Parallel Systems
Events and Futures

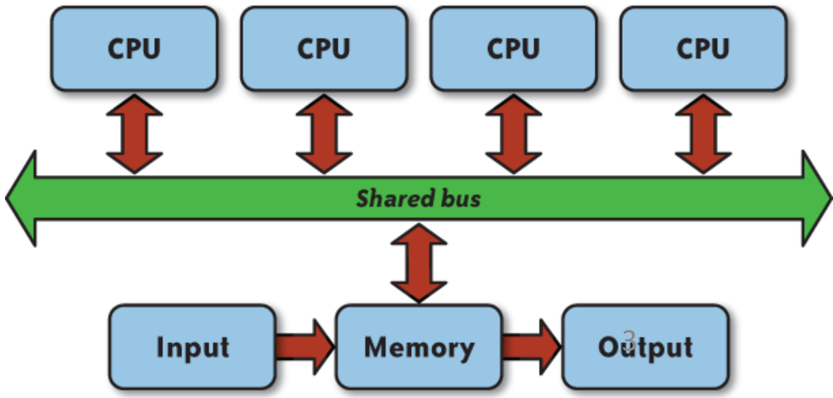
Chris Rossbach + Calvin Lin

CS380p

Outline for Today

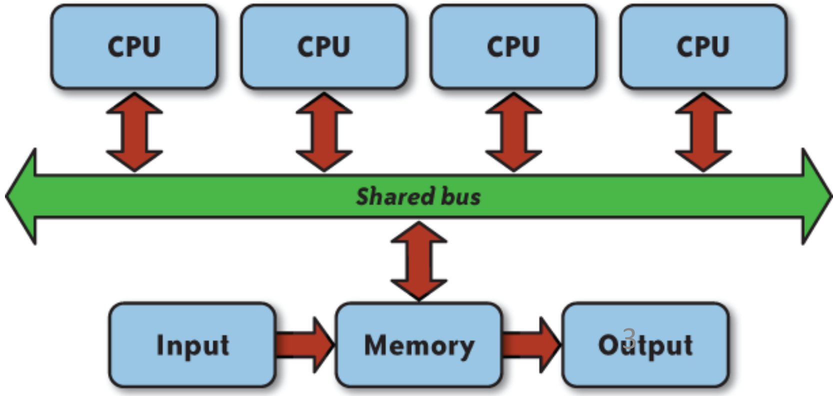
- Asynchronous Programming Models
  - Events
  - Futures

Review: Parallel Programming Models



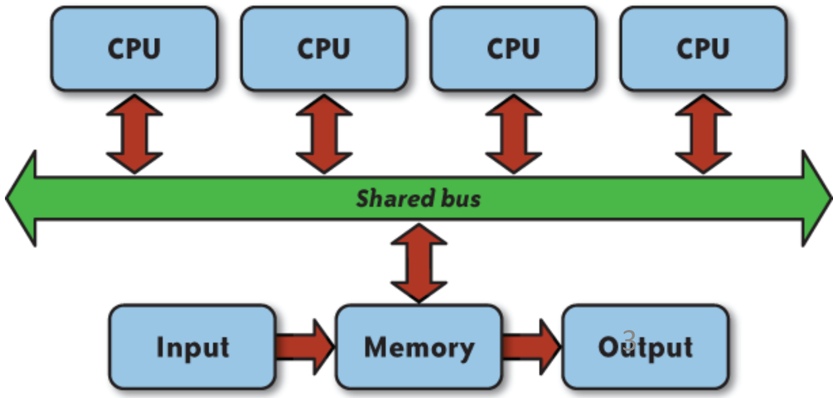
Review: Parallel Programming Models

- Concrete model:
  - CPU(s) execute instructions sequentially



Review: Parallel Programming Models

- Concrete model:
  - CPU(s) execute instructions sequentially
- Dimensions:
  - How to specify computation
  - How to specify communication
  - How to specify coordination/control transfer



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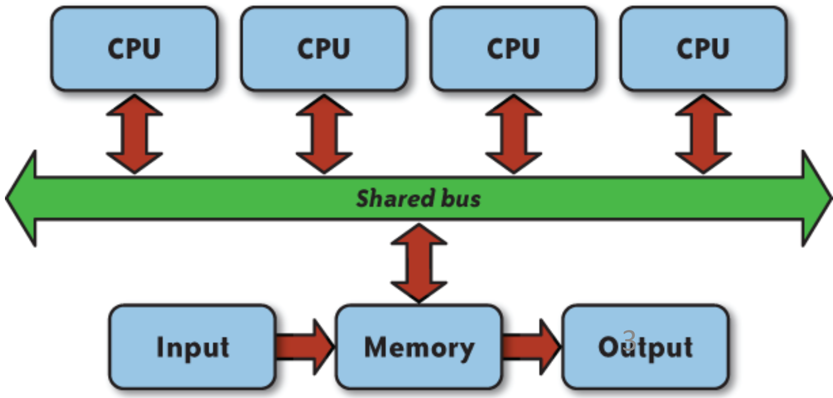
- Techniques/primitives
  - Threads/Processes
  - Message passing vs shared memory
  - Preemption vs Non-preemption



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  - CPU(s) execute instructions sequentially
- Dimensions:
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  - How to specify communication
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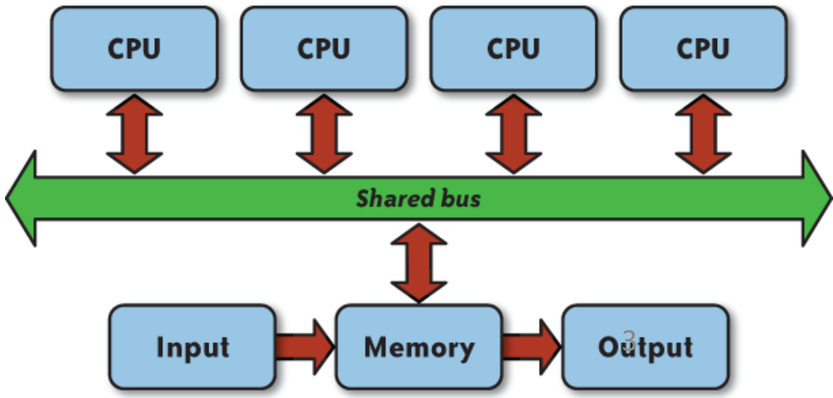
- Techniques/primitives
  - Threads/Processes
  - Message passing vs shared memory
  - Preemption vs Non-preemption
- Dimensions/techniques not always orthogonal



