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Do Microkernels Suck?

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- Talk by Christoph Lameter: “Extreme High Performance Computing or Why Microkernels Suck”
- Contents:
  - This is how we got Linux to scale to 1000's of CPUs
    - clearly knows what he's talking about
    - no need to add to this...
  - This is why microkernels can't do the same
    - clearly hasn't got a clue about microkernels
- I'll explain...

Summary of Paper

- Look, we've scaled Linux to 1000 processors [with a little help of billions of $$ from IBM, HP, SGI, ...], microkernels [developed mostly by cash-strapped universities] haven't done the same, obviously they suck
- Equivalent statement in 1998: Look, Windows has drivers for zillions of devices, Linux doesn't, hence Linux sux.
- Very scientific approach, right?
- OK, I'm exaggerating somewhat, but let's see what it really says...

Common Misconceptions

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- Microkernel-based systems are less reliable, as failure of one component makes whole system fail
- Wrong!
  - Counter example: QNX High Availability Toolkit (sold commercially since 2001)
  - More recent counter example: Minix 3, which is open source — check it out for yourself
- Were reliability matters most, microkernels are used
  - aerospace, automotive, medical devices...

A Voice from the Coal Face

- “NTFS-3G is a user/hybrid-space driver”
- “Similar functionality and performance on commodity hardware as in-kernel file systems”
- “The invested effort and resource were only a fraction of what is usually needed, besides other benefits.”
- “The empirical learnings keep being highly instructive, refuting widely believed folklore”

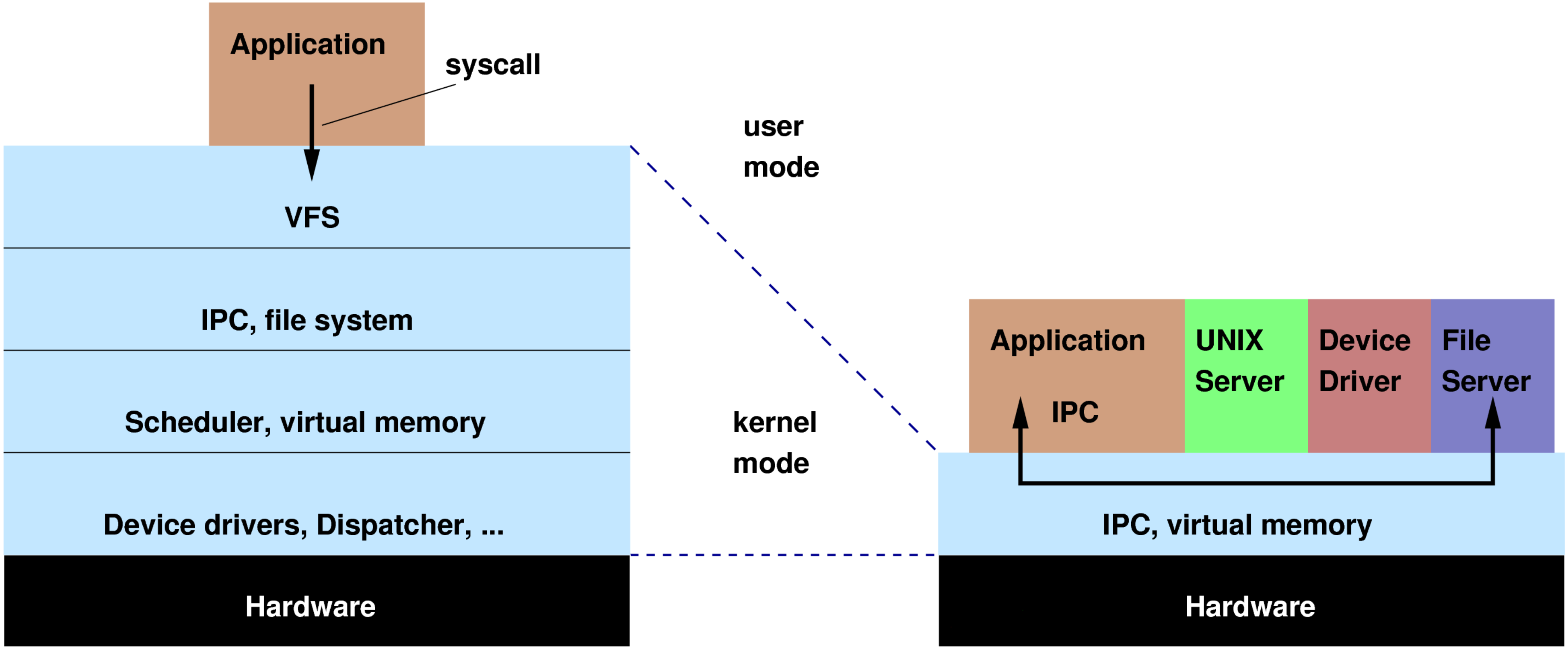
Szaka Szabolcs, leader of NTFS-3G, http://ntfs-3g.org

