CSE 127: Computer Security

Least privilege and privilege separation

Deian Stefan

Slides adopted from John Mitchell, Dan Boneh, and Stefan Savage

This week...

- How to build secure systems
  - Least privilege and privilege separation
  - Sandboxing and isolation
- Key is underlying principles not mechanisms
  - We're going to look at systems techniques
  - Other ways to achieve similar goals: language-based

Principles of secure design

- Principle of least privilege
- Privilege separation
- Defense in depth

  ➤

  ➤

- Keep it simple

Principles of secure design

- Principle of least privilege
- Privilege separation
- Defense in depth
  - Use more than one security mechanism
  - Fail securely/closed
- Keep it simple

Principle of Least Privilege

Defn:

- What’s a privilege?

    ➤

Principle of Least Privilege

Defn: A system should only have the minimal privileges needed for its intended purposes

- What’s a privilege?
  - ➤

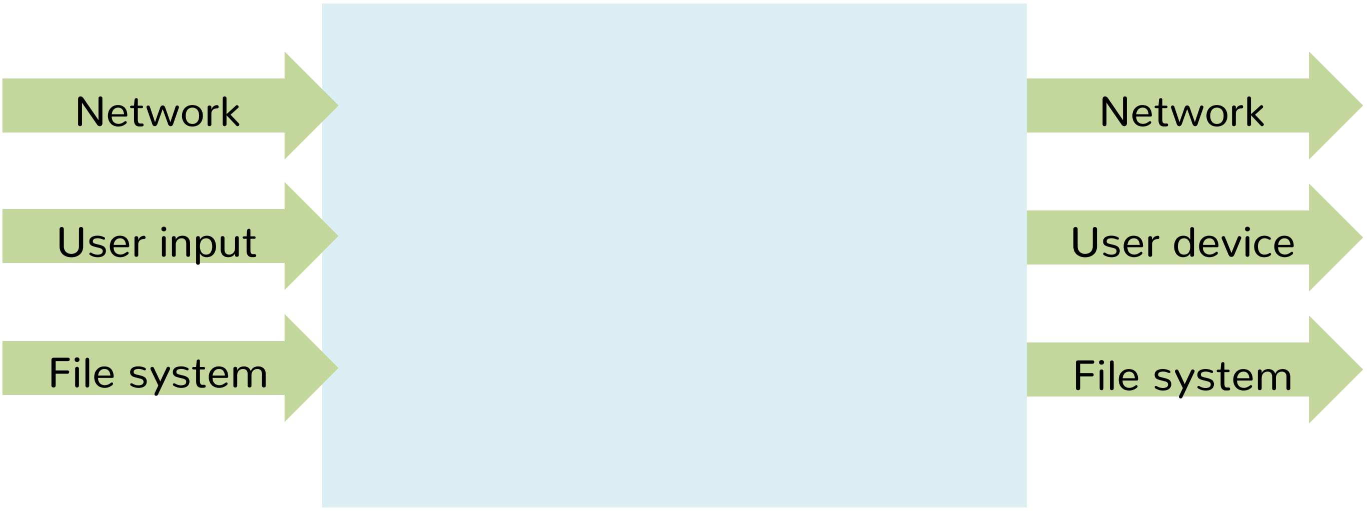
Principle of Least Privilege

Defn: A system should only have the minimal privileges needed for its intended purposes

- What’s a privilege?
  - Ability to access (e.g., read or write) a resource

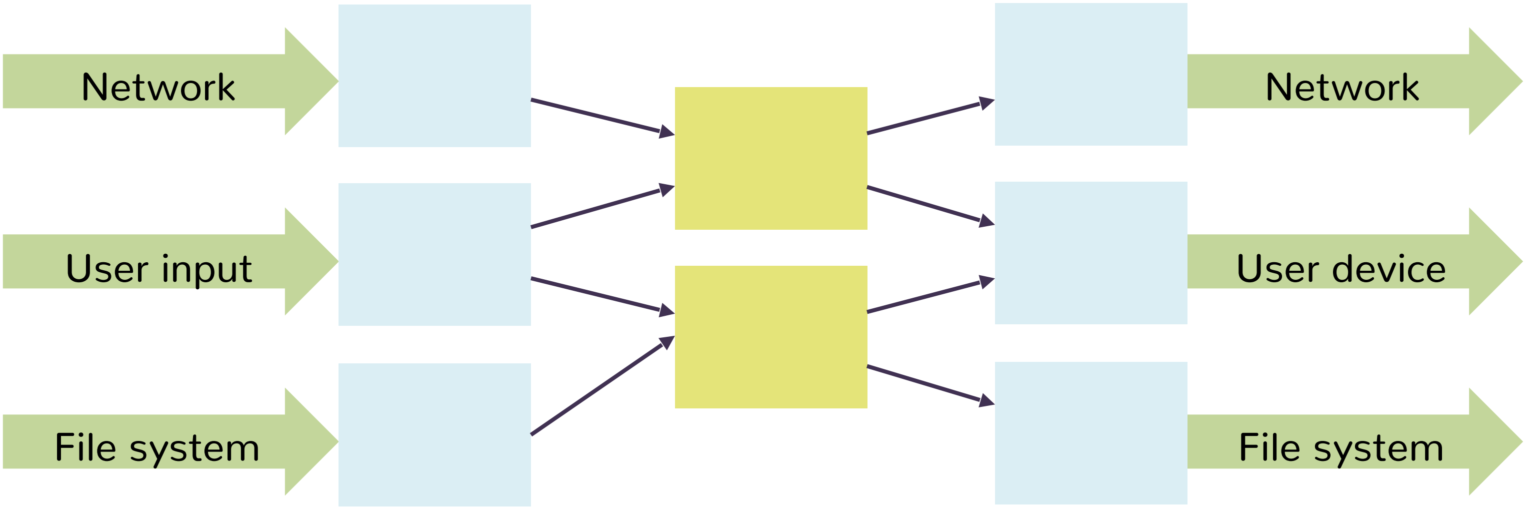
What’s the problem with this defn?

- Talking about a huge, monolith system is not really useful
- Why?



Breaking a system into components

- Compartmentalization and isolation
  - Separate the system into isolated compartments
  - Limit interaction between compartments
- Why is this more meaningful?



How dow we break things apart?

Map compartment to user ids!

- Recall: permissions in UNIX granted according to UID
  - A process may access files, network sockets, ...
- Each process has UID
- Each file has ACL
  - Grants permissions to users according to UIDs and roles (owner, group, other)
  - Everything is a file!

How many UIDs does a process have?

- A: one
- B: two
- C: three
- D: four

Process UIDs

- Real user ID (RUID)
  - ➤
  - ➤ .
- Effective user ID (EUID)
  - ➤
  - ➤
- Saved user ID (SUID)
  - ➤

Process UIDs

- 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)
  -
  -
- Saved user ID (SUID)
  -

Process UIDs

- 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 setuid bit on the file being executed, or syscall
  - determines the permissions for process
- Saved user ID (SUID)

Process UIDs

- 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 setuid bit on the file being executed, or syscall
  - ➢ determines the permissions for process
- Saved user ID (SUID)
  - ➢ Used to save and restore EUID

SetUID demystified (a bit)

- Root
  - ID=0 for superuser root; can access any file
- fork and exec system calls
  -
- setuid system call
  - seteuid(newid) can set EUID to
    -
    -

SetUID demystified (a bit)

- Root
  - ID=0 for superuser root; can access any file
- fork and exec system calls
  - Inherit three IDs, except exec of file with setuid bit
- setuid system call
  - seteuid(newid) can set EUID to
    -
    -

SetUID demystified (a bit)

- Root
  - ID=0 for superuser root; can access any file
- fork and exec system calls
  - Inherit three IDs, except exec of file with setuid bit
- setuid system call
  - seteuid(newid) can set EUID to
    - Real ID or saved ID, regardless of current EUID
    - Any ID, if EUID is root

SetUID demystified (a bit)

- There are actually 3 bits:
  - setuid - set EUID of process to ID of file owner
  - setgid - set EGID of process to GID of file
  - sticky bit
    - on:
    - off:

SetUID demystified (a bit)

- There are actually 3 bits:
  - setuid - set EUID of process to ID of file owner
  - setgid - set EGID of process to GID of file
  - sticky bit
    - on: only file owner, directory owner, and root can rename or remove file in the directory
    - off: if user has write permission on directory, can rename or remove files, even if not owner

