Asynchronous Programming Promises + Futures

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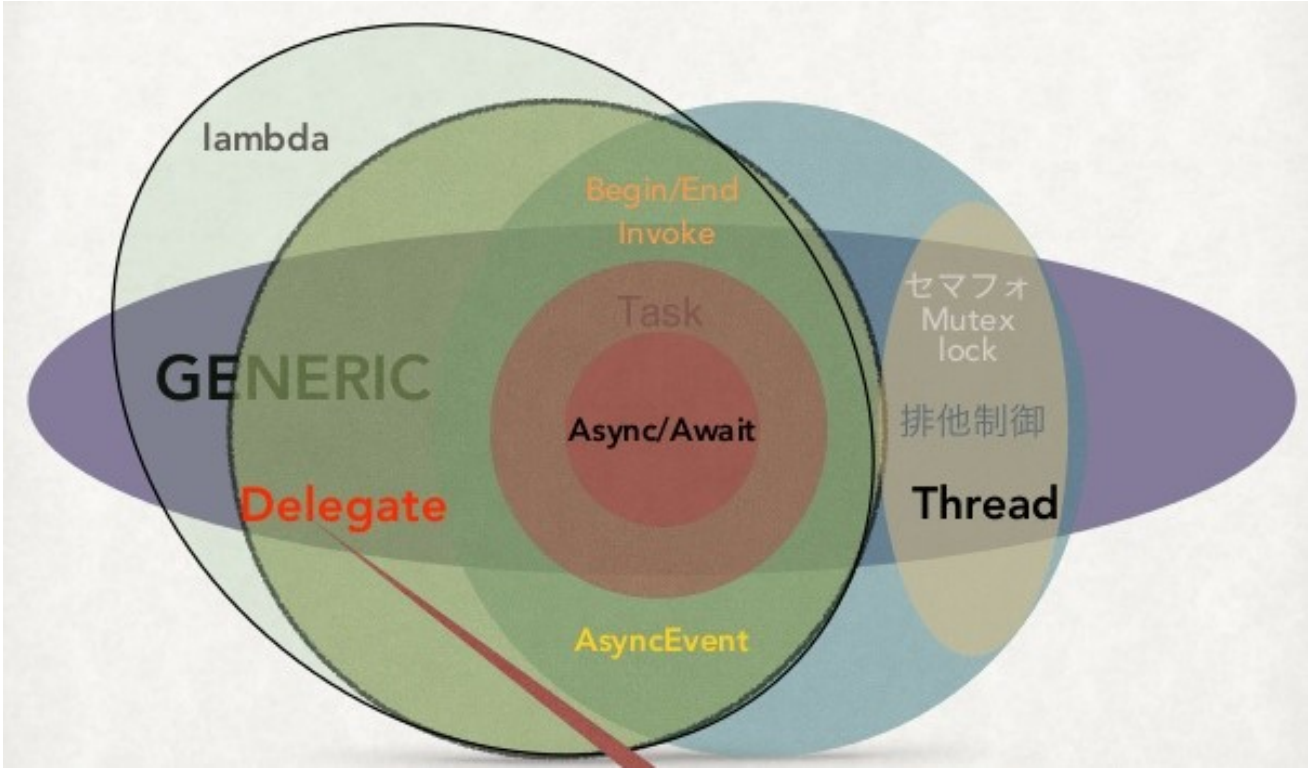
CS378H

Today

- Questions?
- Administrivia
- Material for the day
  - Events / Asynchronous programming
  - Promises & Futures
  - Bonus: memory consistency models

- Acknowledgements
  - Consistency slides borrow some materials from Kevin Boos. Thanks!

Asynchronous Programming
Events, Promises, and Futures



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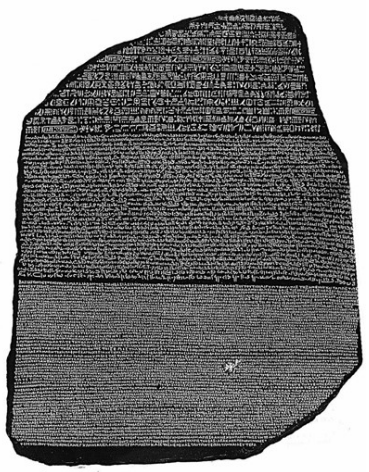

