CS361: Introduction to Computer Security

Covert Channels and Non-Interference

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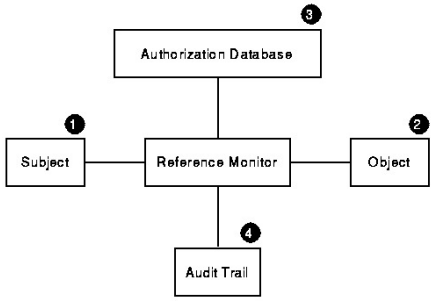
Access Control

The Bell and LaPadula Model (BLP) is an example of an *Access Control Policy*. This is a popular way of conceptualizing and implementing security.

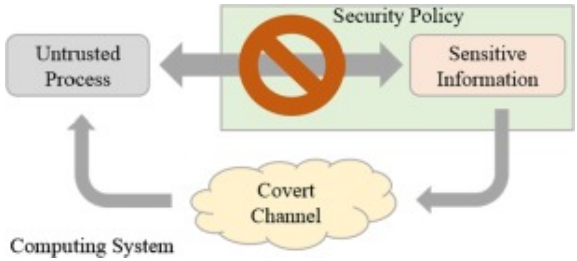
The basic idea is to introduce rules that control what accesses system *subjects* have to system *objects*.



Access Control

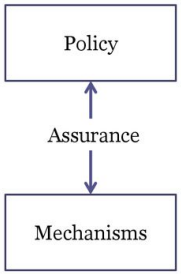
Access control is an important aspect of security.

The problem is that there may be information channels in the system that don't involve the access of subjects to objects.



Levels of Concern

For any secure system, we have to consider the following different areas of concern:



Policy: What is the notion of security that is being enforced?

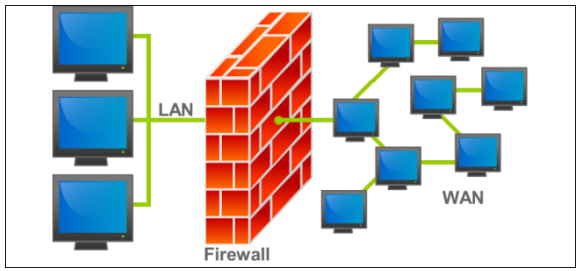
Mechanism: How is that policy enforced in the system?

Assurance: How certain are we that the policy is enforced by the mechanisms?

BLP mixes policy and mechanism.

An Aside: Firewalls

What is a firewall? Essentially, it's just an access control mechanism applied by structuring the system in a particular way.



It applies access control checks *at the system boundary* before accepting any command, perhaps on a separate processor.

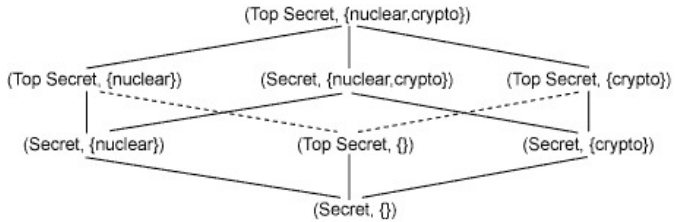
Some Questions

1. Can our system satisfy BLP's security properties and still be intuitively non-secure?
2. Are there ways in which a high level subject could pass *information* to a low level subject without violating our security property?
3. What about instructions beyond READ and WRITE? Can they be added securely?
4. How should we handle exceptions? Eg., what should happen if ill-formed instructions are included in the instruction stream?
5. Is there a "stronger" security policy that we might apply?

The Metapolicy

The real security goal (metapolicy) of any MLS scheme is to *control the flow of information* in the system. I.e., sensitive information should not flow "down" in the system, from a high level to a low level.

More precisely, information must flow through the lattice only along upward arrows.



Is BLP adequate to ensure this metapolicy? What would a counterexample look like? What would it mean?

A Simple BLP System

Consider an MLS system that has READ and WRITE operations that follow the BLP rules. Just to be concrete, suppose we define the semantics as follows:

READ (subj_name, obj_name): if object exists and subject has read access to it, return its current value; otherwise, return a zero.

WRITE (subj_name, obj_name, value): if object exists and the subject has write access to it, change its current value to **value**; otherwise, do nothing.

