semi-open linkages are unable to access the encompassed subroutine; however, each parameter given within the system is stored in real locations. This allows for unnecessary parameters or repeated parameter locations to be disregarded. Semi-closed linkages allow for the calling subroutine and the called subroutine to be processed individually and therefore both are known to the compiler [2].

```
x = 0
for i in range(100):
    x += i
```

Another area where Allen researched compiler optimization techniques was program loops. Each method researched is applicable and beneficial in creating a more efficient compiler environment, though some are more suited to specific situations. This consists of three main methods: loop unrolling, loop fusion, and unswitching [2].

```
#loop unrolling
x = 0
x += 0
x += 1
x += 2
...
x += 99
```

Loop unrolling can occur in two different ways: complete or partial. Complete unrolling converts a loop into code such that each step receives its own line in the program. Partial unrolling allows for a loop to be expanded so it completes several steps at a time. This method allows for fewer instructions to be carried out by the compiler as it will only have to execute the steps themselves, not any instructions directing it to iterate. Furthermore, this allows several steps to be executed at the same time instead of one by one, given that they are independent of one another. However, this technique can only be used when the loop is carrying out simple tasks and isn't iterating too many times as it requires significantly more storage space [2].

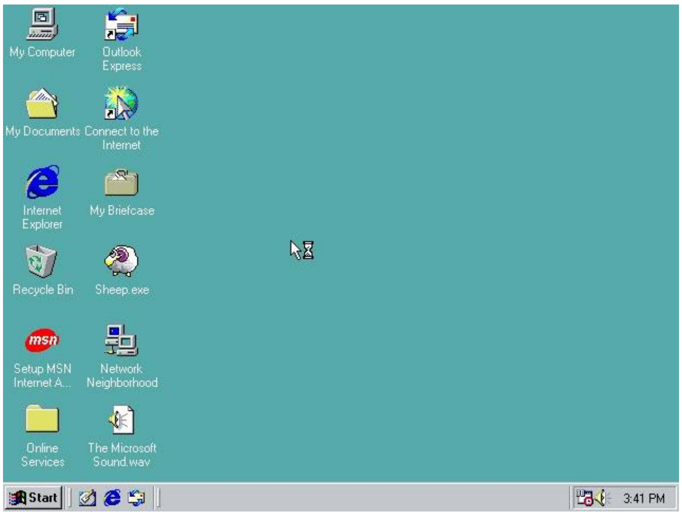
```
x = 0
y = 0

for i in range (100):
    x += i

for i in range (100):
    y += i

#Loop Fusion
for i in range (100):
    x += i
    y += i
```

Loop fusion allows for two separate loops to be fused together. This results in fewer instructions needing to be executed by the compiler and less storage space being required. There are no specific drawbacks that occur from using this method; though, each loop must meet certain requirements before fusion occurs. Both loops must have the same condition and length, and the tasks carried out in each repeating sequence must be independent of each other. If these requirements are not met the loops will be incompatible and unable to fuse [2].

Unswitching performs the opposite function of loop fusion. This allows convoluted loops to be split up and be processed more easily. For instance, loops that contain conditional statements (eg. IF…THEN) will be split into separate iterations contained within a conditional statement instead. This technique is able to reduce the number of instructions processed by the compiler; however, in some cases it may have the opposite effect. In both cases, this method results in an increased amount of required storage space [2].

Each of these techniques, applying to both optimizing subroutine and optimizing loops, can have both positive and negative effects. This shows how Allen's varied research on compiler optimization was crucial to the advancement of compilers. This allows for different situations to be optimized using diverse approaches, producing maximally efficient translations.

Nearly every computer application requires a compiler to run on a computer. The research Allen carried out on compiler optimization have all contributed to the current state of compilers used by programmers every day. Not only did she optimize linked subroutines and loops, but a vast range of aspects which all affected compiler capabilities. Much of the research



carried out by Allen was used by IBM's Fortran compiler, which increased the popularity of compilers to the general public, contributing to the impact they have today.

By Eleanore Shiner 26'

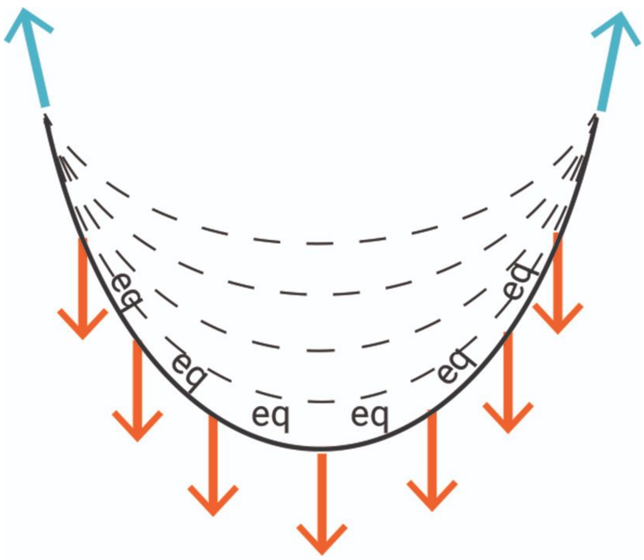
References:
[1] IBM. "Frances Allen" [Online]
[2] F. Allen, J. Cocke. (1971). 'A Catalogue of Optimizing Transformations'

The St. Louis Arch

The Gateway Arch, a defining landmark in St. Louis, stands both 630 feet tall and wide. The vision for this iconic structure originated in 1947 and was spearheaded by Finnish-American architect Eero Saarinen and German-American structural engineer Hannskarl Bandel [1]. Although planning began earlier, actual construction didn't start until 1963, with completion in 1965 at a cost of approximately $15 million [2].

The scientific and engineering accomplishments behind the Arch's creation are extraordinary. One often underestimated factor in architectural design is the influence of gravity and the importance of structural equilibrium. Designers ensured that the opposing forces from both legs of the Arch converged toward the center, giving it exceptional stability and strength. The structure is engineered to behave much like a massive spring, capable of withstanding environmental forces. In a city like St. Louis, where the climate can change rapidly, this resilience is essential. To further fortify the base, equilateral triangle shapes were incorporated into the design, allowing the Arch to absorb seismic activity by swaying as much as 18 inches during an earthquake.

Material selection also played a crucial role in the Arch's durability. Stainless steel was chosen for its strength and resistance to corrosion. Engineers also installed conductive rods deep into the ground to help mitigate lightning strikes. The Arch can expand or contract by up to seven inches depending on temperature variations, demonstrating the foresight that went into its construction [3].



One of the most innovative aspects of the Arch is its unique shape—a catenary curve. This shape mirrors the arc formed when a chain is suspended from both ends, and when inverted, becomes one of the most structurally sound curves in engineering.

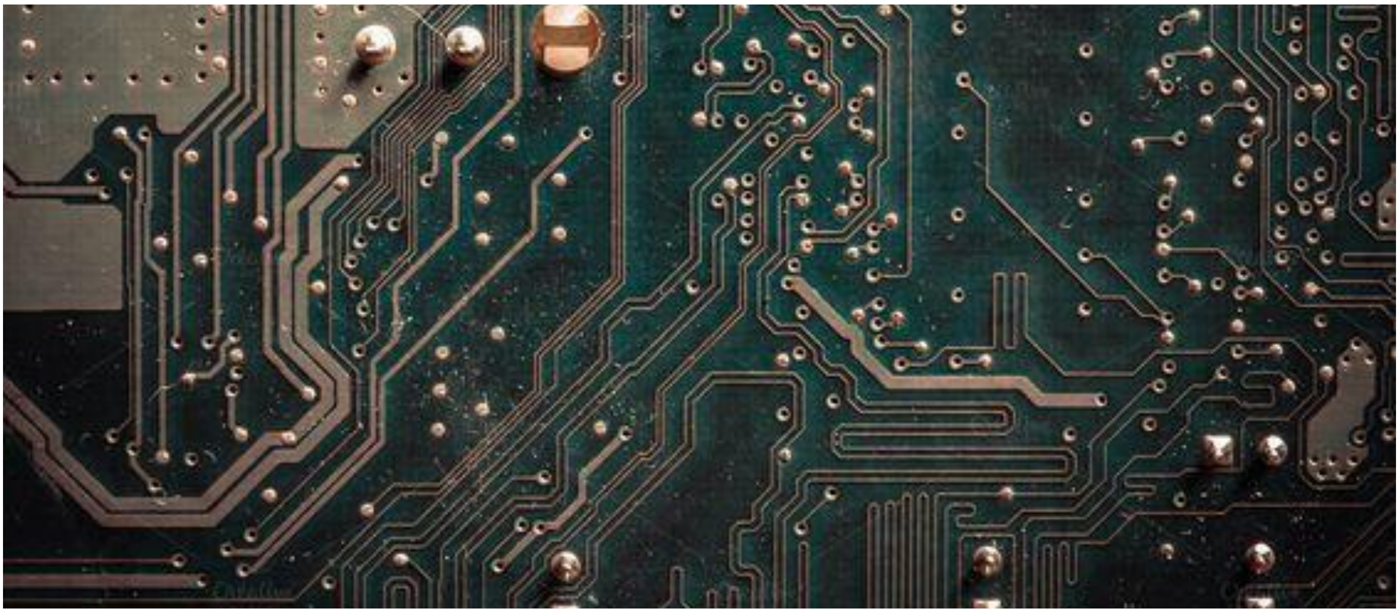
The mathematical representation of a catenary is expressed as $y = a \cosh(x/a)$, a formula that guides the design in evenly distributing weight and handling external forces like wind and gravity [1].

The Arch is composed of 142 prefabricated triangular segments, with 71 on each leg. The lower sections are the heaviest, tipping the scales at around 50 tons, while the upper segments are lighter, ranging from 10 to 15 tons [1]. This gradation in weight was a critical consideration when designing the interior tram system—a key feature that enhances its appeal to visitors. Each leg of the Arch contains eight compact capsules shaped like barrels, each about five feet in diameter. These capsules carry passengers to the top while cleverly adjusting their orientation to remain upright during the journey, similar to how Ferris wheel seats rotate to maintain balance. To achieve this, the design blends elevator-style lifting, cables, and gears that rotate the capsules incrementally as they travel along the Arch's curve [4].

