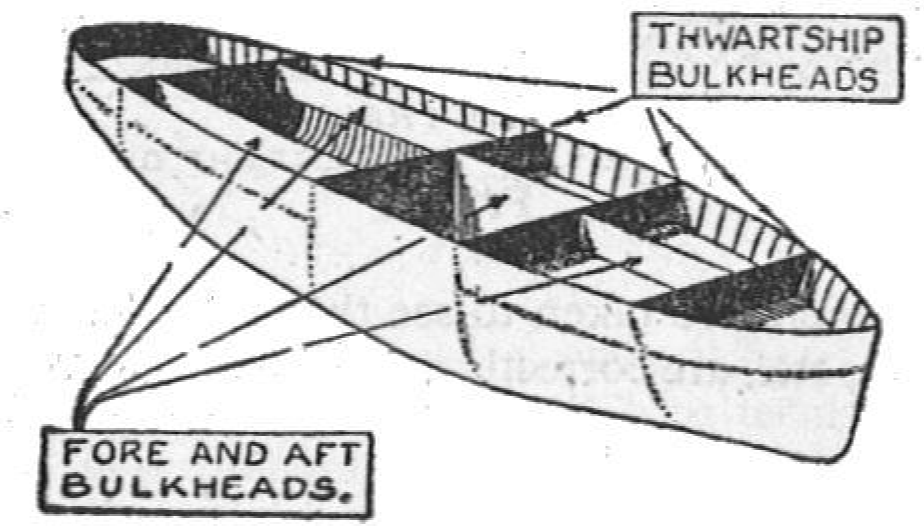
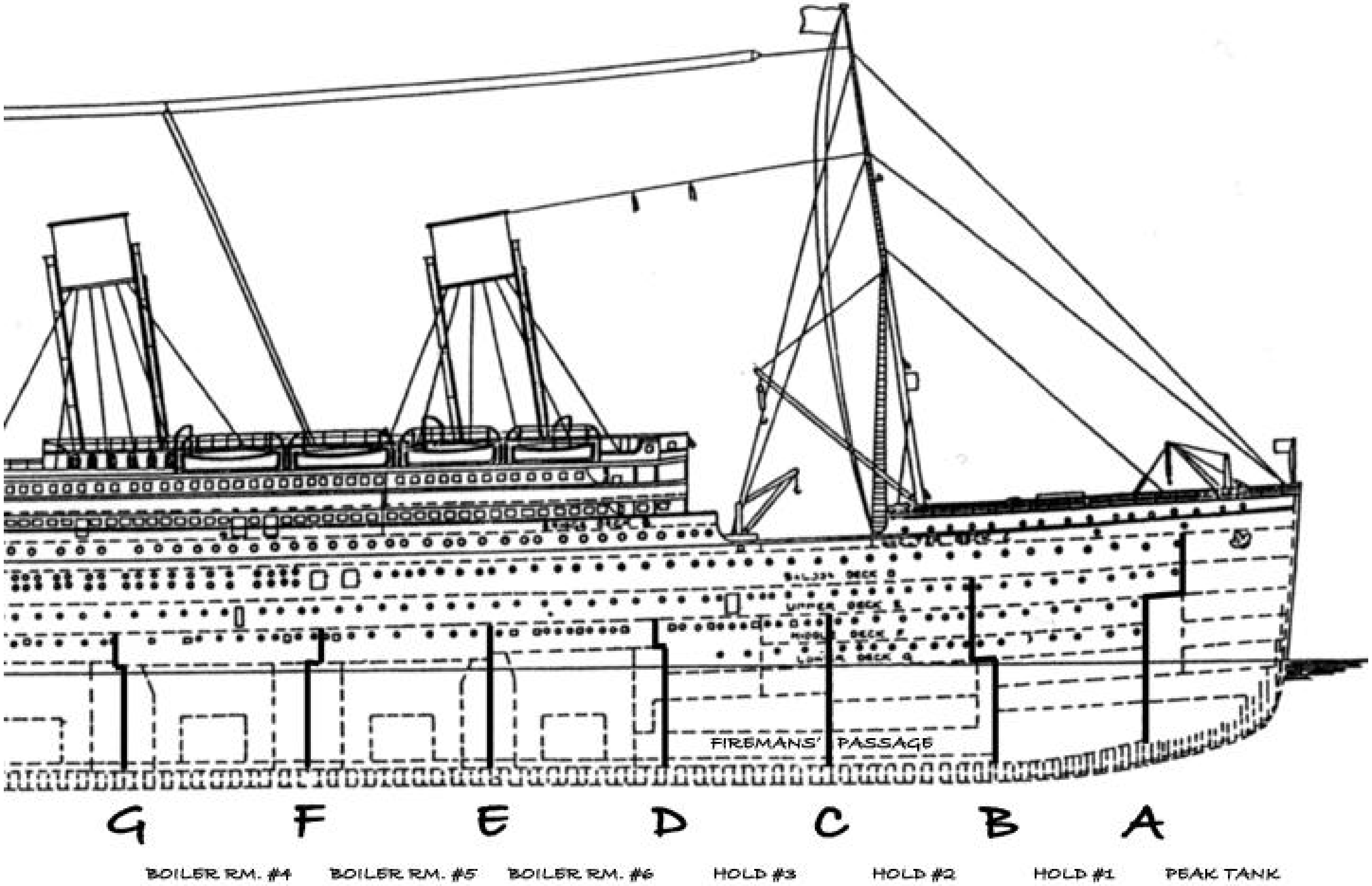
Secure Architecture Principles

Slides credit: John Mitchell

Basic idea: Isolation



A Seaman's Pocket-Book, 1943 (public domain)



Bulkheads & Compartments in the Bow Section

http://staff.imsa.edu/~esmith/treasurefleet/treasurefleet/watertight_compartments.htm

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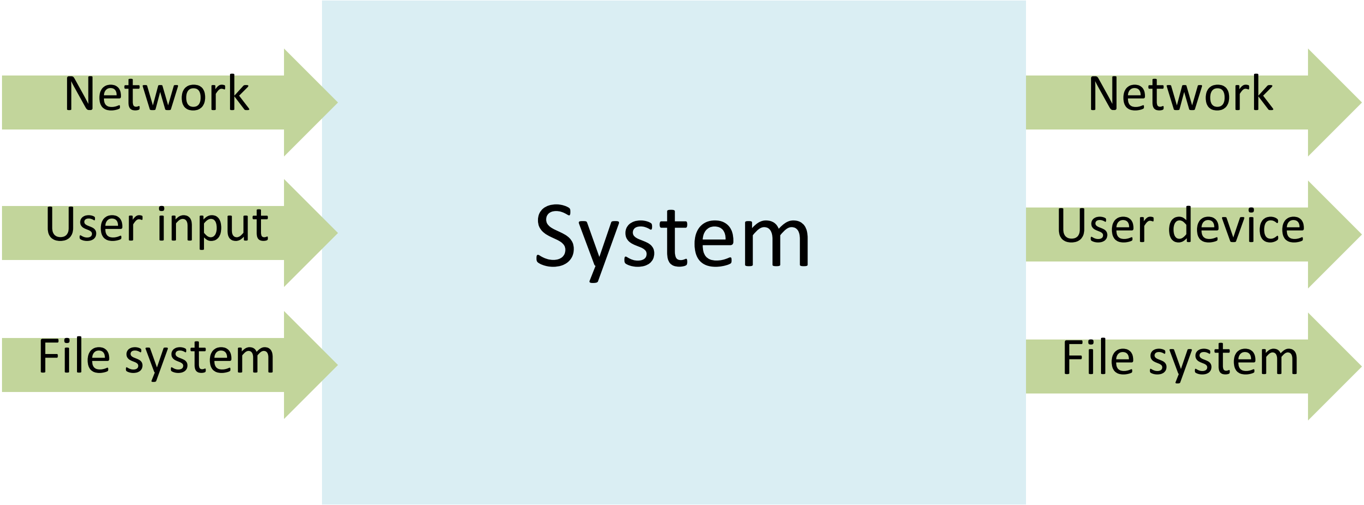
Principles of Secure Design

- Compartmentalization
  - Isolation
  - Principle of least privilege
- Defense in depth
  - Use more than one security mechanism
  - Secure the weakest link
  - Fail securely
- Keep it simple

