

## Curriculum Vitae – Ross Anderson

I am Professor of Security Engineering at Cambridge University and also at Edinburgh University. Security Engineering is about building systems to remain dependable in the face of malice, error or mischance. As a discipline, it focuses on the tools, processes and methods needed to design, implement and test complete systems, and to adapt existing systems as their environment evolves.

My mission has been building security engineering into a discipline. Thirty years ago, some parts of it – cryptography, protocols and operating system security – had some solid theory, but the experts mostly didn't talk to each other. Other aspects, such as software security, were a practitioners' art, while yet other aspects such as hardware security were just black magic.

Since 1992 I've started research programs in neglected areas, ranging from hardware security through API security and signal processing to security economics. I've worked on applications from payments through online medical records to curfew tags, and documented their failure modes so that engineers can learn from them. I wrote the standard textbook, *'Security Engineering – A Guide to Building Dependable Distributed Systems'* of which the first edition came out in 2001, the second in 2008 and the third in 2020 [272]. Along the way I've contributed to the design of a number of widely-deployed systems, from the STS specification for prepayment utility meters (with over 400 million in over 100 countries) through the HomePlug standard for power-line communications (widely used to extend wifi) to the design of Android Pay which enables hundreds of millions of people to make credit card payments with their mobile phones. This work has been recognised by the Lovelace Medal, the UK's top award in computing.

Sustainability is a growing theme as security engineering merges with safety and becomes essential to the next generation of cars, medical devices and much else. Regular security patches for durable goods will make security a larger part of the total lifecycle cost. A law that my work helped the EU to develop (2019/771) requires firms selling consumer goods with software components to patch them for the length of time the customer can reasonably expect; another (the Cyber Resilience Act) will extend this to other goods such as routers.

My Cambridge Cybercrime Centre collects and curates data about online wickedness, from spam and phish to underground crime forums; this is now used by over 150 researchers in over 50 universities worldwide. Now that most acquisitive crime is online, security engineering is moving steadily up the political agenda; our work spills over into the study of violent online political extremism, and it informs a number of policy areas including privacy, surveillance, competition and artificial intelligence.

My university duties at Cambridge include teaching an undergraduate course in security and software engineering, and graduate courses in security and cybercrime. At Edinburgh, where I hold a 20% appointment, I teach a security engineering course.

Ross Anderson FRS FREng  
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# 1 Research

## 1.1 Signal processing and machine learning

Our most recent technical research topic is adversarial machine learning. The revolution in neural networks since 2012 has let us build better pattern-recognition systems, but they are fragile in that an adversary can usually find inputs that look the same to humans but very different to classifiers. We invented a mechanism to diversify neural networks with a key, so that adversarial images will only fool the specific instance of the classifier against which they were trained, and otherwise raise an alarm [257, 259, 261, 268]. We've extended adversarial attacks to the kind of models that play games [267] and the kind that deal with 3-d images [271]. We've also worked out how to poison or backdoor machine-learning systems by manipulating the order in which training samples are presented, rather than by changing the samples or their labels [274]. We also discovered how to develop inputs that take classifiers a lot of time or energy to process, leading to service-denial attacks [269]. This led to the discovery of attacks on almost all large NLP systems based on manipulating Unicode inputs [277], and then to the 'Trojan source' attack which broke almost all compilers using similar techniques [280].

This followed earlier work on applying machine learning to improve side-channel attacks based on signal processing. We can work out what PIN you put in your phone by watching the camera wobble or listening to the taps on the screen; we can do the listening either with the phone's own microphones, or those on a nearby smart speaker [210, 262, 273].

We started applying signal-processing ideas to computer security back in the 1990s. We showed that 'Tempest' attacks on computers, which exploit stray RF emissions, could be mitigated by software as well as by hardware shielding [51, 75]. We also broke almost all the copyright marking schemes in use at the time [50]; our 'Stirmark' software became the industry standard for testing them [73, 72]. We returned to that topic in 2021 with a new way of embedding copyright marks in images which are extremely hard for inpainters based on machine learning to remove [276].

