CS 711

Advanced Programming Languages Seminar

Language-Based Security and Information Flow

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Language-based security

- Language-based security: using language tools to specify and enforce security
  - End-to-end security specifications
  - Program analysis
  - Program transformation
- This seminar: explicitly integrating security policies into the programming model
  - Programmers need help writing secure applications
  - What's the right programming model to achieve this?

Explicit security models

- How can we specify security requirements?
  - Access control policies?
  - Confidentiality? Availability? Anonymity?
- Static or dynamic enforcement?
- How to show that complex systems/programs satisfy security requirements?
  - Formal validation
  - Scalable, modular analysis
- How should security requirements appear in or be connected to programs?
  - Program annotations? External specifications?

Not about:

- Buffer overruns
- Proof-carrying code
- Memory safety
- Type safety

Instead: How to prevent attacks that misuse or exploit application code but *don't* violate "simple" safety properties?

Plan of action

- Participants participate!
- Read recent papers on language-based security (+ a few seminal papers)
- Some lectures for background
  - 611 dependency only later in course
- 35-minute student presentation, 15-30 minute discussion
  - Presentation: review paper, kick off discussion
  - Each student: 1-2 presentations
- Readers:
  - Come prepared with issues, questions, criticisms
  - Speak up (constructively)
- Final project or survey
  - 10-minute presentation
  - One paragraph proposal due Nov. 3

Language-based security models

- Access control
  "You can't scram the core unless you are a reactor supervisor"
  - Principals/authentication
  - Capabilities
  - Static access control
  - Java stack inspection
- Information flow control
  "The plane's location should only be known by traffic controllers"
  - Confidentiality, integrity
  - Absolute security?
- Need both and more
  "The aggregate salaries in this demographic database are only accessible to subscribers who have paid"
  - Inference controls, quantitative information flow, intransitive noninterference

Computer security

- Goal: prevent bad things from happening
  - Clients not paying for services
  - Critical services unavailable
  - Confidential information leaked
  - Important information damaged
  - System used to violate law

When to enforce security

Possible times to respond to security violations:

- Before execution:
  analyze, reject, rewrite
- During execution:
  monitor, log, halt, change
- After execution:
  roll back, restore, audit, sue, call police

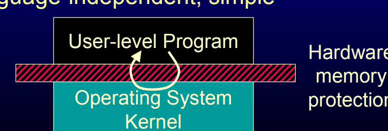
Conventional security mechanisms

- Encryption, firewalls, memory protection
- Treat the program as a black box
  - Not fine-grained enough
  - No help with validation
  - Internal behavior of program is important!

Conventional OS security

- Program is black box
- Program talks to OS via protected interface (system calls)
  - Multiplex hardware
  - Isolate processes from each other
  - Restrict access to persistent data (files)

\+ Language-independent, simple



OS: Coarse-grained control

- Operating system enforces security at system call layer
- Hard to control application when it is not making system calls
- Security enforcement decisions made with regard to large-granularity operating-system abstractions
  - Files, sockets, processes, ports

Need: fine-grained control

- Modern programs make security decisions with respect to *application* abstractions
  - UI: access control at window level
  - mobile code: no network send after file read
  - E-commerce: no goods until payment
  - intellectual property rights management
- Need extensible, reusable mechanism for enforcing security policies
- Language-based security can support an extensible protected interface to control access
  - E.g., Java security
  - Capabilities, access control lists, stack inspection
- Language-based security can also support analyses of information security

End-to-end security

- Near-term problem: ensuring programs are memory-safe, type-safe so fine-grained access control policies can be enforced
- Long-term problem: ensuring that complex (distributed) computing systems enforce system-wide information security policies
  - Confidentiality
  - Integrity
  - Availability
- Confidentiality, integrity: end-to-end security described by *information-flow policies*

Information security: confidentiality

- Confidentiality: valuable information should not be leaked by computation
- Also known as *secrecy*; sometimes a distinction is made:
  - Secrecy: information itself is not leaked
  - Confidentiality: nothing can be learned about information
- Simple (access control) version:
  - Only authorized processes can read from a file
  - But… when should a process be "authorized" ?
- End-to-end version:
  - Information should not be improperly released by a computation no matter how it is used
  - Requires tracking *information flow* in system
  - Encryption provides end-to-end secrecy—but prevents computation

Information security: integrity

- Integrity: valuable information should not be damaged by computation
- Simple (access control) version:
  - Only authorized processes can write to a file
  - But… when should a process be "authorized"
- End-to-end version:
  - Information should not be updated on the basis of less trustworthy information
  - Requires tracking information flow in system

Availability

- System is responsive to requests
- DoS attacks: attempts to destroy availability (perhaps by cutting off network access)
- Fault tolerance: system can recover from *faults* (failures), remain available, reliable
- *Benign* faults: not directed by an adversary
  - Usual province of fault tolerance
- *Malicious* or *Byzantine* faults: adversary can choose time and nature of fault
  - Byzantine faults are attempted security violations
  - usually limited by not knowing some secret keys

Security Property Landscape

"System does exactly what it should"

Privacy

Digital rights

Noninterference

Mandatory access control

Byzantine Fault Tolerance

Discretionary access control

Confinement

Fault Tolerance

Type safety

Memory safety

Availability

Memory protection

Safety properties

Liveness properties

Why put security in the program?

- Part of the programming model – can support conveniently
- Can tie program directly to policy and enforce
- Limits toproperties enforceable through libraries and hardware
- Support separate compilation and modular analysis

Why not?

separation of policy and program

Security specifications

- Is security proving that a program is correct?
- Ordinary correctness specifications:

  {P} S {Q}

  precondition P ➔ postcondition Q
- How do we know the specification satisfies security requirements?
- Example:
  - Precondition: all salaries in the database are nonnegative
  - Postcondition: x contains the average salary
- Partial correctness assertions describe properties satisfies by every execution individually; information flow assertions compare every *pair* of executions