# OXFORD RANKED FIRST IN WORLD

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UNIVERSITY OF OXFORD

DEPARTMENT OF
COMPUTER
SCIENCE

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# Letter from the Head of Department

As 2018 draws to a close we can reflect on another very busy and successful year for the Department of Computer Science. We continue to grow, and are happy to welcome many new members to our ranks (see p14 for details).

With the new academic year came new roles. I have taken on the Head of Department role for this academic year, and Professor Alex Rogers is stepping in to my old role as Deputy Head for Teaching. Professor Michael Wooldridge is taking a well-earned sabbatical year. Professor Marta Kwiatkowska is continuing as Deputy Head for Research, and in particular is leading our preparations for the upcoming Research Excellence Framework (REF).

Our academics and their research have been constantly in the news, and our academics are also being asked to contribute expert opinion on Computer Science topics by government and the newspapers.

We hosted two remarkable events, the Federated Logic Conference (FLoC) 2018 and our AI Expo. Both events drew together top academics and visitors from across the world. They would not have been possible without the huge amount of work and enthusiasm contributed by members of our department.

I'm delighted to pass on the news to everyone that we have retained our Bronze Athena SWAN award. We submitted a detailed 80-page application for the award, analysing the state we are in, and describing what we've done and what we plan to do to eliminate gender bias and foster an inclusive environment. It was a great team effort, and I'd like to acknowledge the hard work of everyone involved. We have much to do over the next four years, and are looking forward to receiving detailed feedback from the panel to work on. You can read more about our Athena SWAN award on p4.

This issue of Inspired Research highlights the huge reach of what we do, with current academics and alumni making a difference all over the world in their areas of research. It is particularly interesting to read about projects in Africa, from the WildCRU collaboration and LabHack to the work being done by alumna Chao Mbogo.

We have continued to perform impressively in various world rankings, and our news pages are filled with awards, from winning conference papers to academic honours. We look forward to 2019 being as busy and exciting as 2018.

*Professor Peter Jeavons*
December 2018

## News in brief

Dr Vint Cerf, who is widely known as one of the 'fathers of the internet', gave Oxford University's prestigious Romanes Lecture in November. The Romanes Lecture is the annual public lecture of the University, and it is attended by members of the University and the public. A public figure from the arts, science or literature is invited by the Vice-Chancellor. Vint was introduced by Oxford's Vice-Chancellor, Professor Louise Richardson, who described the rapid expansion of the internet in recent decades and Vint's impact on the world. Vint discussed 'the pacification of cyberspace' in front of a packed Sheldonian Theatre. The lecture can be seen online at: goo.gl/YCVA5E

Professor Marta Kwiatkowska gave a keynote speech at a Computer Science Global Forum organised by Tsinghua University, China, as part of its 60th anniversary. Marta's topic was 'Computer Science Education in a climate of continuously emerging 'hot' topics'.

The department's Professor Daniel Kroening was one of the winners of the CAV 2018 Award. The group received the award at the International Conference on Computer Aided Verification (CAV) 2018, held as part of the Federated Logic Conference 2018, for its outstanding contribution to the enhancement and scalability of model checking by introducing Bounded Model Checking based on Boolean Satisfiability (SAT) for hardware (BMC) and software (CBMC). The other winners were Armin Biere, Alessandro Cimatti, Edmund M. Clarke, Flavio Lerda, and Yunshan Zhu.

# NEWS

## Athena SWAN Bronze Award

We are very proud that the Department of Computer Science has retained its Athena SWAN Bronze Award.

The Athena SWAN Charter was established in 2005 to encourage and recognise commitment to advancing the careers of women in science, technology, engineering, maths and medicine (STEMM) employed in Higher Education and research. The charter was later expanded to recognise work undertaken to address gender equality more broadly, and not just barriers to progression that affect women.

Head of Department Professor Peter Jeavons commented, 'A Bronze award means the Athena SWAN panel is satisfied we have a solid foundation for eliminating gender bias and developing an inclusive culture that values all staff. Retaining this award is a real achievement – the panel is tough. Let's celebrate the award, which recognises that we really are committed to equality.

We are very proud of what we have achieved so far in terms of supporting career development and enhancing the environment for our staff and students. The Athena SWAN Charter provides a framework against which we can identify our strengths and our gaps and has helped us to examine and plan for what we can do over the next four years to make the Department of Computer Science an even greater place to work and study. This is an important award for us to hold, as it demonstrates to current and future staff and students that we are committed to equality and to identifying and implementing good practice, and that people who work and study with us will do so in an inclusive environment which appreciates the significance of diversity.'

## Oxford ranked first in world for Computer Science and Engineering

The University of Oxford has become the first UK institution to top the Times Higher Education Computer Science and Engineering and Technology global subject rankings. Oxford overtook three US universities known for their strength in technology to lead the two tables.

The ranking is based on criteria measuring teaching, research, industry income, international outlook and citations, which are combined to provide a comparison of universities worldwide.

Oxford was placed first in Times Higher Education's 2019 subject rankings for Medicine and Social Sciences last month. The discipline-specific tables follow on from the announcement that Oxford has been ranked the top university in the world by the same publication for the second year running.

Professor Peter Jeavons, Professor of Computer Science and Head of Department, said: 'The whole department is absolutely delighted by this news. It's testament to a lot of hard work on the part of our staff and students. Computer Science at Oxford has got much bigger in recent years, moving into exciting new areas of technology, and demand for places at undergraduate level is huge. We're looking forward to broadening our outlook further to allow future generations to benefit from Oxford's world-leading teaching and research in Computer Science.'

Read more here: goo.gl/3w1mh8

## ShanghaiRanking places Computer Science and Engineering at Oxford top in UK

Oxford is the highest placed UK university in ShanghaiRanking's Global Ranking of Academic Subjects 2018 for Computer Science and Engineering.

The rankings by ShanghaiRanking, released on 17 July, placed Oxford 13th globally. Indicators used in these rankings include measures of research productivity, research quality, the extent of international collaboration, and academic awards.

## Marta Kwiatkowska gives Royal Society Milner Lecture

Earlier this year Professor Marta Kwiatkowska was awarded the Royal Society's Milner Award – the first recipient in our department of this prestigious award, given annually for outstanding achievement in Computer Science. It was awarded to Marta in recognition of her contribution to the theoretical and practical development of stochastic and quantitative model checking.

The Royal Society Milner Award, kindly supported by Microsoft Research, is given annually for outstanding achievement in computer science by a European researcher. Marta is the first female recipient of the award.

Marta gave the prize lecture at the Royal Society on November 20. The talk was titled 'When to trust a self-driving car…'. It was webcast live and the video recording is available here: goo.gl/boLuWr

## DeepMind Scholarships to encourage wider participation in Computer Science
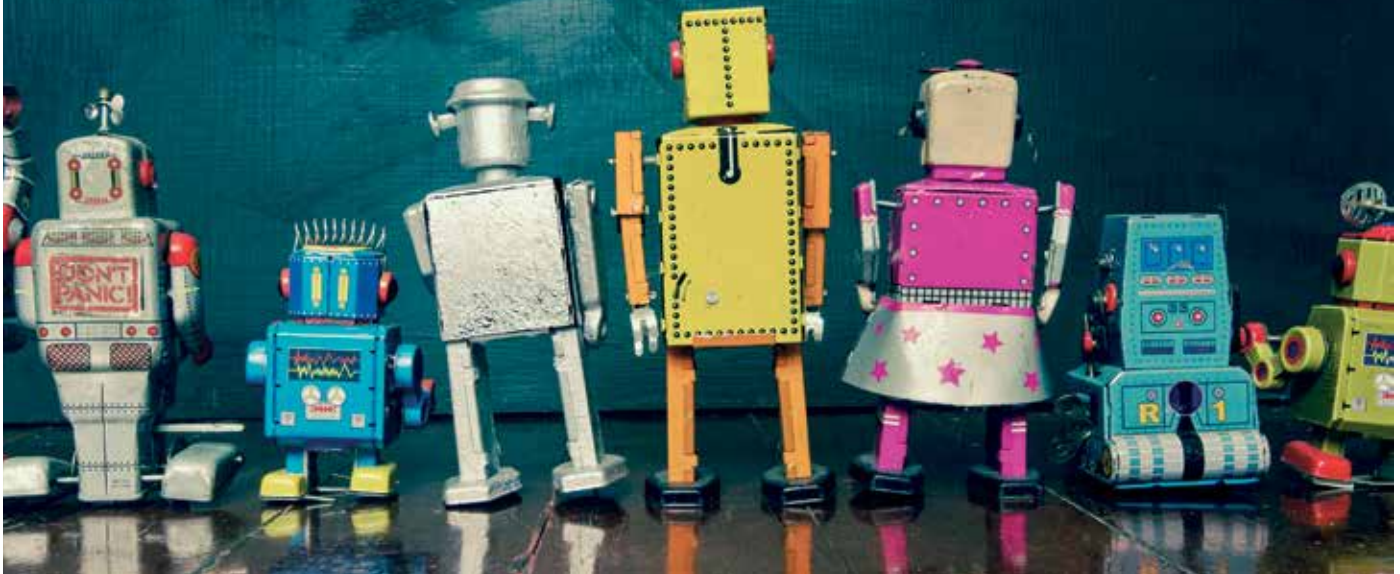
Leading British artificial intelligence company DeepMind has made a generous gift in support of graduate students studying the full–time one year MSc in Computer Science at Oxford.

The donation will be used by Oxford to launch a new scholarship programme to support and encourage under-represented groups in the field to pursue postgraduate education. In addition to the scholarships, which will be awarded at the discretion of the University, DeepMind will also be working with Oxford to offer mentorship and broader support to enhance the students' studies.

During the 2019/20 academic year, four DeepMind Computer Science Scholarships will be awarded to students wishing to pursue the MSc in Computer Science. They are open to individuals who are ordinarily resident in the UK and who belong to one or more of the following groups: identifying as female, BME, or from households with traditionally low progression to higher education. The scholarship programme will play a key role in enabling Oxford to widen participation in the subject at graduate level.

Dr Rebecca Surender, University Advocate for Equality and Diversity, and Pro-Vice-Chancellor, said: 'Encouraging and supporting students from under-represented groups to study STEM subjects at graduate level is a key priority for the University. Not only will this new scholarship programme play an important role in helping us to realise this ambition, but by drawing from the widest possible pool of talent, it will also help to create more diverse role models for young people thinking about studying computer science in the future.'