Ordinarily, the subject would be an *implicit* parameter to the operation; we're just making it explicit to simplify matters.

A BLP System (Cont.)

Now, suppose we want to add the following operations to our simple secure system:

```
CREATE (subject_name, object-name)
DESTROY (subject_name, object-name)
```

Under what conditions would these operations be secure? I.e., what should be the semantics of these operations, if they are not to violate our intuitive notions of confidentiality?

A BLP System (Cont.)

Now, suppose we want to add the following operations to our simple secure system:

```
CREATE (subject_name, object-name)
DESTROY (subject_name, object-name)
```

Under what conditions would these operations be secure? I.e., what should be the semantics of these operations, if they are not to violate our intuitive notions of confidentiality?

What is the level of a created object? What if an object by that name already exists? What if we try to destroy an object that doesn't exist?

A BLP System (Cont.)

Suppose we define these operations as follows:

CREATE (subject, object-name): if no object with name `object-name` exists, create a new object at the subject's level; otherwise, do nothing.

DESTROY (subject, object-name): if an object with name `object-name` exists and the subject has write access to it, destroy it; otherwise, do nothing.

These rules seem to satisfy BLP, but are they "secure" from the standard of the metapolicy? Why or why not?

Covert Channel Example

In this system, a high level subject *H* can signal one bit of information to a low level subject *L* as follows:

H Signals 0	**H Signals 1**
Create (H, F0)	*do nothing*
Create (L, F0)	Create (L, F0)
Write (L, F0, 37)	Write (L, F0, 37)
Read (L, F0)	Read (L, F0)
Destroy (L, F0)	Destroy (L, F0)

Some questions:

1. Could there be a covert channel if L didn't see any difference?
2. What difference does L see in the two cases?
3. Are any pre-conditions required for this to work?
4. Why must L *do the same thing* in both columns?
5. Why is the Destroy needed?
6. Where does the bit of information "reside"?

Covert Channel Example

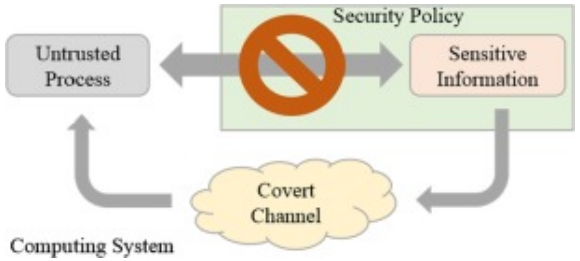
H Signals 0	H Signals 1
Create (H, F0)	*do nothing*
Create (L, F0)	Create (L, F0)
Write (L, F0, 37)	Write (L, F0, 37)
Read (L, F0)	Read (L, F0)
Destroy (L, F0)	Destroy (L, F0)

1. If L sees no difference, no information flows.
2. Left: L sees a value of 0. Right: L sees a value of 37.
3. F0 doesn't exist initially; they've agreed on the encoding.
4. L doesn't know what bit H is sending.
5. They need to reset the state to repeat the channel.
6. In the level of the F0.

Covert Channels

One flaw in BLP (and most access control schemes) is that it only controls the flow of information via *objects* that are explicitly recognized by the security policy as carrying information.

But information can be carried in other ways as well. Such information paths are called *covert channels*.



Covert Channel

Some sources define a covert channel as any channel in violation of the security policy; that's too broad to be useful. A better definition is:

Definition: A *covert channel* is a path for the flow of information between subjects within a system, utilizing system resources that were not designed to be used for inter-subject communication.

Where did the bit of information reside in the previous channel? Was it the contents of any object?

Covert Channel

Note the important features of this definition:

- Information flows from one subject to another, presumably in violation of the security metapolicy *though not necessarily in violation of the policy*.
- The flow is within the system; two human users talking over coffee is not a covert channel.
- The flow occurs via system resources (file attributes, flags, clocks, etc.) that were not intended as communication channels.

A system can satisfy an access control policy (such as BLP) and still contain multiple covert channels.

Sample Covert Channel 1

Process p cannot communicate with process q directly. However, p can create and delete files in a directory. q cannot read or modify files in the directory, but can list them. To send a bit of information, process p deletes any file named **bit*, and then creates a file called either *0bit* or *1bit* in the directory. Process q detects it. This repeats until the message has been delivered.

