



Why Events Are A Bad Idea

(for high-concurrency servers)

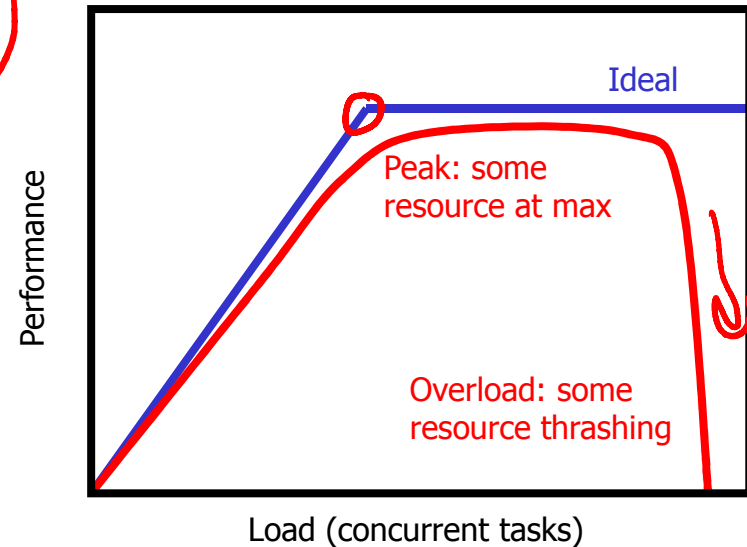
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<http://capriccio.cs.berkeley.edu>

A Talk HotOS 2003

The Stage

- Highly concurrent applications
 - Internet servers (Flash, Ninja, SEDA)
 - Transaction processing databases
- Workload
 - Operate "near the knee"
 - Avoid thrashing!
- What makes concurrency hard?
 - Race conditions
 - Scalability (no $O(n)$ operations)
 - Scheduling & resource sensitivity
 - Inevitable overload
 - Code complexity

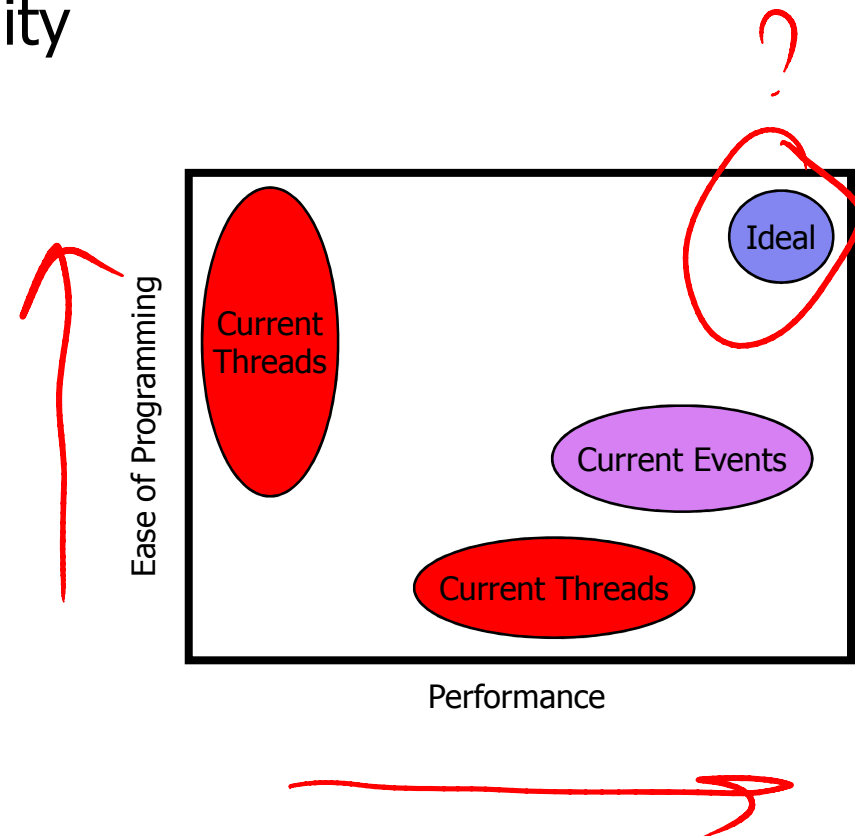
event-based



live lock

The Debate

- Performance vs. Programmability
 - Current threads pick one
 - Events somewhat better
- Questions
 - Threads vs. Events?
 - How do we performance and programmability?





