06-06798 Distributed Systems

Lecture 6:
Operating System Support

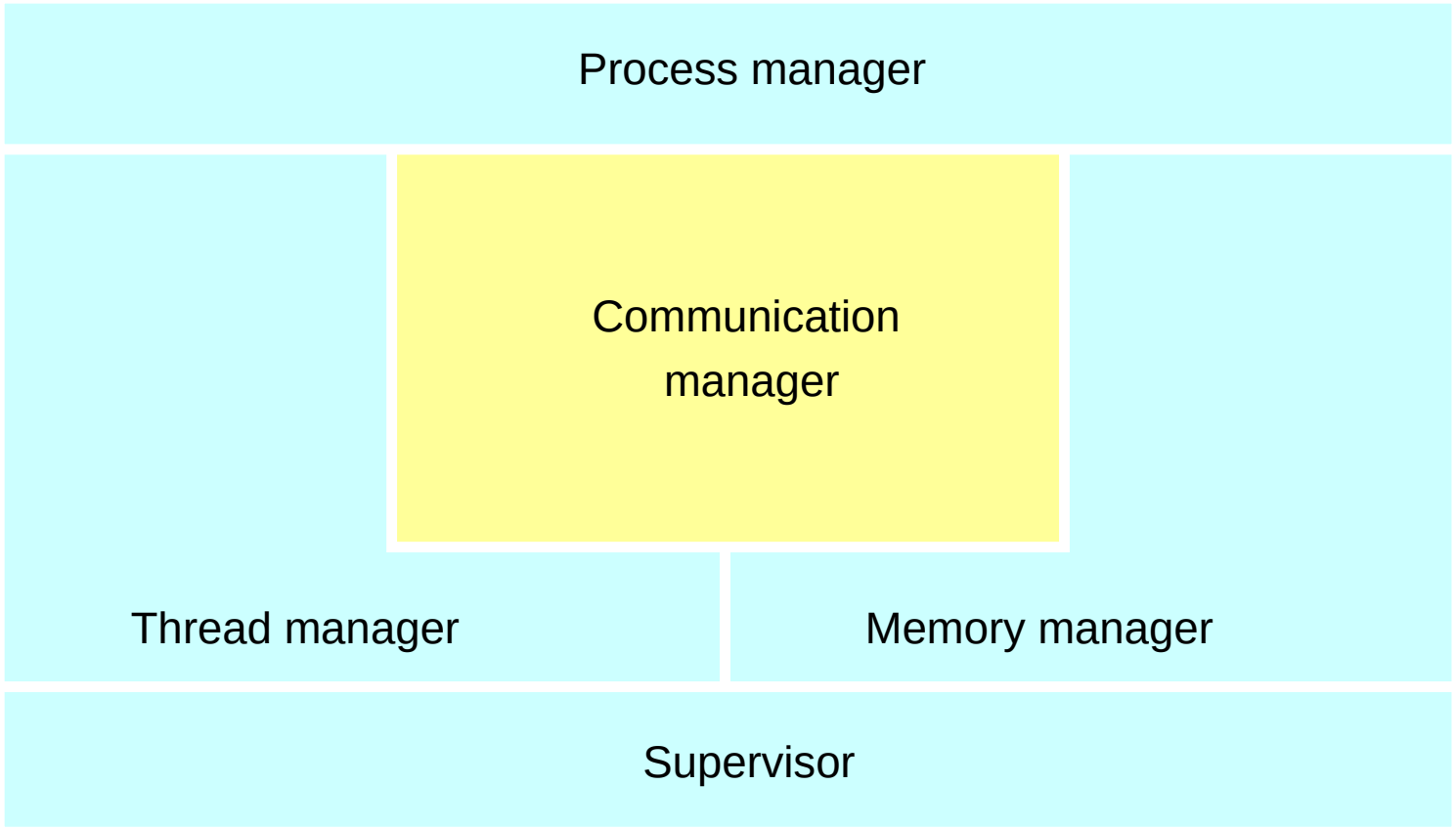
Overview

- Functionality of the Operating System (OS)
  - resource management (CPU, memory, …)
- Processes and Threads
  - similarities, differences
  - multi-threaded servers and clients
- Implementation of...
  - communication primitives
  - invocation

Functionality of OS

- Resource sharing
  - CPU (single/multiprocessor machines)
    - concurrent processes/threads
    - communication/synchronisation primitives
    - process scheduling
  - memory (static/dynamic allocation to programs)
    - memory manager
  - file storage and devices
    - file manager, printer driver, etc
- OS kernel
  - implements CPU and memory sharing
  - abstracts hardware