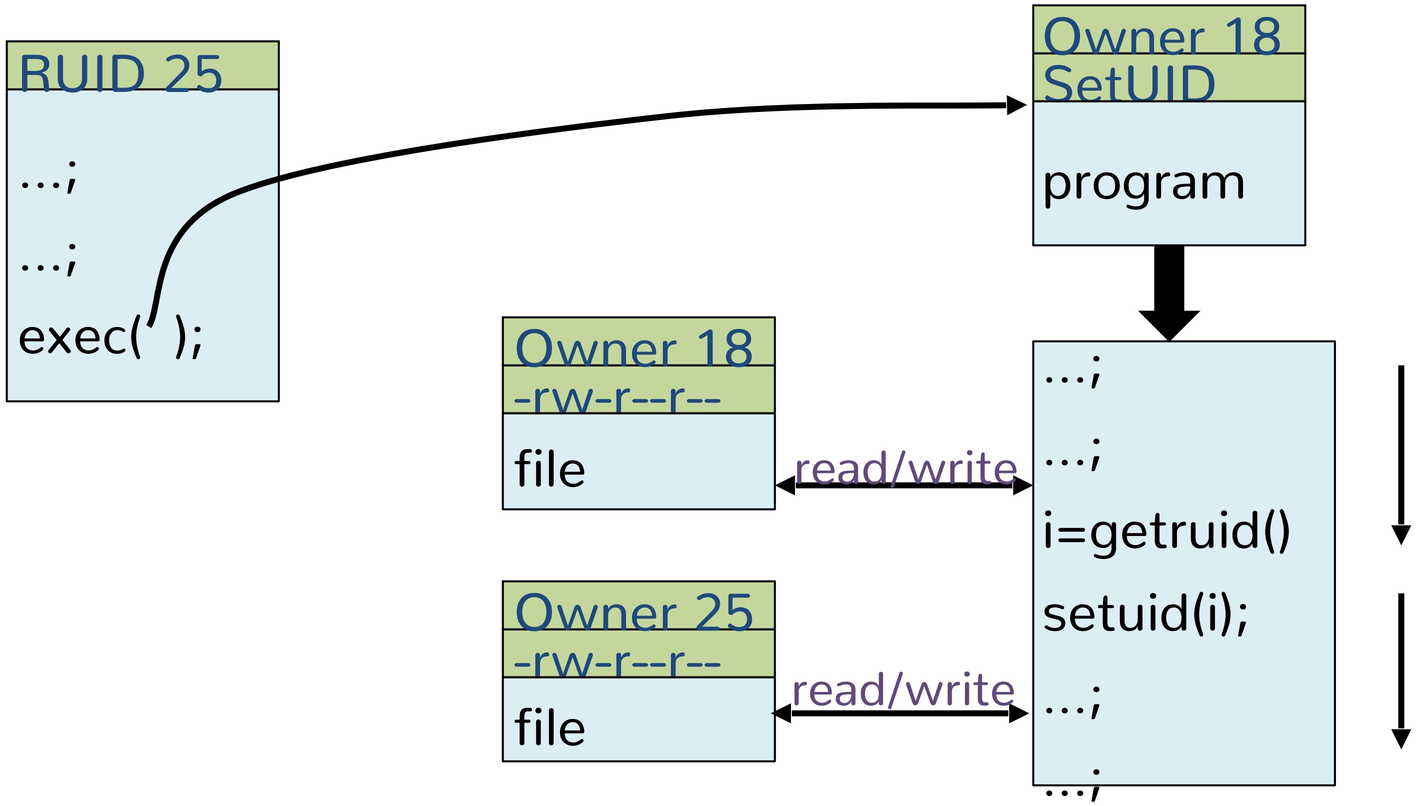
Where have you seen this?

```
-rwsr-xr-x 1 root root 55440 Jul 28  2018 /usr/bin/passwd

drwxrwxrwt 16 root root  700 Feb  6 17:38 /tmp/
```

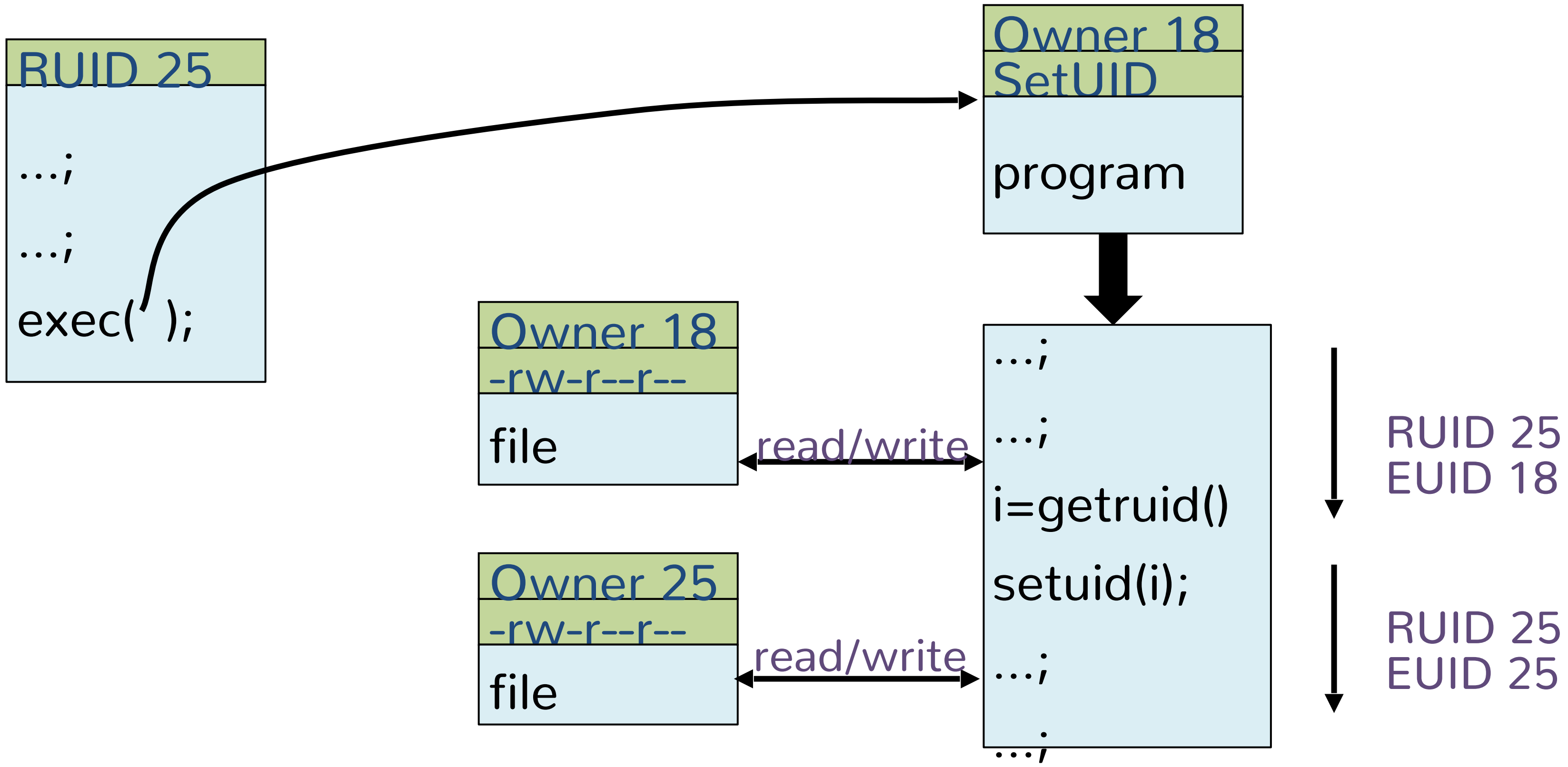
Why are EUIDs even a thing?

We can drop and elevate privileges!



Why are EUIDs even a thing?

We can drop and elevate privileges!



