Operating System Support

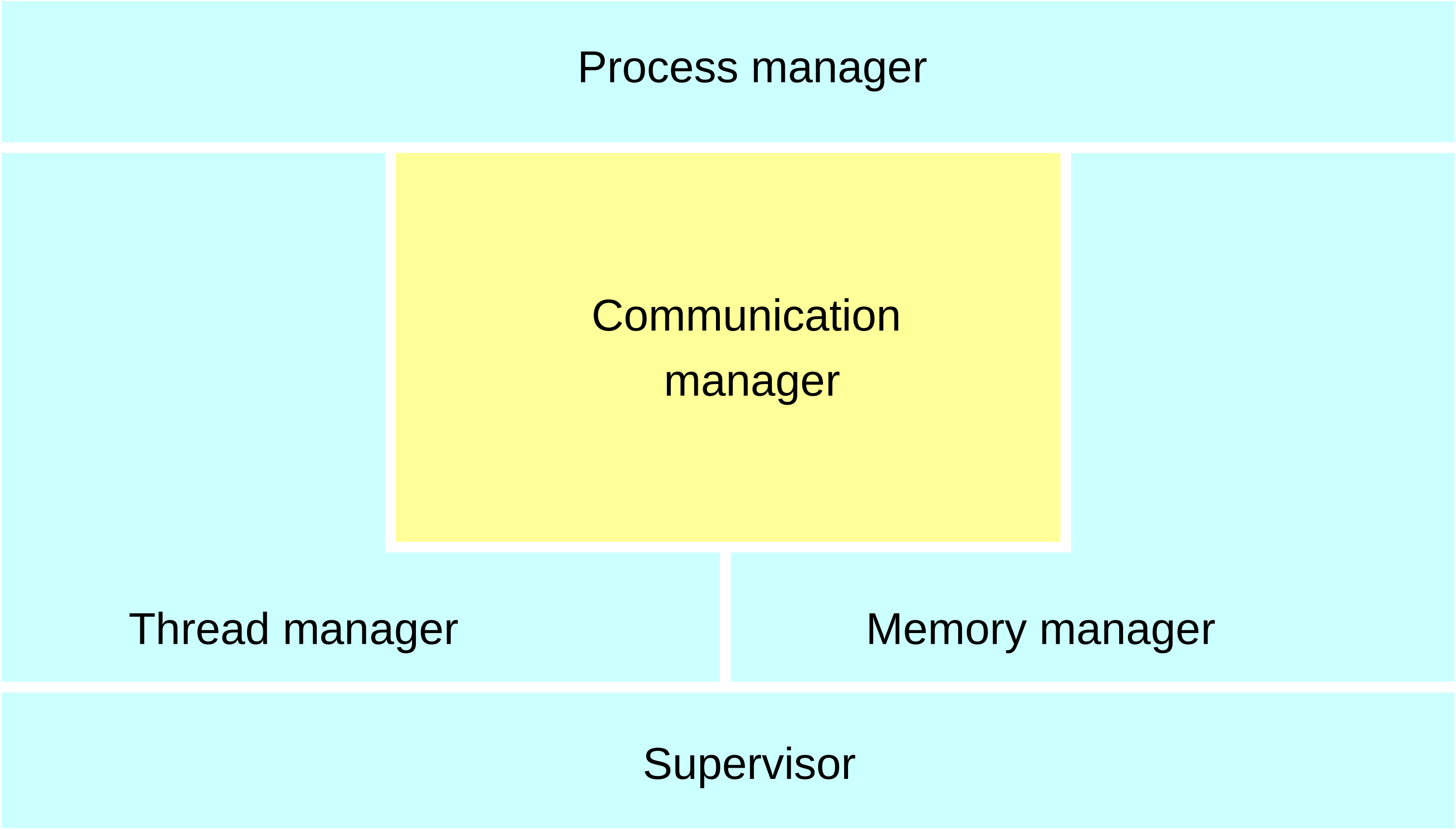
Overview

- 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



Process manager

Communication manager

Thread manager

Memory manager

Supervisor

