Threads

- Recap:
  - Why Threads?
  - User-Level Threads vs. Kernel-Level Threads
- Thread-Based vs. Event-Based System Design?
  - Event-Based: John Ousterhout, "Why Threads are a Bad Idea (for most Purposes)"
  - Thread-Based: von Beren, Condit, Brewer, "Why Threads are a Bad Idea (for high-concurrency Servers)"
- Example: Windows Completion Ports.
- Reading: Silberschatz, Ch 3 & 4.

Why Threads?

- Many interactive applications run in loops.
- For example, an interactive game.

```
while (1) {
    /* Read Keyboard */
    /* Recompute Player Position */
    /* Update Display */
}
```

- Reference [B.O. Gallmeister, "POSIX.4, Programming for the Real World," O'Reilly&Assoc., Inc.]

Why Threads?

- Many interactive applications run in loops.
- For example, an interactive game.

```
while (1) {
    /* Synchronize to Highest
       Frequency */
    /* Read Keyboard */
    /*    AND Read Mouse */
    /* Recompute Player Position */
    /* Update Display */
    /*    AND emit sounds */
}
```

- Reference [B.O. Gallmeister, "POSIX.4, Programming for the Real World," O'Reilly&Assoc., Inc.]

Why Threads?

- Many interactive applications run in loops.
- For example, an interactive game.
- It ain't over yet!
- What about compute-intensive operations, like AI, video compression?
- How about Signal Handlers?

```
while (1) {
    /* Synchronize to Highest
       Frequency */
    /* Read Keyboard */
    /*    AND Read Mouse */
    /* Recompute Player Position */
    /* Update Display */
    /*      AND all other lights */
    /*    AND emit sounds */
    /*      AND more sounds */
    /*      AND move game physically */
}
```

Suddenly, application is getting complex!

- Reference [B.O. Gallmeister, "POSIX.4, Programming for the Real World," O'Reilly&Assoc., Inc.]

Example: Reading the Mouse

```
while (1) {
    /* Synchronize to Highest
       Frequency */
    /* Read Keyboard */
    /*     AND Read Mouse */
    /* Recompute Player Position */
    /* Update Display */
   /*      AND all other lights */
    /*     AND emit sounds */
   /*      AND more sounds */
   /*      AND move game physically */
}
```

Separate Thread

```
read_mouse() {

}
```

Reading the Mouse: Thread Creation

```
/* The Mouse Input Function */

void * read_mouse() {
  char buf[BUFSIZE]; ssize_t nbytes;
  for (;;) {
    if ((nbytes = read_from_mouse(buf,BUFSIZE)) <= 0)
      break;
    dosomething_with(buf, nbytes);
  }
  return NULL;
}
```

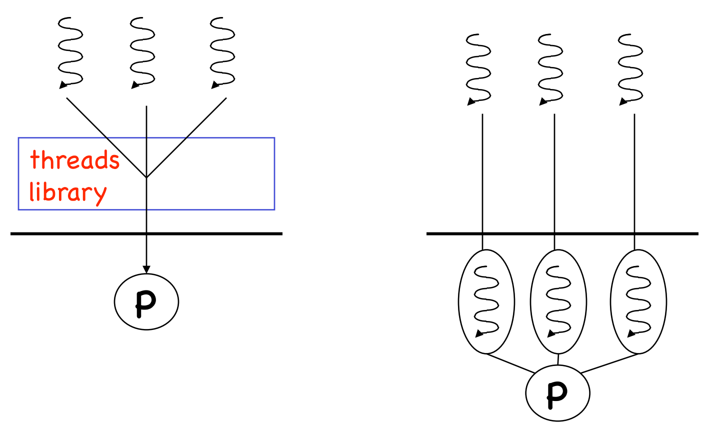
Reading the Mouse: Thread Creation (II)

```
#include <pthread.h>

int error;
pthread_t tid;

if (error = pthread_create(&tid, NULL, read_mouse, NULL))
    perror("Failed to create read_mouse thread");


while (1) {
    /* Synchronize to Highest
       Frequency */
    /* Read Keyboard */
    /*    AND Read Mouse */ <- Handled by separate thread!
    /* Recompute Player Position */
    /* Update Display */
   /*       AND all other lights */
    /*    AND emit sounds */
   /*       AND more sounds */
   /*       AND move game physically */
}
```

f,BUFSIZE)) <= 0)