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

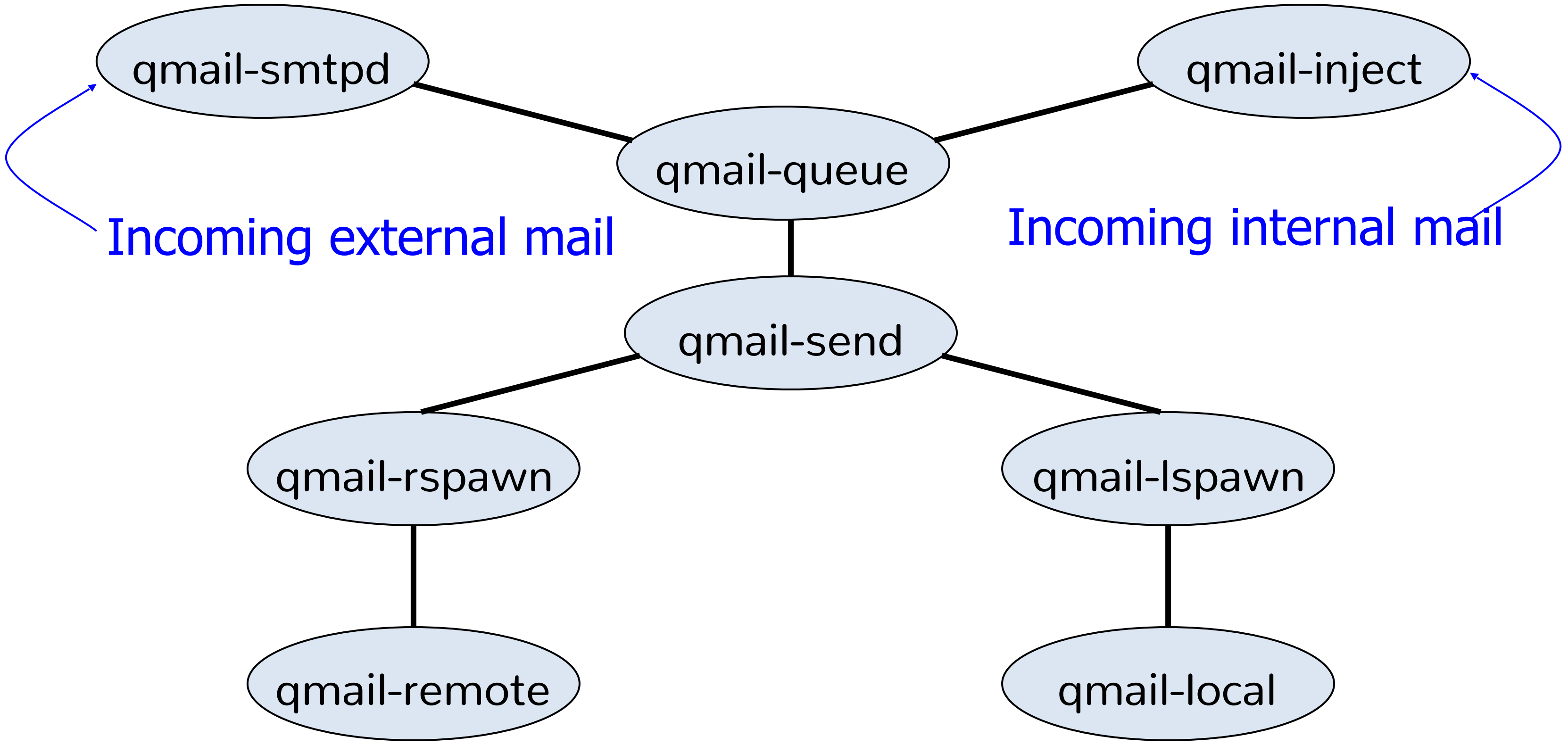
Example 1: Mail agent

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

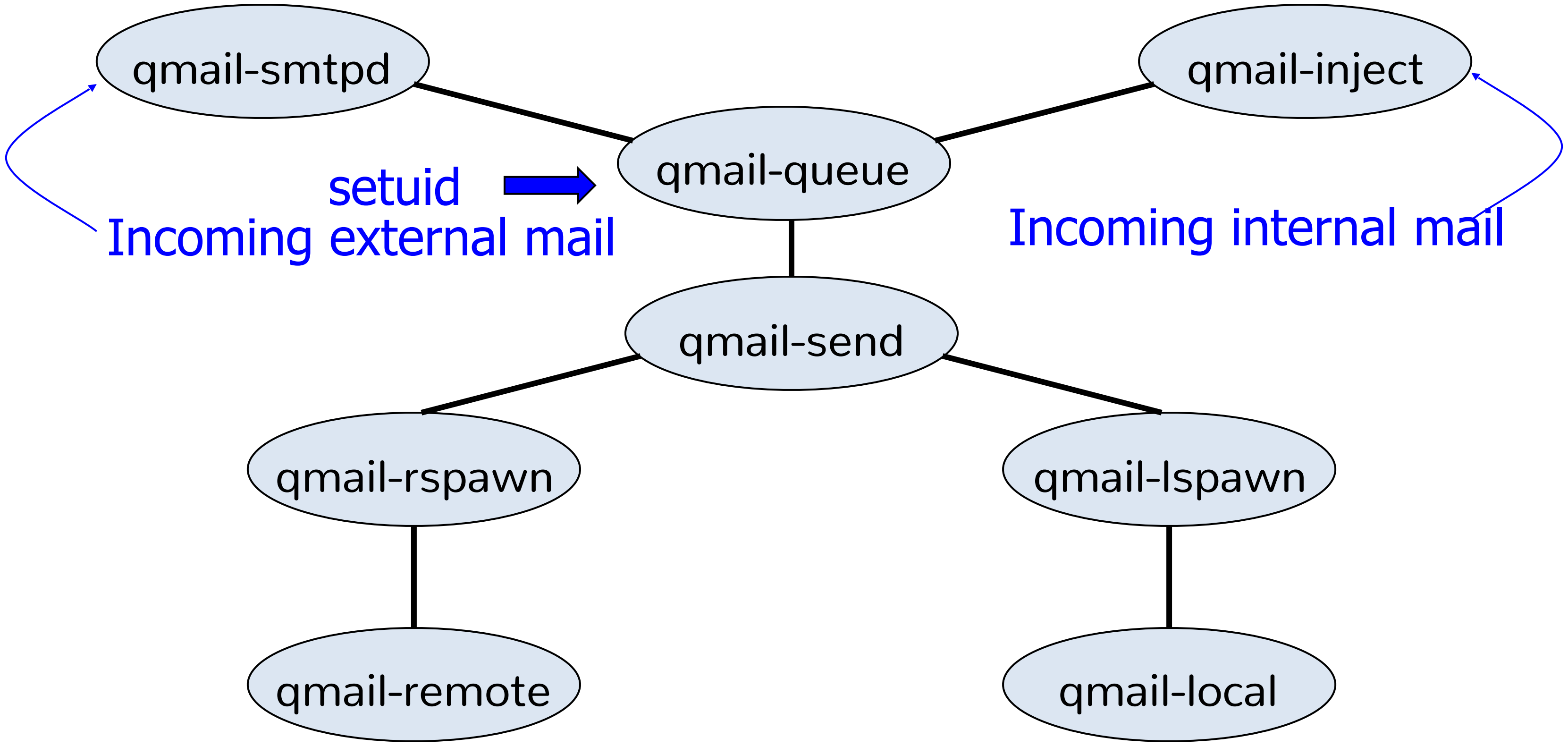
qmail design

- Isolation based on OS isolation
  - Separate modules run as separate “users”
  - Each user only has access to specific resources
- Least privilege
  - Minimal privileges for each UID
  - Only one “setuid” program
  - Only one “root” program

