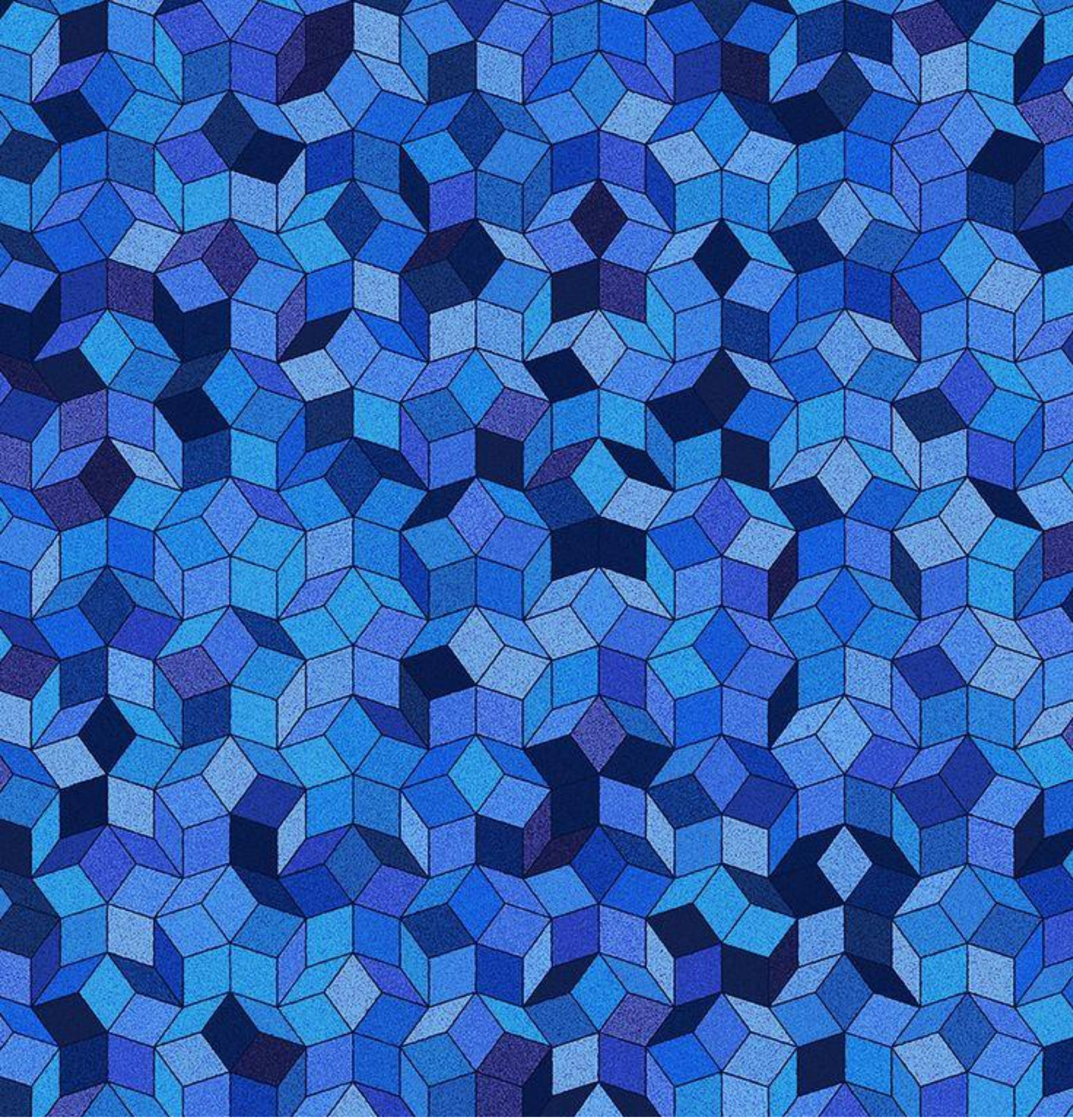

THE PENROSE MAGAZINE

Engineering, Physics, Computer Science

Issue 2, 14 Mar 2025

Welcome to the Second Edition of the Penrose Magazine!

Penrose is our Computer Science, Physics and Engineering 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. In this instalment of the magazine, students have researched a variety of difficult topics from the inner workings of game engines to the effects of supernovae on our understanding of the universe. In honor of Women's History Month, we have included articles about talented women who have made outstanding accomplishments in STEM: Hedy Lamarr and Radia Perlman. We hope to continue fostering an environment where people are encouraged to push themselves to create meaningful work and support each other to grow.

Thank you so much for choosing to read Penrose and we hope you enjoy.

