APPLICATIONS OF LATTICES TO COMPUTER SECURITY

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OUTLINE OF TALK

- Motivation for use of lattices in access control
- Description of my own work in applying lattices to a sub-case of access control -- dynamic security policies
- Show how Millen applied to survivability
  - In the process, proved some new theorems on lattices and access control

RELATION OF LATTICS TO ACCESS CONTROL

- Access control -- saying who has access to what to do what
  - Closely related to set-theoretic lattices
  - If set A of users has set □ of permissions, and set B of users has set □ of permissions, then
    - A□ B has permissions □ □ □
    - A□ B has permissions □ □ □
  - Both access groups and permissions have lattice structure based on set inclusion
- Of particular interest -- multilevel security
  - Security levels (unclassified, secret, top secret, etc.) form a total order
  - Compartments form an unordered set
  - Cross-product of the two forms a lattice

DYNAMIC ACCESS CONTROL

- Access rights depend on data subject has accessed before
- Examples
  - Chinese Walls -- personnel working at a securities company may not be granted access to data on two companies determined to be in conflict of interest
    - If a subject has had access to data from one company, then is denied access to the other
    - Brewer and Nash formalized this policy in a 1989 paper
  - Aggregation problem -- data that may not be sensitive by itself may become so when combined with other data
    - Subject who has had access to data in an aggregation set may be denied access to other data in the set

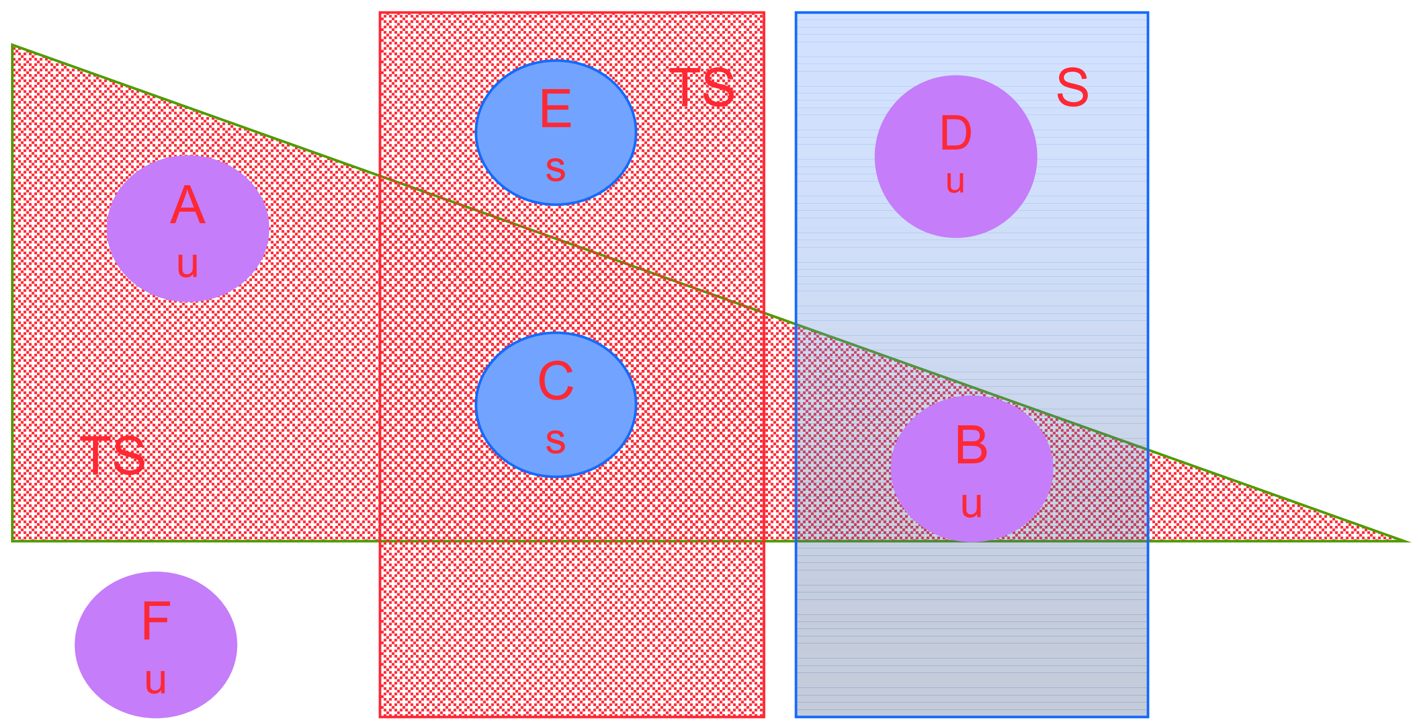
BASIS OF THE POLICY

- A collection of data and subjects, in which datum A and subject S assigned security levels l(A) and l(S)
  - l is a function from data and subjects to a lattice
  - If $l(S) \geq l(A)$ then S can read A
  - If $l(S) \leq l(A)$ then S can modify A
- However, in some cases, classification of a collection of data may be greater than that of any individual item in the collection