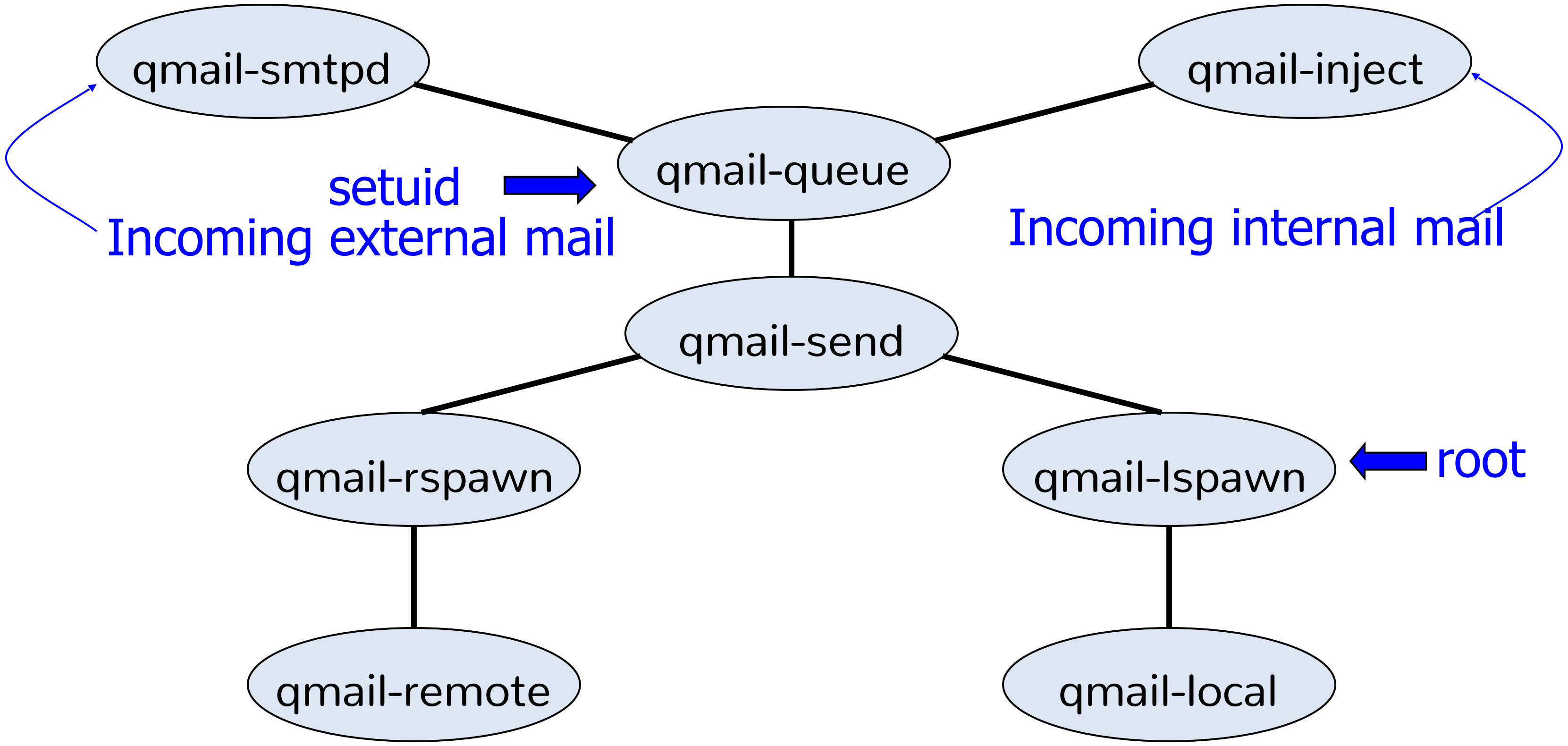
structure of qmail



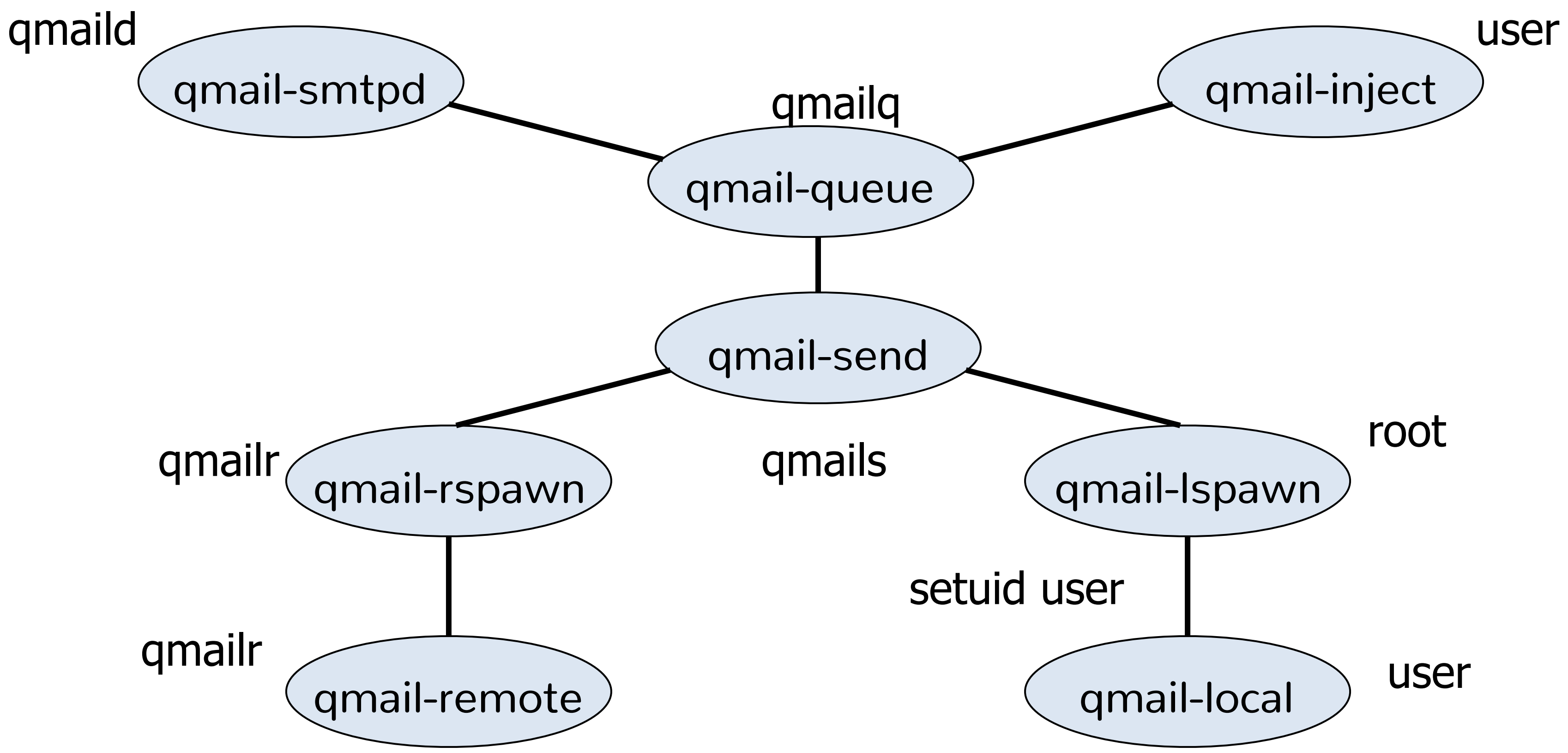
structure of qmail



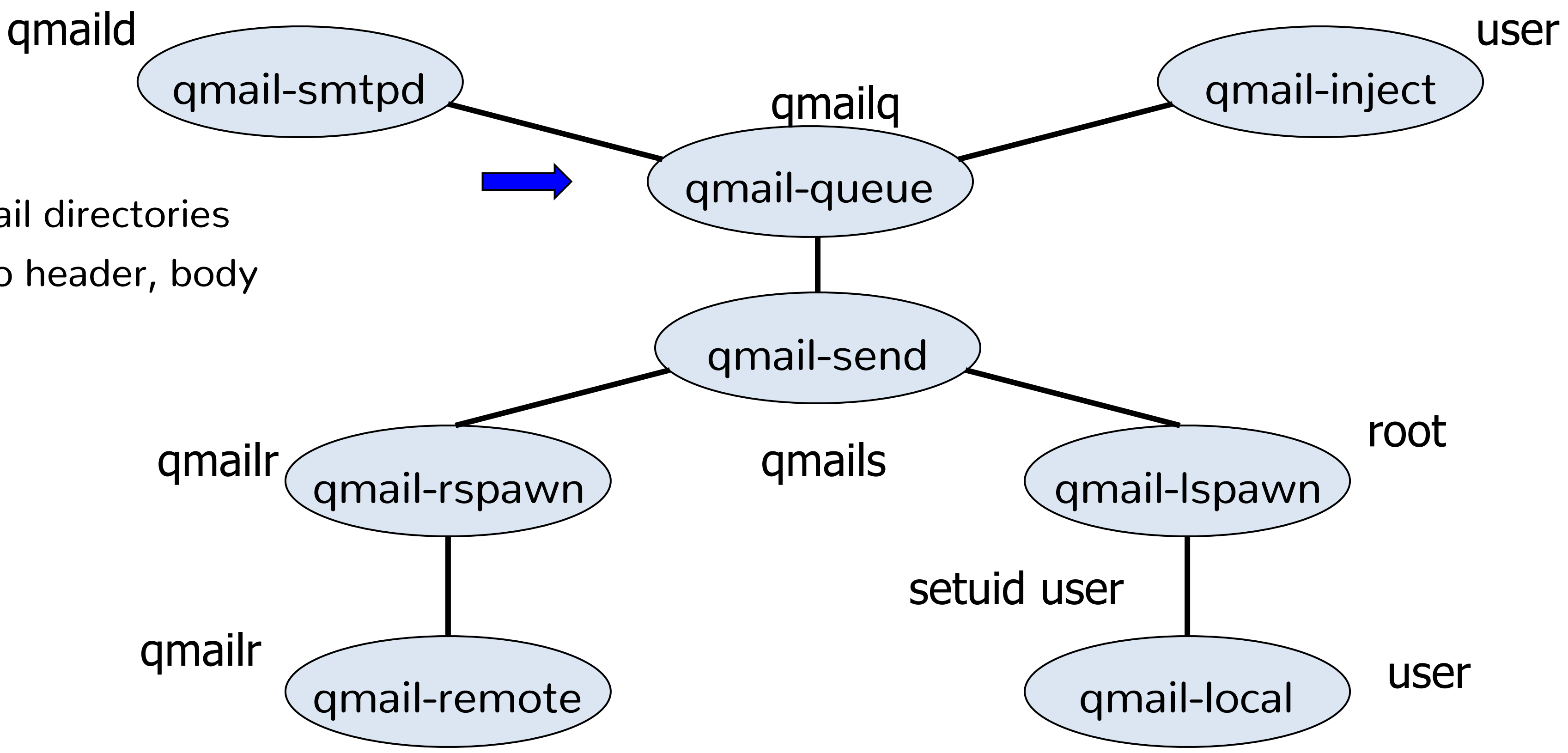
structure of qmail



structure of qmail



structure of qmail



Reads incoming mail directories

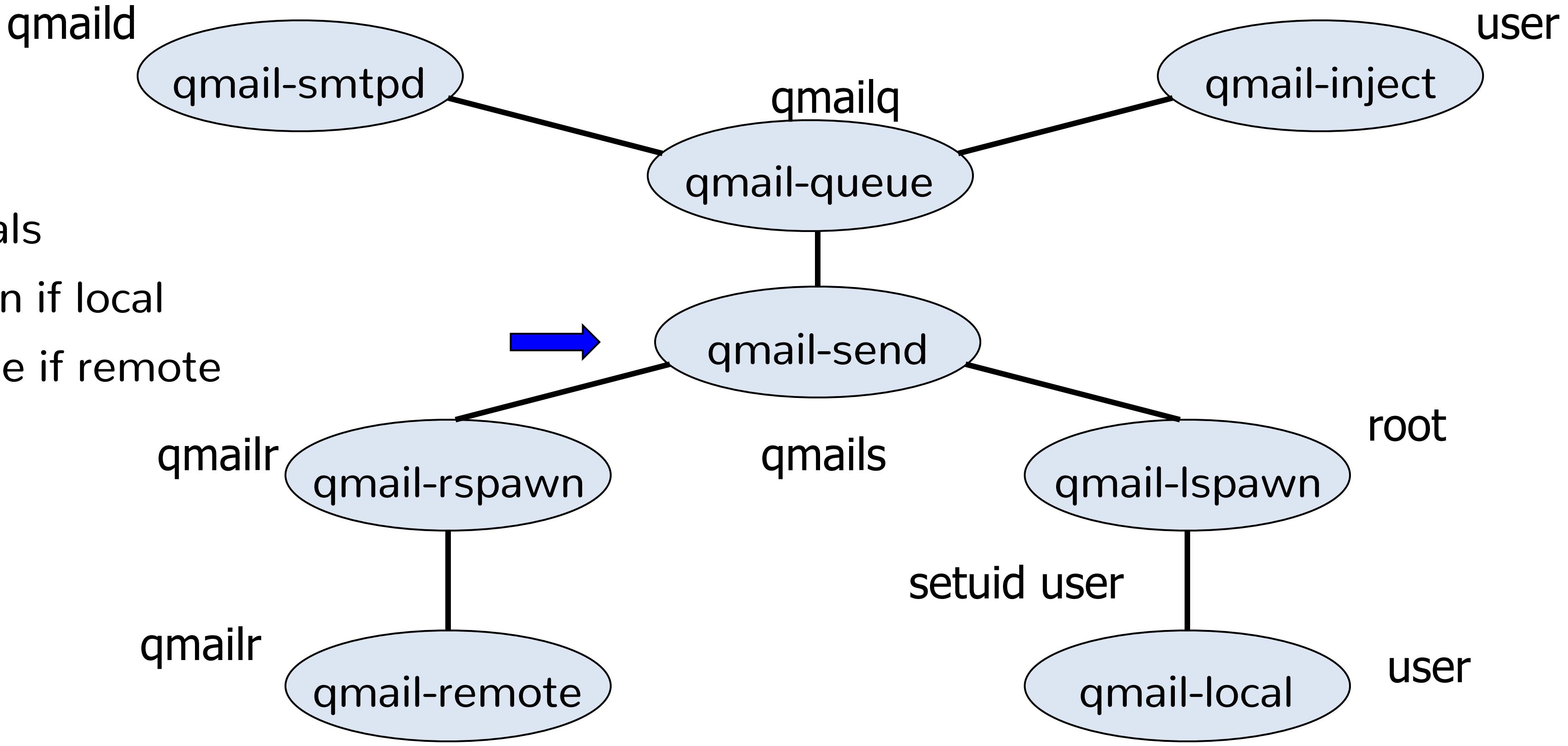
Splits message into header, body

Signals qmail-send

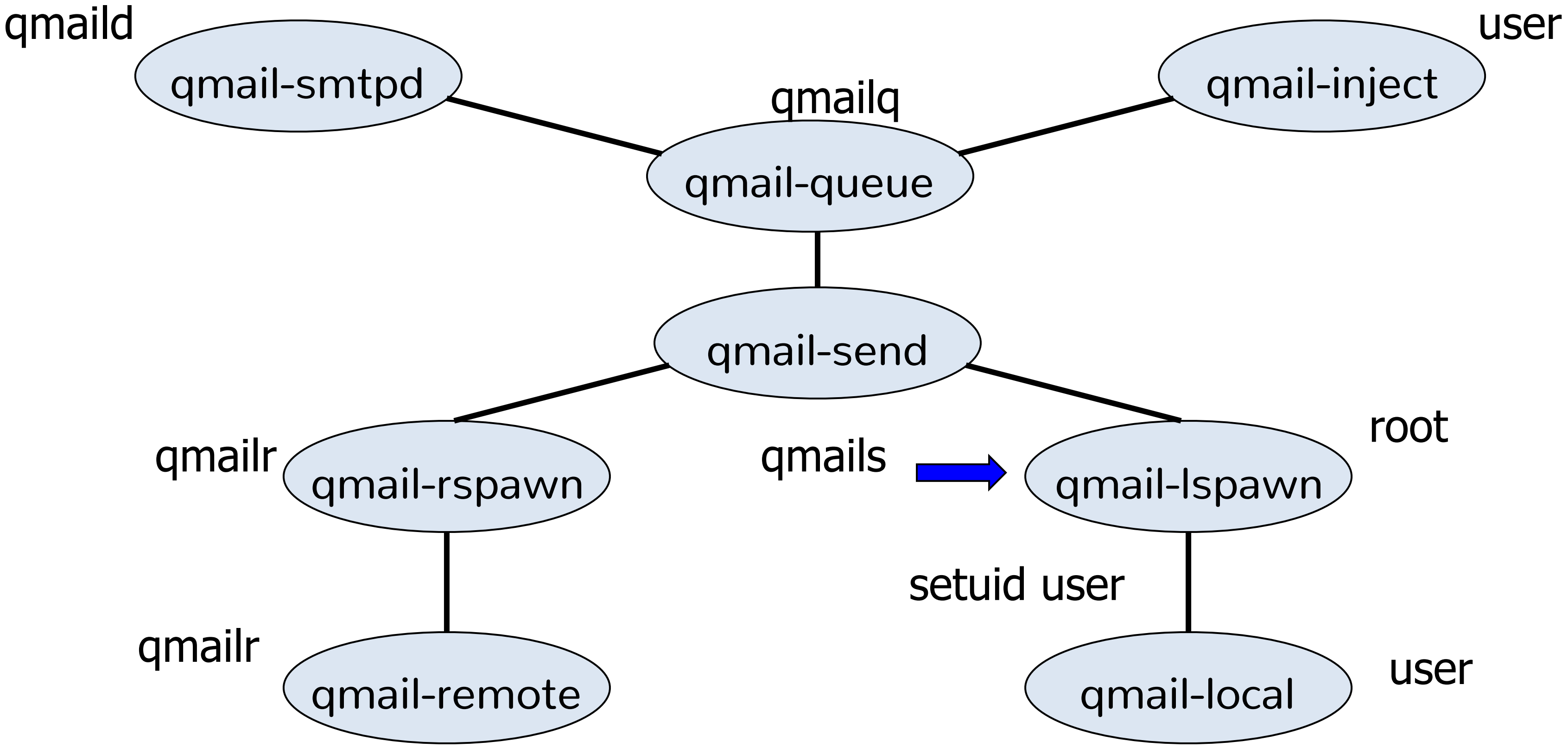
