**Chapter 3**

**Psychology and Usability**

**Humans are incapable of securely storing high-quality**

**cryptographic keys, and they have unacceptable speed and accuracy**

**when performing cryptographic operations. (They are also large,**

**expensive to maintain, difficult to manage, and they pollute the**  
 **environment. It is astonishing that these devices continue to be**

**manufactured and deployed. But they are sufficiently pervasive that**

**we must design our protocols around their limitations.)**

– KAUFMANN, PERLMAN AND SPECINER [1025]

**Only amateurs attack machines; professionals target people.**

– BRUCE SCHNEIER

**Metternich told lies all the time, and never deceived any one;**

**Talleyrand never told a lie and deceived the whole world.**

– THOMAS MACAULAY

**3.1** **Introduction**

Many real attacks exploit psychology at least as much as technology. We saw in  
 the last chapter how some online crimes involve the manipulation of angry mobs,  
 while both property crimes and espionage make heavy use of *phishing*, in which  
 victims are lured by an email to log on to a website that appears genuine but  
 that’s actually designed to steal their passwords or get them to install malware.

Online frauds like phishing are often easier to do, and harder to stop, than

similar real-world frauds because many online protection mechanisms are neither  
 as easy to use nor as difficult to forge as their real-world equivalents. It’s much  
 easier for crooks to create a bogus bank website that passes casual inspection  
 than to build an actual bogus bank branch in a shopping street.

We’ve evolved social and psychological tools over millions of years to help

us deal with deception in face-to-face contexts, but these are less effective when  
 we get an email that asks us to do something. For an ideal technology, good use

75

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

would be easier than bad use. We have many examples in the physical world: a  
 potato peeler is easier to use for peeling potatoes than a knife is, but a lot harder  
 to use for murder. But we’ve not always got this right for computer systems yet.  
 Much of the asymmetry between good and bad on which we rely in our daily  
 business doesn’t just depend on formal exchanges – which can be automated  
 easily – but on some combination of physical objects, judgment of people, and  
 the supporting social protocols. So, as our relationships with employers, banks  
 and government become more formalised via online communication, and we lose  
 both physical and human context, the forgery of these communications becomes  
 more of a risk.

Deception, of various kinds, is now the principal mechanism used to defeat

online security. It can be used to get passwords, to compromise conﬁdential  
 information or to manipulate ﬁnancial transactions directly. Hoaxes and frauds  
 have always happened, but the Internet makes some of them easier, and lets  
 others be repackaged in ways that may bypass our existing controls (be they  
 personal intuitions, company procedures or even laws).

Another driver for the surge in attacks based on social engineering is that

people are getting better at technology. As designers learn how to forestall the  
 easier technical attacks, psychological manipulation of system users or opera-  
 tors becomes ever more attractive. So the security engineer absolutely must  
 understand basic psychology, as a prerequisite for dealing competently with ev-  
 erything from passwords to CAPTCHAs and from phishing to social engineering  
 in general; a working appreciation of risk misperception and scaremongering is  
 also necessary to understand the mechanisms underlying angry online mobs and  
 the societal response to emergencies from terrorism to pandemic disease. So just  
 as research in security economics led to a real shift in perspective between the  
 ﬁrst and second editions of this book, research in security psychology has made  
 much of the difference to how we view the world between the second edition and  
 this one.

In the rest of this chapter, I’ll ﬁrst survey relevant research in psychology,

then work through how we apply the principles to make password authentication  
 mechanisms more robust against attack, to security usability more generally, and  
 beyond that to good design.

**3.2** **Insights from psychology research**

Psychology is a huge subject, ranging from neuroscience through to clinical top-  
 ics, and spilling over into cognate disciplines from philosophy through artiﬁcial  
 intelligence to sociology. Although it has been studied for much longer than  
 computer science, our understanding of the mind is much less complete: the  
 brain is so much more complex. There’s one central problem – the nature of  
 consciousness – that we just don’t understand at all. We know that ‘the mind  
 is what the brain does’, yet the mechanisms that underlie our sense of self and  
 of personal history remain obscure.

Nonetheless a huge amount is known about the functioning of the mind

and the brain, and we’re learning interesting new things all the time. In what

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 76 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

follows I can only offer a helicopter tour of three of the themes in psychology  
 research that are very relevant to our trade: cognitive psychology, which studies  
 topics such as how we remember and what sort of mistakes we make; social  
 psychology, which deals with how we relate to others in groups and to authority;  
 and behavioral economics, which studies the heuristics and biases that lead us  
 to make decisions that are consistently irrational in measurable and exploitable  
 ways.

**3.2.1** **Cognitive psychology**

Cognitive psychology is the classical approach to the subject – building on early  
 empirical work in the nineteenth century. It deals with how we think, remember,  
 make decisions and even daydream. Twentieth-century pioneers such as Ulric  
 Neisser discovered that human memory doesn’t work like a video recorder: our  
 memories are stored in networks across the brain, from which they are recon-  
 structed, so they change over time and can be manipulated [1427]. There are  
 many well-known results. For example, it’s easier to memorise things that are  
 repeated frequently, and it’s easier to store things in context. Many of these  
 insights are used by marketers and scammers, but misunderstood or just ignored  
 by most system developers.

For example, most of us have heard of George Miller’s result that human

short-term memory can cope with about seven (plus or minus two) simultaneous  
 choices [1317] and, as a result, many designers limit menu choices to about ﬁve.  
 But this is not the right conclusion. People search for information ﬁrst by

recalling where to look, and then by scanning; once you’ve found the relevant  
 menu, scanning ten items is only twice as hard as scanning ﬁve. The real

limits on menu size are screen size, which might give you ten choices, and with  
 spoken menus, where the average user has difficulty dealing with more than three  
 or four [1544]. Here, too, Miller’s insight is misused because spatio-structural  
 memory is a different faculty from echoic memory. This illustrates why a broad  
 idea like 7+/-2 can be hazardous; you need to look at the detail.

In recent years, the centre of gravity in this ﬁeld has been shifting from

applied cognitive psychology to the human-computer interaction (HCI) research  
 community, because of the huge amount of empirical know-how gained not just  
 from lab experiments, but from the iterative improvement of ﬁelded systems.  
 As a result, HCI researchers not only model and measure human performance,  
 including perception, motor control, memory and problem-solving; they have  
 also developed an understanding of how users’ mental models of systems work,  
 how they differ from developers’ mental models, and of the techniques (such as  
 task analysis and cognitive walkthrough) that we can use to explore how people  
 learn to use and understand systems.

Security researchers need to ﬁnd ways of turning these ploughshares into

swords (the bad guys are already working on it). There are some low-hanging  
 fruit; for example, the safety research community has put a lot of effort into  
 studying the errors people make when operating equipment [1589]. It’s said  
 that ‘to err is human’ and error research conﬁrms this: the predictable varieties  
 of human error are rooted in the very nature of cognition. The schemata, or  
 mental models, that enable us to recognise people, sounds and concepts so

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 77 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

much better than computers, also make us vulnerable when the wrong model  
 gets activated.

Human errors made while operating equipment fall into broadly three cat-

egories, depending on where they occur in the ‘stack’: slips and lapses at the  
 level of skill, mistakes at the level of rules, and misconceptions at the cognitive  
 level.

*•* Actions performed often become a matter of skill, but we can slip when  
 can also have a lapse where we use the wrong skill. For example, when  
 you intend to go to the supermarket on the way home from work you may  
 take the road home by mistake, if that’s what you do most days (this is  
 also known as a *capture error*). Slips are exploited by typosquatters, who  
 register domains similar to popular ones, and harvest people who make  
 typing errors; other attacks exploit the fact that people are trained to  
 click ‘OK’ to pop-up boxes to get their work done. So when designing  
 a system you need to ensure that dangerous actions, such as installing  
 software, require action sequences that are quite different from routine  
 ones. Errors also commonly follow interruptions and perceptual confusion.  
 One example is the *post-completion error*: once they’ve accomplished their  
 immediate goal, people are easily distracted from tidying-up actions. More  
 people leave cards behind in ATMs that give them the money ﬁrst and  
 the card back second.

*•* Actions that people take by following rules are open to errors when they  
 load – can cause people to follow the strongest rule they know, or the  
 most general rule, rather than the best one. Phishermen use many tricks  
 to get people to follow the wrong rule, ranging from using https (be-  
 cause ‘it’s secure’) to starting URLs with the impersonated bank’s name,  
 as www.citibank.secureauthentication.com – for most people, looking  
 for a name is a stronger rule than parsing its position.

*•* The third category of mistakes are those made by people for cognitive  
 that they do, and ignore advice in order to get their work done. The sem-  
 inal paper on security usability, Alma Whitten and Doug Tygar’s “Why  
 Johnny Can’t Encrypt”, demonstrated that the encryption program PGP  
 was simply too hard for most college students to use as they didn’t un-  
 derstand the subtleties of private versus public keys, encryption and sig-  
 natures [2018]. And there’s growing realisation that many security bugs  
 occur because most programmers can’t use security mechanisms either.  
 Both access control mechanisms and security APIs are hard to under-  
 stand and ﬁddly to use; security testing tools are often not much better.  
 Programs often appear to work even when protection mechanisms are used  
 in quite mistaken ways. Engineers then copy code from each other, and  
 from online code-sharing sites, so misconceptions and errors are propa-  
 gated widely [11]. They often know this is bad, but there’s just not the  
 time to do better.

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| --- | --- | --- |
| **Security Engineering** | 78 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

There is some important science behind all this, and here are just two exam-

ples. James Gibson developed the concept of action possibilities or *affordances*:  
 the physical environment may be climbable or fall-off-able or get-under-able for  
 an animal, and similarly a seat is sit-on-able. People have developed great skill  
 at creating environments that induce others to behave in certain ways: we build  
 stairways and doorways, we make objects portable or graspable; we make pens  
 and swords [762]. Often perceptions are made up of affordances, which can be  
 more fundamental than value or meaning. In exactly the same way, we design  
 software artefacts to train and condition our users’ choices, so the affordances  
 of the systems we use can affect how we think in all sorts of ways. We can also  
 design traps for the unwary: an animal that mistakes a pitfall for solid ground  
 is in trouble.

Gibson also came up with the idea of optical ﬂows, further developed by

Christopher Longuet-Higgins [1185]. As our eyes move relative to the environ-  
 ment, the resulting *optical ﬂow ﬁeld* lets us interpret the image, understanding  
 the size, distance and motion of objects in it. There is an elegant mathematical  
 theory of optical parallax, but our eyes deal with it differently: they contain  
 receptions for speciﬁc aspects of this ﬂow ﬁeld which assume that objects in it  
 are rigid, which then enables us to resolve rotational and translational compo-  
 nents. Optical ﬂows enable us to understand the shapes of objects around us,  
 independently of binocular vision. We use them for some critical tasks such as  
 landing an aeroplane and driving a car.

In short, cognitive science gives useful insights into how to design system

interfaces so as to make certain courses of action easy, hard or impossible. It  
 is increasingly tied up with research into computer human interaction. You

can make mistakes more or less likely by making them easy or difficult; in  
 section 28.2.2 I give real examples of usability failures causing serious accidents  
 involving both medical devices and aircraft. Yet security can be even harder  
 than safety if we have a sentient attacker who can provoke exploitable errors.

What can the defender expect attackers to do? They will use errors whose

effect is predictable, such as capture errors; they will exploit perverse affor-  
 dances; they will disrupt the ﬂows on which safe operation relies; and they will  
 look for, or create, exploitable dissonances between users’ mental models of a  
 system and its actual logic. To look for these, you should try a cognitive walk-  
 through aimed at identifying attack points, just as a code walkthough can be  
 used to search for software vulnerabilities. Attackers also learn by experiment  
 and share techniques with each other, and develop tools to look efficiently for  
 known attacks. So it’s important to be aware of the attacks that have already  
 worked. (That’s one of the functions of this book.)

**3.2.2** **Gender, diversity and interpersonal variation**

Many women die because medical tests and technology assume that patients  
 are men, or because engineers use male crash-test dummies when designing  
 cars; protective equipment, from sportswear through stab-vests to spacesuits,  
 gets tailored for men by default [498]. So do we have problems with information  
 systems too? They are designed by men, and young geeky men at that, yet  
 over half their users may be women. This realisation has led to research on

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 79 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

*gender HCI* – on how software should be designed so that women can also use it  
 effectively. Early experiments started from the study of behaviour: experiments  
 showed that women use peripheral vision more, and it duly turned out that  
 larger displays reduce gender bias. Work on American female programmers

suggested that they tinker less than males, but more effectively [202]. But how  
 much is nature, and how much nurture? Societal factors matter, and US women  
 who program appear to be more thoughtful, but lower self-esteem and higher  
 risk-aversion leads them to use fewer features.

Gender has become a controversial topic in psychology research. In the early

2000s, discussion of male aptitude for computer science was sometimes in terms  
 of an analysis by Simon Baron-Cohen which gives people separate scores as  
 systemisers (good at geometry and some kinds of symbolic reasoning) and as  
 empathisers (good at intuiting the emotions of others and social intelligence  
 generally) [176]. Most men score higher at systematising, while most women do  
 better at empathising. The correspondence isn’t exact; a minority of men are  
 better at empathising while a minority of women are better at systematising.  
 Baron-Cohen’s research is in Asperger’s and autism spectrum disorder, which  
 he sees as an extreme form of male brain. This theory gained some traction  
 among geeks who saw an explanation of why we’re often introverted with more  
 aptitude for understanding things than for understanding people. If we’re born  
 that way, it’s not out fault. It also suggests an explanation for why geek couples  
 often have kids on the spectrum.

Might this explain why men are more interested in computer science than

women, with women consistently taking about a sixth of CS places in the USA  
 and the UK? But here, we run into trouble. Women make up a third of CS  
 students in the former communist countries of Poland, Romania and the Baltic  
 states, while numbers in India are close to equal. Male dominance of software  
 is also a fairly recent phenomenon. When I started out in the 1970s, there

were almost as many women programmers as men, and many of the pioneers  
 were women, whether in industry, academia or government. This suggests that  
 the relevant differences are more cultural than genetic or developmental. The  
 argument for a ‘male brain / female brain’ explanation has been progressively  
 undermined by work such as that of Daphna Joel and colleagues who’ve shown  
 by extensive neuroimaging studies that while there are recognisable male and  
 female features in brains, the brains of individuals are a mosaic of both [985].  
 And although these features are visible in imaging, that does not mean they’re  
 all laid down at birth: our brains have a lot of plasticity. As with our muscles the  
 tissues we exercise grow bigger. Perhaps nothing else might have been expected  
 given the variance in gender identity, sexual preference, aggression, empathy  
 and so on that we see all around us.

Other work has shown that gender performance differences are absent in

newborns, and appear round about age 6–7, by which time children have long  
 learned to distinguish gender and adapt to the social cues all around them,  
 which are reinforced in developed countries by a tsunami of blue/pink gendered  
 toys and marketing. (Some believe that women are happier to work in com-  
 puting in India because India escaped the home computer boom in the 1980s  
 and its evolution into gaming.) This is reinforced in later childhood and ado-  
 lescence by gender stereotypes that they internalise as part of their identity;

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 80 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

in cultures where girls aren’t supposed to be good at maths or interested in  
 computers, praise for being ‘good at maths’ can evoke a *stereotype threat* (the  
 fear of conﬁrming a negative stereotype about a group to which one belongs).  
 Perhaps as a result, men react better to personal praise (‘That was really clever  
 of you!’) while women are motivated better by performance praise (‘You must  
 have put in a hell of a lot of effort’). So it may not be surprising that we see a  
 deﬁcit of women in disciplines that praise genius, such as mathematics. What’s  
 more, similar mechanisms appear to underlie the poorer academic performance  
 of ethnic groups who have been sigmatised as non-academic. In short, people  
 are not just born different; we learn to be different, shaped by power, by cul-  
 tural attitudes, by expectations and by opportunities. There are several layers  
 between gene and culture with emergent behaviour, including the cell and the  
 circuit. So if we want more effective interventions in the pipeline from school  
 through university to professional development, we need a better understanding  
 of the underlying neurological and cultural mechanisms. For a survey of this,  
 see Gina Rippon [1605].

Gender matters at many levels of the stack, from what a product should

do through how it does it. For example, should a car be faster or safer? This  
 is entangled with social values. Are men better drivers because they win car  
 races, or are women better drivers because they have fewer insurance claims?  
 Digging down, we ﬁnd gendered and cultural attitudes to risk. In US surveys,  
 risks are judged lower by white people and by men, and on closer study this is  
 because about 30% of white males judge risks to be extremely low. This bias is  
 consistent across a wide range of hazards but is particularly strong for handguns,  
 second-hand cigarette smoke, multiple sexual partners and street drugs. Asian  
 males show similarly low sensitivity to some hazards, such as motor vehicles.  
 White males are more trusting of technology, and less of government [693].

We engineers must of course work with the world as it is, not as it might

be if our education system and indeed our culture had less bias; but we must  
 be alert to the possibility that computer systems discriminate because they are  
 built by men for men, just like cars and spacesuits. For example, Tyler Moore  
 and I did an experiment to see whether anti-phishing advice given by banks to  
 their customers was easier for men to follow than women, and we found that  
 indeed it was [1337]. No-one seems to have done much work on gender and  
 security usability, so there’s an opportunity.

