Message From the Directors

Welcome to the first issue of the Nanyang Technological University (NTU) Complexity Institute newsletter, and the brave new world of complexity science!

With this newsletter, our goal is to keep the community in Singapore, the region and beyond, informed of the various activities, events, and opportunities related to complexity science. We would also like to use this newsletter to reach out to ‘consumers’ of complexity science, including public policy makers, business leaders, NGOs, and educators at various levels who face challenges understanding and coping with complex problems they encounter in their lines of work. Our hope is that this newsletter can be an instrument for fostering collaborations between complexity scientists in Singapore with colleagues around the world to arrive at a more fundamental understanding of complex systems, and thereafter translate complex systems research into practical solutions through engagement with the public/private sectors.

We plan to come up with one issue every two months. The newsletter will feature upcoming Events, like the Complexity Conference “Silent Transformations” and the Complexity Winter School 2016 in this issue, and also Reflections on past events, which we hope to do in the next issue on the Complexity Winter School 2016. We will also highlight planned or ongoing research like the News Feature on the Kumbh Mela Experiment in this issue, and also Research Highlights of exciting published research by members of the NTU Complexity Institute and beyond. Before eminent scientists visits us from overseas, we will run Visitors features on their research careers and achievements, what they are working on currently, to promote dialogue leading to collaborations between them and the local complexity science community.

More importantly, the newsletter will feature regular articles aimed at a non-expert audience, to help explain important concepts in complexity science using non-technical language accessible to all. These Complexity 101 articles will be written by members of the NTU Complexity Institute and the Singapore complexity science community, and once in a while, we will carry articles written by members of our international partners: Santa Fe Institute in the US, and the Complexity Science Hub in Vienna, Austria.

I hope you enjoy reading this first issue, and all subsequent issues of the NTU Complexity Institute newsletter!
NTU Complexity Conference Silent Transformations

Organized by Para Limes NTU, Silent Transformations is the fifth edition of the NTU flagship Complexity Conference series, which has become widely recognized as unique in Southeast Asia. It will be held between 7 and 9 March 2016 in the Nanyang Executive Centre. Registration is free.

The title of this conference refers to the many processes that take place over long time spans, shaping our universe, our world and our lives, but may go mostly unnoticed until its effects become visible. These processes include well-studied ones like evolution, ageing, and climate change. They also include processes that we do not yet understand, like how computation is changing science, or how information communication technology (ICT) is transforming our lives.

For more information:
http://www.paralimes.ntu.edu.sg/NewsEvents/Silent%20Transformations/Pages/Home.aspx

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Annual NTU-Winter School

Introduction to Complexity Science

10-11, 14-16 March 2016, NTU

Riding on the resounding success and response to last year event, the 2016 Winter School will empower participants with:

- what complexity is really about;
- how complexity manifests itself in the different human activities;
- how it can be harnessed to solve “wicked problems” that defy boundaries;
- what are the tools, models available to study it;
- how to apply your understanding to everyday life and work.

Organised by Complexity Institute, this one-week course welcomes anyone with:

- keen interest & curiosity about complexity & complexity science;
- a motivation to deepen one’s understanding and to apply it in life situations;
- an academic degree (or equivalent) in any field.

For more details:
http://www.complexity.ntu.edu.sg/Programmes/SchoolsCourses/Pages/2016-Winter-School.aspx
**NTU Winter School on Complexity**

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For more details, [visit this page](http://www.complexity.ntu.edu.sg/Programmes/SchoolsCourses/Pages/2016-Winter-School.aspx)
Kumbh Mela is a religious festival that sees the pilgrimage of 100 million Hindus to a sacred river. This is the single largest gathering of people in the world. The next festival will take place in Ujjain from 22 Apr to 21 May 2016. With so many people all converging on this single place there is a real danger of disaster (as was seen in the Haj of 2015). In fact, many of the previous festivals have been marred by accidents and deaths. The real challenge here is that human crowds are complex systems, and hence their behavior is difficult to predict. However, through a combination of computational modeling and analysis of large crowd data, an international team of scientists from the NTU Complexity Institute, the Indian Institute of Science, and the University of Amsterdam expects to find ways for managing the Kumbh Mela crowd in Ujjain 2016.