structure of qmail

qmail-send signals

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



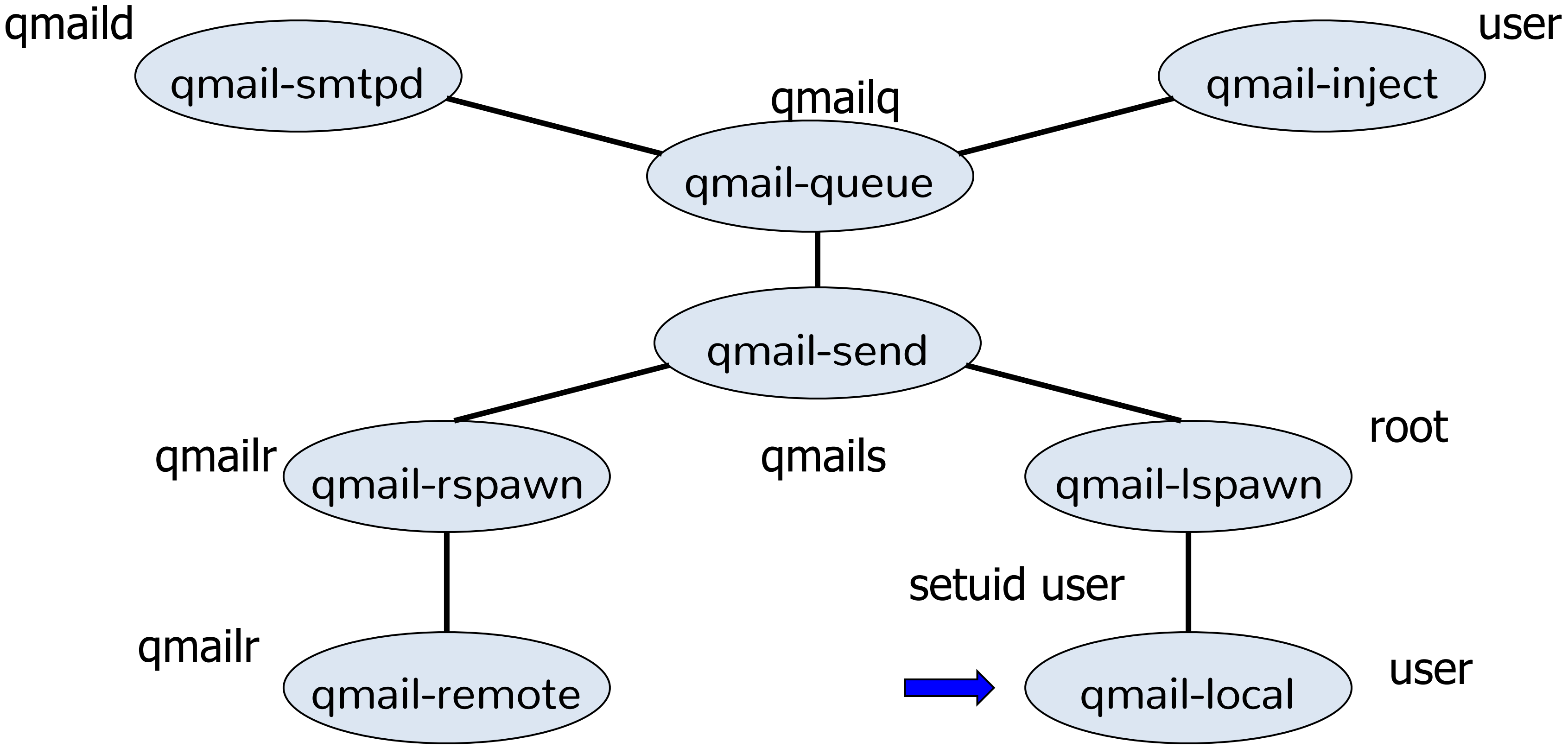
structure of qmail



qmail-lspawn

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

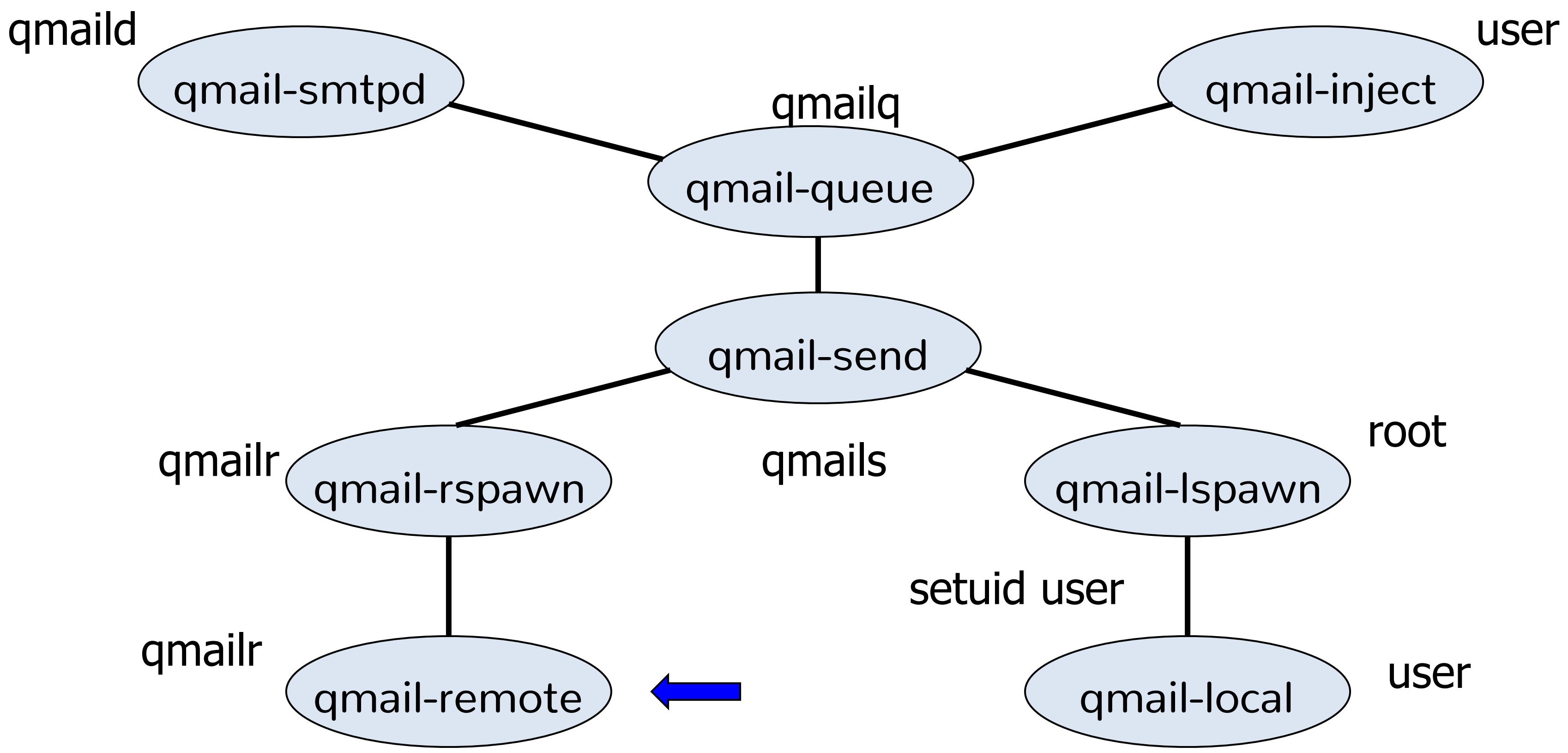
structure of qmail



qmail-local

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

structure of qmail



qmail-remote