But the problem is much wider. Many systems will continue to be designed

by young ﬁt straight clever men who are white or Asian and may not think  
 hard or at all about the various forms of prejudice and disability that they do  
 not encounter directly. You need to think hard about how you mitigate the  
 effects. It’s not enough to just have your new product tested by a token geek  
 girl on your development team; you have to think also of the less educated  
 and the vulnerable – including older people, children and women ﬂeeing abusive  
 relationships (about which I’ll have more to say later). You really have to think  
 of the whole stack. Diversity matters in corporate governance, market research,  
 product design, software development and testing. If you can’t ﬁx the imbalance  
 in dev, you’d better make it up elsewhere. You need to understand your users;  
 it’s also good to understand how power and culture feed the imbalance.

As many of the factors relevant to group behaviour are of social origin, we

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 81 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

next turn to social psychology.

**3.2.3** **Social psychology**

This attempts to explain how the thoughts, feelings, and behaviour of individu-  
 als are inﬂuenced by the actual, imagined, or implied presence of others. It has  
 many aspects, from the identity that people derive from belonging to groups –  
 whether of gender, tribe, team, profession or even religion – through the self-  
 esteem we get by comparing ourselves with others. The results that put it on  
 the map were three early papers that laid the groundwork for understanding  
 the abuse of authority and its relevance to propaganda, interrogation and ag-  
 gression. They were closely followed by work on the bystander effect which is  
 also highly relevant to crime and security.

**3.2.3.1** **Authority and its abuse**

In 1951, Solomon Asch showed that people could be induced to deny the evidence  
 of their own eyes in order to conform to a group. Subjects judged the lengths of  
 lines after hearing wrong opinions from other group members, who were actually  
 the experimenter’s stooges. Most subjects gave in and conformed, with only 29%  
 resisting the bogus majority [135].

Stanley Milgram was inspired by the 1961 trial of Nazi war criminal Adolf

Eichmann to investigate how many experimental subjects were prepared to ad-  
 minister severe electric shocks to an actor playing the role of a ‘learner’ at the  
 behest of an experimenter while the subject played the role of the ‘teacher’ –  
 even when the ‘learner’ appeared to be in severe pain and begged the subject to  
 stop. This experiment was designed to measure what proportion of people will  
 obey an authority rather than their conscience. Most did – Milgram found that  
 consistently over 60% of subjects would do downright immoral things if they  
 were told to [1312]. This experiment is now controversial but had real inﬂuence  
 on the development of the subject.

The third was the Stanford Prisoner Experiment which showed that normal

people can behave wickedly even in the absence of orders. In 1971, experimenter  
 Philip Zimbardo set up a ‘prison’ at Stanford where 24 students were assigned  
 at random to the roles of 12 warders and 12 inmates. The aim of the experiment  
 was to discover whether prison abuses occurred because warders (and possibly  
 prisoners) were self-selecting. However, the students playing the role of warders  
 rapidly became sadistic authoritarians, and the experiment was halted after six  
 days on ethical grounds [2073]. This experiment is also controversial now and it’s  
 unlikely that a repeat would get ethical approval today. But abuse of authority,  
 whether real or ostensible, is a real issue if you are designing operational security  
 measures for a business.

During the period 1995–2005, a telephone hoaxer calling himself ‘Officer

Scott’ ordered the managers of over 68 US stores and restaurants in 32 US  
 states (including at least 17 McDonald’s stores) to detain some young employee  
 on suspicion of theft and strip-search them. Various other degradations were  
 ordered, including beatings and sexual assaults [2033]. A former prison guard

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 82 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

was tried for impersonating a police officer but acquitted. At least 13 people  
 who obeyed the caller and did searches were charged with crimes, and seven were  
 convicted. McDonald’s got sued for not training its store managers properly,  
 even years after the pattern of hoax calls was established; and in October 2007,  
 a jury ordered them to pay $6.1 million dollars to one of the victims, who had  
 been strip-searched when she was an 18-year-old employee. It was a nasty case,  
 as she was left by the store manager in the custody of her boyfriend, who then  
 committed a further indecent assault on her. The boyfriend got ﬁve years, and  
 the manager pleaded guilty to unlawfully detaining her. McDonald’s argued  
 that she was responsible for whatever damages she suffered for not realizing it  
 was a hoax, and that the store manager had failed to apply common sense. A  
 Kentucky jury didn’t buy this and ordered McDonald’s to pay up. The store  
 manager also sued, claiming to be another victim of the ﬁrm’s negligence to  
 warn her of the hoax, and got $1.1 million [1088]. So US employers now risk  
 heavy damages if they fail to train their staff to resist the abuse of authority.

**3.2.3.2** **The bystander effect**

On March 13, 1964, a young lady called Kitty Genovese was stabbed to death  
 in the street outside her apartment in Queens, New York. The press reported  
 that thirty-eight separate witnesses had failed to help or even to call the police,  
 although the assault lasted almost half an hour. Although these reports were  
 later found to be exaggerated, the crime led to the nationwide 911 emergency  
 number, and also to research on why bystanders often don’t get involved.

John Darley and Bibb Latan´e reported experiments in 1968 on what factors

modulated the probability of a bystander helping someone who appeared to  
 be having an epileptic ﬁt. They found that a lone bystander would help 85%  
 of the time, while someone who thought that four other people could see the  
 victim would help only 31% of the time; group size dominated all other effects.  
 Whether another bystander was male, female or even medically qualiﬁed made  
 essentially no difference [513]. The diffusion of responsibility has visible effects  
 in many other contexts. If you want something done, you’ll email one person  
 to ask, not three people. Of course, security is usually seen as something that  
 other people deal with.

However, if you ever ﬁnd yourself in danger, the real question is whether at

least one of the bystanders will help, and here the recent research is much more  
 positive. Lasse Liebst, Mark Levine and others have surveyed CCTV footage of  
 a number of public conﬂicts in several countries over the last ten years, ﬁnding  
 that in 9 out of 10 cases, one or more bystanders intervened to de-escalate a ﬁght,  
 and that the more bystanders intervene, the more successful they are [1163]. So  
 it would be wrong to assume that bystanders generally pass by on the other  
 side; so the bystander effect’s name is rather misleading.

**3.2.4** **The social-brain theory of deception**

Our second big theme, which also ﬁts into social psychology, is the growing body  
 of research into deception. How does deception work, how can we detect and  
 measure it, and how can we deter it?

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 83 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

The modern approach started in 1976 with the social intelligence hypothe-

sis. Until then, anthropologists had assumed that we evolved larger brains in  
 order to make better tools. But the archaeological evidence doesn’t support  
 this. All through the paleolithic period, while our brains evolved from chimp  
 size to human size, we used the same simple stone axes. They only became more  
 sophisticated in the neolithic period, by which time our ancestors were anatom-  
 ically modern homo sapiens. So why, asked Nick Humphrey, did we evolve large  
 brains if we didn’t need them yet? Inspired by observing the behaviour of both  
 caged and wild primates, his hypothesis was that the primary function of the  
 intellect was social. Our ancestors didn’t evolve bigger brains to make better  
 tools, but to use other primates better as tools [934]. This is now supported  
 by a growing body of evidence, and has transformed psychology as a discipline.  
 Social psychology had been a poor country cousin until then and was not seen  
 as rigorous; since then, people have realised it was probably the driving force of  
 cognitive evolution. Almost all intelligent species developed in a social context.  
 (One exception is the octopus, but even it has to understand how predators and  
 prey react.)

The primatologist Andy Whiten then collected much of the early evidence

on tactical deception, and recast social intelligence as the Machiavellian brain  
 hypothesis: we became smart in order to deceive others, and to detect decep-  
 tion too [360]. Not everyone agrees completely with this characterisation, as  
 the positive aspects of socialisation, such as empathy, also matter. But Hugo  
 Mercier and Dan Sperber have recently collected masses of evidence that the  
 modern human brain is more a machine for arguing than anything else [1294].  
 Our goal is persuasion rather than truth; rhetoric comes ﬁrst, and logic second.

The second thread coming from the social intellect hypothesis is theory of

mind, an idea due to David Premack and Guy Woodruff in 1978 but developed  
 by Heinz Wimmer and Josef Perner in a classic 1983 experiment to determine  
 when children are ﬁrst able to tell that someone has been deceived [2029]. In  
 this experiment, the Sally-Anne test, a child sees a sweet hidden under a cup  
 by Sally while Anne and the child watch. Anne then leaves the room and Sally  
 switches the sweet to be under a different cup. Anne then comes back and the  
 child is asked where Anne thinks the sweet is. Normal children get the right  
 answer from about age ﬁve; this is when they acquire the ability to discern  
 others’ beliefs and intentions. Simon Baron-Cohen, Alan Leslie and Uta Frith  
 then showed that children on the Aspergers / autism spectrum acquire this  
 ability signiﬁcantly later [177].

Many computer scientists and engineers appear to be on the spectrum to

some extent, and we’re generally not as good at deception as neurotypical peo-  
 ple are. This has all sorts of implications! We’re under-represented in politics,  
 among senior executives and in marketing. Oh, and there was a lot less cy-  
 bercrime before underground markets brought together geeks who could write  
 wicked code with crooks and spooks who could use it for wicked purposes. Geeks  
 are also more likely to be whistleblowers; we’re less likely to keep quiet about  
 an uncomfortable truth just to please others, as we place less value on their  
 opinions. But this is a complex ﬁeld. Some well-known online miscreants who  
 are on the spectrum were hapless more than anything else; Gary McKinnon  
 claimed to have hacked the Pentagon to discover the truth about ﬂying saucers

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 84 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

and didn’t anticipate the ferocity of the FBI’s response. And other kinds of  
 empathic deﬁcit are involved in many crimes. Other people with dispositional  
 empathy deﬁcits include psychopaths who disregard the feelings of others but  
 understand them well enough to manipulate them, while there are many people  
 whose deﬁcits are situational, ranging from Nigerian scammers who think that  
 any white person who falls for their lure deserves it as they must be a racist, to  
 soldiers and terrorists who consider their opponents to be less than human or  
 to be morally deserving of death. I’ll discuss radicalisation in more detail later  
 in section 26.4.2.

The third thread is self-deception. Robert Trivers argues that we’ve evolved

the ability to deceive ourselves in order to better deceive others: “If deceit is  
 fundamental in animal communication, then there must be strong selection to  
 spot deception and this ought, in turn, to select for a degree of self-deception,  
 rendering some facts and motives unconscious so as to not betray – by the  
 subtle signs of self-knowledge – the deception being practiced” [904]. We forget  
 inconvenient truths and rationalise things we want to believe. There may well  
 be a range of self-deception abilities from honest geeks through to the great  
 salesmen who have a magic ability to believe completely in their product. But  
 it’s controversial, and at a number of levels. For example, if Tony Blair really  
 believed that Iraq had weapons of mass destruction when he persuaded Britain  
 to go to war in 2003, was it actually a lie? How do you deﬁne sincerity? How  
 can you measure it? And would you even elect a national leader if you expected  
 that they’d be unable to lie to you? There is a lengthy discussion in [904], and  
 the debate is linked to other work on motivated reasoning. Russell Golman,  
 David Hagman and George Loewenstein survey research on how people avoid  
 information, even when it is free and could lead to better decision-making:  
 people at risk of illness avoid medical tests, managers avoid information that  
 might show they made bad decisions, and investors look at their portfolios less  
 when markets are down [781]. This strand of research goes all the way back  
 to Sigmund Freud, who described various aspects of the *denial* of unpleasant  
 information, including the ways in which we try to minimise our feelings of guilt  
 for the bad things we do, and to blame others for them.

It also links up with ﬁlter-bubble effects on social media. People prefer to

listen to others who conﬁrm their beliefs and biases, and this can be analysed  
 in terms of the hedonic value of information. People think of themselves as  
 honest and try to avoid the *ethical dissonance* that results from deviations [172];  
 criminologists use the term *neutralisation* to describe the strategies that rule-  
 breakers use to minimise the guilt that they feel about their actions (there’s an  
 overlap with both ﬁlter effects and self-deception). A further link is to Hugo  
 Mercier and Dan Sperber’s work on the brain as a machine for argument, which  
 I mentioned above.

The fourth thread is intent. The detection of hostile intent was a big deal in

our ancestral evolutionary environment; in pre-state societies, perhaps a quarter  
 of men and boys die of homicide, and further back many of our ancestors were  
 killed by animal predators. So we appear to have evolved a sensitivity to sounds  
 and movements that might signal the intent of a person, an animal or even a god.  
 As a result, we now spend too much on defending against threats that involve  
 hostile intent, such as terrorism, and not enough on defending against against

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 85 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

epidemic disease, which kills many more people, or climate change, which could  
 kill even more.

There are other reasons why we might want to think about intent more

carefully. In cryptography, we use logics of belief to analyse the security of au-  
 thentication protocols, and to deal with statements such as ‘Alice believes that  
 Bob believes that Charlie controls the key *K*’; we’ll come to this in the next  
 chapter. And now we realise that people use theories of mind to understand  
 each other, philosophers have got engaged too. Dan Dennett derived the in-  
 tentional stance in philosophy, arguing that the propositional attitudes we use  
 when reasoning – beliefs, desires and perceptions – come down to the intentions  
 of people and animals.

A related matter is socially-motivated reasoning: people do logic much better

if the problem is set in a social role. In the Wason test, subjects are told they  
 have to inspect some cards with a letter grade on one side, and a numerical code  
 on the other, and given a rule such as “If a student has a grade D on the front  
 of their card, then the back must be marked with code 3”. They are shown four  
 cards displaying (say) D, F, 3 and 7 and then asked “Which cards do you have  
 to turn over to check that all cards are marked correctly?” Most subjects get  
 this wrong; in the original experiment, only 48% of 96 subjects got the right  
 answer of D and 7. However the evolutionary psychologists Leda Cosmides and  
 John Tooby found the same problem becomes easier if the rule is changed to ‘If  
 a person is drinking beer, he must be 20 years old’ and the individuals are a beer  
 drinker, a coke drinker, a 25-year-old and a 16-year old. Now three-quarters of  
 subjects deduce that the bouncer should check the age of the beer drinker and  
 the drink of the 16-year-old [483]. Cosmides and Tooby argue that our ability to  
 do logic and perhaps arithmetic evolved as a means of policing social exchanges.

The next factor is rationalisation or minimsation – the process by which

people justify bad actions or make their harm appear to be less. I mentioned  
 Nigerian scammers who think that white people who fall for their scam must  
 think Africans are stupid, so they deserve it; there are many more examples of  
 scammers seeing foreign targets as fair game. The criminologist Donald Cressey  
 developed a *Fraud Triangle* theory to explain the factors that lead to fraud: as  
 well as motive and opportunity, there must be a rationalisation. People may  
 feel that their employer has underpaid them so it’s justiﬁable to ﬁddle expenses,  
 or that the state is wasting money on welfare when they cheat on their taxes.  
 Minimisation is very common in cybercrime. Kids operating DDoS-for-hire

services reassured each other that offering a ‘web stresser’ service was legal, and  
 said on their websites that the service could only be used for legal purposes. So  
 undermining minimisation can work as a crime-ﬁghting tool. The UK National  
 Crime Agency bought Google ads to ensure that anyone searching for a web  
 stresser service would see an official warning that DDoS was a crime. A mere  
 £3,000 spent between January and June 2018 suppressed demand growth; DDoS  
 revenues remained constant in the UK while they grew in the USA [454].

Finally, the loss of social context is a factor in online disinhibition. People

speak more frankly online, and this has both positive and negative effects. Shy  
 people can ﬁnd partners, but we also see vicious ﬂame wars. John Suler analyses  
 the factors as anonymity, invisibility, asynchronicity and the loss of symbols of  
 authority and status; in addition there are effects relating to psychic boundaries

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 86 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

and self-imagination which lead us to drop our guard and express feelings from  
 affection to aggression that we normally rein in for social reasons [1845].

Where all this leads is that the nature and scale of online deception can be

modulated by suitable interaction design. Nobody is as happy as they appear  
 on Facebook, as attractive as they appear on Instagram or as angry as they  
 appear on Twitter. They let their guard down on closed groups such as those  
 supported by WhatsApp, which offer neither celebrity to inspire performance,  
 nor anonymity to promote trolling. However, people are less critical in closed  
 groups, which makes them more suitable for spreading conspiracy theories, and  
 for radicalisation [523].

**3.2.5** **Heuristics, biases and behavioural economics**

One ﬁeld of psychology that has been applied by security researchers since the  
 mid-2000s has been *decision science*, which sits at the boundary of psychology  
 and economics and studies the heuristics that people use, and the biases that in-  
 ﬂuence them, when making decisions. It is also known as *behavioural economics*,  
 as it examines the ways in which people’s decision processes depart from the  
 rational behaviour modeled by economists. An early pioneer was Herb Simon  
 – both an early computer scientist and a Nobel-prizewinning economist – who  
 noted that classical rationality meant doing whatever maximizes your expected  
 utility regardless of how hard that choice is to compute. So how would people  
 behave in a realistic world of bounded rationality? The real limits to human  
 rationality have been explored extensively in the years since, and Daniel Kah-  
 neman won the Nobel prize in economics in 2002 for his major contributions to  
 this ﬁeld (along with the late Amos Tversky) [1004].

