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Is Parallel Programming Hard?

And, If So, Why?

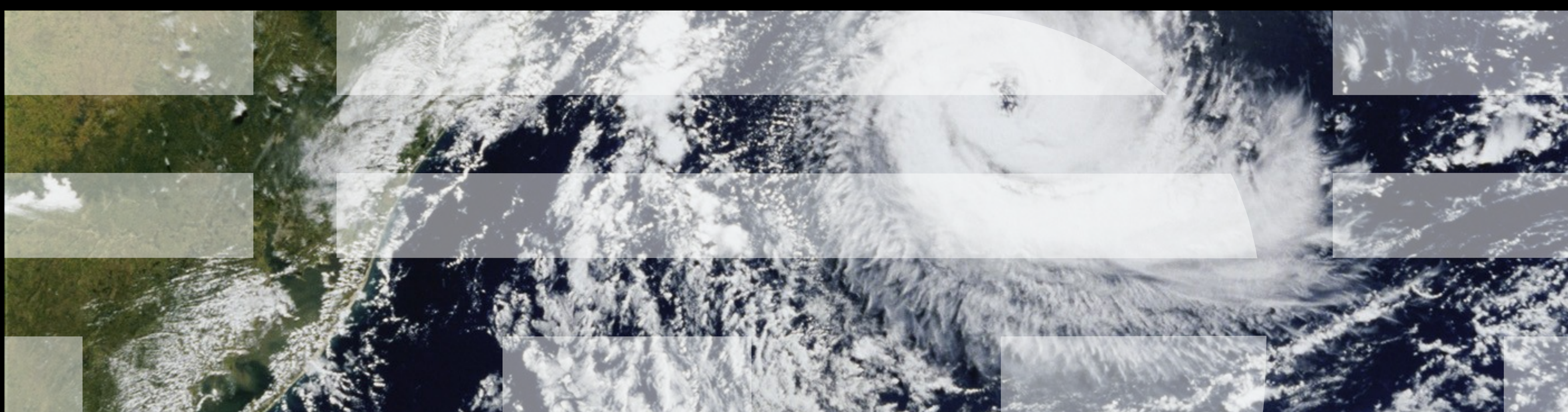

Table of contents

Early Experiences With Parallelism

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- In the mid-1970s, the doorbell rang
  - And like a fool, I answered it...

Nor Were the Quints' Parents Unprecedented

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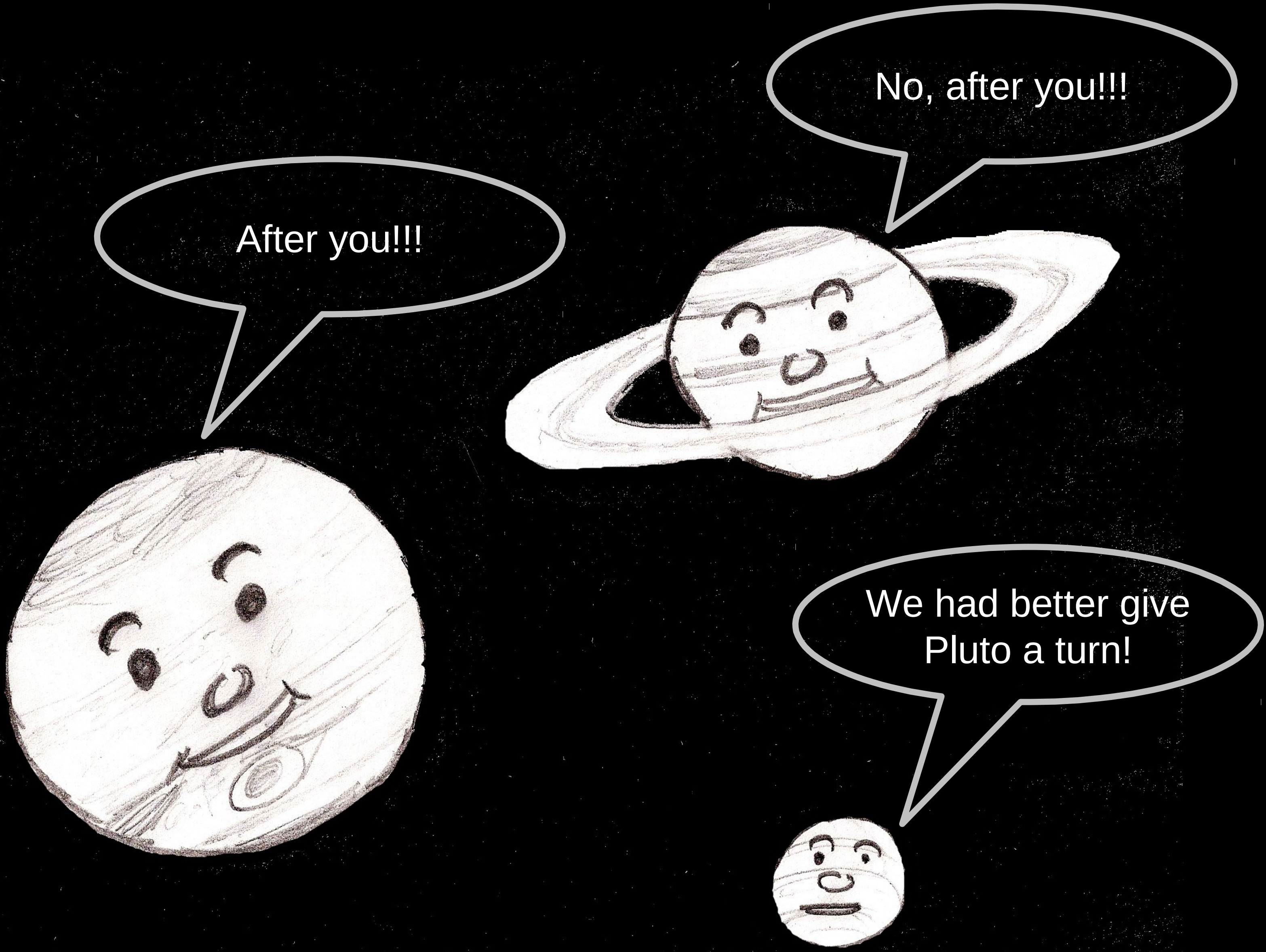
Concurrency comes naturally to human beings