Common Misconceptions

- Microkernel relies on IPC, IPC requires expensive message queue operations, hence IPC is costly
- Wrong!
  - Counter example: L4, since 1993 (publ in SOSP)
  - L4 runs in 10s of millions of mobile phone
  - OS performance is critical for cell-phone baseband processing
  - L4 expected to run on 250M mobile devices within a year
- Why the sudden popularity?
  - it's fast
  - it's small
  - it enables fault containment

Let's Look at IPC

- IPC is used to obtain system service
  - IPC performance is important



Intrinsic Difference Syscall vs IPC

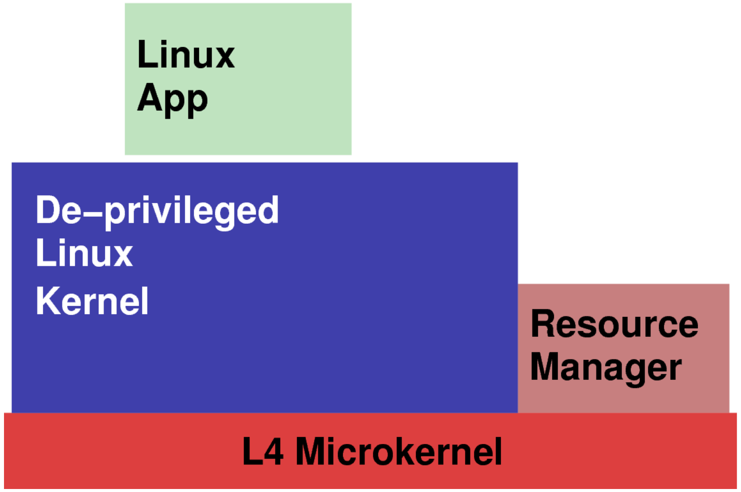
- Syscall: 2 mode switches (user→kernel, kernel→user)
- IPC: 2 mode switches + 1 context switch
- Server invocation needs 2 IPCs
  - extra cost is 2 mode switches, 2 context switches
- This is the inherent microkernel overhead!
  - it is wrong to think that IPC was used inside the system a lot (replacing function calls)
- Is it significant?
  - depends on the ratio between overhead and total cost of service obtained
  - it's a killer for the null system call
  - it's irrelevant for most others

Actual L4 IPC Cost [cycles]

Architecture	Intra address space	Inter address space
Pentium	113	305
AMD-64	125	230
Itanium	36	36
MIPS64	109	109
ARM Xscale	170	180

- How do a couple hundred cycles compare to the typical Linux system call???

Sort-of Extreme Example: Linux on L4



- Cops the full microkernel overhead
- Doesn't get any of the microkernel benefits
- How does it perform?

Linux on L4: ReAIM Macrobenchmark

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ReAIM Benchmark	Native	Virtualised	Ratio
1 Task	45.2	43.6	0.96
2 Tasks	23.6	22.6	0.96
3 Tasks	15.8	15.3	0.97

Native Linux vs Linux virtualized on L4

on Xscale PXA255 @ 400MHz

Not everything in L4 fully optimised yet (fork/exec)

Lmbench microbenchmarks

Benchmark	Native	Virtualized	Ratio
lmbench latencies in microseconds, smaller is better			
lat_proc procedure	0.21	0.21	0.99
lat_proc fork	5679	8222	0.69
lat_proc exec	17400	26000	0.67
lat_proc shell	45600	68800	0.66
lmbench bandwidths, MB/s, larger is better			
bw_file_rd 1024 io_only	38.8	26.5	0.68
bw_mmap_rd 1024 mmap_only	106.7	106	0.99
bw_mem 1024 rd	416	412.4	0.99
bw_mem 1024 wr	192.6	191.9	1
bw_mem 1024 rdwr	218	216.5	0.99
bw_pipe	7.55	20.64	2.73
bw_unix	17.5	11.6	0.66

