CS 370: OPERATING SYSTEMS

[INTER PROCESS COMMUNICATIONS]

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Topics covered in this lecture

- Briefly, microkernels
- Inter Process Communications
  - Messaging
  - Pipes
- Threads

MICROKERNELS

The Microkernel Approach [1/2]

- Mid 1980's at Carnegie Mellon University
  - **Mach**
- Structure OS by *removing non-essential components* from the kernel
  - Implement other things as system/user programs
- Provide minimal process and memory management
- Main function: Provide communication facility between client and services
  - **Message passing**

The Microkernel Approach [2/2]

- Traditionally all the layers went in the kernel
  - But this is not really necessary
- In fact, it may be best to *put as little as possible* in the kernel
  - Bugs in the kernel can bring down the system instantly
- Contrast this with setting up user processes to have less power
  - A bug may not be fatal

Getting there …

- Achieve high reliability by splitting OS in small, well-defined modules
  - One of these, the microkernel, runs in the kernel mode
  - The rest as relatively powerless ordinary user processes
- Running each device driver as a separate process?
  - Bugs cannot crash the entire system

Communications in the micro-kernel

- Client and service never interact directly
- Indirect communications by exchanging messages with the microkernel
- Advantages
  - Easier to port to different hardware
  - More security and reliability
    - Most services run as user, rather than kernel
- **Mac OS X kernel based on Mach microkernel**
  - XNU: 2.5 Mach, 4.3 BSD and Objective-C for device drivers

Increased system function overhead can degrade microkernel performance

- Windows NT: First release, layered microkernel
  - Lower performance than Windows 95
- Windows NT 4.0 solution
  - Move layers from user space to kernel space
- By the time Windows XP came around
  - More monolithic than microkernel

IPC communications: Mach

- Tasks are similar to processes
  - Multiple threads of control

- Most communications in Mach use **messages**
  - System calls
  - Inter-task information
  - Sent and received from mailboxes: *ports*

Mach: Task creation and mailboxes

- Task creation results in 2 more mailboxes
  1. Kernel mailbox: Used by kernel to communicate with task
  2. Notify mailbox: Notification of event occurrences

- System calls for communications
  - `msg_send()`, `msg_receive()` and `msg_rpc()`

Mach: Mailbox creation

- Done using the `port_allocate()`
  - Allocate space for message queue
    - MAX_SIZE default is 8 messages
- Creator is owner and can also receive
- Only task can own/receive from mailbox
  - BUT these **rights can be sent** to other tasks

Mach: Message queue ordering

- FIFO guarantees for messages from same sender
- Messages from multiple senders queued in any order

Mach: Send and receive operations

- If mailbox is not full, copy message
- If mailbox is FULL
  1. Wait indefinitely till there's room
  2. Wait at most **n** milliseconds
     - Don't wait, simply return
  3. Temporarily cache the message
     - **Only 1** message to a full mailbox can be *pending* for a *given* sending thread
- Receive can specify mailbox or mailbox set