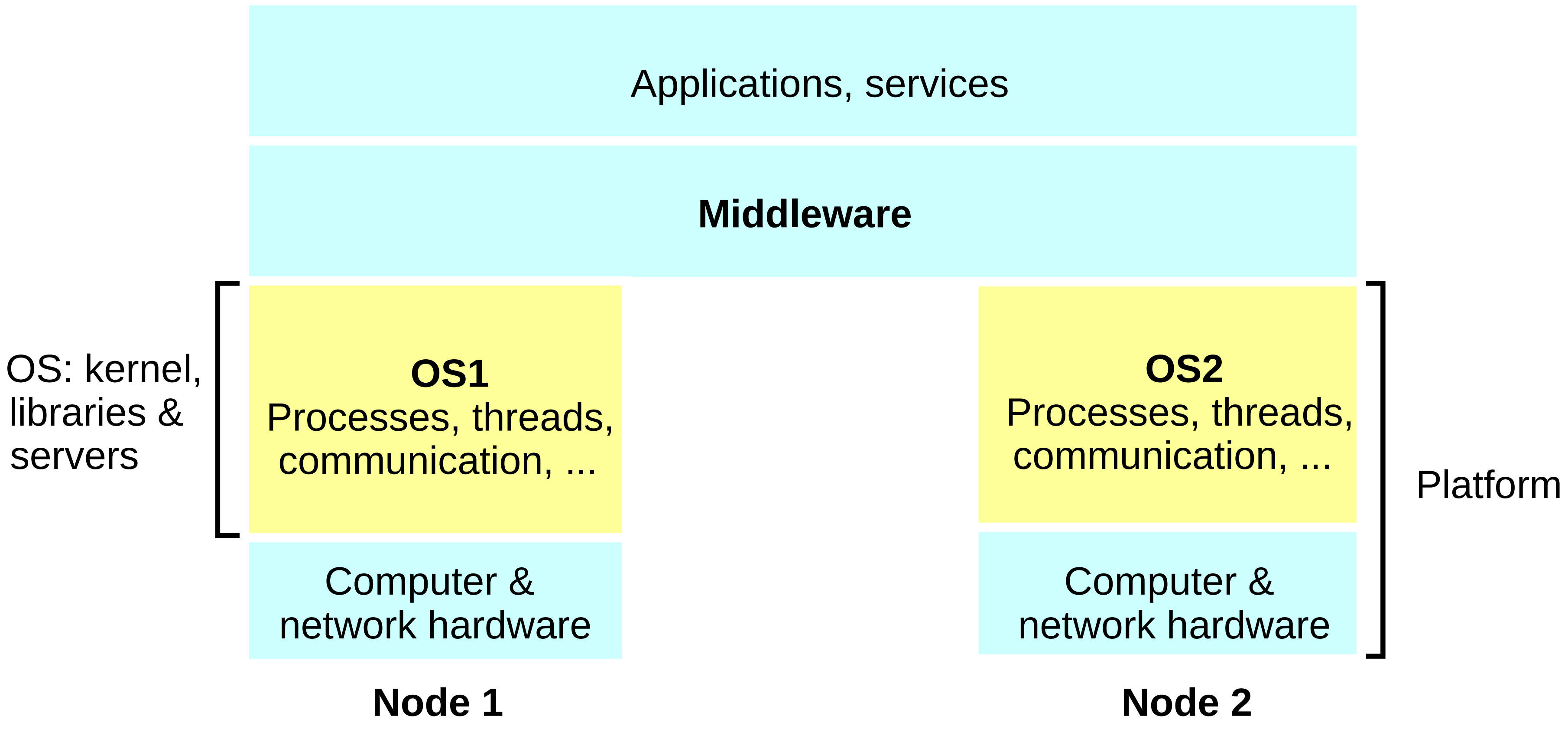
Core OS components

- 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



Applications, services

Middleware

OS: kernel,
libraries &
servers

OS1
Processes, threads,
communication, ...

