Security Models

Computer Security Lecture 7

David Aspinall

School of Informatics
University of Edinburgh

28th January 2008

Outline

Access and information flow

Access control mechanisms

Security levels

The BLP security model

Outline

Controlling access or information flow

A **security policy** describes requirements for a system.
A **security model** is a way of formalizing a policy.

Controlling access or information flow

A **security policy** describes requirements for a system.
A **security model** is a way of formalizing a policy.
There are two basic paradigms:

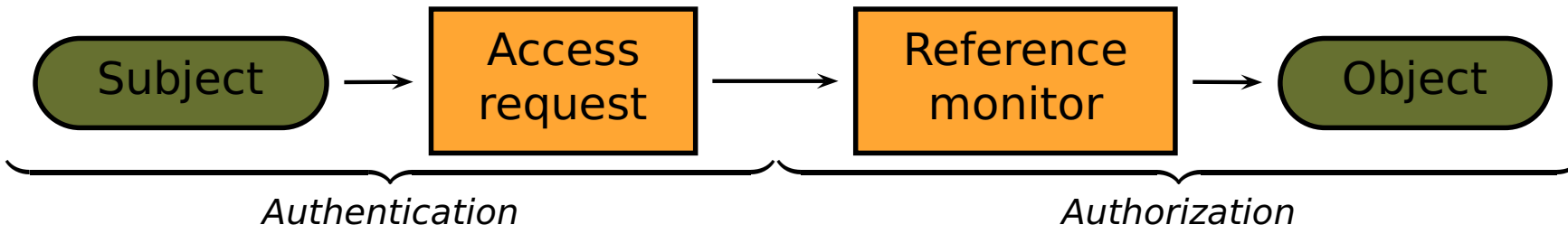
Controlling access or information flow

A **security policy** describes requirements for a system.

A **security model** is a way of formalizing a policy.

There are two basic paradigms:

- **access control**: a guard controls whether a principal (the **subject**) is allowed access to a resource (the **object**).



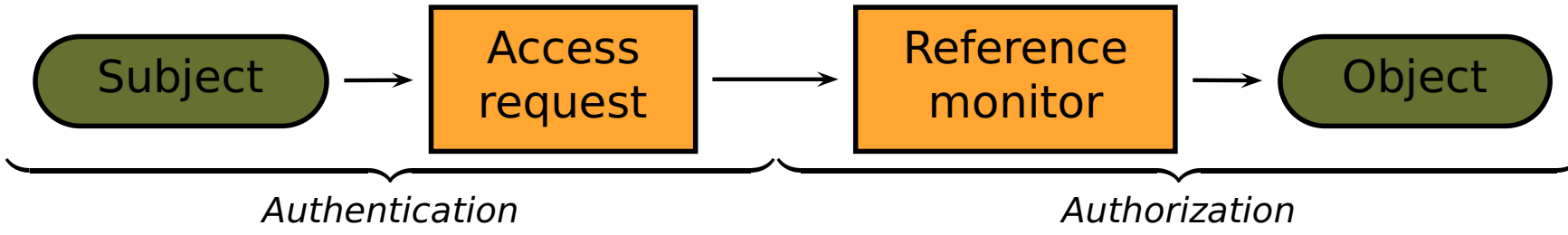
Controlling access or information flow

A **security policy** describes requirements for a system.

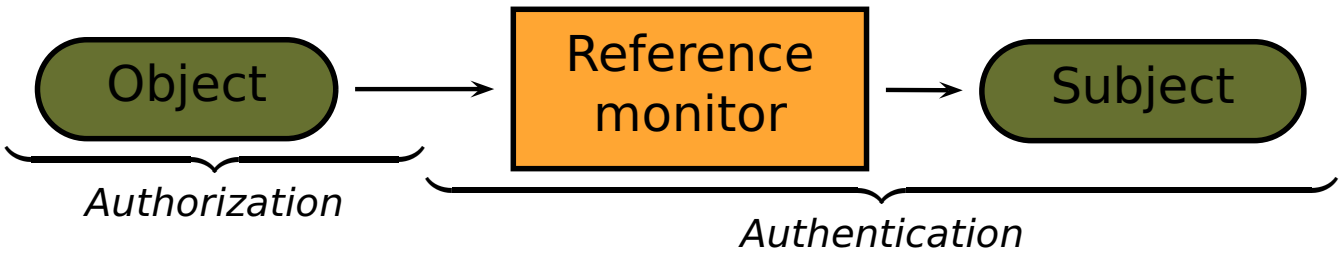
A **security model** is a way of formalizing a policy.