## 1.2 Economics and security

If Alice guards a system but Bob pays the cost of failure, you can expect trouble. We now know that many real-world security problems can be best explained using the language of microeconomics: network externalities, asymmetric information, moral hazard, adverse selection and the tragedy of the commons. This field took off since I wrote about it in 2001 in an award-winning paper [90] and in my Security Engineering textbook [88]; it now has over 100 active researchers. We have helped drive policy via studies for the European Commission of the security economics of cyber-crime [154, 160], the resilience of the Internet [187] and what happens to safety regulation once there's software in everything [246, 247]; and via studies of the costs of cybercrime in 2011 [196] and 2018 [265].

I have spent several years building up the Cambridge Cybercrime Centre, which collects lots of data on malware, spam, phishing and other online bad things as a service to the research community; over 160 researchers in over 50 universities now license our data. For surveys, see [134, 145, 171] and [188]. We have other papers on attitudes to online crime [217], the security economics of critical national infrastructure [170, 175] and surveillance [216], and the ways in which financial regulators ignore abuses [255]. Our most recent initiative has been to extend our collection to online extremism [281], which is making novel data collections available to scholars of topics from misogyny to terrorism. Our data are also helping us in a long-term project to extend our security economics work through behavioural economics into psychology [179, 188, 192, 193, 211, 217, 218, 220, 221, 229, 231, 235, 254, 263].

### **1.3 What goes wrong with real systems**

Engineers learn much more from the bridge that falls down than from the hundred that remain standing. I therefore study the failure modes of a number of critical systems including payment card systems [10, 12, 17, 113, 120, 142, 125, 139, 143, 153, 159, 165, 177, 180, 181, 192, 195, 201, 202, 213, 219, 225, 231, 232, 237], prepayment utility meters [18, 30], medical record systems [23, 29, 61, 68, 69, 129, 136, 151, 222] and vehicle systems [56]. Our laboratory's maxim is that 'good research comes from real problems'. From these case studies, I try to distil the essence of good security design [6, 14, 16, 21, 25, 31, 36, 47]. One piece of work led to the cancellation of badly-designed databases intended to support child protection [135]; another was an investigation into how Chinese agents compromised the Dalai Lama's office computers [167]; another work stream tackled smart grids and smart meters [170, 175, 182, 184, 203]. Recently we've been looking at security vulnerabilities in mobile phones [210, 226, 227, 234], at ways of extending mobile payments offline [233, 245], and at protecting data about wildlife from poachers [256].

Since 2016 we've also been working on the engineering and incentives necessary to maintain the software in durable safety-critical goods like cars and medical devices [246, 247, 251]. Research funded by Bosch (because of their interest in robust machine vision) led to much of the work on machine learning described above; it also led to work on more sustainable toolchains [253].

### **1.4 Cryptographic protocols and APIs**

Many of the interesting technical failures in security systems are where the wrong things are encrypted, or the right things are encrypted in the wrong way. Over the years I have discovered many protocol attacks [5, 14, 21, 33, 40, 41, 43]. I was the first to use formal methods to verify the crypto protocols underlying a real banking system [6, 16, 45]. I have also designed a number of protocols [13, 28, 46, 58, 62, 70, 93, 233], was one of the inventors of micropayments [28], and of the idea of making files sufficiently invisible that their existence can be plausibly denied even in the face of compulsion (the 'Steganographic File System' [52]). I've also worked on protocols in industrial control

systems [183, 184], the interaction between protocols and economics [115, 186], with psychology [179, 192] and the effects on innovation [178, 185, 186, 187, 243].

I designed the key-management protocols for HomePlug, now deployed in millions of consumer electronic devices [128, 138]. I also pioneered API attacks, which extend protocol analysis to the application programming interfaces of cryptographic processors [80, 89, 102, 142, 125, 126]. Our work forced most manufacturers of hardware security modules to redesign their products [122].