Computer &
network hardware

Node 1

OS2
Processes, threads,
communication, ...

Computer &
network hardware

Node 2

Platform

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

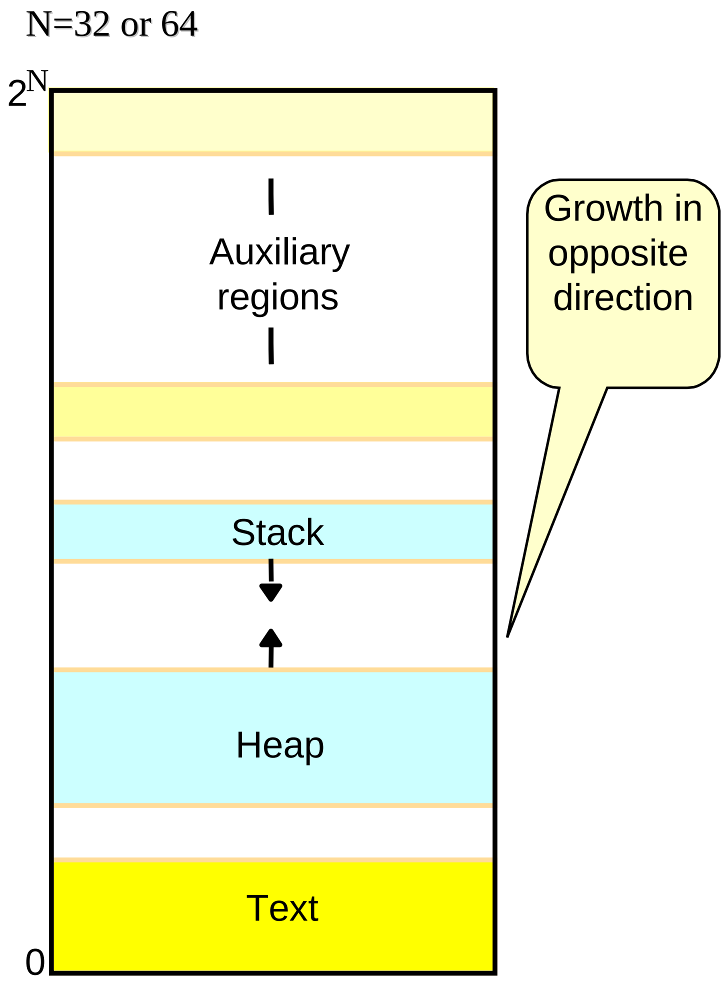
- Kernel
  - complete access privileges to all physical resources
  - executes in supervisor mode
- Application programs
  - have own address space, separate from kernel and others
  - execute in user mode
- Access to resources
  - calls to kernel (system call trap), interrupts
  - switch to kernel address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

