System Architecture

3 System Structures

Structures, System Types, Examples

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Agenda

- Review and Introduction
- Principles of System Architectures
- System Types
- OS Examples
- Middleware (not in this course)
- Application Systems

Review and Introduction

Principles of System Architectures

Monolithic Systems

Layered Systems

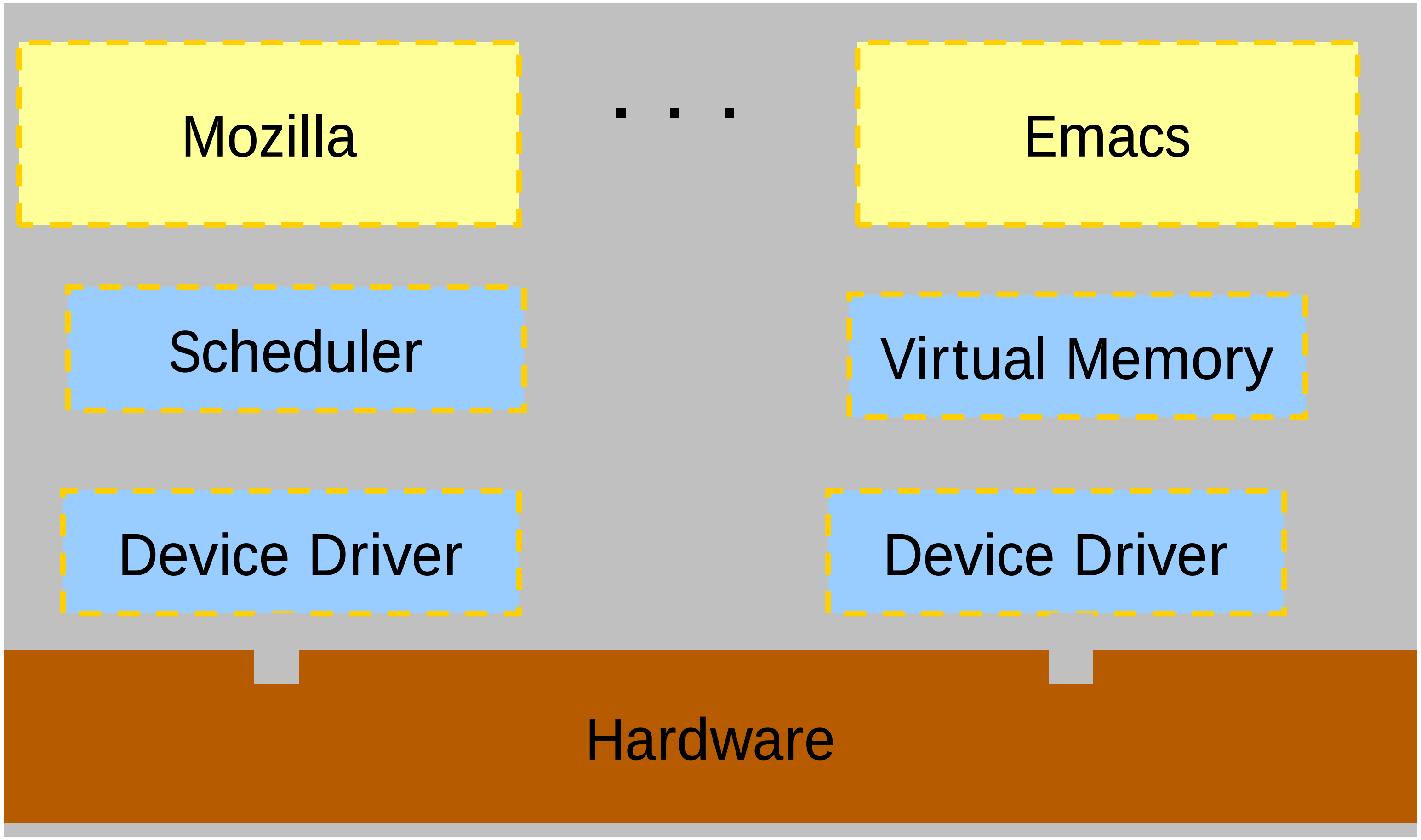
Kernel Systems

Micro-Kernel Systems

Principles of Structuring Systems

- Monolithic system (little structure)
- Layered system (e.g. THE, MULTICS)
- Kernel based system
  - Traditional (monolithic) kernel
  - Object oriented kernel
  - Extensible kernel
- Component- or server-oriented systems
  - Microkernel based

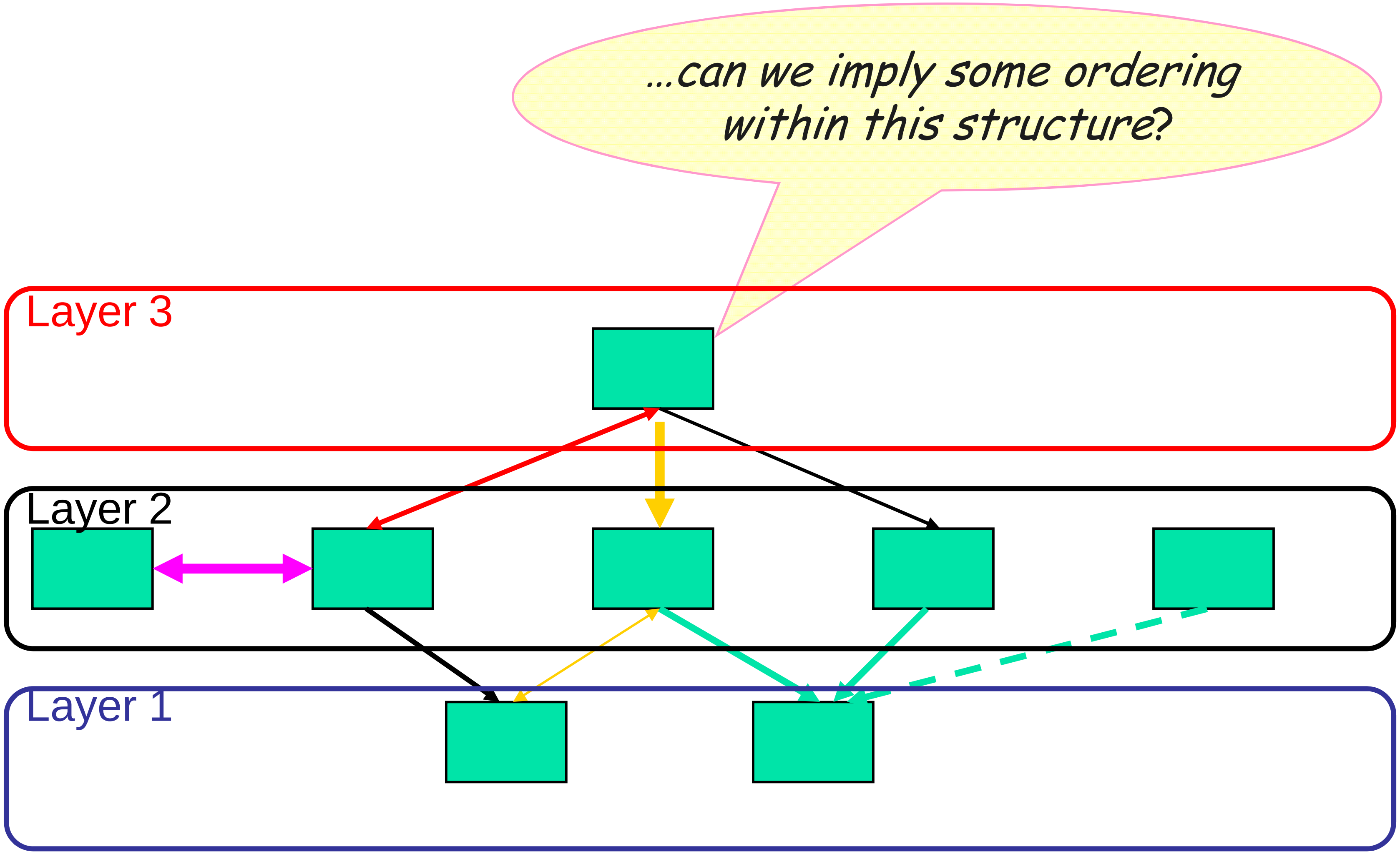
Monolithic Systems



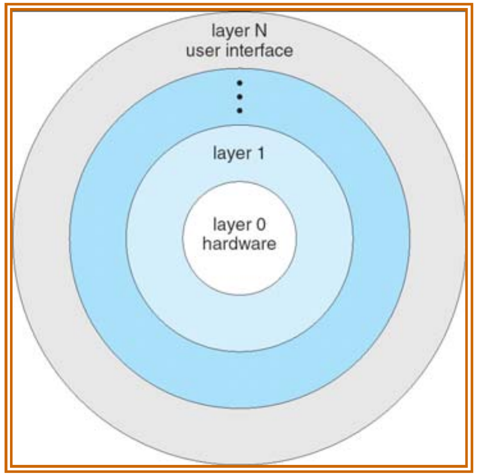
Analysis: Monolithic Systems

- Advantages
  - Easy access to all system data (they are all shared)
  - Cost of module interaction is low (procedure call)
  - In principle extensible, but in practice **NOT**, e.g. ∃ an “extension industry” for Mac & PALM OS
- Disadvantages
  - No protection between system and applications
  - Not particularly stable nor robust
  - Adding extensions → unpredictable results

Layered Systems



Layering Principle



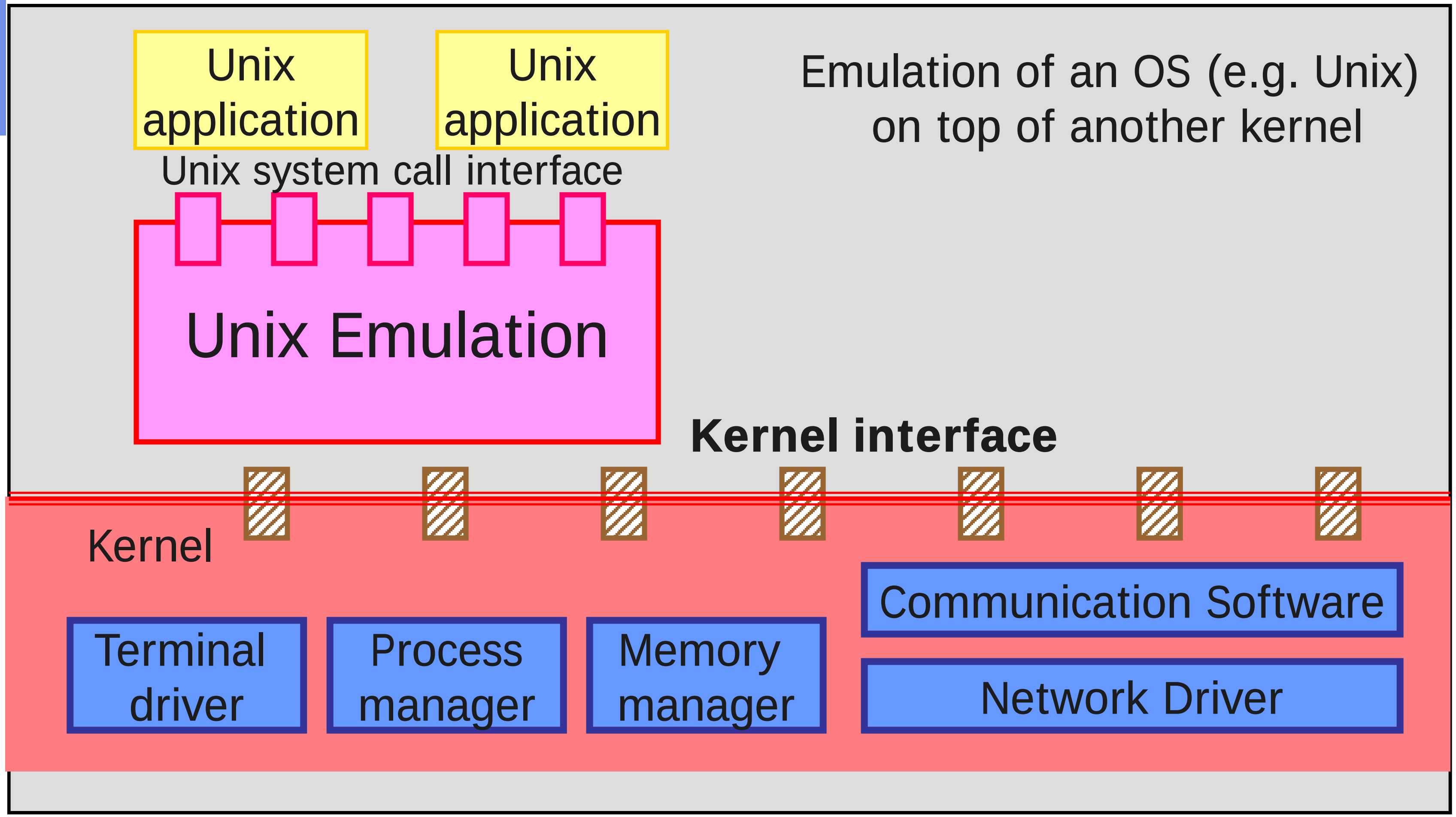
- System is divided into many layers (levels)
  - Each layer is built on top of lower layers
  - Bottom layer (layer 0) is hardware
  - Highest layer (layer N) is the user interface
- Each layer only uses functions (operations) and services of lower-level layers
  - Advantage: modularity $\Rightarrow$ simpler debugging/maintenance
  - Not always possible: Does process management lie above or below memory management?
    - Need to reschedule processor while waiting for paging
    - May need to page in information about tasks
- Important: Machine-dependent versus independent layers
  - Easier migration between platforms
  - Easier evolution of hardware platform