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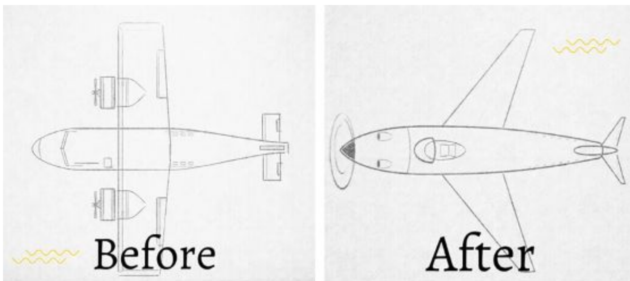
What Hedy Lamarr Means to Science

Throughout all of history, when it came to women, beauty was seen as more of an asset than intelligence. This is the kind of discrimination that Hedy Lamarr was subject to, even when her findings arguably changed the course of the whole world. She was born Hedwig Eva Maria Kiesler on 9th November 1914 in Vienna, Austria, and she is found to be one of the most inspiring women to have lived. [1]

Throughout her childhood, Lamarr's parents fostered a home where she could aspire to be exactly who she wanted to be. Her father would discuss the workings of huge machines with his daughter; she became a young mechanic at the age of 5 where she was taking apart and reassembling her toys to marvel at their working parts. On the flip side, her mother was a pianist. Hedy Lamarr took part in piano and ballet lessons from a young age. [2]

Despite her variety of influence from her parents, Lamarr's intelligence was disregarded as soon as she was scouted at the age of 16 by director Max Reinhardt, later gaining recognition for her role in the controversial 1932 film, “Ecstasy”. After filming this sexually charged film, her unhappy marriage to Fritz Mandl ended and she fled to the United States under the name Hedy Lamarr. She became an immediate box-office sensation on the release of her first American film, “Algiers”. Lacking the support or equipment to fuel her innovative mind, Hedy soon found her achievements to be worthless: “Any girl can be glamorous. All you have to do is stand still and look stupid.” [3][4]

So how was she able to break free from being an idol? Simply put, she dated Howard Hughes who helped her by providing her with a set of equipment that she could use on set and between takes. Hughes took her to see his airplane factories while introducing her to the many scientists behind the processes. She soon aspired to create faster planes to sell to the US; famously, she bought a book of fish and one of birds to help her assimilate a new wing design. She brought her sketches to Mr. Hughes who marveled at her. She had mused on the structure of a bird's wing. She saw the cohesion in the animal's appearance, where everything came from one small point - the beak - and gradually got large towards its rear. She used this to create streamlined planes, allowing the air particles to glide down the plane rather than hit a sharp protruding wing, giving the particles a path to travel down the body of the plane, rather than being forced to come to an abrupt stop. Lamarr's mind did not only help the world then, she went to create an upgraded traffic light and a tablet that dissolved in water to create a carbonated drink.



These were not even her most significant or complicated inventions; in 1940 Lamarr met George Antheil at a dinner party. He was known for his writing and influence on films and music, yet he also shared the same inventive mind as Lamarr. Antheil commented “Hedy said that she did not feel very comfortable, sitting there in Hollywood and making lots of money when things were in such a state.” [5] They soon began to come up with ideas to battle the axis powers. Lamarr was worried about the news of the sinking of the SS City of Benares - a ship that had been torpedoed when travelling from England to Canada; the pair decided to act.[6] They soon created the "Secret Communications System” in 1942; the system prevented the messages being transmitted from being intercepted through the manipulation of the radio waves. It used “frequency hopping” among the radio waves, with the transmitter and receiver “hopping” to the new frequencies together. This allowed the torpedoes to find their intended targets with ease and without the axis from finding them easily.

Wi-Fi also works in the same way as this communication device, which Lamarr set the basis for. The frequency-hopping spread spectrum (FHHS) allows signals to be transmitted in different frequency channels, preventing any kind of interference with the data as each channel would only allow a set number of signals travelling through it per second. [7] This led to a clear set of data being able to be transmitted wirelessly, benefiting this communication system, but also easing the modern world in our communication today.

Lamarr and Antheil sought military support and a patent, and, while being awarded a US patent, the Navy ruled against the implementation of their communication system. Hedy Lamarr then channeled her war efforts elsewhere by selling war bonds. Meanwhile, Lamarr's and Antheil's patent expired before any of them could earn a penny from it; she went back to accumulate awards for her films until 1958. Her career in film began to decline after the

1950s, and she published a best-selling autobiography in 1966, “Ecstasy and me.” [8]

It wasn't until 1997 that she was recognized by the public for her genius when The Electronic Frontier Foundation jointly awarded Lamarr and Antheil with their Pioneer Award for her creation of "frequency hopping” that has an estimated worth of $30 billion. [9] She also became the first woman to receive the Invention Convention's Bulbie Gnass Spirit of Achievement. Sadly, Hedy Lamarr died in 2000, but her efforts did not stop being commended, being admitted into the National Inventors Hall of Fame for her frequency hopping technology in 2014. Her achievements have led her to be named “the mother of Wi-Fi" along with GPS and Bluetooth.

Hedy Lamarr shows the world that one can do just about anything that they put their mind to. Lamarr's work with radio waves and frequency hopping allowed our society to modernize and to advance technologically. We would not have had mobile phones or accessible communication without her ingenuity. I hope that she remains an inspiration to women across the globe and remains a symbol of perseverance as we continue to muse on Lamarr's work as a basis for future technological discoveries.

