THE GIST
GLASGOW INSIGHT INTO SCIENCE AND TECHNOLOGY

IN FOCUS

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EDITORIAL NOTE

When we started writing articles and designing themes for the magazine, the future surrounding COVID-19 was uncertain. Vaccine programmes were being run efficiently in countries that could afford them, but new contagious variants were also being discovered. This uncertainty regarding the pandemic has exacerbated mental health issues around the world. Hence, our winter edition has an article that talks about anxiety and other mental health problems. This issue - "IN FOCUS" - has a vibrant collection of articles pertaining mainly to the importance of science in real-life applications. While on page "20", Owen tanner explains how the bizarre mathematical subject of topology has some useful applications in the field of cardiology, on page "16", Callum Wilson explores the connection between quantum computing and machine learning. This issue also showcases some fantastic articles on biological sciences, with Dr Harshi Dhingra talking about the science behind anxiety disorders on page "10" and Denver Fabiano giving us insights about how amazing our immunological memory is on page "04". This November, the world was watching Glasgow, hoping for some decisive actions and decisions to counter climate change. This has motivated us to turn the spotlight on some important social issues. These include how maritime digitalisation impact the environment by Christian Velasco-Gallego on page "14", if the use of animals for science is ethically justified, by Lydia Melissourgou-Syka on page "06". As the new editor of theGIST, I am really excited and proud to share this issue with you, which was made possible by the hard and diligent work of our wonderful team and all our contributors. We would also like to extend our heartfelt gratitude towards Dr Sunny Bains, our mentor who motivated us by showing how rewarding the field of science communication is. Massive thanks to the previous editors, Deep Bandivadekar and Siobhan McGeechan - we hope to continue your amazing work. Finally, a shout out to all our readers, and we hope you enjoy reading this edition!

Sridevi

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A NOTE FROM DR.SUNNY BAINS

I first came across The Gist through the Association of British Science Writer awards: in which Glasgow's entries have always been impressive. Science communication has never been so important as it has been during the pandemic. For Scotland, or any country, to have an informed and intelligent electorate, people must be able to understand basic concepts in science, medicine, engineering, health, and statistics. The Gist is a unique publication created by students from three great universities working together to achieve this goal in a fantastic city.

I hope that readers — regardless of whether they are in technical areas, the humanities, the professions, or other fields — get a feel for the logic of science through reading your articles and enjoy the exploration of new ideas and technologies.

Dr Sunny Bains

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Antibodies: friends with benefits?

By Denver Correia

Denver investigates our personal frontline workers and immunological historians — antibodies — and their underlying potentials and capabilities.

In the wake of the SARS-CoV-2 pandemic, relying on the body's ability to deal with infections has never been more crucial. From deadly viruses to the common cold, each day our bodies are exposed to many different disease-causing organisms. Our celebrations of the efforts and dedication of frontline workers during the pandemic has been significant. In receipt of less recognition, however, has been the hardworking immune defence we have housed in our own bodies. Antibodies, also known as immunoglobulins or Igs, are some of the frontline workers of our own immune systems, protecting us against infections old and new. As our personal team of superheroes, antibodies have many capabilities and potentials. These are discussed in this article.

Antibodies are the immune system's natural police force against foreign organisms; they are large, Y-shaped, protective immunological protein molecules produced by the immune system. Antibodies, as the name suggests, work against 'bodies' — but not our human bodies. Rather, the bodies they work against are foreign particles called antigens. Antigens can come from a range of sources. For example, they can originate in bacteria and viruses, in flower pollen, and in food additives. Our bodies work in a highly-regulated sequence to recognise, evaluate, and counteract the source of these antigens.

Antigens can be broadly classified into three categories depending on their source — exogenous (produced outside the host), endogenous (produced inside the host by viruses and intracellular bacteria), and autoantigens (produced by the host). Antibodies have a unique specificity allowing them to exclusively recognise and stick to only one kind of antigen.That is, an antibody against one type of bacteria won't be effective against another type. Most antigens that our immune system finds and recognises are autoantigens, however, they only counteract exogenous and endogenous antigens, which could cause harm to the body. Interestingly, a fundamental cause of autoimmune diseases such as rheumatoid arthritis and inflammatory bowel disease is the body's own dysfunctional response against autoantigens.

The interaction between antibody and antigen can help to directly 'neutralise' a threat. This can either be done by blocking the receptor or entry pathway which the pathogen uses to enter a cell, or by signalling other parts of the immune system to attack the target. Anti-

Antibodies are the immune system's natural police force...

bodies against a particular antigen remain in a long-term, distant relationship with our bodies even after an infection episode. They form the basis of our immunological memory so that the next time the same antigen is encountered, the immune response can be quicker and more effective. This relationship works on an 'ad-hoc' basis and forms one of the key components of our body's quick immune response during the second and any subsequent episodes of a specific infection.

The development of antibodies starts from antigens themselves — which, arguably, is somewhat ironic. When antigens bind to a certain type of white blood cell known as a B cell, the binding triggers the B cell's division into another cell type called the plasma cell. These plasma cells are the body's antibody production factories, developing and setting off millions of antibodies on their treasure hunt for the source antigen.

Humans have five classes of antibodies — IgA, IgD, IgE, IgG, IgM. These five immunoglobulins are found throughout the body, from the breathing and digestive pathways, to the skin and mucous membranes. Certain antibodies such as IgG form some of the crucial 'early immunological cocktail' that passes over the placenta from the mother to the fetus during embryo development. This is a key formative step required for the complete development of the newborn's immune system.

Determining how long antibodies actively search for antigens is keyin estimating immunity against a given virus or bacteria. Research has proven that antibodies don't have particular expiry dates, and could remain effective in protecting against infection across varying timelines. Topically, the antibodies our bodies produce against COVID-19 are estimated to be effective for between seven months and for the rest of our lives (1).

Our success with vaccines would not have been possible without the fundamental immunological memory that our antibodies offer.

It may seem odd to say that 'antibodies read the news', but there is some truth in this seemingly bizarre statement... Vaccines have been our antibodies' insightful news source, presenting a complex yet distinctive mechanism of tricking our B cells into differentiating into plasma cells and producing antibodies against inactivated foreign particles. Our success with vaccines would not have been possible without the fundamental immunological memory that our antibodies offer.

In terms of their therapeutic potential, antibodies are a useful, non-invasive co-treatment option for a number of diseases. The possibility of using antibody treatment pathways for conditions such as Alzheimer's, rheumatoid arthritis, multiple sclerosis, and even cancer is being explored. The advantages antibodies present are numerous: they include a short production time, relatively low production costs, high stability to pH, high affinity for antigens, and the ability to continuously adapt to changes in antigen structure and offer higher compatibility.

In conclusion, antibodies are our friends with benefits — as the frontline workers of our bodies, they remain on-guard to constantly recognise, evaluate, and counteract infectious agents. Our working relationship with antibodies lasts a lifetime, with immense potential to modify the scope of their functioning for therapeutic advantages (2). After all, why don't ants get sick? 'Cause they've all got antibodies!

Specialist edited by Anastasija Slapina,
copy-edited by Rachel Shannon

Sacrifices in the name of science: is animal use ethically justified?

By Lydia Melissourgou-Syka

A young cancer research student explores the ethics around animal use in scientific experiments — which approach resonates with you?