Example: Dijkstra's THE OS

Layer	Function
5	The operator
4	User programs
3	Input/output management
2	Operator-process communication
1	Memory and drum management
0	Processor allocation and multiprogramming

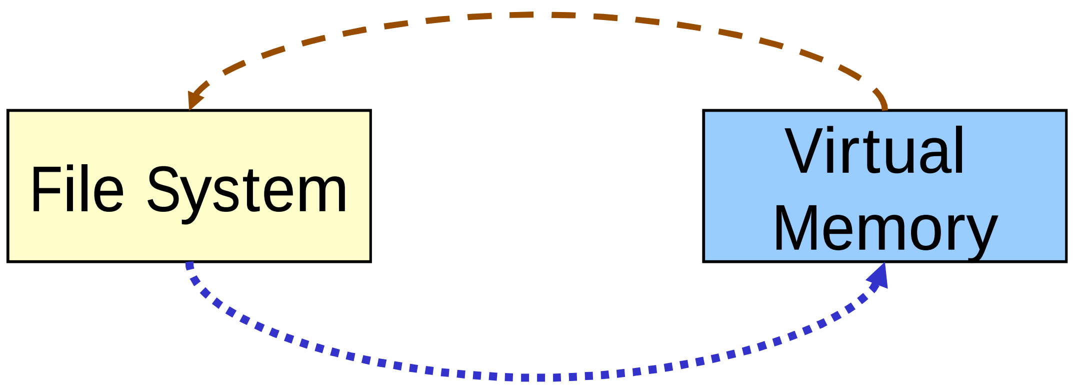
- Structure of the THE operating system
- Main advantage: Each layer can be tested and verified independently

System of Nested Layers



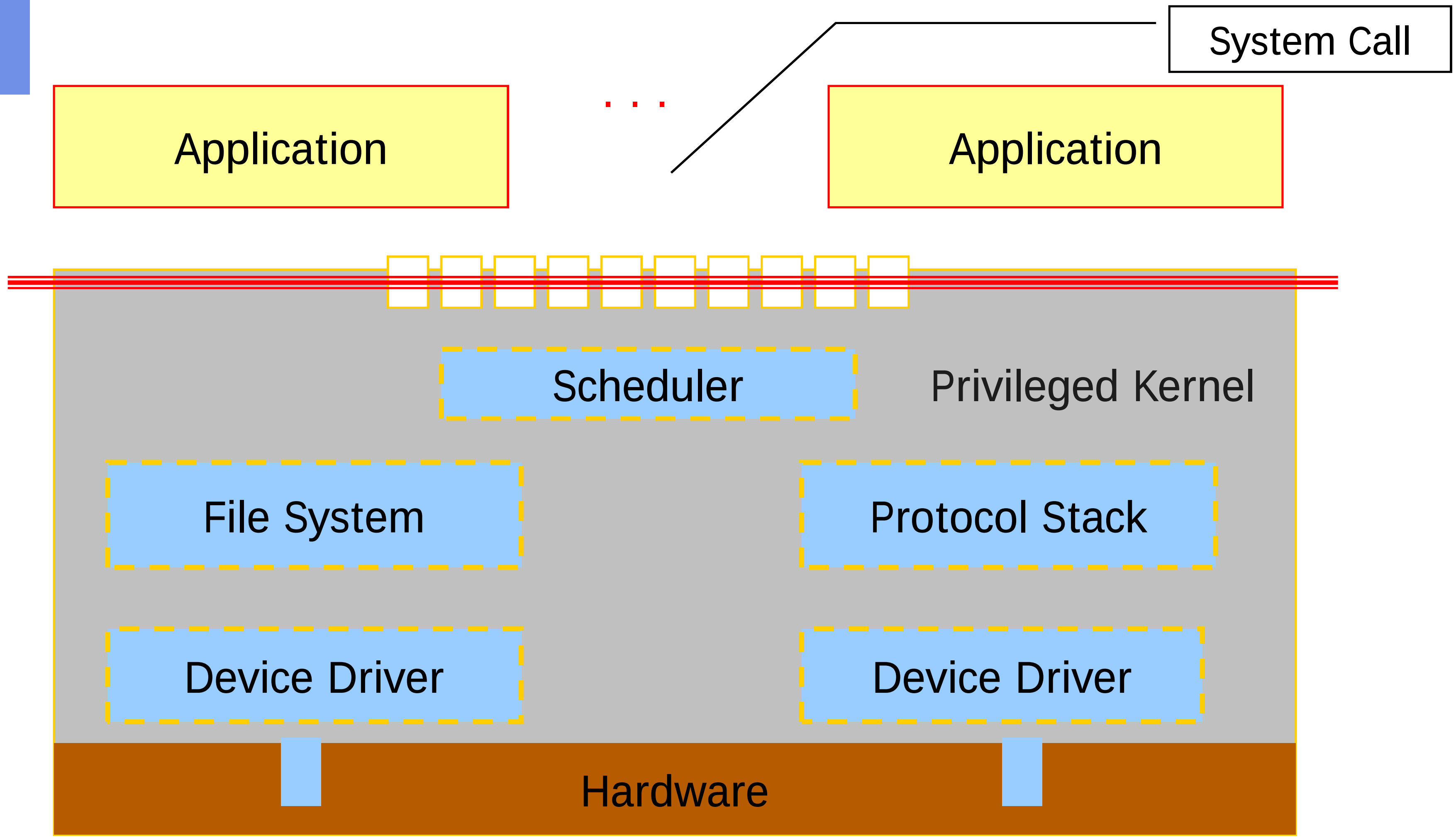
Problems with Layered Systems

- Completely hierarchical layering can be too inflexible
- Real systems include call-cycles, but not too many
  - File system requires virtual memory services for its buffers
  - Virtual memory would like to use files for its backing store



- Reduced performance:
  - Each layer crossing has some overhead associated with it

Monolithic Kernels



Analysis Monolithic Kernels

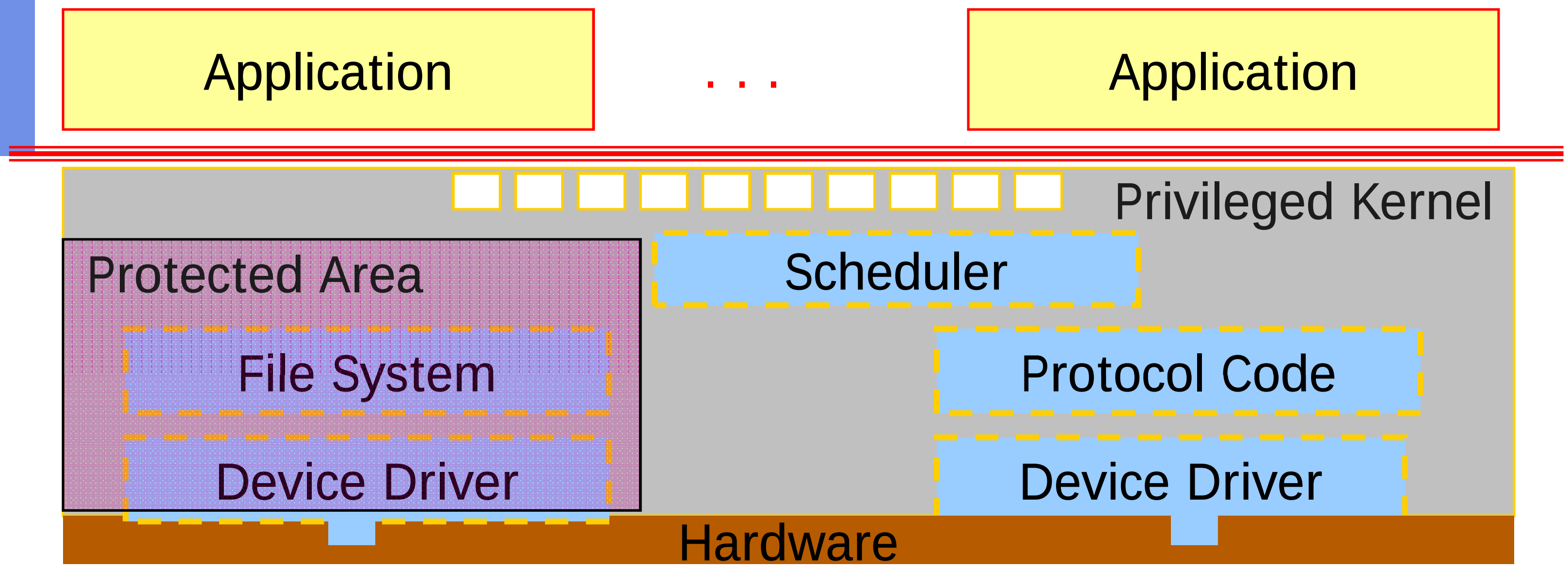
- Advantages
  - Well understood
  - “Good” performance
  - Sufficient protection between applications
- Disadvantages
  - No protection between kernel components
  - Not very extensible
  - Overall structure soon too complicated
    - Every kernel entity is intermixed
    - ∃ no clear boundaries between modules

Approaches tackling Complexity

- Safe kernel extensions
  - SPIN – safe programming language (Modula 3) at Univ. of Washington (UoW)
  - VINO – sandboxing (hardware protection) at Harvard
  - NOW (Berkeley)
  - Spring (SUN)
  - Scout (Uni. of Arizona)
  - Synthetix (OGI*)
- Exokernel (MIT)
  - Kernel offers multiplexing of raw HW
  - All other control is done at application level
- Microkernels

*Oregon Graduate Institute

Extensible Kernel Systems



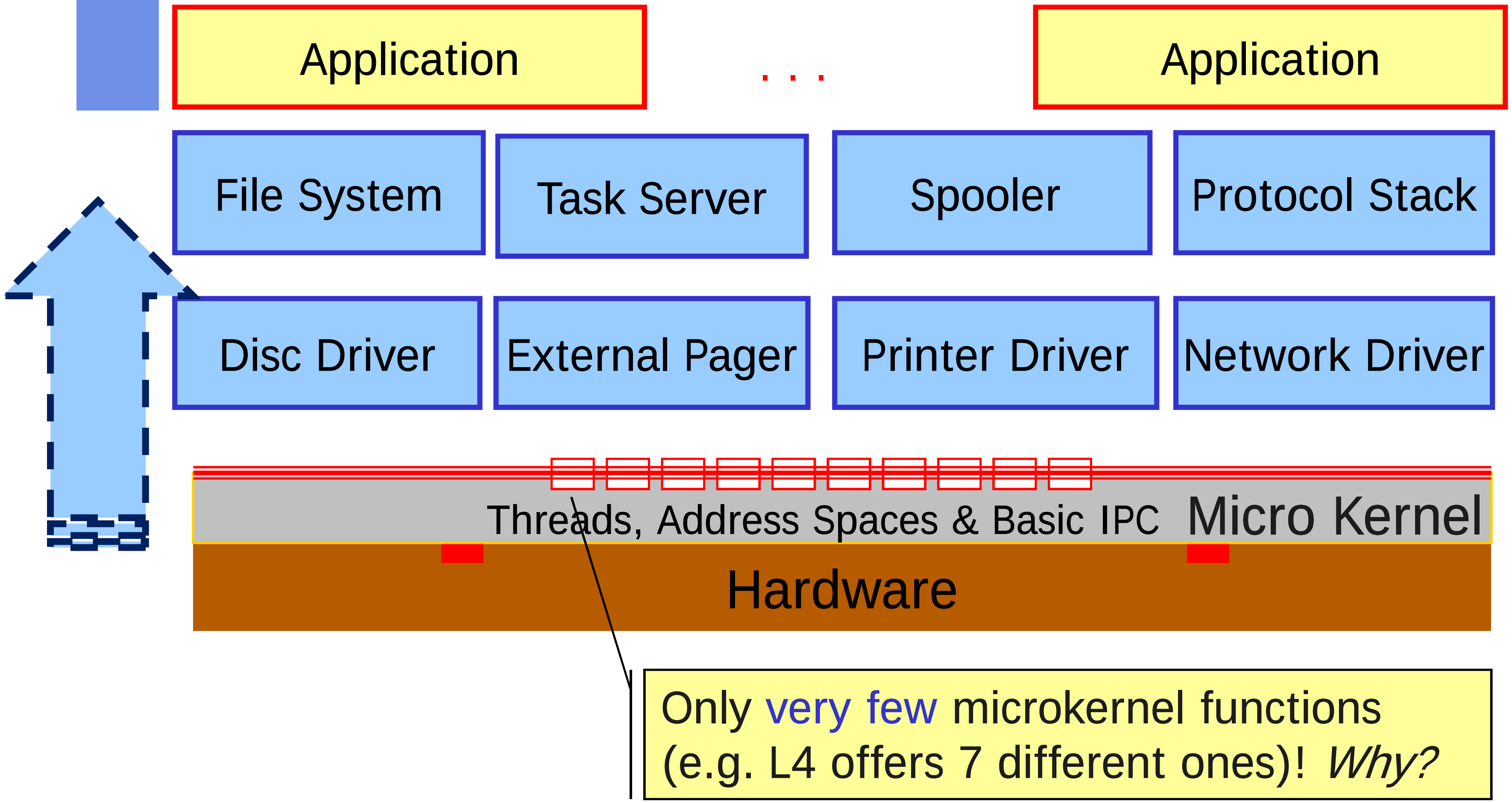
Rating:

Pro: Saves memory by only loading modules (e.g. drivers) that are needed

Pro: Makes it easier to develop new kernel code outside of the main tree

Con: Once loaded, module can destroy kernel if not running in a sandbox

Micro-Kernel Systems



Pros ↔ Cons of Micro-Kernels

Easier to test/prove/modify

Improved robustness & security (each system component in user level is protected from itself)

Improved **maintainability**

Coexistence of *n* APIs

Natural extensibility (add a new server, delete a no longer needed old server)

Additional decomposing

Expensive to re-implement everything using a new model

Low performance due to communication overhead

Bad experiences with **IBMs Workflow (91 -95):**

- 1 kernel for OS/2, OS/400, AIX
- Based on Mach 3.0
- ~ **$2 billion loss**

Arguments against Micro-Kernels

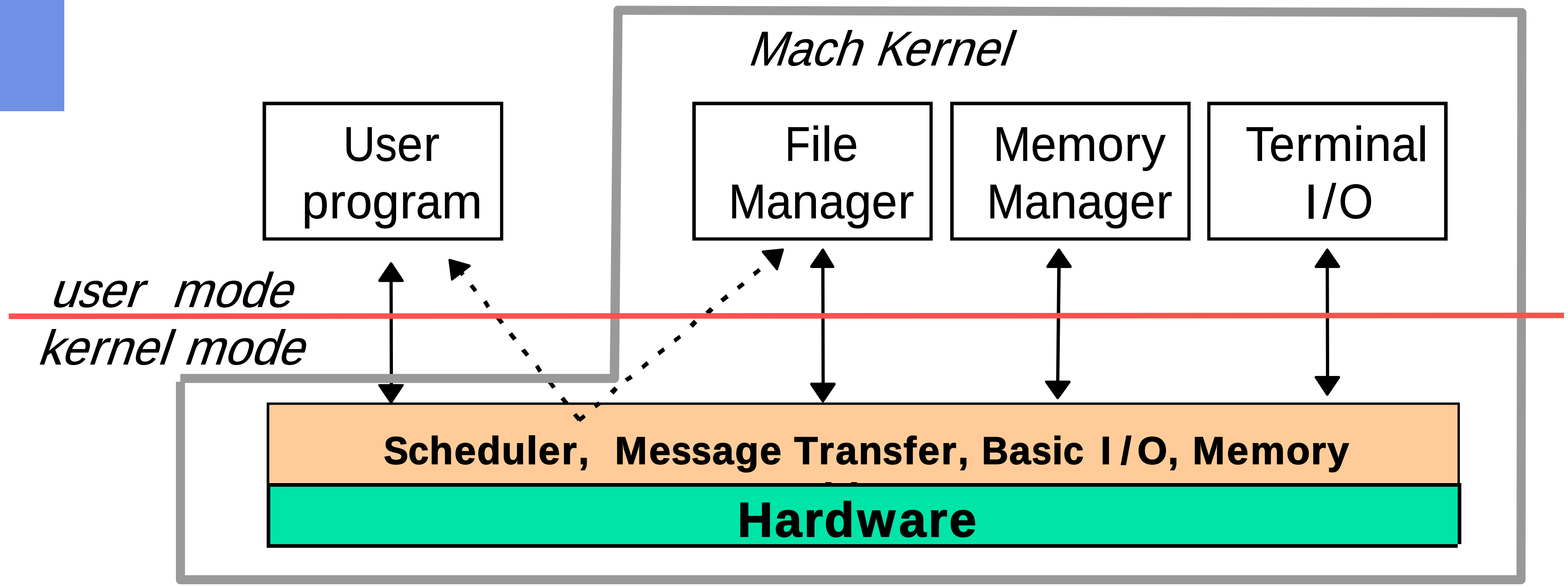
1. Low Performance

2. Still Large and Inflexible Vehicles

Comment: True for micro-kernels of 1st generation, e.g.

- **Mach** **(Bershad, Rashid, CMU, OSF)**
- Chorus (Rozier, Gien, INRIA, Chorus)
- Amoeba (Tanenbaum, Vrije Universiteit)
- L3 (Liedtke, GMD)

MACH “Micro-Kernel” and OS



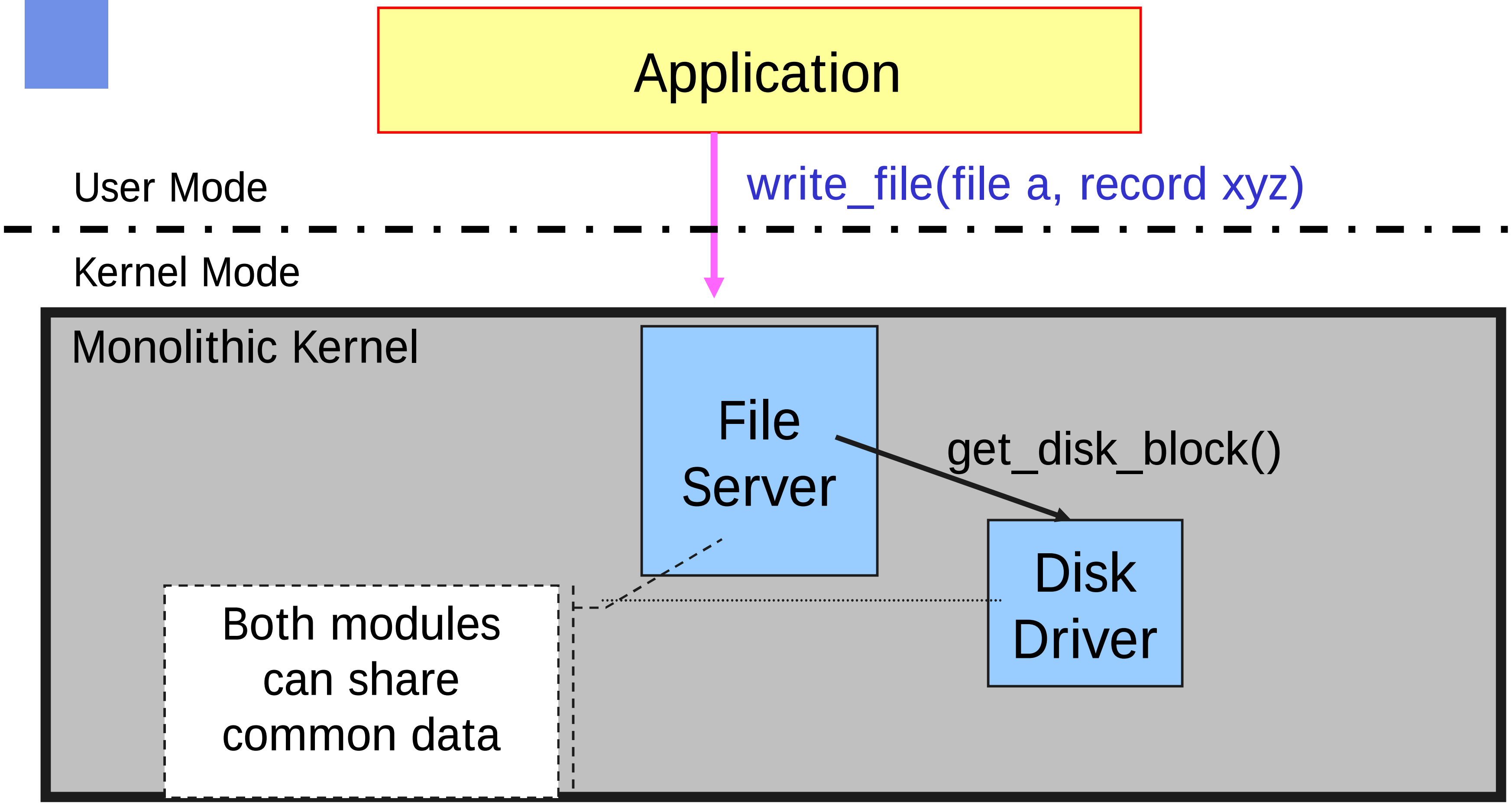
2^{nd} Generation of Micro-Kernels

■ **L4**	(GMD, IBM, U of Karlsruhe)
■ Exokernel	(MIT)
■ EROS	(U of Pennsylvania, Johns Hopkins)
■ Flux	(U of Utah)
■ PARAS	(C-DAC, India)
■ Pebbles	(Bell Labs)
■ **QNX**	(Quantum Software Systems)
■ GNU Hurd	(Free Software Foundation)

have shown **far better performance**

If you are really interested in OS affairs read the related overview papers of these micro-kernels and take the course micro kernel construction next summer term

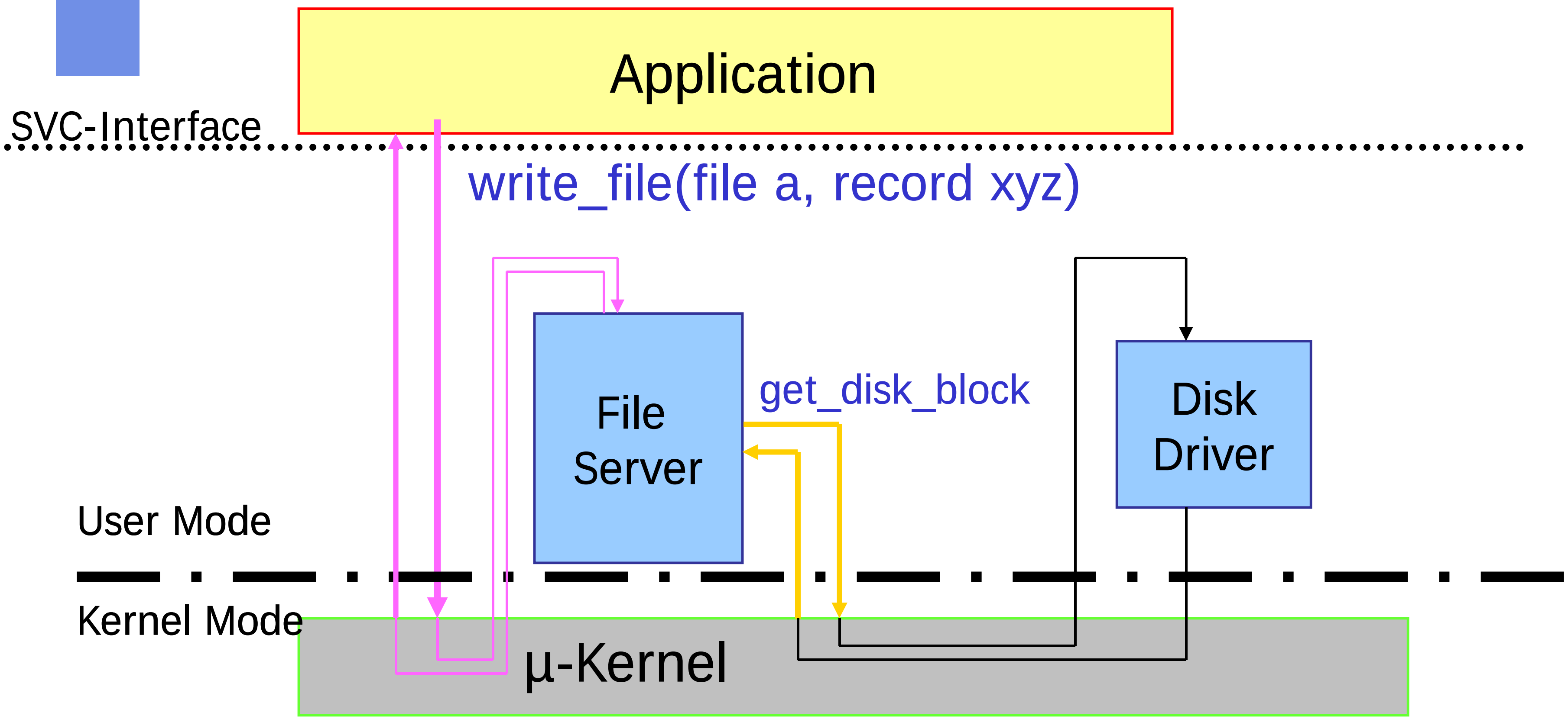
Arch. Costs I (Traditional Kernel)



Architectural Costs II

- 1 System Call
  - (including kernel entrance + leaving)
- 1 Procedure Call + 1 Return
  - (both within kernel address space, potential sharing of data, buffers, ...)