Our Position

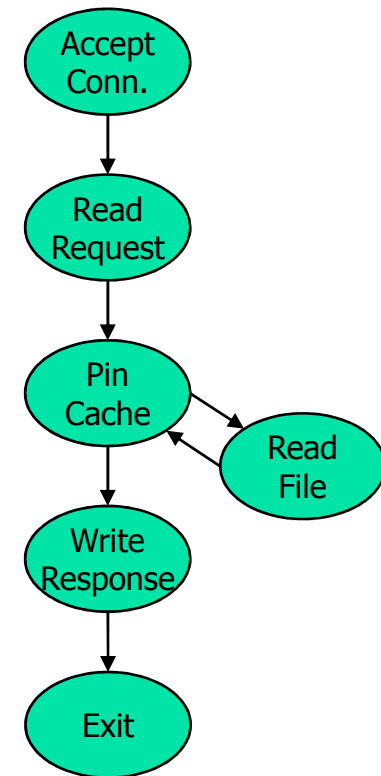
- Thread-event duality still holds
- But threads are better anyway
 - More natural to program
 - Better fit with tools and hardware
- Compiler-runtime integration is key

The Duality Argument

- General assumption: follow “good practices”
- Observations
 - Major concepts are analogous
 - Program structure is similar
 - Performance should be similar
 - Given good implementations!

<i>Threads</i>	<i>Events</i>
<ul style="list-style-type: none">■ Monitors■ Exported functions■ Call/return and fork/join■ Wait on condition variable	<ul style="list-style-type: none">■ Event handler & queue■ Events accepted■ Send message / await reply■ Wait for new messages

Web Server

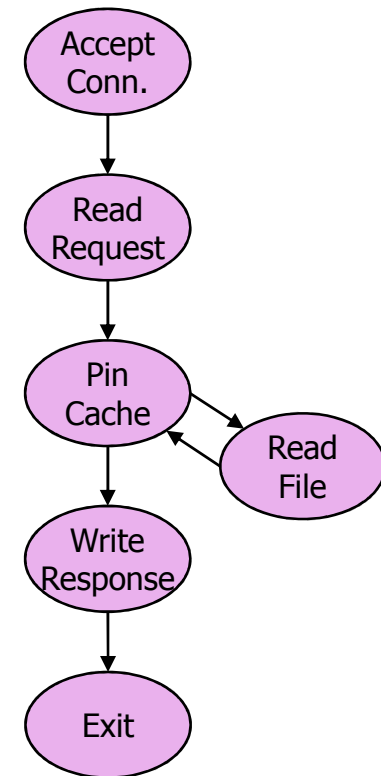


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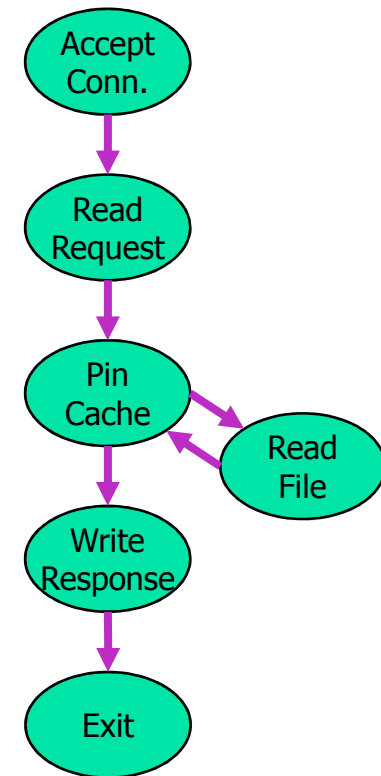


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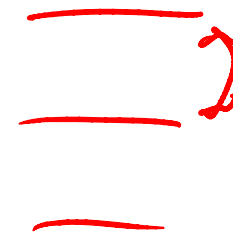
“But Events *Are* Better!”