Ultimately, the Gateway Arch is not only a symbol of westward expansion but also a tribute to the ingenuity of STEM. Its design and functionality reflect the integration of science, technology, engineering, and mathematics in solving complex structural challenges. From its precise curve to the dynamic tram system, every detail showcases the critical role STEM plays in shaping our world.

By Anna Furlong

References:
[1] "How Was the St. Louis Arch Built?," Wonderopolis.org, Dec. 26, 2019.
[2] M. A. O. M. D. S. 730 S. Louis and M. 63102 P. 314 655-1600 C. Us, "Frequently Asked Questions - Gateway Arch National Park," www.nps.gov, Jul. 09, 2024.
[3] M. A. O. M. D. S. 730 S. Louis and M. 63102 P. 314 655-1600 C. Us, "Foundation Depth - Gateway Arch National Park," www.nps.gov, Apr. 10, 2015.
[4] M. A. O. M. D. S. 730 S. Louis and M. 63102 P. 314 655-1600 C. Us, "Tram System - Gateway Arch National Park," www.nps.gov.



The Dangers Of Speculative Execution

Modern CPUs are astronomically faster than anything you could ever think of, with most of them running at 3GHz (3 billion clock cycles per second), they run faster than any other part of the computer. The amount of time that it takes for the CPU to access a point in memory is significant in its perspective. Therefore, as CPUs got faster, it made sense to find a way to limit how much time they spend without the data they need. This idle time is called stalling which is just a small language note. In the 1990s, CPUs started to gain the ability to "speculatively execute" to combat this stalling.

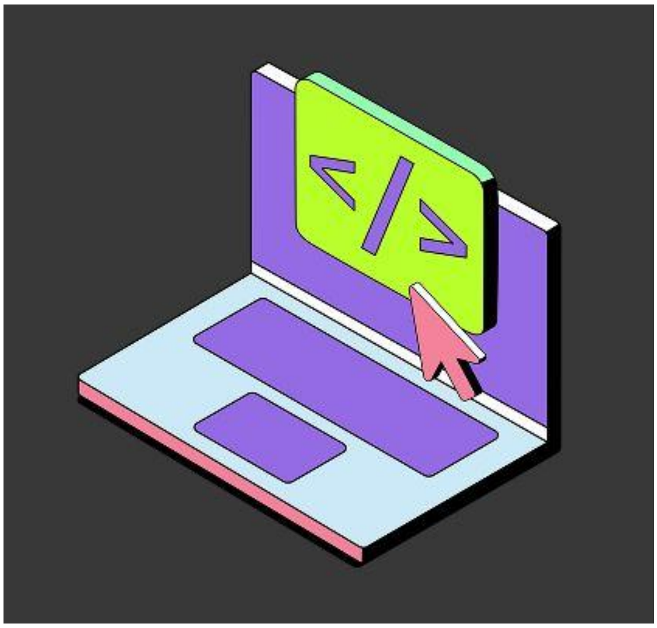
Speculative execution is a powerful technique that accelerates computation. It operates by predicting which instructions the processor will execute before it does. For instance, when traversing an array, it is reasonable to assume that the next memory location accessed will be the subsequent element in the list. This concept is particularly effective with branch conditions, which are typically represented by if statements. With a branch condition, also known as an if statement or conditional jump, entirely new sections of data may need to be loaded. If the CPU can predict which branch will be taken, it can enhance its performance by caching the necessary data before it is required in calculations, thereby reducing stall time.

Because this process is managed by the microcode of the CPU it is often not placed under the same security scrutiny that the application code may be. For example, it can speculatively access any part of memory as it exists at the hardware level, which exists in ring 0, which no application is granted without many permissions. This is where we start to encounter our vulnerability; security checks (such as checking if a process has permission to access this area of memory) do not execute until the instruction is executed, while we exist in speculative execution, we can get the machine to do things we are not allowed to do ourselves.

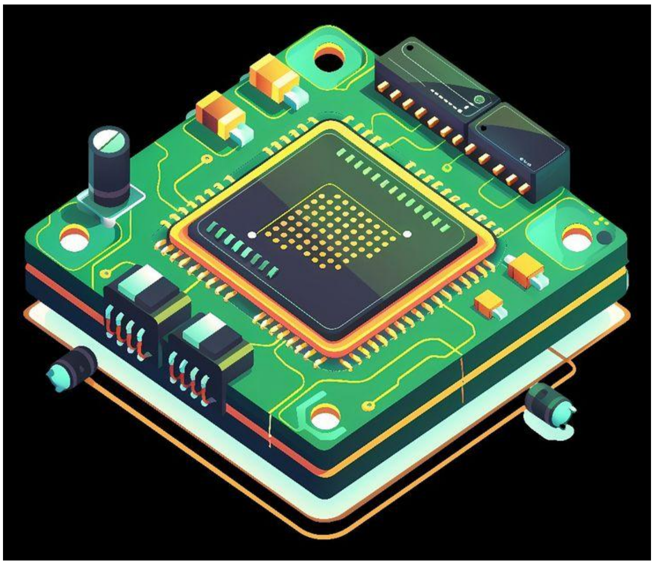
The vulnerability being described here is called spectre, which was initially discovered on all intel chips made with speculative execution; however, similar intel-based attacks (meltdown) and attacks for the Apple silicon (Speculative Load Address Prediction and False Load Output Prediction). The first step of the vulnerability is to trick the CPU into thinking that a memory access pattern is holding so it should fetch what is predicted to come next. This could look like iterating over an array and constantly indexing into it. This teaches the computer that the calls you are making into memory are valid, so the next call will most likely be valid. This leads to a complication; you will never be able to read and store the data outside the region you have been permitted for; however, we will be performing a side channel attack to get this information either way.

A side-channel attack is when we use indirect information about a process to get information about it. This could look like this: we are trying to see if a security camera is on. However, we can't access the network it exists in to see if it is broadcasting, so what we can do is monitor how much power the camera is using, when it is drawing more power, we know it is broadcasting. Therefore, without ever breaking into the system and leaving us vulnerable to getting caught, we have gained crucial information.

We can attempt to apply the same principle to computers by utilising a mechanism called caching. When a process frequently accessed data, or when the computer anticipates that it will access certain data, that data is stored in a region known as the cache, which is a smaller yet faster type of memory. This means that accessing data can be quicker if it is cached. Thus, we have identified our side channel: the time it takes to retrieve a piece of data.



Now, this needs to be turned into code. Let's assume we know where in memory the sensitive data we want to access is. Let's start with an array we can iterate through. We have already "trained" the speculative execution part of the CPU that our calls into our arrays are valid. This can be achieved by looping through the array a few dozen times; the exact number does not matter so long as it is clear there is a pattern. To further show this, a dummy function called vulnerable_function() can be created, all this function does is take in an address in our array, do a check to make sure the address is in the array and then return the value at that point. We know we can never read a forbidden part of memory and record it, this will flag our process to the operating system, and it will get us caught. Hence, as much of the process as possible must be kept in the speculative process because we know this is not performing any checks. However, if we try to directly read the data fetched from memory, we will get caught. To avoid this we can go to the address in memory, which holds the sensitive information and pass that information , such



as binary which could represent an address or data, into the function . The speculative process will fetch the data with no checks, and then it will go to that spot in the array and place it in the cache, however, when that command is processed, we will get caught. This is when the earlier checks we performed will make sure we will not read outside of memory and will prevent our process from accessing the wrong part of memory and getting flagged. This means we have now run the command and found the data at the address; we then used that data as a pointer to our array. However, as this was all speculative, we don't know what was run. This is when we start the side-channel attack. We go through each element in our array, and the index that takes the shortest time is the value of that point in memory we attacked.

There, we have just accessed any point in memory with no checks and no ability to notice it. Unlike traditional vulnerabilities, this leaves no logs and can run invisibly. There are very few ways to combat this except by updating microcode and changing CPU architecture. While these discoveries were made in 2018, new ones were found just this year, and it is a problem that will haunt our CPU architecture for many more years.

By Ethan Benavides-Levy 26'

Teflon

Teflon is a branded name for the chemical polytetrafluoroethylene. Created by Roy J. Plunkett under the corporation DowDupont (then Dupont) in 1938, it went on to take the world by storm as a 'miracle substance' capable of resisting fire, avoiding water, and being unable to stick to much of anything. It seemed impenetrable, untouchable, and unable to break down in landfills. [1]

It was discovered in the process of searching for a better substance to serve as a coolant gas. In the following decades, Teflon had been placed in nearly everything, from the first atomic bombs to raincoats. [1]

In the late 1990s, a cattle farmer noticed something bizarre running through his livestock's population. The water running from the local DuPont factory had turned the water a shade of green - when his cows drank from it they grew sick and foamed at the mouths before passing away.

The water had been contaminated with a highly toxic chemical called PFOA (perfluorooctanoic acid). Not only was it detected on the farmer's land, but the community's water supply. It had embedded itself into the land with no way to break down—a permanent chemical stain. [2]

DuPont had long been aware of the potential dangers PFOAs held since the 60s. Despite this, they failed to take any tangible action including notifying the EPA or working to prevent this mass contamination. The company calculated that the future potential fees were nothing compared to their current and projected profits. Their negligence was a calculated financial decision. [3]

Early workers at Dupont were loyal to the corporation, as many fathers and sons worked at the local facility. The farmer and his family were shunned for attempting to speak up against the mass pollution of the land despite the health effects that many of them had begun to develop.