Two million eight hundred and eighty thousand (2,880,000): that is the number of scientific procedures that were carried out in living animals in the UK in 2020. Quite a high number, right? Yet, the animal use for scientific purposes in the UK has declined by 24% over the past 10 years! Science seems to be moving away from traditional animal testing as technology develops, but those who already have a strong opinion on this topic should be aware that there are valid arguments to support both sides.

...the type of procedures, the level of suffering and the number of animals used each year must be rigorously reported.

The use of living animals for scientific purposes in the UK is regulated by the Animals (Scientific Procedures) Act 1986 (ASPA), which exists to ensure that living vertebrae (other than human) and cephalopods (like octopus and squids) do not undergo unnecessary pain, suffering, distress or lasting harm during scientific procedures. Animals in the UK are quite lucky that the type of procedures, the level of suffering and the number of animals used each year must be rigorously reported. In fact, the reporting of animals for scientific purposes in Great Britain is the most comprehensive in the world! Let's take a closer look at some current statistics to help us understand why animals are needed in science in the first place.

The majority of the research animals employed in the UK last year were used to study the immune system, the nervous system and cancer. Usually, when we hear about animal experimentation, mice come to mind. They are indeed by far the most commonly used members of the animal kingdom in British research centres mainly because they are cheap and offer a relatively accurate reflection of how the human body functions.

Now, bear with me while I throw some numbers at you; 84% of all animals used for scientific purposes in Great Britain last year were mice (57%), rats (14%) and fish (13%). Specially protected species – our beloved pets (cats, dogs, horses), as well as non-human primates – underwent 18,000 scientific procedures last year, amounting to 1% of the total investigations (1).

Now that we have an idea of the type of animals that are used in science and the type of research that they are employed for, let's focus on the hardest and most subjective part: ethics. As with most things in life, there is little room for black and white answers in the realm of ethics and things can turn quite philosophical the more you dive into the whys and what ifs of debatable concepts. However, there are a few popular viewpoints on the use of animals in scientific research, so let's take a look at each of them and see which one resonates with you the most.

Contractarianism

Starting from one extreme on the spectrum of opinions, the contractarian approach in animal ethics bases its arguments on the existence of a "contract" that humans agreed upon a long time ago to allow the prosperity of our species. In essence, after accepting that all beings in nature are in danger of being harmed by others, humans – as a rational species – grouped together and decided that it would be against our chances of survival if we didn't agree not to harm each other. In this view, the rational negotiators of the agreement are also the beneficiaries, since only humans are considered rational. Some contemporary contractarian standpoints argue that the contract could be altered to include those who cannot negotiate for themselves (meaning the animals).

However, as the contractarian approach is based on self-interest, why would someone want to include other species in the agreement?

One possible reason would be based again on self-interest. If we were to consider ourselves the creators of a new society, with no idea of the part that we would play in it or our intelligence level (termed 'veil of ignorance'), it would be to everyone's interest to play fair because we wouldn't want to be harmed if we ended up in the non-rational or minority group. Despite the presence or lack of a 'veil of ignorance', the contractarian approach fails to attribute a moral value to non-human species, as it would only consider them as part of the contract on a self-interest basis. This gives the opportunity to the supporters of this view to sleep well at night when considering animal experimentation, since no rational party of the agreement is being harmed (2).

Utilitarianism

Shifting now a bit more to the centre of the spectrum, the utilitarian approach is slightly more balanced in that it attributes a moral value to all sentient beings that can have ex-

Laboratory mouse by Rama is licensed under CC BY-SA 2.0 FR.

periences — be it human or animals. There are many standpoints in the utilitarian approach, however they all agree that the total amount of benefit or satisfied preferences (what someone wants) should be more than the amount of suffering or frustrated preferences involved. It would therefore be justifiable to allow the suffering of a few if more are going to benefit. Following this line of thought, animal experimentation is only allowed if as a consequence (i.e. the development of a life-saving drug or the understanding of a particular complex disease that could save millions). This view has some logic in it, in that it strives to ensure the maximum good experiences over the maximum bad experiences that can happen. Yet, it follows a 'means to an end' philosophy, not considering the way in which the few are going to suffer for the benefit of the many (3).

The relational view

As the name suggests, this view looks at our moral duty towards animals according to the relationship that we have with them. Pets tend to yield the benefit from that agreement over wild animals or pests for instance because they are under our care and we have a moral duty to ensure their wellbeing. No such duty however exists for wild snakes or rats, which most of us would like to stay as far away as possible! In some cases, we even go as far as killing the rodents that infest our property, so in the eyes of the relational viewers, lab animals (most of which are rodents) do not fall under the scope of our protection. The use of specially protected species on the other hand would be more controversial, as they are considered closer to humans in terms of company, interactions or intelligence. So in summary, as long as we don't have emotional attachments to the animals that are used in scientific research, the relational view accepts it morally. I suppose that Tom is particularly happy with this scenario — poor Jerry!

Animal rights theory

Moving now to the other side of the spectrum, a trending view is the animal rights position, which gives a moral status to the animals, sometimes equal to the one attributed to humans. Despite the presence of various viewpoints, the main idea that this approach conveys is that **animals are born with inherent rights that should prevent us from exploiting them** for our benefit (medicine, beauty, food, breeding, etc.) or killing them. Hopefully you notice the difference of this view to utilitarianism, which allows animal experimentation as a 'means to an end'. On the contrary, supporters of the animal rights theory do not rationalise the sacrifice of animals in the name of science, purely because it violates their right to live and be treated with respect. This view is the perfect example of the phrase 'the end doesn't justify the means'. On the other hand, it would be interesting to consider where we would be right now in medicine without testing the treatments on animals before they are used on humans. Although there are considerable efforts to replace the animals in scientific experiments with in-vitro models (cells growing in the lab) or even computer programmes, we are not quite there yet. That's why there have been compromises by both the UK government and the animal rights activists; the law allows the use of animals in research, however, forces the research centres to perform procedures in the most humane way possible and avoid unnecessary harm and suffering to the animals (4).

Respect for nature

In this final viewpoint – which goes hand in hand with the animal rights approach – respect for nature argues that human intervention to the 'natural way' of things should not be permitted. According to this approach, humans are not superior to animals. Additionally, no species is considered individually, rather as a whole, and it is not acceptable to allow its endangerment because its existence is important for the ecosystem that it is part of. Following the same line of thought, the genetic modification of animals is also not morally acceptable, since 'Mother Nature' did not perform it. Therefore, the use of genetically modified animals for animal experimentation is not ethically justified and should consequently be banned (5).

In summary, the use of animals in science might sound ethically justified to some, acceptable to others (as long as our cute furry friends are not involved in the process) or even utterly gratuitous to those who do not consider animals inferior to humans. However, both animal rights activists and scientists are aware of the ethical issues raised by animal experimentation and both parties agree that an alternative should be sought after when possible. I suppose that, apart from working on alternative methods, acknowledging the sacrifice of those animals for our benefit is currently the humblest thing that we can do. The world community does that by celebrating the World Day for Animals in Laboratories on the 24th of April.

Specialist edited by Annabell Macphee, copy-edited by Claire Thomson

The science of anxiety

Dr. Harshi Dhingra

Anxiety is a feeling of distress or uneasiness everyone experiences from time to time. The feeling is your normal response to stress, uncertainty, or fear of danger. The science of anxiety provides an insight into what goes on in the brain to trigger anxiety and how anxiety disorder sometimes develops as a result.

