Advanced Operating Systems

COMP9242
Introduction

Staff

- Lecturer in Charge
  - Gernot Heiser
- Lecturer
  - Kevin Elphinstone
- Various Support Staff
  - TBA

Why are you here?

- You've done comp3231
  - Did well (minimum credit)
  - You would like to delve deeper into OS issues
  - You'd like to get your hands *really* dirty
- Curious about where field is heading.
- Thinking about doing a thesis in OS
- Thinking about a job in embedded systems industry

What can you expect?

- Challenging Project
- Lectures in general:
  - Background required for project
  - Exposure to local research projects
  - An in-depth look at OS issues
    - Building upon the background in COMP3231
  - Exposure to recent and seminal research papers
  - Guest lectures by active researchers (PhD students and local researchers)

Project Goal

Provide students with a deeper understanding of Operating Systems through practical experience.

- Approach: Participate in the design and implementation of a simple operating system (SOS).

Project Aims

- Provide experience in OS design and development, including:
  - Microkernel based systems (L4::Pistachio).
    - User-level OS servers.
    - User-level page fault handlers.
  - Device drivers
  - Performance evaluation
  - Implications of cache architectures
  - Exposure to alternative OS Designs
- Demonstrate the importance of design
- Provide experience of being a team member in a large software project.

Project Aims

- Expose students to a mostly realistic OS development environment.
  - Similar to professional OS and or embedded systems developer.
- Give an understanding of what's involved in constructing an entire OS on bare hardware.
- Give an understanding of the interaction between low-level software and hardware.
- Encourage you to undertake a thesis, or do research within OS Group / NICTA.

Prerequisites

- Students are expected to be very competent C programmers.
- Students are expected to be familiar with
  - basic computer architecture concepts.
  - Assembly language (read-only)
  - Basic RISC processor characteristics (we'll use a MIPS R4600 for the project)

Lectures

(subject to change)

- Introduction and Overview
- Introduction to the L4 Microkernel
  - L4 system calls and usage (to get you started on the project)
- A close look at selected OS issues
  - Protection, capabilities
  - Caching, and its implications for OS
  - Page tables for wide address spaces
  - SMP issues: locking, cache coherence, scheduling
  - File systems

Lectures

(subject to change)

- Microkernels and User-level Servers
  - History and motivation for microkernel systems, Hydra, Mach, discussion, experiences; second-generation microkernel systems, L4, Exokernel, Spin; design and implementation of microkernel-based systems, including user-level page fault handling and device drivers
- Microkernel Implementation
  - Detailed look at a real microkernel (L4Ka::Pistachio).
- Persistent and single-address-space systems
- OS Projects at UNSW/NICTA
  - Gelato@UNSW, NICTA Embedded OS, Mungi

Project/Lab Work

- Build a simple operating system (SOS) from the ground up
- Major component of the course
- Use L4Ka::Pistachio
  - ported to MIPS here by Carl van Schaik
- Develop and test on U4600 computers
  - R4600 based machines design and built by Kevin Elphinstone and Dave Johnson
  - "Clean" machine to get your hands dirty
- Can also use CPU simulator Sulima
  - Developed locally
  - Demos must be on real hardware

Project

- Some warm-up experiments
- Students will work in groups of two
- End goal:
  - To produce a small efficient operating system
- Project will have a series of due milestones
  - Demo to pass the milestone and be awarded marks
  - Help you manage your time
  - Avoid major problems

Milestones

- Details on class web site
- Late milestones:
  - Max 1 week late: 25% of milestone mark lost
  - 1-2 weeks late: 50% of milestone mark lost
  - More than two weeks: all marks lost
- Bonus task
  - Much pain for little gain ;-)
  - Don't go overboard
  - Full mark doesn't *require* bonus!