In this Kumbh Mela Experiment (http://www.the-kumbh-mela-experiment.com), Peter Sloot (Co-Director of the NTU Complexity Institute), Michael Lees (University of Amsterdam) and their collaborators will use specially designed personal tracking devices, drones, cell phone antennas, video cameras, and hundreds of volunteers to monitor 3000 hectares of the Mela area. These will produce tens of terabytes of data daily, the largest data set on human crowds ever collected, and will provide a unique opportunity to understand the collective behavior of millions of human individuals through build predictive computational models. The team hopes that this work will eventually lead to insights that can help prevent disasters at future events.

The Kumbh Mela Experiment team from the NTU Complexity Institute, University of Amsterdam, and Indian Institute of Science. Peter Sloot, Co-Director of the Complexity Institute, is fourth from the right in the standing row, while Michael Lees is third from the right in the standing row.

About 100 million Hindus will descend upon the city Ujjian in Madhya Pradesh, India for the Kumbh Mela pilgrimage between 22 Apr and 21 May 2016. This is the largest religious gathering in the world. (Photograph taken by ALGraChe on 9 Feb 2013. Use of this photograph is subjected to Flickr's Creative Commons license.)

Various sensors will be used to monitor the Kumbh Mela crowd, including a number of strategically positioned drones like the one shown here being demonstrated in Nov 2015.

News feature article by:
Asst Prof. Michael Harold Lees

Dr Michael Lees is an Asst Prof at the Universiteit van Amsterdam (UvA) in the Computational Science Lab (Informatics Institute). Before this he was an Asst Prof at Nanyang Technological University (NTU) Singapore. His current research interests are primarily in modeling and simulation of large-scale complex systems. In particular understanding the effect that human behaviour has on urban systems and the important role that individual behavioural interactions have on system level dynamics. His research focuses on the study of human crowds and transportation systems.

For further information, visit www.mllees.com.
New to the Community!

Complexity and quantum science appear at first to be two fields that bear little relation. One deals with the science of the very large – seeking the understand how unexpected phenomena can emerge in vast systems consisting of many interacting components. Quantum theory, on the other hand, deals with particles at the microscopic level, and is usually considered limited to the domain of individual photons and atoms. Mile Gu, however, has other ideas. Joining the complexity institute in 2016 as a National Research Foundation Fellow, he seeks to bridge these disciplines, and in doing so, forge new insights into both complex and quantum systems. These two disciplines, different as they appear, both represent a symbiosis of ideas from mathematics, physics and computer science. “This rich melting pot is while makes the disciplines so exciting,” states Gu, “seeing how two different sciences can independently approach the same problem from very different viewpoints, and the unexpected potential that arise when such viewpoints are combined.”

Indeed, Gu, has had a long history with interdisciplinary ideas. A New Zealander from Auckland, he obtained his undergraduate degree from the University of Auckland in three separate majors – mathematics, physics and computer science. In 2009, Gu graduated from the University of Queensland, with a thesis titled ‘Complexity, Emergence and Computation by Measurement’.

The thesis fielded a novel mix of complexity and quantum science. It related the complexity of computational problems to paths of free fall in suitable curved space (Science, 311, 5764), and demonstrated via interacting spins lattices that that ‘More is Different,’ a conjecture made by Nobel Laureate Anderson that not all macroscopic laws cannot be derived directly from laws on fundamental particles (featured in Nature 459, 332-334).

Subsequently, Gu joined the Centre for Quantum Technologies at the National University of Singapore in 2012, and in 2014, joined the faculty at Tsinghua University under the prestigious chinese 1000 talents program. During this period, Gu has made a number of interdisciplinary contributions, including the certification of a new quantum resource using optical means and the discovery that quantum phase transitions have different capabilities in solving complex problems (Nat. Phys. 671-675, Nat. Comms 3, 812). Many of these contributions resulted in entirely new lines of inquiry, and had permanent impact in fostering interdisciplinary research. In March 2016, Gu joins NTU as a Nanyang Asst Prof under the National Research Foundation Fellow Scheme.