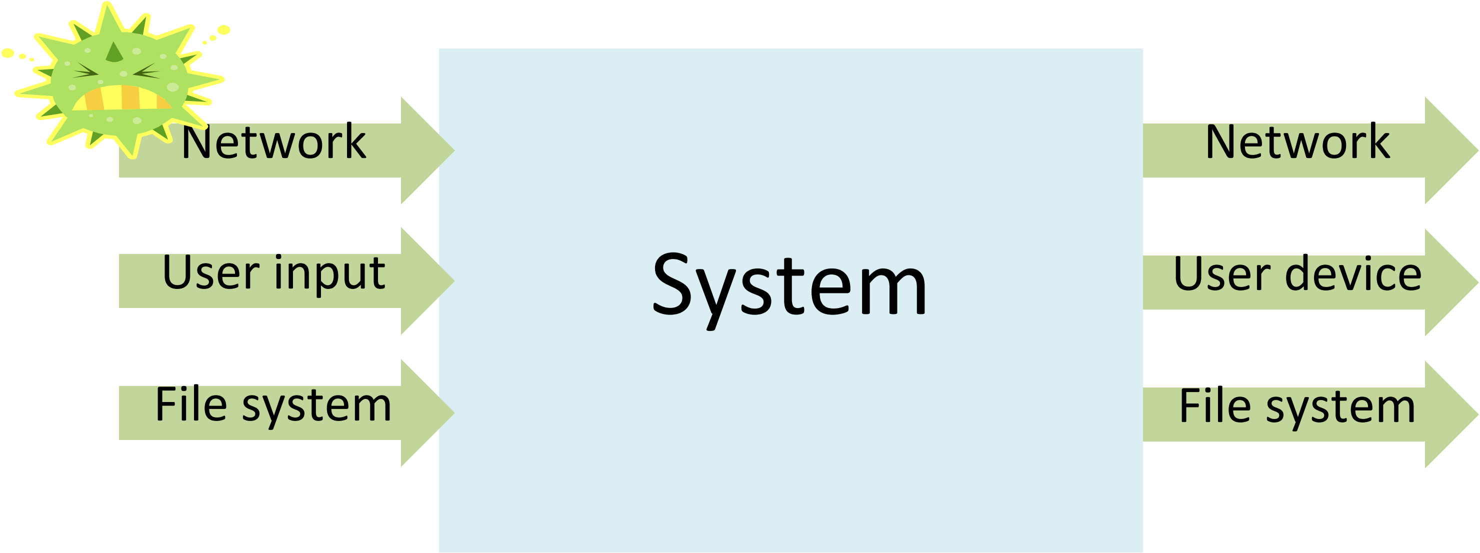
Principle of Least Privilege

- Privilege
  - Ability to access or modify a resource
- Principle of Least Privilege
  - A system module should only have the minimal privileges needed for intended purposes
- Requires compartmentalization and isolation
  - Separate the system into independent modules
  - Limit interaction between modules

