TECHNISCHE UNIVERSITÄT DRESDEN

**Faculty of Computer Science** Institute for System Architecture, Operating Systems Group

# Microkernel-based Operating Systems - Introduction

Björn Döbel

Dresden, Oct 14th 2008

# Lecture Goals

- Provide deeper understanding of OS mechanisms
- Illustrate alternative design concepts
- Promote OS research at TU Dresden
- Make you all enthusiastic about OS development in general and microkernels in special

# Administration - Lecture

- Lecture every Tuesday, 1:00 PM, INF/E08
  - Lecturers: Carsten Weinhold, Michael Roitzsch, Stefan Kalkowski, Björn Döbel
- Slides: http://www.tudos.org -> Teaching -> Microkernel-based Operating Systems
- Subscribe to our mailing list: http://os.inf.tu-dresden.de/mailman/listinfo/mos2008

- This lecture is **not:** Microkernel construction (in summer term)

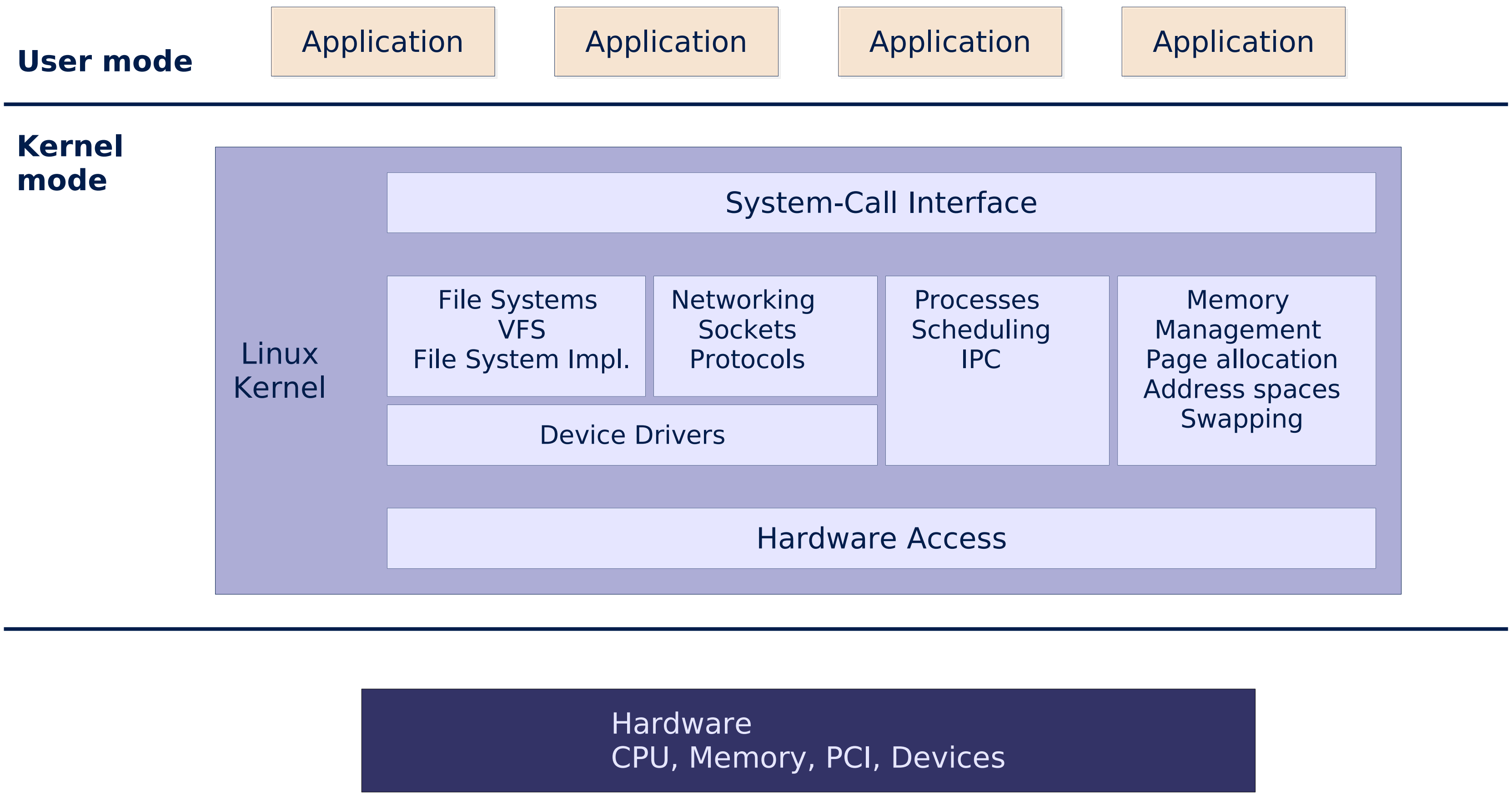
# Administration - Exercises

- Exercises bi-weekly, Tuesday, 2:50 PM, INF/E08
- Practical exercises in the computer pool
- Paper reading exercises
  - Read a paper beforehand.
  - Sum it up and prepare 3 questions.
  - We expect you to actively participate in discussion.
- First exercise: next week, computer pool
  - You'll need a quota raise.

# Complex lab

- Complex lab in parallel to lecture
- Groups of 2-3 students.
- Build several components of an OS (memory server, keyboard driver, binary loader, ...)
- “Komplexpraktikum” for (Media) Computer Science students
- “Internship” for Computational Engineering
- starts on Tuesday, Oct 14th