- Recent arguments for events
 - Lower runtime overhead
 - Better live state management
 - Inexpensive synchronization
 - More flexible control flow
 - Better scheduling and locality
- All true but...
 - No *inherent* problem with threads!
 - Thread implementations can be improved

func() {
local vars

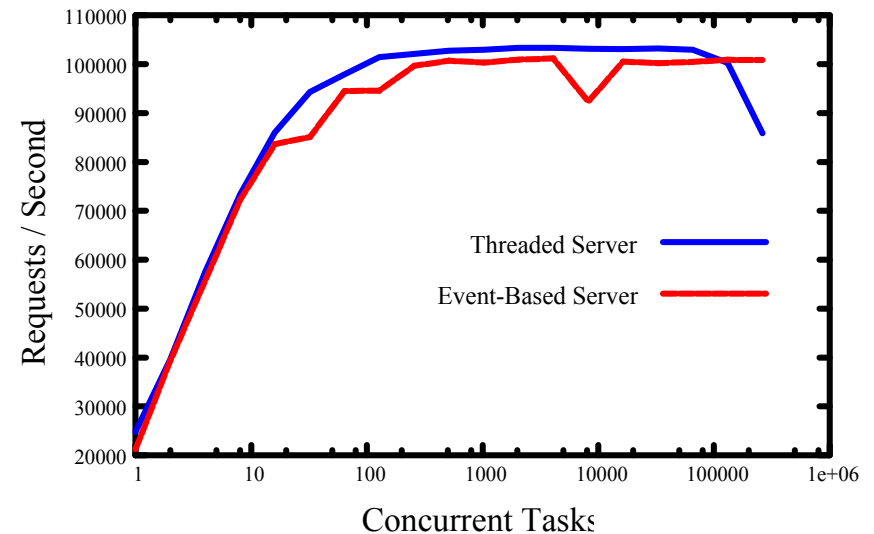
⋮

func()
}



Runtime Overhead

- *Criticism: Threads don't perform well for high concurrency*
- Response
 - Avoid $O(n)$ operations
 - Minimize context switch overhead
- Simple scalability test
 - Slightly modified GNU Pth
 - Thread-per-task vs. single thread
 - Same performance!

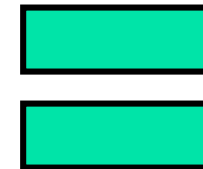


Live State Management

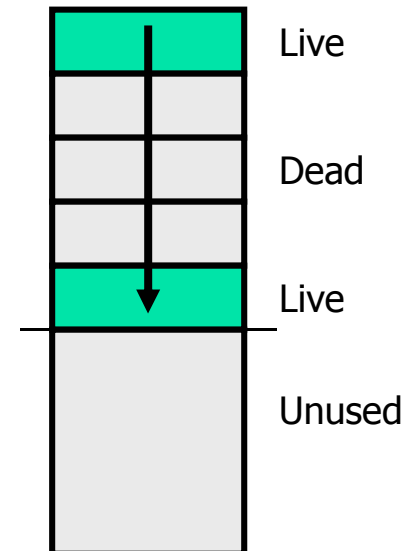
- *Criticism: Stacks are bad for live state*
- Response
 - Fix with compiler help
 - Stack overflow vs. wasted space
 - Dynamically link stack frames
 - Retain dead state
 - Static lifetime analysis
 - Plan arrangement of stack
 - Put some data on heap
 - Pop stack before tail calls
 - Encourage inefficiency
 - Warn about inefficiency



