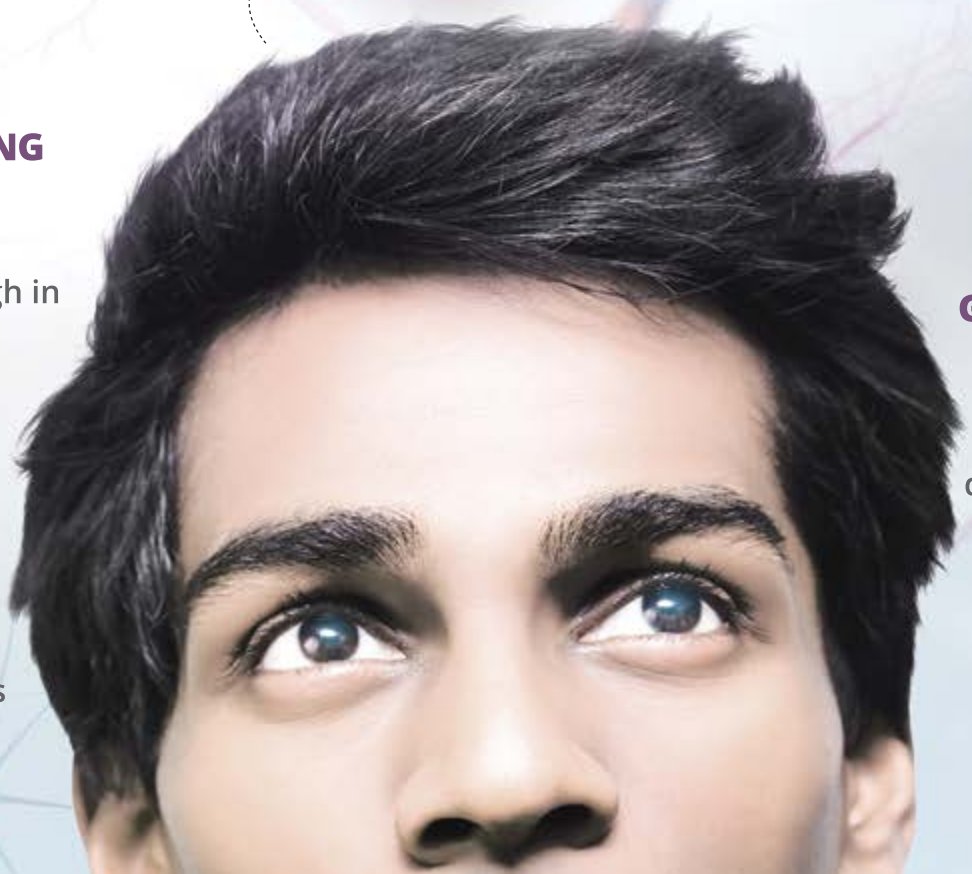
NANYANG TECHNOLOGICAL UNIVERSITY

PUSHING

FRONTIERS

UNRAVELLING THE MARVELS OF THE MIND

MULTIDISCIPLINARY EFFORT ACROSS NTU TO PROBE THE BRAIN'S MYSTERIES



NATURE'S PARADIGMS FOR SECURING ENERGY

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World-class scientists weigh in

WHEN IT COMES TO SATELLITES, SMALL IS BEAUTIFUL

--

The outsized impact of nano-satellites

PROVIDING HEALTH FOR THE NEXT GENERATION

--

Tackling challenges from chronic diseases to HIV

ISSUE 8
2016

NANYANG TECHNOLOGICAL UNIVERSITY

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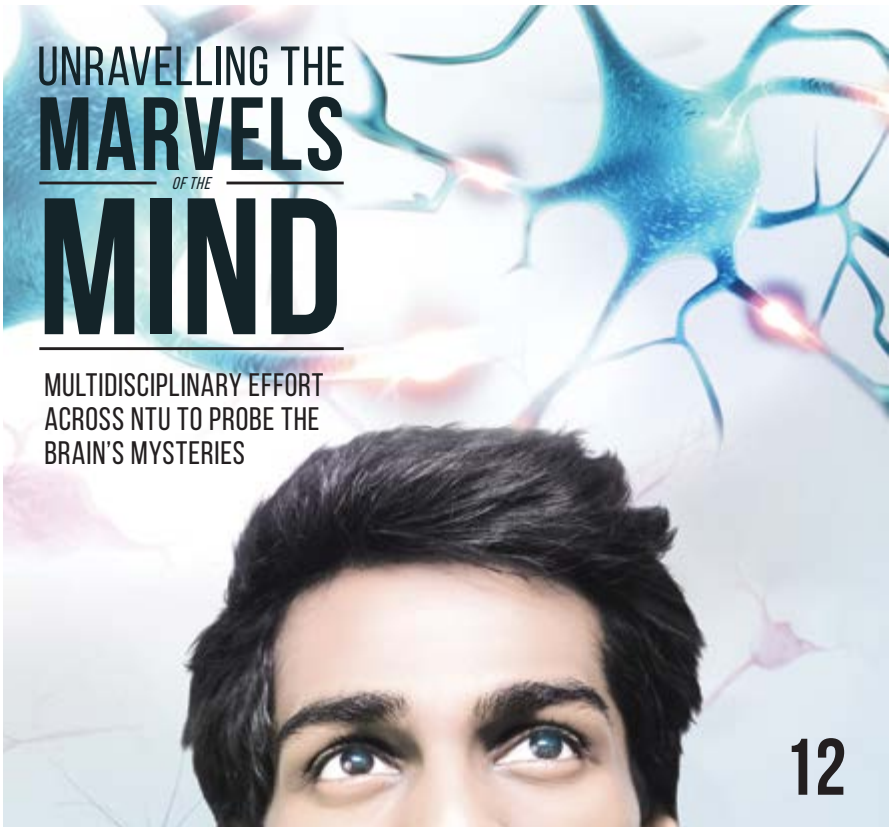

UNRAVELLING THE MARVELS OF THE MIND

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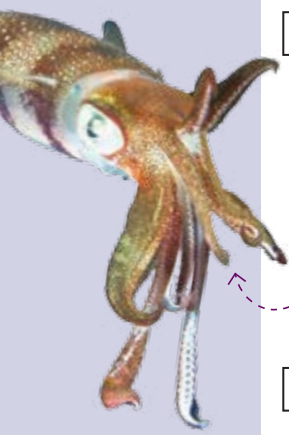

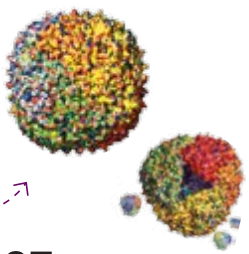

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NATURE'S PARADIGMS FOR SECURING ENERGY

Participants and speakers at the 4th International Workshop on Solar Energy for Sustainability: Photosynthesis and Bioenergetics. Credit: Institute of Advanced Studies, NTU.

Scientists who dream of solving the world's energy concerns have looked to Nature for paradigms to harvest and store energy from the sun.

In March this year, over 100 participants discussed the fundamental aspects of photosynthesis and the conversion and storage of energy in cells at the 4th International Workshop on Solar Energy for Sustainability: Photosynthesis and Bioenergetics, organised by NTU's Institute of Advanced Studies.

1992 Nobel Prize in Chemistry winner Prof Rudy Marcus speaking at the 4th International Workshop on Solar Energy for Sustainability: Photosynthesis and Bioenergetics. Credit: Institute of Advanced Studies, NTU.

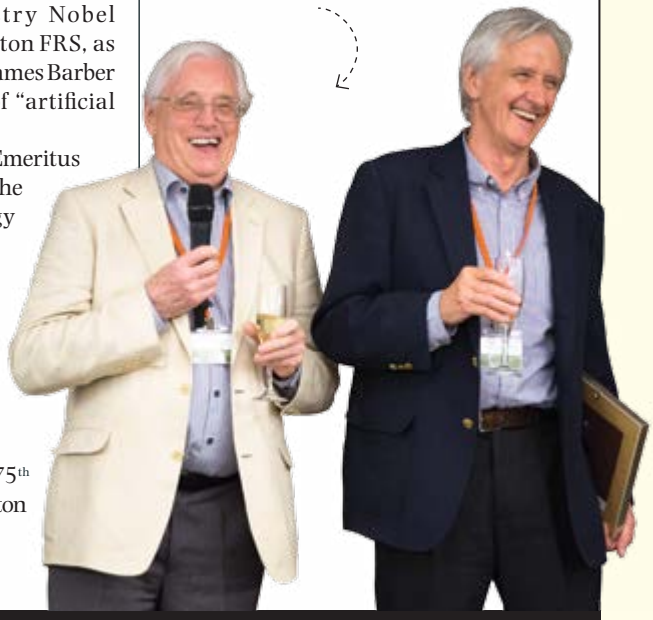
They were treated to presentations by 30 world-class speakers—including Prof Sir John Walker FRS (1997 Nobel Laureate in Chemistry), Prof Rudy Marcus (1992 Chemistry Nobel Laureate), Prof Leslie Dutton FRS, as well as NTU Visiting Prof James Barber FRS, one of the fathers of "artificial leaf" technology.

Prof Sir John Walker, Emeritus Director and Professor at the MRC Mitochondrial Biology Unit in Cambridge, was feted for his Nobel Prize-winning research on the synthesis of adenosine triphosphate, the energy currency of cells, on the occasion of his 75th birthday.

Also celebrating his 75th birthday was Prof Leslie Dutton FRS, Eldridge Reeves Johnson Professor of Biochemistry and Biophysics in the Perelman School of Medicine at the University of Pennsylvania. Prof Dutton was honoured for his lifelong research on the cellular mechanisms of long-distance electron transfer through proteins, which has potential applications in clean energy and medicine.

The workshop also celebrated the life and legacy of Prof Jan Anderson FRS, a New Zealand-born scientist who spent most of her career at Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation. Her discovery that the photosynthetic mechanism involves two distinct components—photosystems I and II—has significantly advanced our understanding of one of the most fundamental processes of life on Earth.

Profs Sir John Walker FRS (left) and Leslie Dutton FRS (right), both celebrating their 75th birthday. Credit: Institute of Advanced Studies, NTU.



CANCER RESEARCH

BACTERIAL MISSILES AGAINST CANCER

Although its tumour-killing abilities have been known since the 19th century, the common soil bacterium *Clostridium sporogenes* is shunned in the clinic because of concerns about toxicity and infection.

Avoiding live bacteria, a team from NTU's School of Chemical and Biomedical Engineering, led by Prof Teoh Swee Hin, used instead heat-inactivated *C. sporogenes* bacteria as killing agents in a three-dimensional cell culture of tumour cells.

"We found that even when *C. sporogenes* bacteria are dead, their natural toxicity continues to kill cancer cells unlike most conventional chemotherapeutic drugs, which depend on the presence of oxygen to work," explains Prof Teoh.

Moreover, conditioned bacteria culture medium—containing only secreted bacterial proteins but no bacteria—was sufficient to inhibit tumour cell growth.

The researchers now aim to understand the mechanisms of tumour growth inhibition and develop cancer therapies based on *C. sporogenes* derivatives.

The research is described in "Effect of heat-inactivated Clostridium sporogenes *and its conditioned media on 3-dimensional colorectal cancer cell models", published in* Scientific Reports *(2015), DOI: 10.1038/srep15681.*

LIGHT-GUIDED NANOMEDICINE

Could this be the Holy Grail of tumour therapy?

To achieve targeted killing of cancer cells without affecting healthy tissue, an interdisciplinary team led by Assoc Prof Xing Bengang from NTU's School of Physical and Mathematical Sciences designed nanoparticles carrying functional groups that can be cut by cathepsin protease, an enzyme that is abundant in the environment of tumours but rarely expressed elsewhere in the body. Once cut, the nanoparticles cross-link and accumulate in tumour regions.

Drugs carried by the nanoparticles are then activated with non-damaging near-infrared light at wavelengths that can reach tumour sites several centimetres deep inside the body. Once activated, reactive oxygen species are formed to effectively kill tumour cells.

The precise molecular sensing technique can also be used for imaging and diagnostics, the researchers say.

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*Details on the research can be found in "*In vivo *covalent cross-linking of photon-converted rare-earth nanostructures for tumour localization and theranostics",* Nature Communications *(2016), DOI: 10.1038/ncomms10432.*

Activating drug-carrying nanoparticles with near-infrared light. Credit: Amin Shah.

INFECTIOUS DISEASES

SEEKING OUT AND DESTROYING BACTERIAL DEFENCES

To survive antibiotic treatments, bacteria have adopted the sophisticated strategy of forming biofilms, which are complex microbial communities typically found at the surface of infection sites.

"According to estimates by the US Centers for Disease Control and Prevention, 60% of all bacterial infections are biofilm-related," says study lead Asst Prof Yang Liang from NTU's Singapore Centre for Environmental Life Sciences Engineering and the School of Biological Sciences.

The research team cultured biofilms both *in vitro* and *in vivo* in a mouse infection model. Using a novel proteomics approach, they showed that bacterial cells which survive antibiotic treatments specifically express proteins that are involved in cell-to-cell signalling and migration, allowing the bacteria to communicate and form microcolonies that shield them from the drugs.

Conversely, disrupting cell-to-cell communication with an inhibitory drug compromised the biofilms and left the bacteria vulnerable to antibiotic treatment.

The study "Selective labelling and eradication of antibiotic-tolerant bacterial populations in Pseudomonas aeruginosa *biofilms" was published in* Nature Communications *(2016), DOI: 10.1038/ncomms10750.*

OCEAN ECOLOGY

KEEPING CORAL REEFS AND OCEANS IN TIP-TOP SHAPE

Combining his dual passions for ocean ecology and sailing, Assoc Prof Federico Lauro from NTU's Asian School of the Environment and the Singapore Centre for Environmental Life Sciences Engineering has conducted the first large-scale ecogenomic survey of microbial diversity across the Indian Ocean.

Using a "citizen oceanography" approach aboard a private yacht, his team was also the first to sample the pristine lagoon of the Salomon Islands—one of the world's healthiest coral reefs—in the uninhabited Chagos Archipelago.

"Surprisingly, the genetic diversity and gene expression patterns of the microorganisms sampled inside the lagoon were very different from those in adjacent ocean waters, even though there is constant water exchange," says Assoc Prof Lauro.

The researchers found that the lagoon was dominated by one type of photosynthetic cyanobacteria and had five times more bacteria-specific viruses. They speculate that these viruses play a major role in the unique ecological niche of the lagoon, possibly by killing all bacteria except for the virus-tolerant cyanobacteria.

Understanding the role of microorganisms in the health of marine environments including coral reefs will help in monitoring environmental changes and in conservation efforts.

The survey "Spatially extensive microbial biogeography of the Indian Ocean provides insights into the unique community structure of a pristine coral reef" was published in Scientific Reports *(2015), DOI: 10.1038/srep15383. In 2015, Assoc Prof Federico Lauro received the Lowell Thomas Award, given to explorers who show innovative approaches in conservation.*

BIORENEWABLES

SQUID TEETH INSPIRE NEW THERMOPLASTICS

Thermoplastics, which are plastic polymer materials that are soft when heated but hard when cooled, have widespread uses. But because they are usually made from petrochemicals, they also come with a big environmental burden.

