Compendium

TDT4237 - Software Security

Part one
Security Engineering, second edition

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Contents

Chapter 1

What is Security Engeneering?

A Framework Good security engeneering requires four things to come together:

1. **Policy:** what you're supposed to achieve.
2. **Mechanism:** the chipers, access controls, hardware tamper-resistance and other mechinery that you assemblein order to implement the policy.
3. **Assurance:** the amount of reliance you can place on each particular mechanism.
4. **Incentive:** the motive that people guarding and maintaining the system have to do their job properly, and also the motive that the attackers have to try to defeat your policy.

Why ae poor policy choices made? Quite simply, the incentives on the decision makers favor visible controls over effective ones. The result is what Bruce Schneier calls "security theatre" - measures designed to produce a feeling of security rather than the reality.

The role as a security engineer:

- We need to be able to put risks and threats in content.
- We need to be able to make realistic assessments of what might go wrong.
- We need to give our clients good advice.

Case studies: I will not describe these in detail. It is described in the book (pages 6-11).

- A bank
- A military base
- A hospital
- The Home

1.1 Definitions

1.1.1 System

1. a product or component, such as a cryptographic protocol, a smartcard or the hardware of a PC.
2. a collection of the above plus an operating system, communications and other things that go to make up an organization's infrastructure.
3. the above plus one or more applications (media player, browser, word processor, accounts / payroll package, and so on).
4. any or all of the above plus IT staff.
5. any or all of the above plus internal users and management;
6. any or all of the above plus customers and other external users

1.1.2 Subject, Person and Principal

- **Subject:** By a subject I will mean a physical person (human, ET, ...), in any role including that of an operator, principal or victim.
- **Person:** By a person, I will mean either a physical person or a legal person such as a company or government.
- **Principal:** A principal is an entity that participates in a security system. This entity can be a subject, a person, a role, or a piece of equipment such as a PC, smartcard, or card reader terminal. A principal can also be a communications channel (which might be a port number, or a crypto key, depending on the circumstance). A principal can also be a compound of other principals

1.1.3 Identity

1.1.4 Trust and Trustworthy

The definitions of trust and trustworthy are often confused. The following example illustrates the difference: if an NSA employee is observed in a toilet stall at Baltimore Washington International airport selling key material to a Chinese diplomat, then (assuming his operation was not authorized) we can describe him as 'trusted but not trustworthy'. Hereafter, we'll use the NSA definition that a trusted system or component is one whose failure can break the security policy, while a trustworthy system or component is one that won't fail.

1.1.5 Confidenciality, Privacy and Secrecy

- **Secrecy** is a technical term which refers to the effect of the mechanisms used to limit the number of principals who can access information, such as cryptography or computer access controls.
- **Confidentiality** involves an obligation to protect some other person's or organization's secrets if you know them.
- **Privacy** is the ability and/or right to protect your personal information and extends to the ability and/or right to prevent invasions of personal space.

1.1.6 Authenticity and Integrity

Summary

- Framework
- Security theatre
- The role as a security engineer
- Case studies (bank, military base, hospital, the Home)
- Definition: System
- Definitions: subject, person and principal
- Identity
- Trust and Trustworthy
- Confidenciality, Privacy and Secrecy
- Authenticity and Integrity

Chapter 2

Usability and Psychology

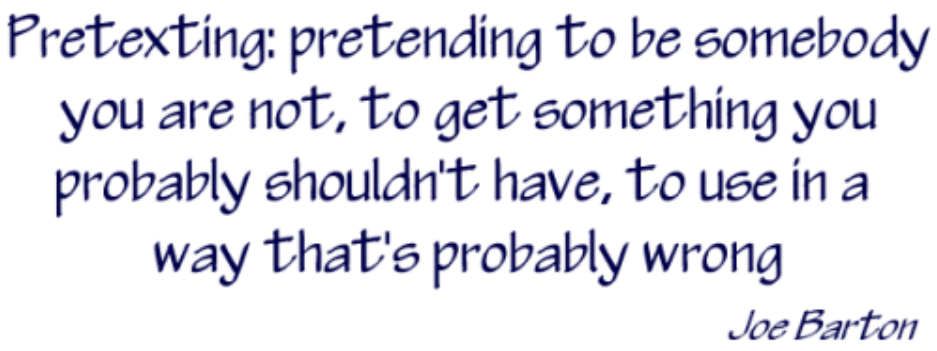
Social engineering

2.1 Attacks Based on Psychology

2.1.1 Pretexting

Pretexting is a form of social engineering in which an individual lies to obtain privileged data. A pretext is a false motive. Pretexting often involves a scam where the liar pretends to need information in order to confirm the identity of the person he is talking to. After establishing trust with the targeted individual, the pretexter might ask a series of questions designed to gather key individual identifiers.

The pretexter's goal is to obtain personal information about you, such as your SSN, your bank or credit card account numbers, mother's maiden name, information contained in your credit report, or the existence and size of your savings and investment portfolios. After getting your answers, the pretexter may call your financial institution pretending to be you or someone with authorized access to your account. The pretexter may, for example, claim that he's forgotten his checkbook and needs information about his account.



2.1.2 Phising

Phishing is a technique of fraudulently obtaining private information. Typically, the phisher sends an e-mail that appears to come from a legitimate business — a bank, or credit card company—requesting "verification" of information and warning of some dire consequence if it is not provided. The e-mail usually contains a link to a fraudulent web page that seems legitimate — with company logos and content and has a form requesting everything from a home address to an ATM card's PIN.