The DeepMind Computer Science Scholarships will complement the department's well-established outreach and widening participation programme. Professor Peter Jeavons, Head of Department, said: 'We are delighted that DeepMind has made this generous gift to the department, so that we can enable excellent students to progress directly to postgraduate study. This is especially timely, as we are beginning to see the results of our efforts to encourage a more diverse group of students to study our undergraduate courses.'

Established in London in 2010, DeepMind is a world leader in artificial intelligence research and its application for positive impact. Dr Demis Hassabis FRS, co-founder and CEO of the company, said: 'We are delighted to partner with Oxford to extend these scholarships. Computer Science is shaping our future in new and exciting ways that impact us all, yet across the field there are groups whose voices remain under-represented. We hope that these scholarships will help to demonstrate that Computer Science is for everyone and go some way in supporting the next generation of leaders to gain a qualification from one of the best universities in the world.'

The DeepMind Scholarships are the latest in a series of similar programmes initiated by the company to support Computer Science education in the UK.

There is no separate application process for this scholarship: to be considered, prospective students must submit their application for the course by the 11 January deadline. If an applicant fulfils the eligibility criteria, they will be automatically considered for these scholarships. Selection is expected to take place by the end of April 2019.

# NEWS

## Professor Sir Nigel Shadbolt receives honorary doctorate

Professor Sir Nigel Shadbolt has been awarded an honorary doctorate by the University of Wales Trinity Saint David. He received his award at a graduation ceremony on 6 July from Jeremy Smith, Dean for the Faculty of Humanities and Performing Arts.

Commenting after the ceremony, Sir Nigel said: 'It is a great privilege to receive this honorary doctorate. In my own research I have always been passionate about ensuring that AI and Computer Science are used to benefit us all. As Principal of Jesus College, Oxford, there is the added joy of pride in the College's Welsh roots and connections.'
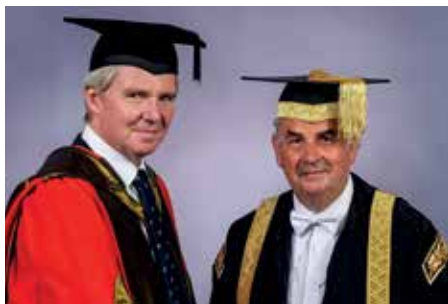


## Success at the ACM International Collegiate Programming Contest's Northwest Europe regional heats

Three teams from the University of Oxford showed off their skills in a programming teamwork challenge on the weekend of 23–25 November, held in Eindhoven. The following teams competed in the Northwestern European Regional Contest (NWERC).

'Los Patrons', achieved second place, a gold medal, and have qualified for the World Finals, in Porto, Portugal, in April 2019; Costin-Andrei Oncescu – (St John's), Stefan Constantin-Buliga – (Balliol) and Alex Tatomir – (Jesus). Coach: George Chichirim – (Keble).

'2 Brits and a Dutchman' came in sixth, winning a silver medal; Shaun Marshall – (St John's), Basim Khajwal – (New) and Arend Mellendijk – (Balliol). Coach: Toby Cathcart Burn – (Pembroke).

'Oxford Ji-geiko' achieved ninth place, and a bronze medal: Andrei-Costin Constantinescu – (Balliol), Leo Feng – (Keble) and Vid Kocijan – (St. Hugh's). Coach: George Chichirim – (Keble).

NWERC is an official regional contest in the ACM International Collegiate Programming Contest. It draws students from colleges and universities throughout Belgium, Luxembourg, Great Britain, Ireland, Iceland, Norway, Sweden, Finland, Denmark, Germany, Estonia and the Netherlands.

In the contest, teams of up to three students had to try to solve as many programming problems as possible (within a five-hour limit) from a given problem set, using only one computer. Potential solutions were submitted and corrected by an automated judging system. Around 120 teams took part this year. The full scoreboard can be found here: goo.gl/L2gYxo

It's not the first time an Oxford team has found success in the competition. In 2017 the Tractor_Specialists team – made up of Andrei-Costin Constantinescu, George Chichirim, and Tamio-Vesa Nakajima – took third place in the NWERC, and went on to compete in the finals held in Beijing.

## Coco Platform wins accolade at No Magic World Symposium

Senior Research Fellow Philippa Hopcroft and Senior Researcher Thomas Gibson-Robinson won an award for the Coco Platform plugin for MagicDraw at this year's No Magic World Symposium (a model-based systems engineering event) in Dallas. They received the 'Cameo Award for Modelling, Simulation & Analysis Excellence 2018' at the symposium, where Philippa and Thomas also gave a demo of the system, and Philippa gave a talk as an invited speaker. The Coco Platform is a revolutionary technology that integrates scalable automated verification and code generation with existing industry standard languages and tools for the purposes of developing large-scale software in practice.

There is a growing need for new technologies to develop the increasingly complex software found in many products today. This increase in complexity is driven by end-user demand for features such as increased automation and autonomy, better diagnostics and prognostics, more availability and improved reliability and safety, increased connectivity, better usability and performance.

To manage this complexity, systems are becoming more distributed, more modular and using increasingly complex hardware. However, this leads to software becoming expensive to develop and makes it more difficult to achieve the required reliability using traditional techniques.

The Coco Platform is being developed to tackle these challenges and reduce the cost of developing software in practice. This work is being supported by EPSRC, Innovate UK and the Aerospace Technology Institute (SECT-AIR project). The research group also works with industry partners across different sectors including high-tech manufacturing, aerospace, defence and automotive.

*Photo below (from left): Thomas Gibson-Robinson, Philippa Hopcroft and Guy Broadfoot (team member).*

## News in brief

The University of Oxford has launched a new podcast titled 'The Future Makers.' It's described as 'the fly on the wall of our colleges, as our academics debate key issues shaping the future of society. Season one is all about Artificial Intelligence. You may already have read a hundred articles about Artificial Intelligence and the future of society, but these longer conversations – featuring four of our academics at the cutting edge of research and at the forefront of their profession – explore each topic in detail, from the automation of jobs to the inherent bias of algorithms.' Topics so far have included 'Does AI have a gender?', 'Are all algorithms biased?', and 'How will automation of jobs likely progress?'. Several members of the department have contributed to the series so far. Listen in at: goo.gl/4BuEbo

The university has launched the first in a series of campaigns which highlight the breadth of Oxford's research and innovation. The first of these campaigns focuses on the university's work in Artificial Intelligence (AI). Oxford University researchers are at the leading edge of the AI revolution: from the fundamental technologies underpinning advancements to the applications that will transform areas such as healthcare and finance, and the critical debates taking place around ethics, governance and privacy.

The campaign started in October and will run until January 2019. It has included documentary-style videos about specific AI projects, as well as in-depth research articles. To find out more visit ox.ac.uk/ai and the main university social media channels, using the hashtag #OxfordAI.



## Former student funds teaching Fellowships in Maths and Computer Science

Worcester College has reported one of the largest single donations to its Tercentenary Campaign to endow the College for the next three hundred years.

With a benefaction of £5,000,000, Ben Delo, who read Mathematics and Computer Science in the early 2000s, has become the youngest major donor in the College's history. The gift will be invested in the College's endowment, with the annual return funding two teaching Fellowships in perpetuity. They will be named the Ben Delo Fellowship in Mathematics and the Bernard Sufrin Fellowship in Computer Science. In addition, there will be a new fund to support research in mathematical and computing based disciplines, to be named the Tony Corner Research Fund, in honour of Worcester College's first Mathematics tutor.

Worcester College Provost Sir Jonathan Bate said: 'It has been an enormous pleasure to get to know Ben in the last few months. He overcame great difficulties in his school career to win a place at Oxford from a local state school, and went on to a stellar performance – as well as a sometimes colourful career – as a student. Since then, his genius in building digital trading platforms and developing advanced cyber security has been a wonder to behold. I am especially delighted that he has chosen to name the Computer Science Fellowship after his tutor, Bernard Sufrin, to whom he feels he owes a great debt – there could be no better vindication of the profound value of the tutorial system.'

Ben Delo said: 'Worcester College and the tutorial system gave me the world-class education that laid the path to my success. I am incredibly grateful and very fortunate to be able to support the College, ensuring it continues tutoring future generations.'

Bernard Sufrin, who is an Emeritus Fellow at Worcester and lecturer at the Department of Computer Science said: 'I am delighted by the honour that Ben and the College have paid me. It is particularly pleasing to see their recognition of Tony Corner's scholarship, his extraordinary dedication to teaching, and the breadth of his vision for the mathematical sciences which led him to make me so very welcome in the College. I am glad that the Corner research fund will be accessible to all tutors of mathematical and computer sciences, for this marks Ben's and the College's appreciation of the work of the many educators who contribute to our students' successes.'

In recognition of his work in computing and his philanthropy, which already extends beyond the College, the Governing Body of Worcester College has elected Ben Delo to an Honorary Fellowship.

On Tuesday 2 October Professor Michael Wooldridge discussed his Ladybird Expert book, '*Artificial Intelligence: Everything You Need To Know About The Coming AI*', at the Henley Literary Festival. In conversation with Scottish Mortgage's Catharine Flood, he looked back to Alan Turing asking in 1950 'Can machines think?' before looking ahead to what a world of ubiquitous AI would look like.

Sir Nigel Shadbolt was a speaker at the Edinburgh International Book Festival, where he spoke to BBC broadcaster Phil Harding about his book '*The Digital Ape*'.

Professor Jeremy Gibbons co-presented the paper 'Relational Algebra by Way of Adjunctions' at the ICFP 2018 conference in St. Louis, Missouri. He is co-author on the paper, which was given a Distinguished Paper Award. Read more: goo.gl/nopzon

The Times and Sunday Times Good University Guide 2019 has found that Oxford Computer Science graduates have among the highest graduate salaries, earning on average a salary of £45,000 after six months. goo.gl/hnVKWa

Several University of Oxford computer scientists have been recognised in a new list compiled by thebestschools.org of the 'Top 50 Most Influential Living Computer Scientists'. Sir Tim Berners-Lee (Professorial Research Fellow, Department of Computer Science), Tony Hoare (Former Head of Department of Computer Science), Dana Scott (Honorary Fellow at Merton) and Donald Knuth (Honorary Fellow at Magdalen) are all mentioned for their significant contributions to the development of Computer Science. Read the whole list here: goo.gl/miHJiv

Cyber security researchers from the Universities of Oxford and Kent have identified a total of at least 57 ways in which cyber-attacks can have a negative impact on individuals, businesses and even nations. Read more: goo.gl/M8b2h4

# Undergraduate prize winners

Congratulations to students who won prizes for their Prelims, the exams at the end of the first year of undergraduate study, and to third and fourth year students who have won prizes for their work.