Architectural Costs: Microkernel



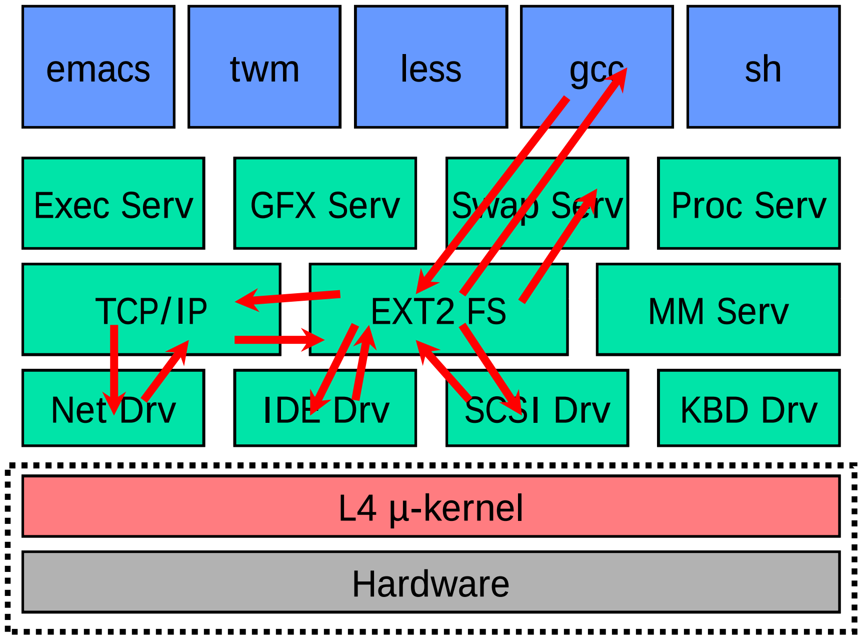
Architectural Costs (Microkernel)

4 x

- 1. µK ipc call to file server (“write_file ... ”), including
  - µK Entrance/Exit
  - message transfer
  - address-space switch to server
- 2. µK ipc call to disk driver (“write_block ... ”), costs see (1.)
- 3. µK ipc reply to file server (“done ... ”), costs see (1.)
- 4. µK ipc reply to application (“done ... ”), costs see (1.)

Result:
Exchanging messages implies additional overhead compared to a monolithic kernel, which can use shared memory for that purpose.

Challenge



Regular OS operations (system calls) can imply many communications

Conclusion

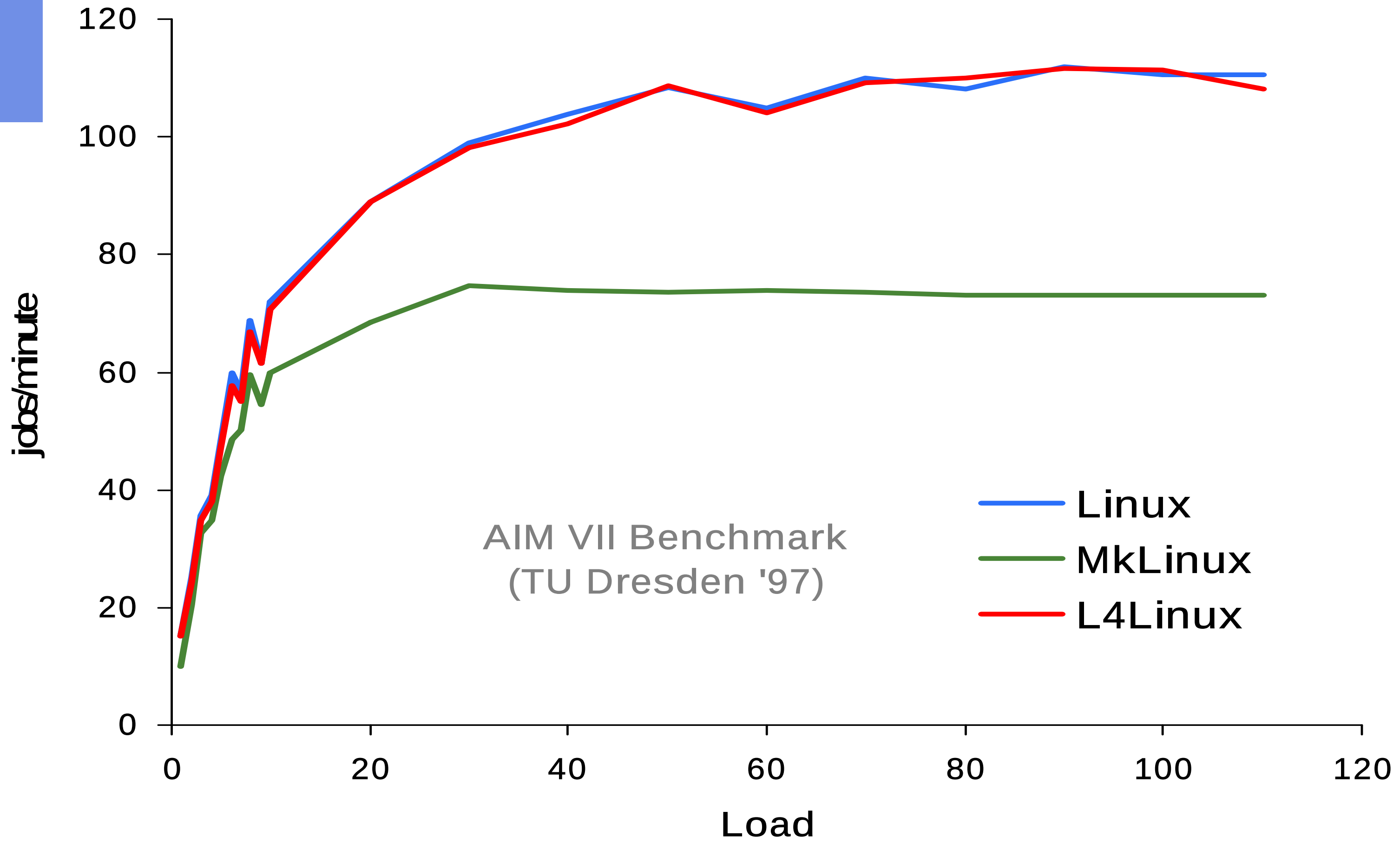
Micro-kernel operations have to be:

fast, faster, fastest !!!

... and additionally we need a fast
micro-kernel entrance and micro-kernel exit

$\Rightarrow$ You have to know your HW very well

Microkernel Based System Performance



Summary

- OS can be quite complicated
- The structure of an OS dominates, at least influences the result of whole system
- *What is the ideal OS structure?*
- Well, it depends where you visit the OS course
  - **CMU** et al.: **Extensible kernel based systems**
  - **KIT** et al.: **Micro kernel based systems**

System Types

Database Systems

Operating Systems ⟵ Our Focus

Real Time Systems

Middleware

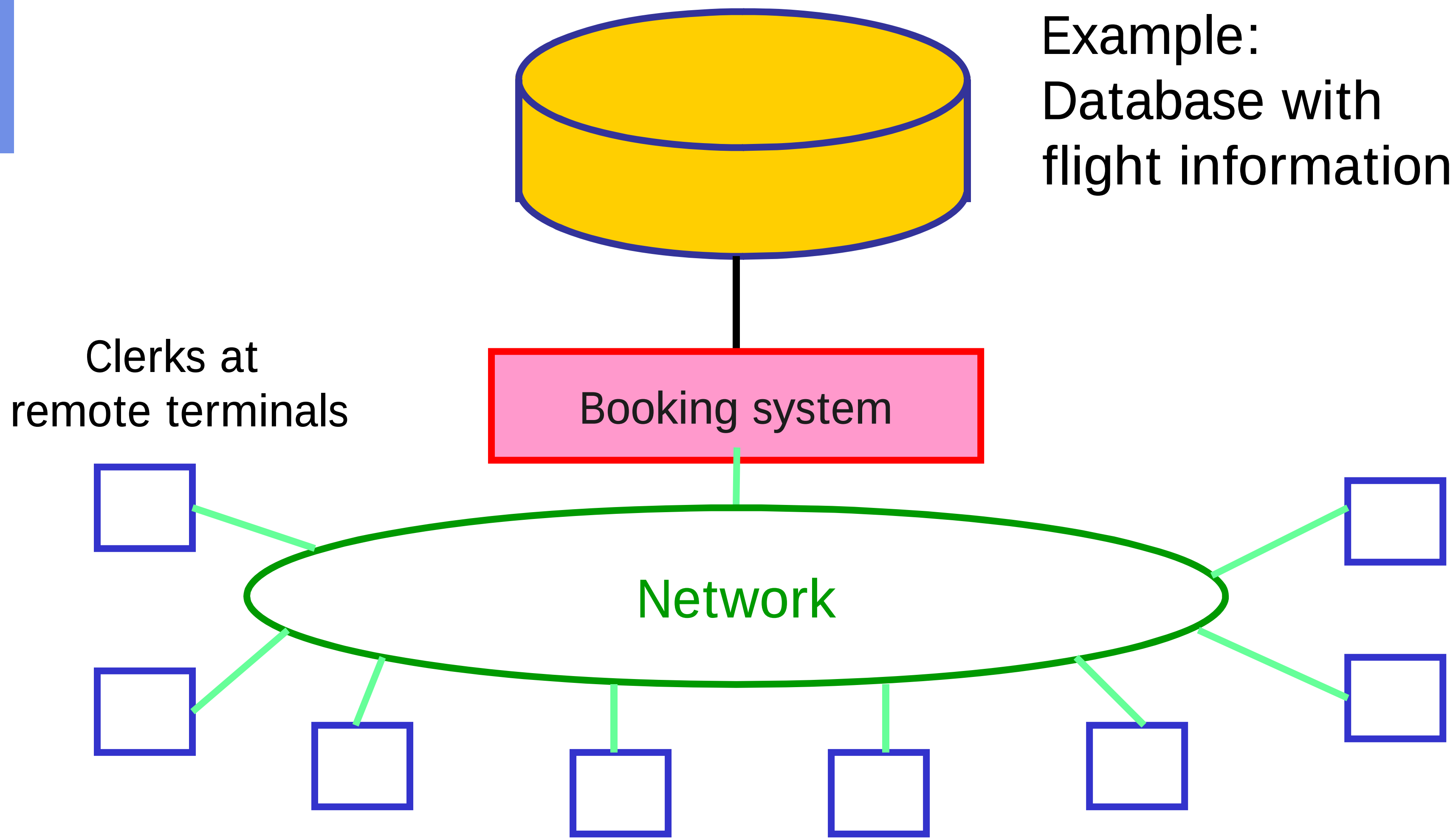
Application Systems

Goal of this Section

- Try to find out common features, e.g.
  - problems
  - requirements
    - concurrency
    - performance
    - robustness
  - ...

