Microkernel Construction

Introduction

SS2013

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Class Goals

Provide deeper understanding of OS mechanisms

Introduce L4 principles and concepts

Make you become enthusiastic L4 hackers

Propaganda for OS research at TU Dresden

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Administration

- Thursday, 4th DS, 2 SWS
- Slides: http://www.tudos.org → Teaching → Microkernel Construction
- Subscribe to our mailing list: http://www.tudos.org/mailman/listinfo/mkc2013
- In winter term:
  - Construction of Microkernel-based Systems (2 SWS)
  - Various Labs

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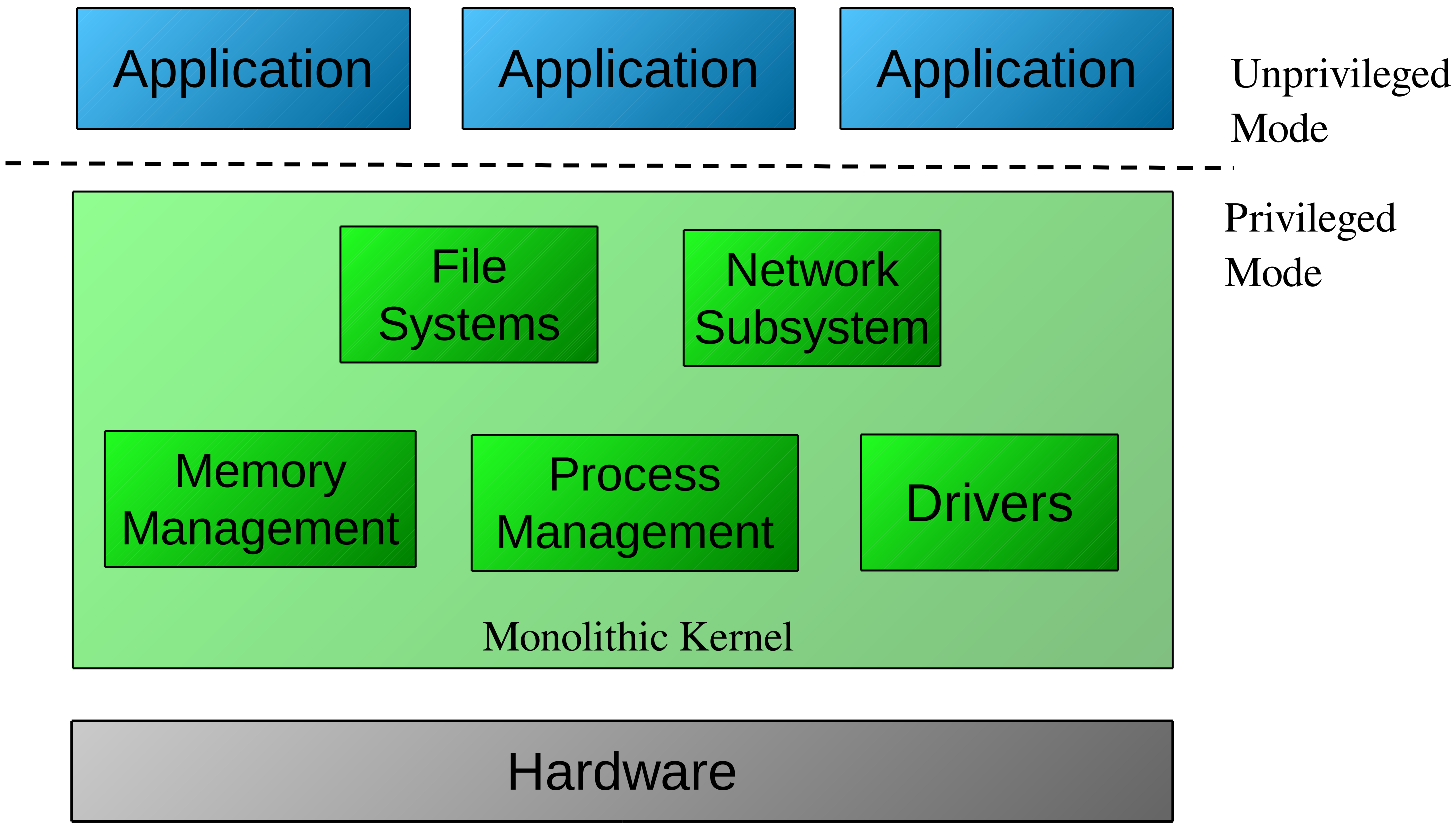
„Monolithic“ Kernel System Design



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Monolithic Kernel OS (Propaganda)

- **System components run in privileged mode**
- ➔ No protection between system components
  - – Faulty driver can crash the whole system
  - – More than 2/3 of today's OS code are drivers
- ➔ No need for good system design
  - – Direct access to data structures
  - – Undocumented and frequently changing interfaces
- ➔ Big and inflexible
  - – Difficult to replace system components

Why something different?

- More and more difficult to manage increasing OS complexity

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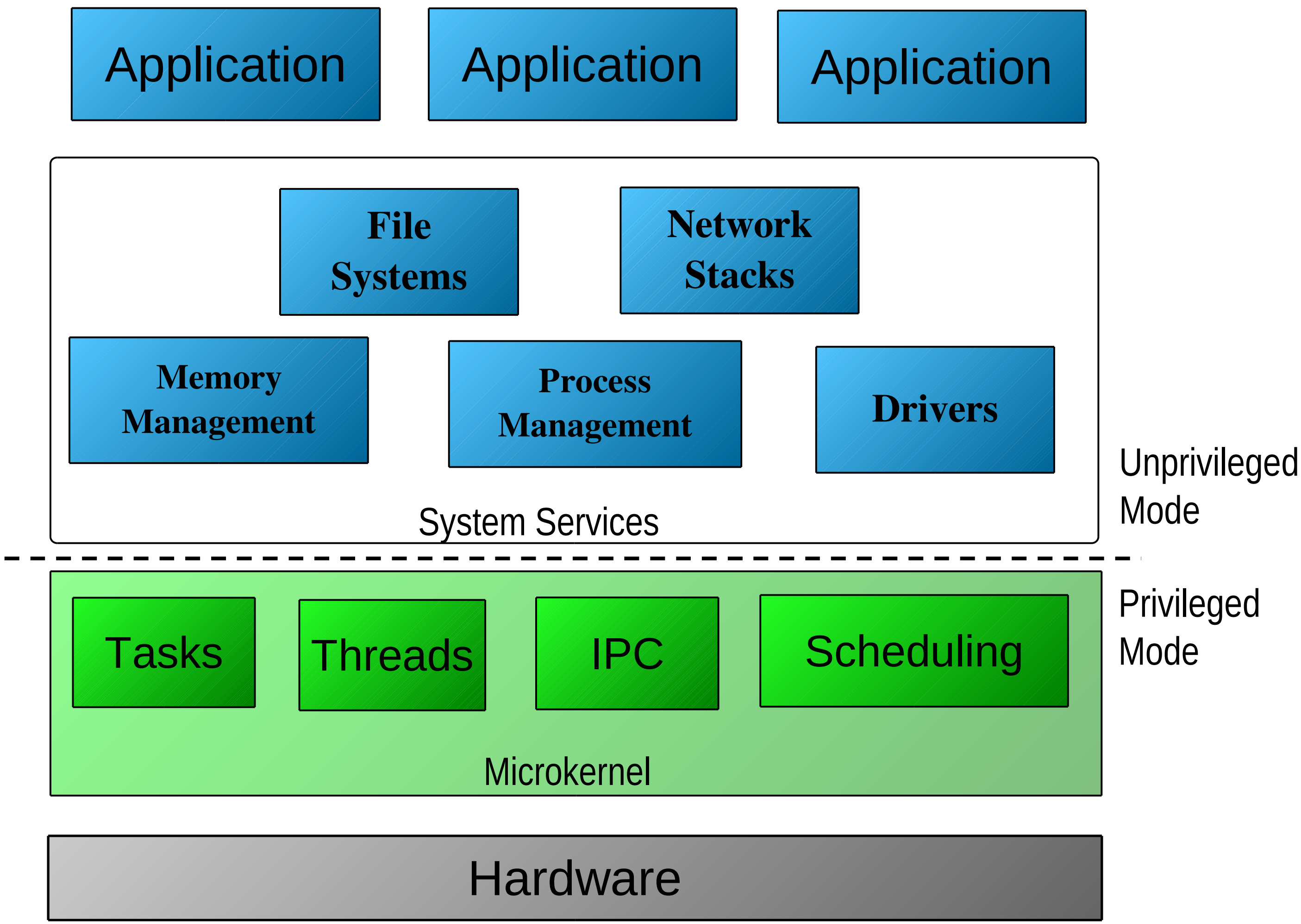
Microkernel System Design