Another idea related to microkernels

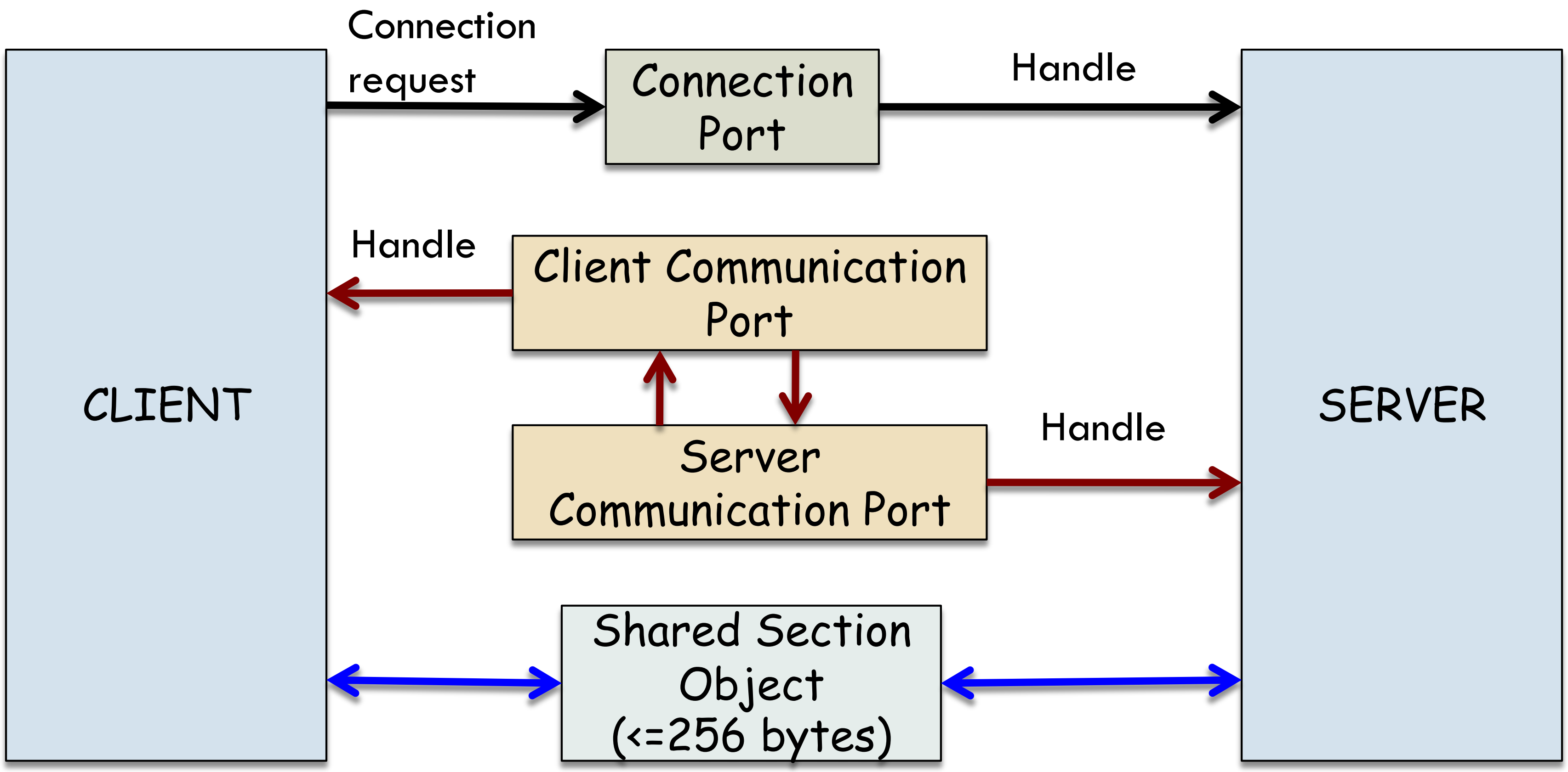
- Put **mechanisms** for doing something in the *kernel*
  - But not the policy
- Example: Scheduling
  - Policy of assigning priorities to processes can be done in the user-mode
  - The mechanism to look for the highest priority process and schedule it is in the kernel

Message Passing in Windows XP

Message passing in Windows XP

- Called the local procedure call (LPC) facility
- Communications provided by **port** objects
  - Give applications a way to set up communication channels
- Uses two types of message passing
  - Small messages (max 256 bytes)
  - Large messages

Connection ports are named objects visible to all processes [LPC in XP]



Sets up a region of shared memory

Windows XP message passing
Small messages

- Use port's internal message queue as intermediate storage
- Copy messages from one process to another

Windows XP message passing: Large messages

- Send message through **section object**
  - Sets up shared memory
- Section object info sent as a <u>small message</u>
  - Contains pointer + size information about section object

Windows XP message passing: Large messages

- 2 ends of communications set up section objects if the request or reply is large
- Complicated, but **avoids data copying**
- **Callbacks** used if the endpoints are busy
  - Allows delayed responses
  - Allows asynchronous message handling

PIPES

Pipes

- Pipes serve as a **conduit** for communications between processes
- One of the first IPC implementation mechanisms