Anxiety is a feeling of distress or uneasiness that everyone experiences from time to time. The feeling is your brain's normal response to stress, uncertainty, or fear of danger. The short-term response stems from the body's internal fight-or-flight system (1) that activates whenever it senses danger and needs to go into survival mode.

The fear of danger can be real or perceived, and may be accompanied by worry or a sense of impending doom. Although it acts as a protective mechanism most of the time, chronic activation (2) of this built-in “approach” or “retreat” system may lead to chronic anxiety or anxiety disorders.

The science of anxiety provides an insight into what goes on in the brain to trigger anxiety and how anxiety disorder develops as a result. A lot of it has to do with changes in activity in the amygdala (3), the part of the brain’s limbic system that deals with emotions, arousal, and fear-related memories.

Anxiety vs Anxiety Disorders

It's normal to worry or feel anxious when you are faced with a problem, have to make an important decision, or encounter a situation where you are under pressure to perform well, like a job interview or meeting your date’s parents for the first time. The feeling usually goes away once the situation passes, but when a person has an anxiety disorder (4), those feelings don’t dissipate immediately. In fact, they worsen over time.

Anxiety disorders are chronic mental conditions that affect 40 million adults in the United States aged 18 and older each year (about 19.1% of the population) (5). The five main types of anxiety disorders are generalized anxiety disorder (GAD) (6), social anxiety disorder, phobias, obsessive-compulsive disorder (OCD), and post-traumatic stress disorder (PTSD). GAD is the most common and involves persistent worry over life events in general.

People affected by any of these disorders live in a constant state of worry or fear that interferes with daily functioning.

People affected by any of these disorders live in a constant state of worry or fear that interferes with daily functioning. They also have difficulty regulating these feelings or symptoms without drug treatment, behavioral therapy, or alternative therapies.

How anxiety affects the body

Anxiety affects the Central Nervous System (CNS) and other systems in the body. Different sensations or symptoms are triggered in these physical systems:

- Sense of doom, panic attacks (7), headaches, irritability, trouble sleeping, or depression)
- Shortness of breath
- Increased blood pressure, racing heartbeat/palpitations, or chest pain

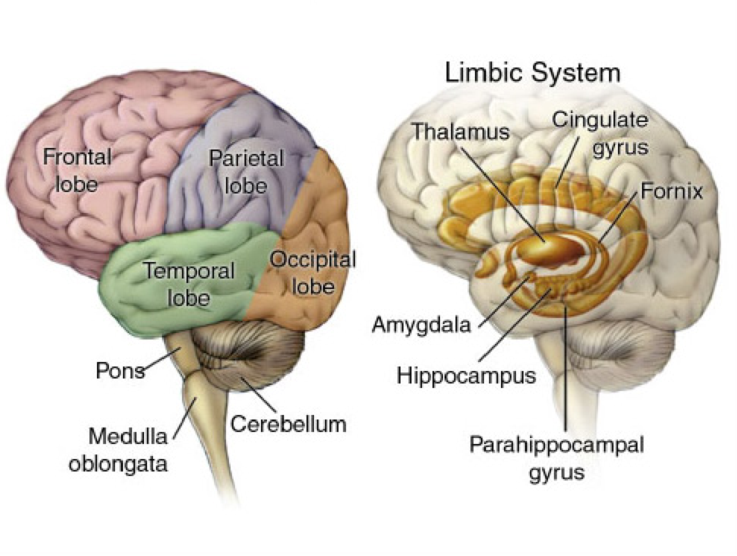
• Stomach aches, nausea, or diarrhea
• Muscle tension, pain, or fatigue
• Reduced sex drive or sexual function

Doctors have identified a range of symptoms that help explain how it feels to have anxiety. Symptoms may depend on the type of anxiety, such as social anxiety (8), which is characterized by an intense fear of being embarrassed or criticized. If you're living with an anxiety condition, you may already be familiar with the following feelings or symptoms that interfere with your daily life:
- Psychological
- Nervous, worried, or afraid
- Tense, uneasy, or on edge
- Fearful that something terrible is about to happen (even in the absence of danger)
- Morbid fear of impending doom, e.g., that you're about to die
- Feeling detached
- Feeling like you're losing control
- Physical
- Chest tightness or pain
- Feeling as if you're choking or out of breath
- Feeling excessively sweaty or cold
- Shaking or trembling
- Numbness or tingling sensations
- Feeling dizzy or as if you're about to faint
- Feeling tired or fatigued, e.g., due to trouble sleeping

...anxiety is thought to happen when signals from the emotional brain overpower the cognitive brain.

The Rational vs Emotional Brain

Cognitive and psychological changes are already happening before you experience the effects of anxiety. By then,



stress hormones such as cortisol and adrenaline, have already flooded the brain. Activities are also happening in the amygdala (9), hypothalamus, and hippocampus in the limbic system. These are areas of the brain that play a key role in anxiety.

Scientists believe that anxiety stems from how the areas of the cognitive and emotional brain interact. The prefrontal cortex (PFC) area of the brain helps process information for rational decision-making, whilst the emotional region of the brain, called the amygdala, detects threats or dangers and triggers fear-related behaviors in response (10).

These are normal functions of the frontal lobe and amygdala in the limbic system. However, anxiety is thought to happen when signals from the emotional brain overpower the cognitive brain (11). The amygdala goes into a heightened arousal state when triggered and sends a message to the hypothalamus to initiate the fight-or-flight response.

People diagnosed with anxiety disorders show more activity or dysfunction in the limbic system. Reduced gamma-aminobutyric acid (GABA) activity is one possible cause of higher activity in the amygdala, as it functions as a natural inhibitor of neuronal activity and helps correct the imbalance in signals between the emotional and cognitive parts of the brain (12).

Experiencing too many fight-or-flight reactions can also lead to long-term activation of the amygdala. Such hyper-activation hinders activity in the prefrontal cortex, making it easier to trigger the amygdala into sending false alarms in response to normal or everyday experiences. This may explain why some people living with anxiety often feel fearful or have panic attacks when there is no real threat or present danger (13).

Being in a constant state of worry or fear also causes stress hormones to continuously flood the brain, causing the brain's threat detector to become stuck in “survival mode” due to over-vigilance. The brain learns to hold onto thoughts or memories that trigger anxiety and this can interfere with rational decision-making, making it difficult for people with anxiety disorders to go about their everyday lives.

For people with anxiety disorders, just about anything that the brain perceives as a threat can trigger a fight-or-flight reaction. Knowing that heightened activity in the emotional brain leads to an oversensitive response, it's no surprise that apart from common triggers such as everyday life stressors, conflicts, or health issues. People with anxiety disorders may also be triggered by

Experiencing too many fight-or-flight reactions can also lead to long-term activation of the amygdala.

seemingly innocuous things like certain smells, sights, sounds, people, or places.

Can Anxiety Disorders be Treated?

Treating anxiety early can help prevent anxiety disorders and other psychiatric disorders, such as depression or substance use disorders (SUDs).

Drug therapy and cognitive behavioral therapy are standard options for anxiety disorders. Doctors commonly prescribe anti-anxiety medications such as benzodiazepines and antidepressants, including selective serotonin reuptake inhibitors (SSRIs). Treatment is intended to manage symptoms and allow patients to go about their daily life —but unfortunately, there is currently no cure for most anxiety disorders.