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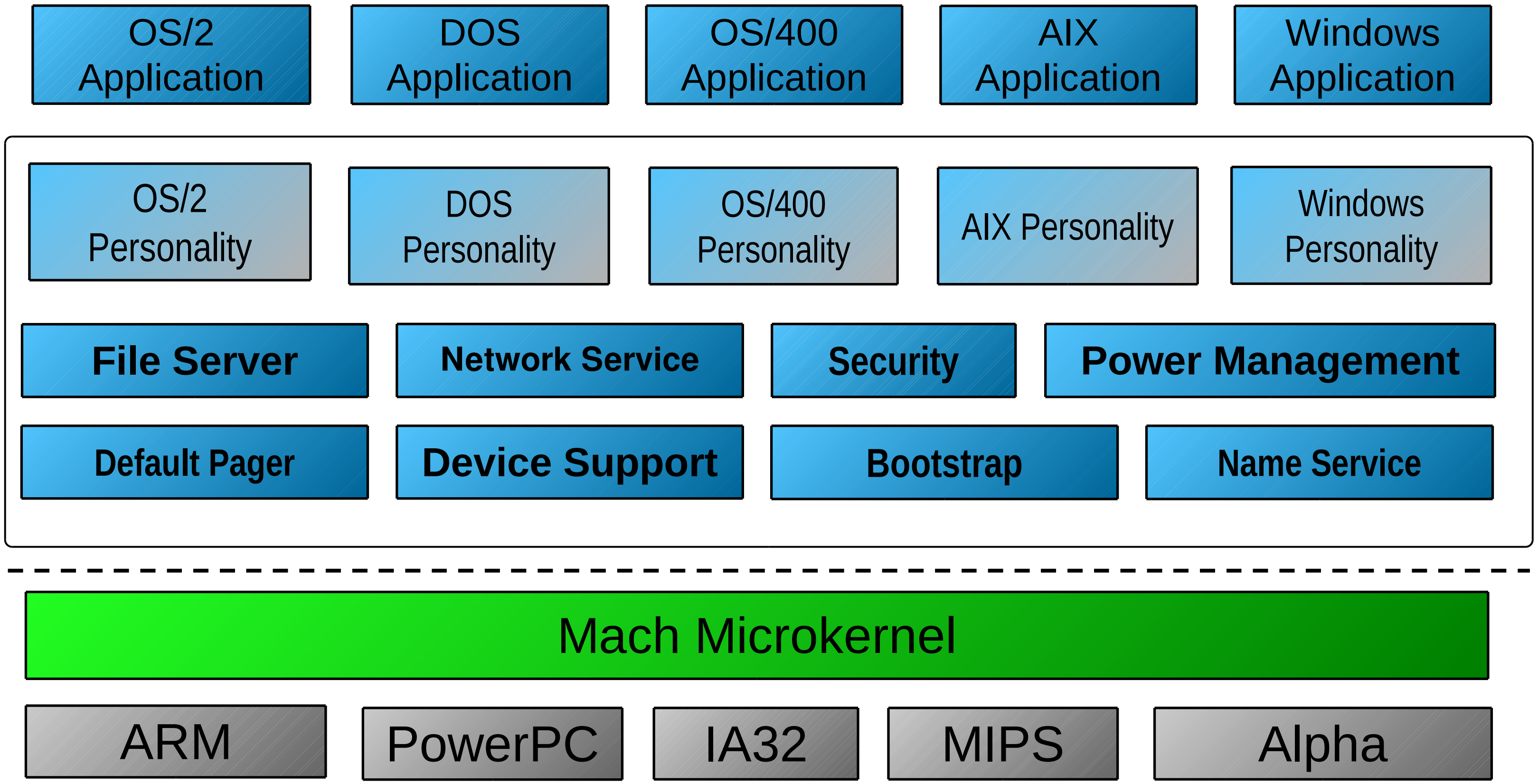
Example – IBM Workplace OS / Mach



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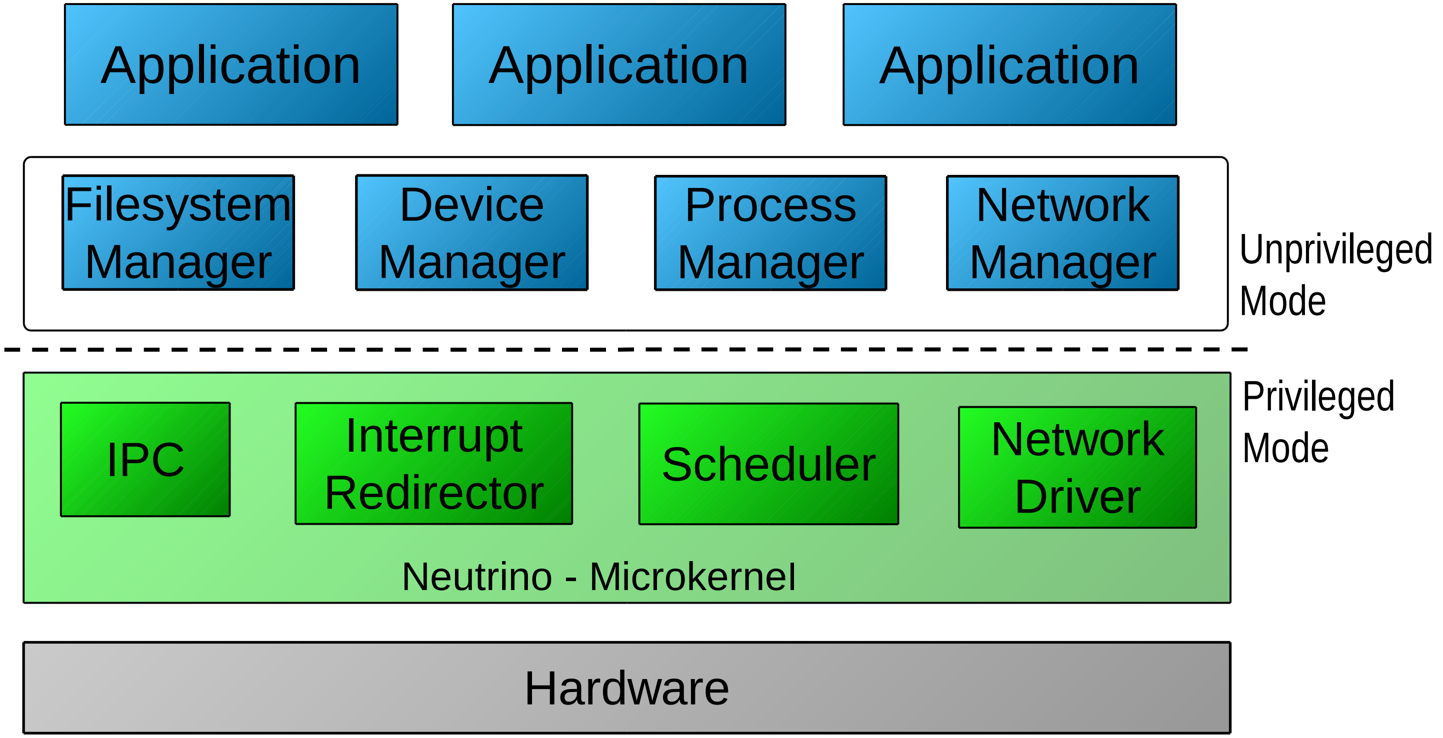
Example – QNX / Neutrino