Core OS functionality



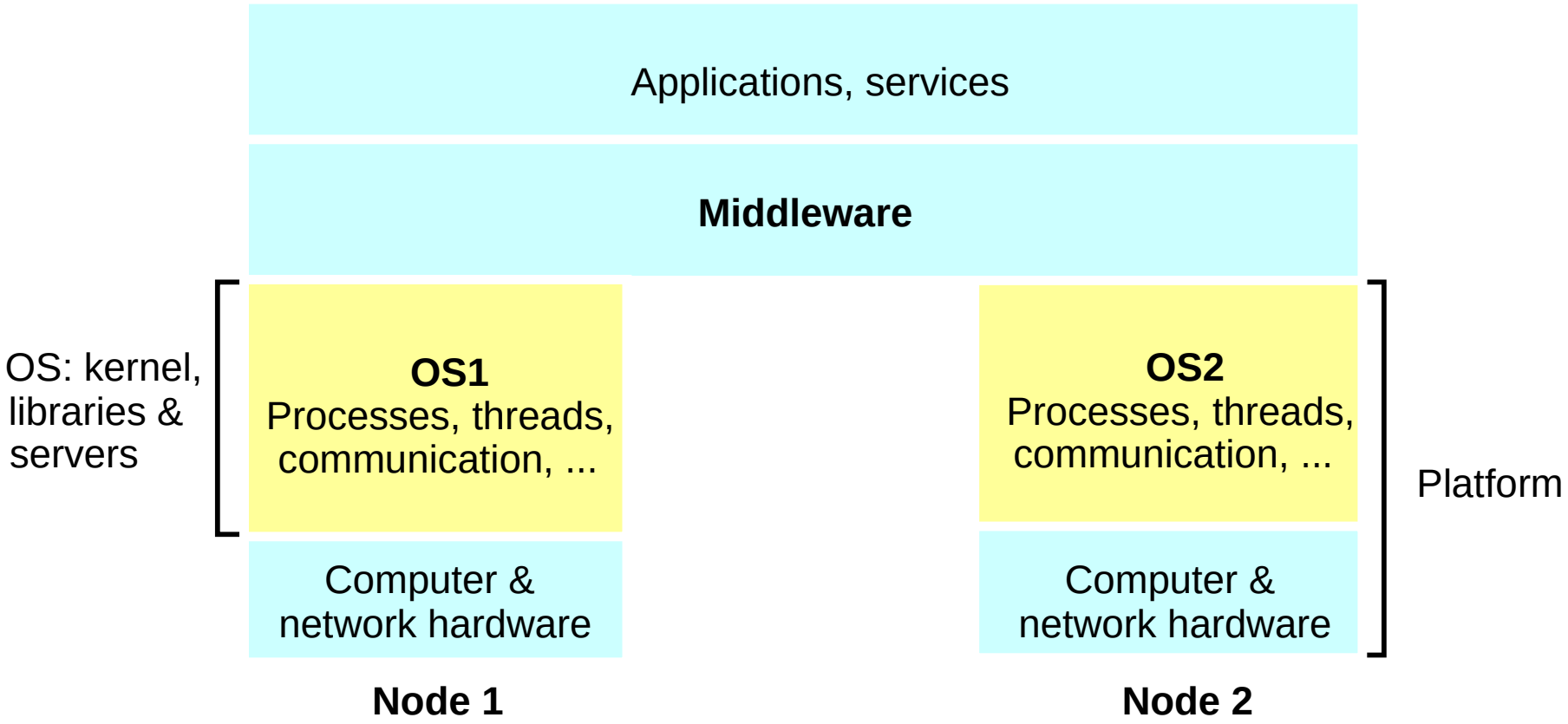
Core OS components

- Process manager
  - creation and operations on processes (= space+threads)
- Threads manager
  - threads creation, synchronisation, scheduling
- Communication manager
  - communication between threads (sockets, semaphores)
- Memory manager
  - physical (RAM) and virtual (disk) memory
- Supervisor
  - hardware abstraction (interrupts, exceptions, caches)

Why middleware again...

