User-Level Device Drivers

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Why User-Level Device Drivers?

- Ease of development
- Maintainability
- Increased system stability/reliability by

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  - ➜ less restrictive programming model, arbitrary languages
  - ➜ availability of standard debugging and profiling tools
  - ➜ release schedule decoupled from kernel
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- Increased system stability/reliability by
  - ➜ running driver in unprivileged mode
  - ➜ encapsulating driver into address space
  - ➜ may not have to trust drivers?

OTHER MOTIVATIONS

- Microkernel work in general
  - ➜ code allowed in microkernel only if it *must* be in kernel
  - ➜ drivers need not be in kernel

    $\Rightarrow$ drivers must *not* be in microkernel

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    - ⇒ drivers must *not* be in microkernel

- Mungi in particular
  - ➜ single-address-space operating system developed at UNSW
  - ➜ implemented from scratch (on top of L4 microkernel)
  - ➜ requires device drivers
    - ➜ attempts at reusing drivers from Linux, BSD, OSkit failed
    - ➜ requires too much emulation of original environment

CHALLENGES

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- Generally ended up moving code *into* the kernel
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  - ➜ IBM Workplace OS: US$2G

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  ➜ e.g., Mach, OSF/1, MacOS X
- Some spectacular failures
  ➜ IBM Workplace OS: US$2G
- Device drivers are performance-critical
  ➜ typically 50% performance loss with user-level drivers
  ➜ results from doubling number of system calls

HOPE

- L4 microkernel (Liedtke, GMD, IBM, Karlsruhe) shown to be fast
  - ➜ 20 times performance of Mach
  - ➜ runs Linux as user-level server with $\approx 5\,\%$ performance degradation
- Microkernel technology has come of age
  - ➜ e.g., Mungi faster than Linux

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Hope

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- Microkernel technology has come of age
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- Time to have another look at user-level drivers

APPROACH

- Clean driver interface based on Mungi component model
- Use domain-specific language
  - ➜ platform-independent specification of device registers
  - ➜ DSL compiler generates access functions (in C)
  - ➜ driver proper implemented in C
  - ➜ significant reduction of driver complexity

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- Drivers presently available:
  - ➜ PCI chipsets, IDE disk, Gigabit Ethernet, video, serial, USB

Restricting DMA

- Some PCI chipsets contain an I/O MMU
  - ➜ maps PCI address space to physical memory
  - ➜ designed to support > 4 GB of RAM with 32-bit PCI
  - ➜ example: HP zx1, DEC Tsunami chipsets

