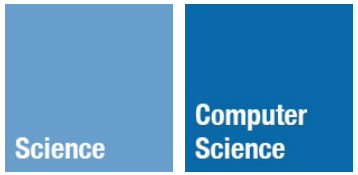
Concurrency



CS 442: Mobile App Development
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note: iOS devices are now (mostly) multi-core; i.e., concurrency may allow for real performance gains!

but the more common incentive is to improve interface *responsiveness*

i.e., by taking lengthy computations off the critical path of UI updates

Mechanisms

- Threads (traditional)
- Grand Central Dispatch
- Dispatch queues/sources
- Operation Queues

Threads:

- Cocoa threads (NSThread)
- ~~POSIX threads~~ (way too low level!)
  - if you do use PThreads, *spawn a single NSThread first*!

```
@interface NSThread : NSObject  {

- (id)initWithTarget:(id)target
             selector:(SEL)selector
               object:(id)argument;

- (void)start;

+ (void)detachNewThreadSelector:(SEL)selector
                       toTarget:(id)target
                     withObject:(id)argument;

+ (NSThread *)currentThread;

- (BOOL)isMainThread;
+ (NSThread *)mainThread;

+ (void)sleepForTimeInterval:(NSTimeInterval)ti;
+ (void)exit;

- (BOOL)isCancelled;
- (void)cancel;

@end
```

```
@interface NSObject (NSThreadPerformAdditions)

- (void)performSelectorInBackground:(SEL)aSelector
                         withObject:(id)arg;

@end
```

```
NSThread *thread = [[NSThread alloc] initWithTarget:someObj
                                           selector:@selector(threadMainMethod:)
                                             object:arg];

[thread start];
```

```
[NSThread detachNewThreadSelector:@selector(threadMainMethod:)
                         toTarget:someObj
                       withObject:arg];
```

```
[someObj performSelectorInBackground:@selector(threadMainMethod:) withObject:arg]
```

all threads automatically run *detached* from the creating thread

- no cleanup is necessary
- "joining" is not directly supported
- but this means the thread must have a means to clean up after itself!

```objc
@implementation ViewController

- (void)viewDidAppear:(BOOL)animated
{
    // spawn new thread when view appears
    [self performSelectorInBackground:@selector(threadMain) withObject:nil];
}

- (void)threadMain
{
    @autoreleasepool {
        // I need my own autorelease pool!
        NSLog(@"Hello from thread!");
    }
}
```

we often want threads to stick around and process multiple work items

— design pattern: thread *work queue*

```
workQueue = [[NSMutableArray alloc] init];
[self performSelectorInBackground:@selector(threadMain:) withObject:workQueue];

@synchronized(workQueue) {
    [workQueue insertObject:@"work item" atIndex:0];
}
```

```
- (void)threadMain:(NSMutableArray *)workQueue
{
    @autoreleasepool {
        id workItem;
        while (![[NSThread currentThread] isCancelled]) {
            if (workQueue.count == 0) {
                [NSThread sleepForTimeInterval:1.0];
                continue;
            }

            @synchronized(workQueue) {
                workItem = [workQueue lastObject];
                [workQueue removeLastObject];
            }

            // process work item
            NSLog(@"%@", workItem);
        }
    }
}
```

possible extensions:

- more than one work queue
- timed (periodic/delayed) work items
- notifying observers of work completion
- monitoring of input devices (asynchronous I/O)

all this and more provided by `NSRunLoop`

— encapsulates multiple input sources & timers, and provides API to dequeue and process work items in the current thread

each work source is associated with one or more *run loop modes*

- when executing a run loop, can specify mode to narrow down work sources

```
@interface NSRunLoop : NSObject

+ (NSRunLoop *)currentRunLoop;

// enter a permanent run loop, processing items from sources
- (void)run;

// process timers and/or one input source before `limitDate'
- (void)runUntilDate:(NSDate *)limitDate;

// like runUntilDate, but only for sources in `mode'
- (BOOL)runMode:(NSString *)mode beforeDate:(NSDate *)limitDate;

@end
```

```
- (void)threadMain {
    @autoreleasepool {
        while (![[NSThread currentThread] isCancelled]) {
            // process a run loop input source (and/or timers)
            [[NSRunLoop currentRunLoop] runMode:NSDefaultRunLoopMode
                                     beforeDate:[NSDate distantFuture]];

            // now do other work before processing run loop sources again
            NSLog(@"Run loop iteration complete");
        }
    }
}
```