There are two basic paradigms:

- **access control**: a guard controls whether a principal (the **subject**) is allowed access to a resource (the **object**).



- **information flow control**: dual notion sometimes used when confidentiality is the primary concern. A guard controls whether information may flow from a resource to a principal.



Access operations

- We can consider some fundamental **access modes**. Typically:

observe	examine contents of an object
alter	change contents of an object

Access operations

- We can consider some fundamental **access modes**. Typically:

observe	examine contents of an object
alter	change contents of an object

- Next we define **access rights** and their profiles:

	exec	read	append	write
observe		✓		✓
alter			✓	✓

These are the access rights of the influential **Bell-LaPadula** (BLP) model. Access rights are the model's level of granularity for defining security policy. Each real operation requires particular access rights.

Access operations

- We can consider some fundamental **access modes**. Typically:

  observe — examine contents of an object
  alter — change contents of an object

- Next we define **access rights** and their profiles:

	exec	read	append	write
observe		✓		✓
alter			✓	✓

  These are the access rights of the influential **Bell-LaPadula** (BLP) model. Access rights are the model's level of granularity for defining security policy. Each real operation requires particular access rights.

- Profiles and names of rights differ between systems, or even for different subject kinds. E.g., sometimes have a delete. In Unix, exec for directories indicates ability to read the directory.

Ownership and identity

- Who may set the security policy? A resource may have a **owner** who controls access on a case-by-case basis, or the resource may be controlled by a uniform system-wide policy.

Ownership and identity

- Who may set the security policy? A resource may have a **owner** who controls access on a case-by-case basis, or the resource may be controlled by a uniform system-wide policy.

Ownership and identity

- Who may set the security policy? A resource may have a **owner** who controls access on a case-by-case basis, or the resource may be controlled by a uniform system-wide policy.
  - **discretionary access control** (DAC): owners decide who may access their objects

A mixture of both may apply.

Ownership and identity

- Who may set the security policy? A resource may have a **owner** who controls access on a case-by-case basis, or the resource may be controlled by a uniform system-wide policy.
  - **discretionary access control** (DAC): owners decide who may access their objects
  - **mandatory access control** (MAC): policy set system-wide

  A mixture of both may apply.

Ownership and identity

- Who may set the security policy? A resource may have a **owner** who controls access on a case-by-case basis, or the resource may be controlled by a uniform system-wide policy.
  - **discretionary access control** (DAC): owners decide who may access their objects
  - **mandatory access control** (MAC): policy set system-wide

  A mixture of both may apply.
- Owners of resources may be principals in the system: *subjects* themselves under access control. BLP does not (directly) consider operations to modify access controls (e.g., chown in Windows), nor explain when such operations are safe.

Ownership and identity

- Who may set the security policy? A resource may have a **owner** who controls access on a case-by-case basis, or the resource may be controlled by a uniform system-wide policy.
  - **discretionary access control** (DAC): owners decide who may access their objects
  - **mandatory access control** (MAC): policy set system-wide

  A mixture of both may apply.
- Owners of resources may be principals in the system: *subjects* themselves under access control. BLP does not (directly) consider operations to modify access controls (e.g., chown in Windows), nor explain when such operations are safe.
- The **identity** of subjects is also flexible: e.g., *identity changes* during operations (SUID programs in Unix). Again, this doesn't fit BLP.

Outline

Access control structures

- How are access control rights defined? Many schemes, but ultimately modelled by:

Access control structures

- How are access control rights defined? Many schemes, but ultimately modelled by:
  - A set S of subjects, a set O of objects

Access control structures

- How are access control rights defined? Many schemes, but ultimately modelled by:
  - A set S of subjects, a set O of objects
  - A set A of operations (modelled by access rights), we'll consider $A = \{\text{exec}, \text{read}, \text{append}, \text{write}\}$.