Issues to consider when implementing a pipe

- Unidirectional or bidirectional
- If it is bidirectional
  - **Half duplex**: Data can travel one way at a time
  - **Full duplex**: Data traversal in both directions *simultaneously*
- Must a relationship exist between the endpoints?
  - e.g parent-child
- Range of communications
  - Intra-machine or Over the network

Pipes in practice

- Set up pipe between commands

```
ls | more
```

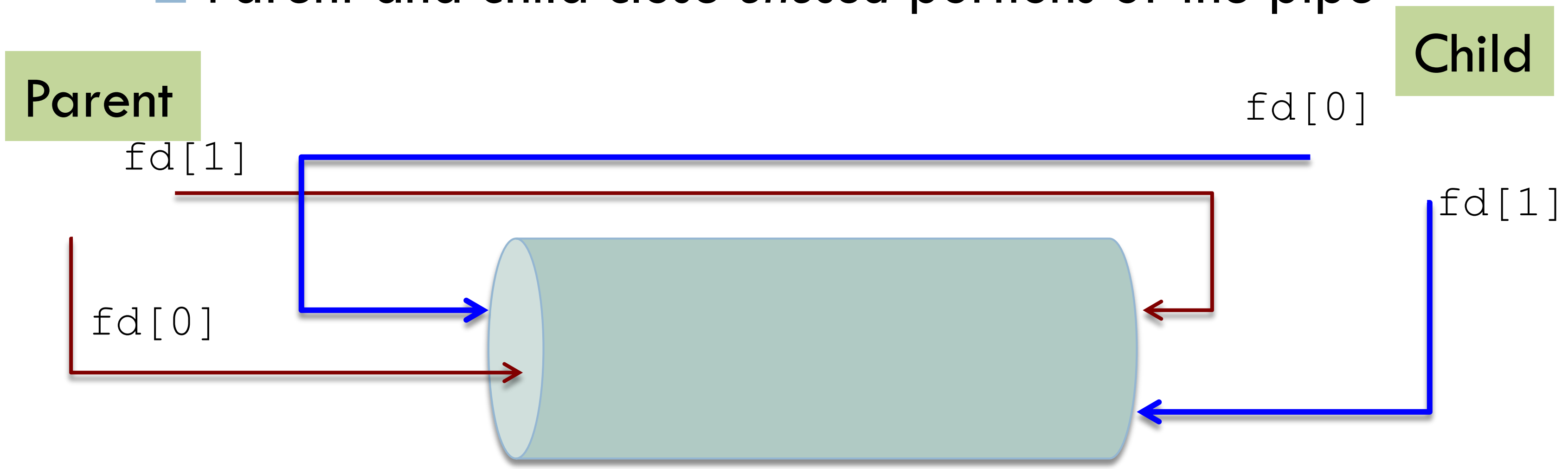
Output of **`ls`** delivered as input to **`more`**

Ordinary (anonymous) pipes

- Producer writes to one end of the pipe
- Consumer reads from the other end
- In UNIX: `pipe(int fd[])` to create pipe
  - `fd[0]` is the read-end
  - `fd[1]` is the write-end
  - Treats a pipe as a **special type of file**
    - Access with `read()` and `write()` system calls

A child inherits open files from its parent

- Since a pipe is a special type of file, the pipe is also inherited.
  - Parent and child close *unused* portions of the pipe



`fd[0]` is the read-end
`fd[1]` is the write-end

Pipes: Example

```
if (pipe(fd) == -1) {
    /* creation failed */
}
pid = fork();

if (pid > 0) {
    close(fd[READ_END]);
   write(fd[WRITE_END], write_msg,…);
}

if (pid == 0) {
    close(fd[WRITE_END]);
   read(fd[READ_END], …);
}
```

Windows Ordinary Pipes: These are unidirectional

- Anonymous Pipes
- Child **does not** automatically inherit pipe
  - Programmer *specifies* attributes a child will inherit
  - Initialize `SECURITY_ATTRIBUTES` to allow handles to be inherited
  - Redirect child's standard I/O handles to read/write handle of pipe
  - Pipes are half duplex

Some other things about ordinary pipes on UNIX and Windows

- Requires **parent-child** relationship
  - MUST be on same machine
- **Exist** only when processes communicate with one another
  - Upon termination, pipe ceases to exist

Named Pipes

- **No** parent-child relationship needed
- Once named pipe is established
  - *Several* processes can use it for communications
- Continues to exist after communicating processes have finished.