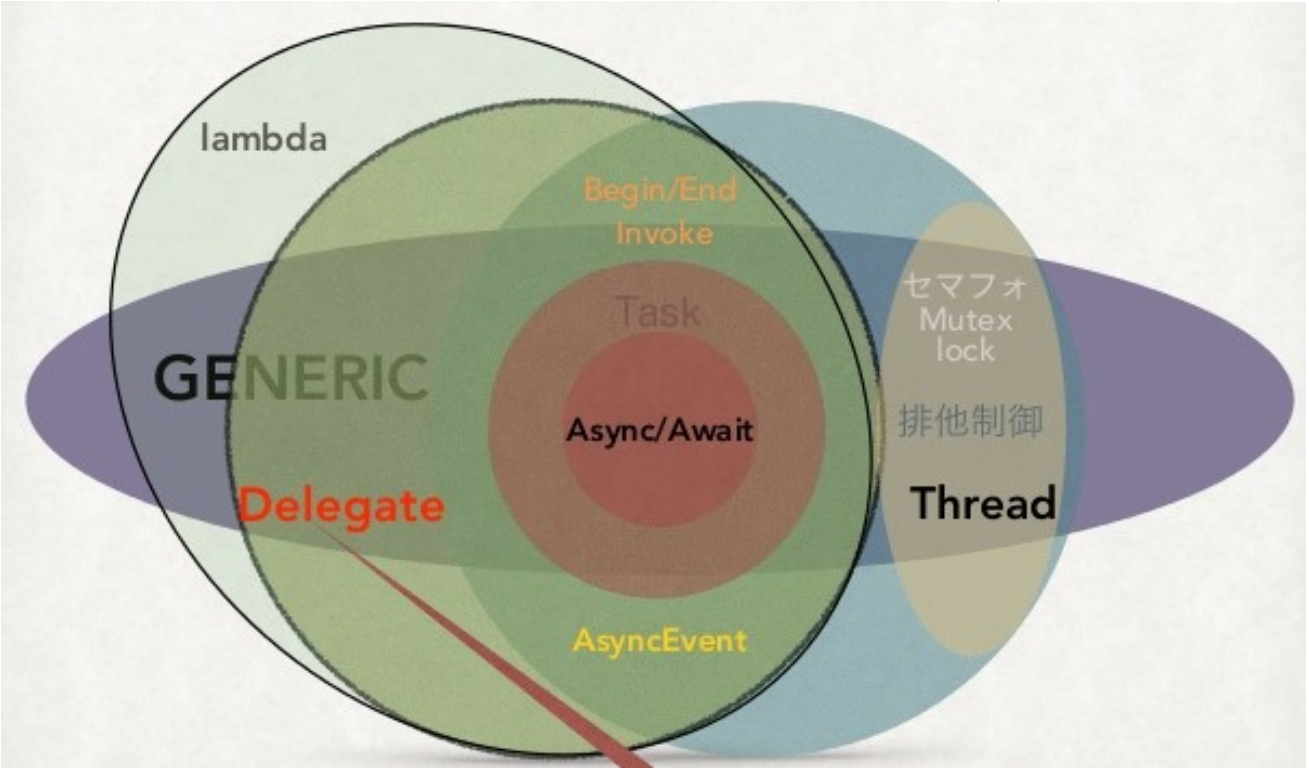

Review: Java Example

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static void runAsyncExample() {
    CompletableFuture cf = CompletableFuture.runAsync(() -> {
        assertTrue(Thread.currentThread().isDaemon());
        randomSleep();
    });
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  - Lambda expression
  - Anonymous function
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- runAsync() immediately returns a waitable object (cf)
- Where (on what thread) does the lambda expression run?

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Futures:

- *abstraction* for concurrent work supported by
  - Compiler: abstractions are ***language-level objects***
  - Runtime: scheduler, task queues, thread-pools are ***transparent***
- Programming remains **mostly** imperative
  - Threads of control peppered with asynchronous/concurrent tasks

Compromise Programming Model between:

- Event-based programming
- Thread-based programming

- Where (on what thread) does the lambda expression run?

GUI Programming Distilled

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1  winmain(...) {
2    while(true) {
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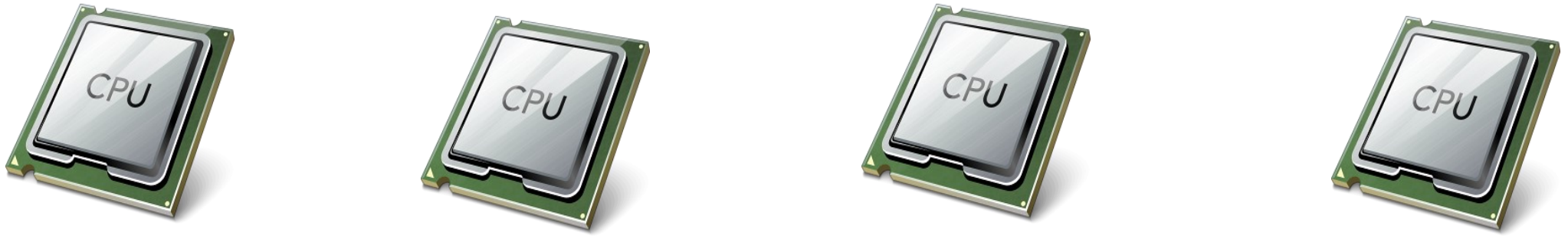
How can we parallelize this?