Every day these workers came into direct contact with high levels of PFAs and PFOAs. This presented a worrying pattern of multiple different types of cancers, weakened immune systems, liver damage, other chronic conditions, and birth defects in their children. [4]

Handling chemicals like PFOA and PTFE was also dangerous. Spills, leaks, or fires were frequent and could release highly toxic fumes or materials. The most infamous example of pollution was the infestation of the Ohio River with these chemicals. [5]

1907

2018

Perfluorooctanoic acid (PFOA) has since been detected in nearly every ecosystem on Earth and in the blood of almost every human being due to its widespread use. After years of legal battles—most notably Jack W. Leach, et al. v. E.I. du Pont de Nemours & Company—PFOA was officially phased out through pressure from The C8 Health Project. [6]

Since then, DuPont has tried to clean up its image by altering the chemical structure of Teflon products and marketing them as "safer." But these replacements often belong to the same chemical family (PFAS) and cause the same effects in lab animals as the original PFOA. The old ones still remain in our water, air, soil, and blood. [7]

By Kelise from Cicada Lit Mag

References:
[1] R. Molinek, "The Long, Strange History of Teflon, the Indestructible Product Nothing Seems to Stick to," Smithsonian Magazine, Aug. 20, 2024. [Online]
[2] A. Rivera-Corona, "The Farmer Who Took On One Of The World's Biggest Chemical Corporations," Science Friday, Jul. 12, 2021. [Online]
[3] D. Woods, "Can breaking the law be good for business?," NPR, Apr. 01, 2024. [Online].
[4] "PFAS and the health of West Virginians," Bridge Initiative for S&T Policy, Leadership, & Communications | West Virginia University, Oct. 16, 2024.
[5] "State Secures $110 Million Settlement with DuPont for Environmental Restoration Along Ohio River | Governor Mike DeWine."
[6] S. J. Frisbee et al., "The C8 Health Project: design, methods, and participants," Environmental Health Perspectives, vol. 117, no. 12, pp. 1873–1882, Jul. 2009, doi: 10.1289/ehp.0800379.
[7] M. Wilson and M. Wilson, "DuPont, former maker of Teflon, debuts a "welcoming" rebrand," Fast Company, Oct. 03, 2018.

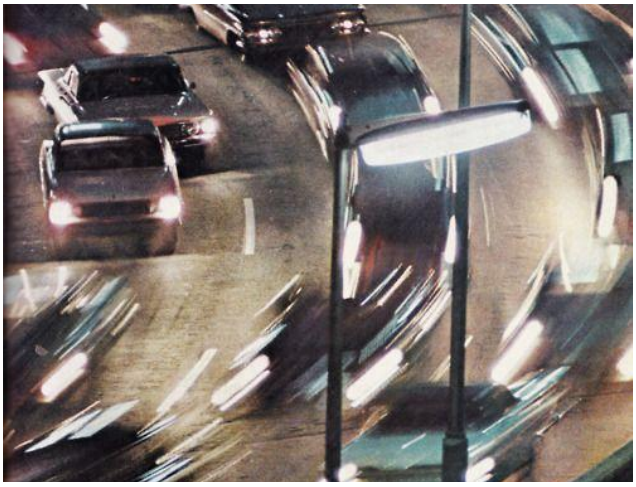
Average Speed Cameras in Action

Average speed cameras are devices that work in pairs to monitor the average speed of a vehicle over a distance. They have been proven to improve road safety by effectively reducing vehicle speeds, which leads to fewer violations [1]. They also decrease the rate of accidents per year as a result of slower and more controlled driving.

Two cameras are placed a certain distance apart above a road, usually on a motorway [2]. To effectively capture vehicle details, these cameras rely on Automatic Number Plate Registration (ANPR) technology [3]. ANPR technology allows the cameras to accurately read number plates in unfavourable conditions, such as at night or during heavy rain. When a car passes the first camera, its registration number and information are recorded, along with the precise time it passed the camera [2]. The second camera records the same details when the car passes it. Once the vehicle's data is captured at both points, the system quickly processes this information to calculate the average speed using the speed formula.

$$Distance = Speed \times Time$$

The distance is fixed, and the difference between the two recorded timestamps allows the system to calculate the vehicle's average speed. If this speed exceeds the road's speed limit, or the time taken to cross the two points is shorter than it should be, the vehicle is flagged for a violation [1]. This method ensures accuracy over the entire monitored section, meaning that simply slowing down near the second camera is unlikely to prevent detection. This differs from fixed-speed cameras, which capture the speed of a vehicle at a specific point [2]. Even though the speed formula itself is simple, the maths behind these cameras must be extremely precise. For this reason, average speed cameras are calibrated to measure time differences with millisecond accuracy.



The design and engineering of average speed cameras ensure that they capture and process data quickly. To achieve this, these devices rely on advanced components that enable fast and effective operation. The materials used to build these systems are carefully selected to resist corrosion and UV damage. They also have to be built to withstand unfavourable weather, such as rain and harsh winds. Additionally, speed cameras are designed to operate 24/7, which requires a constant energy supply [1,4].

The speed monitoring process begins with capturing initial data. High-quality sensors that record the number plate of moving vehicles are integrated into average speed cameras. The devices are also equipped with infrared technology that enables clear visibility at night. Once the data is successfully captured, it proceeds to the next stage of processing.

The recorded data must be processed to monitor speed using the device's internal processing unit. These units record the needed data, calculate the vehicle's speed, and communicate with legal stations if a violation is detected. Additionally, they can recognise special cases, like emergency vehicles and vehicle types, ensuring that speeding violations are detected quickly and processed fairly [1].

Average speed cameras are a prime example of how science, technology, engineering, and mathematics collaborate to address real-world problems. While they appear to be ordinary cameras, they utilise advanced systems to enhance road safety and reduce accidents every day. These cameras highlight how STEM shapes everyday life, often operating in the background to enhance public safety and efficiency.

By Mandisa Jili

References:
[1] J. Ellison (2024. Dec, 12) Understanding the Mechanics of Average Speed Cameras
[2] New Cars Online. Grasping the Mechanics of Average Speed Cameras
[3] An Garda Síochána. Automatic Number Plate Recognition
[4] Bumper. (2025. Feb, 19) How Do Average Speed Cameras Work?
[5] Microsoft Bing. (2024, Aug, 20) Southend council vows to continue average speed camera campaign
[6] Microsoft Bing. (2024, Sep, 19) Speed Camera or Safety Precaution?

Stellar Alchemy: The Cosmic Cycle Of Life and Death

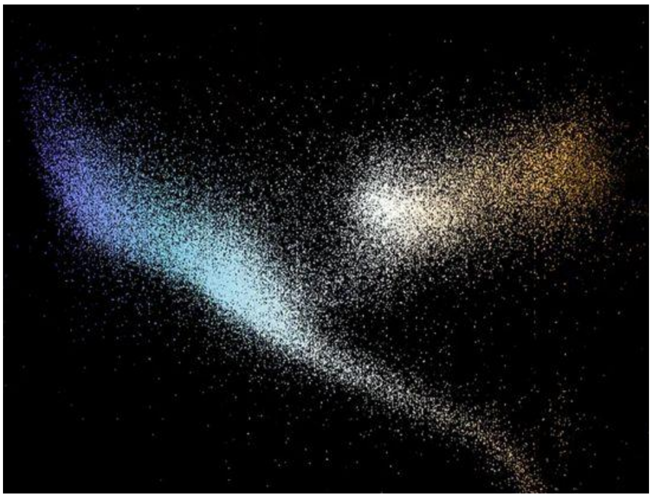
Under a sky full of stars, where the winds hum like ancient songs and the night carries the scent of cold dust and distant fires, you look up to witness the primeval light that bears with it stories of inception, struggles, evolution, and the quiet beauty of death. From the delicate fusion of atoms inside a newborn protostar to the cataclysmic collapse of a massive star into a black hole. Stellar evolution is one of the most fascinating phenomena in astrophysics [1][3]. Learning about the birth, life and demise of stars not only educates us about our distant sun, but it also explores the story of life and how we and things around us came to be [4][11].

The voyage of a star initiates in vast, cold clouds of gas called nebulae. These regions, hundreds of light–years wide, are scattered throughout the galaxies and glow with a faint red and blue hue due to the ionized hydrogen [3]. The formation of stars initiates when fragments of these clouds experience gravitational collapse, sparked by external forces such as shockwaves from distant supernovae or collisions between clouds [6].

As gravity draws matter towards itself, the concentrated gas regions become denser and blazing, assembling what is known as a protostar, often called the embryo of a star. At this stage, the protostar still accumulates mass from its surroundings and ejects infrared radiation due production of heat generated from the compression of gas [3].

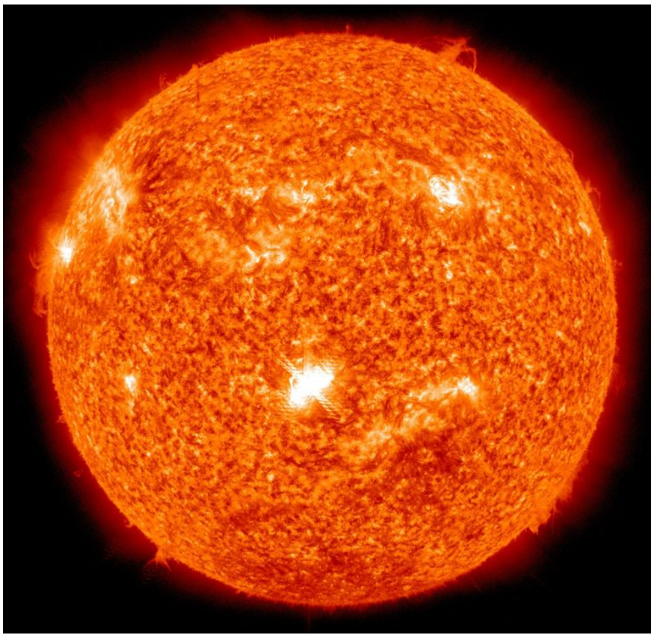
When the temperature of the core reaches ten million kelvin, nuclear fusion proceeds. Hydrogen atoms fuse into helium, emitting a tremendous amount of energy [10]. This denotes the end of the protostar phase and the dawn of a star’s main life called the main sequence. At this point the infant star has achieved hydrostatic equilibrium, where the external pressure from fusion equals the inward pull of gravity [1].

Once a star attains hydrostatic equilibrium, it transitions into the most stable and long lasting stage of its life; the main sequence. Throughout this stage the star persistently fuses hydrogen into helium in its core, producing energy that discharges as light and heat. This energy stabilizes the gravitational forces from collapsing under its own gravity, upholding its shape and size [1][3].