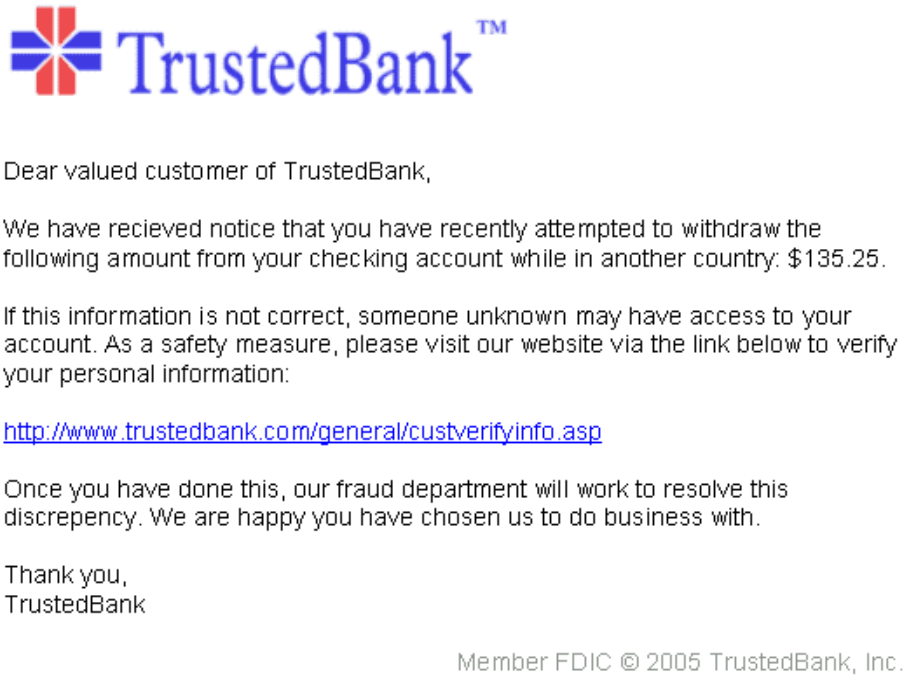


Figure 2.1: Phising attempt

2.2 Insights from Psychology Research

What the Brain does Worse Than the Computer

- Actions performed often become a matter of skill, but this comes with a downside: inattention can cause a practised action to be performed instead of an intended one. We are all familiar with such capture errors; an example is when you intend to go to the supermarket on the way home from work but take the road home by mistake — as that's what you do most days. In computer systems, people are trained to click 'OK' to pop-up boxes as that's often the only way to get the work done; some attacks have used the fact that enough people will do this even when they know they shouldn't.
- Actions that people take by following rules are open to errors when they follow the wrong rule. Various circumstances — such as information overload — can cause people to follow the strongest rule they know, or the most general rule, rather than the best one. Examples of phishermen getting people to follow the wrong rule include using https (because 'it's secure') and starting URLs with the impersonated bank's name, as www.citibank.secureauthentication.com — looking for the name being for many people a stronger rule than parsing its position.
- The third category of mistakes are those made by people for cognitive reasons — they simply don't understand the problem. For example, Microsoft's latest (IE7) anti-phishing toolbar is easily defeated by a picture-in-picture attack.

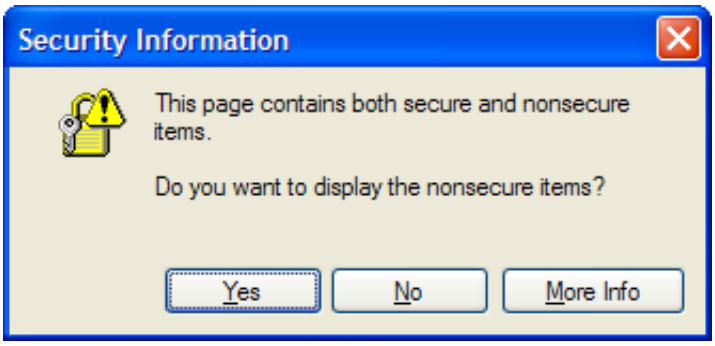


Figure 2.2: Actions performed often become a matter of skill

Preceptual Bias and Behavioural Economics

- How do people make decisions faced with uncertainty?
- By framing an action as a gain rather than as a loss makes people more likely to take it.
- We're also bad at calculating probabilities, and use all sorts of heuristics to help us make decisions: we base inferences on familiar or easily-imagined analogies, and by comparison with recent experiences.
- We also worry too much about unlikely events. We're morelikely to be sceptical about things we've heard than about things we've seen.
- Many frauds work by appealing to our atavistic instincts to trust people more in certain situations or over certain types of decision.
- Many people perceive terrorism to be a much worse threat than food poisoning or road traffic accidents: this is irrational. 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 on TV.
- Global warming doesn't violate anyone's moral sensibilities and it's a long-term threat rather than a clear and present danger. Humans are sensitive to rapid changes in the environment rather than slow ones.
- 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.
- We have a tendency to plump for the alternative that's 'good enough' rather than face the cognitive strain of trying to work out the odds perfectly. Another aspect of this is that many people just plump for the standard configuration of a system, as they assume it will be good enough. This is one reason why secure defaults matter.
- The appearance of protection can matter just as much as the reality. For example, many people don't use electronic banking because of a fear of fraud, so banks pay a fortune for the time of branch and call-center staff. It's not enough for the security engineer to stop bad things happening; you also have to reassure people.

Differences Between People - Gender

Most information systems are designed by men, and yet over half their users may be women. Recently people have realised that software can create barriers to females, and this has led to research work on 'gender HCI' — on how software should be designed so that women as well as men can use it effectively. For example, it's known that women navigate differently from men in the real world, using peripheral vision more, and it duly turns out that larger displays reduce gender bias. Other work has focused on female programmers, especially end-user programmers working with tools like spreadsheets. It turns out that women tinker less than males, but more effectively.

Women appear to be more thoughtful, but lower self-esteem and higher risk-aversion leads them to use fewer features. Given that many of the world's spreadsheet users are women, this work has significant implications for product design.

Simon Baron-Cohen, classifies human brains into type S (systematizers) and type E (empathizers). Type S people are better at geometry and some kinds of symbolic reasoning, while type E's are better at language and multiprocessing. Most men are type S, while most women are type E, a relationship that Baron-Cohen believes is due to fetal testosterone levels.

Figure 2.3: Are security mechanisms gender-neutral?

Social Psychology

This discipline attempts to explain how the thoughts, feelings, and behaviour of individuals 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, through the self-esteem we get by comparing ourselves with others.

The growth of social-networking systems will lead to peer pressure being used as a tool for deception, just as it is currently used as a tool for marketing fashions.

Experiments has showed that people will obey an authority rather than their conscience. Most people will do downright immoral things if they are told to. A Experiment 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. Abuse of authority, whether real or ostensible, is a major issue for people designing operational security measures. Abuse of authority are the key in in security experiments.

What the Brain Does Better Than the Computer

- We are extremely good at recognising other humans visually, an ability shared by many primates.
- We are good at image recognition generally; a task such as 'pick out all scenes in this movie where a girl rides a horse next to water' is trivial for a human child yet a hard research problem in image processing.
- We're also better thanmachines at understanding speech, particularly in noisy environments, and at identifying speakers.
- These abilities mean that it's possible to devise tests that are easy for humans to pass but hard for machines — the so-called 'CAPTCHA' test.

2.3 Passwords

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, frequently-changed, or many similar items; we can't forget on demand; recall is harder than recognition; and non-meaningful words are more difficult.