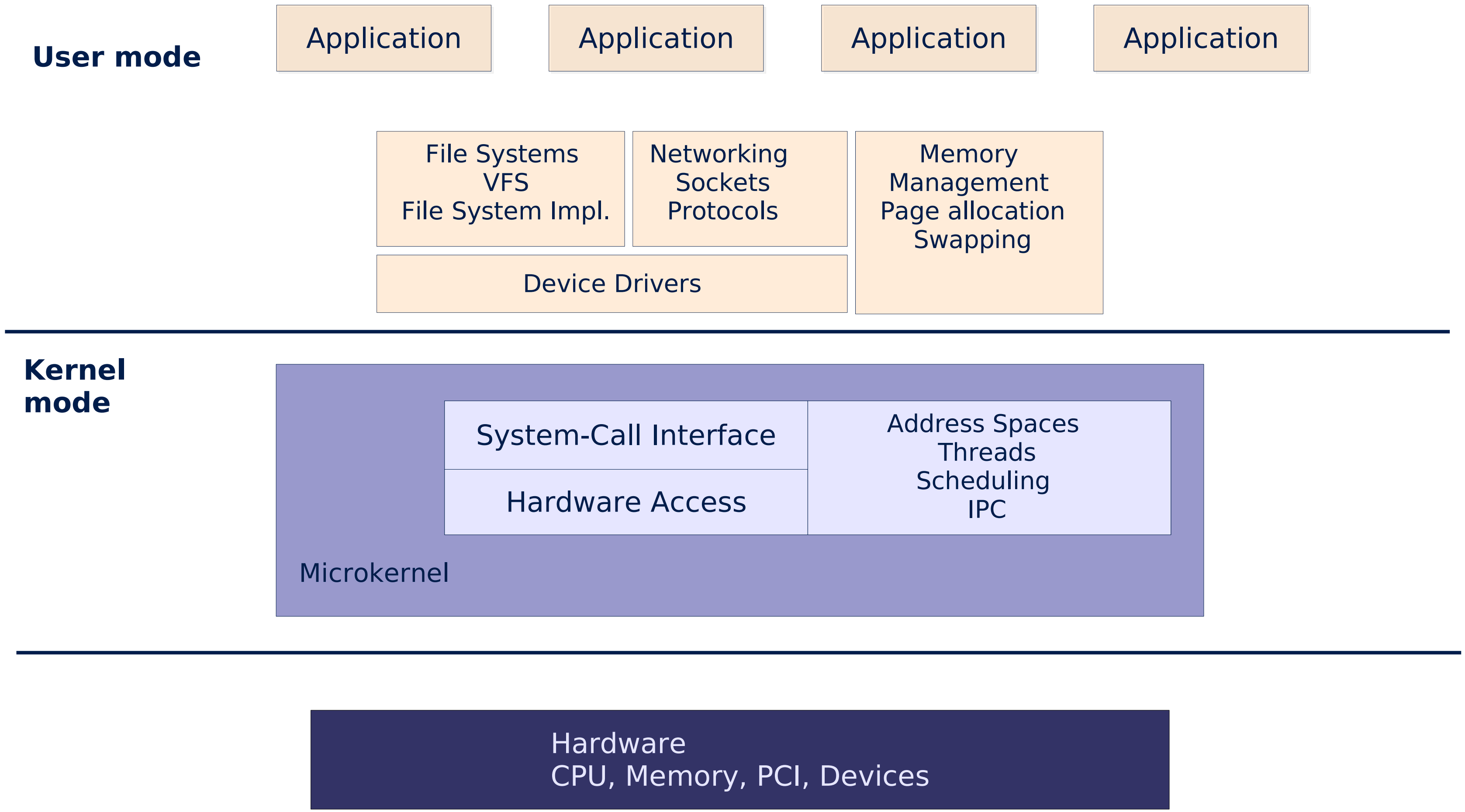
# Monolithic kernels - Linux



# What's the problem?

- All system components run in privileged mode.
- No isolation of components possible.
  - Faulty driver crashes the whole system.
  - More then 2/3 of today's systems are drivers.
- No enforcement of good system design
  - can directly access all kernel data structures
- Size and inflexibility
  - Not suitable for embedded systems.
  - Difficult to replace single components.
- Increasing complexity becomes more and more difficult to manage.

# The microkernel vision



# One vision - microkernels

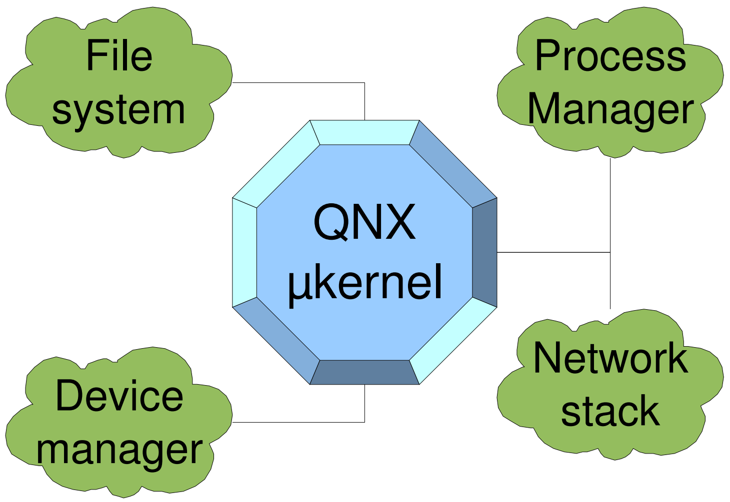
- Minimal OS kernel
  - less error prone
  - small Trusted Computing Base
  - suitable for verification
- System services implemented as user-level servers
  - flexible and extensible
- Protection between individual components
  - systems get
    - More secure – inter-component protection
    - Safer – crashing component does not (necessarily...) crash the whole system

# One vision – microkernels (2)

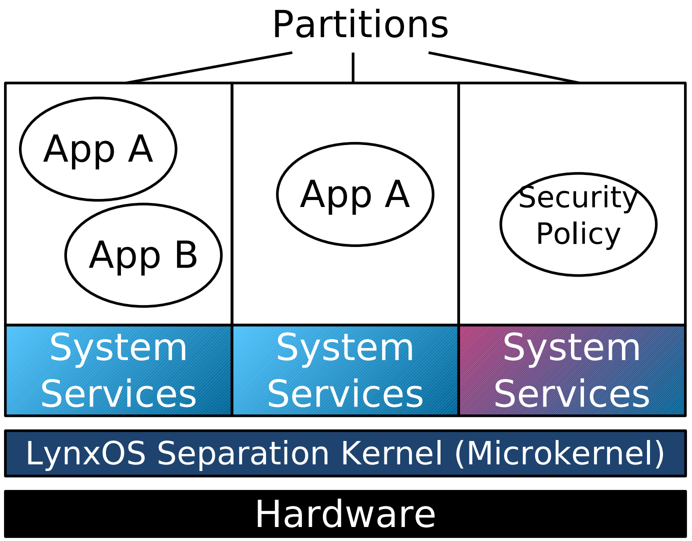
- Servers may implement multiple OS personalities
- Servers may be configured to suit the target system (small embedded systems, desktop PCs, SMP systems, ...)
- Enforce reasonable system design
  - Well-defined interfaces between components
  - No access to components besides these interfaces
  - Improved maintainability