## First year prizes

**Tamio-Vesa Nakajima** (University College) BCS Prize in Computer Science for the best performance in Computer Science Prelims papers

**Jan Lebioda** (St John's College) Gibbs Prize for Mathematics & Computer Science Prelims, paying particular regard to Computer Science papers

**Neil Natarajan** (New College) Gibbs Prize for Computer Science & Philosophy Prelims, paying particular regard to Computer Science papers

## Third year prizes

**Long Pham** (Keble College) G-Research Prize for best project in Computer Science

**Alexander Rice** (St John's College) British Telecom Research and Technology Prize for Mathematics and Computer Science for best overall performance, with special regard for Computer Science papers

**Andrew Kenyon-Roberts** (Merton College) Department of Computer Science Prize for outstanding performance in Mathematics and Computer Science

**Kaashif Hymabaccus** (Wadham College) Junior Mathematics Prize for Mathematics and Computer Science for outstanding performance in the mathematical papers

**Catalin-Andrei Ilie** (Oriel College) Hoare Prize for the best overall performance in Computer Science

**Cong Lu** (Balliol College) Gibbs Prize for Outstanding performance in Computer Science papers

**Axel Ronquist** (Balliol College) Gibbs Prize for Computer Science and Philosophy, paying particular regard to Computer Science papers

## Fourth year prizes

**Mantas Pajarskas** (St Hugh's College) Hoare Prize for best overall performance in Computer Science

**Radu-Bogdan Berteanu** (Somerville College) Microsoft Prize for best Computer Science project

**Anna Bialas** (Magdalen College) Microsoft Prize for best Computer Science project

**Declan Manning** (New College) Hoare Prize for best overall performance in Mathematics & Computer Science

**Borun Shi** (University College) G-Research Prize for best Computer Science project by a Mathematics & Computer Science candidate

**Oscar Darwin** (Magdalen College) G-Research Prize for best Computer Science project by a Mathematics & Computer Science candidate

**Paavan Buddhdev** (Hertford College) Hoare Prize for best overall performance in Computer Science and Philosophy

# Ismail Ilkan Ceylan wins EW Beth Dissertation Prize

Ismail Ilkan Ceylan has been awarded the EW Beth Dissertation Prize 2018 for his doctoral dissertation. The prize was awarded at a ceremony which took place at the University of Sofia during the 30th European Summer School in Logic, Language and Information (ESSLLI 2018).

The Association for Logic, Language and Information (FoLLI) each year awards the EW Beth Dissertation Prize, named in honour of the Dutch mathematician Evert Willem Beth, to outstanding PhD theses in the fields of Logic, Language, and Information. Dissertations are evaluated on the basis of their technical depth, strength and originality.

Ismail is currently a co-investigator in the EPSRC project 'RealPDBs: Realistic Data Models and Query Compilation for Large-Scale Probabilistic Databases' which runs from 2017 to 2021.

# Industry partnerships with Computer Science at Oxford



The last five years have seen an explosion in the interaction that the department has had with partners from industry. From presenting lunch time tech talks on Tuesdays (now extended to Thursdays to meet demand) to involvement with undergraduate group projects. The department is keen to embrace the many different ways that interaction with industry can enhance the experience of students at the Department of Computer Science.

The department works with the university's Careers Service each year to organise the Careers in Computing event, which takes place in mid-October. This year the event, hosted in the Mathematical Institute to meet demands for extra space, had over 35 recruiter stands and was attended by more than 300 students. The event also attracts students from Oxford Brookes University.

Lunch-time tech talks, often with the added incentive of pizza, are events hosted by the department for companies who want to present to students from Computer Science and related backgrounds. Presenters from companies such as Omnitek, Apple, Morgan Stanley and Netcraft give some 'real world' context about applying the skills gained during a computer science or related degree to industry, and also some specific information about working for those companies. It is a fantastic opportunity for students to have some more in-depth information about how to apply for graduate jobs and internships, and to have a chance to ask current employees what it is like to work for the company.

We also use our relationships with industry to give real world context to our degrees. In our second-year undergraduate group projects, the briefs are set by industry, academics and researchers. These briefs are presented to our students in mid-January, a project is chosen and students will be required to have client meetings with the industry project sponsor to help define the brief. After that students have just under four months to come up with a working solution. The projects culminate in a presentation day in May, when students present projects to members of the department and representatives from industry, with a judging panel awarding prizes for best projects and best presentations.

If you are interested in becoming an industry partner please contact industry@cs.ox.ac.uk.

## News in brief

DPhil student Bushra AlAhmadi received a scholarship from Google to attend the Grace Hopper Celebration (GHC) in September. GHC is the world's largest gathering of women technologists with over 22,000 attendees and aims to recognise, celebrate and encourage women in technical fields. Bushra said 'I have been to GHC twice before, and I always get empowered and re-energised by the diverse female technologists sharing their work and elevating others. Attending GHC gave me the opportunity to meet inspiring women technologists, expand my network, and build lasting connections. It was truly an inspiring conference, especially Padmasree Warrior's words that resonated with me "Open doors and go through them, don't wait for people to open doors for you and don't wait for the right door"'.

# Booking.com scholarship students start courses

This academic year, the Department of Computer Science is delighted to have welcomed its first six Booking.com scholars: Vanessa Ackermann, Joanna Materzynska and Marguerite Tong, all studying for the MSc in Computer Science; MSc in Software Engineering students Kinga Varnai and Agnieszka Pasztyla; and Krisztina Matkovics, who is studying on the MSc in Software and Systems Security.

Recognizing an under-representation of women in undergraduate and advanced STEM-related areas of study, this initiative seeks to create more opportunities for talented women to continue further education and post-graduate courses in these areas, and prepare them for future careers in the technology industry.

# Alumni Profile

**Yigit Ihlamur** *is a partner at Vela Partners, where he invests in Artificial Intelligence (AI) startups. He studied MSc Computer Science, 2009–10 and was a member of Kellogg College.*

'Technology has played an ever present and important role in my life. My earliest memory as a 3-year old was seeing my father, a technology executive, carry his desktop computer tirelessly around every night so that he could write code from home. As I grew up, I came to observe first-hand that technology and innovation had the ability to revolutionise emerging economies, such as my own in Turkey. I have committed my own ambitions towards having as large an impact as possible through the power of innovation and technology.

Pursuing such ambitions required me to be thoughtful about what I studied, where I studied, and where I worked. For undergraduate studies, I enrolled in the Industrial Engineering Programme at Koç University, where I became hooked on the power of software and decided that I wanted additional expertise in the area before entering the workforce. I ultimately chose to attend Oxford University due to its centuries long reputation in innovation and strong worldwide recognition.

My Oxford education benefitted me throughout my Google career as I gained exposure to the practical applications of machine learning, a subject that I had studied intensely at Oxford through coursework and my master's thesis on recommendation engines.

After five years at Google I joined Vela Partners, a venture capital firm investing in emerging technologies. At Vela, my responsibility as a partner is to invest in pioneering startups in the AI and deep learning fields. A natural extension of my studies at Oxford, my graduate AI education is put to use daily in my responsibilities at Vela when it comes to learning about new developments in the AI field, assessing the merits of a startup's technology, and contributing to AI driven product features in Vela's own internal AI tools and existing portfolio companies.

My time at Oxford gave me exposure to individuals and ideas that are pioneering in their field. My Oxford education has been and remains pivotal in helping me shape the future of technology and innovation.'

## Chao Mbogo changing Computer Science teaching in Kenya

Chao Mbogo graduated from our department with an MSc in Computer Science in 2007 and since then has worked towards changing the way Computer Science is taught in her home country, Kenya. Kenya has a growing tech industry and has become known as the 'Silicon Savannah', so there are many opportunities for Computer Science graduates.

Chao came to Oxford on a Shell Centenary scholarship and feels that the time she spent here changed the way she approached not only Computer Science but learning in general. She believes that one factor that disadvantages some Kenyan students when seeking opportunities is learning things by rote. Chao found at Oxford that the type of analytical thinking we require of our students challenged her to change her way of thinking and learning.

'My experience at Oxford pushed me to work twice as hard to bring myself on par with my classmates. It was a big lesson. I then realised that, as academics in Kenyan universities, we need to do more to prepare our Computer Science students for the wider world.'

Now the Head of Computer Science at Kenya Methodist University in Nairobi, Chao has launched various initiatives to support Kenyan students applying for local and international scholarships and also to prepare them with the right skills for the job market.

Chao founded KamiLimu, which is a free 6-month structured mentorship program that seeks to augment classroom learning for Computer Science students at Kenyan universities. Chao is passionate about improving access for women to Computer Science and other STEM subjects so in KamiLimu 50% of the mentees are female. KamiLimu was recognised for its impact in the community through Chao's 'Zuri award' in the Leadership category in March 2018. She has also just been recognized and named as one of twenty 2018 Faces of Science in Kenya, during the Africa Science Week.

# Oxford Women in Computer Science

This has been quite a year for the Oxford Women in Computer Science (OxWoCS), focusing on fostering links between our sponsors, collaborating on events as well as welcoming our new undergraduate members.

Oxford Women in Computer Science actively supports and promotes women in the field of Computer Science, running social and academic events to provide networking opportunities and a support network of role models, mentors and peers.

This year we have continued our OxWoCS distinguished lecture series with joint lectures with the Department of Computer Science. Talks included those by Kristin Yvonne Rozier (Iowa State), Virginia Williams (MIT) and Jane Hillston (Edinburgh).

We have also been involved in outreach events, having taken part in the Department of Computer Science's Women in Computer Science Day and the 2018 Hay Festival. OxWoCS have also been part of the ongoing InspireHer! project teaching mothers and daughters about the real world applications of programming concepts and computational thinking in order to encourage and improve participation in computing.

The 5th annual Oxbridge Computer Science Conference took place in Cambridge in March. The aim of the conference is to bring together junior and senior scientists at Cambridge and Oxford as well as encouraging collaboration through formal and informal discussion. The keynote this year was Amanda Prorok (Cambridge) giving a talk titled 'When Robots Hit The Road: New Challenges in Multi-vehicle Coordination and Control'.

