Lecture #11

- Bell-LaPadula model
  - Formal: more mathematical one (but still a lattice!)

Basic Security Theorem

- Define action, secure formally
  - Using a bit of foreshadowing for "secure"
- Restate properties formally
  - Simple security condition
  - *-property
  - Discretionary security property
- State conditions for properties to hold
- State Basic Security Theorem

Action

- A request and decision that causes the system to move from one state to another
  - Final state may be the same as initial state
- $(r, d, v, v') \in R \times D \times V \times V$ is an *action* of $\Sigma(R, D, W, z_0)$ iff there is an $(x, y, z) \in \Sigma(R, D, W, z_0)$ and a $t \in N$ such that $(r, d, v, v') = (x_t, y_t, z_t, z_{t-1})$
  - Request r made when system in state v; decision d moves system into (possibly the same) state v'
  - Correspondence with (x_t, y_t, z_t, z_{t-1}) makes states, requests, part of a sequence

Simple Security Condition

- $(s, o, p) \in S \times O \times P$ satisfies the simple security condition relative to f (written *ssc rel f*) iff one of the following holds:
    1. $p = \underline{\text{e}}$ or $p = \underline{\text{a}}$
    2. $p = \underline{\text{r}}$ or $p = \underline{\text{w}}$ and $f_s(s)$ *dom* $f_o(o)$
- Holds vacuously if rights do not involve reading
- If all elements of b satisfy *ssc rel f*, then state satisfies simple security condition
- If all states satisfy simple security condition, system satisfies simple security condition

Necessary and Sufficient

- $\Sigma(R, D, W, z_0)$ satisfies the simple security condition for any secure state z_0 iff for every action $(r, d, (b, m, f, h), (b', m', f', h'))$, W satisfies
  - Every $(s, o, p) \in b - b'$ satisfies *ssc rel f*
  - Every $(s, o, p) \in b'$ that does not satisfy *ssc rel f* is not in b
- Note: "secure" means z_0 satisfies *ssc rel f*
- First says every (s, o, p) added satisfies *ssc rel f*; second says any (s, o, p) in b' that does not satisfy *ssc rel f* is deleted

*-Property

- $b(s\colon p_1, \ldots, p_n)$ set of all objects that s has $p_1, \ldots, p_n$ access to
- State (b, m, f, h) satisfies the *-property iff for each $s \in S$ the following hold:
  1. $b(s\colon \underline{\mathrm{a}}) \neq \varnothing \Rightarrow [\forall o \in b(s\colon \underline{\mathrm{a}})\ [\ f_o(o)\ dom\ f_c(s)\ ]\ ]$
  2. $b(s\colon \underline{\mathrm{w}}) \neq \varnothing \Rightarrow [\forall o \in b(s\colon \underline{\mathrm{w}})\ [\ f_o(o) = f_c(s)\ ]\ ]$
  3. $b(s\colon \underline{\mathrm{r}}) \neq \varnothing \Rightarrow [\forall o \in b(s\colon \underline{\mathrm{r}})\ [\ f_c(s)\ dom\ f_o(o)\ ]\ ]$
- Idea: for writing, object dominates subject; for reading, subject dominates object

*-Property

- If all states satisfy simple security condition, system satisfies simple security condition
- If a subset S' of subjects satisfy *-property, then *-property satisfied relative to $S' \subseteq S$
- Note: tempting to conclude that *-property includes simple security condition, but this is false
  - See condition placed on <u>w</u> right for each

Necessary and Sufficient

- $\Sigma(R, D, W, z_0)$ satisfies the *-property relative to $S' \subseteq S$ for any secure state z_0 iff for every action $(r, d, (b, m, f, h), (b', m', f', h'))$, W satisfies the following for every $s \in S'$
  - Every $(s, o, p) \in b - b'$ satisfies the *-property relative to S'
  - Every $(s, o, p) \in b'$ that does not satisfy the *-property relative to S' is not in b
- Note: "secure" means z_0 satisfies *-property relative to S'
- First says every (s, o, p) added satisfies the *-property relative to S'; second says any (s, o, p) in b' that does not satisfy the *-property relative to S' is deleted

Discretionary Security Property

- State (b, m, f, h) satisfies the discretionary security property iff, for each $(s, o, p) \in b$, then $p \in m[s, o]$
- Idea: if s can read o, then it must have rights to do so in the access control matrix m
- This is the discretionary access control part of the model
  - The other two properties are the mandatory access control parts of the model

