Design philosophy of operating systems (II)

Hung-Wei Tseng

Outline

- Nucleus (cont.)
- The UNIX time-sharing operating system
- Mach: A New Kernel Foundation For UNIX Development

What the OS kernel should do?

The UNIX Time-Sharing System

Dennis M. Ritchie and Ken Thompson
Bell Laboratories

DENNIS RITCHIE & KEN THOMPSON

Inventors of UNIX.

A.M. TURING AWARD 1983

Poll close in 1:30

Why they built “UNIX”

- How many of following statements is/are the motivations of building UNIX?
  - ① Reducing the cost of building machines with powerful OSes
  - ② Reducing the burden of maintaining the OS code
  - ③ Reducing the size of the OS code
  - ④ Supporting networks and multiprocessors
  - A. 0
  - B. 1
  - C. 2
  - D. 3
  - E. 4

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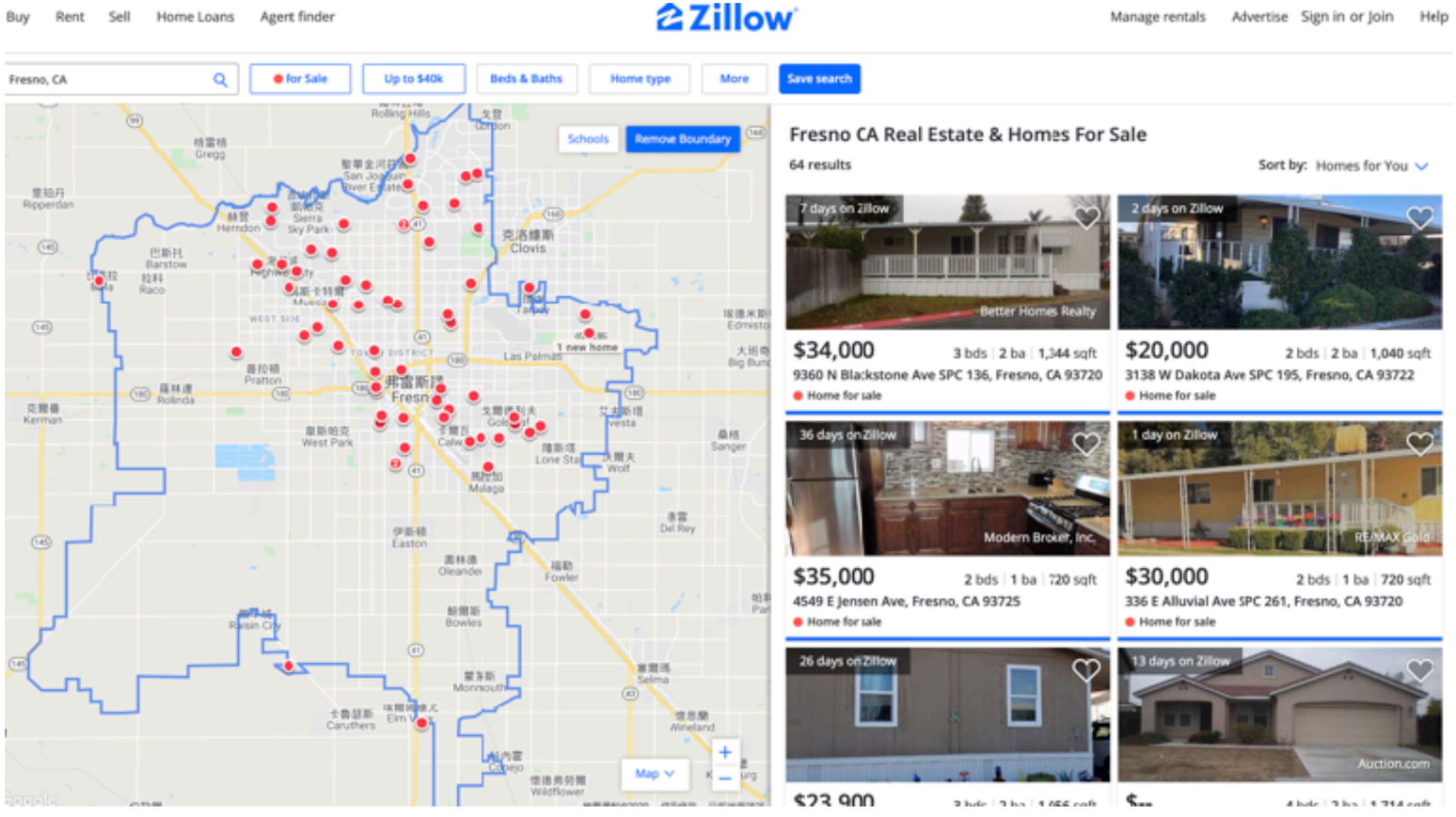
> Perhaps the most important achievement of UNIX is to demonstrate that a powerful operating system for interactive use need not be expensive either in equipment or in human effort: UNIX can run on hardware costing as little as $40,000, and less than two man-years were spent on the main system software. Yet

> The size of the new system is about one third greater than the old. Since the new system is not only much easier to understand and to modify but also includes many functional improvements, including multiprogramming and the ability to share reentrant code among several user programs, we considered this increase in size quite acceptable.

Why should we care about “UNIX”

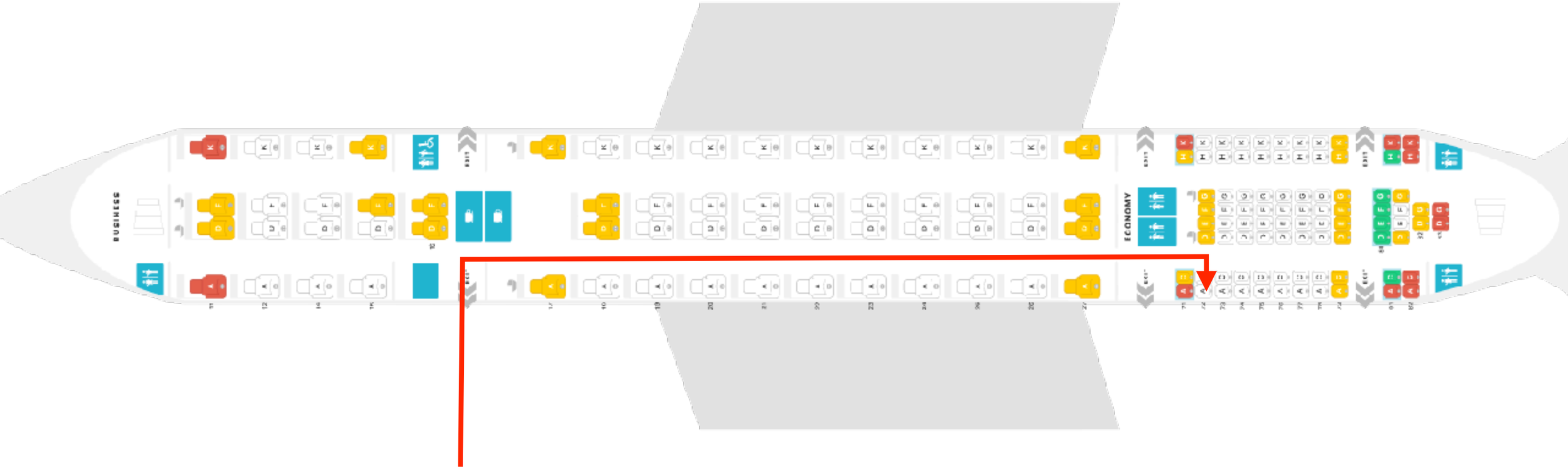
- A powerful operating system on “inexpensive” hardware (still costs USD $40,000)
- An operating system promotes simplicity, elegance, and ease of use
- They made it



What UNIX proposed

- Providing a file system
- File as the unifying abstraction in UNIX
- Remind what we mentioned before

Right amplification



Demo: setuid

- chmod u+s allows “others” to execute the program as the creator
- There exists a file “others” cannot read
- Another program can dump the content
- Without setuid, others still cannot read the content
- With setuid, others can read that!