- Embedded systems
- Message passing system (IPC)
- Network transparency



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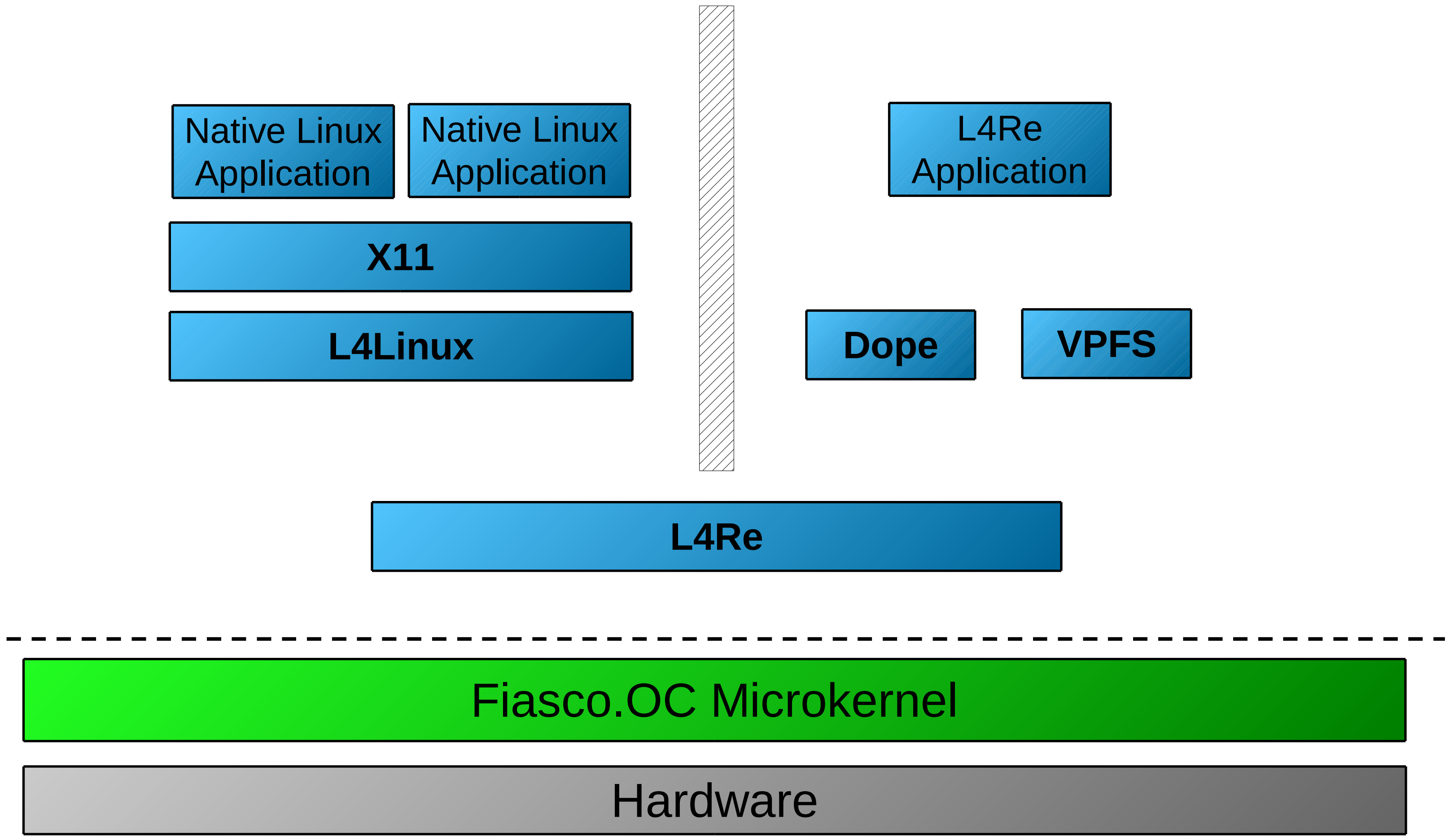
Example – Fiasco.OC



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Visions vs. Reality

- Flexibility and Customizable
  - Monolithic kernels are modular
- Maintainability and complexity
  - Monolithic kernel have layered architecture
- ✔ Robustness
  - Microkernels are superior due to isolated system components
  - Trusted code size (i386)
    - Fiasco kernel: about 15.000 loc
    - Linux kernel: about 300.000 loc (without drivers)
- ✗ Performance
  - Application performance degraded
  - Communication overhead (see next slides)

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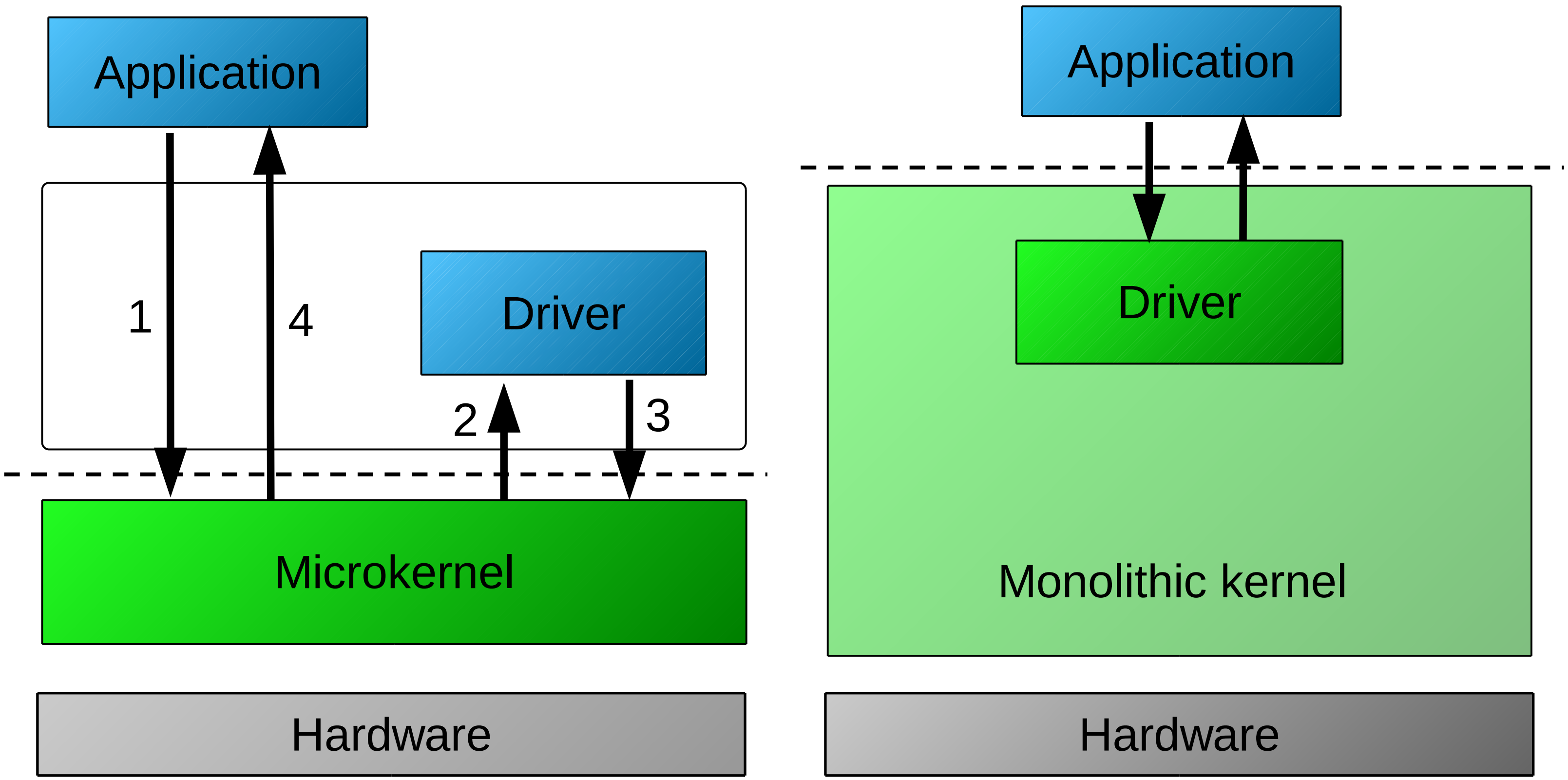
Robustness vs. Performance (1)