- Network OS (UNIX, Windows NT)
  - network transparent access for remote files (NFS)
  - no task/process scheduling across different nodes
- Distributed OS
  - transparent process scheduling across nodes
  - load balancing
  - none in use… cost of switching OS too high, load balancing not always easy to achieve
- Middleware
  - built on top of different network OSs
  - offers distributed resource sharing

System layers



In this lecture...

which OS mechanisms are needed for middleware

- Concurrent processing of client/server processes
  - creation, execution, etc
  - data encapsulation
  - protection against illegal access
- Implementation of invocation
  - communication (parameter passing, local or remote)
  - scheduling of invoked operations

Protection

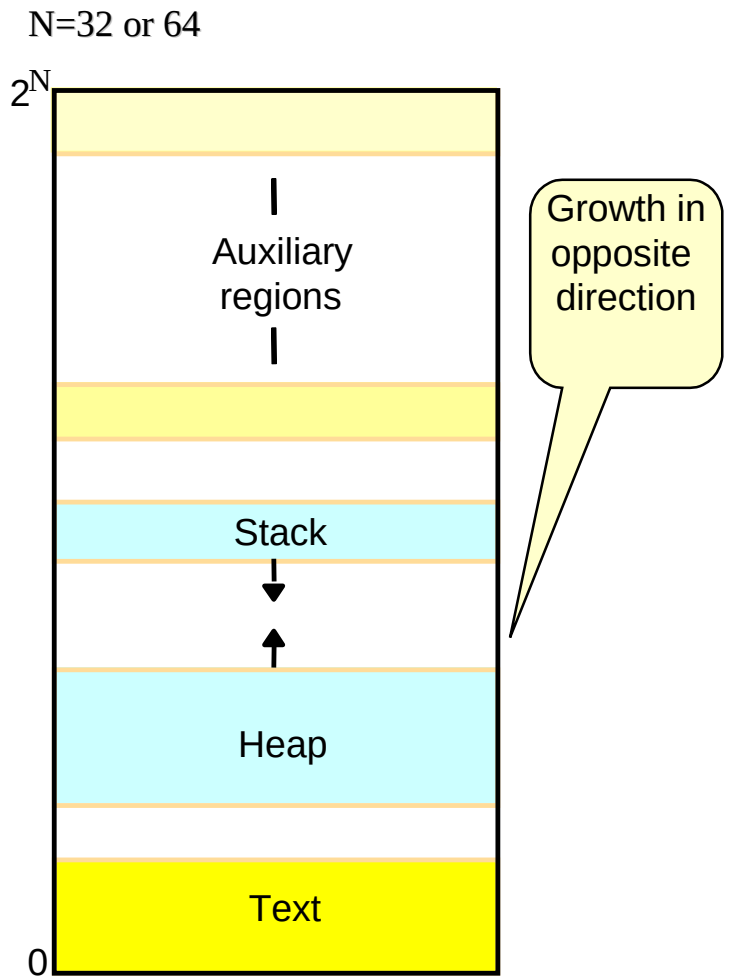
- Kernel
  - complete access privileges to all physical resources
  - executes in supervisor mode
- Application programs
  - have own address space, separate from kernel and others
  - execute in user mode
- Access to resources
  - calls to kernel (system call trap), interrupts
  - switch to kernel address space
  - can be expensive in terms of time

Processes and threads

- Processes
  - historically first abstraction of single thread of activity
  - can run concurrently, CPU sharing if single CPU
  - need own execution environment
    - address space, registers, synchronisation resources (semaphores)
  - scheduling requires switching of environment
- Threads (=lightweight processes)
  - can share execution environment
    - no need for expensive switching
  - can be created/destroyed dynamically
    - multi-threaded processes
    - increased parallelism of operations (=speed up)

Process/thread address space

- Unit of virtual memory
- One or more regions
  - contiguous
  - non-overlapping
  - gaps for growth
- Allocation
  - new region for each thread
  - sharing of some regions
    - shared libraries, data,...



Process/thread creation

- OS kernel operation (cf UNIX *fork*, *exec*)
- Varying policies for
  - choice of host
    - clusters, single- or multi-processors
    - load balancing
  - creation of execution environment
    - allocate address space
    - initialise or copy from parent?