This is a classic *storage covert channel*.

Note: If q could read files in the directory *that wouldn't be a covert channel*. Also, why doesn't p just name his file *the-attack-is-at-dawn* for higher bandwidth? Would that work?

Sample Covert Channel 2

The KVM/370 operating system isolated processes on separate virtual machines. They shared the processor on a time-sliced basis. Processes alternated using the CPU, with each allowed t units of processing time. However, a process could relinquish the CPU early.

Process p could send a bit to process q by either using its total allocation or reliquishing the processor immediately. Process q reads the bit by consulting the system clock to see how much time has elapsed since it was last scheduled.

This is a classic *timing covert channel*.

Sample Covert Channel 3

Suppose two processes share a disk. Process p either accesses cylinder 140 or 160. Process q requests accesses on cylinders 139 and 161. The scanning algorithm services requests in the order of which cylinder is currently closest to the read head. Thus, q receives values from 139 and then 161, or from 161 and then 139, depending on p's most recent read.

Is this a timing or storage channel? Neither? Both?

An Implicit Channel

An implicit channel is one that uses the control flow of a program. For example, consider the following program fragment:

```
h := h mod 2;
l := 0;
if h = 1 then l := 1 else skip;
```

The resulting value of l depends on the value of h.

There are sophisticated *language-based information flow tools* that check for these kinds of dependencies in programming languages.

Taxonomy of Covert Channels

Some possible types of covert channels:

Implicit flows: signal information through the control structure of the program.

Termination channels: signal information through termination or non-termination of a computation.

Timing channels: signal via the amount of time a computation takes.

Probabilistic channels: signal by changing the probability distribution of observable data.

Resource exhaustion channels: signal via possible exhaustion of a finite shared resource, such as memory or disk space.

Power channels: embed information in the power consumed (useful for smartcards where the energy is supplied by the host computer).

Taxonomy of Covert Channels

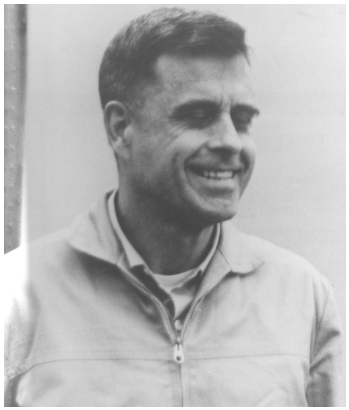
In practice, most researchers distinguish only *storage* and *timing* channels.

Storage channel: bit is encoded as data in the system state; no clock is required.

Timing channel: bit is encoded in the timing/sequence of events in the system; clock may be needed.

One More

Jeremiah Denton, a prisoner of war during the Vietnam War, used a covert channel to communicate without his captors' knowledge. Denton was interviewed by a Japanese TV reporter, and eventually a videotape of the interview made its way to the United States.



As American intelligence agents viewed the tape, one of them noticed Denton was blinking in an unusual manner. They discovered he was blinking letters in Morse code. The letters were T-O-R-T-U-R-E, and Denton was blinking them over and over. This is a real-world example of how a covert channel can be used to send a communication message undetected.

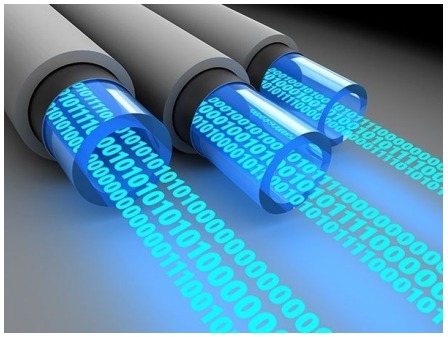
Covert Channels: Who Cares

It might seem that these covert channels would be so slow that you wouldn't really care.

That's not true. Covert channels on real processors operate at thousands of bits per second with no appreciable impact on system processing.

Covert Channels

The two important attributes of covert channels are *existence* and *bandwidth*.



It is usually infeasible for realistic systems to eliminate every potential covert channel. However it is important to identify those that can be used to advantage and to close them or restrict them in such a way that the bandwidth is reduced to a negligible amount.