UNIX’s interface of managing processes

The basic process API of UNIX

- `fork`
- `wait`
- `exec`
- `exit`

`fork()`

- `pid_t fork();`
- `fork` used to create processes (UNIX)
- What does `fork()` do?
  - Creates a **new** address space (for child)
  - **Copies** parent's address space to child's
  - Points kernel resources to the parent's resources (e.g. open files)
  - Inserts child process into ready queue
- `fork()` returns twice
  - Returns the child's PID to the parent
  - Returns "0" to the child

`exit()`

- `void exit(int status)`
- `exit` frees resources and terminates the process
  - Runs an functions registered with atexit
  - Flush and close all open files/streams
  - Releases allocated memory.
  - Remove process from kernel data structures (e.g. queues)
- `status` is passed to parent process
  - By convention, 0 indicates “normal exit”

The cost of creating processes

- Measure process creation overhead using lmbench http://www.bitmover.com/lmbench/

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  - More than 16K cycles

Zombies, Orphans, and Adoption

- Zombie: process that exits but whose parent doesn't call wait
  - Can't be killed normally
  - Resources freed but pid remains in use
- Orphan: Process whose parent has exited before it has
  - Orphans are **adopted** by init process, which calls wait periodically

Let’s write our own shells

How to implement redirection in shell

- Say, we want to do ./a > b.txt
- fork
- The forked code opens b.txt
- The forked code dup the file descriptor
- The forked code assigns b.txt to stdin/stdout
- The forked code closes b.txt
- exec("./a", NULL)

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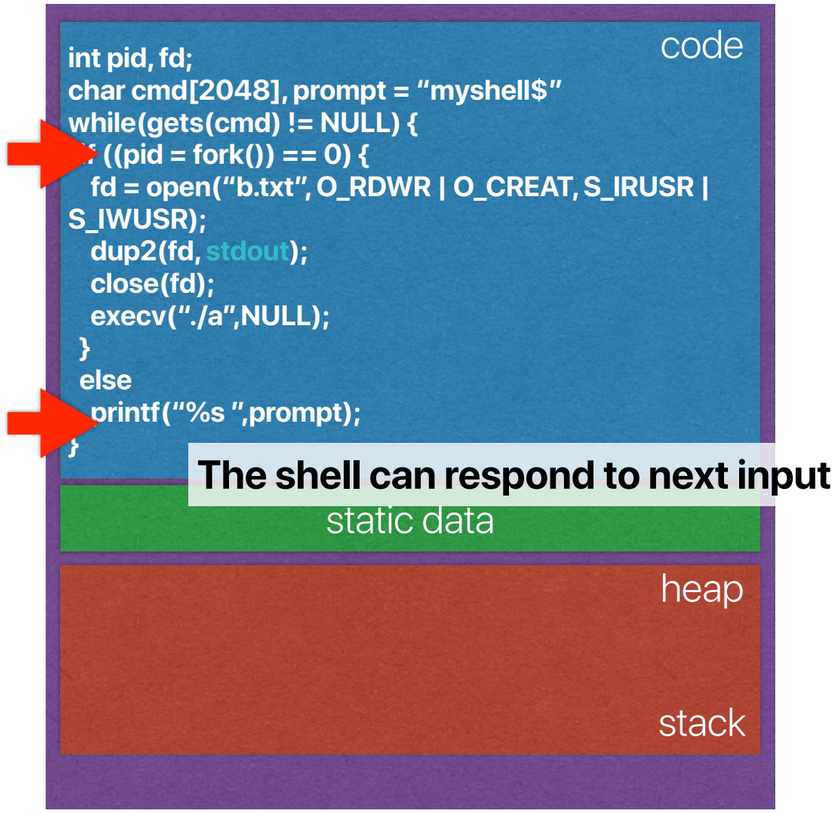
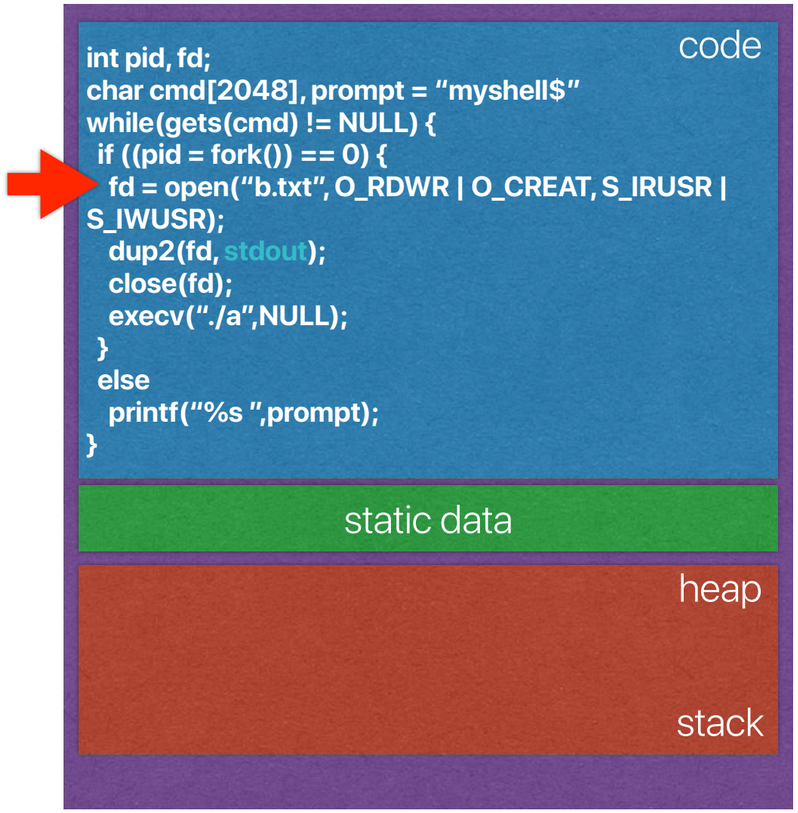
Homework for you:
Think about the case when
your `fork` is equivalent to `fork+exec()`





wait()

- `pid_t wait(int *stat)`
- `pid_t waitpid(pid_t pid, int *stat, int opts)`
- `wait` / `waitpid` suspends process until a child process ends
  - `wait` resumes when any child ends
  - `waitpid` resumes with child with pid ends
  - `exit` status info 1 is stored in *stat
  - Returns pid of child that ended, or -1 on error
- Unix requires a corresponding `wait` for every `fork`

What's in the kernel?

