Amplifying

- Allows *temporary* increase of privileges
- Needed for modular programming
  - Module pushes, pops data onto stack

    `module stack … endmodule.`
  - Variable *x* declared of type stack

    `var x: module;`
  - *Only* stack module can alter, read *x*
    - So process doesn't get capability, but needs it when *x* is referenced—a problem!
  - Solution: give process the required capabilities while it is in module

Examples

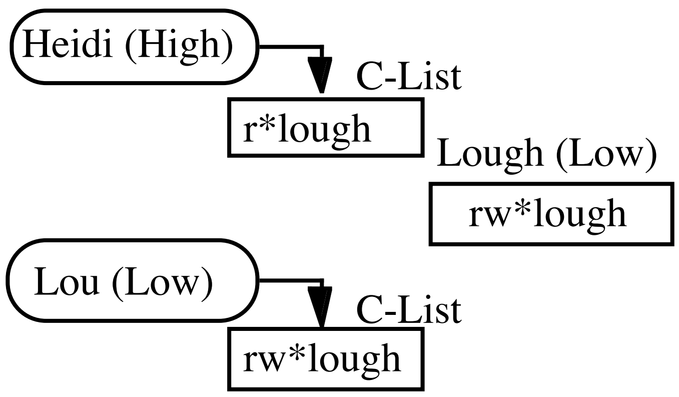
- HYDRA: templates
  - Associated with each procedure, function in module
  - Adds rights to process capability *while the procedure or function is being executed*
  - Rights deleted on exit
- Intel iAPX 432: access descriptors for objects
  - These are really capabilities
  - 1 bit in this controls amplification
  - When ADT constructed, permission bits of type control object set to what procedure needs
  - On call, if amplification bit in this permission is set, the above bits or'ed with rights in access descriptor of object being passed

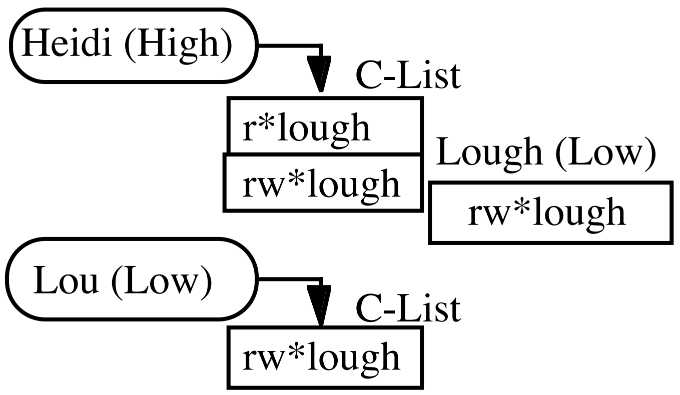
Revocation

- Scan all C-lists, remove relevant capabilities
  - Far too expensive!
- Use indirection
  - Each object has entry in a global object table
  - Names in capabilities name the entry, not the object
    - To revoke, zap the entry in the table
    - Can have multiple entries for a single object to allow control of different sets of rights and/or groups of users for each object
  - Example: Amoeba: owner requests server change random number in server table
    - All capabilities for that object now invalid

Limits

- Problems if you don't control copying of capabilities





The capability to write file *lough* is Low, and Heidi is High so she reads (copies) the capability; now she can write to a Low file, violating the *-property!

Remedies

- Label capability itself
  - Rights in capability depends on relation between its compartment and that of object to which it refers
    - In example, as as capability copied to High, and High dominates object compartment (Low), write right removed
- Check to see if passing capability violates security properties
  - In example, it does, so copying refused
- Distinguish between “read” and “copy capability”
  - Take-Grant Protection Model does this (“read”, “take”)

ACLs vs. Capabilities

- Both theoretically equivalent; consider 2 questions
  1. Given a subject, what objects can it access, and how?
  2. Given an object, what subjects can access it, and how?
  - ACLs answer second easily; C-Lists, first
- Suggested that the second question, which in the past has been of most interest, is the reason ACL-based systems more common than capability-based systems
  - As first question becomes more important (in incident response, for example), this may change