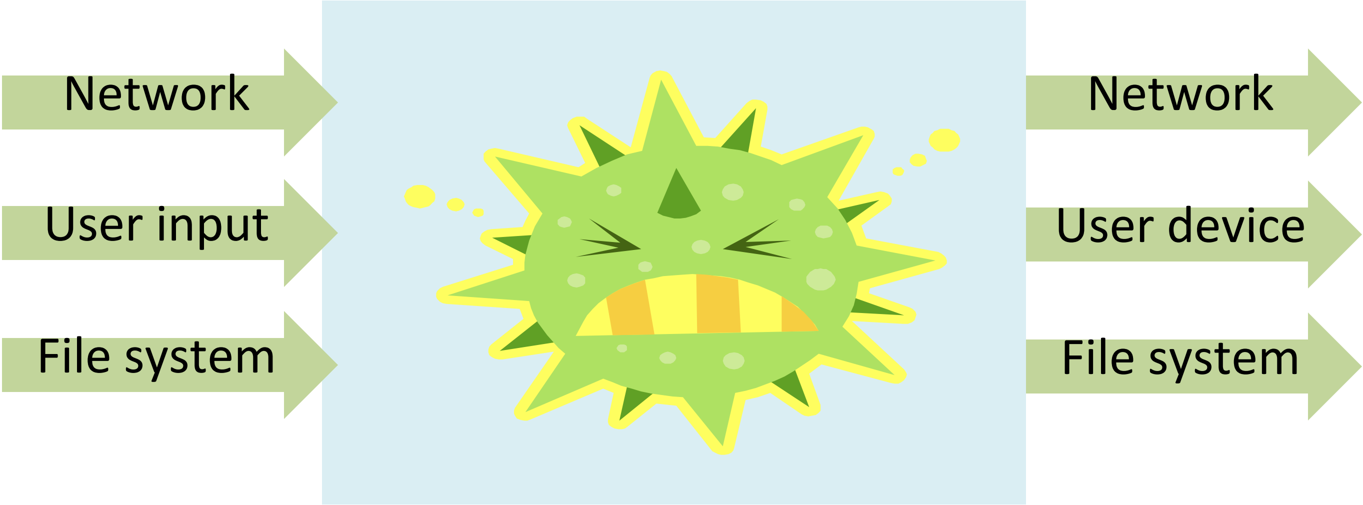
Monolithic design



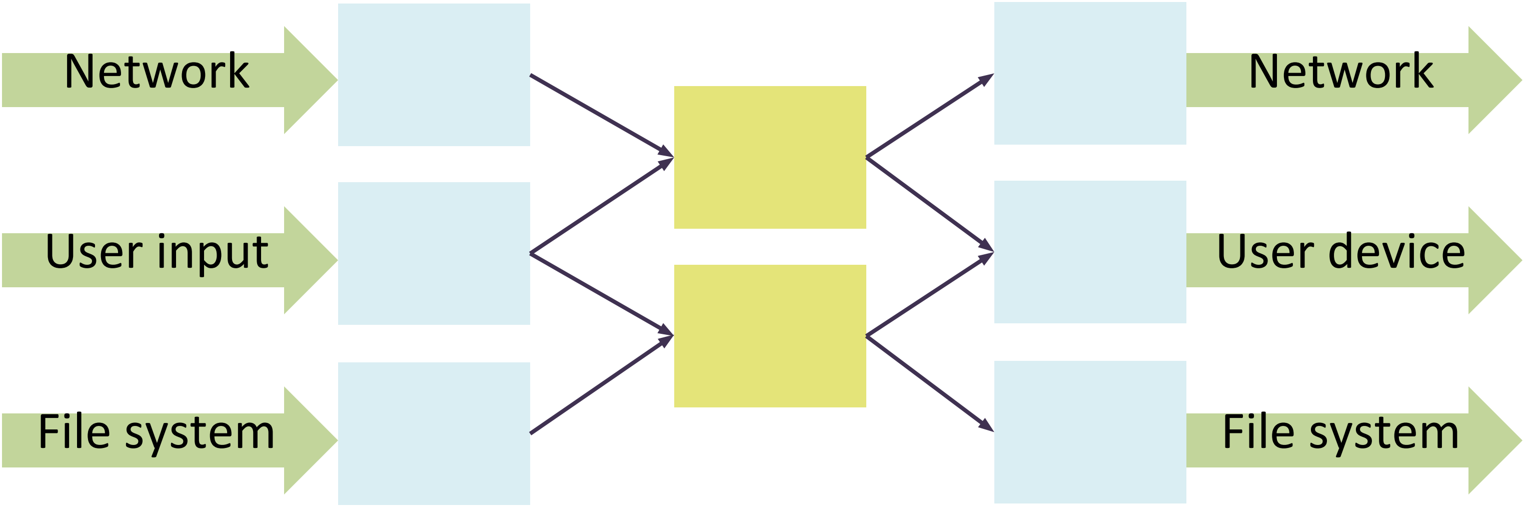
Monolithic design



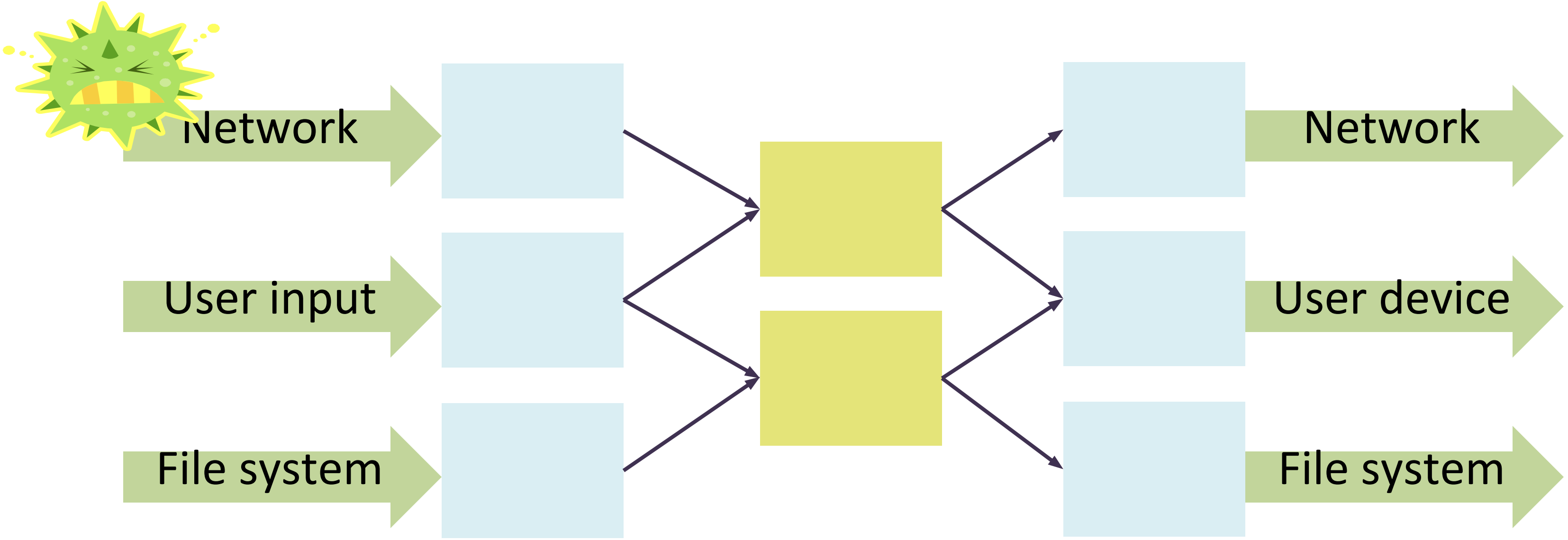
Monolithic design



Component design



Component design



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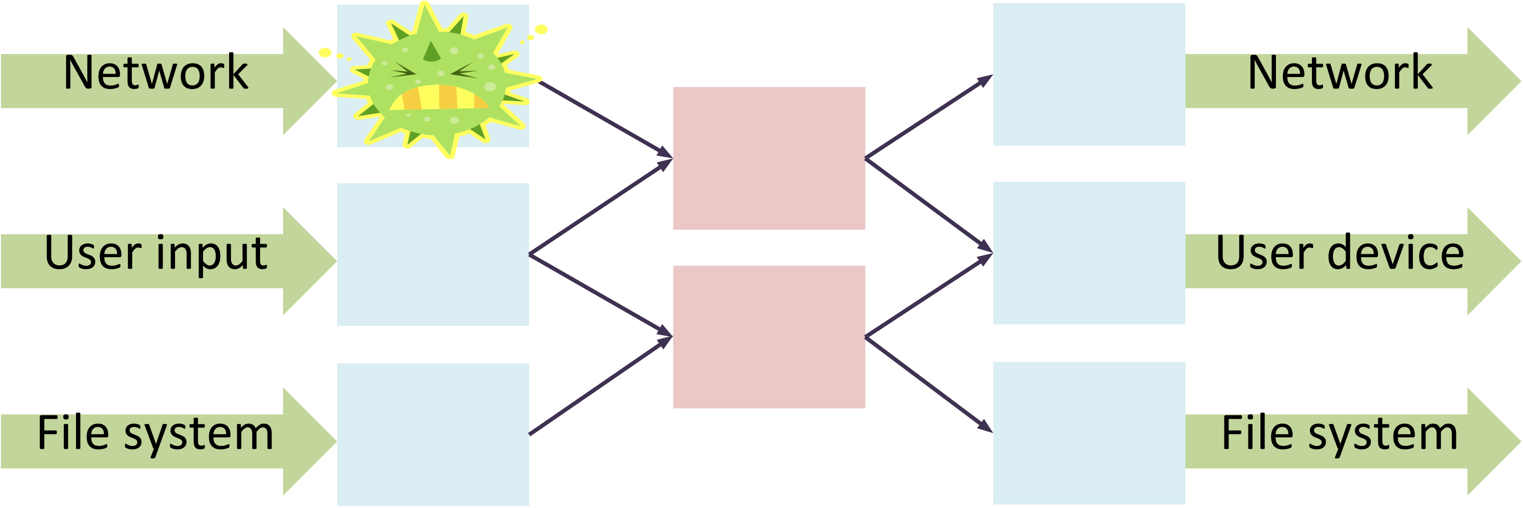
Component design



Which of these are privileges that allow one component to affect another component or system?

Send a message on the network

Add two numbers stored in two local variables

Call a function defined in the same component

Call a function defined in a different component

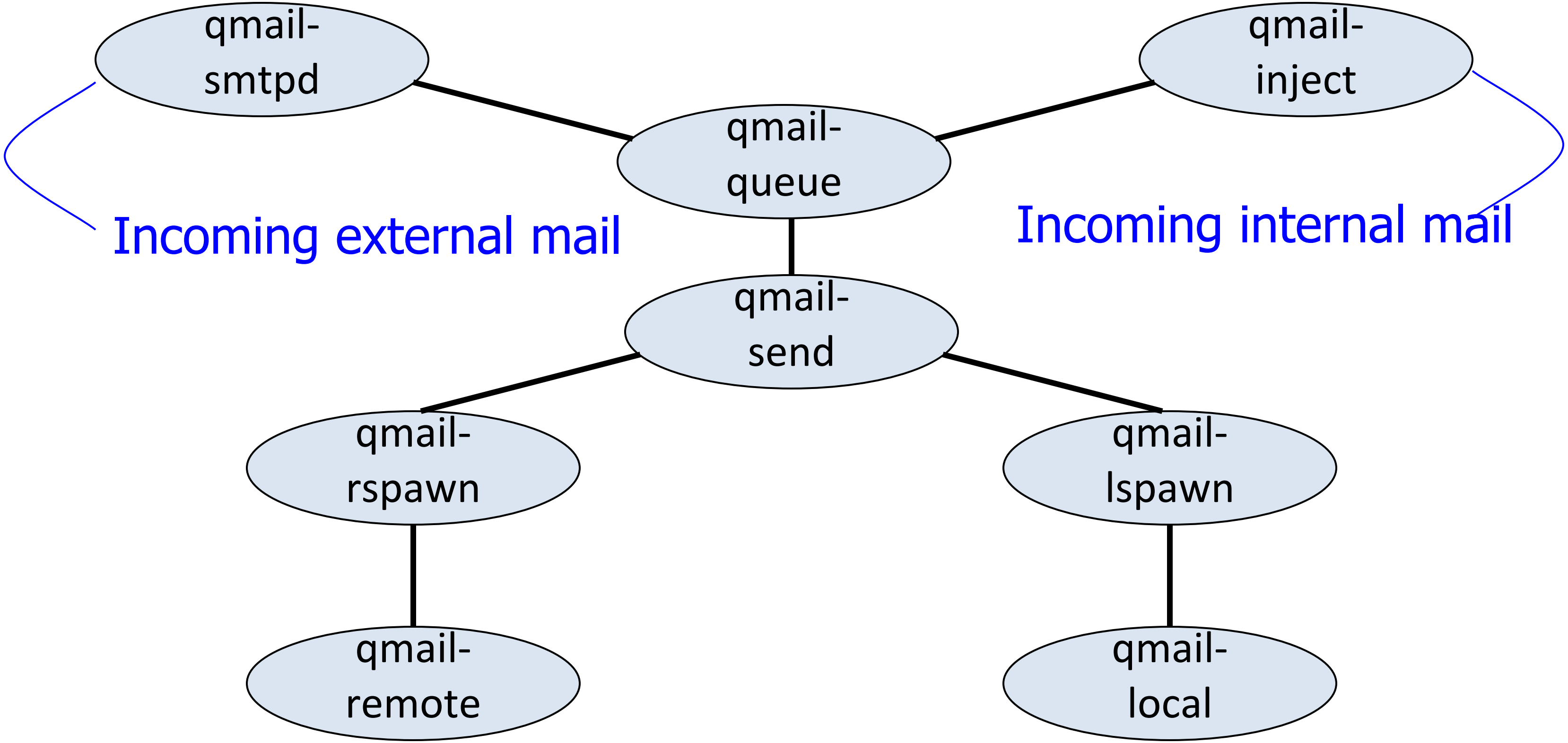
Example: Mail Agents

- Requirements
  - Receive and send email over external network
  - Place incoming email into local user inbox files
- Sendmail
  - Traditional Unix
  - Monolithic design
  - Historical source of many vulnerabilities
- Qmail
  - Component design