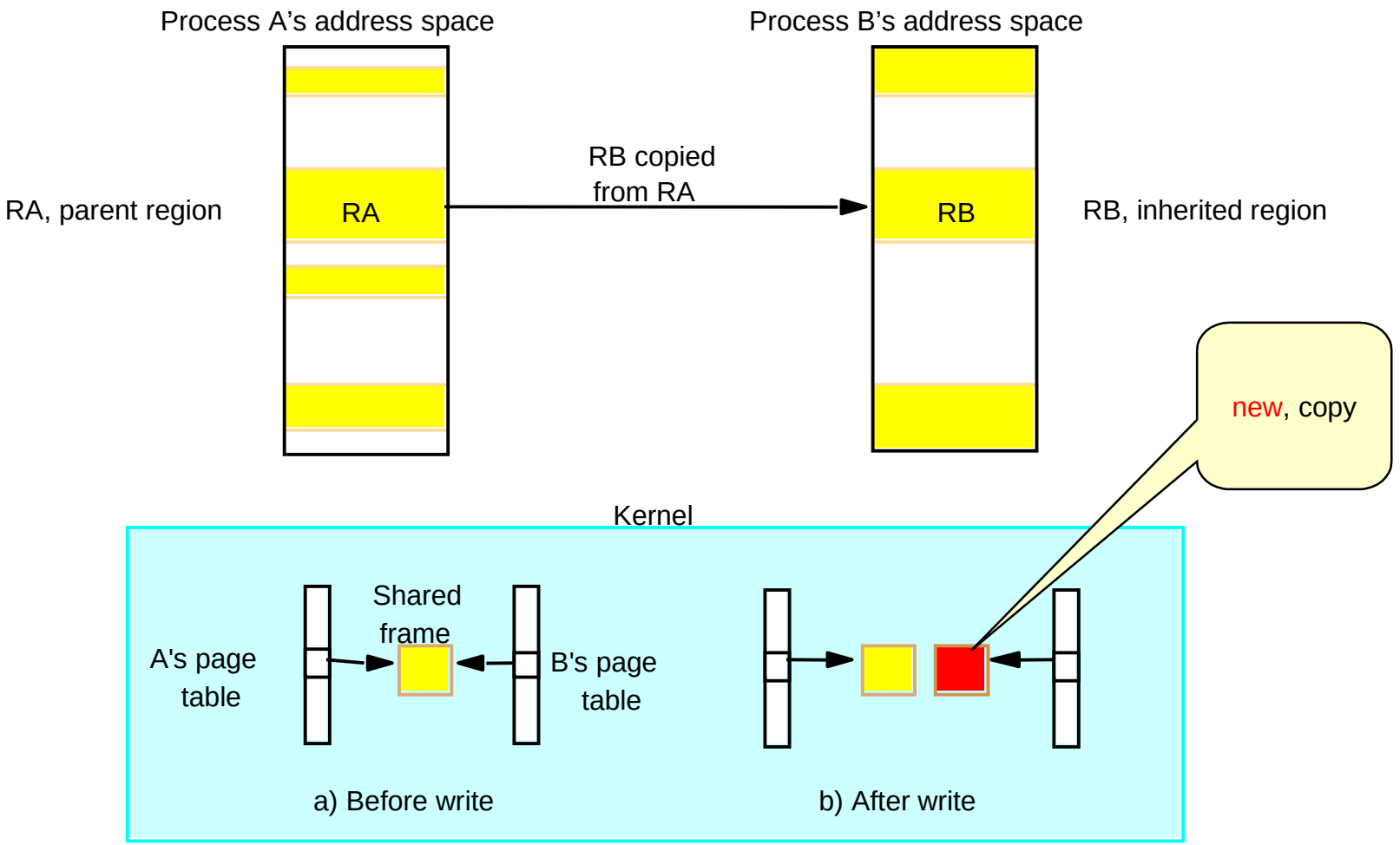
Choosing a host...

- Local or remote?
  - migrate process if load on local host high
- Load sharing to optimise throughput?
  - static: choose host at random/deterministically
  - adaptive: observe state of the system, measure load & use heuristics
- Many approaches
  - simplicity preferred
  - load measuring expensive.

Creating execution environment

- Allocate address space
- Initialise contents
  - fill with values from file or zeroes
    - for static address space but time consuming
  - copy-on-write
    - allow sharing of regions between parent & child
    - physical copying only when either attempts to modify (hardware *page fault*)