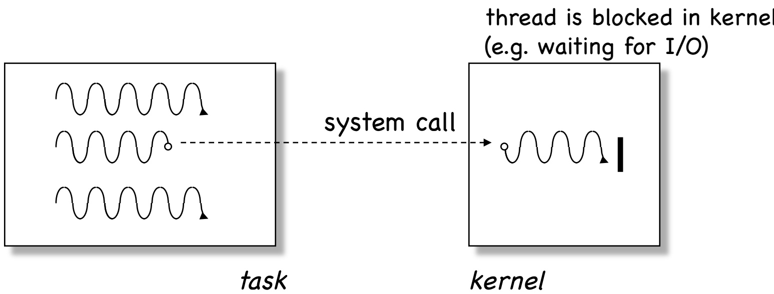
User-Level *vs.* Kernel-Level Threads

- User-level: kernel not aware of threads
- Kernel-level: all thread-management done in kernel

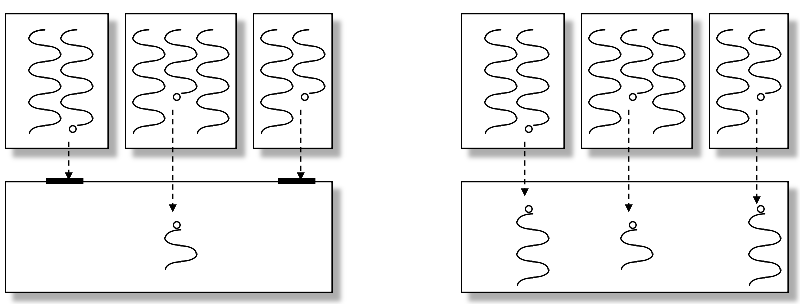


Potential Problems with Threads

- General: Several threads run in the same address space:
  - Protection must be explicitly programmed (by appropriate thread synchronization)
  - Effects of misbehaving threads limited to task
- User-level threads: Some problems at the interface to the kernel: With a single-threaded kernel, as system call blocks the entire process.

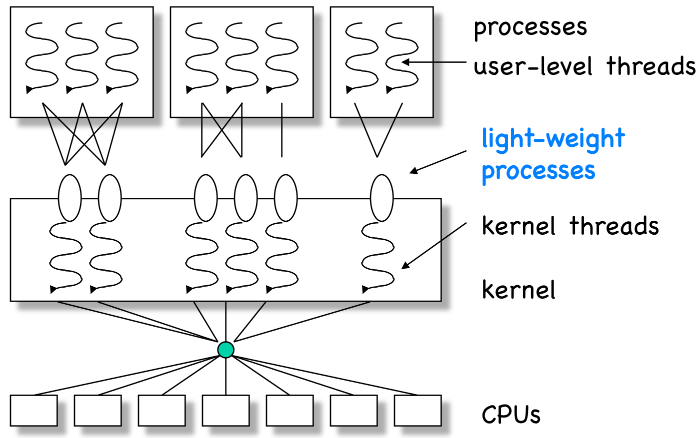


Singlethreaded vs. Multithreaded **Kernel**



- Protection of kernel data structures is trivial, since only one process is allowed to be in the kernel at any time.
- Special protection mechanism is needed for shared data structures in kernel.

Hybrid Multithreading



Threaded vs. Event-Driven Design

Figures from: M. Welsh, D. Culler, and E. Brewer, **SEDA: An Architecture for Well Conditioned, Scalable Internet Services**

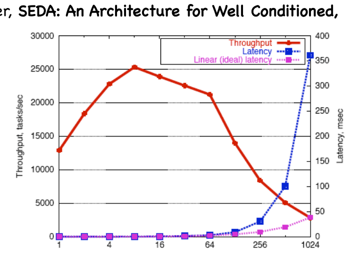


Figure 2: **Threaded server throughput degradation:** *This benchmark measures a simple threaded server which creates a single thread for each task in the pipeline. After receiving a task, each thread performs an 8 KB read from a disk file; all threads read from the same file, so the data is always in the buffer cache.*

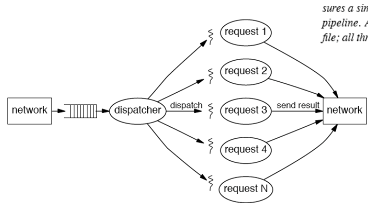


Figure 1: **Threaded server design:** *Each incoming request is dispatched to a separate thread, which processes the request and returns a result to the client. Edges represent control flow between components. Note that other I/O operations, such as disk access, are not shown here, but would be incorporated into each threads' request processing.*