## **1.5 Hardware reverse engineering**

In 1996, we opened up the field of semiconductor security with a paper on the tamper-resistance of smartcards [37]. Our biggest contribution was probably in [95, 97] where we pioneered semi-invasive semiconductor testing: the idea is to use lasers to read out memory contents by inducing photocurrents and also to induce revealing faults. We then showed that common PIN entry devices could be hacked, explaining a number of payment frauds [153, 201]. We've also shown that you can recast decompilation as a search problem [209], which helps the analysis of large malware families that differ from each other by small tweaks. Most recently my postdocs Sergei Skorobogatov and Franck Courbon have shown how to read Flash and EEPROM memory at scale using a scanning electron microscope.

## **1.6 Peer-to-Peer systems and networks**

I wrote one of the seminal papers on peer-to-peer systems when I proposed the Eternity Service [35]; the ideas were taken up by Freenet, Gnutella, Publius, Kazaa and others. We also developed mechanisms for authenticating distributed content using hash trees and hash chains [58, 62]. Further papers include [70, 71, 76, 82, 84, 105, 106, 108, 121, 229].

We later found that the topology of insurgent networks shapes, and is shaped by, strategies of attack and defence; our models can explain why insurgents form cells, and the circumstances under which suicide attacks are rational strategy. This led us to develop metrics and other analysis techniques for both static and dynamic networks [118, 121, 144, 155, 148, 202, 190, 191, 207]. We also looked at the privacy problems of social networks [161, 168].

## **1.7 Analysis and design of ciphers**

Breaking ciphers was my introduction to information security in the mid-1980's when I found a number of attacks on the stream ciphers then in use [3, 4] and proposed improved versions [1]. Further work on stream ciphers [7, 15, 19] led to work on hash functions [11, 26] and to ways of constructing block ciphers from hash functions and stream ciphers [27]. My big project was 'Serpent', a block cipher which was a finalist in the Advanced Encryption Standard contest [54, 59, 60]. The winner, Rijndael, got 87 votes at the final AES conference while Serpent with 59 votes was second.

## 1.8 Physics and security

We used ideas from statistical physics to model why the reliability growth of large systems in response to testing is as poor as can possibly be: a software version of ‘Murphy’s Law’ [74]. One consequence is that, under standard assumptions, open-source and proprietary systems are equivalent – in the sense that opening up the design helps the attacker and the defender to exactly the same extent [96]. If you want to know whether one or the other is better, you need to look at which of our model’s assumptions are violated.

We have also been working to show that many of the claims made on behalf of quantum systems hinge on a particular interpretation of the Bell tests, which is not the only one [205, 208, 212, 223], raising issues with the security proofs offered for quantum crypto based on entanglement.

## 1.9 Policy

The 1990s brought the ‘Crypto wars’. The Clinton government claimed that they needed to control cryptography; I was one of the authors of the most widely-cited paper rebutting this claim [44]. Further writings on crypto policy and technology policy include [22, 43, 48, 53, 65, 87, 100, 101, 103, 110, 130, 131, 132, 133, 140, 172, 173, 197, 198]).

In 1998, I was one of the founders of the Foundation for Information Policy Research, a think-tank. We secured amendments to various laws including the RIP Act and the Export Control Act in the UK and the IPR Enforcement Directive in Brussels. We also worked with other NGOs to set up European Digital Rights (EDRi) in Brussels. I was on the UK GCSA’s Blackett Review of Cyber Security, which led in 2011 to an extra £640m being spent on cyber security over the period 2011–5.

After Ed Snowden disclosed large-scale lawbreaking by the signals intelligence agencies in 2013, crypto controls were brought back on the agenda by UK Prime Minister David Cameron and FBI Director James Comey; we updated our classic paper on the costs and risks of government-mandated exceptional access to systems [230]. Most recently, following the push by the intelligence community and the European Commission for client-side scanning and the announcement by Apple of such a product, we wrote a third paper explaining why this exposes democracy and the rule of law to unacceptable risks [280].