DEFINITION OF A DATASET AGGREGATION SYSTEM

- **A triple (D,L,*l*), where D is a set of pairwise disjoint datasets, L is a lattice, and *l* is a function from P(D) to L such that if H □J then *l*(H) ≤ *l*(J)**
  - **If level of H strictly dominates level of all subaggregates, call H an excepted aggregate**
  - **Otherwise, it's an unexcepted aggregate**
- **L is motivated by the lattice of security levels from multilevel security**

EXAMPLE



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DEFINING ACCESS CONTROL POLICIES

- Let (D,L,*l*) be a dataset aggregate system. An information flow policy is a transitive relation R on P(D) such that H□ K implies (H,K) □ R.
- We say that R is safe if
  - for all H and K such that (H,K) □ R, *l*(H) ≤ *l*(K)
  - For all H1, H2, and K such that (H1,K) □ R and (H2,K) □ R, (H1□ H2,K) □ R
- We define the multilevel information flow policy to be the relation R defined by (H,K) □ R if and only if, for each J, *l*(H □ J) ≤ *l*(K □ J)
- Intuitive idea: information flow policy says in what direction information can flow
  - If (H,K) □ R then information can flow from H to K

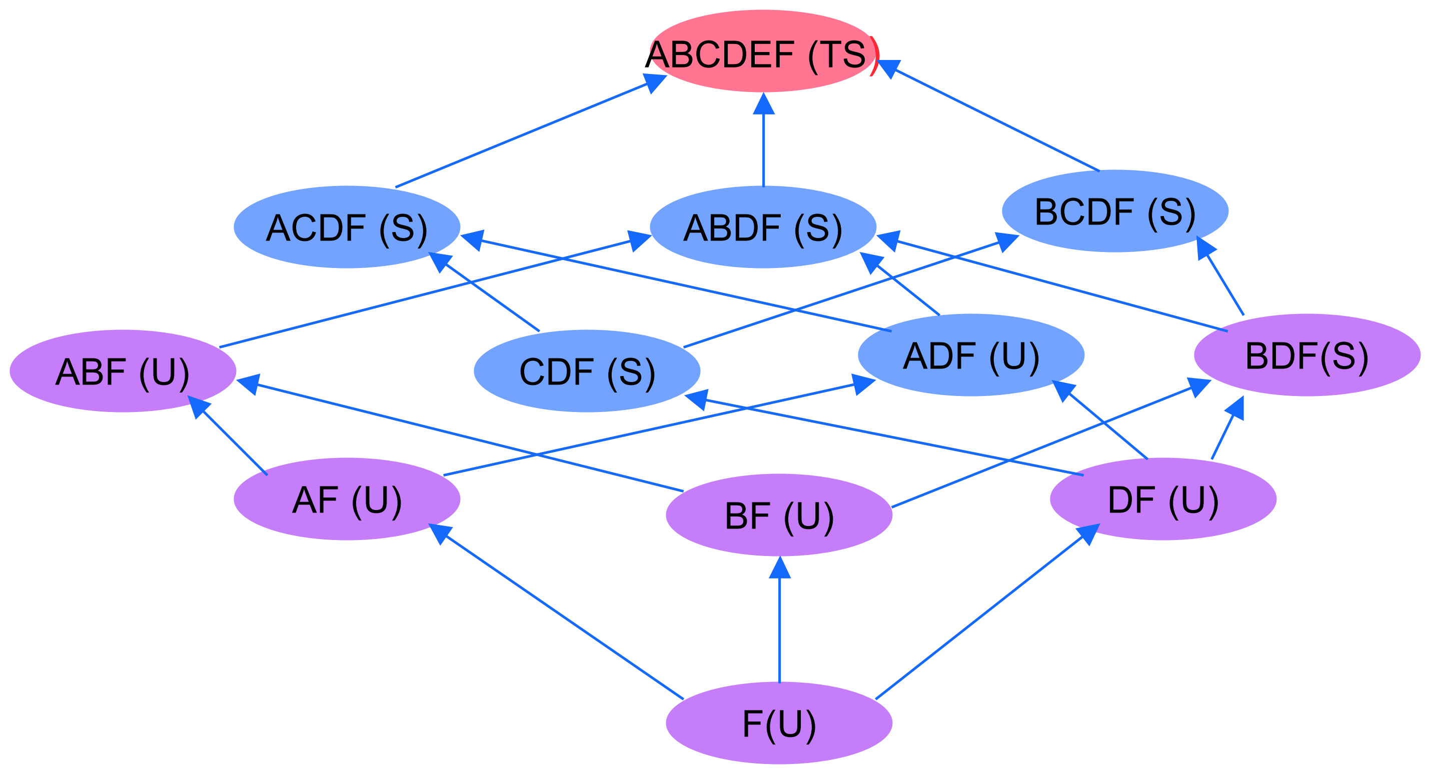
A THEOREM ON INFORMATION FLOW POLICIES

- Let (D,L,*l*) be a data aggregate system. Then the multilevel information flow policy on (D,L,*l*) is the unique maximal safe information flow policy on (D,L,*l*)