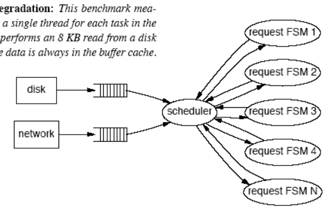


Figure 3: **Event-driven server design:** *This figure shows the flow of events through an event-driven server. The main thread processes incoming events from the network, disk, and other sources, and uses these to drive the execution of many finite state machines. Each FSM represents a single request or flow of execution through the system. The key source of complexity in this design is the event scheduler, which must control the execution of each FSM.*

Why Threads Are A Bad Idea (for most purposes)

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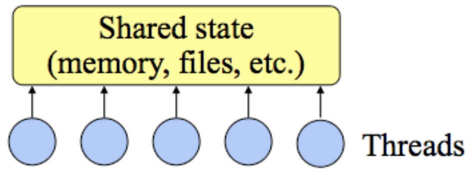
Introduction

- **Threads:**
  - Grew up in OS world (processes).
  - Evolved into user-level tool.
  - Proposed as solution for a variety of problems.
  - Every programmer should be a threads programmer?
- **Problem: threads are very hard to program.**
- **Alternative: events.**
- **Claims:**
  - For most purposes proposed for threads, events are better.
  - Threads should be used only when true CPU concurrency is needed.

Why Threads Are A Bad Idea *September 28, 1995, slide 2*

What Are Threads?



- General-purpose solution for managing concurrency.
- Multiple independent execution streams.
- Shared state.
- Pre-emptive scheduling.
- Synchronization (e.g. locks, conditions).

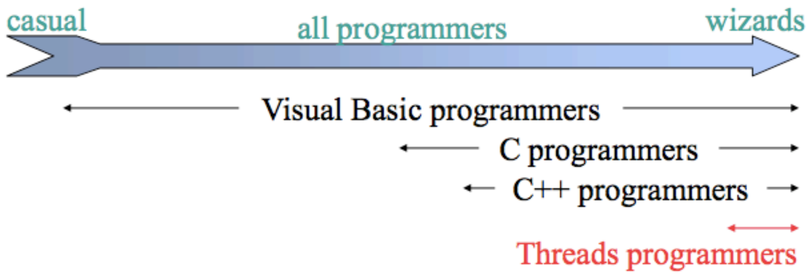
Why Threads Are A Bad Idea *September 28, 1995, slide 3*

What Are Threads Used For?

- **Operating systems:** one kernel thread for each user process.
- **Scientific applications:** one thread per CPU (solve problems more quickly).
- **Distributed systems:** process requests concurrently (overlap I/Os).
- **GUIs:**
  - Threads correspond to user actions; can service display during long-running computations.
  - Multimedia, animations.

Why Threads Are A Bad Idea *September 28, 1995, slide 4*

What's Wrong With Threads?

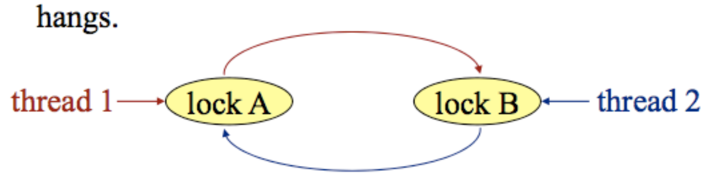


- **Too hard for most programmers to use.**
- **Even for experts, development is painful.**

Why Threads Are A Bad Idea *September 28, 1995, slide 5*

Why Threads Are Hard

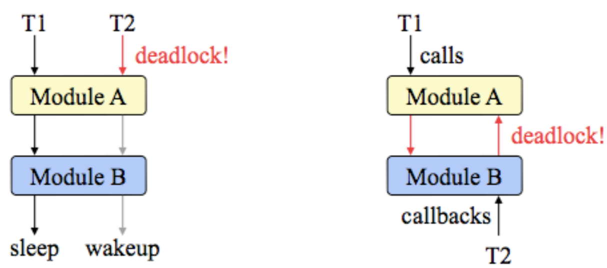
- **Synchronization:**
  - Must coordinate access to shared data with locks.
  - Forget a lock? Corrupted data.
- **Deadlock:**
  - Circular dependencies among locks.
  - Each process waits for some other process: system hangs.