There are system and policy issues too: as people become principals in more and more electronic systems, the same passwords get used over and over again. Not only may attacks be carried out by outsiders guessing passwords, but by insiders in other systems. People are now asked to choose passwords for a large number of websites that they visit rarely.

Passwords are not, of course, the only way of authenticating users to systems. There are basically three options. The person may retain physical control of the device — as with a remote car door key. The second is that she presents something she knows, such as a password. The third is to use something like a fingerprint or iris pattern

Passwords matter, and managing them is a serious real world problem that mixes issues of psychology with technical issues. 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?

2.3.1 Difficulties with Remembering the Password

Our first human-factors issue is that if a password is too long or complex, users might have difficulty entering it correctly.

when customers are expected to memorize passwords, they either choose values which are easy for attackers to guess, or write them down, or both. In fact, the password problem has been neatly summed up as: "Choose a password you can't remember, and don't write it down."

People choose naive passwords. People will use names, single letters, or even just hit carriage return giving an empty string as their password. So some systems started to require minimum password lengths, or even check user entered passwords against a dictionary of bad choices. However, password quality enforcement is harder than you might think.

2.3.2 User Abilities, Training and Design Errors

So what can you realistically expect from users when it comes to choosing and remembering passwords?

After a experiment (page 35-36) on password an humans, the conclusion was:

- For users who follow instructions, passwords based on mnemonic phrases offer the best of both worlds. They are as easy to remember as naively selected passwords, and as hard to guess as random passwords.
- The problem then becomes one of user compliance. A significant number of users (perhaps a third of them) just don't do what they're told.

An important 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 authenticate their customers in this way. But there are two rather obvious problems. First, your mother's maiden name is easy for a thief to find out, whether by asking around or using online genealogical databases. Second, asking for a maiden name makes assumptions which don't hold for all cultures, so you can end up accused of discrimination: Icelanders have no surnames, and women from many other countries don't change their names on marriage. Third, there is often no provision for changing 'your mother's maiden name', so if it ever becomes known to a thief your customer would have to close bank accounts (and presumably reopen them elsewhere).

A general error is failing to reset the default password in systems. Often is the default password the same in many different systems!

Banks have put som effort into trying to train their customers to look for certain features in websites: check the english, look for the lock symbol, it is ok to click on images, but not on URL's, hover your mouse over links before clicking on it, etc. This sort of arms race is more likely to benefit the attackers because the customers get very predictable in how they act.

2.3.3 Social-Engineering Attacks

'This is the security department of your bank. We see that your card has been used fraudulently to buy gold coins. I wonder if you can tell me the PIN, so I can get into the computer and cancel it?'. This even works by email!

A huge problem is that many banks and other businesses train their customers to act in unsafe ways. It's not prudent to click on links in emails, so if you want to contact your bank you should type in the URL or use a bookmark — yet bank marketing departments continue to send out emails containing clickable links. Many email clients — including Apple's, Microsoft's, and Google's — make plaintext URLs clickable, and indeed their users may never see a URL that isn't. This makes it harder for banks to do the right thing.

If even the fraud department doesn't understand that banks ought to be able to identify themselves, and that customers should not be trained to give out security information on the phone, what hope is there? When even a bank's security department can't tell spam from phish, how are their customers supposed to?

Trusted Path: A thread in the background of phishing is trusted path, which refers to some means of being sure that you're logging into a genuine machine through a channel that isn't open to eavesdropping. Here the deception is more technical than psychological; rather than inveigling a bank customer into revealing her PIN to you by claiming to be a policeman, you steal her PIN directly by putting a false ATM in a shopping mall. 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 does this, it will save the password somewhere in the system, reply 'sorry, wrong password' and then vanish, invoking the genuine password program. The user will assume that he made a typing error first time and think no more of it.

Have you wondered why Windows have the anoying ctrl-alt-del part befor login? It is there to make sure you will be entering genuine password prompt.

Other similar attacks is mofifoed keyboard, keyloggers, and skimmed bank terminals. I sometimes wonder, what if there is a keylogger in a windows system? If you press ctrl-alt-del, you will simply tell the attacker where your password is. The logged txt file will then have something like "ctrl alt del username password".

Two-factor authentication is now widley used. The basic idea is that it consists of something you have and something you know. It will be described in later chapters.

2.4 System Issues

There are also technical issues to do with password entry and storage that will be briefly covered here. Here are some examples of attacks we are trying to defend against:

- Targeted attack on one account (when sending email it is known as spear phishing)
- Attempt to penetrate any account on a system
- Service denial attack

Can you deny service? Banks often have a rule that a terminal and user account are frozen after three bad password attempts; after that, an administrator has to reactivate them. It sure works in a website, but what in the military? Could a system like this benefit the enemy/attacker? Many commercial websites nowadays don't limit guessing becuase of the possibility of such an attack (service denial attack).

Interface design: I usually cover my dialling hand with my body or my other hand when entering a card number or PIN in a public place — but you shouldn't design systems on the assumption that all your customers will do this. Many people are uncomfortable shielding a PIN from others as it's a visible signal of distrust. Because of this, a targeted attack against a person could be easy!

Eavesdropping: The latest modus operandi is for bad people to offer free WiFi access in public places, and harvest the passwords that users enter into websites. This is a kind of attempt to just get all sensitive information about anyone, and not just a specific person.

Timing attack: 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

Car keys (fail): Have you ever heard a story about someone that could open many cars at a parking lot with their own key? Yes, this is a kind of system fails where the number of bits used for opening a car was to small in order of how many cars that needed an uniqe key.

One-way encryption and plaintext storage: Password storage has also been a problem for some systems. Keeping a plaintext file of passwords can

be dangerous. The best way of storing a password is password + salt + hashing (can also add pepper to it).

Prevent more than x attempts or log all attempts?

There are various problems with this doctrine, of which the worst may be that the attacker's goal is often not to guess some particular user's password but to get access to any account. If a large defense network has a million possible passwords and a million users, and the alarm goes off after three bad password attempts on any account, then the attack is to try one password for every single account. Thus the quantity of real interest is the probability that the password space can be exhausted in the lifetime of the system at the maximum feasible password guess rate.

To prevent more than one password guess every few seconds per user account, or (if you can) by source IP address. You might also keep a count of all the failed logon attempts and analyse them: is there a constant series of guesses that could indicate an attempted intrusion? (And what would you do if you noticed one?).