- How many of the following UNIX features/functions are implemented in the kernel?
  - ① I/O device drivers
  - ② File system
  - ③ Shell
  - ④ Virtual memory management
  - A. 0
  - B. 1
  - C. 2
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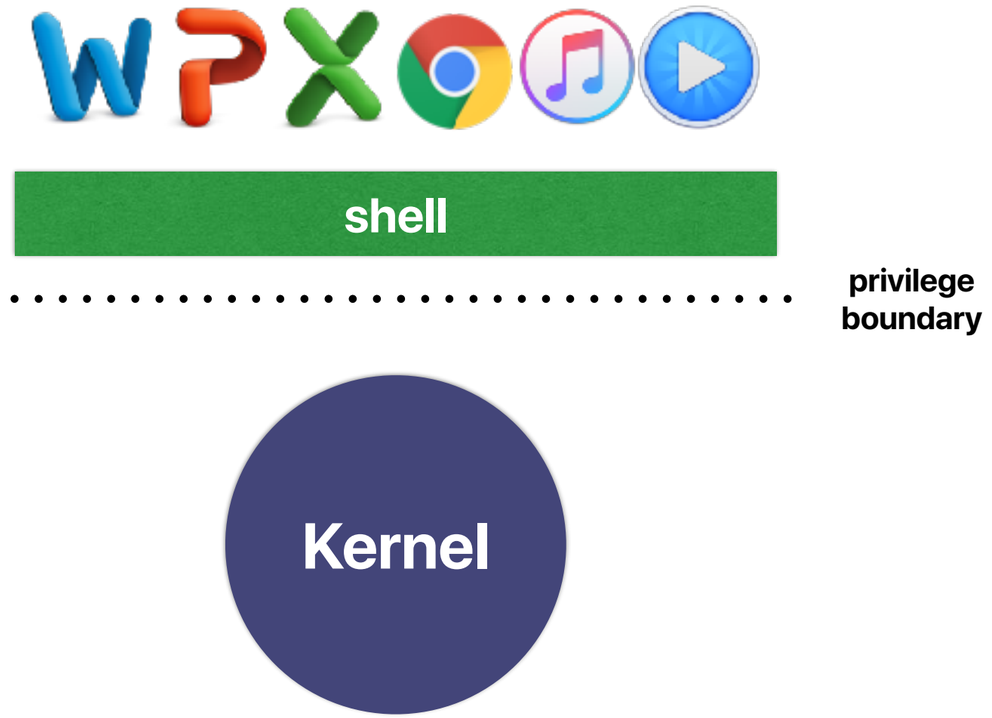


Shell

- A user program provides an interactive UI
- Interprets user command into OS functions
- Basic semantics:
  command argument_1 argument_2 …
- Advanced semantics
  - Redirection
    - >
    - <
  - Pipe
    - |
  - Multitasking
    - &

The impact of UNIX

- Clean abstraction
- File system — will discuss in detail after midterm
- Portable OS
  - Written in high-level C programming language
  - The unshakable position of C programming language
- We are still using it!

Perhaps paradoxically, the success of UNIX is largely due to the fact that it was not designed to meet any predefined objectives. The first version was written when one of us (Thompson), dissatisfied with the available computer facilities, discovered a little-used PDP-7 and set out to create a more hospitable environment. This essentially personal effort was sufficiently successful to gain the interest of the remaining author and others, and later to justify the acquisition of the PDP-11/20, specifically to support a text editing and formatting system. When in turn the 11/20 was outgrown, UNIX had proved useful enough to persuade management to invest in the PDP-11/45. Our goals throughout the effort, when articulated at all, have always concerned themselves with building a comfortable relationship with the machine and with exploring ideas and inventions in operating systems. We have not been faced with the need to satisfy someone else's requirements, and for this freedom we are grateful.

Mach: A New Kernel Foundation For UNIX Development

Mike Accetta , Robert Baron , William Bolosky , David Golub , Richard Rashid , Avadis Tevanian , Michael Young
Computer Science Department, Carnegie Mellon University

Why "Mach"?

- The hardware is changing
  - Multiprocessors
  - Networked computing
- The software
  - The demand of extending an OS easily
  - Repetitive but confusing mechanisms for similar stuffs

> be built and future development of UNIX-like systems for new architectures can continue. The computing environment for which Mach is targeted spans a wide class of systems, providing basic support for large, general purpose multiprocessors, smaller multiprocessor networks and individual workstations (see

> As the complexity of distributed environments and multiprocessor architectures increases, it becomes increasingly important to return to the original UNIX model of consistent interfaces to system facilities. Moreover, there is a clear need to allow the underlying system to be transparently extended to allow user-state processes to provide services which in the past could only be fully integrated into UNIX by adding code to the operating system kernel.