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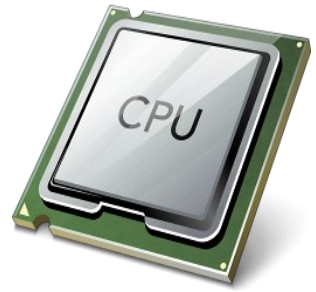

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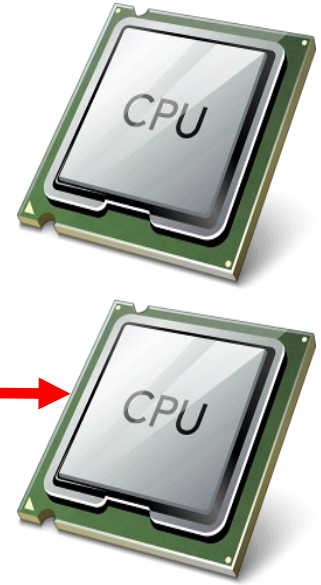

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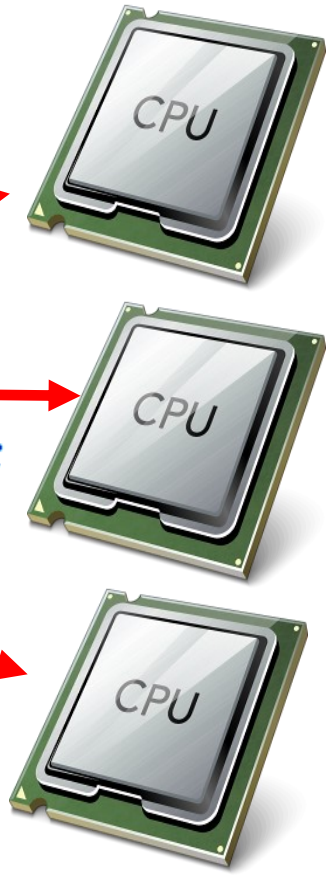

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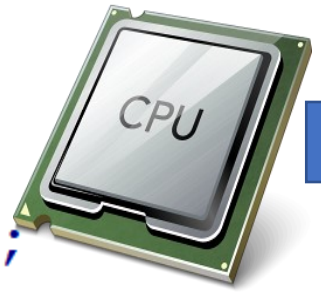

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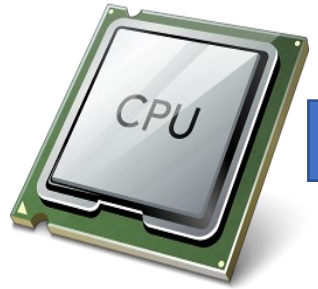

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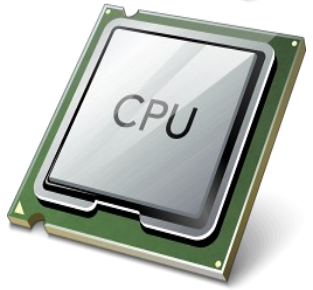

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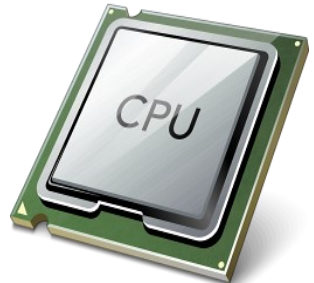

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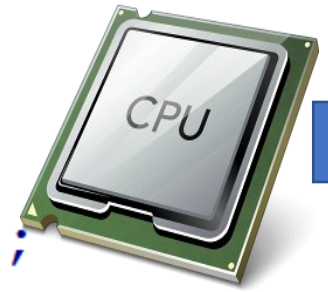

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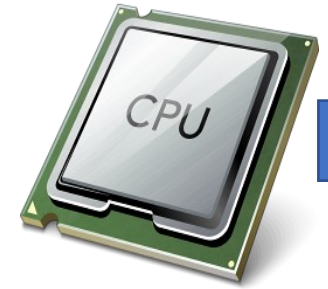

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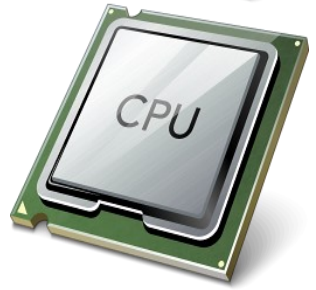

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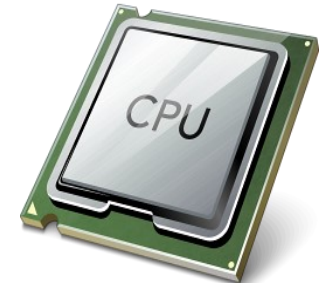

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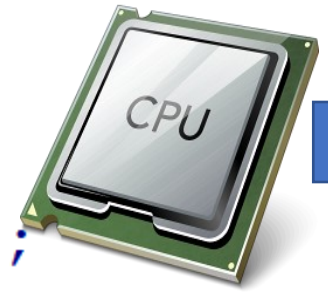
Pros/cons?