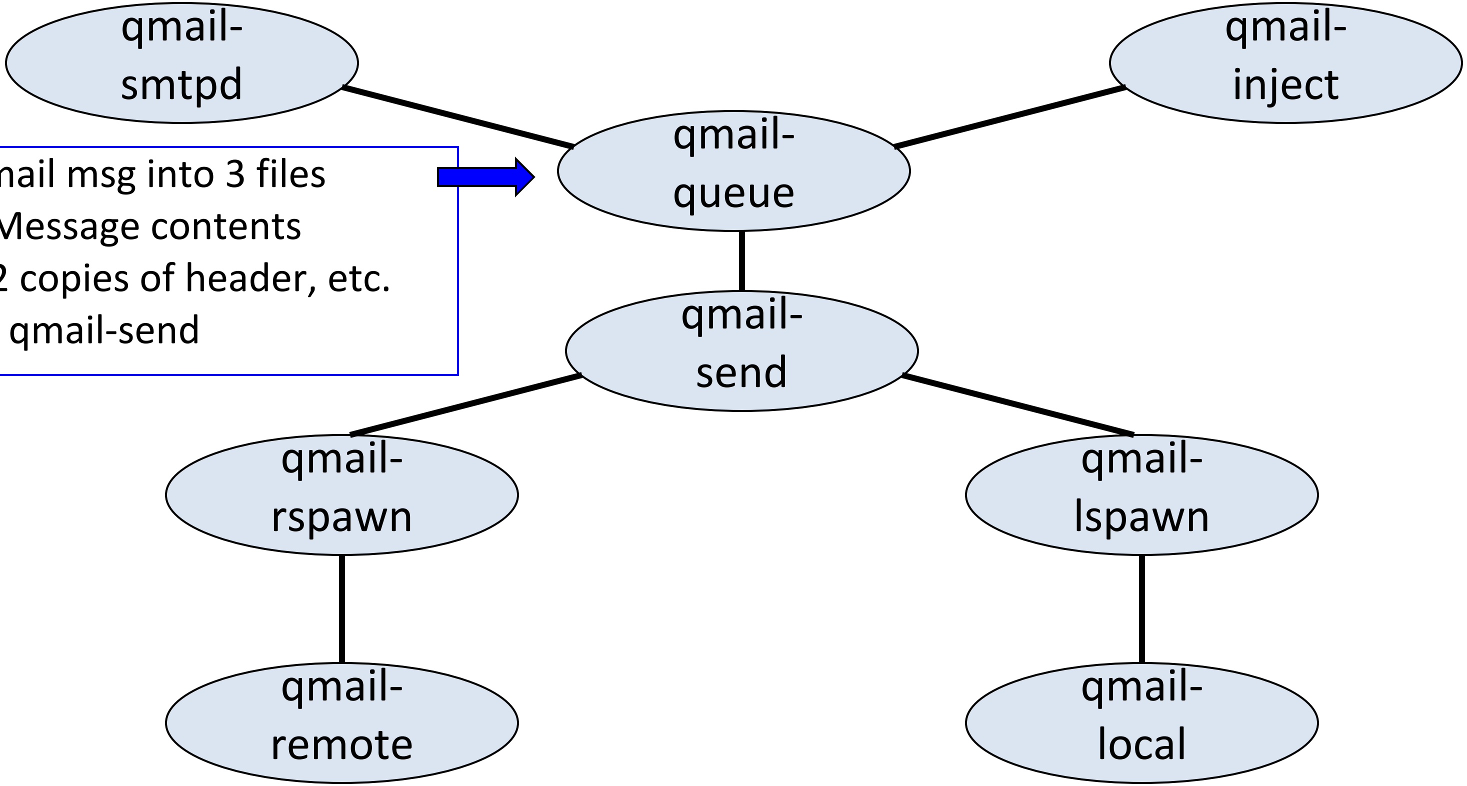
Qmail design

- Isolation
  - Separate modules run as separate “users”
  - Each user only has access to specific resources
- Least privilege
  - Each module has least privileges necessary
  - Only one “setuid” program
    - setuid allows a program to run as different users
  - Only one “root” program
    - root program has all privileges

Structure of qmail



Structure of qmail

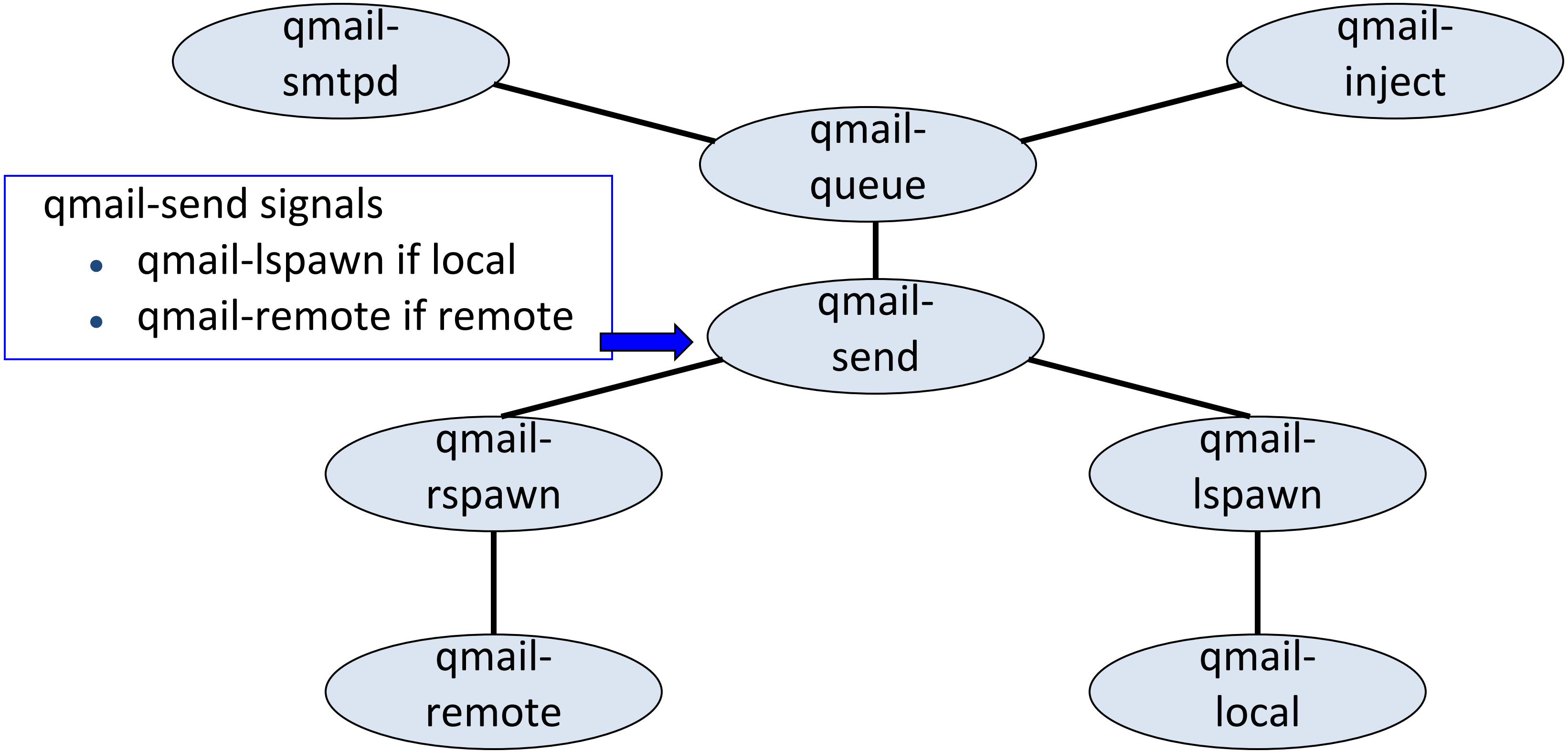


Splits mail msg into 3 files

- Message contents
- 2 copies of header, etc.

