ECS 235B Module 44
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 $\underline{x}$ 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 = { 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, $\le_Q$) is a *quasi-ordered set* when $\le_Q$ 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 …

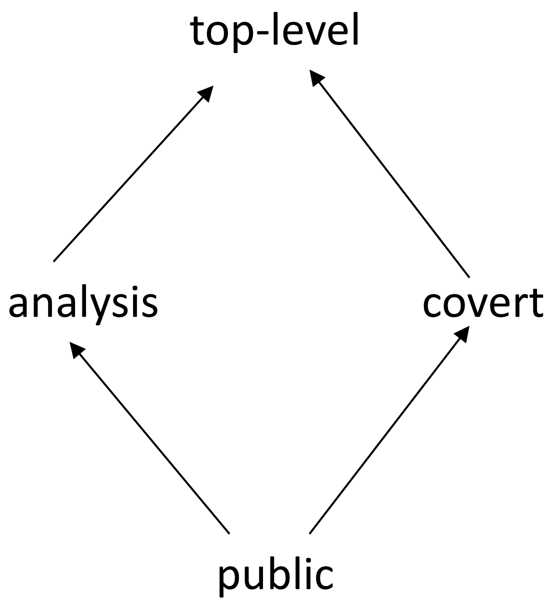
- Now (S_{QP}', $\leq_{QP}$) is lattice
- Information flow policy on quasi-ordered set emulates that of this lattice!

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:

public $\leq_R$ public	
public $\leq_R$ analysis	analysis $\leq_R$ analysis
public $\leq_R$ covert	covert $\leq_R$ covert
public $\leq_R$ top-level	covert $\leq_R$ top-level
analysis $\leq_R$ top-level	top-level $\leq_R$ 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 …

- $p \to a$ as $l_R(p) \subseteq h_R(a)$
    - $l_R(p)$ = { public }
    - $h_R(a)$ = { public, analysis, covert, top-level }
- Similarly: $a \to p$, $p \to s$, $a \to s$, $s \to a$
- But $s \to p$ 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, $\leq_R$, $join_R$)

Quiz

Which of the following is most correct about non-lattice policies?

1. They indicate that whoever designed the policy doesn’t know what they are doing
2. They are important to analyze policy models, but never occur in the “real world”
3. They can be embedded in lattice policies, and hence can be analyzed in the same way
4. They are isomorphic with lattice policies