Native Linux vs Linux virtualized on L4

on Xscale PXA255 @ 400MHz

Not everything in L4 fully optimised yet (fork/exec)

Lmbench Context Switching

Benchmark	Native	Virtualized	Ratio
lmbench latencies in microseconds, smaller is better			
lat_ctx -s 0 1	11	20	0.55
lat_ctx -s 0 2	262	5	52.4
lat_ctx -s 0 10	298	45	6.62
lat_ctx -s 4 1	48	58	0.83
lat_ctx -s 4 10	419	203	2.06
lat_fifo	509	49	10.39
lat_pipe	509	49	10.39
lat_unix	1015	77	13.18
lat_syscall null	0.8	4.8	0.17

Native Linux vs Linux virtualized on L4

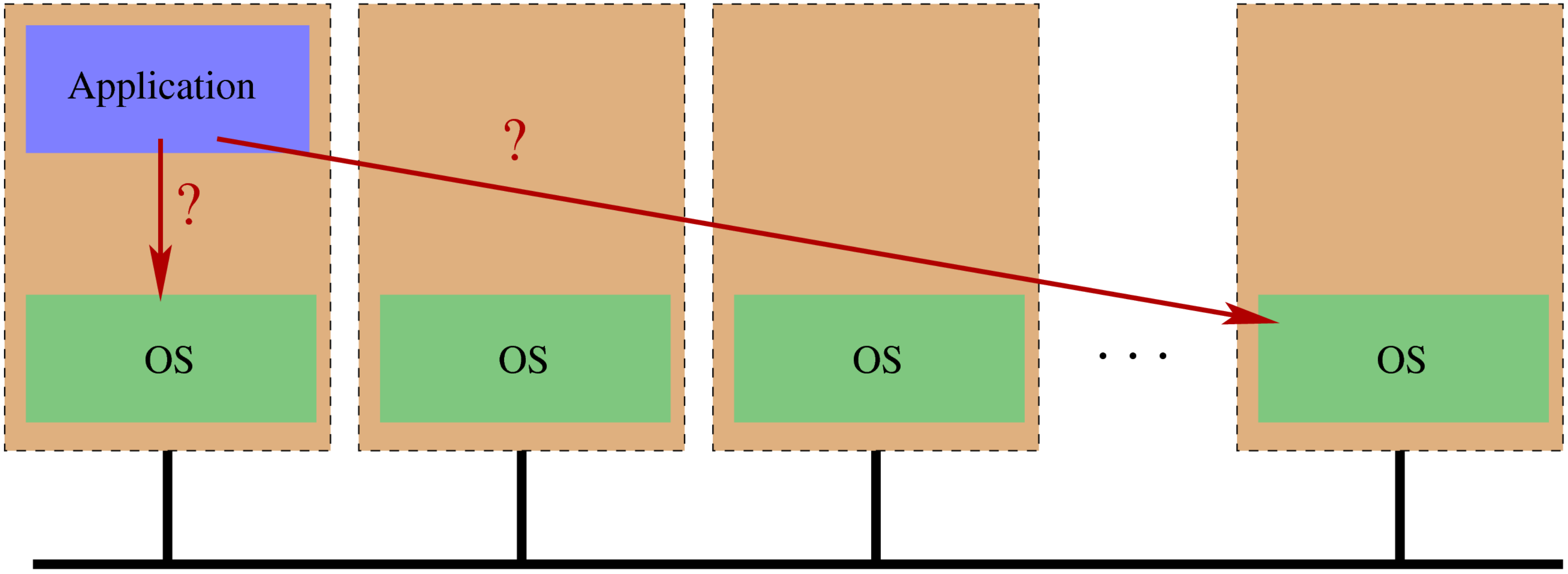
on Xscale PXA255 @ 400MHz

How Can Virtual be Faster than Real?