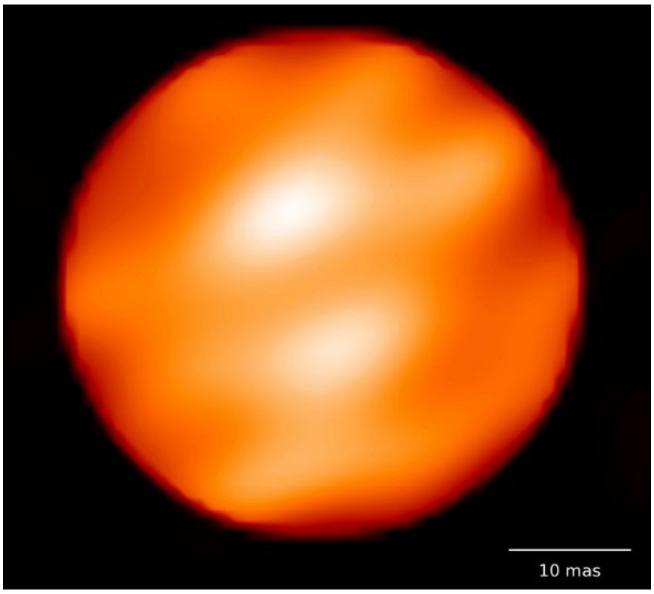
The amount of time a star dedicates in the main sequence is inversely proportional to its mass [3]. Massive stars like blue giants exhaust their fuel rapidly, remaining on the main sequence for a few million years. In contrast, smaller stars like our sun can stay in this sage for billions of years [1]. Our sun is about 4.6 billion years into its roughly 10-billion-year main sequence life [3].

Stars on the main sequence pursue a pattern defined by the Hertzsprung-Russell (HR) diagram where their position is identified by temperature and luminosity [1]. While on this path, the star's core progressively accumulates helium, making fusion less productive over a course of time period. Eventually when the hydrogen in the core is exhausted, the delicate balance holding the star stable starts breaking – marking the end of the main sequence and initiates the final, dramatic stages of a star's life [5].



The demise of a star completely depends on one main thing: its mass [1]. As hydrogen in the core is depleted, fusion retards and gravity begins to seize control. What follows next alters from gentle departures to stellar eruptions [6].

When a star with a low to medium mass comparable to our sun empties its core hydrogen, fusion halts and the core collapses under the gravity [3]. The outer layer elongates and eventually the star becomes a red giant. Soon it sheds these outer layers building blazing planetary nebulae, while the hot core remnant transforms into a white dwarf. A white dwarf is an earth sized, highly dense object made up primarily with carbon and oxygen [7]. White dwarfs do not fuse elements anymore but they can gleam softly for billions of years before fading into a theoretical black dwarf [7][8].



A massive star refers to a stellar body whose mass exceeds eight times the Sun's. These stars blaze through life and vanish in fury [3]. After exhausting their primary fuel, these massive stars begin fusing stronger and heavier elements within their cores , including helium , carbon , neon , oxygen and iron [5][10].

Ultimately, the fusion halts at iron, as it no longer releases energy .As iron accumulates in the core , it collapses in less than a second, triggering a supernova, a titanic explosion more luminous than an entire galaxy [6]. Based on the mass of the remnant , the star's core either becomes a neutron star , an ultra - dense object so compact that a single teaspoon would weigh billions of tons , or a black hole , where gravity is so powerful that not even light can escape [1][3].

Every atom heavier than helium in our bodies – carbon, oxygen, iron – was synthesized in a dying star [2][4][11]. In a very real sense we all are made up of stardust [2][12]. Learning the developmental stages of a star is not about just distant stars. It is a gateway into our own cosmic ancestry. The atoms of blood, bones and breath were once forged in stellar cores and

dispersed by supernovae. By studying stars, astrophysicists unlock the mysteries about the structure of galaxies, the origin of elements and the fate of the universe itself [3][10].

In the end, the tale of stars is the tale of transmutation, from gas to light, and from turmoil to structure. As we gaze at the night sky, we are not just looking at stars, we are looking at the history of everything [12].

By Amna Zaman from Rouge Letters 26'

References:

[1] Stellar evolution, ESA CESAR Booklet, 2018. [Online]. Available:

[2] J. Pfeiffer, *Chapter 14: Stellar Evolution I,* TCNJ Course Notes, 2013. [Online].

[3] Wikipedia, *Stellar evolution, Jun. 2025. Summarizes nebulae, protostars, main sequence, H-R diagram stages. [Online].*

[4] Wikipedia, *Main sequence, Jun. 2025. [Online]*

[5] Wikipedia, *White dwarf, Jun. 2025. [Online].*

[6] KITP/UCSB, *White Dwarfs, Supernovae, Neutron Stars, Black Holes, 2010. [Online].*

[7] arXiv:1806.07267, *Neutron star formation and Core Collapse Supernovae, 2018. Discusses core collapse and remnant formation. [Online].*

[8] ResearchGate, *The Physics of Core*‑*Collapse Supernovae*, Publication (6 months ago) [Online].

[9] Wikipedia, *Supernova nucleosynthesis, May 2025. [Online]*

[10] arXiv:2304.09350, Black holes as the end state of stellar evolution, 2023. [Online]

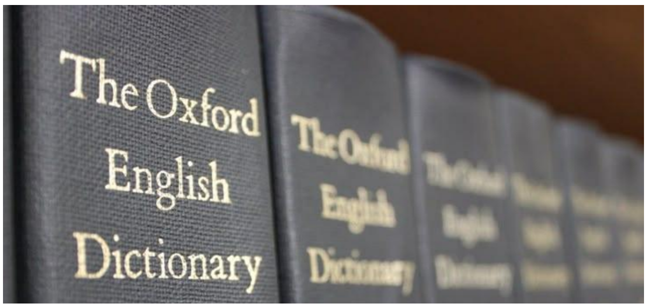
[11] Nasa *"Are We Really Made Of Stardust" [Online]*

[12] M. Lemonick, "The Exploding Stars Inside of Us," The New Yorker, Annals of Technology,May 20,2013. [Online].

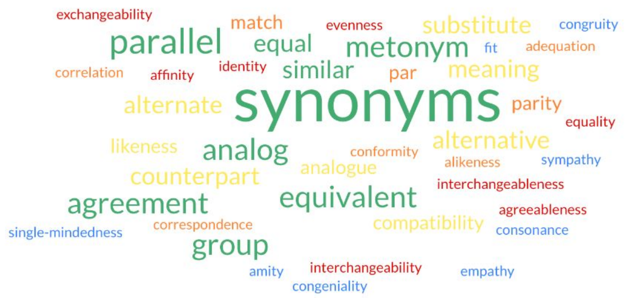
How Autocomplete Works

Going on the internet almost always involves using Google's search engine. Most modern and popular browsers such as Chrome, Safari, Firefox, Opera use Google's search engine as a default. One of the reasons for its success is its autocomplete algorithm. Autocomplete guesses whatever you are looking for based on previous searches from other people. However, not many people are aware of how the algorithm determines exactly what they want so accurately.

The mechanism relies on complex algorithms, data analysis, and predictive models to provide relevant predictions based on user behavior and even location-based data. As Google Search Help states, when entering a statement in the search bar, their systems look for similar queries but also consider aspects such as the language, location, trending topics and your past searches. For example, in case of trending topics, a recent slang word would be prioritised over long term trends. This helps the searches stay as relevant as possible to a particular location or time, such as for breaking news events.



In addition, Google Search engine states that a similar process is followed in order to predict individual words based on words from dictionaries and patterns that appear on the web [1]. Additionally to the initial algorithms, the search engine also handles problematic predictions. Autocomplete has systems designed to prevent predictions that can potentially violate their policy from appearing at all. The systems try to identify predictions that are violent, sexually explicit, hateful, or dangerous. This includes predictions that are unlikely to return results.



RankBrain, which has been supplementing Google HummingBird since October 2015. RankBrain is a major part of the Google algorithm that uses artificial intelligence and machine learning to learn about users and how they respond to the search results, particularly on previously unseen queries. It is sometimes used for autocomplete but is more utilised when deciding in which order and what links to show on the results page. These two algorithms help translate a string of characters from the search into understandable text. Therefore, the algorithm ignores punctuation and unnecessary words such as 'please', 'a', 'the', 'without' and 'etc' [2]. One of RankBrain's abilities is to make two words, which seem unrelated to the computer, actually have the context that you expect. For example, if the query was a name of a famous actor, previous results would suggest the name represents one entity rather than a separate first name and second name. Furthermore, RankBrain optimises the use of synonyms to rank suggested queries with similar meanings.

Another prominent medium where autocomplete is used is texting. The algorithm here is much simpler as it solely consists of a large moving dictionary of all words. For example, if you try to enter a

word “hello”, as soon as the first letter is typed the pointer will move to the letter “h”, then the letter “e” etc.. In addition, the words in the dictionary are sorted by popularity and how often they are used to provide the most relevant result. However, when suggesting the next word after several have already been typed out, the dictionary uses statistics and probability as the next word is chosen based on personal previous typing history. To further improve the accuracy of these predictions, machine learning and AI can be applied to a greater extent. This will allow the algorithm to adapt to an individual’s typing habits and make suggestions more personalised [3].

In conclusion, autocomplete is a powerful feature which many people use more often than they realize. Whether someone uses Google or messenger apps, people’s queries or texts rely on autocomplete and predictive models to provide relevant results. With advancement in machine learning technology these autocomplete algorithms will continue to improve, helping people around the world search exactly what they desire with a single typed letter.

By Denys Zazuliak 26’

References:
[1] Google Search Help. “How Google autocomplete predictions work” [Online]
[2] Brightedge. “Understanding Google RankBrain: The Ultimate Guide to AI and SEO” [Online]
[3] B. Lutkevich, (2022. 31, Oct). “predictive text” [Online]

How Genetics Influences Our Day to Day Life

Introduction

Genetics is a branch of biology that looks at how hereditary traits or characteristics are passed from one generation to another. A person's hair color, eye color, or even how a person's body responds to certain medications are encoded in our DNA. Genetics has a surprising impact on many aspects of our daily lives.