Aside from drug therapy, some patients also benefit from Transcranial Magnetic Stimulation (TMS), psychodynamic therapy, and hypnotherapy, which have been shown to have some success at alleviating pathological anxiety. For general anxiety, alternative therapies include stress management and relaxation techniques, such as meditation, mindfulness, yoga, and art.

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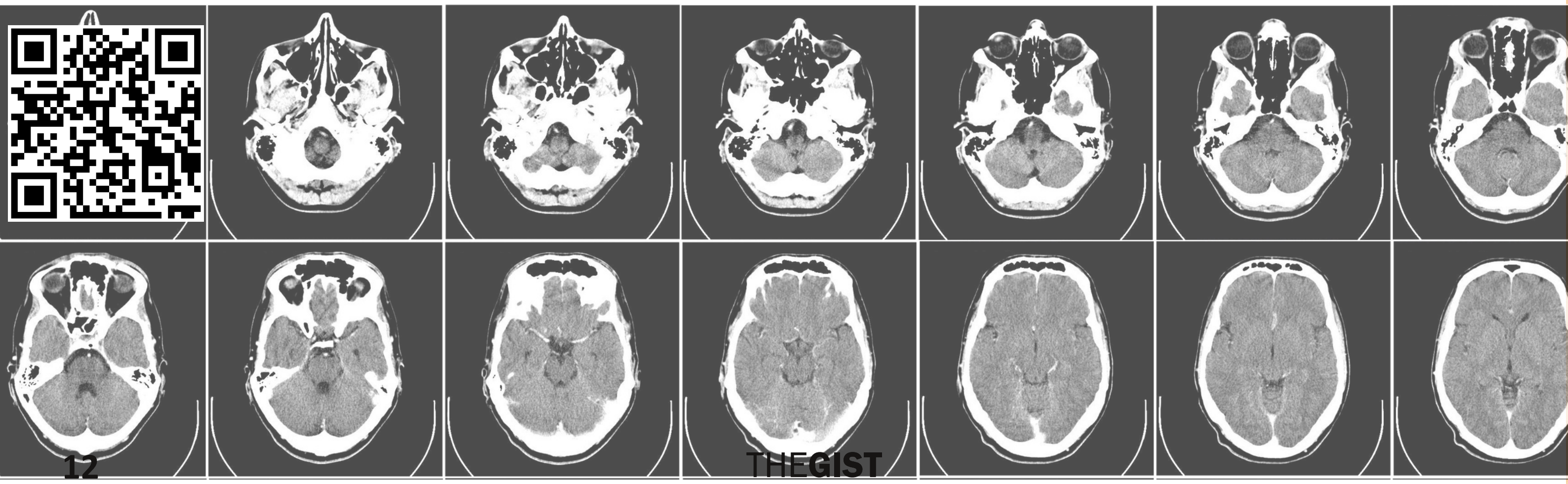


The brain learns to hold onto thoughts or memories that trigger anxiety and this can interfere with rational decision-making, making it difficult for people with anxiety disorders to go about their everyday lives

Maritime digitalisation and its impact on sustainability

By Christian Velasco-Gallego

Can digitalisation facilitate the Net Zero goal within the maritime industry?

In 2018, 1,076 million tonnes of greenhouse gases were emitted by international shipping. This is a growth of around 9% since 2012 and is projected to increase substantially by 2050 (1). For this reason, the maritime industry became a focal point for discussion at the UN Climate Change Conference COP26. Countries deliberated over establishing more ambitious targets with select nations signing a declaration of zero shipping emissions by 2050 (2). However, progress towards the reduction of carbon dioxide emissions, or decarbonisation, within the maritime sector is perhaps the industry's greatest modern-day challenge.

Both academia and industries are investigating novel technologies that will make decarbonisation more feasible. These technologies prioritise energy-saving solutions, renewable energies, alternative fuels, vessel speed reduction, and incorporating digital technologies. However, a transition towards the latter must be accelerated in the sector to enhance operational efficiency and direct shipping along this decarbonisation path.

The maritime sector is a conservative one, disinclined toward change they perceive as a risk to the sector model and not as an opportunity. Digitalisation was initially considered as a potential hazard rather than an advancement. However, practice, as well as parallel industries such as aerospace and railway, has proven that the digital process not only generates innovation, efficiency, and service improvement, but also sustainability. Numerous opportunities arise from emerging technologies that help facilitate the net zero goal. Such opportunities in the maritime sector include the implementation of Internet on Ships, the development and operations of autonomous ships, the increased interest in health monitoring and management tools, and the necessity to guarantee environmental management and resource efficiency.

Smart Maintenance within the maritime sector can be roughly defined as the analysis of data obtained from multiple sources...

Of course, these opportunities are only possible when maritime stakeholders become critical of their current strategies. Strategies that need to be adapted in a way that ensures efficient and sustainable operations whilst simultaneously maintaining increased competitiveness. In fact, introducing new and novel technologies can assist in this regard. Smart Maintenance, for example, is fuelled by digitalisation and has undoubtedly proven to be beneficial in enhancing ship Operations & Maintenance (O&M) activities; increasing vessel efficiency while safeguarding cost-effectiveness (3).

Smart Maintenance within the maritime sector can be roughly defined as the analysis of data obtained from multiple sources (e.g., Internet of Ships, crew members availability database, asset inventory lists, and so on) to visualise, automate, and optimise decision alternatives in relation to O&M activities through software systems (4). It determines the condition of the marine machinery through data analysis to promote an improvement in maintenance actions. With an increase in data accessibility through digitalisation, data-driven models can be widely applied, and thus expand within this industrial sector concepts like Smart Maintenance and those akin to it. Smart Maintenance is a field that demonstrated its ability to enhance efficiency, reliability, profitability, and performance of a vessel, while facilitating the emissions reduction all along its operational lifetime (5).

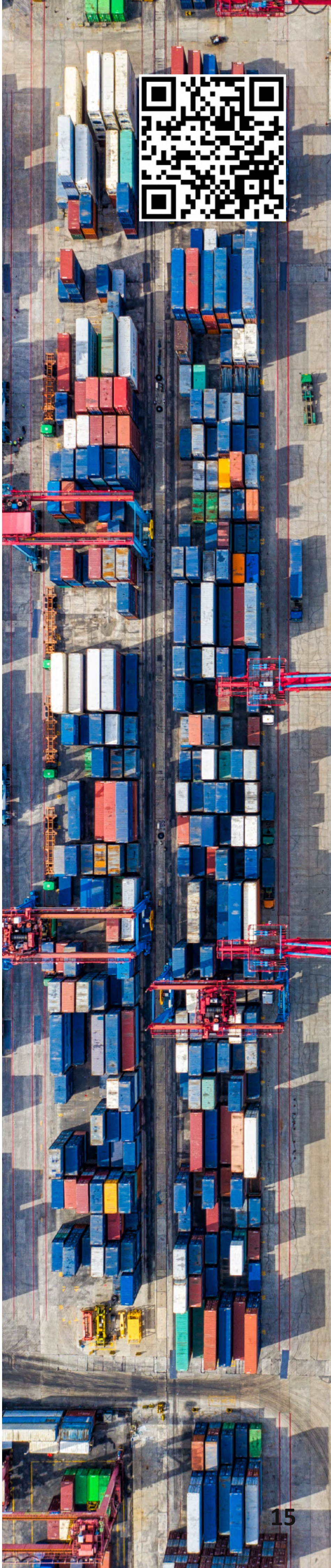
...the digital process not only generates innovation, efficiency, and service improvement, but also sustainability.