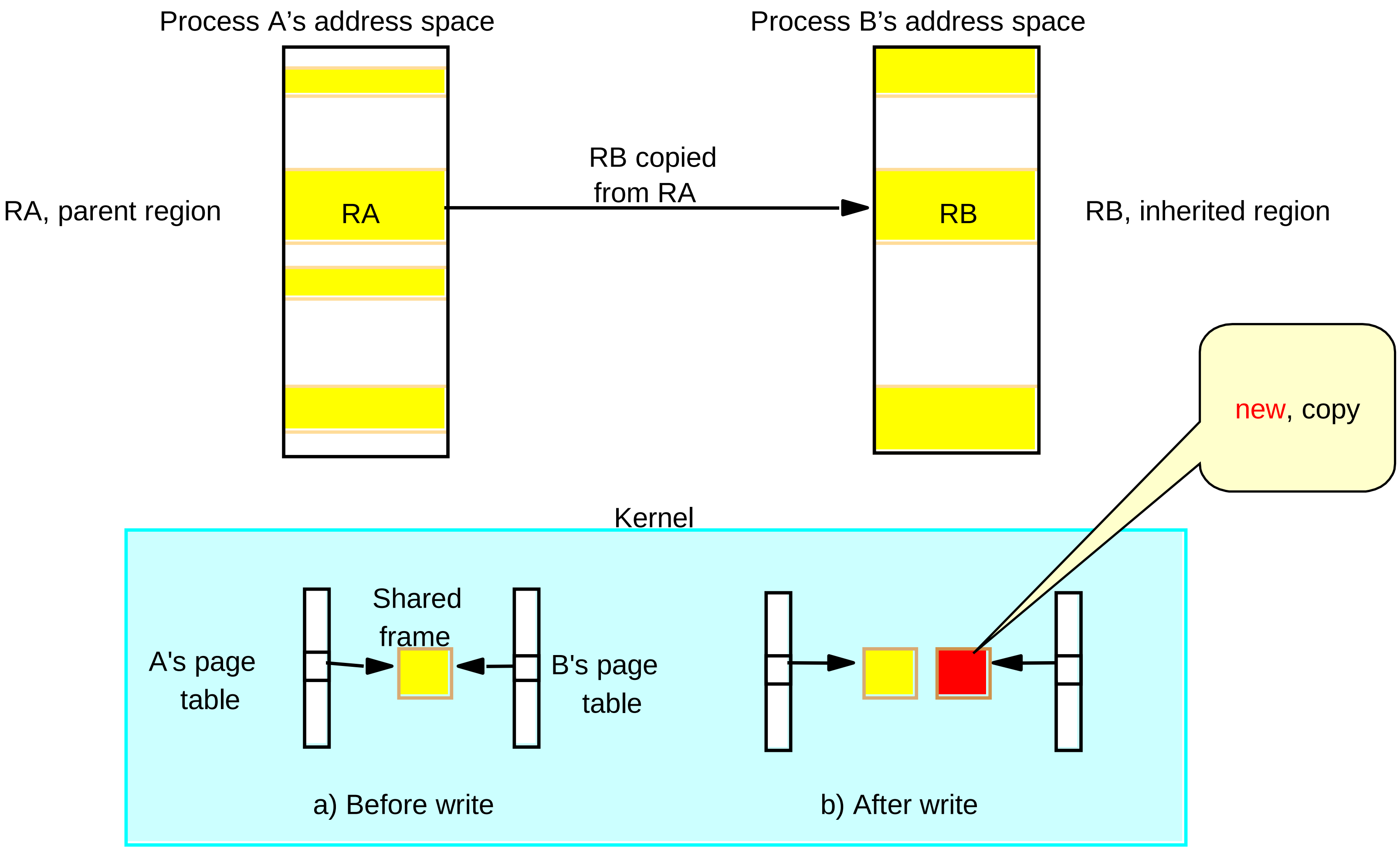
Choosing a host...