Necessary and Sufficient

- $\Sigma(R, D, W, z_0)$ satisfies the ds-property for any secure state z_0 iff, for every action $(r, d, (b, m, f, h), (b', m', f', h'))$, W satisfies:
  - Every $(s, o, p) \in b - b'$ satisfies the ds-property
  - Every $(s, o, p) \in b'$ that does not satisfy the ds-property is not in b
- Note: "secure" means z_0 satisfies ds-property
- First says every (s, o, p) added satisfies the ds-property; second says any (s, o, p) in b' that does not satisfy the *-property is deleted

Secure

- A system is secure iff it satisfies:
  - Simple security condition
  - *-property
  - Discretionary security property
- A state meeting these three properties is also said to be secure

Basic Security Theorem

- $\Sigma(R, D, W, z_0)$ is a secure system if z_0 is a secure state and W satisfies the conditions for the preceding three theorems
  - The theorems are on the slides titled "Necessary and Sufficient"

Rule

- $\rho: R \times V \rightarrow D \times V$
- Takes a state and a request, returns a decision and a (possibly new) state
- Rule ρ *ssc-preserving* if for all $(r, v) \in R \times V$ and v satisfying *ssc rel* f, $\rho(r, v) = (d, v')$ means that v' satisfies *ssc rel* f'.
  - Similar definitions for *-property, ds-property
  - If rule meets all 3 conditions, it is *security-preserving*

Unambiguous Rule Selection

- Problem: multiple rules may apply to a request in a state
  - if two rules act on a read request in state v …
- Solution: define relation $W(\omega)$ for a set of rules $\omega = \{ \rho_1, \ldots, \rho_m \}$ such that a state $(r, d, v', v) \in W(\omega)$ iff either
  - $d = \underline{\mathrm{i}}$; or
  - for exactly one integer j, $\rho_j(r, v) = (d, v')$
- Either request is illegal, or only one rule applies

Rules Preserving *SSC*

- Let ω be set of *ssc*-preserving rules. Let state z_0 satisfy simple security condition. Then $\Sigma(R, D, W(\omega), z_0)$ satisfies simple security condition
  - Proof: by contradiction.
    - Choose $(x, y, z) \in \Sigma(R, D, W(\omega), z_0)$ as state not satisfying simple security condition; then choose $t \in N$ such that (x_t, y_t, z_t) is first appearance not meeting simple security condition
    - As $(x_t, y_t, z_t, z_{t-1}) \in W(\omega)$, there is unique rule $\rho \in \omega$ such that $\rho(x_t, z_{t-1}) = (y_t, z_t)$ and $y_t \neq \underline{\mathrm{i}}$.
    - As ρ ssc-preserving, and z_{t-1} satisfies simple security condition, then z_t meets simple security condition, contradiction.

Adding States Preserving *SSC*

- Let $v = (b, m, f, h)$ satisfy simple security condition. Let $(s, o, p) \notin b$, $b' = b \cup \{ (s, o, p) \}$, and $v' = (b', m, f, h)$. Then v' satisfies simple security condition iff:
  1. Either $p = \underline{\text{e}}$ or $p = \underline{\text{a}}$; or
  2. Either $p = \underline{\text{r}}$ or $p = \underline{\text{w}}$, and $f_c(s)$ *dom* $f_o(o)$
  - Proof
    1. Immediate from definition of simple security condition and v' satisfying *ssc rel f*
    2. v' satisfies simple security condition means $f_c(s)$ *dom* $f_o(o)$, and for converse, $(s, o, p) \in b'$ satisfies *ssc rel f*, so v' satisfies simple security condition

Rules, States Preserving *-Property

- Let ω be set of *-property-preserving rules, state z_0 satisfies *-property. Then $\Sigma(R, D, W(\omega), z_0)$ satisfies *-property

Rules, States Preserving ds-Property

- Let ω be set of ds-property-preserving rules, state z_0 satisfies ds-property. Then $\Sigma(R, D, W(\omega), z_0)$ satisfies ds-property

Combining

- Let ρ be a rule and $\rho(r, v) = (d, v')$, where $v = (b, m, f, h)$ and $v' = (b', m', f', h')$. Then:
  1. If $b' \subseteq b, f' = f$, and v satisfies the simple security condition, then v' satisfies the simple security condition
  2. If $b' \subseteq b, f' = f$, and v satisfies the *-property, then v' satisfies the *-property
  3. If $b' \subseteq b$, $m[s, o] \subseteq m'[s, o]$ for all $s \in S$ and $o \in O$, and v satisfies the ds-property, then v' satisfies the ds-property