2.5 CAPTCHA's

Recently people have tried to design protection mechanisms that use the brain's strengths rather than its weaknesses. One early attempt was Passfaces: this is an authentication system that presents users with nine faces, only one of which is of a person they know; they have to pick the right face several times in a row to log on [356]. The rationale is that people are very good at recognising other people's faces, but very bad at describing them: so you could build a system where it was all but impossible for people to give away their passwords, whether by accident or on purpose. Other proposals of this general type have people selecting a series of points on an image — again, easy to remember but hard to disclose. Both types of system make shoulder surfing harder, as well as deliberate disclosure offline.

The most successful innovation in this field, however, is the CAPTCHA — which stands for 'Completely Automated Public Turing Test to Tell Computers and Humans Apart.'

The idea is that a program generates some random text, and produces a distorted version of it that the user must decipher. Humans are good at reading distorted text, while programs are less good.

It is inspired by the test famously posed by Alan Turing as to whether a computer was intelligent, where you put a computer in one room and a human in another, and invite a human to try to tell them apart.

Chapter 3

Protocols

3.1 Password Eavesdropping Risks

A good case study comes from simple embedded systems, such as the remote control used to open your garage or to unlock the doors of cars manufactured up to the mid-1990's. These primitive remote controls just broadcast their serial number, which also acts as the password. An attack that became common was to use a 'grabber', a device that would record a code broadcast locally and replay it later.

sixteen-bit passwords are too short. It occasionally happened that people found they could unlock the wrong car by mistake. By the mid-1990's, devices appeared which could try all possible codes one after the other. A code will be found on average after about 215 tries, which at ten per second takes under an hour. A thief operating in a parking lot with a hundred vehicles within range would be rewarded in less than a minute with a car helpfully flashing its lights.

3.2 Simple Authentication

Nonce: The term nonce can mean anything that guarantees the freshness of a message. A nonce can, according to the context, be a random number, a serial number, a random challenge received from a third party, or even a timestamp.

Security and business: Security mechanisms are used more and more to support business models, by accessory control, rights management, product tying and bundling. It is wrong to assume blindly that security protocols exist to keep 'bad' guys 'out'. They are increasingly used to constrain the lawful owner of the equipment in which they are built; their purpose may be of questionable legality or contrary to public policy. For example: Many printer companies embed authentication mechanisms in printers to ensure that genuine toner cartridges are used. If a competitor's product is loaded instead, the printer may quietly downgrade from 1200 dpi to 300 dpi, or simply refuse to work at all. Mobile phone vendors make a lot of money from replacement batteries, and now use authentication protocols to spot competitors' products so they can be blocked or even drained more quickly.

3.2.1 Challenge and response

Many cars use a more sophisticated two-pass protocol, called challenge-response, to actually authorise engine start. As the car key is inserted into the steering lock, the engine controller sends a challenge consisting of a random n-bit number to the key using short-range radio. The car key computes a response by encrypting the challenge. This is still not bulletproof, how random is random?

two-factor authentication: A much more visible use of challenge-response is in two-factor authentication. Many organizations issue their staff with password generators to let them log on to corporate computer systems. These may look like calculators but their main function is as follows; when you want to log in to a machine on the network, you call up a logon screen and are presented with a random challenge of maybe seven digits. You key this into your password generator, together with a PIN of maybe four digits. The device encrypts these eleven digits using a secret key shared with the corporate security server, and displays the first seven digits of the result. You enter these seven digits as your password.

3.2.2 Reflection Attacks

–Write something here?–

3.3 Manipulating the Message

An example is when dishonest cabbies insert pulse generators in the cable that connects their taximeter to a sensor in their taxi's gearbox. The sensor sends pulses as the prop shaft turns, which lets the meter work out how far the taxi has gone. A pirate device, which inserts extra pulses, makes the taxi appear to have gone further.

Another example is a key log attack which defeated many pay-TV systems. If the messages that pass between the smartcard and the decoder are the same for all decoders (which is usually the case) then a subscriber can log all the keys sent by his card to his decoder and post it online somewhere. People without a subscription, but who have video-recorded the enciphered program, can then download the key log and use it to decipher the tape.

3.4 Changing the Environment

A very common cause of protocol failure is that the environment changes, so that assumptions which were originally true no longer hold and the security protocols cannot cope with the new threats.

For example, a passenger who commuted a long distance from a suburban station to downtown might buy two cheaper, short distance season tickets — one between his suburban station and a nearby one, and the other between his destination and another downtown station.

An other example is a one-day travel pass in London. When a one-day travel pass was sold, the revenue was distributed between the various bus, train and subway operators using a formula that depended on where it was sold. Suddenly, the train companies had a motive to book all their ticket sales through the outlet that let them keep the largest percentage. As well as bad outsiders (passengers), we now had bad insiders (rail companies), and the design just hadn't allowed for them. Chaos and litigation ensued.

The transport system's problem was not new; it had been observed in the Italian ski resort of Val di Fassa in the mid-1970's. There, one could buy a monthly pass for all the ski lifts in the valley. An attendant at one of the lifts was observed with a deck of cards, one of which he swiped through the reader between each of the guests. It turned out that the revenue was divided up between the various lift operators according to the number of people who had passed their turnstiles. So each operator sought to inflate its own figures as much as it could.

3.5 Chosen Protocol Attacks

Here's one example. It used to be common for people visiting a porn website to be asked for 'proof of age,' which usually involves giving a credit card number, whether to the site itself or to an age checking service. If credit and debit cards become usable in PCs, it would be natural for the porn site to ask the customer to authenticate a random challenge as proof of age. A porn site can then mount a 'Mafia-in-the-middle' attack. They wait until an unsuspecting customer visits their site, then order something resellable (such as gold coins) from a dealer, playing the role of the coin dealer's customer. When the coin dealer sends them the transaction data for authentication, they relay it through their porn site to the waiting customer. The poor man OKs it, the Mafia gets the gold coins, and when thousands of people suddenly complain about the huge charges to their cards at the end of the month, the porn site has vanished — along with the gold.

3.6 Managing Encryption Keys

Authentication protocols are now also used in distributed computer systems for general key management purposes, and are therefore becoming ever more important. Kerberos was the first such system to come into widespread use, and a variant of it is used in Windows.

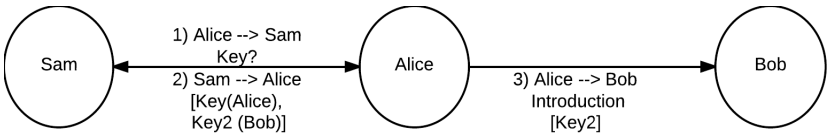
3.6.1 Basic Key Management

The basic idea behind key distribution protocols is that where two principals want to communicate, they may use a trusted third party to effect an introduction. When discussing authentication protocols, it is conventional to give the principals human names in order to avoid getting lost in too much algebraic notation. So we will call the two communicating principals **'Alice'** and **'Bob'**, and the trusted third party **'Sam'**.

