Curriculum Vitae – Ross Anderson

I am Professor of Security Engineering at the Computer Laboratory at Cambridge University, and a Fellow of Churchill College. 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.

The focus of my work in academia has been building security engineering into a discipline. Twenty-five years ago, some tractable parts of it – cryptography, protocols and operating system security – had well-developed 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.

Over the last quarter century I've started research programs in neglected areas, ranging from hardware security to the uses of signal processing. I've worked on interesting new applications from ATMs through digital tachographs to online medical records, which have failure modes from which engineers can learn. I've developed security economics as a discipline: very often systems fail not because of some technical mistake but because of misaligned incentives. For example, the people guarding a system are often not the people who suffer when it fails. This work is now spreading into the behavioural economics and psychology of security. I wrote a book, *'Security Engineering – A Guide to Building Dependable Distributed Systems'* [88, 157], which is now the standard reference. Along the way I've contributed to the design of a number of widely-deployed systems, from peer-to-peer systems through the STS specification for prepayment utility meters (with 400 million installed) to the HomePlug standard for power-line communications (widely used to extend wifi). This work has been recognised by the Lovelace Medal, the UK's top award in computing.

Security engineering is now merging with safety engineering, and is becoming essential to the next generation of cars, medical devices, railway signals and much else. And as we start doing regular security patches for durable goods, security will become a larger part of the total lifecycle cost; Mercedes can't just refuse to patch the products they sold five years ago the way that Google or Microsoft can. And as crime has moved online, and AI takes more and more decisions that matter to us, security is moving steadily up the political agenda – along with privacy, surveillance and competition policy.

Although I'm on sabbatical for 2019, my regular duties include teaching security and software engineering, and graduate courses in security. I am also the Principal Investigator of the Cambridge Cybercrime Centre which collects and curates data on spam, phish, malware and other online wickedness for use by researchers worldwide.

Ross Anderson FRS FREng
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1 Research

1.1 Economics and security

If Alice guards a system but Bob pays the cost of failure, you can expect trouble. This observation led me to work on establishing security economics as an academic discipline. We now know that many real problems can be best explained using the language of microeconomics: network externalities, asymmetric information, moral hazard, adverse selection, liability games and the tragedy of the commons. Although I did some early work in 1993-4 [10, 12], the field took off since I wrote about it in 2001, in a paper [90] and in my textbook [88]. Further papers followed [94, 101, 103, 105, 106]; for surveys, see [134, 145, 171] and [188]. My most important recent work may have been major studies for the European Commission of the security economics of cybercrime [154, 160], the resilience of the Internet [187] and what happens to safety regulation once there's software in everything [245, 246]; and a major study of the costs of cybercrime that was originally commissioned by the UK Ministry of Defence [196]. I have other papers on online crime [176], attitudes to online crime [216], the security economics of critical national infrastructure [170, 175] and surveillance [215], and the ways in which financial regulators are missing the risks with bitcoin [255]. I'm Principal Investigator for the Cambridge Cybercrime Centre, which collects large quantities of data on maleware, spam, phish and other online bad things as raw material for researchers doing econometric and criminological work; two dozen researchers in ten universities across six countries now work with our data. A new topic is the engineering and incentives necessary to maintain the software in durable safety-critical goods like cars and medical devices [245, 246, 250]. This in turn has led to work on more sustainable toolchains [252]. Another long-term project is to grow security economics out through behavioural economics into psychology [179, 188, 192, 193, 210, 216, 217, 219, 220, 228, 230, 234, 253].

1.2 Peer-to-Peer systems and networks

Since 2000, there has been an explosion of interest in peer-to-peer networking – building useful systems out of intermittently connected machines, with virtual infrastructures tailored to the application. I wrote one of the seminal papers, on The Eternity Service [35]. My ideas were taken up by Freenet, Gnutella, Publius, Kazaa and others. We also developed mechanisms for authenticating distributed content using hash trees and chains [58, 62]. Further papers include [70, 71, 76, 82, 84, 105, 106, 108, 121, 228]. I designed the key-management protocols for HomePlug, now deployed in millions of consumer electronic devices [128, 138]. We also looked at social networks where we've discovered all sorts of privacy problems [161, 168].

In a related thread of work, we 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 a number of metrics and other analysis techiques for both static and dynamic networks [118, 121, 144, 155, 148, 202, 190, 191, 206].

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 applied this principle to computer security by studying the failure modes of a number of important distributed systems including ATM and bank card systems [10, 12, 17, 113, 120, 142, 125, 139, 143, 153, 159, 165, 177, 180, 181, 192, 195, 201, 202, 212, 218, 224, 230, 231, 236], prepayment electricity meters [18, 30], medical record systems [23, 29, 61, 68, 69, 129, 136, 151, 221] and digital tachographs [56]. This work follows our laboratory's maxim that 'good research comes from real problems'. It has led to a number of papers in which I try to distil the essence of good security design [6, 14, 16, 21, 25, 31, 36, 47]. One high-impact 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 tackled smart grids and smart meters [170, 175, 182, 184, 203]. Recently we've been looking at security vulnerabilities in mobile phones [209, 225, 226, 233], at ways of extending mobile payments offline [232, 244], and at protecting data about wildlife from poachers [256]. Our most recent topic is adversarial machine learning [257, 259, 261].