Event State (heap)



Thread State (stack)



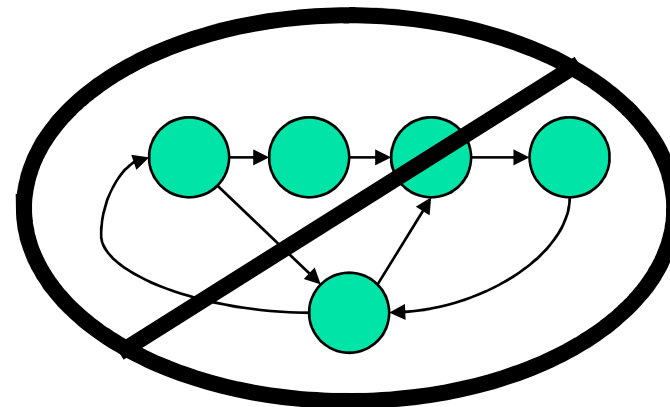
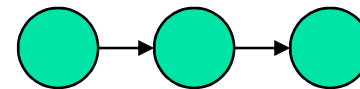
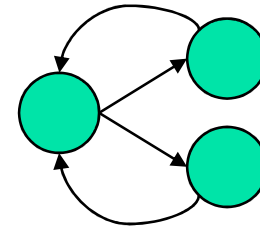
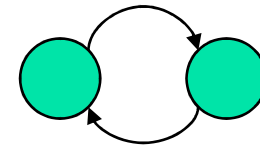


Synchronization

- *Criticism: Thread synchronization is heavyweight*
- Response
 - Cooperative multitasking works for threads, too! *d*
 - Also presents same problems
 - Starvation & fairness
 - Multiprocessors
 - Unexpected blocking (page faults, etc.)
 - Compiler support helps

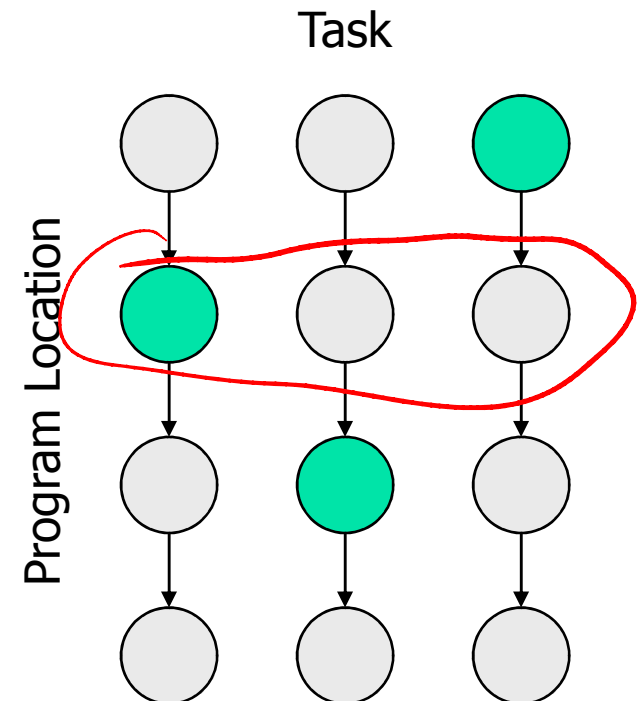
Control Flow

- *Criticism: Threads have restricted control flow*
- Response
 - Programmers use simple patterns
 - Call / return
 - Parallel calls
 - Pipelines
 - Complicated patterns are unnatural
 - Hard to understand
 - Likely to cause bugs