A simple authentication protocol could run as follows.

1. Alice first calls Sam and asks for a key for communicating with Bob.
2. Sam responds by sending Alice a pair of certificates. Each contains a copy of a key, the first encrypted so only Alice can read it, and the second encrypted so only Bob can read it.
3. Alice then calls Bob and presents the second certificate as her introduction. Each of them decrypts the appropriate certificate under the key they share with Sam and thereby gets access to the new key. Alice

can now use the key to send encrypted messages to Bob, and to receive messages from him in return.



Expanding the notation, Alice calls Sam and says she'd like to talk to Bob. Sam makes up a session key message consisting of Alice's name, Bob's name, a key for them to use, and a timestamp. He encrypts all this under the key he shares with Alice, and he encrypts another copy of it under the key he shares with Bob. He gives both ciphertexts to Alice. Alice retrieves the key from the ciphertext that was encrypted to her, and passes on to Bob the ciphertext encrypted for him. She now sends him whatever message she wanted to send, encrypted using this key. Replay attacks are a known problem with authentication protocols, so in order that both Bob and Alice can check that the certificates are fresh, Sam may include a timestamp in each of them. If certificates never expire, there might be serious problems dealing with users whose privileges have been revoked.

$$
\begin{array}{ll}
A \rightarrow S: & A, B \\
S \rightarrow A: & \{A, B, K_{AB}, T\}_{K_{AS}}, \{A, B, K_{AB}, T\}_{K_{BS}} \\
A \rightarrow B: & \{A, B, K_{AB}, T\}_{K_{BS}}, \{M\}_{K_{AB}}
\end{array}
$$

3.6.2 The Needham-Schroeder Protocol

Many existing key distribution protocols are derived from the Needham-Schroeder protocol, which appeared in 1978 [960]. It is somewhat similar to the above, but uses nonces rather than timestamps. It runs as follows:

$$
\begin{array}{lll}
\text{Message 1} & A \rightarrow S: & A, B, N_A \\
\text{Message 2} & S \rightarrow A: & \{N_A, B, K_{AB}, \{K_{AB}, A\}_{K_{BS}}\}_{K_{AS}} \\
\text{Message 3} & A \rightarrow B: & \{K_{AB}, A\}_{K_{BS}} \\
\text{Message 4} & B \rightarrow A: & \{N_B\}_{K_{AB}} \\
\text{Message 5} & A \rightarrow B: & \{N_B - 1\}_{K_{AB}}
\end{array}
$$

Here Alice takes the initiative, and tells Sam: 'I'm Alice, I want to talk to Bob, and my random nonce is NA .' Sam provides her with a session key, encrypted using the key she shares with him. This ciphertext also

contains her nonce so she can confirm it's not a replay. He also gives her a certificate to convey this key to Bob. She passes it to Bob, who then does a challenge-response to check that she is present and alert.

There is a subtle problem with this protocol — Bob has to assume that the key KAB he receives from Sam (via Alice) is fresh. This is not necessarily so.

3.6.3 Kerberos

An important practical derivative of the Needham-Schroeder protocol may be found in Kerberos, a distributed access control system that originated at MIT and is now one of the standard authentication tools in Windows. Instead of a single trusted third party, Kerberos has two kinds: an authentication server to which users log on, and a ticket granting server which gives them tickets allowing access to various resources such as files. This enables more scalable access management. In a university, for example, one might manage students through their halls of residence but manage file servers by departments; in a company, the personnel people might register users to the payroll system while departmental administrators manage resources such as servers and printers.

$$
\begin{aligned}
A \to S: &\quad A, B \\
S \to A: &\quad \{T_S, L, K_{AB}, B, \{T_S, L, K_{AB}, A\}_{K_{BS}}\}_{K_{AS}} \\
A \to B: &\quad \{T_S, L, K_{AB}, A\}_{K_{BS}}, \{A, T_A\}_{K_{AB}} \\
B \to A: &\quad \{T_A + 1\}_{K_{AB}}
\end{aligned}
$$

Translating this into English: Alice asks the ticket granting server for access to B. If this is permissible, the ticket TS , L, KAB , AKBS is created containing a suitable key KAB and given to Alice to use. She also gets a copy of the key in a form readable by her, namely encrypted under KAS . She now verifies the ticket by sending a timestamp TA to the resource, which confirms it's alive by sending back the timestamp incremented by one (this shows it was able to decrypt the ticket correctly and extract the key KAB). The vulnerability of Needham-Schroeder has been fixed by introducing timestamps rather than random nonces. But, as in most of life, we get little in security for free. There is now a new vulnerability, namely that the clocks on our various clients and servers might get out of synch; they might even be desynchronized deliberately as part of a more complex attack.

3.7 Getting Formal

There are a number of different approaches to verifying the correctness of protocols. The best known is the logic of belief, or BAN logic. It reasons about what a principal might reasonably believe having seen of certain messages, time- stamps and so on. A second is the random oracle model, which is described in the chapter on cryptology and which is favored by people working on the theory of cryptography. Finally, a number of researchers have applied mainstream formal methods such as CSP and verification tools such as Isabelle.

3.7.1 The BAN Logic

$A \mid\equiv X$ *A believes X*, or, more accurately, that A is entitled to believe X;

$A \mid\sim X$ *A once said X* (without implying that this utterance was recent or not);

$A \mid\Rightarrow X$ *A has jurisdiction over X*, in other words A is the authority on X and is to be trusted on it;

$A \triangleleft X$ *A sees X*, that is, someone sent a message to A containing X in such a way that he can read and repeat it;

$\sharp X$ *X is fresh*, that is, contains a current timestamp or some information showing that it was uttered by the relevant principal during the current run of the protocol;

$\{X\}_K$ *X encrypted under the key K*, as in the rest of this chapter;

$A \leftrightarrow^K B$ *A and B share the key K*, in other words it is an appropriate key for them to use to communicate.

the message meaning rule states that if A sees a message encrypted under K, and K is a good key for communicating with B, then he will believe that the message was once said by B. (We assume that each principal can recognize and ignore his or her own messages.) Formally, $\frac{A \mid\equiv A \leftrightarrow^K B, A \triangleleft \{X\}_K}{A \mid\equiv B \mid\sim X}$

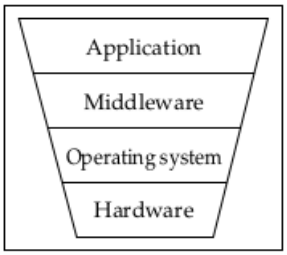
the nonce-verification rule states that if a principal once said a message, and the message is fresh, then that principal still believes it. Formally, $\frac{A \mid\equiv \sharp X, A \mid\equiv B \mid\sim X}{A \mid\equiv B \mid\equiv X}$

the jurisdiction rule states that if a principal believes something, and is an authority on the matter, then he or she should be believed. Formally, we write that $\frac{A \mid\equiv B \mid\Rightarrow X, A \mid\equiv B \mid\equiv X}{A \mid\equiv X}$

Chapter 4

Access Control

Access control is the traditional center of gravity of computer security. Its function is to control which principals (persons, processes, machines, . . .) have access to which resources in the system — which files they can read, which programs they can execute, how they share data with other principals, and so on.