- 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



Process A’s address space

Process B’s address space

RB copied from RA

RA, parent region

RA

RB

RB, inherited region

new, copy

Kernel

Shared frame

A's page table

B's page table

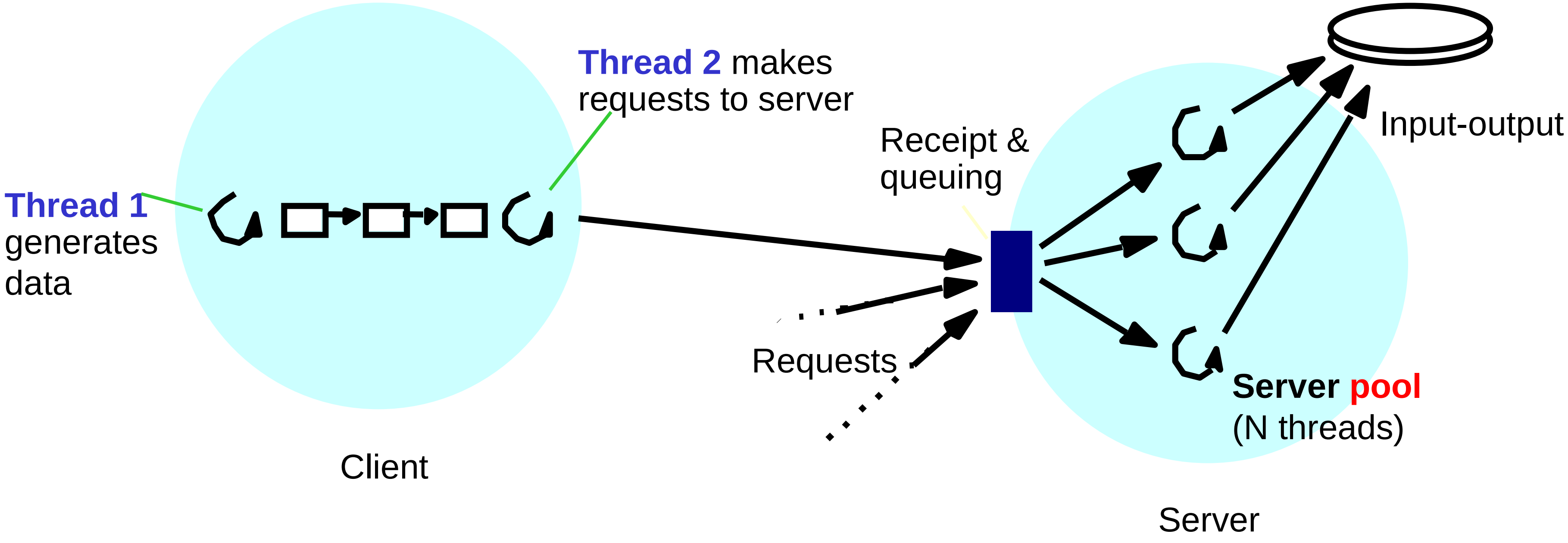
a) Before write

b) After write

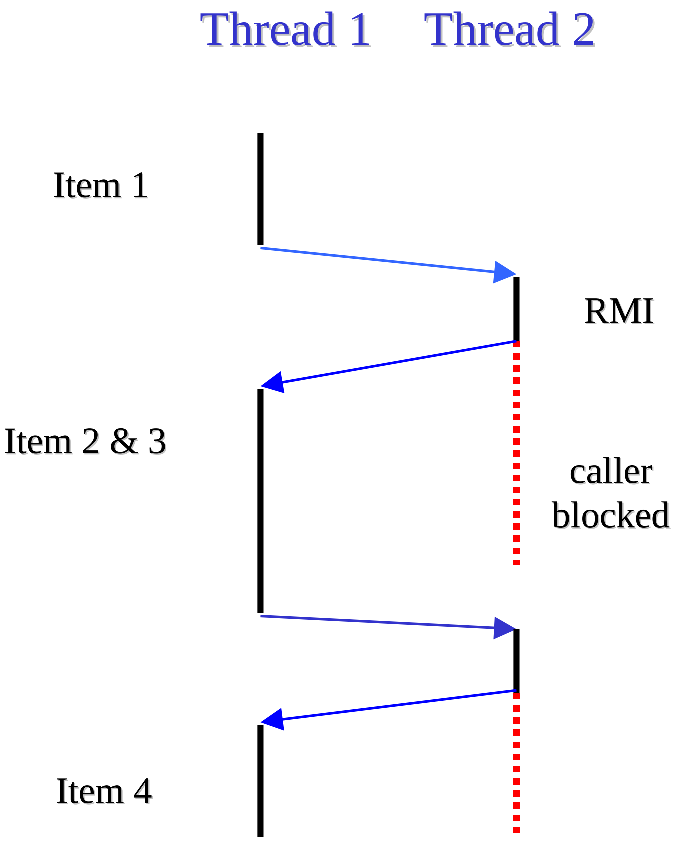
Role of threads in clients/servers

- 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

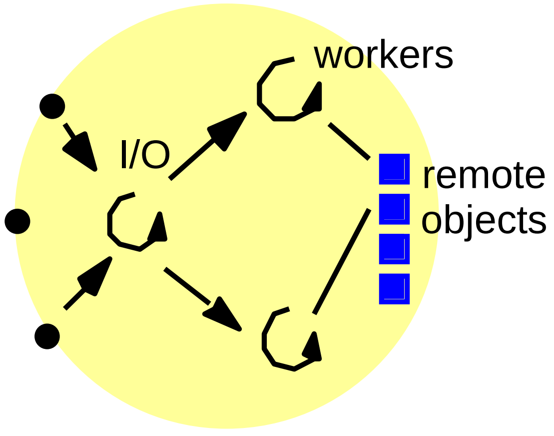
Assume stream of client requests, each 2ms processing + 8ms I/O.