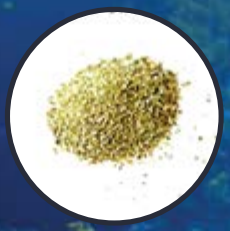
Researchers from the Biological & Biomimetic Materials Laboratory @ NTU in the School of Materials Science and Engineering, together with collaborators in Germany and the United States, may have discovered a sustainable alternative to thermoplastics.

The scientists studied the properties of sucker ring teeth from squid and cuttlefish and found that these biomaterials can be melted and re-formed—similar to conventional thermoplastics—while keeping the materials' mechanical properties.

Future work will involve designing biomimetic thermoplastic biopolymers for applications in biomedicine and 3D printing.

Details of the study "Multi-scale thermal stability of a hard thermoplastic protein-based material" can be found in Nature Communications *(2015), DOI: 10.1038/ncomms9313.*

Native sucker rings



Post grinding

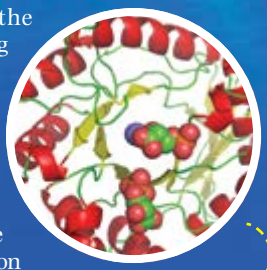
Bulk thermal processing

Thermal processing of native sucker ring teeth proteins. Credit: Ali Miserez.

BIOENGINEERING

ACTIVATING THE EARTH'S MOST ABUNDANT PROTEIN

Carbon fixation, the process of converting carbon dioxide into sugars by living organisms, occurs in plants, algae and some bacteria during photosynthesis. The key enzyme for carbon fixation, rubisco, constitutes up to 50% of all plant proteins and is the most abundant protein on the planet.



Structural model of rubisco, the key enzyme for carbon fixation. Credit: Protein Data Bank.

Proper activity of rubisco relies on helper enzymes—so-called rubisco activases—to overcome periodic inhibition of the enzyme by metabolites.

While two classes of rubisco activases—one each from plants and photosynthetic bacteria—are already known, a team from NTU's School of Biological Sciences, led by Asst Prof Oliver Mueller-Cajar, has discovered a third class of rubisco activases in a group of bacteria known as chemoautotrophs, which harvest energy from chemical compounds instead of from the sun.

"Though the structure and mechanism of rubisco is very similar in all carbon dioxide-fixing organisms, the helper enzymes operate by different mechanisms," explains Asst Prof Mueller-Cajar.

Coupling bacterial rubisco activases with plant rubisco enzymes might help to enhance photosynthesis in crop species or algae for increased food and biomass production, the researchers say.

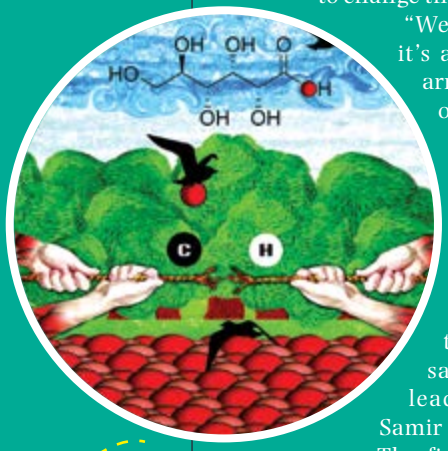
The study "Identification and characterization of multiple rubisco activases in chemoautotrophic bacteria" was published in Nature Communications *(2015), DOI: 10.1038/ncomms9883.*

ENERGY

OXYGEN, NOT METAL, MAKES A CATALYST

Natural gas and biomass—consisting mainly of methane and other hydrocarbons—can be chemically converted into useful fuels, bulk chemicals and plastics.

Manufacturers typically use transition metal catalysts to break chemical bonds, under the general assumption that the metal component plays the key role in the reaction. Now, a discovery made by a team from NTU's School of Chemical and Biomedical Engineering is set to change this paradigm.



Lattice oxygen as catalysts to break strong C-H bonds. Reproduced with permission from *Angewandte Chemie International Edition.*

"We found that it's actually the arrangement of oxygen atoms in the metal oxide that is crucial for efficient catalysis, and not necessarily the metal," says research lead Asst Prof Samir Mushrif.

The finding paves the way to designing novel catalysts that are cheaper and more environmentally friendly, require less energy input and can even be regenerated to 100%, Asst Prof Mushrif explains.

The discovery has been published as "Biomass oxidation: Formyl C-H bond activation by the surface lattice oxygen of regenerative CuO nanoleaves" in Angewandte Chemie International Edition *(2015), DOI: 10.1002/anie.201503916, and has been featured as a frontispiece of the issue.*

SAVING ENERGY THE SMART WAY

A new algorithm called "software as a sensor" could help companies cut their energy bills by as much as 10%.

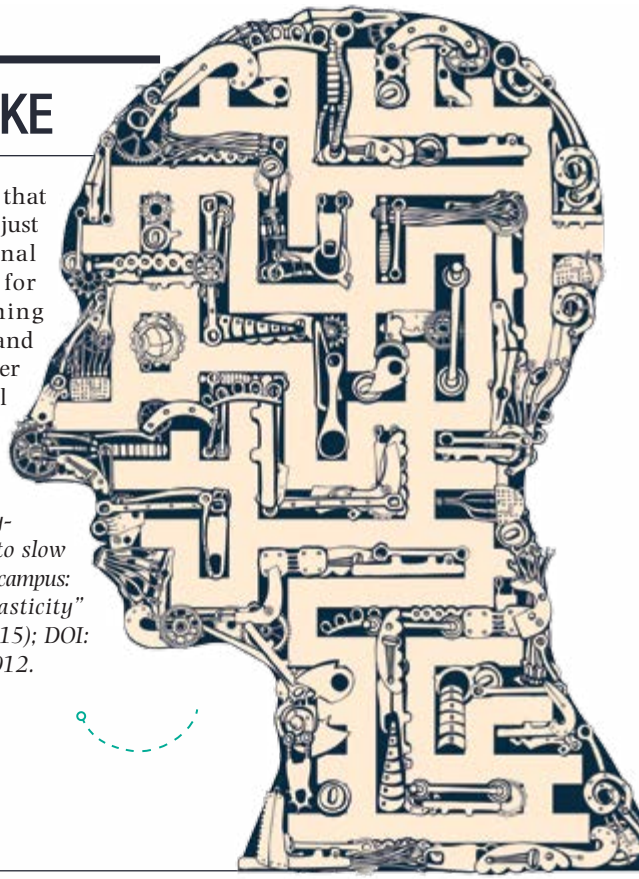
The energy-analysing technology, designed to be integrated in sensors on chips found in computers, servers, air-conditioning systems and industrial machinery, was developed by Assoc Prof Wen Yonggang from NTU's School of Computer Science and Engineering.

Licensed through an NTU-incubated company, EverComm Uni-Tech Pte Ltd Singapore, the algorithm has been successfully applied in several commercial projects, such as Taiwan's National Dong Hwa University venture aimed at reducing their campus energy bill.

EverComm, which was founded by NTU's School of Electrical and Electronic Engineering graduates Ted Chen and Phyo Ko Ko, helps companies to save costs by collecting and analysing energy data and matching it against verified solutions.

The "software as a sensor" technology is described in "Toward green data centers as an interruptible load for grid stabilization in Singapore", published in IEEE Communications Magazine *(2015), DOI: 10.1109/MCOM.2015.7321990. The technology has been accredited by the Infocomm Development Authority of Singapore and potentially adopted for Singapore's Smart Nation initiative.*

WHAT A MENTAL MAP LOOKS LIKE



An international study led by Asst Prof Ayumu Tashiro from NTU's School of Biological Sciences has shown in detail what happens in the brains of rats when they become exposed to unfamiliar environments.

The researchers used a technique that allows signals from up to 40 individual neurons to be simultaneously read by tiny electrodes planted in the hippocampus of rats.

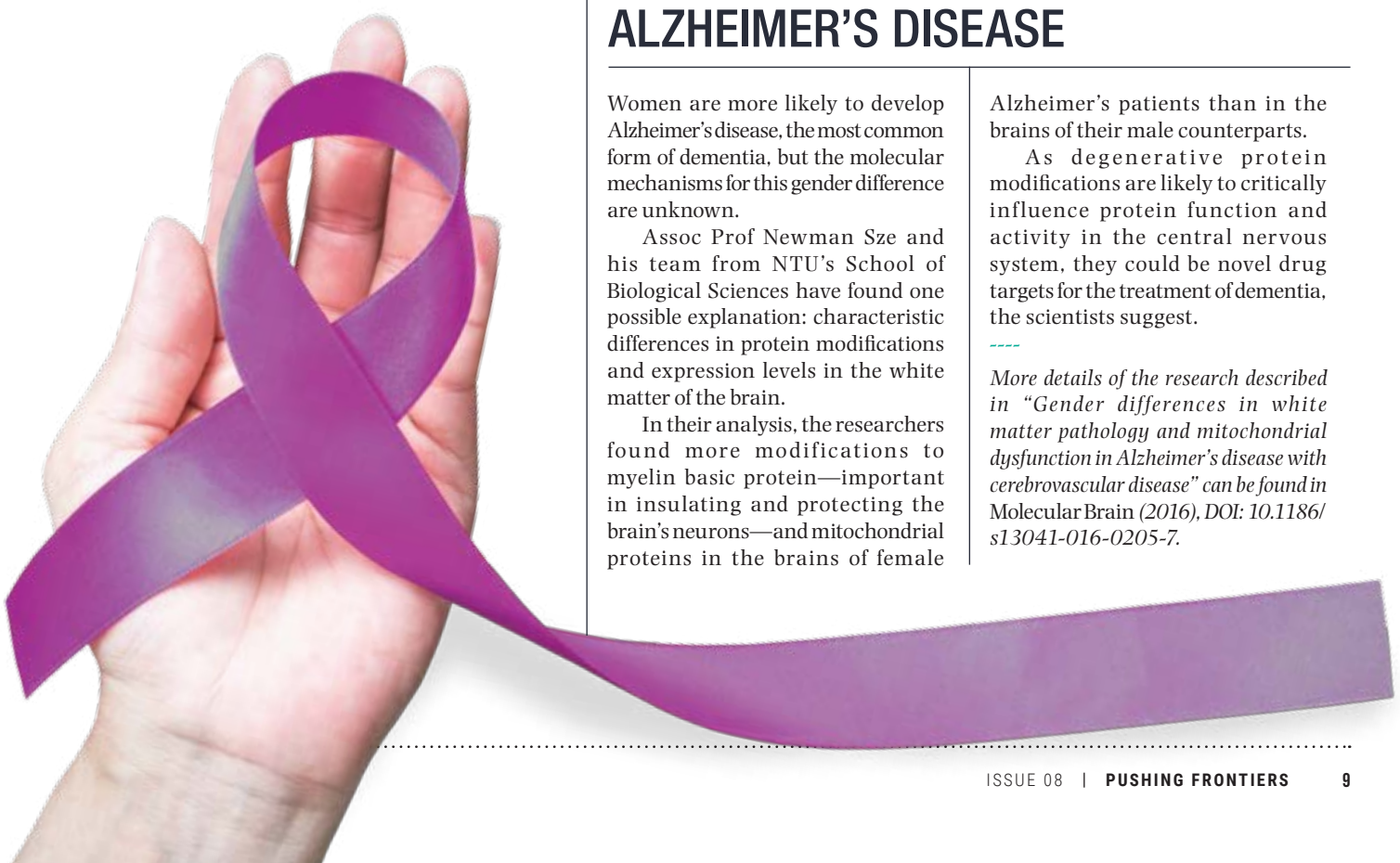
Within minutes of the rats entering the new environment, characteristic patterns of neuronal activities that reflected the rats' positions formed in their brains, functioning as internal GPS-like systems.

When synaptic plasticity—the ability of neuronal synapses to become stronger or weaker in transmitting signals—was blocked, the rats showed very slow learning.

These results indicate that synaptic plasticity, and not just formation of new neuronal networks, is essential for effective and fast learning and memory formation, and may help researchers better understand neurological disorders such as dementia and schizophrenia.

Details of the study "Novelty-induced phase-locked firing to slow gamma oscillations in the hippocampus: requirement of synaptic plasticity" can be found in Neuron *(2015); DOI: 10.1016/j.neuron.2015.05.012.*

WHY MORE WOMEN GET ALZHEIMER'S DISEASE



Women are more likely to develop Alzheimer's disease, the most common form of dementia, but the molecular mechanisms for this gender difference are unknown.

Assoc Prof Newman Sze and his team from NTU's School of Biological Sciences have found one possible explanation: characteristic differences in protein modifications and expression levels in the white matter of the brain.

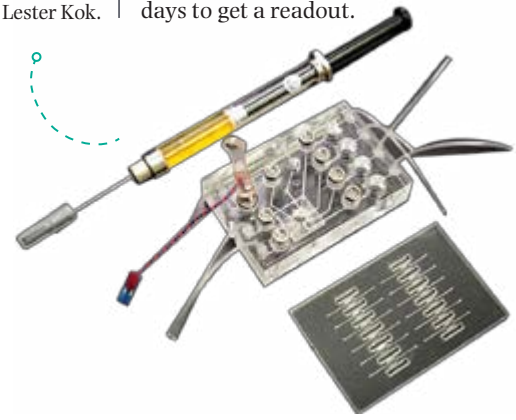
In their analysis, the researchers found more modifications to myelin basic protein—important in insulating and protecting the brain's neurons—and mitochondrial proteins in the brains of female Alzheimer's patients than in the brains of their male counterparts.

As degenerative protein modifications are likely to critically influence protein function and activity in the central nervous system, they could be novel drug targets for the treatment of dementia, the scientists suggest.

More details of the research described in "Gender differences in white matter pathology and mitochondrial dysfunction in Alzheimer's disease with cerebrovascular disease" can be found in Molecular Brain *(2016), DOI: 10.1186/s13041-016-0205-7.*

MEDICAL DIAGNOSTICS

TEST YOUR LIVER IN JUST 30 MINUTES



The two key lab-on-a-chip components with a syringe for scale. Credit: Lester Kok.

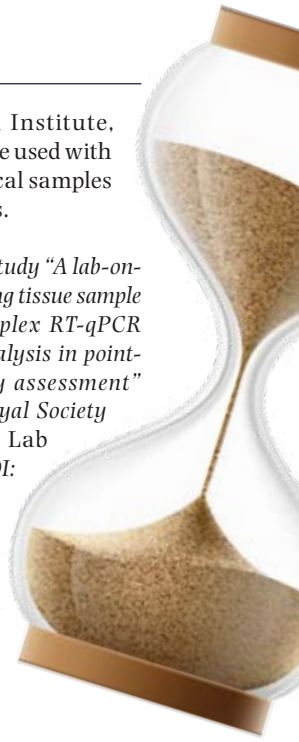
As the first organ in the body to be damaged by chemicals, the liver is prone to diseases such as cirrhosis or liver cancer. However, current tests of liver health—including tissue histopathology and blood tests for liver function—are costly and take days to get a readout.

Thanks to a novel "sample-in-answer-out" diagnostic kit, testing for liver toxicity can now be done in less than 30 minutes from the comfort of one's home or in remote areas.

The "lab-in-a-needle" device combines collection of tissue or blood through a biopsy needle, sample preparation, mRNA/DNA amplification and detection, and analysis of liver health biomarkers in one fast and efficient process, allowing doctors to make on-the-spot decisions during surgeries.