Other Examples of Human Tolerance of Concurrency

- Team sports:
  - Basketball: Nine other players plus referees
  - American football: 21 other players plus referees
  - Football/soccer: 21 other players plus referees
  - Ice Hockey: 11 other players plus referees
  - Massively Multiplayer Online Gaming: lots of other players
- Teaching: tens of students
- Construction: tens of workers
- Driving in congested conditions: many other drivers
  - Hopefully also paying attention to pedestrians and bicyclists!
- Air-traffic control: many aircraft
- Emergency services: large numbers of people

Let's Face It: Concurrency Comes Naturally To The Entire Universe



But Just Because Concurrency Comes Naturally Does Not Necessarily Mean That Concurrent ***Programming*** Comes Naturally

More on this later...

Early Experiences With Parallel Computing

- 1989: distributed simulation on network of workstations
- 1990-1999: DYNIX/ptx parallel UNIX kernel
- 2000: AIX parallel UNIX kernel
- 2001-present: Linux UNIX kernel

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- So why all the excitement after all these decades?

Why Excitement About Parallelism After All These Decades?

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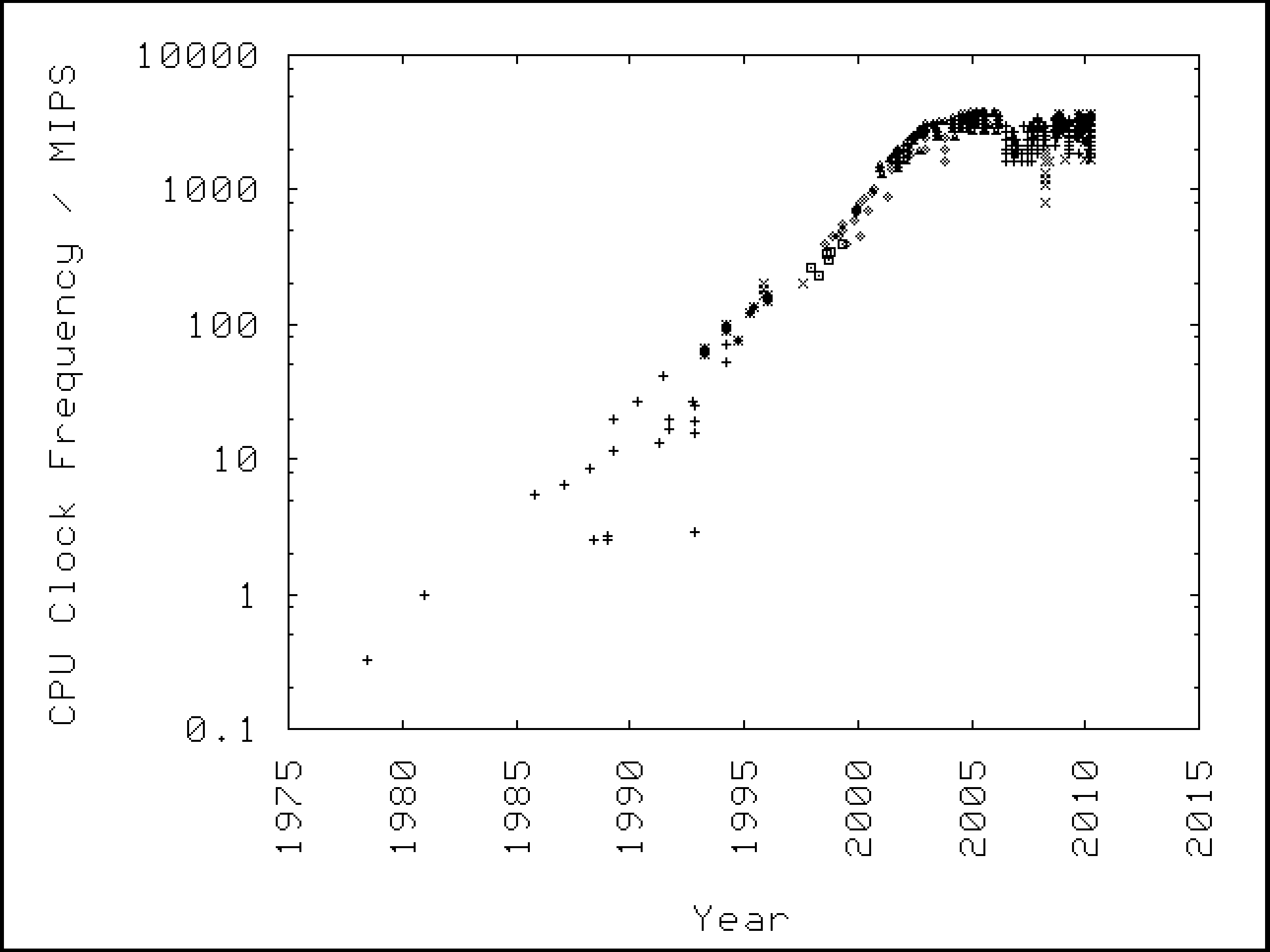
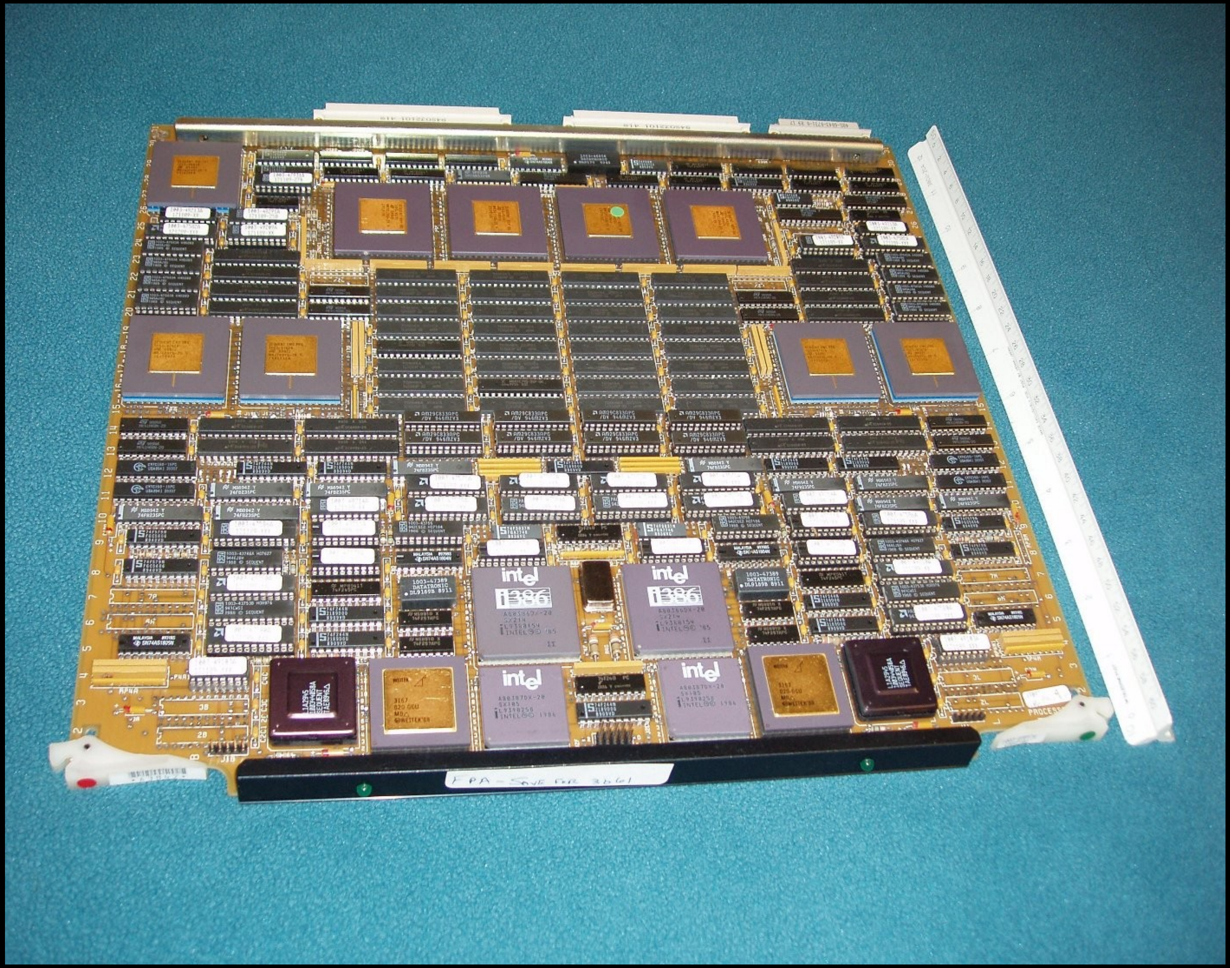


The Party Line

Simple Economics!



Why Excitement About Parallelism After All These Decades? Simple Economics!

- 1990: “Low-cost” multiprocessors system >> $100K
- 2006: Grad student buys dual-core Mac on whim
- 2011: Multiprocessor systems << $1K

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- Suddenly, multiprocessor systems can be used ***everywhere***
- Suddenly there is an acute shortage of parallel programmers

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- Suddenly, multiprocessor systems can be used ***everywhere***
- Suddenly there is an acute shortage of parallel programmers
  – But we have been here before...

The Great Software Crisis

History And Causes

- 1960s: “Low-cost” computer system >> $100K
- 1970: Minicomputers for $25K
- Late 1970s: Microcomputers << $1K

- Suddenly, computer systems can be used ***everywhere***
- Suddenly there is an acute shortage of programmers
  - But somehow the problem was solved. How?