Pros:
- Encapsulates parallel work

Cons:
- Obliterates original code structure
- How to assign handlers→CPUs?
- Load balance?!?
- Utilization



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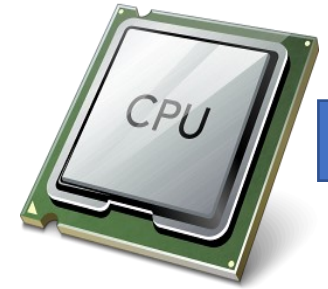

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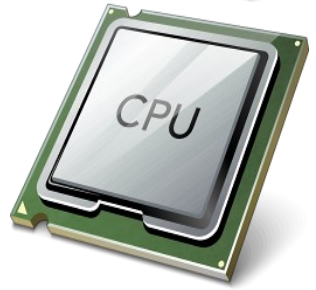

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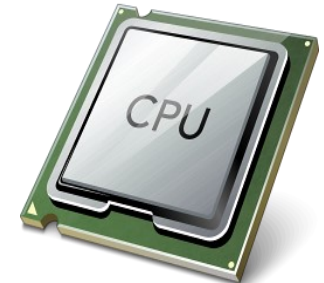

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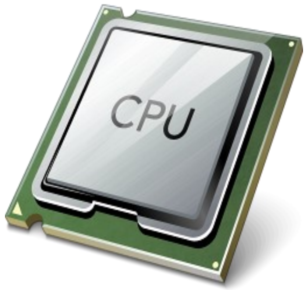

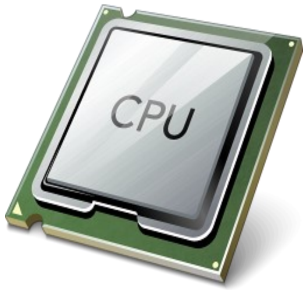

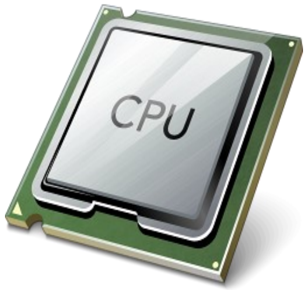

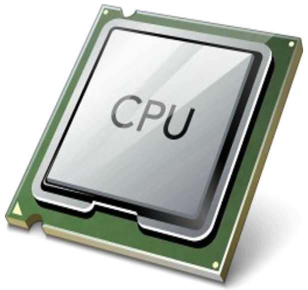

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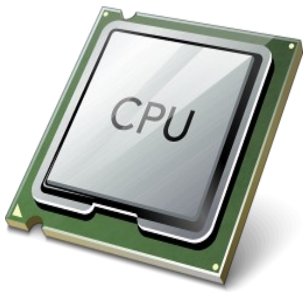

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- Can recover some parallelism

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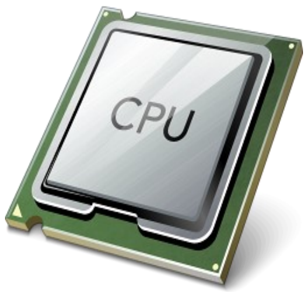

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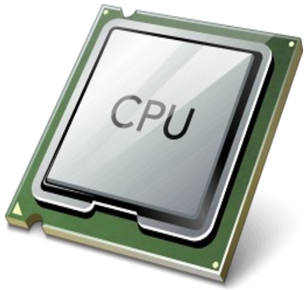

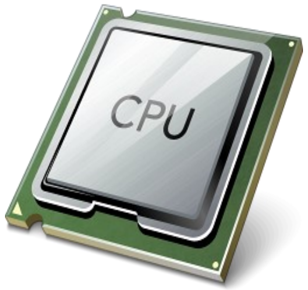

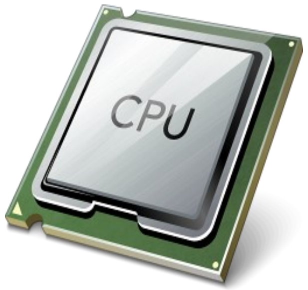

Extremely difficult to solve without changing the whole programming model…so

change it

Event-based Programming: Motivation

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- Threads have a *lot* of down-sides:
  - Tuning parallelism for different environments
  - Load balancing/assignment brittle
  - Shared state requires locks →
    - Priority inversion
    - Deadlock
    - Incorrect synchronization
  - …

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- Events: *restructure programming model so threads are not exposed!*

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- Basic primitives
  - create_event_queue(handler) → event_q
  - enqueue_event(event_q, event-object)
    - Invokes handler (eventually)
- Scheduler decides which event to execute next
  - E.g. based on priority, CPU usage, etc.

Event-based programming

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```
switch (message)
{
        //case WM_COMMAND:
          // handle menu selections etc.
        //break;
        //case WM_PAINT:
          // draw our window - note: you must paint something here or not trap it!
        //break;
        case WM_DESTROY:
             PostQuitMessage(0);
        break;
        default:
            // We do not want to handle this message so pass back to Windows
            // to handle it in a default way
            return DefWindowProc(hWnd, message, wParam, lParam);
}
```

Event-based programming

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```
PROGRAM MyProgram {
    OnSize() {}
    OnMove() {}
    OnClick() {}
    OnPaint() {}
}
```