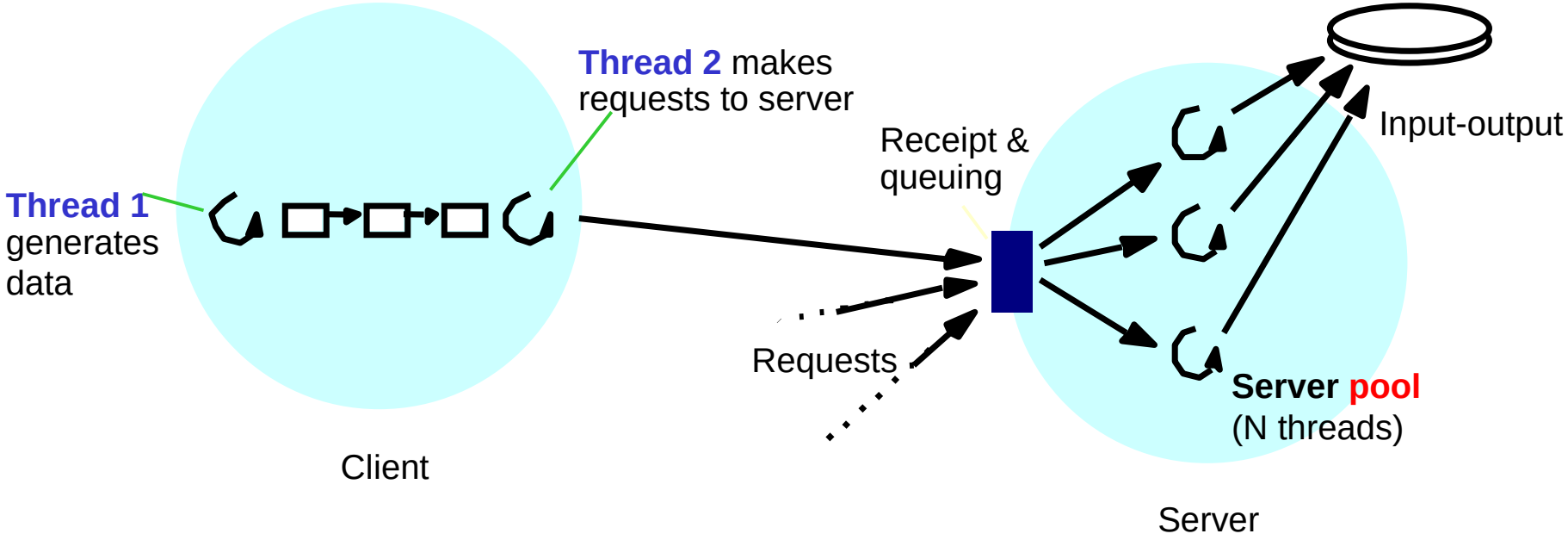
Copy-on-write



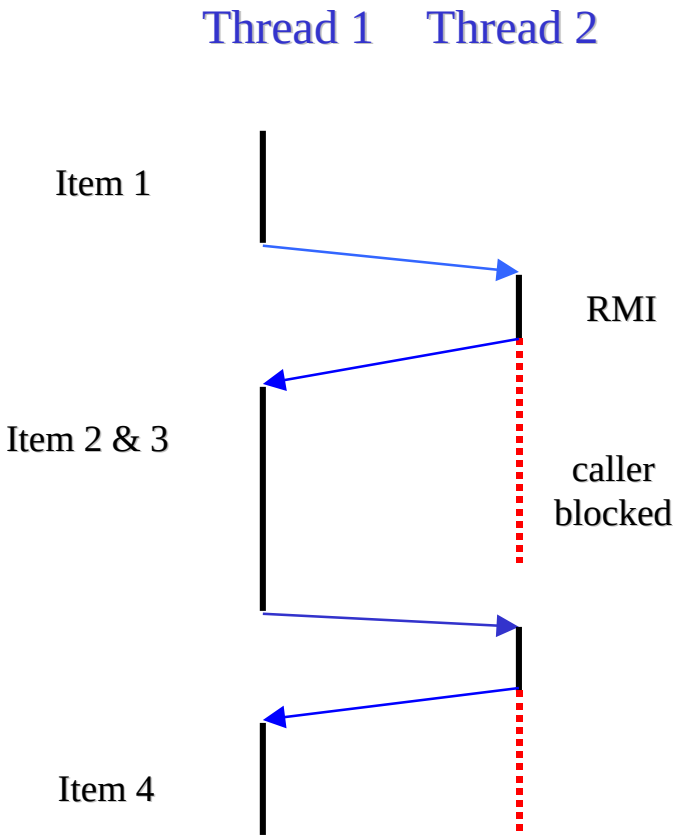
Role of threads in clients/servers

- On a single CPU system
  - threads help to logically decompose problem
  - not much speed-up from CPU-sharing
- In a distributed system, more waiting
  - for remote invocations (blocking of invoker)
  - for disk access (unless caching)
  - obtain better speed up with threads