By Rosalia Bialek (Y11)

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Spanning Tree Protocol : The Groundwork of Networking

The Internet is a crucial part of the modern world, used for communication, education, business, etc, but the seamless connections we experience now did not always exist. Contrary to popular belief, the internet wasn't immediately popular with the average consumer when it was first created. The first foundations for the internet were invented in the 1960's by ARPANET, but it wasn't until the 1990s that the Internet was made mainstream through the introduction of web browsers such as Mosaic or Netscape Navigator [1].

Simultaneous to the development of the internet, local Ethernet networks which were primarily used to create local area networks (LAN) encountered a problem: network loops. Network loops cause extreme network traffic due to information looping instead of stopping once it reaches its destination [2]. This led to slower network connections which in some cases can even lead to network failure, resulting in what is known as a broadcast storm. This continued until an MIT researcher, Radia Perlman, was able to prevent network loops occurring on these local Ethernet networks by inventing the Spanning Tree Protocol (STP). The advancements STP made to networking later on contributed to turning the Internet into what it is today.

Radia Perlman is an American engineer and mathematician from Portsmouth, Virginia. Perlman studied at Massachusetts Institute of Technology, obtaining a Bachelor's degree in mathematics in 1973, a Master's degree in mathematics in 1976 and a PhD in computer science in 1988 [3]. Throughout her career, Perlman has worked at Sun Microsystems, BBN as well as taught at Harvard and the University of Washington, but is most known for creating STP whilst at Digital Equipment Corporation. In 1985 while working at Digital Equipment Corporation, Perlman created STP as a way to improve how information is routed within a network [3].

Data is sent across a LAN in segments of data - known as frames - rather than as a whole. This is achieved in a process called framing which encapsulates the data into frames which contain the source and destination mac address of each frame [4]. These frames are then sent between switches, a device used to connect networked devices in a LAN, which use the mac addresses attached to the frames in order to forward them to their destination. Between each of these switches, there are multiple paths each frame could be forwarded, allowing frames to still have a route in case one path becomes busy or unavailable. Although this is helpful with efficiency, having multiple routes available can cause data to take unnecessary paths or even become caught within a loop.

STP works at Layer 2 of the Open Systems Interconnection (OSI) model [5]. Layer 2, also known as the Data Link Layer, allows data to be accessed by upper layers through framing and controls how data is received and stored [4]. STP selectively chooses paths to block while it monitors the entire network, ensuring the prevention of any loops. This is done by assigning a switch, typically the one with the lowest bridge ID, in the network to be the root bridge - other switches in the network use it as a reference to calculate the shortest path, determined by the link speed, through which frames can be forwarded to their destination [5].

After the shortest path has been calculated, STP assigns different roles to each port on each switch using a set of states: blocking state, listening state, learning state, forwarding state, disabled state [5]. Ports in the blocking state will be unable to forward frames to prevent loops from occurring. Ports in the blocked state will also enter the listening state to determine whether they should forward the frame instead of remaining blocked, and if so they are put in the learning state which prepares them to do so by learning mac addresses. The forwarding state has the opposite effect of the blocked state and is applied to ports on the route of the shortest possible path, allowing the data to move forward. Finally, the disabled state is applied to ports that have no participation in the forwarding frames down the shortest possible path.

STP has a plethora of positive impacts on networks - improving performance, reliability, and security - however there are areas where STP has proven to be limited or even detrimental. One of these limitations is the speed at which STP is able to adapt to changes that have occurred in the network, often leading to network delays or disruptions. This can also be caused by the use of a single root bridge throughout the entire network, which could also lead to the entire network becoming unstable in the case of an error with the root bridge.

Newer versions of STP such as Per VLAN Spanning Tree (PVST) and Rapid Spanning Tree Protocol (RSTP) have been able to overcome these limitations. PVST achieved this by operating a separate instance of STP at each Virtual Local Area Network (VLAN) allowing independent changes at each VLAN to not affect the entire network, allowing quicker convergence times, and for the network as a whole to still function if one root bridge fails.

RSTP achieved this by using different states from STP : discarding state, learning state, and forwarding state. Though the forwarding state and the learning state have the same functions as with STP, the discarding state is a new state which combines the blocking and listening states from STP. This allows a faster convergence time by reducing the number of states ports have to experience.

STP is a fundamental baseline for networking, allowing new technologies and ideas to stem from it that never would have been created otherwise. These advancements are the reason we are able to communicate with people - whether that is a few meters away, or on the other side of the planet. Though STP works on layer 2 and modern networks are now moving towards layer 3 solutions, the research done with STP has been invaluable to creating more advanced networking protocols and furthering networking as a whole.