# Examples

- QNX kernel only contains
  - IPC
  - Scheduling
  - IRQ redirection



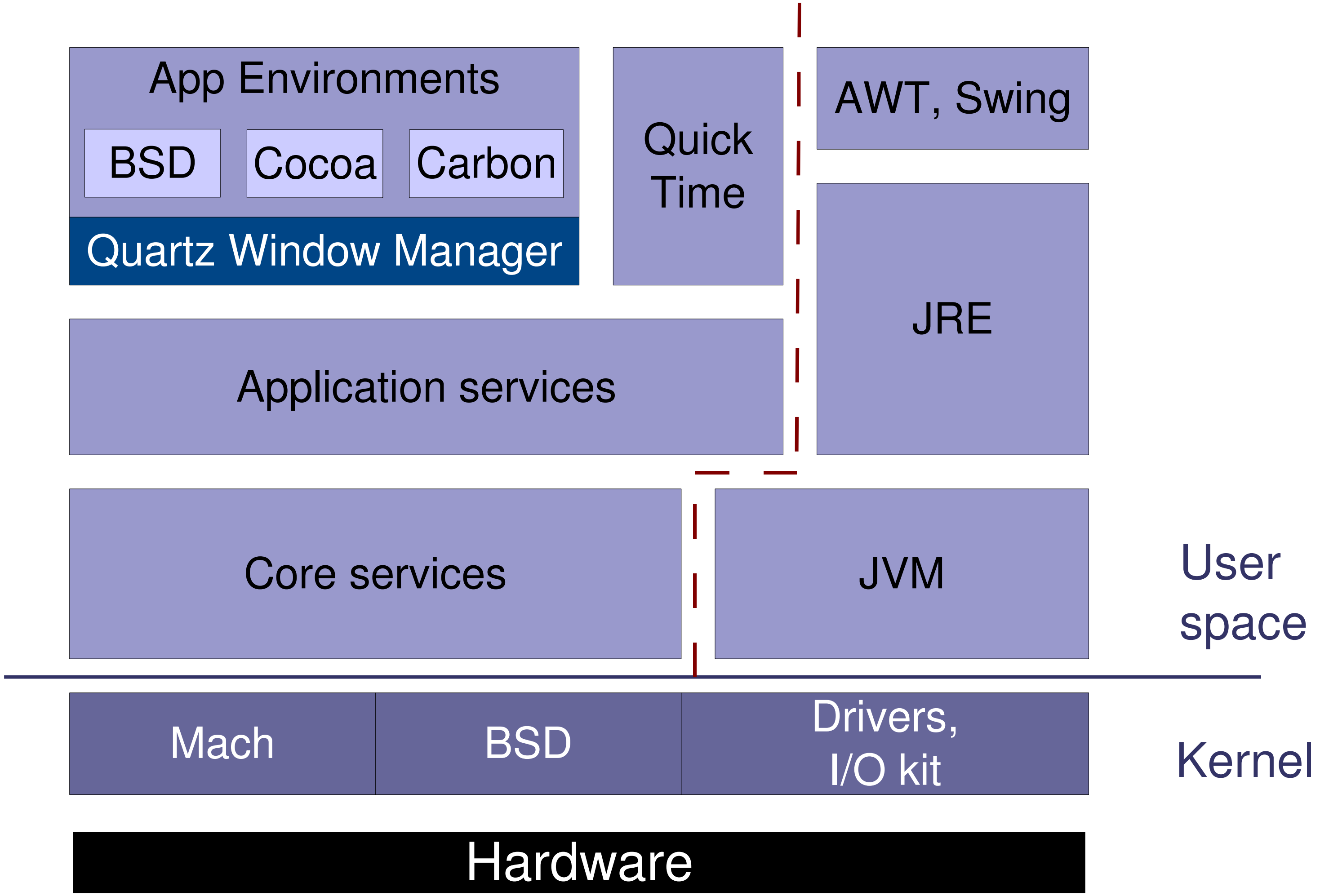

- LynxOS
  - "separation kernel"
  - combine secure and real-time components



# The mother of all microkernels

- Mach – developed at CMU
  - designed as simple, extensible “communication kernel”
  - “ports” for communication channels and memory objects
- Foundation for several real systems
  - Single Server Unix (BSD4.3 on Mach)
  - MkLinux (OSF)
  - IBM Workplace OS
  - Mac OS X
- Shortcomings
  - performance
  - drivers still in the kernel

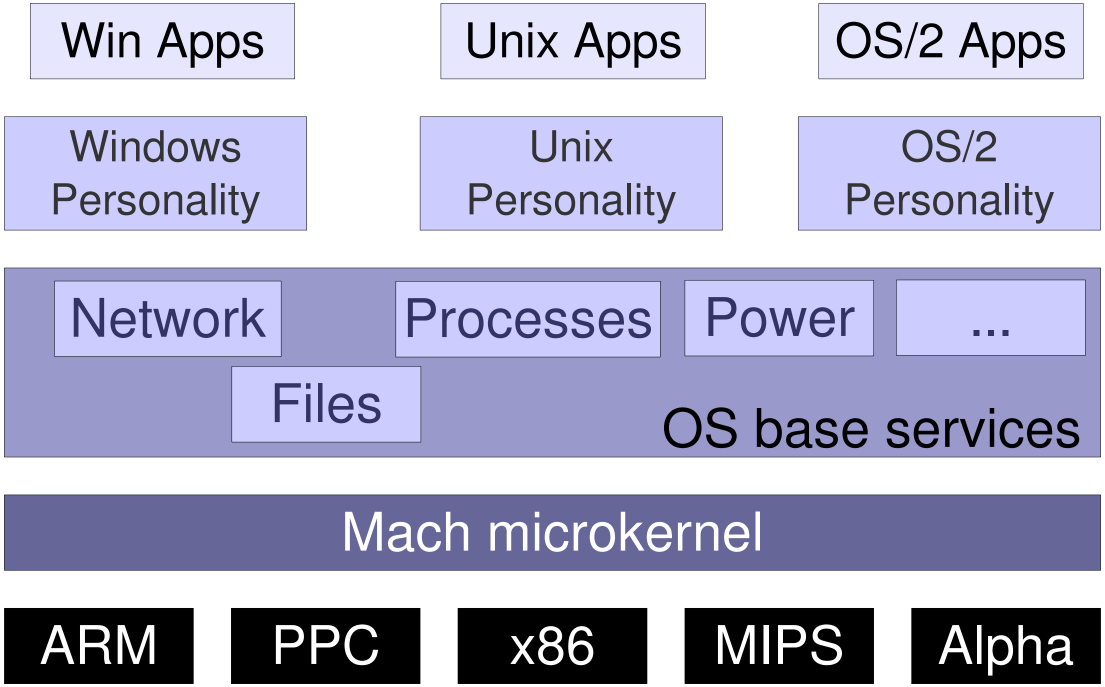
# Mac OS X



App Environments
BSD
Cocoa
Carbon
Quartz Window Manager
Quick Time
AWT, Swing
JRE
Application services
Core services
JVM
User space
Mach
BSD
Drivers, I/O kit
Kernel
Hardware

# IBM Workplace OS

- Main goals:
  - multiple OS personalities
  - run on multiple HW architectures



# IBM Workplace OS (2)

- Never finished
- Failure causes:
  - Underestimated difficulties in creating OS personalities
  - Management errors, forced divisions to adopt new system without having a system
  - "Second System Effect": too many fancy features
  - Too slow
- Conclusion: Microkernel worked, but system atop the microkernel did not

# Lessons learned

- OS personalities did not work
- Flexibility – but monolithic kernels became flexible, too (Linux kernel modules)
- Better design – but monolithic kernels also improved (restricted symbol access, layered architectures)
- Maintainability – still very complex
- Performance matters a lot

# Proven advantages

- Subsystem protection / isolation
- Code size
  - Fiasco kernel: ~ 15,000 LoC
  - Minimal application:
    (boot loader + “hello world”):
    ~ 6,000 LoC
  - Linux kernel (2.6.24, x86 architecture):
    ~ 1.6 million LoC
    (+drivers: ~ 2.8 million LoC)

    (*generated using David A. Wheeler's 'SLOCCount'*)
- Customizable
  - Tailored memory management / scheduling / … algorithms
  - Adaptable to embedded / real-time / secure / … systems