Alternative Projects

- Special arrangements might be made for particular student to do alternative projects
  - Must be at least as challenging as the original project
  - Must have some relevance to you or us.
  - Must convince us that you can actually do it.
  - Unable to get bonus marks

Assessment

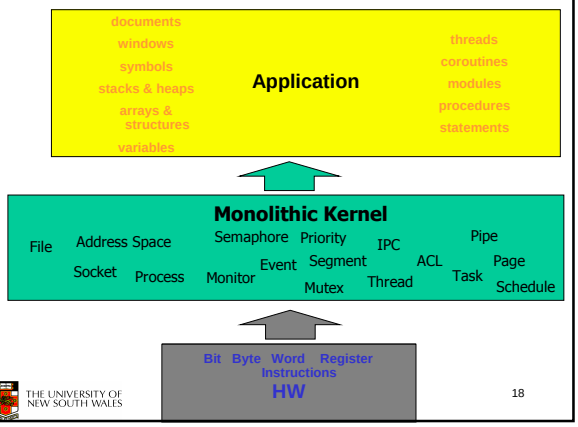
- 65% for project work
- 35% for final exam
  - A minimum of 14 (40%) required in final exam to pass
- Final Exam
  - 24hr take-home exam
  - Read and analyse two recent research papers and submit a critical report

Textbook

- No particular textbook for course
  - See course web page for useful reference books
- Selected research papers referred to in the course
- Manuals provided in hardcopy and via class web site

L4 and Microkernels

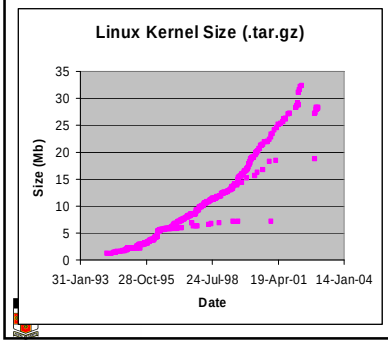
Background



Monolithic Kernels - Advantages

- Kernel has access to everything, potentially:
  - All optimisations are possible
  - All techniques/mechanisms/concepts are implementable
- Can be extended by simply adding more code to the kernel

Linux Kernel Evolution

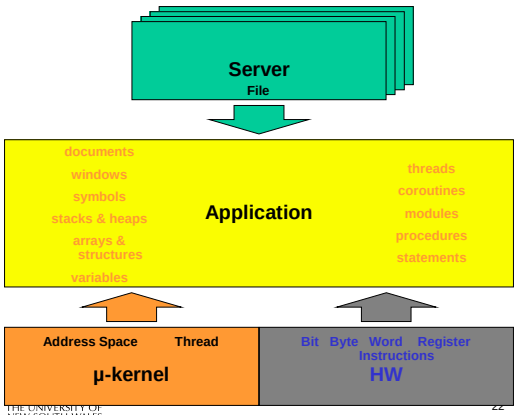


For reference:

Linux 2.4.18 = 2.7 million lines of code

Approaches to tackling complexity

- Monolithic approaches
  - Layered Kernels
  - Modular Kernels
  - Object Oriented Kernels
- Alternatives
  - Extensible Kernels
  - Microkernels



History

- monolithic kernels

History

- monolithic kernels

- 1st- generation µ-kernels
  - Mach — *CMU, OSF* — **External Pager**
  - Chorus — *Inria, Chorus*
  - Amoeba — *Vrije Universiteit*
  - (L3) — *GMD* — **User-Level Driver**

Brief History

- monolithic kernels
- 1st- generation µ-kernels
  - Mach — *CMU, OSF*
  - Chorus — *Inria, Chorus*
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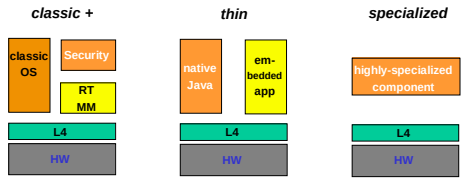
  - (L3) — *GMD*

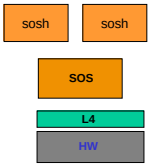
  External Pager

  User-Level Driver
- 2nd- generation µ-kernels
  - (Spin) — *U Washington*
  - Exokernel — *MIT*
  - L4 — *GMD / IBM / UKa*