Multi-threaded client/server



Threads within clients



- Separate
  - data production
  - RMI calls to server
- Pass data via buffer
- Run concurrently
- Improved speed, throughput

Server threads and throughput

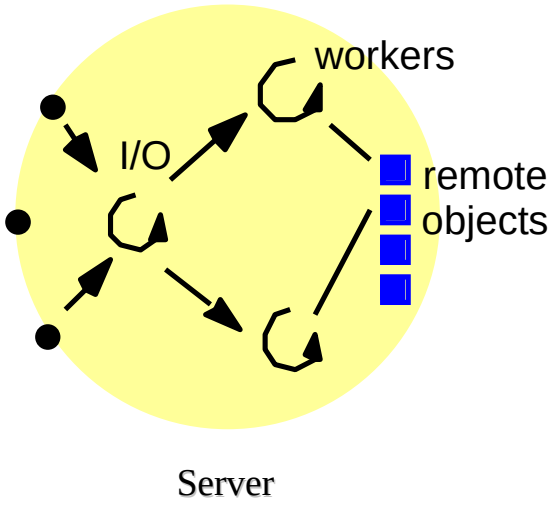
Assume stream of client requests, each 2ms processing + 8ms I/O.

- Single thread
  - max 100 client requests per second =1000/(2+8)
- Two threads, no disk caching
  - max 125 client requests per second =1000/8
- Two threads, with disk caching (75% hit rate)
  - max 400 client requests per second =1000/(0.75*0+0.25*8)

Multi-threaded server architectures

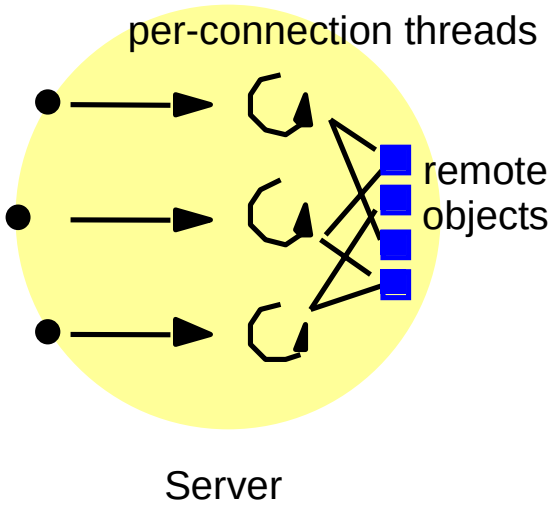
- Worker pool
  - fixed pool of worker threads, size does not change
  - can accommodate priorities but inflexible
- Other architectures
  - thread-per-request
  - thread-per-connection
  - thread-per-object
- Physical parallelism
  - multi-processor machines (cf casper, SoCS file server; noo-noo)

Thread-per-request



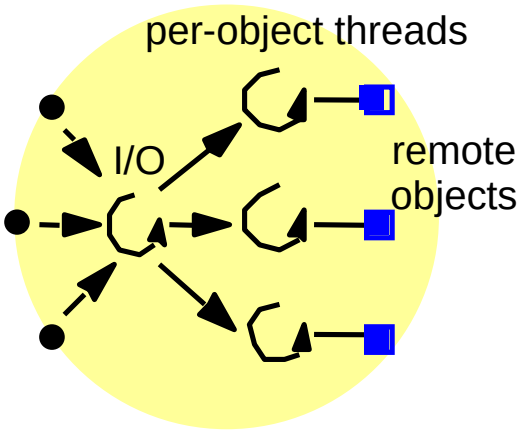
- Spawns
  - new worker for each request
  - worker destroys itself when finished
- Allows max throughput
  - no queuing
  - no I/O delays
- but overhead of creation & destruction high

Thread-per-connection



- Create new thread for each connection
- Multiple requests
- Destroy thread on close
- Lower o/heads
- but unbalanced load

Thread-per-object



As per-connection, but new thread created for each object.

Why threads not processes?