By Eleanore Shiner (Y12)

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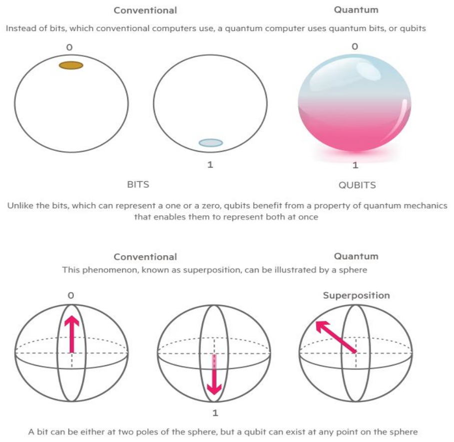
Current Headlines

Microsoft unveil their first Quantum chip: The Majorana 1

In February, Microsoft unveiled their first quantum chip, Majorana 1, which is built on a new topological qubit infrastructure. Topological qubits store information in the unique properties of Majorana zero modes. These zero modes are exotic quantum states that emerge in supercooled superconducting nanowires made from Indium Arsenide paired with an Aluminium superconducting layer. This design helps protect the qubits from environmental noise, making them more stable and less error-prone than conventional qubits, a breakthrough that could address one of quantum computing's biggest challenges. Currently, Majorana 1 operates with only 8 qubits, but Microsoft claims its design is far more scalable than existing architectures with the company hoping to surpass Google's Sycamore chip (which utilised 53 qubits), aiming to build a quantum processor with 1 million qubits.

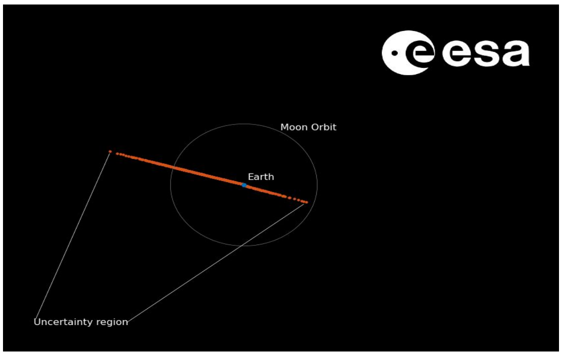
Microsoft(2025,Feb.19). Microsoft's Majorna 1 Chip *[Online]*



Asteroid 2024 YR4's Impact Risk Plummets

Discovered in December of 2024, Asteroid 2024 YR4 was predicted to hit earth in 2032 with a probability over 1%. This probability increased to 3% by February 2025, making it the highest recorded probability for an asteroid of its size. However, not long after new data was recorded the probability dropped to approximately 0.001%. This rapid change was due to uncertainty caused by limited data, making the asteroid's orbit difficult to predict, but as more observations were made its path became more clear. The chance of a possible collision with Earth is negligible but tracking its orbit has now been made more difficult as it moves away from Earth. This situation has shown the importance of collecting data continuously to gain a more precise understanding of any outcome.

ESA (2025, Feb. 25). Asteroid 2024 YR4 No Longer Poses Significant Impact Risk [Online]

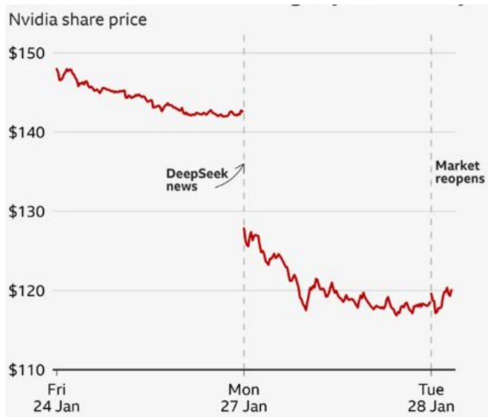


Current Headlines

Deepseek enters the LLM space, disrupting the Western AI market

In January, Chinese AI startup DeepSeek, a GPT-like chatbot, experienced a boom in popularity, quickly surpassing ChatGPT in popularity. Claiming to have developed it with just $5 million compared to GPT-4's $100 million budget, DeepSeek caused shockwaves throughout the western AI market. This led to a 18% drop in Nvidia's stock and a $1 trillion market loss for U.S. tech companies as investors placed their confidence into China's cheaper development process instead of established Western models. While DeepSeek's model didn't sustain long-term success, it reaffirmed China as a huge player in AI development and raised questions over whether US companies such as Nvidia are overcharging for their AI-related products.

Forbes (2025, Jan. 28). Deepseek has disrupted AI - What it means for you [Online]



China's Successful Test of a 66-Satellite Space-Based Cargo Tracking System

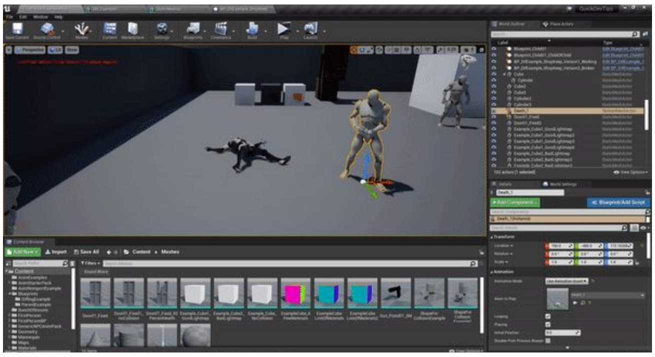
In 2020, China launched a system designed to track cargo around the world and recently completed its testing phase. The system consists of a network of 66 low cost nanosatellites that enable smooth data transmission regardless of any signal interference. This will allow millions of shipping containers to be tracked in real time and can differentiate between different types of transport based on the cargo's speed. This marks a significant advancement in global tracking, enhancing security and efficiency whilst remaining cost efficient.

