ECS 235B Module 49
Information Flow Policies

Information Flow Policies

Information flow policies are usually:

- reflexive
  - So information can flow freely among members of a single class
- transitive
  - So if information can flow from class 1 to class 2, and from class 2 to class 3, then information can flow from class 1 to class 3

Non-Transitive Policies

- Betty is a confident of Anne
- Cathy is a confident of Betty
  - With transitivity, information flows from Anne to Betty to Cathy
- Anne confides to Betty she is having an affair with Cathy’s spouse
  - Transitivity undesirable in this case, probably

Non-Lattice Transitive Policies

- 2 faculty members co-PIs on a grant
  - Equal authority; neither can overrule the other
- Grad students report to faculty members
- Undergrads report to grad students
- Information flow relation is:
  - Reflexive and transitive
- But some elements (people) have no “least upper bound” element
  - What is it for the faculty members?

Confidentiality Policy Model

- Lattice model fails in previous 2 cases
- Generalize: policy $I = (SC_I, \leq_I, join_I)$:
  - SC_I set of security classes
  - $\leq_I$ ordering relation on elements of SC_I
  - $join_I$ function to combine two elements of SC_I
- Example: Bell-LaPadula Model
  - SC_I set of security compartments
  - $\leq_I$ ordering relation *dom*
  - $join_I$ function *lub*

Confinement Flow Model

- $(I, O, confine, \rightarrow)$
  - $I = (SC_I, \leq_I, join_I)$
  - O set of entities
  - $\rightarrow$: $O \times O$ with $(a, b) \in \rightarrow$ (written $a \rightarrow b$) iff information can flow from a to b
  - for $a \in O$, $confine(a) = (a_L, a_U) \in SC_I \times SC_I$ with $a_L \leq_I a_U$
    - Interpretation: for $a \in O$, if $x \leq_I a_U$, information can flow from x to a, and if $a_L \leq_I x$, information can flow from a to x
    - So a_L lowest classification of information allowed to flow out of a, and a_U highest classification of information allowed to flow into a

Assumptions, *etc*.

- Assumes: object can change security classes
  - So, variable can take on security class of its data
- Object *x* has security class <u>x</u> currently
- Note transitivity *not* required
- If information can flow from *a* to *b*, then *b* dominates *a* under ordering of policy *I*:

  $(\forall\ a, b \in O)[\ a \rightarrow b \Rightarrow a_L \leq_I b_U\ ]$

Example 1

- $SC_I = \{ \text{U, C, S, TS} \}$, with U $\leq_I$ C, C $\leq_I$ S, and S $\leq_I$ TS
- $a, b, c \in O$
  - confine(a) = [C, C]
  - confine(b) = [S, S]
  - confine(c) = [TS, TS]
- Secure information flows: $a \rightarrow b$, $a \rightarrow c$, $b \rightarrow c$
  - As $a_L \leq_I b_U$, $a_L \leq_I c_U$, $b_L \leq_I c_U$
  - Transitivity holds

Example 2

- SC_I, $\leq_I$ as in Example 1
- $x, y, z \in O$
  - confine(x) = [C, C]
  - confine(y) = [S, S]
  - confine(z) = [C, TS]
- Secure information flows: $x \rightarrow y$, $x \rightarrow z$, $y \rightarrow z$, $z \rightarrow x$, $z \rightarrow y$
  - As $x_L \leq_I y_U$, $x_L \leq_I z_U$, $y_L \leq_I z_U$, $z_L \leq_I x_U$, $z_L \leq_I y_U$
  - Transitivity does not hold
    - $y \rightarrow z$ and $z \rightarrow x$, but $y \rightarrow x$ is false, because $y_L \leq_I x_U$ is false

Transitive Non-Lattice Policies

- Q = (S_Q, $\leq_Q$) is a *quasi-ordered set* when $\leq_Q$ is transitive and reflexive over S_Q
- How to handle information flow?
  - Define a partially ordered set containing quasi-ordered set
  - Add least upper bound, greatest lower bound to partially ordered set
  - It's a lattice, so apply lattice rules!

In Detail …

- $\forall x \in S_Q$: let $f(x) = \{ y \mid y \in S_Q \wedge y \leq_Q x \}$
  - Define $S_{QP} = \{ f(x) \mid x \in S_Q \}$
  - Define $\leq_{QP} = \{ (x, y) \mid x, y \in S_{QP} \wedge x \subseteq y \}$
    - S_{QP} partially ordered set under $\leq_{QP}$
    - f preserves order, so $y \leq_Q x$ iff $f(x) \leq_{QP} f(y)$
- Add upper, lower bounds
  - $S_{QP}' = S_{QP} \cup \{ S_Q, \varnothing \}$
  - Upper bound $ub(x, y) = \{ z \mid z \in S_{QP} \wedge x \subseteq z \wedge y \subseteq z \}$
  - Least upper bound $lub(x, y) = \cap ub(x, y)$
    - Lower bound, greatest lower bound defined analogously

And the Policy Is …

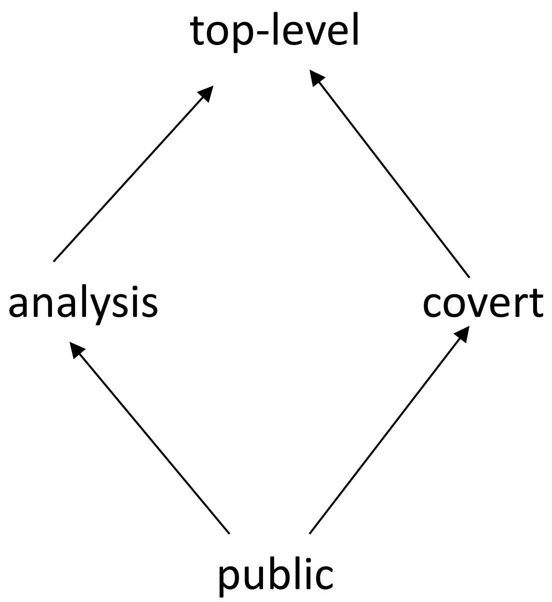
- Now (S_{QP}', $\leq_{QP}$) is lattice
- Information flow policy on quasi-ordered set emulates that of this lattice!