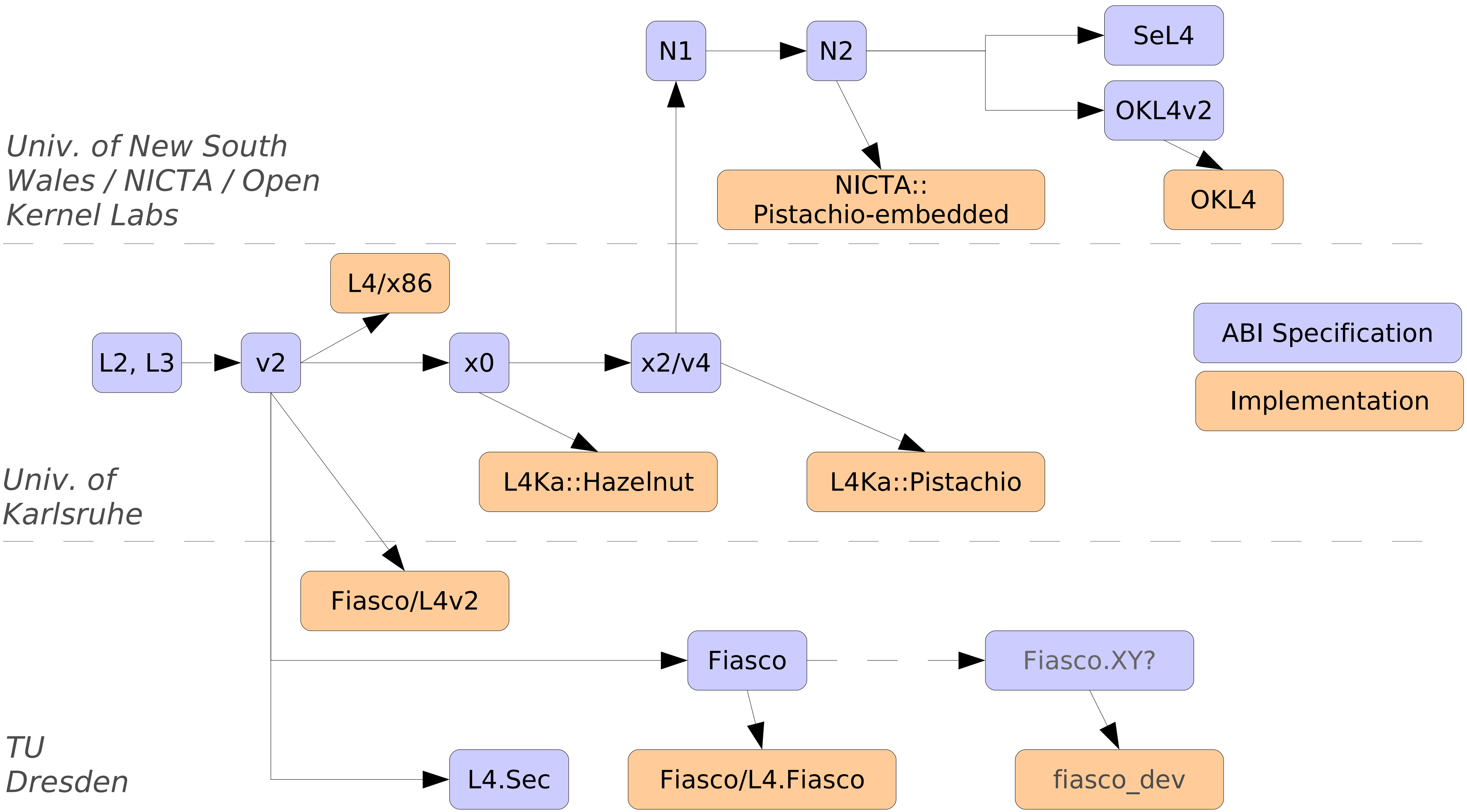
# Challenges

- We need fast and efficient kernels
  - covered in the “Microkernel construction” lecture in the summer term
- We need fast and efficient OS services
  - Memory and resource management
  - Synchronization
  - Device Drivers
  - File systems
  - Communication interfaces
  - subject of this lecture

# Who's out there?

- Minix @ FU Amsterdam (Tanenbaum)
- Singularity @ MS Research
- Eros/CoyotOS @ Johns Hopkins University
- The L4 Microkernel Family
  - Originally developed by Jochen Liedtke at IBM and GMD
  - 2nd generation microkernel
  - Several kernel ABI versions

# The L4 family – a timeline

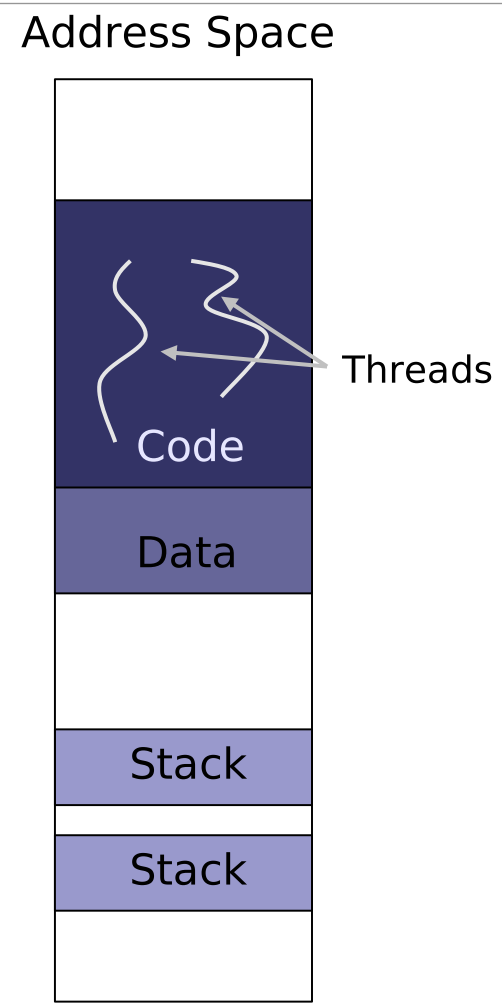


# L4 concepts

- Jochen Liedtke: “A microkernel does no real work.”
  - kernel provides inevitable mechanisms
  - kernel does not enforce policies
- But what *is* inevitable?
  - Abstractions
    - Threads
    - Address spaces (tasks)
  - Mechanisms
    - Communication
    - Mapping
    - (Scheduling)

# L4 - Threads

- Thread ::= Unit of Execution
- Unique Thread ID
- Properties managed by L4 kernel:
  - Instruction Pointer (EIP)
  - Stack (ESP)
  - Registers
- User-level applications need to
  - allocate stack memory
  - provide memory for application binary
  - find entry point
  - ...
- 1 addr. space contains up to 128 threads