Noisy vs. Noiseless Channels

A characteristic of *any* communication channel that affects bandwidth is whether it is *noiseless* or *noisy*. Information theory provides a very precise definition; the following is an intuitive approximation.

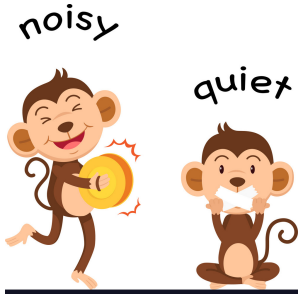
Definition: A *noiseless* channel is one where the message can be transmitted without distortion or loss of information.

Definition: A *noisy* channel is one where there is distortion or loss of information.

Noisy vs. Noiseless Channels

For covert channels, a noiseless channel might be one where the shared resource is only available to the two colluding parties.

A noisy channel might be one where there are other users potentially accessing the resource.



Dealing with Covert Channels

Once a potential covert channel is identified, several responses are possible.

- We can eliminate it by modifying the system implementation.
- We can reduce the bandwidth by introducing noise into the channel.
- We can monitor it for patterns of usage that indicate someone is trying to exploit it. This is *intrusion detection*.

The solution could introduce other problems. For example, one might eliminate a covert channel on a shared resource by always giving priority to the low process (and possibly terminating the high process). This obviously introduces a denial of service vulnerability.

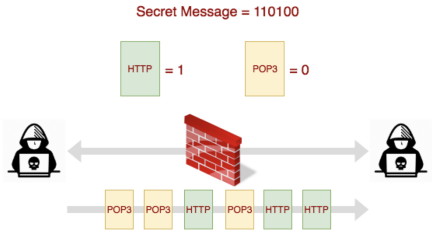
Dealing with Covert Channels

In the early 1990's the U.S. Government published guidelines for covert channels in secure systems they certified:

> *"Covert storage channels shall be treated as follows:*
>
> 1. *There shall be no covert storage channels with a capacity exceeding 100 bits/second;*
> 2. *All covert storage channels with capacities exceeding 10 bits/second shall be auditable;*
> 3. *All covert storage channels with capacities exceeding 1 bit/second shall be described in the product's covert channel analysis."*

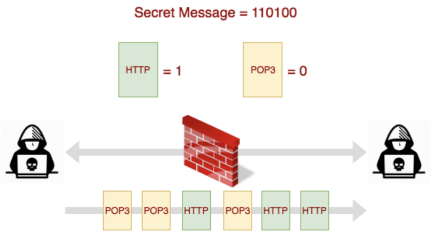
These numbers are hopelessly out of date, but note that this presumes that it is possible to find all covert channels in the system. How might you do that?

Using a Covert Storage Channel



For a sender and receiver to use a covert *storage* channel, what must be true?

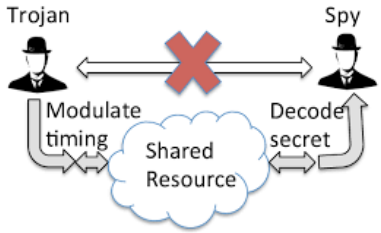
Using a Covert Storage Channel



For a sender and receiver to use a covert *storage* channel, what must be true?

1. Both sender and receiver must have access to some attribute of a shared object.
2. The sender must be able to modify the attribute.
3. The receiver must be able to reference (view) that attribute.
4. A mechanism for initiating both processes, and sequencing their accesses to the shared resource, must exist.

Using a Covert Timing Channel



What's required for a covert *timing* channel?

1. Sender and receiver must have access to some attribute of a shared object.
2. Both have access to a time reference (real-time clock, timer, ordering of events).
3. Sender must be able to control the timing of the detection of a change in the attribute of the receiver.
4. A mechanism for initiating both processes, and sequencing their accesses to the shared resource, must exist.

Detecting Covert Channels

Richard Kemmerer (UC Santa Barbara) introduced the Shared Resource Matrix Methodology (SRMM).

The idea is to build a table for each command and its potential effect on shared attributes of objects.

SRMM doesn't tell you where covert channels are, only where to look.