IE (2025, Mar. 1). China's Successful Test of a 66-Satellite Space-Based Cargo Tracking System [Online]

How Game Engines Work

As technology advances, we are provided with an ever increasing amount of tools that help us complete numerous tasks. These tasks can range from iterating through billions of possibilities to find combinations of materials that make a perfect compound for rockets, to simply making a game. Contrary to popular belief, games are one of the biggest industries on the planet. This has driven people to make products more efficiently while still keeping the high quality achieved by programming everything manually. This is how the idea for game engines was formed.

Game engines were aimed to help the programmers skip the area of development that included all the basics such as colour display, matrices, vector management, collision, etc.. This allows programmers to focus on improving the actual gameplay or mechanics of the game. The core functionality of game engines may include: a rendering engine for 2D or 3D graphics, a physics engine or collision response, animation tools, artificial intelligence, and audio engines [1]. This allows game engines to make the creation process easier by providing reusable software components inside an Integrated Development Environment (IDE).

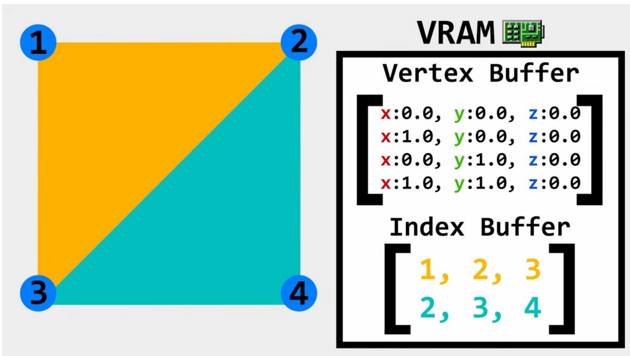


All game engines use some form of interface that allows them to render graphics more easily. Examples of such interfaces are: OpenGL, DirectX 11, Vulkan, DirectX 12, the last 2 of which are modern but fundamentally have the same purpose. These applications are known as graphics Software Development Kits (SDKs) or graphics application programming interfaces (APIs) [2].

Graphics API is a program library designed to aid in rendering computer graphics to a monitor. This typically involves providing optimized versions of functions that handle common rendering tasks. When an image is displayed on a monitor it is rendered on a back buffer. Before it can be displayed all the data given has to be rendered first, only then can the back buffer be swapped with the front buffer (what you see on the screen) [2]. Though It is possible to write a gaming engine without them, it will require a custom counterpart.

These APIs can be used to display almost any shape. This works by breaking them down into triangles and storing the coordinates of unique vertices. When displaying any object the data goes through a graphic pipeline. The pipeline consists of an input assembler, vertex shader, pixel shader and output merger. The first stage prepares the inputs by changing their format from raw data supplied by clients into a standardized internal representation of data understood by the API [3].

The data (e.g. coordinates) then gets mapped onto the screen in the vertex shader phase in which 3D vertex coordinates are mapped onto a 2D plane. Lighting calculations are then used to determine how light appears at each vertex before applying textures to the models [3]. Following the vertex shader phase, data will undergo the pixel shader stage which includes Graphical Processing Units (GPU) rendering an image and processing all vertices, whilst simultaneously rendering all the pixels using an algorithm called Single Instruction/Multiple Data [3]. In the output merger stage the shapes are merged with the back and depth buffers. Finally, the back buffer is swapped with the front buffer and the image is rendered.



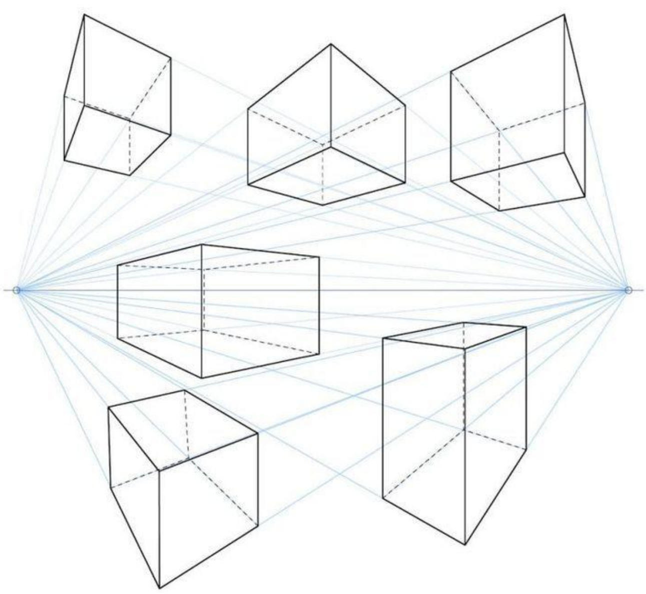
3D games require a way to control what is being shown on the screen. The screen, camera and perspective are represented as matrices, which due to not being commutative, have to be updated before everything else in order to properly render an image. This causes rendering to require extensive linear algebra as well as computer science to be applied in order to achieve adequate results.

