Multi-Level Security & Information Flow Control

Software Security

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21st November 2018

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Objectives of today's lecture

- ➜ Repetition: What are the main rules of the *Bell-LaPadula model*?
- ➜ Getting to know other security models and design principles of a *Trusted Computing Base*
- ➜ Understanding and applying analytical techniques to detect undesirable information flows in a program code
- ➜ Being able to implement security policies for small code examples based on JiF (Java + Information Flow)

Repetition: Bell-LaPadula Model (BLP)

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1. Which protection goal is implemented by BLP?

- ➜ Confidentiality

2. What are the most important rules of BLP?

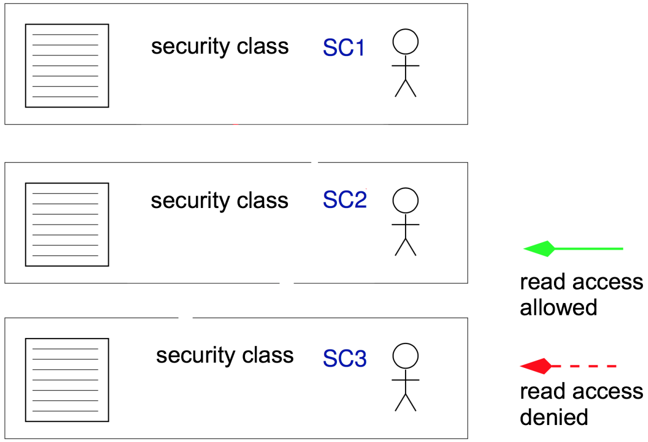
- ➜ No Read Up: Subjects are not allowed to read an object of a higher security class
- ➜ No Write Down: Subjects are not allowed to write an object of a lower security class

3. How are security classes represented and how are they ordered?

- ➜ Represented as pairs (A, C), where A is a *sensitivity level* and C is a *set of compartments*
- ➜ Information from (A, C) to (A', C') shall flow iff $A \leq A'$ and $C \subseteq C'$

No Read Up (Simple Security Property)

... assumed if $SC3 \leq SC2 < SC1$, then what is allowed?



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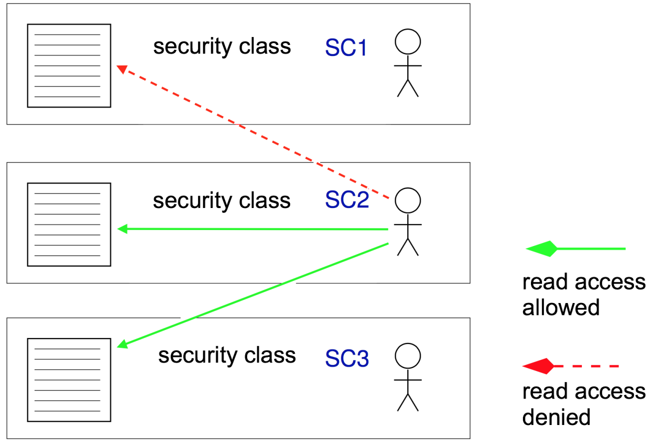
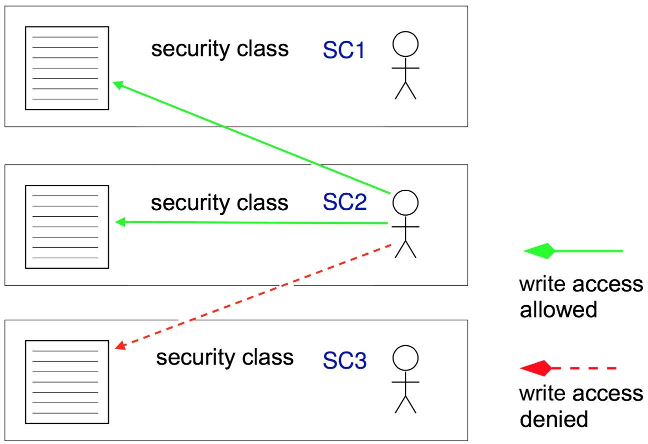
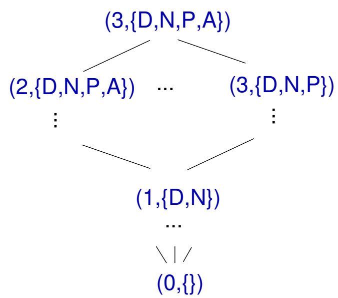


No Write Down (*-Property)

... assumed if $SC3 < SC2 \leq SC1$, then what is allowed?