- 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)

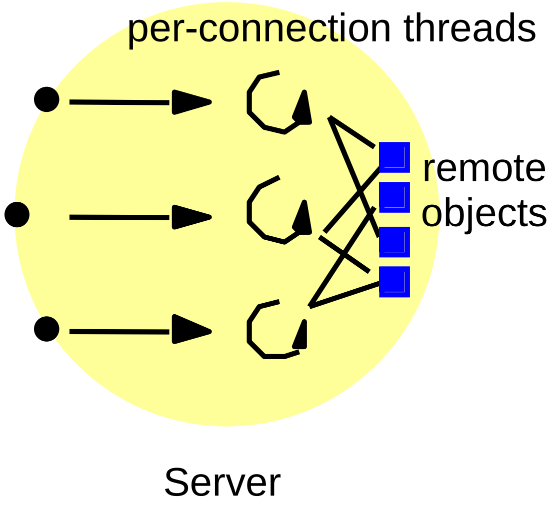
Thread-per-request



Server

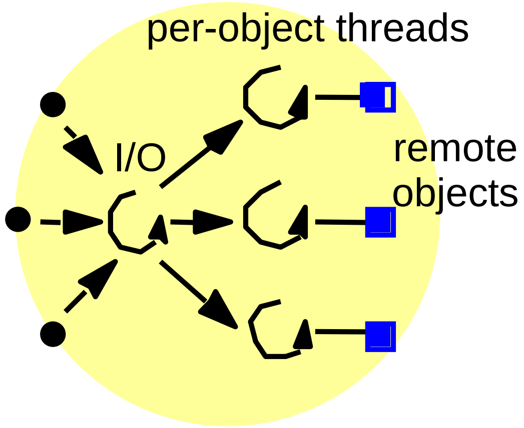
- Spawns
  - new worker for each request
  - worker destroys itself when finished
- Allows max throughput
  - no queuing
  - no I/O delays
- but overhead of creation & destruction high

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.

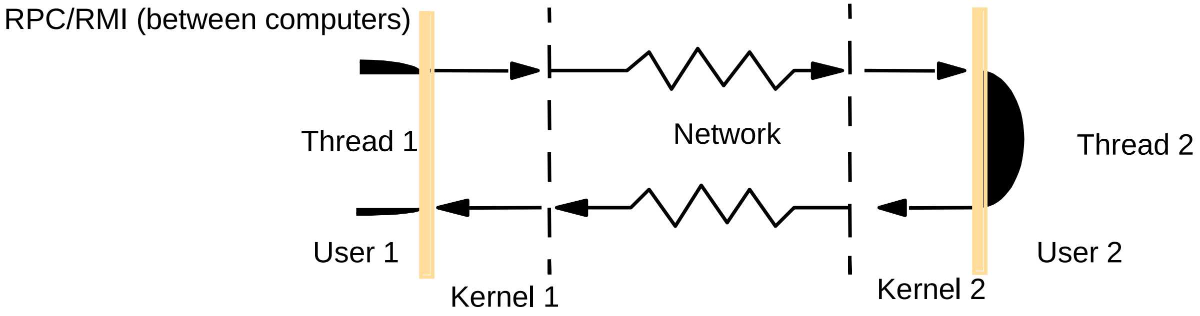
object.notify(), object.notifyAll()

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!