of the different types of systems

Database Systems



Example:
Database with
flight information

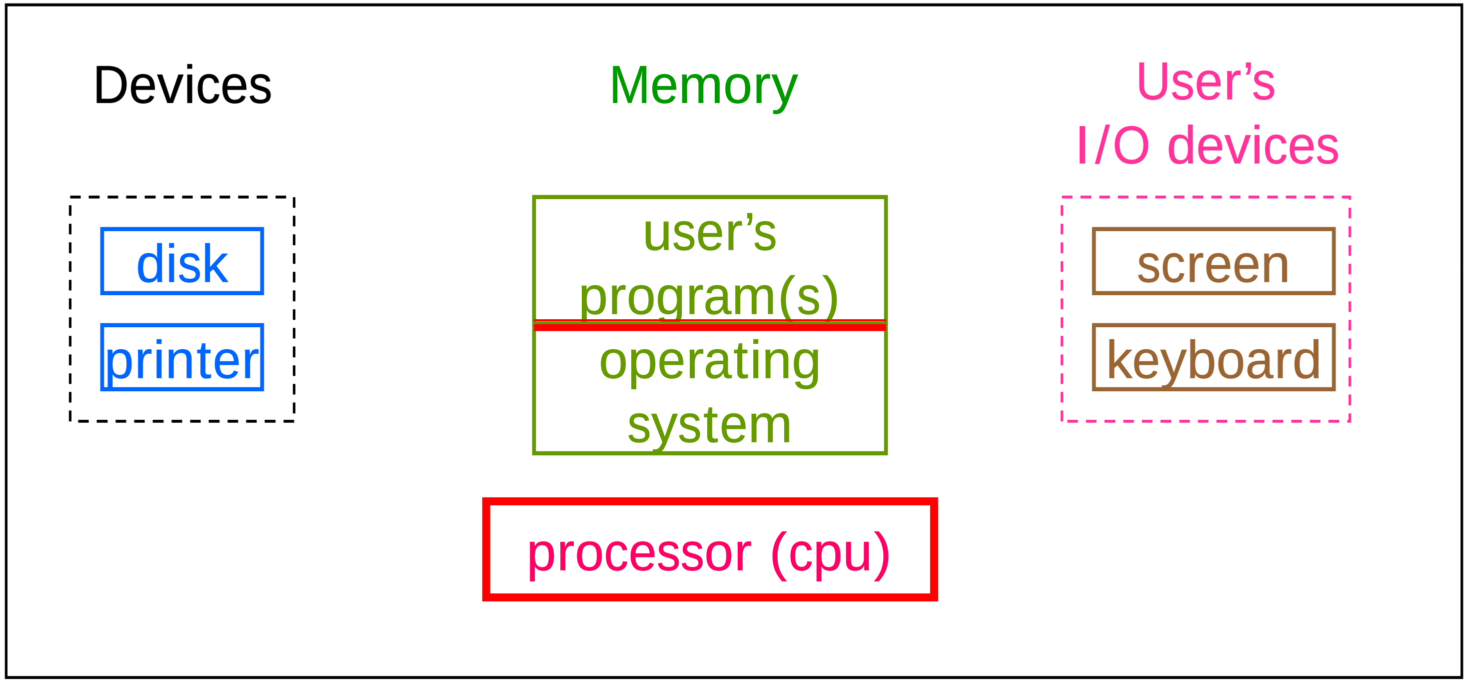
Requirements for DB Systems

- Support separate concurrent activities
- Support concurrent accesses and updates to the database without interference ⇒
  - We need synchronization features
  - Confidence in consistent state of the database
  - Solution: TRANSACTIONS ← **See next summer term**
- Results of a transaction are recorded permanently and securely before a client is told that her/his request has completed

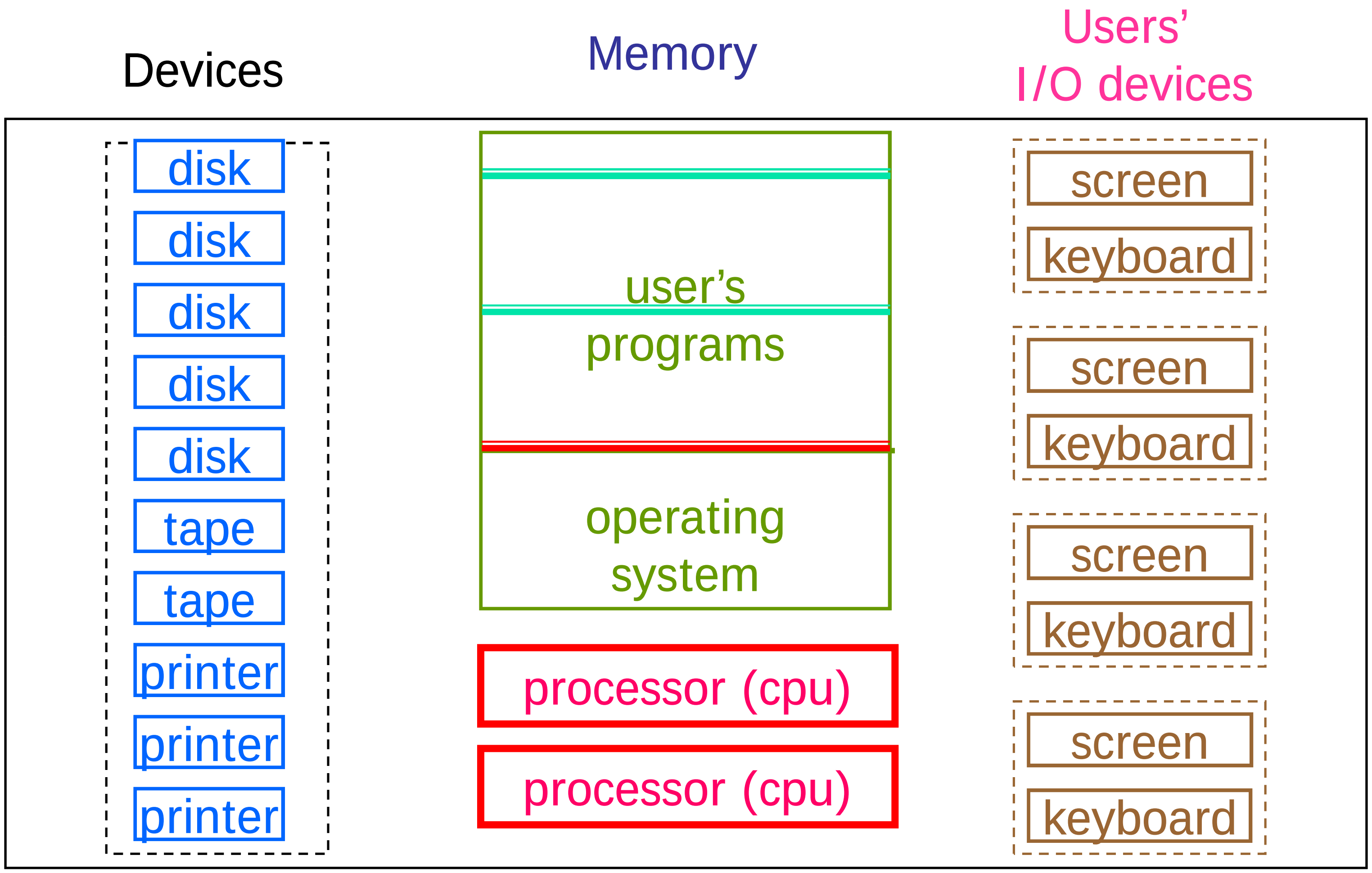
Operating Systems

- Single-User System
- Multi-User System
- Virtual Machine
- Distributed System (e.g. Client-Server)

Single User OS



Multi User OS



Multiprogramming Systems

- I/O routines supplied by the system
- Memory management – the system must allocate the memory to several jobs
- CPU scheduling – the system must choose among several jobs ready to run
- Allocation of devices

Time-Sharing Systems

- CPU is multiplexed among several jobs that are kept in memory and on disk
  - CPU is allocated to a job only if the job is in RAM
- A job swaps in and out of RAM to the disk
- On-line interaction between user & system
  - When OS finishes execution of one command, it waits for the next “control statement” from the user’s keyboard
- On-line system must be available for users to access data and code

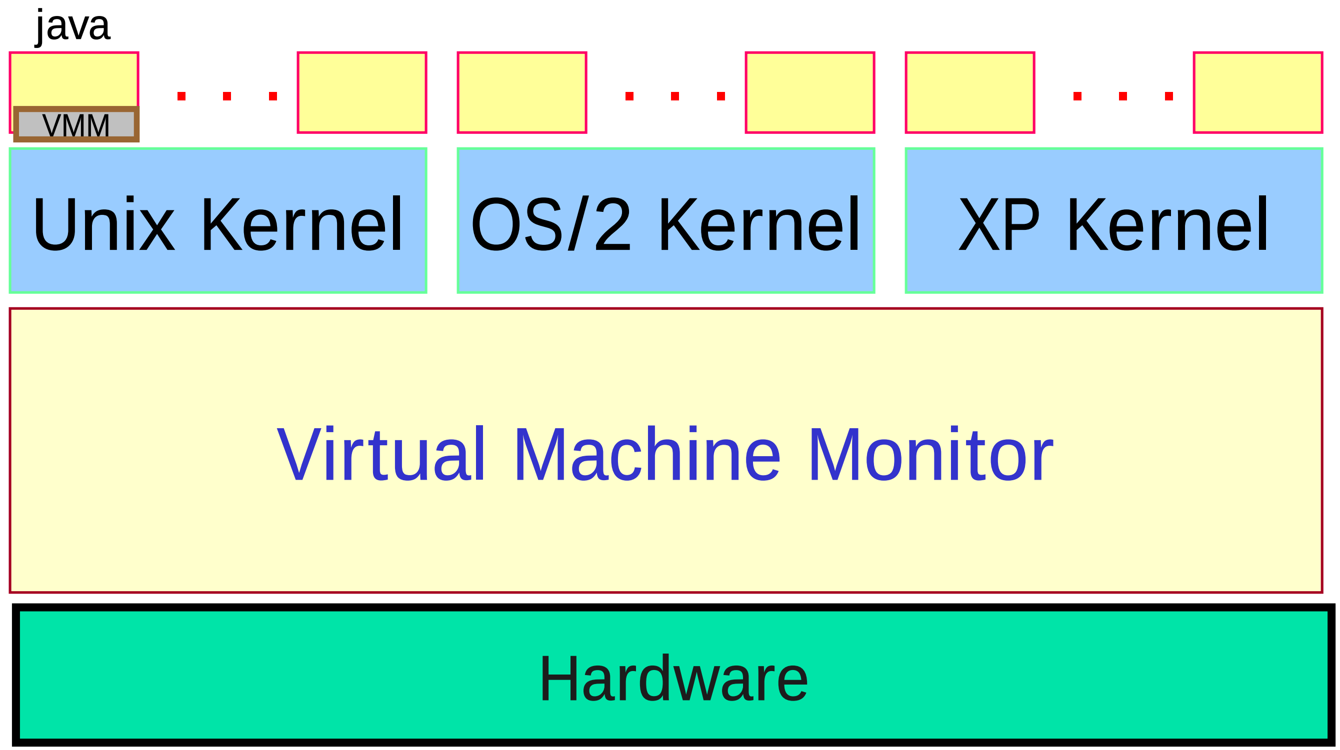
Desktop Systems

- PCs – computer system dedicated to a single user
- I/O devices – keyboards, mice, display screens, small printers
- Provides user with convenience and responsiveness
- Can adopt technology developed for larger OSs
  - Often individuals have sole use of computer and do not need advanced CPU utilization or protection features
- May run several different types of operating systems (Windows, MacOS, UNIX, Linux, ...)

Requirements for OSes

- Separate activities on application level
- Even separate activities within OS
  - Separate system activities might work together (e.g. file system, spooler)
- Resource management
- Synchronization and communication features, e.g. reading/writing shared data
- Protection and security

Virtual Machines*



*Notion also used in context of Java

Virtual machines are one of our current research topics.

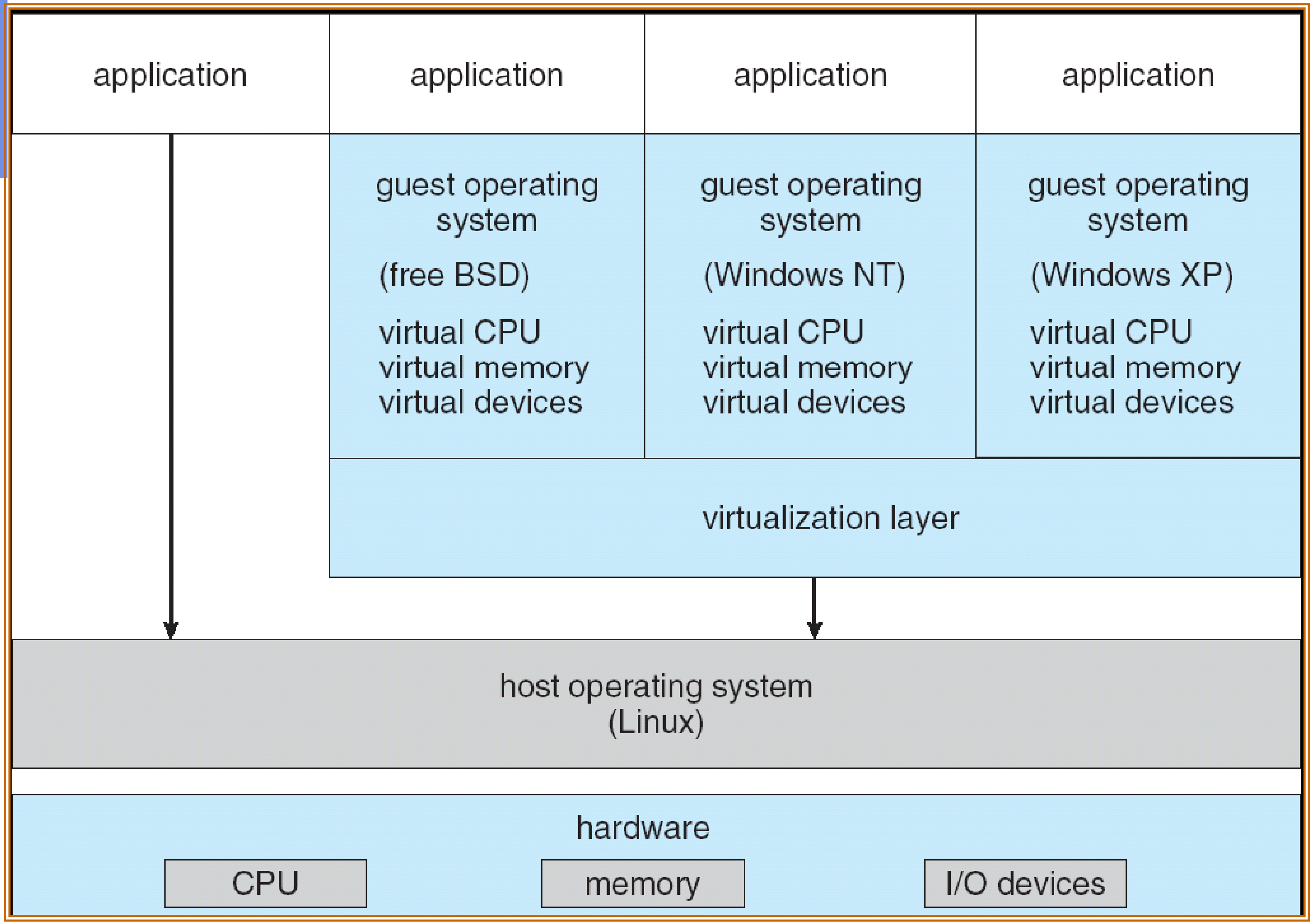
Advantages of Virtual Machines

- A VM provides complete protection of resources since each VM is isolated from all other VMs. This isolation permits no direct sharing of resources.