Proof

1. Suppose v satisfies simple security property.
   a) $b' \subseteq b$ and $(s, o, \underline{\text{r}}) \in b'$ implies $(s, o, \underline{\text{r}}) \in b$
   b) $b' \subseteq b$ and $(s, o, \underline{\text{w}}) \in b'$ implies $(s, o, \underline{\text{w}}) \in b$
   c) So $f_c(s)$ *dom* $f_o(o)$
   d) But $f' = f$
   e) Hence $f'_c(s)$ *dom* $f'_o(o)$
   f) So v' satisfies simple security condition

2, 3 proved similarly

Example Instantiation: Multics

- 11 rules affect rights:
  - set to request, release access
  - set to give, remove access to different subject
  - set to create, reclassify objects
  - set to remove objects
  - set to change subject security level
- Set of "trusted" subjects $S_T \subseteq S$
  - *-property not enforced; subjects trusted not to violate
- $\Delta(\rho)$ domain
  - determines if components of request are valid

get-read Rule

- Request $r = (get, s, o, \underline{\mathrm{r}})$
  - s gets (requests) the right to read o
- Rule is $\rho_1(r, v)$:

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if $(r \neq \Delta(\rho_1))$ then $\rho_1(r, v) = (\underline{\mathrm{i}}, v)$;
else if $(f_s(s)\ dom\ f_o(o)$ and $[s \in S_T$ or $f_c(s)\ dom\ f_o(o)]$
    and $r \in m[s, o])$
            then $\rho_1(r, v) = (y, (b \cup \{ (s, o, \underline{\mathrm{r}}) \}, m, f, h))$;
else $\rho_1(r, v) = (\underline{\mathrm{n}}, v)$;
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Security of Rule

- The get-read rule preserves the simple security condition, the *-property, and the ds-property
  - Proof
    - Let v satisfy all conditions. Let $\rho_1(r, v) = (d, v')$. If $v' = v$, result is trivial. So let $v' = (b \cup \{ (s_2, o, \underline{\text{r}}) \}, m, f, h)$.

Proof

- Consider the simple security condition.
  - From the choice of v', either $b' - b = \varnothing$ or $\{ (s_2, o, \underline{\mathrm{r}}) \}$
  - If $b' - b = \varnothing$, then $\{ (s_2, o, \underline{\mathrm{r}}) \} \in b$, so $v = v'$, proving that v' satisfies the simple security condition.
  - If $b' - b = \{ (s_2, o, \underline{\mathrm{r}}) \}$, because the *get-read* rule requires that $f_c(s)$ *dom* $f_o(o)$, an earlier result says that v' satisfies the simple security condition.

Proof

- Consider the *-property.
  - Either $s_2 \in S_T$ or $f_c(s)$ *dom* $f_o(o)$ from the definition of *get-read*
  - If $s_2 \in S_T$, then s_2 is trusted, so *-property holds by definition of trusted and S_T.
  - If $f_c(s)$ *dom* $f_o(o)$, an earlier result says that v' satisfies the simple security condition.

Proof

- Consider the discretionary security property.
  - Conditions in the *get-read* rule require $\underline{\mathrm{r}} \in m[s, o]$ and either $b' - b = \varnothing$ or $\{ (s_2, o, \underline{\mathrm{r}}) \}$
  - If $b' - b = \varnothing$, then $\{ (s_2, o, \underline{\mathrm{r}}) \} \in b$, so $v = v'$, proving that v' satisfies the simple security condition.
  - If $b' - b = \{ (s_2, o, \underline{\mathrm{r}}) \}$, then $\{ (s_2, o, \underline{\mathrm{r}}) \} \notin b$, an earlier result says that v' satisfies the ds-property.