- System calls
  - Monolithic kernel: 2 kernel entries/exits
  - Microkernel: 4 kernel entries/exits + 2 context switches



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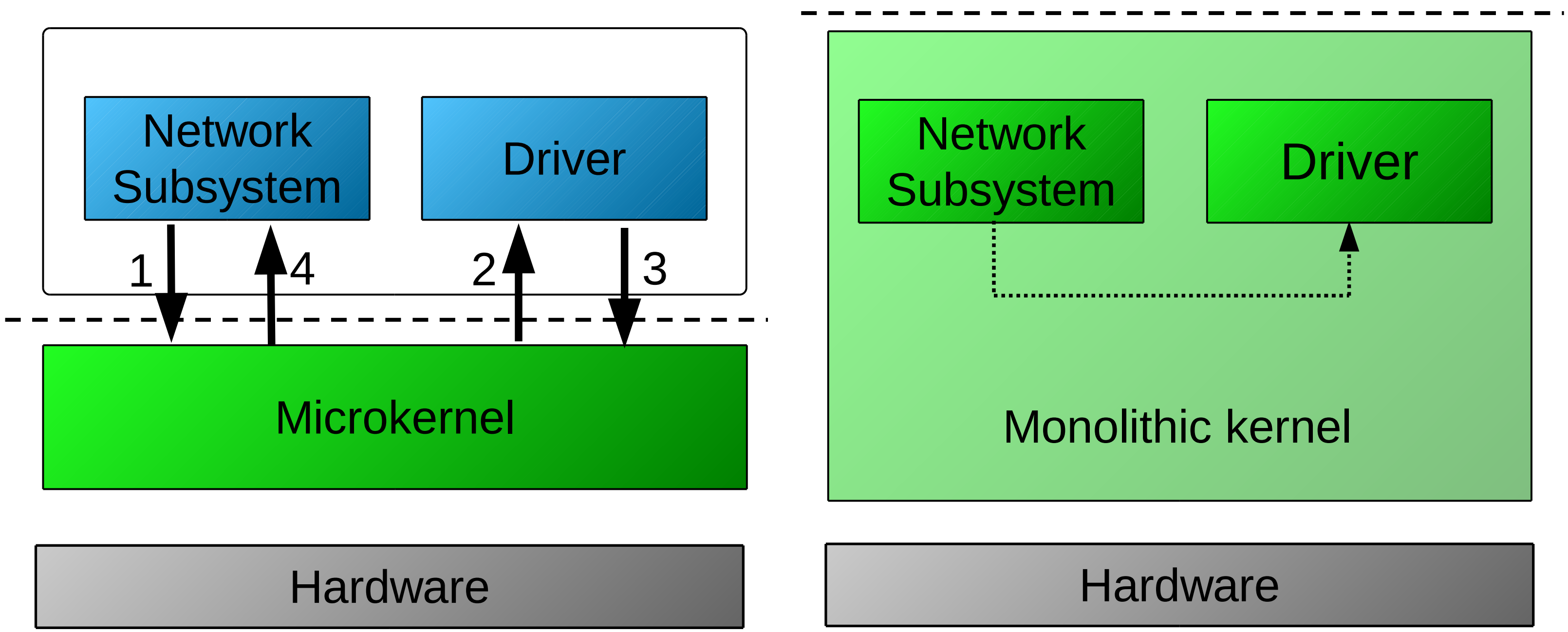
Robustness vs. Performance (2)

- Calls between system services
  - Monolithic kernel: 1 function call
  - Microkernel: 4 kernel entries/exits + 2 context switches



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Challenges

- Build functional powerful and fast microkernels
  - Provide abstractions and mechanisms
  - Fast communication primitive (IPC)
  - Fast context switches and kernel entries/exits

➔ *Subject of this lecture*

- Build efficient OS services
  - Memory Management
  - Synchronization
  - Device Drivers
  - File Systems
  - Communication Interfaces

➔ *Subject of lecture “Construction of Microkernel-based systems” (in winter term)*

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L4 Microkernel Family

- Originally developed by Jochen Liedtke (GMD / IBM Research)
- Current development:
  - Uni Karlsruhe: Pistachio
  - UNSW/NICTA/OKLABS: OKL4, SEL4, L4Verified
  - TU Dresden: Fiasco.OC, Nova
- Support for hardware architectures:
  - **X86, ARM, ...**

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More Microkernels (Incomplete list)

- Commercial kernels
  - Singularity @ Microsoft Research
  - K42 @ IBM Research
  - velOSity/INTEGRITY @ Green Hills Software
  - Chorus/ChorusOS @ Sun Microsystems
  - PikeOS @ SYSGO AG
  - OKL4
- Research kernels
  - EROS/CoyotOS @ John Hopkins University
  - Minix @ FU Amsterdam
  - Amoeba @ FU Amsterdam
  - Pebble @ Bell Labs
  - Grasshopper @ University of Sterling
  - Flux/Fluke @ University of Utah

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L4 - Concepts

- Jochen Liedtke: “A microkernel does no real work”
  - Kernel provides only inevitable mechanisms
  - No policies implemented in the kernel
- Abstractions
  - Tasks with address spaces
  - Threads executing programs/code
- Mechanisms
  - Resource access control
  - Scheduling
  - Communication (IPC)