Collision detection and rigid body dynamics, known simply as 'physics', are provided by physics SDKs such as: Havok; a popular industrial-strength physics and collision engine, PhysX; a multi-physics engine that simulates autonomous physics, and Open Dynamics Engine (ODE); a open source physics engine used to simulate rigid bodies physics and detect collisions [1]. It requires a significant amount of math to program physics in the game engine.

In order to move a basic object (e.g. a cube) either kinematics or forces can be used, both of which require intermediate physics knowledge despite having useful tools such as physics SDKs [4]. Though there are many physics game engines which allow for more complicated physics, it is important to note that game engines typically contain their own built in physics.

When displaying graphics some computers struggle to keep up with the constant updates that occur on screen. To accommodate for this, a front buffer and a few back buffers were applied to the game engines allowing consecutive graphics to be presented more fluidly in a process known as double buffering. Back buffers are used to copy the information from the front buffer before the program makes changes on the back buffer. After all the changes have been made, the front buffer swaps places with the back buffer [5].

Another optimization method is not displaying objects that are outside of the camera's perspective and don't have a function. For example, when displaying two cubes in 3D space and one of them is behind another one there is no need to map hidden vertices and lines on the screen. To solve this problem the hidden-line removal algorithm is used by computing depth values and removing lines hidden by other surfaces [6]. This allows game engines to run more efficiently and to prioritize more important tasks as well as for smoother graphics.



Game engines require deep understanding of how to make the game and despite providing incredible functionality. However, for some companies or teams, there are still limitations. When developing a game, specific functionality, which is not provided or supported in any available game engines, might be needed. For example, when making a game takes input from a musical instrument (eg. what string was pressed down on a guitar) a customized game engine might be required.

Though the process of creating game engines from scratch can be immensely time consuming, it can provide applications that are perfect for whatever purpose it is needed for. This also allows the game engines to be changed or adapted in case additional functionality is required or a bug needs fixing. Additionally, some programmers may create their own game engines as an opportunity to practice and learn. However, beyond this it is uncommon for original game engines to be created.Overall, the evolution of game engines revolutionized game development by providing the majority of required tools and helping programmers focus on how to make games have a more immersive experience rather than on building up the basics. As we improve on the technologies that go into game development, we can further enable the creation of increasingly more complex and enjoyable games.

Image: Unreal Engine 4 UI and models(put this in the graphics section)

By Denys Zazuliak (Y12)

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The Effect Of Supernovae On Our Understanding Of The Universe

Supernovae (hereafter SNe, SN for supernova) form in multiple ways. They add enriching elements to the clouds of dust and gas surrounding them and produce shock waves that compress this dust and gas to aid the formation of new stars.

Types of Supernovae [1]

There are two types of SNe and they are categorised by the method by which the SN is formed. SNI are hydrogen-free. They are categorised into three subcategories. Type Ia SNe are attributed to the thermonuclear detonation of white dwarf stars and leave no stellar remnant. Type Ib/c SNe are formed when massive stars undergo core collapse after losing their hydrogen atmospheres. The second type: SNII, are attributed to the core collapse of massive stars and are responsible for the formation of neutron stars and Black Holes.

Formation of Supernovae [2]

The formation of type Ib/c SNe begins with a drop in outward pressure due to the slowing of fusion within the star. This causes the star's core to condense under gravity. To outward appearances, the star will begin to grow and swell into a red supergiant. However, within the star, the core shrinks and collapses until the pressure within the core increases to a critical level, restarting nuclear fusion. This cycle continues until the core is composed largely of iron and therefore can no longer sustain star fusion. The core then collapses fully and, in a microsecond, the core temperature drastically increases, reaching temperatures in the region of billions of degrees Celsius. The core becomes so compact that the iron's nuclear repulsive force creates an outward recoil force causing the star to explode in a SN.

Type Ia SNe are formed when, in a binary system, a white dwarf, with a strong gravitational field, pulls material from the second star, if the two bodies are close enough together. If the white dwarf then proceeds to take on enough mass it will surpass the Chandrasekhar Limit (the theoretical maximum mass that a white dwarf can have and still remain a white dwarf). It is at this point that the pressure in the core increases and runaway fusion begins, causing the star to detonate in a thermonuclear SN.