**3.2.5.1** **Prospect theory and risk misperception**

Kahneman and Tversky did extensive experimental work on how people made  
 decisions faced with uncertainty. They ﬁrst developed *prospect theory* which  
 models risk appetite: in many circumstances, people dislike losing $100 they  
 already have more than they value winning $100. Framing an action as avoiding  
 a loss can make people more likely to take it; phishermen hook people by sending  
 messages like ‘Your PayPal account has been frozen, and you need to click here  
 to unlock it.’ We’re also bad at calculating probabilities, and use all sorts of  
 heuristics to help us make decisions:

*•* we often base a judgment on an initial guess or comparison and then adjust

*•* we base inferences on the ease of bringing examples to mind – the *avail-*  
 the wrong answers when mass media bombard us with images of terrorism;

*•* we’re more likely to be sceptical about things we’ve heard than about

*•* we worry too much about events that are very unlikely but have very bad

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| --- | --- | --- |
| **Security Engineering** | 87 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

*•* we’re more likely to believe things we’ve worked out for ourselves rather

Behavioral economics is not just relevant to working out how likely people

are to click on links in phishing emails, but to the much deeper problem of the  
 perception of risk. Many people perceive terrorism to be a much worse threat  
 than epidemic disease, road traffic accidents or even food poisoning: this is  
 wrong, but hardly surprising to a behavioural economist. We overestimate the  
 small risk of dying in a terrorist attack not just because it’s small but because of  
 the visual effect of the 9/11 TV coverage, the ease of remembering the event, the  
 outrage of an enemy attack, and the effort we put into thinking and worrying  
 about it. (There are further factors, which we’ll explore in Part III when we  
 discuss terrorism.)

The misperception of risk underlies many other public-policy problems. The

psychologist Daniel Gilbert, in an article provocatively entitled ‘If only gay sex  
 caused global warming’, compares our fear of terrorism with our fear of climate  
 change. First, we evolved to be much more wary of hostile intent than of nature;  
 100,000 years ago, a man with a club (or a hungry lion) was a much worse threat  
 than a thunderstorm. Second, global warming doesn’t violate anyone’s moral  
 sensibilities; third, it’s a long-term threat rather than a clear and present danger;  
 and fourth, we’re sensitive to rapid changes in the environment rather than slow  
 ones [764]. There are many more risk biases: we are less afraid when we’re in  
 control, such as when driving a car, as opposed to being a passenger in a car  
 or airplane; and we are more afraid of uncertainty, that is, when the magnitude  
 of the risk is unknown (even when it’s small) [1671, 1675]. We also indulge  
 in *satisﬁcing* which means we go for an alternative that’s ‘good enough’ rather  
 than going to the trouble of trying to work out the odds perfectly, especially for  
 small transactions. (The misperception here is not that of the risk taker, but of  
 the economists who ignored the fact that real people include transaction costs  
 in their calculations.)

So, starting out from the folk saying that a bird in the hand is worth two

in the bush, we can develop quite a lot of machinery to help us understand and  
 model people’s attitudes towards risk.

**3.2.5.2** **Present bias and hyperbolic discounting**

Saint Augustine famously prayed ‘Lord, make me chaste, but not yet.’ We

ﬁnd a similar sentiment with applying security updates, where people may pay  
 more attention to the costs as they’re immediate and determinate in time, stor-  
 age and bandwidth, than the unpredictable future beneﬁts. This *present bias*  
 causes many people to decline updates, which was the major source of technical  
 vulnerability online for many years. One way software companies pushed back  
 was by allowing people to delay updates: Windows has ‘restart / pick a time /  
 snooze’. Reminders cut the ignore rate from about 90% to about 34%, and may  
 ultimately double overall compliance [726]. A better design is to make updates  
 so painless that they can be made mandatory, or nearly so; this is the approach  
 now followed by some web browsers, and by cloud-based services generally.

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| --- | --- | --- |
| **Security Engineering** | 88 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

*Hyperbolic discounting* is a model used by decision scientists to quantify

present bias. Intuitive reasoning may lead people to use utility functions that  
 discount the future so deeply that immediate gratiﬁcation seems to be the best  
 course of action, even when it isn’t. Such models have been applied to try to  
 explain the *privacy paradox* – why people say in surveys that they care about  
 privacy but act otherwise online. I discuss this in more detail in section 8.6.6:  
 other factors, such as uncertainty about the risks and about the efficacy of  
 privacy measures, play a part too. Taken together, the immediate and determi-  
 nate positive utility of getting free stuff outweighs the random future costs of  
 disclosing too much personal information, or disclosing it to dubious websites.

**3.2.5.3** **Defaults and nudges**

This leads to the importance of defaults. Many people usually take the easiest  
 path and use the standard conﬁguration of a system, as they assume it will  
 be good enough. In 2009, Richard Thaler and Cass Sunnstein wrote a best-  
 seller *‘Nudge’* exploring this, pointing out that governments can achieve many  
 policy goals without infringing personal liberty simply by setting the right de-  
 faults [1876]. For example, if a ﬁrm’s staff are enrolled in a pension plan by  
 default, most will not bother to opt out, while if it’s optional most will not  
 bother to opt in. A second example is that many more organs are made avail-  
 able for transplant in Spain, where the law lets a dead person’s organs be used  
 unless they objected, than in Britain where donors have to consent actively. A  
 third example is that tax evasion can be cut by having the taxpayer declare that  
 the information in the form is true when they start to ﬁll it out, rather than at  
 the end. The set of choices people have to make, the order in which they make  
 them, and the defaults if they do nothing, are called the *choice architecture*.  
 Sunnstein got a job in the Obama administration implementing some of these  
 ideas while Thaler won the 2017 economics Nobel prize.

Defaults matter in security too, but often they are set by an adversary so

as to trip you up. For example, Facebook defaults to fairly open information  
 sharing, and whenever enough people have ﬁgured out how to increase their  
 privacy settings, the architecture is changed so you have to opt out all over  
 again. This exploits not just hazardous defaults but also the *control paradox* –  
 providing the illusion of control causes people to share more information. We  
 like to feel in control; we feel more comfortable driving in our cars than letting  
 someone else ﬂy us in an airplane – even if the latter is an order of magnitude  
 safer. “Privacy control settings give people more rope to hang themselves,” as  
 behavioral economist George Loewenstein puts it. “Facebook has ﬁgured this  
 out, so they give you incredibly granular controls.” [1533]

**3.2.5.4** **The default to intentionality**

Behavioral economists follow a long tradition in psychology of seeing the mind  
 as composed of interacting rational and emotional components – ‘heart’ and  
 ‘head’, or ‘affective’ and ‘cognitive’ systems. Studies of developmental biology  
 have shown that, from an early age, we have different mental processing systems  
 for social phenomena (such as recognising parents and siblings) and physical

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 89 | Ross Anderson |

*3.2. INSIGHTS FROM PSYCHOLOGY RESEARCH*

phenomena. Paul Bloom argues that the tension between them explains why  
 many people believe that mind and body are basically different [268]. Children  
 try to explain what they see using physics, but when their understanding falls  
 short, they explain phenomena in terms of intentional action. This has survival  
 value to the young, as it disposes them to get advice from parents or other adults  
 about novel natural phenomena. Bloom suggests that it has an interesting side  
 effect: it predisposes humans to believe that body and soul are different, and  
 thus lays the ground for religious belief. This argument may not overwhelm  
 the faithful (who will retort that Bloom simply stumbled across a mechanism  
 created by the Intelligent Designer to cause us to have faith in Him). But it  
 may have relevance for the security engineer.

First, it goes some way to explaining the *fundamental attribution error* –

people often err by trying to explain things from intentionality rather than from  
 context. Second, attempts to curb phishing by teaching users about the gory  
 design details of the Internet – for example, by telling them to parse URLs in  
 emails that seem to come from a bank – will be of limited value once they get  
 bewildered. If the emotional is programmed to take over whenever the rational  
 runs out, then engaging in a war of technical instruction and counter-instruction  
 with the phishermen is unsound, as they’ll be better at it. Safe defaults would  
 be better.

**3.2.5.5** **The affect heuristic**

Nudging people to think in terms of intent rather than of mechanism can exploit  
 the *affect heuristic*, explored by Paul Slovic and colleagues [1787]. The idea is  
 that while the human brain can handle multiple threads of cognitive processing,  
 our emotions remain resolutely single-threaded, and they are even less good at  
 probability theory than the rational part of our brains. So by making emotion  
 salient, a marketer or a fraudster can try to get you to answer questions using  
 emotion rather than reason, and using heuristics rather than calculation. A  
 common trick is to ask an emotional question (whether ‘How many dates did  
 you have last month?’ or even ‘What do you think of President Trump?’) to  
 make people insensitive to probability.

So it should not surprise anyone that porn websites have been used to install

a lot of malware – as have church websites, which are often poorly maintained  
 and easy to hack. Similarly, events that evoke a feeling of dread – from cancer  
 to terrorism – not only scare people more than the naked probabilities justify,  
 but also make those probabilities harder to calculate, and deter people from  
 even making the effort.

Other factors that can reinforce our tendency to explain things by intent

include cognitive overload, where the rational part of the brain simply gets  
 tired. Our capacity for self-control is also liable to fatigue, both physical and  
 mental; some mental arithmetic will increase the probability that we’ll pick up  
 a chocolate rather than an apple. So a bank that builds a busy website may be  
 able to sell more life insurance, but it’s also likely to make its customers more  
 vulnerable to phishing.

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| --- | --- | --- |
| **Security Engineering** | 90 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

**3.2.5.6** **Cognitive dissonance**

Another interesting offshoot of social psychology is cognitive dissonance theory.  
 People are uncomfortable when they hold conﬂicting views; they seek out infor-  
 mation that conﬁrms their existing views of the world and of themselves, and try  
 to reject information that conﬂicts with their views or might undermine their  
 self-esteem. One practical consequence is that people are remarkably able to  
 persist in wrong courses of action in the face of mounting evidence that things  
 have gone wrong [1863]. Admitting to yourself or to others that you were duped  
 can be painful; hustlers know this and exploit it. A security professional should  
 ‘feel the hustle’ – that is, be alert for a situation in which recently established  
 social cues and expectations place you under pressure to ‘just do’ something  
 about which you’d normally have reservations. That’s the time to step back  
 and ask yourself whether you’re being had. But training people to perceive this  
 is hard enough, and getting the average person to break the social ﬂow and say  
 ‘stop!’ is hard. There have been some experiments, for example with training  
 health-service staff to not give out health information on the phone, and train-  
 ing people in women’s self-defence classes to resist demands for extra personal  
 information. The problem with mainstreaming such training is that the money  
 available for it is orders of magnitude less than the marketing budgets of the  
 ﬁrms whose business model is to hustle their customers.

**3.2.5.7** **The risk thermostat**

Some interesting empirical work has been done on how people manage their ex-  
 posure to risk. John Adams studied mandatory seat belt laws, and established  
 that they don’t actually save lives: they just transfer casualties from vehicle  
 occupants to pedestrians and cyclists [20]. Seat belts make drivers feel safer, so  
 they drive faster in order to bring their perceived risk back up to its previous  
 level. He calls this a *risk thermostat* and the model is borne out in other appli-  
 cations too [19]. The lesson is that testing needs to have ecological validity: you  
 need to evaluate the effect of a proposed intervention in as realistic a setting as  
 possible.

**3.3** **Deception in practice**

This takes us from the theory to the practice. Deception often involves an abuse  
 of the techniques developed by *compliance professionals* – those people whose  
 job it is to get other people to do things. While a sales executive might dazzle  
 you with an offer of a ﬁnance plan for a holiday apartment, a police officer might  
 nudge you by their presence to drive more carefully, a park ranger might tell  
 you to extinguish campﬁres carefully and not feed the bears, and a corporate  
 lawyer might threaten you into taking down something from your website.

The behavioural economics pioneer and apostle of ‘nudge’, Dick Thaler,

refers to the selﬁsh use of behavioural economics as ‘sludge’ [1875]. But it’s  
 odd that economists ever thought that the altruistic use of such techniques  
 would ever be more common than the selﬁsh ones. Not only do marketers push

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 91 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

the most proﬁtable option rather than the best value, but they use every other  
 available trick too. Stanford’s Persuasive Technology Lab has been at the fore-  
 front of developing techniques to keep people addicted to their screens, and one  
 of their alumni, ex-Googler Tristan Harris, has become a vocal critic. Sometimes  
 dubbed ‘Silicon valley’s conscience’, he explains how tech earns its money by  
 manipulating not just defaults but choices, and asks how this can be done eth-  
 ically [867]. Phones and other screens present menus and thus control choices,  
 but there’s more to it than that. Two techniques that screens have made main-  
 stream are the casino’s technique of using intermittent variable rewards to create  
 addiction (we check our phones 150 times a day to see if someone has rewarded  
 us with attention) and bottomless message feeds (to keep us consuming even  
 when we aren’t hungry any more). But there are many older techniques that  
 predate computers.

**3.3.1** **The salesman and the scamster**

Deception is the twin brother of marketing, so one starting point is the huge  
 literature about sales techniques. One eminent writer is Robert Cialdini, a

psychology professor who took summer jobs selling everything from used cars  
 to home improvements and life insurance in order to document the tricks of  
 the trade. His book *‘Inﬂuence: science and Practice’* is widely read by sales  
 professionals and describes six main classes of technique used to inﬂuence people  
 and close a sale [424].

These are:

1. Reciprocity: most people feel the need to return favours;

2. Commitment and consistency: people suffer cognitive dissonance if they

feel they’re being inconsistent;

3. Social proof: most people want the approval of others. This means fol-

lowing others in a group of which they’re a member, and the smaller the  
 group the stronger the pressure;

4. Liking: most people want to do what a good-looking or otherwise likeable

person asks;

5. Authority: most people are deferential to authority ﬁgures (recall the

Milgram study mentioned above);

6. Scarcity: we’re afraid of missing out, if something we might want could

suddenly be unavailable.

All of these are psychological phenomena that are the subject of continuing

research. They are also traceable to pressures in our ancestral evolutionary

environment, where food scarcity was a real threat, strangers could be dangerous  
 and group solidarity against them (and in the provision of food and shelter) was  
 vital. All are used repeatedly in the advertising and other messages we encounter  
 constantly.

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| **Security Engineering** | 92 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

Frank Stajano and Paul Wilson built on this foundation to analyse the prin-

ciples behind scams. Wilson researched and appeared in nine seasons of TV  
 programs on the most common scams – ‘The Real Hustle’ – where the scams  
 would be perpetrated on unsuspecting members of the public, who would then  
 be given their money back, debriefed and asked permission for video footage to  
 be used on TV. The know-how from experimenting with several hundred frauds  
 on thousands of marks over several years was distilled into the following seven  
 principles [1820].

1. Distraction – the fraudster gets the mark to concentrate on the wrong

thing. This is at the heart of most magic performances.

2. Social compliance – society trains us not to question people who seem to

have authority, leaving people vulnerable to conmen who pretend to be  
 from their bank or from the police.

3. The herd principle – people let their guard down when everyone around

them appears to share the same risks. This is a mainstay of the three-card  
 trick, and a growing number of scams on social networks.

4. Dishonesty – if the mark is doing something dodgy, they’re less likely to

complain. Many are attracted by the idea that ‘you’re getting a good

deal because it’s illegal’, and whole scam families – such as the resale of  
 fraudulently obtained plane tickets – turn on this.

5. Kindness – this is the ﬂip side of dishonesty, and an adaptation of Cialdini’s

principle of reciprocity. Many social engineering scams rely on the victims’  
 helpfulness, from tailgating into a building to phoning up with a sob story  
 to ask for a password reset.

6. Need and greed – sales trainers tell us we should ﬁnd what someone really

wants and then show them how to get it. A good fraudster can help the  
 mark dream a dream and use this to milk them.

7. Time pressure – this causes people to act viscerally rather than stopping

to think. Normal marketers use this all the time (‘only 2 seats left at this  
 price’); so do crooks.

The relationship with Cialdini’s principles should be obvious. A cynic might

say that fraud is just a subdivision of marketing; or perhaps that, as marketing  
 becomes ever more aggressive, it comes to look ever more like fraud. When we  
 investigated online accommodation scams we found it hard to code detectors,  
 since many real estate agents use the same techniques. In fact, the fraudsters’  
 behaviour was already well described by Cialdini’s model, except the scamsters  
 added appeals to sympathy, arguments to establish their own credibility, and  
 ways of dealing with objections [2062]. (These are also found elsewhere in the  
 regular marketing literature.)

Oh, and we ﬁnd the same in software, where there’s a blurry dividing line

between illegal malware and just-about-legal ‘Potentially Unwanted Programs’  
 (PUPs) such as browser plugins that replace your ads with different ones. One  
 good distinguisher seems to be technical: malware is distributed by many small

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 93 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

botnets because of the risk of arrest, while PUPs are mostly distributed by  
 one large network [954]. But crooks use regular marketing channels too: Ben  
 Edelman found in 2006 that while 2.73% of companies ranked top in a web  
 search were bad, 4.44% of companies that appeared alongside in the search ads  
 were bad [612]. Bad companies were also more likely to exhibit cheap trust  
 signals, such as TRUSTe privacy certiﬁcates on their websites. Similarly, bogus  
 landlords often send reference letters or even copies of their ID to prospective  
 tenants, something that genuine landlords never do.

