# Graduate Operating Systems

Spring 2023

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## Today's Papers

- **[15]** Rob von Behren, Jeremy Condit, and Eric Brewer, "Why Events are a Bad Idea (for high-concurrency servers)", Workshop on Hot Topics in Operating Systems, 2003.
- **[16]** Matt Welsh, David Culler, and Eric Brewer, "SEDA: An Architecture for Well-Conditioned, Scalable Internet Services", ACM Symposium on Operating Systems Principles, 2001.

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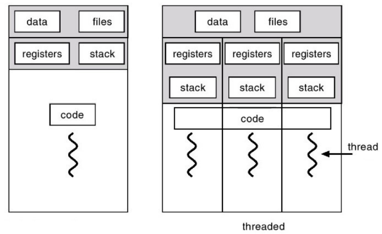
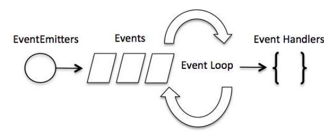
# Threads vs. Events

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# Threads vs. Events

- 1995: *Why Threads are a Bad Idea (for most purposes)*
  - John Ousterhout (UC Berkeley, Sun Labs)
- 2001: *SEDA: An Architecture for Well-Conditioned, Scalable Internet Services*
  - Staged, Event-driven Architecture
  - M. Welsh, D. Culler, and Eric Brewer (UC Berkeley)
- 2003: *Why Events are a Bad Idea (for high-concurrency servers)*
  - R. van Behren, J. Condit, Eric Brewer (UC Berkeley)

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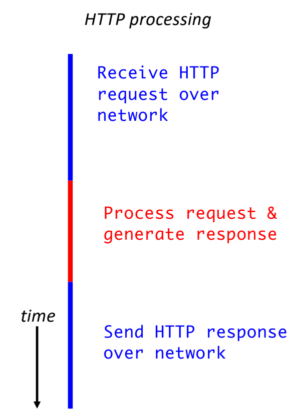
## Background

- *How can we scale up servers to handle many simultaneous requests?*

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## Quick Example

- *Suppose it takes 1 second for a web server to transfer a file to the client. Of this time, 10 milliseconds is dedicated to CPU processing. How many simultaneous requests do we need to keep the CPU fully utilized?*

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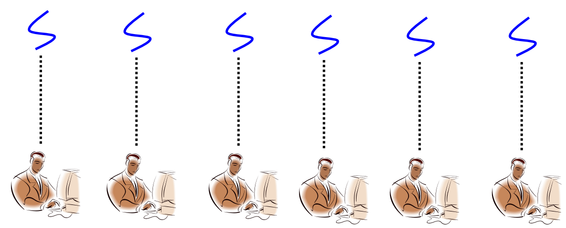
## Strategy #1: Thread-per-Request

- Run each web request in its own thread
  - Assuming kernel threads, blocking I/O operations only stall one thread



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## Strategy #1: Thread-per-Request

*while (true) {*

*read request from socket*

*read requested file into buffer*

*write buffer content over socket*

*close socket*

*}*

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## Strategy #2: Event-Driven Execution

- Use a single thread for all requests
- Use non-blocking I/O
  - Replace blocking I/O with calls that return immediately
  - Program is notified about interesting I/O events
- This is philosophically similar to hardware interrupts
  - "Tell me when something interesting happens"

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## Strategy #2: Event-Driven Execution

```
while (true) {
    find sockets with active I/O
    Socket sock = getActiveSocket();
    if (sock.isReadable())
        handleReadEvent(sock);
    if (sock.isWriteable())
        handleWriteEvent(sock);
}
```

- Example: GUI frameworks (*What are examples of events?*)

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## UNIX “select” System Call

int select(int nfds, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);

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## Threads vs. Events

- *What is biggest problem with threads (in reading assignment)?*
- Threads:
  - Independent execution streams
  - Preemptive scheduling
  - Synchronization
  - Deadlocks
  - Debugging
  - “Threads break abstraction”
  - Getting good performance
  - OS support of threads

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# Threads vs. Events

- Events:
  - No CPU concurrency
  - Callbacks; event handlers
  - No preemption
  - Long-running handlers
  - State across handler invocations
  - Debugging
  - Overheads
  - Portability

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# Problems with Threads (Paper)

- Performance
  - Poor design; not intrinsic properties
- Control flow
  - Complicated control flow patterns are rare (call/return most common)
- Synchronization
  - Cooperative multitasking (no preemption)
- State management
  - Minimize live stack (dynamic stack growth and live state management)
- Scheduling
  - Event scheduling tricks can be applied to threads too

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## Conclusions

- Threads?
- Events?
- Future directions?
  - Many-core systems
  - Locking
  - New languages, compilers, thread packages
  - Hybrid models?