Gu’s research at the Complexity Institute will continue this cross disciplinary theme. His latest research seeks another unexpected connection – quantum mechanics may reduce the complexity of modelling data, even if the data represents observations of classical, macroscopic systems of everyday life, such as traffic networks or the rise and fall of stock markets (see New Scientist Issue 2995). The consequences are exciting, both in practical and foundational arena. On the one hand, it heralds quantum technologies can us better model complex systems in everyday life, on the other it indicates that what is complex may fundamentally depend on what sort of information theory we use to understand it. Indeed, Gu is currently principle investigator ‘quantum epsilon project’ funded by the John Templeton foundation, which aims to isolate quantum theory purely from the ideal of Occam’s razor – by showing that quantum theory emerges as the most efficient way for the universe to simulate itself.
Professor Geoffrey West
will be in NTU from 8 March to 14 March 2016

Geoffrey West received his BA from Cambridge University in 1961 and doctorate from Stanford University in 1966, where he returned in 1970 to become a faculty member. He was a former President (2005 - 2009) and is a Distinguished Professor at Santa Fe Institute.

Prior to joining the Santa Fe in 2003, he was the leader & founder, of the high energy physics group at Los Alamos National Laboratory. His long term fascination with general scaling phenomena evolved into a highly productive collaboration on the origin of universal scaling laws that pervade biology from the molecular genomic scale up through mitochondria and cells to whole organisms and ecosystems. This led to the development of realistic quantitative models for the structural and functional design of organisms based on underlying universal principles. It provides a framework for quantitative understanding of problems ranging from fundamental issues in biology (e.g. cell size, growth, metabolic rate, DNA nucleotide substitution rates, and the structure and dynamics of ecosystems) to questions at the forefront of medical research (such as aging, sleep, and cancer). This work received much attention in both the scientific and popular press.

Extending these ideas to understand quantitatively the structure and dynamics of social organizations, his current interests include cities and corporations, their relationships between economies of scale, growth, innovation and wealth creation and implications for sustainability. His work states that by doubling of a city’s size, services per capita will generally increase by 15%. For this, he was named one of TIME magazine’s 100 most influential people in 2006. In 2007 he cited by Harvard Business Review in Breakthrough Ideas. "[Geoffrey] West’s feature, entitled "Innovation and Growth: Size Matters," details recent work on the application of well-known scaling phenomena to cities and social organizations, particularly the ramifications of the "superlinear" scaling phenomenon: "...by almost any measure, the larger a city’s population, the greater the innovation and wealth creation per person." Among his other honours, he was a co-receiver of the Mercer Award from the Ecological Society of America, Weldon Memorial Prize (2005), Oxford University and the Glenn Award for research on Aging and APS Szilard Award (2013).

He is also the author of several books and lectured in many popular and distinguished scientist series worldwide e.g. World Economic Forum.
Professor William Brian Arthur
will be in NTU from 5 March to 4 April 2016

Born in 1946 in Northern Ireland, W. Brian Arthur was received his BSc in Electrical Engineering at Queens University Belfast (1966), a M. A. in Operational Research (1967), at Lancaster University, England, and an M. A. in Mathematics at the University of Michigan (1969). Arthur received his PhD in Operations Research (1973) and an M. A. in Economics (1973) from the University of California, Berkeley. At age 37, Dr. Arthur was the youngest endowed chair holder at Stanford University. He is awarded the inaugural Lagrange Prize in Complexity Science in 2008, and the Schumpeter Prize in Economics in 1990. He is a Guggenheim Fellow, 1987-88, Fellow of the Econometric Society, and IBM Faculty Fellow. He holds honorary doctorates from the National University of Ireland in 2000 and Lancaster University in 2009.

A leading economist and a pioneer of the complexity science, he is also a founder of the Santa Fe Institute, ran its first research program in 1988, serves its Science Board & Board of Trustees for 18 & 10 years respectively. He is currently its distinguished External Professor.