Locks and Keys

- Associate information (*lock*) with object, information (*key*) with subject
  - Latter controls what the subject can access and how
  - Subject presents key; if it corresponds to any of the locks on the object, access granted
- This can be dynamic
  - ACLs, C-Lists static and must be manually changed
  - Locks and keys can change based on system constraints, other factors (not necessarily manual)

Cryptographic Implementation

- Enciphering key is lock; deciphering key is key
  - Encipher object o; store $E_k(o)$
  - Use subject's key k' to compute $D_{k'}(E_k(o))$
  - Any of n can access o: store

$$o' = (E_1(o), \ldots, E_n(o))$$

  - Requires consent of all n to access o: store

$$o' = (E_1(E_2(\ldots(E_n(o))\ldots))$$

Example: IBM

- IBM 370: process gets access key; pages get storage key and fetch bit
  - Fetch bit clear: read access only
  - Fetch bit set, access key 0: process can write to (any) page
  - Fetch bit set, access key matches storage key: process can write to page
  - Fetch bit set, access key non-zero and does not match storage key: no access allowed

Example: Cisco Router

- Dynamic access control lists

```
access-list 100 permit tcp any host 10.1.1.1 eq telnet
access-list 100 dynamic test timeout 180 permit ip any host \
   10.1.2.3 time-range my-time
time-range my-time
   periodic weekdays 9:00 to 17:00
line vty 0 2
   login local
   autocommand access-enable host timeout 10
```

- Limits external access to 10.1.2.3 to 9AM–5PM
  - Adds temporary entry for connecting host once user supplies name, password to router
  - Connections good for 180 minutes
    - Drops access control entry after that

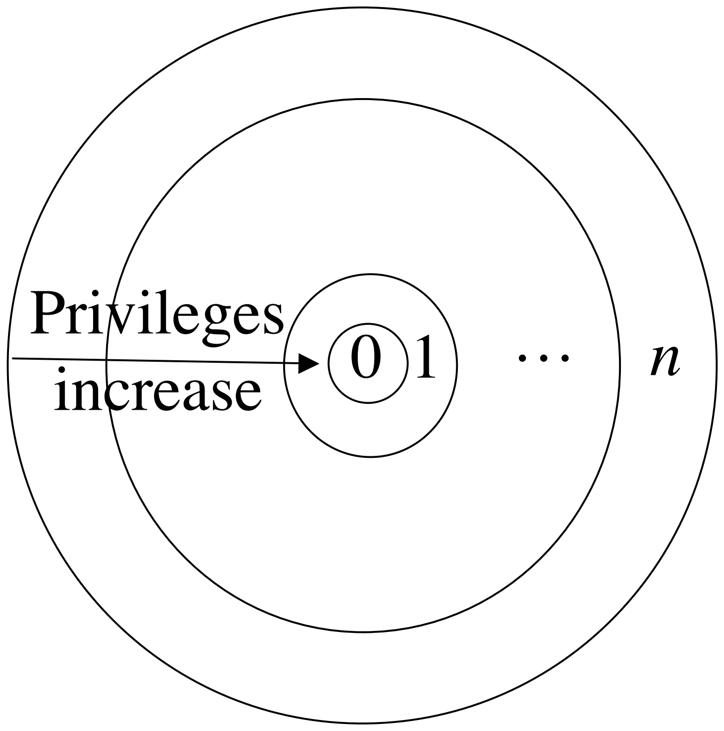
Type Checking

- Lock is type, key is operation
  - Example: UNIX system call *write* can't work on directory object but does work on file
  - Example: split I&D space of PDP-11
  - Example: countering buffer overflow attacks on the stack by putting stack on non-executable pages/segments
    - Then code uploaded to buffer won't execute
    - Does not stop other forms of this attack, though …

More Examples

- LOCK system:
  - Compiler produces “data”
  - Trusted process must change this type to “executable” becore program can be executed
- Sidewinder firewall
  - Subjects assigned domain, objects assigned type
    - Example: ingress packets get one type, egress packets another
  - All actions controlled by type, so ingress packets cannot masquerade as egress packets (and vice versa)