Named Pipes on UNIX/Windows

- Referred to as **FIFO** on UNIX systems, manipulated like a file
  - Created with `mkfifo()`
  - Manipulated with `open()`, `read()`, `write()` etc
- FIFO: **half-duplex** transmissions on Linux
  - If data must go both ways: use 2 FIFOs
  - Sockets can be used for inter-machine communications
- Windows: Full duplex communications

Communications in Client-Server Systems

Remote Procedure Calls

- Abstracts procedure call mechanisms for use with network endpoints
- Based on the **request/reply** model
- Message is addressed to the **RPC daemon** listening to a port for incoming traffic
  - Contains identifiers of function to execute
  - Parameters to pass to the function

Remote Procedure Calls

- Application makes CALL into a procedure
  - May be local or remote **and**
  - BLOCKS until call returns

- Origins:
  - **RFC 707** (1976).
  - First use by Xerox 1981 (Courier)
  - 1984 paper by Birell and Nelson

RPCs are slightly more complicated than local procedure calls

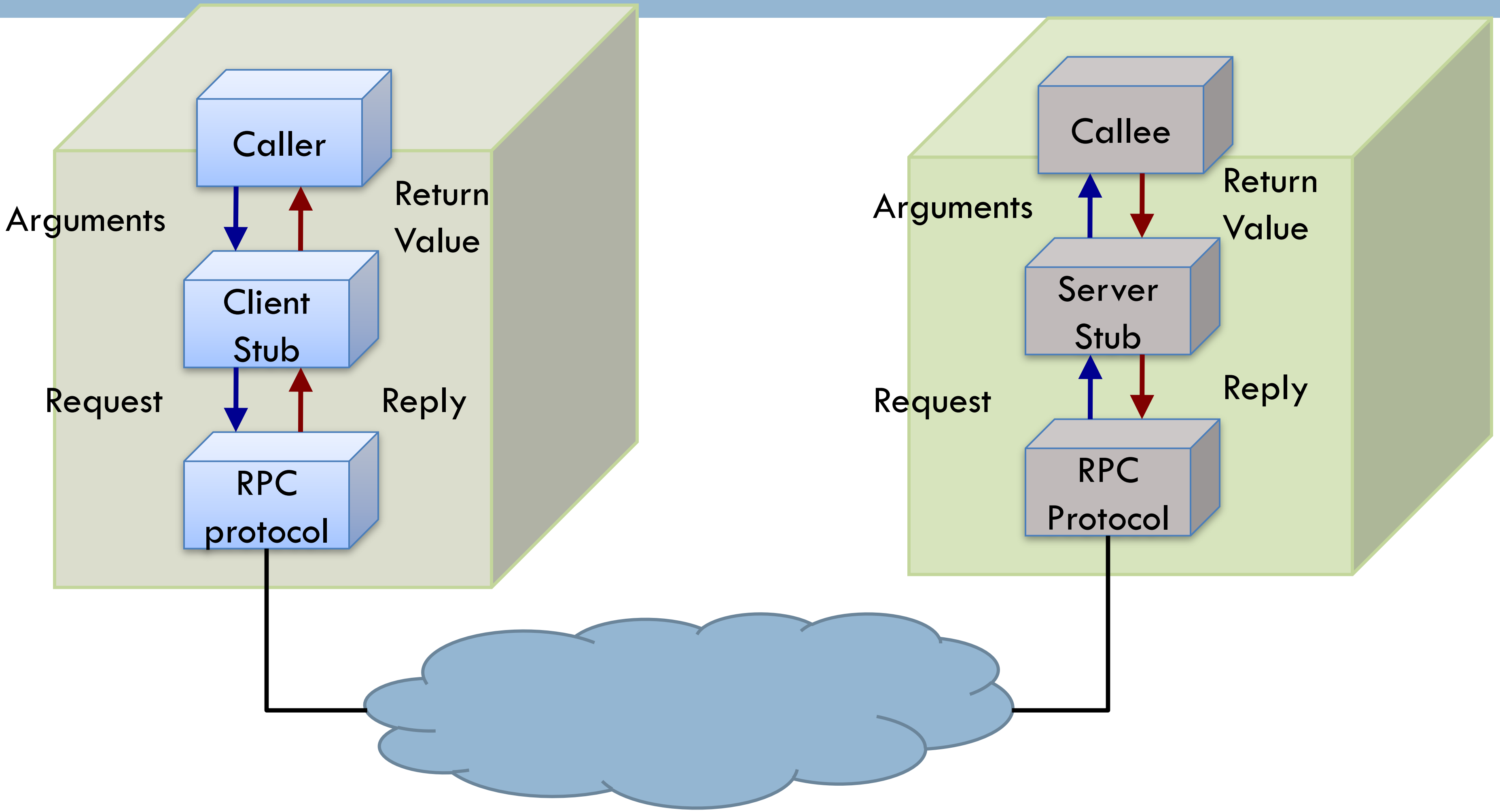
- Network between the *Calling* process and *Called* process can
  - **Limit** message sizes,
  - **Reorder** them or
  - **Lose** them