Access control structures

- How are access control rights defined? Many schemes, but ultimately modelled by:
  - A set S of subjects, a set O of objects
  - A set A of operations (modelled by access rights), we'll consider $A = \{\text{exec}, \text{read}, \text{append}, \text{write}\}$.
  - An **access control matrix**

$$M = (M_{so})_{s \in S, o \in O}$$

where each entry $M_{so} \subseteq A$ defines rights for s to access o.

Access control structures

- How are access control rights defined? Many schemes, but ultimately modelled by:
  - A set S of subjects, a set O of objects
  - A set A of operations (modelled by access rights), we'll consider $A = \{\text{exec}, \text{read}, \text{append}, \text{write}\}$.
  - An **access control matrix**

$$M = (M_{so})_{s \in S, o \in O}$$

    where each entry $M_{so} \subseteq A$ defines rights for s to access o.

- Example matrix for $S = \{\text{Alice}, \text{Bob}\}$ and three objects:

	`bob.doc`	`edit.exe`	`fun.com`
Alice	{}	{exec}	{exec, read}
Bob	{read, write}	{exec}	{exec, read, write}

Representing the access control matrix

- Implementing M directly is impractical, so different schemes are used. Complementary possibilities: either use **capabilities** (store M by rows) or use **access control lists** (store M by columns)

Representing the access control matrix

- Implementing M directly is impractical, so different schemes are used. Complementary possibilities: either use **capabilities** (store M by rows) or use **access control lists** (store M by columns)
- A **capability** is an unforgeable token that specifies a subject's access rights. Pros: can pass around capabilities; good fit with discr. AC. Cons: difficult to revoke, or find out who has, access to a particular resource (must examine all capabilities). Interest reinstated recently with distributed and mobile computation.

Representing the access control matrix

- Implementing *M* directly is impractical, so different schemes are used. Complementary possibilities: either use **capabilities** (store *M* by rows) or use **access control lists** (store *M* by columns)
- A **capability** is an unforgeable token that specifies a subject's access rights. Pros: can pass around capabilities; good fit with discr. AC. Cons: difficult to revoke, or find out who has, access to a particular resource (must examine all capabilities). Interest reinstated recently with distributed and mobile computation.
- An **access control list** (ACL) stores the access rights to an object with the object itself. Pros: good fit with object-biased OSes. Cons: difficult to revoke, or find out, permissions of a particular subject (must search all ACLs).

Outline

Security levels

- **Multi Level Security** (MLS) systems originated in the military. A **security level** is a label for subjects and objects, to describe a policy.

Security levels

- **Multi Level Security** (MLS) systems originated in the military. A **security level** is a label for subjects and objects, to describe a policy.
- Security levels are ordered:

$$\text{unclassified} \leq \text{confidential} \leq \text{secret} \leq \text{topsecret}.$$

Security levels

- **Multi Level Security** (MLS) systems originated in the military. A **security level** is a label for subjects and objects, to describe a policy.
- Security levels are ordered:

  $$\text{unclassified} \leq \text{confidential} \leq \text{secret} \leq \text{topsecret}.$$

- Ordering can express policies like “no write-down” which means that a high-level subject cannot write down to a low-level object. (A user with confidential clearance cannot write an unclassified file: it might contain confidential information read earlier.)

Security levels

- **Multi Level Security** (MLS) systems originated in the military. A **security level** is a label for subjects and objects, to describe a policy.
- Security levels are ordered:

  $$\text{unclassified} \leq \text{confidential} \leq \text{secret} \leq \text{topsecret}.$$

- Ordering can express policies like “no write-down” which means that a high-level subject cannot write down to a low-level object. (A user with confidential clearance cannot write an unclassified file: it might contain confidential information read earlier.)
- In practice, we need more flexibility. We may want *categorizations* as well, for example, describing departments or divisions in an organization. Then individual levels may not be comparable. . .

Security lattices

- A *lattice* is a set L equipped with a partial ordering $\leq$ such every two elements $a, b \in L$ has a *least upper bound* $a \vee b$ and a *greatest lower bound* $a \wedge b$. A finite lattice must have top and bottom elements.

Security lattices

- A *lattice* is a set L equipped with a partial ordering $\leq$ such every two elements $a, b \in L$ has a *least upper bound* $a \vee b$ and a *greatest lower bound* $a \wedge b$. A finite lattice must have top and bottom elements.
- In security, if $a \leq b$, we say that b **dominates** a. The bottom level dominated by all others is system low; the top level which dominates all others is system high.

