Bell-LaPadula and Other Security Models

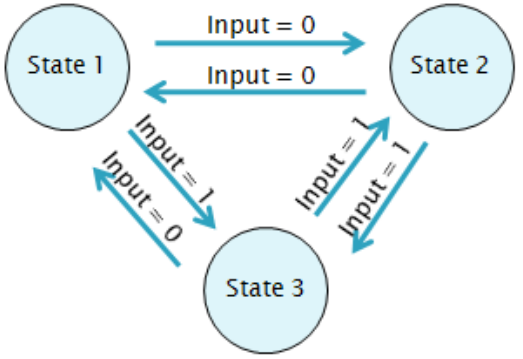
- Bell-LaPadula model
- Biba model
- Chinese Wall model
- (Clark-Wilson model)

Motivation

- Demonstrate how security policies can be expressed in a *formal* way.
- Give some history of computer security
- Understand the limitations of various models

State Machine Model

- State – Representation of the system at some given time
- State transition – next state depends on current state + input.
- **Idea:** If we start in a secure state and all state transitions preserve security, then the system will be secure.



Question:
What is a secure state?

Bell-LaPadula Model

- Most famous security model
- First developed around 1973
- ”Unified exposition and Multics interpretation”, 1976
- Focus on confidentiality, not integrity
- Based on state transitions
- Both **mandatory** and **discretionary** access control
  - Multilevel security
  - Access control matrix

Notation

- Set of subjects S
- Set of objects O
- Set of access operations A
  - execute, read, append, write

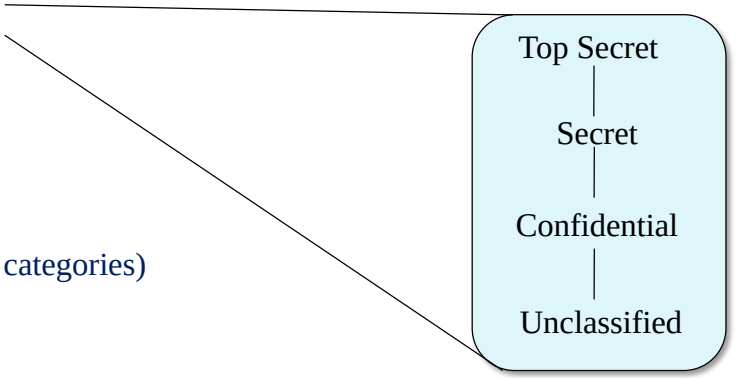
	Execute	Append	Read	Write
Observe			X	X
Alter		X		X

- Set of security levels L with ordering $\leq$
- Functions
  - $f_S: S \rightarrow L$, maximum security level
  - $f_C: S \rightarrow L$, current security level
  - $f_O: O \rightarrow L$, security level of object

Security Levels

- *Multilevel security*
- *Categories*
  - *{Division A, Division B}*
- *Security level* given by pair

  (Classification, Set of categories)
- *Ordering:*



$(h_1,c_1) \leq (h_2,c_2)$ if and only if $h_1 \leq h_2$ and $c_1 \subseteq c_2$

- Security level (h_2,c_2) dominates (h_1,c_1)

The State

The state consists of three parts

1. Current access given by a set of *(s,o,a)* tuples
   - An element of the powerset P(S x O x A)
   - Can be written as matrix *b*.
   - *s* is row, *o* is column, *a* is current access operation
2. Access matrix given by M
   - Defines what is allowed
3. Functions f = (f_S, f_C, f_O)

- State is given by (b, M, f)

State Example

- We have a system with 5 subjects and 5 objects, 2 classifications and 2 categories
  - Subjects: Alice, Bob, Charlie, David, Erika
  - Objects: file_a, file_b, file_c, file_d, file_e
  - Classifications : public, private
  - Categories: A, B

State Example

Current access set *b*

(Alice, file_b, r)
(David, file_c, w)
(Erika, file_a, a)

Access Control Matrix M

	file_a	file_b	file_c	file_d	file_e
Alice		r,w,a		e	a
Bob			a	r,e	
Charlie	r	r			a
David			r,w,a		r,w,a
Erika	a			e	

Functions f = (f_S, f_C, f_O)

f_S :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (private, {A,B}), Erika: (public, {A})
f_C :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (public, {A,B}), Erika: (public, {A})
f_O :
file_a: (private, {A}), file_b: (private, {∅}), file_c: (public, {A,B}), file_d: (public, {A}), file_e: (private, {A,B})