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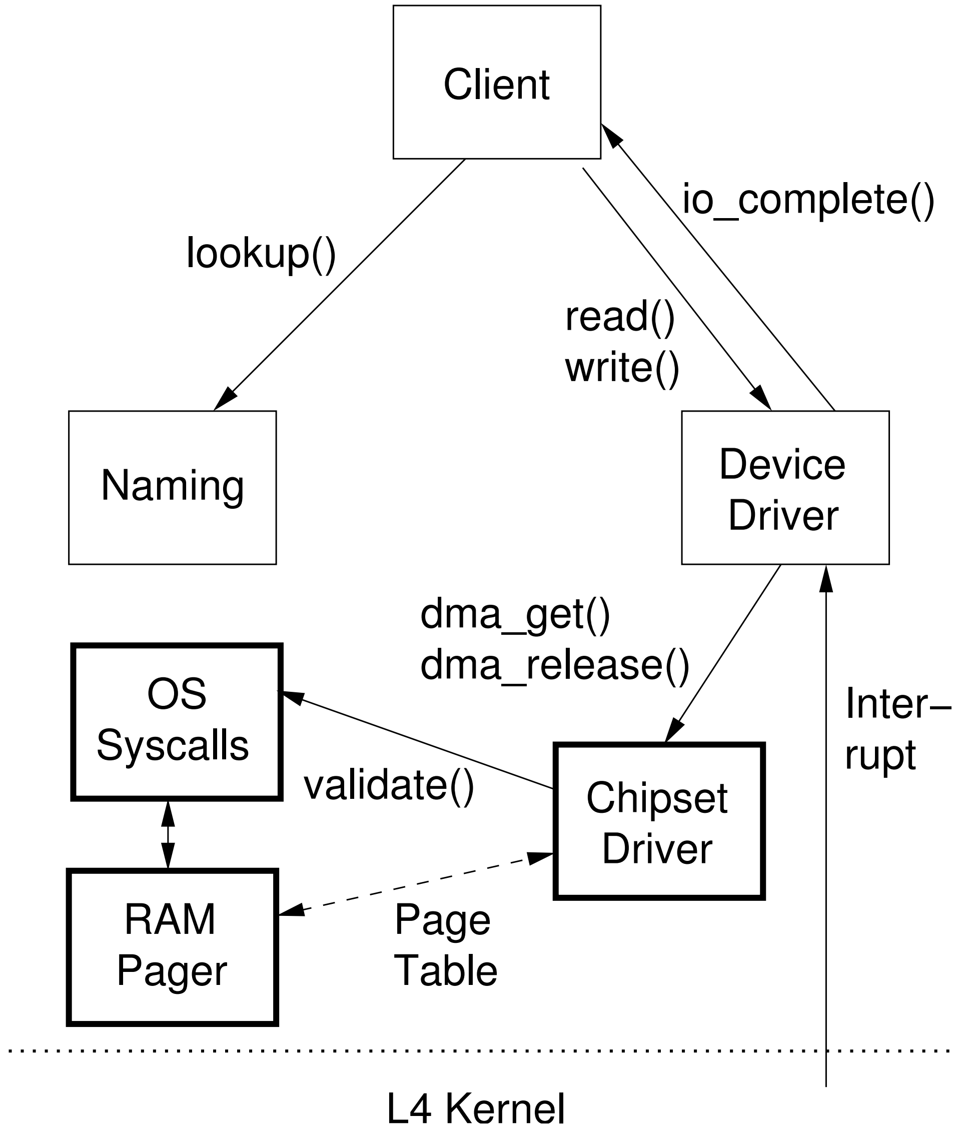
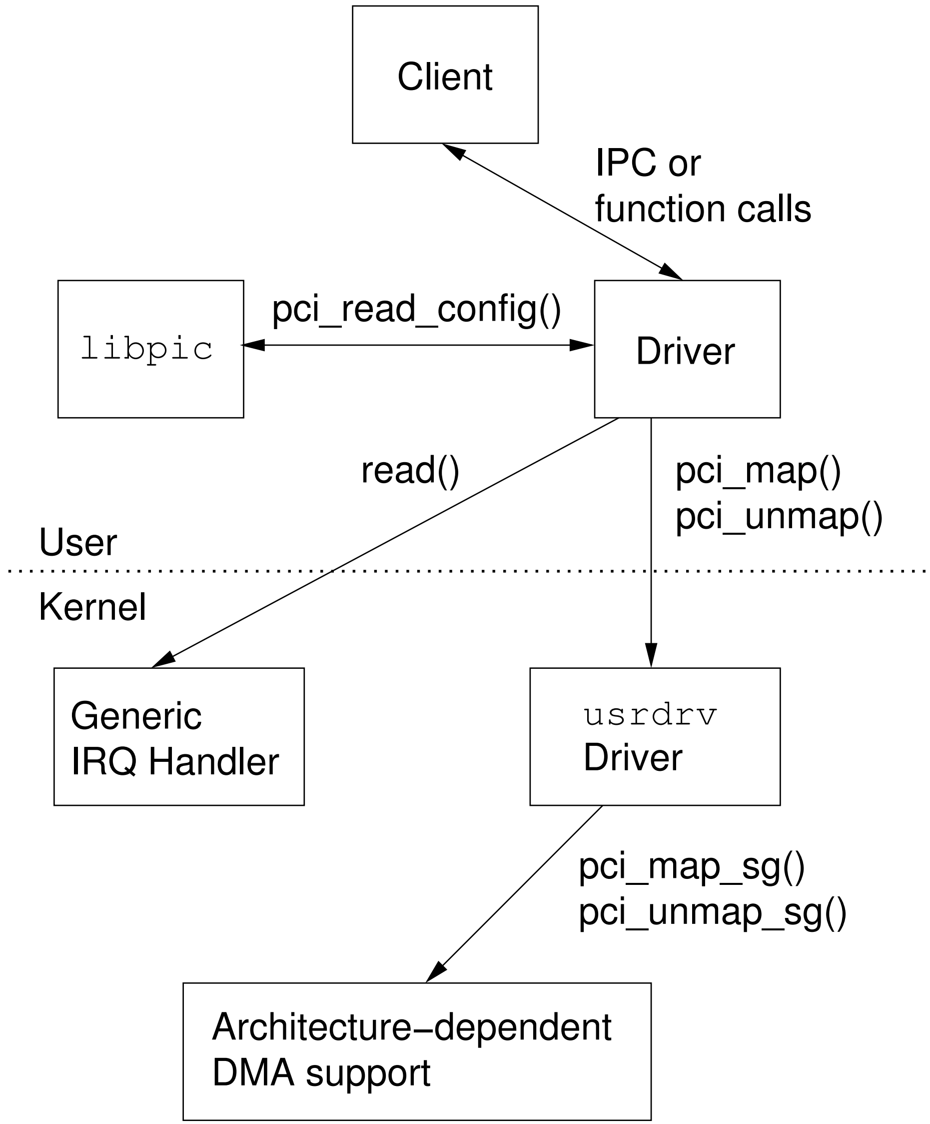
  - ➜ example: HP zx1, DEC Tsunami chipsets
- Can use I/O MMU to restrict DMA
  - ➜ device driver requests DMA mapping for memory region from chipset driver
  - ➜ chipset driver validates access and sets up PCI mapping
  - ➜ chipset driver revokes mapping when DMA buffer is released