We also can't end without mentioning our trips to sponsor HQs. This year we have had visits to DeepMind, Microsoft and Visa. All those who took part had a wonderful time, it was a great to see the opportunities within industry that could await members on graduation. A particularly good time was had by all at the Visa Innovation Centre, trying out new tech!

[Above] The 2018-19 OxWoCS Committee: Top *(left to right): Chia-Man (Researcher Representative), Paula (Outreach Officer), Anna (Undergraduate Representative & Conference Coordinator), Saumya (Outreach Officer), Lucy (Social Event Officer), Ellie (Social Event Officer), Ioana (Sponsorship Officer), Catherine (Seminar Series Coordinator).* Bottom *(left to right): Catherine (Industry Event Officer), Tajwar (Undergraduate Representative), Mary (Secretary), Klaudia (President), Alexandra (Undergraduate Representative), Alina (IT Officer), Daniela (Industry Event Officer).* Missing: *Sarah (Departmental Liaison and Treasurer) and Fatimah (Conference Coordinator)*

# OxWoCS team win

The Oxford Women in Computer Science team won the JP Morgan Code for Good London hackathon in November 2018. The team members were Paula Fiddi, Clara Pavillet, Margot Tong, Danlei Zhu and Phoebe Yao.

The Code for Good Challenge is described as bringing together 'talented university students studying technology'. Participants come together to work alongside JP Morgan technology experts in teams to solve real-world problems for nonprofits. The event is designed to not only aid local nonprofit organisations, but to also give students the opportunity to see what it's like to work in technology at a major investment bank. The UK Code for Good Challenge was held at the firm's London headquarters, with similar events also taking place in New York, Ohio and Delaware, as well as Mumbai.

# Answers on a postcard:
# Artificial Intelligence predictions

As a little bit of fun, during the Oxford Artificial Intelligence Exposition (AI Expo), and other recent events, we've been asking delegates and students to make their predictions on the future of Artificial Intelligence. We asked participants – who ranged from school children to professors and CEOs of technology companies – a series of questions such as 'when will a completely autonomous car safely drive from London to Oxford?' and 'when will a robot tennis player beat a reigning Wimbledon champion?'. A few of the answers to this entirely non-scientific poll can be found below.
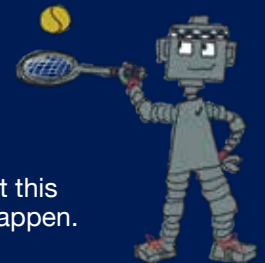
**90%** thought that a completely autonomous car will drive safely from London to Oxford in the next 10 years.

**80%** thought that by 2038 London's black cabs will by replaced by driverless cars.

**26%** thought that in the next 10 years the Wimbledon champion would be a robot.

**19%** thought that this will never happen.

**14%** thought that AI would **never** write a New York Times best seller novel.

**20%** thought that the best seller will happen in the next 10 years.

**60%** thought that by 2038 robot surgeons will routinely operate on human patients.
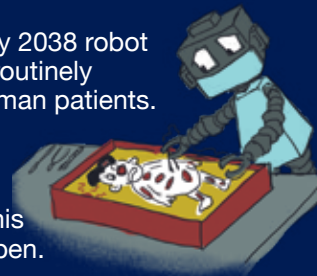
**2%** thought that this will never happen.

**How would you have answered?**

## Semmle identifies Apple security vulnerability

Semmle is a software engineering analytics platform whose CEO is Oege de Moor, a former Professor at the Department of Computer Science.

In August it was announced that Semmle had received an additional $21 million in funding, led by Accel Partners, and with participation from Work-Bench.

The Security Research Team at Semmle has recently discovered a series of critical remote code execution vulnerabilities in Apple's XNU operating system kernel. This may allow malicious attackers on the same network to take control of any vulnerable Apple device. The vulnerabilities were found using Semmle's variant-analysis engine to search for vulnerability patterns in source code.

Read more and watch a demonstration video here: goo.gl/cpM9yx

## New grant awarded for LAMBDA project

The Department of Computer Science has been awarded a European Commission grant under the Horizon 2020 Twinning scheme.

The goal of the LAMBDA ('Learning, Applying, Multiplying Big Data Analytics') project, led at Oxford by Emanuel Sallinger and Tim Furche, is to spread excellence in research, teaching and innovation in knowledge graphs and big data analytics. This is highly synergetic with the department's existing strengths in information systems, databases, artificial intelligence, knowledge representation, and reasoning.

The Oxford team will participate in all aspects of the project, and will focus particularly on the knowledge graph aspect. Knowledge graphs have become a focus of research at Oxford, notably leading to the development of the Vadalog system within the EPSRC Value Added Data Systems project at the department. Among its benefits, the LAMBDA grant will allow the team to develop new teaching and learning materials, ensuring that excellence in research also has a direct impact on excellence in teaching and innovation. After three successful awards in the Medical Sciences division of the university, this is a first for the Mathematical, Physical, Engineering and Life Sciences division.

EC-funded Horizon 2020 grants aim to spread excellence and widen participation by decreasing disparity in European research and innovation. The LAMBDA project's core is formed by the University of Oxford (Department of Computer Science), The Fraunhofer Society (Institute for Intelligent Analysis and Information Systems), the University of Bonn (Institute for Computer Science) and the University of Belgrade (Institute Mihajlo Pupin, the oldest and largest ICT research institute in Serbia and the West Balkan region).

# FLoC 2018
# All good things come to an end

The 7th Federated Logic Conference (FLoC 2018) was a huge event, with a total of 1,986 people registered for the conference over the course of its two week period. FLoC was a huge undertaking for the department, and so many people contributed to its success. We have had so many wonderful comments from attendees, including:

**'FLoC has been excellent again. Many interesting and inspiring talks'**

Dr Marijn Heule,
The University of Texas at Austin



**'Thank you very much for the great FLoC 2018 organisation'**

Antoine Miné, Sorbonne Université



**'It was an unforgettable experience at FLoC 2018'**

Jinxu Zhao,
University of Hong Kong



**'For me as a new PhD student it is amazing to know how many people are working on the same problem as I am and it is great to know their approach!'**

Simin Oraee, Max Planck Institute for Software Systems



**'It's been really exciting being here, meeting so many elite researchers in my field and interacting with fellow graduate researchers!'**

Shromona Ghosh, UC Berkeley

We should especially like to thank:
- the speakers, especially keynote, plenary, public event and summit speakers and panellists
- conference and workshop invited speakers
- our sponsors
- FLoC Steering Committee
- FLoC Programme Committee Chairs
- FLoC Programme and Organising Committees
- FLoC Workshops Committee and Workshop Organisers
- FLoC Local Organising Committee
- FoPSS Summer School organisers
- the Department of Computer Science at Oxford
- our army of nearly 200 volunteers, all of whom gave up their time to make FLoC a success
- EasyChair (conference management software system)

FLoC was an enormous undertaking, and it would not have been possible without community engagement and support.

The next FLoC will take place in 2022.

A number of FLoC recordings are available online. Please visit our FLoC YouTube channel here: goo.gl/fXqSNF

# New Starters/New Roles ●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●

**In the last six months we have welcomed to the department a large number of new researchers and academics. These include:**

- Alastair Janse van Rensburg, Research Associate in Cyber Security
- Alexandros Voudouris, Research Associate in Computational Social Choice
- Andraz Kastelic, Research Associate at the Global Cyber Security Capacity Centre (Prosperity)
- Andreas Galanis, Associate Professor of Algorithms and Complexity Theory. Tutorial Fellow, Hertford College
- Chris Hargreaves, Departmental Lecturer
- Damianos Veskoukis, Research Assistant in Hardware and Software Co-Verification
- Georgios Birmpas, Research Associate in Algorithms, Games, Mechanisms, and the Price of Anarchy
- Jan Pich, Research Associate in Computational Complexity Theory and Proof Complexity
- Louise Axon, Research Associate in Cyber Security Analytics

- Matt Kusner, Associate Professor of Machine Learning and Tutorial Fellow in Computer Science, Jesus College
- Medha Atre, Senior Researcher in Information Systems
- Norbert Nthala, Research Associate in Cyber Security
- Philip Lazos, Research Associate in Algorithms, Games, Mechanisms, and the Price of Anarchy
- Riccardo Spolaor, Research Associate in Mobile Systems Security
- Sina Salek, Postdoctoral Researcher in Quantum Causal Structures
- Stanislav Kikot, Research Associate in Proof-driven Query Planning
- Stefano Rosa, Senior Researcher in Healthcare Efficiency Through Infrastructure Free Indoor Localisation
- Warut Suksompong, Research Associate in Computational Social Choice
- Xuan Bach Le, Research Associate in Algorithmic Verification of String-Manipulating Programs.

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# Student Ambassador scheme grows



Nobody is better placed than our current students to spread the word about what it's really like to study Computer Science at Oxford; and our Student Ambassador scheme is designed to allow them to do just that. Ambassadors are all current students – undergraduate or postgraduate – and their role is to work with members of the public, especially young people and their parents and teachers, and be the friendly face of Oxford Computer Science.

Any current student is very welcome to sign up, and once they've completed a short training session, they're all ready to go. Ambassador duties range from giving a talk at a school or an open day, to assisting with a practical session and making robots dance, to simply chatting with a prospective student about student life. Perks of the job include a free 'This is what a computer scientist looks like' t-shirt; often free food; and ambassadors are paid for their work on full day events. Some ambassadors even find that they enjoy the job so much that they don't want to give it up after they graduate...

As much as academics and staff members can talk about what they think current student life is like, it's no substitute for hearing it first hand from a real, live, current Oxford student. Introducing prospective students to our student ambassadors is great for breaking down stereotypes and reassuring prospective students that people like them really do go to Oxford and study Computer Science, and that they really do have a great time while they're here.

One new group of student ambassadors has already been trained this academic year; with another group still to be trained.

# Ethical and societal responsibility debated at 2018 conference

The 2018 Oxford Computer Science Conference took place on 1 June at the department. This year, the conference was sponsored by DeepMind, Accenture and Ocado, and featured more than 25 talk and poster presentations of cutting-edge research by DPhil and MSc students.

One of the highlights of the day was the keynote panel 'Coding the Future: Values in Computer Science', where former Head of Department Professor Michael Wooldridge, Head of Human Centered Computing Professor Sir Nigel Shadbolt, Deputy Director of the Digital Ethics Lab Mariarosaria Taddeo, and Microsoft's Governmental Affairs Manager David Franke debated how to integrate ethical and societal responsibility into Computer Science.