Review: Execution Context Management

“Task” == “Flow of Control”
“Stack” == Task State

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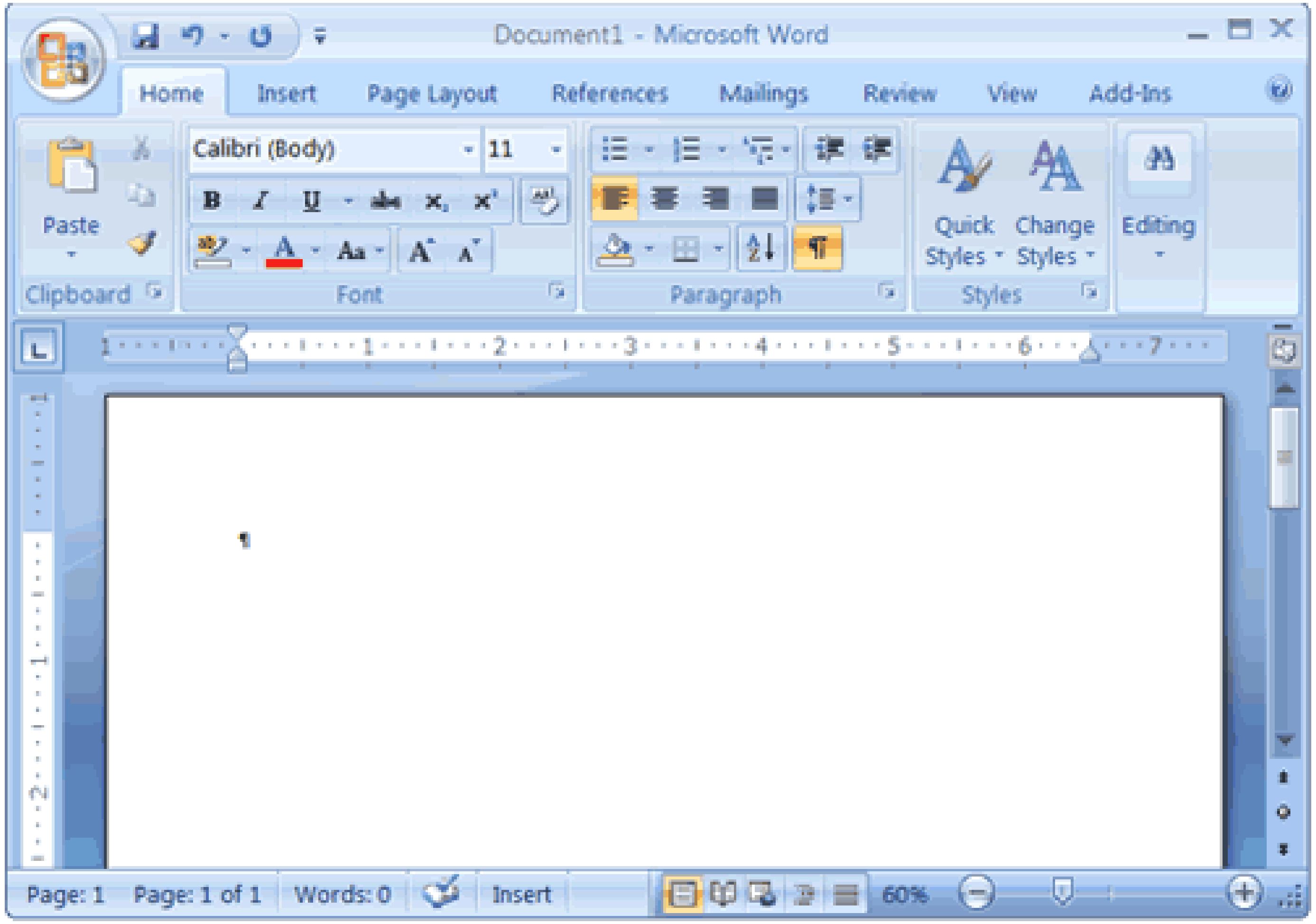
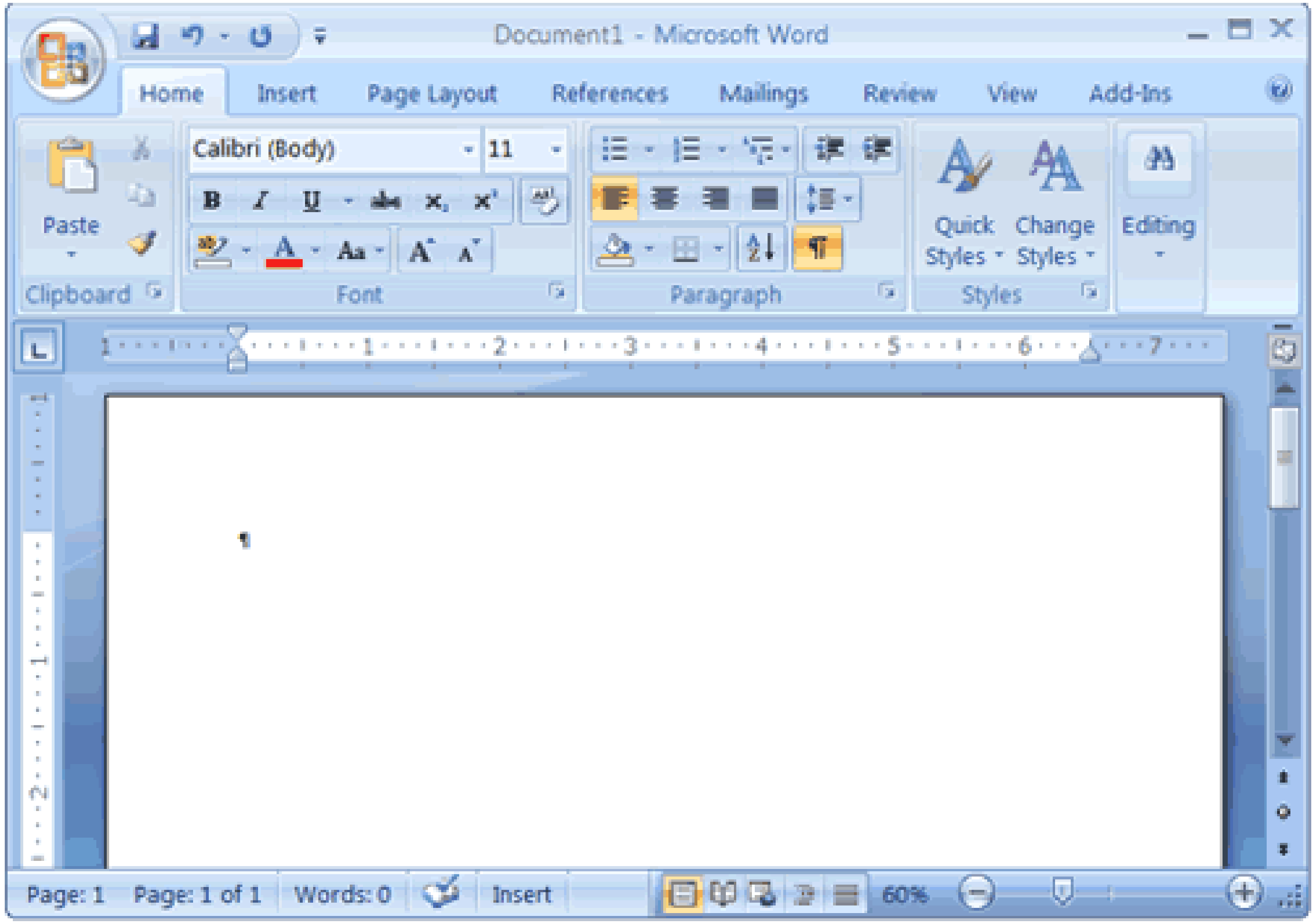
Stack Management