USER-LEVEL I/O ARCHITECTURE — MUNGI



USER-LEVEL I/O ARCHITECTURE — LINUX



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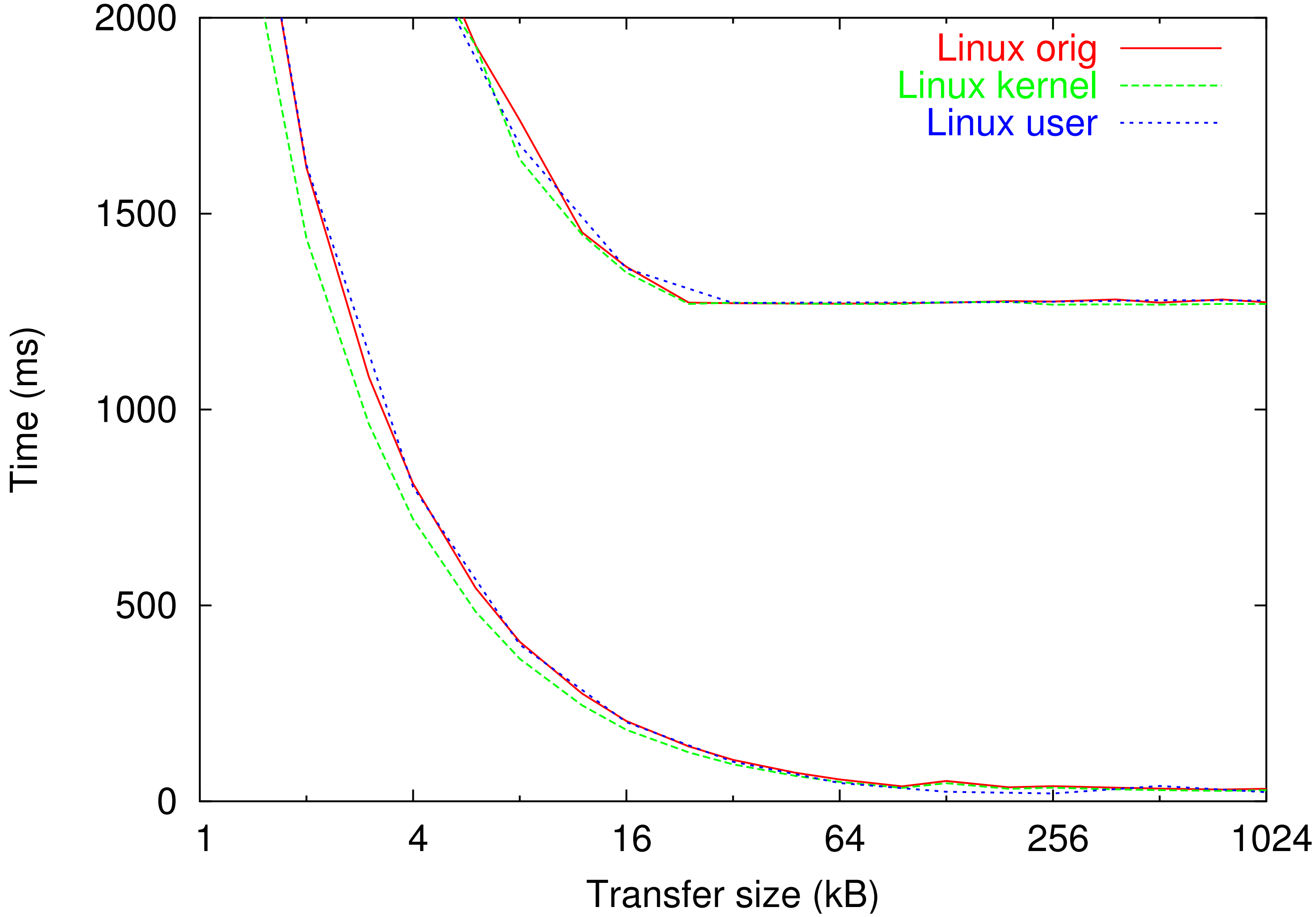
IMPLEMENTATION