Among other points, the panel provided a great discussion of the challenges around designing ethics courses that can prepare tomorrow's Computer Science students for careers where their work has a high impact on society.

Thanks to the industry sponsors, the conference also featured a number of prizes for outstanding submissions and presentations: 'Best talk' was won by Martin Dehnel-Wild, with Gareth Molyneux as runner-up. 'Best poster' was won by Meredydd Williams, with Prince Abudu as runner-up. 'Best abstract' was won by Anna Bialas, with David Tena Cucala as runner-up.

# AI and ethics – the ORBIT 2018 conference

The ORBIT project, based in the department's Human-Centred Computing theme, held its first conference this autumn to look at the hot topic of AI and ethics.

Lord Tim Clement-Jones opened the conference with a summary of the House of Lords Select Committee's Report on AI. He stressed the importance of public debate on Artificial Intelligence and the inclusion of a wide group of stakeholders to ensure that societal factors are incorporated into the development of AI.

The challenge of doing this effectively was highlighted by another speaker, Maria de Kleijn-Lloyd. As the lead on Elsevier's AI team, she discussed how Elsevier's data analysis had found little overlap in how terminologies and technologies are understood in research, education and journalism. Such lack of cross-disciplinary understanding is disturbing, as the ramifications of AI cannot be sensibly discussed without a clear understanding of common terms.

This needs to change. Neil Viner of the Engineering and Physical Sciences Research Council (EPSRC) pointed out that, as the pace of change increases, we have less and less time to adapt to technological developments or to consider whether we want them at all. Abigail Sellen of Microsoft Research believes an inflection point may have been reached, particularly with the advent of generative adversarial networks (GANs) that have created a step-change in the abilities of computer networks. EPSRC is responding to developments such as this by stipulating that its new Centres for Doctoral Training (CDTs) must incorporate Responsible Research and Innovation. ORBIT plans to use its 2019 conference to examine how Responsible Research and Innovation is being included in CDTs.

Elsewhere, AI optimists like Sir Anthony Seldon point out the potential benefits, while movers and shakers in the field such as Virginia Dignum argue for common sense. We have experienced new technology before, and one way or another, we have worked out how to incorporate it into the way we design our future. AI belongs to us – we need to make sure we design it the way we want it to go.

# Algorithmic fairness

Governments and companies worldwide are looking to machine learning to automate certain decision tasks. From deciding whether shop owners violate government policies, to assessing the likelihood of someone paying back a home loan, to assisting judges on whether to release someone from jail, machine learning algorithms are now making life-changing decisions. Alongside the benefits of automation, the hope is that such algorithms will be free of any existing biases in human decision making.

## Matt Kusner is trying a new approach to identify and eliminate algorithmic bias

Algorithms learn to make their decisions by detecting patterns in historical data. Therefore, if this historical data contains biases against certain groups of individuals (certain races, genders, sexual orientations, or otherwise), machine learning algorithms will learn them too. When such algorithms replace human decision-makers, they will perpetuate the biases against groups that have historically been discriminated against.

Recently, machine learning researchers have begun to look for solutions. In large part, current work has focused on defining metrics that indicate when decisions are fair. As long as predictions satisfy the metric those predictions are fair.

However, people often disagree, for good reasons, on the right fairness metric for a given problem. Furthermore, we cannot apply all of them as a number of them are impossible to satisfy at once.

Instead, our approach has been to look at the underlying causal effects in society, to understand how discrimination is impacting the data. We propose to leverage the extensive tools of causal inference to not only detect such unfairness but to start to correct for it. With such tools we are able to formally answer the question: 'how would a decision have changed if instead you had been a different race?' To do so, we apply a technique called counterfactual inference. This works by first trying to estimate an individual's unobserved abilities, as postulated by a causal model. Once estimated, we can then imagine an individual had a different race by simply changing the variable corresponding to race. To observe the effect of this change, we take the changed variable and the estimated unobserved abilities, and use them with the equations of the causal model to recompute their observed data. If this new data changes the prediction for that individual, then having a different race affects this decision unfairly.

The nice thing about this approach is that instead of arguing about what the right fairness metric should be, we now can debate what the right causal model should be. This can be done in a much more principled way, by interrogating any necessary assumptions, introducing additional data, and using additional tools in causality, among many other ways. Our hope is that (a) this work encourages researchers in fair machine learning and causality to consider if there may be other ways causality can address problems of algorithmic discrimination; and (b) to encourage joint work with experts in other fields such as law, philosophy, policy, anthropology, and economics, that uses causal models to address historical and algorithmic biases in these fields.

## UnBias final Showcase

For the past two years our project 'UnBias' has examined the ways in which algorithmic processes filter and personalise the internet content we see on social media news feeds, search engines and recommendation platforms.

To celebrate the end of the UnBias project in winter 2018 we held a showcase workshop to present our key findings. Over 70 attendees from the fields of research, policy, law, industry and education joined us at the Digital Catapult in London for a day of discussion and debate.

We began by describing the research work we have undertaken in the project to explore the user experience of algorithm-driven online platforms. Our findings identify the existence of concerns across different groups in society about the ways in which algorithmic processes can negatively shape the online experience – for instance by showing 'biased' search results or personalised content that is inaccurate or intrusive. We also identify a genuine desire for change to improve the user experience online; many young Internet users we spoke to wanted to have more control over the ways in which platforms collect and use their personal data, and many professional stakeholders argue for better regulation of platforms. We have used our findings to highlight several opportunities for positive change – in particular in relation to i) education and empowerment for online users ii) engagement activities

*from previous page* ▶

through which the developers of algorithms can listen to and act on different viewpoints about what makes an automated process 'fair' or 'unfair' and iii) regulatory changes, such as the monitoring of algorithms and their outcomes by independent intermediaries, to better ensure that online platforms are accountable to government and society.

Following the presentation of our UnBias findings, we invited a panel of experts to discuss them. Our panelists were: Ben Wagner, Vienna University of Economics and Business; Lord Tim Clement-Jones, Former Chair of the House of Lords Select Committee on Artificial Intelligence; Jack Stilgoe, University College London; Becky Hogge, Program Officer at Open Society Foundations; and Baroness Beeban Kidron, House of Lords, and Founder and Chair of 5Rights Foundation.

In a lively and engaging session these panelists debated the implications of our work and the further steps that might be needed to ensure that algorithmic systems operate in our best interests. We then invited external speakers to present. This included a powerful keynote speech by Baroness Beeban Kidron. Baroness Kidron stated that change is crucial and that a healthy Internet is one that fosters the well-being of users and promotes the ethical use of data. She described the UnBias project as an important component of the push towards this healthy internet.

A full overview of our findings and video recordings from the Showcase event can be seen on our project website: goo.gl/BsCJkX

# The UnBias Toolkit

The UnBias Fairness Toolkit was recently launched at the Digital Design Weekend at the Victoria and Albert Museum, London. The toolkit is a collection of practical tools that aim to help raise awareness of and to stimulate dialogue about bias, trust and fairness in algorithms and digital technologies.

The tools include a set of 'Awareness Cards', and worksheets ('TrustScapes') for people to articulate and share their concerns as well as their hopes for a free and fair internet for all. It also includes worksheets ('MetaMaps') for industry stakeholders and those in public policy and regulation to respond to the public's views. All of these tools are documented and shared on the UnBias website.

The toolkit is designed to make complex and often abstract ideas tangible and accessible to young people and to non-experts across society. It supports the development of critical thinking skills that can help people feel empowered to make better informed decisions about how they interact with algorithmic systems. In addition, it helps users to collect evidence of how people feel about the issues and what motivates them to share their concerns by contributing to a public civic dialogue.

It can also be used by developers of algorithms and digital systems to support them in reflecting on ethical issues, as well as a practical method for implementing Responsible Research and Innovation.

It has been designed and created by Giles Lane of arts organisation 'Proboscis', in collaboration with researchers from Oxford's Department of Computer Science – Professor Marina Jirotka, Helena Webb, Menisha Patel and doctoral student Paula Fiddi. It features illustrations by artist Alice Angus and improvisation exercises devised by theatre-maker Alex Murdoch.

The toolkit is one of the outcomes of UnBias: Emancipating Users against Bias in Algorithmic Systems, a partnership between Oxford, the Horizon Digital Economy Institute at University of Nottingham and the School of Informatics at the University of Edinburgh.

https://unbias.wp.horizon.ac.uk/fairness-toolkit

# Pictorial Reasoning as a tool for understanding quantum computing

Quantum theory has always been shrouded by mystery; anything coined with 'quantum' is superior to the non-quantum version and will always be 'too difficult to understand'. This is true to some extent: as Richard Feynman, one of the most influential physicists of modern times, famously said: 'Nobody understands quantum mechanics.' In the case of quantum computing, this is mostly true too. However, the mathematics of it may not be that mysterious…

The everyday computers in our homes calculate with binary numbers, also called 'bits'. These have two states – sometimes called the TRUE/FALSE states or ON/OFF states, or more commonly, the '1' and '0' states – and the calculations on the states are logical operations like AND, OR, NOT. There is a quantum analogue of a bit which is called a 'qubit': states are written as pairs of numbers (vectors) – for example,

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix} , \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

and the calculations are quantum operations performed on the states. In simple terms, this is just multiplying the state by a block of numbers, or in slightly more technical terms, matrix multiplication. The rules of multiplication in this setting are pretty simple, and are often taught to teenagers in schools. Even though the underlying computation is simple, it took physicists decades to come up with the first quantum computing algorithm. This may be due to the presentation of the theory: after all, visualising numbers is hard enough, let alone visualising a block of numbers.

This issue is a focus of the Quantum Group in Oxford's Department of Computer Science. Our researchers abstract these blocks of numbers by representing them as pictures, and calculations are done by moving the pictures around on the whiteboard, deforming the pictures, and replacing part of the picture with another picture according to some very simple rules. This method of performing calculations is called 'pictorial reasoning', and it can be made into a 'diagrammatic calculus' which formalises seemingly hand-wavy pictorial arguments by underpinning them with proper mathematical rigour. One such diagrammatic calculus that is designed for reasoning in quantum computation is the ZX calculus.