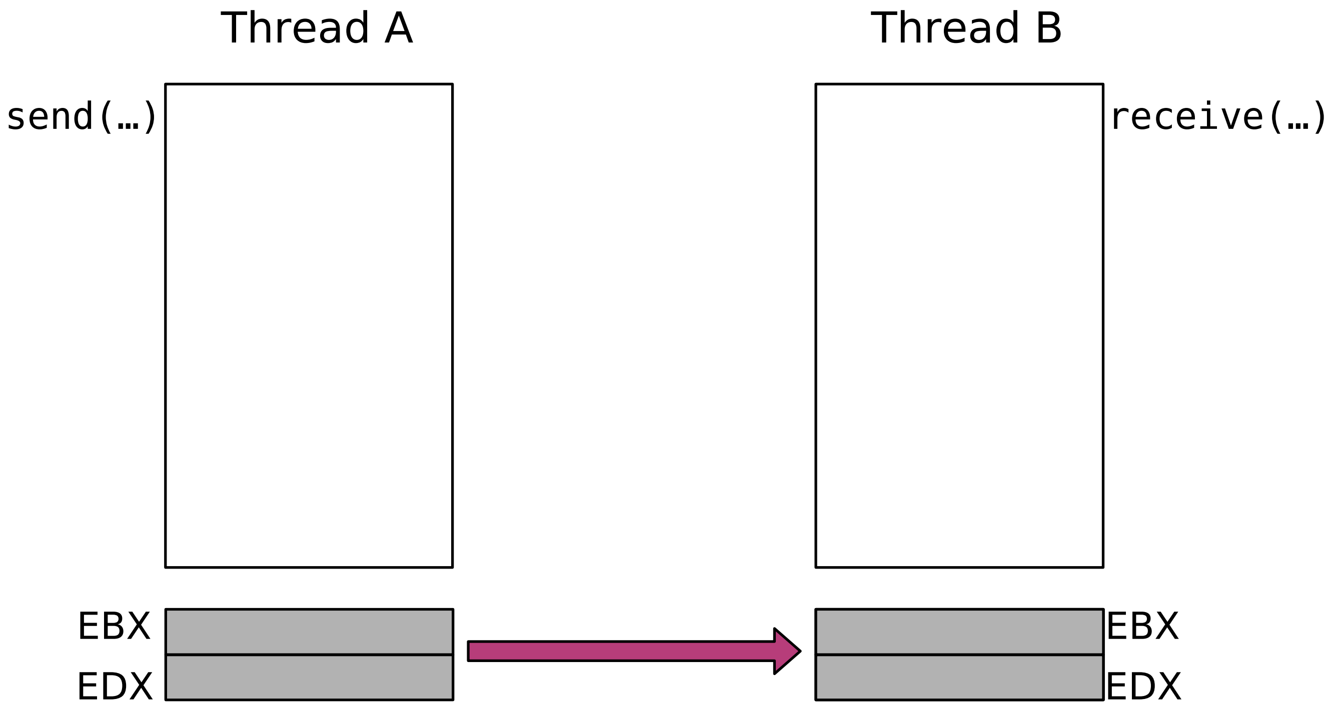


# L4 - Communication

- Synchronous inter-process communication (IPC) between threads
  - agreement between partners necessary
  - timeouts
  - no in-kernel buffering
  - efficient implementation necessary
- IPC flavors:
  - *send*
  - *receive_from* (closed wait)
  - *receive* (open wait)
  - *call* (send and receive_from)
  - *reply and wait* (send and receive)

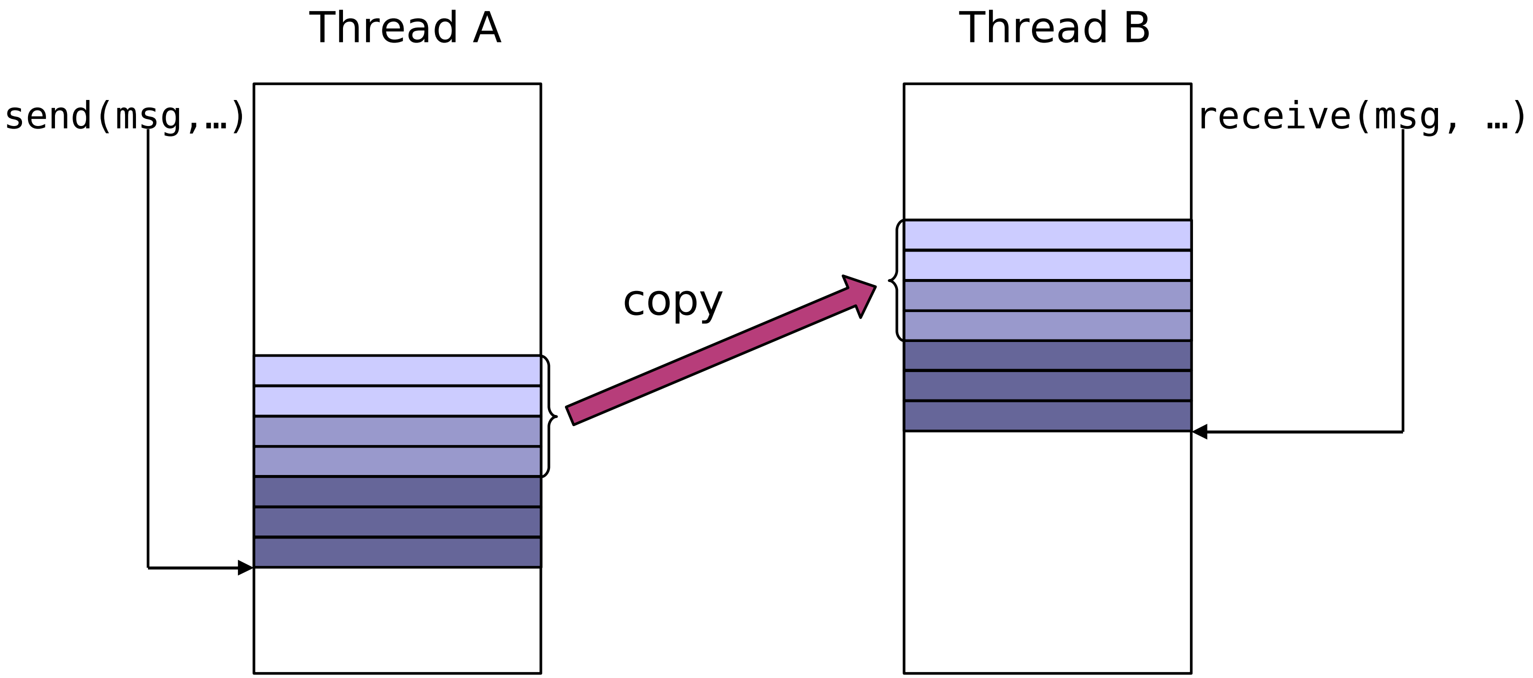
# L4 IPC – Message types

- short (register-only) IPC
- fast – no memory access



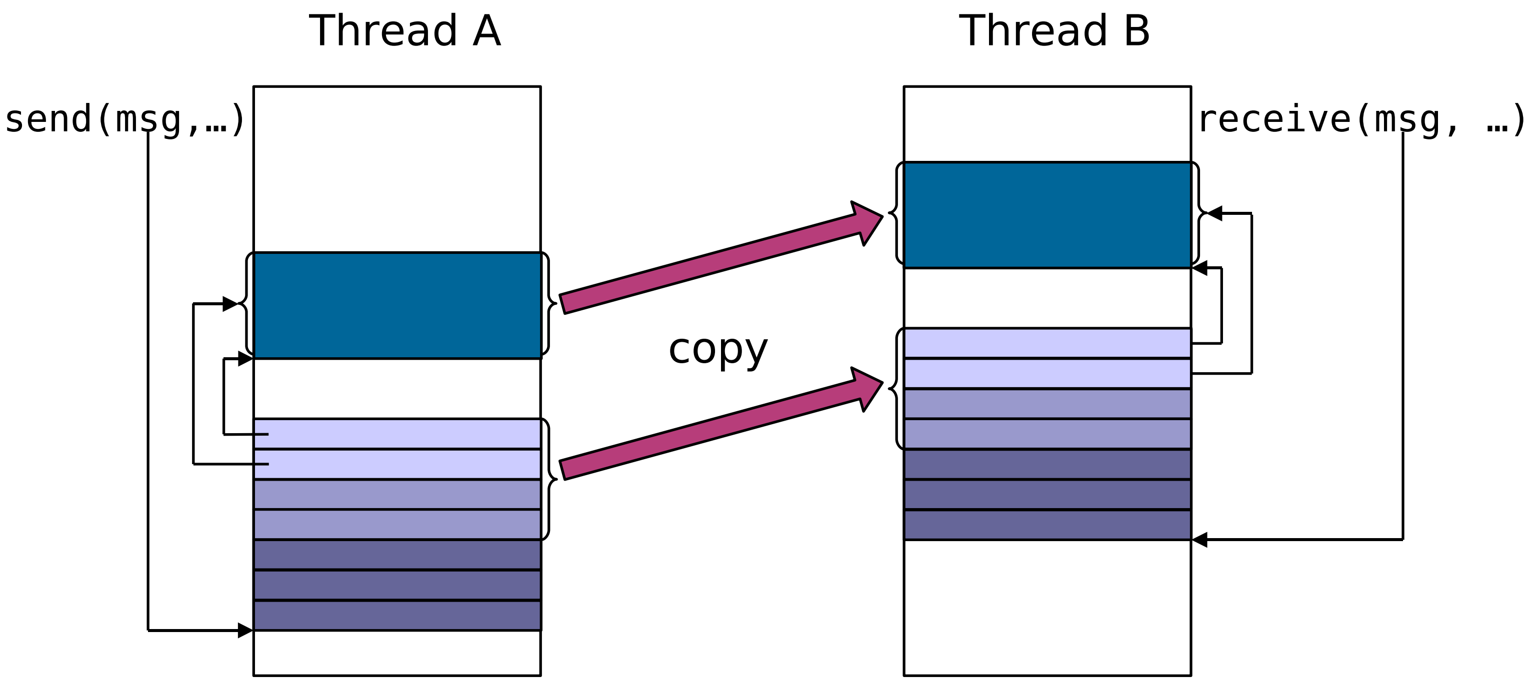
# L4 IPC – Message types

- Direct long IPC – more than 2 words at a time
- Words are directly copied:



# L4 IPC – Message types

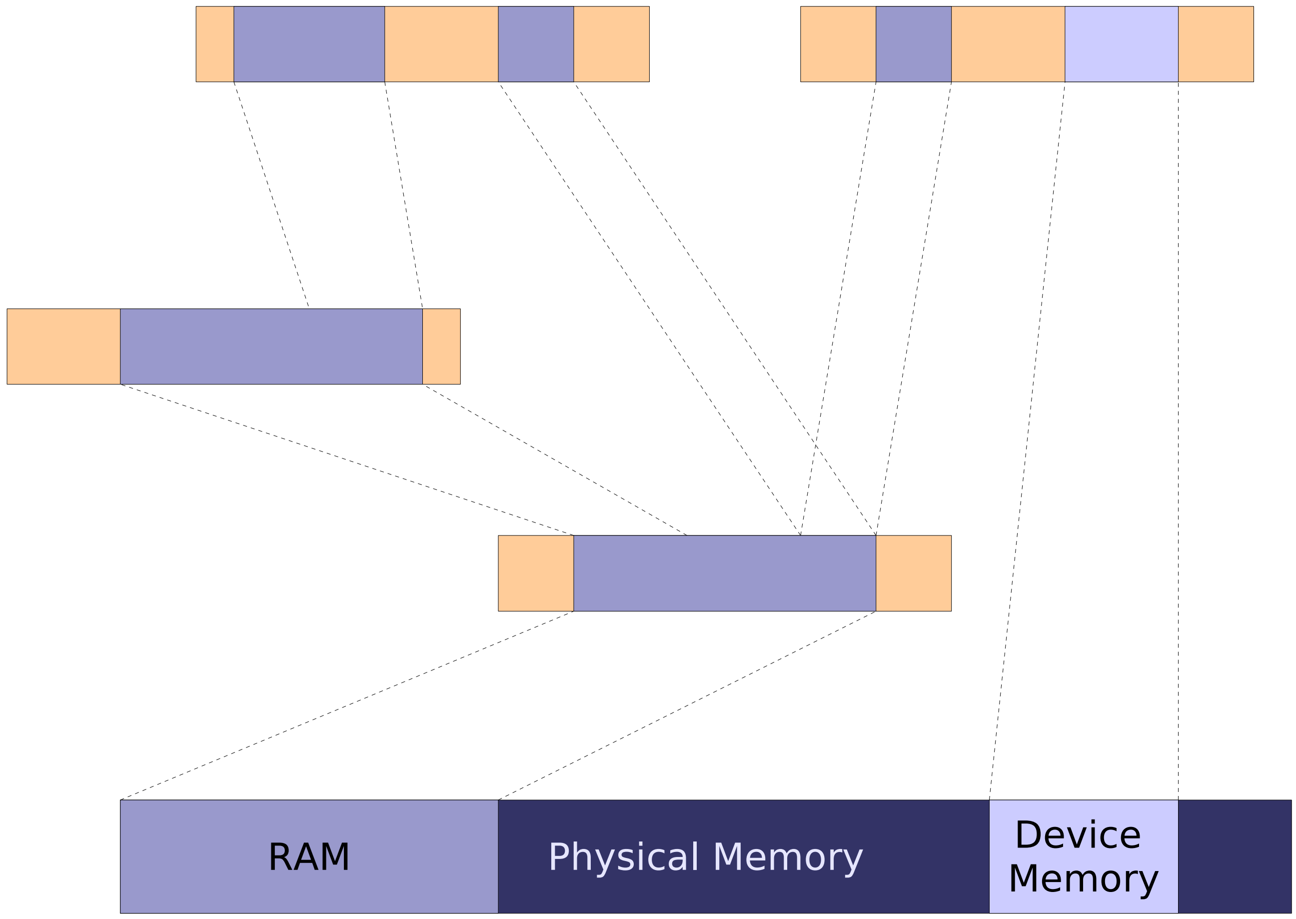
- Indirect Long IPC (String IPC)
- Words in message buffer point to external memory areas that are copied



# L4 - Mappings

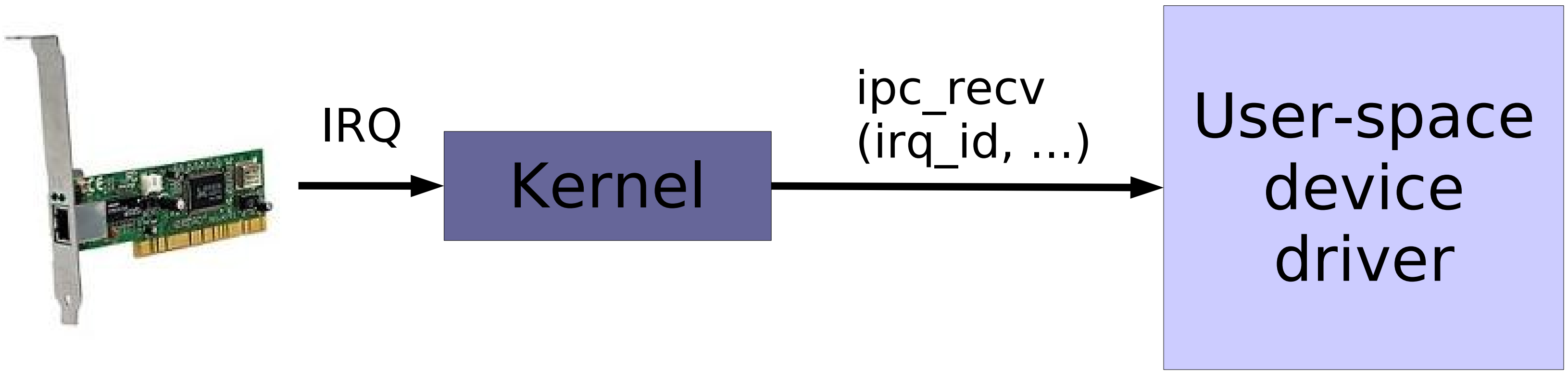
- Threads can map pages from their address space to other address spaces.
- This is achieved by adding a Flexpage descriptor to the IPC message buffer.
- Flexpages describe mapping
  - location and size of memory area
  - receiver's rights (read-only, read-writable)
  - type (memory, IO, communication capability)
- More general: flexpages as fundamental resource abstraction