Why Threads Are A Bad Idea *September 28, 1995, slide 6*

Why Threads Are Hard, cont'd

- **Hard to debug:** data dependencies, timing dependencies.
- **Threads break abstraction:** can't design modules independently.
- **Callbacks don't work with locks.**



Why Threads Are A Bad Idea — *September 28, 1995, slide 7*

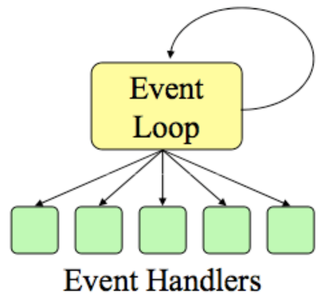
Why Threads Are Hard, cont'd

- **Achieving good performance is hard:**
  - Simple locking (e.g. monitors) yields low concurrency.
  - Fine-grain locking increases complexity, reduces performance in normal case.
  - OSes limit performance (scheduling, context switches).
- **Threads not well supported:**
  - Hard to port threaded code (PCs? Macs?).
  - Standard libraries not thread-safe.
  - Kernel calls, window systems not multi-threaded.
  - Few debugging tools (LockLint, debuggers?).
- **Often don't want concurrency anyway (e.g. window events).**

Why Threads Are A Bad Idea — *September 28, 1995, slide 8*

Event-Driven Programming

- **One execution stream: no CPU concurrency.**
- **Register interest in events (callbacks).**
- **Event loop waits for events, invokes handlers.**
- **No preemption of event handlers.**
- **Handlers generally short-lived.**



Why Threads Are A Bad Idea *September 28, 1995, slide 9*

What Are Events Used For?

- **Mostly GUIs:**
  - One handler for each event (press button, invoke menu entry, etc.).
  - Handler implements behavior (undo, delete file, etc.).
- **Distributed systems:**
  - One handler for each source of input (socket, etc.).
  - Handler processes incoming request, sends response.
  - Event-driven I/O for I/O overlap.

Why Threads Are A Bad Idea *September 28, 1995, slide 10*

Problems With Events

- **Long-running handlers make application non-responsive.**
  - Fork off subprocesses for long-running things (e.g. multimedia), use events to find out when done.
  - Break up handlers (e.g. event-driven I/O).
  - Periodically call event loop in handler (reentrancy adds complexity).
- **Can't maintain local state across events (handler must return).**
- **No CPU concurrency (not suitable for scientific apps).**
- **Event-driven I/O not always well supported (e.g. poor write buffering).**

Why Threads Are A Bad Idea *September 28, 1995, slide 11*

Events vs. Threads

- **Events avoid concurrency as much as possible, threads embrace:**
  - Easy to get started with events: no concurrency, no preemption, no synchronization, no deadlock.
  - Use complicated techniques only for unusual cases.
  - With threads, even the simplest application faces the full complexity.
- **Debugging easier with events:**
  - Timing dependencies only related to events, not to internal scheduling.
  - Problems easier to track down: slow response to button vs. corrupted memory.

Why Threads Are A Bad Idea *September 28, 1995, slide 12*

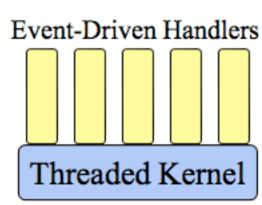
Events vs. Threads, cont'd

- **Events faster than threads on single CPU:**
  - No locking overheads.
  - No context switching.
- **Events more portable than threads.**
- **Threads provide true concurrency:**
  - Can have long-running stateful handlers without freezes.
  - Scalable performance on multiple CPUs.

Why Threads Are A Bad Idea *September 28, 1995, slide 13*

Should You Abandon Threads?

- **No: important for high-end servers (e.g. databases).**
- **But, avoid threads wherever possible:**
  - Use events, not threads, for GUIs, distributed systems, low-end servers.
  - Only use threads where true CPU concurrency is needed.
  - Where threads needed, isolate usage in threaded application kernel: keep most of code single-threaded.



Why Threads Are A Bad Idea *September 28, 1995, slide 14*

Conclusions

- **Concurrency is fundamentally hard; avoid whenever possible.**
- **Threads more powerful than events, but power is rarely needed.**
- **Threads much harder to program than events; for experts only.**
- **Use events as primary development tool (both GUIs and distributed systems).**
- **Use threads only for performance-critical kernels.**

Why Threads Are A Bad Idea *September 28, 1995, slide 15*

A Dissenting Opinion (selected slides)

Why Events Are A Bad Idea

(for high-concurrency servers)

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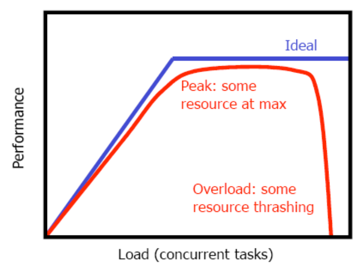
A Talk HotOS 2003