Example: Hospital Scenario



Note:

- all compartments of a security class must be linked by conjunction
- e.g. $(\_, \{D, N\})$ means, reading is only allowed if the subject is authorized for both compartments doctor and nurse

1. Will it be possible for a person or process P with $SC = (1, \{D\})$ to read a document with $SC = (0, \{D\})$? yes
2. Is it possible for P to expand/write a document with $SC = (2, \{D, N\})$? yes
3. Are there documents that P is allowed to read and write at the same time? yes, documents with $SC = (1, \{D\})$!

Generalization by Dorothy Denning

Complete Lattice $((A, C);\ \leq;\ \oplus;\ \otimes)$

with $(A, C) \oplus (A', C') = (\max\ (A, A'), C \cup C')$

$(A, C) \otimes (A', C') = (\min\ (A, A'), C \cap C')$

$Low = (0, \varnothing)$

$High = (n, c)$

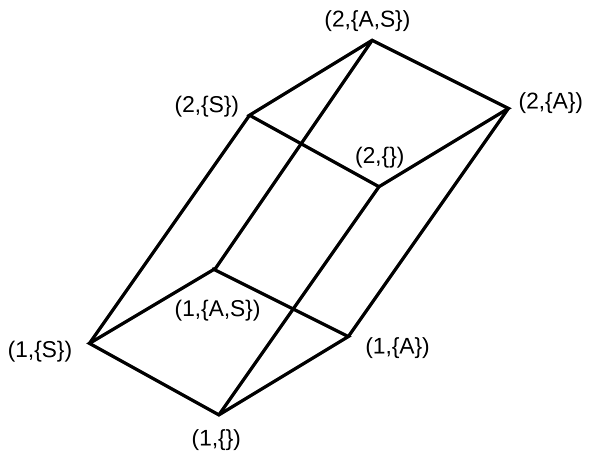
where n: highest security level

c: universal (largest) set of compartments

Note: Completeness follows from finiteness of A and C!

Visualisation by Hasse Diagram

- Often used to represent a finite partially ordered set
- Each edge links smaller and larger elements
- The lower end of an edge represents the smaller element



Benefits of the Generalization

Idea

- Information flows of a program are generated by program statements that combine data or processes from different security classes
- Denning's formalization makes it possible to describe information flows with the help of the lattice operators

Example $Y := X_1 + X_2 * X_3$

induces the information flows

$X_1 \rightarrow Y$, $X_2 \rightarrow Y$ und $X_3 \rightarrow Y$

Using the operator $\oplus$, the test can be reduced to the following check

$SC(X_1) \oplus SC(X_2) \oplus SC(X_3) \leq SC(Y)$

Limitations of the Bell-LaPadula Model

Advantages

- Comprehensible theory and an excellent mathematical basis

Drawbacks

- Rules in practice often not sufficient and not flexible enough
- Consequence: User prompts Admin to temporarily classify documents in a lower security class

Solution

- Use of Tranquility Properties
  ➜ Security classes of objects or subject are allowed to change under certain rules
- Assumption is that the classification of an object does not change as long as it is still referenced

Use of Tranquility Properties

Strong

- Subjects and objects do not change security classes during the lifetime of the system

Weak

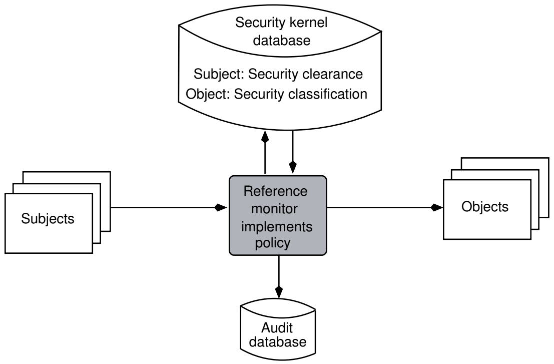
- Security classes are only modified in conformance with the specified security policy model
  ⇒ High Watermark Principle
- e.g. process starts with low security class and is upgraded when accessing objects of higher security classes
- An upgrade is only possible if the security model is not violated

Limits of BLP & High Watermark Principle

- Standard software often doesn't run without errors, because temporary files created before an upgrade can't be written afterwards
- WriteUp must be *blind*, because confirming the successful writing would open an information channel about the state of the higher class
- How to create excerpts from documents for publication (downgrading)?
- How do you classify certain documents that are only to be protected in combination?
- Conclusion: The assumption of the Tranquility Property is often too strong in practice!