Now one of the biggest challenges in computer security is preventing one program from interfering with another. You don't want a virus to be able to steal the passwords from your browser, or to patch a banking application so as to steal your money.

Microsoft Vista, place more emphasis on separating applications from each other; even if you don't care about security, preventing your programs from overwriting each others' configuration files should make your PC much more reliable.

More secure operating systems have led to ever more technical attacks on software other than the operating system; you don't want your brokerage account hacked via a computer game you downloaded that later truns out to be insecure. And employers would like ways of ensuring that employees' laptops don't pick up malware at home, so it makes sense to have one partition (or virtual machine) for work and another for play.

4.1 Operating System Access Control

The access controls provided with an operating system typically authenticate principals using a mechanism such as passwords or Kerberos, then mediate their access to files, communications ports and other system resources. Their effect can often be modelled by a **matrix** of access permissions, with columns for files and rows for users. We'll write **r** for permission to read, **w** for permission to write, **x** for permission to execute a program, and **-** for no access at all.

	Operating System	Accounts Program	Accounting Data	Audit Trail
Sam	rwx	rwx	rw	r
Alice	x	x	rw	–
Bob	rx	r	r	r

This is often enough, but in the specific case of a bookkeeping system it's not quite what we need. We want to ensure that transactions are well- formed — that each debit is matched by a credit somewhere else — so we would not want Alice to have uninhibited write access to the account file. We would also rather that Sam didn't have this access. So we would prefer that write access to the accounting data file be possible only via the accounting program.

User	Operating System	Accounts Program	Accounting Data	Audit Trail
Sam	rwx	rwx	r	r
Alice	rx	x	–	–
Accounts program	rx	r	rw	w
Bob	rx	r	r	r

Another way of expressing a policy of this type would be with access triples of (user, program, file). In the general case, our concern isn't with a program so much as a protection domain which is a set of processes or threads which share access to the same resources. Access control matrices (whether in two or three dimensions) can be used to implement protection mechanisms as well as just model them. But they do not scale well. For instance, a bank with 50,000 staff and 300 applications would have an access control matrix of 15,000,000 entries.

The two main ways of doing this are to compress the users and to compress the rights. As for the first of these, the simplest is to use groups or roles to

manage the privileges of **large sets of users** simultaneously, while in the second we may store the access control matrix either by **columns (access control lists)** or **rows (capabilities, sometimes known as 'tickets')**.

4.1.1 Groups and Roles

When we look at large organisations, we usually find that most staff fit into one or other of a small number of categories. A bank might have 40 or 50: teller, chief teller, branch accountant, branch manager, and so on. Only a few dozen people (security manager, chief foreign exchange dealer, . . .) will need to have their access rights defined individually. So we want a small number of pre-defined groups, or functional roles, to which staff can be assigned.

Group and roles: some people use the words group and role interchangeably, and with many systems they are; but the more careful definition is that a group is a list of principals, while a role is a fixed set of access permissions that one or more principals may assume for a period of time using some defined procedure.

4.1.2 Access Control Lists

Another way of simplifying the management of access rights is to store the access control matrix a column at a time, along with the resource to which the column refers. This is called an access control list or ACL (pronounced 'ackle').

User	Accounting Data
Sam	rw
Alice	rw
Bob	r

ACLs have a number of advantages and disadvantages as a means of managing security state:

- ACLs are a natural choice in environments where users manage their own file security, and became widespread in the Unix systems. They are the basic access control mechanism in Unix-based systems such as GNU/Linux and Apple's OS/X; the access controls in Windows are also based on ACLs, but have become more complex over time.
- Where access control policy is set centrally, ACLs are suited to environments where protection is data-oriented; they are less suited where

the user population is large and constantly changing, or where users want to be able to delegate their authority to run a particular program to another user for some set period of time.

- ACLs are simple to implement, but are not efficient as a means of doing security checking at runtime.
- Finally, distributing the access rules into ACLs means that it can be tedious to find all the files to which a user has access.

4.1.3 Unix OS Security

In Unix (including its popular variant Linux), files are not allowed to have arbitrary access control lists, but simply rwx attributes for the resource owner, the group, and the world. These attributes allow the file to be read, written and executed. The access control list as normally displayed has a flag to show whether the file is a directory, then flags r, w and x for world, group and owner respectively; it then has the owner's name and the group name. A directory with all flags set would have the ACL:

drwxrwxrwx Alice Accounts

In the example below: records that the file is not a directory; the file owner can read and write it; group members can read it but not write it; non-group members have no access at all; the file owner is Alice; and the group is Accounts.In our previous example, the ACL of the figure would be:

-rw-r—— Alice Accounts

User	Accounting Data
Sam	rw
Alice	rw
Bob	r

In Unix, the program that gets control when the machine is booted (the operating system kernel) runs as the supervisor, and has unrestricted access to the whole machine. All other programs run as users and have their access mediated by the supervisor.

This means that (with most flavours of Unix) the system administrator can do anything, so we have difficulty implementing an audit trail as a file that he cannot modify. This not only means that, in our example, Sam could tinker with the accounts, and have difficulty defending himself if he were falsely accused of tinkering, but that a hacker who managed to become the system administrator could remove all evidence of his intrusion. Second, ACLs only contain the names of users, not of programs; so there is no straightforward way to implement access triples of (user, program, file). Third, ACLs are not very good at expressing mutable state.

4.1.4 Apple's OS/X

Apple's OS/X operating system is based on the FreeBSD version of Unix running on top of the Mach kernel. The BSD layer provides memory protection; applications cannot access system memory (or each others') unless running with advanced permissions. At the file system level, OS/X is almost a standard Unix.

