



(for high-concurrency servers)

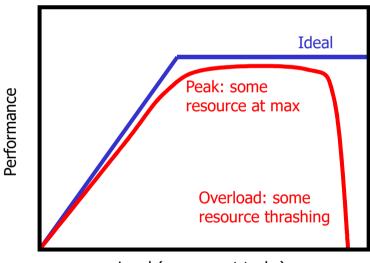
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A Talk HotOS 2003



# 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

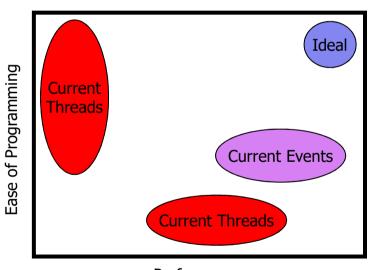


Load (concurrent tasks)



### The Debate

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



Performance



- 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

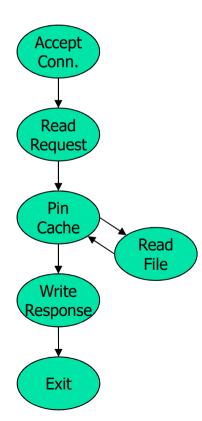
- General assumption: follow "good practices"
- Observations
  - Major concepts are analogous
  - Program structure is similar
  - Performance should be similar
    - Given good implementations!

#### **Threads**

- Monitors
- Exported functions
- Call/return and fork/join
- Wait on condition variable

### **Events**

- Event handler & queue
- Events accepted
- Send message / await reply
- Wait for new messages





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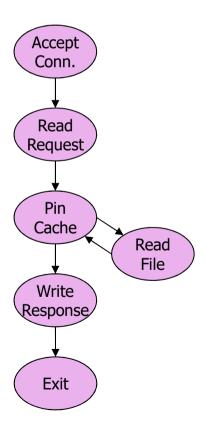
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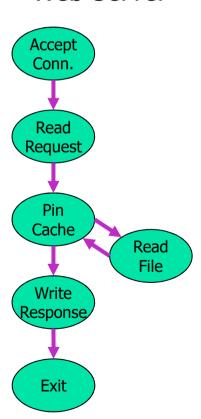
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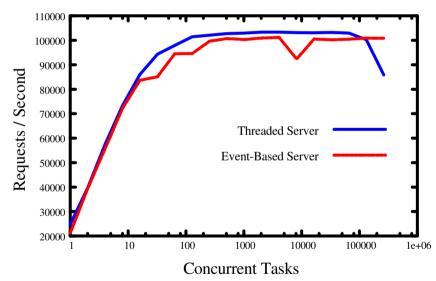
### "But Events Are Better!"

- 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



### 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!



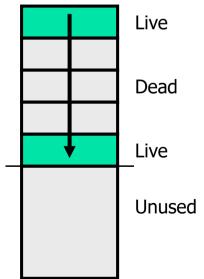


# Live State Management

- 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



Thread State (stack)



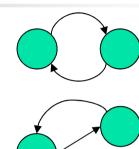
# Synchronization

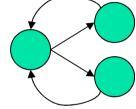
- Criticism: Thread synchronization is heavyweight
- Response
  - Cooperative multitasking works for threads, too!
  - Also presents same problems
    - Starvation & fairness
    - Multiprocessors
    - Unexpected blocking (page faults, etc.)
  - Compiler support helps