And then there are the deceptive marketing practices of ‘legal’ businesses. To

take just one of many studies, a 2019 crawl of 11K shopping websites by Arunesh  
 Mathur and colleagues found 1,818 instances of ‘dark patterns’ – manipulative  
 marketing practices such as hidden subscriptions, hidden costs, pressure selling,  
 sneak-into-basket tactics and forced account opening. Of these at least 183 were  
 clearly deceptive [1242]. What’s more, the bad websites were among the most  
 popular; perhaps a quarter to a third of websites you visit, weighted by traffic,  
 try to hustle you. This constant pressure from scams that lie just short of the  
 threshold for a fraud prosecution has a chilling effect on trust generally. People  
 are less likely to believe security warnings if they are mixed with marketing, or  
 smack of marketing in any way. And we even see some loss of trust in software  
 updates; people say in surveys that they’re less likely to apply a security-plus-  
 features upgrade than a security patch, though the ﬁeld data on upgrades don’t  
 (yet) show any difference [1591].

**3.3.2** **Social engineering**

Hacking systems through the people who operate them is not new. Military and  
 intelligence organisations have always targeted each other’s staff; most of the  
 intelligence successes of the old Soviet Union were of this kind [118]. Private  
 investigation agencies have not been far behind.

Investigative journalists, private detectives and fraudsters developed the

false-pretext phone call into something between an industrial process and an  
 art form in the latter half of the 20th century. An example of the industrial  
 process was how private detectives tracked people in Britain. Given that the  
 country has a National Health Service with which everyone’s registered, the trick  
 was to phone up someone with access to the administrative systems in the area  
 you thought the target was, pretend to be someone else in the health service,  
 and ask. Colleagues of mine did an experiment in England in 1996 where they  
 trained the staff at a local health authority to identify and report such calls1.  
 They detected about 30 false-pretext calls a week, which would scale to 6000  
 a week or 300,000 a year for the whole of Britain. That eventually got sort-of  
 ﬁxed but it took over a decade. The real ﬁx wasn’t the enforcement of privacy  
 law, but that administrators simply stopped answering the phone.

Another old scam from the 20th century is to steal someone’s ATM card and

then phone them up pretending to be from the bank asking whether their card’s  
 been stolen. On hearing that it has, the conman says ‘We thought so. Please

1The story is told in detail in chapter 9 of the second edition of this book, available free

online.

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 94 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

just tell me your PIN now so I can go into the system and cancel your card.’  
 The most rapidly growing recent variety is the ‘authorised push payment’, where  
 the conman again pretends to be from the bank, and persuades the customer  
 to make a transfer to another account, typically by confusing the customer  
 about the bank’s authentication procedures, which most customers ﬁnd rather  
 mysterious anyway2.

As for art form, one of the most disturbing security books ever published is

Kevin Mitnick’s *‘Art of Deception’*. Mitnick, who was arrested and convicted  
 for breaking into US phone systems, related after his release from prison how  
 almost all of his exploits had involved social engineering. His typical hack was  
 to pretend to a phone company employee that he was a colleague, and solicit  
 ‘help’ such as a password. Ways of getting past a company’s switchboard and  
 winning its people’s trust are a staple of sales-training courses, and hackers apply  
 these directly. A harassed system administrator is called once or twice on trivial  
 matters by someone claiming to be the CEO’s personal assistant; once this idea  
 has been accepted, the caller demands a new password for the boss. Mitnick  
 became an expert at using such tricks to defeat company security procedures,  
 and his book recounts a fascinating range of exploits [1325].

Social engineering became world headline news in September 2006 when it

emerged that Hewlett-Packard chairwoman Patricia Dunn had hired private  
 investigators who used pretexting to obtain the phone records of other board  
 members of whom she was suspicious, and of journalists she considered hostile.  
 She was forced to resign. The detectives were convicted of fraudulent wire

communications and sentenced to do community service [138]. In the same

year, the UK privacy authorities prosecuted a private detective agency that did  
 pretexting jobs for top law ﬁrms [1138].

Amid growing publicity about social engineering, there was an audit of the

IRS in 2007 by the Treasury Inspector General for Tax Administration, whose  
 staff called 102 IRS employees at all levels, asked for their user IDs, and told  
 them to change their passwords to a known value; 62 did so. What’s worse,  
 this happened despite similar audit tests in 2001 and 2004 [1673]. Since then,  
 a number of audit ﬁrms have offered social engineering as a service; they phish  
 their audit clients to show how easy it is. Since the mid-2010s, opinion has  
 shifted against this practice, as it causes a lot of distress to staff without changing  
 behaviour very much.

Social engineering isn’t limited to stealing private information. It can also

be about getting people to believe bogus public information. The quote from  
 Bruce Schneier at the head of this chapter appeared in a report of a stock scam,  
 where a bogus press release said that a company’s CEO had resigned and its  
 earnings would be restated. Several wire services passed this on, and the stock  
 dropped 61% until the hoax was exposed [1670]. Fake news of this kind has  
 been around forever, but the Internet has made it easier to promote and social  
 media seem to be making it ubiquitous. We’ll revisit this issue when I discuss  
 censorship in section 26.4.

2Very occasionally, a customer can confuse the bank; a 2019 innovation was the ‘callham-

mer’ attack, where someone phones up repeatedly to ‘correct’ the spelling of ‘his name’ and  
 changes it one character at a time into another one.

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 95 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

**3.3.3** **Phishing**

While phone-based social engineering was the favoured tactic of the 20th cen-  
 tury, online phishing seems to have replaced it as the main tactic of the 21st.  
 The operators include both spooks and crooks, while the targets are both your  
 staff and your customers. It is difficult enough to train your staff; training the  
 average customer is even harder. They’ll assume you’re trying to hustle them,  
 ignore your warnings and just ﬁgure out the easiest way to get what they want  
 from your system. And you can’t design simply for the average. If your systems  
 are not safe to use by people who don’t speak English well, or who are dyslexic,  
 or who have learning difficulties, you are asking for serious legal trouble. So the  
 easiest way to use your system had better be the safest.

The word ‘phishing’ appeared in 1996 in the context of the theft of AOL

passwords. By then, attempts to crack email accounts to send spam had become  
 common enough for AOL to have a ‘report password solicitation’ button on its  
 web page; and the ﬁrst reference to ‘password ﬁshing’ is in 1990, in the context of  
 people altering terminal ﬁrmware to collect Unix logon passwords [443]. Also in  
 1996, Tony Greening reported a systematic experimental study: 336 computer  
 science students at the University of Sydney were sent an email message asking  
 them to supply their password on the pretext that it was required to ‘validate’  
 the password database after a suspected break-in. 138 of them returned a valid  
 password. Some were suspicious: 30 returned a plausible looking but invalid  
 password, while over 200 changed their passwords without official prompting.  
 But very few of them reported the email to authority [812].

Phishing attacks against banks started seven years later in 2003, with half-

a-dozen attempts reported [441]. The early attacks imitated bank websites, but  
 were both crude and greedy; the attackers asked for all sorts of information  
 such as ATM PINs, and their emails were also written in poor English. Most  
 customers smelt a rat. By about 2008, the attackers learned to use better

psychology; they often reused genuine bank emails, with just the URLs changed,  
 or sent an email saying something like ‘Thank you for adding a new email address  
 to your PayPal account’ to provoke the customer to log on to complain that they  
 hadn’t. Of course, customers who used the provided link rather than typing  
 in www.paypal.com or using an existing bookmark would get their accounts  
 emptied. By then phishing was being used by state actors too; I described in  
 section 2.2.2 how Chinese intelligence compromised the Dalai Lama’s private  
 office during the 2008 Olympic games. They used crimeware tools that were  
 originally used by Russian fraud gangs, which they seemed to think gave them  
 some deniability afterwards.

Fraud losses grew rapidly but stabilised by about 2015. A number of coun-

termeasures helped bring things under control, including more complex logon  
 schemes (using two-factor authentication, or its low-cost cousin, the request for  
 some random letters of your password); a move to webmail systems that ﬁlter  
 spam better; and back-end fraud engines that look for cashout patterns. The  
 competitive landscape was rough, in that the phishermen would hit the easiest  
 targets at any time in each country, both in terms of stealing their customer cre-  
 dentials and using their accounts to launder stolen funds. Concentrated losses  
 caused the targets to wake up and take action. Since then, we’ve seen large-

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 96 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

scale attacks on non-ﬁnancial ﬁrms like Amazon; in the late 2000s, the crook  
 would change your email and street address, then use your credit card to order  
 a wide-screen TV. Since about 2016, the action has been in gift vouchers.

As we noted in the last chapter, phishing is also used at scale by botmasters

to recruit new machines to their botnets, and in targeted ways both by crooks  
 aiming at speciﬁc people or ﬁrms, and by intelligence agencies. There’s a big  
 difference between attacks conducted at scale, where the economics dictate that  
 the cost of recruiting a new machine to a botnet can be at most a few cents,  
 and targeted attacks, where spooks can spend years trying to hack the phone  
 of a rival head of government, or a smart crook can spend weeks or months of  
 effort stalking a chief ﬁnancial officer in the hope of a large payout. The lures  
 and techniques used are different, even if the crimeware installed on the target’s  
 laptop or phone comes from the same stable. Cormac Herley argues that this  
 gulf between the economics of targeted crime and volume crime is one of the  
 reasons why cybercrime isn’t much worse than it is [887]. After all, given that  
 we depend on computers, and that all computers are insecure, and that there  
 are attacks all the time, how come civilisation hasn’t collapsed? Cybercrime  
 can’t always be as easy as it looks.

Another factor is that it takes time for innovations to be developed and

disseminated. We noted that it took seven years for the bad guys to catch

up with Tony Greening’s 1995 phishing work. As another example, a 2007

paper by Tom Jagatic and colleagues showed how to make phishing much more  
 effective by automatically personalising each phish using context mined from  
 the target’s social network [971]. I cited that in the second edition of this

book, and in 2016 we saw it in the wild: a gang sent hundreds of thousands  
 of phish with US and Australian banking Trojans to individuals working in  
 ﬁnance departments of companies, with their names and job titles apparently  
 scraped from LinkedIn [1297]. This seems to have been crude and hasn’t really  
 caught on, but once the bad guys ﬁgure it out we may see spear-phishing at  
 scale in the future, and it’s interesting to think of how we might respond. The  
 other personalised bulk scams we see are blackmail attempts where the victims  
 get email claiming that their personal information has been compromised and  
 including a password or the last four digits of a credit card number as evidence,  
 but the yield from such scams seems to be low.

As I write, crime gangs have been making ever more use of spear-phishing in

targeted attacks on companies where they install ransomware, steal gift coupons  
 and launch other scams. In 2020, a group of young men hacked Twitter, where  
 over a thousand employees had access to internal tools that enabled them to take  
 control of user accounts; the gang sent bitcoin scam tweets from the accounts  
 of such well-known users as Bill Gates, Barack Obama and Elon Musk [1292].  
 They appear to have honed their spear-phishing skills on SIM swap fraud, which  
 I’ll discuss later in sections 3.4.1 and 12.7.4. The spread of such ‘transferable  
 skills’ among crooks is similar in many ways to the adoption of mainstream  
 technology.

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| --- | --- | --- |
| **Security Engineering** | 97 | Ross Anderson |

*3.3. DECEPTION IN PRACTICE*

**3.3.4** **Opsec**

Getting your staff to resist attempts by outsiders to inveigle them into revealing  
 secrets, whether over the phone or online, is known in military circles as *opera-*  
 *tional security* or Opsec. Protecting really valuable secrets, such as unpublished  
 ﬁnancial data, not-yet-patented industrial research and military plans, depends  
 on limiting the number of people with access, and also on doctrines about what  
 may be discussed with whom and how. It’s not enough for rules to exist; you  
 have to train the staff who have access, explain the reasons behind the rules,  
 and embed them socially in the organisation. In our medical privacy case, we  
 educated health service staff about pretext calls and set up a strict callback  
 policy: they would not discuss medical records on the phone unless they had  
 called a number they had got from the health service internal phone book rather  
 than from a caller. Once the staff have detected and defeated a few false-pretext  
 calls, they talk about it and the message gets embedded in the way everybody  
 works.

Another example comes from a large Silicon Valley service ﬁrm, which suf-

fered intrusion attempts when outsiders tailgated staff into buildings on campus.  
 Stopping this with airport-style ID checks, or even card-activated turnstiles,  
 would have changed the ambience and clashed with the culture. The solution  
 was to create and embed a social rule that when someone holds open a building  
 door for you, you show them your badge. The critical factor, as with the bogus  
 phone calls, is social embedding rather than just training.

Often the hardest people to educate are the most senior; a consultancy sent

the ﬁnance directors of 500 publicly-quoted companies a USB memory stick as  
 part of an anonymous invitation saying ‘For Your Chance to Attend the Party  
 of a Lifetime’, and 46% of them put it into their computers [1031]. In my own  
 experience in banking, the people you couldn’t train were those who were paid  
 more than you, such as traders in the dealing rooms.

Some operational security measures are common sense, such as not throwing

sensitive papers in the trash. Less obvious is the need to train the people you  
 trust. A leak of embarrassing emails that appeared to come from the office of  
 UK Prime Minister Tony Blair and was initially blamed on ‘hackers’ turned out  
 to have been ﬁshed out of the trash at his personal pollster’s home by a private  
 detective [1208].

People operate systems however they have to, and this usually means break-

ing some of the rules in order to get their work done. Research shows that  
 company staff have only so much *compliance budget*, that is, they’re only pre-  
 pared to put so many hours a year into tasks that are not obviously helping  
 them achieve their goals [196]. You need to ﬁgure out what this budget is, and  
 use it wisely. If there’s some information you don’t want your staff to be tricked  
 into disclosing, it’s safer to design systems so that they just can’t disclose it, or  
 at least so that disclosures involve talking to other staff members or jumping  
 through other hoops.

But what about a ﬁrm’s customers? There is a lot of scope for phishermen

to simply order bank customers to reveal their security data, and this happens  
 at scale, against both retail and business customers. There are also the many

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 98 | Ross Anderson |

*3.4. PASSWORDS*

small scams that customers try on when they ﬁnd vulnerabilities in your business  
 processes. I’ll discuss both types of fraud further in the chapter on banking and  
 bookkeeping.

**3.3.5** **Deception research**

Finally, a word on deception research. Since 9/11, huge amounts of money have  
 been spent by governments trying to ﬁnd better lie detectors, and deception  
 researchers are funded across about ﬁve different subdisciplines of psychology.  
 The polygraph measures stress via heart rate and skin conductance; it has been  
 around since the 1920s and is used by some US states in criminal investiga-  
 tions, as well as by the Federal government in screening people for Top Secret  
 clearances. The evidence on its effectiveness is patchy at best, and surveyed ex-  
 tensively by Aldert Vrij [1970]. While it can be an effective prop in the hands of  
 a skilled interrogator, the key factor is the skill rather than the prop. When used  
 by unskilled people in a lab environment, against experimental subjects telling  
 low-stakes lies, its output is little better than random. As well as measuring  
 stress via skin conductance, you can measure distraction using eye movements  
 and guilt by upper body movements. In a research project with Sophie van der  
 Zee, we used body motion-capture suits and also the gesture-recognition cam-  
 eras in an Xbox and got slightly better results than a polygraph [2063]. However  
 such technologies can at best augment the interrogator’s skill, and claims that  
 they work well should be treated as junk science. Thankfully, the government  
 dream of an effective interrogation robot is some way off.

A second approach to dealing with deception is to train a machine-learning

classiﬁer on real customer behaviour. This is what credit-card fraud engines  
 have been doing since the late 1990s, and recent research has pushed into other  
 ﬁelds too. For example, Noam Brown and Tuomas Sandholm have created a  
 poker-playing bot called Pluribus that beat a dozen expert players over a 12-  
 day marathon of 10,000 hands of Texas Hold ’em. It doesn’t use psychology but  
 game theory, playing against itself millions of times and tracking regret at bids  
 that could have given better outcomes. That it can consistently beat experts  
 without access to ‘tells’ such as its opponents’ facial gestures or body language  
 is itself telling. Dealing with deception using statistical machine learning rather  
 than physiological monitoring may also be felt to intrude less into privacy.

**3.4** **Passwords**

The management of passwords gives an instructive context in which usability,  
 applied psychology and security meet. Passwords have been one of the biggest  
 practical problems facing security engineers since perhaps the 1970s. In fact,  
 as the usability researcher Angela Sasse puts it, it’s hard to think of a worse  
 authentication mechanism than passwords, given what we know about human  
 memory: people can’t remember infrequently-used or frequently-changed items;  
 we can’t forget on demand; recall is harder than recognition; and non-meaningful  
 words are more difficult.

To place the problem in context, most passwords you’re asked to set are not

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 99 | Ross Anderson |

*3.4. PASSWORDS*

for your beneﬁt but for somebody else’s. The modern media ecosystem is driven  
 by websites seeking to maximise both their page views and their registered user  
 bases so as to maximise their value when they are sold. That’s why, when

you’re pointed to a news article that’s so annoying you feel you have to leave a  
 comment, you ﬁnd you have to register. Click, and there’s a page of ads. Fill  
 out the form with an email address and submit. Got the CAPTCHA wrong, so  
 do it again and see another page of ads. Click on the email link, and see a page  
 with another ad. Now you can add a comment that nobody will ever read. In  
 such circumstances you’re better to type random garbage and let the browser  
 remember it; or better still, don’t bother. Even major news sites use passwords  
 against the reader’s interest, for example by limiting the number of free page  
 views you get per month unless you register again with a different browser. This  
 ecosystem is described in detail by Ryan Holiday [913].