  User-Level Address Space



Project



The Great Promise

- coexistence of different
  - APIs
  - file systems
  - OS personalities
- flexibility
- extensibility
- simplicity
- maintainability
- security
- safety

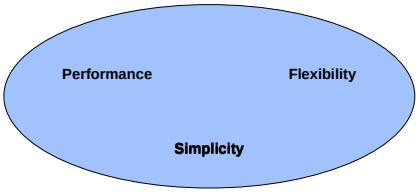
The Great Promise
The Big Disaster

- ~~coexistence of different~~
  - ~~APIs~~
  - ~~file systems~~
  - ~~OS personalities~~
- ~~flexibility~~
- ~~extensibility~~
- ~~simplicity~~
- ~~maintainability~~
- ~~security~~
- ~~safety~~

- ***SLOW***
- ***UNFLEXIBLE***
- ***LARGE***

Macro → µ

Macro → μ

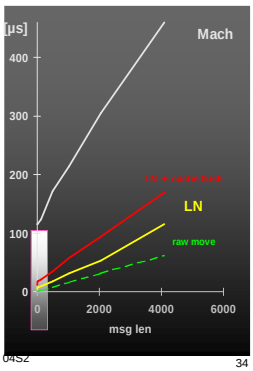


The 100-μs Disaster

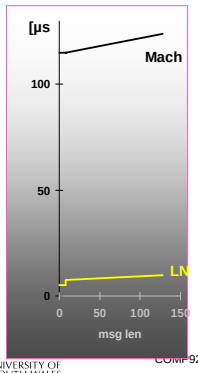
The 100-μs Disaster

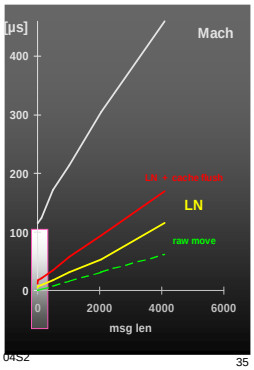
25 MHz 386 → 50 MHz 486 → 90 MHz Pentium → 133 MHz Alpha

IPC Costs (486, 50 MHz)

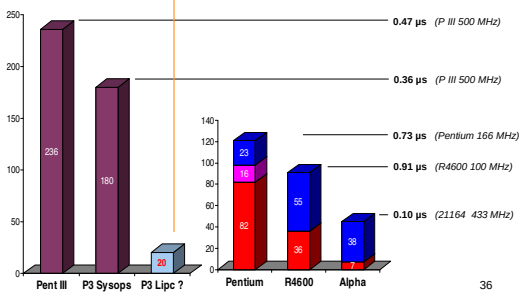


IPC Costs (486, 50 MHz)





L4 IPC



Thesis:

- A µ-Kernel does the Job
  - if Properly Designed
- if Carefully Implemented

Minimality
Elegance
Architectural Integration

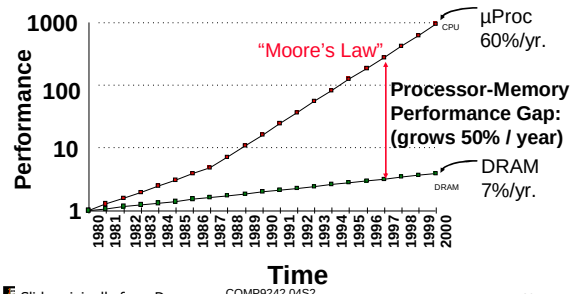
⇨

Efficiency
Flexibility

When analyzing IPC performance,

Cycles are not the only the to consider!!