In most cases, the only evidence that remains of a SN is a spinning neutron star which radiates a steady stream of radio waves, or in a more specific case regarding pulsars (rapidly rotating neutron stars that emit mainly radio waves at rates of up to

one thousand pulses per second) in intermittent bursts. However, there is another outcome for the material left behind ten solar masses. This causes the core left behind to collapse under its own gravity and become a black hole.

Uses of Supernovae in Cosmological Discovery [3]

Cosmologists and astrophysicists discovered that SNe can be used to measure distances to much higher degrees of accuracy than previously possible and different types of SNe, due to differing properties, can be utilised in varying ways. Type Ia SNe are empirical tools due to their intrinsic brightness that makes them sensitive probes of the cosmological expansion. Through observations of type Ia SNe, teams of cosmologists traced the expansion of the universe to a time more than 60% of the age of the Universe. These observations included results that indicated an accelerating expansion of the Universe which, at present, is best explained by a cosmological constant or other form of dark energy.

SNII can also be used to measure distances independent of the extragalactic distance scale, which is a series of techniques used by astronomers to determine the distance of cosmological bodies when traditional methods cannot be used.

One of the main tests "in the repertoire of the cosmologists is observing how a standard candle dims as a function of redshift" [3]. In this quote 'standard candle' refers to an astronomical body with known or accurately predictable luminosity whose dimming can be used to help determine cosmic expansion.

SNe are preferred over previous methods, using bright galaxies, due to their intrinsic brightness, allowing them to be observable in the distant Universe, ubiquity (they are visible both in the near and distant universe) and their precision with type Ia SNe providing distances with a precision of approximately 8%.

Type II Supernovae and the Expanding Photosphere Method [3]

SNII (the result of the explosion of massive stars) have varying brightness but a method called Expanding Photosphere Method (EPM) can be used to estimate distances

with ~ 10% accuracy. EPM (developed by Kirshner and Kwan [4]) uses the observed size, velocity, and temperature of the explosion to determine distance. EMP assumes that SNII radiate as dilute blackbodies.

$$t = D\left(\frac{\theta ph}{vph}\right) + t_0$$

Where t is the time elapsed since the explosion that occurred at t_0, D is the distance to the SNe, v_{ph} is the observed velocity of material at the position of the photosphere and θ_{ph} is the angular size of the photosphere of the SNe and can be calculated via the equation:

$$\theta ph = \frac{Rph}{D}$$

Where R_{ph} is the radius of the photosphere.

These equations are used in the EPM to calculate the distances to the SNe.

Type Ia Supernovae as Standardised Candles [3]

Type Ia SNe provide much more accurate

distance measurements compared to previously used galaxy methods. They offer measurements with about 6-8% uncertainty.

Type Ia SNe can be used as extragalactic distance indicators due to their standardised candle properties. By the late 1980s/early 1990s, it was argued by scientists from the University of Basel, amongst others, that the vast majority of

true type Ia SNe had incredibly similar light curves, spectral time series and absolute magnitudes. From these observations type Ia SNe were coined “the best standard candles known so far” by Branch and Tammann in their 1992 review [5]. The methods outlined in Schmidt and Perlmutter’s paper include using the known properties of type Ia SNe to then compare with observed data and calculate distance based off of redshift and changes in the known properties.

In conclusion, the combination of type I SNe and SNII allow cosmologists to obtain extragalactic distance measurements to much higher degrees of accuracy. These measurements provide data crucial to many other strands of astrophysics, constituting the furthering of astrophysical discovery.

By Charlotte Reynaert (Y12)

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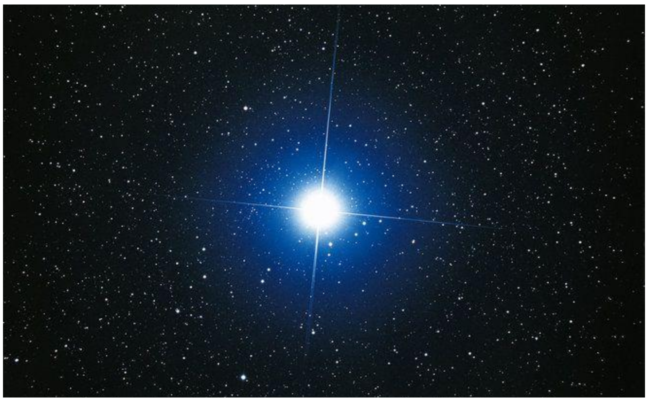

Siriusly Fast: A 5-minute Round Trip With Lorentz Fitzgerald

What if you could take a quick trip to another galaxy and be back in time for dinner? Sounds impossible but special relativity tells a different story.

The famous Twin Paradox describes what would happen if one twin stayed on Earth while the other travels at near-light speeds—when they return, the traveler has barely aged, but centuries have passed on earth. This isn't just theoretical; experiments with high-speed muons (one of the fundamental subatomic particles) show they live much longer when moving close to c, proving time slows at high speeds. Hypothetical particles called tachyons are believed to be able to travel faster than light. Although their existence has not been confirmed by experiment, it seems to be in line with the theory of relativity, which was first believed to only apply to particles moving at or slower than the speed of light. Wormholes may allow us to cheat the speed limit by bending space itself. While these ideas remain speculative, they all hint at a universe where motion through space and time is much stranger than our everyday experience suggests. Near-light-speed travel could shrink the galaxy, change our perception of time, and make distant stars just a short ride away—at least from the perspective of the traveller.