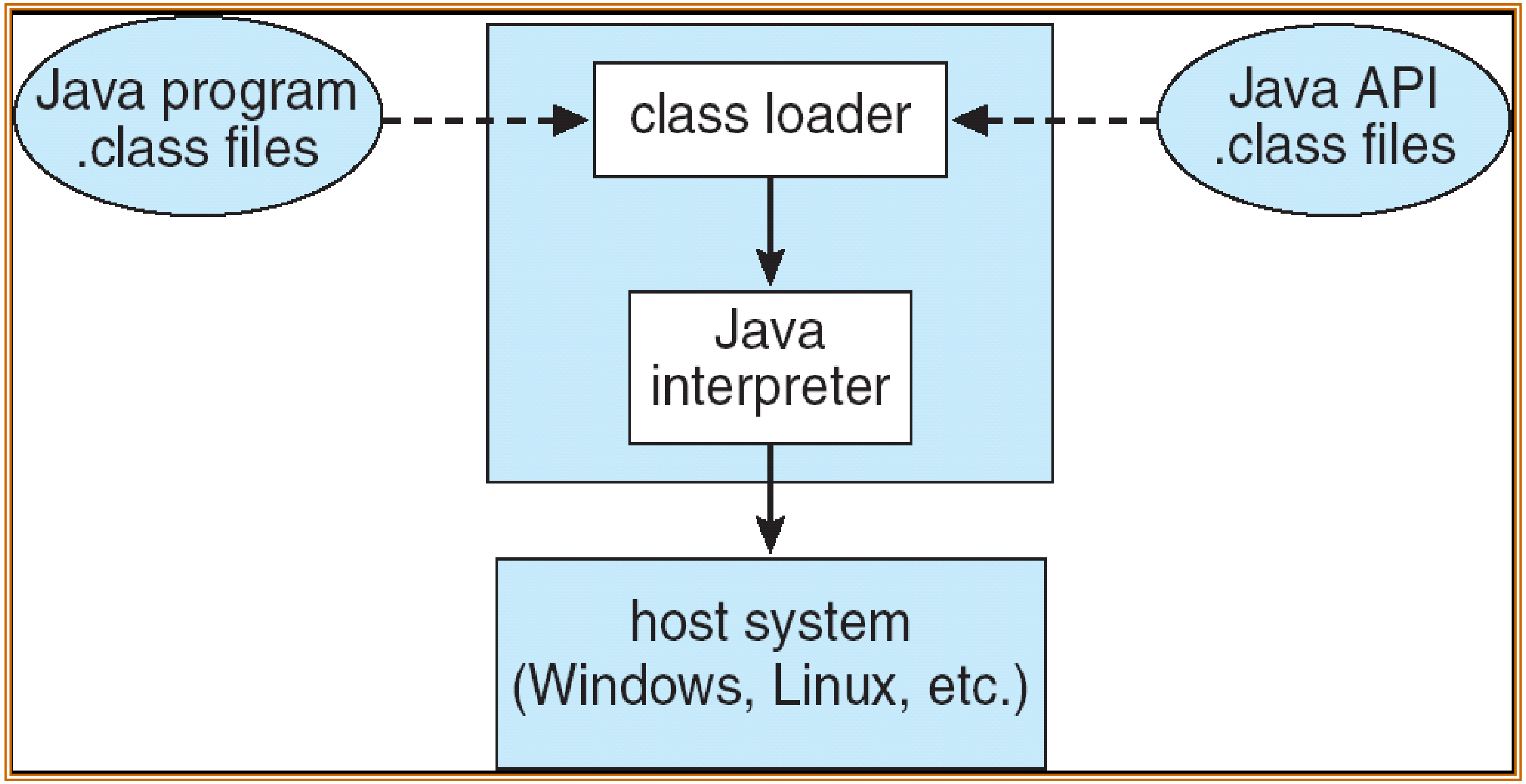
- VM = perfect for OS research + development
  - development is done on the VM $\Rightarrow$
  - does not disrupt normal system operation

- Implementing an VM is a bit tricky, because you have to provide an exact duplicate of the underlying physical machine $\Rightarrow$
  - Tools to support, e.g. "afterburner" from Joshua LeVasseur

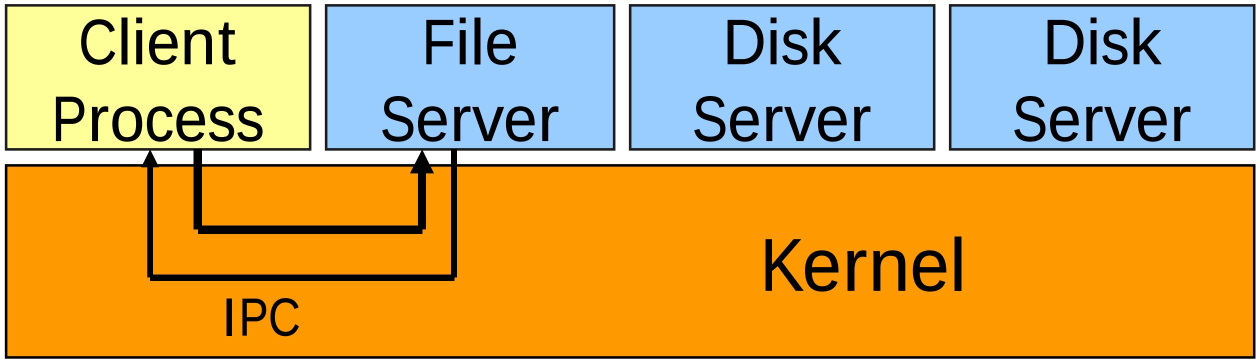
Example 1: VMware



Example 2: Java VM



Local Client Server Model



Note: Microkernels are an appropriate base for an “LCSM”

Real-Time Systems (RTS)

- Controlling dedicated applications, e.g.
  - measuring scientific experiments
  - representing medical images to a surgeon
  - controlling industrial robots
- Timing constraints
- Two types of RTS
  - hard real time system
  - soft real-time system

Real-Time Systems (2)

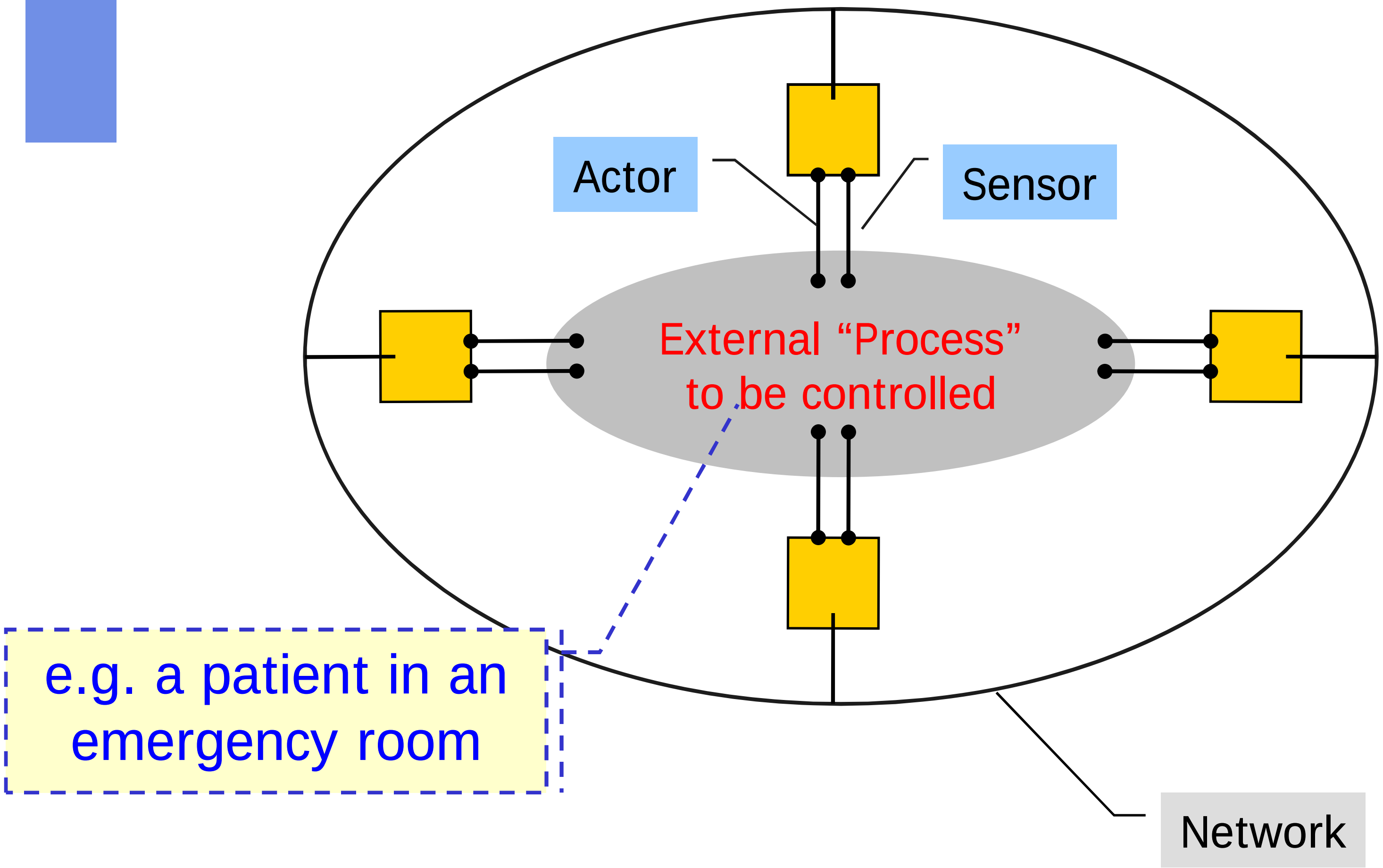
- Hard real-time
  - Persistent (secondary) storage limited or absent, data stored in short term memory or read-only memory (ROM) or MEMS
  - Must fulfill deadlines, otherwise disaster
- Soft real-time
  - Limited use in industrial control of robotics
  - Combinable with time-sharing systems
  - Useful in applications (multimedia, virtual reality) requiring tight response times

Real-Time Systems (3)