Signals qmail-send

Structure of qmail



qmail-smtpd

qmail-inject

qmail-queue

qmail-send

qmail-rspawn

qmail-lspawn

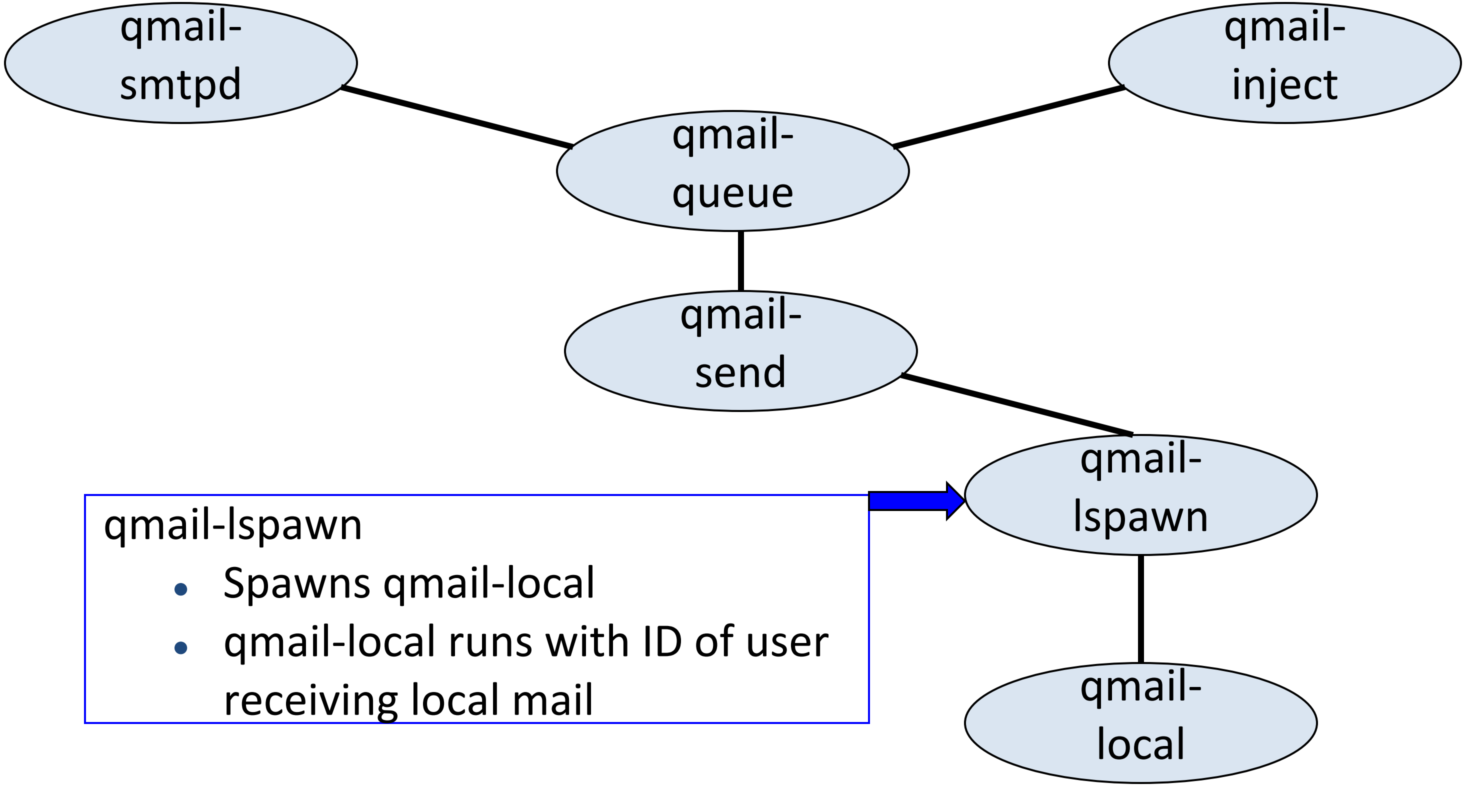
qmail-remote

qmail-local

qmail-send signals

- qmail-lspawn if local
- qmail-remote if remote

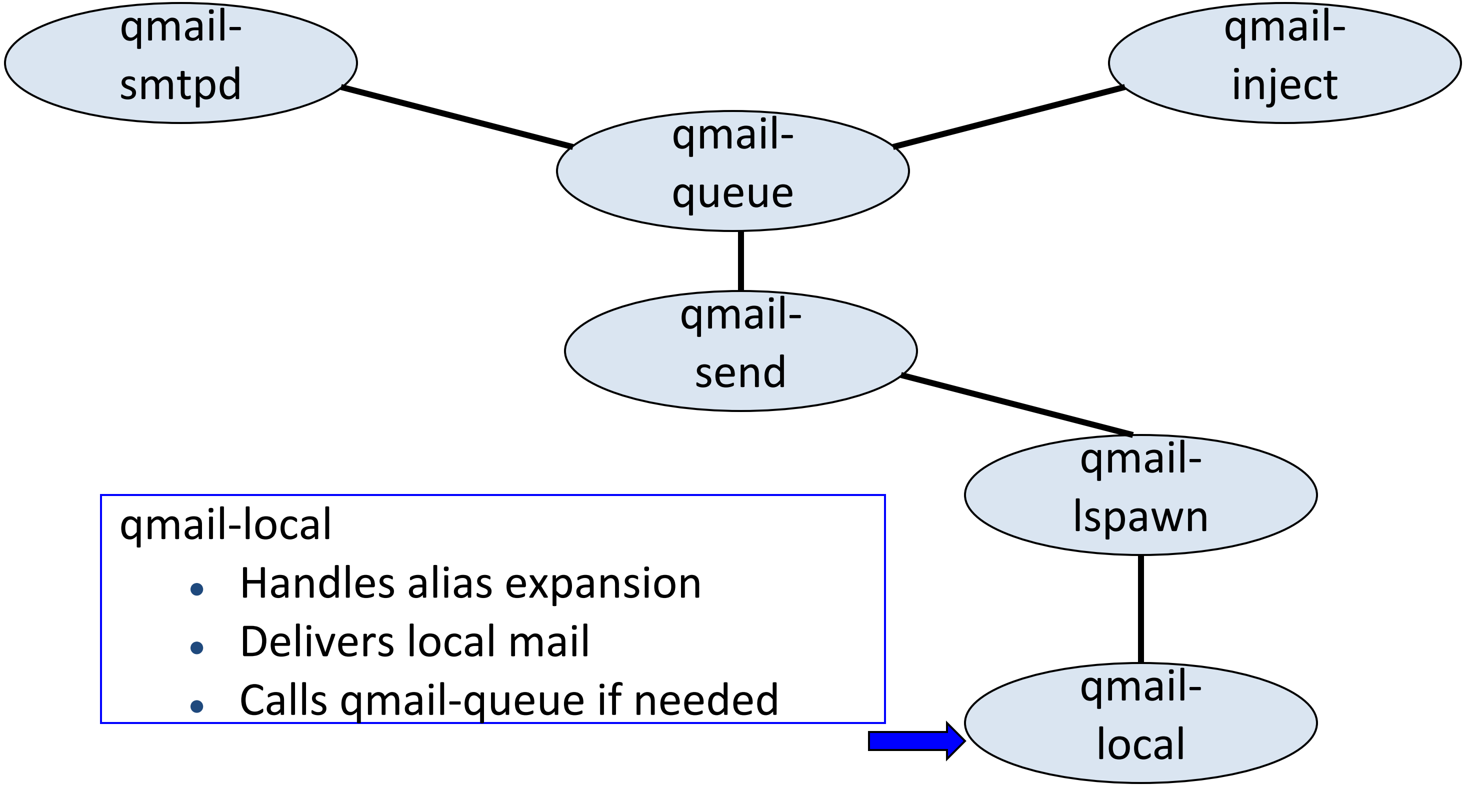
Structure of qmail



qmail-lspawn

- Spawns qmail-local
- qmail-local runs with ID of user receiving local mail

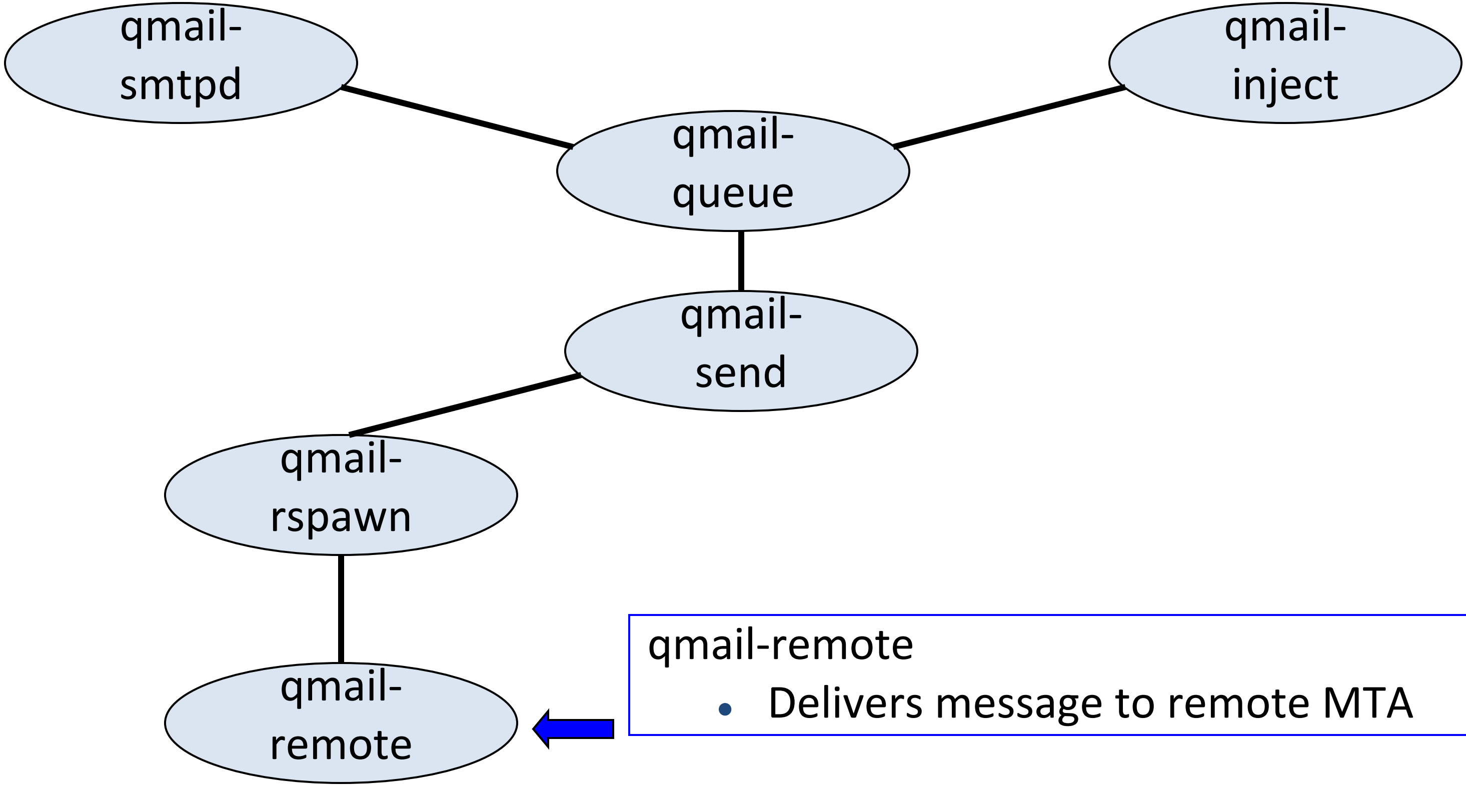
Structure of qmail



qmail-local

- Handles alias expansion
- Delivers local mail
- Calls qmail-queue if needed

Structure of qmail

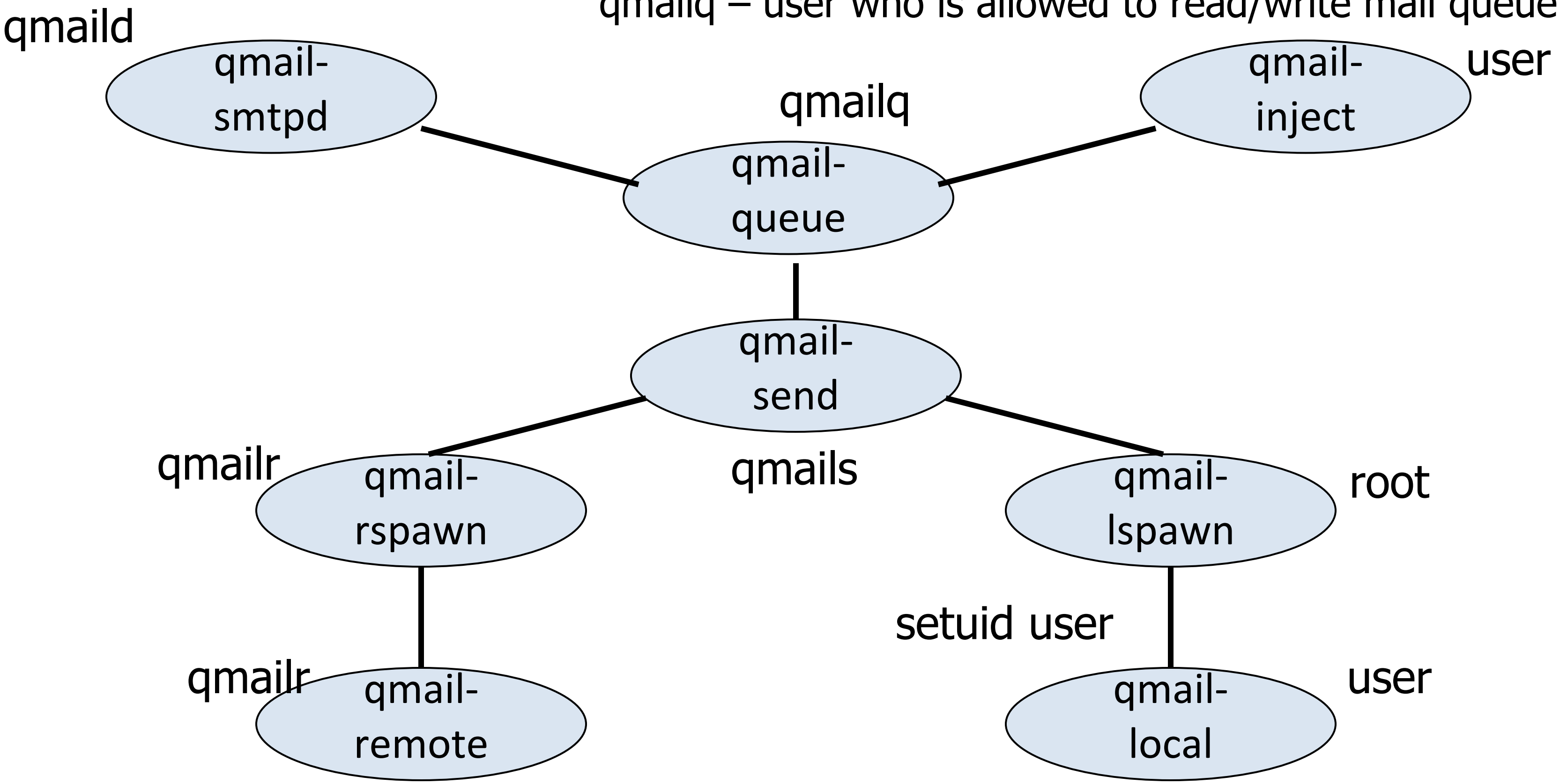


qmail-remote

- Delivers message to remote MTA

Isolation by Unix UIDs