Digitalisation initiatives and data sharing can also provide new opportunities by connecting carriers, ports, people, and infrastructure through emerging technologies; technologies which enable the development of other smart concepts to the same degree of Smart Maintenance. These concepts include Smart Ships, Smart Transportation, and Smart Ports. Traditional ships will be transformed into Smart Ships that are either partially or fully automated. Smart Transportation implements computing, telecommunications, radiolocation, and automation technologies so that performance, management, and security in transportation systems are enhanced. Similarly, a combination of wireless devices, smart sensors, actuators, data centres, and other Internet of Things (IoT)-based port devices, will constitute the main infrastructure of smart ports, thus providing port authorities with more reliable information and new services offered to their clients.

While such concepts may initially sound futuristic, they are starting to become a fact. The port of Rotterdam, for instance, utilises IoT-based sensors for enabling augmented intelligence and generating digital twins, while the Seville port exploits mobile network technology for monitoring goods and traffic in the port in real time (6).

Though not without its challenges (cyber security threats, mid-ocean internet connectivity issues, and unreliable data being notable trials to contend with), the transition toward maritime digitalisation is foreseeable and essential, with the benefits significantly outweighing the difficulties. Given all these emergent technologies, there is no doubt that the maritime industry as we know it today will be near unrecognisable in the coming years. The question is, can digitalisation be the main driving force behind the industry's more sustainable future?

Specialist Editor: Lauren Shotter
Copy Editor: Dzachary Zainudden



Quantum computing and machine learning: a mutually beneficial partnership

By Callum Wilson

Specialist Editor: Callum Duncan
Copy Editor: Sridevi Kuriyattil

Combining quantum computing with artificial intelligence sounds like a dangerous game, but Callum will consider how this partnership could be useful.

The phrase "artificial intelligence" has been circling in the public domain for several decades and inspires fear and awe. When we think of artificial intelligence (AI), many ideas come to mind, such as people being automated out of jobs, Asimov's laws of robotics, Terminator, Hal, and other dystopian scenarios pushed in films and other media. Despite this doomsday perception, various forms of AI have now infiltrated everyday life, whether we like it or not. This can bring real benefits but should be used carefully and not seen as a magic solution to all ills (1). We are now perhaps witnessing a similar story to the development of AI in the recent hype around quantum computers. Previously only viewed as ideas in theoretical physics, quantum computers now exist and run their own algorithms. As with AI, some see this as excellent; others panic. People might imagine scenarios where the knowledge of every programmer becomes obsolete as every computer is replaced with a quantum computer or that a hacker will implement Shor's algorithm and break the cryptographic methods currently used to keep the internet secure. Again, despite the trepidation from some, the development of quantum computers carries on.

Given the similarities in the perception of the fields of AI and quantum computing, it is interesting to look at how they can work together. The phrase "quantum artificial intelligence" can easily conjure even more dramatic images of the apocalypse than just quantum computing or AI. However, when we look at quantum AI through a more realistic and critical lens, we see that this combination can be very useful. Google even has a team dedicated to researching quantum AI and providing services for current applications of such technology (2). Here we will explore the synergies between the fields of AI and quantum computing and consider how this can be useful.

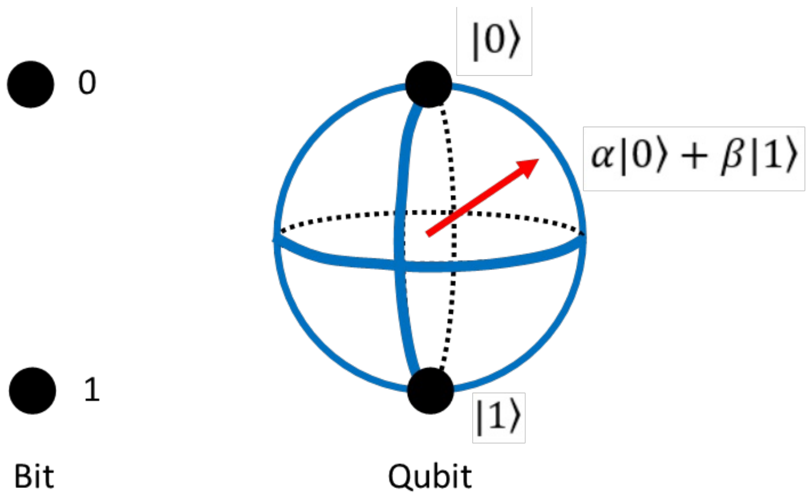
Previously only viewed as ideas in theoretical physics, quantum computers now exist and run their own algorithms

Before diving into quantum AI, I will make a distinction between "classical" computers and "quantum" computers (3). Classical computers run algorithms using bits, which are values of 0 or 1 represented in the computer's circuitry, and logic gates, which perform operations on these bits. Quantum computers run algorithms using qubits, defined as a "superposition" of 0 and 1, and quantum gates, which operate on qubits. Creating a physical quantum computer requires manipulating the quantum-mechanical properties of individual particles. If this sounds incredibly complex and difficult to achieve, that is because it is. Here we will not worry too much about the lower level operation of quantum computers but will look at what quantum computers could realistically do with near-term hardware and how AI can fit into the mix.

"Quantum AI" is a very broad term that can be applied to various methods and applications involving quantum mechanics and AI. Here we will look at three main categories of quantum AI that are currently researched:

1. Classical AI applied to problems in quantum physics
2. Quantum computing enhancements to classical AI algorithms
3. Ground-up design of AI using quantum computing theories

From these categories, it is interesting to note that much of the current quantum AI research uses existing and fundamentally "classical" AI algorithms. These can be applied to problems in quantum systems, as in category 1), or they can incorporate quantum algorithms to improve, for example, the al-



A common graphical representation of a qubit versus a bit, illustrating the superposition of values for a qubit.

gorithm's speed, as in category 2). Aside from these more classical AI approaches, category 3) refers to current research in creating entirely new "intelligent" algorithms with quantum computing as their foundation.

First, let us consider how AI can be applied to quantum physics problems. These applications have much the same motivation as other applications of AI: designing and controlling a quantum mechanical system is challenging. This is mainly because any interaction with the external environment affects a system's quantum-mechanical properties, thereby creating noise in the system and possibly resulting in information loss. We cannot completely detach a quantum computer from the outside world; otherwise, we would not be able to observe any useful information from it. However, we can use AI methods to mitigate these issues, for

Google even has a team dedicated to researching quantum AI and providing services for current applications of such technology

example by designing more efficient and robust computations for a quantum computer that are less prone to errors, or devising strategies to correct such errors, known generally as quantum error correction.