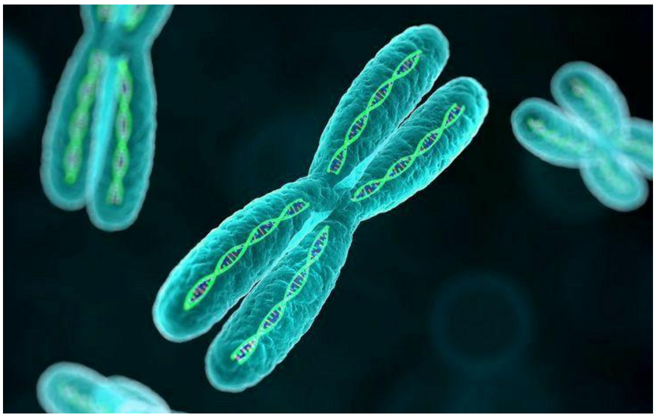
Genetics is being used in increasingly impactful ways, from personalized medicine to solving crimes. Genetic science explains what DNA is, and how it impacts our everyday decisions when it comes to health, food, ancestry, and more.

Understanding the Basics of Genetics

DNA, scientifically known as deoxyribonucleic acid, is the molecule that carries the instructions for how living organisms grow, function, and reproduce. These instructions are stored in sequences called genes, which determine characteristics such as height, blood type, or even the risk of certain diseases.

Humans have around 20,000 to 25,000 genes organized into 46 chromosomes (23 pairs), which are found inside the nucleus of every cell. Each person inherits half of these chromosomes from the mother, while the other half come from the father. This is why children often look similar to their parents or siblings and may also inherit similar or the same health conditions.

A major breakthrough in understanding genetics came with the Human Genome Project, conducted in 2003. This international project mapped out the entire sequence of human DNA, giving scientists and doctors tools to better understand how genes are linked to diseases and other traits [1].



Personalized Medicine

One of the most prominent ways genetics is being used today is in personalized medicine, also known as pharmacogenomics. Rather than giving every patient the same medicine for a condition, doctors can now look at a person's specific genes to determine which treatment will work the best for them. This helps improve the effectiveness and reduce potential side effects.

For example, certain individuals have genetic variations which affect how they are able to break down certain drugs. A blood thinner, such as warfarin, can be dangerous in people with a specific gene variant because their body processes the drug either too quickly or too slowly [2].

In cancer treatment, doctors can now sequence the DNA of a tumor to understand which mutations are driving its growth. Then, targeted therapies can be used to attack those mutations without harming healthy cells. This strategy is already used in breast cancer and lung cancer treatment plans. The future of medicine will likely involve even more genetic testing before any drug is prescribed.

At-Home Genetic Testing and Ancestry

In the past years, millions of people have sent samples of their DNA in the form of saliva to companies such as 23andMe, AncestryDNA, and MyHeritage to learn about their background, family tree, and any health risks they may have. These tests examine a person's DNA and compare it to databases from around the world to estimate ancestry percentages and certain genetic traits. Some tests go even further and check for gene variants linked to diseases like Alzheimer's or Parkinson's. Others look at different traits such as lactose intolerance or even athletic performance [3].

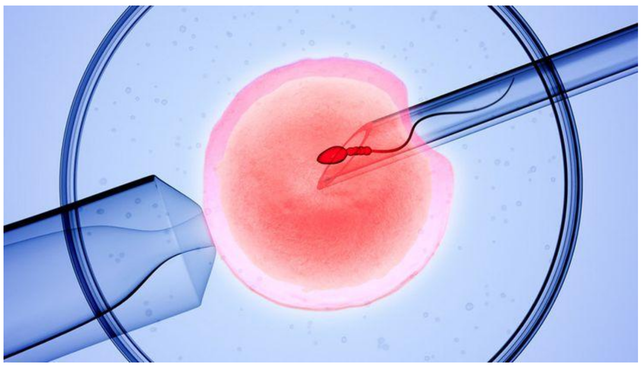
However, it's important to understand that these tests do not predict the future. Having a certain gene variant does not guarantee that the individual will develop the condition. Environment, lifestyle, and other genes also play a role.

Privacy tends to be another concern. When people use at-home DNA tests, they often agree (sometimes without realizing it) to allow their genetic data to be used for research, or even shared with law enforcement under certain circumstances.

Reproductive and Prenatal Genetics

Genetics is also important for family planning and pregnancy. Couples who are planning to have children can get what's called a carrier screening to see if they are carriers of certain genetic diseases, like Tay-Sachs or cystic fibrosis. If both parents are carriers, there is a higher chance that the child could inherit the condition [4].

During pregnancy, doctors can use non-invasive prenatal testing, or NIPT, to look at the baby's DNA within the mother's blood. This allows them to check for certain conditions, like Down syndrome, without performing more invasive procedures. In some cases, people also consider in vitro fertilization, or IVF, combined with preimplantation genetic diagnosis, or PGD. This allows embryos to be tested for genetic disorders before being inserted into the uterus.



These tools give parents more information, but they also raise ethical questions, such as whether or not people should be allowed to select traits like eye color or height in the future.

Genetically Modified Foods (GMOs)

Another way the science of genetics impacts everyday life is through the food we eat. Many of the fruits, vegetables, and grains sold in grocery stores are genetically modified to improve their growth or resistance to certain diseases. These are called genetically modified organisms, or GMOs. Examples of this would be corn and soybeans, which are often modified to resist insects or herbicides. This means farmers can grow more food using fewer chemicals, which helps reduce costs and environmental damage [5].

In developing countries, scientists have created genetically modified crops like Golden Rice, which is rich in vitamin A. This helps prevent blindness in children who don't get enough vitamins in their diet. Although some people worry about the safety of GMOs, most scientific organizations, including the National Academy of Sciences, agree that GMOs are safe to eat. However, labeling laws and the public's opinion continue to impact how these foods are viewed in different countries.

Forensic Genetics and Crime Solving

One of the most famous real-world applications of genetics is in forensic science. Investigators collect DNA from a crime scene, such as a drop of blood or strand of hair, and compare it to a suspect's DNA. This process has helped solve thousands of crimes and has also freed innocent people from prison [6]. More recently, forensic experts have started using genetic genealogy. This involves uploading DNA to public databases to find distant relatives of a suspect. Using family trees and records, detectives can then work backwards to find the criminal.

One well-known case involved the capture of the Golden State Killer, a man who committed crimes in the 1970s and 1980s. He was identified in 2018 using DNA from a distant relative who had uploaded their data to a public ancestry website.

As useful as this tool is, it once again brings up privacy concerns. People who share their DNA online may unintentionally expose their relatives to police investigations, even if those relatives never gave consent.

Ethics, Discrimination, and DNA Privacy

As genetics becomes more widespread, society must consider a range of ethical challenges. Concerns include whether or not employers and schools should have access to someone's genetic information, the potential of being denied insurance based on disease risk, and the fairness of selecting a baby's sex or other physical traits before birth.

GINA

GENETIC INFORMATION NONDISCRIMINATION ACT

In the United States, a law called the Genetic Information Nondiscrimination Act (GINA) was passed in 2008. This law protects people from being treated unfairly by employers or health insurance companies based on their DNA [7].

Still, there are areas not covered by the law, like life insurance or disability insurance. That's why it's important for people to understand their rights when it comes to using genetic services.

Conclusion

Genetics is no longer just a science topic for the textbooks; it's an everyday part of life. From choosing the right medicine to understanding our ancestry, DNA plays a bigger role in our personal lives than ever before. It has helped doctors treat patients more effectively, helped parents plan healthy pregnancies, and even helped police solve decades-old crimes.

But as our understanding of genetics grows, so does the need for responsibility. People must be informed about how their genetic data is used and protected. By learning about how genes work and how they affect us, we can make smarter decisions for our health, families, and the future. Genetics is a perfect example of how STEM, especially biology and technology, can be woven into everyday choices.

By Sasya Koneru

References:
[1] International Human Genome Sequencing Consortium, "Initial sequencing and analysis of the human genome," Nature, vol. 409, no. 6822, pp. 860–921, Feb. 2001.
[2]M. Solaiman, S. Jannath, and M. Dawood, "Impact Factor: 8.232." [Online].
[3]A. Regalado, "More than 26 million people have taken an at-home ancestry test," MIT Technology Review, Feb. 11, 2019.
[4]D. W. Bianchi et al., "DNA Sequencing versus Standard Prenatal Aneuploidy Screening," New England Journal of Medicine, vol. 370, no. 9, pp. 799–808, Feb. 2014
[5]E. National Academies of Sciences, "Genetically Engineered Crops: Experiences and Prospects." National Academies of Sciences, Engineering, and Medicine, 2016.
[6]C. U. Press, "Interview with Sheldon Krimsky and Tania Simoncelli, coauthors of Genetic Justice - Columbia University Press Blog," Columbia University Press Blog - Publishing a universe of knowledge for readers worldwide, Mar. 28, 2011.
[7]U.S. Equal Employment Opportunity Commission, "Genetic information discrimination," www.eeoc.gov, 2009.

How VEX Robotics Connects Us to Everyday STEM

VEX Robotics was founded by Bob Mimlitch and Tony Norman, two high school students from Greenville, Texas who later worked together in engineering. Among the VEX robotics programs, V5RC is a VEX V5 Robotics Competition for students from 9th grade to University. It is a match played on a 12 by 12 feet square field with one red and one blue side, and two alliances on each side. Each match consists of a fifteen second Autonomous Period, followed by a one minute and forty-five second Driver Control Period. There is also a separate skills match where a team will do a sixty second Autonomous Period, followed by another sixty second Driver Control Period. In addition, players create engineering notebooks with documentation of the engineering process.

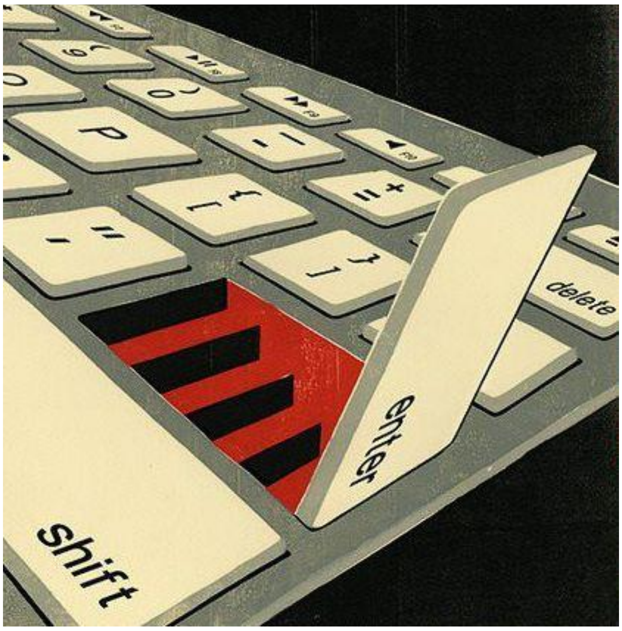
Team presentation also plays an important role at the match. Typically, a team of three, driver, strategist, and timekeeper, will participate in 6 to 7 matches with random alliances. With the results, teams will be ranked. A new alliance will form with the top half having first pick. This alliance will remain the same until the matches are over. Then, an elimination round takes place. If you survive the elimination round, you will advance to quarterfinal, semifinal, and final matches. There are certain awards that will allow you to advance from these tournaments to the regional tournaments. For us in region 4, it is held in LA. To do well in the V5RC competition, a team must have solid robot building expertise, coding knowledge, driving ability, thorough engineering documentation, presentation skills, and teamwork.