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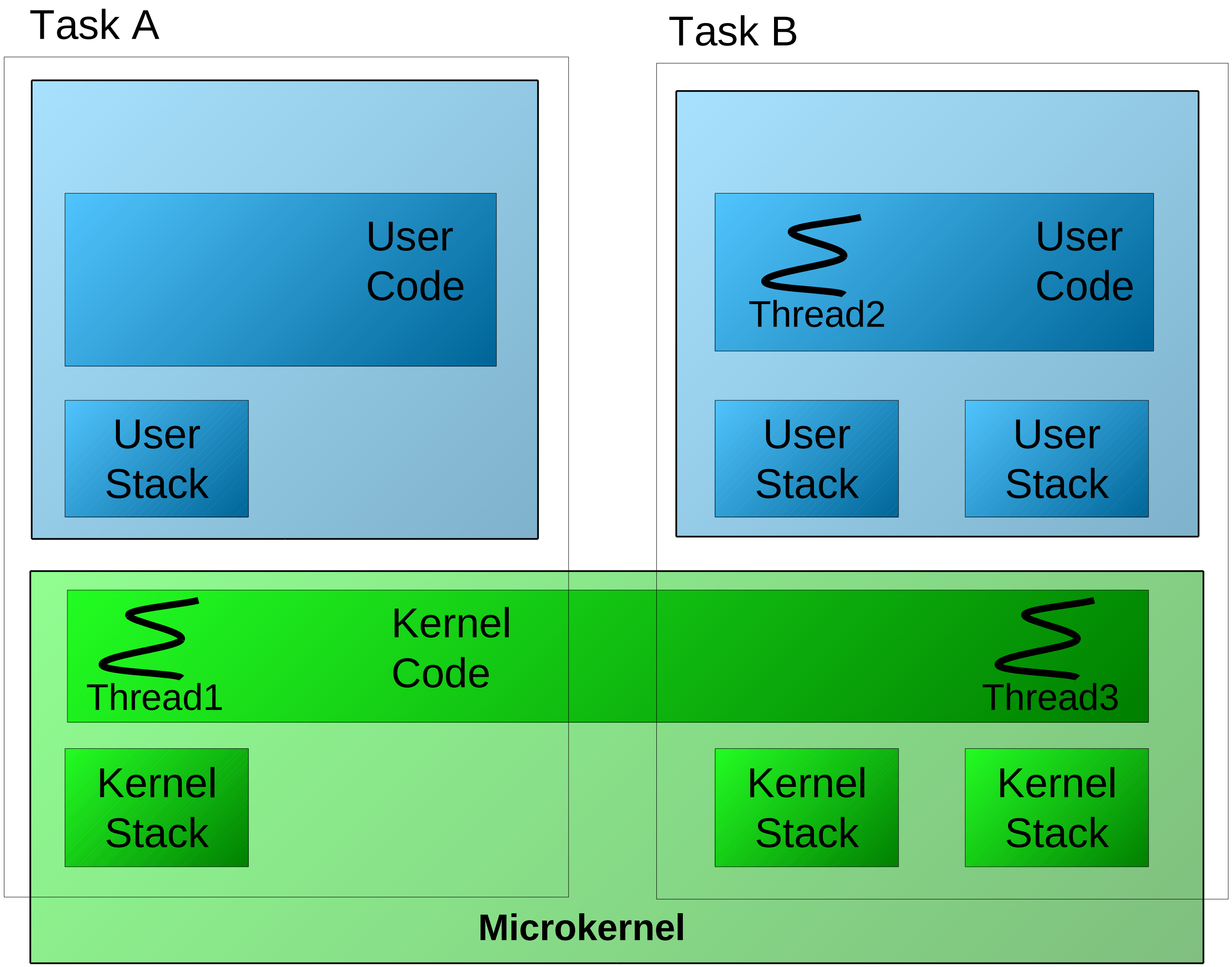
Threads and Tasks



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Threads

- Represent unit of execution
  - Execute user code (application)
  - Execute kernel code (system calls, page faults, interrupts, exceptions)
- Subject to scheduling
  - Quasi-parallel execution on one CPU
  - Parallel execution on multiple CPUs
  - Voluntarily switch to another thread possible
  - Preemptive scheduling by the kernel according to certain parameters
- Associated with an address space
  - Executes code in one task at one point in time
    - Migration allows threads move to another task
  - Several threads can execute in one task

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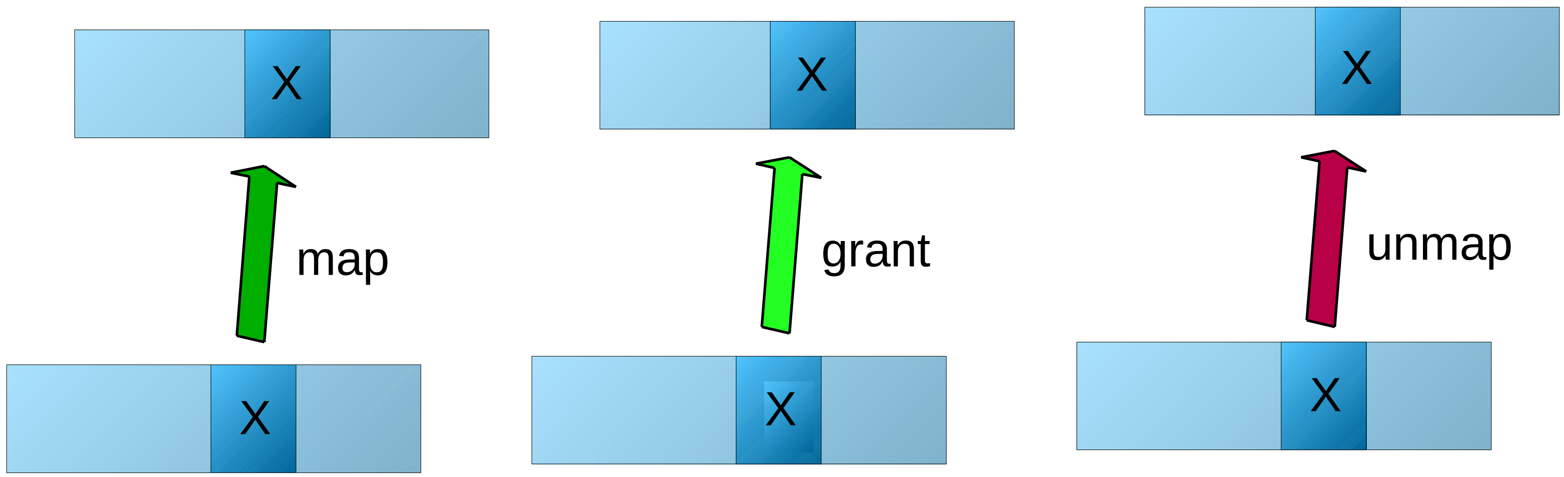
Tasks

- Represent domain of protection and isolation
- Container for code, data and resources
- Address space: capabilities + memory pages
- Three management operations:
  - Map: share page with other address space
  - Grant: give page to other address space
  - Unmap: revoke previously mapped page