The Solution To The Great Software Crisis

- Low-cost PCs meant that lots of people could afford them
- Lots of people bought PCs and other computers
  - Both for themselves and for their children
- As a result, lots of people gained experience with computers and with software
- These people produced the software that allows anyone to make good use of computers
  - Even my grandparents used computers

- The advent of low-cost multicore systems will solve the Great Multicore Software Crisis

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- The advent of low-cost multicore systems will solve the Great Multicore Software Crisis... Eventually...

Three Classes Of Attempted Solutions To The Great Software Crisis

- The Good
  - Orders of magnitude improvement in productivity
  - Orders of magnitude increase in people able to use computers
  - Preferably both simultaneously
- The Fad
  - Lots of excitement at the time, but long forgotten
- The Ugly
  - Was in use then, still in use now
  - To ugly to die

- Your nominations for these categories?
  - If you remember the 1980s...

Three Classes Of Attempted Solutions To The Great Software Crisis

- The Good
  - Spreadsheet
  - Presentation manager and word processor
  - Computer-aided engineering
- The Fad
  - An amazingly large number of long-forgotten languages
- The Ugly
  - The C language
  - sed, awk, perl, Visual BASIC, …

- There will be the same three classes of attempted solutions to the Great Multicore Crisis

What Is Hard About Programming?

Erroneous Expectations

- People expect anything that seems intelligent to have some degree of common sense
- People expect intelligent beings to understand their intent
- People expect to be successful despite fragmentary and incomplete plans

Erroneous Expectations

- People expect anything that seems intelligent to have some degree of common sense
- People expect intelligent beings to understand their intent
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- Most of this has little to do with parallelism

Managing Erroneous Expectations

- People expect anything that seems intelligent to have some degree of common sense
  - Computers are usually marketed as tools rather than beings
  - Eliza, Aibo, and Watson notwithstanding
- People expect intelligent beings to understand their intent
  - Computers are used in situations where intent is known implicitly
  - GPS units, web browsers, autopilots, ...
- People expect to be successful despite fragmentary and incomplete plans
  - And this one is the most relevant to parallel programming
  - Deadlocks, livelocks, and data races are ***planning failures***
  - Solution: Let the computer do the planning!!! Tools – Lots of tools!!!

Pathways To Multicore Software Success

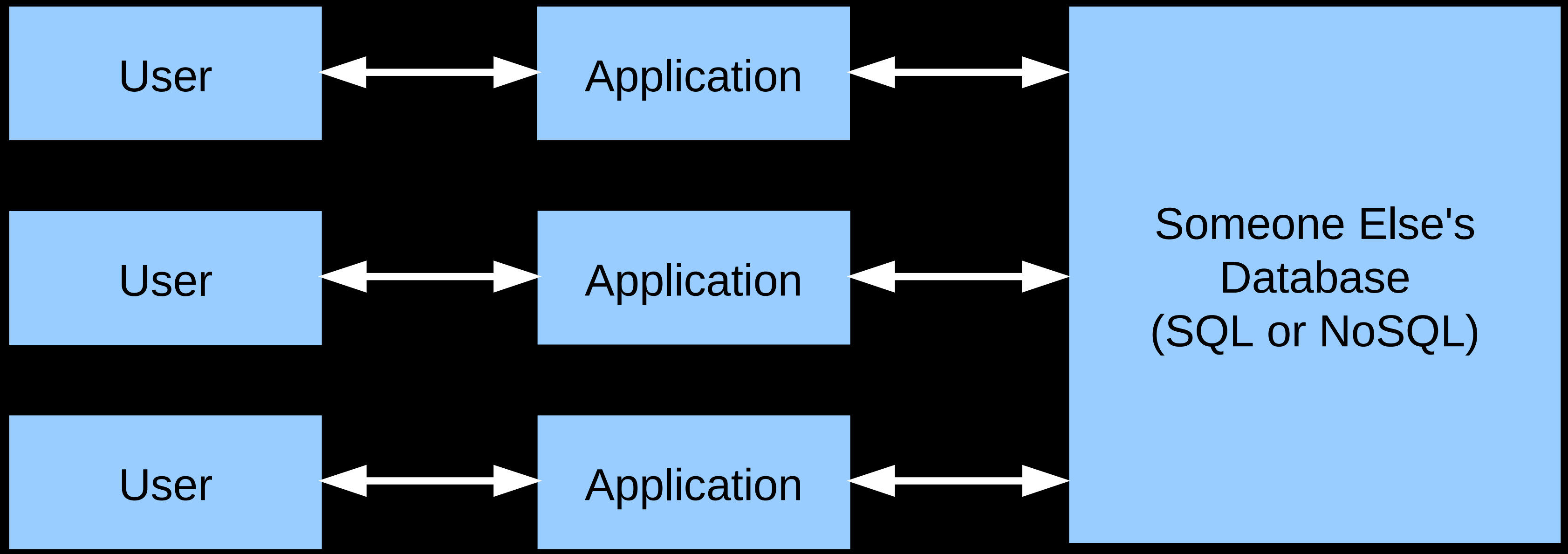
What Has Worked In The Past?