State is given by (b,M,f)

ss-property

- Simple Security Property
- Mandatory access control

	Execute	Append	Read	Write
Observe			X	X
Alter		X		X

State *(b,M,f)* satisfies the *ss-property* if for each element *(s,o,a)* ∈ *b* where the access operation *a* is *read* or *write*, the security level of *s* dominates security level of *o*, i.e., $f_O(o) \leq f_S(s)$

- **No read-up** – A user is not allowed read (observe) access to objects with higher security level

Example

Current access set *b*

(Alice, file_b, r)

(David, file_c, w)

(Erika, file_a, a)

Access Control Matrix M

	file_a	file_b	file_c	file_d	file_e
Alice		r,w,a		e	a
Bob			a	r,e	
Charlie	r	r			a
David			r,w,a		r,w,a
Erika	a			e	

Functions f = (f_S, f_C, f_O)

f_S :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (private, {A,B}), Erika: (public, {A})

f_C :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (public, {A,B}), Erika: (public, {A})

f_O :
file_a: (private, {A}), file_b: (private, {∅}), file_c: (public, {A,B}), file_d: (public, {A}), file_e: (private, {A,B})

According to ss-property:

- Alice is allowed to read file_b since $f_O(\text{file\_b}) \leq f_S(\text{Alice})$
- David is allowed write access to file_c since $f_O(\text{file\_c}) \leq f_S(\text{David})$

Controlling Write Access

- A subject can append to any object with higher security level than the subject.
- We do not allow information to flow downwards.
  - Easy way: A subject can not send any information to an object with lower security level – Not practical
  - Better solution:
    - Possible to temporarily downgrade a subject – the reason to introduce $f_C(s)$
    - Let *trusted subjects* send information downwards
- Note that we assume that a subject does not have an internal memory – We have to see it as a process, not a human being
  - Only know the contents of the objects it is currently accessing

*-property (Incomplete Version)

- Star-Property
- Mandatory access control
- Does not apply to *trusted subjects*

	Execute	Append	Read	Write
Observe			X	X
Alter		X		X

State *(b,M,f)* satisfies the **-property* if for each element *(s,o,a)* ∈ *b* where the access operation *a* is *append* or *write*, the current security level of *s* is dominated by the security level of *o*, i.e., $f_C(s) \leq f_O(o)$

- No write-down – A user is not allowed write (alter) access to object with lower security level than the current security level of subject

Example

Current access set *b*
(Alice, file_b, r)
(David, file_c, w)
(Erika, file_a, a)

Access Control Matrix M

	file_a	file_b	file_c	file_d	file_e
Alice		r,w,a		e	a
Bob			a	r,e	
Charlie	r	r			a
David			r,w,a		r,w,a
Erika	a			e	

Functions f = (f_S, f_C, f_O)

f_S :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (private, {A,B}), Erika: (public, {A})

f_C :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (public, {A,B}), Erika: (public, {A})

f_O :
file_a: (private, {A}), file_b: (private, {∅}), file_c: (public, {A,B}), file_d: (public, {A}), file_e: (private, {A,B})

According to *-property:

- David is allowed write access to file_c since $f_C(\text{David}) \leq f_O(\text{file\_c})$
- Erika is allowed append access to file_a since $f_C(\text{Erika}) \leq f_O(\text{file\_a})$

Problem

- ss-property considers maximum level of subject – $f_S(s)$
- *-property considers current level of subject $f_C(s)$
- David has append access to file_c, but he would also be granted read access to file_e

Functions f = (f_S, f_C, f_O)