- It's a **microkernel**!
  - Complete kernel is about 10–11kloc!
- Linux is **big**!
  - 100s of kloc not counting drivers, file systems etc
- ARM MMU is quirky, needs a lot of effort to optimise
  - **much easier to optimize a small code base**
- Of course, the same can be achieved with Linux
  - in fact, we did it and offered patches upstream
  - maintainers didn't take — who cares about factor of 50!
  - Snapgear is running our patches in their modems

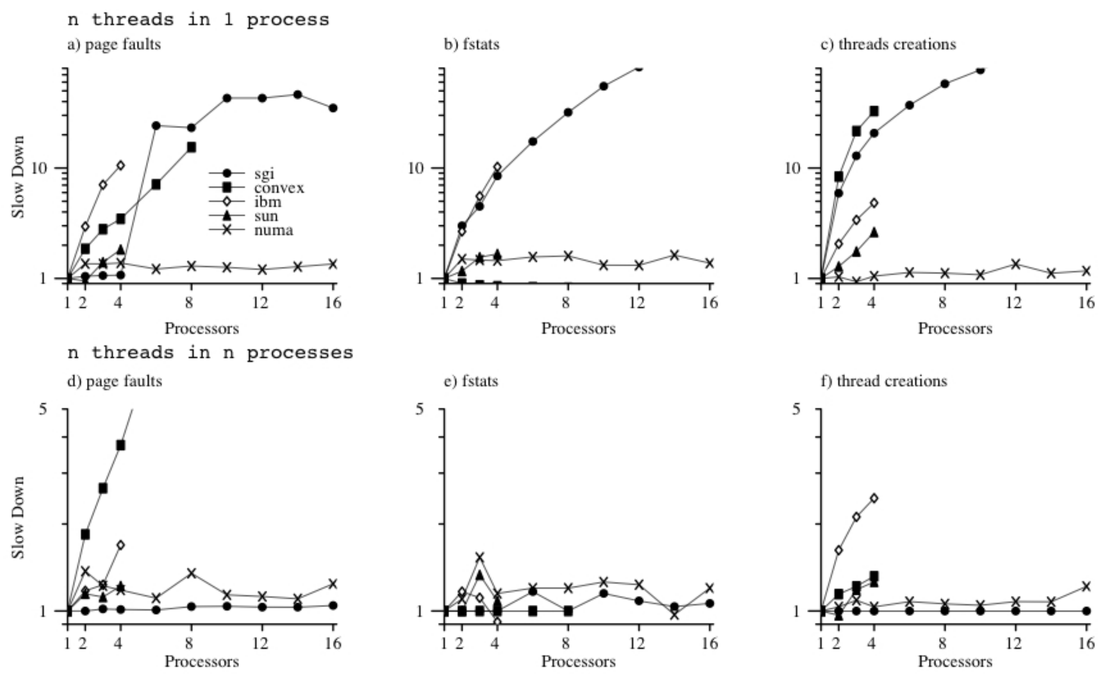
Back to Multiprocessor Scalability

- Lameter myth: IPC is needed across nodes inside a microkernel OS, and on NUMA this causes problems allocating the message queues NUMA-friendly



Whom you gonna call — local or remote OS????

Multiprocessor Scalability



- syscall slowdown vs # CPUs
- compare against several commercial systems
- only one system scales (constant slowdown)
- which is it?

What's the story?

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- **Tornado microkernel** scales perfectly to 16p
  - this is 1999! [Gamsa et al, 3rd OSDI]
  - done by a small group at Univ of Toronto
  - Tornado is predecessor of IBM's K42
- How far did Linux scale in 1999?
- How far would Linux scale **today** on the same bechmarks?
  - Note: the benchmarks show **concurrent** ops on all CPUs
    - page faults, fstats, thread creation

Synchronization Claims

- “Microkernel isolation limits synchronization methods”
- “Data structures have to be particular to subsystems”
- “Linux would never have been able to scale to these extremes with a microkernel approach because of the rigid constraints that strict microkernel designs place on the architecture of operating systems”
- **This is simply wrong (repeating doesn't make it right)**
  - synchronisation in a well-designed system is local to subsystems
  - there is no reason why subsystems can't share memory, even if microkernel-based

OS Scalability Principles

- OS must not impose synchronisation overhead except as forced by user code
- Then user code scalable ⇒ system scalable
- What does this mean?
  - keep data structures local
  - process system calls on the caller's CPU
  - only involve other CPUs if the caller explicitly asks for it!
    - creating/killing/signalling a thread on another CPU
    - invoking a synchronisation system call
    - unmap pages
- If this is done, you get a scalable OS
  - even if the apps actually perform system calls
  - user pays what user asks for...

Summary

- Hey, I can do this cool thing but you can't
  - How do you know if you don't understand me?
- Linux is cool
  - but this doesn't mean it is perfect for everything
  - nor does it mean Linux will remain as is forever
- Same is true for microkernels