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## Paper "SEDA"

- "Slashdot effect"; peak load
- "Well-conditioned service"
  - Throughput: saturate with load
  - Response time: increase linearly with load
  - Graceful degradation

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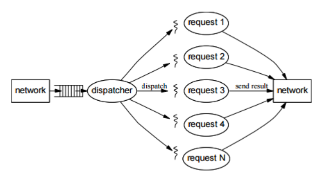
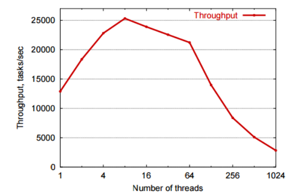
# Thread-Based Concurrency

- Easy to program; high concurrency
- Overheads
- Throughput degradation (bounded thread pools)
- Latency

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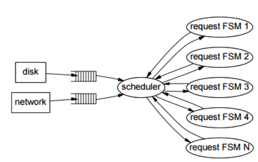
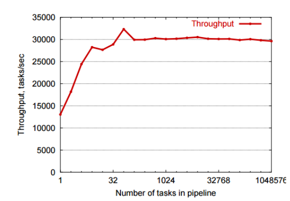
# Event-Driven Concurrency

- Small number of threads (typically one per CPU); non-blocking I/O
- Robust to load
- Latency
- Scheduling decisions; load dropping

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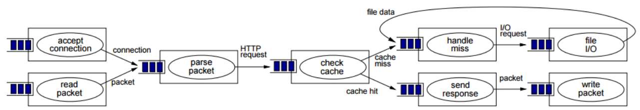
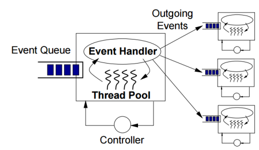
# SEDA: Staged Event Driven Architecture

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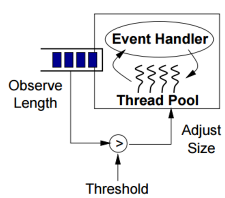
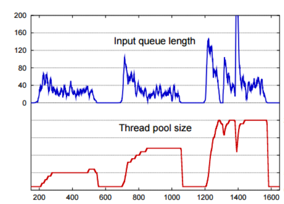
# Resource Controllers

- Thread pool controller
  - Adjust number of threads executing

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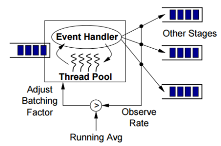
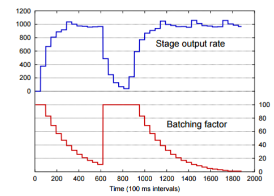
# Resource Controllers

- Batching controller
  - Adjust number of events processed by each iteration of the event handler

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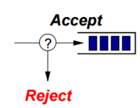
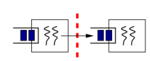
# Queues

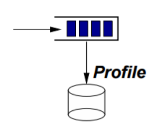
- Queues are finite
  - Enqueuing may fail
  - Block on full queue -> backpressure
  - Drop rejected events -> load shedding




- Queues introduce explicit execution boundaries
  - Threads may only execute within a single stage
  - Performance isolation, modularity, independent load management



- Explicit event delivery support inspection
  - Trace flow of events through application
  - Monitor queue lengths to detect bottleneck

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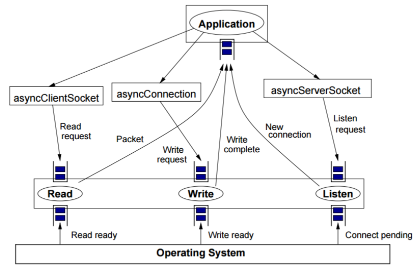
# Asynchronous I/O

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# Summary & Discussion

- SEDA: Staged, Event-Driven Architecture
  - Applications consist of **connected stages each serviced by one or more threads**
  - **Dynamic resource controllers** examine and react to high load conditions and control thread usage
- Measurement and control vs. reservation
  - Mechanisms for detecting overload
  - Policies to deal with overload
- SEDA ease of programming
  - Reduced need for synchronization & race conditions
  - Separate stages for different components of application/server

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