Ring-Based Access Control



- Process (segment) accesses another segment
  - Read
  - Execute
- *Gate* is an entry point for calling segment
- Rights:
  - *r* read
  - *w* write
  - *a* append
  - *e* execute

Reading/Writing/Appending

- Procedure executing in ring *r*
- Data segment with *access bracket* (a_1, a_2)
- Mandatory access rule
  - $r \leq a_1$ allow access
  - $a_1 < r \leq a_2$ allow *r* access; not *w*, *a* access
  - $a_2 < r$ deny all access

Executing

- Procedure executing in ring *r*
- Call procedure in segment with *access bracket* (a_1, a_2) and *call bracket* (a_2, a_3)
  - Often written (a_1, a_2, a_3)
- Mandatory access rule

– $r < a_1$	allow access; ring-crossing fault
– $a_1 \le r \le a_2$	allow access; no ring-crossing fault
– $a_2 < r \le a_3$	allow access if through valid gate
– $a_3 < r$	deny all access

Versions

- Multics
  - 8 rings (from 0 to 7)
- Digital Equipment's VAX
  - 4 levels of privilege: user, monitor, executive, kernel
- Older systems
  - 2 levels of privilege: user, supervisor

PACLs

- Propagated Access Control List
  - Implements ORGON
- Creator kept with PACL, copies
  - Only owner can change PACL
  - Subject reads object: object's PACL associated with subject
  - Subject writes object: subject's PACL associated with object
- Notation: PACL_s means *s* created object; PACL(*e*) is PACL associated with entity *e*

Multiple Creators

- Betty reads Ann's file *dates*

  $\text{PACL(Betty)} = \text{PACL}_{\text{Betty}} \cap \text{PACL}(\textit{dates})$

  $= \text{PACL}_{\text{Betty}} \cap \text{PACL}_{\text{Ann}}$

- Betty creates file *dc*

  $\text{PACL}(\textit{dc}) = \text{PACL}_{\text{Betty}} \cap \text{PACL}_{\text{Ann}}$

- $\text{PACL}_{\text{Betty}}$ allows Char to access objects, but PACL_{Ann} does not; both allow June to access objects
  - June can read *dc*
  - Char cannot read *dc*

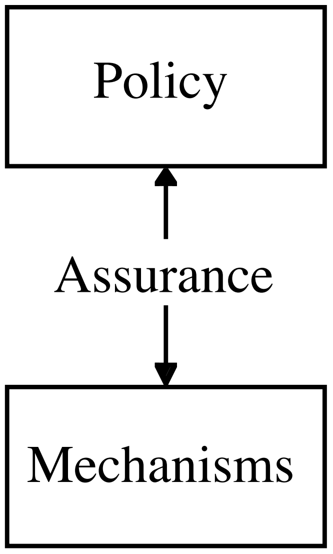
Assurance Overview

- Trust
- Problems from lack of assurance
- Types of assurance
- Life cycle and assurance
- Waterfall life cycle model
- Other life cycle models

Trust

- *Trustworthy* entity has sufficient credible evidence leading one to believe that the system will meet a set of requirements
- *Trust* is a measure of trustworthiness relying on the evidence
- *Assurance* is confidence that an entity meets its security requirements based on evidence provided by applying assurance techniques

Relationships



Statement of requirements that explicitly defines the security expectations of the mechanism(s)

Provides justification that the mechanism meets policy through assurance evidence and approvals based on evidence

Executable entities that are designed and implemented to meet the requirements of the policy

Problem Sources

1. Requirements definitions, omissions, and mistakes
2. System design flaws
3. Hardware implementation flaws, such as wiring and chip flaws
4. Software implementation errors, program bugs, and compiler bugs
5. System use and operation errors and inadvertent mistakes
6. Willful system misuse
7. Hardware, communication, or other equipment malfunction
8. Environmental problems, natural causes, and acts of God
9. Evolution, maintenance, faulty upgrades, and decommissions

Examples

- Challenger explosion
  - Sensors removed from booster rockets to meet accelerated launch schedule
- Deaths from faulty radiation therapy system
  - Hardware safety interlock removed
  - Flaws in software design
- Bell V22 Osprey crashes
  - Failure to correct for malfunctioning components; two faulty ones could outvote a third
- Intel 486 chip
  - Bug in trigonometric functions