SRMM Example

	readFile	writeFile	deleteFile	createFile
file existence	R	R	R, M	R, M
file owner			R, M	M
file name	R	R	R, M	M
file size	R	M	M	M

An R in the matrix means the operation References (provides information about) the attribute *under some possible circumstances*. An M means the operation Modifies (affects the value of) the attribute under *under some possible circumstances*.

Under what possible conditions would you have the matrix values above?

Working with the SRMM

The only resources/attributes that are *potential* channels are those with both R and M in a row. Why is that?

Building the matrix requires detailed knowledge of the system architecture.

Any shared resource matrix is *for a specific system*. Other systems may have different semantics for the operations.

A Subtlety of SRMM

Suppose you have the following operation:

CREATE: if no object with name `obj_name` exists, create a new object at the subject's level; otherwise, do nothing.

For the attribute *file existence*, should you have an R or not for this operation? Consider this: you *know* that the file exists after this operation. Why?

But that's not enough. It's not important that you *know* something about the attribute; what's important is that the operation *tells* you something about the attribute. A low-level process couldn't use CREATE to get the information it would need to carry out its part of a covert channel.

Using the SRMM: Exercise

Build a Shared Resource Matrix for each of the covert channel examples on the previous slides.

Channel 1: Process p cannot communicate with process q directly. However, both can list files in a common directory. Process p creates a file called either *0bit* or *1bit* in the directory. Process q detects it and deletes it. This repeats until the message has been delivered.

	Read	Write	Create	Delete	ListFiles
file existence	R	R	R, M	R, M	R
file label	R	R	R, M	M	R

Now try a similar exercise for samples 2 and 3.

Covert Channels and System Analysis

One approach to secure system design is to use an access control security model like Bell and LaPadula, and then to use a separate technique (such as SRMM) to find and close covert channels.

The question arises, is it possible to define a security model that is strong enough to cover access control and covert channels. That is one goal of *information flow policies* such as non-interference.

Non-Interference

An alternative to access control policies is a class of policies called *information flow* policies. The best known is *non-interference*.

The *policy* of the system is a binary relation ($a \mapsto b$) over the subjects of the system that says which subjects are permitted to "interfere with" which other subjects.

You can think of "can interfere with" as meaning "can communicate to" or "can direct information to." In the types of systems we have been discussing, ($a \mapsto b$) means that a can write into b's view, or b can read from a's view. But there is no distinction between these two.

Non-Interference (Cont.)

It is possible to take any MLS policy and turn it into a non-interference policy, *but not vice versa.*

Consider a BLP system with three subject's:

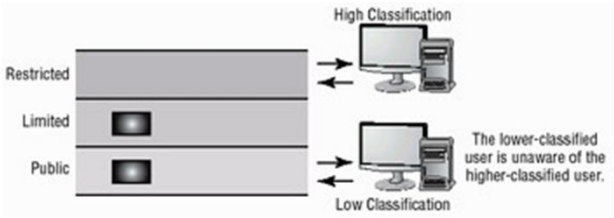
- A at **(Secret: {Crypto, Nuclear})**,
- B at **(Secret: {Crypto})**, and
- C at **(Unclass: { })**.

What is the corresponding NI policy? Suppose you add D at **(Top Secret: {Crypto, Nuclear})**?

In general, given a BLP system, how do you compute the corresponding NI policy?

Non-Interference (Cont.)

Intuitively, the idea of non-interference is that a low-level user's "view" of the system should not be affected by *anything* that a high-level user does.



Though strictly speaking, talk of "high" and "low" here is misleading. There is only a notion of who is allowed to interfere with whom.

Levels of Concern

Recall that we considered the following different areas of concern: policy, mechanism, and assurance.

Non-interference is another *policy*, more abstract than BLP. The enforcement *mechanisms* may be anything, including the BLP rules. In this context, enhancing our level of *assurance* could mean formulating and proving a theorem about the system.

The policy of the system is a binary relation ($a \mapsto b$) over the subjects of the system that says which subjects are permitted to "interfere with" which other subjects. What would this look like for a BLP system?