Security lattices

- A *lattice* is a set L equipped with a partial ordering $\leq$ such every two elements $a, b \in L$ has a *least upper bound* $a \vee b$ and a *greatest lower bound* $a \wedge b$. A finite lattice must have top and bottom elements.
- In security, if $a \leq b$, we say that b **dominates** a. The bottom level dominated by all others is system low; the top level which dominates all others is system high.
- Lattices are used for MLS policies because they allow an ordering where:

Security lattices

- A *lattice* is a set L equipped with a partial ordering $\leq$ such every two elements $a, b \in L$ has a *least upper bound* $a \vee b$ and a *greatest lower bound* $a \wedge b$. A finite lattice must have top and bottom elements.
- In security, if $a \leq b$, we say that b **dominates** a. The bottom level dominated by all others is system low; the top level which dominates all others is system high.
- Lattices are used for MLS policies because they allow an ordering where:

Security lattices

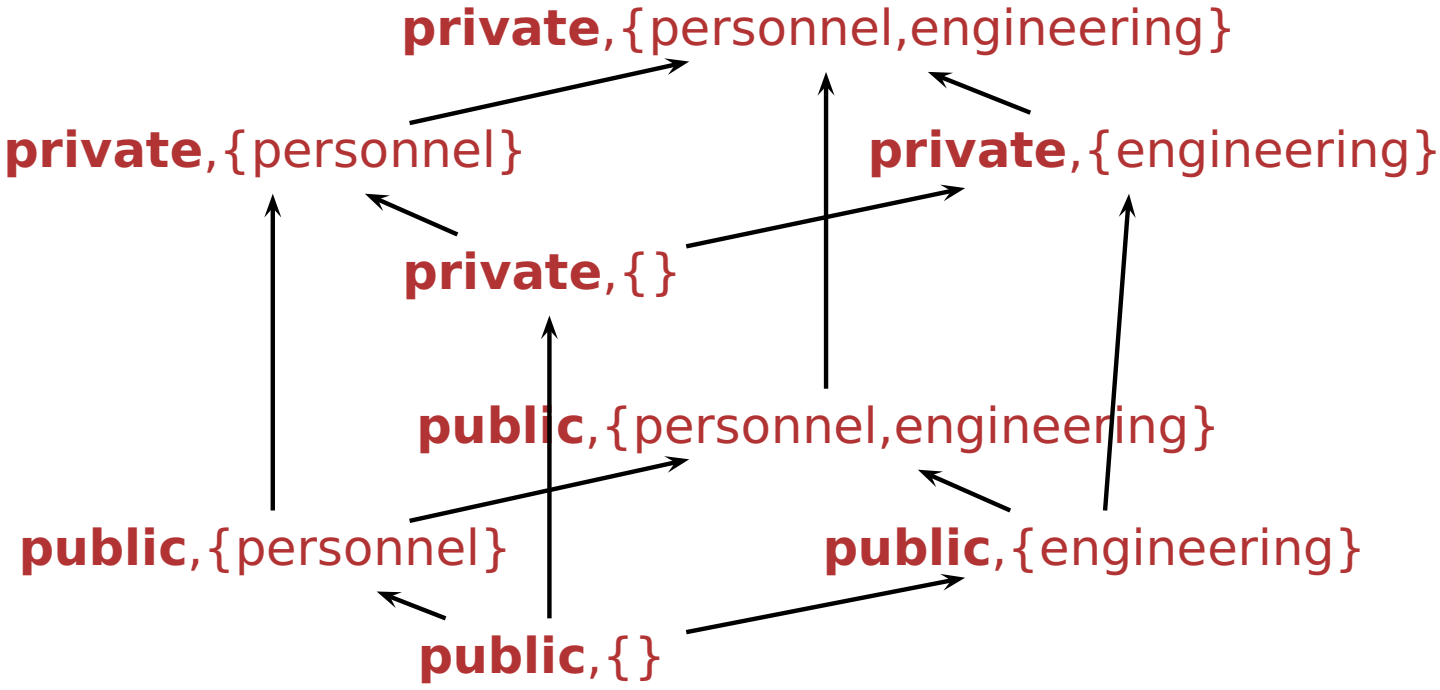
- A *lattice* is a set L equipped with a partial ordering $\leq$ such every two elements $a, b \in L$ has a *least upper bound* $a \vee b$ and a *greatest lower bound* $a \wedge b$. A finite lattice must have top and bottom elements.
- In security, if $a \leq b$, we say that b **dominates** a. The bottom level dominated by all others is system low; the top level which dominates all others is system high.
- Lattices are used for MLS policies because they allow an ordering where:
  - given two objects at different levels a and b, there is a minimal security level $a \vee b$ needed to access both a and b;