MAKING R INTO A LATTICE

- Take advantage of usual technique for transforming quasi-ordered set into a lattice
- Let (D,L,*l*) be a dataset aggregate system. Define g: P(D) -> P(D) by g(H) = {X □ D | ({X},H) □ R}
- Theorem: The collection of sets g(P(D)) together with the subset relation forms a lattice with
  - lub(H,K) = g(H□ K)
  - glb(H,K) = (H□ K)

EXAMPLE


ABCDEF (TS)
ACDF (S)
ABDF (S)
BCDF (S)
ABF (U)
CDF (S)
ADF (U)
BDF(S)
AF (U)
BF (U)
DF (U)
F(U)

MILLEN’S APPLICATION TO SURVIVABILITY

- Consider a system built out of a number of components
- Subsets of components can be configured to provide different sets of essential services
  - Components = datasets
  - Services = security levels

DEFINITION OF A SYSTEM

- A pair $S = (S_1,S_2)$ consisting of a set of services S_2 and a set of components S_1 is a system if there is a basis mapping s -> [s] defined on S_2 such that for all s □ S_2
  1. u □ [s] => u □ S_1, and;
  2. u,v □ [s] and u □ v => u = v
- A composition (subset of S_1) supports a service if and only if it contains a basis element for that service
- Define a survivability preordering
  – $s \preceq t$ means u supports s implies u supports t
  – Reflexive and transitive, but not anti-symmetric
  – However, does define a partial ordering on bases

DEFINITION OF STATE

- A state p of a system S is a pair $p = (p_1,p_2)$ such that
  1. p_2 □ S_2 is a set of services
  2. p_1 □ S_1 is a set of components called the support of p such that p_1 supports every s □ p_2.

Furthermore, there exists at least one function f on p_2 called a configuration of p such that

1. f(s) □ p_1
2. f(s) supports s

The configuration shows how each service is supported by p_1

REALIZABLE CONFIGURATIONS

- A configuration is realizable if it is possible to build a system that implements it
  - For example, it may not be possible to have a configuration in which the same component supports two different services
  - What is considered realizable may vary from system to system
- Let the set of realizable states of a system S be denoted by R
- Axioms
  - Adding components or deleting services does not destroy the realizability of a state
  - Disjoint configurations (in which no component supports more than one service) are always realizable

TRANSLATING INTO AGGREGATION PROBLEM

- Define composition "sensitivity level" as follows

$$\square_s(u) = \{p_2 \mid (u, p_2) \; \square \; R\}$$

- $\square_s(u)$ is monotone
- Theorem: Let $D = P(S_2)$ be the collection of sets of services. Then $(S_1, P(D), \square_s)$ is a dataset aggregate system

THEOREM ON SERVICE-PRESERVING TRANSITIONS

Def. A state transition is service-preserving if the new state supports all the services of the old state.

These two properties are equivalent:

P1. $\square_s(u)\ \square\ \square_s(v)$

P2. For all $p\ \square\ R$ **such that** $p_1 = u$ **there exists** $q\ \square\ R$ **such that** $q_1 = v$ **and** $p_2 = q_2$

P1 is the first of the two properties of a safe flow relation.

P2 says any state supported by u can be reconfigured to a state supported by v with a service-supporting transition

USING FLOW POLICIES TO INDUCE CONFIGURATION POLICIES

- Induced reconfiguration: If $\square_R$ is a flow policy with respect to $\square_S$ (as defined by Meadows), the induced reconfiguration policy $==>_R$ is defined by $p ==>_R q$ if $(p,q) \square R$ and $p_1 \square_R q_1$
- Corollary: Service-Preserving Configuration

Suppose that $\square_R$ is a safe flow policy. Then

1. Any reconfiguration $p ==>_R q$ is service-preserving.
2. If $p_1 \square_R v$ then there exists q such that $p_1 = v$ and $p ==>_R q$.

COMPARISON BETWEEN AGGREGATION AND RECONFIGURATION

AGGREGATION	RECONFIGURATION
DATASETS X	COMPONENTS S_1
AGGREGATES u □ X	COMPOSITIONS u □ S_1
SENSITIVITY LEVEL *l*	$□_s(u) = \{p_1 \vert p$ □ R and $p_2 = u\}$
FLOW POLICY □ $_R$	INDUCED RECONFIGURATION POLICY $==>_R$

MAXIMAL SAFE FLOW POLICY

- Define Maximal Safe Reconfiguration: if $\square_{R}$ is the maximal safe flow policy, then $==>_{R}$ is the maximal safe reconfiguration policy.
- Millen develops techniques for constructing maximal safe reconfiguration
  - Also apply to maximal safe flow policy
  - No complexity results, but best algorithm found is exponential time

CONCLUSION

- Some intriguing connections between aggregation in a secure database and policies for reconstructing survivable systems
- Follows general connection secrecy and integrity
  - Often can get from one to another by turning policy upside down
  - Connection is usually not trivial, need to think about how to apply results from one to problems of another
- Lattices, which have long been the backbone of the multilevel security model, can be applied in similar ways to other security problems

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