Non-Interference

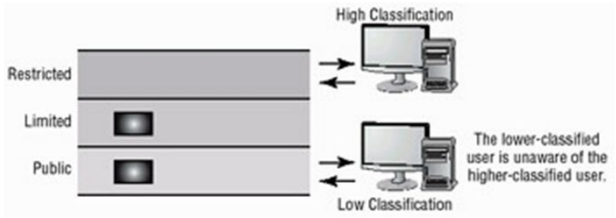
One way to formalize non-interference is as follows. Suppose L is a subject in the system. Now suppose you:

1. run the system normally, interleaving the operations of all users;
2. run the system again after deleting all operations requested by subjects which should not be able to pass information to (interfere with) L.

Assuming the system is non-interference secure, what should L see differently in the two runs?

Non-Interference

From L's point of view, there should be *no visible difference*.



The system is *non-interference secure* if this is true of *every* subject in the system under *every* possible program. Explain this.

Non-Interference Formalization

Non-Interference Property: A system is *non-interference secure* iff:

$$\forall s \in Subjects, \forall S_0 \in States, \forall I \in InstructionList,$$
$$view(s, run(I, S_0)) = view(s, run(purge(I, s), S_0))$$

where:

- run (I, S): is our system interpreter of instruction sequence I from initial state S.
- purge (I, s): removes from I any instruction on behalf of any subject s_1 such that $\neg(s_1 \mapsto s)$.
- view (s, S): is everything in state S that s can reference.

Non-Interference

Note: this assumes that the system is *deterministic* and that the policy is *transitive*. Why?

It is possible to formulate a related theorem for a non-deterministic system and/or intransitive policy. Think about what that would look like?

Non-Interference View

The policy can be made as strong as you like by characterizing "view." The more things that you consider to be within the view of the user, the stronger the policy.

For example, if you include within a subject's view the values of system flags, then they could not be used in a covert channel.

If you include the system clock, then you could not use that in a covert channel.

What is the "view" for BLP?

Unwinding Theorem

Note that the non-interference formal definition refers to *all* subjects, *all* states, and *all* instruction sequences and requires an induction that touches every reachable state of the system. This may seem very difficult to carry out.

Instead prove an *unwinding theorem*:

1. Identify an invariant on the system state.
2. Prove that *each instruction* preserves the invariant.
3. Correctness follows automatically.

Unwinding Theorem

It happens that the global non-interference property follows from two *local* properties. Let $(a \mapsto b)$ mean that "a can permissibly interfere with b" and let i_a denote an instruction executed on behalf of a.

The system *locally respects* the interference relation iff:

$$\forall a, b \in \mathit{Subjects}, \forall s \in \mathit{States}, \forall i_a \in \mathit{Instruction},$$
$$\neg(a \mapsto b) \Rightarrow \mathit{view}(b, \mathit{step}(i_a, s)) = \mathit{view}(b, s)$$

The system is *step consistent* iff:

$$\forall a, b \in \mathit{Subjects}, \forall s_1, s_2 \in \mathit{States}, \forall i_a \in \mathit{Instruction},$$
$$\mathit{view}(b, s_1) = \mathit{view}(b, s_2)$$
$$\Rightarrow \mathit{view}(b, \mathit{step}(i_a, s_1)) = \mathit{view}(b, \mathit{step}(i_a, s_2))$$

Exercise: Try to prove that locally respects and step consistent imply the non-interference property.

Generalizing Non-Interference

The previous idea of non-interference assumes that the "interferes" relation is transitive and possibilistic and that the system is deterministic.

It is possible to define related notions that allow for an intransitive interference relation, probabilistic notion of security, and non-deterministic systems.

What do these mean? Can you intuit what changes need to be made for these various different system models?

Non-Interference

How does non-interference address the problem of covert channels?

Answer: By adding to a subject's *view* elements of the system state other than files, it makes visible changes in those elements that might convey information.

Note that this is a very powerful approach, but it has some limitations. Ideally, a non-interference approach requires no separate covert channel analysis.

Limitations of Non-Interference

Complete non-interference is very difficult to achieve for realistic systems.

- It requires identifying within the "view" function all potential channels of information.
- Realistic systems have many such channels.
- Modeling must be at very low level to capture most channels.
- Dealing with timing channels is possible, but difficult.
- Very few systems are completely deterministic.
- Some "interferences" are benign, e.g., encrypted files.