1.4 Cryptographic protocols and APIs

Many of the most interesting technical attacks on security systems fall under the general heading of protocol failure. This includes design flaws in which the wrong things are encrypted, or the right things are encrypted in the wrong way; such flaws are common in practice but rather hard to spot. 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, 232], 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, 242].

Perhaps my biggest innovation was API attacks, which extend protocol analysis to the application programming interfaces of cryptographic processors. These devices typically have from dozens of transactions that can be performed using internally protected keys; most of the devices we've looked at could be broken by issuing a suitably chosen sequence of transactions. I initiated this field of research with [80]; further papers can be found at [89, 102, 142, 125, 126] and a survey at [122]. Our work forced many manufacturers to redesign products.

1.5 Hardware reverse engineering

In 1996, we demolished a popular belief in the tamper-resistance of smartcards: our initial paper on attack techniques [37] opened up the field. Later work on this topic can

be found in [41, 122], while in [95, 97] we opened up the new field of semi-invasive semiconductor testing in which laser probing is used to induce revealing faults in semiconductors and to read out memory contents by inducing photocurrents – enabling us to bypass the circuits supplied by the chip vendor for that purpose. We investigated whether we could make CPUs much less vulnerable using self-timed dual-rail logic with inbuilt alarm circuitry [86, 92, 98] (you can but it's too fragile to commonly used fabrication toolchains). We've shown that the supposed tamper-resistance of common PIN Entry Devices is unsatisfactory [153, 201]. We've also shown that you can recast decompilation as a search problem [208], which facilitates the analysis of large malware families that differ from each other by small tweaks. We're now applying this know-how to the many versions of IoT botnets and to firmware recovered by my postdocs Sergei Skorobogatov and Franck Courbon from chips using a scanning electron microscope.

1.6 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]. I returned to the subject again in the early 1990s [7, 15, 19]; this, plus some work on hash functions [11, 26] led me to find ways to construct 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.

1.7 Signal processing and security

In the late 1990s, I spent some time applying signal processing ideas to computer security. The most novel development was 'Soft Tempest'. It had previously been believed that Tempest protection (preventing opponents from reconstructing information from stray RF emanations from computers) necessarily involved hardware techniques such as metal shielding. We showed that substantial protection can be given using software [51, 75]. We also got interested in digital copyright watermarking in 1995 and within a few years we broke essentially all the existing copyright marking schemes [50]. The 'Stirmark' software we wrote became the industry standard for testing marking systems [72] (see also [32, 42, 49, 55], and our survey paper [73]).

1.8 Odds and ends

The main lesson learned from studying real security systems was that most real life failures resulted from the opportunistic exploitation of bugs and blunders. This motivated the study of design assurance. My first paper on the subject provided a rigorous explanation, under quite general assumptions, of why the growth in reliability of large systems in response to testing is often as poor as can possibly be: a software engineer's

version of 'Murphy's Law' [74]; this means that testing should be parallelised as much as possible. I conducted an experiment which shows that the same applies in large part to requirements engineering [77]. The most controversial result is a proof that, under standard assumptions, open source and proprietary systems are security equivalent – in the sense that opening up the design helps the attacker and the defender to exactly the same extent [96].

Like many cryptographers, I am a sceptic about quantum computing and quantum cryptography, which have failed to deliver the goods despite enormous funding. Many of the claims made on behalf of future quantum systems hinge on a particular interpretation of the Bell tests; I have been working with a physicist colleague to show that this is not the only one [204, 207, 211, 222]. Our work raises hard questions about the security proofs offered for quantum cryptosystems based on entanglement.

1.9 Policy

With the Snowden revelations, the world of information security has lost its innocence, as physics did in 1945. But this was just the latest incident in a long process, as states, citizens, businesses and spooks have tussled for control in cyberspace. The 1990s saw the 'Crypto wars'. The Clinton government claimed that they needed to control cryptography; I was an author of the most influential and widely cited paper rebutting this claim [44]. I was also the first to point out that it was not a straight fight between crypto and state surveillance, as most privacy compromises come from the abuse of authorised access and most of the rest from metadata [22] (for further writings on crypto policy, see [43, 48, 53, 65, 87, 130, 131, 132, 133, 140, 172, 173]). In 2014, crypto controls were brought back on the agenda by UK Prime Minister David Cameron and FBI Director James Comey; we updated our classic paper to demonstrate that the arguments against government-mandated exceptional access to systems are as strong as ever [229].

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.

The FAQ I wrote on'Trusted Computing' [100, 101] together with my economic analysis [103] helped kill the project. I coauthored a copyright policy document adopted by many European NGOs [110] wrote many other NGO submissions on policy [130, 131, 132, 133, 140, 141, 150, 152, 172, 173, 197, 198, 198]. I was on the UK Government Chief Scientific Adviser's Blackett Review of Cyber Security, which led in 2011 to an extra £640m being spent on cyber security over the period 2011–5. I was one of the authors of the Nuffield Bioethics Council's recent report on biodata [221].