The ZX calculus is a powerful tool for work in quantum computing. This is best illustrated with a couple of simple examples: this is the teleportation protocol, an important quantum protocol which took physicists sixty years to design from the initial formulation of quantum mechanics:
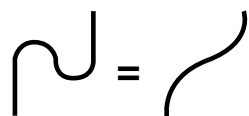
and this is the entanglement swapping protocol, an important variant of the teleportation protocol which was proposed a year later:
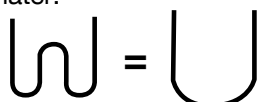
These examples involve yanking of wires, which looks almost trivial. In fact, many results in quantum computing, when drawn as diagrams, are so simple and intuitive that a team from the Oxford Quantum Group, led by Professor Bob Coecke, is initiating a project to teach quantum theory to high school students.

Each of these diagrammatic examples we have given represents some complicated manipulations of blocks of numbers. Using these diagrams, we can conceptualise these algebraic gymnastics, stripping away the irrelevant details and leaving only the essence of the calculation. This makes it easier for quantum computer scientists and engineers to analyse and design quantum protocols.

However, the use of such diagrammatic calculus brings a major concern: can it describe all possible matrix calculations? If we are not able to describe all matrix calculations, then there will be some part of quantum theory that we are not able to describe using the diagrams, which would be a fatal blow to the calculus. This is called the completeness problem: is the ZX calculus complete?

Just recently, in 2017, breakthroughs have been made concerning the completeness problem: the ZX calculus is now proved to be able to describe all matrix calculations! The team in Oxford (and in France) have proposed a ZX calculus that is complete. This is important news as now we can safely replace all matrix calculations with the more intuitive diagrammatic moves.

The ZX calculus has many applications. It is readily integrable in quantum compilers as an interface between quantum computer users and hardware; hence we can write 'quantum programs' without too much effort. Coding in quantum computers is made easier with the existing (semi-) automated software for diagrammatic reasoning, Quantomatic, which mostly supports ZX diagrams.

Furthermore, the completeness result has opened up many avenues of new research using the ZX calculus: from designing new quantum algorithms, to having a unified diagrammatic language for hybrid quantum-classical computing. The team in the Oxford Quantum Group is exploring more exciting possibilities with the complete ZX calculus.

# Report explores public perceptions of quantum technologies

The results of a public dialogue on quantum technologies, commissioned by the Engineering and Physical Sciences Research Council (EPSRC), have been published. The department's Professor Marina Jirotka is on the oversight board for this public dialogue project.

The report presents the results from an EPSRC-commissioned dialogue with the public about how they view and feel about the development of quantum technologies (QTs), and their possible applications.

The dialogue, which was highly exploratory in nature, took place in York, Oxford, Glasgow and Birmingham in late 2017. The aim was to explore public perceptions of QTs and to gather opinion on possible applications and uses of quantum devices and technology and to identify new and interesting directions. Experts and researchers entered into the dialogue to engage and inform participants about QT and the devices that might emerge from the National Quantum Technology Programme and the wider quantum community.

The dialogue found that there was wide familiarity with the word 'quantum' but low knowledge of what it is or about QTs. Participants broadly associated quantum with being related to advanced technology and science/physics.

Having had limited exposure to information about QTs, many participants initially felt neutral towards them. However, some participants with lower engagement with science tended to express some anxiety going into the start of the dialogue, while those more interested in science generally felt curious and excited.

As researchers explained more about QTs, many participants became more engaged and excited by the range of potential benefits associated with them, particularly once they understood the possible impact and relevance to their own lives. Whilst no participants became more negative about QTs, there was a small number of participants who felt disengaged from science and their level of interest remained unchanged.

Participants understood that QTs have a wide range of benefits for individuals and society, and were most engaged by those viewed as having the greatest potential impact on individuals and society: saving or extending life (such as health technologies and humanitarian applications); finding cost-efficiencies in healthcare; and improving national and financial security. At the same time, there were some concerns expressed about who would control and have access to these powerful technologies, and whether they might lead to job losses or environmental damage. Participants identified some possibilities for misuse, as with all new technologies, but, overall, they felt that, on balance, the potential benefits outweigh the risks.

The results of the dialogue will be used to inform research and innovation priorities in the next phase of the National Quantum Technology Programme, which aims to ensure the successful transition of quantum technologies from laboratory to industry. The current phase of the programme comprises four hubs; Professor Marina Jirotka is leading the incorporation of responsible innovation in the Networked Quantum Information Technologies (NQIT) Hub, based here in Oxford across several departments including Computer Science. Read the full report here: goo.gl/DQLnhv

# The GCSCC continues its work across the world

The Global Cyber Security Capacity Centre (GCSCC) at the University of Oxford is a joint research programme between the department and the Oxford Martin School and is a leading international centre for multidisciplinary research on efficient and effective cyber security capacity-building, and promoting an increase in the scale, pace, quality and impact of cyber security capacity-building initiatives across the world. In a global consultation process with cyber security experts, the GCSCC has developed a comprehensive methodology for the review of a country's cyber security capacity and for informing resource allocation for cyber security capacity investment: The Cyber Security Capacity Maturity Model for Nations (CMM).

The CMM is a systematic model that facilitates a review of the maturity of a country's cyber security capacity. It was developed in consultation with over two hundred experts from around the world representing governments, international organisations, academia, public and private sectors, and civil society.

The GCSCC considers national cyber security capacity to be clustered into five dimensions. These dimensions cover the broad expanse of areas that ought to be considered when seeking to enhance cyber security capacity.



*Figure 1 [above] – five dimensions of the CMM and their interrelationships*

*[Right] The Opening Ceremony for CMM Review in Samoa. [front row, left ]  Eva Nagyfejeo, [back row, middle] Matthew Griffin, [front row, right] Carolin Weisser, plus representatives from APNIC, the ITU, the Oceania Cyber Security Centre. and the Samoan Government*

## Deploying the CMM

In order to gather evidence as part of the CMM Review, in-country consultations take place in the form of focus group discussions in which the review team will gather the evidence necessary to identify the stages of maturity across the CMM. To ensure a holistic understanding of the cyber security capacity environment in a country, the research team meets with stakeholders from various areas across the public, private, and civil society sectors including government ministries, internet service providers, academia, critical infrastructure, business, law enforcement, international organisations and more.

Working on the research team for the GCSCC can be a fascinating exercise, requiring international visits to countries across the world. As an example, Dr Eva Nagyfejeo is a Research Fellow at the GCSCC supporting the delivery of global cyber security capacity-building expertise by promoting the CMM through country reviews. In particular, her role involves developing knowledge-transfer material and supporting the Oceania Cyber Security Centre in Melbourne, Australia, in their deployment of the maturity model across the Oceania region. Her work also includes close work with high-level stakeholders. By the end of 2018, she will have completed eight country reviews around the world:
• Ghana – January 2018

• FYROM – January 2018
• Brazil – March 2018
• Samoa – April 2018
• Tonga – June 2018
• Bosnia and Herzegovina – October 2018
• The Gambia – October 2018
• Georgia – November 2018

Eva comments: 'It has been an exciting and challenging experience completing field work in different countries around the world and having the chance to learn about different cultures. The opportunity to gain a deeper understanding of the cyber security capacity challenges and opportunities from stakeholders on the ground in these countries provides rich and valuable information for our research. As part of our deployment of the CMM, we deliver to each government a comprehensive assessment report on the maturity of national cyber security capacity which supports future capacity building in this area. I am confident that the research we complete can have a really positive impact for each country that we visit and also help strengthen the global academic field of cyber security capacity knowledge'.

Further to the above, the GCSCC team has also completed the following CMM Reviews this year:
• Bangladesh – July 2018
• Albania – September 2018
• Nigeria – October 2018

# Professor Rodney Brookes delivers Strachey Lecture

**In November 2018 Professor Rodney Brookes, from MIT, gave the latest Strachey Lecture, titled 'Steps Towards Super Intelligence'**

In his 1950 paper 'Computing Machinery and Intelligence' Alan Turing estimated that sixty people working for fifty years should be able to program a computer (running at 1950 speed) to have human level intelligence. Artificial Intelligence (AI) researchers have spent orders of magnitude more effort than that and are still not close. Why has AI been so hard and what are the problems that we might work on in order to make real progress to human level intelligence, or even the super intelligence that many pundits believe is just around the corner?

In his talk, Rodney discussed those steps we can take, what aspects we really still do not have much of a clue about, what we might be currently getting completely wrong, and why it all could be centuries away. He made distinctions between research questions and barriers to technology adoption from research results, with a little speculation on things that might go wrong. (Spoiler alert: it is the mundane that will have the big consequences, not the Hollywood scenarios that the press and some academics love to talk about.)

One attendee described the talk as a 'most refreshing and robust argument for why we are just as far from super intelligence as we have always been, but how we have much productive work to do to make AI work better.'

The Strachey Lectures are generously supported by OxFORD Asset Management.

If you missed the lecture you can watch it again here: goo.gl/sWsWk5

## Media Wall

*On our website we have a Media Wall of videos, podcasts and animations which we add to throughout the year.*

This year we have added videos on numerous topics. Marta Kwiatkowska talks about how she manages the work/life balance. Sir Nigel Shadbolt contributed to a film called Minds Wide Open and we added to our Strachey Lecture series with a video of Professor Jon Crowcroft delivering his lecture on 'Privacy – preserving analytics in, or out of the cloud'. We have added many videos relating to AI, including Shimon Whiteson talking about robots, Sir Nigel Shadbolt chatting to BBC presenter Spencer Kelly at the Hay Festival, and Marina Jirotka chairing a panel discussion on AI and ethics.

*Visit goo.gl/z5CiWm to see these videos and others.*

# Oxford Sparks expands technology-related podcast and animations

Looking for new ways to inspire and educate the young people in your life, and instil in them a love of science and technology? Oxford Sparks is the University's digital engagement platform for sciences, and produces high quality media such as podcasts and animations, aimed at people aged 11 and upwards. Topics include anything from 'Bacteria Safari: The Forest on your Fingernail' to 'Ancient Mysteries in Marvellous Mud'. Recent releases include 'Why does my phone battery suck?' and 'How do you teach a robot social cues?'. Find out more at www.oxfordsparks.ox.ac.uk

## News in brief

Professor Paul Goldberg will be hosting the 14th annual Conference on Web and Internet Economics taking place from Saturday 15 December to Monday 17 December in St Anne's College. The conference aims to bring together researchers in theoretical Computer Science, Artificial Intelligence and microeconomics for the exchange of ideas and results to tackle problems involving incentives and computations. For further details please see: www.cs.ox.ac.uk/conferences/wine2018/

# Research aims to enhance large-scale probabilistic databases



A team from the department has begun work on a project which aims to enhance large-scale probabilistic databases (and so unlock their full data modelling potential) by including more realistic data models, while preserving their computational properties.