- Delivers message to remote MTA

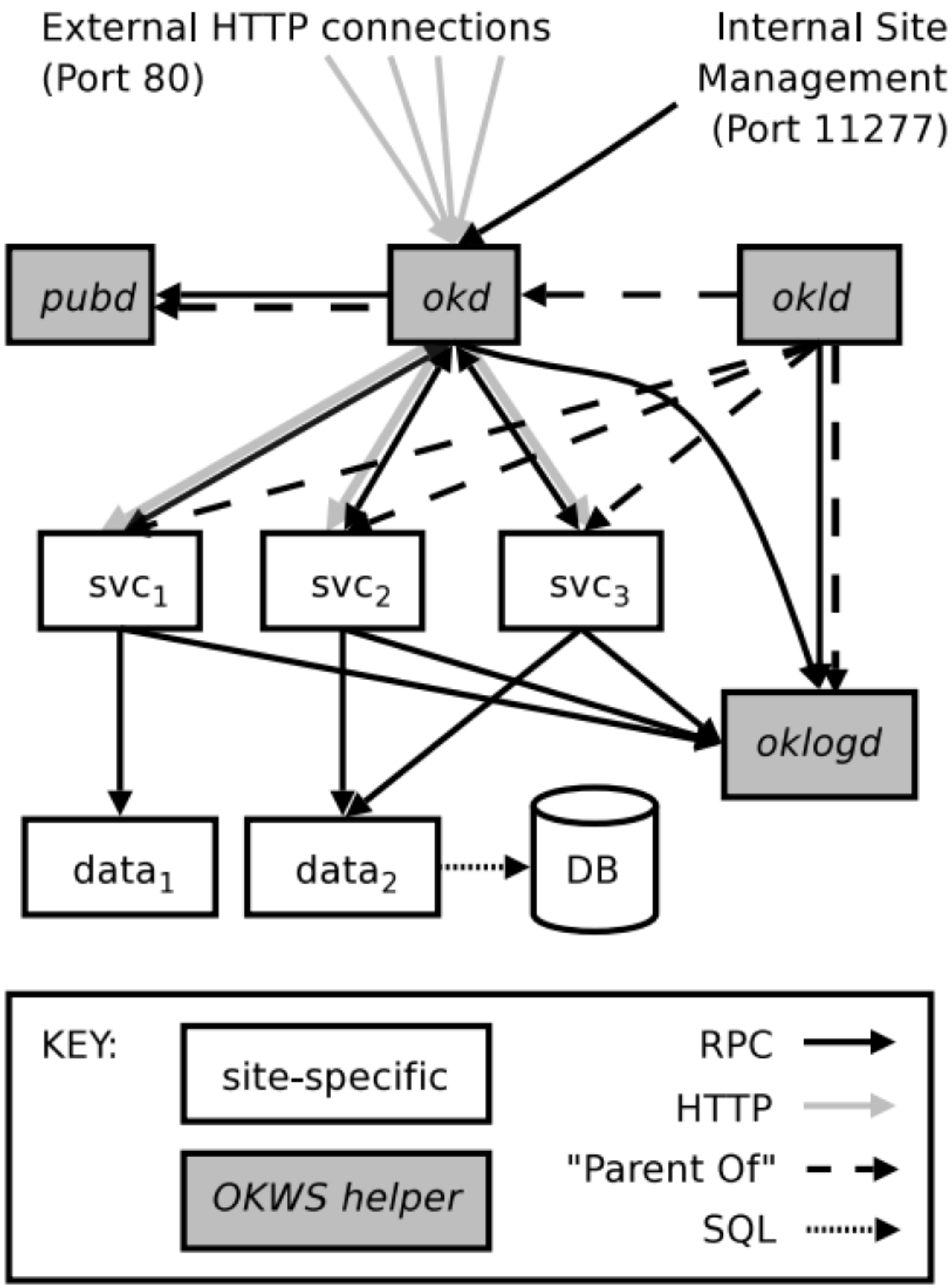
Android design

- Isolation: Each app runs with own UID (own VM)
  - ➤ Provides memory protection
  - ➤ Communication limited to using UNIX domain sockets + reference monitor checks permissions
  - ➤ Only ping and zygote run as root
- Least Privilege: Applications announces permission
  - ➤ User grants access at install time + runtime