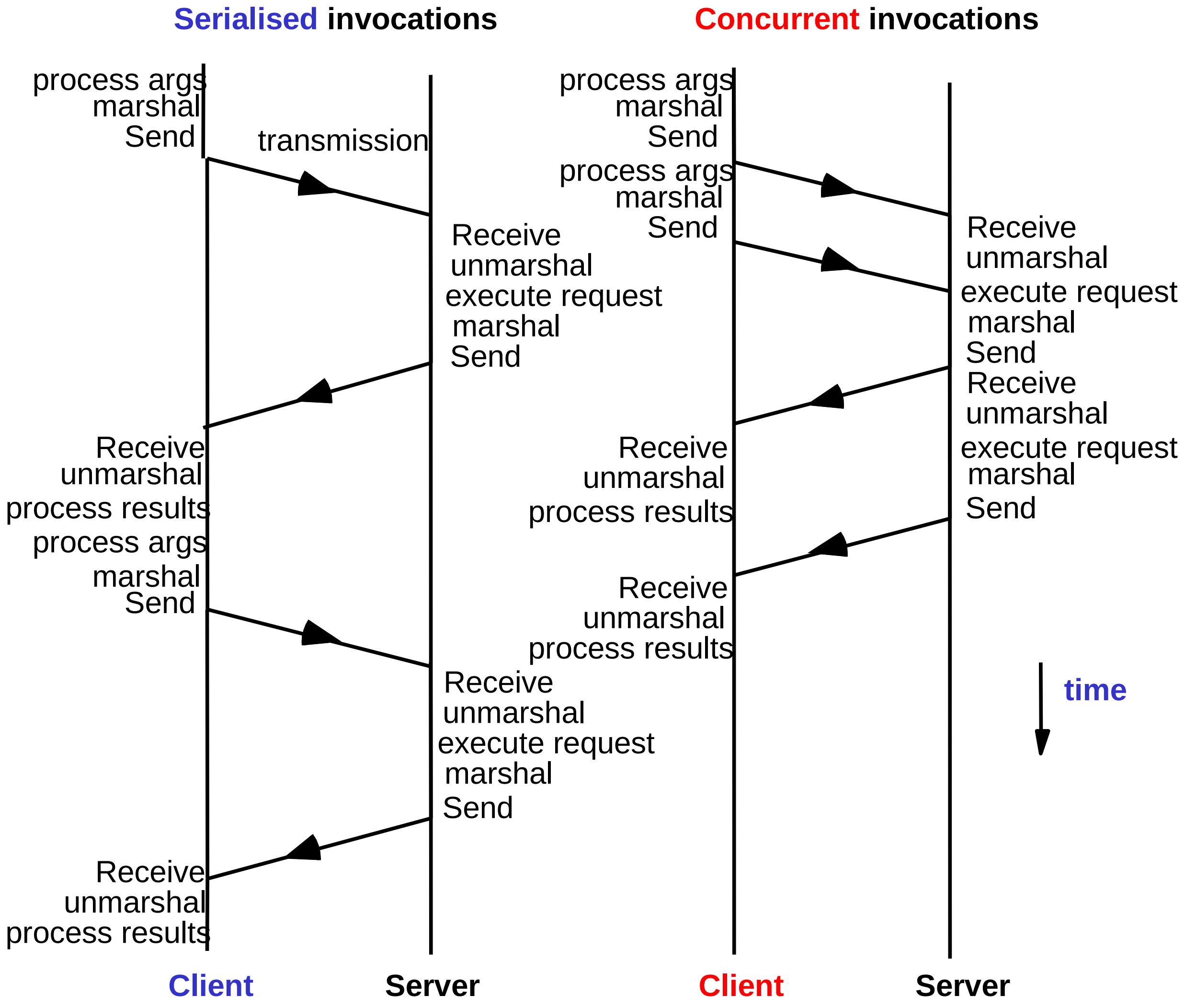
Factors affecting RPC/RMI delays

- 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