His keen interest is to construct an economics that is more realistic. Standard economics has long been based on the idea of hyper-rational actors operating in a static equilibrium world. In late-1980s, Arthur and his Santa Fe group developed an alternative view called “Complexity Economics”. It assumes that the economy is not a perfectly balanced machine, but an evolving complex system. Actors in the economy do not necessarily face well-defined problems or use super-human rationality in making their decisions. They explore, try to make sense, and react and re-react to the outcomes they together create. As such the economy is not in stasis, but always forming, always evolving, always “discovering” fresh novelty. Bubbles and crashes happen, markets can be “gamed” or exploited, and history and institutions matter. The result is a rigorous but realistic picture of the economy.

He is best known for his pioneering work on positive feedbacks or increasing returns in the economy—what happens when products that gain market share find it easier to gain further market share—and their role in locking markets in to the domination of a single player. See his 1994 book Increasing Returns and Path Dependence in the Economy. In mid-1990s, Arthur became intrigued with questions about technology. Where do new technologies come from & how exactly does invention work? What constitutes innovation & how is it achieved? Why are certain regions e.g. Silicon Valley, are hotbeds of innovation, while others languish? Does technology, like biological life, evolve from earlier forms? And how does the economy itself emerge from its technologies?

His book “The Nature of Technology: What it Is and How it Evolves”, attempts to answer these questions. It argues that all technologies share certain principles; these determine the character of technology and how novel technologies come into being —and hence how innovation works.

Quotes by others about Brian Arthur:

"Brian Arthur has made a great contribution by reorienting the way we look at economic phenomena. It is very good to have many of the papers in which Arthur introduced the complexity approach reproduced here. " -- Kenneth J. Arrow

"W. Brian Arthur is one of the true pioneers of 'complexity economics', an approach to understanding the economy as it really is - a complex and constantly changing ecosystem of imperfect people, evolving institutions, and disruptive technologies. Will be studied and referred to for decades to come." -- Eric Beinhocker

Professor Stefan Thurner
will be in NTU from 6 March to 3 April 2016

Stefan Thurner is full professor for Science of Complex Systems at the Medical University of Vienna, where he founded the Complex Systems Research Group (now Section for Science of Complex Systems) in 2003. Since 2007 he is external professor at the Santa Fe institute.

After his PhD in theoretical physics at the Technical University of Vienna in 1995 he held postdoc research positions at Humboldt Universität zu Berlin and Boston University before he joined the University of Vienna in 1999 and later Medical University. In 2001 he got a second PhD in economics at the University of Vienna and his Habilitation in theoretical physics. About this time - strongly influenced by visits to the Santa Fe Institute - he began to shift his focus from theoretical physics to biological and complex systems, which are now his main areas of scientific work.

Since 1995 Thurner has published more than 120 scientific articles in fundamental physics (topological excitations in quantum field theories, alternative entropy formulations), applied mathematics (wavelet statistics, fractal harmonic analysis, diffusion processes), complex systems (network theory, evolutionary systems), life sciences (heart beat dynamics, gene regulatory networks, cell motility, bioinformatics), econophysics (price formation, banking regulation, systemic risk) and lately in social sciences (opinion formation and buerocratic inefficiency). He holds 2 patents.

Thurner has (co-) organized several international workshops, conferences and summerschools, and has himself presented more than 150 talks. His work has received broad interest from the media such as the New York Times, BBC world, Nature, New Scientist, Physics World and is featured in more than 100 newspaper, radio and television reports. He works in a network of scientists mostly around the Santa Fe Institute, the Collegium Budapest, where he was a fellow in 2007, and several European initiatives, such as COST actions, where he serves as the Austrian delegate. Thurner serves as a member of several scientific boards.

Biography write up by: Santa Fe Institute
What are Complex Systems and Why Should We Care?

In a January 2000 newspaper interview, renowned Cambridge University physicist and best-selling author of the book *A Brief History of Time* Stephen Hawking said, “the 21st century will be the century of complexity.”

What is complexity? Why does one of the most intelligent people alive believe it will occupy the minds and energies of scientists for the present century?