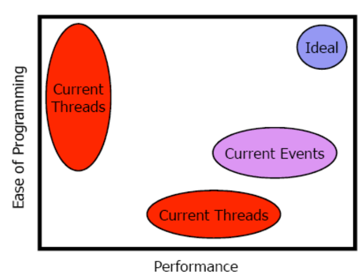
The Stage

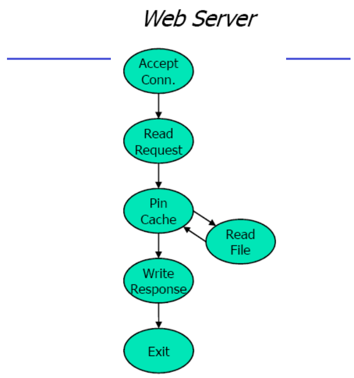
- Highly concurrent applications
  - Internet servers (Flash, Ninja, SEDA)
  - Transaction processing databases
- Workload
  - Operate "near the knee"
  - Avoid thrashing!
- What makes concurrency hard?
  - Race conditions
  - Scalability (no *O(n)* operations)
  - Scheduling & resource sensitivity
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



The Debate

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





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	*Events*
Monitors	Event handler & queue
Exported functions	Events accepted
Call/return and fork/join	Send message / await reply
Wait on condition variable	Wait for new messages

Our Position

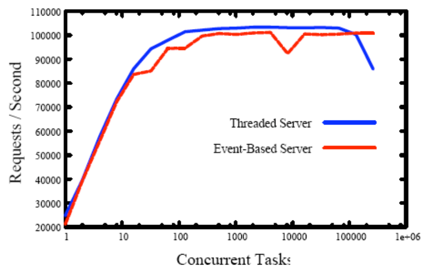
- Thread-event duality still holds
- But threads are better anyway
  - More natural to program
  - Better fit with tools and hardware
- Compiler-runtime integration is key

"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!

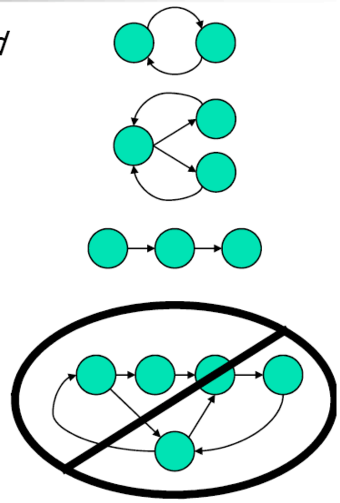


Synchronization

- *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

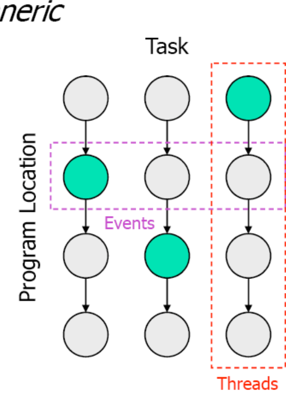
Control Flow

- *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



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

Threads

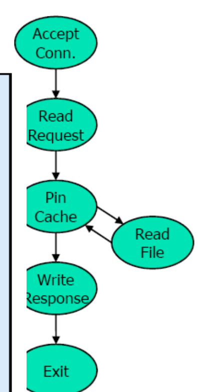
```
thread_main(int sock) {
    struct session s;
    accept_conn(sock, &s);
    read_request(&s);
    pin_cache(&s);
    write_response(&s);
    unpin(&s);
}

pin_cache(struct session *s) {
    pin(&s);
    if( !in_cache(&s) )
        read_file(&s);
}
```

Events

```
CacheHandler(struct session *s) {
    pin(s);
    if( !in_cache(s) )  ReadFileHandler.enqueue(s);
    else                ResponseHandler.enqueue(s);
}
RequestHandler(struct session *s) {
    ...; CacheHandler.enqueue(s);
}
. . .
ExitHandlerr(struct session *s) {
    ...; unpin(&s);  free_session(s);
}
AcceptHandler(event e) {
    struct session *s = new_session(e);
    RequestHandler.enqueue(s); }
```

Web Server



Exceptions

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

Threads

```
thread_main(int sock) {
    struct session s;
    accept_conn(sock, &s);
    if( !read_request(&s) )
        return;
    pin_cache(&s);
    write_response(&s);
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}

pin_cache(struct session *s) {
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Events

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RequestHandler(struct session *s) {
    ...; if( error ) return;  CacheHandler.enqueue(s);
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. . .
ExitHandlerr(struct session *s) {
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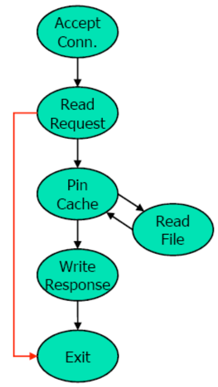
Web Server



State Management

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

Threads