According to the theory of relativity, nothing with a mass can ever truly travel at the speed of light; only massless particles can. This is because of Einstein's equations, stating that an object's energy consumption increases exponentially as its speed approaches the speed of light (299 792 458 m/s). This means that pushing a big item to the speed of light would require an infinite amount of energy, but the particles that make up light, photons, are inherently massless. They are the greatest cosmic speed limit enforcers as of their ability to always travel at precisely the speed of light, regardless of acceleration or deceleration.

Space and Time behaviour at high speeds

The faster you move through the three dimensions that define physical space, the more slowly you're moving through the fourth dimension, time. At near-light speeds, the effects of Lorentz contraction and time dilation can make theoretical fast journeys possible, completely changing how we experience space and time.

Lorentz contraction means that the faster you travel, the shorter distances become, in the direction you are travelling at. Usually a journey to the brightest star in the night sky, Sirius (8.6 light-years away), would take more than eight years at normal rates but from the point of view of the traveller, it can be completed in a matter of minutes. While the astronaut may only experience a few minutes or hours, years or even centuries may pass on Earth due to time dilation, which slows down time inside the spaceship.

L_0 is the original distance, and L is the contracted length observed by the:

$$L = L_0\sqrt{1 - \frac{v^2}{c^2}}$$

The Lorentz Contraction

Space itself contracts only in the direction of motion as an object approaches the speed of light. Length contraction in special relativity occurs only in the direction of motion because of the way spacetime transforms under high velocities. According to the Lorentz transformation, spatial coordinates shift as: Since only X is altered, contraction affects only the motion's direction, leaving y and z unchanged.

$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}}.$$

$$x' = \gamma(x - vt), \quad y' = y, \quad z' = z$$

This happens because: spacetime mixing, invariant spacetime intervals, and experimental evidence. Spacetime mixing causes motion at relativistic speeds to distort time and space, but simultaneity shifts occur only along the travel axis. Invariant spacetime intervals cause the fundamental structure of Minkowski spacetime to ensure contraction only occurs in the moving direction. Experimental evidence causes fast-moving particles (e.g., cosmic-ray muons) observe contracted distances in their motion direction, explaining their extended travel.

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \approx 223$$

As an object approaches the speed of light, the contraction of space occurs only along its trajectory, while any dimensions perpendicular to this remain unchanged. For instance, if a spacecraft were to travel to Sirius at a velocity of 99.999% of c, the astronaut would witness the distance being reduced to approximately 0.012 light-years.

Upon the astronaut's return

If the astronaut were to immediately turn around and travel back in their previous direction, upon reaching Sirius and travel back to Earth at the same near-light speed, the round trip would feel like only 4.6 minutes.

However, for those remaining on Earth, the reality would be quite a different story. The phenomenon of time dilation causes time to stretch dramatically for an observer in a stationary frame. While the astronaut perceives only a few minutes, time on Earth continues at its usual pace, but at a vastly different rate. The journey that feels like only moments to the traveller would, in reality, span 17.1 years from Earth's perspective.

This dramatic difference in observed time illustrates one of the most astonishing effects of Einstein's special relativity where the idea that movement at near-light speeds fundamentally alters the way time and space are experienced. If such interstellar journeys were ever possible, astronauts could venture across the cosmos and return to find that entire generations had passed, making them, in effect, time travellers to the future.

The ultimate thought experiment

An astronaut journeying to Andromeda, located 2.5 million light-years from Earth, at a velocity of 99.999% of the speed of light would experience one of the most extreme effects of special relativity. Due to the effects of the Lorentz contraction, the distance, which would take millions of years to traverse at conventional speeds, would shrink drastically, appearing as only a few light-years. This means that instead of an impossibly long journey, the astronaut would reach Andromeda in just a few decades as measured by the ship's onboard clock.

However, for those still on Earth, more than 2.5 million years would pass. By the time they return, the world they knew would be unrecognizable and humanity as they knew it might no longer exist. This journey, while breathtakingly fast from the traveller's perspective, effectively turns the astronaut into a one-way time traveller to the distant future, showing just how much near-light-speed travel warps our perception of space and time.

To conclude, energy requirements make near-light-speed travel almost impossible with current technology. Theoretical ideas like nuclear fusion drives, antimatter propulsion, and warp drives might one day make this a reality but we are far from this.

By Raiana Nurlan (Y12)

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Thank You!

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

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If you would like to write for the next edition of the Penrose magazine, please email:

Eleanore Shiner (eleshi18@highgateschool.org.uk)

Milan Gal (milgal1112@highgateschool.org.uk)