To better appreciate complexity science, which is the study of complex systems, let us go back in time to 1948, when American scientist Warren Weaver reflected on the state of science at that time. In his essay, Weaver explained that over the 17th, 18th, and 19th centuries, scientists like Newton, Faraday, and Maxwell worked on and solved many problems of simplicity. These are problems like the orbit of planets around the Sun, the link between electric and magnetic fields with light and radio waves; problems that can be written mathematically in terms of a small number of variables.

From the late 1800s onwards, scientists like Boltzmann and Gibbs also started attacking problems of disorganized complexity. The problems they confronted, like the pressure of a gas, or the magnetization of a bar of iron, must be written in terms of $10^{27}$ variables. Finding individual solutions for this many variables is mathematically impossible, so Boltzmann and Gibbs switched from a mechanistic picture to a statistical picture, to understand macroscopic properties in terms of the average behaviors of microscopic variables.

With these two successes under our belt, Weaver then called on scientists to move on to problems of organized complexity. These include problems in biology, social science, and earth systems. Like problems of disorganized complexity, these involve a large number of variables, and are therefore not simple. However, unlike problems of disorganized complexity, a purely statistical description in terms of averages falls far short of explaining the diverse phenomena observed in such systems.

After Weaver’s call, the response was tentative at first. The field really took off in the 1980s, when complexity scientists started to get themselves organized, founding the Santa Fe Institute in 1984. After more than three decades of intense study, we now understand that a complex system typically consists of a large number of parts, like cars in traffic, individuals in crowd, biological molecules in a human body, traders and stocks in a financial market, producers and consumers in an economy. When we put these parts together, we get complex behaviors that none of the parts have, as a result of strong interactions between them. Describing this emergence or self-organization phenomenon that can occur on multiple levels, Nobel Laureate in Physics Philip W. Anderson explained that “the whole is more than and also different from the sum of parts”.

Complex systems are robust. When their environment changes, their behaviors frequently do not, until the changes go past a critical point, where we see abrupt switches in the behaviors of these complex systems. We call robust behaviors regimes, and when a complex system switches from one regime to another, we say that it has undergone a regime shift. Over a long time, a complex system will wander from regime to regime. This sequence of transitions, and the times spent in each regime, are hard to predict. More importantly, when several outcomes are possible in a given transition, the actual outcome depends on previous transitions. This is called history dependence or contingency.

All this is nice and well, but why should we care about complex systems?

I can think of three reasons.

**Complex systems are clearly the next frontier of scientific knowledge**

First, complex systems are clearly the next frontier of scientific knowledge. While we already know defining characteristics of complex systems, we do not really know why complex systems are so common in nature and human societies. In fact, most complex systems seemingly defy the Second Law of Thermodynamics, which states that the Universe must become more disordered over time. Nobel Laureate in Chemistry Ilya Prigogine resolved this ‘paradox’ in living organisms, by suggesting that these dissipative structures can continue to grow in complexity using energy supplied by the Sun. We suspect the behaviors of complex systems are intermediate between simple deterministic and completely random, due to some kind of compromise between the ability to tell different situations apart and the ability to recognize the same situation each and every time. We believe this information processing aspect is key to building a theory of complex systems, one that allows us to explain the evolutionary advantages complex systems have over simple ones, but much work is needed to develop such a theory.
**Engineers are interested in complex systems**

Second, engineers are also increasingly interested in complex systems. Engineers are good at building complicated structures like cars and road networks, but struggle to understand why it is so difficult to tame vehicular traffic. A car is a complicated system, because it is made up of more than 30,000 parts. However, a car is not complex, because we can make it go faster by stepping on the accelerator, make it go slower and eventually come to a stop by stepping on the brake, and change directions by turning the steering wheel. Ultimately, vehicular traffic is complex because of the human drivers, and the choices they make navigating the road network.

When a highway jams frequently, the standard engineering reaction to the problem would be to add lanes to the highway. This is what the Land Transport Authority did, when traffic jams persisted along the Central Expressway (CTE) even after electronic road pricing (ERP) was introduced. They undertook a 4-year widening of the CTE, adding one more lane to the section between Bukit Timah and Yio Chu Kang. After the widening, traffic was smooth for a while, before jams returned, ever larger in size. The wider CTE attracted drivers who previously used other southerly roads to get into the city area.