- Apprenticeship approach
  - Pair newbie with experienced parallel programmers
    - Sequent Computer Systems
    - Linux kernel community
  - Very effective: very ordinary engineers will produce competent parallel code within a few months
- Learn from existing parallel open-source projects
  - Linux kernel, PostgreSQL, Samba, …
  - Find the one that most closely matches your needs
- Exploit embarrassing parallelism
  - Transform your problem into an embarrassing one if need be
- Take validation seriously, from the ground up

What Has Worked In The Past?

- Work out what you need up front
  - If single-threaded software is fast enough, ignore parallelism!
  - Avoid the N+1 trap
    - “Do a single-threaded implementation.” “Good, now do a 2-CPU implementation.” “Great, now make it handle 3 CPUs.” …
    - Easier to do it once for (say) 32 CPUs than to rewrite it 32 times!!!
- Make sure you have a solid core of experienced engineers
  - Trust me, you don't want the blind mentoring the blind!!!
- Make sure all engineers have access to parallel hardware
  - And that they understand its properties and capabilities
- Make sure all engineers have access to all source code
- Make sure your team can deliver decent software...

Pattern for Success: Let Someone Else Be Parallel



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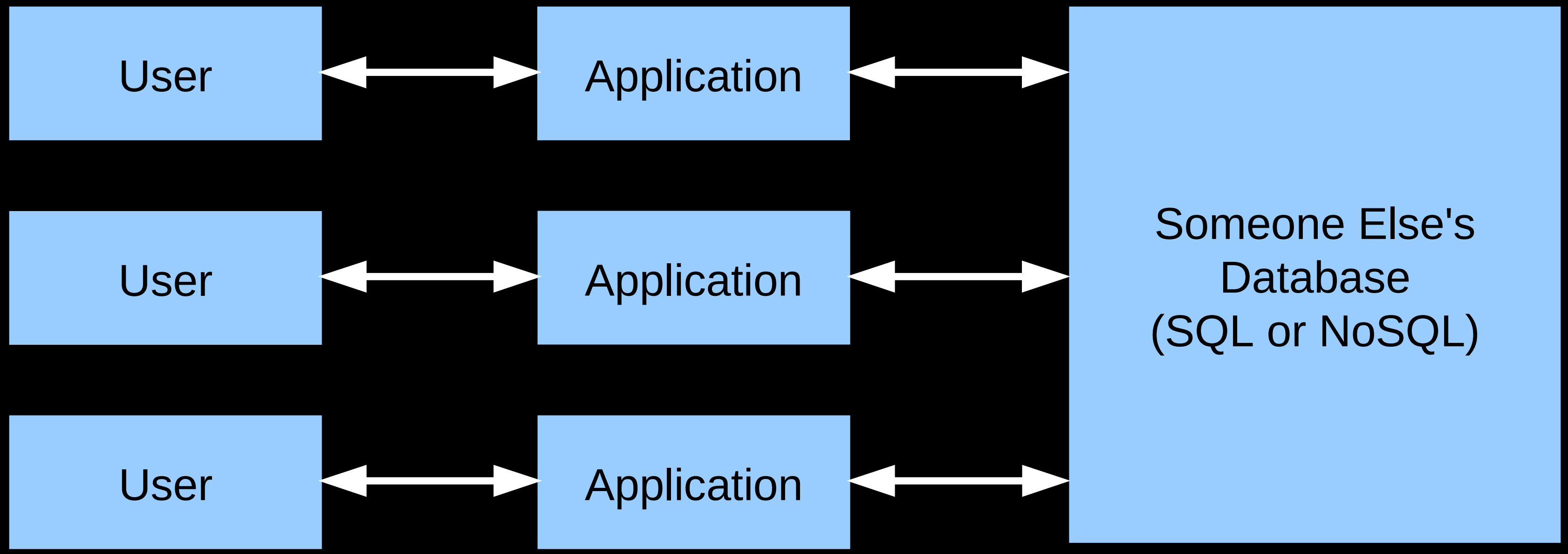
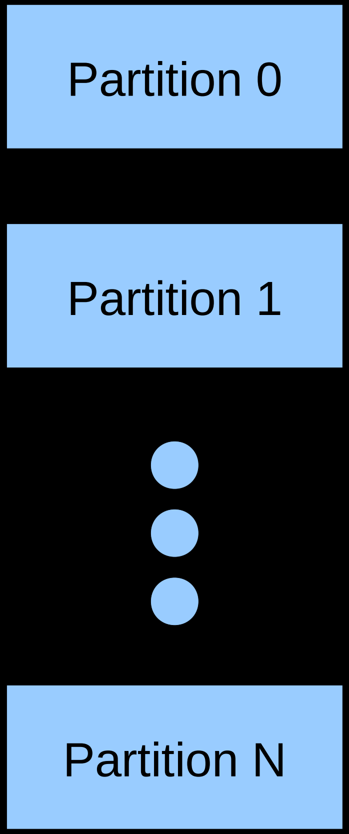


You can use an in-memory database, for example, Samba's TDB

Pattern for Success: Treasure Trivial Solutions



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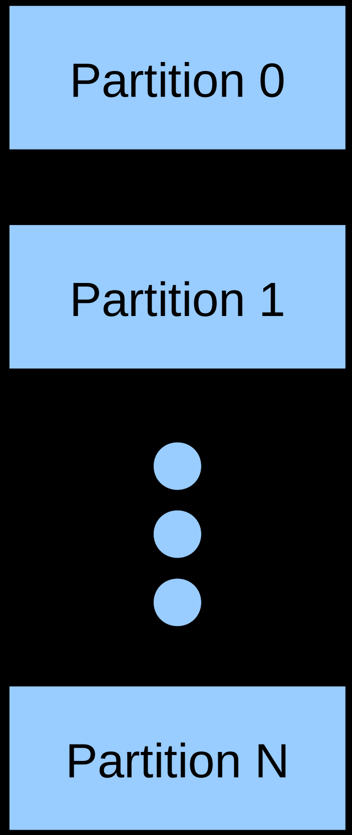


Which is one step away from map-reduce

Pattern for Success: Stick With Single-Threaded Code!!!