give-read Rule

- Request $r = (s_1, give, s_2, o, \underline{\mathrm{r}})$
  - s_1 gives (request to give) s_2 the (discretionary) right to read o
  - Rule: can be done if giver can alter parent of object
    - If object or parent is root of hierarchy, special authorization required
- Useful definitions
  - $root(o)$: root object of hierarchy h containing o
  - $parent(o)$: parent of o in h (so $o \in h(parent(o))$)
  - $canallow(s, o, v)$: s specially authorized to grant access when object or parent of object is root of hierarchy
  - $m \wedge m[s, o] \leftarrow \underline{\mathrm{r}}$: access control matrix m with $\underline{\mathrm{r}}$ added to $m[s, o]$

give-read Rule

- Rule is $\rho_6(r, v)$:

  if $(r \neq \Delta(\rho_6))$ **then** $\rho_6(r, v) = (\underline{\mathrm{i}}, v)$;
  else if $([o \neq root(o)$ **and** $parent(o) \neq root(o)$ **and**
  $parent(o) \in b(s_1{:}\underline{\mathrm{w}})]$ **or**
  $[parent(o) = root(o)$ **and** $canallow(s_1, o, v)\ ]$ **or**
  $[o = root(o)$ and $canallow(s_1, o, v)\ ])$
  then $\rho_6(r, v) = (y, (b, m \wedge m[s_2, o] \leftarrow \underline{\mathrm{r}}, f, h))$;
  else $\rho_1(r, v) = (\underline{\mathrm{n}}, v)$;

Security of Rule

- The *give-read* rule preserves the simple security condition, the *-property, and the ds-property
  - Proof: Let v satisfy all conditions. Let $\rho_1(r, v) = (d, v')$. If $v' = v$, result is trivial. So let $v' = (b, m[s_2, o] \leftarrow \underline{r}, f, h)$. So $b' = b, f' = f, m[x, y] = m'[x, y]$ for all $x \in S$ and $y \in O$ such that $x \neq s$ and $y \neq o$, and $m[s, o] \subseteq m'[s, o]$. Then by earlier result, v' satisfies the simple security condition, the *-property, and the ds-property.

Principle of Tranquility

- Raising object’s security level
  - Information once available to some subjects is no longer available
  - Usually assume information has already been accessed, so this does nothing
- Lowering object’s security level
  - The *declassification problem*
  - Essentially, a “write down” violating *-property
  - Solution: define set of trusted subjects that *sanitize* or remove sensitive information before security level lowered

Types of Tranquility

- Strong Tranquility
  - The clearances of subjects, and the classifications of objects, do not change during the lifetime of the system
- Weak Tranquility
  - The clearances of subjects, and the classifications of objects, do not change in a way that violates the simple security condition or the *-property during the lifetime of the system

Example of Weak Tranquility

- Only one subject at TOP SECRET
- Document at CONFIDENTIAL
- New CONFIDENTIAL user to be added
  - User should not see document
- Raise document to SECRET
  - Subject still cannot write document
  - All security relationships unchanged

Declassification

- Lowering the security level of a document
  - Direct violation of the "no writes down" rule
  - May be necessary for legal or other purposes
- Declassification policy
  - Part of security policy covering this
  - Here, "secure" means classification changes to a lower level in accordance with declassification policy

Principles

- Principle of Semantic Consistency
  - You can change parts of a system not involved in declassification without affecting security
- Principle of Occlusion
  - Declassification cannot conceal *improper* lowering of security levels

Principles

- Principle of Conservativity
  - Absent any declassification, the system is secure
- Principle of Monotonicity of Release
  - Declassifying information *in accordance with the declassification policy* does not make the system less secure

Principle of Semantic Consistency

- As long as the semantics of the parts of the system not involved in the declassification do not change, those parts may be changed without affecting system security
  - No leaking due to semantic incompatibilities
  - *Delimited release*: allow declassification, release of information only through specific channels ("escape hatches")

Principle of Occlusion

- Declassification mechanism cannot conceal *improper* lowering of security levels
  - Robust declassification property: attacker cannot use escape hatches to obtain information unless it is properly declassified

Other Principles

- Principle of Conservativity
  - Absent declassification, system is secure
- Principle of Monotonicity of Release
  - When declassification is performed in an authorized manner by authorized subjects, the system remains secure

Idea: declassifying information in accordance with declassification policy does not affect security

Controversy

- McLean:
  - “value of the BST is much overrated since there is a great deal more to security than it captures. Further, what is captured by the BST is so trivial that it is hard to imagine a realistic security model for which it does not hold.”
  - Basis: given assumptions known to be non-secure, BST can prove a non-secure system to be secure