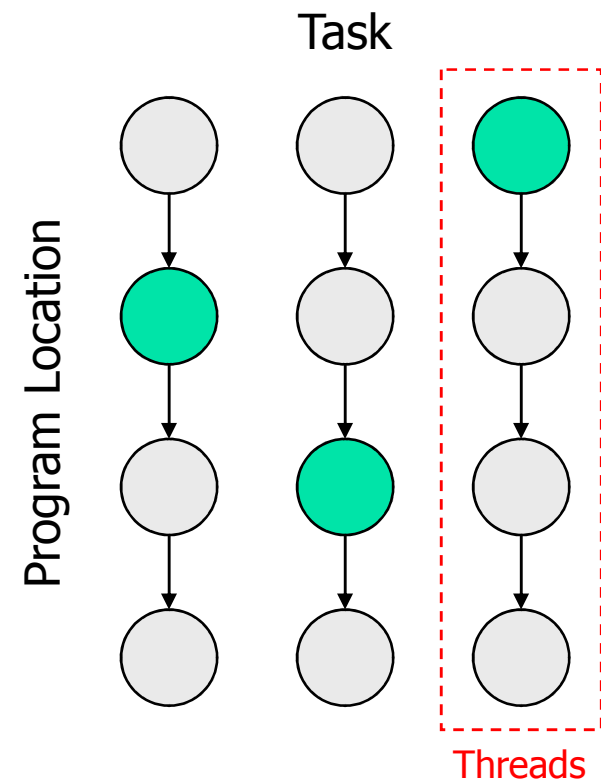
Scheduling

- *Criticism: Thread schedulers are too generic*
 - Can't use application-specific information
- Response
 - 2D scheduling: task & program location
 - Threads schedule based on task only
 - Events schedule by location (e.g. SEDA)
 - Allows batching
 - Allows prediction for SRCT
 - Threads can use 2D, too!
 - Runtime system tracks current location
 - Call graph allows prediction



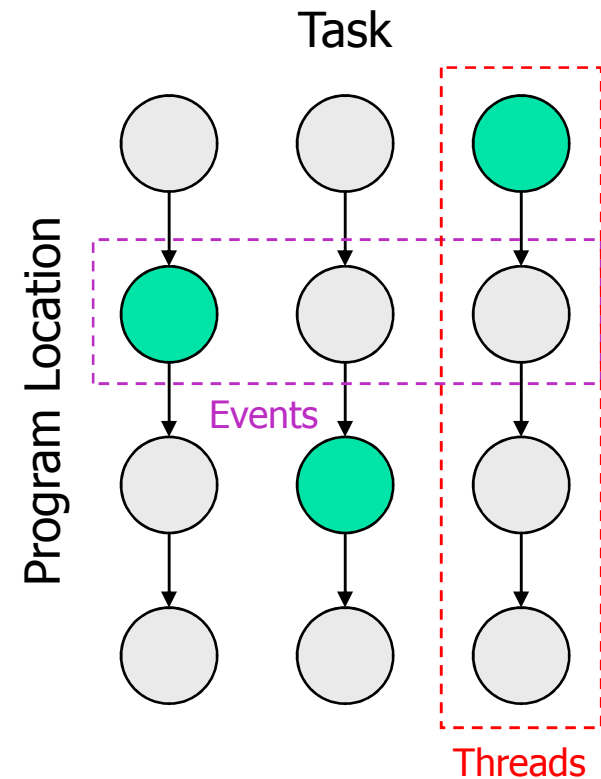
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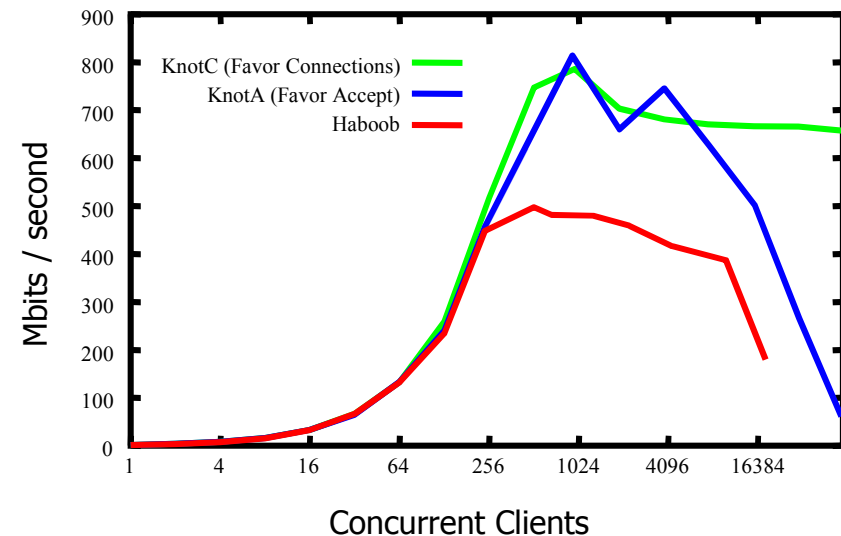
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The Proof's in the Pudding