If single-threaded is fast enough, why bother with parallelism???

Don't Forget Simple Techniques

- Partitioning is simple, but can be extremely effective
- Batching is simple, but amortizes synchronization overhead
- Sequential execution is simple, and should be used when the resulting performance is sufficient
- Pipelining is simple, but can greatly reduce synchronization overhead
- Never be afraid to exploit important special cases:
  - Read-only and read-most situations, partitionable common-case execution, privatizable data, …
- Finding bottlenecks should be simple, but often isn't

Traps and Pitfalls

Traps and Pitfalls

Not that sequential code has any traps and pitfalls...

Parallelizing An Existing Single-Threaded Project

- Single-Threaded Design, Code, and APIs
- Sequential Staff
- Darwin Strikes Again!!!
- Weak or Non-Existent Validation
- Failing to Understand Underlying Software and Hardware

Single-Threaded Design, Code, and APIs

- Things that are cheap and easy for single-threaded code:
  - Singleton pattern/objects through which all control passes
    - Global counters
    - Hoare monitors
    - Global transaction IDs
  - Ordering guarantees
  - Stop-the-world processing
  - Global locks
  - Strongly non-commutative APIs that guarantee determinism and linearizability (Attiya et al. "Laws of Order")
- These are all quite expensive for parallel code: Often fatal!!!
- Parallelizing your single-threaded software may require big-animal changes.

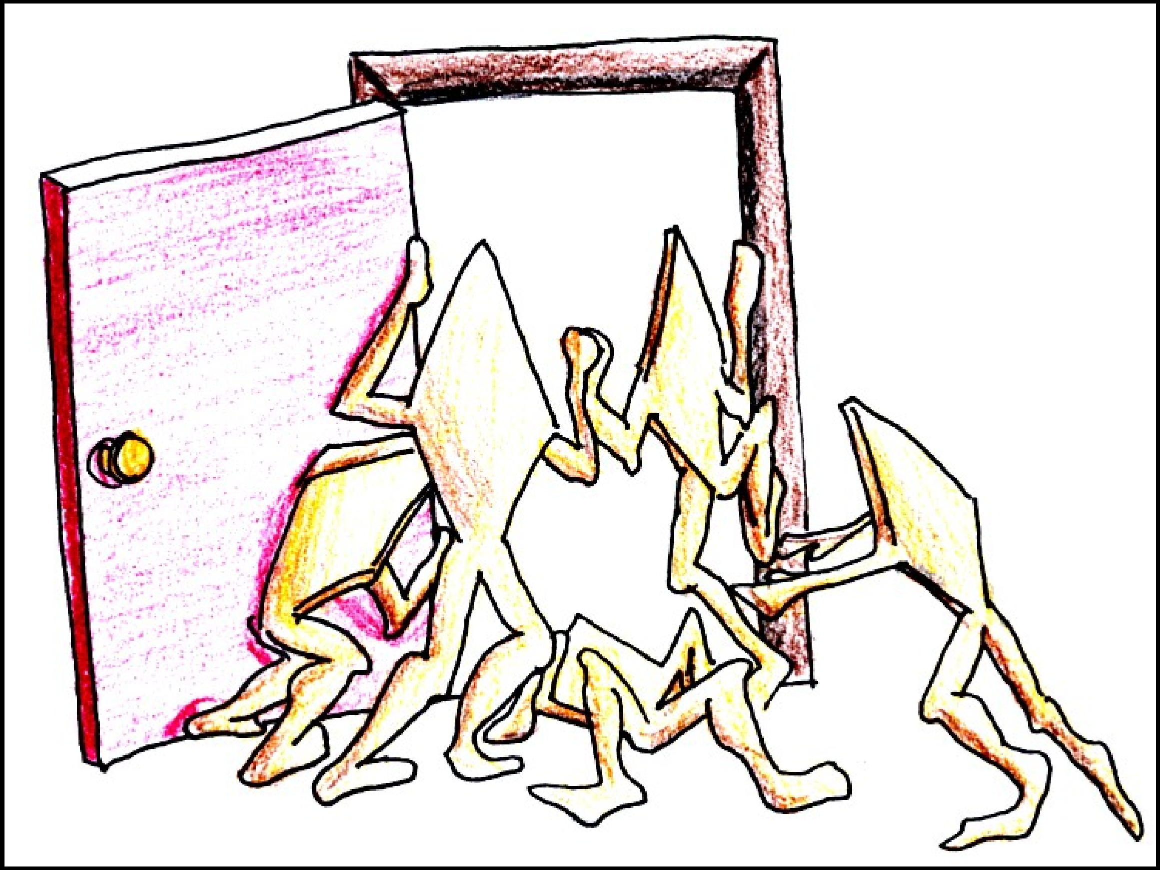
Sequential Staff

- If you have an existing sequential software project, you probably already have people working on it
  - Who probably know nothing about parallel software
- You might be able to attract (or hire) an experienced parallel programmer (preferably in the required type of parallelism)
- You will then need:
  - Readily available parallel/multicore hardware
  - Large body of high-quality parallel code for review and tinkering
  - Easy access to parallel-programming experts
    - Preferably with a wide variety of viewpoints
  - Immediate “frank and open” expert feedback for multicore newbies
- What if you can't get an experienced parallel programmer?