# L4 – Recursive address spaces



# L4 – Hardware Interrupts

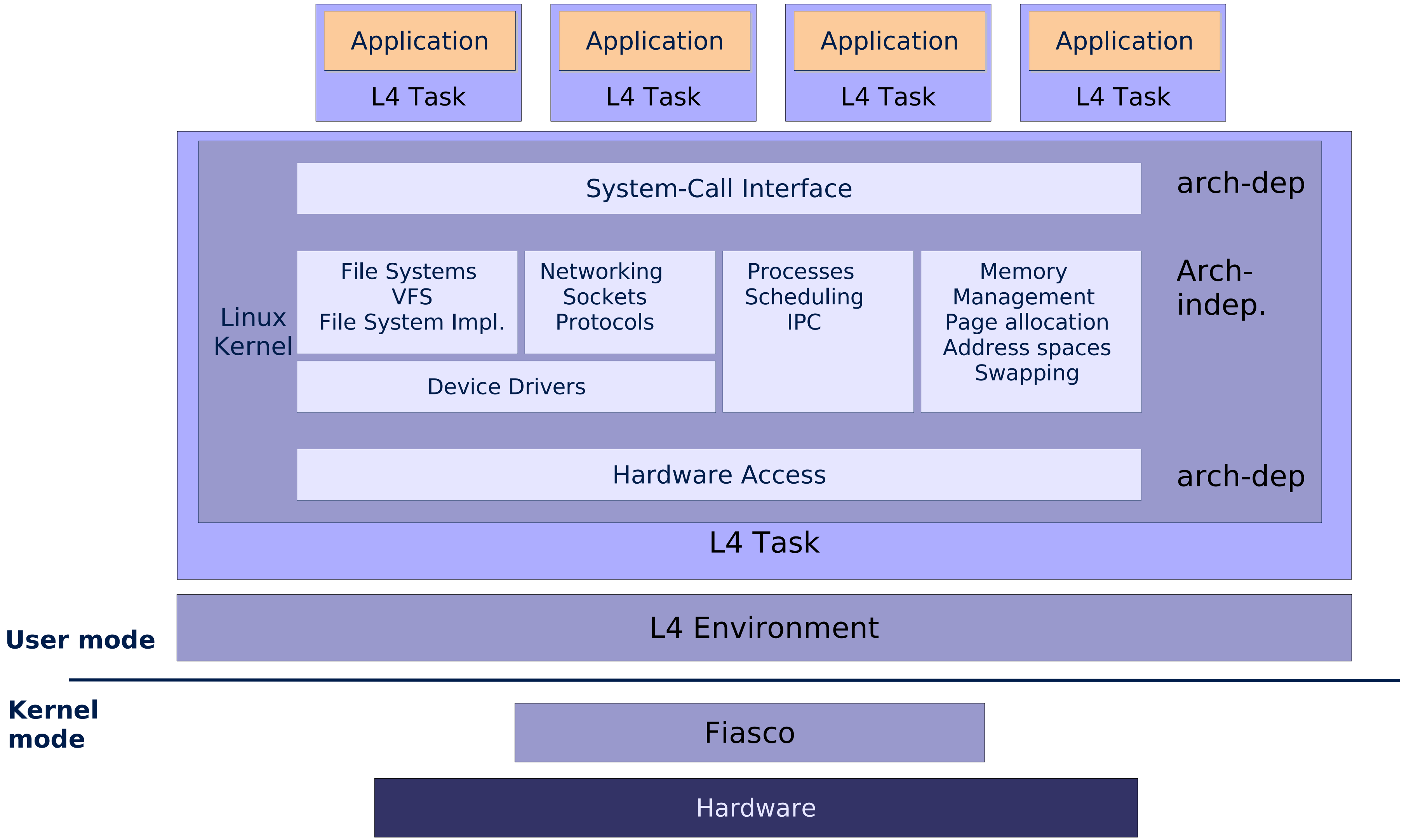
- Special Thread ID to receive HW interrupts from the kernel
- Exaclty one thread can listen to exactly one interrupt – multiplexing in userspace necessary.
- I/O Memory and I/O ports are manages using flexpages.



# System Calls in L4.Fiasco

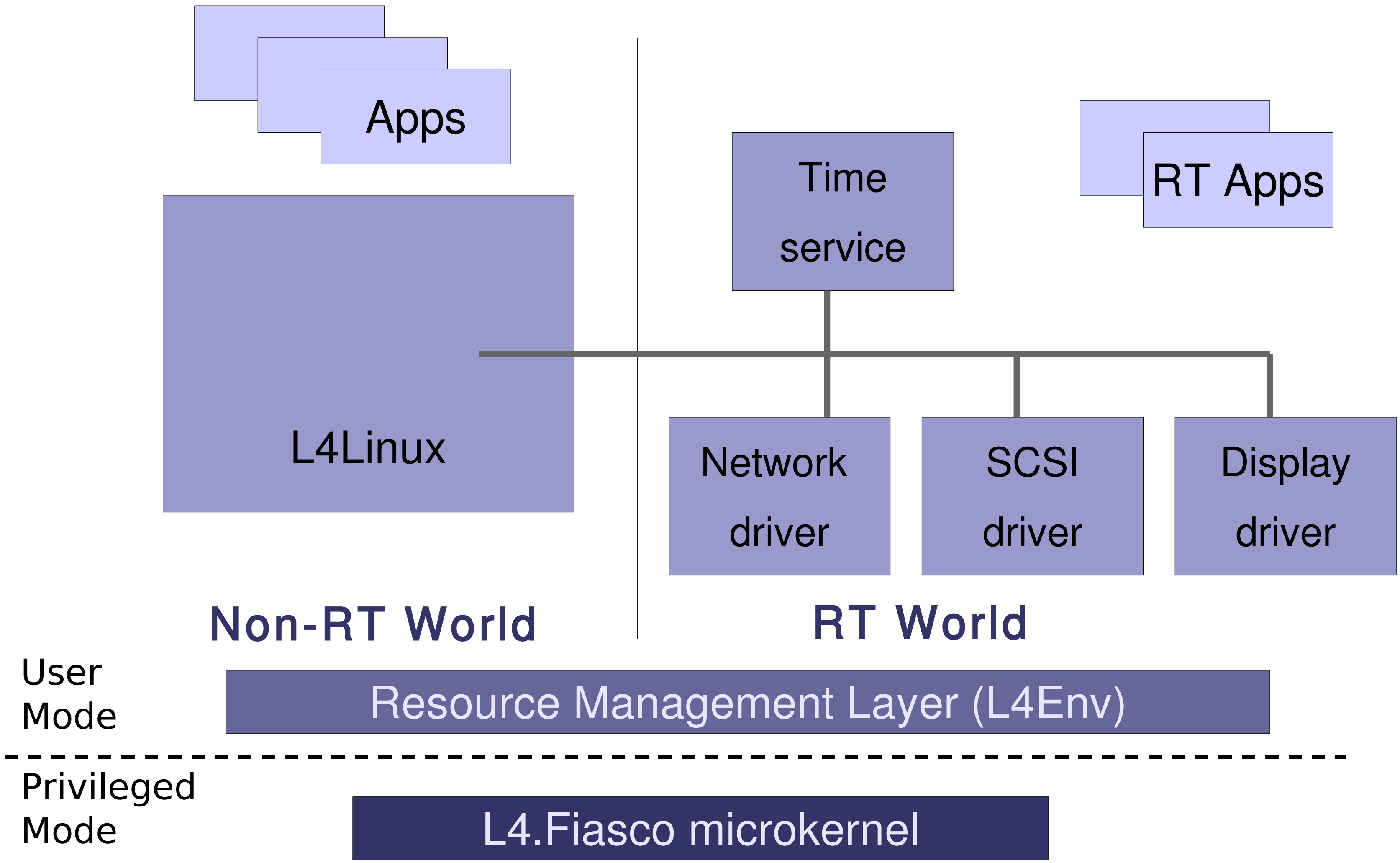
- Address spaces
  - `l4_task_new` – create/delete tasks
- Threads
  - `l4_thread_ex_regs` – create/modify threads
  - `l4_thread_schedule` – setup scheduling parameters
  - `l4_thread_switch` – switch to another thread
- IPC
  - `l4_ipc` – perform IPC
  - `l4_fpage_unmap` – revoke flexpage mapping
  - `l4_nchief` – find next chief