Invented by an international team led by Prof Joseph Chang from NTU's School of Electrical and Electronic Engineering, Dr Wang Zhiping from the Singapore Institute of Manufacturing Technology, and Prof Stephen Wong from the Houston Methodist Research Institute, USA, the kit can also be used with other types of biological samples and for other diseases.

The proof-of-principle study "A lab-on-a-chip system integrating tissue sample preparation and multiplex RT-qPCR for gene expression analysis in point-of-care hepatotoxicity assessment" can be found in the Royal Society of Chemistry journal Lab on a Chip *(2015), DOI: 10.1039/C5LC00798D.*

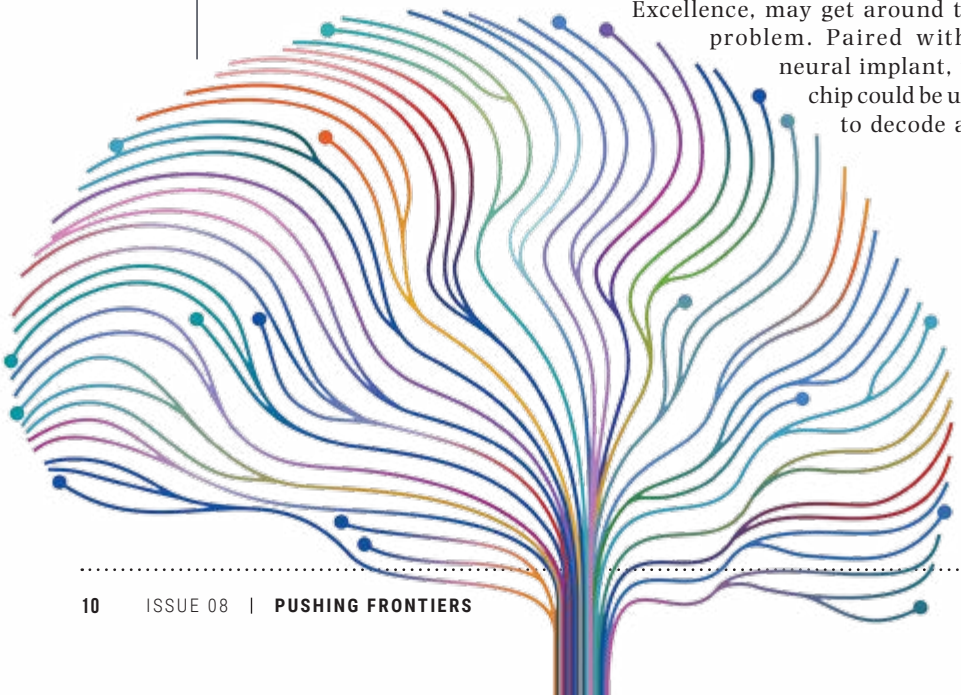


MEDICAL DEVICES

MIND-READING MICROCHIPS

In the near future, neural implants connected to exoskeletal devices could help paraplegics move on their own. Current prototype devices, however, require wires for transmission and bulky external computers for decoding the large amounts of raw data from the brain.

A power-efficient chip that can accurately analyse data patterns, developed by scientists at NTU's VIRTUS IC Design Centre of Excellence, may get around this problem. Paired with a neural implant, the chip could be used to decode and wirelessly transmit neural signals from the brain to small, wearable external receivers.



"The chip is about a hundred times more efficient than current processing chips on the market. It could lead to more compact wearable medical devices, such as portable ECG monitoring devices and neural implants, since we no longer need large batteries to power them," says study lead Asst Prof Arindam Basu.

The chip's ability to analyse data patterns and spot unusual patterns—already tested successfully on neural data recorded from animal models—also opens the door to applications in camera surveillance or smart home sensor networks.

More about the chip's use for neural data can be found in "A 128-channel extreme learning machine-based neural decoder for brain machine interfaces", published in IEEE Transactions on Biomedical Circuits and Systems *(2015), DOI: 10.1109/TBCAS.2015.2483618.*

NEW RADAR EYES ON THE ROAD

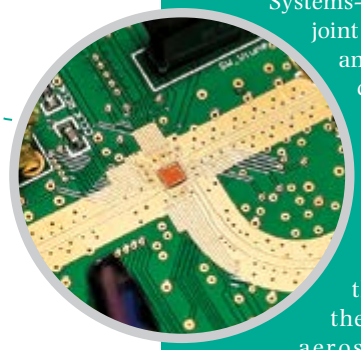
Measuring 2mm by 3mm, a new microchip from NTU's VIRTUS IC Design Centre of Excellence is set to shrink the size of radar cameras 100-fold—from bulky 200kg behemoths into palm-sized devices.

The microchip at the core of the new camera technology is 20 times cheaper to produce—slashing costs from US$1 million to US$10,000 per unit. The chip also reduces energy consumption by 75% while producing images of higher quality and accuracy.

"Our new system allows high-resolution imaging radar technology to be used in objects and applications never before possible, like small drones, driverless cars and small satellite systems," says project lead Asst Prof Zheng Yuanjin from NTU's School of Electrical and Electronic Engineering.

The team has secured US$1.8 million (S$2.5 million) in research funding to further develop the chip at S4TIN (Smart Small Satellite Systems-Thales in NTU), a joint laboratory of NTU and French aerospace company Thales Alenia Space.

Presented at the International Solid-State Circuits Conference 2016, the chip attracted the attention of US aerospace company SpaceX, Dutch semiconductor company NXP and Japanese electronics giant Panasonic.



Microchip for radar imaging embedded on a printed circuit board. Credit: Lester Kok.

BATTERY FIRES—A THREAT OF THE PAST

Billions of devices—from smartphones to electric vehicles and aeroplanes—use lithium ion batteries, which may catch fire or explode when overheated. Current batteries only warn of overheating if it's already happening, often too late to avoid damage to the device.

Using a special algorithm based on electrochemical thermodynamics measurements, Prof Rachid Yazami, Director of the Battery Programme at the Energy Research Institute @ NTU, has developed a chip that is able to check on the health of a battery and detect symptoms of a malfunction even before the battery heats up.

Part of the chip's underlying technology is being patented through NTUitive, NTU's commercialisation arm, and the chip will soon be available for licensing by NTU's spin-off company KVI Pte Ltd, which was founded by Prof Yazami.

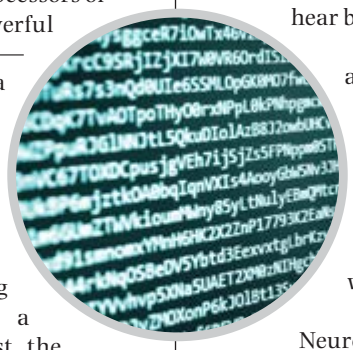
The smart battery chip invented by Prof Rachid Yazami placed beside a Singapore 10 cent coin for scale. Credit: Lester Kok.

UNRAVELLING THE MARVELS OF THE MIND

MULTIDISCIPLINARY EFFORT ACROSS NTU TO PROBE THE BRAIN'S MYSTERIES

The human brain boggles the mind. To understand its amazing abilities, NTU's researchers are approaching the subject from all angles.

As the seat of the mind, our brains endow us with uniquely human abilities such as reasoning, speech and emotion. Made of roughly 90 billion neurons in a network of over 100 billion synapses, the brain is capable of astounding feats of computation, performing in one second what would take some 83,000 processors of the world's most powerful supercomputer—Japan's K computer—a full 40 minutes.



Amazingly, the brain achieves this impressive processing speed with remarkable efficiency, requiring less energy than a lightbulb. In contrast, the K computer runs on energy that could power 10,000 homes.

"Indeed, the brain is the most sophisticated system known to mankind; we cannot even imagine a more complex system in the universe," says Prof Balázs Gulyás, Scientific Director of the Neuroscience and Mental Health Research Programme at the Lee Kong Chian School of Medicine, NTU's joint medical school with Imperial College London.

But the brain's complexity has not put NTU researchers off from plumbing the depths of its mysteries. Quite the contrary, according to Asst Prof Alice Chan from NTU's School of Humanities and Social Sciences.

"Neuroscience is a very fascinating field precisely because of the complexities of the brain," she says. "To approach this complexity, we need to have a multidisciplinary outlook spanning not just hardcore neuroscience research, but also encompassing all the cognitive aspects of being human."

INVOLVING ALL PARTS OF THE NTU BODY

Asst Prof Chan, a neurolinguist, leads the School of Humanities and Social Sciences' Cognition and Neuroscience cluster together with Asst Prof Xu Hong from the Division of Psychology. Formed in 2012, the cluster brings together researchers interested in the brain's role in cognition and behaviour.

Collectively, the cluster members work on research problems in cognition spanning vision, hearing, development, language disorders, language acquisition and ageing. These include projects ranging from how children pick up moral standards, to cognitive and behavioural interventions that help the elderly hear better in noisy environments.

In addition, the cluster has hosted two international conferences at NTU within the past year: the Asia-Pacific Conference on Vision in July 2015 and the inaugural International Symposium on Cognition and Neuroscience in February this year.

"There is a critical mass of faculty at NTU researching cognition and neuroscience," Asst Prof Chan explains. "We hope that such conferences will act as catalysts to connect researchers across diverse academic disciplines—both internationally and within Singapore."

"In fact, for the International Symposium on Cognition and Neuroscience, we had participants from every single part of NTU, from the National Institute of Education to the College of Engineering, the Lee Kong Chian School of Medicine and, of course, our own humanities and social sciences school."

"The brain is the most sophisticated system known to mankind; we cannot even imagine a more complex system in the universe."

Prof Balázs Gulyás
Scientific Director of the Neuroscience and Mental Health Research Programme at NTU's Lee Kong Chian School of Medicine

MIND ON THE FUTURE

On the personal front, Asst Prof Chan is tackling mental issues related to ageing. "Ageing is one of the key challenges Singapore expects to face in the future. Our research to counter the negative effects of an ageing population could also shed light on adult learning in general," Asst Prof Chan says.

Together with Assoc Prof Tan Ying Ying, who is a socio-phonetician at the School of Humanities and Social Sciences, and Assoc Prof Annabel Chen, who is Deputy Director of the Centre for Research and Development in Learning (CRADLE) at NTU, Asst Prof Chan has received a grant worth more than US$607,000 (S$838,000) from Singapore's education ministry to search for therapeutic interventions that could delay or even reverse age-related cognitive decline.

The project, which started earlier this year, investigates whether learning a second language can help older adults stave off the negative effects of ageing. Noting that studies have shown bilingualism delays the onset of dementia by a few years, Asst Prof Chan hopes to examine the design and feasibility of community-based language training in the elderly.

"Although adult second language training is already available, we don't know if the current programmes are sufficient or whether they are really effective in helping the elderly maintain a healthy lifestyle," she says.

"Furthermore, older learners can be very different from young learners. We hope to shed light on adult learning in general, and produce findings that can be applied to other areas of language learning and research."

THE SOONER, THE BETTER

The elderly are also a key risk group of concern to researchers of the Neuroscience and Mental Health Research Programme, says Prof Gulyás.

"Surprisingly, the rise of neurodegenerative diseases such as Alzheimer's does not increase linearly with the ageing of a population in developed countries; the numbers are rising faster than what you would expect based on our longer life spans. This suggests that there are other factors at play."

Noting that proneness to mental diseases is ten times higher in rapidly urbanised megacities than in small village communities, Prof Gulyás points to shifting societal structures as one major cause of mental health issues globally.

"Psychiatric problems are on the rise in our modern industrialised societies, and Singapore is not spared," he warns. "So it is not surprising that our medical school has put so much emphasis on mental health research."

And the strategy taken is a bold one, with a strong focus on the early stages of disease. The Neuroscience and Mental Health Research Programme has three main thrusts: basic mechanisms of disease, identification and validation of early disease biomarkers, and research into preventive therapeutic interventions.

This strategic focus brings together outstanding researchers from different schools across NTU, including Prof George Augustine from the Lee Kong Chian School of Medicine, a world leader in synaptic studies, and Assoc Prof Ajai Vyas from the School of Biological Sciences, who studies how parasites can manipulate the brain.

"'Early' is the common denominator," Prof Gulyás emphasises. "In most other cases, you work on late disease biomarkers. For instance, in positron emission imaging, you are looking for amyloid traces. But why do you want to demonstrate that the poor patient also has amyloid depositions when the diagnosis has already been established by a clinician and it is too late to do something?"

"What we want to do is to go 10 or 20 years earlier. If a person has a family history of neurodegenerative diseases, you want to test that person at age 40, 45 and 50 for early signs of disease and tell him or her immediately."

Acknowledging that it has been difficult to attain this predictive power with existing experimental designs, Prof Gulyás highlights newer techniques such as Bayesian analysis. The Bayesian approach allows researchers to create predictive models that can be justified, validated or refuted as new data comes in. "You can build up these nice analytical approaches if you have a large enough database," he adds.

By contributing to large cohort studies such as the UK Biobank Imaging Study and the Alzheimer's Disease Neuroimaging Initiative in the US, Prof Gulyás and his research team are hoping to do just that.

"I aim to recruit at least 3,000 subjects from Singapore, focusing on the three major ethnicities of Chinese, Malay and Indian. It's a very ambitious aim, but you need a few thousand subjects just to have an idea of what is going on," he explains.

TRANSLATING IN BOTH DIRECTIONS

As part of the Lee Kong Chian School of Medicine, the Neuroscience and Mental Health Research Programme has objectives that draw on clinical and translational approaches.

"Translation is not a unidirectional thing—it can be forward or backward. Whether we are working on a diagnostic or therapeutic approach, there should be a continuous dialogue between clinicians and researchers," Prof Gulyás elaborates.

In line with this objective, the medical school co-organised a symposium with Singapore's Institute of Mental Health in February this year. The Frontiers in Mental Health Symposium brought together both basic and clinical neuroscientists to exchange ideas and better understand each other's areas of interest.

"It was an excellent platform-building opportunity, paving the way for future joint projects, more collaborations and the mutual exchange of our experts," Prof Gulyás says.

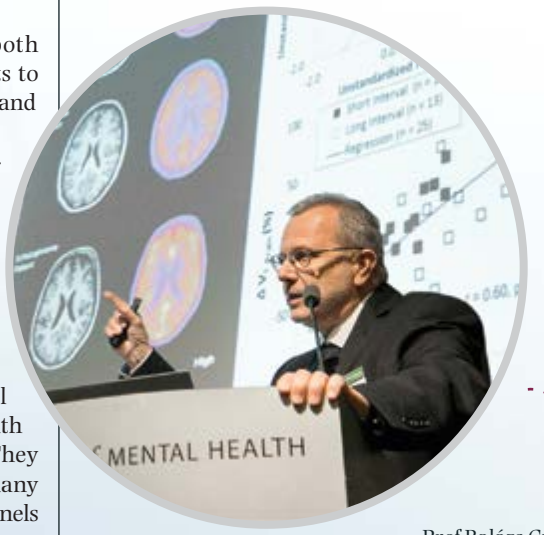
"We were also very pleased because we could demonstrate clearly that basic and clinical research in the field of mental health are not two independent silos. They are in fact one complex field with many touchpoints, communication channels and common denominators."

Such conferences are only the beginning of NTU's journey in neuroscience research, Prof Gulyás adds. The Ageing Research Institute for Society and Education (ARISE), launched on 6 May 2016, marks another significant milestone.