Systems that crawl the web encountering new sources and adding facts to their databases have a huge number of potential uses. However, a lack of common-sense knowledge about their stored data is currently limiting their potential in practice. Oxford researchers are working to overcome these constraints. As part of this EPSRC-funded research, the team (Professor Thomas Lukasiewicz as principal investigator with İsmail İlkan Ceylan and Professors Georg Gottlob and Dan Olteanu as co-investigators) is planning to develop different semantics for the resulting probabilistic databases and analyse their computational properties and sources of intractability.

Over the three and a half years of the project, they are also planning to design practical scalable query-answering algorithms for databases, especially algorithms based on knowledge compilation techniques. They will extend existing knowledge compilation approaches and elaborate new ones, based on tensor factorisation and neural-symbolic knowledge compilation.

Once designed, the team plans to produce a prototype implementation and experimentally evaluate the proposed algorithms. These prototypes should help demonstrate the full potential of large-scale probabilistic knowledge.

Read more about the project at: goo.gl/pQESqC

# New fellowship awarded to study deep learning efficiency

Nicholas Lane has been awarded a three-year EPSRC-UKRI Fellowship titled 'MOA: High Efficiency Deep Learning for Embedded and Mobile Platforms'. Nic's fellowship is motivated by breakthroughs in the last few years from the field of deep learning that have transformed how computers perform a wide variety of tasks such as recognising a face, understanding speech, or monitoring physical activities.

However, the models and algorithms used by deep learning typically exert severe energy, memory and compute demands on local device resources and this conventionally limits their adoption within mobile and embedded devices. Because sensor perception and understanding tasks powered by deep learning are so fundamental to platforms like phones, wearables and home/industrial sensors, we must reach a point where current – and future – innovations in this area can be simply and efficiently integrated within even such resource constrained systems.

The MOA fellowship, which began in July 2018, seeks to perform a mixture of basic research and translational work (through a collaboration with its industrial partner Samsung) towards the discovery of methods that collectively can overcome some of the most severe barriers to on-device inference and training of deep learning suited for smart devices. To accomplish this, MOA plans to examine a range of opportunities for full-stack solutions starting with approaches directly targeting model representations and algorithms themselves, extending to software systems like schedulers and memory managers – and even including methods grounded in processor and architecture level considerations.

If successful, the outcomes of MOA will enable, for instance, brand new types of sensor-based products in the home and workplace, as well as enabling increasing the intelligence within not only consumer devices, but also in fields like medicine (smart stethoscopes) and autonomous systems (robotics/drones).

# Finding new ways to understand security risks in aircraft software

**Martin Brain discusses the issues in question.**

Silicon Valley would have us believe that only the very latest technology is valuable. But when it comes to the software that flies planes, runs trains or heals brains, getting it right first time, *every time* and then upgrading it is rarely the order of the day. The software embedded in the most critical parts of the modern world has often been built up over decades of careful engineering and testing. It's not glamorous work but it builds systems that are safe against a wide range of accidents and faults.

But what if the errors in the system are not accidents? When many of today's aircraft were designed, the idea of a passenger using a hand-held computer to hijack the plane from their seat was science-fiction. To ensure that it remains sci-fi in the sky, we need to check that critical systems are not just safe, they are also secure. Creating secure systems is challenging at the best of times and the popular wisdom is that security must be designed in from day one. That's fine for new systems but what about all of the

existing critical systems keeping the world running? It would be too expensive (not to mention risky and hugely time consuming) to rewrite all existing embedded control systems from scratch. What is needed is another way of assessing, managing and guaranteeing the security risk of embedded systems.

This is a problem that DSTL (Defence, Science and Technology Laboratory) has run into with the latest standard for security of aircraft software, DO-326A. Alongside DO-178C, which ensures the safety of aircraft software, DO-326A is becoming a key part of showing airworthiness and getting legal permission to fly in the UK and worldwide. Since redeveloping the software following modern security best practice would not be possible and existing software analysis tools would require too much human involvement, making them too costly to use, DSTL has turned to the University of Oxford to develop a new class of software analysis technique.

Instead of focusing on simply proving or disproving assertions about the software, the Ada Security Vulnerability Analysis Tool (ASVAT) analyser aims to provide an Actionable Automatic Assessment of the software. For each potential security vulnerability, component, file, function or even line of code, it produces a risk assessment. These allow individual developers to see where the code can be improved but more importantly, they enable the project management and the aviation authorities to understand and manage the security risk; even for large, complex and pre-existing systems.

# Whose clutter is this? – Tending smart homes



Assistants, household helpers, toys and smart building technology, powered by electricity and data, all are making their way into ever more households. Research highlights how we are having to adapt to change brought about by the very same internet-connected devices. Do we understand how they work? What do we do if they don't work? This is the process of domesticating new technologies: eventually shoehorning them into our lifestyles or changing the way we live our lives.

However, people go about such things in inherently different ways, following the established communal order of the home, and personal knowledge, preferences, and attitudes. Such situations can lead to social conflicts between different household members, relating to usage but also to security or privacy. What data is being collected, and whose is it? In which situations is it being collected? Is everyone equally content with its collection? What does the collected data say about others in the household?

Smart homes have the potential to exaggerate bewilderment and resistance, feelings people express when their privacy is infringed. Our research approach considers privacy as inherently social and shaped by technology over time.

Martin Kraemer's DPhil research seeks to empower householders' privacy practices, the routine way householders go about defining and managing their own privacy. Existing research focusses on individuals rather than groups and attitudes and preferences more than behaviour. Martin is looking beyond the individual in order to explore how the collaborative work of privacy practices can be understood and supported through system design. Ultimately this research will improve on the understanding of privacy in smart homes through its empirical contribution. From that, implications for design will help to shape product design, and also inform future work in privacy research for ubiquitous computing.

As part of a larger initiative, Martin is working with his supervisor Professor Ivan Flechais and Research Associate Norbert Nthala to empower households in managing the challenges of achieving a more balanced relationship with technology through digital wellbeing.

# Technology to measure chance of news being fake

A 'FakeNewsRank' system that aims to show the likelihood of facts, articles, authors and websites being fake is to be developed with funding from the University of Oxford's EPSRC Impact Acceleration Account (IAA).

Fake news items on the web influence many people and have started to become a huge problem in important political and economic decisions, such as Brexit and the presidential elections in the USA. For this reason, there is major interest from governments and



web companies alike (for example, social networks, web search companies and online newspapers) in the detection and removal of fake news. Clearly, this cannot be done manually anymore, given that there are more than a billion daily active users on Facebook. It is a natural step to think about developing Artificial Intelligence technologies to detect fake online news.

The one-year FakeNewsRank project led by Professor Thomas Lukasiewicz is a step towards a spin-out company developing such technology. The initial goal of the project is to create a proof-of-concept demonstrator for computing a fake news score, provisionally named FakeNewsRank, for facts, articles, authors and websites. It will measure their likelihood of being fake, and identify any still existing key gaps or challenges in preventing this. The project will also produce datasets (for two different domains, such as politics and the economy) of sample blog messages and news articles, containing true and fake facts, along with their authors and web addresses, and background knowledge graphs underlying these datasets.

The demonstrator will be based on the deep-learning-based system developed by Thomas and his group for extracting facts from plain text. The system extracts facts relative to a background knowledge graph from plain natural language text on a web page. Furthermore, the project will also draw on the group's deep-learning-based system for ontology reasoning, which will be used to determine the likelihood of truth of an extracted fact relative to the underlying background knowledge graph. The FakeNewsRank computed by the demonstrator will be based on this likelihood of extracted facts and on other parameters.

# LabHack


photo by Jeffrey Barbee

Science, Technology, Engineering and Mathematics (STEM) education in Africa is often held back by shortages of laboratory equipment in teaching institutions. Even very basic pieces of equipment can be very expensive to buy, import, repair and maintain. As a result, many laboratories in African schools and universities are critically under-resourced and students are required to share single items between large groups. This makes it difficult for them to gain the hands-on experience they need to develop their skills.

Researchers at Oxford, in the Department of Computer Science and Institute for Science, Innovation and Society, have worked together to develop a novel approach to address resource scarcity in African laboratories. The idea is to hold competitions in which students design and build the equipment themselves! These are LabHackathons – fun events in which multidisciplinary teams compete around design challenges to build low cost and reproducible laboratory equipment. The idea of the LabHackathon builds on the traditional hackathon competition, and the ethical hackathon format as developed by members of the Human Centred Computing theme at Oxford's Department of Computer Science. It also draws on the emerging field of Open Hardware. This global movement includes a drive towards the free online dissemination of equipment plans and thereby offers alternatives to reliance on expensive, proprietary laboratory equipment.

Thanks to a Global Challenges Research Fund award from the Engineering and Physical Sciences Research Council (EPSRC), the first LabHackathon in Zimbabwe was held in June 2018. Teams of university students and hobbyists from across the country took part, signing up for challenges to design and build pieces of laboratory equipment such as magnetic stirrers, centrifuges and PCR machines. The teams worked on their designs ahead of the event; they were supplied with Arduino kits to help them and were also encouraged to make use of freely available Open Hardware resources.

The LabHackathon event itself took place at the Harare Institute of Technology in June. The teams showed off their completed designs in presentations and demonstration sessions. The quality of work was very high and the ingenuity shown by the teams to build frugally was very impressive. The teams produced excellent working prototypes, often for less than $100, when commercial versions would typically cost thousands of dollars. A panel of judges awarded prizes for, among others, 'Best Prototype', 'Best Design Documentation' and 'Most Frugal Design'. Participants also had the opportunity to attend a variety of social events, and interactive, educational sessions run by the event organisers and local companies.

The organisers and participants alike were delighted with the outcomes of the first LabHackathon event. The teams were highly motivated and enthusiastic, truly rising to the challenges they were set, displaying great skill and ingenuity as young innovators.

Since the event, teams have been encouraged to share their designs as part of the Open Hardware movement and have showcased them at research and public engagement events. Further opportunities are being pursued to run more LabHackathon competitions and to build up a network of events across Africa. The team hope that the LabHackathon can become a platform through which students and educators can take matters into their own hands in order to design and build the equipment they need in their institutions.