Trusted Computing Base (TCB)

- TCB covers all hardware and software components for implementing the security concepts
- Implementable as a *reference monitor* or as a part of an operating system core



Properties of a Trusted Computing Base

Design Principles

- TCB should be as *small as possible* and consist of just a few components
- Reference monitor and databases have to be protected from unauthorized access
- Verify the correctness of all TCB components if possible
- Every access to the system must be controlled by the TCB!

Covered Channels

If a Trojan horse enters a high security class level and transmits information to lower security class level by bypassing the protection mechanism, a hidden channel is present

Such information flows can be implemented via ...

➜ Storage Channels:
- Process of high security class transmits confidential information by actions with the hard disk drive
- e.g. modify the position of the hard disk's read head or open, close or lock files
- Process of low security class is able to monitor these actions

➜ Timing Channels:
- Information transmission by measuring the runtime of processes

Other Security Policy Models

Bell-LaPadula-Model (BLP, 1969/73)

➜ Protection goal: Confidentiality of data

➜ Rules: *No-Read-Up* and *No-Write-Down*

Biba-Model (1977)

➜ Protection goal: Integrity of data

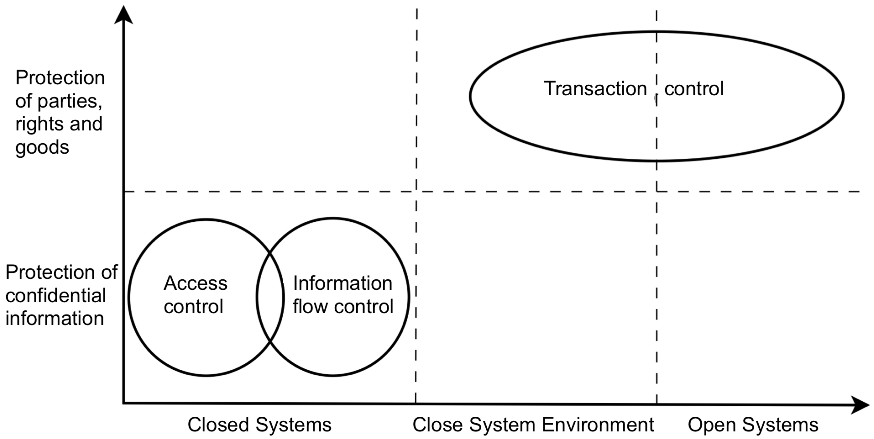
➜ Biba is dual of BLP, i.e.
Rules: *No-Read-Down* and *No-Write-Up*

Low-Watermark Mandatory Access Control (LoMAC)

➜ Variant of the Biba model, allows read access for objects with high integrity to objects of low integrity

➜ Reading subject is then downgraded to a lower integrity level

Relationship between Protection Goals and Operational Environment



Source: Vitali Keppel: Klassifikation und Analyse von IT-Sicherheitsmodellen, Masterarbeit, Uni Koblenz-Landau, Juni 2013.

Implementation of MLS Security Models

Hersteller/Implementation	Typus	System	Akkreditiert
NSA/Red Hat - SELinux	Variante von Bell-LaPadula	Red Hat, Gentoo Linux, SUSE, Debian, Darwin	-
TrustedBSD	Biba, LoMAC	TrustedBSD, Mac OS X, Darwin	-
Novell AppArmor	-	Ubuntu, SUSE	-
Rule Set Based Access Control (RSBAC)	Variante von Bell-LaPadula	Gentoo Linux, Debian, Fedora	-
Sun Microsystems	Variante von Bell-LaPadula	Sun Trusted Solaris	-
Microsoft	Biba	Windows Vista	-
Unisys	Biba, Bell-LaPadula, Lattice (compartment), Clark-Wilson	OS2200	TCSEC B1
Argus Systems Group PitBull LX	Lattice (compartment)	AIX, Sun Solaris, Linux	ITSEC F-B1, E3