The new initiative will be a pan-university research institute that involves colleagues at the Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY) and the Singapore Phenome Centre at NTU, among others.

Ultimately, the research efforts across NTU are united in improving quality of life, Prof Gulyás says, whether for those suffering from developmental issues or neurodegenerative conditions.

"You can answer this question from different angles, but you always come to the same conclusion: the brain is so interesting that it is worth exploring in more detail," he concludes.

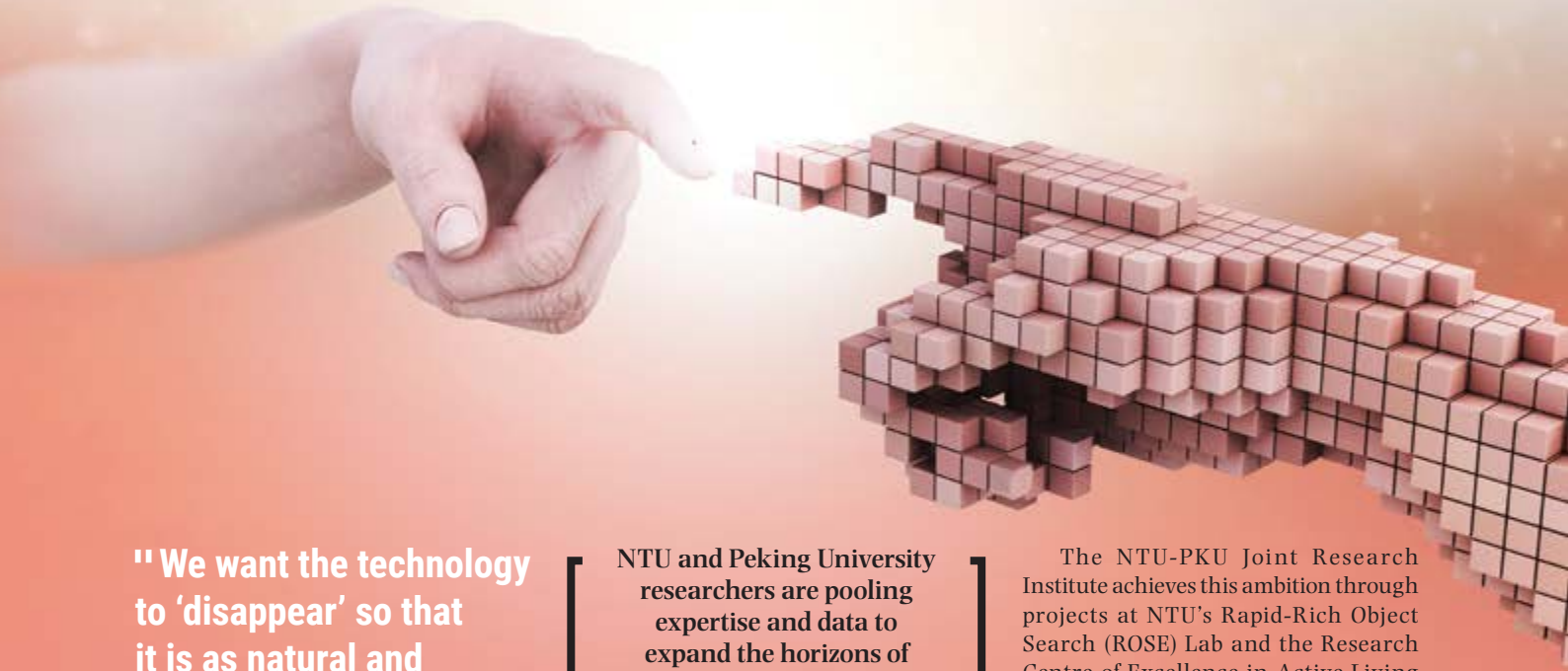


Prof Balázs Gulyás presenting at the Frontiers in Mental Health Symposium. Credit: Lee Kong Chian School of Medicine, NTU.

"Our research to counter the negative effects of an ageing population could also shed light on adult learning in general."

Asst Prof Alice Chan
Coordinator of the Cognition and Neuroscience cluster at NTU's School of Humanities and Social Sciences

MAKING ARTIFICIAL INTELLIGENCE SMARTER



"We want the technology to 'disappear' so that it is as natural and unnoticeable to the elderly as wearing glasses is to the short-sighted."

Assoc Prof Miao Chunyan
Director of the Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY)

[NTU and Peking University researchers are pooling expertise and data to expand the horizons of artificial intelligence.]

Humans are visual beings—we rely on what we see to interpret the world. But our visual readings are hardly perfect, especially when it comes to observing human behaviour or recognising things out of their usual context. So is it realistic to expect machines to assist humans based on what they see?

Research at NTU shows it's possible, if one is prepared to collect terabytes of data and give machines the intense training they need to make sense of it.

As part of celebrations of the 25th anniversary of diplomatic relations between Singapore and China last year, NTU and Peking University (PKU) joined forces to infuse technology with the "life experiences" needed to interpret the world as humans might see it.

The NTU-PKU Joint Research Institute achieves this ambition through projects at NTU's Rapid-Rich Object Search (ROSE) Lab and the Research Centre of Excellence in Active Living for the Elderly (LILY) to create visual-based search technologies and integrate technology and artificial intelligence into life-improving tools for the elderly.

THE WORLD IS YOUR MUSEUM

Take, for example, a picture of a woman walking in front of the Eiffel Tower in Paris. She is wearing a cap, a T-shirt featuring a flag of ISIS (Islamic State of Iraq and Syria), a watch, a backpack and a pair of bright orange sneakers.

To a casual observer, this image might give the impression that the woman is a tourist, while it may stir up more complex associations in a person who has experienced the Paris terrorist attacks.

However, a computer will have neither of these emotions. To find information

relevant to this image, text-based search engines would need words like 'backpack", "shoe" or "watch", if you are interested in shopping, while a counter-terrorist officer would be searching for "ISIS", "cap" and "backpack", as Prof Alex Kot, Director of the ROSE Lab explains.

"In either case, the actual design of the backpack, shoe or cap may be hard to describe in words, but if you could show the computer sample images, it would be able to retrieve images of a similar nature."

Through the creation of structured domain object databases, the ROSE Lab is giving search engines the knowledge needed for image search, which Prof Kot says "could turn the whole of Singapore into a museum."

"But first, the system needs to be taught how to recognise and differentiate between the various landmarks and monuments in the database. You would need to train the system with a lot of samples of a given landmark, providing images from many different angles, including examples where the landmark is partly obscured by obstacles like trees, vehicles or people," he explains.

Sounds like a lot of work? "It is!" exclaims Prof Kot, pointing to the even tougher challenge of facial recognition. "The search engine requires a lot of training—the lighting can change, hair styles can change, people may wear glasses, and so on. So the database becomes very important."

SCALING UP

The need for scale is a key driver behind NTU's collaboration with Peking University, he says, especially if the end goal is to support national needs and Singapore's plans to be a "smart nation".

Peking University not only brings strong image-based research to the partnership, but also opens up a rich source of data for the ROSE Lab, through its ties with large companies in China. One such company is IT giant Tencent, which has an online footprint equivalent to Facebook of close to a billion users, Prof Kot estimates. "This relationship has given us big data, which allows us to try out more ideas in our research."

In addition to social media and search engines, Prof Kot emphasises the contribution of image-based data to many industries, from homeland security to tourism.

"We have a lot of exciting things going on, in the areas of visual analytics using machine learning and deep learning," he enthuses, citing partners such as Singapore's Ministry of Home Affairs, consulting company Accenture, and soon, Germany's BMW. The ROSE Lab has also formed a close partnership with NVIDIA, the globally dominant manufacturer of graphics processing units.

Singapore and China are both increasingly using video footage, whether for work or for play, he says, highlighting an urgent need to find ways to better extract information from the voluminous footage and search engines.

"The ultimate question is, can we get machines to understand video and images the way our eyes see them, and in real time? If machines like surveillance cameras and robots can extract meaningful information from visual data, they can help humans make good decisions."

ELDERLY WISDOM FOR ARTIFICIAL INTELLIGENCE

A similar shared interest drives NTU LILY's collaboration with Peking University to develop unobtrusive technology supporting elderly living.

"We want the technology to 'disappear' so that it is as natural and unnoticeable to the elderly as wearing glasses is to the short-sighted. That's why we call it 'ageless ageing'," explains Assoc Prof Miao Chunyan, founding Director of LILY, a joint institute with the University of British Columbia fuelling elderly-friendly technologies.

In an interesting contrast to the work at ROSE Lab, this aim has moved LILY's research beyond the video camera. Previously, researchers designed cameras to monitor elderly behaviour at home, which can reveal age-related problems such as depression.

Yet for many of the elderly, being "watched" by video cameras leads to a loss of dignity, says Assoc Prof Miao. As a solution, LILY has developed sensors that monitor movement and action and combined these with data analysis to detect patterns that reflect signs of illness.

"The collaboration with Peking University has been 'win-win'," says Assoc Prof Miao. Besides a shared pool of expertise, it has given LILY access to hospitals in China where they can develop and pilot the technology, as was done with Tan Tock Seng Hospital, a large public hospital in Singapore with special interests in neurology and geriatric medicine.

TECHNOLOGY WITH A HUMAN TOUCH

LILY's relationship with Tan Tock Seng Hospital and PKU provides much-needed learning opportunities for the technology itself. Just getting the language right is a challenge, says Assoc Prof Miao, recounting how LILY had to develop multilingual versions of its tools to suit the elderly patients.

Their next big goal: teachable intelligence—technology that the elderly themselves can train. In turn, the technology might also be persuasive. "A persuasive agent might use an avatar that looks like a relative, to persuade the elderly to stand up or go to the park," she says.

And while the researchers are technology experts, they too concede that it is the human element that lies at the heart of any successful artificial intelligence.

"The ultimate question is, can we get machines to understand video and images the way our eyes see them, and in real time?"

Prof Alex Kot
Director of the Rapid-Rich Object Search Lab

WHEN IT COMES TO SATELLITES,

SMALL IS BEAUTIFUL

Reaching for the stars need not cost an arm and a leg. Pioneering work being done at NTU's Satellite Research Centre shows us how nano-satellites can have an outsized impact.

There is no denying it—space is hot right now. Two Asian powerhouses, in particular, are going into space in a big way. As the world celebrated the landmark discovery of gravitational waves earlier this year, India announced plans to build its own Laser Interferometer Gravitational-wave Observatory. Not to be outdone, China ambitiously highlighted deep space exploration as one of the selected priority science projects in its new five-year plan.

In a decidedly smaller but no less impactful way, Singapore is attempting to break into the space industry as well—and with good reason. In 2014, the global space economy was valued at a total of US$330 billion worldwide, up almost 10% from the year before, according to the Space Foundation's *The Space Report 2015: The Authoritative Guide to Global Space Activity.* And with the current buzz of space activity within the region and beyond, the timing is just right.

GROWING SINGAPORE'S SATELLITE INDUSTRY

NTU's satellite-building activities are an integral part of Singapore's space ambitions. To date, the University's Satellite Research Centre has sent six satellites into orbit. X-SAT, the inaugural satellite launched in 2011, was also Singapore's first locally built, remote sensing micro-satellite.

The success of X-SAT led to the satellite team and its collaborator, DSO National Laboratories, receiving the national Defence Technology Prize in 2011, and kick-starting a joint venture with local company ST Electronics (Satellite Systems) Pte Ltd. In 2015, the company successfully launched the first Singapore commercial satellite, TeLEOS-1, which is being used for earth observation.

Since 2009, the Satellite Research Centre has grown from strength to strength, developing smaller, more cost-efficient satellites and introducing experimental technology payloads. "We have demonstrated to the world that Singapore has the technology and people to design, build and operate the satellites," says Assoc Prof Low Kay Soon, Director of the Satellite Research Centre. However, before Singapore can nurture a local space industry and make a mark in global space research, it needs a strong talent pool of multidisciplinary and team-oriented engineers trained in space technology, he adds.

In response to this need, the Centre introduced its Undergraduate Satellite Programme in 2009, open to second- to final-year engineering students. Their first triumphs were to build two 1.3 kg pico-satellites called VELOX-PI and VELOX-PII—velox in Latin means rapid or swift—and VELOX-PII was launched into space in 2013.

Next up was the VELOX-I, a 4.3 kg nano-satellite for imaging, GPS navigation and communication purposes. As the Centre's first nano-satellite, it proved to be quite a learning experience for the students.

"To begin something entirely new is always difficult. Being the pioneer batch of students working on the design of VELOX-I, there were no references available for us to follow," says research fellow Dr Charlie Soon, who as an undergraduate student began working on the solar energy power system for VELOX-I.

SMALL SATELLITES, BIG IMPACT

Most regular satellites weigh at least 500 kg. Though much smaller, micro-, nano- and pico-satellites—ranging from a mere 193 g to over 100 kg, about the size of a refrigerator—punch well above their weight when it comes to functionality.

"The main motivation to develop smaller satellites is to reduce launch costs and also enable missions that larger satellites cannot do," says Asst Prof Chen Shoushun from the School of Electrical and Electronic Engineering, who was involved in developing remote sensing systems for VELOX-I and the slightly larger VELOX-II, launched in 2014 and 2015 respectively. According to Asst Prof Chen, launch costs can be US$50,000 for every kilogramme, with large satellite launches running into the millions.

There are other advantages to developing these smaller satellites, notes Asst Prof Chen. "When it comes to larger satellites, which can cost millions of dollars, people will only dare to use mature technology from maybe ten years ago. For small satellites, we can afford to test new technologies because the launch costs are significantly lower."

One key new technology the Satellite Research Centre is testing out with its VELOX-II satellite is radiation-resistant hardware. "The high levels of radiation in space can damage the electronic circuits. The satellite carries a memory SD card, but because of its fragility, all it takes is one error for the entire satellite to fail. To get around this problem, we developed a special integrated circuit that can protect this critical data," Asst Prof Chen explains.

Besides technological hurdles, actually getting the satellites into orbit brought its own set of challenges. "We had to go through many logistical issues, such as filing the satellite frequency with the International Telecommunication Union through the Infocomm Development Authority of Singapore, applying for an orbit licence, and contending with import and export controls," Assoc Prof Low shares.

DEVELOPING A NICHE IN NANO-SATELLITES

With all that has been achieved so far for Singapore's budding satellite industry, yet more exciting milestones await the Centre. According to Assoc Prof Low, the Satellite Research Centre is putting the finishing touches to its latest satellite, AOBA VELOX-III, which is due for delivery to the Japan Aerospace Exploration Agency by July this year, for launch via the International Space Station. "We have also started building the AOBA VELOX-IV, a pathfinding satellite that can potentially be used for a future moon observation programme," he adds.

"We have demonstrated to the world that Singapore has the technology and people to design, build and operate satellites."

Assoc Prof Low Kay Soon
Director of NTU's Satellite Research Centre

Credit: Lester Kok.

Assoc Prof Low believes that Singapore will be able to establish a successful space industry by focusing on small satellites and satellite-based services. "In particular, we may see several companies providing hundreds of nano-satellites flying in formation, providing worldwide observation of ships, aircrafts or vehicle traffic in real time."