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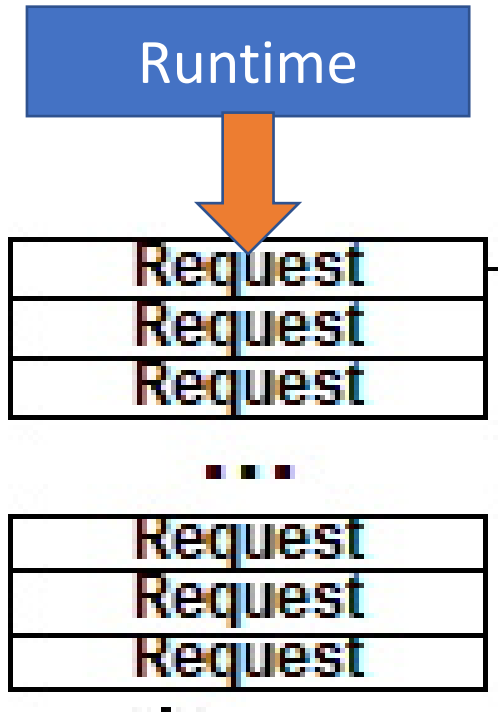

Event-based programming

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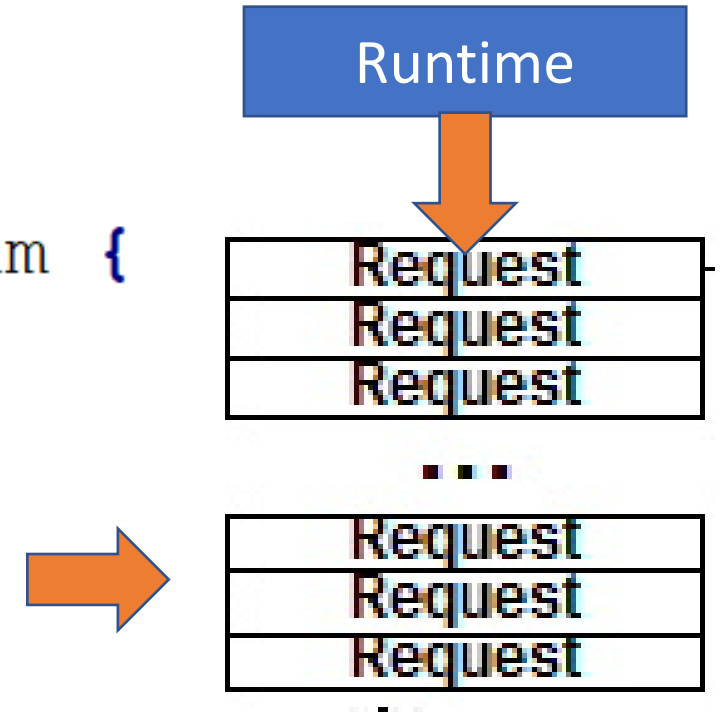

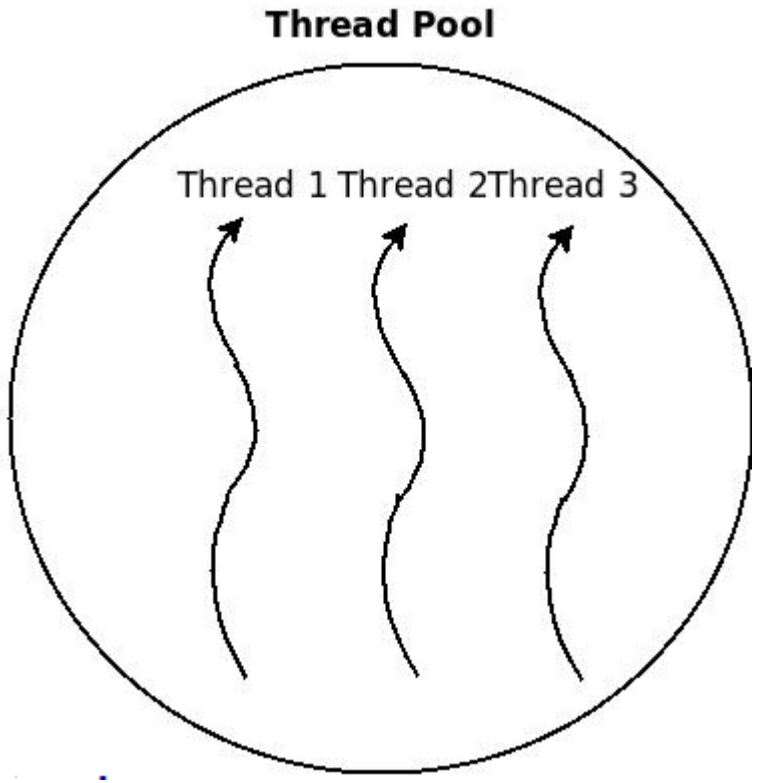

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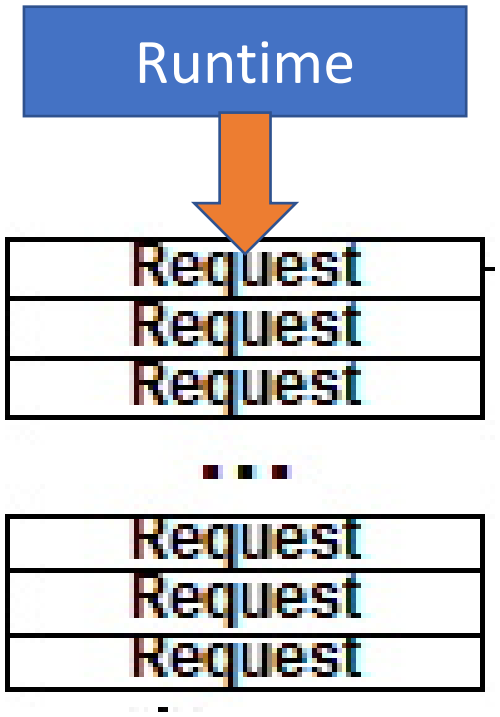