Coding

C++ is a popular language used to program

Coding

VEXcode PRO V5 in robotics, allowing robots to move across the field, operate belts, lift arms, and rotate intake wheels. C++ is a powerful and versatile language that is also used in video games, smart appliances, product testing, and scientific simulations. However, it is now outdated. A more user-friendly C++ alternative is Easy Template on the Visual Studio Code App and PROS V5.



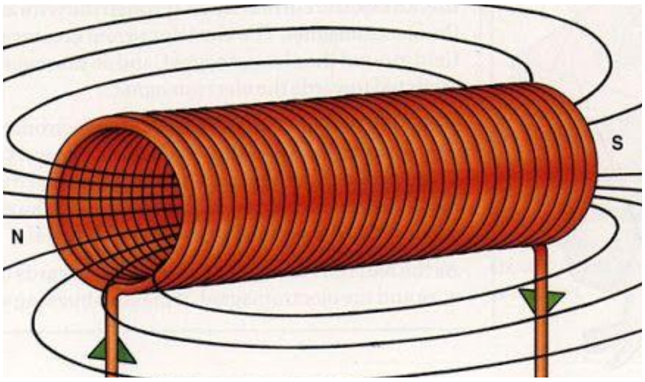
Motors and Gears

DC (Direct Current) motors are commonly used to power robots' movements. These same types of motors are found in everyday devices, from electric cars to home appliances. In fact, a robot is essentially a small electric vehicle powered by batteries. VEX smart motors are rated for 11 Watts peak and continuous power. They provide position, current, voltage, power, torque, efficiency, and temperature feedback to the robot brain. Generally, it comes with the green gear cartridge, which is designed to be 200 RPM for a standard gear ratio. The red one is 100 RPM for high torque and low speed, and the blue one is 600 RPM for the opposite. Depending on the V5RC season, different cartridge and tooth gear couplings should be prioritized. For instance, in a game requiring quick navigation, a 360 RPM drivebase (36:60 gear ratio) can be achieved by using a blue cartridge, 36 tooth gear, and 60 tooth gear Omni (all directional) wheel (36/60 multiplied by the 600 rpm cartridge).

Sensors

Sensors play a huge role in robotics. An inertial sensor is a combination of a 3-axis accelerometer and gyroscope which can help a robot travel straight and turn precisely, while an optical sensor is used to detect and accept/reject game pieces by color. To control a robot using sensor data, the Inertial Sensor and Optical Sensor must be paired with a programming language like VEXcode V5 or VEXcode Pro V5. The Inertial Sensor provides readings such as heading, rotation, orientation, and acceleration. The Optical Sensor detects and sorts objects by color by converting light into electrical signals, which are processed by the V5 Brain. It works best within 100 mm and is affected by ambient light and object reflectivity. The Optical Sensor can also control its LED, detect objects and colors, and measure light brightness and hue.

Other sensors include GPS, vision, distance, and rotational sensors. These technologies are everywhere around us, such as garage doors, elevators, automatic doors, vehicles, and smart lighting.



Pneumatics and Solenoids

A regular VEX pneumatic tank holds up to 100 psig (rated up to 150 psig). To put that into perspective, car tires only hold up to about 35 psig, and bike tires about 40 psig. Pneumatics allow for smooth linear movement but require careful design due to potential air leaks and limited air supply. Solenoids, which release air by converting electrical signals into mechanical action, are widely used in appliances such as dishwashers, car door locks, and gas stoves. VEX robotics uses double acting solenoids to control air flow to pneumatic cylinders, which means it will actuate in both ways (e.g. open/close or forward/backward). They work with the V5 Brain and a special driver cable, and are included in the V5 Pneumatics Kit. These solenoids have two positions (double-acting), operate at 100 psig system pressure, and support a maximum pressure of 130 psig. They come with two 1-meter cables and have a flow rating of 0.24 Cv (flow coefficient). A typical shower head has a CV of around 2.5, so it is a very small flow rate. The new version weighs 68 grams, while the old one weighs 42 grams.

VEX Robotics not only helps students gain new skills in programming and engineering; it also helps them connect what they learn to everyday technology. Programs like VEX inspire the next generation of innovators by making STEM fun, hands-on, and very relevant.

By Kailey Yoon 28'

The Science of Tears

On average, man collectively produces around 15 to 30 million gallons of tears every year [5]. And yet, crying is perceived as a sign of weakness, or fragility. There are several layers and different aspects of tears, including its classifications, compositions, and benefits that you might have not known before. Crying is often overlooked; It is seen in a bad light as it commonly follows negative emotions. However, there's a hidden beauty we often overlook that makes tears vital in our day to day life.

On surface level, all tears look the same. Yet, scientists have found a way to classify our tears into three different types according to their chemical compositions. These are reflex, emotional, and basal tears. Reflex tears are emitted from reflex, and act as protection from bacteria attacking your eyes. Some common instances where people cry reflex tears are when we cut onions, or get out faces covered in dust or sand. Emotional tears flow when people experience an overwhelming amount of emotions. These are the tears produced from grief or immense joy, and are often the tears that produce "happy" hormones. Lastly, basal tears are not as prominent as emotional or reflexive tears, but play a huge part in moisturizing and nourishing our eyes. These are produced in small amounts everyday [2].

The AAO (American Academy of Ophthalmology) states that our tears contain 3 main layers; an inner mucus layer that keeps the eye lubricated, a thick, watery layer in the middle to help with hydration, and an oily outer layer to prevent the tear from evaporating and to make it clearer for us to see through our tears [5].

According to the Cleveland Clinic, tears are composed of several chemicals, but its predominating components are water and salt; specifically potassium chloride (KCl) and sodium chloride (NaCl) [4]. These are often mixed in with antibodies and protein, all depending on the types of tear you shed. For example, emotional tears may produce more protein than reflex tears, but reflex tears produce more antibodies to fight against bacteria. Basal tears on the other hand produce excess mucus to help stick to the eye [1].

The salty taste of our tears is the effect of these components. Even if crying is often a response to negative emotions or circumstances, a Harvard study conducted by Leo Newhouse and other scientists suggests that it can actually be more beneficial than repressing sobs. Most if not all of our tears emit "happy" chemicals like oxytocin to reduce pain and keep our emotions in check [3]. In other words, it's a line of defense our body has in order to stabilize our emotions.

To conclude, tears are necessary for the wellbeing of our eyes. Different stimuli often produce different types of tears, all with the common goal of protecting and relieving our bodily systems. Lastly, their chemical makeup differs from each type, but all consist primarily of water and salt. Given everything aforementioned, understanding the nature behind our tears can help grow a newfound appreciation for the inner workings of our eyes, and give us a reason to stop repressing the cries that would otherwise help you along the way.

By Lou from Dulcet Literary 28'

References:

[1]C. Clinic, "What Are Tears Made Of? Types of Tears," *Cleveland Clinic*, Jan. 10, 2025.

[2]A. H.-C. BSc, "What are Tears Made of? The Biochemistry of Emotion," *News-Medical*, Oct. 02, 2023.

[3]L. Newhouse, "Is crying good for you?," *Harvard Health Blog*, Mar. 01, 2021.

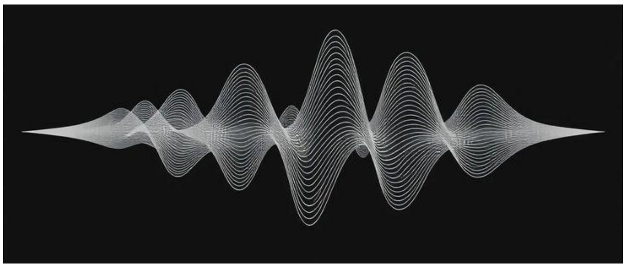
[4]"www.ChemistryIsLife.com - The Chemistry of Tears," *www.chemistryislife.com*.

[5]Facts About Tears, "Facts About Tears," *American Academy of Ophthalmology*, Dec. 21, 2016.

How Headphones Work

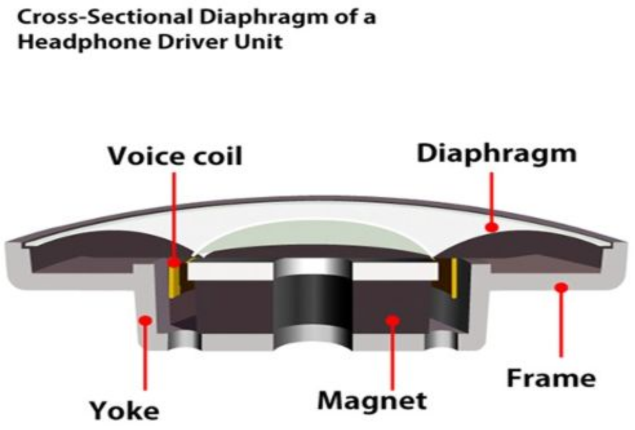
Most people use headphones every single day. Headphones have evolved into essential accessories that enhance our productivity, entertainment, safety and overall quality of life. This includes hands-free headsets which contribute to safer communication during activities like driving. Headsets maintain privacy by confining audio to the listener's ears ensuring conversation remains private and are designed for comfort as most headphones offer adjustable headbands. [7]

Headphones were invented in the 1890s by a British telecommunications company, the Electrophone Company, developed a seminal set of headphones that hung below the face, called an electrophone. This device consisted of earpieces connected to a y-shaped handle which looked a lot like the modern-day stethoscope. The electrophone would plug into a home telephone line on one end and cover the users' ears on the other, using this device users could listen to music broadcast over these lines. [1]



An important aspect of headphones is understanding how they produce sound. Most of the audio you hear starts off as a sound wave, which is made up of vibrations. To produce these vibrations we need mechanical movement [2]. These vibrations are created by digital information being passed through a Digital-to-Analog Converter (DAC). This converts the signal into an electric current. Therefore creating mechanical movement thus producing a sound [1].