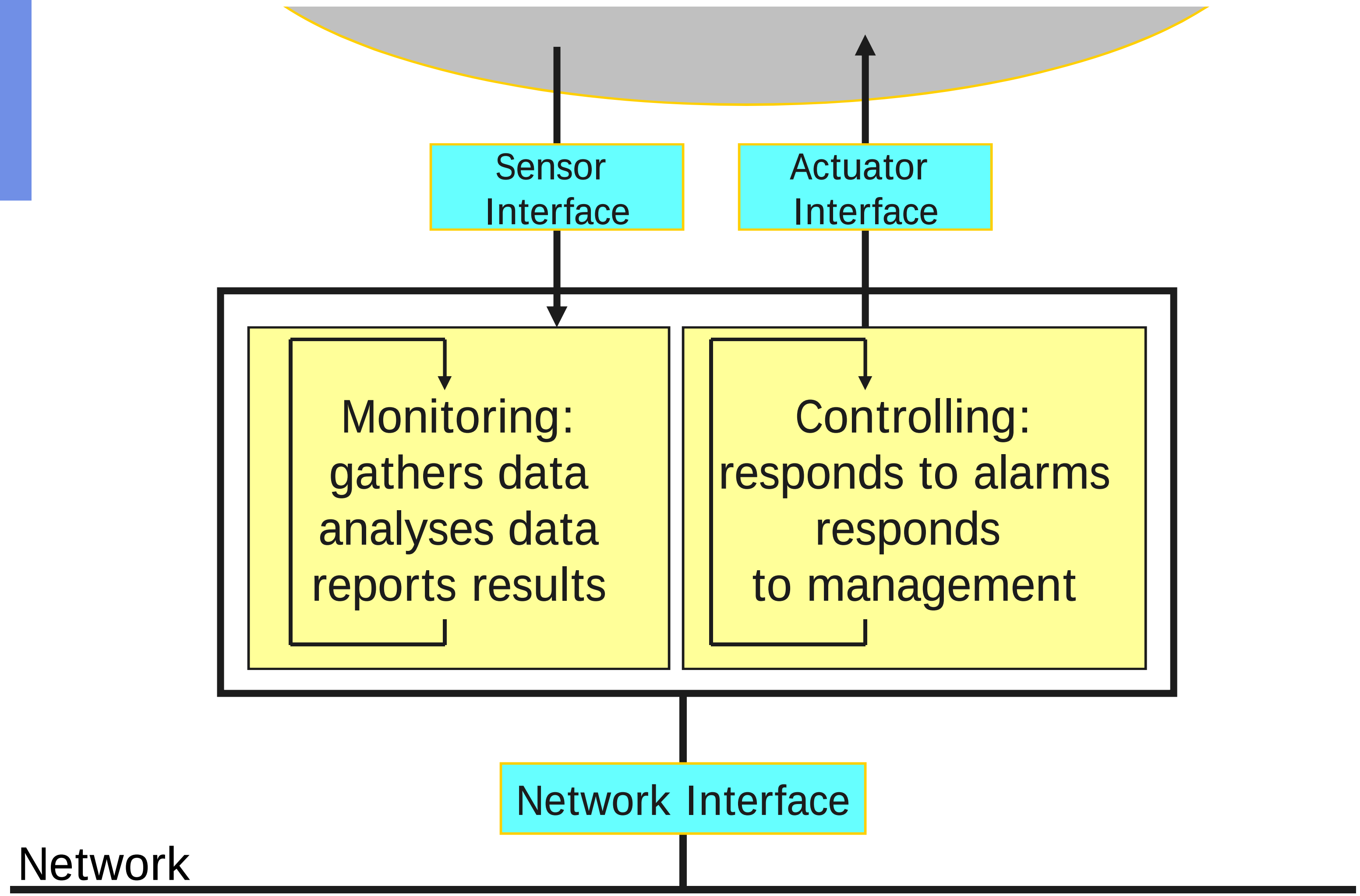
- Process Control (hard real time requirements)
  - responds to an “alarm signal” in predictable time, otherwise an expensive disaster or even a catastrophe might happen,
    - fuel injection control, ABS or Air Bag in a car
    - flight control, nuclear power station, military equipment, ...
  - signals may arrive in some unpredictable way

- Multimedia (soft real time requirements)
  - responds to a “signal” in a more or less specified time, otherwise something unpleasant will happen (not a catastrophe)
    - unsynchronized audio and video signals
  - signals tend to occur more or less periodically

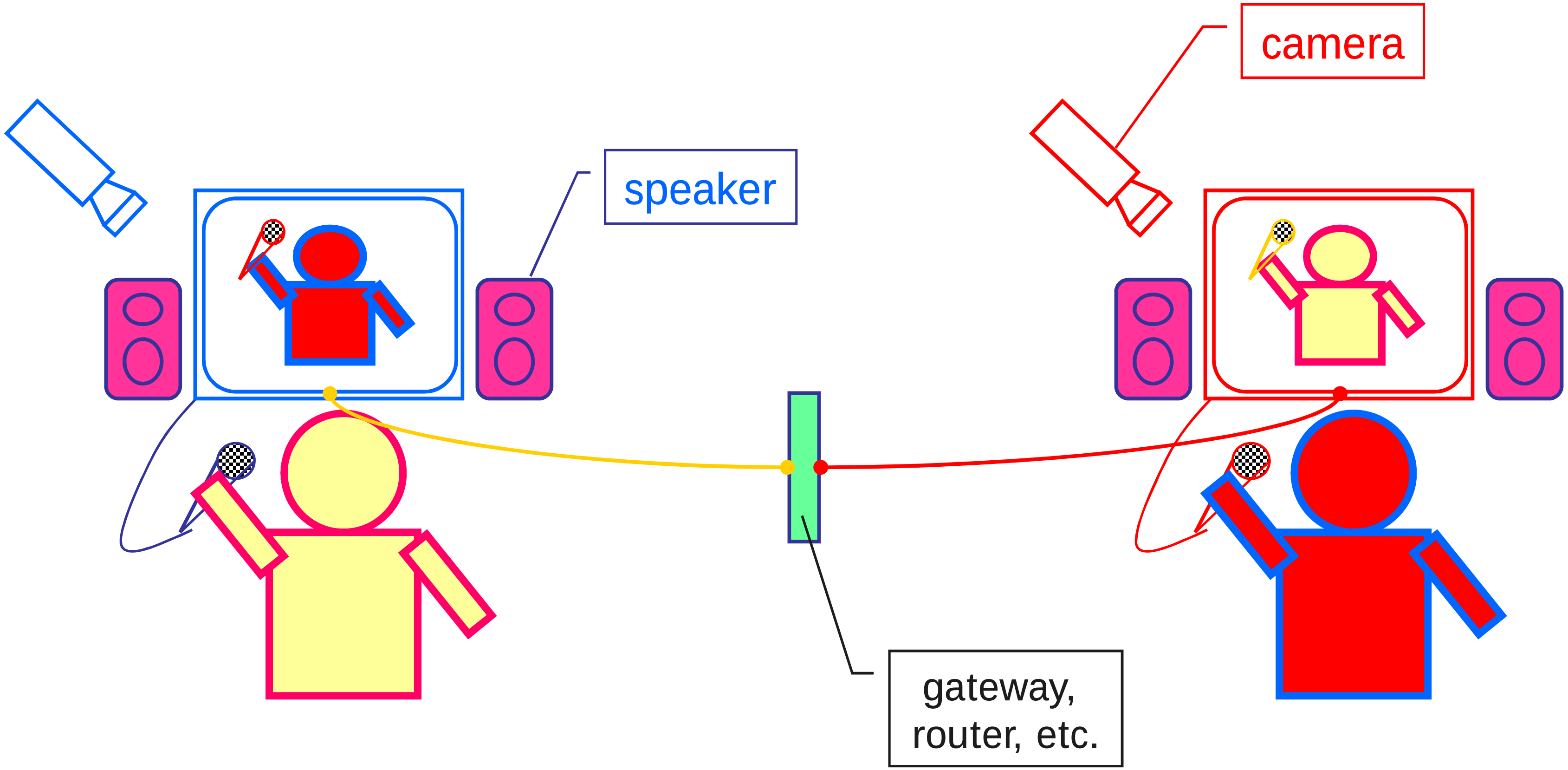
Process Control Systems



Component Computer



Multi Media Systems



- Videophone, -mail or -conferencing
- Multimedia docs (museum catalogue, video archive, etc.)

Req. for Real-Time Systems

- Support separate concurrent activities (some are periodic, some are sporadic, i.e. unpredictable)
- Requirements for the scheduling of activities (meet deadlines, ensure quality of service)
- Support for teamwork in some activities (achieving a common goal)

Handheld Systems

- Personal Digital Assistants (PDAs)
- Cellular telephones
- Issues
  - Limited memory
  - Slow processors
  - Small displays

Computing Environments

- Traditional computing
  - PCs, servers, limited remote access
- Web-Based Computing
  - Client/Server and web services, convenient remote access, location-less servers
- Embedded Computing
  - Most computers (auto engine controllers, microwaves)
  - Up to now limited OS features
  - Little or no user interface, remote access

Example OS

Unix

http://www.cl.cam.ac.uk/~smh22/os-net.html#unix

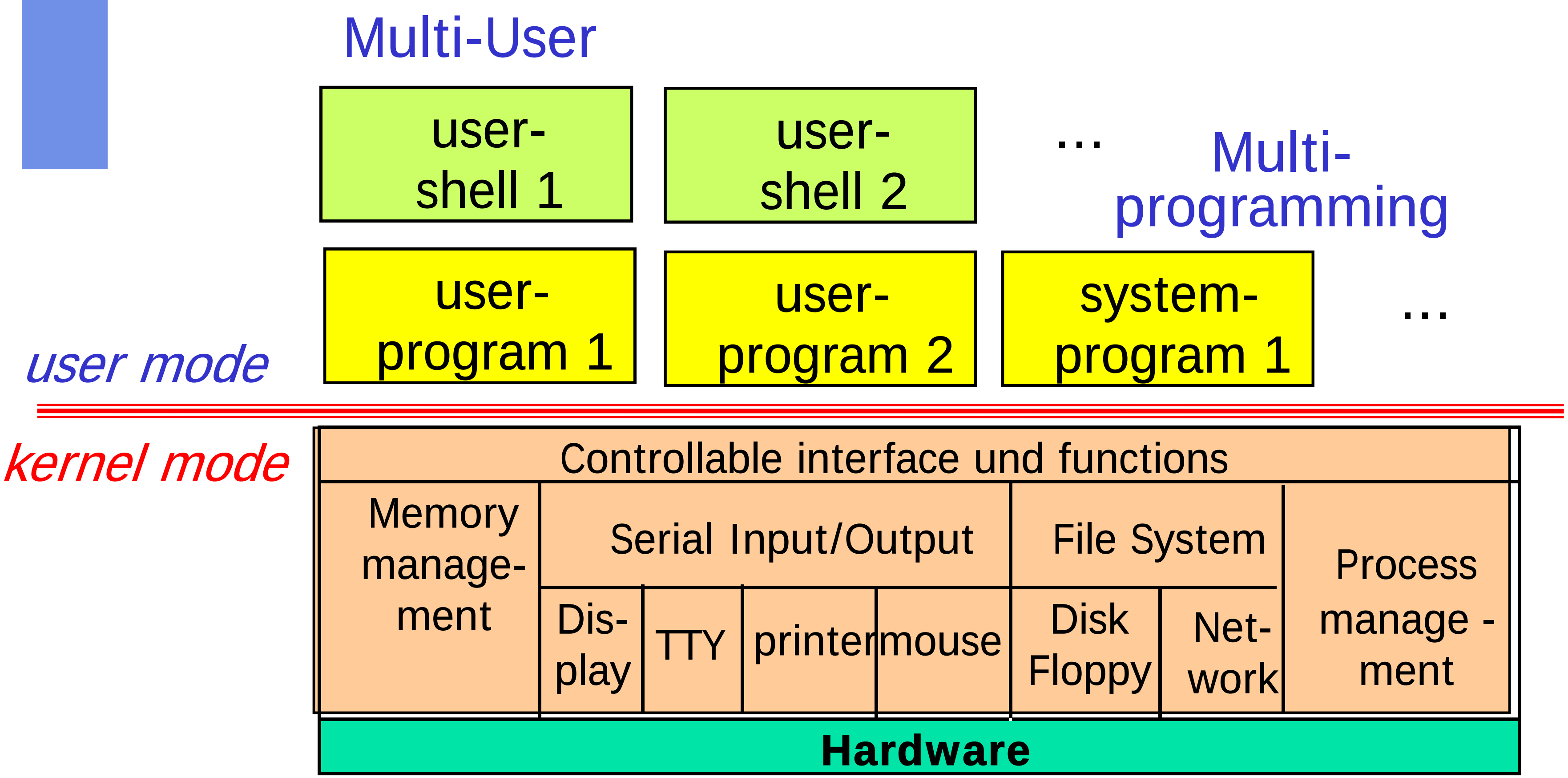
Windows

http://www.sysinternals.com/

Linux

http://www.linuxhq.com/guides/TLK/tlk.html

Unix System Architecture



An OS interface independent of implementation is **POSIX:**
Portable **O**perating **S**ystem **I**nterface based on Uni**X**