# Linux on L4



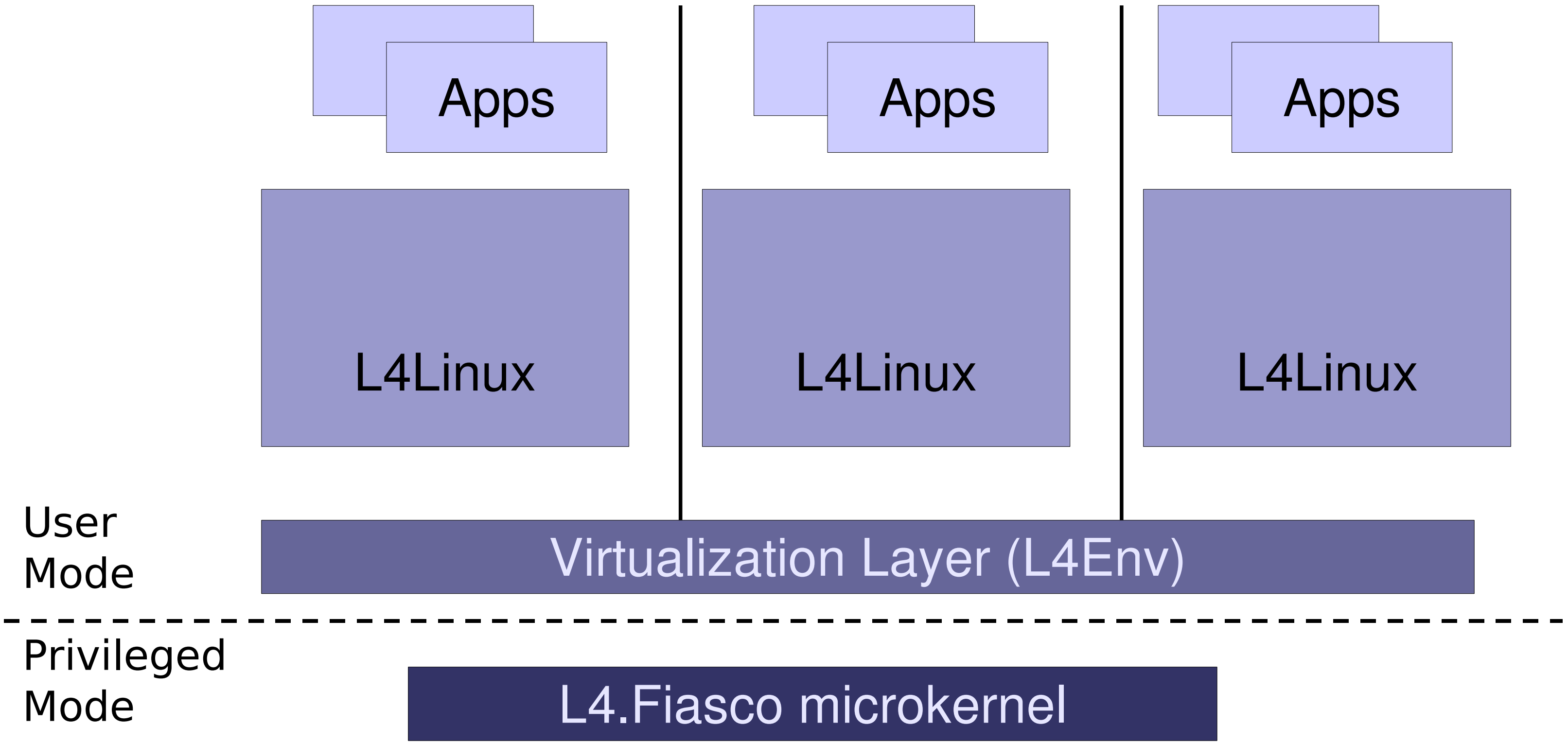
Application
L4 Task
Application
L4 Task
Application
L4 Task
Application
L4 Task
System-Call Interface
arch-dep
Linux Kernel
File Systems
VFS
File System Impl.
Networking
Sockets
Protocols
Processes
Scheduling
IPC
Memory Management
Page allocation
Address spaces
Swapping
Arch-indep.
Device Drivers
Hardware Access
arch-dep
L4 Task
User mode
L4 Environment
Kernel mode
Fiasco
Hardware

# The Dresden Real-Time Operating System



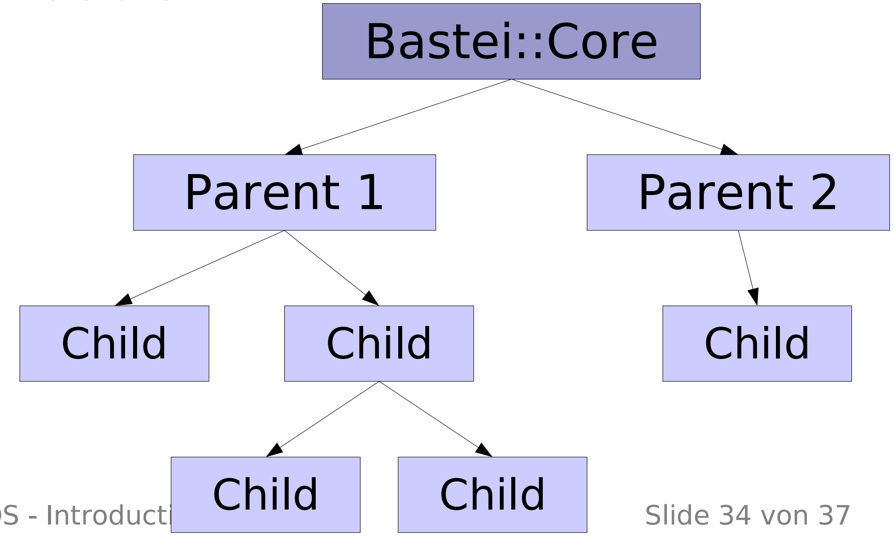
# Virtual machines

- Isolate not only processes, but also complete Operating Systems (compartments)
- "Server consolidation"



# Bastei

- Disadvantages of existing systems (microkernels as well as monoliths):
  - global naming
  - resource management and revokation difficult
  - hard to get security policies right
- Bastei := C++-based OS framework developed here in Dresden
  - recursive system design
  - capabilities
  - stacked security policies



# Design alternatives

- Hardware isolation
  - x86 privilege rings, privileged instructions
- Software isolation
  - N. Wirth's Oberon language and OS since 1980s
  - Singularity from MS Research written in a dialect of C# (since 2000s)
- Exokernels
  - build OS interface into a library and link it to single applications (library OS)

# Lecture outline

- **Basic mechanisms and concepts**
  - Memory management
  - Tasks, Threads, Synchronization
  - Communication
- **Building real systems**
  - What are resources and how to manage them?
  - How to build a secure system?
  - How to build a real-time system?
  - How to reuse existing code (Linux, standard system libraries, device drivers)?
  - How to improve robustness and safety?

# Outlook

- Next lecture:
  - “Tasks, Threads and Synchronization” on Oct 21st

- Next exercise:
  - Oct 21st
  - Building and booting an L4 system