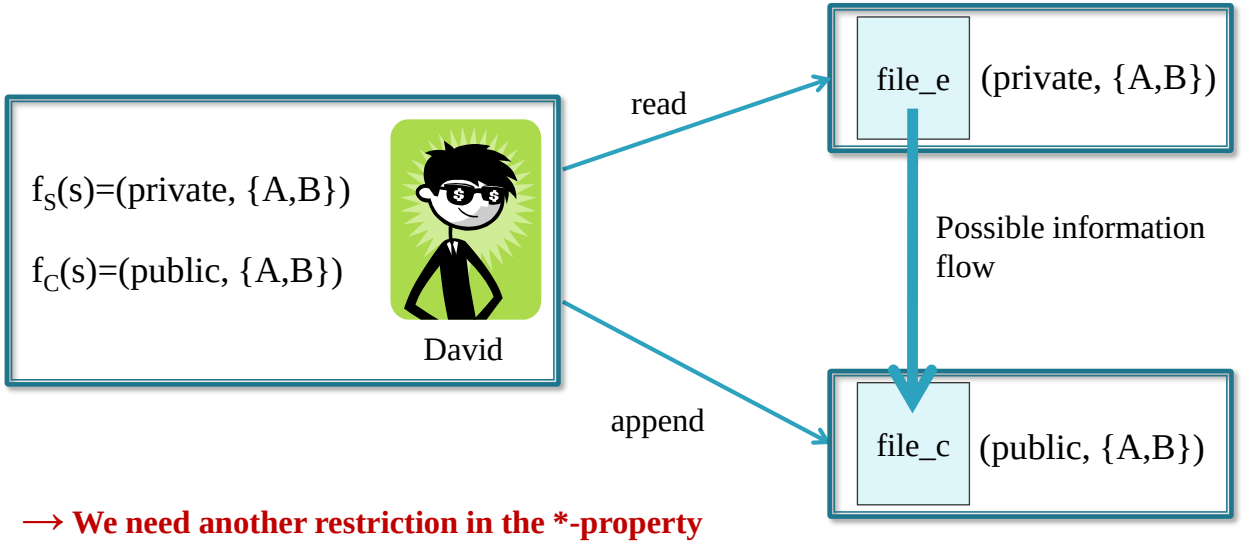
f_S :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (private, {A,B}), Erika: (public, {A})

f_C :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (public, {A,B}), Erika: (public, {A})

f_O :
file_a: (private, {A}), file_b: (private, {∅}), file_c: (public, {A,B}), file_d: (public, {A}), file_e: (private, {A,B})

Problem

- Result: It would be possible for information to flow from file_e to file_c



→ **We need another restriction in the *-property**

*-property

State *(b,M,f)* satisfies the **-property* if for each element *(s,o,a)* ∈ *b* where the access operation *a* is *append* or *write*, the current security level of *s* is dominated by the security level of *o*, i.e., $f_C(s) \leq f_O(o)$

Furthermore, if there exists an element *(s,o,a)* ∈ *b* where the access operation *a* is *append* or *write*, then we must have $f_O(o') \leq f_O(o)$ for all objects o' with *(s,o',a')* ∈ *b* and *a'* is *read* or *write*

- **In other words:** If a subject has access to several objects at the same time, all objects with observe access must have lower (or equal) security level than all objects with alter access
- Still does not apply to *trusted subjects*

ds-property

- Subject may pass an access permission on to other users.
- Discretionary access control

State *(b,M,f)* satisfies the *ds-property* if for each element *(s,o,a)* ∈ *b* we have a ∈ M_{SO}

- Access rights given in access control matrix must also be followed

Example

Current access set *b*

(Alice, file_b, r)
(David, file_c, w)
(Erika, file_a, a)

Access Control Matrix M

	file_a	file_b	file_c	file_d	file_e
Alice		r,w,a		e	a
Bob			a	r,e	
Charlie	r	r			a
David			r,w,a		r,w,a
Erika	a			e	

Functions $f = (f_S, f_C, f_O)$

f_S :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (private, {A,B}), Erika: (public, {A})

f_C :
Alice: (private, {A}), Bob: (public, {A,B}), Charlie: (public, {B}), David: (public, {A,B}), Erika: (public, {A})

f_O :
file_a: (private, {A}), file_b: (private, {∅}), file_c: (public, {A,B}), file_d: (public, {A}), file_e: (private, {A,B})

- All accesses given in *b* are allowed in the access control matrix M

Basic Security Theorem

- Current state is *secure* if and only if each $(s_i,o_i,a_i) \in b$ satisfies the three properties
  - ss-property, *-property and ds-property
- State of the system changes if any component in (b,M,f) changes
- As long as any state change does not violate any of the three properties, the system remains secure

If all state transitions are secure and if the initial state is secure then every subsequent state will be secure

State Transitions

- Get access – add triple (subject, object, access operation) to current access set *b*
- Release access – remove triple from *b*
- Change object level – change value of $f_O(o)$ for object o
- Change current level – change value of $f_C(s)$ for subject s
- Give access permission – add an access operation to M
- Rescind access permission – remove an access operation from M
- Create object – add an object to system
- Remove object – remove an object from system

} Change *b* in state

} Change f in state

} Change M in state

} Not supported by ”our” state

Tranquility

McLean criticism:

Make a state transition that

- downgrade all subjects and objects to lowest security level
- enter all access rights in all entries of M

→ Everyone can do everything – not secure

Bell standpoint:

- If such a transition is required, it should be ok.
- Otherwise, it should not be implemented.