Source: http://de.wikipedia.org/wiki/Mandatory_Access_Control

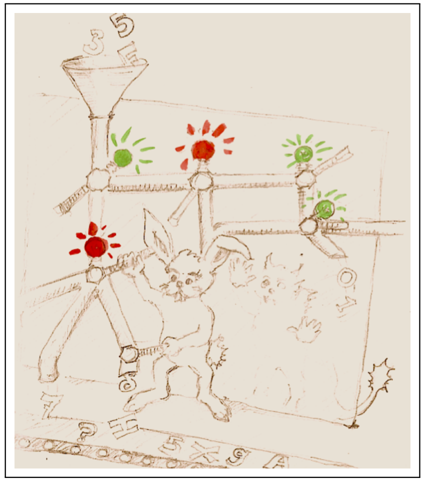
JIF: Java + Information Flow

Information Flow Security

➜ Attacker should not learn confidential (red) information by observing visible (green) events/outputs

Attacker interface

Developer interface



Motivation for Information Flow Control

Problem

- Security engineering methods support the systematic derivation of security policies on an abstract level, e.g. information may only flow up ($L \rightarrow H$)
- Mapping security rules into the program code is challenging
- Specifying access modifiers (e.g. private, public etc.) is generally not powerful enough

Solution

- Labelling of the program code with security labels to express security policies more precisely
- Performing security analysis based on labels, e.g. by compilers

JIF: Java + Information Flow

General Remarks

- Development 1997 at the Cornell University
- Security-typed programming language that extends Java
- Based on a *Decentralized Label Model* (DLM)

Language Features

- Labels for *Integrity* & *Confidentiality*
- Policy specification using *Principals*
- Hierarchical relationships between principals can be specified (*acts-for relation*)
- Declassification of labeled objects with respect to confidentiality & integrity is supported

JIF-Homepage: http://www.cs.cornell.edu/jif/

Decentralized Model of Security Labels

Confidentiality Rules

- Notation: $u \rightarrow p$
- Owner u trusts the reader p not to give the information to unauthorized persons

Integrity Rules

- Notation: $u \leftarrow p$
- Owner u trusts the writer p not to destroy or damage the information

```
// only Alice and Bob are allowed to read a
int{Alice -> Bob} a;

// only Alice is allowed to write b
int{Alice <- Alice} b;

// combined read and write permissions
int{Alice -> Bob; Alice <- Alice} c;
```


Example: Assignment Operator of JIF

Example for Confidentiality

```
// only Alice and Bob are allowed to read a
int{Alice -> Bob} a;

// only Alice is allowed to read b
int{Alice -> Alice} b;

a = b;
b = a;
```


Example: Assignment Operator of JIF

Example for Confidentiality

```
// only Alice and Bob are allowed to read a
int{Alice -> Bob} a;

// only Alice is allowed to read b
int{Alice -> Alice} b;

a = b; // not allowed!
b = a; // allowed, because readers(b) ⊆ readers(a)
```


Example: Assignment Operator of JIF

Example for Integrity

```
// only Alice and Bob are allowed to write a
int{Alice <- Bob} a;

// only Alice is allowed to write b
int{Alice <- Alice} b;

a = b;
b = a;
```

Example: Assignment Operator of JIF

Example for Integrity

```
// only Alice and Bob are allowed to write a
int{Alice <- Bob} a;

// only Alice is allowed to write b
int{Alice <- Alice} b;

a = b; // allowed, because writers(b) ⊆ writers(a)
b = a; // not allowed!
```


How principals are created?

Concept

- ➜ *Principals* are entities with some power to observe and change certain aspects of the system
- ➜ Useful to model *users*, *processes*, *user groups*, or other application-specific entities, like *nodes of a netwerk*

Example

- ➜ There are several ways to create principals, e.g.

```
import jif.util.*;
class Test {
 public static void main (String args[])   {
  String sAlice = "Alice";
  final principal Alice = new ExternalPrincipal(sAlice);...
}}
```

Note: When defining labels, the bottom and top can be represented by $*$ (*no principals*) and _ (*all principals*). These characters represent only principal sets and not objects of the class Principal

How principals are created?