Role of Requirements

- *Requirements* are statements of goals that must be met
  - Vary from high-level, generic issues to low-level, concrete issues
- *Security objectives* are high-level security issues
- *Security requirements* are specific, concrete issues

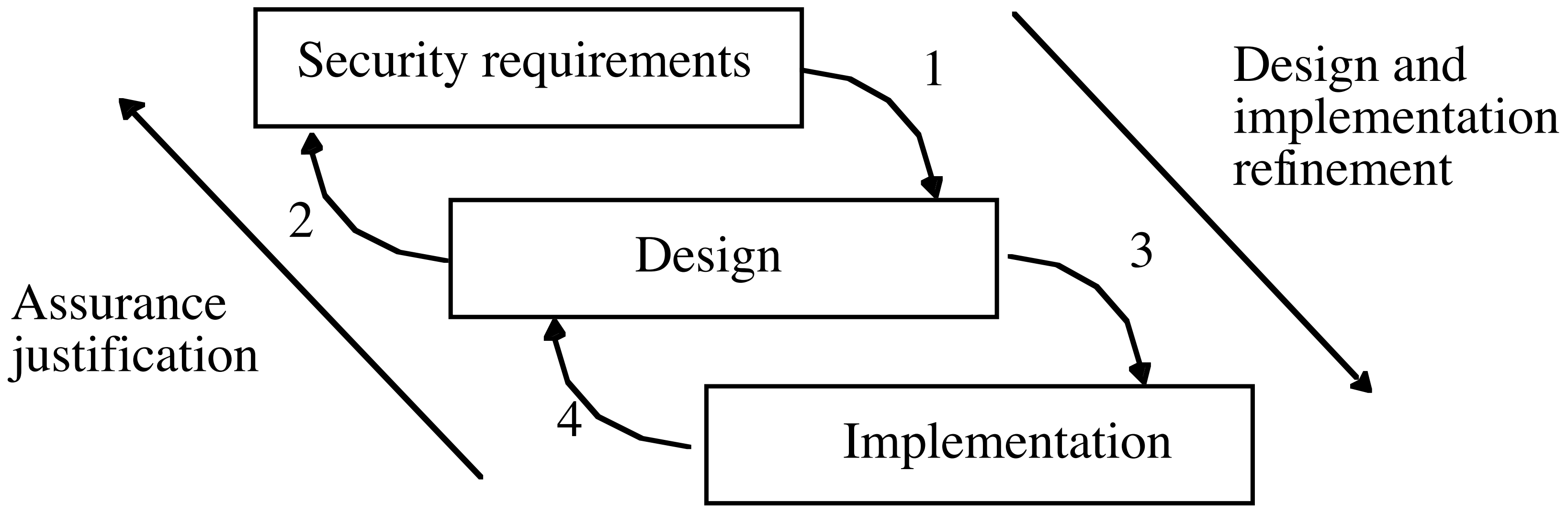
Types of Assurance

- *Policy assurance* is evidence establishing security requirements in policy is complete, consistent, technically sound
- *Design assurance* is evidence establishing design sufficient to meet requirements of security policy
- *Implementation assurance* is evidence establishing implementation consistent with security requirements of security policy

Types of Assurance

- *Operational assurance* is evidence establishing system sustains the security policy requirements during installation, configuration, and day-to-day operation
  - Also called *administrative assurance*

Life Cycle


Security requirements
Design
Implementation
1
2
3
4
Assurance justification
Design and implementation refinement

Life Cycle

- Conception
- Manufacture
- Deployment
- Fielded Product Life

Conception

- Idea
  - Decisions to pursue it
- Proof of concept
  - See if idea has merit
- High-level requirements analysis
  - What does “secure” mean for this concept?
  - Is it possible for this concept to meet this meaning of security?
  - Is the organization willing to support the additional resources required to make this concept meet this meaning of security?