Windows NT Architecture

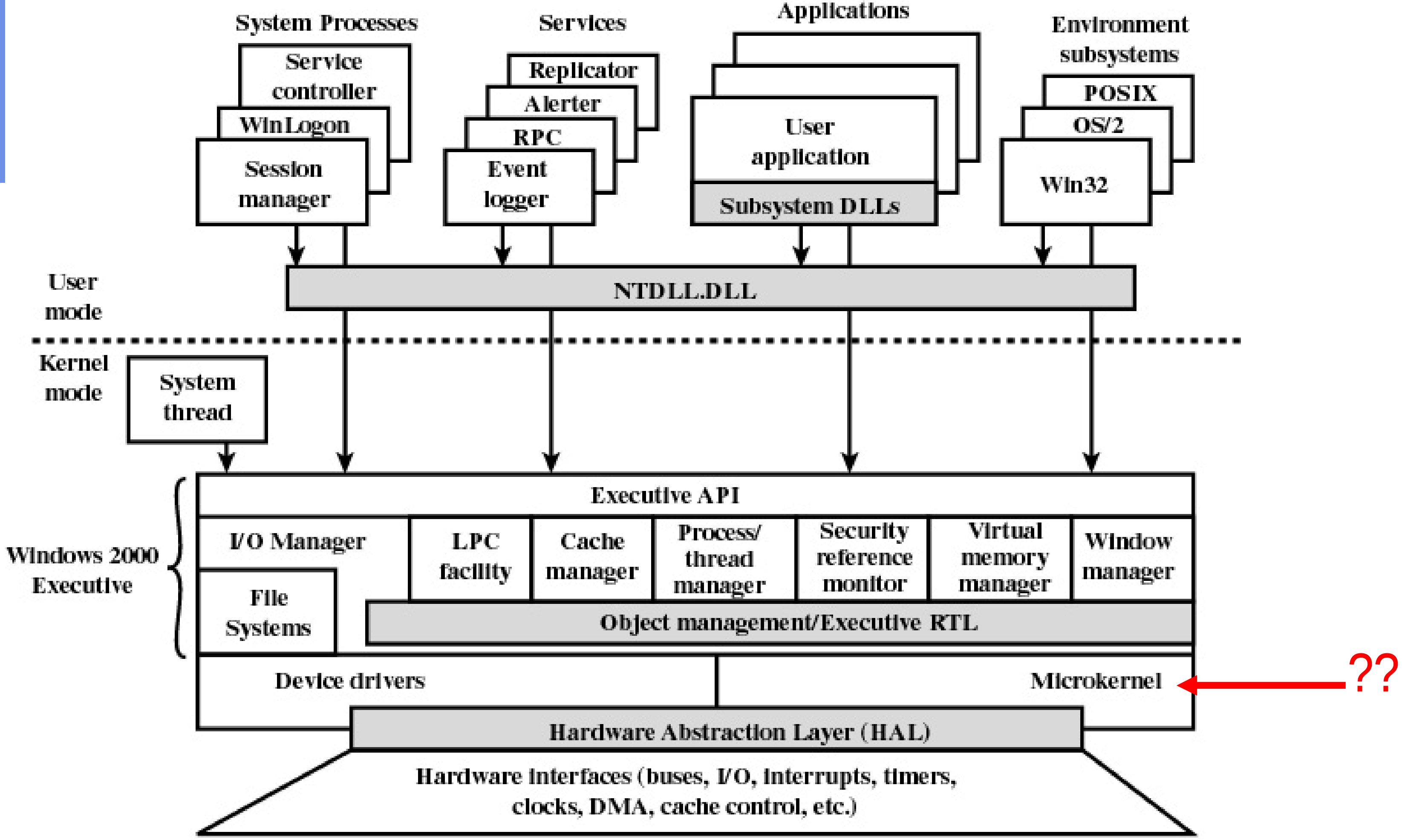


Figure 2.13 Windows 2000 Architecture

Application Systems

Why Application Systems?

- Without an application-specific controlling interface, you can only abort and restart a simulation (via usual system commands such as kill).
- With an application-specific controlling interface, you can stop, protocol an endlessly running simulation, and resume it later with corrected input data

⇒ Paradigms, principles, policies, and mechanisms of OSes can also be used within other systems

⇒ Try to parallelize your applications whenever you can

Challenge of Parallel Computing

- *How do we get a speedup of f(N) on an N-way multi-processor*[1]?
  - Software must be parallelizable
- Speedup can refer to
  - Turnaround time: length of time to complete a single task
  - Throughput: rate at which tasks are completed

[1] In practice speedup is quite limited

Parallelization Theory

- Amdahl's Law predicts speedup on a parallel machine:

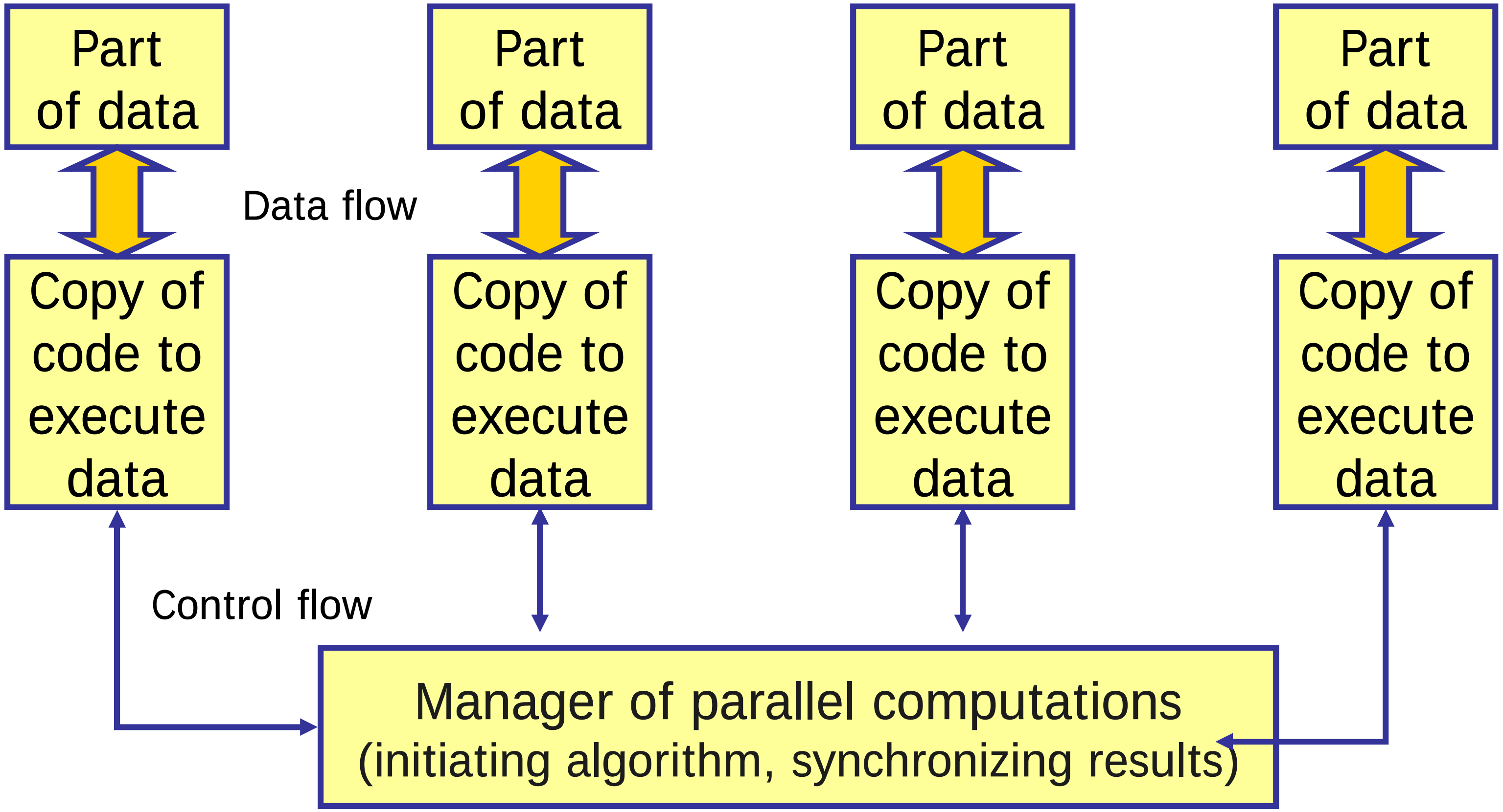
$$\text{speedup} = \frac{\mathbf{1}}{\mathbf{F + (1\text{-}F) / N}}$$

- N: number of processors
- F: fraction of computation that is sequential

Parallelization in Practice

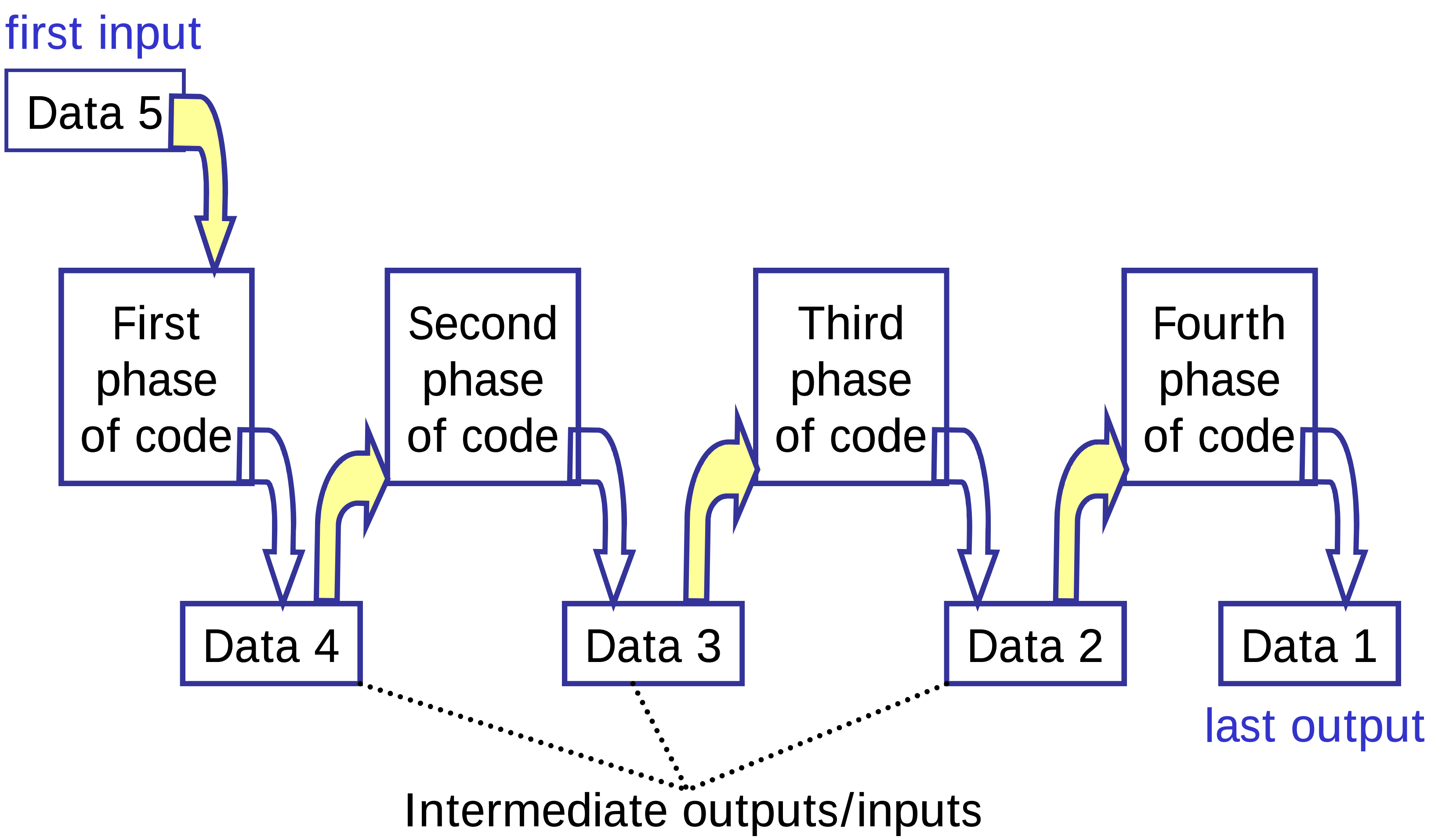
- Predicting performance is difficult because there are many flavors of parallelism
  - Multiple processors (in a SMP)
  - Multi-core processors
  - Multi-threaded processors (Hyper threading)
  - Clusters of machines
- Running and measuring your application software is the only way to know for sure

Parallel Application



Hint: Design a simple model to show the potential performance improvements .

Parallel Application (Pipeline)



Req. for Parallel Applications

- Support for separate activities including controlling them (i.e. create, start, stop activities)
- Support for synchronizing activities and/or allowing cooperation on shared data
- Support for communication mechanisms
- ...

Ultimate Design Goal

- Only few dedicated systems can be optimized to achieve high performance
- In general, we must live with compromises that are suitable (due to conflicting requirements)
- However, any system we are modeling or implementing has to be correct
- **Correctness is mandatory**
- Although correctness is hardly achievable, we have to work hard to make a system "as correct as possible"