qmailq – user who is allowed to read/write mail queue



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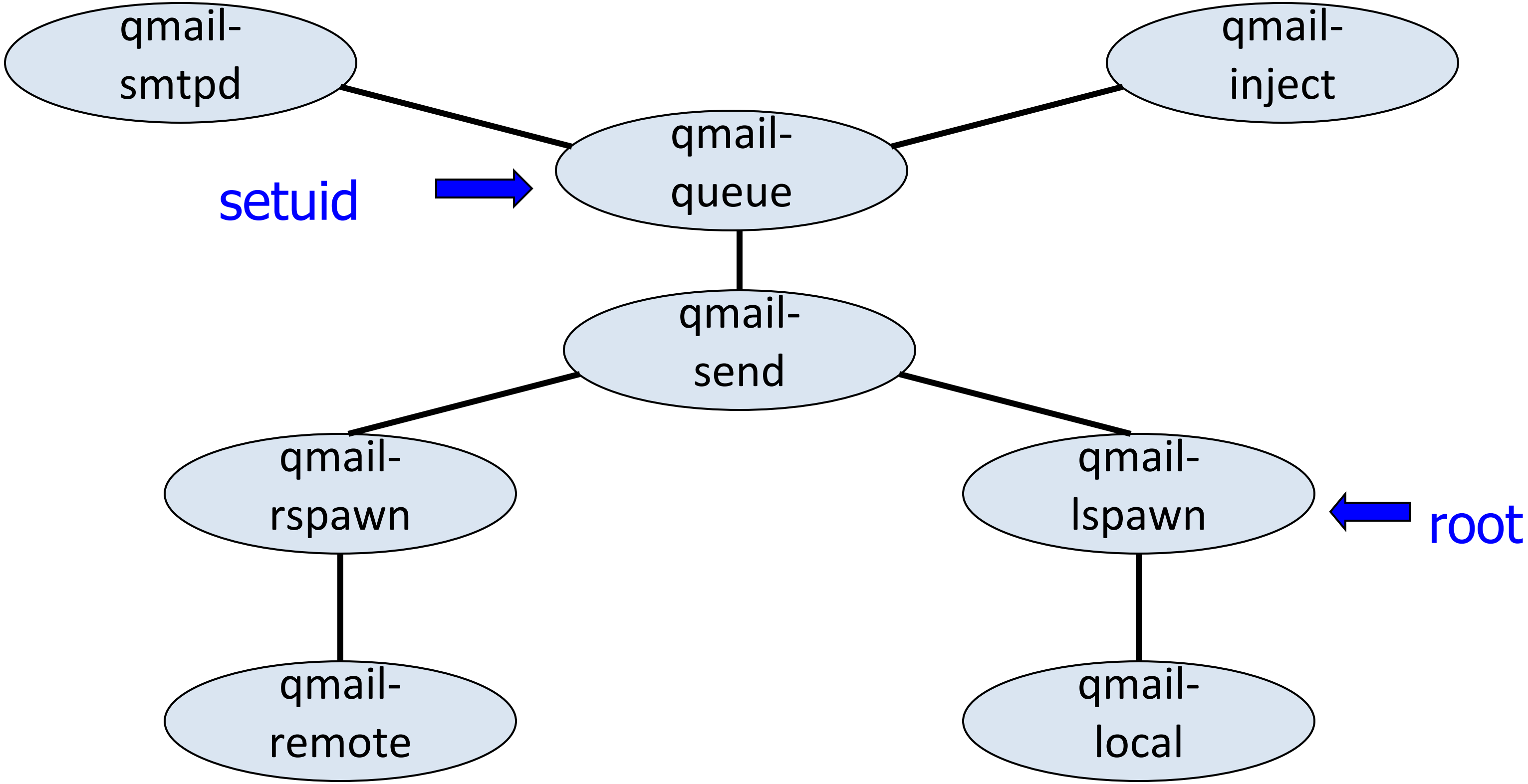
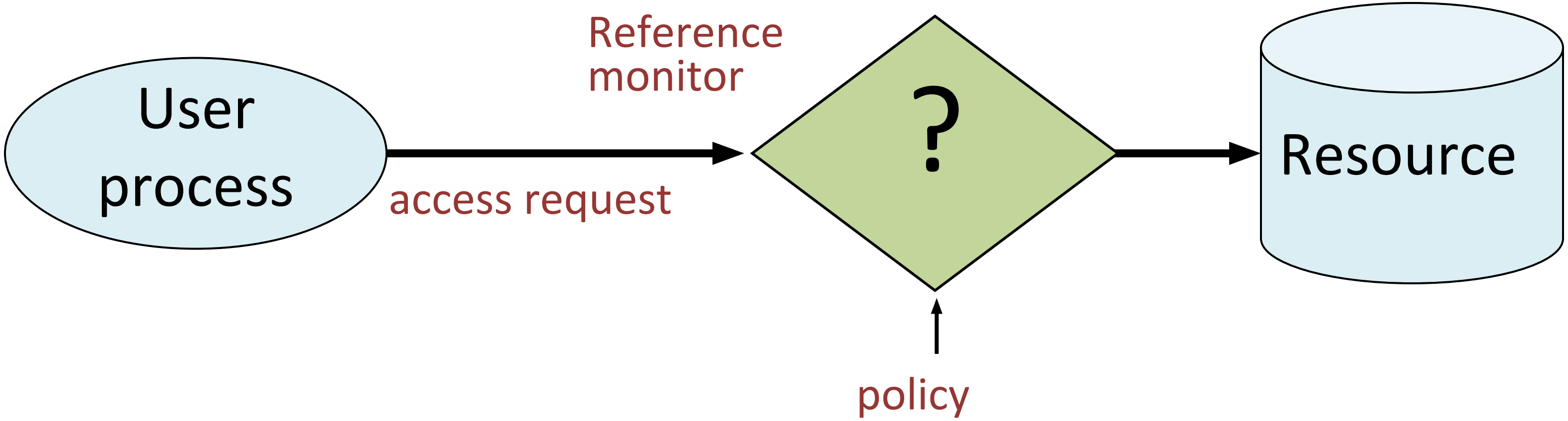
Least privilege



Access Control & Capabilities

Access control

- Assumptions
  - System knows who the user is
    - Authentication via name and password, other credential
  - Access requests pass through gatekeeper (reference monitor)
    - System must not allow monitor to be bypassed



Access control matrix [Lampson]

Objects

Subjects

	File 1	File 2	File 3	…	File n
User 1	read	write	-	-	read
User 2	write	write	write	-	-
User 3	-	-	-	read	read
…					
User m	read	write	read	write	read