- ➜ Principals can also be created by independent classes with static attributes *using a singleton pattern*
- ➜ Advantage is that e.g. the principal *Steffen* is created only once and can be used by other classes of the package

```
package jif.principals;

public class Steffen extends ExternalPrincipal {
    public Steffen() {
        super("Steffen");
    }

    private static Steffen{*!:*} P;
    public static Principal getInstance{*!:*}() {
        if (P == null) {
            P = new Steffen();
        }
        return P;
    }}
```


Example: Defaultlabel of JIF

Security label without explicit information

- ➜ .. means that everyone is allowed to read or modify the variable

```
// everything is allowed
int{} a; // abbreviation for int {_->_ ; _<-_} a;

// only Alice is allowed to read b
int{Alice -> Alice} b;

a = b; // not allowed!
b = a; // allowed, because readers(b) ⊆ readers(a)
```

Under which condition can an arbitrary value be assigned?

- ➜ ... if the variable is *unreadable for anyone* and *writable for everyone*

```
int{* -> *; _<-_} a;

int{Alice -> Alice; Alice <- Bob} b;

a = b;
```

Generalization: Assignments

What does the JIF compiler check for the assignment

```
a = b;
```

?

➜ Main target: $sc(b)$ is less restricted than $sc(a)$
i.e. $sc(b) \sqsubseteq sc(a) := sc(b) \sqsubseteq_C sc(a) \wedge sc(b) \sqsubseteq_I sc(a)$

➜ Consists of the following subgoals:

1. b has a greater or equal number of readers than a
$sc(b) \sqsubseteq_C sc(a) := readers(b) \supseteq readers(a)$,
2. b has a lower or equal number of writers than a
$sc(b) \sqsubseteq_I sc(a) := writers(b) \subseteq writers(a)$

➜ This results in the following partial order relation with a bottom and top element {_ −> _; ∗ <− ∗} ⊑ ... ⊑ {∗ −> ∗; _ <− _}

Note: The JIF-operator ∗ represents *no* principals and the JIF-operator _ represents *all* principals, $sc(x)$ is the security label of the variable x

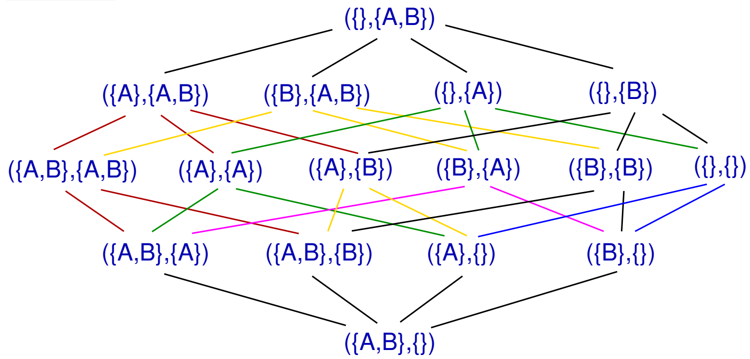
Complete Lattice for JiF-Labels

Assumptions

➜ The number of principals is limited to two with $P = \{A, B\}$

➜ Security labels are described by tuple (R, W), with R = authorized readers and W = authorized writers

Solution



How to deal with implicit information flows?

- Analysis of implicit information flows is implemented using a *pc label* (*program-counter label*)
- *pc labels* are initial empty

```
class Test {
   int {Bob −> Alice,Bob} a = 0;
   int {Bob −> Bob} b;

   public void f {} () {
     if (a == 0) {
         b = 4;   // check the pc label
     }
   }
}
```

➜ For each assignment the *pc label* has to be checked

➜ Proof obligation of the example for b = 4;
{Bob −> Alice,Bob} ⊑ {Bob −> Bob}

Implicit information flows and method calls

Question: What is problematic with a method call?

```
class Test {
   int {Bob −> Alice,Bob,Steffen} a = 0;
   int {Bob −> Bob} b;

   public void f {} () {
     if (a == 0)
        setB();
   }
   private void setB () {
     b = 4;
}}
```

➜ Value assignment in the method setB() must be checked for all possible contexts in which this method is potentially called

Implicit information flows and method calls

- Implicit information flows for method calls are handled in JIF by so-called *begin labels*
- A *begin label* defines the *upper bound* for all pc labels at which the method can be called

```
class Test {
   int {Bob -> Alice,Bob,Steffen} a = 0;
   int {Bob -> Bob} b;

   public void f {} () {
     if (a == 0)
        setB();
   }
   private void setB {Bob -> Bob,Steffen} () {
     b = 4;
}}
```

➜ Check at the method call of setB(): *pc-label* $\sqsubseteq$ *begin-label*
{Bob -> Alice , Bob , Steffen} $\sqsubseteq$ {Bob -> Bob , Steffen}