The LabHackathon team was Professor Marina Jirotka, Helena Webb, Jason RC Nurse (Computer Science) and Louise Bezuidenhout (Institute for Science, Innovation and Society). We were assisted in the organisation of our Zimbabwe event by Arianna Schuler Scott (Computer Science) and a number of local organisations – in particular the Harare Institute of Technology, the National Biotechnology Authority of Zimbabwe and the NEPAD Southern African Network of Biosciences.


photo by Jeffrey Barbee

# Fortnite is setting a dangerous security trend

Visiting Lecturer Jason RC Nurse [*pictured right*] shares his thoughts on security issues around apps that bypass official app stores.

Cyber criminals have just been given yet another route to get malicious software (malware) onto your personal mobile devices. The hugely popular video game Fortnite has become one of the first major apps to bypass official app stores and encourage users to download its software directly.

In doing so, it's also bypassing the security protections of the app stores and chipping away at a system that has worked reasonably well at keeping malware off people's phones and tablets. We're already starting to see the dangerous results of this, as Fortnite's installation method created a security vulnerability that may have opened up some users' devices to hacking.

Fortnite's maker, Epic Games, shocked the industry when it announced at the start of August that it would release the app directly to consumers instead of through the official Google Play store (although it's still available through Apple's App Store). The firm said this was to create a direct relationship with customers instead of depending on middlemen distributors. Google takes 30% of the money paid for any app or in-app purchase in the Play store.

This goes even further than the likes of Netflix, which recently confirmed it was testing a bypass of Apple's iTunes billing system in 33 markets worldwide. This meant that some subscribers would be unable to pay using iTunes and instead would have to complete payments via Netflix's website, reducing their engagement with the official Apple store.

Current estimates suggest that in the first half of 2018, users of the Apple App Store and the Google Play Store spent a combined US$34.4 billion on mobile apps and games. These official stores still represent the first port-of-call for millions of mobile users, and in return they have come to expect trustworthy, vetted, malware-free, high-quality apps.

The issue with attempts to bypass official stores is that they contradict recommended security best practice. Engaging with these stores is highly endorsed because of the added protection they offer. Apple, for instance, has a set of detailed guidelines that app submissions are checked against. Similarly, Google has a series of automated and manual techniques to vet apps.

Directing users away from these stores means less protection. And even worse, it stands to encourage a wider behaviour change. It sends the message to users that official app stores are no longer the primary trusted way to engage with apps.

Bypassing official app stores is a risky game. Shutterstock Industry research has validated the importance of this advice time and time again, by revealing that third-party app sources – particularly on the Android platform – are often plagued with malware and can expose users and their data to a variety of security and privacy risks. According to the 2018 Symantec Threat Report, the vast majority (99.9%) of discovered mobile malware was found in third-party app stores. This doesn't mean that official stores are free from malware but they do have the advantage of another set of specialists checking apps for potential problems. As such, direct downloads create a
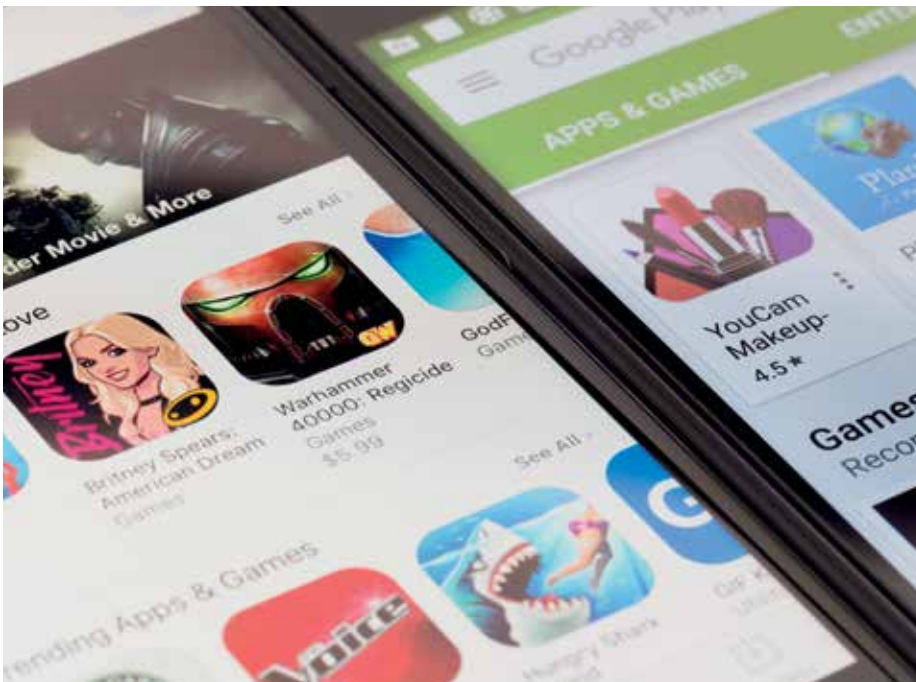
substantially greater security risk. A perfect example of this was revealed recently when Google discovered a severe security vulnerability in the Fortnite installation process. This essentially made it possible for malicious apps to download and install anything on a user's device without their permission – a cyber security nightmare. Although Epic Games has since released a fix, it is very likely that many users have yet to install it, which means they may still be vulnerable.

**Eroding good habits**

A more long-term impact of the shift to direct downloads and engagement is the potential erosion of best security practice. For years, security awareness campaigns and guidance have emphasised the importance of sourcing apps only from official stores. This has been a difficult (yet crucial) task as security awareness campaigns are hard to get right, actually changing people's behaviour is even harder, and

attackers are constantly updating their tricks.

Encouraging or redirecting users away from traditional channels may well undo some of these ingrained secure habits. For example, the Fortnite installation process requires gamers to enable installations from unknown apps. But doing so puts users at higher risk. A user would need to navigate to this setting later to disable third-party installations as it does not reset automatically.

If more large app developers bypass the official stores in this way, it will almost certainly have an impact on people's broader behaviours. This could result in the belief that trusted sources of apps are no longer necessary and that disabling protective security measures isn't a problem. What's more, it could create a higher temptation to look to third-party app stores for new apps or better deals – app channels that are, as mentioned, unfortunately infested with malware.

The ultimate result of these actions will be further malware infections and a higher compromise in privacy and security. Ordinary users will pay the costs of app developers' desire to avoid the regulations and fees of the official stores.

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Read the original article at: goo.gl/LCBE6A

**THE CONVERSATION**

# Jason and the children's book

A children's book aimed at explaining what sorts of careers are available to them in the future includes an interview with Jason RC Nurse.

Jason is featured in the book called '*Fantastic Jobs and How to Get Them*', which has a particular focus on jobs in the fields of science, technology, engineering and mathematics (STEM). Jason is included as a 'social media scientist' in reference to his work examining how we use the internet, stay safe online, and identify and avoid fake news. He also talks about what his research involves to understand these,

and other complex topics – such as cyber crime and connected smart devices – as they evolve.

The book also includes advice for children interested in a careers in these sorts of areas, such as understanding as much as they can about computers, learning to code and the importance of mathematics.

Jason undertook research in this area while in the department for more than seven years. He now holds a Visiting Lectureship at Oxford, while taking up a new position at the University of Kent. You can find out more about Jason's public engagement work – including

lots of podcasts and videos – on the OxfordSparks website: goo.gl/5p6v2v

# Collaborating with WildCRU to develop better animal tracking

**A lion finishes feeding on its prey and decides to walk to a nearby waterhole to quench its thirst after the hunt. A simple series of behaviours is exhibited here – feeding, walking and drinking. Each of these behavioural states has characteristic sounds that accompany it such as bone crunching, footfalls and lapping water. Could these sounds provide valuable clues for monitoring animal behaviour?** – *by Matthew Wijers*

In 2014, the Wildlife Conservation Research Unit (WildCRU), founded by Professor David Macdonald, formed a collaborative partnership with Professor Andrew Markham from the Department of Computer Science. This partnership stemmed from the need to improve the classification of animal behavioural states from accelerometer data. Typically, researchers have built behavioural classifiers using ground truth information either from video recordings or direct observation. While these may be viable methods, continuous observations of an elusive species, or a species that occurs in inaccessible habitats, may be impossible to achieve. To overcome these challenges, custom acoustic bio-loggers were designed, each capable of recording sound in conjunction with accelerometer and magnetometer data. These bio-loggers were then fitted to lions in Bubye Valley Conservancy, Zimbabwe by bolting them to existing GPS tracking collars (figure 1).

A total of 44 lion-days of audio from 7 individual lions provided considerably more data for calibration of rarer behavioural events (eating, drinking and running) than could have been realistically achieved using video footage recorded by an observer or a video collar. The audio recordings were used to train random forest models as well as to provide additional predictor variables for behaviour classification. Further analysis revealed near-perfect classification performance for five lion behaviour classes (eating, drinking, running, walking and stationary) when all component variables were combined, with an average per-class precision of 98.5%. This demonstrates the advantages of using audio sensors compared to accelerometers alone.
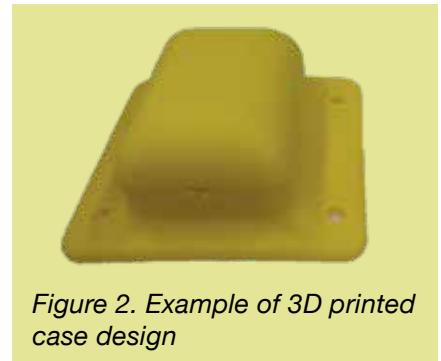


*Figure 2. Example of 3D printed case design*

More recently, this technology has been applied to European badgers in Wytham Woods, as part of WildCRU's long-running badger research project. A new generation of acoustic bio-loggers were designed for this purpose using 3D printed cases (figure 2), off-the-shelf hardware and open-source software. The use of 3D printing not only accelerates the manufacturing process, but also allows for re-use of the bio-logger with a simple battery change. So far, a total of 30 badgers have been fitted with these loggers over the course of three deployments resulting in 125 days of data.

The success of the collaboration between WildCRU and the Department of Computer Science has led to new ideas for bio-acoustic monitoring of wildlife. This highlights the value of collaborative partnerships between biologists, engineers and computer scientists for harnessing the potential of technology that can advance ecological research and conservation.



*Figure 1. [left] Acoustic bio-logger attached to GPS collar on a lioness.*