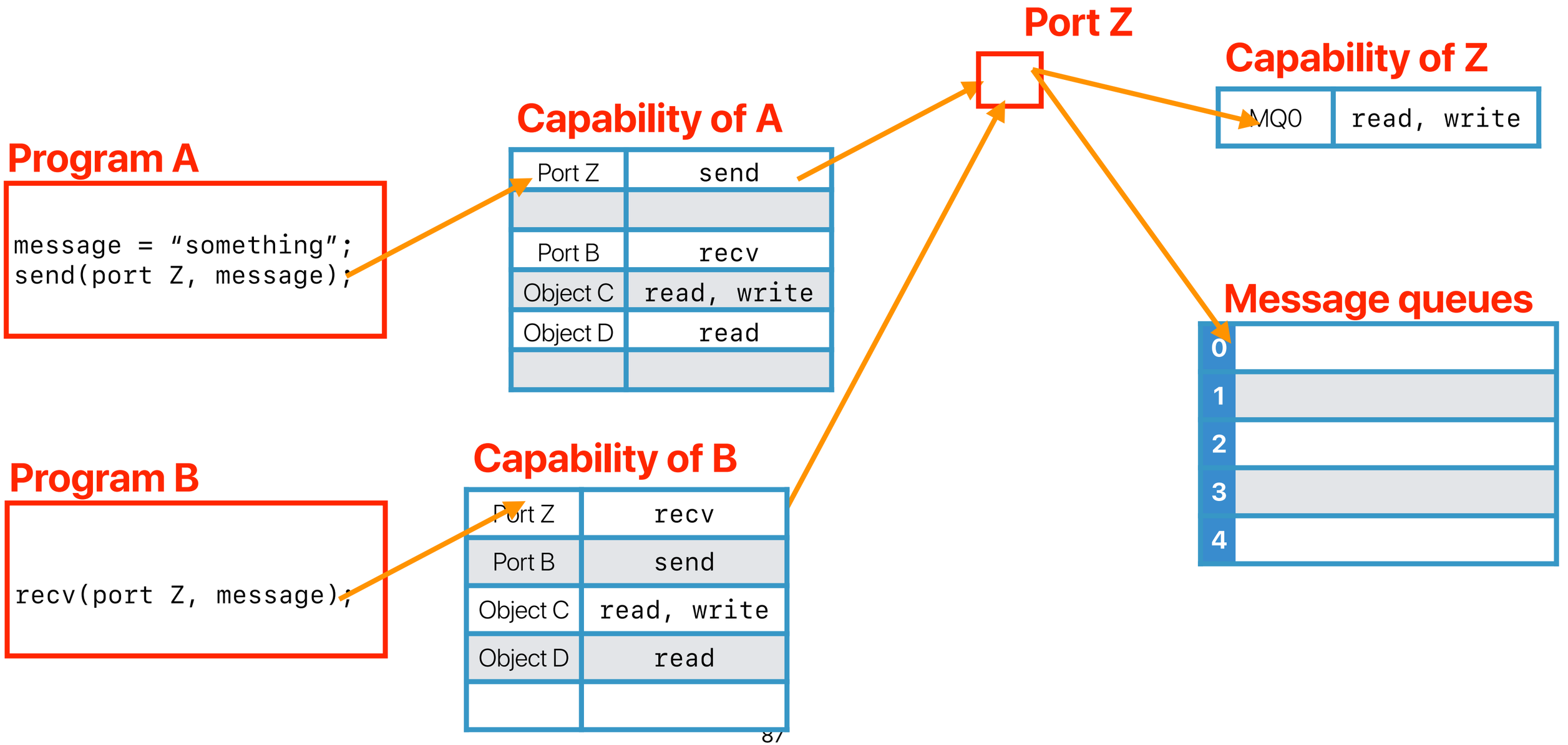
Interprocess communication

- UNIX provides a variety of mechanisms
  - Pipes
  - Pty's
  - Signals
  - Sockets
- No protection
- No consistency
- Location dependent

Ports/Messages

- Port is an abstraction of:
  - Message queues
  - Capability
- What do ports/messages promote?
  - Location independence — everything is communicating with ports/messages, no matter where it is

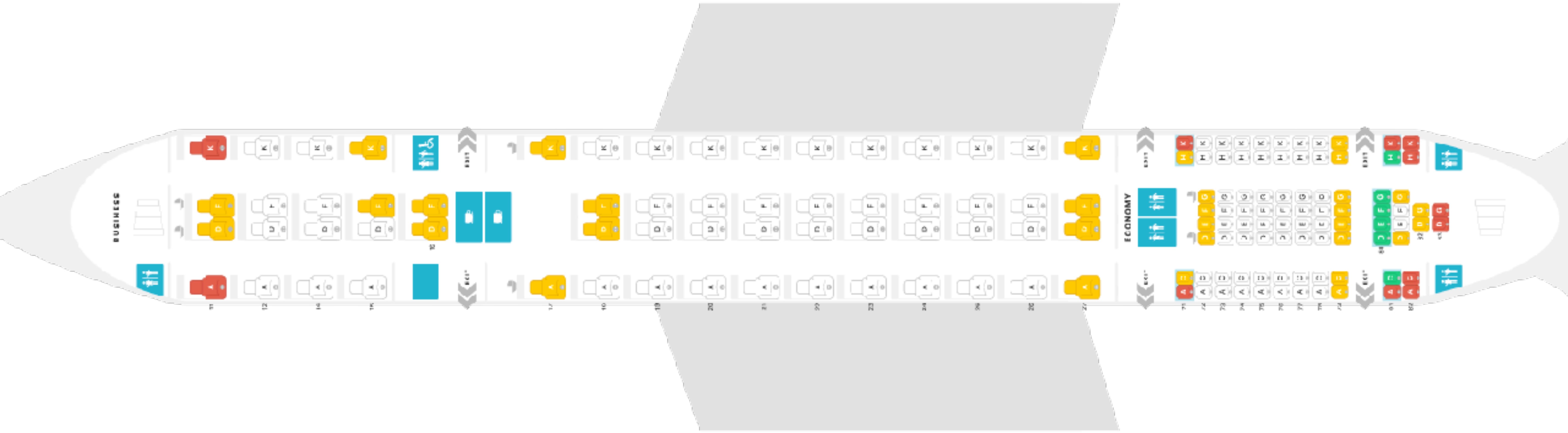
Ports/Messages



```java
class JBT {

   int variable = 5;

   public static void main(String args[]) {
      JBT obj = new JBT();

      obj.method(20);
      obj.method();
   }

   void method(int variable) {
      variable = 10;
      System.out.println("Value of Instance variable :" + this.variable);
      System.out.println("Value of Local variable :" + variable);
   }

   void method() {
      int variable = 40;
      System.out.println("Value of Instance variable :" + this.variable);
      System.out.println("Value of Local variable :" + variable);
   }
}
```

What is capability? — Hydra

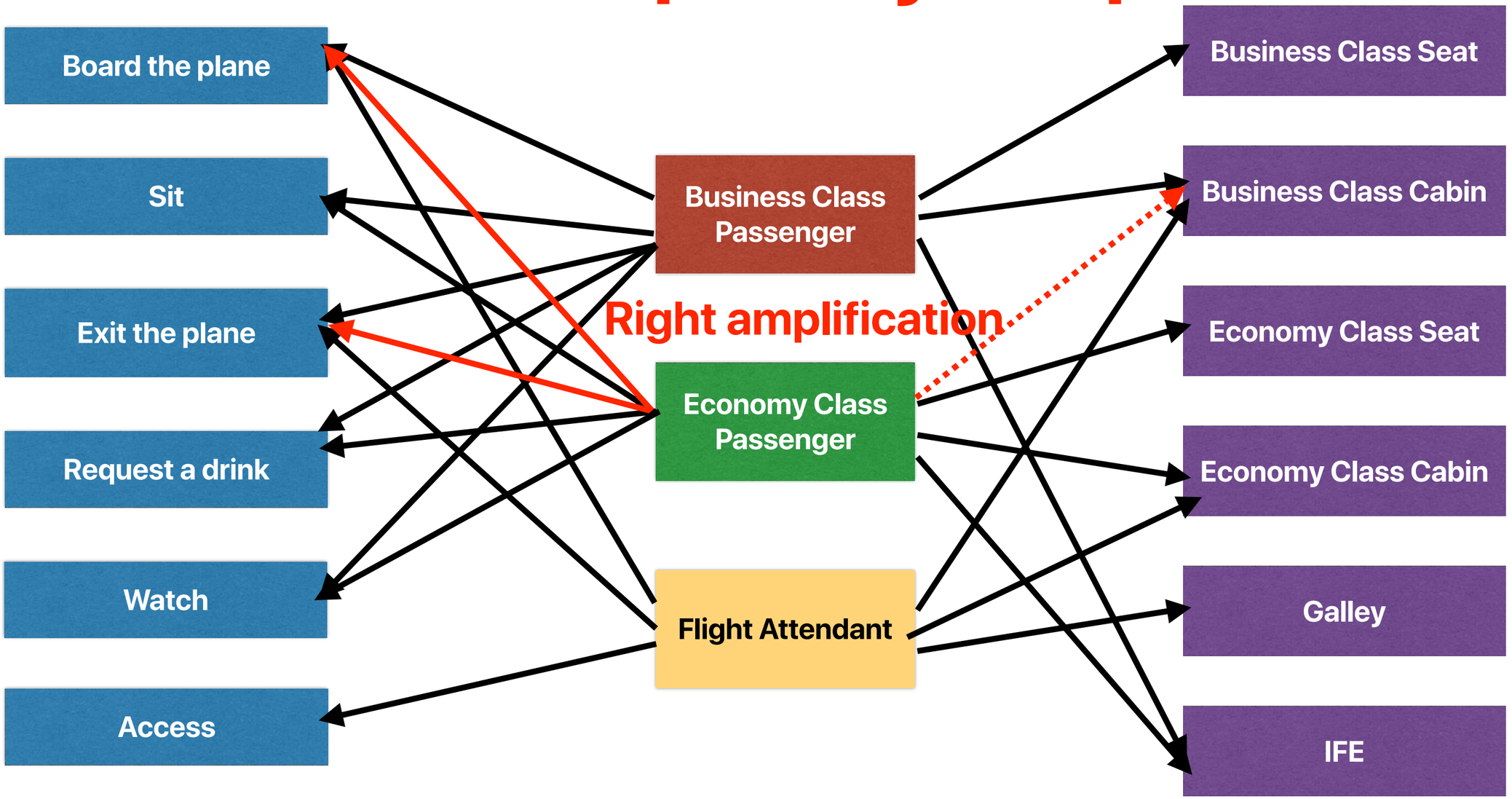
- An access control list associated with an object
- Contains the following:
  - A reference to an object
  - A list of access rights
- Whenever an operation is attempted:
  - The requester supplies a capability of referencing the requesting object — like presenting the boarding pass
  - The OS kernel examines the access rights
    - Type-independant rights
    - Type-dependent rights