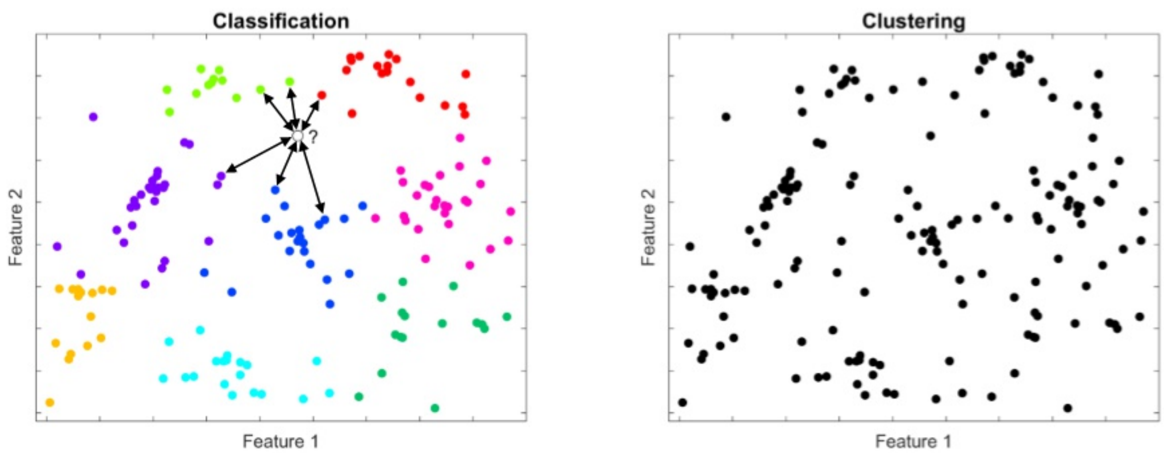
Now we shall look at how quantum computing can be incorporated into a classical AI algorithm. Quantum computers have specific tasks at which they outperform classical computers in terms of speed; this is commonly referred to as "quantum advantage". In other tasks, they have no advantage over classical algorithms. One important assumption made when considering quantum enhancements to AI relates to data representation. For the methods shown here to work, it is assumed that data are pre-processed and loaded into a quantum state which can be queried by a quantum computer. Research is ongoing into how feasible this would be in reality. Nevertheless, by considering what quantum computers could do "better" than classical computers, with the assumption on data holding, we can develop a library of "tools" that could benefit classical AI. Some of these are as follows:

- Calculating distances between vectors
- Computing vector inner products
- Solving systems of linear equations

The most common theoretical applications of these tools are for classification and clustering problems. In classification, a computer learns patterns from vectors of features

We cannot completely detach a quantum computer from the outside world; otherwise, we would not be able to observe any useful information from it

(e.g. measurements of physical quantities or pixel colour values in an image) that belong to certain classes. Using these patterns, the computer identifies the class of new vectors. Similarly, clustering deals with vectors of features that are all unlabelled, and the task is to find groups of features. Both methods require computing distances



Supervised learning looks at data that are labelled (indicated here by their colour) and works out the label for a new point. Clustering looks at unlabelled data and aims to divide them into groups.

between all or a subset of the vectors. As the dimensionality of the vector space increases, this becomes much more computationally expensive. It is, therefore, useful to have more efficient methods for calculating distances using quantum computing. Another common method involving vectors of features is Principal Component Analysis (PCA). For its application in AI, the main goal of PCA is to project these vectors in a way which maximises distances between different groups. The process of computing principal components also involves some linear algebra which presents another opportunity for potential quantum advantage.

can we capture some of the key biological processes of the human brain in a computer program?

Thus far, we have considered AI and quantum computing separately by applying one to the other. This can be useful as discussed but perhaps does not fully exploit the potential of using quantum computing for creating "intelligent" machines. What if we tried to create new quantum algorithms which can be considered "intelligent"? Certain paradigms in AI which relate more broadly to theories of learning are now being generalised from classical computing concepts to quantum computing. These are presented as sorts of building blocks that could be used to create fully quantum AI. As per the original aims of AI research in the early 20th century, some current research also seeks to replicate human intelligence using computers. This leads to the following question: can we capture some of the key biological processes of the human brain in a computer program? When only using classical computing, it seems the answer is no.

simulating aspects of the brain with quantum computers remains a possibility

Given the underlying processes in the brain are governed by quantum physics, quantum computers could be better suited to this task. Much of the research in this domain is rather metaphysical and philosophical, and some of it is outright pseudoscience. However, simulating aspects of the brain with quantum computers remains a possibility.

So to summarise – will quantum AI kickstart the robot apocalypse and steal your bank details? Not in the very near future, since it is currently difficult enough to make quantum computers do anything, and threats posed by would-be quantum hackers are already well known with measures being put in place to stop them. However, steady progress is being made in quantum computing with the support of AI, which will also help accelerate certain AI methods. Both fields of quantum computing and AI are still developing, and I expect they will continue to be combined and produce more useful and interesting results. Hopefully, full quantum intelligence does not arrive too soon, though, lest my own measly classical AI research becomes irrelevant.

Topology: the mathematics of Play-Doh

By Owen Tanner

Whether or not you agree with Neil Degrasse Tyson that "A scientist is just a kid that never grew up.", one thing is for sure, topologists sure like playing with play-doh. But what does playing with play-doh tell us about the world we live in?

Specialist edited by Alexander Telfar, copy-edited by Sridevi Kuriyattil

Topology is a branch of mathematics, that emerged very slowly from studies of geometry (1). However, in the late 1800s and early 1900s, it exploded into one of the largest fields of pure mathematics, a status that remains to this day! The core question of topology is how much can we learn about shapes, spaces, and other mathematical objects by treating them like play-doh (or in posh maths-speak, up to something called continuous deformation).

Continuous deformation (described rigorously through the notion of homeomorphisms) is commonly introduced by giving a sense of what kind of things we can or can't do with play-doh. When playing with play-doh, we are allowed to stretch objects, make them larger, flatten them, make them spiky, but they remain the same object. A stretched, big, spiky sphere is still a sphere.

But there is one crucial rule of topology: we cannot change the number of holes in an object. We can't punch a hole in a disc or glue up the hole in a doughnut. Such moves are "discontinuous". There is always a point in time where a hole suddenly becomes a not-hole. Keeping track of holes allows us to answer age-old questions such as "How many holes does a straw have, 0,1, or 2?" The answer is 1, since we may continuously deform a straw by squashing it down into a ring, which clearly has just one hole! Also, one cannot find a continuous deformation from the straw into a sphere or a genus (two doughnuts glued together), so it does not have 0 or 2 holes.

Also, we can slowly morph a coffee mug and a doughnut, so to a topologist, they are the same shape!

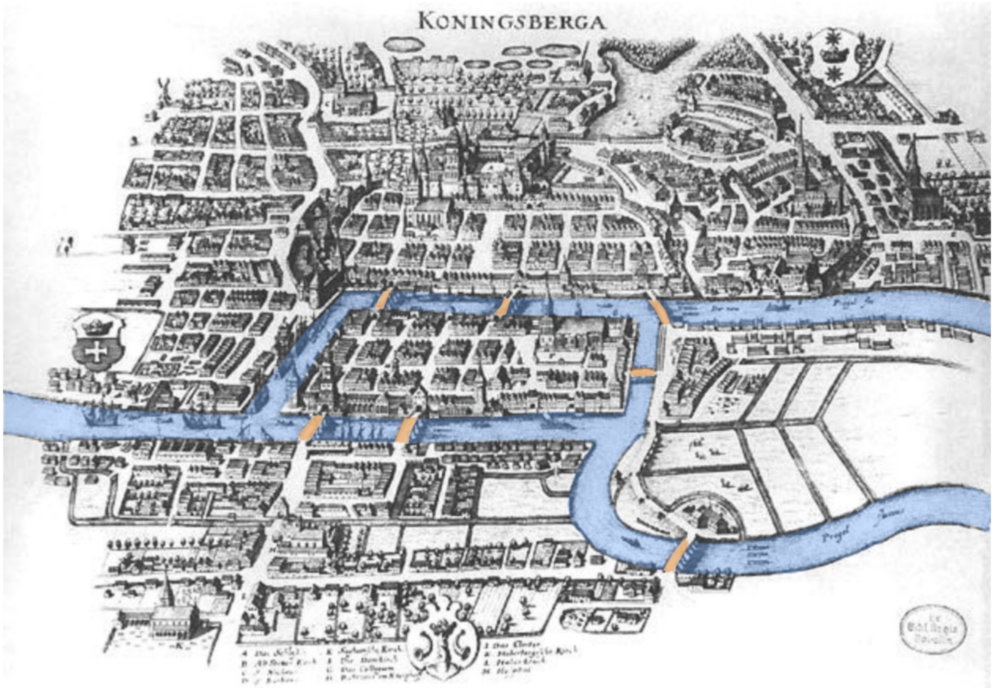
The core question of topology is how much can we learn about shapes, spaces, and other mathematical objects by treating them like play-doh