Turning now to the more honest uses, the password system used by a big

modern service ﬁrm has a number of components.

1. The visible part is the logon page, which asks you to choose a password

when you register and probably checks its strength in some way. It later  
 asks for this password whenever you log on.

2. There will be recovery mechanisms that enable you to deal with a forgot-

ten password or even a compromised account, typically by asking further  
 security questions, or via your primary email account, or by sending an  
 SMS to your phone.

3. Behind this lie technical protocol mechanisms for password checking, typi-

cally routines that encrypt your password when you enter it at your laptop  
 or phone, and then either compare it with a local encrypted value, or take  
 it to a remote server for checking.

4. There are often protocol mechanisms to synchronise passwords across mul-

tiple platforms, so that if you change your password on your laptop, your  
 phone won’t let you use that service until you enter the new one there too.  
 And these mechanisms may enable you to blacklist a stolen phone without  
 having to reset the passwords for all the services it was able to access.

5. There will be intrusion-detection mechanisms to propagate an alarm if one

of your passwords is used somewhere it probably shouldn’t be.

6. There are single-signon mechanisms to use one logon for many websites, as

when you use your Google or Facebook account to log on to a newspaper.

Let’s work up from the bottom. Developing a full-feature password manage-

ment system can be a lot of work, and providing support for password recovery  
 also costs money (a few years ago, the UK phone company BT had two hun-  
 dred people in its password-reset centre). So outsourcing ‘identity management’  
 can make business sense. In addition, intrusion detection works best at scale: if  
 someone uses my gmail password in an Internet cafe in Peru while Google knows  
 I’m in Scotland, they send an SMS to my phone to check, and a small website  
 can’t do that. The main cause of attempted password abuse is when one ﬁrm  
 gets hacked, disclosing millions of email addresses and passwords, which the bad

|  |  |  |
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| **Security Engineering** | 100 | Ross Anderson |

*3.4. PASSWORDS*

guys try out elsewhere; big ﬁrms spot this quickly while small ones don’t. The  
 big ﬁrms also help their customers maintain situational awareness, by alerting  
 you to logons from new devices or from strange places. Again, it’s hard to do  
 that if you’re a small website or one that people visit infrequently.

As for syncing passwords between devices, only the device vendors can really

do that well; and the protocol mechanisms for encrypting passwords in transit  
 to a server that veriﬁes them will be discussed in the next chapter. That brings  
 us to password recovery.

**3.4.1** **Password recovery**

The experience of the 2010s, as the large service ﬁrms scaled up and people  
 moved en masse to smartphones, is that password recovery is often the hardest  
 aspect of authentication. If people you know, such as your staff, forget their  
 passwords, you can get them to interact with an administrator or manager who  
 knows them. But for people you don’t know such as your online customers

it’s harder. And as a large service ﬁrm will be recovering tens of thousands of  
 accounts every day, you need some way of doing it without human intervention  
 in the vast majority of cases.

During the 1990s and 2000s, many websites did password recovery using

‘security questions’ such as asking for your favourite team, the name of your  
 pet or even that old chestnut, your mother’s maiden name. Such near-public  
 information is often easy to guess so it gave an easier way to break into accounts  
 than guessing the password itself. This was made even worse by everyone asking  
 the same questions. In the case of celebrities – or abuse by a former intimate  
 partner – there may be no usable secrets. This was brought home to the public  
 in 2008, when a student hacked the Yahoo email account of US Vice-Presidential  
 candidate Sarah Palin via the password recovery questions – her date of birth  
 and the name of her ﬁrst school. Both of these were public information. Since  
 then, crooks have learned to use security questions to loot accounts when they  
 can; at the US Social Security Administration, a common fraud was to open an  
 online account for a pensioner who’s dealt with their pension by snail mail in  
 the past, and redirect the payments to a different bank account. This peaked  
 in 2013; the countermeasure that ﬁxed it was to always notify beneﬁciaries of  
 account changes by snail mail.

In 2015, ﬁve Google engineers published a thorough analysis of security ques-

tions, and many turned out to be extremely weak. For example, an attacker  
 could get a 19.7% success rate against ‘Favourite food?’ in English. Some 37%  
 of people provided wrong answers, in some cases to make them stronger, but  
 sometimes not. Fully 16% of people’s answers were public. In addition to being  
 insecure, the ‘security questions’ turned out to be hard to use: 40% of English-  
 speaking US users were unable to recall the answers when needed, while twice  
 as many could recover accounts using an SMS reset code [291].

Given these problems with security and memorability, most websites now

let you recover your password by an email to the address with which you ﬁrst  
 registered. But if someone compromises that email account, they can get all  
 your dependent accounts too. Email recovery may be adequate for websites

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 101 | Ross Anderson |

*3.4. PASSWORDS*

where a compromise is of little consequence, but for important accounts – such  
 as banking and email itself – standard practice is now to use a second factor.  
 This is typically a code sent to your phone by SMS, or better still using an  
 app that can encrypt the code and tie it to a speciﬁc handset. Many service  
 providers that allow email recovery are nudging people towards using such a code  
 instead where possible. Google research shows that SMSs stop all bulk password  
 guessing by bots, 96% of bulk phishing and 76% of targeted attacks [574].

But this depends on phone companies taking care over who can get a re-

placement SIM card, and many don’t. The problem in 2020 is rapid growth in  
 attacks based on intercepting SMS authentication codes, which mostly seem to  
 involve SIM swap, where the attacker pretends to be you to your mobile phone  
 company and gets a replacement SIM card for your account. SIM-swap attacks  
 started in South Africa in 2007, became the main form of bank fraud in Nige-  
 ria, then caught on in America – initially as a means of taking over valuable  
 Instagram accounts, then to loot people’s accounts at bitcoin exchanges, then  
 for bank fraud more generally [1092]. I will discuss SIM-swap attacks in more  
 detail in section 12.7.4.

Attackers have also exploited the SS7 signalling protocol to wiretap targets’

mobile phones remotely and steal codes [489]. I’ll discuss such attacks in more  
 detail in the chapters on phones and on banking. The next step in the arms race  
 will be moving customers from SMS messages for authentication and account  
 recovery to an app; the same Google research shows that this improves these  
 last two ﬁgures to 99% for bulk phishing and 90% for targeted attacks [574]. As  
 for the targeted attacks, other research by Ariana Mirian along with colleagues  
 from UCSD and Google approached gangs who advertised ‘hack-for-hire’ ser-  
 vices online and asked them to phish Gmail passwords. Three of the gangs

succeeded, defeating SMS-based 2fa with a middleperson attack; forensics then  
 revealed 372 other attacks on Gmail users from the same IP addresses during  
 March to October 2018 [1322]. This is still an immature criminal market, but to  
 stop such attacks an app or authentication token is the way to go. It also raises  
 further questions about account recovery. If I use a hardware security key on my  
 Gmail, do I need a second one in a safe as a recovery mechanism? (Probably.)  
 If I use one app on my phone to do banking and another as an authenticator,  
 do I comply with rules on two-factor authentication? (See section 12.7.4 in the  
 chapter on banking.)

Email notiﬁcation is the default for telling people not just of suspicious

login attempts, but of logins to new devices that succeeded with the help of  
 a code. That way, if someone plants malware on your phone, you have some  
 chance of detecting it. How a victim recovers then is the next question. If all  
 else fails, a service provider may eventually let them speak to a real person.  
 But when designing such a system, never forget that it’s only as strong as the  
 weakest fallback mechanism – be it a recovery email loop with an email provider  
 you don’t control, a phone code that’s vulnerable to SIM swapping or mobile  
 malware, or a human who’s open to social engineering.

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| **Security Engineering** | 102 | Ross Anderson |

*3.4. PASSWORDS*

**3.4.2** **Password choice**

Many accounts are compromised by guessing PINs or passwords. There are

botnets constantly breaking into online accounts by guessing passwords and  
 password-recovery questions, as I described in 2.3.1.4, in order to use email  
 accounts to send spam and to recruit machines to botnets. And as people

invent new services and put passwords on them, the password guessers ﬁnd new  
 targets. A recent example is cryptocurrency wallets: an anonymous ‘bitcoin  
 bandit’ managed to steal $50m by trying lots of weak passwords for ethereum  
 wallets [809]. Meanwhile, billions of dollars’ worth of cryptocurrency has been  
 lost because passwords were forgotten. So passwords matter, and there are

basically three broad concerns, in ascending order of importance and difficulty:

1. Will the user enter the password correctly with a high enough probability?

2. Will the user remember the password, or will they have to either write it

down or choose one that’s easy for the attacker to guess?

3. Will the user break the system security by disclosing the password to a

third party, whether accidentally, on purpose, or as a result of deception?

**3.4.3** **Difficulties with reliable password entry**

The ﬁrst human-factors issue is that if a password is too long or complex, users  
 might have difficulty entering it correctly. If the operation they’re trying to per-  
 form is urgent, this might have safety implications. If customers have difficulty  
 entering software product activation codes, this can generate expensive calls to  
 your support desk. And the move from laptops to smartphones during the 2010s  
 has made password rules such as ‘at least one lower-case letter, upper-case let-  
 ter, number and special character’ really ﬁddly and annoying. This is one of the  
 factors pushing people toward longer but simpler secrets, such as passphrases  
 of three or four words. But will people be able to enter them without making  
 too many errors?

An interesting study was done for the STS prepayment meters used to sell

electricity in many less-developed countries. The customer hands some money  
 to a sales agent, and gets a 20-digit number printed out on a receipt. They take  
 this receipt home, enter the numbers at a keypad in the meter, and the lights  
 come on. The STS designers worried that since a lot of the population was  
 illiterate, and since people might get lost halfway through entering the number,  
 the system might be unusable. But illiteracy was not a problem: even people  
 who could not read had no difficulty with numbers (‘everybody can use a phone’,  
 as one of the engineers said). The biggest problem was entry errors, and these  
 were dealt with by printing the twenty digits in two rows, with three groups of  
 four digits in the ﬁrst row followed by two in the second [93]. I’ll describe this  
 in detail in section 14.2.

A quite different application is the ﬁring codes for US nuclear weapons.

These consist of only 12 decimal digits. If they are ever used, the operators will  
 be under extreme stress, and possibly using improvised or obsolete communi-  
 cations channels. Experiments suggested that 12 digits was the maximum that

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| **Security Engineering** | 103 | Ross Anderson |

*3.4. PASSWORDS*

could be conveyed reliably in such circumstances. I’ll discuss how this evolved  
 in 15.2.

**3.4.4** **Difficulties with remembering the password**

Our second psychological issue is that people often ﬁnd passwords hard to re-  
 member [2076]. Twelve to twenty digits may be easy to copy from a telegram or  
 a meter ticket, but when customers are expected to memorize passwords, they  
 either choose values that are easy for attackers to guess, or write them down,  
 or both. In fact, standard password advice has been summed up as: “Choose a  
 password you can’t remember, and don’t write it down”.

The problems are not limited to computer access. For example, one chain of

cheap hotels in France introduced self service. You’d turn up at the hotel, swipe  
 your credit card in the reception machine, and get a receipt with a numerical  
 access code to unlock your room door. To keep costs down, the rooms did not  
 have en-suite bathrooms. A common failure mode was that you’d get up in the  
 middle of the night to go to the bathroom, forget your access code, and realise  
 you hadn’t taken the receipt with you. So you’d have to sleep on the bathroom  
 ﬂoor until the staff arrived the following morning.

Password memorability can be discussed under ﬁve main headings: na¨ıve

choice, user abilities and training, design errors, operational failures and vulner-  
 ability to social-engineering attacks.

**3.4.4.1** **Na¨ıve choice**

Since the mid-1980s, people have studied what sort of passwords people choose,  
 and found they use spouses’ names, single letters, or even just hit carriage  
 return giving an empty string as their password. Cryptanalysis of tapes from  
 a 1980 Unix system showed that of the pioneers, Dennis Ritchie used ‘dmac’  
 (his middle name was MacAlistair); the later Google chairman Eric Schmidt  
 used ‘wendy!!!’ (his wife’s name) and Brian Kernighan used ‘/.,/.,’ [795]. Fred  
 Grampp and Robert Morris’s classic 1984 paper on Unix security [805] reports  
 that after software became available which forced passwords to be at least six  
 characters long and have at least one nonletter, they made a ﬁle of the 20 most  
 common female names, each followed by a single digit. Of these 200 passwords,  
 at least one was in use on each of several dozen machines they examined. At  
 the time, Unix systems kept encrypted passwords in a ﬁle /etc/passwd that  
 all system users could read, so any user could verify a guess of any other user’s  
 password. Other studies showed that requiring a non-letter simply changed the  
 most popular password from ‘password’ to ‘password1’ [1672].

In 1990, Daniel Klein gathered 25,000 Unix passwords and found that 21–

25% of passwords could be guessed depending on the amount of effort put  
 in [1056]. Dictionary words accounted for 7.4%, common names for 4%, combi-  
 nations of user and account name 2.7%, and so on down a list of less probable  
 choices such as words from science ﬁction (0.4%) and sports terms (0.2%). Other  
 password guesses used patterns, such as by taking an account *‘klone’* belong-  
 ing to the user ‘Daniel V. Klein’ and trying passwords such as klone, klone1,

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| **Security Engineering** | 104 | Ross Anderson |

*3.4. PASSWORDS*

klone123, dvk, dvkdvk, leinad, neilk, DvkkvD, and so on. The following year,  
 Alec Muffett released ‘crack’, software that would try to brute-force Unix pass-  
 words using dictionaries and patterns derived from them by a set of mangling  
 rules.

The largest academic study of password choice of which I am aware is by Joe

Bonneau, who in 2012 analysed tens of millions of passwords in leaked password  
 ﬁles, and also interned at Yahoo where he instrumented the login system to  
 collect live statistics on the choices of 70 million users. He also worked out the  
 best metrics to use for password guessability, both in standalone systems and  
 where attackers use passwords harvested from one system to crack accounts on  
 another [289]. This work informed the design of password strength checkers and  
 other current practices at the big service ﬁrms.

**3.4.4.2** **User abilities and training**

Sometimes you can train the users. Password checkers have trained them to use  
 longer passwords with numbers as well as letters, and the effect spills over to  
 websites that don’t use them [444]. But you do not want to drive customers  
 away, so the marketing folks will limit what you can do. In fact, research shows  
 that password rule enforcement is not a function of the value at risk, but of  
 whether the website is a monopoly. Such websites typically have very annoying  
 rules, while websites with competitors, such as Amazon, are more usable, placing  
 more reliance on back-end intrusion-detection systems.

In a corporate or military environment you can enforce password choice rules,

or password change rules, or issue random passwords. But then people will have  
 to write them down. So you can insist that passwords are treated the same way  
 as the data they protect: bank master passwords go in the vault overnight, while  
 military ‘Top Secret’ passwords must be sealed in an envelope, in a safe, in a  
 room that’s locked when not occupied, in a building patrolled by guards. You  
 can send guards round at night to clean all desks and bin everything that hasn’t  
 been locked up. But if you want to hire and retain good people, you’d better  
 think things through a bit more carefully. For example, one Silicon Valley ﬁrm  
 had a policy that the root password for each machine would be written down  
 on a card and put in an envelope taped to the side of the machine – a more  
 human version of the rule that passwords be treated the same way as the data  
 they protect. The domestic equivalent is the card in the back of your wiﬁ router  
 with the password.

While writing the ﬁrst edition of this book, I could not ﬁnd any account of

experiments on training people in password choice that would hold water by the  
 standards of applied psychology (i.e., randomized controlled trials with adequate  
 statistical power). The closest I found was a study of the recall rates, forgetting  
 rates, and guessing rates of various types of password [345]; this didn’t tell us  
 the actual effects of giving users various kinds of advice. We therefore decided  
 to see what could be achieved by training, and selected three groups of about a  
 hundred volunteers from our ﬁrst-year science students [2055]:

*•* the red (control) group was given the usual advice (password at least six

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| **Security Engineering** | 105 | Ross Anderson |

*3.4. PASSWORDS*

*•* the green group was told to think of a passphrase and select letters from  
 ‘I’S12&IAH’

*•* the yellow group was told to select eight characters (alpha or numeric) at  
 note after a week or two once they’d memorized the password.

What we expected to ﬁnd was that the red group’s passwords would be easier

to guess than the green group’s which would in turn be easier than the yellow  
 group’s; and that the yellow group would have the most difficulty remembering  
 their passwords (or would be forced to reset them more often), followed by green  
 and then red. But that’s not what we found.

About 30% of the control group chose passwords that could be guessed using

Alec Muffett’s ‘crack’ software, versus about 10 percent for the other two groups.  
 So passphrases and random passwords seemed to be about equally effective.  
 When we looked at password reset rates, there was no signiﬁcant difference  
 between the three groups. When we asked the students whether they’d found  
 their passwords hard to remember (or had written them down), the yellow group  
 had signiﬁcantly more problems than the other two; but there was no signiﬁcant  
 difference between red and green.

The conclusions we drew were as follows.

*•* For users who follow instructions, passwords based on mnemonic phrases  
 selected passwords, and as hard to guess as random passwords.

*•* The problem then becomes one of *user compliance*. A signiﬁcant number

So when the army gives soldiers randomly-selected passwords, its value comes

from the fact that the password assignment compels user compliance, rather  
 than from the fact that they’re random (as mnemonic phrases would do just as  
 well).