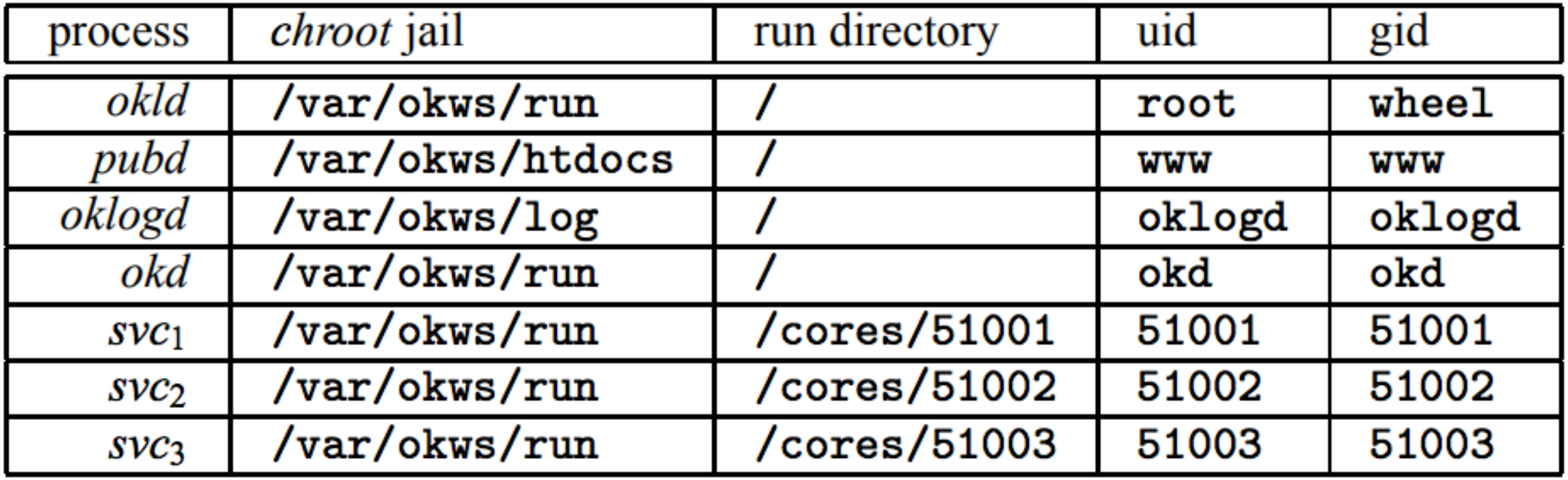
okws design

- Isolation: each service runs with own UID
  - Each service run in a chroot jail, restricted to
  - Communication limited to structured RPC between service and DB
- Least privilege
  - Each UID is unique non privileged user
  - Only okld (launcher daemon) runs as root

okws design


External HTTP connections
(Port 80)
Internal Site
Management
(Port 11277)
pubd
okd
okld
svc₁
svc₂
svc₃
oklogd
data₁
data₂
DB
KEY:
site-specific
OKWS helper
RPC
HTTP
"Parent Of"
SQL

okws design



process	*chroot* jail	run directory	uid	gid
okld	`/var/okws/run`	`/`	`root`	`wheel`
pubd	`/var/okws/htdocs`	`/`	`www`	`www`
oklogd	`/var/okws/log`	`/`	`oklogd`	`oklogd`
okd	`/var/okws/run`	`/`	`okd`	`okd`
svc_1	`/var/okws/run`	`/cores/51001`	`51001`	`51001`
svc_2	`/var/okws/run`	`/cores/51002`	`51002`	`51002`
svc_3	`/var/okws/run`	`/cores/51003`	`51003`	`51003`

Browser security architecture

- Browser is an execution environment
  - ➤ Has access control policies similar to an OS
- Browser runs under control of an OS
  - ➤ Use least privilege to keep the browser code secure against attacks that would break the browser enforcement of web security policy

What’s the security model?

Operating system

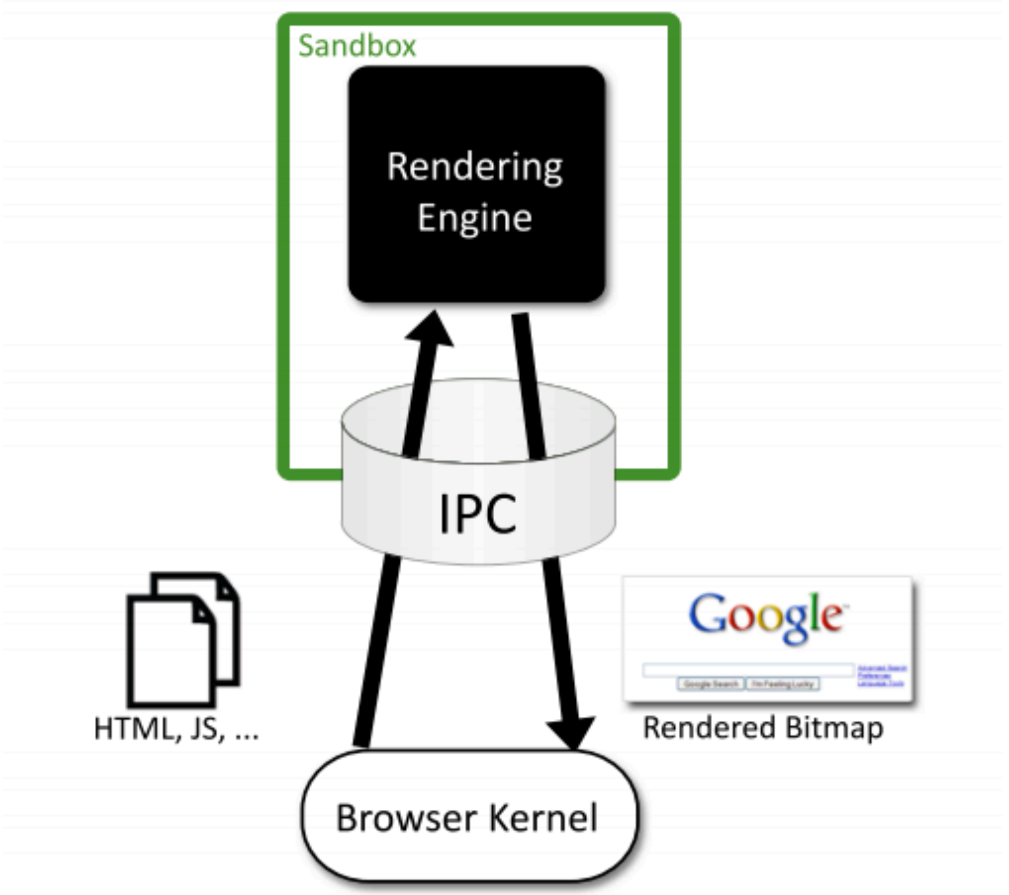
- Subject: Processes
  - Has User ID (UID, SID)
  - Discretionary access control
- Objects
  - File
  - Network
  - …
- Vulnerabilities
  - Untrusted programs
  - Buffer overflow
  - …