- Manual
  - Inherent in Cooperative
  - Changing at quiescent points
- Automatic
  - Inherent in pre-emptive
  - Downside: Hidden concurrency assumptions

UI Programming



UI Programming




```
do {
  WaitForSomething();
  RespondToThing();
} until(forever);
```

UI Programming

```
int WINAPI WinMain(HINSTANCE hInstance, HINSTANCE hPrevInstance,
    LPSTR lpCmdLine, int nCmdShow)
{
    WNDCLASSEX wc;
    HWND hwnd;
    MSG Msg;

    //Step 1: Registering the Window Class
    wc.cbSize        = sizeof(WNDCLASSEX);
    wc.style         = 0;
    wc.lpfnWndProc   = WndProc;
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    wc.lpszMenuName  = NULL;
    wc.lpszClassName = g_szClassName;
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    if(!RegisterClassEx(&wc))
    {
        MessageBox(NULL, "Window Registration Failed!", "Error!",
            MB_ICONEXCLAMATION | MB_OK);
        return 0;
    }

    // Step 2: Creating the Window
    hwnd = CreateWindowEx(
        WS_EX_CLIENTEDGE,
        g_szClassName,
        "The title of my window",
        WS_OVERLAPPEDWINDOW,
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    if(hwnd == NULL)
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    ShowWindow(hwnd, nCmdShow);
    UpdateWindow(hwnd);

    // Step 3: The Message Loop
    while(GetMessage(&Msg, NULL, 0, 0) > 0)
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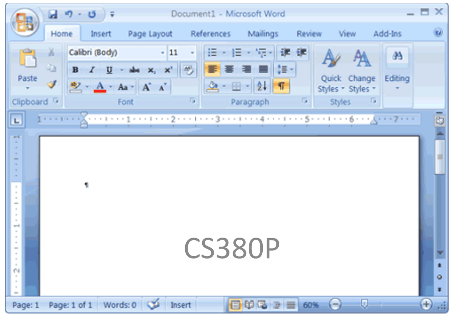

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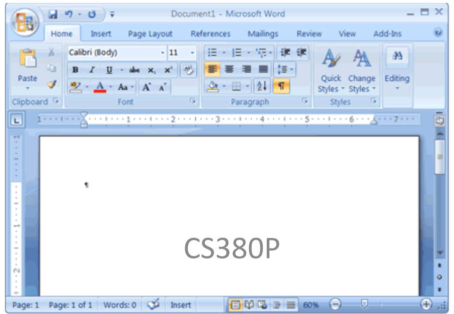

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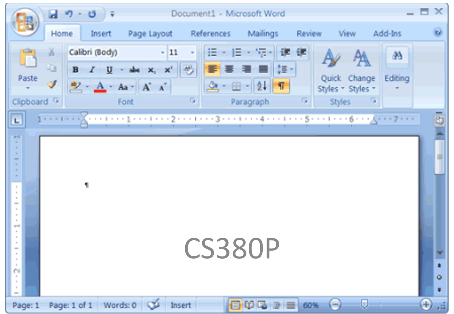

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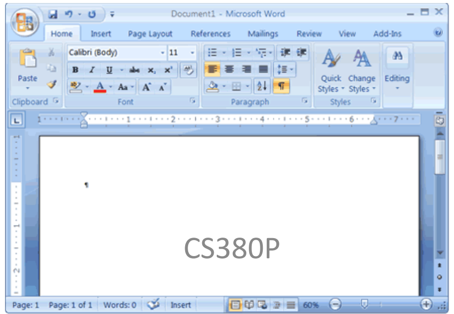

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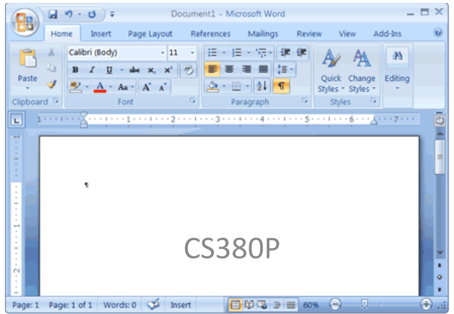

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0007	7	WM_SETFOCUS
0008	8	WM_KILLFOCUS
000a	10	WM_ENABLE
000b	11	WM_SETREDRAW
000c	12	WM_SETTEXT
000d	13	WM_GETTEXT
000e	14	WM_GETTEXTLENGTH
000f	15	WM_PAINT
0010	16	WM_CLOSE
0011	17	WM_QUERYENDSESSION
0012	18	WM_QUIT
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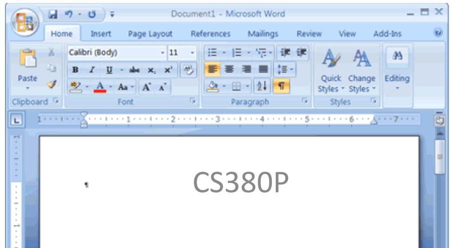

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Over 1000 last time I checked!

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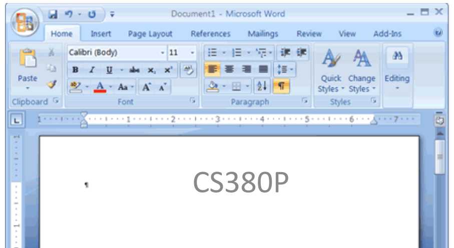

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```
void OnMove() { … }
void OnSize() { … }

void OnPaint() { … }
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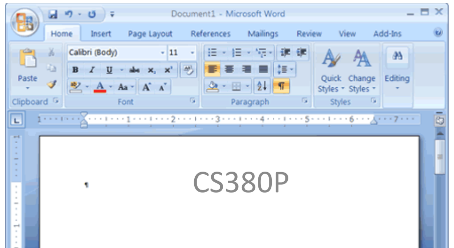

UI Programming Distilled

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- Simple imperative programming
- Good fit for uni-processor

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- Awkward/verbose
- **Obscures available parallelism**

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  while(true) {
      message = GetMessage();
      switch(message) {
      case WM_LONGRUNNING_CPU_HOG: HogCPU(); break;
      case WM_HIGH_LATENCY_IO: BlockForALongTime(); break;
      case WM_DO_QUICK_IMPORTANT_THING: HopeForTheBest(); break;
      }
  }
}
}
```

Pros

- Simple imperative programming
- Good fit for uni-processor

Cons

- Awkward/verbose
- **Obscures available parallelism**

UI Programming Distilled

```
winmain(...) {
  while(true) {
      message = GetMessage();
      switch(message) {
      case WM_THIS: DoThis(); break;
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}
```

How can we parallelize this?

