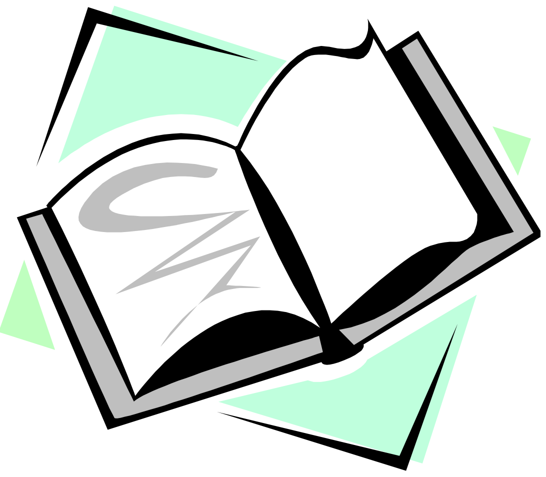
Data Security and Privacy

Topic 17: Non-interference and Non-deducibility

Optional Readings for This Lecture

- Security Policies and Security Models. J.A.Goguen and J.Meseguer. Oakland'1982

- Non-deducibility is from the paper "A Model of Information" by David Sutherland
  - Not available online



What is a Security Model?

- A model describes the system
  - e.g., a high level specification or an abstract machine description of what the system does
- A security policy
  - defines the security requirements for a given system
- Verification techniques that can be used to show that a policy is satisfied by a system
- System Model + Security Policy = Security Model

Motivations

- Multi-level security is about information flow
  - Information in high level objects should not flow into low-level subjects
- The BLP model describes access control mechanisms that prevents illegal information flow, but not the meaning of no illegal information flow
  - BLP describes “how”, not “what” for information flow protection
    - E.g., define secure encryption by giving a particular encryption algorithm and say this is secure encryption
  - As a result, BLP does not prevent information flow through covert channels
  - Also, it doesn’t say whether other mechanisms can be used do information flow protection

Non-interference in Programs

- Consider the following functions, is there information flow between x and output of the functions?

```
add(int x, int y) {
  return x+y;
}

check_pw(char *s) {
    char *x;
    return strcmp(x,s);
}
```

```
f(int x, int y) {
  if x>0 return y+y;
  else return 2*y;
}

g(int x, int y){
  return x*y/x;
}
```

Deterministic Non-Interference in Programs

- A set X of inputs is non-interfering with a set Y of outputs if and only if
  - No matter what values X take, the outputs Y remain the same
    - When one changes only values of inputs in X, the output remain unchanged
    - Observing only Y, one learns nothing about any input in X.
  - More formally, let Y=f(X,Z), where f is a deterministic function, and X,Z represents two sets of inputs, X is non-interfering with Y iff $\forall Z_0 \exists Y_0\ \forall X_0\ f(X_0, Z_0) = Y_0$
    or equivalently, $\forall Z_0\ \forall X_0\ \forall X_1\ f(X_0, Z_0) = f(X_1, Z_0)$
  - X interferes with Y iff. $\exists Z_0\ \exists X_0\ \exists X_1\ f(X_0, Z_0) \neq f(X_1, Z_0)$
- For randomized programs, non-interference is harder to define, and we do not cover it in this course

More on Non-interference Properties

- Two classes of techniques to ensure that security properties are satisfied by programs
  - Monitor execution of a program and deny illegal actions or terminate the program if illegal action is detected.
    - Can enforce BLP property.
    - Cannot enforce non-interference.
      - Why? Because non-interference is not defined on one execution of a program; it is a property on a program's behaviors on different inputs.
  - Statically verifying that certain non-interference relation holds by analyzing the program
    - Can be used only with access to source code

Language-Based Security

- Using programming language technique to ensure certain security properties hold
  - A large body of work focuses on using type theory and compiling-time checks to ensure information-flow properties
- Challenges to apply in real world:
  - Non-interference is often too strong
    - Suppose that one want to ensure that a secret password is not leaked, can one require non-interference between the password input and observable output?
    - Needs declassification mechanism that specify certain information dependent on sensitive inputs can be leaked.
  - Specifying such policies is impractical
    - Too much work for programmers, especially for large programs
    - Many policies need to be determined by end users, not programmers
  - Need source code, unable to deal with the real security challenge of external code.