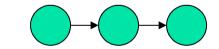


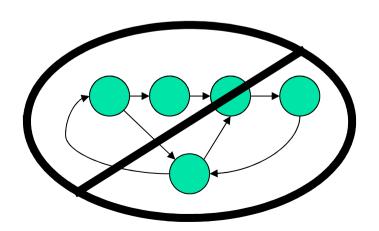
### **Control Flow**

- 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





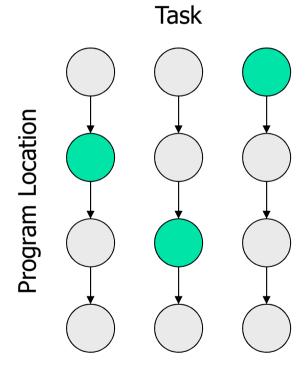






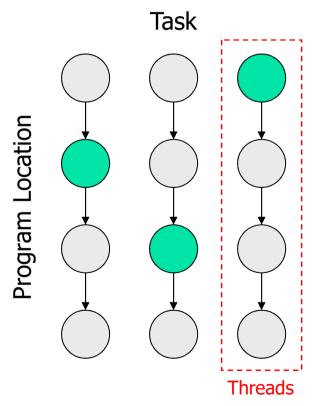
# Scheduling

- 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



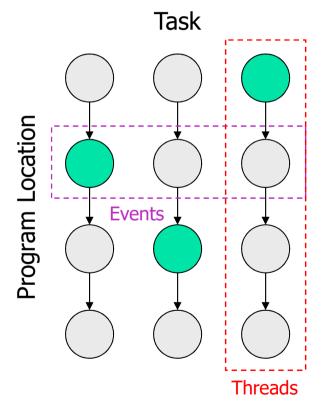


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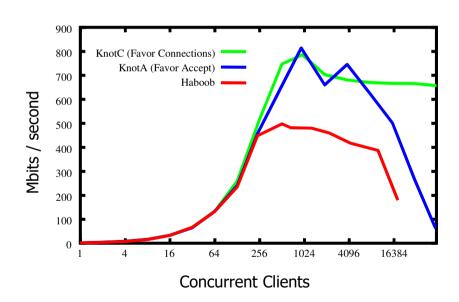
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# The Proof's in the Pudding

- 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





- 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

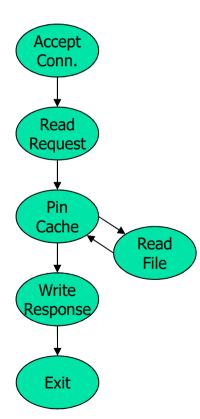
### **Threads**

```
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);
}
```

### **Events**

```
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);
}
...
ExitHandlerr(struct session *s) {
    ...; unpin(&s); free_session(s); }
```





### **Control Flow**

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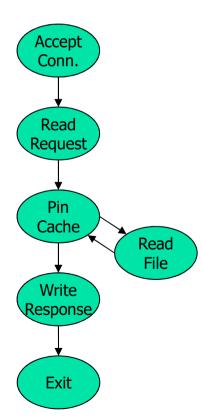
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## Exceptions

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

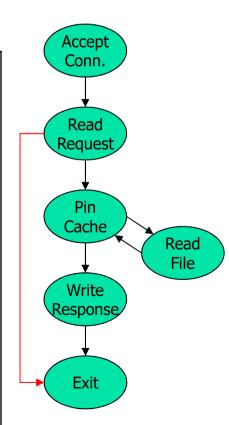
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# State Management

- Évents require manual state management
- Hard to know when to free

Use GC or risk bugs

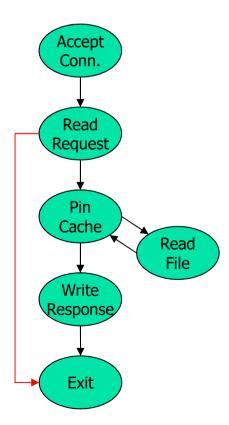
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# **Existing Infrastructure**

- 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!

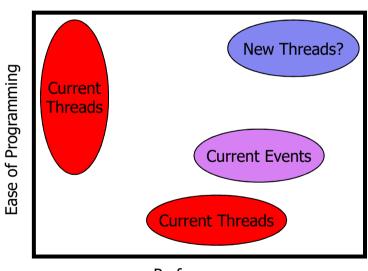


- Insight
  - Automate things event programmers do by hand
  - Additional analysis for other things
- Specific targets
  - Dynamic stack growth\*
  - Live state management
  - Synchronization
  - Scheduling\*
- Improve performance and decrease complexity



### Conclusion

- Threads ≈ Events
  - Performance
  - Expressiveness
- Threads > Events
  - Complexity / Manageability
- Performance and Ease of use?
  - Compiler-runtime integration is key



Performance