Dr Soon, on the other hand, reminds us that the curiosity and wonder of going to space will never fail to inspire—and it makes all the hard work worth it. "The most exciting moment for me is still the day when the satellite is launched and everyone is waiting for the first ground contact with it," he says. "Once the first contact signal is received, the scene where everyone bursts into happy applause is priceless."

Brains can change

Neuroplasticity in both healthy ageing and disorders

By Annabel Chen

Assoc Prof Annabel Chen is a clinical neuropsychologist with joint appointments at NTU's School of Humanities and Social Sciences and the Lee Kong Chian School of Medicine. She is also Deputy Director of NTU's Centre for Research and Development in Learning (CRADLE).

The research presented here was published in NeuroImage *(2016), DOI: 10.1016/j.neuroimage.2015.09.038;* Human Brain Mapping *(2014), DOI: 10.1002/hbm.22194;* Schizophrenia Research *(2013), DOI: 10.1016/j.schres.2013.10.028;* Brain Imaging and Behavior *(2012), DOI: 10.1007/s11682-012-9148-5;* Human Brain Mapping *(2011), DOI: 10.1002/hbm.21364; and* Neuropsychologia *(2005), DOI: 10.1016/j.neuropsychologia.2004.12.015*

Over the last few decades, research has begun to unravel the mysteries of the brain, dramatically changing our understanding of how one of the most complex organs in the human body works. Neuroimaging research has shown that the adult brain is still able to rewire itself, altering its physical structure and function through changes in thought, experience and behaviour. The brain is thus more plastic than we ever thought; it never stops changing in response to the learning of new skills and the retaining of information over time.

In our research, we apply neuropsychological principles and neuroimaging to study the relationship between brain structure and behaviour in healthy and clinical populations. Based on these insights into the workings of the brain, we are investigating a range of neurodevelopmental and neurodegenerative conditions to develop more precise interventions. In addition, our understanding of structural changes that happen during ageing informs strategies to keep our brains healthy and optimally functioning as we age.

THE CEREBELLUM'S ROLE IN HIGHER COGNITION

Cognitive, affective and behavioural changes correlated to neuropsychiatric disorders, such as autism, schizophrenia and dyslexia, are known to be linked to abnormalities in a structure of the brain known as the cerebellum. In addition, functional neuroimaging has shown that the cerebellum contributes to a wide range of cognitive, perceptual and motor functions.

One of the research thrusts in our lab is to investigate the role of the cerebellum in higher cognition and interventions for complex psychiatric disorders. In particular, we are focused on working memory, a cognitive process where new information has to be held briefly in our minds to perform ongoing activities such as reading long text with several ideas and mathematical calculations. We have shown that whole brain neural networks, including brain areas from the cerebrum to the cerebellum (called cerebro-cerebellar networks), are involved in several cognitive processes such as working memory.

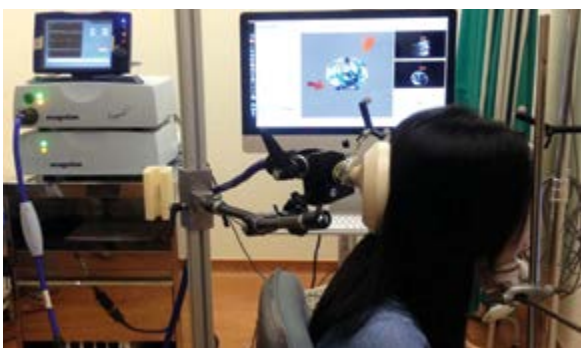


Figure 1: A participant performing a task on the computer, while undergoing transcranial magnetic stimulation (TMS). The TMS coil is placed over the cerebellum guided by the brain activation seen in the functional magnetic resonance image acquired in the MRI scanner.

Furthermore, using transcranial magnetic stimulation (TMS), we were able to verify that the right hemisphere of the cerebellum is dominant for verbal working memory. For visual working memory, though brain activation is seen largely in both cerebellar hemispheres, some emphasis on the left is observed (Figure 1). We have also used diffusion magnetic resonance imaging (MRI) and tractography to map this structural network *in vivo* for the first time in humans (whole brain functional MRI and diffusion MRI are shown in Figures 2 and 3, respectively).

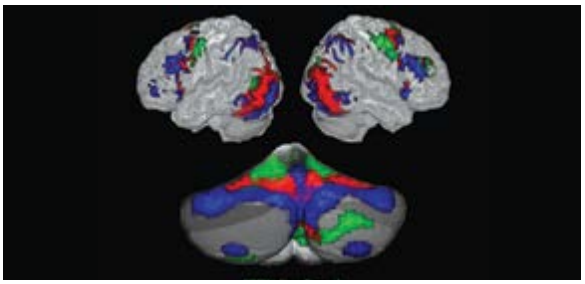


Figure 2: Brain activation during the different phases of visual working memory shown by functional MRI in the two hemispheres of the cerebral cortex (top) and in the cerebellum (bottom). Green: memory encoding; blue: memory maintenance; red: both memory encoding and maintenance.

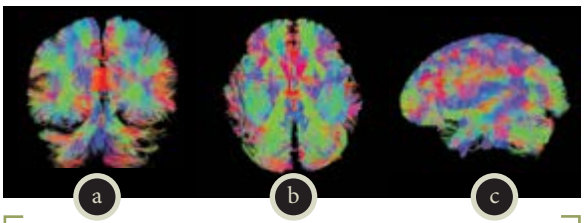


Figure 3: Coronal (a), axial (b) and sagittal (c) view of the brain showing the white matter fibre tracts in the whole brain using diffusion spectrum imaging.

BRAIN CIRCUITS IN SCHIZOPHRENIA, DYSLEXIA AND OBSESSIVE-COMPULSIVE DISORDERS

Using the insights we gained from studying the cerebro-cerebellar working memory, we have made big strides in understanding the cerebro-cerebellar-thalamic-cerebro-circuit (CCTCC), a functional framework currently used to examine schizophrenia. We observed dysconnectivity in the CCTCC network in individuals with schizophrenia compared to healthy controls. In particular, we found that the dysconnectivity in subcortical regions of the brain (such as the thalamus and cerebellum) was not affected by the length of illness. Currently, we are using this approach to investigate dyslexia and obsessive-compulsive disorder.

Using neuroimaging techniques, we are also building predictive models together with sensitive and specific behavioural tests that can help identify neurodevelopmental disorders much earlier on. It is hoped that with early identification, early intervention through cognitive and behavioural training could mitigate or even ameliorate symptoms of neurodevelopmental disorders such as dyslexia and attention-deficit hyperactivity disorder.

TRAINING THE AGEING BRAIN TO OPTIMISE PERFORMANCE

Functional neuroimaging has helped us to understand structural changes happening in the ageing brain in the hopes of optimising brain functions for healthy ageing. For example, we have observed that the ageing brain is still able to form a fair amount of new neural connections—a capability called neuroplasticity.

However, one of our studies found a shift in functional activity in an area of the brain called the hippocampal axis, which is associated with memory. This activity change was similar to—though less intense—than that seen at stages prior to the onset of dementia.

Currently, we are investigating the ability of intensive cognitive training to minimise age-related changes using electroencephalography (EEG) analysis. We hope to show evidence that cognitive training not only improves the cognitive function that is trained, but can also be transferred to other cognitive abilities such as fluid intelligence and long-term memory. Our preliminary findings suggest that after 20 sessions of 20 minutes a day, precision memory—the ability to accurately identify items just seen from similar ones—is improved.

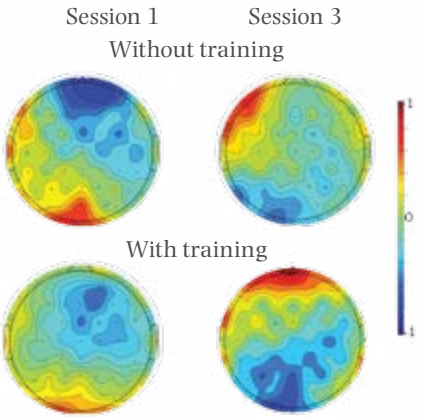


Figure 4: Brain activity shown by electroencephalography during a working memory task. There is a greater shift of activity to the front of the brain (top of the images) for individuals who underwent cognitive training. Colour bar: red: more brain activity; blue: less brain activity.

Apart from furthering research in cognitive training, we hope to examine and apply non-invasive brain modulation methods such as TMS and transcranial direct current stimulation. Both methods have shown promise in improving the learning of language and executive functions and have possible effects on mood.

With the new neuroimaging facilities in place at NTU, we plan to apply multi-modal neuroimaging techniques combining EEG and functional MRI (fMRI), magnetoencephalography and fMRI, diffusion tensor imaging and fMRI, or EEG and near infrared spectroscopy to further our understanding of how targeting various neural networks could change brain function.

The discovery of plasticity in the adult brain is an impetus for new research into improving brain function and measuring how the brain changes. Non-invasive neuroimaging techniques at our disposal complement this driving force, allowing us to investigate more specific intervention methods for targeting different cognitive functions and optimising brain health.

Extreme Learning Machines

Enabling pervasive learning and pervasive intelligence

By Huang Guangbin

Assoc Prof Huang Guangbin from NTU's School of Electrical and Electronic Engineering is among the world's Highly Cited Researchers in two separate fields, Engineering and Computer Science, and is listed in Thomson Reuters' 2015 The World's Most Influential Scientific Minds. He is also a Principal Investigator working on research in human machine interface in the BMW Group-NTU Future Mobility Research Lab and on marine data analysis and prediction in the Rolls-Royce@NTU Corporate Lab.

More details of his research can be found in IEEE Computational Intelligence Magazine *(2015), DOI: 10.1109/MCI.2015.2405316;* Cognitive Computation *(2015), DOI: 10.1007/s12559-015-9333-0;* IEEE Transactions on Systems, Man, and Cybernetics—Part B *(2012), DOI: 10.1109/TSMCB.2011.2168604;* Neurocomputing *(2007), DOI: 10.1016/j.neucom.2007.02.009; and* IEEE Transactions on Neural Networks *(2006), DOI: 10.1109/TNN.2006.875977.*

With recent developments such as Google DeepMind's victory over Go master Lee Sedol, few doubt that we have entered an era of machine learning. In fact, machine learning has passed both the warm-up stage (1950s-1970s) and the research-driven stage (1980s-2010), and is now thought to be entering the data-driven stage (from 2010 onwards).

However, a true machine learning era needs to satisfy three conditions: powerful computing environments (including distributed implementation, powerful servers and smart local mobile devices), rich dynamic data, and efficient machine learning techniques.

Thus, in the past decade, our main research interest has been in the interdisciplinary development of efficient machine learning theories and techniques. In particular, over the past three years, we have taken the following four directions:

NEW LEARNING THEORIES FOR NEURAL NETWORKS

Artificial neural networks and support vector machines (SVM) have played key roles in machine learning and data analysis in the past decades. Deep neural networks have gained favour of late. However, deep learning as a popular learning technique faces challenging limitations such as slow learning speeds and the need for intensive human intervention.

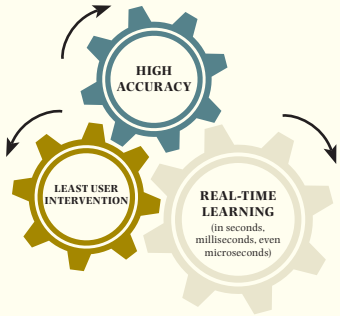
We have introduced a new generation of learning theories called Extreme Learning Machines (ELM). ELM provides a unifying theoretical solution to hierarchical neural networks, in which a hidden node could be a subnetwork consisting of a few neurons.

Unlike conventional learning theories popular in the past 60 years, one key property of ELM theories is that universal learning capabilities (feature learning, clustering, regression and classification, etc.) can be achieved without adjusting hidden neurons. For example, hidden neurons can be inherited from ancestors or randomly generated. Furthermore, ELM theories give theoretical support to convolutional neural networks (including local receptive fields and pooling strategies), which are core components of deep learning.

UNIFYING LEARNING ALGORITHMS FOR NEURAL NETWORKS

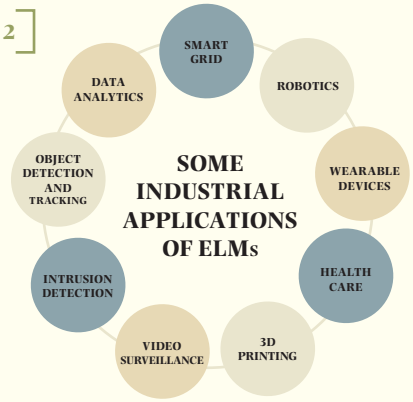
ELM-based machine learning algorithms are valid for many types of neural networks as well as wavelet networks and Fourier series, and may learn up to tens of thousands of times faster than popular machine learning techniques such as deep learning and SVMs. Thus, our new machine learning techniques can help to realise "learning in real-time", producing good results from sparse datasets and for large applications (Figure 1).

Figure 1



From both the theoretical and practical points of view, ELM may generally produce better solutions than popular SVM and its variants. ELM also outperforms deep learning in many applications. In fact, ELM set new records of learning accuracies in some benchmark datasets and applications such as the recognition of handwritten characters, traffic signs and hand gestures, as well as 3D graphics (Figure 2).

Figure 2



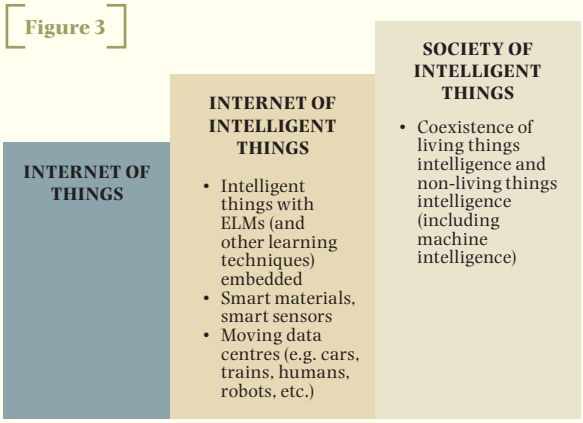
Our new machine learning algorithms have been used in real-word applications such as big data analytics, robotics, smart grids, healthcare, wearable devices, anomaly detection, geoscience and remote sensing, and also by several of our NTU colleagues in various research contexts (for example, ELM-based short-term forecasting of renewable energy generation, ELM-based facial emotion recognition and indoor local positioning systems).

ELM CHIPS FOR PERVASIVE LEARNING

Moving beyond the Internet of Things (IoT), most appliances will come with embedded intelligence and learning capabilities in the near future. We believe that alongside a society of living things that include humans, these intelligent appliances and devices will develop into what we call a Society of Intelligent Things in which all intelligent things with embedded learning capabilities can interact with one another (Figure 3).

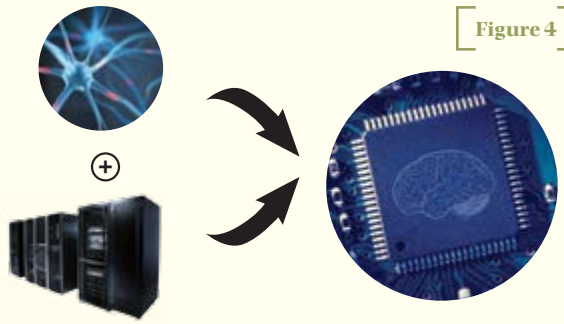
Here, ELM, which enables learning up to tens of thousands of times faster than deep learning, will help us to realise this Society of Intelligent Things. ELM-based smart chips that can be integrated into hardware as small as a single micron of space and can learn real-time

Figure 3



and locally are essential to enable pervasive learning and pervasive intelligence. In the past years, we have driven the research of ELM-based chips along two main directions: multicore accelerators (field-programmable gate arrays (FPGA) and application-specific integrated circuits (ASIC), research led by Asst Prof Yu Hao), and neuromorphic chips (research led by Asst Prof Arindam Basu) (Figure 4).