Manufacture

- Develop detailed plans for each group involved
  - May depend on use; internal product requires no sales
- Implement the plans to create entity
  - Includes decisions whether to proceed, for example due to market needs

Deployment

- Delivery
  - Assure that correct masters are delivered to production and protected
  - Distribute to customers, sales organizations
- Installation and configuration
  - Ensure product works appropriately for specific environment into which it is installed
  - Service people know security procedures

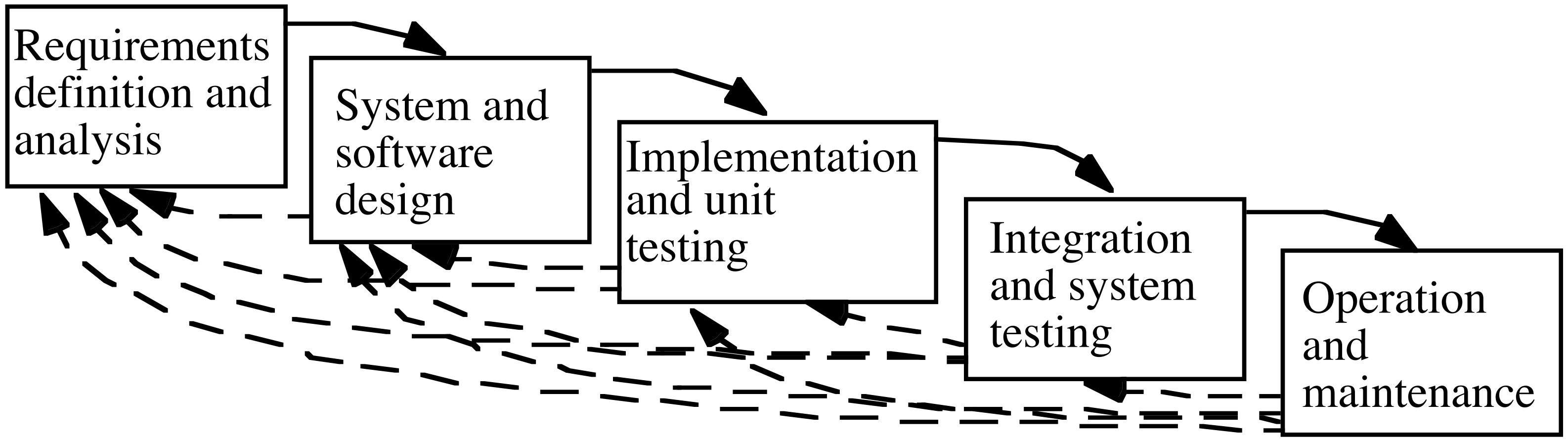
Fielded Product Life

- Routine maintenance, patching
  - Responsibility of engineering in small organizations
  - Responsibility may be in different group than one that manufactures product
- Customer service, support organizations
- Retirement or decommission of product

Waterfall Life Cycle Model

- Requirements definition and analysis
  - Functional and non-functional
  - General (for customer), specifications
- System and software design
- Implementation and unit testing
- Integration and system testing
- Operation and maintenance

Relationship of Stages


Requirements definition and analysis
System and software design
Implementation and unit testing
Integration and system testing
Operation and maintenance

Models

- Exploratory programming
  - Develop working system quickly
  - Used when detailed requirements specification cannot be formulated in advance, and adequacy is goal
  - No requirements or design specification, so low assurance
- Prototyping
  - Objective is to establish system requirements
  - Future iterations (after first) allow assurance techniques

Models

- Formal transformation
  - Create formal specification
  - Translate it into program using correctness-preserving transformations
  - Very conducive to assurance methods
- System assembly from reusable components
  - Depends on whether components are trusted
  - Must assure connections, composition as well
  - Very complex, difficult to assure

Models

- Extreme programming
  - Rapid prototyping and “best practices”
  - Project driven by business decisions
  - Requirements open until project complete
  - Programmers work in teams
  - Components tested, integrated several times a day
  - Objective is to get system into production as quickly as possible, then enhance it
  - Evidence adduced *after* development needed for assurance

Key Points

- Assurance critical for determining trustworthiness of systems
- Different levels of assurance, from informal evidence to rigorous mathematical evidence
- Assurance needed at all stages of system life cycle