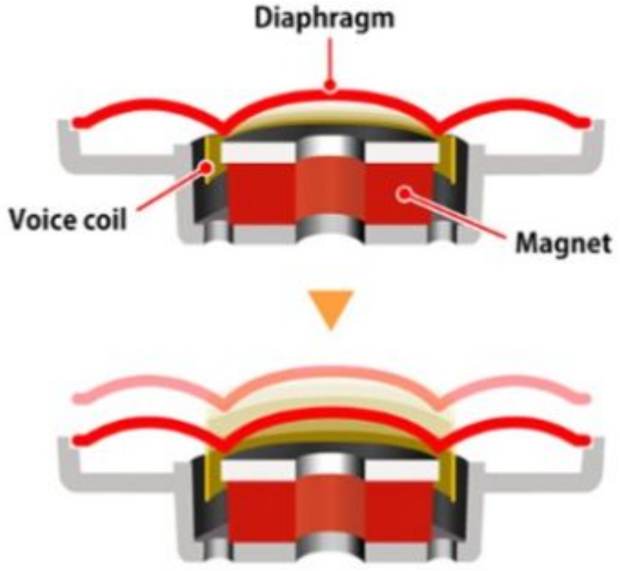
Driver units are used in headphones as they are one of the core components responsible for producing sound. Driver units are often referred to as transducers because they convert analogue signs into vibrations. The size and corresponding performance of a driver changes from earphone to earphone, though typically their sizes range from 6mm to 15mm. [2]



A diaphragm is an important part within every driver unit. It contains a thin membrane which creates audio waves [2]. When the coil vibrates the diaphragm moves with it, this movement causes pressure waves (sound waves). These waves are the sounds you hear. The diaphragm moves quickly for higher pitched sounds and lower/slower for slower pitched sounds [1]. The intensity and direction of movement is directed by the electrical signal which enters the driver. [2]

There are multiple types or driver units out there such as the dynamic driver unit, planar magnetic driver unit, balanced armature driver and electrostatic driver units. [3]

A driver unit uses 3 main parts: a permanent magnet, electromagnetic coils and a diaphragm [4]. It is typically referred to as a "moving coil driver". Electrical current flows to the voice coil and creates an electromagnetic field [2].



The electromagnetic fields switch their polarity back and forth depending on the pattern it's sent, or the sounds being produced. When the electromagnet switches its polarity, it is rapidly repelled and attracted to the permanent magnet which makes it vibrate. This causes the diaphragm to vibrate [4]. Altering the strength and direction of the electric current causes the diaphragm to vibrate and to produce the sound.

Dynamic drivers are more susceptible to audio distortion than other drivers especially if the volume becomes too high. [2]

A planar magnetic driver commonly referred to as "orthodynamic drivers", they function very similarly to dynamic drivers [2]. It uses extremely thin magnetic conductors which are spread out across the diaphragm to move an electromagnetic coil. Instead of the use of a signal permanent magnet an array of magnets is placed behind the diaphragm in order to help it react when the current is passed through the conductors. [4]

The driver has a very thin flat diaphragm that has wire which crosses the surface of the diaphragm and pushes and pulls against the magnets when the AC signal is applied to the wire [3]. When electrical current passes through the conductor the polarity is changed and the diaphragm interacts with the permanent magnets and sound is created [4].

An electrostatic driver is responsible for some of the most well-respected headphones ever built [4]. Electrostatic drivers utilize static electricity to create an electric field [2]. The diaphragm is made from a very thin sheet of electrically charged materials and it sits between two conductive plates, one of which is positively charged and the other negatively [4]. The current flowing into the plates causes them to produce an electric field which makes the diaphragm move, creating the sound waves.

Electrostatic drivers can produce a wide range of frequencies with very low distortion but may need additional amplification. [2]

Balanced Armature Drivers are only available for in-ear monitors. The drivers have a coil which is wrapped around an armature and located between two magnets. The armature drivers are balanced because the distance between the armature and the two magnets is equal [2]. The armature drivers also incorporate a drive pin and a protective case to allow for a more compact means of recreating audio signals. When the audio source applies current to these drivers the armatures move in response to the magnets push and pull. This is facilitated by the drive pin and manipulates the diaphragm. In ear headphones typically employ balanced armature drivers delivering a more detailed sound [3].

Bluetooth / Wireless Devices

Wireless is very common due to ease of use; however, there's not much difference between wired and wireless/Bluetooth headphones. In Bluetooth technology, instead of the DAC being within your computer/phone the data is instead transferred via a Bluetooth radio chip within your headphone and is then sent to the DAC within your headphones [4].

Additional Features

Active noise cancellation (ANC), which is very common across headphones, typically increases in price value. It actively blocks out background noise by producing sound waves that counteract the detected ambient noise. This utilizes small external microphones to accurately capture the background noise to generate anti-noise signals [3].

However, the time available for the headphones to produce this anti-noise signal is extremely short. A microphone is placed in the environment that senses sound and sends them over wireless signals to an earpiece. Since wireless signals travel a million times faster than sound, the earphone can receive the sound information much faster than the actual sound itself. [6]

Equalisation is typically found in specialised headphones. It allows you to adjust the loudness of specific frequency ranges. By dividing the sound into multiple separate frequency bands, headphones with EQ capabilities provide virtual sliders that enable you to increase or decrease the volume of each band. This feature allows you to emphasize aspects of music that suit your preferences [3].

IP ratings indicate the numerical level of water resistance they are designed to have. The ratings range from IPX0, which describes headphones designed without offering water resistance, to IPX9, which describes headphones that can safely withstand steam cleaning and high pressure washing [3].

Conclusion

In conclusion the development of headphone technology has introduced a wide variety of sound enhancements, wireless capabilities, noise cancellation technologies and driver mechanisms, including planar magnetic, dynamic and electrostatic types. This diversity in driver types and integration of new technologies such as Bluetooth and ANC, which shows how technologies are continuing to adapt as consumer expectations rise. The headphone industry will likely continue adapting and expanding as time goes on.

By Fatima Patel 26'

References:
[1] A. Brown, "MUO Make Use Of," 19 August 2021. [Online].
[2] "Panasonic," [Online].
[3] A. Kalsi, "MIXX," February 2024. [Online].
[4] C. D. Looper, "Headphone Review," 30 September 2016. [Online].
[5] Panasonic, "Panasonic," [Online].
[6] S. Sheng, "University of Illinois Urbana-Champaign," 15 08 2018. [Online].
[7] S. Mekha, "How do headsets enhance and transform our daily lives?," 10 01 2024. [Online].

Can Medicines Really Be Magical

Think about your favourite fantasy movies, books and series that you watch and read in your everyday life and consider any medicines in them that seem unreal. Marvellous medicines and comical cures show up by the dozen in fantasy, but these medicines are not necessarily just for the magical. These medicines use modern science which has advanced enough to be considered magical. Some of the most iconic fantasy medicines are grounded in science, blurring the border between what we believe to be possible and impossible.

Lord of the rings

After Frodo is stabbed by the Witch King of Angmar, Aragorn brings him a herb called Athelas, commonly known as Kingsfoil. The herb slows and soothes the wound slightly until Arwen brings him to Rivendell for proper healing. Whilst Tolkien did invent the herb called Kingsfoil, he likely got inspiration from a garden herb known as basil. The binomial name for Basil is Ocimum basilicum, coming from the Greek word Basileus, meaning “King”. So etymologically, basil is likely linked to this medicine. Historically, different species of basil have been medicinally exploited across cultures in the Middle East, parts of Africa, India and South-East Asia as Phytomedicines, mainly treating inflammation, stress, respiratory and digestive issues and immunity strengthening. However currently, basil is used in Indian Ayurvedic medicine, a branch of medicine that tackles a balanced diet and lifestyle and is an approved branch of medicine by the Indian health system. In Africa, a type of Basil leaf called Ocimum tenuiflorum, or “holy basil”, can alleviate symptoms of malaria, such as inflammation and joint pain. Basil leaves can also soothe bee stings as bee stings are acidic and basil leaves are alkaline, therefore they can effectively neutralise each other. In South and central Asia, a branch of medicine called Unani uses Basil leaves to soothe nerves and aid digestion. Whilst it might not save you from a Morgul wound, basil leaves have great value in ancient and modern medicinal practices.

Star wars

Mentioned throughout the series, the Bacta tank is filled with a liquid called Bacta that can speed up the healing of wounds, and can even repair nerves, skin and muscle tissue. Bacta tanks were used to alleviate the pains of Darth Vader's burns, to heal wounds of Luke Skywalker and Obi-Wan Kenobi and to treat injured soldiers of the Galactic Republic in the Clone Wars. But this miraculous substance isn't necessarily in a galaxy far, far away, but can also be seen on planet Earth. 45 years after the Bacta tank was first mentioned in *The Empire Strikes Back*, scientists in Aalto University, in Finland and The University of Bayreuth, in Germany have created a hydrogel that can heal small cuts and wounds [1]. The gel is made by mixing stretchy polymers and clay nanosheets under a UV light. After it is applied onto the skin, it creates a moist pseudo-skin, which gives skin cells optimal conditions for healing. Within twenty-four hours, the skin will look as if it had never been injured. Furthermore, if the gel is cut or damaged, due to the sticky structure of the polymers, it will naturally reconnect. Whilst it may not be able to heal any injuries sustained from a Wampa attack, Tetra-PEG-TAA hydrogel is a major technological advance in the field of medicine and is an example of how medicines that seem futuristic and from other galaxies are not necessarily as unreachable as they appear.