But centrally-assigned passwords are often inappropriate. When you are

offering a service to the public, your customers expect you to present broadly  
 the same interfaces as your competitors. So you must let users choose their own  
 website passwords, subject to some lightweight algorithm to reject passwords  
 that are ‘clearly bad’. (GCHQ suggests using a ‘bad password list’ of the 100,000  
 passwords most commonly found in online password dumps.) In the case of  
 bank cards, users expect a bank-issued initial PIN plus the ability to change the  
 PIN afterwards to one of their choosing (though again you may block a ‘clearly  
 bad’ PIN such as 0000 or 1234). Over half of cardholders keep a random PIN,  
 but about a quarter choose PINs such as children’s birth dates which have less  
 entropy than random PINs would, and have the same PIN on different cards.  
 The upshot is that a thief who steals a purse or wallet may have a chance of  
 about one in eleven to get lucky, if he tries the most common PINs on all the  
 cards ﬁrst in offline mode and then in online mode, so he gets six goes at each.  
 Banks that forbid popular choices such as 1234 can increase the odds to about  
 one in eighteen [295].

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| **Security Engineering** | 106 | Ross Anderson |

*3.4. PASSWORDS*

**3.4.4.3** **Design errors**

Attempts to make passwords memorable are a frequent source of severe design  
 errors. The classic example of how not to do it is to ask for ‘your mother’s  
 maiden name’. A surprising number of banks, government departments and  
 other organisations still authenticate their customers in this way, though nowa-  
 days it tends to be not a password but a password recovery question. You could  
 always try to tell ‘Yngstrom’ to your bank, ‘Jones’ to the phone company, ‘Ger-  
 aghty’ to the travel agent, and so on; but data are shared extensively between  
 companies, so you could easily end up confusing their systems – not to mention  
 yourself. And if you try to phone up your bank and tell them that you’ve de-  
 cided to change your mother’s maiden name from Yngstrom to yGt5r4ad – or  
 even Smith – then good luck. In fact, given the large number of data breaches,  
 you might as well assume that anyone who wants to can get all your common  
 password recovery information – including your address, your date of birth, your  
 ﬁrst school and your social security number, as well as your mother’s maiden  
 name.

Some organisations use contextual security information. A bank I once used

asks its business customers the value of the last check from their account that  
 was cleared. In theory, this could be helpful: if someone overhears me doing a  
 transaction on the telephone, then it’s not a long-term compromise. The details  
 bear some attention though. When this system was ﬁrst introduced, I wondered  
 whether a supplier, to whom I’d just written a check, might impersonate me,  
 and concluded that asking for the last three checks’ values would be safer. But  
 the problem we actually had was unexpected. Having given the checkbook to  
 our accountant for the annual audit, we couldn’t talk to the bank. I also don’t  
 like the idea that someone who steals my physical post can also steal my money.

The sheer number of applications demanding a password nowadays exceeds

the powers of human memory. A 2007 study by Dinei Florˆencio and Cormac  
 Herley of half a million web users over three months showed that the average user  
 has 6.5 passwords, each shared across 3.9 different sites; has about 25 accounts  
 that require passwords; and types an average of 8 passwords per day. Bonneau  
 published more extensive statistics in 2012 [289] but since then the frequency of  
 user password entry has fallen, thanks to smartphones. Modern web browsers  
 also cache passwords; see the discussion of password managers at section 3.4.11  
 below. But many people use the same password for many different purposes  
 and don’t work out special processes to deal with their high-value logons such  
 as to their bank, their social media accounts and their email. So you have

to expect that the password chosen by the customer of the electronic banking  
 system you’ve just designed, may be known to a Maﬁa-operated porn site as  
 well. (There’s even a website, http://haveibeenpwned.com, that will tell you  
 which security breaches have leaked your email address and password.)

One of the most pervasive and persistent errors has been forcing users to

change passwords regularly. When I ﬁrst came across enforced monthly pass-  
 word changes in the 1980s, I observed that it led people to choose passwords  
 such as ‘julia03’ for March, ‘julia04’ for April, and so on, and said as much in  
 the ﬁrst (2001) edition of this book (chapter 3, page 48). However, in 2003, Bill  
 Burr of NIST wrote password guidelines recommending regular update [1096].

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| **Security Engineering** | 107 | Ross Anderson |

*3.4. PASSWORDS*

This was adopted by the Big Four auditors, who pushed it out to all their audit  
 clients3. Meanwhile, security usability researchers conducted survey after survey  
 showing that monthly change was suboptimal. The ﬁrst systematic study by  
 Yinqian Zhang, Fabian Monrose and Mike Reiter of the password transforma-  
 tion techniques users invented showed that in a system with forced expiration,  
 over 40% of passwords could be guessed from previous ones, that forced change  
 didn’t do much to help people who chose weak passwords, and that the effort of  
 regular password choice may also have diminished password quality [2070]. Fi-  
 nally a survey was written by usability guru Lorrie Cranor while she was Chief  
 Technologist at the FTC [492], and backed up by an academic study [1505].  
 In 2017, NIST recanted; they now recommend long passphrases that are only  
 changed on compromise4. Other governments’ agencies such as Britain’s GCHQ  
 followed, and Microsoft ﬁnally announced the end of password-expiration poli-  
 cies in Windows 10 from April 2019. However, many ﬁrms are caught by the  
 PCI standards set by the credit-card issuers, which haven’t caught up and still  
 dictate three-monthly changes; another problem is that the auditors dictate  
 compliance to many companies, and will no doubt take time to catch up.

The current fashion, in 2020, is to invite users to select passphrases of three

or more random dictionary words. This was promoted by a famous xkcd cartoon  
 which suggested ‘correct horse battery staple’ as a password. Empirical research,  
 however, shows that real users select multi-word passphrases with much less  
 entropy than they’d get if they really did select at random from a dictionary;  
 they tend to go for common noun bigrams, and moving to three or four words  
 brings rapidly diminishing returns [296]. The Electronic Frontier Foundation  
 now promotes using dice to pick words; they have a list of 7,776 words (65, so  
 ﬁve dice rolls to pick a word) and note that a six-word phrase has 77 bits of  
 entropy and is memorable [290].

**3.4.4.4** **Operational failures**

The most pervasive operational error is failing to reset default passwords. This  
 has been a chronic problem since the early dial access systems in the 1980s  
 attracted attention from mischievous schoolkids. A particularly bad example  
 is where systems have default passwords that can’t be changed, checked by  
 software that can’t be patched. We see ever more such devices in the Internet  
 of Things; they remain vulnerable for their operational lives. The Mirai botnets  
 have emerged to recruit and exploit them, as I described in Chapter 2.

Passwords in plain sight are another long-running problem, whether on sticky

notes or some electronic equivalent. A famous early case was R v Gold and  
 Schifreen, where two young hackers saw a phone number for the development  
 version of Prestel, an early public email service run by British Telecom, in a  
 note stuck on a terminal at an exhibition. They dialed in later, and found the  
 welcome screen had a maintenance password displayed on it. They tried this

3Our university’s auditors wrote in their annual report for three years in a row that we

should have monthly enforced password change, but couldn’t provide any evidence to support  
 this and weren’t even aware that their policy came ultimately from NIST. Unimpressed, we  
 asked the chair of our Audit Committee to appoint a new lot of auditors, and eventually that  
 happened.

4NIST SP 800-63-3

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| **Security Engineering** | 108 | Ross Anderson |

*3.4. PASSWORDS*

on the live system too, and it worked! They proceeded to hack into the Duke  
 of Edinburgh’s electronic mail account, and sent mail ‘from’ him to someone  
 they didn’t like, announcing the award of a knighthood. This heinous crime so  
 shocked the establishment that when prosecutors failed to persuade the courts  
 to convict the young men, Britain’s parliament passed its ﬁrst Computer Misuse  
 Act.

A third operational issue is asking for passwords when they’re not really

needed, or wanted for dishonest reasons, as I discussed at the start of this  
 section. Most of the passwords you’re forced to set up on websites are there  
 for marketing reasons – to get your email address or give you the feeling of  
 belonging to a ‘club’ [294]. So it’s perfectly rational for users who never plan to  
 visit that site again to express their exasperation by entering ‘123456’ or even  
 ruder words in the password ﬁeld.

A fourth is atrocious password management systems: some don’t encrypt

passwords at all, and there are reports from time to time of enterprising hackers  
 smuggling back doors into password management libraries [427].

But perhaps the biggest operational issue is vulnerability to social-engineering

attacks.

**3.4.4.5** **Social-engineering attacks**

Careful organisations communicate security context in various ways to help staff  
 avoid making mistakes. The NSA, for example, had different colored internal  
 and external telephones, and when an external phone in a room is off-hook,  
 classiﬁed material can’t even be discussed in the room – let alone on the phone.

Yet while many banks and other businesses maintain some internal security

context, they often train their customers to act in unsafe ways. Because of

pervasive phishing, it’s not prudent to try to log on to your bank by clicking  
 on a link in an email, so you should always use a browser bookmark or type  
 in the URL by hand. Yet bank marketing departments send out lots of emails  
 containing clickable links. Indeed much of the marketing industry is devoted  
 to getting people to click on links. Many email clients – including Apple’s,

Microsoft’s, and Google’s – make plaintext URLs clickable, so their users may  
 never see a URL that isn’t. Bank customers are well trained to do the wrong  
 thing.

A prudent customer should also be cautious if a web service directs them

somewhere else – yet bank systems use all sorts of strange URLs for their ser-  
 vices. A spam from the Bank of America directed UK customers to mynew-  
 card.com and got the certiﬁcate wrong (it was for mynewcard.bankofamerica.com).  
 There are many more examples of major banks training their customers to  
 practice unsafe computing – by disregarding domain names, ignoring certiﬁcate  
 warnings, and merrily clicking links [582]. As a result, even security experts  
 have difficulty telling bank spam from phish [443].

It’s not prudent to give out security information over the phone to unidenti-

ﬁed callers – yet we all get phoned by bank staff who demand security informa-  
 tion. Banks also call us on our mobiles now and expect us to give out security  
 information to a whole train carriage of strangers, rather than letting us text

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| **Security Engineering** | 109 | Ross Anderson |

*3.4. PASSWORDS*

a response. (I’ve had a card blocked because a bank security team phoned me  
 while I was driving; it would have been against the law to deal with the call  
 other than in hands-free mode, and there was nowhere safe to stop.) It’s also  
 not prudent to put a bank card PIN into any device other than an ATM or a  
 PIN entry device (PED) in a store; and Citibank even asks customers to dis-  
 regard and report emails that ask for personal information, including PIN and  
 account details. So what happened? You guessed it – it sent its Australian  
 customers an email asking customers ‘as part of a security upgrade’ to log on  
 to its website and authenticate themselves using a card number and an ATM  
 PIN [1087]. And in one 2005 case, the Halifax sent a spam to the mother of a  
 student of ours who contacted the bank’s security department, which told her  
 it was a phish. The student then contacted the ISP to report abuse, and found  
 that the URL and the service were genuine [1241]. The Halifax disappeared  
 during the crash of 2008, and given that their own security department couldn’t  
 tell spam from phish, perhaps that was justice (though it cost us taxpayers a  
 shedload of money).

**3.4.4.6** **Customer education**

After phishing became a real threat to online banking in the mid-2000s, banks  
 tried to train their customers to look for certain features in websites. This has  
 been partly risk reduction, but partly risk dumping – seeing to it that customers  
 who don’t understand or can’t follow instructions can be held responsible for  
 the resulting loss. The general pattern has been that as soon as customers

are trained to follow some particular rule, the phishermen exploit this, as the  
 reasons for the rule are not adequately explained.

At the beginning, the advice was ‘Check the English’, so the bad guys either

got someone who could write English, or simply started using the banks’ own  
 emails but with the URLs changed. Then it was ‘Look for the lock symbol’,  
 so the phishing sites started to use SSL (or just forging it by putting graphics  
 of lock symbols on their web pages). Some banks started putting the last four  
 digits of the customer account number into emails; the phishermen responded by  
 putting in the ﬁrst four (which are constant for a given bank and card product).  
 Next the advice was that it was OK to click on images, but not on URLs;  
 the phishermen promptly put in links that appeared to be images but actually  
 pointed at executables. The advice then was to check where a link would really  
 go by hovering your mouse over it; the bad guys then either inserted a non-  
 printing character into the URL to stop Internet Explorer from displaying the  
 rest, or used an unmanageably long URL (as many banks also did).

This sort of arms race is most likely to beneﬁt the attackers. The coun-

termeasures become so complex and counterintuitive that they confuse more  
 and more users – exactly what the phishermen need. The safety and usability  
 communities have known for years that ‘blame and train’ is not the way to deal  
 with unusable systems – the only real ﬁx is to design for safe usability in the  
 ﬁrst place [1451].

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| **Security Engineering** | 110 | Ross Anderson |

*3.4. PASSWORDS*

**3.4.4.7** **Phishing warnings**

Part of the solution is to give users better tools. Modern browsers alert you  
 to wicked URLs, with a range of mechanisms under the hood. First, there are  
 lists of bad URLs collated by the anti-virus and threat intelligence community.  
 Second, there’s logic to look for expired certiﬁcates and other compliance failures  
 (as the majority of those alerts are false alarms).

There has been a lot of research, in both industry and academia, about how

you get people to pay attention to warnings. We see so many of them, most are  
 irrelevant, and many are designed to shift risk to us from someone else. So when  
 do people pay attention? In our own work, we tried a number of things and found  
 that people paid most attention when the warnings were not vague and general  
 (*‘Warning - visiting this web site may harm your computer!’*) but speciﬁc and  
 concrete (*‘The site you are about to visit has been conﬁrmed to contain software*  
 *that poses a signiﬁcant risk to you, with no tangible beneﬁt. It would try to infect*  
 *your computer with malware designed to steal your bank account and credit card*  
 *details in order to defraud you*) [1327]. Subsequent research by Adrienne Porter  
 Felt and Google’s usability team has tried many ideas including making warnings  
 psychologically salient using faces (which doesn’t work), simplifying the text  
 (which helps) and making the safe defaults both attractive and prominent (which  
 also helps). Optimising these factors improves compliance from about 35% to  
 about 50% [675]. However, if you want to stop the great majority of people  
 from clicking on known-bad URLs, then voluntary compliance isn’t enough.  
 You either have to block them at your ﬁrewall, or block them at the browser (as  
 both Chrome and Firefox do for different types of certiﬁcate error – a matter to  
 which we’ll return in 21.6.1).

**3.4.5** **System issues**

Not all phishing attacks involve psychology. Some involve technical mechanisms  
 to do with password entry and storage together with some broader system issues.

As we already noted, a key question is whether we can restrict the number

of password guesses. Security engineers sometimes refer to password systems as  
 ‘online’ if guessing is limited (as with ATM PINs) and ‘offline’ if it is not (this  
 originally meant systems where a user could fetch the password ﬁle and take  
 it away to try to guess the passwords of other users, including more privileged  
 users). But the terms are no longer really accurate. Some offline systems can  
 restrict guesses, such as payment cards which use physical tamper-resistance to  
 limit you to three PIN guesses, while some online systems cannot. For example,  
 if you log on using Kerberos, an opponent who taps the line can observe your key  
 encrypted with your password ﬂowing from the server to your client, and then  
 data encrypted with that key ﬂowing on the line; so they can take their time to  
 try out all possible passwords. The most common trap here is the system that  
 normally restricts password guesses but then suddenly fails to do so, when it  
 gets hacked and a one-way encrypted password ﬁle is leaked, together with the  
 encryption keys. Then the bad guys can try out their entire password dictionary  
 against each account at their leisure.

Password guessability ultimately depends on the entropy of the chosen pass-

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| **Security Engineering** | 111 | Ross Anderson |

*3.4. PASSWORDS*

words and the number of allowed guesses, but this plays out in the context of a  
 speciﬁc threat model, so you need to consider the type of attacks you are trying  
 to defend against. Broadly speaking, these are as follows.

**Targeted attack on one account:** an intruder tries to guess a speciﬁc user’s

password. They might try to guess a rival’s logon password at the office,  
 in order to do mischief directly.

**Attempt to penetrate any account belonging to a speciﬁc target:** an en-

emy tries to hack any account you own, anywhere, to get information that  
 might might help take over other accounts, or do harm directly.

**Attempt to penetrate any account on a target system:** the intruder tries

to get a logon as any user of the system. This is the classic case of the  
 phisherman trying to hack any account at a target bank so he can launder  
 stolen money through it.

**Attempt to penetrate any account on any system:** the intruder merely

wants an account at any system in a given domain but doesn’t care which  
 one. Examples are bad guys trying to guess passwords on any online

email service so they can send spam from the compromised account, and  
 a targeted attacker who wants a logon to any random machine in the  
 domain of a target company as a beachhead.

**Attempt to use a breach of one system to penetrate a related one:** the

intruder has got a beachhead and now wants to move inland to capture  
 higher-value targets.

**Service denial attack:** the attacker may wish to block one or more legitimate

users from using the system. This might be targeted on a particular

account or system-wide.

This taxonomy helps us ask relevant questions when evaluating a password

system.