Built in support for delegating work between threads, and for scheduling timed events:

```
@interface NSObject (NSThreadPerformAdditions)

- (void)performSelector:(SEL)aSelector
                onThread:(NSThread *)thr
              withObject:(id)arg
           waitUntilDone:(BOOL)wait;

@end

@interface NSObject (NSDelayedPerforming)

- (void)performSelector:(SEL)aSelector
              withObject:(id)anArgument
              afterDelay:(NSTimeInterval)delay;

@end
```

```
- (void)blinkView {
    self.blinkerView.backgroundColor = [UIColor whiteColor];

    [UIView animateWithDuration:1.0
                     animations:^{
                         self.blinkerView.backgroundColor = [UIColor redColor];
                     }];

    // not a recursive call!
    [self performSelector:@selector(blinkView) withObject:nil afterDelay:3.0];
}
```

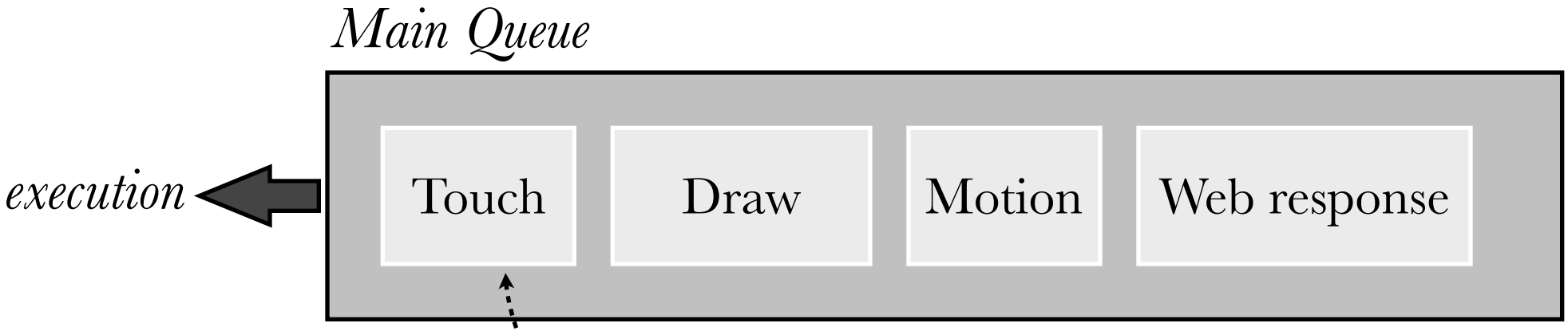
the main run loop:

```
[NSRunLoop mainRunLoop]
```