The Non-Interference Model in the Original Goguen-Meseguer paper

- A state-transition model, where state changes occur by subjects executing commands
  - S: set of states
  - U: set of subjects
  - SC: set of state commands
  - Out: set of all possible outputs
  - do: $S \times U \times SC \rightarrow S$
    - do(s,u,c)=s' means that at state s, when u performs command c, the resulting state is s'
  - out: $S \times U \rightarrow Out$
    - out(s,u) gives the output that u sees at state s
  - $s_0 \in S$ initial state

Model focuses on interfaces (inputs/outputs) of a system, rather than internal aspects (e.g., objects)

Security Policies in the Non-interefence Model

- A security policy is a set of noninterference assertions
- Definition of noninterference: Given two group of users G and G', we say G does not interfere with G' if for any sequence of commands w,
  - View_G'(w) = View_G'(P_G(w))
    - P_G(w) is w with commands initiated by users in G removed.
    - No matter what users in G do, users in G' will observe the same.
- Implicit assumptions:
  - Initial state of the system does not contain any sensitive information
  - Information comes into the system by commands
  - Only way to get information is through outputs

Comparisons of the BLP work & the Noninterference work

- Differences in model
  - BLP models internals of a system (e.g., objects)
  - GM models the interface (input & output)
- Differences in formulating security policies
  - BLP specifies access control requirement, noninterference specifies information flow goal
- Noninterference could address covert channels concerns
  - Provided that one defines observable behavior to include those in covert channels; doesn't make stopping covert channel easier
- Under noninterference, a low user is allowed to copy one high-level file to another high-level file
  - In general not allowed by BLP

Evaluation of The Non-Interference Policy

- The notion of noninterference is elegant and natural
  - Focuses on policy objective, rather than mechanism, such as BLP
  - Could be useful in other settings
- Mostly concerned with deterministic systems
  - For randomized or otherwise non-deterministic systems, definition is more complicated
- May be too restrictive
  - e.g., consider encrypt and then communicate

Non-deducibility

- Attempt to define information flow in non-deterministic as well as deterministic systems
- Intuition: there is no information flow between X and Y, iff., when observing only Y, one can never eliminate any value from the domain in X as a possible value
- Definition: let Y=f(X,Z), where f is not necessarily deterministic, there is information flow between X and Y in the non-deducibility sense iff.

  $\exists Y_0 \in \{ f(X,Z) \}\ \exists X_0$ s.t. $Y_0 \notin \{ f(X_0, Z) \}$

  - When one observes the value of Y is Y_0, one learns that $X \neq X_0$.
  - There is no information flow between X and Y in the non-deducibility sense when $\forall Y_0 \in \{ f(X,Z) \}\ \forall X_0\ \exists Z_0$ s.t. $Y_0 \in \{ f(X_0, Z_0) \}$

- Go to the examples for non-interference

An Example Illustrating that Non-deducibility is Too Weak

- A high user and a low user
  - the high user can write to a file
    - one letter at a time
  - the low user can try to read the n’th character in a file
    - if file is shorter than n, or if the the n’th character is blank, returns a random letter
    - otherwise, with 99.9% probability return the letter, and with 0.1% probalility return a random letter
- The system is nondeducible secure
- The system is intuitively insecure
- Non-deducibility can often be too weak. It deals with possibilistic inference, not probabilistic inference

Examples:

High int x = …;

High int y = …;

Low int z;

if x>0 z = y+y;

else z = 3*y;

- x interferes with z
- y interferes with z
- x and z are not non-deduciable secure
- y and z are not non-deduciable secure

High int x = …;

High int y = …;

Low int z;

if x>0 z= y+y;

else z=2*y;

- x does not interfere with z
- y interferes with z
- x and z are non-deduciable secure
- y and z are not non-deduciable secure

Examples

High int x = …;

High int y = …;

Low int z1 = x + y;

Low int z2 = x – y;

- x interferes with z1
- x interferes with z2
- x and z1 are non-deducible secure
- x and {z1,z2} are not non-deduciable secure
-

High char * x = …;

Low char * entered_pw = …;

Low boolean z;

z = strcmp(entered_pw,x);

- x interferes with z
- x and {z, entered_pw} are not non-deduciable secure

Relationships Between Nondeducibility & Noninterference

- For deterministic systems with just one high input var (and possibly many other low input vars) and one low output, a system is noninterference secure if and only if it is nondeducibility secure.

- For deterministic systems with more than one high input vars, non-interference is stronger than non-deducibility

Proof.

- Theorem: For deterministic programs with just one high input variable x, let Z be the set of all low variables, x does not interfere with the set Z if and only if x and Z are nondeducible secure.
- Proof. If x does not interfere with Z, no matter what values x takes, the variables in Z are uniquely determined by inputs in Z. Observing values in Z cannot eliminate any value for x.

- If x interferes with Z, then there exist $x_1 \neq x_2$ and $Z_2 \neq Z_1$ such that $Z=Z_1$ when $x=x_1$ and $Z=Z_2 \neq Z_1$ when $x=x_2$. Observing $Z=Z_2$, one knows $x \neq x_1$, making x and X not nondeduciable secure. This is because as x is the only high var and the system is deterministic, when fixing input variables in Z to values in Z_2, the output variables are fixed as well.

Relationship Between Security Notions

- Perfect secrecy
- IND-CPA security
- Non-interference
- Non-deducability

Next Lecture

- Data Privacy