Figure 4

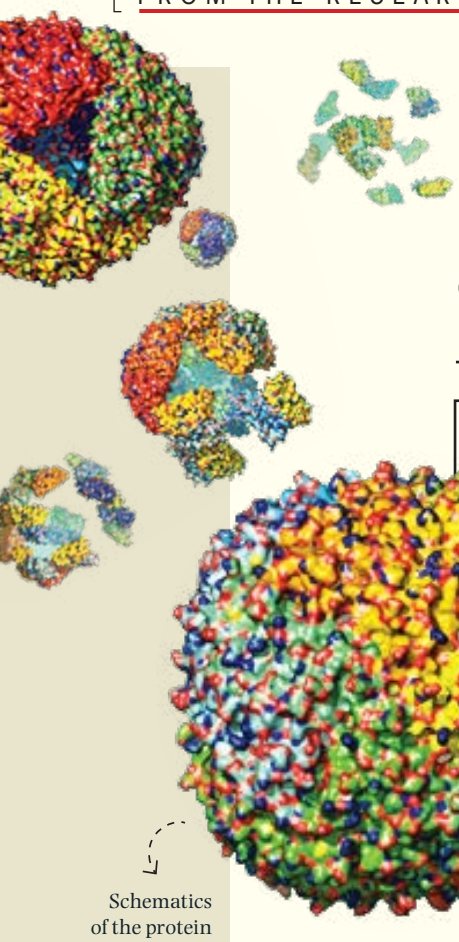


FILLING THE GAP BETWEEN HOW LIVING THINGS AND MACHINES LEARN

One objective of ELM theory is to break the barriers between machine learning and biological learning. While animal brains are overall structured and ordered, they may seem locally "unstructured" in a particular layer or area of neurons. We ask whether, unlike conventional machine learning theories, all hidden neurons actually need to be tuned in biological learning systems.

Our theories may be able to address a puzzle, which was first posed by John von Neumann, the "Father of Computers". The puzzle is how an imperfect (biological) neural network, which contains many random connections, can reliably perform "ideal" functions that might be represented by computers with idealised wiring diagrams.

To this end, we are collaborating with neuroscientists to investigate fundamental learning mechanisms based on principles from neuroscience. Biological learning systems consist of many fundamental learning elements that we are still far from fully understanding, and our curiosity about the relationship between machine learning and biological learning is what motivates us to move our research forward.



Inspired by Nature

Tweaking Mother Nature's designs for medicine and beyond

By Sierin Lim

Assoc Prof Sierin Lim is Assistant Chair (Research) at NTU's School of Chemical and Biomedical Engineering. She received the 2013 L'Oréal-UNESCO Singapore For Women In Science National Fellowship.

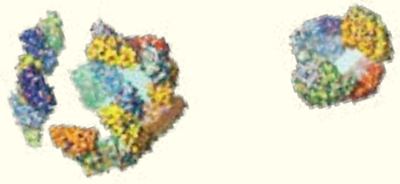
Parts of this research have been published in [1] Chemical Communications *(2012), DOI: 10.1039/C1CC15189D; [2]* Journal of Nanoparticle Research *(2013), DOI: 10.1007/s11051-012-1409-0; [3]* Advanced Materials *(2016), DOI: 10.1002/adma.201504402; [4]* Small *(2014), DOI: 10.1002/smll.201300810; [5]* Small *(2014), DOI: 10.1002/smll.201303516; and [6]* ACS Applied Materials and Interfaces *(2013), DOI: 10.1021/am3022366.*

Schematics of the protein nanocage self-assembly process where the subunits come together in a very specific manner. Credit: Eric Johnson, Pfizer.

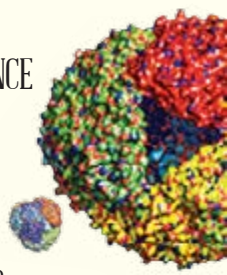
Nature has perfected her ability to build highly symmetrical and complex structures from proteins, lipids and carbohydrates with a wide variety of functions in biological systems. For example, DNA-binding proteins such as Dps protect DNA from oxidative damage, while heat shock proteins fold or unfold other proteins in response to temperature changes. Virus capsids serve as enclosures for genetic materials of the viruses.

At the Bioengineered and Applied Nanomaterials Laboratory (BeANs Lab) at NTU's School of Chemical and Biomedical Engineering, we aim to stretch the functions of these structures beyond what Mother Nature had originally intended. We synthesise hybrid bionanomaterials based on protein nanocages for applications as drug carriers, contrast enhancers in imaging, and ligand display platforms.

The BeANs Lab is working on three cage-like proteins: Ferritin (15 nm in diameter), E2 (25 nm in diameter) and Vault (40 x 70 nm in size) (Figure 1). Ferritin is a ubiquitous protein nanocage that maintains iron homeostasis in almost all organisms, including humans. It stores iron within its hollow core, forming a metal-protein core-shell structure. E2 is found in the core of the pyruvate dehydrogenase multi-enzyme complex, an enzyme that is involved in glucose metabolism. Vault, whose function is yet to be revealed, is one of the biggest protein nanocages in nature with a distinct barrel-shaped structure.



CONTRAST AGENTS FOR MAGNETIC RESONANCE IMAGING (MRI)



Ferritin is naturally magnetic as its hollow core contains iron, allowing it to act as an MRI contrast agent. Current gadolinium-based contrast agents have been reported to cause kidney problems in patients who are predisposed to kidney conditions, so alternatives are continuously being sought. We have shown that Ferritin loaded with iron or manganese has good contrast-enhancing properties (Figure 2) and we are currently investigating the molecular basis of such enhancements.

HOLLOW CORES TO CARRY DRUGS AND TRANSFER ELECTRONS

The hollow cores of protein nanocages can be engineered to increase their affinity for molecules that are not their natural cargo. In our lab, we have loaded Ferritin with platinum-based anticancer drugs and shown that the Ferritin-encapsulated drugs retain their efficacy while minimising adverse cell toxic effects at the same time. Engineered E2 has been loaded with paclitaxel, a hydrophobic anti-cancer drug, and Vault with other hydrophobic drugs or biomolecules.

Apart from drug delivery, we have exploited Ferritin's ability to store iron in its hollow core for the synthesis of nanoparticles that include manganese, platinum, cobalt, or other metals and their combinations. The nanoparticles formed are highly uniform in size. In the case of platinum, nanoparticles reached ultra-small sizes of about 5 nm—a size range that otherwise requires extensive efforts including modifications using chemical methods.

When combined with graphene, Ferritin-synthesised platinum nanoparticles show promise for various applications involving electron transfer, such as electrode materials in methanol reduction/oxidation fuel cells. Another advantage of protein nanocages over synthetic nanoparticles is the presence of hydrophobic patches on the nanocages' protein shells, which aid in the even deposition of nanoparticles onto substrates such as carbon cloth and graphene foam, and avoid the aggregation and clumping observed with chemically synthesised ultra-small nanoparticles. We are further investigating the electron transfer processes through Ferritin nanocages for molecular electronic device applications.

MODIFYING THE SHELL TO DISPLAY MOIETIES FOR VACCINES AND TUMOUR DETECTION

In addition to the hollow core, the external surface of the protein nanocages shell can also be modified. We have attached ligands, such as engineered antibodies, to the shells of protein nanocages as a means to target cancer cells, enhancing the contrast around tumours and minimising chemotherapy dosage and side effects (Figure 2). If each subunit displays one engineered antibody, the fully assembled protein nanocage can potentially display as many engineered antibodies as it has subunits—24 for Ferritin and 60 for E2.

As engineered antibodies are relatively large moieties, overcrowding may occur, leading to a lower number of displayed antibodies. In contrast, using smaller moieties such as viral epitopes—parts of the virus particle that can be recognised by human immune cells—maximises the number of moieties that can be displayed. We have successfully displayed various epitopes—including those from chikungunya, malaria, and respiratory syncytial virus—on nanocages and are currently looking for collaborators to test our constructs in animal models. It has been shown that epitopes of the parasitic bacterium *Chlamydia* packaged within Vault can provide immune protection in mice models.

The precise control of spatial arrangement of moieties on the protein shell is a major advantage of protein nanocages over synthetic nanoparticles that is yet to be exploited.

INTERESTING DISCOVERIES OF NEW PROPERTIES

Recently, we discovered that protein nanocages aggregate at the interface of oil/water and stabilise the nano-sized emulsions formed during the process. We are currently patenting this discovery, which is potentially of interest to the food and cosmetics industries, and exploring avenues for collaboration.

We are also investigating the basic properties of Ferritin's metal core and its interactions with the protein shell, as well as the interactions of the nanocages with their immediate surroundings. This basic understanding is important for applications in different fields, such as for the design of next-generation MRI contrast agents and emulsifiers.

Protein nanocages have many unique properties, including highly symmetrical structures to precisely control the display of moieties on their shells and the ability to form metal cores. Our lab is dedicated to exploring these properties, from gaining fundamental insights to applying these properties to various uses in medicine and beyond.

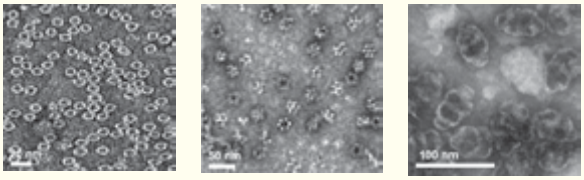


Figure 1. Protein nanocages have potential applications as MRI contrast agents, drug carriers, and ligand display platforms. Electron micrographs of Ferritin (left), E2 (middle), and Vault (right), with scale bars of 20 nm, 50 nm, and 100 nm, respectively. Credit: (left) reproduced from [1] with permission from the Royal Society of Chemistry; (middle and right) BeANs Lab.

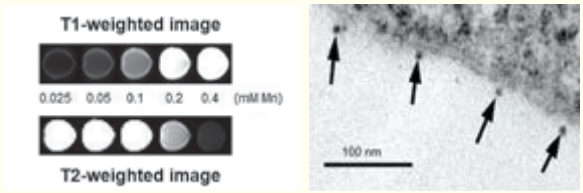
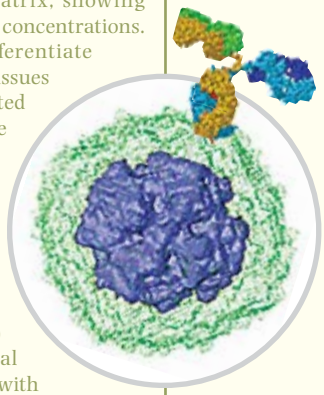


Figure 2. (top left) Magnetic resonance images of manganese-loaded Ferritin embedded in agarose matrix, showing enhanced contrasts with increasing metal concentrations. T1-/T2-weighted: Parameters set to differentiate anatomical structures; water-containing tissues (e.g. kidney) appear dark under T1-weighted and bright under T2-weighted imaging while protein-containing tissues (e.g. pancreas) appear bright under T1-weighted and dark under T2-weighted imaging; (top right) Electron micrograph of antibody-decorated Ferritin targeting transformed rat prostate epithelial cells overexpressing Necl-5, a surface glycoprotein that is abundant in carcinomas. Picture credits: (top left) Reproduced with permission from the Royal Society of Chemistry; (top right) Reproduced with permission from Springer.



Schematic of Ferritin carrying a cargo and displaying an antibody. Credit: BeANs Lab

LEADING DREAM TEAMS

Bringing the best people together to solve some of the world's biggest problems

High-quality healthcare for everyone who needs it—that's the dream of surgeon Prof Russell Gruen, Director of NTU's Nanyang Institute of Technology in Health and Medicine (NITHM) and Vice-Dean for Research at the Lee Kong Chian School of Medicine.

Q *You are working with* The Lancet, *one of the world's leading medical journals, as a member of its Commission on Global Surgery. What is the goal of this work?*

A We now know that five billion out of the seven billion people living on Earth today can't get a safe operation when they need it, even for basic emergencies like appendicitis, complicated childbirth or a nasty broken leg. This is really a failure of health systems, especially in low- and middle-income countries, but of course inefficiencies exist in higher income countries too.

The Lancet Commission on Global Surgery—as outlined in a report that we published in *The Lancet* in August 2015—planned how healthcare systems could be strengthened to improve access to safe surgery and anaesthesia. Aligned to World Bank targets for universal health coverage, we have set an ambitious goal—by 2030, 85% of the world's population should be able to receive safe emergency surgery within two hours.

The Commission brought together global leaders in the field to appraise the current situation, set future goals and work out what it would take to achieve them. Through research and modelling the future, as well as engaging professional groups and key government and international agencies, we set in motion a global process that is already making a difference to many people who need surgical care.

Q *Surgery and public health are typically two separate disciplines in medicine. How did the two come together in your career?*

A Surgery typically demands technical precision and focus during the course of an operation, whereas public health addresses whole populations, and relates strongly to politics, economics and social sciences. However, it's become clear that the two fields are not as separate as might be thought. They come together in concerns about the cost of healthcare and healthcare quality, safety and accessibility.

I had a formative experience during a medical student placement in Nepal, where I assisted with reconstructive surgery in a leprosy hospital, and then followed up my patients by walking for a few days at a time to visit them in remote clinics.

Later, as a PhD student, I studied the impact of a new programme to bring specialist doctors out to people in remote communities in northern Australia, reducing the need for Aboriginal people to travel long distances to the hospital. It got me thinking about how we could do things better, using, for example, telemedicine, different types of training and remote screening services.

These experiences have helped me to realise that surgery is an indivisible and indispensable part of healthcare, and that public health expertise can guide the optimal organisation of surgical services.

"That is our opportunity—to bring together the brightest minds and all the necessary expertise to tackle the world's most challenging problems."

Q *How did your multifaceted career and your work on global health lead to your move to NTU and Singapore?*

A During the last decade as a professor and surgeon at The Alfred and Royal Melbourne Hospitals, I looked after the most seriously injured people in Victoria. Our system of care gained a reputation for saving many lives, and I became increasingly involved in leading trauma and health systems development programmes in other countries.

As a young, research-intensive and globally-engaged university, NTU provides a great opportunity to do work with global impact. And it's a university committed to interdisciplinary research, recognising that big challenges require smart people with a diverse range of skills working together, supported with state-of-the-art facilities and equipment.

And it's also a unique opportunity to contribute to the development of the Lee Kong Chian School of Medicine—an ambitious, technology-oriented medical school with high-calibre parents: NTU and Imperial College London.

On the personal side, it's also relevant that my wife, Theresa Yee, is from Singapore; we met at medical school in Australia almost 30 years ago.

Q *Having been in Singapore since August 2015, what would you say are strengths of the Singapore healthcare system compared to what you have seen elsewhere? What is NTU's unique competitive advantage as a contributor to this?*

A Like all countries, Singapore is wrestling with the cost of care and diseases of older age—diabetes, cancer, obesity and so on—but we also have assets, such as a very well-educated population and well-trained healthcare professionals. Technology and health systems development have much to offer to the quality and affordability of future healthcare. These systems could serve as models for other big cities, particularly those that are rapidly emerging in Asia.