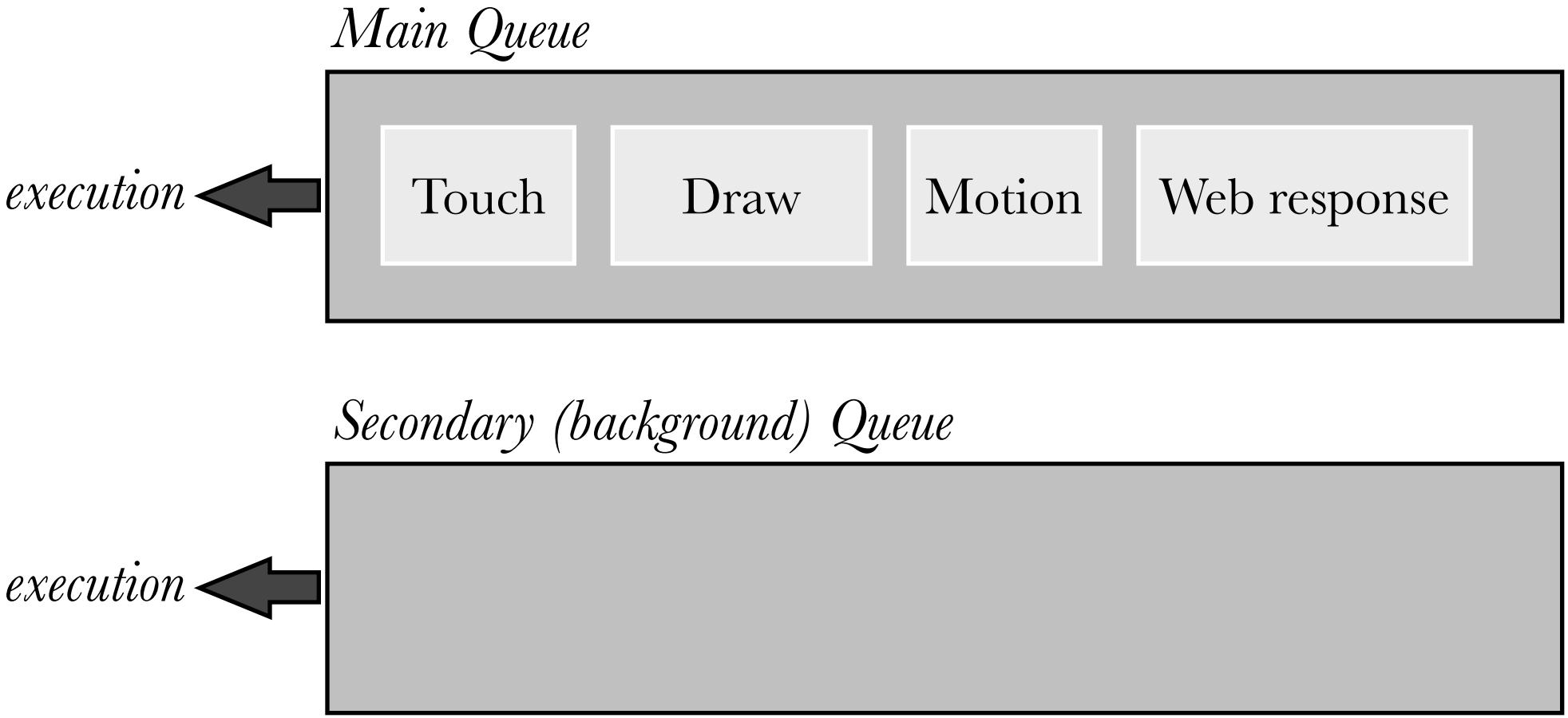
- this is where everything's been happening (until now)!
  - event handling, UI drawing, etc.

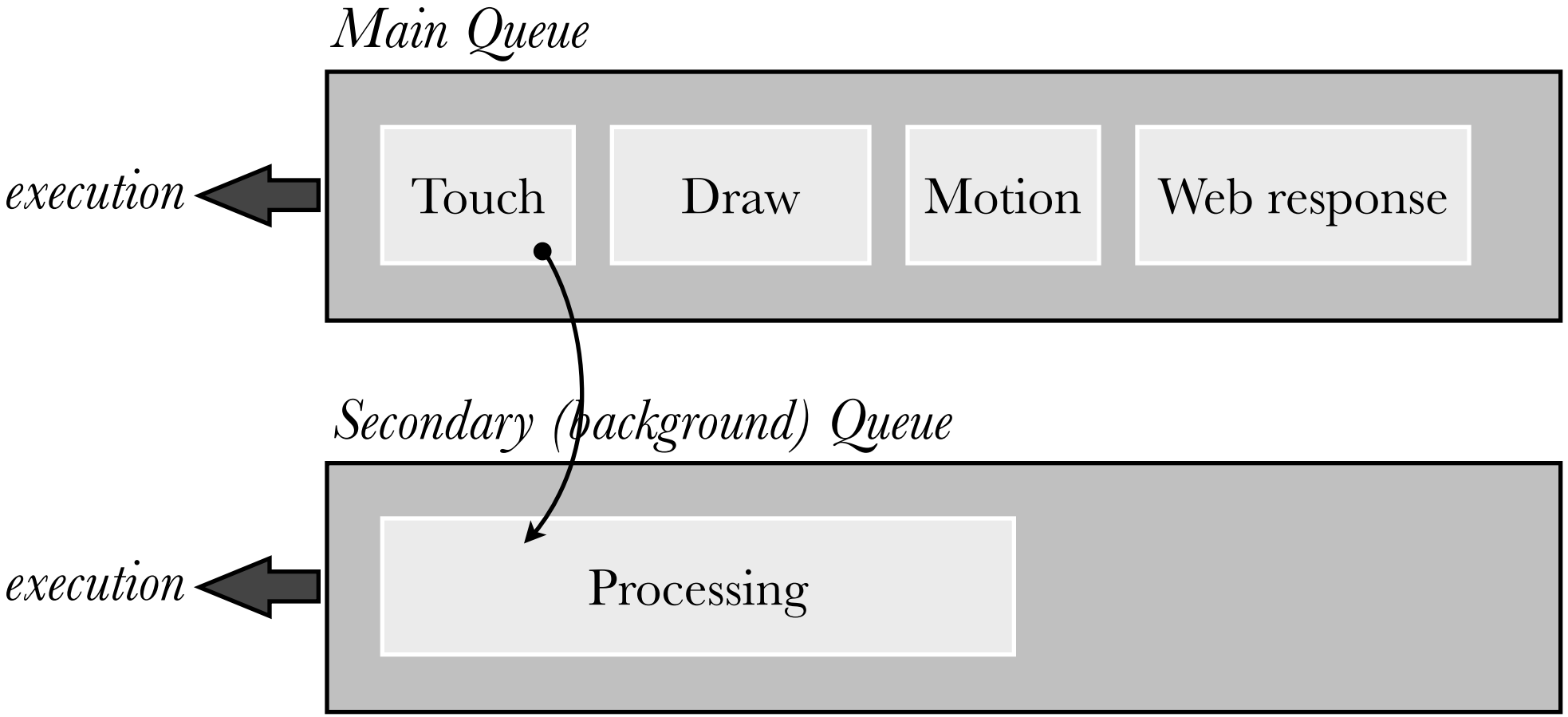
event handling can be handed off to other threads, but **all UI updates must be performed by the main thread**!