Parallel UI Implementation 1

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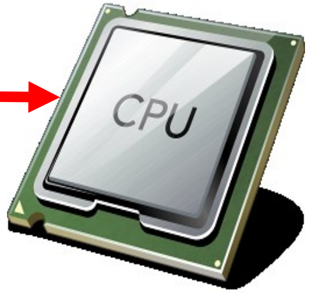

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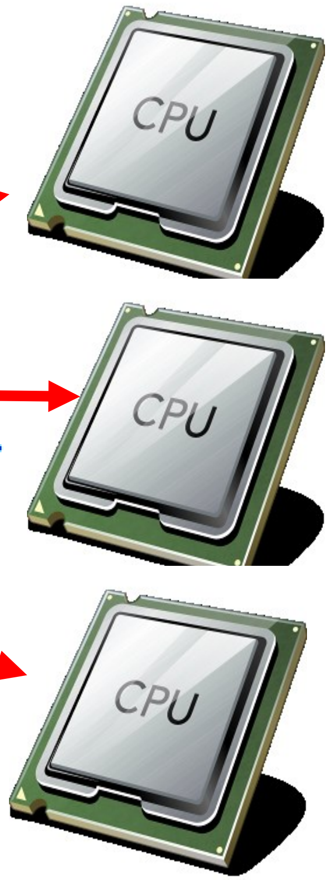

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winmain() {
    pthread_create(&tids[i++], DoThisProc);
    pthread_create(&tids[i++], DoThatProc);
    pthread_create(&tids[i++], DoOtherThingProc);
    for(j=0; j<i; j++)
        pthread_join(&tids[j]);
}

DoThisProc() {
    while(true){
        if(ThisHasHappened)
            DoThis();
    }
}
```

DoThisProc

DoThatProc

OtherThing

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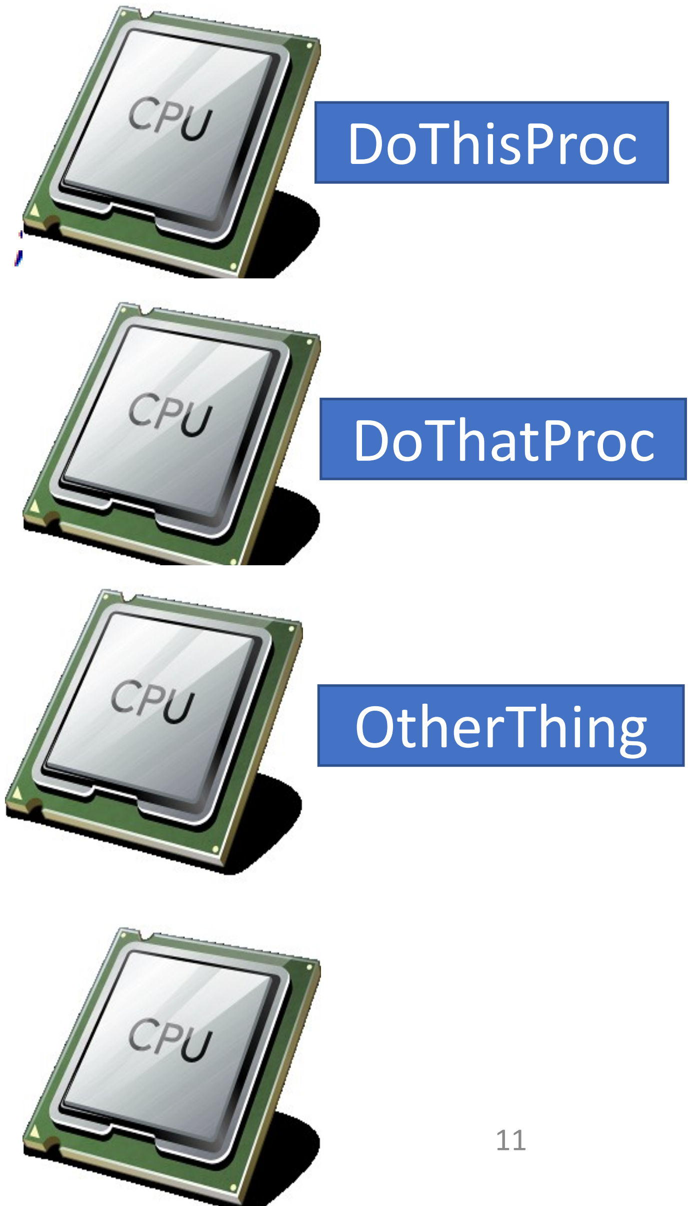

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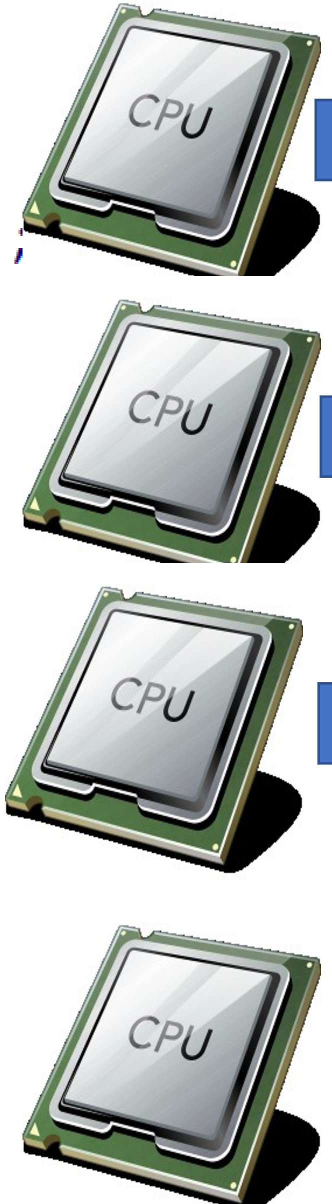
```

Pros/cons?