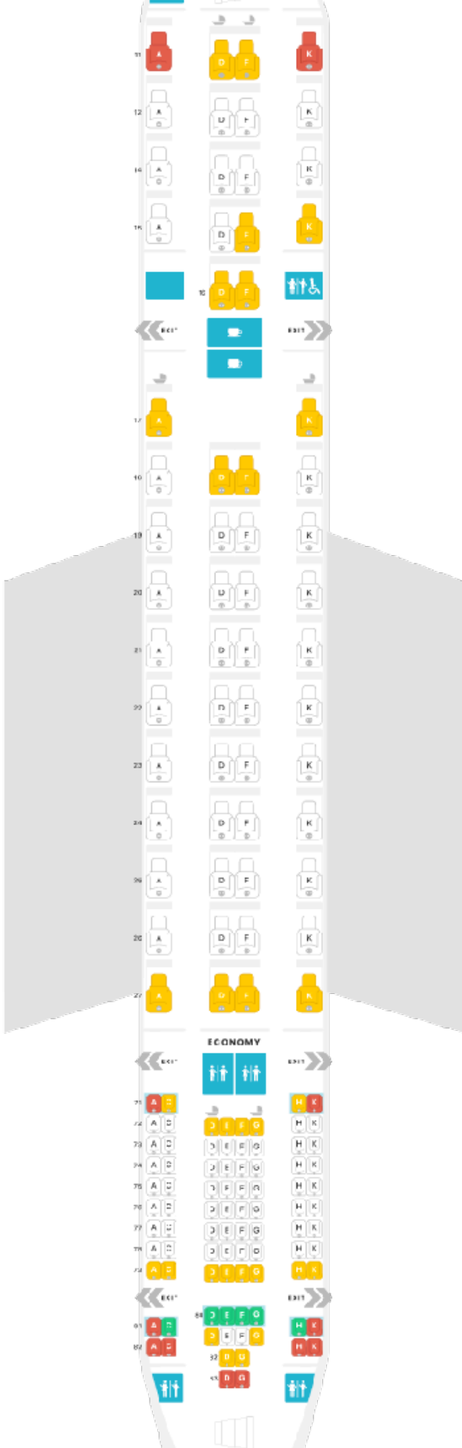

BUSINESS
ECONOMY

Capability v.s. boarding pass

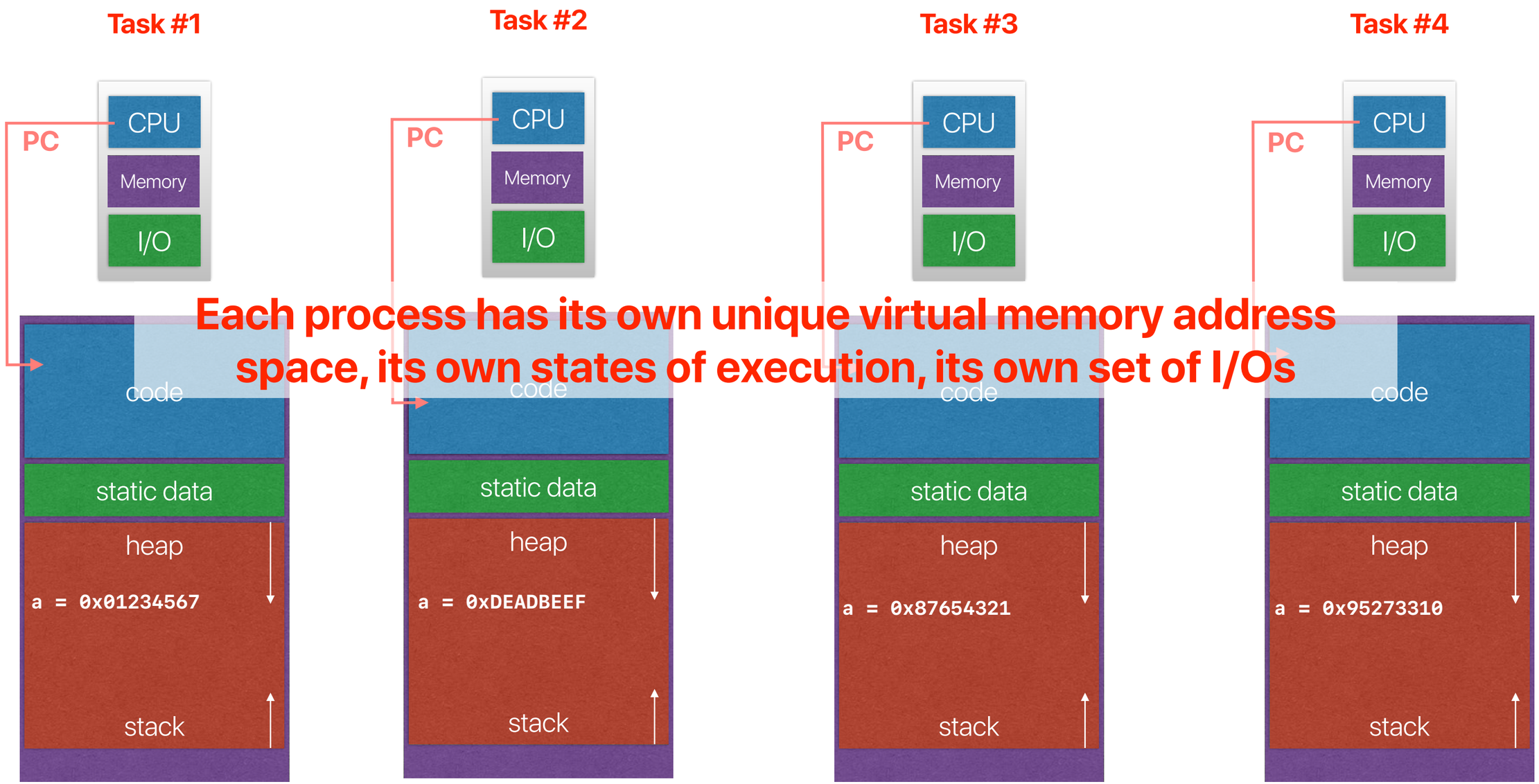
- You can only enjoy the ground services (objects) that your booking class provides
- You can only access the facilities (objects) on the airplane according to the booking class