**3.4.6** **Can you deny service?**

There are basically three ways to deal with password guessing when you detect it:  
 lockout, throttling, and protective monitoring. Banks may freeze your card after  
 three wrong PINs; but if they freeze your online account after three bad password  
 attempts they open themselves up to a denial-of-service attack. Service can  
 also fail by accident; poorly-conﬁgured systems can generate repeat fails with  
 stale credentials. So many commercial websites nowadays use throttling rather  
 than lockout. In a military system, you might not want even that, in case an  
 enemy who gets access to the network could jam it with a ﬂood of false logon  
 attempts. In this case, protective monitoring might be the preferred option,  
 with a plan to abandon rate-limiting if need be in a crisis. Joe Bonneau and  
 Soren Preibusch collected statistics of how many major websites use account  
 locking versus various types of rate control [294]. They found that popular,  
 growing, competent sites tend to be more secure, as do payment sites, while

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| **Security Engineering** | 112 | Ross Anderson |

*3.4. PASSWORDS*

content sites do worst. Microsoft Research’s Yuan Tian, Cormac Herley and  
 Stuart Schechter investigated how to do locking or throttling properly; among  
 other things, it’s best to penalise guesses of weak passwords (as otherwise an  
 attacker gets advantage by guessing them ﬁrst), to be more aggressive when  
 protecting users who have selected weak passwords, and to not punish IPs or  
 clients that repeatedly submit the same wrong password [1888].

**3.4.7** **Protecting oneself or others?**

Next, to what extent does the system need to protect users and subsystems  
 from each other? In global systems on which anyone can get an account – such  
 as mobile phone systems and cash machine systems – you must assume that  
 the attackers are already legitimate users, and see to it that no-one can use  
 the service at someone else’s expense. So knowledge of one user’s password will  
 not allow another user’s account to be compromised. This has both personal  
 aspects, and system aspects.

On the personal side, don’t forget what we said about intimate partner abuse

in 2.5.4: the passwords people choose are often easy for their spouses or partners  
 to guess, and the same goes for password recovery questions: so some thought  
 needs to be given to how abuse victims can recover their security.

On the system side, there are all sorts of passwords used for mutual au-

thentication between subsystems, few mechanisms to enforce password quality  
 in server-server environments, and many well-known issues (for example, the  
 default password for the Java trusted keystore ﬁle is ‘changeit’). Development  
 teams often share passwords that end up in live systems, even 30 years after  
 this practice led to the well-publicised hack of the Duke of Edinburgh’s email  
 described in section 3.4.4.4. Within a single big service ﬁrm you can lock stuff  
 down by having named crypto keys and seeing to it that each name generates  
 a call to an underlying hardware security module; or you can even use mecha-  
 nisms like SGX to tie keys to known software. But that costs real money, and  
 money isn’t the only problem. Enterprise system components are often hosted  
 at different service companies, which makes adoption of better practices a hard  
 coordination problem too. As a result, server passwords often appear in scripts  
 or other plaintext ﬁles, which can end up in Dropbox or Splunk. So it is vital  
 to think of password practices beyond end users. In later chapters we’ll look at  
 protocols such as Kerberos and ssh; for now, recall Ed Snowden’s remark that  
 it was trivial to hack the typical large company: just spear-phish a sysadmin  
 and then chain your way in. Much of this chapter is about the ‘spear-phish a  
 sysadmin’ part; but don’t neglect the ‘chain your way in’ part.

**3.4.8** **Attacks on password entry**

Password entry is often poorly protected.

|  |  |  |
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| **Security Engineering** | 113 | Ross Anderson |

*3.4. PASSWORDS*

**3.4.8.1** **Interface design**

Thoughtless interface design is all too common. Some common makes of cash  
 machine have a vertical keyboard at head height, making it simple for a pick-  
 pocket to watch a woman enter her PIN before lifting her purse from her hand-  
 bag. The keyboards may have been at a reasonable height for the men who  
 designed them, but women who are a few inches shorter are exposed.

When entering a card number or PIN in a public place, I usually cover my

typing hand with my body or my other hand – but you can’t assume that all  
 your customers will. Many people are uncomfortable shielding a PIN as it’s a  
 signal of distrust, especially if they’re in a supermarket queue and a friend is  
 standing nearby. UK banks found that 20% of users never shield their PIN [127]  
 – and then used this to blame customers whose PINs were compromised by an  
 overhead CCTV camera, rather than designing better PIN entry devices.

**3.4.8.2** **Trusted path, and bogus terminals**

A *trusted path* is some means of being sure that you’re logging into a genuine  
 machine through a channel that isn’t open to eavesdropping. False terminal  
 attacks go back to the dawn of time-shared computing. A public terminal

would be left running an attack program that looks just like the usual logon  
 screen – asking for a user name and password. When an unsuspecting user

did this, it would save the password, reply ‘sorry, wrong password’ and then  
 vanish, invoking the genuine password program. The user assumed they’d made  
 a typing error and just entered the password again. This is why Windows had a  
 *secure attention sequence*; hitting ctrl-alt-del was guaranteed to take you to  
 a genuine password prompt. But eventually, in Windows 10, this got removed to  
 prepare the way for Windows tablets, and because almost nobody understood  
 it.

ATM skimmers are devices that sit on an ATM’s throat, copy card details,

and have a camera to record the customer PIN. There are many variants on  
 the theme. Fraudsters deploy bad PIN entry devices too, and have even been  
 jailed for attaching password-stealing hardware to terminals in bank branches.  
 I’ll describe this world in much more detail in the chapter on banking and  
 bookkeeping; the long-term solution has been to move from magnetic-strip cards  
 that are easy to copy to chip cards that are much harder. In any case, if a  
 terminal might contain malicious hardware or software, then passwords alone  
 will not be enough.

**3.4.8.3** **Technical defeats of password retry counters**

Many kids ﬁnd out that a bicycle combination lock can usually be broken in a  
 few minutes by solving each ring in order of looseness. The same idea worked  
 against a number of computer systems. The PDP-10 TENEX operating system  
 checked passwords one character at a time, and stopped as soon as one of them  
 was wrong. This opened up a *timing attack*: the attacker would repeatedly place  
 a guessed password in memory at a suitable location, have it veriﬁed as part of  
 a ﬁle access request, and wait to see how long it took to be rejected [1129]. An

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 114 | Ross Anderson |

*3.4. PASSWORDS*

error in the ﬁrst character would be reported almost at once, an error in the  
 second character would take a little longer to report, and in the third character  
 a little longer still, and so on. So you could guess the characters one after

another, and instead of a password of *N* characters drawn from an alphabet of  
 *A* characters taking *AN/*2 guesses on average, it took *AN/*2. (Bear in mind  
 that in thirty years’ time, all that might remain of the system you’re building  
 today is the memory of its more newsworthy security failures.)

These same mistakes are being made all over again in the world of embedded

systems. With one remote car locking device, as soon as a wrong byte was

transmitted from the key fob, the red telltale light on the receiver came on. With  
 some smartcards, it has been possible to determine the customer PIN by trying  
 each possible input value and looking at the card’s power consumption, then  
 issuing a reset if the input was wrong. The reason was that a wrong PIN caused  
 a PIN retry counter to be decremented, and writing to the EEPROM memory  
 which held this counter caused a current surge of several milliamps – which  
 could be detected in time to reset the card before the write was complete [1105].  
 These implementation details matter. Timing channels are a serious problem  
 for people implementing cryptography, as we’ll discuss at greater length in the  
 next chapter.

A recent high-proﬁle issue was the PIN retry counter in the iPhone. My

colleague Sergei Skorobogatov noted that the iPhone keeps sensitive data en-  
 crypted in ﬂash memory, and built an adapter that enabled him to save the  
 encrypted memory contents and restore them to their original condition after  
 several PIN attempts. This enabled him to try all 10,000 possible PINs rather  
 than the ten PINs limit that Apple tried to impose [1777]5.

**3.4.9** **Attacks on password storage**

Passwords have often been vulnerable where they are stored. In MIT’s ‘Com-  
 patible Time Sharing System’ ctss – a 1960s predecessor of Multics – it once  
 happened that one person was editing the message of the day, while another was  
 editing the password ﬁle. Because of a software bug, the two editor temporary  
 ﬁles got swapped, and everyone who logged on was greeted with a copy of the  
 password ﬁle! [476].

Another horrible programming error struck a UK bank in the late 1980s,

which issued all its customers with the same PIN by mistake [54]. As the

procedures for handling PINs meant that no one in the bank got access to any-  
 one’s PIN other than their own, the bug wasn’t spotted until after thousands of  
 customer cards had been shipped. Big blunders continue: in 2019 the security  
 company that does the Biostar and AEOS biometric lock system for building en-  
 try control and whose customers include banks and police forces in 83 countries  
 left a database unprotected online with over a million people’s IDs, plaintext  
 passwords, ﬁngerprints and facial recognition data; security researchers who dis-  
 covered this from an Internet scan were able to add themselves as users [1864].

5This was done to undermine an argument by then FBI Director James Comey that the

iPhone was unhackable and so Apple should be ordered to produce an operating system  
 upgrade that created a backdoor; see section 26.2.8.

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| **Security Engineering** | 115 | Ross Anderson |

*3.4. PASSWORDS*

Auditing provides another hazard. When systems log failed password at-

tempts, the log usually contains a large number of passwords, as users get the  
 ‘username, password’ sequence out of phase. If the logs are not well protected  
 then someone who sees an audit record of a failed login with a non-existent user  
 name of e5gv\*8yp just has to try this as a password for all the valid user names.

**3.4.9.1** **One-way encryption**

Such incidents taught people to protect passwords by encrypting them using  
 a one-way algorithm, an innovation due to Roger Needham and Mike Guy.  
 The password, when entered, is passed through a one-way function and the  
 user is logged on only if it matches a previously stored value. However, it’s  
 often implemented wrong. The right way to do it is to generate a random key,  
 historically known in this context as a *salt*; combine the password with the salt  
 using a slow, cryptographically strong one-way function; and store both the salt  
 and the hash.

**3.4.9.2** **Password cracking**

Some systems that use an encrypted password ﬁle make it widely readable. Unix  
 used to be the prime example – the password ﬁle /etc/passwd was readable by  
 all users. So any user could fetch it and try to break passwords by encrypting  
 all the passwords in a dictionary and comparing them with the encrypted values  
 in the ﬁle. We already mentioned in 3.4.4.1 the ‘Crack’ software that people  
 have used for years for this purpose.

Most modern operating systems have sort-of ﬁxed this problem; in modern

Linux distributions, for example, passwords are salted, hashed using 5000 rounds  
 of SHA-512, and stored in a ﬁle that only the root user can read. But there are  
 still password-recovery tools to help you if, for example, you’ve encrypted an  
 Office document with a password you’ve forgotten [1674]. Such tools can also  
 be used by a crook who has got root access, and there are still lots of badly  
 designed systems out there where the password ﬁle is vulnerable in other ways.

There is also *credential stuffing*: when a system is hacked and passwords

are cracked (or were even found unencrypted), they are then tried out on other  
 systems to catch the many people who reused them. This remains a live problem.  
 So password cracking is still worth some attention. One countermeasure worth  
 considering is deception, which can work at all levels in the stack. You can  
 have honeypot systems that alarm if anyone ever logs on to them, honeypot  
 accounts on a system, or password canaries – bogus encrypted passwords for  
 genuine accounts [996].

**3.4.9.3** **Remote password checking**

Many systems check passwords remotely, using cryptographic protocols to pro-  
 tect the password in transit, and the interaction between password security and  
 network security can be complex. Local networks often use a protocol called  
 Kerberos, where a server sends you a key encrypted under your password; if you

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 116 | Ross Anderson |

*3.4. PASSWORDS*

know the password you can decrypt the key and use it to get tickets that give  
 you access to resources. I’ll discuss this in the next chapter, in section 4.7.4; it  
 doesn’t always protect weak passwords against an opponent who can wiretap  
 encrypted traffic. Web servers mostly use a protocol called TLS to encrypt your  
 traffic from the browser on your phone or laptop; I discuss TLS in the following  
 chapter, in section 5.7.5. TLS does not protect you if the server gets hacked.  
 However there is a new protocol called Simultaneous Authentication of Equals  
 (SAE) which is designed to set up secure sessions even where the password is  
 guessable, and which has been adopted from 2018 in the WPA3 standard for  
 WiFi authentication. I’ll discuss this later too.

And then there’s OAuth, a protocol which allows access delegation, so you

can grant one website the right to authenticate you using the mechanisms pro-  
 vided by another. Developed by Twitter from 2006, it’s now used by the main  
 service providers such as Google, Microsoft and Facebook to let you log on to  
 media and other sites; an authorisation server issues access tokens for the pur-  
 pose. We’ll discuss the mechanisms later too. The concomitant risk is cross-site  
 attacks; we are now (2019) seeing OAuth being used by state actors in author-  
 itarian countries to phish local human-rights defenders. The technique is to  
 create a malicious app with a plausible name (say ‘Outlook Security Defender’)  
 and send an email, purportedly from Microsoft, asking for access. If the target  
 responds they end up at a Microsoft web page where they’re asked to authorise  
 the app to have access to their data [46].

**3.4.10** **Absolute limits**

If you have conﬁdence in the cryptographic algorithms and operating-system  
 security mechanisms that protect passwords, then the probability of a success-  
 ful password guessing attack is a function of the entropy of passwords, if they  
 are centrally assigned, and the psychology of users if they’re allowed to choose  
 them. Military sysadmins often prefer to issue random passwords, so the prob-  
 ability of password guessing attacks can be managed. For example, if *L* is the  
 maximum password lifetime, *R* is login attempt rate, *S* is the size of the pass-  
 word space, then the probability that a password can be guessed in its lifetime is  
 *P* = *LR/S*, according to the US Department of Defense password management  
 guideline [546].

There are issues with such a ‘provable security’ doctrine, starting with the

attackers’ goal. Do they want to crack a target account, or just any account?  
 If an army has a million possible passwords and a million users, and the alarm  
 goes off after three bad password attempts on any account, then the attacker  
 can just try one password for every different account. If you want to stop this,  
 you have to do rate control not just for every account, but for all accounts.

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| To take a concrete example, Unix systems used to be limited to eight char-  acter passwords, so there were 968 or about 252 possible passwords. Some UK | | |
| government systems used to issue passwords randomly selected with a ﬁxed  template of consonants, vowels and numbers designed to make them easier to  remember, such as CVCNCVCN (e.g. fuR5xEb8). If passwords are not case  sensitive, the guess probability is cut drastically, to only one in 214*.*52*.*102 or  about 2*�*29. So if an attacker could guess 100 passwords a second – perhaps | | |
| **Security Engineering** | 117 | Ross Anderson |

*3.4. PASSWORDS*

distributed across 10,000 accounts on hundreds of machines on a network, so  
 as not to raise the alarm – then they would need about 5 million seconds, or  
 two months, to get in. If you’re defending such a system, you might ﬁnd it pru-  
 dent to do rate control: set a limit of say one password guess per ten seconds  
 per user account, and perhaps by source IP address. You might also count the  
 failed logon attempts and analyse them: is there a constant series of guesses  
 that suggests an attacker using a botnet, or some other attempted intrusion?  
 And what will you do once you notice one? Will you close the system down?  
 Welcome back to the world of service denial.

With a commercial website, 100 passwords per second may translate to one

compromised user account per second, because of poor user password choices.  
 That may not be a big deal for a web service with 100 million accounts – but it  
 may still be worth trying to identify the source of any industrial-scale password-  
 guessing attacks. If they’re from a small number of IP addresses, you can block  
 them, but doing this properly is harder than it looks, as we noted in section 3.4.6  
 above. And if an automated guessing attack does persist, then another way of  
 dealing with it is the CAPTCHA, which I’ll describe in section 3.5.

**3.4.11** **Using a password manager**

Since the 1980s, companies have been selling single sign-on systems that remem-  
 ber your passwords for multiple applications, and when browsers came along  
 in the mid-1990s and people started logging into dozens of websites, password  
 managers became a mass-market product. Browser vendors noticed, and started  
 providing much the same functionality for free.

Choosing random passwords and letting your browser remember them can

be a pragmatic way of operating. The browser will only enter the password into  
 a web page with the right URL (IE) or the same hostname and ﬁeld name (Fire-  
 fox). Browsers let you set a master password, which encrypts all the individual  
 site passwords and which you only have to enter when your browser is updated.  
 The main drawbacks of password managers in general are that you might forget  
 the master password; and that all your passwords may be compromised at once,  
 since malware writers can work out how to hack common products. This is a  
 particular issue when using a browser, and another is that a master password is  
 not always the default so many users don’t set one. (The same holds for other  
 security services you get as options with platforms, such as encrypting your  
 phone or laptop.) An advantage of using the browser is that you may be able  
 to sync passwords between the browser in your phone and that in your laptop.

Third-party password managers can offer more, such as choosing long ran-

dom passwords for you, identifying passwords shared across more than one web-  
 site, and providing more controllable ways for you to manage the backup and  
 recovery of your password collection. (With a browser, this comes down to

backing up your whole laptop or phone.) They can also help you track your ac-  
 counts, so you can see whether you had a password on a system that’s announced  
 a breach. The downside is that many products are truly dreadful, with even  
 some hardware password managers storing all your secrets in the clear [130],  
 while the top ﬁve software products suffer from serious and systemic vulnerabil-  
 ities, from autocomplete to ignoring subdomains [389]. How do you know that

|  |  |  |
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| **Security Engineering** | 118 | Ross Anderson |

*3.4. PASSWORDS*

any given product is actually sound?