Security lattices

- A *lattice* is a set L equipped with a partial ordering $\leq$ such every two elements $a, b \in L$ has a *least upper bound* $a \vee b$ and a *greatest lower bound* $a \wedge b$. A finite lattice must have top and bottom elements.
- In security, if $a \leq b$, we say that b **dominates** a. The bottom level dominated by all others is system low; the top level which dominates all others is system high.
- Lattices are used for MLS policies because they allow an ordering where:
  - given two objects at different levels a and b, there is a minimal security level $a \vee b$ needed to access both a and b;
  - given two subjects at different levels a and b, there is a maximal security level $a \wedge b$ for an object which must be readable by both.

An Example Lattice [Gollmann]

A standard construction is to take a set of *classifications* H, with a linear ordering $\leq_H$, together with a set C of categories. Define a *compartment* as a set of categories, and then a security level as a pair (h, c) where $h \in H$ and $c \subseteq C$. Then the ordering $(h_1, c_1) \leq (h_2, c_2) \iff h_1 \leq h_2, c_1 \subseteq c_2$ defines a lattice.



Outline

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.
- A set L of security levels, with a partial ordering $\leq$.

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.
- A set L of security levels, with a partial ordering $\leq$.
- The state set $\mathcal{B} \times \mathcal{M} \times \mathcal{F}$ captures the current permissions and subjects accessing objects. It has three parts:

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.
- A set L of security levels, with a partial ordering $\leq$.
- The state set $\mathcal{B} \times \mathcal{M} \times \mathcal{F}$ captures the current permissions and subjects accessing objects. It has three parts:
  - $\mathcal{B}$ possible current accesses

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.
- A set L of security levels, with a partial ordering $\leq$.
- The state set $\mathcal{B} \times \mathcal{M} \times \mathcal{F}$ captures the current permissions and subjects accessing objects. It has three parts:
  - $\mathcal{B}$ possible current accesses
  - $\mathcal{M}$ permissions matrices

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.
- A set L of security levels, with a partial ordering $\leq$.
- The state set $\mathcal{B} \times \mathcal{M} \times \mathcal{F}$ captures the current permissions and subjects accessing objects. It has three parts:
  - $\mathcal{B}$ possible current accesses
  - $\mathcal{M}$ permissions matrices
  - $\mathcal{F}$ security level assignments

Bell-LaPadula Model (BLP)

- BLP (1973) is state machine model for confidentiality.
- Permissions use an AC matrix and **security levels**. The **security policy** prevents information flowing from a high level to a lower level.
- Assume subjects S, objects O, accesses A as before.
- A set L of security levels, with a partial ordering $\leq$.
- The state set $\mathcal{B} \times \mathcal{M} \times \mathcal{F}$ captures the current permissions and subjects accessing objects. It has three parts:
  - $\mathcal{B}$ possible current accesses
  - $\mathcal{M}$ permissions matrices
  - $\mathcal{F}$ security level assignments
- A BLP state is a triple (b, M, f).

BLP state set

- $\mathcal{B} = \mathcal{P}(S \times O \times A)$ is the set of all possible current accesses.
  An element $b \in B$ is a set of tuples (s, o, a) meaning s is performing operation a on an object o.

BLP state set

- $\mathcal{B} = \mathcal{P}(S \times O \times A)$ is the set of all possible current accesses.
  An element $b \in B$ is a set of tuples (s, o, a) meaning s is performing operation a on an object o.
- $\mathcal{M}$ is the set of permission matrices $M = (M_{so})_{s \in S, o \in O}$.