Capability in a plane



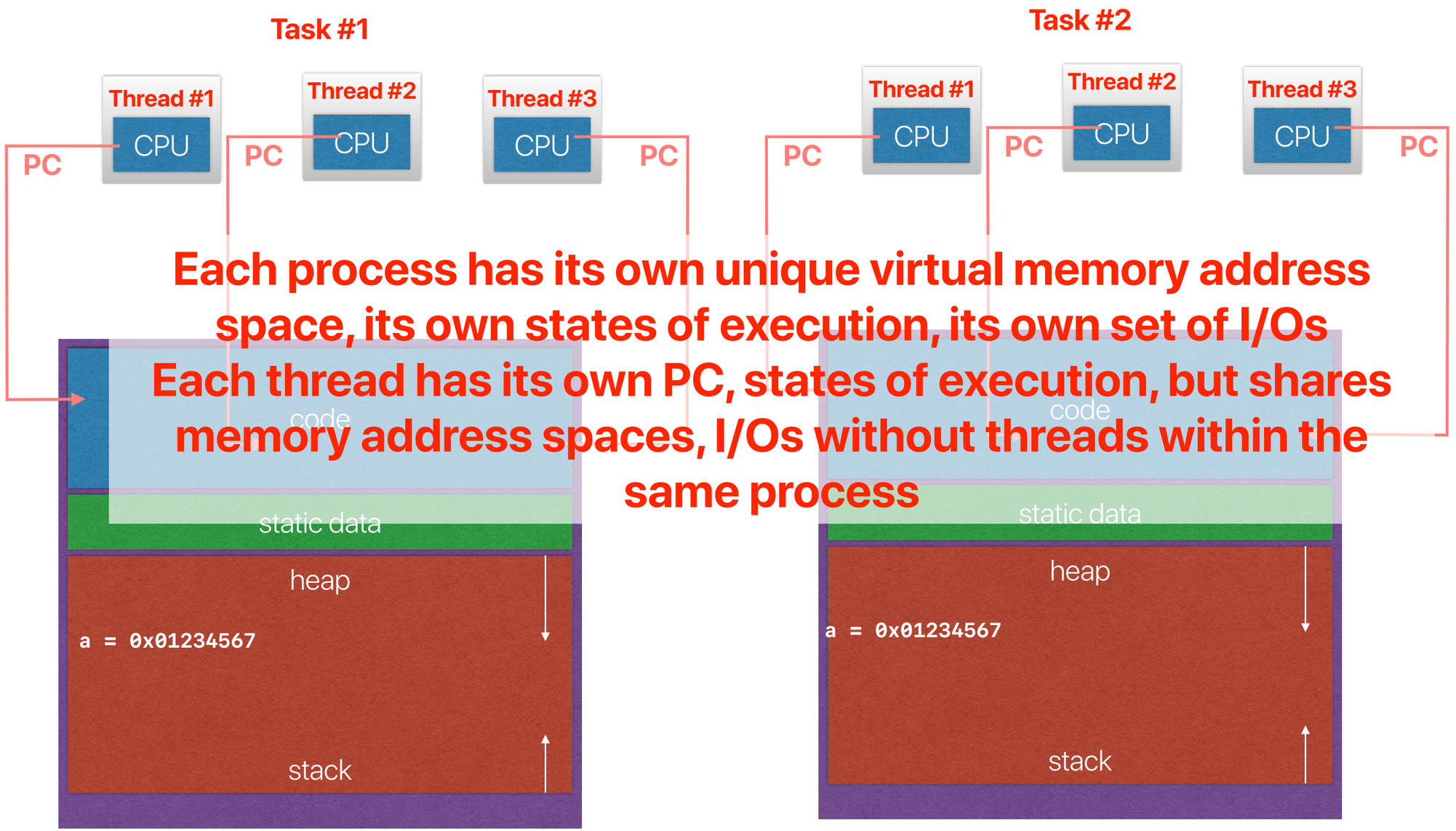


Tasks/processes



Each process has its own unique virtual memory address space, its own states of execution, its own set of I/Os