Sequential Staff With No Experts?

- Decent classes are becoming available
  - But I cannot judge: I learned this stuff directly from the hardware
  - But I do know the single most important lesson!!!
- Any number of parallel open-source projects are out there
  - One quick (if brutal) way to get employee training!
  - If your project has an incompatible license, use carefully crafted procedures to avoid contamination
  - But it might be easier to select a project with a compatible license

Sequential Staff: The Most Important Parallel/Multicore Lesson:



Avoid having only one of something on the fastpath!!!

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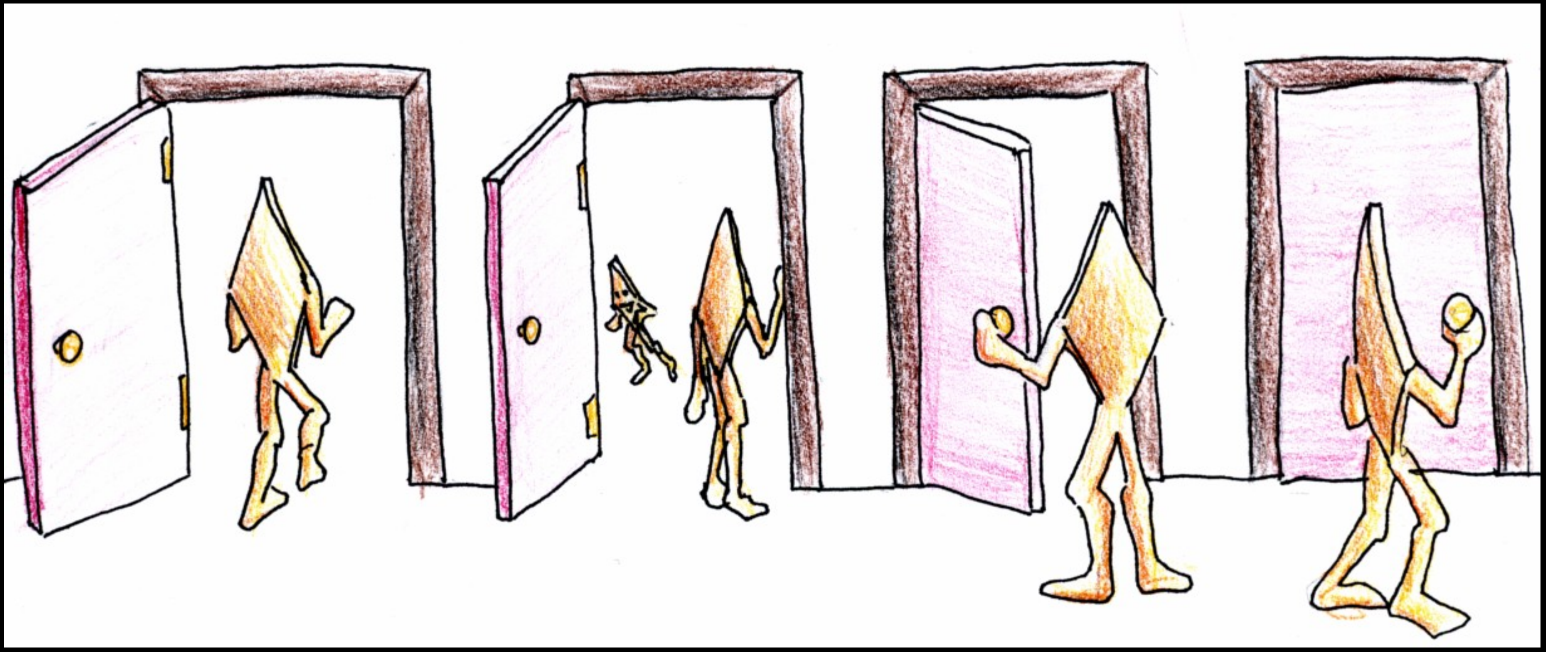

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- But how about just hiring a bunch of really smart people?

Sequential Staff With Really Smart Newbies?

- This can work if the newbies have access to hardware, software, experts, and feedback
- Otherwise, added intelligence is a negative
  - The smarter you are, the deeper a hole you will dig for yourself before you realize that you are in trouble
  - There are a ***very*** small number of exceptions to this rule, and I am ***not*** one of them
- Fortunately, the increasing quantities of readily available multicore hardware and parallel software is increasing the odds that newbies will have parallel/multicore experience
- Just as with the Great Software Crisis!

Sequential Staff: One More Question...

- There is a good chance that your single-threaded software base will need big-animal changes
- So can your existing developers make big-animal changes in your current code base?

Sequential Staff: One More Question...

- There is a good chance that your single-threaded software base will need big-animal changes
- So can your existing developers make big-animal changes in your current code base?
- Or have your original developers long since departed?