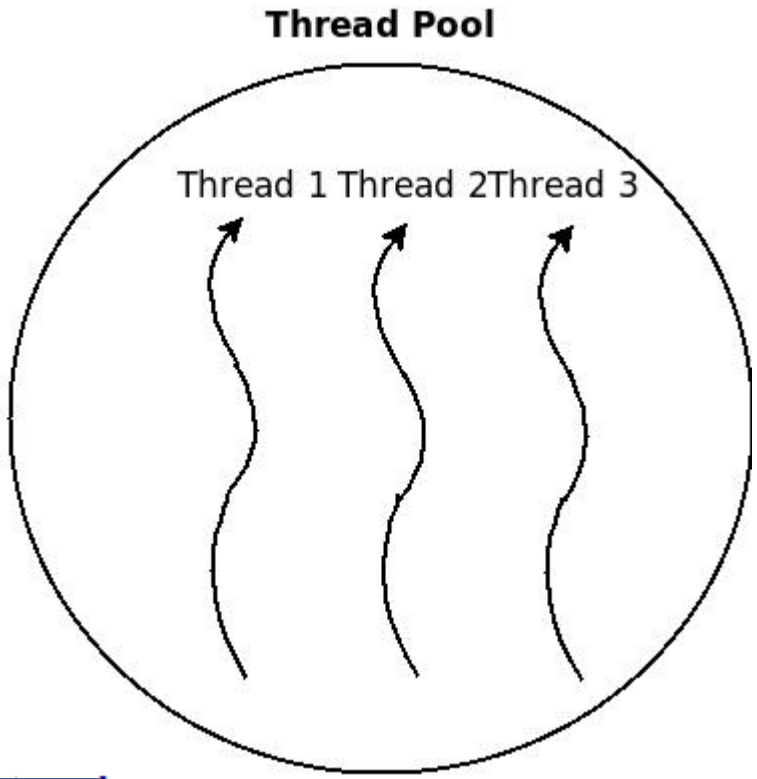

Is the problem solved?