BLP state set

- $\mathcal{B} = \mathcal{P}(S \times O \times A)$ is the set of all possible current accesses.
  An element $b \in B$ is a set of tuples (s, o, a) meaning s is performing operation a on an object o.
- $\mathcal{M}$ is the set of permission matrices $M = (M_{so})_{s \in S, o \in O}$.
- $\mathcal{F} \subset L^S \times L^S \times L^O$ is the set of security level assignments.
  An element $f \in \mathcal{F}$ is a triple (f_S, f_C, f_O) where

BLP state set

- $\mathcal{B} = \mathcal{P}(S \times O \times A)$ is the set of all possible current accesses.
  An element $b \in B$ is a set of tuples (s, o, a) meaning s is performing operation a on an object o.
- $\mathcal{M}$ is the set of permission matrices $M = (M_{so})_{s \in S, o \in O}$.
- $\mathcal{F} \subset L^S \times L^S \times L^O$ is the set of security level assignments.
  An element $f \in \mathcal{F}$ is a triple (f_S, f_C, f_O) where
  - $f_S : S \to L$ gives the **maximal security level** each subject can have;

BLP state set

- $\mathcal{B} = \mathcal{P}(S \times O \times A)$ is the set of all possible current accesses.
  An element $b \in B$ is a set of tuples (s, o, a) meaning s is performing operation a on an object o.
- $\mathcal{M}$ is the set of permission matrices $M = (M_{so})_{s \in S, o \in O}$.
- $\mathcal{F} \subset L^S \times L^S \times L^O$ is the set of security level assignments.
  An element $f \in \mathcal{F}$ is a triple (f_S, f_C, f_O) where
  - $f_S : S \to L$ gives the **maximal security level** each subject can have;
  - $f_C : S \to L$ gives the **current security level** of each subject (st $f_C \leq f_S$), and

BLP state set

- $\mathcal{B} = \mathcal{P}(S \times O \times A)$ is the set of all possible current accesses.
  An element $b \in B$ is a set of tuples (s, o, a) meaning s is performing operation a on an object o.
- $\mathcal{M}$ is the set of permission matrices $M = (M_{so})_{s \in S, o \in O}$.
- $\mathcal{F} \subset L^S \times L^S \times L^O$ is the set of security level assignments.
  An element $f \in \mathcal{F}$ is a triple (f_S, f_C, f_O) where
  - $f_S : S \to L$ gives the **maximal security level** each subject can have;
  - $f_C : S \to L$ gives the **current security level** of each subject (st $f_C \leq f_S$), and
  - $f_O : O \to L$ gives the **classification** of all objects.

BLP Mandatory Access Control Policy

Consider a state (b, M, f), where b is the set of current accesses.

BLP Mandatory Access Control Policy

Consider a state (b, M, f), where b is the set of current accesses.

Simple security property

The **ss-property** states for each access $(s, o, a) \in b$ where $a \in \{\text{read}, \text{write}\}$, then $f_O(o) \leq f_S(s)$ (*no read-up*).

Star property

The $*$**-property** states for each access $(s, o, a) \in b$ where $a \in \{\text{append}, \text{write}\}$, then $f_C(s) \leq f_O(o)$ (*no write-down*) and moreover, we must have $f_O(o') \leq f_O(o)$ for all o' with $(s, o', a') \in b$ and $a' \in \{\text{read}, \text{write}\}$ (*o must dominate any other object s can read*).

BLP Mandatory Access Control Policy

Consider a state (b, M, f), where b is the set of current accesses.

Simple security property

The **ss-property** states for each access $(s, o, a) \in b$ where $a \in \{\text{read}, \text{write}\}$, then $f_O(o) \leq f_S(s)$ (*no read-up*).

Star property

The $*$**-property** states for each access $(s, o, a) \in b$ where $a \in \{\text{append}, \text{write}\}$, then $f_C(s) \leq f_O(o)$ (*no write-down*) and moreover, we must have $f_O(o') \leq f_O(o)$ for all o' with $(s, o', a') \in b$ and $a' \in \{\text{read}, \text{write}\}$ (*o must dominate any other object s can read*).

Together these form the *mandatory access control* policy for BLP.

BLP Discretionary Control and Security

The access control matrix M allows DAC as well.

Discretionary security property

The **ds-property**: for each access $(s, o, a) \in b$, we have that $a \in M_{so}$ (*discretionary access controls are obeyed*).