Pros:
- Encapsulates parallel work

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



DoThisProc

DoThatProc

OtherThing

Parallel GUI Implementation 2

```
winmain() {
    for(i=0; i<NUMPROCS; i++)
        pthread_create(&tids[i], HandlerProc);
    for(i=0; i<NUMPROCS; i++)
        pthread_join(&tids[i]);
}
```

```
threadproc(...) {
  while(true) {
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Parallel GUI Implementation 2

```
winmain() {
    for(i=0; i<NUMPROCS; i++)
        pthread_create(&tids[i], H
    for(i=0; i<NUMPROCS; i++)
        pthread_join(&tids[i]);
}
```

Pros/cons?

Pros:
- Preserves programming model
- Can recover some parallelism

Cons:
- Workers still have same problem
- How to load balance?
- Shared mutable state a problem

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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 to have no threads!*

Event Programming Model Basics

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  - create_event_queue(handler) → event_q
  - enqueue_event(event_q, event-object)
    - Invokes handler (eventually)

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- Event: an object queued for a module (think future/promise)
- 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

Event-based programming

```
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

Event-based programming

```
PROGRAM MyProgram {
    OnSize() {}
    OnMove() {}
    OnClick() {}
    OnPaint() {}
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Event-based programming

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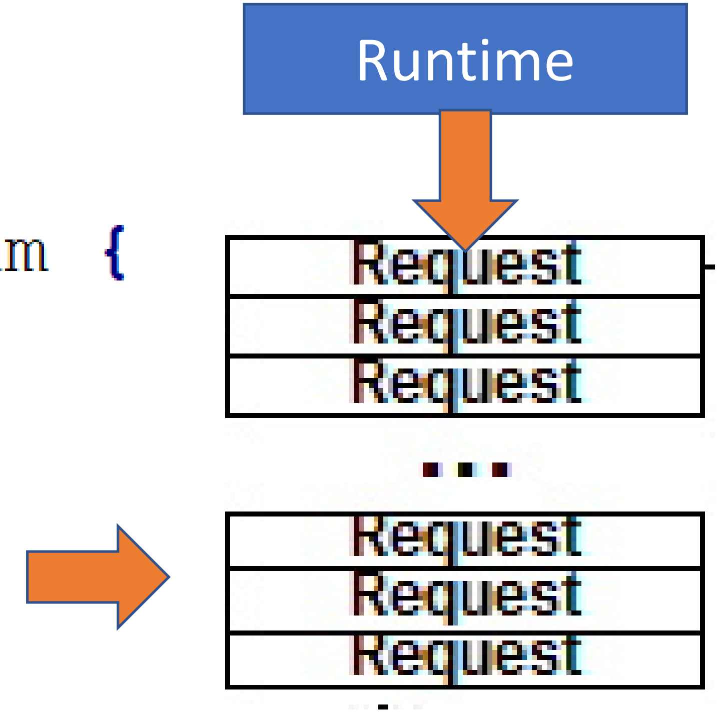

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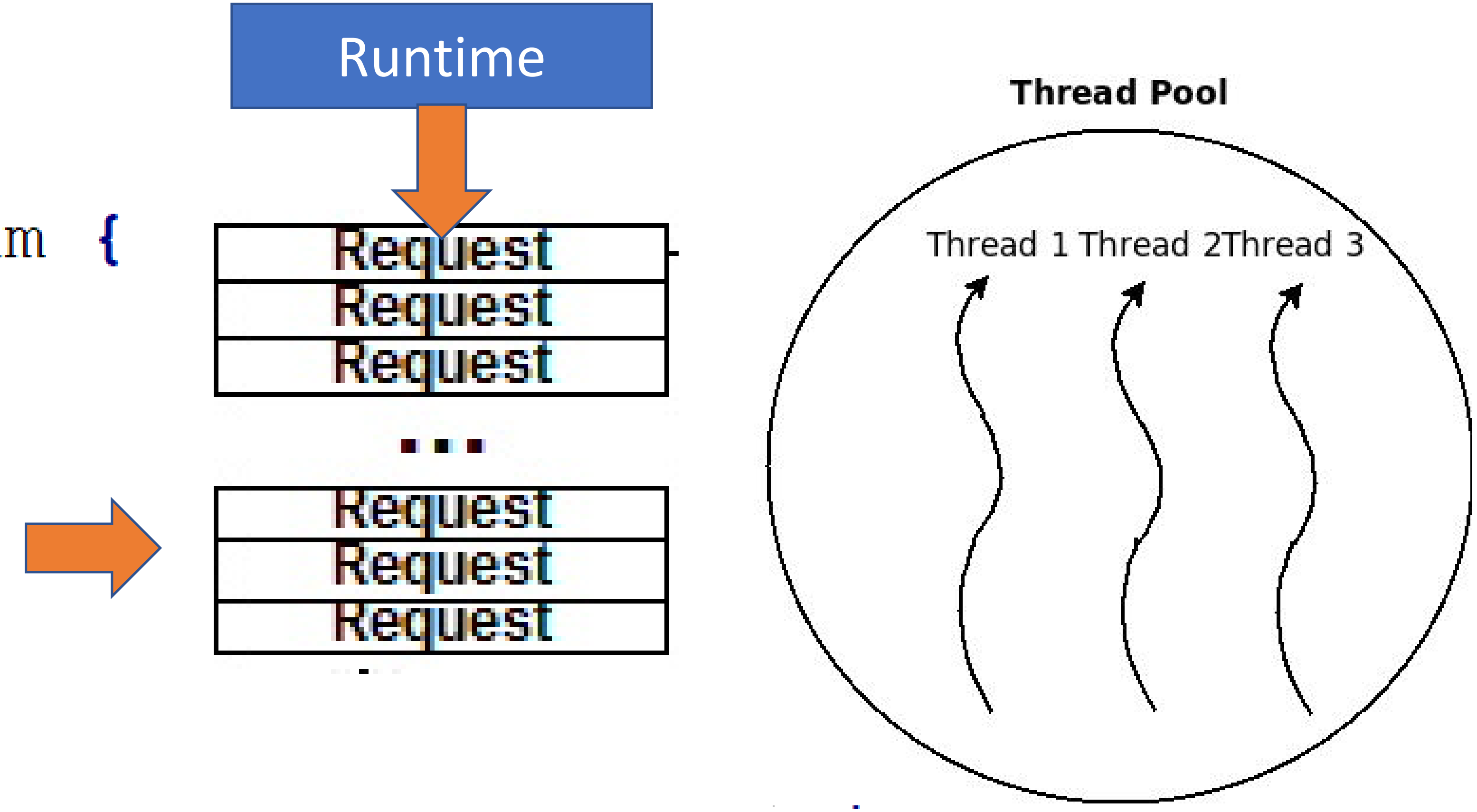

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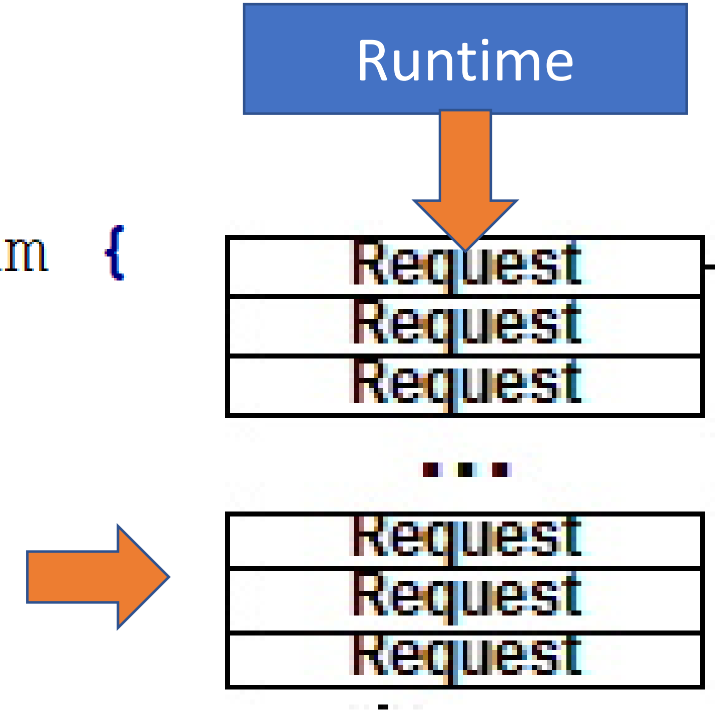

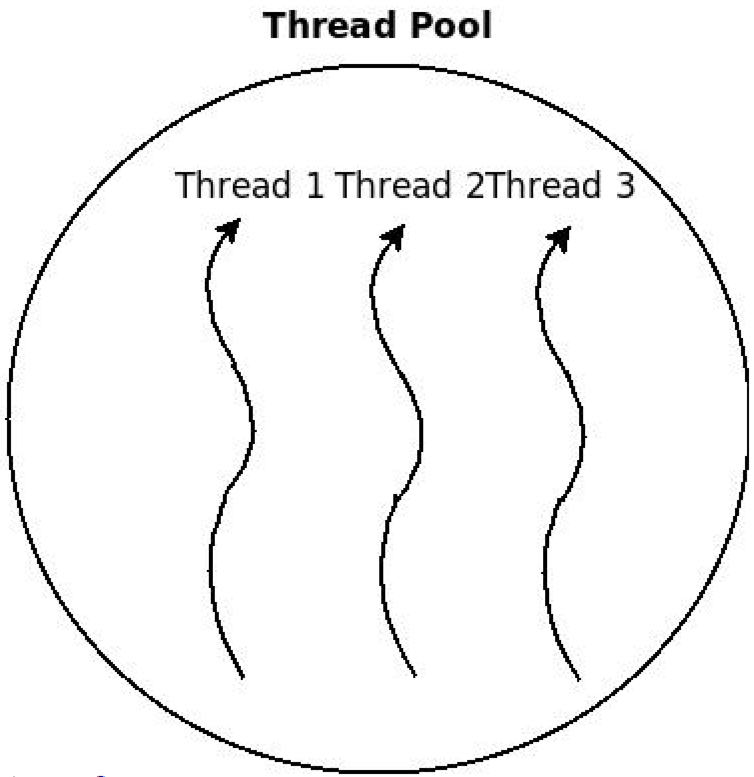

Is the problem solved?

Another Event-based Program

Another Event-based Program