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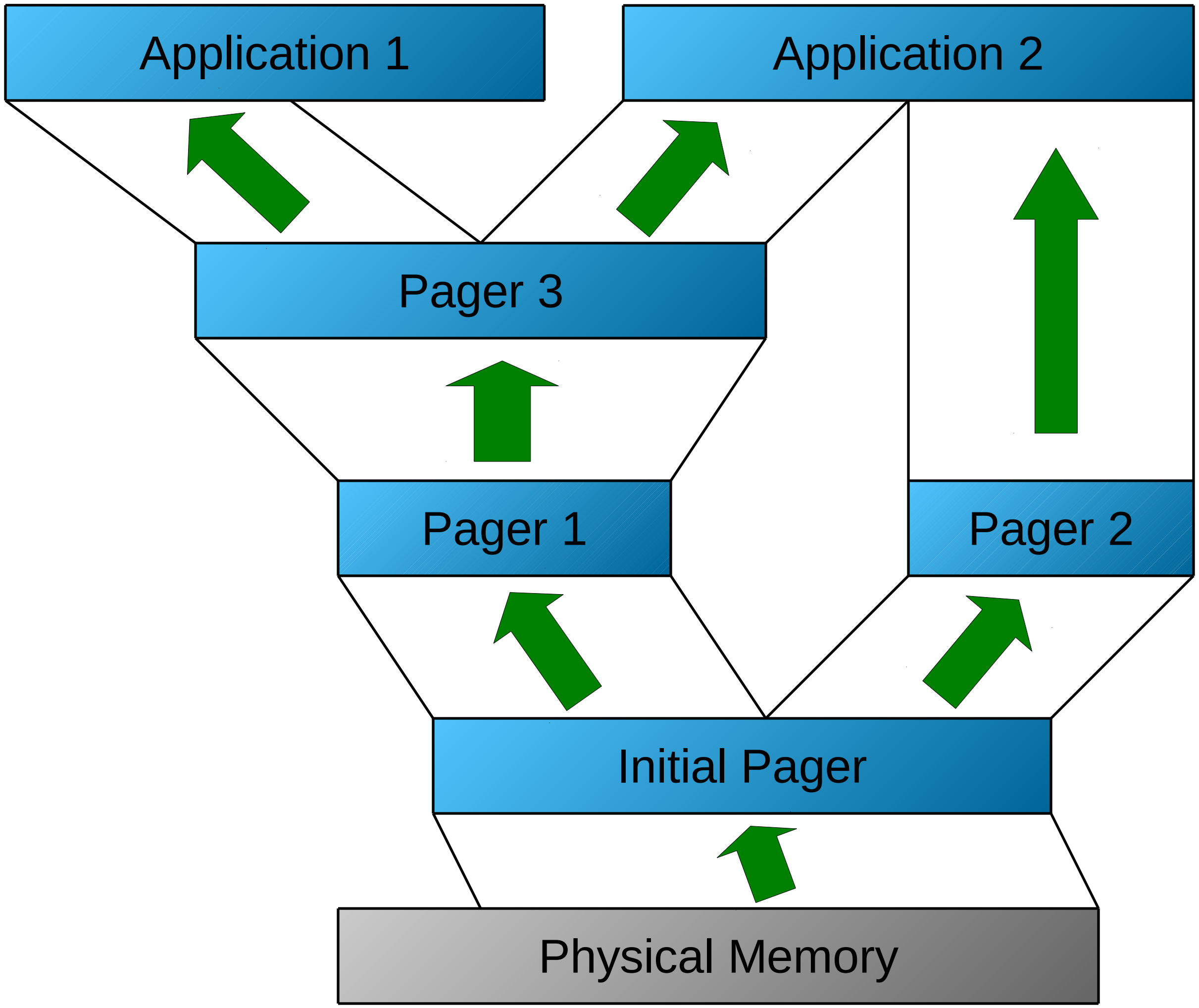
Recursive Address Spaces



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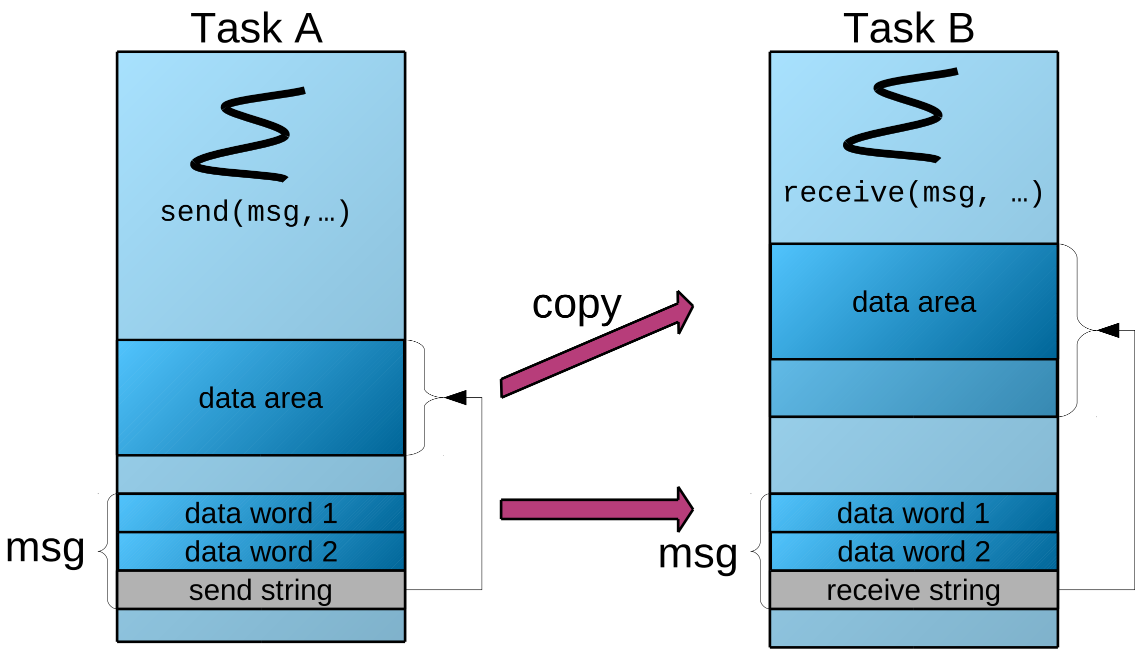
Messages: Copy Data

- Direct and indirect data copy
- UTCB message (special area)
- Special case: register-only message
- Pagefaults during user-level memory access possible



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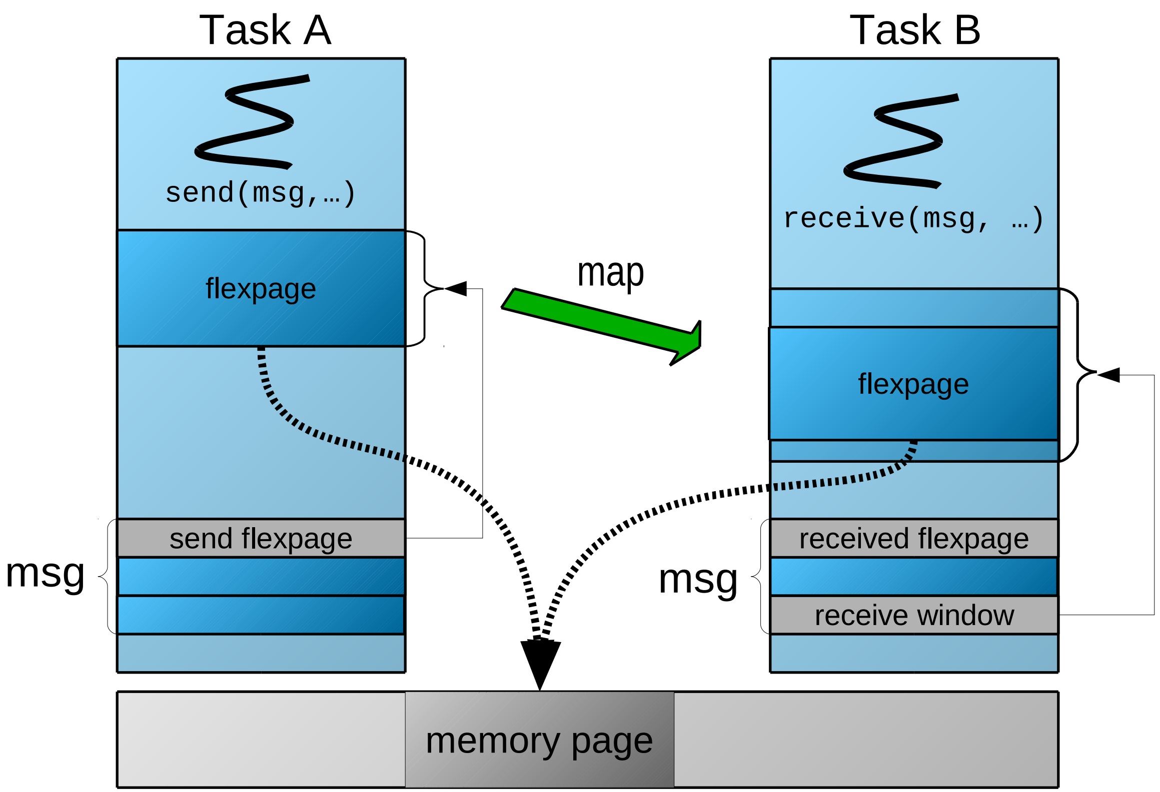
Message: Map References

- Used to transfer memory pages and capabilities
- Kernel manipulates page tables
- Used to implement the map/grant operations