- Computers hosting processes may differ
  - Architectures and data representation formats.

Resolving big-endian/little endian issues

- Big endian: Store **MSB** first
- Little endian: Store **LSB** first
- Machine independent data representation
  - XDR: e**X**ternal **D**ata **R**epresentation
  - Client side parameter marshalling
    - Convert machine-dependent data to XDR
  - Server side
    - Convert XDR data to machine dependent representation

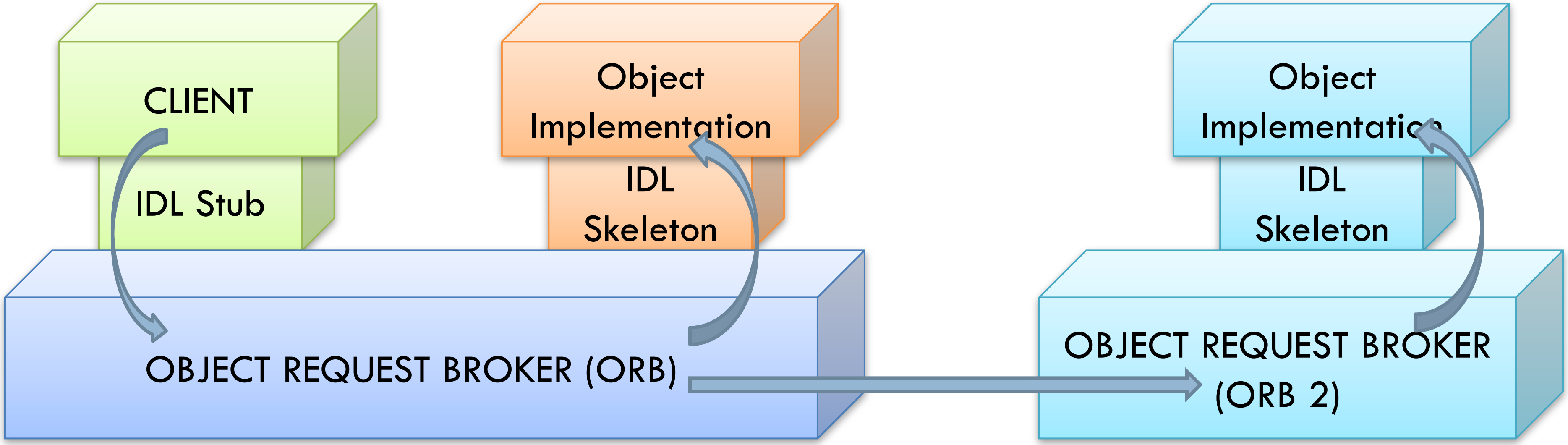
RPC mechanism



Distributed Objects

- RPC based on distributed objects with an **inheritance** mechanism
- *Create*, *invoke* or *destroy* remote objects, and interact as if they are local objects
- Data sent over network:
  - **References**: class, object and method
  - Method *arguments*
- CORBA early1990s, RMI mid-late 90s