Standard geometry takes into account information like the distance between objects and the size of objects. For a topologist, all triangles are the same. And triangles are the same as a circle. They can all be continuously deformed to one another. So it might seem perplexing how topology can have anything useful to say when objects so obviously different are considered 'similar'.

One advantage of this approach is that many phenomena in nature change shape continuously; strings of proteins, the sea, leaves, even the shape of our universe itself. Proteins, for example, can get themselves into tangles which make them incredibly hard to identify. However, every tangleresults from a sequence of continuous deformations, so using topology, we can untangle them to get a proper look!

In the same way, topology makes the task of classifying shapes easier by grouping lots of different shapes together via their topological similarities. There are a huge number of 2D and 3D shapes, but not so many if we say it doesn't matter how many sides a shape has or how big it is, only whether we can continuously deform one into another. It lets us see similarities where, without topology, we would only see differences and untameable complexity.

Topology can help us solve all kinds of mathematical problems where distances and size don't matter, only the structure of a shape. A classic example is the Seven Bridges of Königsberg where it is asked: can you cross all 7 Bridges in Königsberg in one round trip (2)? This problem is considered to be one of the founding prob-



The Seven Bridges of Königsberg. Blue colour represents the river and brown colour represents the bridge. PD-US.

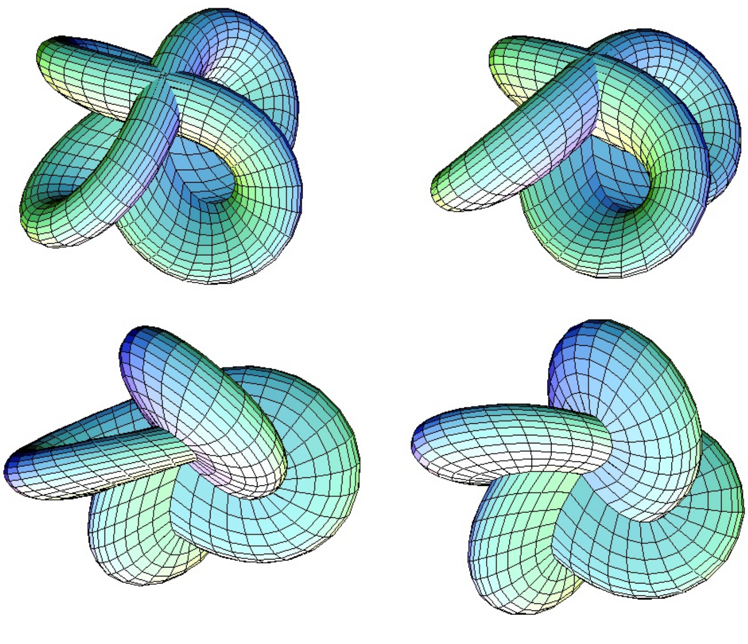
lems of topology, and Euler's solution remains one of the most celebrated papers in all of mathematics to this day.

Crucially, Euler noticed the aspects of the problem which were relevant (the number of islands and bridges between them) and irrelevant (how long the bridges are, or whether the landmasses were mainland or an island). In short, there were a number of continuous deformations (changing the lengths of bridges, for example) that would change Königsberg on the one hand, but end up with equivalent questions on the other. Noticing this led to a general solution by Euler (showing there is no way to make the round trip), and in turn, began the mathematical field of topology.

The first course in topology, given by Hausdorff, was rumoured to have had only three students. But now, hundreds of undergraduates attend topology courses every year in Scotland alone. This isn't just for the sake of mathematical pedantry and the joys of solving puzzles; it's also because topology is now a vital part of mathematics and science as a whole. Within mathematics, topology has solved several problems, ranging from defining derivatives on complex shapes (differential topology) to the classification of algebras foundational to quantum field theory (K-Theory groups of C* algebras). But even outside of mathematics, topology has found all manner of applications...

...topology is now a vital part of mathematics and science as a whole.

The topology of knots alone has found incredibly broad applications from cancer research to cryptography (3). In Mario Livio's book "Is God a mathematician", he explains how knot theory can be used to describe quantum field



Four different views of the Morin surface by AugPi. Licensed under CC BY-SA 3.0.

theory, a large branch of theoretical physics. When we think of untying a knot, this is a kind of continuous deformation, so it makes sense to talk about them using topology.

A branch of topology called persistent homology has led to the emerging field of topological data analysis (4). This means that topology helps us detect things like someone hacking into your Facebook account, as well as what kinds of content you might like on tik tok. Using topology, we can group data sets that look similar and notice outliers.

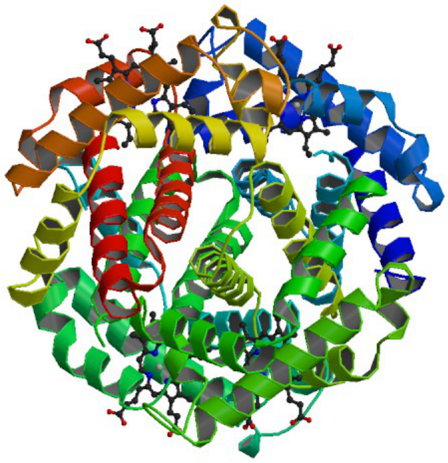
Configuration spaces have found applications in robotics (5). A key thing we use to analyse topological spaces is the paths we can take inside them. The mathematics behind this has proved completely essential in motion planning for robots-- knowing how to move around objects or find their way through mazes. Robots use invariants in topology to navigate cave networks, sew together clothes and move around obstacles in a room. These technologies, in turn, tell us more about the natural world we live in, make production cheaper and pave the way for self-driving cars.

...many phenomena in nature change shape continuously; strings of proteins, the sea, leaves, even the shape of our universe itself.

In civil engineering, topology has been used to help us build bridges (6). Methods have been found that allow us to use far fewer materials to create structures just as strong as before. In turn, this creates greener, more elegant ways to build bridges using topological methods.

Disruption to muscle fibers can cause stress in the body. Topology has helped us understand which shapes cause stress on our heart, in the process solving a number of life or death problems. This is a huge success of topology. In fact, topology has proven so useful in the study of heart disease that Arthur Winfree claimed that sudden cardiac death is a "problem in topology" (7).

Hemoglobin subunit beta protein structure.



In short, one of the largest and least known areas of mathematics appears at first to be child's play but ends up solving some of the most pressing issues of science and technology today.