4.1.5 Windows - Basic Architecture

The most widespread PC operating system is Windows, whose protection has been largely based on access control lists.

First, rather than just read, write and execute there are separate attributes for take ownership, change permissions and delete, which means that more flexible delegation can be supported. These attributes apply to groups as well as users, and group permissions allow you to achieve much the same effect as suid programs in Unix. Attributes are not simply on or off, as in Unix, but have multiple values: you can set AccessDenied, AccessAllowed or SystemAudit.

Second, users and resources can be partitioned into domains with distinct administrators, and trust can be inherited between domains in one direction or both.

4.1.6 Capabilities

The next way to manage the access control matrix is to store it by rows. These are called capabilities. Bob's capabilities would be:

User	Operating System	Accounts Program	Accounting Data	Audit Trail
Bob	rx	r	r	r

The strengths and weaknesses of capabilities are more or less the opposite of ACLs. Runtime security checking is more efficient, and we can delegate a right without much difficulty. On the other hand, changing a file's status can suddenly become more tricky as it can be difficult to find out which users have access. This can be tiresome when we have to investigate an incident or prepare evidence of a crime.

4.2 Middleware

Doing access control at the level of files and programs was all very well in the early days of computing, when these were the resources that mattered. Since about the 1980s, growing scale and complexity has meant led to access control being done at other levels instead of (sometimes as well as) at the operating system level. For example, a bank's branch bookkeeping system will typically run on top of a database product, and the database looks to the operating system as one large file. This means that the access control has to be done in the database; all the operating system supplies it may be an authenticated ID for each user who logs on.

4.2.1 Database Access Control

The databases now contain much of the data of greatest relevance to our lives — such as bank accounts, vehicle regis-trations and employment records — and front-end failures sometimes expose the database itself to random online users. Database products, such as Oracle, DB2 and MySQL, have their own access control mechanisms. As the database looks to the operating system as a single large file, the most the operating system can do is to identify users and to separate the database from other applications running on the same machine.

4.2.2 General Middleware Issues

There are a number of aspects common to middleware security and application-level controls. The first is **granularity:** as the operating system works with files, these are usually the smallest objects with which its access control mechanisms can deal. The second is **state**. An access rule such as 'a nurse can see the records of any patient on her ward' or 'a transaction over $100,000 must be authorised by a manager and an accountant' both involve managing state. The third is **level:** we may end up with separate access control systems at the machine, network and application levels, and as these typically come from different vendors it may be difficult to keep them consistent.

Ease of administration is often a critical bottleneck. In companies the administration of the operating system and the database system have been done by different departments, which do not talk to each other; and often user pressure drives IT departments to put in crude hacks which make the various access control systems seem to work as one, but which open up serious holes. An example is 'single sign-on'.

Despite the best efforts of computer managers, most large companies accumulate systems of many different architectures, so users get more and more logons to different systems and the cost of administering them escalates. Many organisations want to give each employee a single logon to all the machines on the network. Commercial solutions may involve a single security server through which all logons must pass, and the use of a smartcard to do multiple authentication protocols for different systems. Such solutions are hard to engineer properly, and the security of the best system can very easily be reduced to that of the worst.

4.2.3 ORBs and Policy Languages

Problems with middleware led researchers to look for ways in which access control for a number of applications might be handled by standard middleware. Research in the 1990s focussed on object request brokers (ORBs). An ORB is a software component that mediates communications between objects. An ORB typically provides a means of controlling calls that are made across protection domains. The Common Object Request Broker Architecture (CORBA) is an attempt at an industry standard for object-oriented system.

Languages to express security policy, with projects such as XACML (Sun), XrML (ISO) and SecPAL (Microsoft).

4.2.4 Sandboxing and Proof-Carrying Code

The late 1990s saw the emergence of yet another way of implementing access control: the software **sandbox**. The model is that a user wants to run some code that she has downloaded from the web as an applet, but is concerned that the applet might do something nasty, such as taking a list of all her files and mailing it off to a software marketing company. The designers of Java tackled this problem by providing a 'sandbox' for such code — a restricted environment in which it has no access to the local hard disk, and is only allowed to communicate with the host it came from.

An alternative is **proof-carrying code**. Here, code to be executed must carry with it a proof that it doesn't do anything that contravenes the local security policy. This way, rather than using an interpreter with the resulting speed penalty, one merely has to trust a short program that checks the proofs supplied by downloaded programs before allowing them to be executed.

4.2.5 Trusted Computing

The 'Trusted Computing' initiative was launched by Microsoft, Intel, IBM, HP and Compaq to provide a more secure PC. Their stated aim was to provide software and hardware add-ons to the PC architecture that would enable people to be sure that a given program was running on a machine with a given specification; that is, that software had not been patched (whether by the user or by other software) and was running on a identifiable type and configuration of PC rather than on an emulator. The initial motivation was to support digital rights management.

4.3 Hardware Protection

–Write something?–

Chapter 5

Cryptography

Chapter 6

Multilevel Security

A military database systems, which can hold information at a number of different levels of classification (Confidential, Secret, Top Secret, . . .), have to ensure that data can only be read by a principal whose level is at least as high as the data's classification. The policies they implement are known as **multilevel secure** or alternatively as **mandatory access control** or **MAC**.

6.1 What Is a Security Policy Model?

Where a top-down approach to security engineering is possible, it will typically take the form of **threat model — security policy — security mechanisms**. The critical, and often neglected, part of this process is the security policy. By a security policy, we mean a document that expresses clearly and concisely what the protection mechanisms are to achieve. It is driven by our understanding of threats, and in turn drives our system design. It will often take the form of statements about which users may access which data.

Many organizations use the phrase 'security policy' to mean a collection of vapid statements. Here is an example:

1. This policy is approved by Management.
2. All staff shall obey this security policy.
3. Data shall be available only to those with a 'need-to-know'.
4. All breaches of this policy shall be reported at once to Security.

This is a typical corporate information security policy. This sort of waffle is very common but is useless to the security engineer.

A security policy model is a succinct statement of the protection properties which a system, or generic type of system, must have. Its key points can typically be written down in a page or less. It is the document in which the protection goals of the system are agreed with an entire community, or with the top management of a customer. It may also be the basis of formal mathematical analysis.

A security target is a more detailed description of the protection mechanisms that a specific implementation provides, and how they relate to a list of control objectives (some but not all of which are typically derived from the policy model). The security target forms the basis for testing and evaluation of a product.