Papers with real impact on UK policy include a 2006 report for the Information Commissioner on children’s databases [135], and a 2009 report published by the Joseph Rowntree Reform Trust entitled ‘*Database State*’ on the safety, privacy and legality of large UK public-sector databases [166]; this was adopted by both Conservative and Liberal Democrat parties before the 2010 election, which they won – leading to the abandonment of two children’s databases.

Papers with impact in the EU include a 2008 study of the security economics and policy options in cybercrime [154]; a 2011 study for ENISA of the resilience of the Internet [187]; and a 2016 report on what happens to safety regulation in a world full

of Internet-connected things [246, 247, 251]. This led to the Sales of Goods directive 2019/771 which mandates software maintenance among other things.

Other policy topics include tracing stolen bitcoin [252, 255, 260] and what tracing tools say about financial regulation; a report on the costs of cybercrime, commissioned by the Ministry of Defence [196]; and a Nuffield Bioethics Council report on what happens to medical ethics in a world of cloud-based medical records and pervasive genomics [222].

## 1.10 Research mentoring and management

I am currently supervising three research students (David Khachaturov, Nicholas Boucher and Jenny Blessing) and have three postdocs (Richard Clayton, Sergei Skorobogatov and Hridoy Dutta). Five former students are full professors (George Danezis and Steven Murdoch at UCL, Frank Stajano at Cambridge, Jeff Yan at Strathclyde, Feng Hao at Warwick and Tyler Moore at Tulsa); two former students lecture at Cambridge (Markus Kuhn and Robert Watson) along with one former postdoc (Alice Hutchings). Shishir Nagaraja teaches at Strathclyde, Hyounghick Kim in Korea and Susan Pancho in the Phillipines. Thirty of my former research students have earned PhDs (Jong-Hyeon Lee, Fabien Petitcolas, Frank Stajano, Harry Manifavas, Markus Kuhn, Ulrich Lang, Jeff Yan, Susan Pancho, Mike Bond, George Danezis, Sergei Skorobogatov, Hyun-Jin Choi, Richard Clayton, Jolyon Clulow, Feng Hao, Andy Ozment, Tyler Moore, Shishir Nagaraja, Robert Watson, Hyounghick Kim, Shailendra Fuloria, Joe Bonneau, Wei-Ming Khoo, Rubin Xu, Kumar Sharad, Laurent Simon, Dongting Yu, Shehar Bano, Khaled Baqer, Alexander Vetterl, Mansoor Ahmed and Ilia Shumailov).

I have started four conference series (Fast Software Encryption in 1993 [9], Information Hiding [38] in 1996, the Workshop on Economics and Information Security in 2002 and the Workshop on Security and Human Behaviour in 2008), as well as one journal (Computer and Communications Security Reviews). I helped Sophie van der Zee start Decepticon.

I am a special adviser on information security to the risk committee of the board of Infosys. Other consultancy clients over the last twenty years include Raspberry Pi, RealVNC, Alcatel-Lucent, Qualcomm, Samsung, Actel, Securicor, Lehman Brothers, Kudelski, Matsushita, Microsoft, Intel, VISA, the UK Department of Transport, the British and Icelandic Medical Associations, the Government of Singapore and the Electricity Supply Commission of South Africa. Many of these assignments led to research papers.

## 2 Teaching and other activities

My teaching responsibilities at Cambridge have covered those areas of the curriculum that have to do with the dependability of computer systems. My lecture courses in 2022–23 are in Software and Security Engineering (for first-year undergraduates), on Computer Security and on Cybercrime (both MPhil). I've served on numerous commit-

tees having been elected to the University's governing body, Council, for 2003–2006, 2007–10, and 2015–18.

Since February 2021 I have also been appointed to a chair at Edinburgh one day per week. In 2021–22 I taught a new masters-level course in Security Engineering which continues in 2022–23.