```
thread_main(int sock) {
    struct session s;
    accept_conn(sock, &s);
    if( !read_request(&s) )
        return;
    pin_cache(&s);
    write_response(&s);
    unpin(&s);
}

pin_cache(struct session *s) {
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Events

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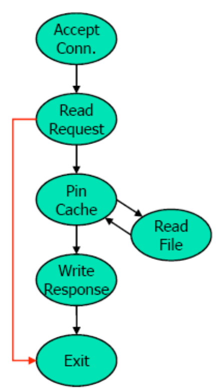


Existing Infrastructure

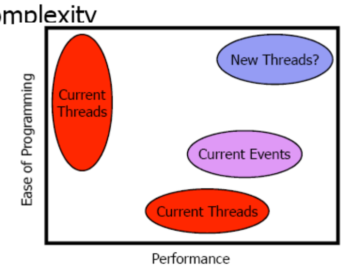
- Lots of infrastructure for threads
  - Debuggers
  - Languages & compilers
- Consequences
  - More amenable to analysis
  - Less effort to get working systems

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

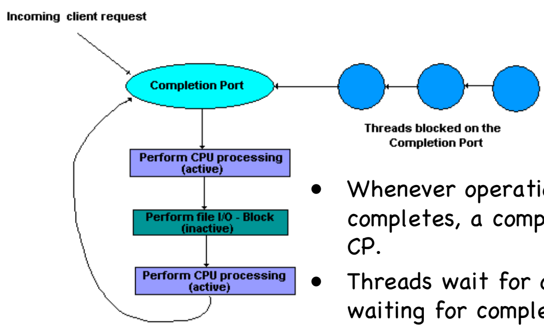
- Insight
  - Automate things event programmers do by hand
  - Additional analysis for other things
- Specific targets
  - Dynamic stack growth*
  - Live state management
  - Synchronization
  - Scheduling*
- Improve performance *and* decrease complexity



Event-Driven Programming: Completion Ports

- Rationale:
  - Minimize context switches by having threads avoid unnecessary blocking.
  - Maximize parallelism by using multiple threads.
  - Ideally, have one thread actively servicing a request on every processor.
  - Do not block thread if there are additional requests waiting when thread completes a request.
  - The application must be able to activate another thread when current thread blocks on I/O (e.g. when it reads from a file)
- Resources:
  - Inside IO Completion Ports: http://technet.microsoft.com/en-us/sysinternals/bb963891.aspx
  - Multithreaded Asynchronous I/O & I/O Completion Ports: http://www.ddj.com/cpp/20120292
  - Parallel Programming with C++ – I/O Completion Ports: http://weblogs.asp.net/kennykerr/archive/2008/01/03/parallel-programming-with-c-part-4-i-o-completion-ports.aspx

Completion Ports (CPs): Operation



- Whenever operations on files associated with CP's completes, a completion packet is queued on the CP.
- Threads wait for outstanding I/Os to complete by waiting for completion packets to be queued on CP.
- Application specifies concurrently value associated with CP.
- Whenever active thread finishes processing current request, it checks for next packet at the port. (If there is, grabs it without context switch.)
- Whenever thread gets blocked, number of active threads drops below concurrency value, and next thread can start.

Completion Ports: APIs

CP creation:

```
HANDLE CreateIoCompletionPort(
   HANDLE FileHandle,
   HANDLE ExistingCompletionPort,    /* NULL -> create new CP */
   DWORD  CompletionKey,
   DWORD  NumberOfConcurrentThreads /* Concurrency value */
);
```

Retrieve next completion packet:

```
BOOL GetQueuedCompletionStatus(
   HANDLE        CompletionPort,
   LPDWORD       lpNumberOfBytesTransferred,
   LPDWORD       CompletionKey,
   LPOVERLAPPED *lpOverlapped,
   DWORD         dwMiillisecondTimeout
);
```

Generate completion packets:

```
PostQueuedCompletionStatus(…); /* e.g. server informs threads about
                                  external events. */
```