Distributed Objects in CORBA defined using the Interface Definition Language



GIOP/IIOP
General Inter-ORB Protocol/Internet Inter-Orb Protocol

THREADS

Some background on threading

- Exploited to make programs **easier** to write
  - Split programs into separate tasks
- Took off when GUIs became standard
  - User **perceives** better performance
    - Programs did not run faster: this was an illusion
    - Dedicated thread to service input OR display output
- Growing trend to **exploit** available processors on a machine

What are threads?

- Miniprocesses or lightweight processes
- Why would anyone want to have a *kind of process* **within** a process?

The main reason for using threads

- In many applications *multiple activities* are going on at once
  - Some of these may block from time to time
- Decompose application into multiple sequential threads
  - Running in **quasi-parallel**

Isn’t this precisely the argument for processes?

- Yes, *but* there is a new dimension …
- Threads have the ability to **share the address space** (and all of its data) among themselves
- For several applications
  - Processes (with their *separate* address spaces) don’t work

Threads are also lighter weight than processes

- **Faster** to create and destroy than processes
- In many systems thread creation is 10-100 times faster
- When number of threads needed changes dynamically and rapidly?
  - Lightweight property is very useful

Threads: The performance argument

- When all threads are CPU bound all the time?
  - Additional threads would likely yield **no** performance gain

- But when there is substantial computing ***and substantial I/O***
  - Having threads allows activities to **overlap**
  - Speeds up the application possibly

An Example Application
Word Processor

Our Word Processor

- Displays document being created on the screen
- Document formatted exactly as it will appear on a printed page

Let’s take a look at someone editing a 800-page document

- User deletes one sentence from Page-1 of a 800-page document

- Now user wants to make a change on page 600
  - Either go to that page or search for term that only appears there

Page 600 after the edit on Page 1

- Word processor *does not know* what's the first line on page 600
- Word processor has to **reformat** entire book up to page 600
- Threads could help here …

Suppose the word processor is written as a 2-threaded program

- One thread **interacts** with the user
- The second thread handles **formatting** in the background
- As soon as the sentence is deleted
  - Interactive thread tells formatter thread to format the book

While we are at it, why not add a third thread?

- Automatically save file every few minutes
- Handle disk backups *without interfering* with the other 2 threads

What if the program were single threaded?

- Whenever disk backup started
  - Commands from keyboard/mouse would be **ignored** till backup was finished
  - User perceives sluggish performance
- Alternatively, keyboard/mouse events could *interrupt* the disk backup
  - Good performance
  - Complex, interrupt-driven programming

With 3 threads the programming model is simpler

- First thread **interact**s with the user
- Second thread **reformat**s when told to
- Third thread **write**s contents of RAM on to disk periodically

Three separate processes WOULD work here

- **All three** threads need to operate on document
- By having 3 threads instead of 3 processes
  1. The threads share a **common memory**
  2. Have access to document being edited

- Using processes would require setting up shared memory space, synchronizations, IPC etc. Doable, but much more tedious
  - Tend to use threads when working on the same data within the process

Applications are typically implemented as a process with multiple threads of control

- Perform different tasks in the application
  - Web browser
    - Thread A: Render images and text
    - Thread B: Fetch network data
- Assist in the performance of several similar tasks
  - Web Server: Manages requests for web content
    - Single threaded model: One client at a time
      - Poor response times
    - Multithreaded model: Multiple clients served *concurrently*

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 3]
- *Andrew S Tanenbaum. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2]
- *Kay Robbins & Steve Robbins. Unix Systems Programming, 2nd edition, Prentice Hall ISBN-13: 978-0-13-042411-2.* [Chapter 3, 4]