Another Event-based Program

Another Event-based Program

```
1  PROGRAM MyProgram {
2      OnOpenFile() {
3          char szFileName[BUFSIZE]
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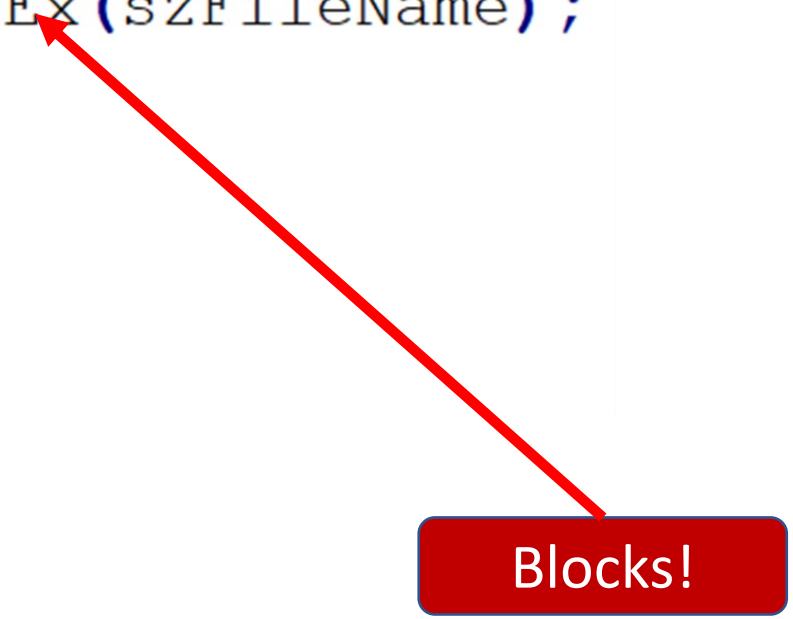

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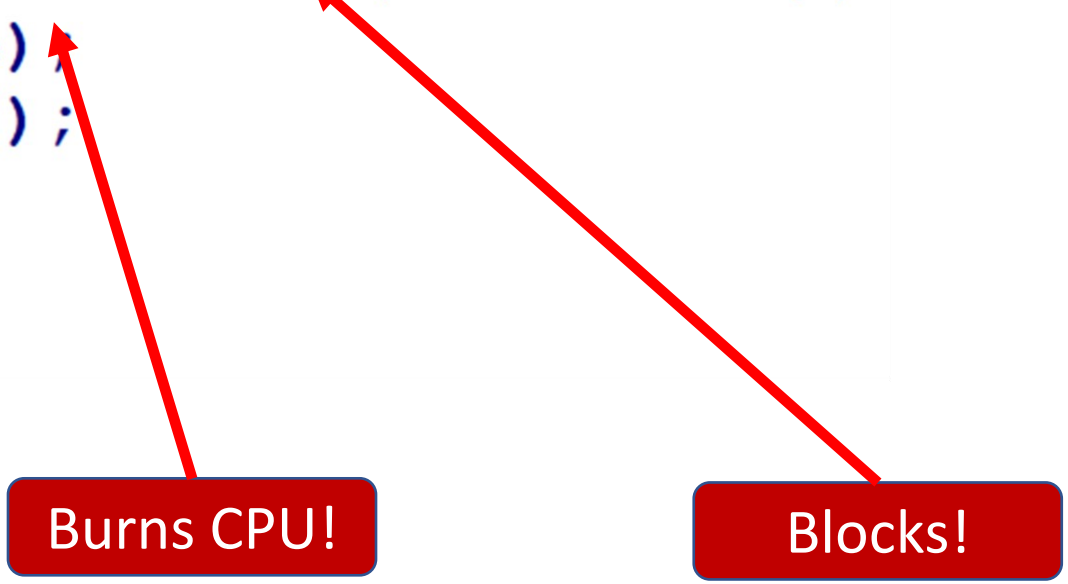

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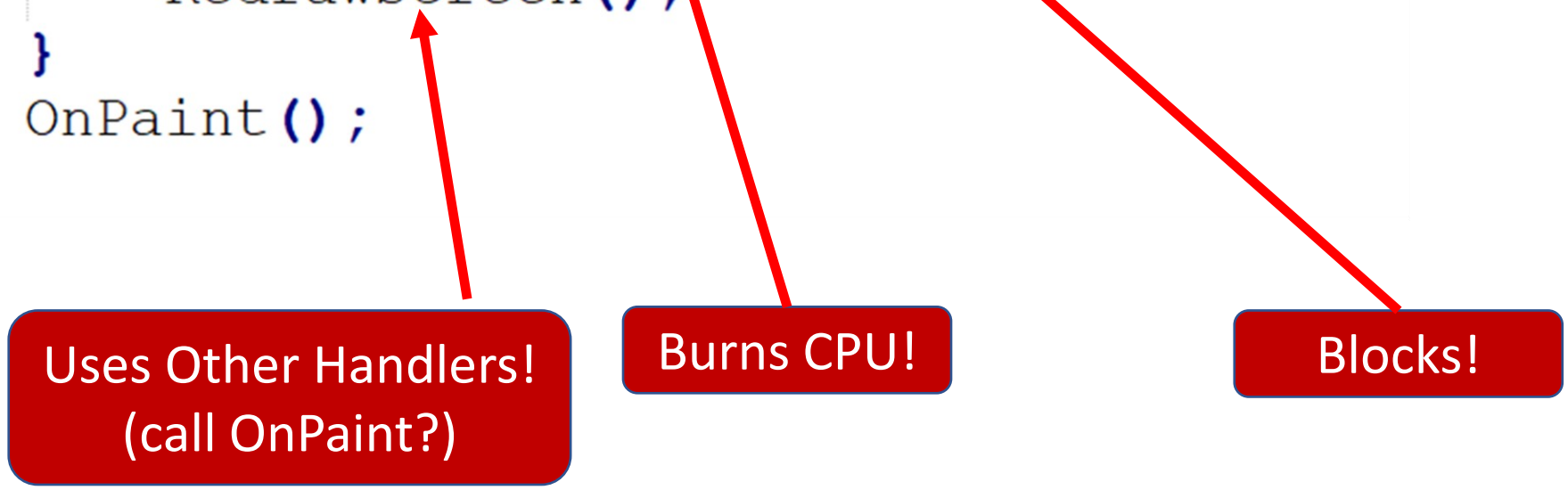

No problem!
Just use more events/handlers, right?

```
1  PROGRAM MyProgram {
2      TASK ReadFileAsync(name, callback) {
3          ReadFileSync(name);
4          Call(callback);
5      }
6      CALLBACK FinishOpeningFile() {
7          LoadFile(file);
8          RedrawScreen();
9      }
10     OnOpenFile() {
11         FILE file;
12         char szName[BUFSIZE]
13         InitFileName(szName);
14         EnqueueTask(ReadFileAsync(szName, FinishOpeningFile));
15     }
16     OnPaint();
17 }
```

Continuations, BTW