CP Example: Web Server: Startup

Tom R. Dial, *"Multithreaded Asynchronous I/O & I/O Completion Ports," Dr. Dobbs, Aug.2007)*

```
/* Fire.cpp - The Fire Web Server
 * Copyright (C) 2007 Tom R. Dial  tdial@kavaga.com */
int main(int /*argc*/, char* /*argv*/[]) {
   // Initialize the Microsoft Windows Sockets Library
   WSADATA Wsa={0};
   WSAStartup( MAKEWORD(2,2), &Wsa );
   // Get the working directory; this is used when transmitting files back.
   GetCurrentDirectory( _MAX_PATH, RootDirectory );
   // Create an event to use to synchronize the shutdown process.
   StopEvent = CreateEvent( 0, FALSE, FALSE, 0 );
   // Setup a console control handler: We stop the server on CTRL-C
   SetConsoleCtrlHandler( ConsoleCtrlHandler, TRUE );

   // Create a new I/O Completion port.
   HANDLE IoPort = CreateIoCompletionPort( INVALID_HANDLE_VALUE, 0, 0, WORKER_THREAD_COUNT );

   // Set up a socket on which to listen for new connections.
   SOCKET Listener = WSASocket( PF_INET, SOCK_STREAM, IPPROTO_TCP, 0, 0, WSA_FLAG_OVERLAPPED );
   struct sockaddr_in Addr={0};
   Addr.sin_family = AF_INET;
   Addr.sin_addr.S_un.S_addr = INADDR_ANY;
   Addr.sin_port = htons( DEFAULT_PORT );
   // Bind the listener to the local interface and set to listening state.
   bind( Listener, (struct sockaddr*)&Addr, sizeof(struct sockaddr_in) );
   listen( Listener, DEFAULT_LISTEN_QUEUE_SIZE );
```

CP Example: Web Server: Start Threads

```
// Create worker threads
HANDLE Workers[WORKER_THREAD_COUNT]={0};
unsigned int WorkerIds[WORKER_THREAD_COUNT]={0};

for (size_t i=0; i<WORKER_THREAD_COUNT; i++)
    Workers[i] = (HANDLE)_beginthreadex( 0, 0, WorkerProc, IoPort, 0, WorkerIds+i );

// Associate the Listener socket with the I/O Completion Port.
CreateIoCompletionPort( (HANDLE)Listener, IoPort, COMPLETION_KEY_IO, 0 );

// Allocate an array of connections; constructor binds them to the port.
Connection*  Connections[MAX_CONCURRENT_CONNECTIONS]={0};
for (size_t i=0; i<MAX_CONCURRENT_CONNECTIONS; i++)
        Connections[i] = new Connection( Listener, IoPort );
// Print instructions for stopping the server.
printf("Fire Web Server: Press CTRL-C To shut down.\n");
// Wait for the user to press CTRL-C...
WaitForSingleObject( StopEvent, INFINITE );

// ...
```

CP Example: Web Server: Shutdown

```
// Deregister console control handler: We stop the server on CTRL-C
SetConsoleCtrlHandler( NULL, FALSE );
// Post a quit completion message, one per worker thread.
for (size_t i=0; i<WORKER_THREAD_COUNT; i++)
        PostQueuedCompletionStatus( IoPort, 0, COMPLETION_KEY_SHUTDOWN, 0 );
// Wait for all of the worker threads to terminate...
WaitForMultipleObjects( WORKER_THREAD_COUNT, Workers, TRUE, INFINITE );
// Close worker thread handles.
for (size_t i=0; i<WORKER_THREAD_COUNT; i++)
        CloseHandle( Workers[i] );
// Close stop event.
CloseHandle( StopEvent );
// Shut down the listener socket and close the I/O port.
shutdown( Listener, SD_BOTH );
closesocket( Listener );
CloseHandle( IoPort );
// Delete connections.
for (size_t i=0; i<MAX_CONCURRENT_CONNECTIONS; i++)
        delete( Connections[i] );
WSACleanup();
return 0;
}
```

CP Example: Web Server: Worker Threads

```
// Worker thread procedure.
unsigned int __stdcall WorkerProc(void* IoPort) {
    for (;;) {
        BOOL          Status          = 0;
        DWORD         NumTransferred = 0;
        ULONG_PTR     CompKey         = COMPLETION_KEY_NONE;
        LPOVERLAPPED pOver            = 0;
        Status = GetQueuedCompletionStatus( reinterpret_cast<HANDLE>(IoPort),
                                            &NumTransferred, &CompKey, &pOver,INFINITE );
        Connection* pConn = reinterpret_cast<Connection*>( pOver );
        if ( FALSE == Status ) {
            // An error occurred; reset to a known state.
            if ( pConn )  pConn->IssueReset();
        } else if ( COMPLETION_KEY_IO == CompKey ) {
             pConn->OnIoComplete( NumTransferred );
        } else if ( COMPLETION_KEY_SHUTDOWN == CompKey ) {
            break;
        }
    }
    return 0;
}
```