Other high-impact policy works include a report commissioned by the Chief Scientific Adviser at the Ministry of Defence on the costs of cybercrime [196]; a report for the Information Commissioner on children's databases [135]; a report published by the Joseph Rowntree Reform Trust entitled *'Database State'* on the safety, privacy and legality of large UK public-sector databases [166]; a study of the security economics and policy options in cybercrime [154]; and a study of the resilience of the Internet [187]. The 'Database State' report was adopted by both Conservative and Liberal Democrat

parties before the 2010 election, which they won – leading to the abandonment of the ContactPoint and eCAF children's databases.

The hot topic since 2017 is our report on what happens to safety regulation in a world full of Internet-connected things [245, 246, 250]. I've also worked on tracing stolen bitcoin237,240,246 and what our tracing tools tell us about the failures of financial regulation.

1.10 Research mentoring and management

I am currently supervising three research students (Alexander Vetterl, Mansoor Ahmed and Ilia Shumailov). I have six postdocs (Richard Clayton, Franck Courbon, Sergei Skorobogatov, Daniel Thomas, Ben Collier and Maria Bada) with two more starting this term. Four former students are full professors (George Danezis at UCL, Frank Stajano at Cambridge, Jeff Yan at Linnköping and Feng Hao at Warwick); two former students lecture here (Markus Kuhn, and Robert Watson) along with one former postdoc (Alice Hutchings); while Shishir Nagaraja teaches at Strathclyde, Steven Murdoch at UCL, Tyler Moore at Tulsa, Harry Manifavas in Dubai, Hyoungshick Kim in Korea and Susan Pancho in the Phillipines. Twenty-nine of my former research students have earned PhDs (Jong-Hyeon Lee, Fabien Petitcolas, Frank Stajano, Harry Manifavas, Markus Kuhn, Ulrich Lang, Jianxin 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, Hyoungshick Kim, Shailendra Fuloria, Joe Bonneau, Wei-Ming Khoo, Rubin Xu, Kumar Sharad, Laurent Simon, Dongting Yu, Sheharbano Khattak and Khaled Baqer).

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.

Current direct research funding sources include Thales, EPSRC and the Bosch Foundation.

Consultancy clients over the last twenty years include Infosys, 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 cover those areas of the curriculum which have to do with the dependability of computer systems. I'm on sabbatical in 2019; my lecture courses in 2017–8 were in software and security engineering (for part Ia), economics, law and ethics (for part Ib), and security (two courses for the MPhil).

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

3 Work history

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. The project which had the greatest impact was probably the design of protocols for a smartcard payment system [45].

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

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 and 2017; Security of Internet of Things 2012 (program co-chair); 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: Workshop on Economics and Information Security, 2002–19; SHB 2008–19; Financial Cryptography 2009–2019; 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; IPTPWS 2002; RSA 2001; ACISP 2001; Asiacrypt 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: Usenix Security 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; ESORICS 2011; AusCERT 2011; CMU Cylab 2011; DHS/SRI ITTC 2011; OII 2011; Visions of Computer Science (launch of the 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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[18] "Cryptographic Credit Control in Prepayment Metering Systems" (with SJ Bezuidenhout), in *Proceedings of the 1995 IEEE Symposium on Security and Privacy* pp 15–23

[19] "On Fibonacci Keystream Generators", in *'Fast Software Encryption'* (1994), Springer LNCS vol 1008 pp 346–352

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[21] "Programming Satan's Computer" (with RM Needham) in *'Computer Science Today'*, commemorative issue of Springer Lecture Notes in Computer Science (vol 1000, 1995) pp 426–441

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[27] "Two Practical and Provably Secure Block Ciphers: BEAR and LION", (with E Biham) in *'Fast Software Encryption'* (1996), Springer LNCS vol 1039 pp 113–120

[28] "NetCard - A Practical Electronic Cash Scheme" (with C Manifavas and C Sutherland), in *Security Protocols* (1996), Springer LNCS vol 1189 pp 49–57

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[30] "On the Reliability of Electronic Payment Systems", (with SJ Beduidenhoudt) in *IEEE Transactions on Software Engineering* vol 22 no 5 (May 1996) pp 294–301

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[37] "Tamper Resistance – a Cautionary Note" (with MG Kuhn), in *Proceedings of the Second Usenix Workshop on Electronic Commerce* (Nov 96) pp 1–11 *best paper award*

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[39] *'Personal Medical Information – Security, Engineering and Ethics'*, June 21–22 1996; sponsored by the BMA and the Isaac Newton Institute; proceedings published by Springer in July 1997 as ISBN 3-540-63244-1 (*editor*)

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[51] "Soft Tempest: Hidden Data Transmission Using Electromagnetic Emanations", (with MG Kuhn) in *Proceedings of the Second International Workshop on Information Hiding* (Portland, Apr 98), Springer LNCS vol 1525 pp 126–143

[52] "The Steganographic File System" (with RM Needham and A Shamir), in *Proceedings of the Second International Workshop on Information Hiding* (Portland, Apr 98) Springer LNCS vol 1525 pp 74–84

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