Threads



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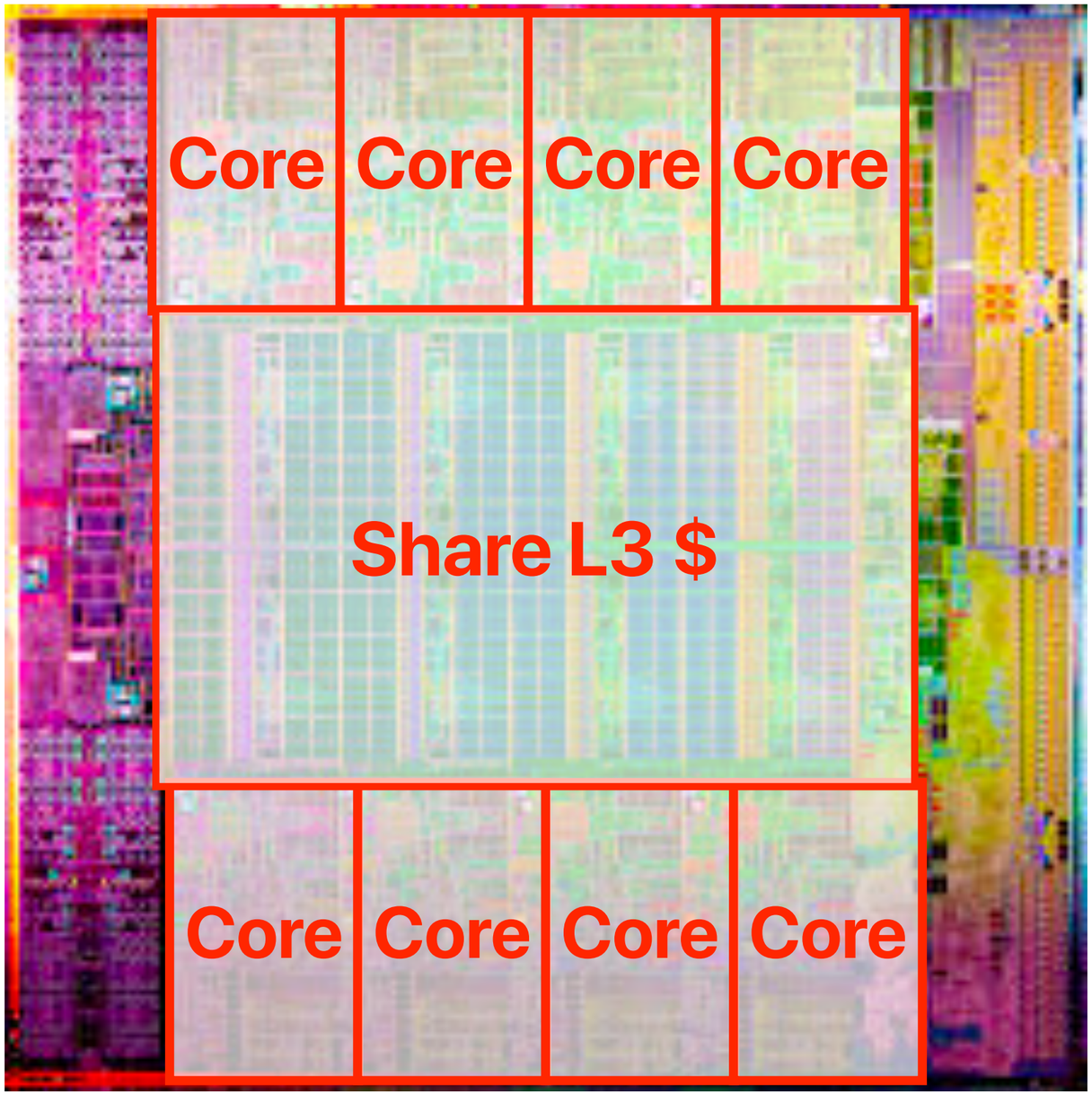
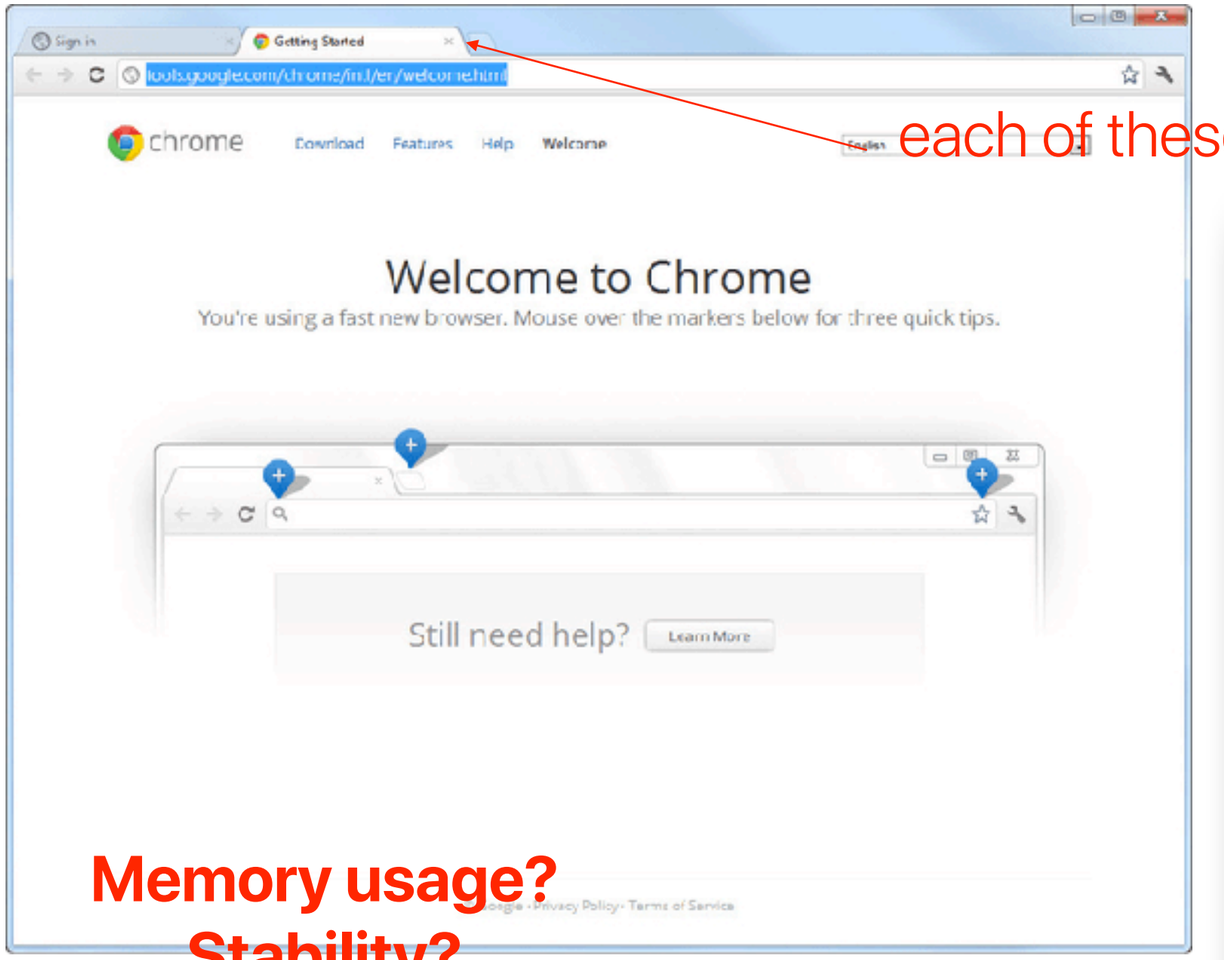
Each thread has its own PC, states of execution, but shares memory address spaces, I/Os without threads within the same process