By Tanvir Alim

Science news

International Year of Basic Sciences for Sustainable Development 2022

The year 2022 has been proclaimed as the International Year of Basic Sciences for sustainable development by the UNESCO general conference. It will be officially inaugurated with an opening conference from 30 June - 1 July 2022 at the UNESCO headquarters in Paris. The main motivation behind this decision was to raise awareness about the importance of basic sciences and other emerging technologies for sustainable development, following national priorities.

Studies show that Omicron is less likely to damage lungs

Research groups across the UK have found compelling evidence indicating that the Omicron variant is more likely to infect the throat than the lungs. Scientists believe that since the infection and replication of the virus is more in the throat, the possibility of transmission is also much greater. Various studies conducted at the University of Glasgow's Centre for Virus Research showed that Omicron is likely to evade the immunity of people who have two doses of the vaccine, but a booster dose gives a "partial restoration of immunity."

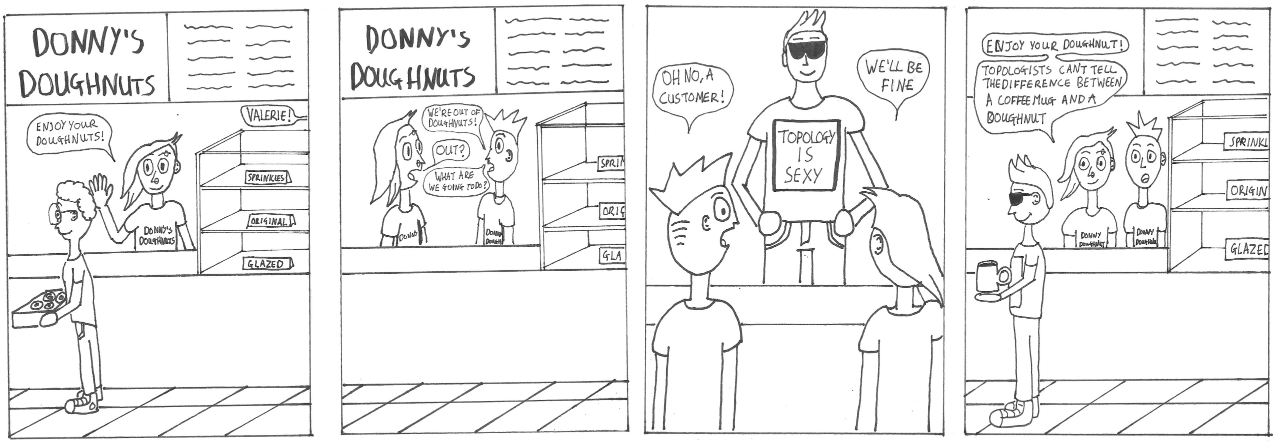
The UK's largest ichthyosaur fossil discovered in Rutland Water

The 10m long ichthyosaur fossil excavated from the Rutland nature water reserve is the largest and most complete ichthyosaur found in the UK. Researchers claim that the fossil of this ancient reptile is about 180 million years old and is also the first ichthyosaur of its specific species found in the country. The palaeontology world is excited by this discovery and is waiting to listen to the untold stories of the fossil.

Drug-resistant MRSA originated in hedgehogs

Methicillin-resistant Staphylococcus aureus (MRSA) is a common drug-resistant pathogen that is harder to treat than other infectious diseases. One type of MRSA has been traced back to hedgehogs. It is believed that a fungus found on the hedgehog skin drove the natural selection of some S. aureus organisms. This has probably led to these microbes becoming resistant to penicillin-like antibiotics released by the fungus.

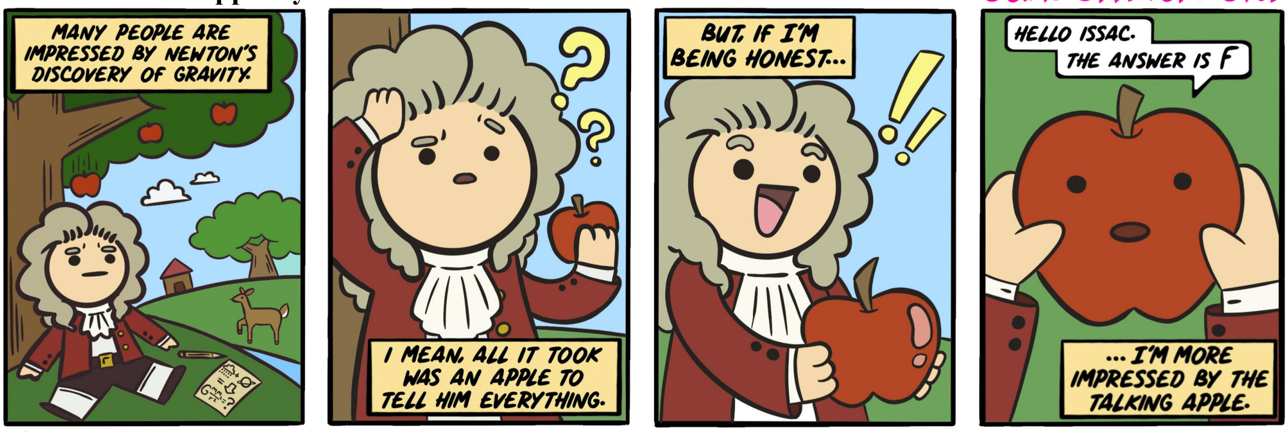
Comic Creators Club By Gerard Mooney 05/01/22



Inspired by Topology: the mathematics of Play-Doh by Owen Tanner (see page 20)

Newton & The Apple by Jordan Fraser

Comic Creators Club



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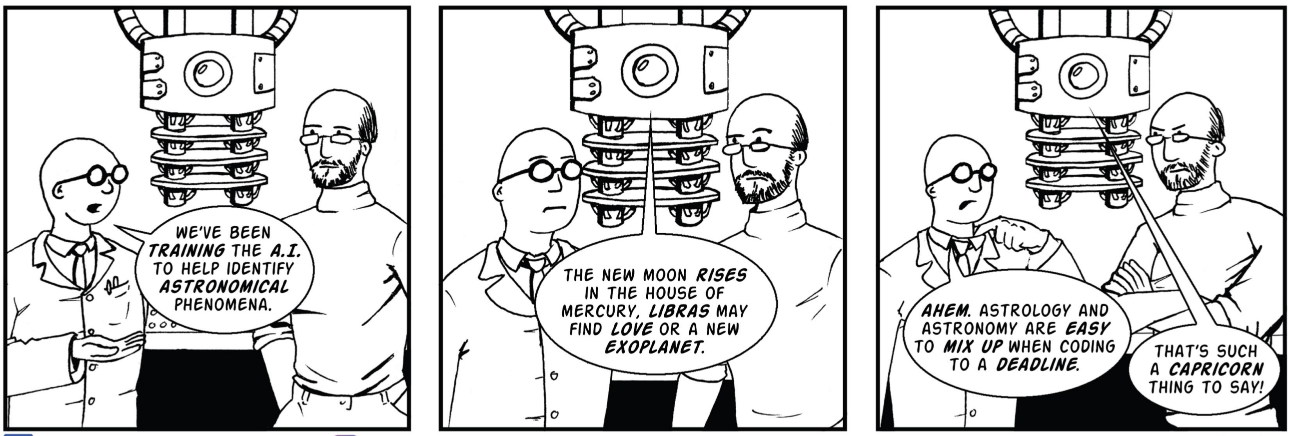

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