- Process context switching
  - requires save/restore of execution environment
    - registers, program counters, etc
- Threads within a process
  - cheaper to create/manage
  - no need to save execution environments (shared between threads)
  - resource sharing more efficient and convenient
  - but less protection from interference by other threads

Storing execution environment

Execution environment	***Thread***
Address space tables	Saved processor registers
Communication interfaces, open files	Priority and execution state (such as *BLOCKED*)
Semaphores, other synchronisation objects	Software interrupt handling information
List of thread identifiers	Execution environment identifier
Pages of address space resident in memory; hardware cache entries	

An aside: Java threads

- Class *Thread*
  - constructor/destructor, SUSPENDED/RUNNABLE
  - priorities (useful for *servlets*, dynamic web pages)
- Synchronisation
  - monitors (keyword *synchronised*)
  - at most one thread within monitor
- Scheduling
  - Preemptive (suspended at any time), non-preemptive
  - no real-time thread scheduling
- More info www.cdk3.net and
  - 06-02324 Real-Time Systems Programming

Java threads: management

Thread(ThreadGroup group, Runnable target, String name)

Creates a new thread in the *SUSPENDED* state, which will belong to *group* and be identified as *name*; the thread will execute the *run()* method of *target*.

setPriority(int newPriority), getPriority()

Set and return the thread's priority.

run()

A thread executes the *run()* method of its target object, if it has one, and otherwise its own *run()* method (*Thread* implements *Runnable*).

start()

Change the state of the thread from *SUSPENDED* to *RUNNABLE*.

sleep(int millisecs)

Cause the thread to enter the *SUSPENDED* state for the specified time.

yield()

Enter the *READY* state and invoke the scheduler.

destroy()

Destroy the thread.

Java threads: synchronisation

thread.join(int millisecs)

Blocks the calling thread for up to the specified time until *thread* has terminated.

thread.interrupt()

Interrupts *thread*: causes it to return from a blocking method call such as *sleep()*.

object.wait(long millisecs, int nanosecs)

Blocks the calling thread until a call made to *notify()* or *notifyAll()* on *object* wakes the thread, or the thread is interrupted, or the specified time has elapsed.

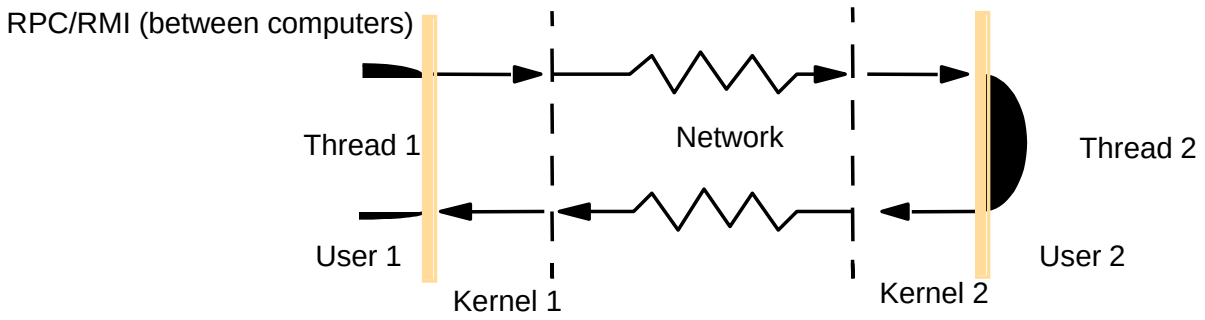
object.notify(), object.notifyAll()

Wakes, respectively, one or all of any threads that have called *wait()* on *object*.

Implementation of invocation

- Types of invocation
  - system call, RMI/RPC call, sending a message…
- Performance critical!
  - very high number of invocation per system lifetime
  - high latencies over WANs, Internet
- Counting cost of invocation
  - does it cross address space or not?
  - synchronous or asynchronous?
  - over the network or within computer?

Costing invocations over network



- Latency (=time of null invocation)
  - 0.1millisecond for RPC vs fraction of microsecond for local call
- Delay (=total RPC/RMI time experience by user)
  - marshalling, thread switching, which protocol, etc
- Need to design OS carefully!