Processor-DRAM Gap (latency)



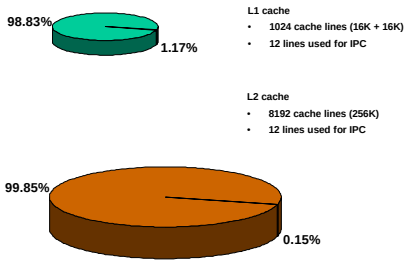
Slide originally from Dave Patterson, Parcon 98

Today's Situation: Microprocessor

- Microprocessor-DRAM performance gap
  - time of a full cache miss in instructions executed
  - 1st Alpha (7000): 340 ns/5.0 ns = 68 clks x 2 or 136
  - 2nd Alpha (8400): 266 ns/3.3 ns = 80 clks x 4 or 320
  - 3rd Alpha (t.b.d.): 180 ns/1.7 ns =108 clks x 6 or 648
  - 1/2X latency x 3X clock rate x 3X Instr/clock ⇒ ≈5X

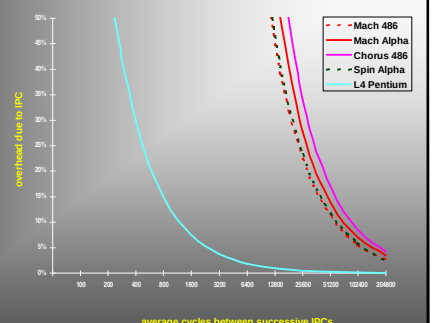
Slide originally from Dave Patterson, Parcon 98

Cache Working Sets



Other Complications

- P4 trace cache
  - A cache of recently translated µ-ops
  - Flushed on every page-table switch
- Virtual Caches
  - Need to be flushed on address space switch



A µ-kernel does no real work.

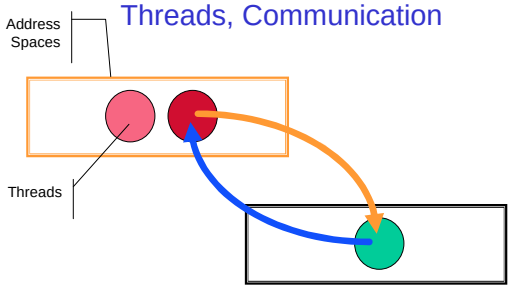
µ-Kernel services are only required to overcome µ-kernel constraints.

Therefore, µ-kernels have to be infinitely fast!

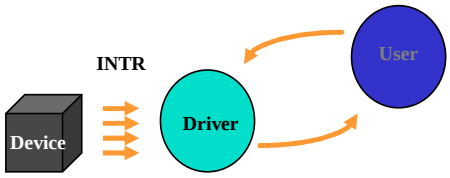
Minimality is the key!

- **Threads** — ***IPC***
- **Address Spaces** — ***Mapping***

Threads, Communication



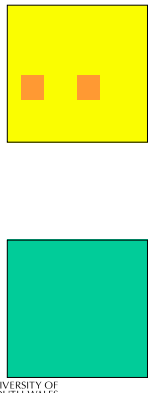
Drivers at User Level



= ipc

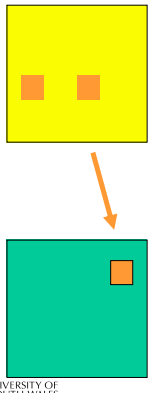
- **IO ports: part of the user address space**
- **interrupts: messages from hardware**

Address Spaces



Address Spaces

- **map**



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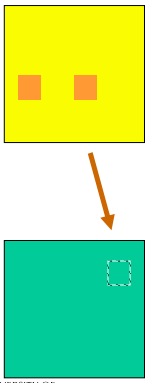
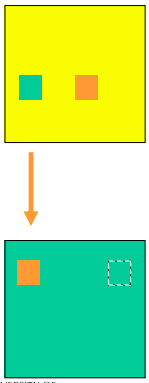


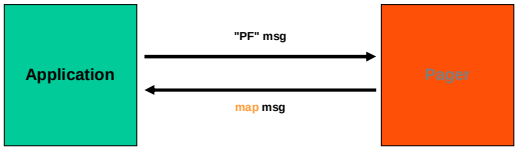
- map
- **unmap**

Address Spaces



- map
- unmap
- **grant**

Page Fault Handling



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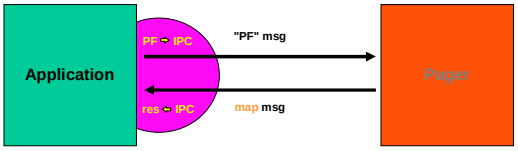