Tranquility: security levels and access rights never change.

Drawbacks

- Only focus on confidentiality, not integrity
- Not addressing management of access control

- Contains *covert channels* – information flow not controlled by the security mechanisms.

Example:

- Low level subject creates file.txt at low level
- High level subject upgrades file.txt to higher level, or leaves it alone
- Low level subject tries to read file.txt

Example 2:

- If low-level subjects can read filenames at high levels the filename can also be used to send information from high-level subjects

Biba Model

- Focuses on integrity, i.e., unauthorized modification of data
- Proposed in 1977
- Similar to Bell-LaPadula in several ways
  - Based on multilevel security with a partial ordering
  - Based on subjects and objects
- Subjects and objects mapped to *integrity levels* forming a lattice
  - $f_S: S \rightarrow L$ subject integrity level
  - $f_O: O \rightarrow L$ object integrity level

Subjects and Objects

- Information flows downward
- High integrity subjects and objects are called clean, low integrity subjects and objects are called dirty
  - Clean objects are more accurate or reliable than dirty
  - We have more confidence in clean subjects to execute as expected or to validate input
- Clean objects cannot be contaminated by information from low-integrity processes (subjects)
- Clean subjects should not *read* dirty objects
- **Operations of interest:** Modify, Read, Invoke

Static Integrity Levels

- Simple integrity property
  - Corresponds to ss-property in Bell-LaPadula
  - If subject *s* can modify object *o*, then $f_O(o) \leq f_S(s)$.
  - no write-up

- Integrity *-property
  - Corresponds to *-property in Bell-LaPadula
  - A subject *s* can read an object *o* only if $f_S(s) \leq f_O(o)$
  - No read down

Dynamic Integrity Levels

- Integrity levels are automatically adjusted
- Subject low watermark property

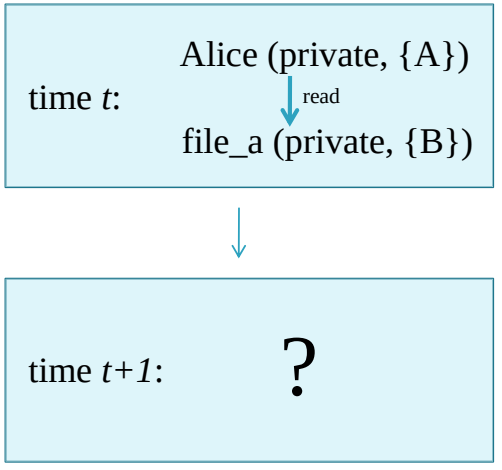
> Subject *s* can read an object *o* at any integrity level. The new integrity level of the subject is the greatest lower bound of $f_S(s)$ and $f_O(o)$.

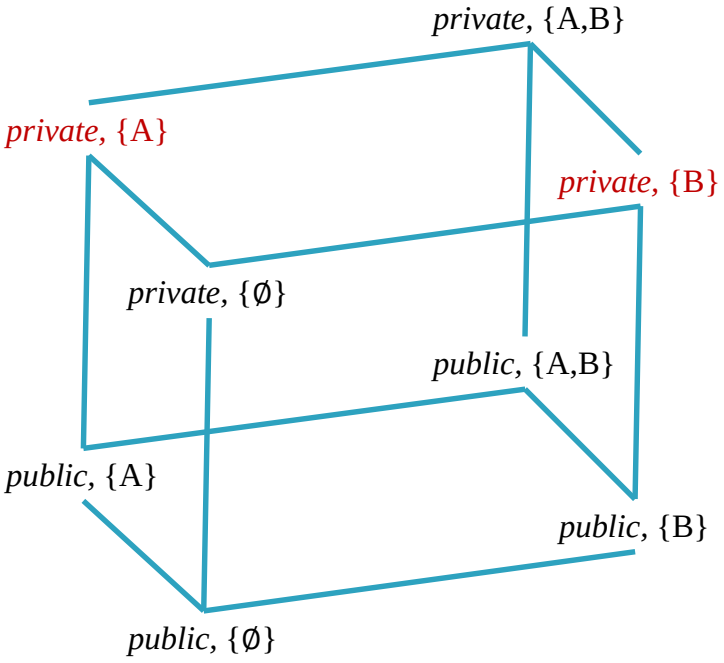
- Object low watermark property

> Subject *s* can modify an object *o* at any integrity level. The new integrity level of the object is the greatest lower bound of $f_S(s)$ and $f_O(o)$.