Two implementation concepts

- Access control list (ACL)
  - Store column of matrix with the resource
- Capability
  - User holds a “ticket” for each resource
  - Two variations
    - store row of matrix with user, under OS control
    - unforgeable ticket in user space

	File 1	File 2	…
User 1	read	write	-
User 2	write	write	-
User 3	-	-	read
…			
User m	Read	write	write

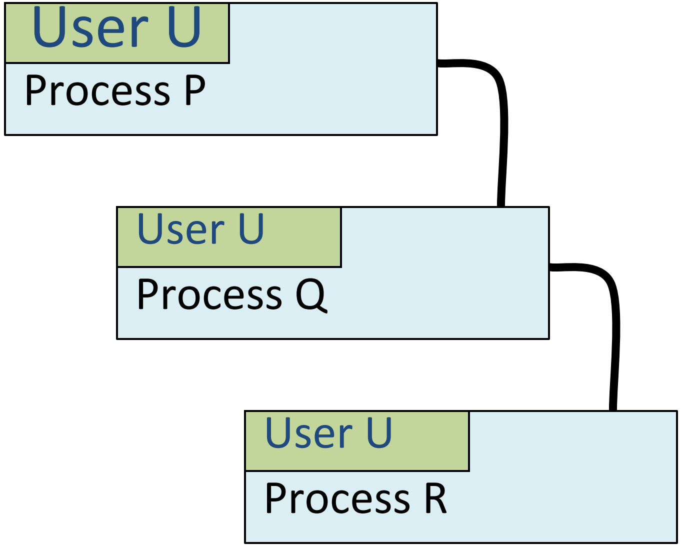
Access control lists are widely used, often with groups

Some aspects of capability concept are used in many systems

ACL vs Capabilities

- Access control list
  - Associate list with each object
  - Check user/group against list
  - Relies on authentication: need to know user
- Capabilities
  - Capability is unforgeable ticket
    - Random bit sequence, or managed by OS
    - Can be passed from one process to another
  - Reference monitor checks ticket
    - Does not need to know identify of user/process

ACL vs Capabilities



User U

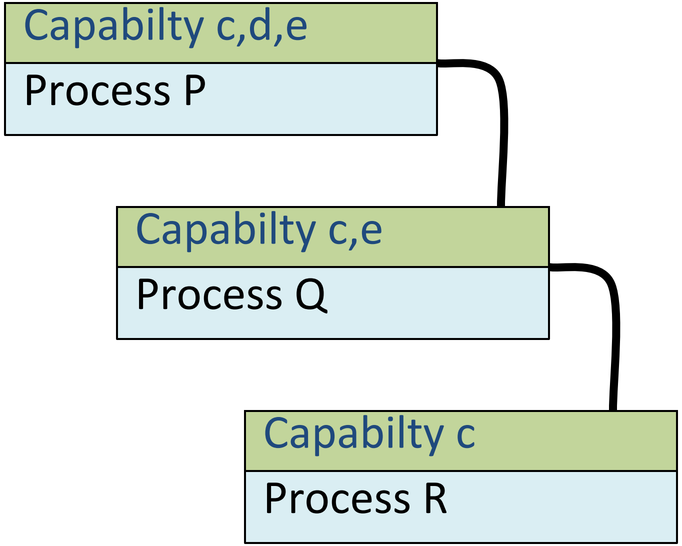
Process P

User U

Process Q

User U

Process R



Capabilty c,d,e

Process P

Capabilty c,e

Process Q

Capabilty c

Process R

ACL vs Capabilities

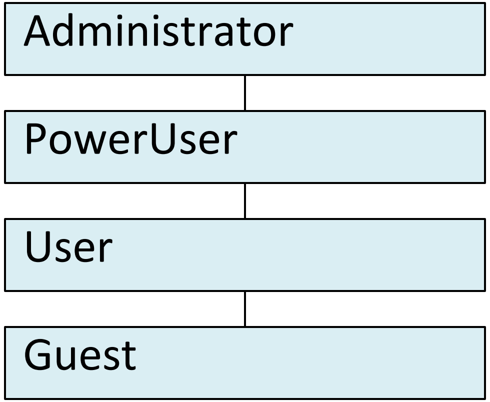
- Delegation
  - Cap: Process can pass capability at run time
  - ACL: Try to get owner to add permission to list?
    - More common: let other process act under current user
- Revocation
  - ACL: Remove user or group from list
  - Cap: Try to get capability back from process?
    - Possible in some systems if appropriate bookkeeping
      - OS knows which data is capability
      - If capability is used for multiple resources, have to revoke all or none …
    - Indirection: capability points to pointer to resource
      - If $C \rightarrow P \rightarrow R$, then revoke capability C by setting $P=0$

Roles (also called Groups)

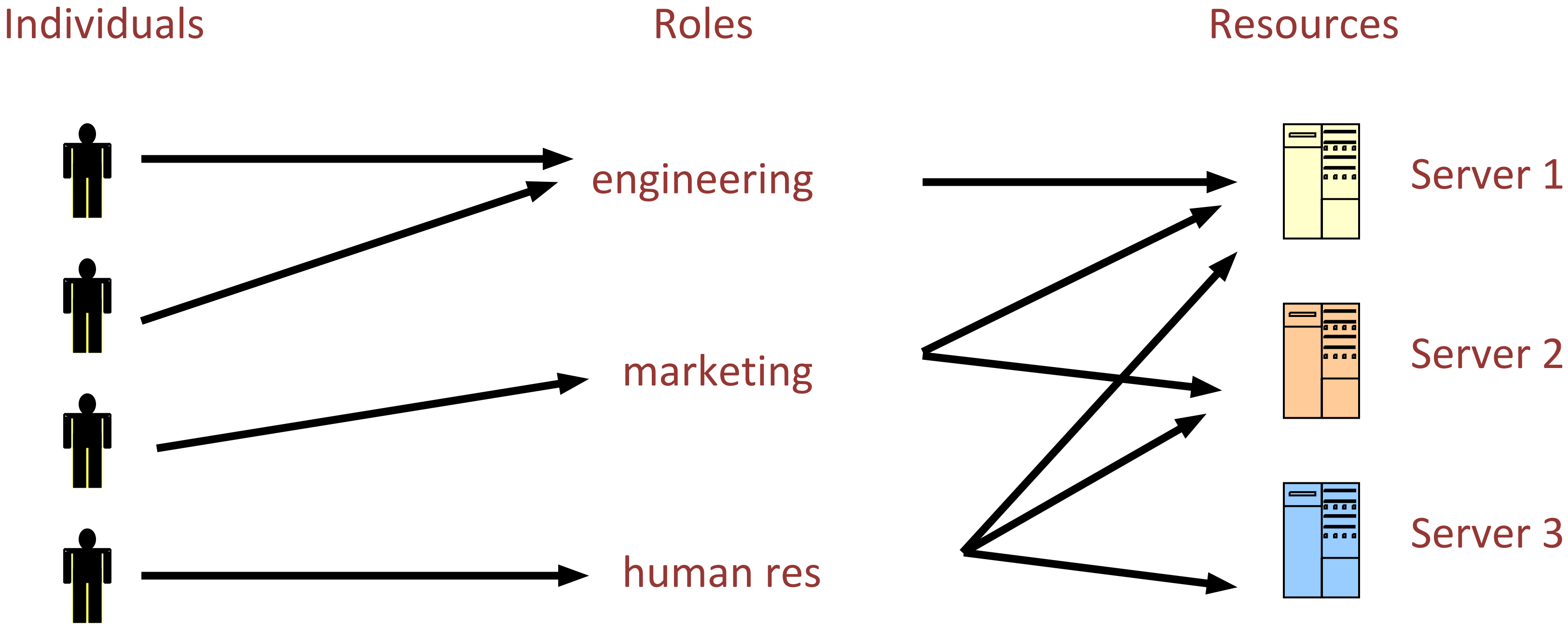
- Role = set of users
  - Administrator, PowerUser, User, Guest
  - Assign permissions to roles; each user gets permission
- Role hierarchy
  - Partial order of roles
  - Each role gets

    permissions of roles below
  - List only new permissions

  given to each role



Role-Based Access Control



Individuals

Roles

Resources

engineering

marketing

human res

Server 1

Server 2

Server 3

Advantage: user's change more frequently than roles

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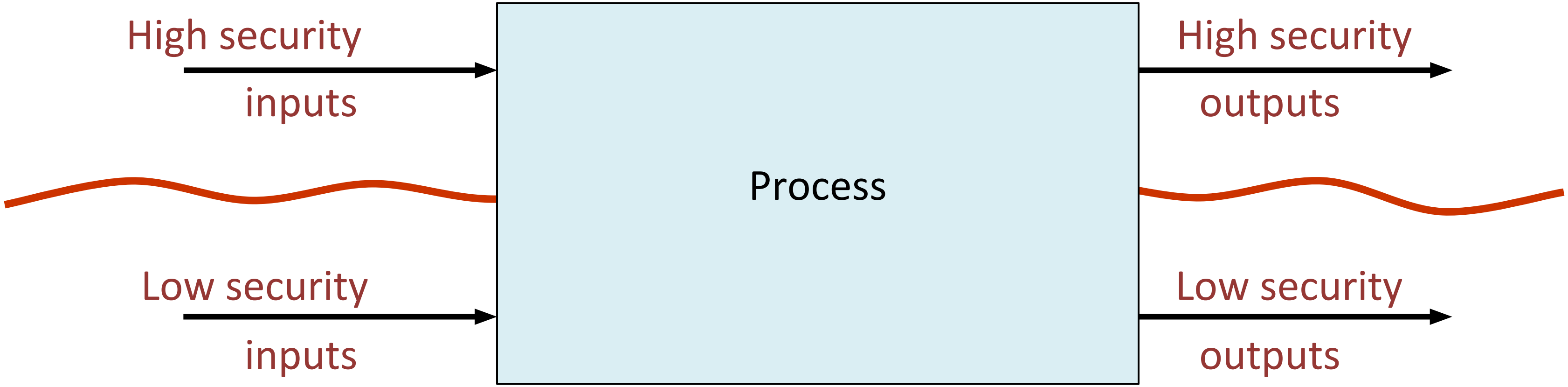
Information flow