```
PROGRAM MyProgram {
        OnOpenFile() {
                char szFileName[BUFSIZE]
                InitFileName(szFileName);
                FILE file = ReadFileEx(szFileName);
                LoadFile(file);
                RedrawScreen();
        }
        OnPaint();
}
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Blocks!

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Burns CPU!

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```

Uses Other Handlers!
(call OnPaint?)

Burns CPU!

Blocks!

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

```
PROGRAM MyProgram {
    TASK ReadFileAsync(name, callback) {
        ReadFileSync(name);
        Call(callback);
    }
    CALLBACK FinishOpeningFile() {
        LoadFile(file);
        RedrawScreen();
    }
    OnOpenFile() {
        FILE file;
        char szName[BUFSIZE]
        InitFileName(szName);
        EnqueueTask(ReadFileAsync(szName, FinishOpeningFile));
    }
    OnPaint();
}
```

Continuations, BTW

```
PROGRAM MyProgram {
    OnOpenFile() {
        ReadFile(file, FinishOpeningFile);
    }
    OnFinishOpeningFile() {
        LoadFile(file, OnFinishLoadingFile);
    }
    OnFinishLoadingFile() {
        RedrawScreen();
    }
    OnPaint();
}
```

Stack-Ripping

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

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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- Values *that will eventually become available*
- Time-dependent states:
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- Construct (future X)
  - immediately returns value
  - concurrently executes X

Java Example

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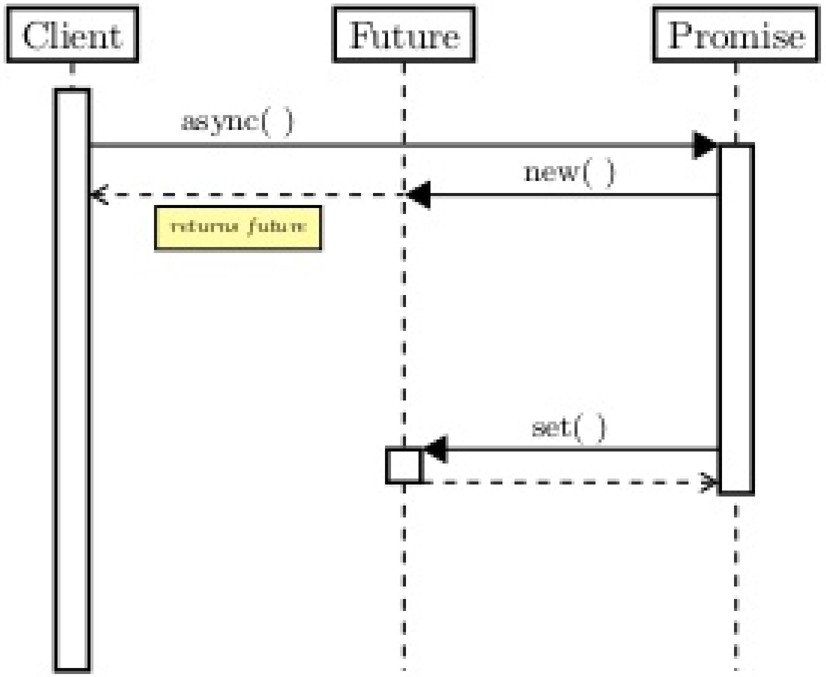
  - Anonymous function
  - Functor
- runAsync() immediately returns a waitable object (cf)
- Where (on what thread) does the lambda expression run?