```
1  PROGRAM MyProgram {
2      OnOpenFile() {
3          ReadFile(file, FinishOpeningFile);
4      }
5      OnFinishOpeningFile() {
6          LoadFile(file, OnFinishLoadingFile);
7      }
8      OnFinishLoadingFile() {
9          RedrawScreen();
10     }
11     OnPaint();
12 }
```

Stack-Ripping

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Stack-based state out-of-scope!
Requests must carry state

Threads vs Events

- Thread Pros
- Thread Cons
- Event Pros
- Event Cons

Threads vs Events

- Thread Pros
  - Overlap I/O and computation
    - While looking sequential
  - Intermediate state on stack
  - Control flow naturally expressed
- Thread Cons
  - Synchronization required
  - Overflowable stack
  - Stack memory pressure

- Event Pros
  - Easier to create well-conditioned system
  - Easier to express dynamic change in level of parallelism
- Event Cons
  - Difficult to program
  - Control flow between callbacks obscure
  - When to deallocate memory
  - Incomplete language/tool/debugger support
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Thread Pool Implementation

```
///-------------------------------------------------------------------------------------------------
/// <summary>   Starts the threads. </summary>
///
/// <remarks>   crossbac, 8/22/2013. </remarks>
///
/// <param name="uiThreads">             The threads. </param>
/// <param name="bWaitAllThreadsAlive"> The wait all threads alive. </param>
///-------------------------------------------------------------------------------------------------

void
ThreadPool::StartThreads(
    __in UINT uiThreads,
    __in BOOL bWaitAllThreadsAlive
    )
{
    Lock();
    if(uiThreads != 0 && m_vhThreadDescs.size() < m_uiTargetSize)
        ResetEvent(m_hAllThreadsAlive);
    while(m_vhThreadDescs.size() < m_uiTargetSize) {
        for(UINT i=0; i<uiThreads; i++) {
            THREADDESC* pDesc = new THREADDESC(this);
            HANDLE * phThread = &pDesc->hThread;
            *phThread = CreateThread(NULL, 0, _ThreadPoolProc, pDesc, 0, NULL);
            m_vhAvailable.push_back(*phThread);
            m_vhThreadDescs[*phThread] = pDesc;
        }
    }
    m_uiThreads = (UINT)m_vhThreadDescs.size();
    Unlock();
    if(bWaitAllThreadsAlive)
        WaitThreadsAlive();
}
```

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            m_vhThreadDescs[*phThread] = pDesc;
        }
    }
    m_uiThreads = (UINT)m_vhThreadDescs.size();
    Unlock();
    if(bWaitAllThreadsAlive)
        WaitThreadsAlive();
}
```

Cool project idea: build a thread pool!

Thread Pool Implementation

```
DWORD
ThreadPool::ThreadPoolProc(
    __in THREADDESC * pDesc
    )
{
    HANDLE hThread = pDesc->hThread;
    HANDLE hStartEvent = pDesc->hStartEvent;
    HANDLE hRuntimeTerminate = PTask::Runtime::GetRuntimeTerminateEvent();
    HANDLE vEvents[] = { hStartEvent, hRuntimeTerminate };


    NotifyThreadAlive(hThread);
    while(!pDesc->bTerminate) {

        DWORD dwWait = WaitForMultipleObjects(dwEvents, vEvents, FALSE, INFINITE);
        pDesc->Lock();
        pDesc->bTerminate |= bTerminate;
        if(pDesc->bRoutineValid && !pDesc->bTerminate) {
            LPTHREAD_START_ROUTINE lpRoutine = pDesc->lpRoutine;
            LPVOID lpParameter = pDesc->lpParameter;
            pDesc->bActive = TRUE;
            pDesc->Unlock();
            dwResult = (*lpRoutine)(lpParameter);
            pDesc->Lock();
            pDesc->bActive = FALSE;
            pDesc->bRoutineValid = FALSE;
        }
        pDesc->Unlock();
        Lock();
        m_vhInFlight.erase(pDesc->hThread);
        if(!pDesc->bTerminate)
            m_vhAvailable.push_back(pDesc->hThread);
        Unlock();
    }
    NotifyThreadExit(hThread);
    return dwResult;
}
```

ThreadPool Implementation

```
///-------------------------------------------------------------------------------------------------
/// <summary>   Starts a thread: if a previous call to RequestThread was made with
///             the bStartThread parameter set to false, this API signals the thread
///             to begin. Otherwise, the call has no effect (returns FALSE). </summary>
///
/// <remarks>   crossbac, 8/29/2013. </remarks>
///
/// <param name="hThread">  The thread. </param>
///
/// <returns>   true if it succeeds, false if it fails. </returns>
///-------------------------------------------------------------------------------------------------

BOOL
ThreadPool::SignalThread(
    __in HANDLE hThread
    )
{
    Lock();
    BOOL bResult = FALSE;
    std::set<HANDLE>::iterator si = m_vhWaitingStartSignal.find(hThread);
    if(si!=m_vhWaitingStartSignal.end()) {
        m_vhWaitingStartSignal.erase(hThread);
        THREADDESC * pDesc = m_vhThreadDescs[hThread];
        HANDLE hEvent = pDesc->hStartEvent;
        SetEvent(hEvent);
        bResult = TRUE;
    }
    Unlock();
    return bResult;
}
```

Redux: Futures in Context

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Futures:

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```
1 static void runAsyncExample() {
2     CompletableFuture cf = CompletableFuture.runAsync(() -> {
3         assertTrue(Thread.currentThread().isDaemon());
4         randomSleep();
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Currently: 2nd renaissance IMHO

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Questions?