We see from the CTE example, when we do not recognize a problem as complex and go for the 'obvious' solution, we end up with unintended consequences. Engineers should learn complexity thinking, and understand that complex systems cannot be controlled, but can be steered. For many complex problems, the complexity solutions also may not lie entirely within the engineering domain. We may need people to change their behaviors, or make sacrifices. So lastly, once people become part of the complexity solution, we need to talk about public policies.

**Public policy makers**

Complex systems and complex problems are not entirely new to public policy makers. As early as the late 1960s and early 1970s, Horst Rittel, Melvin M. Webber, and C. West Churchman talked about wicked problems. Using pre-complexity management terminologies, Rittel and Webber came up with 10 defining characteristics of wicked problems. If we recast these characteristics into complexity terms, then wicked problems are essentially problems that are strongly history dependent, where variables are strongly interdependent, and eliminating symptoms in one set of variables lead to the emergence of symptoms in another set of variables. In other words, 'obvious' solutions to wicked problems are merely treatments that suppress symptoms.

As our world gets increasingly global, we will encounter more and more of these complex wicked problems. We should expect complexity solutions to not only cross domains (from technological to sociological), but also cross political and cultural borders. This is perhaps what went through the minds of Heinz R. Pagels, when he said famously, "The great unexplored frontier is complexity...I am convinced that nations and people that master the new science of complexity will become the economic, cultural, and political superpowers of the next century."

The Singapore Government has always impressed other world leaders with its foresight and long-term vision. It seems that our leaders also understand the importance of complexity science in public policy. As early as 2004, Prime Minister Lee Hsien Loong spoke at the opening of the Commonwealth Association of Public Administration and Management on how globalization makes governance more complex. He then explained that to cope with this trend, the Singapore government has undertaken to "function in a more networked fashion, to cope with new issues that are complex and multifaceted."

More recently, Prime Minister Lee mentioned at his swearing-in ceremony on 1 October 2015 that Singapore will "[be] entering a new phase of our nationhood. We face more complex challenges and new issues that cut across multiple domains". Therefore, he appointed three Coordinating Ministers, in National Security, in Economic and Social Policies, and in Infrastructure. Speaking at The Straits Times Global Outlook Forum on 20 November 2015, Deputy Prime Minister and Coordinating Minister for Economic and Social Policies Tharman Shanmugaratnam spoke about the challenges posed by global economic complexity that arise as a result of restructuring in the United States, and reforms in China.
Transport Minister and Coordinating Minister for Infrastructure Khaw Boon Wan, also urged the public to be “realistic about such a complex system - it’s not rocket science but also not straightforward. There will be fires big and small but I hope for Singaporeans’ patience and we will do our best” as his ministry strives to improve the transportation system’s reliability.

To sum it all up, Singapore’s leaders understand the importance of complexity and complex systems to public policy since the early 2000s.

This recognition is important, but we must also be honest: there are not yet complexity solutions to complex policy problems. In fact, there is not yet a scientific theory of complex systems within which we can work these solutions out, or engage in any semblance of complex systems engineering. There is much work to be done, by scientists, engineers, and policy makers interested in complex systems. This is therefore a research area where public funding can be put to good use. As early as the late 1940s, Weaver felt the urgency of complexity research, and suggested that to solve problems of organized complexity, we need to harness the power of computer simulations, and to form multidisciplinary teams. Weaver was indeed prophetic.

Article by:
Asst Prof CHEONG Siew Ann

CHEONG Siew Ann is an Assistant Professor with the Division of Physics and Applied Physics, School of Physical and Mathematical Sciences and Deputy Director of the Complexity Institute, Nanyang Technological University. He is interested in understanding complex systems from both modeling and data perspectives, using a comparative approach on markets and economies, epidemics, earthquakes and tectonics, biological macromolecules, brain, society and language to distill more universal theoretical understanding of complex systems. Ultimately, his goal is to develop a computational theory of complex systems, by treating their dynamics as information processing, and discover the underlying logic. Using this theory, he would like to shed light on how evolutionary processes shape the complex network topologies and dynamics of complex systems.