### **3 Work history**

**2021–present:** Edinburgh University School of Informatics. Professor of Security Engineering.

**1992–present:** Cambridge University Computer Laboratory. Professor of Security Engineering since October 2003; Reader in Security Engineering 2000–3; University Lecturer 1995–2000; Senior Research Associate 1995; research student 1992–4.

**2011:** Visiting scientist, Google; visiting professor, CMU

**1984–1991:** Self employed consultant working mostly in projects related to computer security.

**1981–83:** worked on multilingual typesetting

**1979–80:** gap-year travel in Europe, Africa, and the Middle East

**1974–5:** worked for Ferranti as a development engineer on inertial navigation

### **4 Education, qualifications and awards**

**2022:** Doctor Honoris Causa, Masaryk University, Brno

**2021:** Kristian Beckman award, IFIP

**2016:** Lovelace medal (the top UK award in computing)

**2016:** Electronic Frontier Foundation Pioneer Award

**2015:** ACM SIGSAC Outstanding Innovation Award

**2012:** Louis D. Brandeis Privacy Award

**2009:** Fellow, Royal Society

**2009:** Fellow, Royal Academy of Engineering

**2009:** Fellow, Institute of Physics

**2000:** Fellow, IEE (now IET)

**1995:** PhD, University of Cambridge

**1994:** Member, IEE; Chartered Engineer

**1993:** Fellow, IMA; Chartered Mathematician

**1987:** Member, Institute of Bankers (lapsed)

**1974–8:** BA, Trinity College, Cambridge; part II Mathematics, part II History and Philosophy of Science (converted to MA, 1982)

**1976:** CEI part II in computer engineering; AMIEE

**1973:** Higher grade maths, physics, chemistry, biology, geography, english, french, german, latin; High School of Glasgow

## 5 Appointments and editorships

**Foundation for Information Policy Research, Chair,** since 1998; <http://www.fipr.org>

**Chair:** Workshop on Security and Human Behaviour 2008–2010 and 2013–4, 2017 and 2020–21; Workshop on Economics and Information Security, 2002 and 2006; Computer Security Applications Conference (European Co-Chair), 2000 and 2001; Eurocrypt 99 (rump session); Scrambling for Safety, 1998; Workshop on Personal Information, Isaac Newton Institute, Cambridge, June 1996 [38]; Workshop on Information Hiding, Isaac Newton Institute, Cambridge, May-June 1996 [39]; Workshop on Fast Software Encryption, Cambridge, December 1993 [9]

**Program Committee Member:** Usenix Security 2023; SaTML 23; Workshop on Economics and Information Security, 2002–23; SHB 2008–23; Financial Cryptography 2009–2021; GameSec 2012–6; Decepticon 2015; WISCS 2015; ACM CCS 2014; USEC 2014; SOUPS 2006, 2011 and 2013; NDSS 2012; Laser 2012; Information Hiding 1996–2012; FOCI 2011; ACM Electronic Commerce 2000, 2004, 2006 and 2010; Oakland (IEEE Computer Society Symposium on Security and Privacy), 1994–5, 2002 and 2009; ESORICS 2002, 2005 and 2007; ESCAR 2005–7; USEC 2007; Workshop on the Economics of Securing the Information Infrastructure 2006; CHES 2001, 2003 and 2005; SIGCOMM 2003; Fast Software Encryption 1993–2007; IPT-PWS 2002; RSA 2001; ACISP 2001; Asiacypt 1996 and 2000; ICICS 99; EICAR 99; Usenix Electronic Commerce 96–8; Mednet 97; Crypto 95; Cryptography Policy and Algorithms 95; Cardis 94.