Many banks try to disable storage, whether by setting autocomplete="off"

in their web pages or using other tricks that block password managers too. Banks  
 think this improves security, but I’m not at all convinced. Stopping people using  
 password managers or the browser’s own storage will probably make most of  
 them use weaker passwords. The banks may argue that killing autocomplete  
 makes compromise following device theft harder, and may stop malware stealing  
 the password from the database of your browser or password manager, but  
 the phishing defence provided by that product is disabled – which may expose  
 the average customer to greater risk [1355]. It’s also inconvenient; one bank  
 that suddenly disabled password storage had to back down the following day,  
 because of the reaction from customers [1278]. People manage risk in all sorts  
 of ways. I personally use different browsers for different purposes, and let them  
 store low-value passwords; for important accounts, such as email and banking, I  
 always enter passwords manually, and always navigate to them via bookmarks  
 rather than by clicking on links. But most people are less careful. And be sure  
 to think through backup and recovery, and exercise it to make sure it works.  
 What happens when your laptop dies? When your phone dies? When someone  
 persuades your phone company to link your phone number to their SIM? When  
 you die – or when you fall ill and your partner needs to manage your stuff? Do  
 they know where to ﬁnd the master passwords? Writing them down in a book  
 can make sense, if all you (and your executor) have to remember is ‘page 169,  
 Great Expectations.’ Writing them down in a diary you tote with you, on a  
 page saying ‘passwords’, is not so great. Very few people get all this right.

**3.4.12** **Will we ever get rid of passwords?**

Passwords are annoying, so many people have discussed getting rid of them, and  
 the move from laptops to phones gives us a chance. The proliferation of IoT  
 devices that don’t have keyboards will force us to do without them for some  
 purposes. A handful of ﬁrms have tried to get rid of them completely. One  
 example is the online bank Monzo, which operates exclusively via an app. They  
 leave it up to the customer whether they protect their phone using a ﬁnger-  
 print, a pattern lock, a PIN or a password. However they still use email to  
 prompt people to upgrade, and to authenticate people who buy a new phone,  
 so account takeover involves either phone takeover, or guessing a password or  
 a password recovery question. The most popular app that uses SMS to au-  
 thenticate rather than a password may be WhatsApp. I expect that this will  
 become more widespread; so we’ll see more attacks based on phone takeover,  
 from SIM swaps through Android malware, SS7 and RCS hacking, to simple  
 physical theft. In such cases, recovery often means an email loop, making your  
 email password more critical than ever – or phoning a call centre and telling  
 them your mother’s maiden name. So things may change less than they seem.

Joe Bonneau and colleagues analysed the options in 2012 [292]. There are

many criteria against which an authentication system can be evaluated, and  
 we’ve worked through them here: resilience to theft, to physical observation,  
 to guessing, to malware and other internal compromise, to leaks from other  
 veriﬁers, to phishing and to targeted impersonation. Other factors include ease

|  |  |  |
| --- | --- | --- |
| **Security Engineering** | 119 | Ross Anderson |

*3.4. PASSWORDS*

of use, ease of learning, whether you need to carry something extra, error rate,  
 ease of recovery, cost per user, and whether it’s an open design that anyone  
 can use. They concluded that most of the schemes involving net beneﬁts were  
 variants on single sign-on – and OpenID has indeed become widespread, with  
 many people logging in to their newspaper using Google or Facebook, despite the  
 obvious privacy cost6. Beyond that, any security improvements involve giving  
 up one or more of the beneﬁts of passwords, namely that they’re easy, efficient  
 and cheap.

Bonneau’s survey gave high security ratings to physical authentication to-

kens such as the CAP reader, which enables people to use their bank cards to  
 log on to online banking; bank regulators have already mandated two-factor au-  
 thentication in a number of countries. Using something tied to a bank card gives  
 a more traditional root of trust, at least with traditional high-street banks; a  
 customer can walk into a branch and order a new card7. Firms that are targets  
 of state-level attackers, such as Google and Microsoft, now give authentication  
 tokens of some kind or another to all their staff.

Did the survey miss anything? Well, the old saying is ‘something you have,

something you know, or something you are’ – or, as Simson Garﬁnkel engagingly  
 puts it, ‘something you had once, something you’ve forgotten, or something you  
 once were’. The third option, biometrics, has started coming into wide use since  
 high-end mobile phones started offering ﬁngerprint readers. Some countries, like  
 Germany, issue their citizens with ID cards containing a ﬁngerprint, which may  
 provide an alternate root of trust for when everything else goes wrong. We’ll  
 discuss biometrics in its own chapter later in the book.

Both tokens and biometrics are still mostly used with passwords, ﬁrst as

a backstop in case a device gets stolen, and second as part of the process of  
 security recovery. So passwords remain the (shaky) foundation on which much  
 of information security is built. What may change this is the growing number of  
 devices that have no user interface at all, and so have to be authenticated using  
 other mechanisms. One approach that’s getting ever more common is trust on  
 ﬁrst use, also known as the ‘resurrecting duckling’ after the fact that a duckling  
 bonds on the ﬁrst moving animal it sees after it hatches. We’ll discuss this in the  
 next chapter, and also when we dive into speciﬁc applications such as security  
 in vehicles.

Finally, you should think hard about how to authenticate customers or other

people who exercise their right to demand copies of their personal information  
 under data-protection law. In 2019, James Pavur sent out 150 such requests to  
 companies, impersonating his ﬁanc´ee [1886]. 86 ﬁrms admitted they had infor-

6Government attempts to set up single sign-on for public services have been less successful,

with the UK ‘Verify’ program due to be shuttered in 2020 [1392]. There have been many  
 problems around attempts to entrench government’s role in identity assurance, which I’ll  
 discuss further in the chapter on biometrics, and which spill over into issues from online  
 services to the security of elections. It was also hard for other private-sector ﬁrms to compete  
 because of the network effects enjoyed by incumbents. However in 2019 Apple announced that  
 it would provide a new, more privacy-friendly single sign-on mechanism, and use the market  
 power of its app store to force websites to support it. Thus the quality and nature of privacy  
 on offer is becoming a side-effect of battles fought for other motives. We’ll analyse this in  
 more depth in the chapter on economics.

7This doesn’t work for branchless banks like Monzo; but they do take a video of you when

you register so that their call centre can recognise you later.

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| **Security Engineering** | 120 | Ross Anderson |

*3.5. CAPTCHAS*

mation about her, and many had the sense to demand her logon and password  
 to authenticate her. But about a quarter were prepared to accept an email

address or phone number as authentication; and a further 16 percent asked for  
 easily forgeable ID. He collected full personal information about her, including  
 her credit card number, her social security number and her mother’s maiden  
 name. A threat intelligence ﬁrm with which she’d never interacted sent a list  
 of her accounts and passwords that had been compromised. Given that ﬁrms  
 face big ﬁnes in the EU if they don’t comply with such requests within 30 days,  
 you’d better work out in advance how to cope with them, rather than leaving  
 it to an assistant in your law office to improvise a procedure. If you abolish  
 passwords, and a former customer claims their phone was stolen, what do you  
 do then? And if you hold personal data on people who have never been your  
 customers, how do you identify them?

**3.5** **CAPTCHAs**

Can we have protection mechanisms that use the brain’s strengths rather than  
 its weaknesses? The most successful innovation in this ﬁeld is probably the

CAPTCHA – the ‘Completely Automated Public Turing Test to Tell Comput-  
 ers and Humans Apart’. These are the little visual puzzles that you often have to  
 solve to post to a blog, to register for a free online account, or to recover a pass-  
 word. The idea is that people can solve such problems easily, while computers  
 ﬁnd them hard.

CAPTCHAs ﬁrst came into use in a big way in 2003 to stop spammers using

scripts to open thousands of accounts on free email services, and to make it  
 harder for attackers to try a few simple passwords with each of a large number  
 of existing accounts. They were invented by Luis von Ahn and colleagues [1969],  
 who were inspired by the test famously posed by Alan Turing as to whether a  
 computer was intelligent: you put a computer in one room and a human in  
 another, and invite a human to try to tell them apart. The test is turned round  
 so that a computer can tell the difference between human and machine.

Early versions set out to use a known ‘hard problem’ in AI such as the recog-

nition of distorted text against a noisy background. The idea is that breaking  
 the CAPTCHA was equivalent to solving the AI problem, so an attacker would  
 actually have to do the work by hand, or come up with a real innovation in  
 computer science. Humans were good at reading distorted text, while programs  
 were less good. It turned out to be harder than it seemed. A lot of the attacks  
 on CAPTCHAs, even to this day, exploit the implementation details.

Many of the image recognition problems posed by early systems also turned

out not to be too hard at all once smart people tried hard to solve them. There  
 are also protocol-level attacks; von Ahn mentioned that in theory a spammer  
 could get people to solve them as the price of access to free porn [1968]. This  
 soon started to happen: spammers created a game in which you undress a  
 woman by solving one CAPTCHA after another [191]. Within a few years, we  
 saw commercial CAPTCHA-breaking tools arriving on the market [843]. Within  
 a few more, generic attacks using signal-processing techniques inspired by the  
 human visual system had become fairly efficient at solving at least a subset

|  |  |  |
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| **Security Engineering** | 121 | Ross Anderson |

*3.6. SUMMARY*

of most types of text CAPTCHA [746]. And security-economics research in

underground markets has shown that by 2011 the action had moved to using  
 humans; people in countries with incomes of a few dollars a day will solve  
 CAPTCHAs for about 50c per 1000.

From 2014, the CAPTCHA has been superseded by the ReCAPTCHA, an-

other of Luis von Ahn’s inventions. Here the idea is to get a number of users to  
 do some useful piece of work, and check their answers against each other. The  
 service initially asked people to transcribe fragments of text from Google books  
 that confused OCR software; more recently you get a puzzle with eight pictures  
 asking ‘click on all images containing a shop front’, which helps Google train its  
 vision-recognition AI systems8. It pushes back on the cheap-labour attack by  
 putting up two or three multiple-choice puzzles and taking tens of seconds over  
 it, rather than allowing rapid responses.

The implementation of CAPTCHAs is often thoughtless, with accessibility

issues for users who are visually impaired. And try paying a road toll in Portugal  
 where the website throws up a CAPTCHA asking you to identify pictures with  
 an object, if you can’t understand Portuguese well enough to ﬁgure out what  
 you’re supposed to look for!

**3.6** **Summary**

Psychology matters to the security engineer, because of deception and because of  
 usability. Most real attacks nowadays target the user. Various kinds of phishing  
 are the main national-security threat, the principal means of developing and  
 maintaining the cybercrime infrastructure, and one of the principal threats to  
 online banking systems. Other forms of deception account for much of the rest  
 of the cybercrime ecosystem, which is roughly equal to legacy crime in both  
 volume and value.

Part of the remedy is security usability, yet research in this ﬁeld was long

neglected, being seen as less glamorous than cryptography or operating systems.  
 That was a serious error on our part, and from the mid-2000s we have started  
 to realise the importance of making it easier for ordinary people to use systems  
 in safe ways. Since the mid-2010s we’ve also started to realise that we also have  
 to make things easier for ordinary programmers; many of the security bugs that  
 have broken real systems have been the result of tools that were just too hard to  
 use, from cryptographic APIs that used unsafe defaults to the C programming  
 language. Getting usability right also helps business directly: PayPal has built a  
 $100bn business through being a safer and more convenient way to shop online9.

In this chapter, we took a whistle-stop tour through psychology research

relevant to deception and to the kinds of errors people make, and then tackled  
 authentication as a case study. Much of the early work on security usability  
 focused on password systems, which raise dozens of interesting questions. We

8There’s been pushback from users who see a ReCAPTCHA saying ‘click on all images

containing a helicopter’ and don’t want to help in military AI research. Google’s own staff  
 protested at this research too and the program was discontinued. But other users still object  
 to working for Google for free.

9Full disclosure: I consult for them.

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| **Security Engineering** | 122 | Ross Anderson |

*3.6. SUMMARY*

now have more and more data not just on things we can measure in the lab such  
 as guessability, memorability, and user trainability, but also on factors that can  
 only be observed in the ﬁeld such as how real systems break, how real attacks  
 scale and how the incentives facing different players lead to unsafe equilibria.

At the end of the ﬁrst workshop on security and human behavior in 2008,

the psychologist Nick Humphrey summed up a long discussion on risk. “We’re  
 all agreed,” he said, “that people pay too much attention to terrorism and not  
 enough to cybercrime. But to a psychologist this is obvious. If you want people  
 to be more relaxed in airports, take away the tanks and guns, put in some nice  
 sofas and Mozart in the loudspeakers, and people will relax soon enough. And  
 if you want people to be more wary online, make everyone use Jaws as their  
 screen saver. But that’s not going to happen as the computer industry goes out  
 of its way to make computers seem a lot less scary than they used to be.” And of  
 course governments want people to be anxious about terrorism, as it bids up the  
 police budgets and helps politicians get re-elected. So we give people the wrong  
 signals as well as spending our money on the wrong things. Understanding the  
 many tensions between the demands of psychology, economics and engineering  
 is essential to building robust systems at global scale.

**Research problems**

Security psychology is one of the hot topics in 2020. In the second edition of this  
 book, I noted that the whole ﬁeld of security economics had sprung into life since  
 the ﬁrst edition in 2001, and wrote ‘We also need more fundamental thinking  
 about the relationship between psychology and security’. Security usability

has become a discipline too, with the annual Symposium on Usable Privacy and  
 Security, and we’ve been running workshops to bring security engineers together  
 with anthropologists, psychologists, philosophers and others who work on risk  
 and how people cope with it.

My meta-algorithm for ﬁnding research topics is to look ﬁrst at applications

and then at neighbouring disciplines. An example of the ﬁrst is safe usability:  
 as safety-critical products from cars to medical devices acquire not just software  
 and Internet connections, but complex interfaces and even their own apps, how  
 can we design them so that they won’t harm people by accident, or as a result  
 of malice?

An example of the second, and the theme of the Workshop on Security

and Human Behaviour, is what we can learn from disciplines that study how  
 people deal with risk, ranging from anthropology and psychology to sociology,  
 history and philosophy. Our 2020 event is hosting leading criminologists. The  
 pandemic now suggests that maybe we should work with architects too. They’re  
 now working out how people can be physically distant but socially engaged, and  
 their skill is understanding how form facilitates human experience and human  
 interaction. There’s more to design than just hacking code.

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| **Security Engineering** | 123 | Ross Anderson |

*3.6. SUMMARY*

**Further reading**

The Real Hustle videos are probably the best tutorial on deception; a number  
 of episodes are on YouTube. Meanwhile, the best book on social engineering is  
 still Kevin Mitnick’s *‘The Art of Deception’* [1325]. Amit Katwala wrote a short  
 survey of deception detection technologies [1024] while Tony Docan-Morgan has  
 edited a 2019 handbook on the state of deception research with 51 chapters by  
 specialists on its many aspects [569].

For how social psychology gets used and abused in marketing, the must-

read book is Tim Wu’s *‘The Attention Merchants’* which tells the history of  
 advertising [2050].

In the computer science literature, perhaps a good starting point is James

Reason’s *‘Human Error’*, which tells us what the safety-critical systems com-  
 munity has learned from many years studying the cognate problems in their  
 ﬁeld [1589]. Then there are standard HCI texts such as [1544], while early pa-  
 pers on security usability appeared as [493] and on phishing appeared as [976].  
 As we move to a world of autonomous devices, there is a growing body of research  
 on how we can get people to trust robots more by Disneyﬁcation – for example,  
 giving library robots eyes that follow the direction of travel, and making them  
 chirp with happiness when they help a customer [1687]. Similar research on  
 autonomous vehicles shows that people trust such vehicles more if they’re given  
 some personality, and the passengers are given some strategic control such as  
 the ability to select routes or even just to order the car to stop.

As for behavioral economics, I get my students to read Danny Kahneman’s

Nobel prize lecture. For more technical detail, there’s a volume of papers Danny  
 edited just before that with Tom Gilovich and Dale Griffin [769], or the pop  
 science book *‘Thinking, Fast and Slow’* that he wrote afterwards [1005]. An  
 alternative view, which gives the whole history of behavioral economics, is Dick  
 Thaler’s *‘Misbehaving: The Making of Behavioural Economics’* [1874]. For the  
 applications of this theory in government and elsewhere, the standard reference  
 is Dick Thaler and Cass Sunnstein’s *‘Nudge’* [1876]. Dick’s later second thoughts  
 about ‘Sludge’ are at [1875].

For a detailed history of passwords and related mechanisms, as well as many

empirical results and an analysis of statistical techniques for measuring both  
 guessability and recall, I strongly recommend Joe Bonneau’s thesis [289], a  
 number of whose chapters ended up as papers I cited above.

Finally, if you’re interested in the dark side, *‘The Manipulation of Human*

*Behavior’* by Albert Biderman and Herb Zimmer reports experiments on inter-  
 rogation carried out after the Korean War with US Government funding [239].  
 Known as the Torturer’s Bible, it describes the relative effectiveness of sensory  
 deprivation, drugs, hypnosis, social pressure and so on when interrogating and  
 brainwashing prisoners. As for the polygraph and other deception-detection

techniques used nowadays, the standard reference is by Aldert Vrij [1970].

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| **Security Engineering** | 124 | Ross Anderson |