Web browser

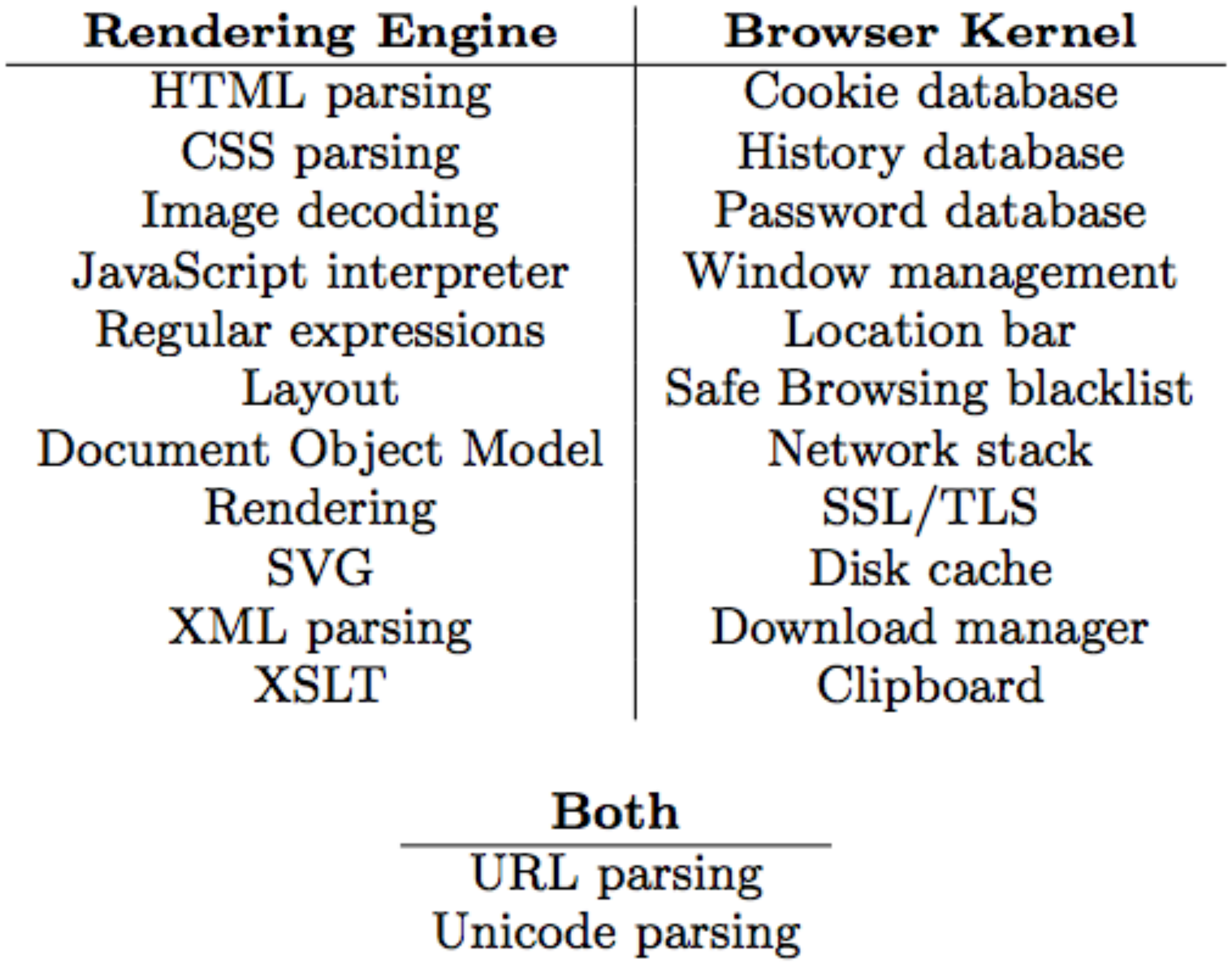
- Subject: web content (JavaScript)
  - Has “Origin”
  - Mandatory access control
- Objects
  - Document object model
  - Frames
  - Cookies / localStorage
- Vulnerabilities
  - Cross-site scripting
  - Implementation bugs
  - …

Chromium security architecture

- Browser ("kernel")
  - ➤ Full privileges (file system, networking)
- Rendering engine
  - ➤ Can have multiple processes
  - ➤ Sandboxed
- One process per plugin
  - ➤ Full privileges of browser



Privilege separation

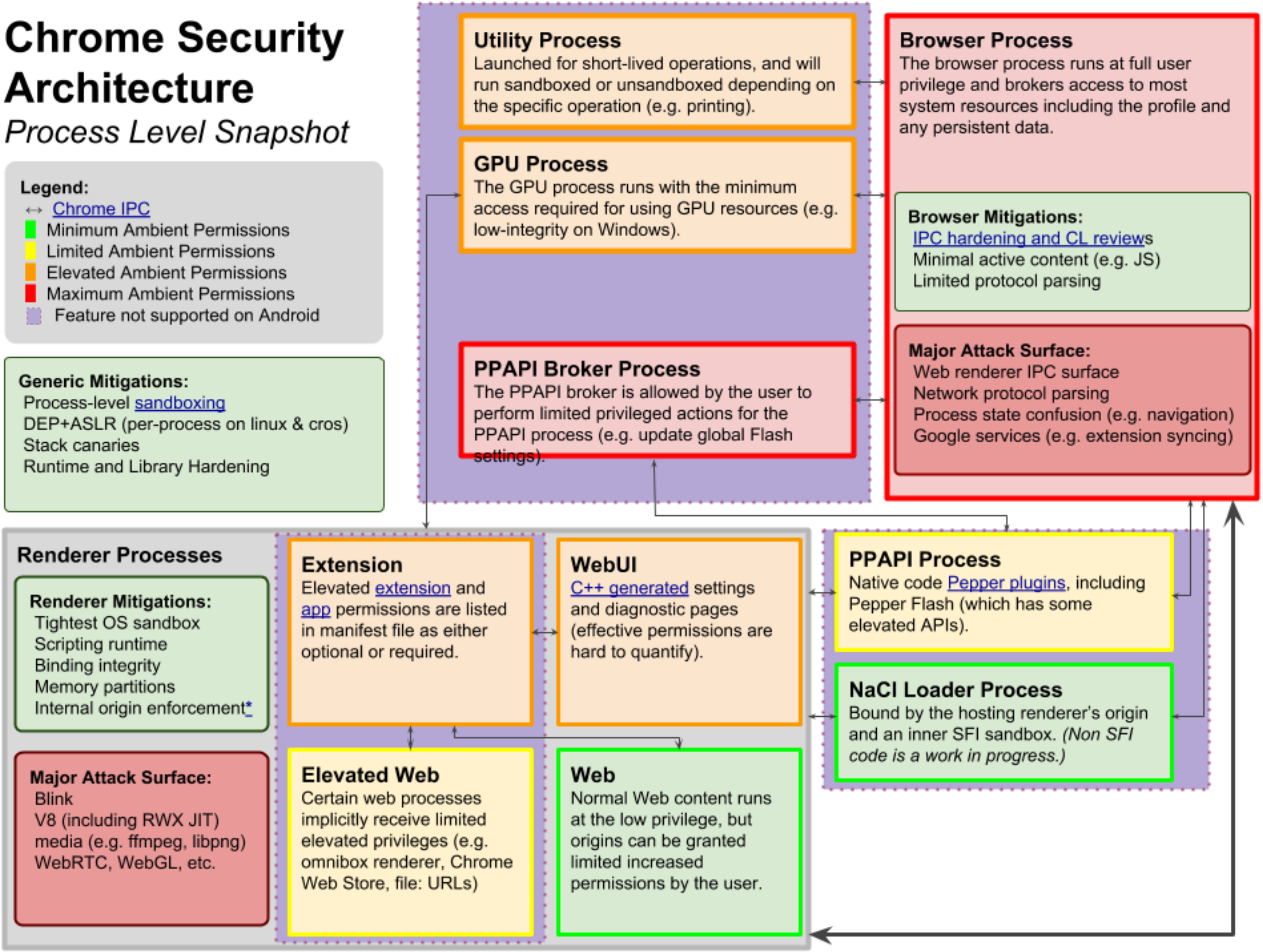


Rendering Engine	Browser Kernel
HTML parsing	Cookie database
CSS parsing	History database
Image decoding	Password database
JavaScript interpreter	Window management
Regular expressions	Location bar
Layout	Safe Browsing blacklist
Document Object Model	Network stack
Rendering	SSL/TLS
SVG	Disk cache
XML parsing	Download manager
XSLT	Clipboard

Both
URL parsing
Unicode parsing

Chrome Security Architecture

Process Level Snapshot



Legend:

- ↔ Chrome IPC
- 🟩 Minimum Ambient Permissions
- 🟨 Limited Ambient Permissions
- 🟧 Elevated Ambient Permissions
- 🟥 Maximum Ambient Permissions
- ▨ Feature not supported on Android

Generic Mitigations:

Process-level sandboxing
DEP+ASLR (per-process on linux & cros)
Stack canaries
Runtime and Library Hardening

Utility Process

Launched for short-lived operations, and will run sandboxed or unsandboxed depending on the specific operation (e.g. printing).

GPU Process

The GPU process runs with the minimum access required for using GPU resources (e.g. low-integrity on Windows).

PPAPI Broker Process

The PPAPI broker is allowed by the user to perform limited privileged actions for the PPAPI process (e.g. update global Flash settings).

Browser Process

The browser process runs at full user privilege and brokers access to most system resources including the profile and any persistent data.

Browser Mitigations:

IPC hardening and CL reviews
Minimal active content (e.g. JS)
Limited protocol parsing

Major Attack Surface:

Web renderer IPC surface
Network protocol parsing
Process state confusion (e.g. navigation)
Google services (e.g. extension syncing)

Renderer Processes

Renderer Mitigations:

Tightest OS sandbox
Scripting runtime
Binding integrity
Memory partitions
Internal origin enforcement*

Major Attack Surface:

Blink
V8 (including RWX JIT)
media (e.g. ffmpeg, libpng)
WebRTC, WebGL, etc.

Extension

Elevated extension and app permissions are listed in manifest file as either optional or required.

WebUI

C++ generated settings and diagnostic pages (effective permissions are hard to quantify).

Elevated Web

Certain web processes implicitly receive limited elevated privileges (e.g. omnibox renderer, Chrome Web Store, file: URLs)

Web

Normal Web content runs at the low privilege, but origins can be granted limited increased permissions by the user.

PPAPI Process

Native code Pepper plugins, including Pepper Flash (which has some elevated APIs).

NaCl Loader Process

Bound by the hosting renderer's origin and an inner SFI sandbox. *(Non SFI code is a work in progress.)*

Are UIDs enough?

- A: yes
- B: no

What else do we need?

- We need to confine code running in renderer
  - Restrict code from reading the filesystem, talking to network, etc. if compromised
- On Linux this is done with seccomp-bpf
  - seccomp - “secure computing mode”: no sys calls except exit, sigreturn, read, and write to already open FDs
  - seccomp-bpf - syscall firewall filtering