Example

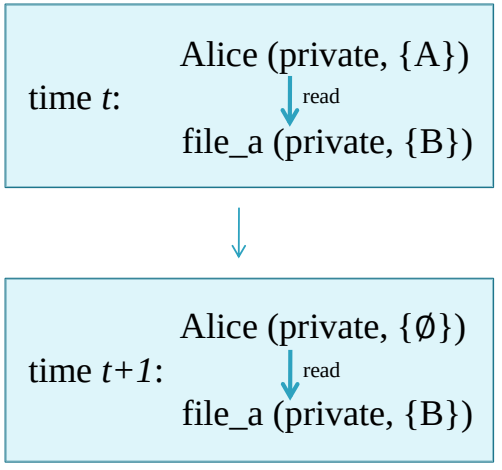
- Subject low watermark policy

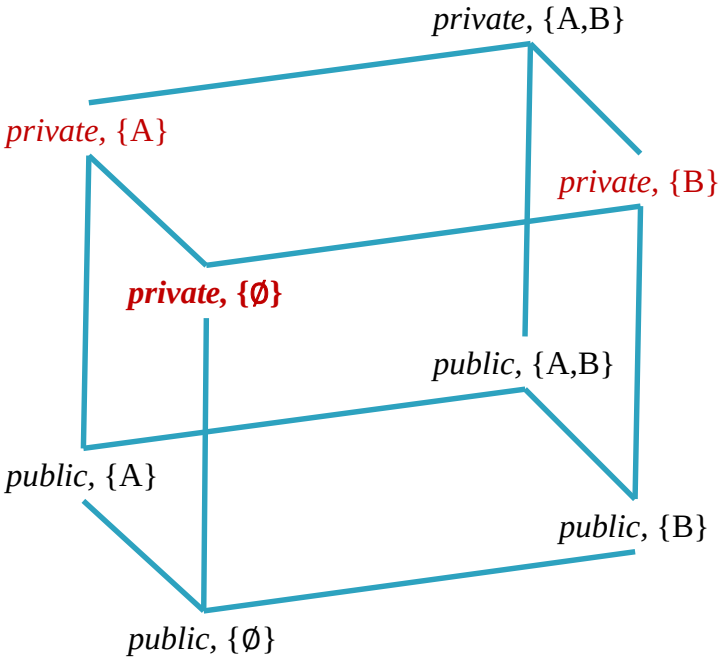




Example

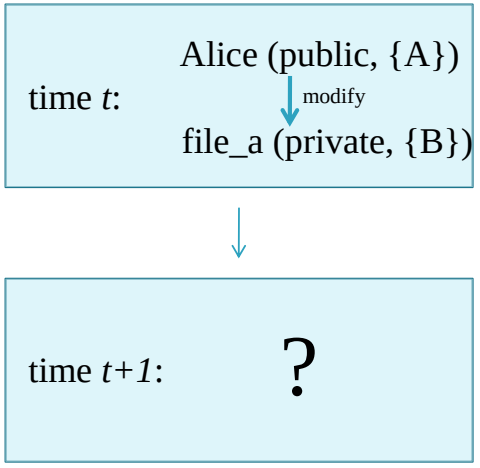
- Subject low watermark policy

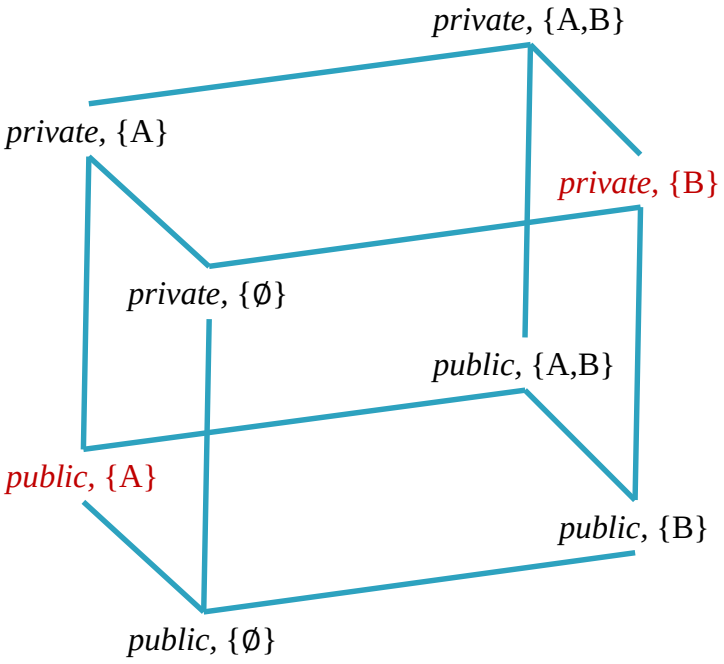




Example

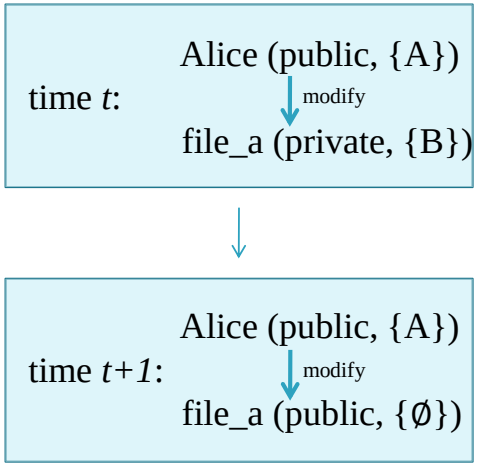
- Object low watermark policy

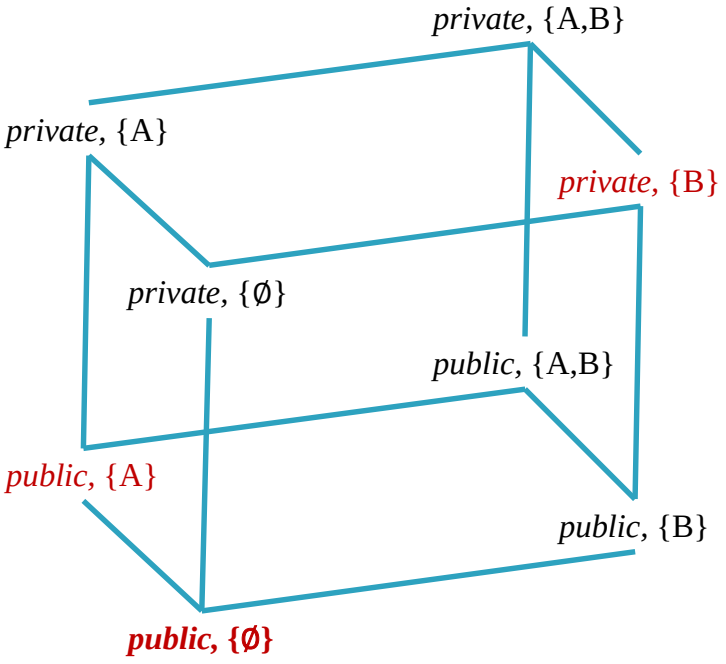




Example

- Object low watermark policy





Invocation

- A subject may invoke another subject to access an object
- Invoke property

Subject s_1 can invoke subject s_2 only if $f_S(s_2) \leq f_S(s_1)$

- Only invoke subjects (e.g., software tools) at lower levels
  - Otherwise dirty subjects could use clean tools to alter clean objects
  - But maybe this is what we want? Controlled invocation!
- Ring property

A subject s_1 can read all objects. It can only modify objects with $f_O(o) \leq f_S(s_1)$ and it can invoke subject s_2 only if $f_S(s_1) \leq f_S(s_2)$

Chinese Wall Model

- Proposed by Brewer and Nash, 1989
- Aimed at consultancy business
- Based on avoiding conflicts of interest
- Motivation:
  - A business consultant should not give advice to Volvo if he has insider knowledge about Scania.
  - A business consultant can give advice to both Volvo and H&M since they are not competitors.