Address Spaces

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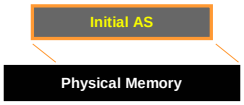

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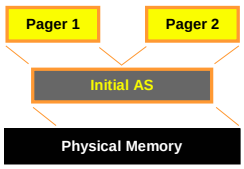

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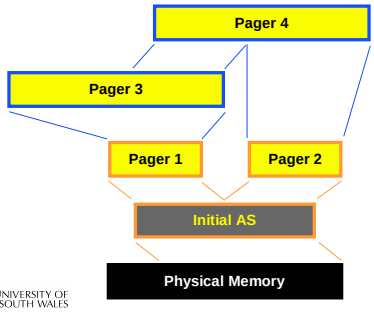

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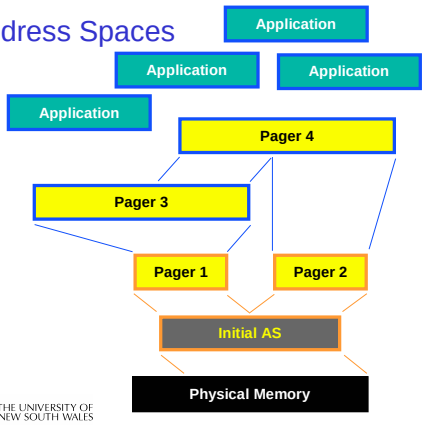

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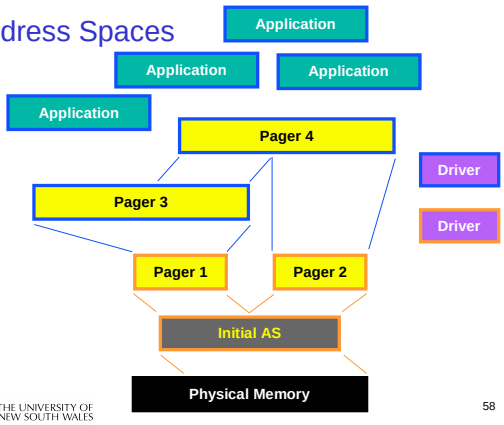
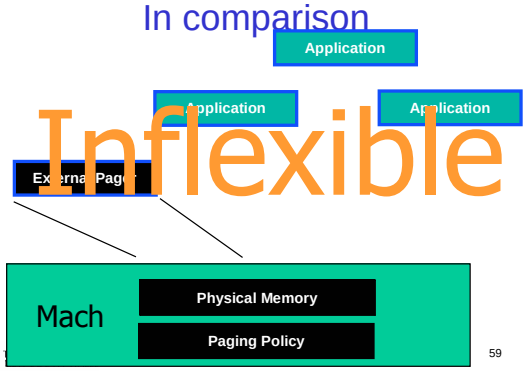
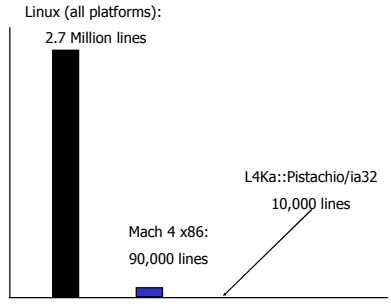
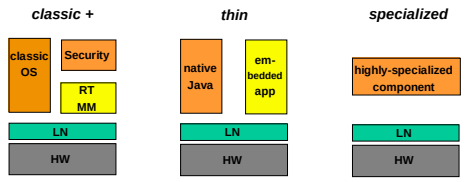


Mach Virtual Memory In comparison



Size Comparison




classic +
classic OS
Security
RT MM
LN
HW
thin
native Java
em-bedded app
LN
HW
specialized
highly-specialized component
LN
HW