- User-level threads package
 - Subset of pthreads
 - Intercept blocking system calls
 - No $O(n)$ operations
 - Support > 100K threads
 - 5000 lines of C code
- Simple web server: Knot
 - 700 lines of C code
- Similar performance
 - Linear increase, then steady
 - Drop-off due to `poll()` overhead





Our Big But...

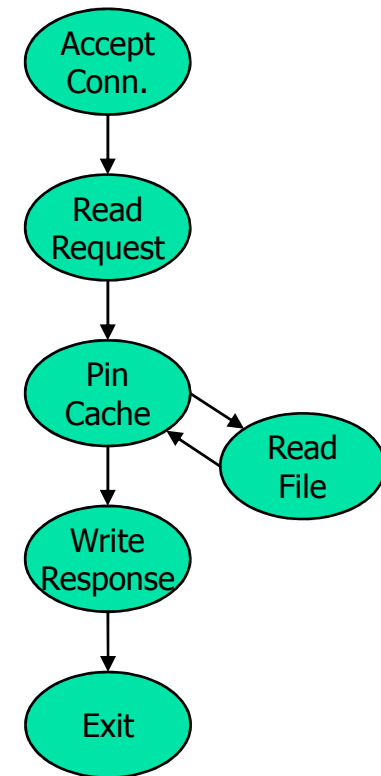
- More natural programming model
 - Control flow is more apparent
 - Exception handling is easier
 - State management is automatic
- Better fit with current tools & hardware
 - Better existing infrastructure
 - Allows better performance?

Control Flow

- Events obscure control flow
 - For programmers *and* tools

<i>Threads</i>	<i>Events</i>
<pre>thread_main(int sock) { struct session s; accept_conn(sock, &s); read_request(&s); pin_cache(&s); write_response(&s); unpin(&s); } pin_cache(struct session *s) { pin(&s); if(!in_cache(&s)) read_file(&s); }</pre>	<pre>AcceptHandler(event e) { struct session *s = new_session(e); RequestHandler.enqueue(s); } RequestHandler(struct session *s) { ...; CacheHandler.enqueue(s); } CacheHandler(struct session *s) { pin(s); if(!in_cache(s)) ReadFileHandler.enqueue(s); else ResponseHandler.enqueue(s); } ... ExitHandler(struct session *s) { ...; unpin(&s); free_session(s); }</pre>

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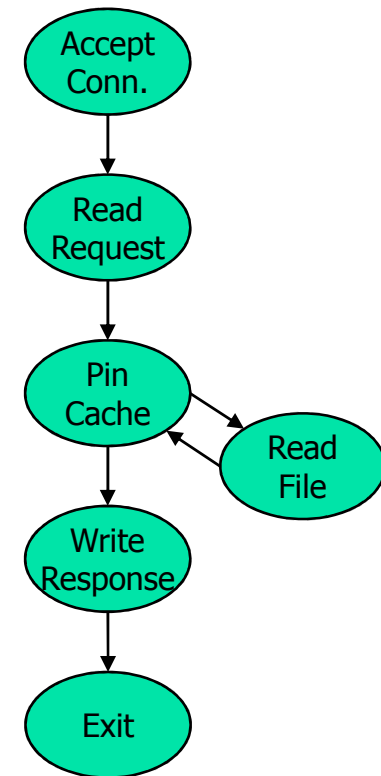