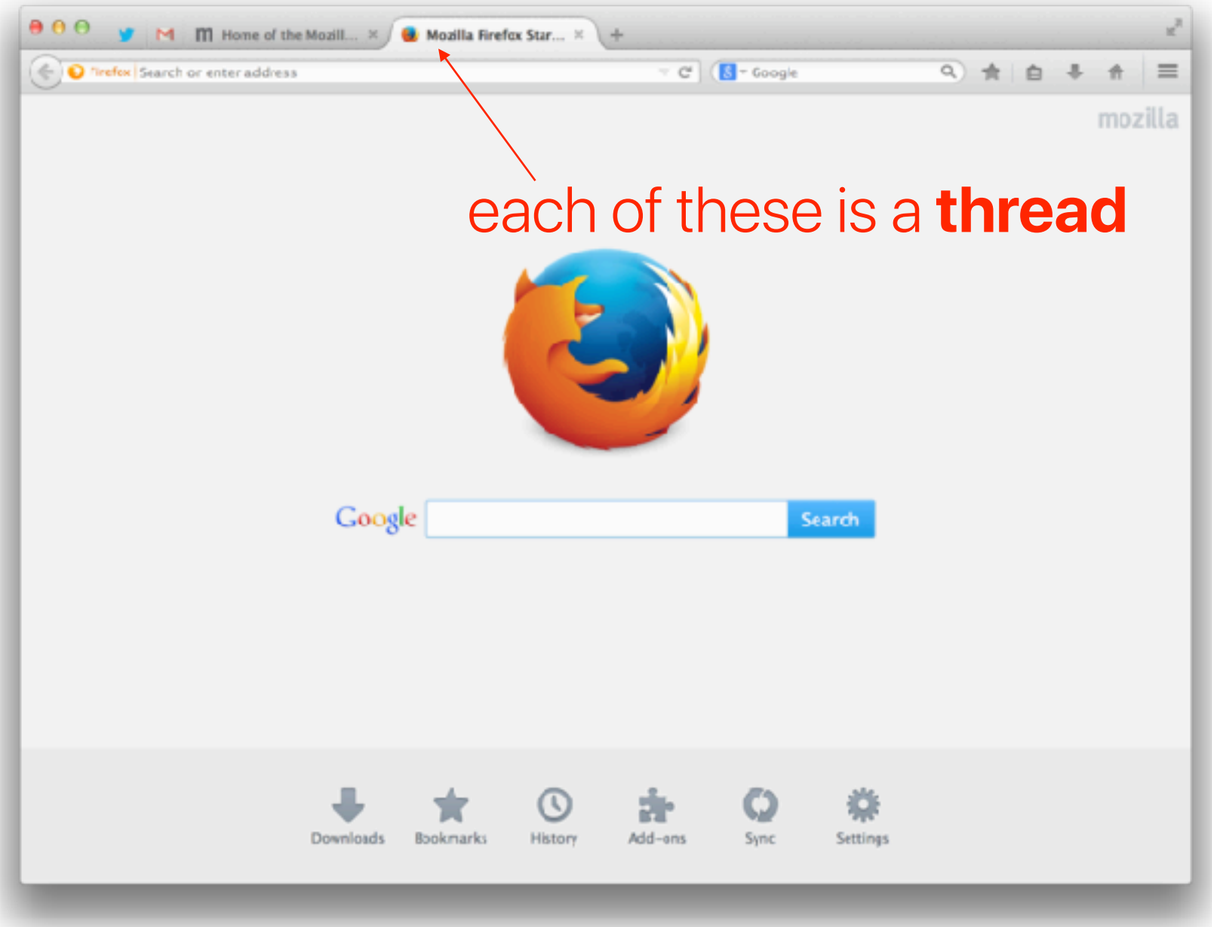
Intel Sandy Bridge



Case study: Chrome v.s. Firefox



each of these is a **process**



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Memory usage?

Stability?

Security?

Latency?

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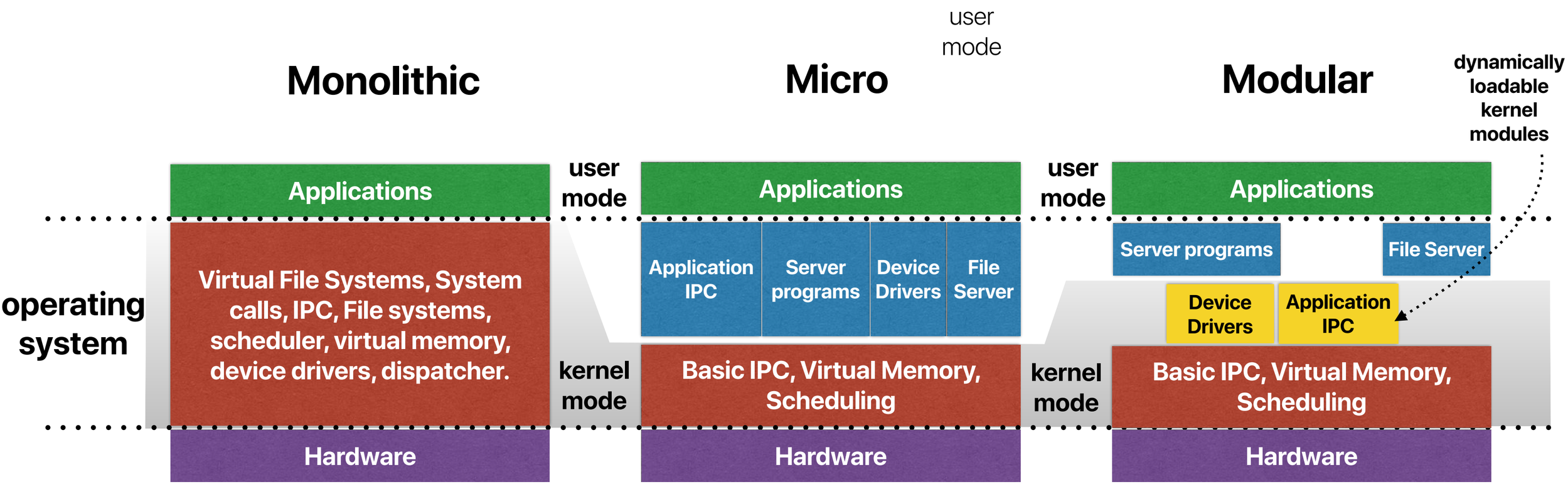
Types of Kernels



Original UNIX

Hydra, Mach

Linux, Windows, MacOS

Poll close in 1:30

Why not microkernels?

- Although Mach's design strongly influenced modern operating systems, why most modern operating systems do not adopt the design of microkernels?
  A. Microkernels are more difficult to extend than monolithic kernels
  B. Microkernels are more difficult to maintain than monolithic kernels
  C. Microkernels are less stable than monolithic kernels
  D. Microkernels are not as competitive as monolithic kernels in terms of application performance
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  D. Microkernels are not as competitive as monolithic kernels in terms of application performance **Context switches!**
  E. Microkernels are less flexible than monolithic kernels

The impact of Mach

- Threads
- Extensible operating system kernel design
- Strongly influenced modern operating systems
  - Windows NT/2000/XP/7/8/10
  - MacOS

Mach Overview

The fundamental services and primitives of the OS X kernel are based on Mach 3.0. Apple has modified and extended Mach to better meet OS X functional and p

Mach 3.0 was originally conceived as a simple, extensible, communications microkernel. It is capable of running as a stand-alone kernel, with other traditional o networking stacks running as user-mode servers.

However, in OS X, Mach is linked with other kernel components into a single kernel address space. This is primarily for performance; it is much faster to make a messages or do remote procedure calls (*RPC*) between separate tasks. This modular structure results in a more robust and extensible system than a monolithic k microkernel.

Thus in OS X, Mach is not primarily a communication hub between clients and servers. Instead, its value consists of its abstractions, its extensibility, and its flex

- object-based APIs with communication channels (for example, ports) as object references
- highly parallel execution, including preemptively scheduled threads and support for *SMP*
- a flexible scheduling framework, with support for real-time usage
- a complete set of *IPC* primitives, including messaging, *RPC*, synchronization, and notification
- support for large virtual address spaces, shared memory regions, and memory objects backed by persistent store
- proven extensibility and portability, for example across instruction set architectures and in distributed environments
- security and resource management as a fundamental principle of design; all resources are virtualized

Mach Kernel Abstractions

Mach provides a small set of abstractions that have been designed to be both simple and powerful. These are the main kernel abstractions:

- *Tasks*. The units of resource ownership; each task consists of a virtual address space, a *port right namespace*, and one or more *threads*. (Similar to a process.
- *Threads*. The units of CPU execution within a task.
- *Address space*. In conjunction with memory managers, Mach implements the notion of a sparse virtual address space and shared memory.
- *Memory objects*. The internal units of memory management. Memory objects include named entries and regions; they are representations of potentially persi
- *Ports*. Secure, simplex communication channels, accessible only via send and receive capabilities (known as port rights).
- *IPC*. Message queues, remote procedure calls, notifications, semaphores, and lock sets.
- *Time*. Clocks, timers, and waiting.

Announcement

- Reading quizzes due next Tuesday
  - Welcome new friends! — will drop a total of 6 reading quizzes for the quarter
  - Attendance count as 4 reading quizzes
  - We plan to have a total of 11 reading quizzes
- Office Hour links are inside Google Calendar events
  - https://calendar.google.com/calendar/u/0/r?cid=ucr.edu_b8u6dvkretn6kq6igunlc6bldg@group.calendar.google.com
  - Different links from lecture ones
  - We cannot share through any public channels so that we can better avoid Zoom bombing
- We will make both midterm and final exams online this quarter
  - Avoid the uncertainty of COVID-19
  - Avoid high-density in the classroom (only sits 60 and we have 59 for now) during examines

Computer
Science &
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