- Driver framework & drivers originally implemented on Mungi
  - ➜ drivers can only execute at user level
- Framework was ported to Linux
  - ➜ Linux drivers can execute in-kernel or at user level
- Initial performance evaluation for IDE disk and Gigabit Ethernet

Performance: Disk Read Latency (Preliminary)



HP i2000 (Itanium 2, zx1 chipset) reading 64MB

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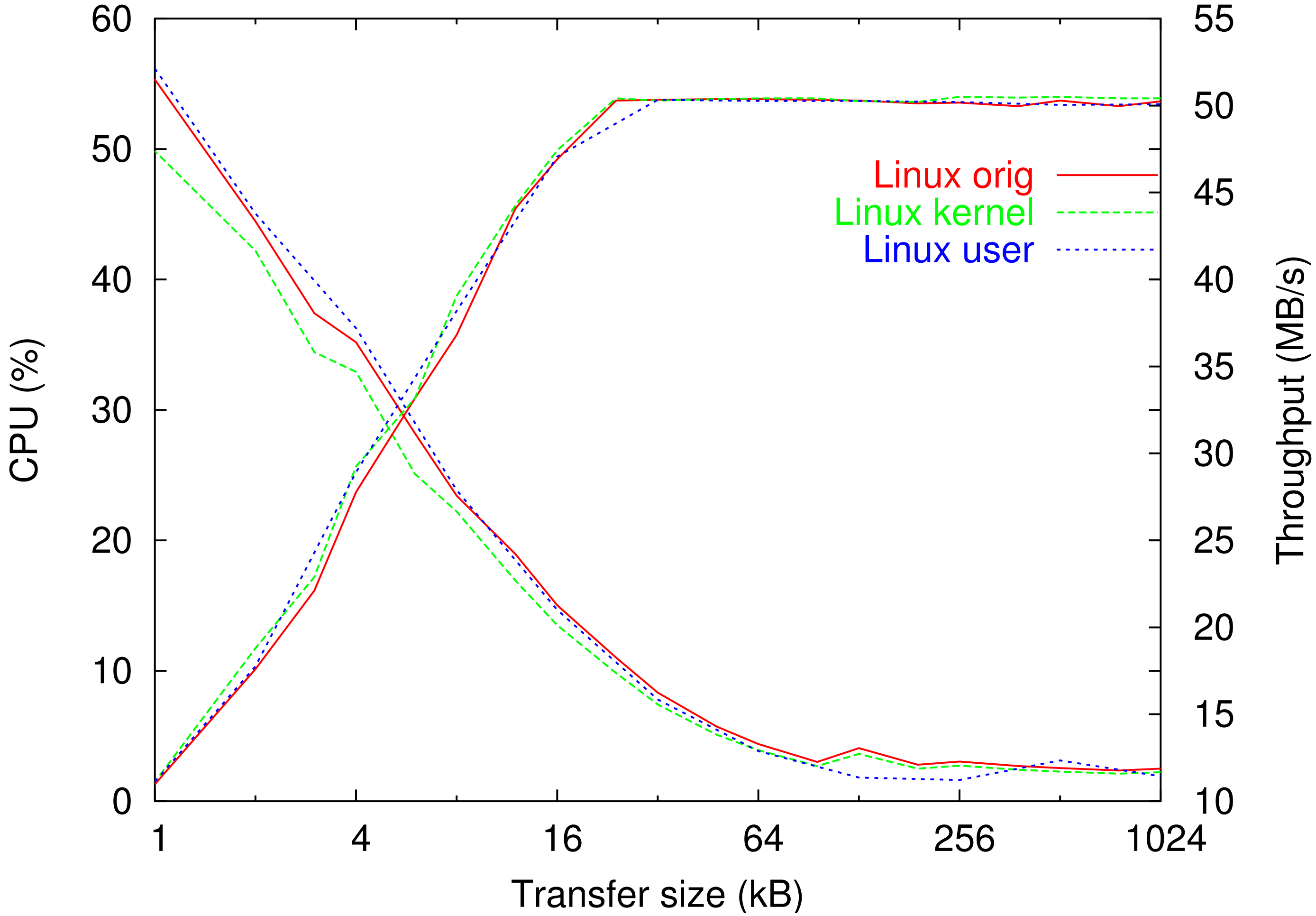
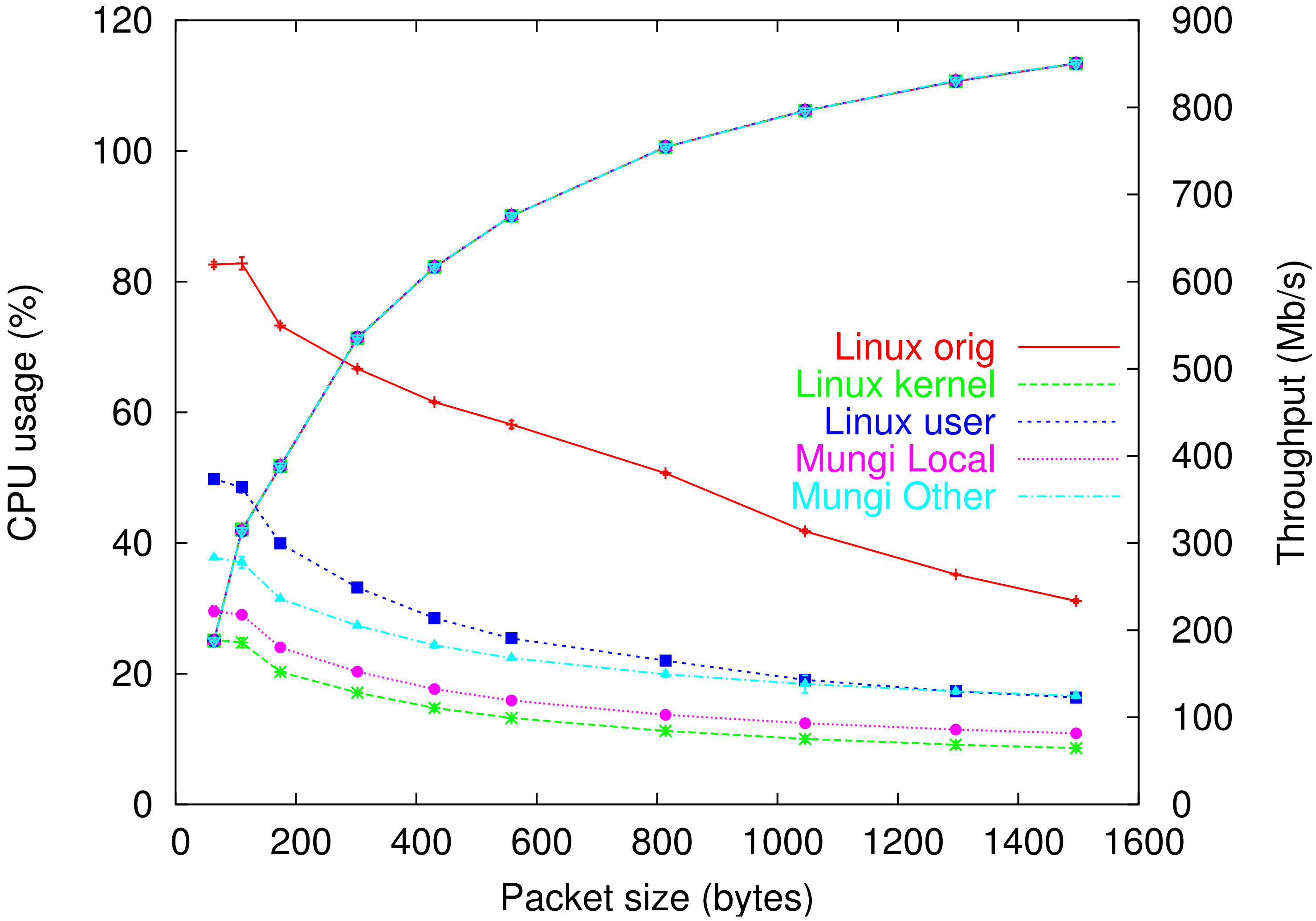


HP i2000 (Itanium 2, zx1 chipset) reading 64MB

Performance: Gigabit Ethernet (Preliminary)



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  - ➜ Performance bug in vanilla Linux 2.5.64 makes fair comparison impossible
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  - ➜ include TCP/IP stack
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- To be done:
  - ➜ loop drivers back into file system
  - ➜ include TCP/IP stack
  - ➜ evaluate application-visible performance
- Device drivers are a critical test of microkernel approach
  - ➜ acceptable performance *might* be achievable
  - ➜ encapsulation of drivers has great potential for reliability