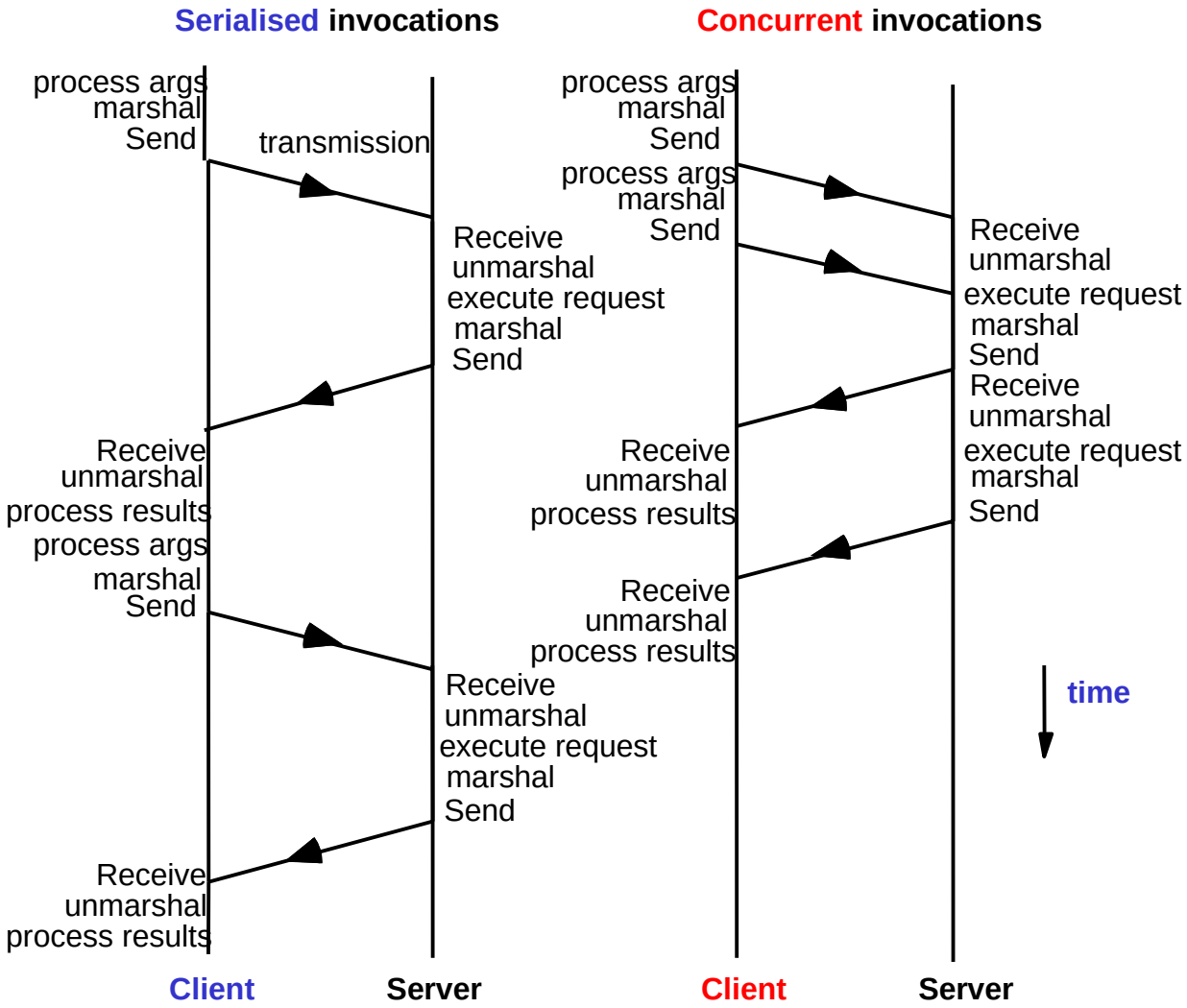
Factors affecting RPC/RMI delays

- Marshalling
- Data copying
  - user to kernel, across network, etc
- Packet initialisation
  - protocol headers, checksums
- Thread scheduling, context switching
- Waiting for acknowledgement
  - TCP or UDP?

Concurrent invocations

- Idea (similar to client threads earlier)
  - blocking invocations
  - perform them concurrently
- Example: web browser
  - issues separate HTTP *GET* requests for images within webpage
  - performed concurrently
- Gains
  - improved total delay and throughput
  - communication overlaps with rendering

Serialised and concurrent invocations



Asynchronous invocation

- Non-blocking invocation
  - client makes call (cf Mercury obtains *promise*)
  - continues processing
- Response
  - sometimes not needed
  - otherwise, separate call to collect results,
  - then *claim* on *promise* (test if results ready, block until results ready)
- Improved delay and throughput

Summary

- OS support crucial to performance of distributed systems
  - threads/process management
  - communication (sockets), protocols
  - support for asynchronous/concurrent invocation
- Design issues
  - structure and relationship of kernel & middleware
  - selection of multi-threaded or multi-processor architecture
  - understanding system requirements
    - max number of requests, min acceptable delay, throughput
    - network latency, bandwith, etc