Harry potter

In the Half Blood prince, Ronald Weasley drank a glass of poisoned oak-matured mead, causing him to suffer severe convulsions while struggling to breath. With perspicacious thinking, Harry fed him a bezoar. Bezoars, as well as sometimes causing blockage in the human digestive tract, are stone shaped objects that are found in the digestive system of animals such as goats, deer and cows. It immediately stopped the effects of the poison, saving Ron's life. However, in the Muggle world bezoars have historically been believed to be an antidote to poisons. Originating in the Middle East in the 11th century, bezoars were first believed to be a universal antidote to all poisons. Its use travelled to Europe through the writings of Arab and Persian physicians, and at the height of its popularity, bezoars were considered more valuable than precious gems. Queen Elizabeth the first famously had a ring with a bezoar in the centre. But, in the 16th century, bezoars waned in appeal when physician Ambroise Paré proved that bezoars did not cure poisons, by devising a test that proved their lack of effect.

However, modern science experiments discovered that although bezoars do not "cure" all poisons, they can be useful in neutralising arsenic. In 2013, Gustaf Arrhenius and Andrew A. Benson of the Scripps Institution of Oceanography re-examined the use of bezoar stones as an antidote to poison [2]. Arsenic contains two lethal compounds, arsenite and arsenate. In a process called chelation, the hair in bezoars contain sulphur-like proteins and brushite crystals that react with the toxic compounds, leaving the poison useless and ineffective. Whilst not as exciting as a universal antidote to poison, bezoars have further use outside of Professor Snape's potion class.

Disney Princess Films

Across many Disney films, when we see princesses in a cursed state or near death, often the cure is "an act of true love". Whether it's from your sister (Frozen), someone you've only ever met once (Snow White and Sleeping Beauty), or your husband (Princess and the Frog). Although this solution feels overused and romantically idealised, it may have great merit. In 1938, Harvard College enlisted 268 male sophomores (including the future president, John F. Kennedy) in an experiment called the Harvard Study of Adult Development, in which across 80 years they tracked the participant's health and social relationships to observe how the two factors correlated. It was one of the longest studies on aging and happiness in the world, and throughout the experiment the group expanded to over 1000 members enlisted. The study found that people who are happier in their relationships and marriages often live longer than those struggling [3]. According to an article published in the Harvard Gazette, several studies found that people's level of satisfaction with their relationships at age 50 was a better predictor of physical health than their cholesterol levels were [3]. Similarly, Yale conducted an experiment where over 7 years, they questioned any adults over aged 65 that were admitted to the ICU about their social relationships and interactions. They then gave each adult a score from 0-6 on a social isolation scale, 6 being the most socially isolated. Yale News summarised the experiment results being that "The most socially isolated older adults had a 50% higher burden of functional disability in the year after an ICU admission and a 119% greater risk of death." Yale's suggested solution was organizing a more personal and interactive support system for elderly adults after being released from the hospital, including weekly phone calls and setting up social engagements for the adults[4]. After analysing 42,000 adult blood samples, a joint study between Cambridge University and Fudan University in Shanghai showed that when the brain feels lonely or isolated, it negatively changes the behaviour of several proteins in the body, which can lead to increased risks of cardiovascular disease, stroke, type 2 diabetes, and early mortality[5]. So, although not necessarily the cure to all maladies, "an act of true love" can certainly increase the likelihood of a person's recovery from illness and reduce the possibility of medical difficulties in later life.

Conclusion

To conclude, not all medicines in fantasy are strictly supernatural. Whether the medicine is emotional, real world or futuristic, fantasy has a wonderful way of subtly highlighting the advancement of science to the point that it is possible to really see science and medicine as magical. And that is truly awe – inspiring.

By Eleanor Sapir 30'

References:

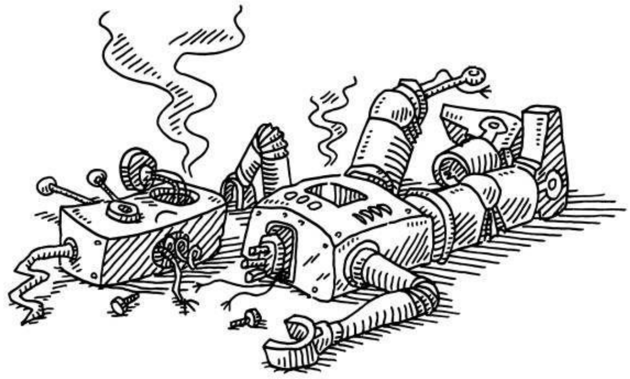
[1] T. Salvati, "Star Wars' greatest miracle is real: 45 years later, science has caught up with The Empire Strikes Back," MSN, Mar. 2025. [Online].

[2] "Bezoar Stone," All That History, Aug. 2, 2024. [Online].

[3] L. Mineo, "Over nearly 80 years, Harvard study has been showing how to live a healthy and happy life," Harvard Gazette, Apr. 11, 2017. [Online].

[4] B. Hathaway, "Social isolation can be deadly for older adults," Yale News, Sep. 7, 2021. [Online].

[5] N. Silliman, "Loneliness linked to higher risk of heart disease and stroke and susceptibility to infection," Cambridge University, Jan. 3, 2025. [Online].



Designing for Failure:

Introduction

Failure is typically seen as undesirable in engineering systems. However, as complexity grows in mechanical and digital systems, the assumption that failure can be entirely prevented becomes unrealistic. Instead, engineers focus on graceful failure, the ability of a system to continue operating in a safe and predictable manner even when components fail. This concept appears in elevators, airplanes, and power systems, but it also emerges in robotics, where it plays a key role in design thinking.

FTC Robotics and Graceful Failure

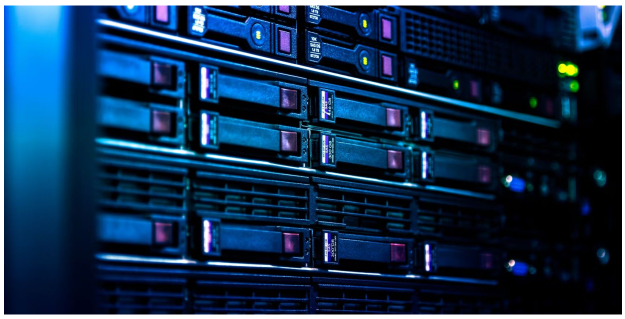
FIRST®

FTC (FIRST Tech Challenge) is an international robotics competition where student teams build and program robots to perform specific tasks in a dynamic environment. The trial-and-error nature of robot development provides a real-world microcosm of engineering practice: testing, breaking, redesigning, and iterating.

In FTC, passive gravity-based claws are commonly used. Though simple and efficient, the claw tends to jam or fail to release objects properly. Instead of adding complex software solutions, a 4-bar linkage, a mechanical alternative that naturally limited unwanted motion and prevented damage when stressed can be used. The mechanism was designed such that if the actuator failed, the claw would remain closed, securing the object rather than dropping it mid-match.

Another example of “failing gracefully” in FTC is moving away from the rotational “clip” designed intake to a rack-and-pinion setup. The previous mechanism frequently jams and requires excessive driver intervention. Inspired by linear motion systems in industrial automation, the rack-and-pinion setup is simpler, more controllable, and far less prone to unpredictable failure. This solution mirrored real-world design principles: reduce moving parts, isolate failure points, and prioritize predictability.

The Science Behind Graceful Failure



The idea of graceful failure aligns with a fundamental principle in system design: fault tolerance. A fault-tolerant system maintains function despite hardware or software malfunctions. This can be seen in aerospace engineering where redundant navigation systems in aircraft ensure control even if one fails [1]. It is also common in civil infrastructure where earthquake-resistant buildings incorporate shock-absorbing foundations that allow controlled deformation [2]. Additionally, it often appears in computing RAID (Redundant Array of Independent Disks) storage systems that maintain data integrity even if a hard drive fails [3].

In FTC, while life-threatening risks are not present, the same design logic applies. Components cannot be guaranteed to not break during competition, but it can be ensured that if they do, they fail in a way that protects the rest of the system and allows recovery.

Everyday Examples of Failing Well

Fault tolerance doesn't just belong to rocket ships and robots, but it can also be seen in automatic braking systems in cars to detect and mitigate the impact of human error [4]. Controlled failure is also often applied to power strips with surge protection that isolate and absorb sudden voltage spikes [5], and web browsers with autosave features that recover text after a crash. [6]

Educational Impact

FTC teaches students to learn to accept and analyze failure and reshape the approach to both design and teamwork. Instead of attempting to prevent failure, they learn to control behavior when failure inevitably occurs. This shift mirrors a growing trend in STEM education: teaching systems thinking and resilience rather than rigid perfectionism.

Competitions like FTC provide a safe but rigorous environment where students learn from mechanical failure, software bugs, and communication breakdowns. Teams are encouraged not only to solve problems, but to document failures and iterate transparently, skills that extend far beyond the classroom.

Conclusion

Designing for failure may seem counterintuitive, but it is a core aspect of real-world engineering. From robotics to transportation systems, building systems that fail gracefully ensures safety, sustainability, and resilience. FTC reinforces that failure is not the opposite of success, it is often the path toward it. In a world increasingly dependent on technology, understanding and embracing graceful failure is not only good engineering, it's essential STEM thinking.

By Daisy Huo

References:

[1] M. Jackson, Systems Engineering for Aircraft: Fault Tolerance and Redundancy, 2nd ed. McGraw-Hill, 2018.

[2] C. Williams, "Structural Dampers in Seismic Design," Journal of Civil Engineering, vol. 52, no. 3, Mar. 2022.

[3] S. Kumar, "RAID Technology and Data Recovery Mechanisms," IEEE Transactions on Computers, vol. 68, no. 9, Sept. 2019.

[4] K. Bengler, K. Dietmayer, B. Farber, M. Maurer, C. Stiller, and H. Winner, "Three decades of driver assistance systems: Review and future perspectives," IEEE Intelligent Transportation Systems Magazine, vol. 6, no. 4, Winter 2014.

[5] A. Gurevich and A. V. Mamishev, "Power surge protection and safety in consumer electronics," IEEE Transactions on Industry Applications, vol. 41, no. 4, Jul.–Aug. 2005.

[6] Mozilla Foundation, "How Firefox recovers tabs and forms data after a crash" Mozilla Support, [Online]

Thank You!

That concludes the fourth installment of the Penrose Magazine. Thank you so much to everyone who wrote articles for this installment and we hope you enjoyed reading!

Finally, we would like to thank our authors for taking the time to write the articles, as this magazine would not have been possible without them.

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