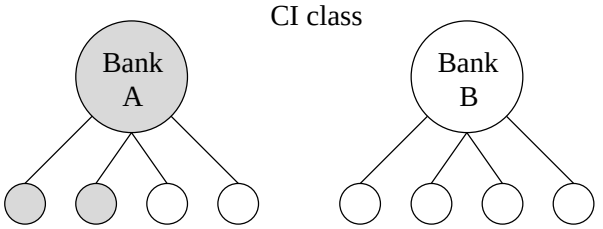
Elements of the Model

- **Company** denoted $c \in C$
- **Subjects** $s \in S$ are the analysts having access to company information
- **Objects** $o \in O$ are items of information, each belonging to a company
- **Company dataset** are all objects concerning a company
  - Function $y : O \rightarrow C$ maps object to its company dataset
- **Conflict of interest class** indicates which companies are in competition
  - Function $x : O \rightarrow P(C)$ maps object to its conflict of interest class, an element in the powerset of C
- **Security label** is a pair $(x(o), y(o))$
- **Sanitized information** is object with no sensitive information
  - Label is $(\emptyset, y(o))$
- **Matrix** $N_{S,O}$ records history of subjects actions (true or false)

Prevent Direct Information Flow

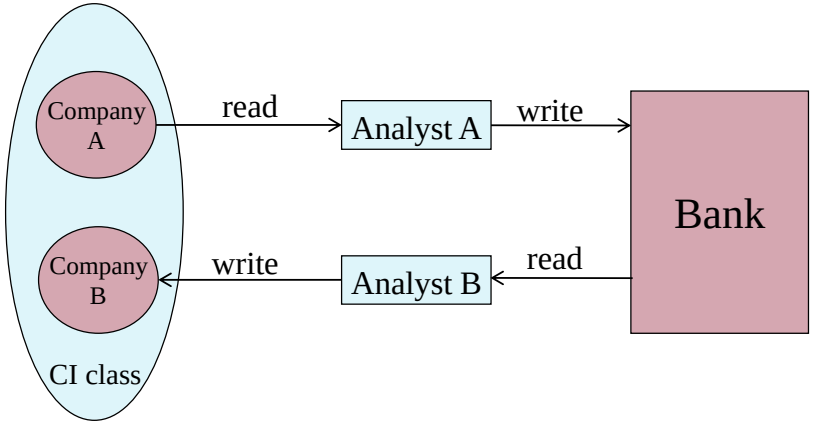
- Access granted only if object belongs to
  - A company data set already accessed by the subject or
  - A different conflict of interest class than previous objects
- ss-property

A subject *s* is permitted to access an object *o* only if for all objects *o'* with $N_{so'}$ = true, *y(o)=y(o')* or *y(o)* $\notin$ *x(o')*



An analyst with access to grey shaded areas, will have access to other objects in Bank A data set, but not Bank B dataset

Indirect Information Flow



- Analyst A updates bank information about company A
- Analyst B can read this bank information and write to an object in company B

Avoiding Indirect Information Flow

- *-property regulates write access

A subject *s* can write to an object *o*, only if *s* has no read access to an object *o'* with $y(o) \neq y(o') \text{ and } x(o') \neq \emptyset$

Other data set

Unsanitized data

- Very restrictive: If you can read sensitive information in one company, you can not write to objects in any other company – ever

Clark-Wilson Model

- Developed in 1987
- Security (integrity) in commercial systems
  - Bank system will be used as example
- Differences between military and commercial applications (according to Clark and Wilson):

Military: Data item associated with a particular level.

Commercial: Data item associated by a set of programs permitted to manipulate it.

Military: Users constrained by what they can read or write.

Commercial: Users constrained by which programs they are allowed to execute.

Clark-Wilson Model

- Consistency – data is consistent if it satisfies some given properties
  - Balance day i = balance day i–1 + deposits – withdrawals
- Two important concepts
  - Well formed transactions – users can only change system through programs
  - Separation of duties – User can only use a certain set of programs
    - If you can create a well-formed transaction you may not be allowed to run it
    - Users have to collaborate to manipulate data

Parts of the System

- Two kinds of data items
  - Constrained data items (CDI) – data items subject to integrity control. E.g., account balances.
  - Unconstrained data items (UDI) – data items *not* subject to integrity control. E.g., unimportant text files
- Integrity verification procedures (IVP) – check the integrity of CDIs. E.g., check that account balance is what it should be
- Transformation procedures (TP) – changes the state of the system, i.e., manipulates CDIs. E.g., deposit money, withdraw money, transfer money
- Certification rules – How should the system behave
- Enforcement rules – How do we make the system behave the way we want

Rules

- **Certification rule 1:** IVPs must ensure that all CDIs are in a valid state
- **Certification rule 2:** A TP has an associated set of CDIs. TP must transform these CDIs from valid states to valid states.