BLP Discretionary Control and Security

The access control matrix M allows DAC as well.

Discretionary security property

The **ds-property**: for each access $(s, o, a) \in b$, we have that $a \in M_{so}$ (*discretionary access controls are obeyed*).

- **Definition of Security:** The state (b, M, f) is **secure** if the three properties above are satisfied.

Notice that BLP's notion of security is entirely captured in the current state.

Current clearance level

- Unfortunately, the $*$-property means a high-level subject cannot send messages to a low-level subject. This is unrealistic!

Current clearance level

- Unfortunately, the $*$-property means a high-level subject cannot send messages to a low-level subject. This is unrealistic!
- There are two ways out:

Current clearance level

- Unfortunately, the $*$-property means a high-level subject cannot send messages to a low-level subject. This is unrealistic!
- There are two ways out:
  1. temporarily downgrade a high-level subject, which is why the model includes the current **clearance level** setting f_C, or

Current clearance level

- Unfortunately, the $*$-property means a high-level subject cannot send messages to a low-level subject. This is unrealistic!
- There are two ways out:
  1. temporarily downgrade a high-level subject, which is why the model includes the current **clearance level** setting f_C, or
  2. identify a set of **trusted subjects** allowed to violate the $*$-property.

Current clearance level

- Unfortunately, the $*$-property means a high-level subject cannot send messages to a low-level subject. This is unrealistic!
- There are two ways out:
  1. temporarily downgrade a high-level subject, which is why the model includes the current **clearance level** setting f_C, or
  2. identify a set of **trusted subjects** allowed to violate the $*$-property.
- Approach 1 works because the current state describes exactly what each subject knows. So if a subject (e.g. a process) is downgraded, it cannot access higher-level material, so may safely write at any lower level than its maximum.

Current clearance level

- Unfortunately, the $*$-property means a high-level subject cannot send messages to a low-level subject. This is unrealistic!
- There are two ways out:
  1. temporarily downgrade a high-level subject, which is why the model includes the current **clearance level** setting f_C, or
  2. identify a set of **trusted subjects** allowed to violate the $*$-property.
- Approach 1 works because the current state describes exactly what each subject knows. So if a subject (e.g. a process) is downgraded, it cannot access higher-level material, so may safely write at any lower level than its maximum.
- When subjects are people with high-level clearances, approach 2 works: we trust someone to violate the property in the model, e.g., by publishing part of a secret document.

Basic security theorem

- A transition from state v_1 to v_2 is **secure** simply if both states v_1 and v_2 are secure.

Basic security theorem

- A transition from state v_1 to v_2 is **secure** simply if both states v_1 and v_2 are secure.
- This leads to a rather simple and general theorem:

Basic security theorem

- A transition from state v_1 to v_2 is **secure** simply if both states v_1 and v_2 are secure.
- This leads to a rather simple and general theorem:

Basic security theorem

If all state transitions in a system are secure and the initial state of the system is secure, then every subsequent state is also secure.

Basic security theorem

- A transition from state v_1 to v_2 is **secure** simply if both states v_1 and v_2 are secure.
- This leads to a rather simple and general theorem:

Basic security theorem

If all state transitions in a system are secure and the initial state of the system is secure, then every subsequent state is also secure.

Basic security theorem

- A transition from state v_1 to v_2 is **secure** simply if both states v_1 and v_2 are secure.
- This leads to a rather simple and general theorem:

Basic security theorem

If all state transitions in a system are secure and the initial state of the system is secure, then every subsequent state is also secure.

(NB: this follows immediately by induction, it has nothing to do with the properties of BLP!)

- The point: we can reduce checking the system for all possible inputs to checking that each kind of possible state transition preserves security. Of course, to do this we need a concrete instance of the model which describes possible transitions.

References

See Ch 3–5 of Gollmann, Ch 7–9 of Anderson and Parts 2–3 of Bishop.

- Ross Anderson. *Security Engineering: A Comprehensive Guide to Building Dependable Distributed Systems*.
  Wiley & Sons, 2001.
- Matt Bishop. *Computer Security: Art and Science*.
  Addison-Wesley, 2003.
- Dieter Gollmann. *Computer Security*.
  John Wiley & Sons, second edition, 2006.

Recommended Reading

Chapters 3-4 of Gollmann.