NTU is an extraordinary resource in this environment, with its breadth and depth of expertise, its strengths in engineering and other health-related areas, and its problem-solving orientation.

The vision of the medical school—redefining medicine, reforming healthcare—is a radical vision in the conservative world of medicine and it is one that NTU and Imperial College London are ideally suited to champion, as technological universities committed to innovation.

Q *What goals do you hope to achieve as Director of NITHM and Vice-Dean for Research at the medical school? Have you been able to implement some of these since your move to NTU in August 2015?*

A My passion is creating an environment in which research and researchers can flourish, and building a system that helps NTU and Singapore thrive on the global health stage.

With NITHM, we are now taking it to the next stage, from being a virtual institute to a more powerful research institute with dedicated centres and facilities on NTU's main campus and its medical campus in Novena. These centres will bring together clinicians, scientists and engineers to create better health and healthcare solutions, develop new medical technologies, and eventually test these new technologies in real populations.

By bringing together the health, technological, business and social science expertise that exists at NTU, in Singapore and throughout the world, we have unparalleled opportunities to improve our population's health. Our partnerships with industry will also help make new technologies accessible to larger numbers of people in the world.

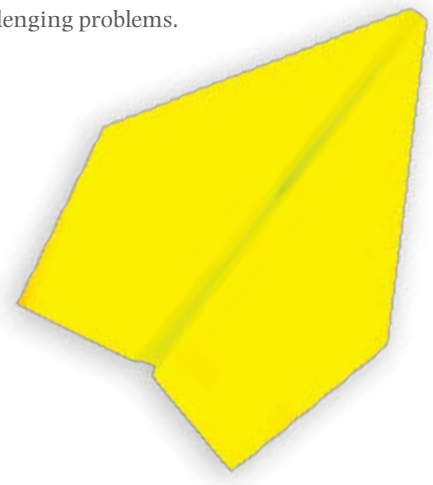
In my role as Vice-Dean for Research at the Lee Kong Chian School of Medicine, I am working to attract the best and brightest scientists to NTU. Our leadership is now strengthening the research areas in which we are best placed to have major impact, such as neuroscience and mental health, diabetes and metabolic disorders, infectious diseases and skin health.

Furthermore, we're making the most of opportunities for interdisciplinary research with the vast breadth and depth of expertise across NTU. In new ways of imaging the human body, in genomics and phenomics, in understanding and promoting healthy ageing, and in developing new and innovative ways of delivering healthcare services, we're living up to the medical school's vision of redefining medicine and transforming healthcare.

Q *What is your personal research philosophy?*

A I know from experience that even big problems can be solved when you bring the best people together and you create opportunities for them to flourish as a team. Just as in sports, music or business, high-performing research teams require brilliant people with different types of expertise to focus on the many facets of a shared challenge, and the support needed for them to work seamlessly together and to perform at their best.

This is my passion—creating an environment in which individual brilliance can shine and excellent teams are nurtured. And that is our opportunity—to bring together the brightest minds and all the necessary expertise to tackle the world's most challenging problems.



PROVIDING HEALTH — *FOR THE NEXT* — GENERATION

Rapidly ageing populations, urbanisation and globalisation all call for multifaceted answers to curb the spread of infectious diseases and improve human health. Various research programmes across NTU's schools and institutes take on the complex aspects of health systems for a future that benefits both the individual and the global community.

ASSOC PROF JOSIP CAR

"It takes an average of 17 years from basic discovery to a new treatment becoming part of routine medical practice," says Assoc Prof Josip Car, citing a study by the US National Academies of Sciences.

As Founding Director of the Health Services and Outcomes Research programme at NTU's Lee Kong Chian School of Medicine and Director of the Global eHealth Unit at Imperial College London, Assoc Prof Car wants to shorten this gap with the help of digital health, also called eHealth.

He is assembling a multidisciplinary team under the new university-level Centre for Population Health Sciences (CePHaS), where researchers are developing new approaches such as mobile apps for the management of chronic diseases.

"We have counted that people from more than 27 research disciplines—from software developers to designers and psychologists—need to work together with health professionals to develop a product that leads to real improvements in healthcare outcome," he says. "For example, there are already more than 1,000 diabetes apps available today, but not a single one has made significant change to how we deliver diabetes care," he explains.

Besides eHealth, another area that deserves attention in developed and ageing societies like Singapore is care at the end of life, he says, adding that 70% of people who would prefer to die at home end up dying in a hospital.

In collaboration with Singapore's Ministry of Health, Assoc Prof Car has assembled a team to conduct a national evaluation for advanced care planning, with the goal of helping modern societies organise end-of-life care and grant more people their wish to die at home. This includes dealing with questions about the extent of intensive medical care at the end of life, practical care of dying persons, economics, and educating society to be prepared for making informed decisions.

Supporting him in this endeavour are economists from NTU's School of Humanities and Social Sciences who are constructing an economic model for advanced care planning in Singapore, based on comprehensive databases of the Singapore population provided by the health ministry.

"Individuals, families and societies need to be prepared so that we can embrace that part of life," says Assoc Prof Car. "Singapore's health system is one of the best-performing in the world, but with a rapidly ageing population, chronic diseases and other societal changes, it requires significant modifications and adaptations to continue to serve our population well and maintain its world-leading role," he concludes.

Credit: Lee Kong Chian School of Medicine, NTU.

Credit: Kok Wee Lim.

PROF PETER SLOOT

"We want to create *in silico* systems that can predict the course and outcome of a disease on a personal level," says Prof Peter Sloot, Co-Director of NTU's Complexity Institute and Head of the Health Systems Complexity programme under NTU's Nanyang Institute of Technology in Health and Medicine.

The data analytics expert is leading an international network of scientists on a project to develop a "virtual physiological human", a computational model that simulates the physiological, immunological and biological processes of the human body and its susceptibility to and interactions with diseases.

"Our vision is to integrate all different levels of physiological processes in one big system that is able to predict the outcome of a disease or medical condition for a specific patient at a specific point in time," he explains.

Holding dual professorships for Complex Systems Simulations at NTU and Computational Science at the University of Amsterdam in The Netherlands, Prof Sloot is currently also developing a predictive outcome system for HIV infection that is being tested in several hospitals worldwide.

"Using long-term data from several HIV cohorts, we have developed numerical models for all levels—from virus biology and its complex interactions with the immune system to population behaviour and virus transmission—to comprehensively understand HIV dynamics," he says.

The model aims to predict the best combination of the 23 drugs commonly used against HIV for a specific patient in real time, allowing the therapy to rapidly adapt if, for instance, the virus mutates and prompts changing reactions by the immune system.

Practice tests of the system have already proved valuable, revealing that the dosages of antiretroviral therapy drugs given to HIV patients in European countries can be reduced by as much as 30%, and that many combination drugs are not optimal for individual patients. Worldwide initiation of the system—available in the public domain and to all medical doctors—is planned for World AIDS Day on 1 December 2016.

A lack of understanding of the immune system's complex workings is currently the biggest hurdle to including other medical conditions in the virtual physiological human, according to Prof Sloot.

"The immune system is one of the most complex systems that exist, constantly changing, adapting and evolving. A deep understanding of its systemic response to outside stimuli will not only define the best therapies for individual patients and all kinds of diseases—cancer, infectious diseases, diabetes and so on—but will provide an understanding of how to nudge the immune system itself towards dealing with these diseases," he adds.

PROF ANNELIES WILDER-SMITH

Planning to attend the FIFA World Cup in Brazil this year? You might run a risk of being one of about 33 unlucky visitors, out of an estimated 600,000 international non-immune travellers, who acquire dengue during that trip.

This risk estimate is the result of a modelling study co-led by Prof Annelies Wilder-Smith from NTU's Lee Kong Chian School of Medicine, who is a key opinion leader on emerging mosquito-borne infectious diseases such as dengue, chikungunya and Zika.

An expert in global health, communicable diseases and travel medicine, Prof Wilder-Smith is the coordinator of the international dengue research consortium, DengueTools, which investigates novel strategies and tools for surveillance and control of dengue.

For example, she is leading a large field study in Thailand to investigate if treating school uniforms with insect repellents might help to prevent dengue in school children—the most affected age group for dengue infection. She is also collaborating with mathematical modellers to model maps on the dengue epidemic potential in Europe, depending on future climate scenarios and mobility patterns.

A clinician scientist by training, Prof Wilder-Smith is also studying whether small mutations in the viral genome are associated with more severe disease or more severe outbreaks.

"One of the most interesting studies I did in Singapore recently," she shares, "has been to tease out the main driving factors for the dengue upsurge that we have seen in the past 40 years in this country".

The results of this study point to population growth and urban density as the major culprits, and highlight the urgency for good urban planning and a dengue vaccine.

Credit: The Straits Times © Singapore Press Holdings Limited. Reproduced with permission.

Prof Wilder-Smith is also President of the International Society of Travel Medicine and Senior Advisor to the Dengue Vaccine Initiative, a consortium of organisations—including the World Health Organisation—that strives to promote vaccination in endemic areas to prevent the further spread of dengue.

[COMING YOUR WAY]

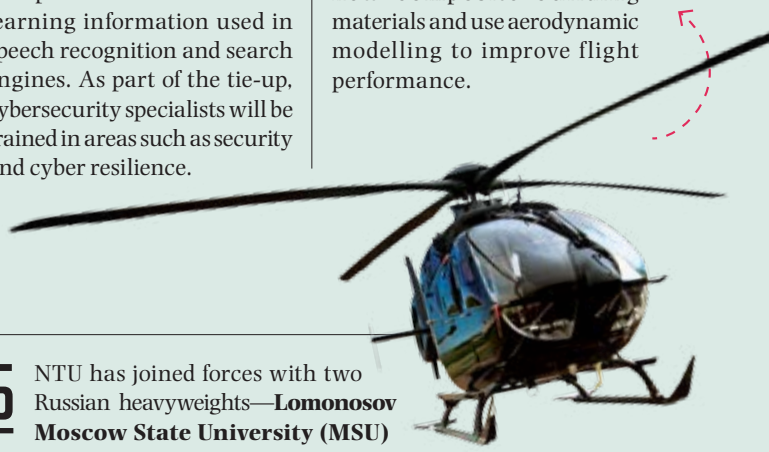
1 Next-generation cars, new medicines and even safer food; these are just some of the possibilities promised by the **Sino-Singapore International Joint Research Institute**, set up to commercialise technology that solves pressing societal issues. The Institute, which is NTU's latest tie-up with South China University of Technology, will be based in China's Sino-Singapore Guangzhou Knowledge City, a government-backed initiative to nurture high-end, knowledge-intensive industries in Guangdong province.

Witnessed by Chinese President Xi Jinping (standing, 2nd from left) and Singapore's Prime Minister Lee Hsien Loong (standing, 2nd from right), the agreement was signed by (front row, from left) Mr Chen Zhiying, Chairman of Sino-Singapore Guangzhou Knowledge City (SSGKC) Administrative Committee; Prof Wang Yingjun, President of South China University of Technology; Prof Lam Khin Yong, Chief of Staff and Vice President (Research), NTU; and Mr Ng Kok Siong, CEO of SSGKC Investment and Development Co. Ltd. Credit: NTU.

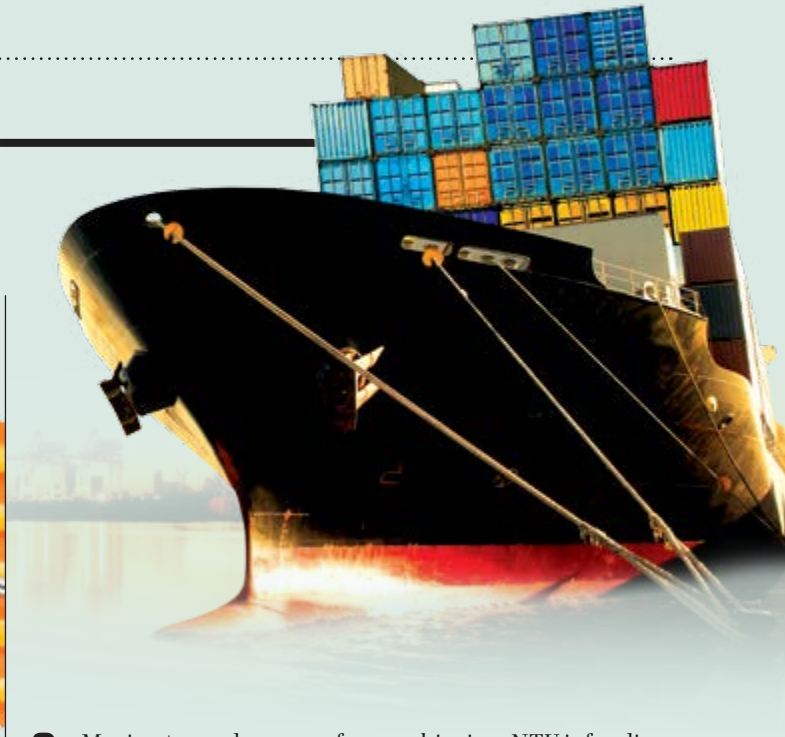
2 Imagine a future where we live and work underground. The **NTU-Hyundai Urban System Centre**, Hyundai Engineering & Construction's first joint research centre outside of South Korea, will explore ways to extend Singapore's restricted land space by developing rock caverns and offshore floating platforms. "The joint research centre is expected to produce solutions that will give us more space to live and work in, turn waste into resources, lower the cost of drinking water and help increase productivity and efficiency in construction," says NTU Provost Prof Freddy Boey.

3 With cyber attacks becoming more complex, **NTU and BAE Systems** have set up a **centre to develop cyber-security technologies** relevant to both industry and government agencies. BAE Systems, a UK-based multinational company, will work with NTU on projects ranging from data mining and processing of unstructured complex data to machine learning information used in speech recognition and search engines. As part of the tie-up, cybersecurity specialists will be trained in areas such as security and cyber resilience.

4 NTU is conquering the air with lighter, stronger and more energy-efficient choppers. The University and Italian Aerospace firm **Leonardo-Finmeccanica** have signed an agreement to develop new technologies in helicopter manufacturing. At the **joint technology research centre** based at NTU, researchers will develop new composite building materials and use aerodynamic modelling to improve flight performance.



5 NTU has joined forces with two Russian heavyweights—**Lomonosov Moscow State University (MSU)** and sports retail giant **Sportmaster Group**—to put research to good use. The pact with MSU aims to attract top Russian students to pursue PhD studies at NTU, particularly in chemistry, physics and materials science, and paves the way for a future agreement with the Russian Academy of Sciences' Institute of Problems of Chemical Physics in energy storage and photovoltaics. The collaboration with Sportmaster extends an earlier tie-up in 2013 to create research opportunities that can be translated into sports products for the international market.



6 NTU and global insurance company **AIA Group** have started the **EDGE LAB** to drive innovation in the life insurance sector. Launched by NTU's innovation and enterprise company, NTUitive, the lab brings together start-ups, government agencies, university experts and private sector collaborators to identify ways to address new healthcare challenges.