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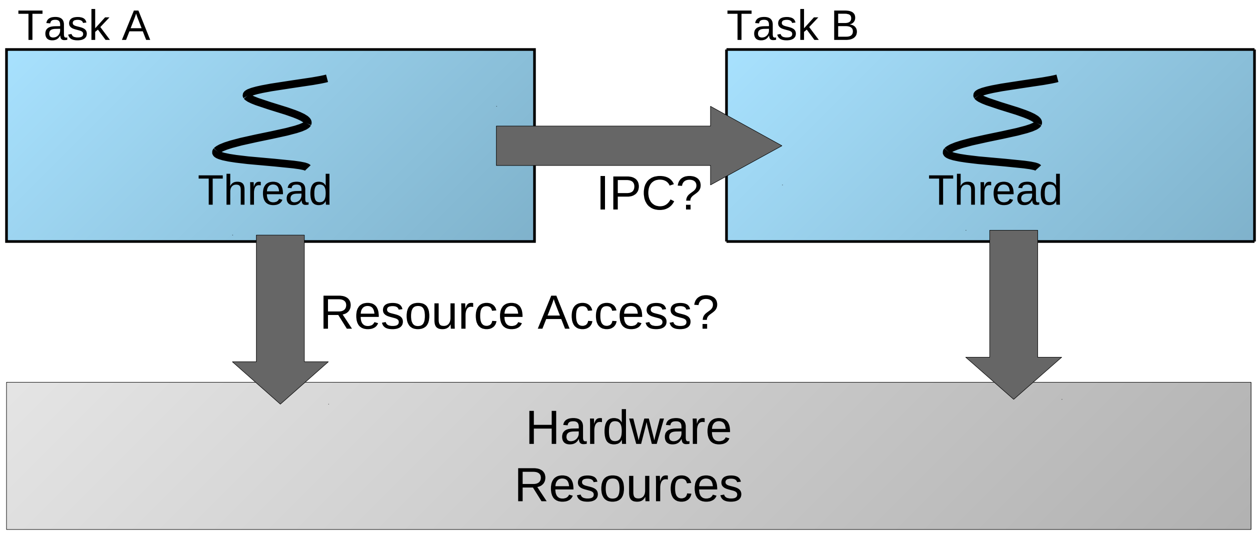
Communication and Resource Control

- Need to control who can send data to whom
  - Security and isolation
  - Access to resources
- Approaches
  - IPC-redirection/introspection
  - Central vs. Distributed policy and mechanism
  - ACL-based vs. capability-based



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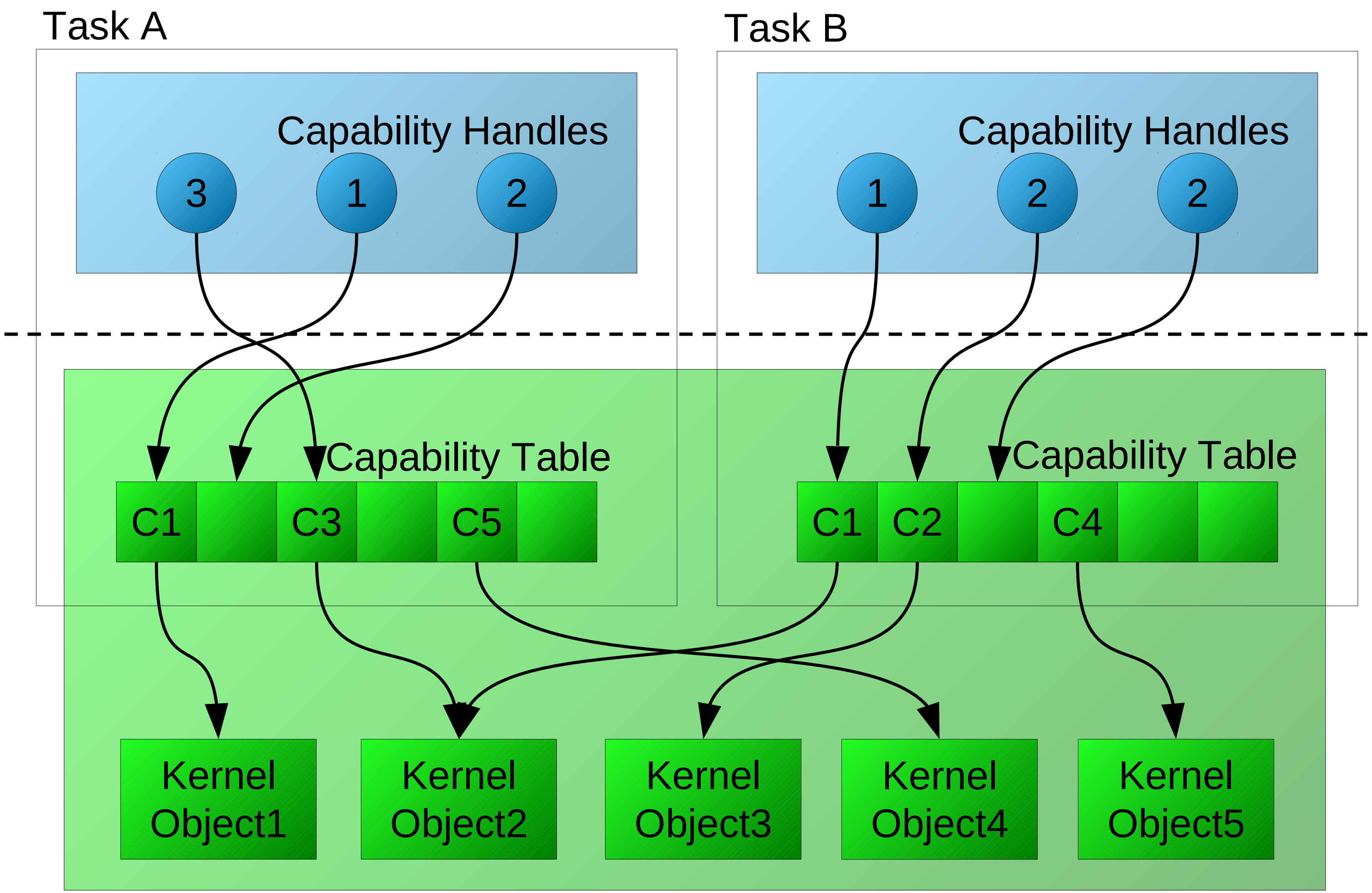
Capabilities



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Capabilities - Details

- Kernel objects represent resources and communication channels
- Capability
  - Reference to kernel object
  - Associated with access rights
  - Can be mapped from task to another task
- Capability table is task-local data structure inside the kernel
  - Similar to page table
  - Valid entries contain capabilities
- Capability handle is index number to reference entry into capability table
  - Similar to file handle (in POSIX)
- Mapping capabilities establishes a new valid entry into the capability table

