LATTICE-BASED ACCESS-CONTROL MODELS

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LATTICE-BASED MODELS

• Denning's axioms
• Bell-LaPadula model (BLP)
• Biba model and its duality (or equivalence) to BLP
• Dynamic labels in BLP

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DENNING'S AXIOMS

< \text{\textbf{SC}, \rightarrow, \oplus} >

\begin{align*}
\text{SC} & \quad \text{set of security classes} \\
\rightarrow & \subseteq \text{SC} \times \text{SC} \quad \text{flow relation (i.e., can-flow)} \\
\oplus & : \text{SC} \times \text{SC} \rightarrow \text{SC} \quad \text{class-combining operator}
\end{align*}

1. SC is finite
2. \rightarrow is a partial order on SC
3. SC has a lower bound L such that L \rightarrow A for all A \in SC
4. \oplus is a least upper bound (lub) operator on SC

Justification for 1 and 2 is stronger than for 3 and 4. In practice we may therefore end up with a partially ordered set (poset) rather than a lattice.
DENNING'S AXIOMS IMPLY

- SC is a universally bounded lattice
- there exists a Greatest Lower Bound (glb) operator $\otimes$ (also called meet)
- there exists a highest security class H

LATTICE STRUCTURES

- Top Secret
- Secret
- Confidential
- Unclassified

reflexive and transitive edges are implied but not shown
LATTICE STRUCTURES

dominance \geq \text{can-flow}

Top Secret
Secret
Confidential
Unclassified

{ARMY, CRYPTO}

Compartments and Categories

{ARMY}

{CRYPTO}

{}
LATTICE STRUCTURES

Compartments and Categories

Hierarchical Classes with Compartments

product of 2 lattices is a lattice
LATTICE STRUCTURES

Hierarchical Classes with Compartments

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SMITH'S LATTICE

- With large lattices a vanishingly small fraction of the labels will actually be used
  - Smith's lattice: 4 hierarchical levels, 8 compartments, therefore
    number of possible labels = $4 \times 2^8 = 1024$
    Only 21 labels are actually used (2%)
  - Consider 16 hierarchical levels, 64 compartments which gives $10^{20}$ labels

EMBEDDING A POSET IN A LATTICE

- Smith's subset of 21 labels do form a lattice. In general, however, selecting a subset of labels from a given lattice
  - may not yield a lattice, but
  - is guaranteed to yield a partial ordering
- Given a partial ordering we can always add extra labels to make it a lattice
EMBEDDING A POSET IN A LATTICE

such embedding is always possible

BLP BASIC ASSUMPTIONS

- \( \text{SUB} = \{S_1, S_2, \ldots, S_m\} \), a fixed set of subjects
- \( \text{OBJ} = \{O_1, O_2, \ldots, O_n\} \), a fixed set of objects
- \( R \supseteq \{r, w\} \), a fixed set of rights
- \( D \), an \( m \times n \) discretionary access matrix with \( D[i,j] \subseteq R \)
- \( M \), an \( m \times n \) current access matrix with \( M[i,j] \subseteq \{r, w\} \)
BLP MODEL

• Lattice of confidentiality labels
  \[ \Lambda = \{ \lambda_1, \lambda_2, ..., \lambda_p \} \]

• Static assignment of confidentiality labels
  \[ \lambda: \text{SUB} \cup \text{OBJ} \rightarrow \Lambda \]

• \( M \), an \( m \times n \) current access matrix with
  - \( r \in M[i,j] \Rightarrow r \in D[i,j] \land \lambda(S_i) \geq \lambda(O_j) \) (simple security)
  - \( w \in M[i,j] \Rightarrow w \in D[i,j] \land \lambda(S_i) \leq \lambda(O_j) \) (star-property)

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**STAR-PROPERTY**

- applies to subjects not to users
- users are trusted (must be trusted) not to disclose secret information outside of the computer system
- subjects are not trusted because they may have Trojan Horses embedded in the code they execute
- star-property prevents overt leakage of information and does not address the covert channel problem

**BIBA MODEL**

- Lattice of integrity labels
  \[ \Omega = \{ \omega_1, \omega_2, ..., \omega_q \} \]
- Assignment of integrity labels
  \( \omega: \text{SUB} \cup \text{OBJ} \rightarrow \Omega \)
- \( M \), an \( m \times n \) current access matrix with
  - \( r \in M[i,j] \Rightarrow r \in D[i,j] \land \omega(Si) \leq \omega(Oj) \) simple integrity
  - \( w \in M[i,j] \Rightarrow w \in D[i,j] \land \omega(Si) \geq \omega(Oj) \) integrity confinement
EQUIVALENCE OF BLP AND BIBA

- Information flow in the Biba model is from top to bottom
- Information flow in the BLP model is from bottom to top
- Since top and bottom are relative terms, the two models are fundamentally equivalent
EQUIVALENCE OF BLP AND BIBA

\[
\begin{array}{c}
\text{HS (High Secrecy)} \\
\text{⇒} \\
\text{LS (Low Secrecy)} \\
\end{array}
\]

\[
\begin{array}{c}
\text{BLP LATTICE} \\
\text{EQUIVALENT BIBA LATTICE} \\
\end{array}
\]

COMBINATION OF DISTINCT LATTICES

\[
\begin{array}{c}
\text{HS} \\
\text{⇒} \\
\text{HS, LI} \\
\text{HS, HI} \\
\text{⇒} \\
\text{HS, HI} \\
\text{LS, LI} \\
\text{LS, HI} \\
\text{⇒} \\
\text{BLP} \\
\text{GIVEN} \\
\text{BIBA} \\
\text{EQUIVALENT BLP LATTICE} \\
\end{array}
\]

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BLP AND BIBA

- BLP and Biba are fundamentally equivalent and interchangeable
- Lattice-based access control is a mechanism for enforcing one-way information flow, which can be applied to confidentiality or integrity goals
- We will use the BLP formulation with high confidentiality at the top of the lattice, and high integrity at the bottom

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LIPNER'S LATTICE

- Lipner's lattice uses 9 labels from a possible space of 192 labels (3 integrity levels, 2 integrity compartments, 2 confidentiality levels, and 3 confidentiality compartments)
- The single lattice shown here can be constructed directly from first principles

The position of the audit trail at lowest integrity demonstrates the limitation of an information flow approach to integrity
- System control subjects are exempted from the star-property and allowed to
  - write down (with respect to confidentiality)
    or equivalently
  - write up (with respect to integrity)
DYNAMIC LABELS IN BLP

- Tranquility (most common):
  \( \lambda \) is static for subjects and objects
- BLP without tranquility may be secure or insecure depending upon the specific dynamics of labelling
- Noninterference can be used to prove the security of BLP with dynamic labels

DYNAMIC LABELS IN BLP

- High water mark on subjects:
  \( \lambda \) is static for objects
  \( \lambda \) may increase but not decrease for subjects
  Is secure and is useful
- High water mark on objects:
  \( \lambda \) is static for subjects
  \( \lambda \) may increase but not decrease for subjects
  Is insecure due to disappearing object signaling channel
REFERENCES

- Ravi Sandhu, "Lattice-Based Access Control Models."
  Manuscript handed out in class