Futures and Promises:

Why two kinds of objects?

```
future<int> f1 = async(foo1);
...
int result = f1.get();
```



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Promise: “thing to be done”

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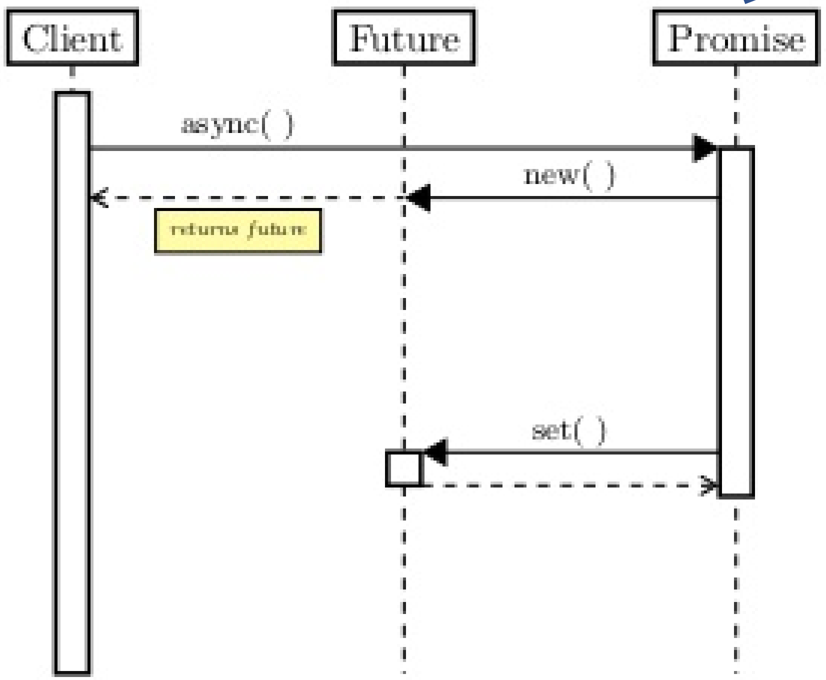

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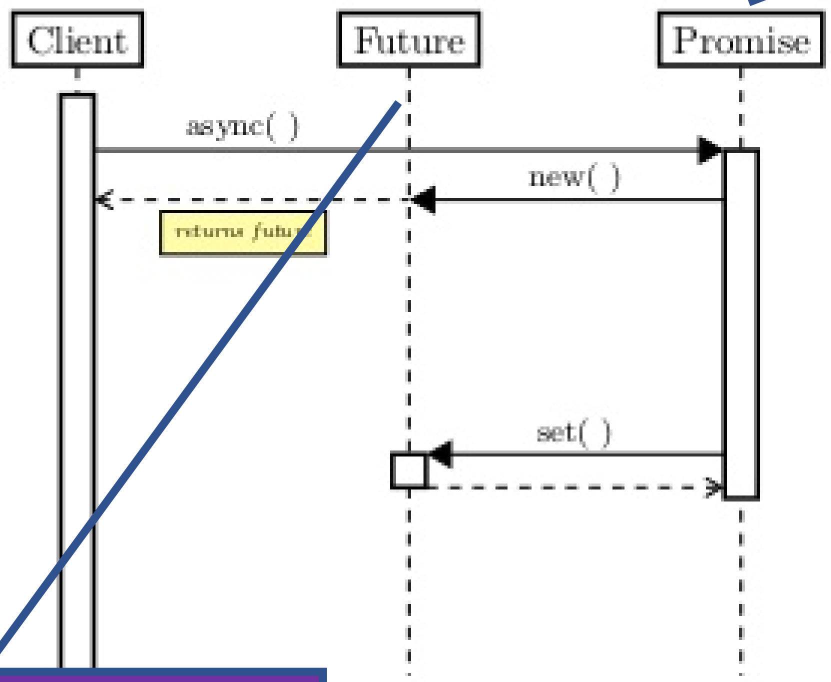

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(something to give caller)

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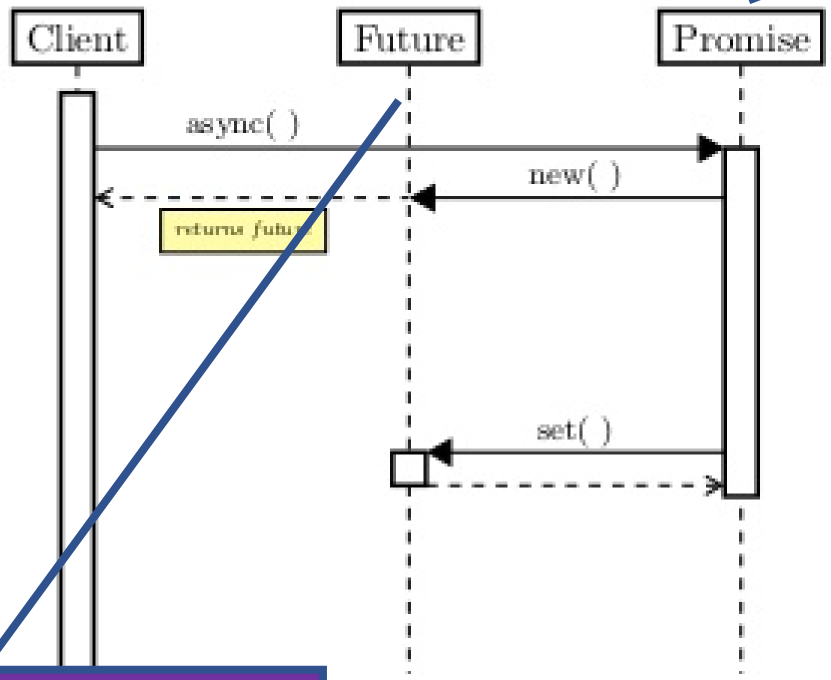


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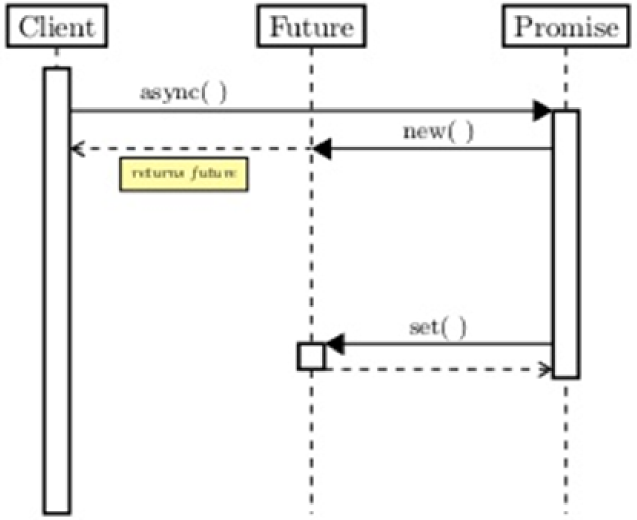
Future: encapsulation
(something to give caller)

Promise to do something in the future

Futures vs Promises

- **Future:** read-only reference to uncompleted value
- **Promise:** single-assignment variable that the future refers to
- Promises *complete* the future with:
  - Result with success/failure
  - Exception