Nontransitive Flow Policies

- Government agency information flow policy (on next slide)
- Entities public relations officers PRO, analysts A, spymasters S
  - *confine*(PRO) = [public, analysis]
  - *confine*(A) = [analysis, top-level]
  - *confine*(S) = [covert, top-level]

Information Flow

- By confinement flow model:
  - PRO ≤ A, A ≤ PRO
  - PRO ≤ S
  - A ≤ S, S ≤ A
- Data *cannot* flow to public relations officers; not transitive
  - S ≤ A, A ≤ PRO
  - S ≤ PRO is *false*



Transforming Into Lattice

- Rough idea: apply a special mapping to generate a subset of the power set of the set of classes
  - Done so this set is partially ordered
  - Means it can be transformed into a lattice
- Can show this mapping preserves ordering relation
  - So it preserves non-orderings and non-transitivity of elements corresponding to those of original set

Dual Mapping

- $R = (SC_R, \leq_R, join_R)$ reflexive info flow policy
- $P = (S_P, \leq_P)$ ordered set
  - Define *dual mapping* functions l_R, h_R: $SC_R \rightarrow S_P$
    - $l_R(x) = \{ x \}$
    - $h_R(x) = \{ y \mid y \in SC_R \wedge y \leq_R x \}$
  - S_P contains subsets of SC_R; $\leq_P$ subset relation
  - Dual mapping function *order preserving* iff

$$(\forall a, b \in SC_R)[\, a \leq_R b \Leftrightarrow l_R(a) \leq_P h_R(b) \,]$$

Theorem

Dual mapping from reflexive information flow policy R to ordered set P order-preserving

Proof sketch: all notation as before

($\Rightarrow$) Let $a \leq_R b$. Then $a \in l_R(a)$, $a \in h_R(b)$, so $l_R(a) \subseteq h_R(b)$, or $l_R(a) \leq_P h_R(b)$

($\Leftarrow$) Let $l_R(a) \leq_P h_R(b)$. Then $l_R(a) \subseteq h_R(b)$. But $l_R(a) = \{ a \}$, so $a \in h_R(b)$, giving $a \leq_R b$

Information Flow Requirements

- Interpretation: let *confine*(x) = [$\underline{x}_L$, $\underline{x}_U$], consider class $\underline{y}$
  - Information can flow from x to element of $\underline{y}$ iff $\underline{x}_L \leq_R \underline{y}$, or $l_R(\underline{x}_L) \subseteq h_R(\underline{y})$
  - Information can flow from element of $\underline{y}$ to x iff y $\leq_R \underline{x}_U$, or $l_R(\underline{y}) \subseteq h_R(\underline{x}_U)$

Revisit Government Example

- Information flow policy is *R*
- Flow relationships among classes are:

$\text{public} \leq_R \text{public}$

$\text{public} \leq_R \text{analysis}$

$\text{public} \leq_R \text{covert}$

$\text{public} \leq_R \text{top-level}$

$\text{analysis} \leq_R \text{top-level}$

$\text{analysis} \leq_R \text{analysis}$

$\text{covert} \leq_R \text{covert}$

$\text{covert} \leq_R \text{top-level}$

$\text{top-level} \leq_R \text{top-level}$

Dual Mapping of *R*

- Elements l_R, h_R:
  - l_R(public) = { public }
  - h_R(public = { public }
  - l_R(analysis) = { analysis }
  - h_R(analysis) = { public, analysis }
  - l_R(covert) = { covert }
  - h_R(covert) = { public, covert }
  - l_R(top-level) = { top-level }
  - h_R(top-level) = { public, analysis, covert, top-level }

confine

- Let *p* be entity of type PRO, *a* of type A, *s* of type S
- In terms of *P* (not *R*), we get:
  - *confine*(*p*) = [{ public }, { public, analysis }]
  - *confine*(*a*) = [{ analysis }, { public, analysis, covert, top-level }]
  - *confine*(*s*) = [{ covert }, { public, analysis, covert, top-level }]

And the Flow Relations Are …

- $p \rightarrow a$ as $l_R(p) \subseteq h_R(a)$
  - $l_R(p)$ = { public }
  - $h_R(a)$ = { public, analysis, covert, top-level }
- Similarly: $a \rightarrow p$, $p \rightarrow s$, $a \rightarrow s$, $s \rightarrow a$
- But $s \rightarrow p$ is false as $l_R(s) \not\subset h_R(p)$
  - $l_R(s)$ = { covert }
  - $h_R(p)$ = { public, analysis }

Analysis

- (S_P, $\leq_P$) is a lattice, so it can be analyzed like a lattice policy
- Dual mapping preserves ordering, hence non-ordering and non-transitivity, of original policy
  - So results of analysis of (S_P, $\leq_P$) can be mapped back into (SC_R, $\leq_R$, $join_R$)