CR2 implies that nonassociated CDIs can be corrupted by a TP.

- **Enforcement rule 1:** System must maintain list of CDIs associated to each TP. Only these CDIs can be manipulated by this TP.

Not everyone should be able to run any TP

- **Enforcement rule 2:** System must associate a list of TPs with each user. A TP can not be run by a user not associated with that TP.

Now we have a set of triples *(user, TP, {CDI set})*. These must be certified.

- **Certification rule 3:** All triples must meet the separation of duties requirements

Rules Continued

Only certain users are allowed to run a certain TP. How do we know the user is who he claims to be?

- **Enforcement rule 3:** The system must authenticate each user trying to execute a TP.

Each operation must be logged

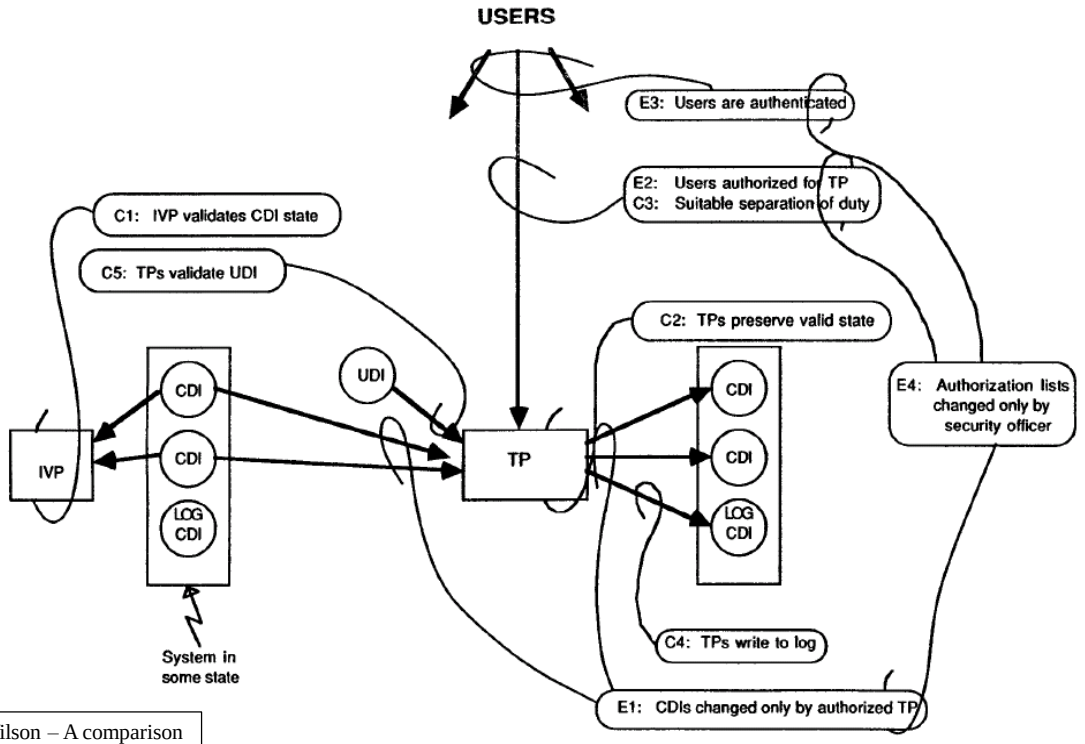
- **Certification rule 4:** All TPs must log information about all operations

An UDI entering the system may not be trusted

- **Certification rule 5:** A TP taking a UDI as input must either transform it to a valid CDI or reject it

No person should be able to both create and run a TP

- **Enforcement rule 4:** Only certifier of TP may change the list of entities associated with that TP. No certifier may ever execute the TP. (separation of duties)



Picture from D. Clark and D. Wilson – A comparison of commercial and military computer security policies, IEEE 1987.