CP Example: Web Server: Connections

```
// Class representing a single connection.
class Connection : public OVERLAPPED {
    enum STATE { WAIT_ACCEPT    =   0,  WAIT_REQUEST  =   1,
                 WAIT_TRANSMIT =   2,  WAIT_RESET    =   3 };
public:
    Connection(SOCKET Listener, HANDLE IoPort) : myListener(Listener)   {
            myState = WAIT_ACCEPT;
            // [...]
            mySock = WSASocket( PF_INET, SOCK_STREAM, IPPROTO_TCP,
                                0, 0, WSA_FLAG_OVERLAPPED );
            // Associate the client socket with the I/O Completion Port.
            CreateIoCompletionPort( reinterpret_cast<HANDLE>(mySock),
                                    IoPort, COMPLETION_KEY_IO, 0 );
            IssueAccept();
    }
    ~Connection() {
        shutdown( mySock, SD_BOTH );
        closesocket( mySock );
    }
```

CP Example: Web Server: State Machines (I)

// ACCEPT OPERATION

```
// Issue an asynchronous accept.
void Connection::IssueAccept() {
        myState = WAIT_ACCEPT;
        DWORD ReceiveLen = 0; // This gets thrown away, but must be passed.
        AcceptEx( myListener, mySock, myAddrBlock, 0, ACCEPT_ADDRESS_LENGTH,
                  ACCEPT_ADDRESS_LENGTH, &ReceiveLen, this );
}
// Complete the accept and update the client socket's context.
void Connection::CompleteAccept() {
        setsockopt( mySock, SOL_SOCKET, SO_UPDATE_ACCEPT_CONTEXT,
                   (char*)&myListener, sizeof(SOCKET) );
        // Transition to "reading request" state.
        IssueRead();
}
```

CP Example: Web Server: State Machines (II)

// READ OPERATION

```
// Issue an asynchronous read operation.
void Connection::IssueRead(void) {
        myState = WAIT_REQUEST;
        ReadFile( (HANDLE)mySock, myReadBuf, DEFAULT_READ_BUFFER_SIZE,
           0, (OVERLAPPED*)this );
}

// Complete the read operation, appending the request with the latest data.
void Connection::CompleteRead(size_t NumBytesRead) {
        // [...]
        // Has the client finished sending the request?
        if ( IsRequestComplete( NumBytesRead ) ) {
            // Yes. Transmit the response.
            IssueTransmit();
        } else {
            // The client is not finished. If data was read this pass, we assume the connection
            // is still good and read more.  If not, we assume that the client closed the socket
            // prematurely.
            if ( NumBytesRead )      IssueRead();
            else                     IssueReset();

        }
    }
```

CP Example: Web Server: State Machines (III)

```
// Parse the request, and transmit the response.
void Connection::IssueTransmit() {
    myState = WAIT_TRANSMIT;
    // Simplified parsing of the request: just ignore first token.
    char* Method = strtok( (&myRequest[0]), " ");
    if (!Method) {
        IssueReset();
        return;
    }
    // Parse second token, create file, transmit file ..
    // [...]
    myFile = CreateFile( /* ... */ );
    TransmitFile( mySock, myFile,
                 Info.nFileSizeLow, 0, this,
                 &myTransmitBuffers, 0 );
}
void Connection::CompleteTransmit() {
    // Issue the reset; this prepares the
    // socket for reuse.
    IssueReset();
}
```

```
void Connection::IssueReset()
  {
    myState = WAIT_RESET;
    TransmitFile( mySock, 0, 0, 0, this, 0,
        TF_DISCONNECT | TF_REUSE_SOCKET );
  }

  void Connection::CompleteReset(void)
  {
    ClearBuffers();
    IssueAccept(); // Continue to next request!
  }
```

CP Example: Web Server: Dispatching

```
// The main handler for the connection, responsible for state transitions.
  void Connection::OnIoComplete(DWORD NumTransferred) {
    switch ( myState ) {
    case WAIT_ACCEPT:
        CompleteAccept();
        break;
    case WAIT_REQUEST:
        CompleteRead( NumTransferred );
        break;
    case WAIT_TRANSMIT:
        CompleteTransmit();
        break;
    case WAIT_RESET:
        CompleteReset();
        break;
    }
  }
```