ECS 289M Lecture 7

April 14, 2006

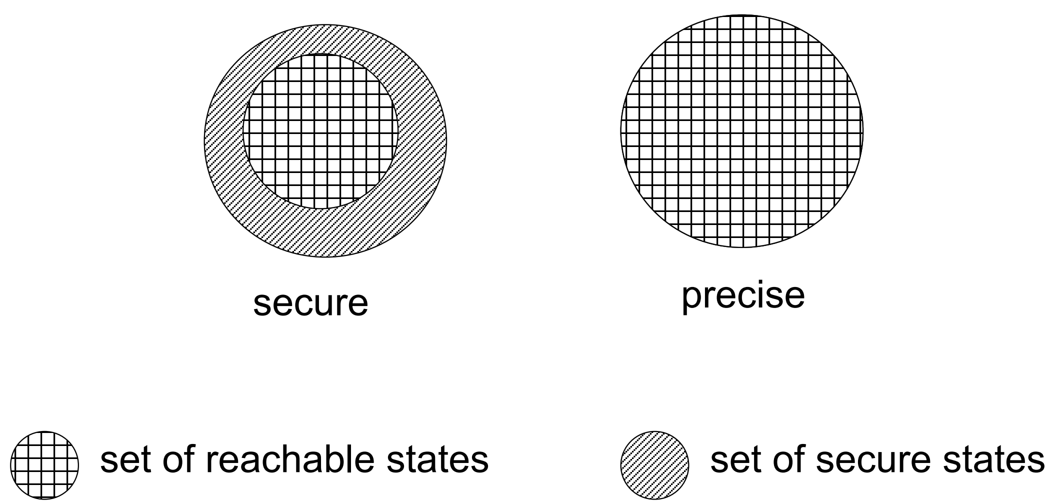
Security Policy

- Policy partitions system states into:
  - Authorized (secure)
    - These are states the system can enter
  - Unauthorized (nonsecure)
    - If the system enters any of these states, it's a security violation
- Secure system
  - Starts in authorized state
  - Never enters unauthorized state

Policies and Mechanisms

- Policy says what is, and is not, allowed
  - This defines "security" for the site/system/*etc*.
- Mechanisms enforce policies
- Composition of policies
  - If policies conflict, discrepancies may create security vulnerabilities

Types of Mechanisms



Secure, Precise Mechanisms

- Can one devise a procedure for developing a mechanism that is both secure *and* precise?
  - Consider confidentiality policies only here
  - Integrity policies produce same result
- Program a function with multiple inputs and one output
  - Let p be a function p: $I_1 \times ... \times I_n \rightarrow R$. Then p is a program with n inputs $i_k \in I_k$, $1 \leq k \leq n$, and one output $r \in R$

Programs and Postulates

- Observability Postulate: the output of a function encodes all available information about its inputs
  - Covert channels considered part of the output
- Example: authentication function
  - Inputs name, password; output Good or Bad
  - If name invalid, immediately print Bad; else access database
  - Problem: time output of Bad, can determine if name valid
  - This means timing is part of output

Protection Mechanism

- Let p be a function $p: I_1 \times ... \times I_n \rightarrow R$. A protection mechanism m is a function $m: I_1 \times ... \times I_n \rightarrow R \cup E$ for which, when $i_k \in I_k$, $1 \leq k \leq n$, either
  - $m(i_1, ..., i_n) = p(i_1, ..., i_n)$ or
  - $m(i_1, ..., i_n) \in E$.
- E is set of error outputs
  - In above example, E = { "Password Database Missing", "Password Database Locked" }

Confidentiality Policy

- Confidentiality policy for program p says which inputs can be revealed
  - Formally, for $p: I_1 \times ... \times I_n \rightarrow R$, it is a function $c: I_1 \times ... \times I_n \rightarrow A$, where $A \subseteq I_1 \times ... \times I_n$
  - A is set of inputs available to observer
- Security mechanism is function $m: I_1 \times ... \times I_n \rightarrow R \cup E$
  - *m secure* iff $\exists\, m': A \rightarrow R \cup E$ such that, for all $i_k \in I_k$, $1 \leq k \leq n$, $m(i_1, ..., i_n) = m'(c(i_1, ..., i_n))$
  - m returns values consistent with c