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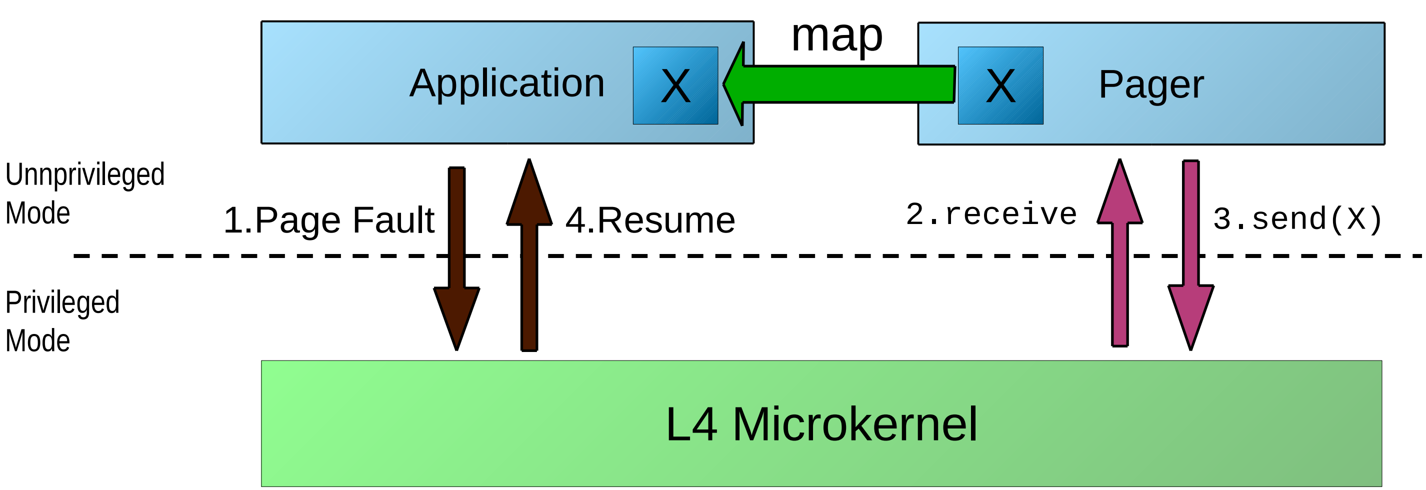
Page Faults and Pagers

- Page Faults are mapped to IPC
  - Pager is special thread that receives page faults
  - Page fault IPC cannot trigger another page fault
- Kernel receives the flexpage from pager and inserts mapping into page table of application
- Other faults normally terminate threads



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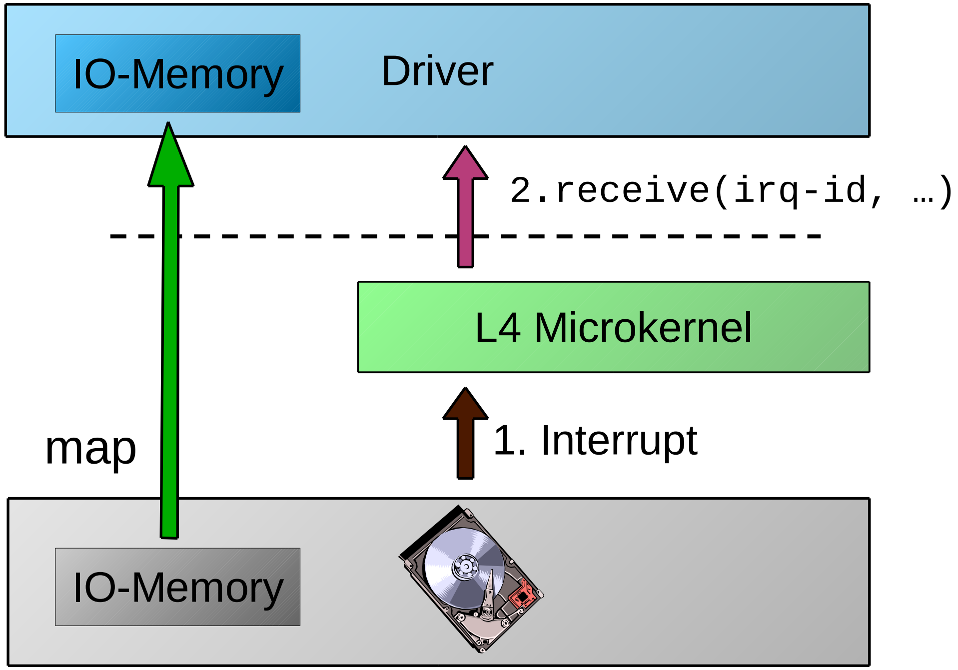
Device Drivers

- Hardware interrupts: mapped to IPC
- I/O memory & I/O ports: mapped via flexpages



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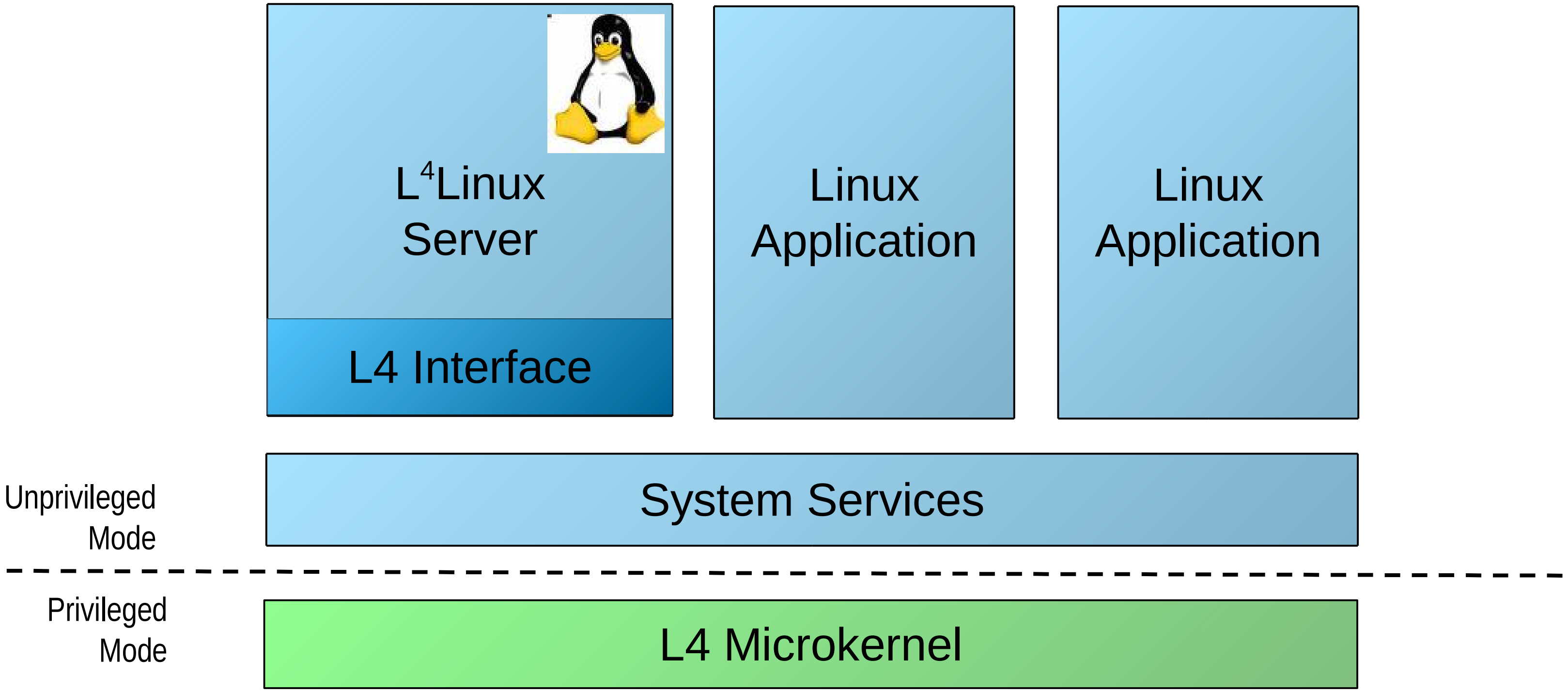
L4 Applications - L⁴Linux

- Paravirtualized Linux kernel and native Linux applications run as user-level L4 tasks
- System calls / page faults are mapped to L4 IPC



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Lecture Outline

- **Introduction**
- Address spaces, threads, thread switching
- Kernel entry and exit
- IPC
- Address space management
- Capabilities
- Synchronization
- Case Studies: Fiasco, Nova, SeL4
- Hands-on experience

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