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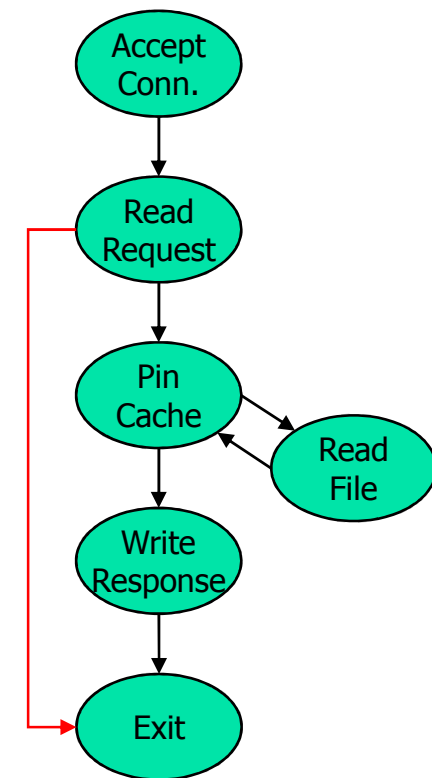


Exceptions

- Exceptions complicate control flow
 - Harder to understand program flow
 - Cause bugs in cleanup code

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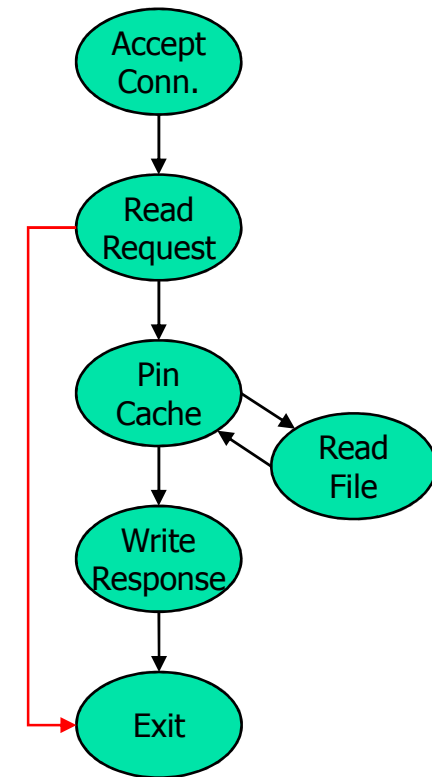


State Management

- Events require manual state management
- Hard to know when to free
 - Use GC or risk bugs

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Existing Infrastructure

- Lots of infrastructure for threads
 - Debuggers
 - Languages & compilers
- Consequences
 - More amenable to analysis
 - Less effort to get working systems



Better Performance?

- Function pointers & dynamic dispatch
 - Limit compiler optimizations
 - Hurt branch prediction & I-cache locality
- More context switches with events?
 - Example: Haboob does 6x more than Knot
 - Natural result of queues
- More investigation needed!



The Future: Compiler-Runtime Integration

- Insight
 - Automate things event programmers do by hand
 - Additional analysis for other things
- Specific targets
 - Dynamic stack growth*
 - Live state management
 - Synchronization
 - Scheduling*
- Improve performance *and* decrease complexity

* Working prototype in threads package

Conclusion

- Threads \approx Events
 - Performance
 - Expressiveness
- Threads $>$ Events
 - Complexity / Manageability
- Performance *and* Ease of use?
 - Compiler-runtime integration is key