Examples

- $c(i_1, ..., i_n) = C$, a constant
  - Deny observer any information (output does not vary with inputs)
- $c(i_1, ..., i_n) = (i_1, ..., i_n)$, and $m' = m$
  - Allow observer full access to information
- $c(i_1, ..., i_n) = i_1$
  - Allow observer information about first input but no information about other inputs.

Precision

- Security policy may be over-restrictive
  - Precision measures how over-restrictive
- m_1, m_2 distinct protection mechanisms for program p under policy c
  - m_1 as precise as m_2 ($m_1 \approx m_2$) if, for all inputs $i_1, \dots, i_n$, $m_2(i_1, \dots, i_n) = p(i_1, \dots, i_n) \Rightarrow m_1(i_1, \dots, i_n) = p(i_1, \dots, i_n)$
  - m_1 more precise than m_2 ($m_1 \sim m_2$) if there is an input $(i_1', \dots, i_n')$ such that $m_1(i_1', \dots, i_n') = p(i_1', \dots, i_n')$ and $m_2(i_1', \dots, i_n') \neq p(i_1', \dots, i_n')$.

Combining Mechanisms

- m_1, m_2 protection mechanisms
- $m_3 = m_1 \cup m_2$
  - For inputs on which m_1 returns same value as p, or m_2 returns same value as p, m_3 does also; otherwise, m_3 returns same value as m_1
- Theorem: if m_1, m_2 secure, then m_3 secure
  - Also, $m_3 \approx m_1$ and $m_3 \approx m_2$
  - Follows from definitions of secure, precise, and m_3

Existence Theorem

- For any program p and security policy c, there exists a precise, secure mechanism m^* such that, for all secure mechanisms m associated with p and c, $m^* \approx m$
  - Maximally precise mechanism
  - Ensures security
  - Minimizes number of denials of legitimate actions

Lack of Effective Procedure

- There is no effective procedure that determines a maximally precise, secure mechanism for any policy and program.
  - Sketch of proof: let *c* be constant function, and *p* compute function $T(x)$. Assume $T(x) = 0$. Consider program *q*, where

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p;
if z = 0 then y := 1 else y := 2;
halt;
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Rest of Sketch

- *m* associated with *q*, *y* value of *m*, *z* output of *p* corresponding to $T(x)$
- $\forall x[T(x) = 0] \rightarrow m(x) = 1$
- $\exists x' \, [T(x') \neq 0] \rightarrow m(x) = 2$ or $m(x)\uparrow$
- If you can determine *m*, you can determine whether $T(x) = 0$ for all *x*
- This is not possible
- Therefore no such procedure exists

Confidentiality Policy

- Goal: prevent the unauthorized disclosure of information
  - Deals with information flow
  - Integrity incidental
- Multi-level security models are best-known examples
  - Bell-LaPadula Model basis for many, or most, of these

Bell-LaPadula Model, Step 1

- Security levels arranged in linear ordering
  - Top Secret: highest
  - Secret
  - Confidential
  - Unclassified: lowest
- Levels consist of *security clearance* $L(s)$
  - Objects have *security classification* $L(o)$

Example

security level	*subject*	*object*
Top Secret	Tamara	Personnel Files
Secret	Samuel	E-Mail Files
Confidential	Claire	Activity Logs
Unclassified	Ulaley	Telephone Lists

- Tamara can read all files
- Claire cannot read Personnel or E-Mail Files
- Ulaley can only read Telephone Lists

Reading Information

- Information flows *up*, not *down*
  - "Reads up" disallowed, "reads down" allowed
- Simple Security Condition (Step 1)
  - Subject *s* can read object *o* iff, $L(o) \le L(s)$ and *s* has permission to read *o*
    - Note: combines mandatory control (relationship of security levels) and discretionary control (the required permission)
  - Sometimes called "no reads up" rule