7 Patients come first under **NTU's new five-year tie-up with Singapore's biggest healthcare provider, SingHealth**. A sum of US$1.45 million (S$2 million) will be granted to six joint research projects led by NTU scientists and SingHealth clinicians to develop biomedical devices, drugs and methods to prevent, diagnose or treat diseases. Innovations by previous NTU-SingHealth teams include a vibrating surgical blade to make corneal transplants safer and a slow-release pill that makes life easier for patients with Parkinson's disease.

8 Researchers at NTU's medical school, together with supporting partners, are conducting population health studies and consolidating data to identify modifiable risk factors that can help to prevent or slow down the onset of diseases. It is part of the latest **tie-up between NTU and Singapore's National Healthcare Group** to understand risk factors unique to Asians for chronic conditions such as diabetes and high blood pressure.

9 Moving towards an era of green shipping, NTU is funding the development of cleaner and more sustainable maritime energy solutions jointly with the Singapore Maritime Institute. Backed by the Maritime and Port Authority of Singapore, the US$5.8 million (S$8 million) **Maritime Energy Test Bed** on campus will come up with eco-friendly technologies that cut costs, mitigate the effects of climate change and address growing environmental regulations. There, students and engineers can also get hands-on experience with these new technologies.

10 Technology powerhouses NTU, Korea Advanced Institute of Science and Technology (KAIST) and Technion-Israel Institute of Technology (Technion) have sealed a five-year research pact. The **KAIST-NTU-Technion Joint Research Programme** will focus on high-growth areas with commercialisation potential, such as medical technologies, satellites, materials science and entrepreneurship. A global innovation platform will also be set up to promote sharing among the partners.

(From left) NTU President Prof Bertil Andersson, KAIST President Prof Steve Kang Sung-mo and Technion President Prof Peretz Lavie. Credit: KAIST.

[THE HONOUR ROLL]

GLITTERING GALLERY OF ENGINEERS

Joining eminent scientists Albert Einstein and Thomas Edison as well as super inventor Elon Musk, **Prof Er Meng Hwa**, NTU's Vice President (International Affairs), was elected by The Institution of Engineering and Technology as **one of the 126 most influential engineers** representing the past, present and future of engineering. He is the only scientist from Asia to be featured on a special sculpture along with the other winners.

BIG IMPACT IN THE SCIENCE OF SMALL

For his scientific contributions that have made a major impact in the field of nanoscience and nanotechnology, **Prof Zhang Hua** from the School of Materials Science and Engineering was honoured with the 2015 ACS Nano Lectureship Award for the Asia/Pacific region. He was among three recipients worldwide chosen for each of the three major global regions.

L'ORÉAL-UNESCO FELLOWSHIP WINNER

Asst Prof Ling Xing Yi from the School of Physical and Mathematical Sciences was one of two Singapore scientists honoured with the 2015 L'Oréal-UNESCO For Women In Science National Fellowship (Singapore). She received a grant for her work on an ultra-sensitive platform that can detect trace amounts of environmental toxins.

AT THE FRONTIERS OF MALARIA RESEARCH

Dr Sachel Mok, a research fellow with the School of Biological Sciences, received a Long-Term Fellowship under the Human Frontier Science Programme. The competitive fellowship supports early-career scientists who conduct original research at the interface of the life and natural sciences and engineering. With the funding award, Dr Mok will be able to further her research in antimalarial drug resistance during a three-year stint at an American university.

PRIZED WATER-REFINING TECHNOLOGY

NanoSun, an NTU spin-off that develops titanium dioxide nano-membrane technology to purify water, won the 2015 Frost & Sullivan Asia Pacific Technology Innovation Award in Water Filtration for its efforts "to solve key challenges in the water filtration industry such as membrane biofouling and breakage". Founded by **Assoc Prof Darren Sun** from the School of Civil and Environmental Engineering, the company also received a Fast-Track Environmental and Water Technologies Incubator grant under Singapore's Environment & Water Industry Programme.

Four out of the five grants awarded nationally since 2007 have been given to start-up companies spun off from NTU.

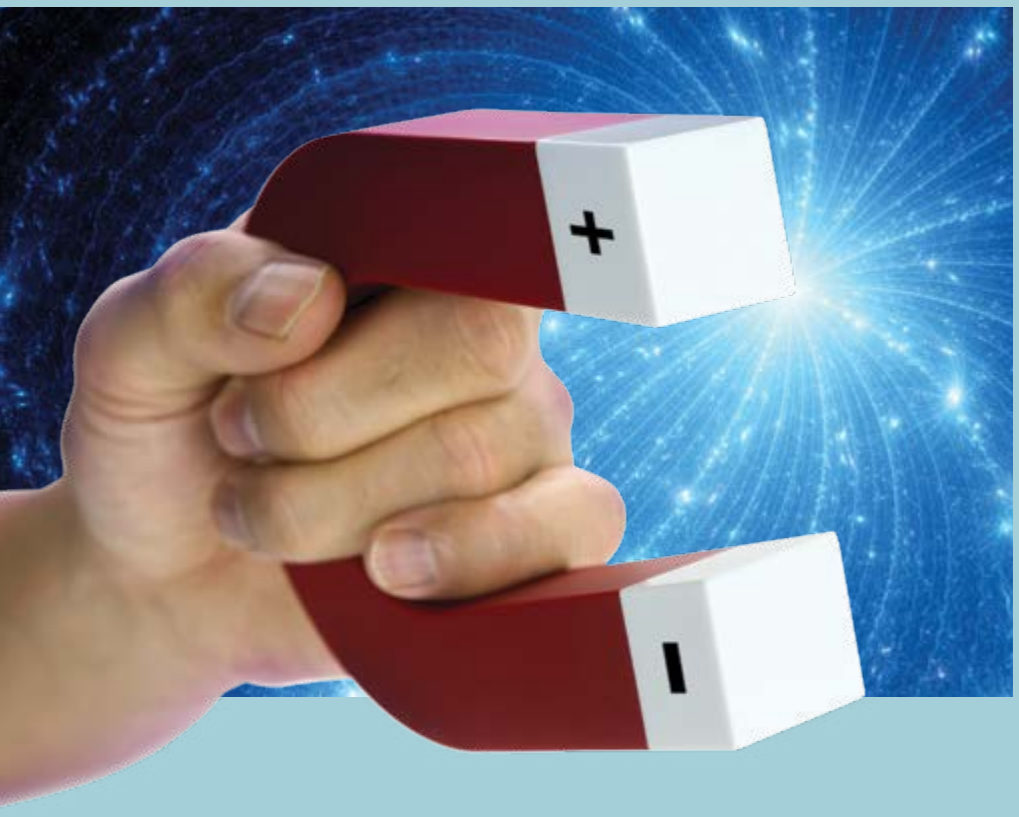
SIX AWARDS IN ECO-CAR RACE

Solar energy combined with 3D printing stole the show at the Shell Eco-marathon Asia in Manila, where two NTU undergraduate teams—both mentored by Assoc Prof Ng Heong Wah from the School of Mechanical and Aerospace Engineering—bagged a total of six awards. Four awards—for vehicle design, communications, safety and urban concept (battery electric)—went to NTU Venture 8, Singapore's first 3D-printed urban solar electric car, while NTU's lightweight three-wheel racer—NTU Venture 9—clinched the other two awards in the prototype (battery electric) and technical innovation categories.

NTU's winning teams with NTU Venture 9 (left) and 3D-printed solar electric car NTU Venture 8 (right). Credit: Shell.

TRANSFORMATIONAL SCIENCE

One of the most prolific and exciting scientists of the 20th century, Abdus Salam was the first Nobel Laureate from Pakistan as well as the first Muslim to win a Nobel Prize in science. The pioneering theoretical physicist passed away in 1996.



He developed a ground-breaking theory for the unification of the weak nuclear and electromagnetic forces—two of the so-called fundamental forces of nature—and also paved the way for the discovery of another milestone in our understanding of the universe, the Higgs boson.

Dr Salam maintained that "scientific thought is the common heritage of all mankind". In 1964, his belief that the developing world should play its part—not merely by importing technology but by being the arbiter of its own scientific destiny—led to the founding of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, where thousands of scientists from developing countries have since been trained.

In January 2016, his phenomenal contributions to high-energy and quantum physics were celebrated at a conference held in NTU. The four-day **Memorial Meeting for Nobel Laureate Prof Abdus Salam's 90th Birthday** drew about 120 attendees and around 30 distinguished speakers that included winners of the Nobel Prize in Physics, Profs David Gross (2004), Tony Leggett (2003), Carlo Rubbia (1984) and Gerard 't Hooft (1999).

Silent transformations—changes that go largely unnoticed until their effects "suddenly" transform our view of the world—were the focus of this year's complexity conference organised by NTU's Para Limes.

Over three days at the **"Silent Transformations" conference** in March, eminent scientists, thinkers and artists discussed their views on the nature of change and ways to understand transformation processes as essential parts of the big and complex problems of our world.

The annual complexity conference, which has become widely recognised as unique in Southeast Asia, attracted speakers such as Prof Geoffrey West, Distinguished Professor and Past President of the Santa Fe Institute; Eörs Szathmáry, Director of the Parmenides Center for the Conceptual Foundations of Science in Munich and Professor at Eötvös Loránd University; and Norwegian video artist Tone Bjordam.

SINKING ROOTS IN SCIENCE

"My first ambition was to be a neurobiologist. But I met a Swedish professor and we talked about the Big Bang in evolution. He got me thinking about how life dramatically developed with photosynthesis.

Nature, some two and a half billion years ago, developed the perfect system to provide the essentials we need. It provides energy with the release of oxygen and consumption of carbon dioxide. This oxygen paved the way for animal and human life.

All the oil and coal on this planet are the products of photosynthesis. Food and timber are also derived from this reaction, which takes place even faster than how our brain works! Photosynthesis is the engine of life.

I became very excited and it attracted me to dedicate a large part of my life to investigating plants.

The best place to study photosynthesis at that time was in Australia. So I set out for Canberra in Australia in 1979 and stopped in Singapore for the first time while I was en route to Australia. When I moved back to Sweden with my family after two years, I stopped by Singapore again. Thus, my newborn daughter knew Singapore even before her motherland, Sweden.

So it was photosynthesis that brought me to Singapore. Photosynthesis changed my destiny.

A lot about the engine of life has been unravelled, though we still do not have all the details. But we have come to a stage where we are able to make artificial leaves, an area of research that I helped pioneer and which I continue to contribute to with a small research group at NTU.

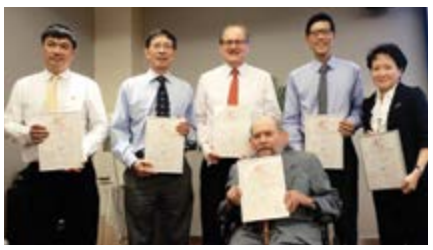
Today, I am still a curious biochemist. I am also a practitioner working with trees. I own a pine tree forest in Sweden. Photosynthesis takes many shapes, and I do have a fantastic time studying how pine trees do this and survive in wintry conditions of -30°C. When I am not busy working on my career in Singapore, it is great to do a bit of research in my own backyard sometimes. "

Bertil Andersson

NTU President Prof Bertil Andersson was conferred a prestigious fellowship by the Singapore National Academy of Science (SNAS) on 10 May.

*He received the honour for his contributions to the advancement of science in Singapore and for leading NTU to global distinction as its President since 2011. Other recipients of the fellowship include Prof Tan Chorh Chuan (second from right), President of the National University of Singapore, and Prof Jackie Ying, Executive Director of the A*STAR Institute of Bioengineering and Nanotechnology.*

The fellowships were presented by Nobel Laureate Dr Sydney Brenner, who was conferred the SNAS Honorary Fellowship for his role in developing the life sciences in Singapore.



Fellow honourees: NTU President Prof Bertil Andersson (left) and Nobel Laureate Dr Sydney Brenner.

EVENTS

EXHIBITION: "SEA STATE" BY CHARLES LIM YI YONG; SYMPOSIUM: THE GEOPOLITICAL AND THE BIOPHYSICAL: A STRUCTURED CONVERSATION ON ART AND SOUTHEAST ASIA IN CONTEXT, PART II

Organised by NTU Centre for Contemporary Art Singapore

Exhibition: 30 April – 10 July 2016

Venue: NTU Centre for Contemporary Art Singapore

Symposium: 17 – 18 June 2016

Venue: Day 1: National Gallery Singapore; Day 2: NTU Centre for Contemporary Art Singapore

ntu.ccasingapore.org/exhibitions/charles-lim-sea-state/

INTERNATIONAL CONFERENCE: "SPONTANEOUS BEAUTIES"? WORLD GARDENS AND GARDENS IN THE WORLD

Organised by NTU's School of Humanities and Social Sciences

10 – 12 June 2016

Venue: School of Humanities and Social Sciences, NTU, Singapore

www.hss.ntu.edu.sg/Programmes/english/spontaneousbeauties/Pages/Home.aspx

SCELSE SUMMER COURSE 2016 ON ENVIRONMENTAL LIFE SCIENCES ENGINEERING AND BIOPHYSICS AND BIOFILMS SYMPOSIUM

Organised by the Singapore Centre for Environmental Life Sciences Engineering, NTU, and National University of Singapore

3 – 21 July 2016

Venue: NTU, Singapore

www.scelse.sg/Highlights/Detail/4cc98b39-0eaa-42cc-9201-355a62aad5b4

WORKSHOP: EAST-WEST CONNECTIONS: GRAND CHALLENGES IN BRAIN, COGNITION AND GOOD LIFE RESEARCH

Organised by NTU's Para Limes

3 – 5 October 2016

Venue: Nanyang Executive Centre, NTU, Singapore

www.bit.ly/1ZE22me

NTU-ASEAN MICROSCOPY WORKSHOP 2016

Organised by NTU's School of Biological Sciences

12 – 15 July 2016

Venue: School of Biological Sciences, NTU, Singapore

www.sbs.ntu.edu.sg/NTU-ASEAN-MW2016/Documents/SG_NTU-ASEAN_Microscopy_Workshop_2016.pdf

2016 CONFERENCE ON COMPLEX SYSTEMS

Organised by NTU's Complexity Institute, University of Amsterdam, Netherlands Platform Complex Systems, Santa Fe Institute and Complexity Science Hub Vienna

19 – 22 September 2016

Venue: Beurs Van Berlage, Amsterdam, The Netherlands

www.ccs2016.org

3RD ASIAN WAVE AND TIDAL ENERGY CONFERENCE SERIES (AWTEC 2016)

Organised by the Energy Research Institute @ NTU and Sustainable Energy Association of Singapore

24 – 28 October 2016

Venue: Marina Bay Sands, Singapore

www.awtec.asia/awtec-2016

ASIAN CONFERENCE ON ENERGY, POWER AND TRANSPORTATION ELECTRIFICATION (ACEPT) – PART OF ASIA CLEAN ENERGY SUMMIT (ACES)

Organised by the Energy Research Institute @ NTU

25 – 27 October 2016

Venue: Sands Expo and Convention Centre, Marina Bay Sands, Singapore

erian.ntu.edu.sg/ACEPT-2016/Pages/Home.aspx

2ND INTERNATIONAL CONFERENCE IN SPORTS SCIENCE & TECHNOLOGY (ICSST)

Organised by NTU's Institute for Sports Research

12 – 13 December 2016

Venue: Nanyang Executive Centre, NTU, Singapore

www.icsst.sg

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