Sequential Staff: Software Janitors?

Your multicore strategy must take into account available skills!

Darwin Strikes Again!!!

- Through the 80s, 90s, and the first half of the 00s, parallel systems and programmers were rare and expensive
  - Extreme cost, itty bitty unit volumes
- With a very few exceptions, projects and products whose developers disliked parallelism were at a large advantage
  - Most of the market at reasonably low cost
- If your product or project is decades old, some attitude adjustments may be required...

Weak or Non-Existent Validation

- Parallelism adds failure modes, requiring tougher validation
- So get your validation in good shape before parallelizing!!!

Failing to Understand Underlying Software and Hardware

- Would you trust:
  - A bridge designed by someone who didn't understand that concrete, while strong in compression, is weak in tension?
  - A home heating system designed by someone who didn't understand that would houses burn?
  - A home in the rainy Pacific Northwest designed by someone who didn't understand that wood rots in temperate rain forests?
  - A space shuttle designed by someone who didn't understand the low-temperature properties of O-rings?

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- If not, why would you trust an algorithm designed by someone who didn't understand hardware properties?

How Far Should You Take Parallelism?

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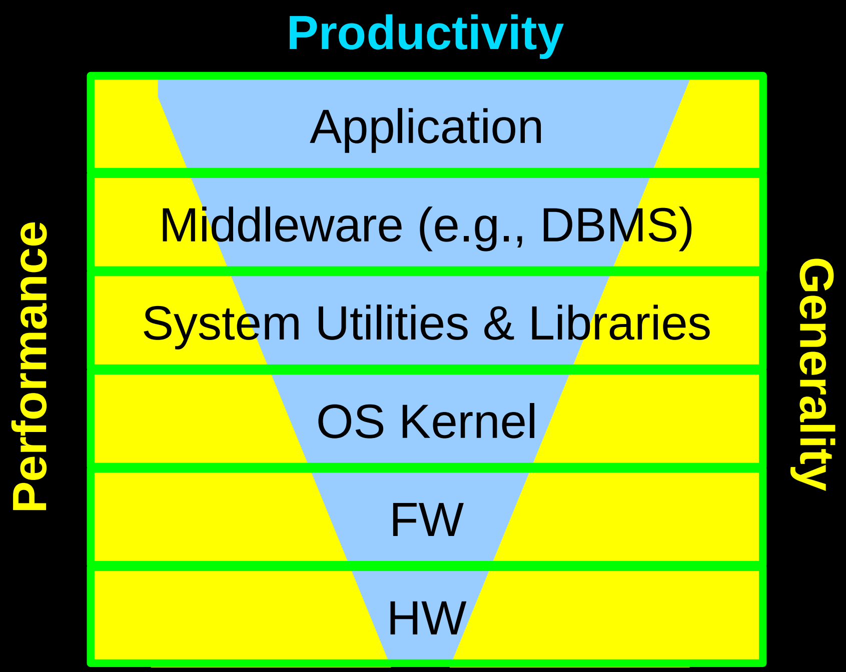
It Depends!

It Depends On Your Position In The Software Stack



There is great variety at the application level

How Does the Linux Kernel Community Cope?

Kernel-Community Approaches to Concurrency (Subset 1/2)

- Organizational mechanisms
  - Maintainers and quality assurance: recognition and responsibility
  - Informal apprenticeship/mentoring model
  - Design/code review required for acceptance
  - Aggressive pursuit of modularity and simplicity
- Use sane idioms and abstractions
  - Locking, sequence locking, sleep/wakeup, memory fences, RCU, ...
  - Conventional use of memory-ordering primitives, for example:
  - Needing to know too much about the underlying memory model indicates broken abstraction, broken design, or both

Kernel-Community Approaches to Concurrency (Subset 2/2)

- Static source-code analysis
  - “checkpatch.pl” to enforce coding standards
  - “sparse” static analyzer to check lock acquire/release mismatches
  - “coccinelle” to automate inspection and generation of bug fixes
- Dynamic analysis
  - “lockdep” deadlock detector (also checks for misuse of RCU)
  - Tracing and performance analysis
  - Assertions
- Aggressive automation
  - “git” source-code control system: from weeks to minutes for rebases and merges
- Testing
  - In-kernel test facilities such as rcutorture
  - Out-of-kernel test suites

Kernel-Community Approaches to Concurrency

- To err is human, and therefore...
  - People/organizational mechanisms are at least as important as concurrency technology
  - Use multiple error-detection mechanisms
  - For core of RCU, validation starts at the very beginning:
    - Write a design document: safety factors and conservative design
    - Consult with experts, update design as needed
    - Write code in pen on paper: Recopy until last two copies identical
    - Do proofs of correctness for anything non-obvious
    - Do full-up functional and stress testing
    - Document the resulting code (e.g., publish on LWN)
  - If I do all this, then there are probably only a few bugs left
    - And I detect those at least half the time

Summary

Summary: Many Promising Starts On Parallelism

- Linux kernel
- Apache
- MySQL (whichever fork you like)
- PostgreSQL
- Samba
- liburcu
- OpenMP
- POSIX threads
- C/C++ concurrency
- Intel TBB
- RapidMind
- Open Parallel
- Erlang
- Apple GCS
- CCAN
- Your project here...

Parallelism: Some fear is indeed warranted

Summary

But don't be a slave to your fear

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QUESTIONS?