High security inputs

Low security inputs

Process

High security outputs

Low security outputs

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Security Architecture Examples

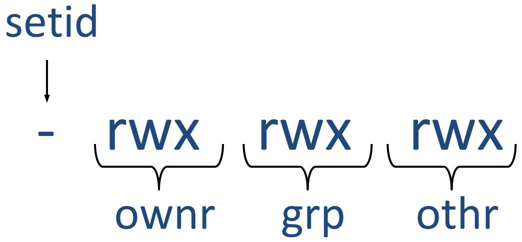
Unix access control

- File has access control list (ACL)
  - Grants permission to user ids
  - Owner, group, other
- Process has user id
  - Inherit from creating process
  - Process can change id
    - Restricted set of options
  - Special “root” id
    - Bypass access control restrictions

	File 1	File 2	…
User 1	read	write	-
User 2	write	write	-
User 3	-	-	read
…			
User m	Read	write	write

Unix file access control list

- Each file has owner and group
- Permissions set by owner
  - Read, write, execute
  - Owner, group, other
  - Represented by vector of four octal values
- Only owner, root can change permissions
  - This privilege cannot be delegated or shared
- Setid bits – Discuss in a few slides



setid

- rwx rwx rwx

ownr grp othr

Question

- Owner can have fewer privileges than other
  - What happens?
    - Owner gets access?
    - Owner does not?

Prioritized resolution of differences

```
if user = owner then owner  permission
     else if user in group then group  permission
          else other  permission
```

Privileged Programs

- Privilege management is coarse-grained in today's OS
  - Root can do anything
- Many programs run as root
  - Even though they only need to perform a small number of priviledged operations
- What's the problem?
  - Privileged programs are juicy targets for attackers
  - By finding a bug in parts of the program that do not need privilege, attacker can gain root

What Can We Do?

- Drop privilege as soon as possible
- Ex: a network daemon only needs privilege to bind to low port # (<1024) at the beginning
  - Solution?
  - Drop privilege right after binding the port
- What benefit do we gain?
  - Even if attacker finds a bug in later part of the code, can't gain privilege any more
- How to drop privilege?
  - Setuid programming in UNIX

Unix file permission

- Each file has owner and group
- Permissions set by owner
    - Read, write, execute
    - Owner, group, other
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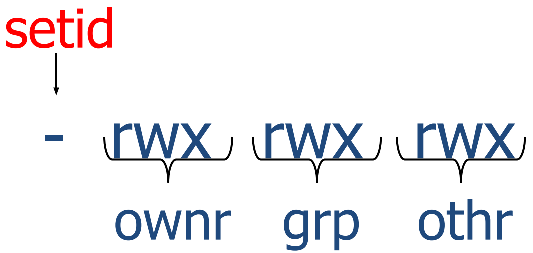


setid

- rwx rwx rwx

ownr grp othr

Effective user id (EUID) in UNIX

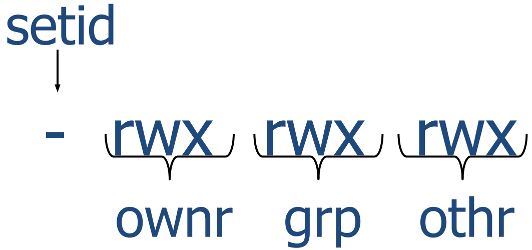
- Each process has three Ids
  - Real user ID (RUID)
    - same as the user ID of parent (unless changed)
    - used to determine which user started the process
  - Effective user ID (EUID)
    - from set user ID bit on the file being executed, or sys call
    - determines the permissions for process
      - file access and port binding
  - Saved user ID (SUID)
    - So previous EUID can be restored
- Real group ID, effective group ID, used similarly

Operations on UIDs

- Root
  - ID=0 for superuser root; can access any file
- Fork and Exec
  - Inherit three IDs, except exec of file with setuid bit
- Setuid system calls
  - seteuid(newid) can set EUID to
    - Real ID or saved ID, regardless of current EUID
    - Any ID, if EUID=0
- Details are actually more complicated
  - Several different calls: setuid, seteuid, setreuid

Setid bits on executable Unix file

- Three setid bits
  - Setuid – set EUID of process to ID of file owner
  - Setgid – set EGID of process to GID of file
  - Sticky
    - Off: if user has write permission on directory, can rename or remove files, even if not owner
    - On: only file owner, directory owner, and root can rename or remove file in the directory

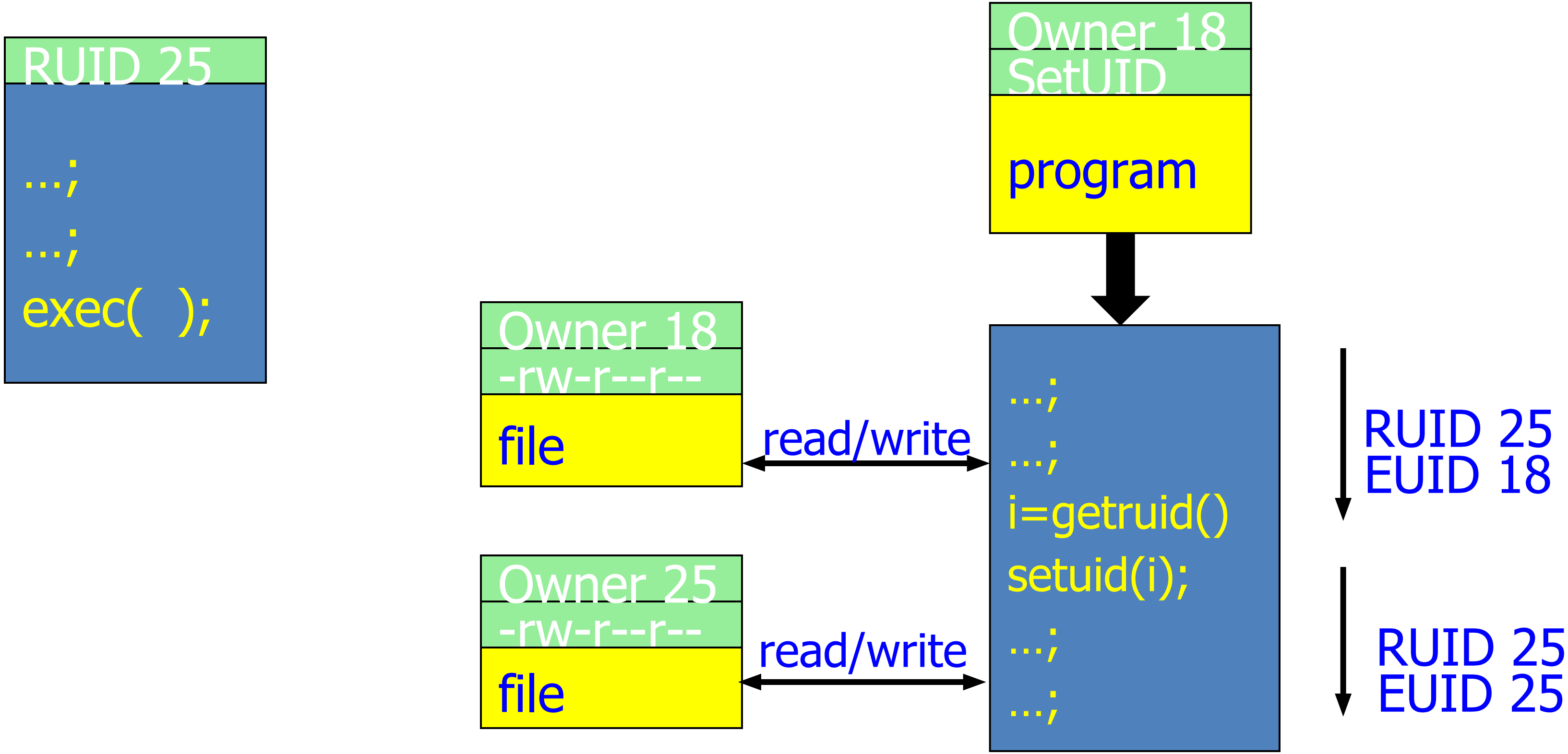


setid

- rwx rwx rwx

ownr grp othr

Drop Privilege



RUID 25
…;
…;
exec( );
Owner 18
SetUID
program
Owner 18
-rw-r--r--
file
read/write
Owner 25
-rw-r--r--
file
read/write
…;
…;
i=getruid()
setuid(i);
…;
…;
RUID 25
EUID 18
RUID 25
EUID 25