**World Economic Forum:** Member, Global Agenda Council on the Future of the Internet (2008–2012)

**Visiting Professor:** CMU Cylab; 2011; Rukmini Gopalakrishnan Chair, India Institute of Science, 2009; UC Berkeley, 2001–2; MIT, 2002; Queensland University of Technology, July 1995

**Distinguished / Keynote / Invited Speaker:** Cybersecurity@CEPS Summit 2022; Digitalize 2022; LangSec 22; DLD Summer 22; ICISC 2022; USEC 2022; IFIP SEC 2021; ACNS 2021; MIT Dertouzos Lecture, 2021; Remote Chaos Experience 2020; Chaos Communications Congress 2019; Safecomp 2019; 2018; Information Hiding 2018; CCS Asia 2017; ACM CCS 2016; Royal Institute of Navigation 2016; EISIC 2015; Information Security for the Public Sector, Stockholm 2015; Crossing 2015; eHelse 2015; Sackler Forum 2014; Black Hat 2014; Cathie Marsh Lecture, Royal Statistical Society, 2014; Annual Privacy Lecture, Berkeley Law School 2014; Financial Crypto 2014; ESSoS 2014; DIVMA 2014; Technion 2013; NADPO 2013; EST 2013; USEC/WESCSR 2012; ACSAC 2012; Amsterdam Privacy Conference 2012; Obradoiro de Criptografia, Privacidade e seguridade 2012; Payment Systems Economics 2012; Indocrypt 2011; Govcert 2011; ETAPS 2011; ESORICS 2011; AusCERT



2011; CMU Cylab 2011; DHS/SRI ITTC 2011; OII 2011; Visions of Computer Science, Academy of Computer Science, Edinburgh 2010; Plenary lecture, Federal Reserve Conference on the Economics of Payments, 2010; IET Prestige Lecture, 2010; Centenary lecture, India Institute of Science, Bangalore, 2009; OWASP 2009; De Montfort STRL Annual Distinguished Seminar 2009; Wisec 2009; UK Unix User Group 2009; International Symposium on Resilient Control Systems 2009; SCADA Security Scientific Symposium 2009; ITU Telecom World 2009; SOUPS 2008; DEON'08; All Hands e-Science Conference 2008; TTeC (Tromso Telemedicine and e-Health Conference) 2008; Gartner IT Security Summit 2008; Crypto 2007; IFIP SEC 2007; Federal Reserve Santa Fe Conference 2007; IDC Security Conference 2007; Softint 2007; University of Edinburgh 2006; Science, Technology and Society 2006; EMIS NUG 2006; Networkshop 2006; University of Washington 2005; ISSE 2005; Science and Society 2005; Body Sensor Networks 2005; 3rd DRM Conference, 2005; IST 2004; Wizards of OS 2004; NITES 2004; Principles of Distributed Computing, 2003; J. Barkley Rosser Memorial Lecture, University of Wisconsin, 2002; IFIP 2002; Economics of Open Source Software, 2002; Symposium on Operating System Principles, 2001; CHES 2001; MIT Distinguished Lecture Series, 2000; Carnegie Mellon University, 1999; Applications Security, 1999; Symposium für Datenschutz und Datensicherheit, 1998; ACM Conference on Computer and Communications Security, 1997; Royal Dutch Medical Association, 1997; HealthCare 96; Securicom 1995; and the Cryptography Policy and Algorithms Conference, Brisbane, 1995. Invited seminar talks include ETH Zürich and the Universities of Michigan, Frankfurt, Århus, Twente, York and Newcastle; the National Physical Laboratory; the Centrum voor Wiskunde en Informatik, Amsterdam; SRI, California; Microsoft Inc., Seattle; Dansk Dataforening, Copenhagen; and the Ecole Normale Supérieure, Paris.

**Royal Society Committees:** sectional committee 4, 2012–5

**House of Commons:** Special adviser to the Health Committee Inquiry into the Electronic Patient Record, 2007

**Isaac Newton Institute:** *Principal Organiser*, research programme on Computer Security, Cryptology and Coding Theory, January – June 1996

**Computer and Communications Security Reviews, Editor-in-Chief, 1998-9; Editor, 1992-98.** I founded this in 1992 and sold it in 1998

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