†-Property

- State (b, m, f, h) satisfies the †-property iff for each $s \in S$ the following hold:
  1. $b(s: \underline{\mathrm{a}}) \neq \varnothing \Rightarrow [\forall o \in b(s: \underline{\mathrm{a}})\ [\ f_c(s)\ dom\ f_o(o)\ ]\ ]$
  2. $b(s: \underline{\mathrm{w}}) \neq \varnothing \Rightarrow [\forall o \in b(s: \underline{\mathrm{w}})\ [\ f_o(o) = f_c(s)\ ]\ ]$
  3. $b(s: \underline{\mathrm{r}}) \neq \varnothing \Rightarrow [\forall o \in b(s: \underline{\mathrm{r}})\ [\ f_c(s)\ dom\ f_o(o)\ ]\ ]$
- Idea: for writing, subject dominates object; for reading, subject also dominates object
- Differs from *-property in that the mandatory condition for writing is reversed
  - For *-property, it's object dominates subject

Analogues

The following two theorems can be proved

- $\Sigma(R, D, W, z_0)$ satisfies the †-property relative to $S' \subseteq S$ for any secure state z_0 iff for every action $(r, d, (b, m, f, h), (b', m', f', h'))$, W satisfies the following for every $s \in S'$
  - Every $(s, o, p) \in b - b'$ satisfies the †-property relative to S'
  - Every $(s, o, p) \in b'$ that does not satisfy the †-property relative to S' is not in b
- $\Sigma(R, D, W, z_0)$ is a secure system if z_0 is a secure state and W satisfies the conditions for the simple security condition, the †-property, and the ds-property.

Problem

- This system is *clearly* non-secure!
  - Information flows from higher to lower because of the †-property

Discussion

- Role of Basic Security Theorem is to demonstrate that rules preserve security
- Key question: what is security?
  - Bell-LaPadula defines it in terms of 3 properties (simple security condition, *-property, discretionary security property)
  - Theorems are assertions about these properties
  - Rules describe changes to a *particular* system instantiating the model
  - Showing system is secure requires proving rules preserve these 3 properties

Rules and Model

- Nature of rules is irrelevant to model
- Model treats “security” as axiomatic
- Policy defines “security”
  - This instantiates the model
  - Policy reflects the requirements of the systems
- McLean’s definition differs from Bell-LaPadula
  - … and is not suitable for a confidentiality policy
- Analysts cannot prove “security” definition is appropriate through the model

System Z

- System supporting weak tranquility
- On *any* request, system downgrades *all* subjects and objects to lowest level and adds the requested access permission
  - Let initial state satisfy all 3 properties
  - Successive states also satisfy all 3 properties
- Clearly not secure
  - On first request, everyone can read everything

Reformulation of Secure Action

- Given state that satisfies the 3 properties, the action transforms the system into a state that satisfies these properties and eliminates any accesses present in the transformed state that would violate the property in the initial state, then the action is secure
- BST holds with these modified versions of the 3 properties

Reconsider System Z

- Initial state:
  - subject s, object o
  - $C = \{\text{High}, \text{Low}\}$, $K = \{\text{All}\}$
- Take:
  - $f_c(s) = (\text{Low}, \{\text{All}\})$, $f_o(\text{o}) = (\text{High}, \{\text{All}\})$
  - $m[s, o] = \{ \underline{\text{w}} \}$, and $b = \{ (s, o, \underline{\text{w}}) \}$.
- s requests r access to o
- Now:
  - $f'_o(o) = (\text{Low}, \{\text{All}\})$
  - $(s, o, \underline{\text{r}}) \in b'$, $m'[s, o] = \{\underline{\text{r}}, \underline{\text{w}}\}$

Non-Secure System Z

- As $(s, o, \underline{\mathrm{r}}) \in b' - b$ and $f_o(o)$ *dom* $f_c(s)$, access added that was illegal in previous state
  - Under the new version of the Basic Security Theorem, System Z is not secure
  - Under the old version of the Basic Security Theorem, as $f'_c(s) = f'_o(o)$, System Z is secure

Response: What Is Modeling?

- Two types of models
  1. Abstract physical phenomenon to fundamental properties
  2. Begin with axioms and construct a structure to examine the effects of those axioms
- Bell-LaPadula Model developed as a model in the first sense
  - McLean assumes it was developed as a model in the second sense

Reconciling System Z

- Different definitions of security create different results
  - Under one (original definition in Bell-LaPadula Model), System Z is secure
  - Under other (McLean's definition), System Z is not secure