A protection profile is like a security target but expressed in an implementation-independent way to enable comparable evaluations across products and versions.

You may come across a use of the phrase 'security pol- icy' — as a list of specific configuration settings for some protection product. We will refer to this as **configuration management**, or occasionally as trusted configuration management.

6.2 The Bell-LaPadula Security Policy Model

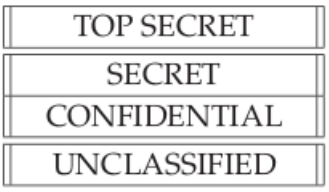
A study by James Anderson led the US government to conclude that a secure system should do one or two things well; and that these protection properties should be enforced by mechanisms which were simple enough to verify and that would change only rarely.

It introduced the concept of a **reference monitor** — a component of the operating system which would mediate access control decisions and be small enough to be subject to analysis and tests, the completeness of which could be assured. In modern parlance, such components — together with their associated operating procedures — make up the **Trusted Computing Base (TCB)**. More formally, the TCB is defined as the set of components (hardware, software, human, . . .) whose correct functioning is sufficient to ensure that the security policy is enforced, or, more vividly, whose failure could cause a breach of the security policy. The Anderson report's goal was to make the security policy simple enough for the TCB to be amenable to careful verification.

But what are these core security properties that should be enforced above all others?

6.2.1 Classification and Clearances

The Second World War, and the Cold War which followed, led NATO governments to move to a common protective marking scheme for labelling the sensitivity of documents. **Classifications** are labels, which run upwards from Unclassified through Confidential, Secret and Top Secret.



The access control policy was simple: an official could read a document only if his **clearance** was at least as high as the document's classification. So an official cleared to 'Top Secret' could read a 'Secret' document, but not vice versa. The effect is that information may only flow upwards, from confidential to secret to top secret, but it may never flow downwards unless an authorized person takes a deliberate decision to declassify it.

6.2.2 Information Flow Control

It was in this context of the classification of government data that the **Bell-LaPadula or BLP model** of computer security was formulated in 1973. It is also known as multilevel security and systems which implement it are often called **multilevel secure or MLS systems**. Their basic property is that information cannot flow downwards. More formally, the Bell-LaPadula model enforces two properties:

- **The simple security property:** no process may read data at a higher level. This is also known as no read up (NRU);
- **The *-property:** no process may write data to a lower level. This is also known as no write down (NWD).

So we must prevent programs running at 'Secret' from writing to files at 'Unclassified', or more generally prevent any process at High from signalling to any object (or subject) at Low. In general, when systems enforce a security policy independently of user actions, they are described as having **mandatory access control**, as opposed to the **discretionary access control** in systems like Unix where users can take their own access decisions about their files.

6.2.3 Criticisms of Bell-LaPadula

The introduction of BLP caused a lot of excitement: here was a straightforward security policy which was clear to the intuitive understanding yet still allowed people to prove theorems. But John McLean showed that the BLP rules were not in themselves enough. He introduced System Z, defined as a BLP system with the added feature that a user can ask the system administrator to temporarily declassify any file from High to Low. In this way, Low users can read any High file without breaking the BLP assumptions.

Bell's argument was that **System Z cheats** by doing something the model doesn't allow (changing labels isn't a valid operation on the state), and McLean's argument was that it didn't explicitly tell him so. The issue is dealt with by introducing a tranquility property.

The strong tranquility property says that security labels never change during system operation.
The weak tranquility property says that labels never change in such a way as to violate a defined security policy.

The motivation for the weak property is that in a real system we often want to observe the principle of least privilege and start off a process at the uncleared level, even if the owner of the process were cleared to 'Top Secret'. If she then accesses a confidential email, her session is automatically upgraded to 'Confidential'; and in general, her process is upgraded each time it accesses data at a higher level. **This is known as the high water mark principle**. As subjects are usually an abstraction of the memory management sub-system and file handles, rather than processes, this means that state changes when access rights change, rather than when data actually moves.

Finally it's worth noting that even with the high-water-mark refinement, BLP still doesn't deal with the creation or destruction of subjects or objects (which is one of the hard problems of building a real MLS system).

6.2.4 Alternative Formulations

The first multilevel security policy was a version of high water mark. There is a lot of other formulations of multilevel security.

- **Noninterference** was introduced by Joseph Goguen and Jose Meseguer in 1982. In a system with this property, High's actions have no effect on what Low can see. The motive for nondeducibility is to find a model that can deal with applications such as a LAN on which there are machines at both Low and High, with the High machines encrypting their LAN traffic.
- **Generalized Noninterference and restrictiveness**. The former is the requirement that if one alters a high level input event in a legal sequence of system events, the resulting sequence can be made legal by, at most, altering one or more subsequent high-level output events. The latter adds a further restriction on the part of the trace where the alteration of the high-level outputs can take place. This is needed for technical reasons to ensure that two systems satisfying the restrictiveness property can be composed into a third which also does.
- **The Harrison-Ruzzo-Ullman model** tackles the problem of how to deal with the creation and deletion of files, an issue on which BLP is silent.
- **Compartmented Mode Workstation (CMW)** policy, which attempted to model the classification of information using floating labels, as opposed to the fixed labels associated with BLP.
- **The type enforcement model** assigns subjects to domains and objects to types, with matrices defining permitted domain-domain and domain-type interactions.
- **Role-based access control (RBAC)**. This provides a more general framework for mandatory access control than BLP in which access decisions don't depend on users' names but on the functions which they are currently performing within the organization.

6.2.5 The Biba Model

Many refer the Biba Model as the **'Bell-LaPadula upside down'**. The Biba model deals with integrity alone and ignores confidentiality. The key observation is that confidentiality and integrity are in some sense dual concepts:
Confidentiality is a constraint on who can read a message, while
Integrity is a constraint on who can write or alter it.

To model such a system, we can use a multilevel integrity policy with the rules that we **can read data at higher levels and write to lower levels**, but we must **never read down or write up**, as either could allow High integrity objects to become contaminated with Low — that is potentially unreliable — data. The Biba model is often formulated in terms of the **low water mark principle**, which is the dual of the high water mark principle discussed above: the integrity of an object is the lowest level of all the objects that contributed to its creation.

Vista marks file objects with an integrity level, which can be Low, Medium, High or System, and implements a default policy of NoWriteUp. Critical Vista files are at System and other objects are at Medium by default — except for Internet Explorer which is at Low. The effect is that things downloaded using IE can read most files in a Vista system, but cannot write them. The idea is to limit the damage that can be done by viruses and other malware.

Chapter 7

Multilateral Security