Futures vs Promises

- **Future:** read-only reference to uncompleted value
- **Promise:** single-assignment variable that the future refers to
- Promises *complete* the future with:
  - Result with success/failure
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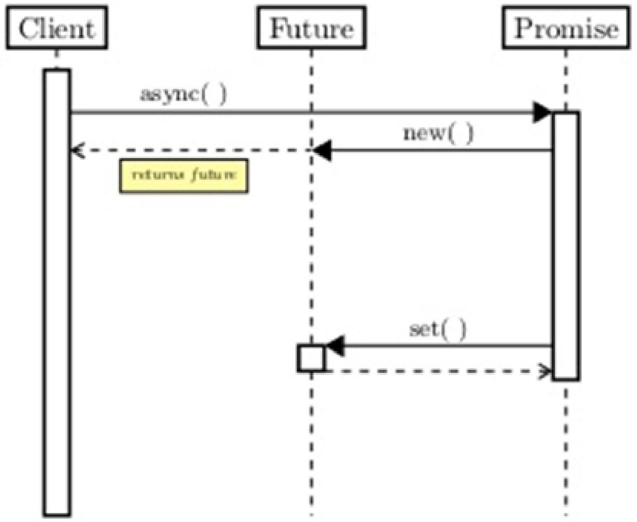
Language	Promise	Future
Algol	Thunk	Address of async result
Java	CompletableFuture<T>	Future<T>
C#/.NET	TaskCompletionSource<T>	Task<T>
JavaScript	Deferred	Promise
C++	std::promise	std::future



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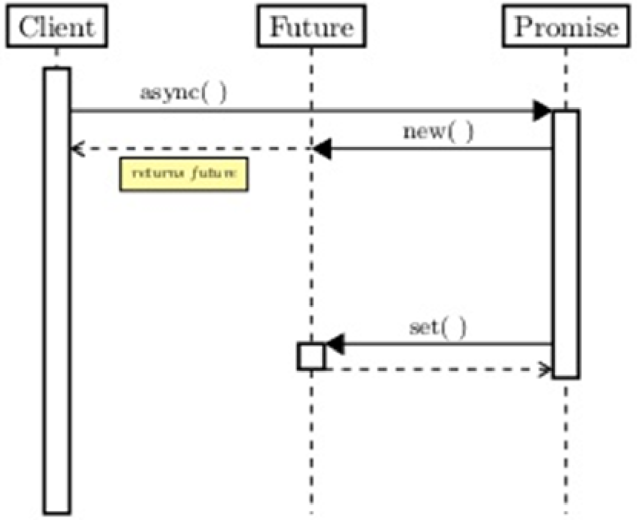

Futures vs Promises

Mnemonic:
Promise to ***do*** something
Make a promise ***for*** the future

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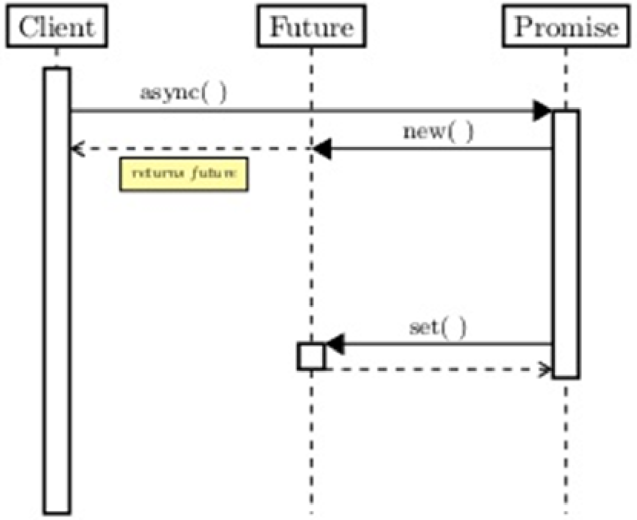

Putting Futures in Context

My unvarnished opinion

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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***

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```java
static void runAsyncExample() {
    CompletableFuture cf = CompletableFuture.runAsync(() -> {
        assertTrue(Thread.currentThread().isDaemon());
        randomSleep();
    });
    assertFalse(cf.isDone());
    sleepEnough();
    assertTrue(cf.isDone());
}
```

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Compromise Programming Model between:

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Compromise Programming Model between:

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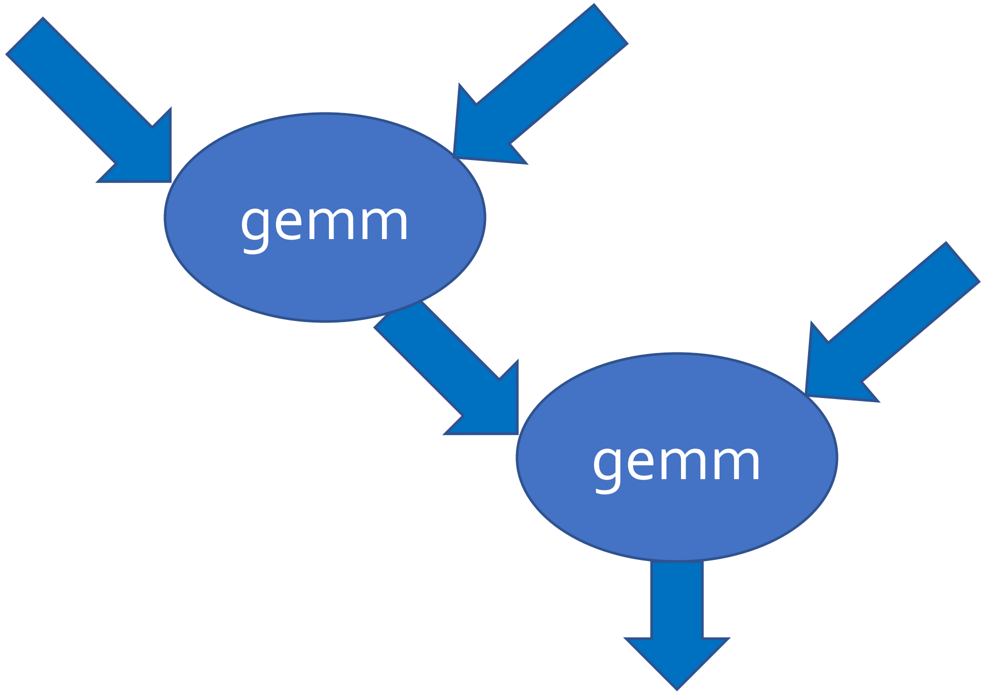
Events vs. Threads!

Dataflow: a better abstraction?



- nodes → computation
- edges → communication
- Expresses parallelism explicitly
- Minimal specification of data movement: runtime does it.
- asynchrony is a runtime concern (not programmer concern)
- No specification of compute→device mapping: like threads!