Writing Information

- Information flows up, not down
  - "Writes up" allowed, "writes down" disallowed
- *-Property (Step 1)
  - Subject *s* can write object *o* iff $L(s) \leq L(o)$ and *s* has permission to write *o*
    - Note: combines mandatory control (relationship of security levels) and discretionary control (the required permission)
  - Sometimes called "no writes down" rule

Basic Security Theorem Step 1

- If a system is initially in a secure state, and every transition of the system satisfies the simple security condition, step 1, and the *-property, step 1, then every state of the system is secure
  - Proof: induct on the number of transitions

Bell-LaPadula Model, Step 2

- Expand notion of security level to include categories
- Security level is (*clearance*, *category set*)
- Examples
  - (Top Secret, { NUC, EUR, ASI })
  - (Confidential, { EUR, ASI })
  - (Secret, { NUC, ASI })

Lattices

- S set, R: $S \times S$ relation
  - If a, $b \in S$, and $(a, b) \in R$, write aRb
- Example
  - $I = \{ 1, 2, 3\}$; R is $\leq$
  - $R = \{ (1, 1), (1, 2), (1, 3), (2, 2), (2, 3), (3, 3) \}$
  - So we write $1 \leq 2$ and $3 \leq 3$ but not $3 \leq 2$

Relation Properties

- Reflexive
  - For all $a \in S$, aRa
  - On I, ≤ is reflexive as 1 ≤ 1, 2 ≤ 2, 3 ≤ 3
- Antisymmetric
  - For all a, $b \in S$, $aRb \wedge bRa \Rightarrow a = b$
  - On I, ≤ is antisymmetric
- Transitive
  - For all a, b, $c \in S$, $aRb \wedge bRc \Rightarrow aRc$
  - On I, ≤ is transitive as 1 ≤ 2 and 2 ≤ 3 means 1 ≤ 3

Bigger Example

- C set of complex numbers
- $a \in C \Rightarrow a = a_R + a_I i$, a_R, a_I integers
- $a \leq_C b$ if, and only if, $a_R \leq b_R$ and $a_I \leq b_I$
- $a \leq_C b$ is reflexive, antisymmetric, transitive
  - As ≤ is over integers, and a_R , a_I are integers

Partial Ordering

- Relation R orders some members of set S
  - If all ordered, it's total ordering
- Example
  - $\leq$ on integers is total ordering
  - $\leq_C$ is partial ordering on C (because neither $3+5i \leq_C 4+2i$ nor $4+2i \leq_C 3+5i$ holds)

Upper Bounds

- For a, $b \in S$, if u in S with aRu, bRu exists, then u is upper bound
  - Least upper if there is no $t \in S$ such that aRt, bRt, and tRu
- Example
  - For $1 + 5i$, $2 + 4i \in C$, upper bounds include $2 + 5i$, $3 + 8i$, and $9 + 100i$
  - Least upper bound of those is $2 + 5i$

Lower Bounds

- For a, $b \in S$, if l in S with lRa, lRb exists, then l is lower bound
  - Greatest lower if there is no $t \in S$ such that tRa, tRb, and lRt
- Example
  - For 1 + 5*i*, 2 + 4*i* $\in C$, lower bounds include 0, -1 + 2*i*, 1 + 1*i*, and 1+4*i*
  - Greatest lower bound of those is 1 + 4*i*

Lattices

- Set S, relation R
  - R is reflexive, antisymmetric, transitive on elements of S
  - For every s, $t \in S$, there exists a greatest lower bound under R
  - For every s, $t \in S$, there exists a least upper bound under R

Example

- *S* = { 0, 1, 2 }; *R* = ≤ is a lattice
  – *R* is clearly reflexive, antisymmetric, transitive on elements of *S*
  – Least upper bound of any two elements of *S* is the greater
  – Greatest lower bound of any two elements of *S* is the lesser