dilemma: if UI updates must happen in main thread, how can UI events be processed in secondary threads?



needs to perform lengthy processing … but would hold up the main thread if done here


Main Queue
execution
Touch
Draw
Motion
Web response
Secondary (background) Queue
execution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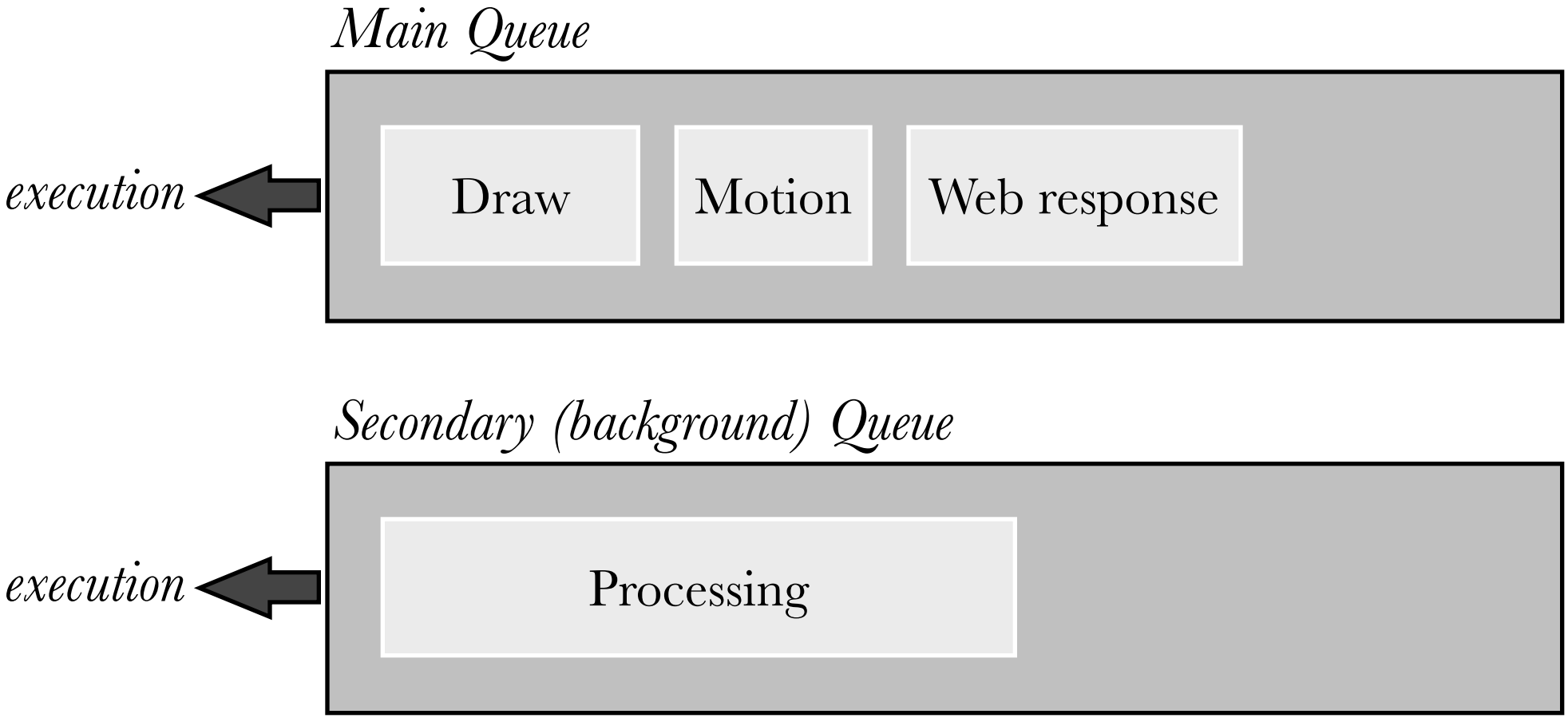
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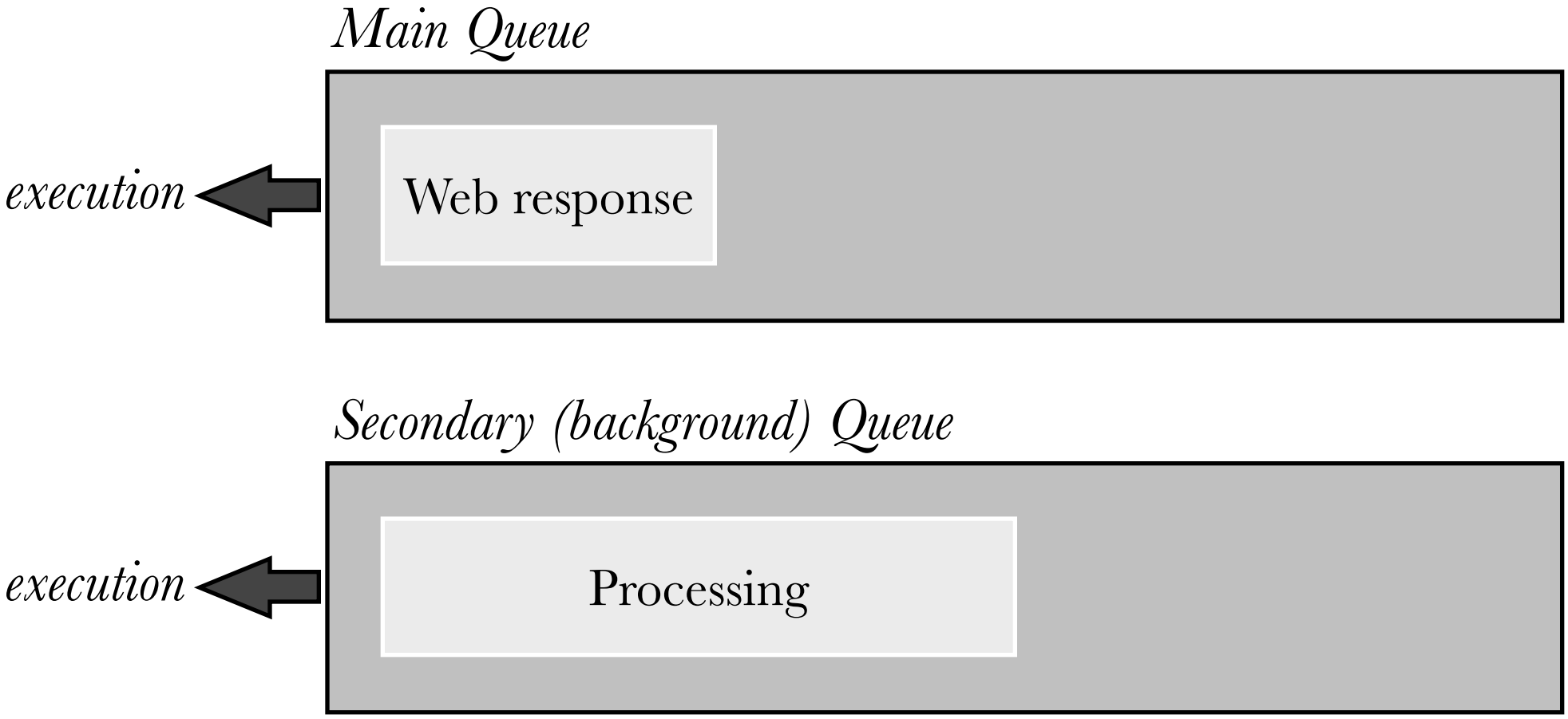
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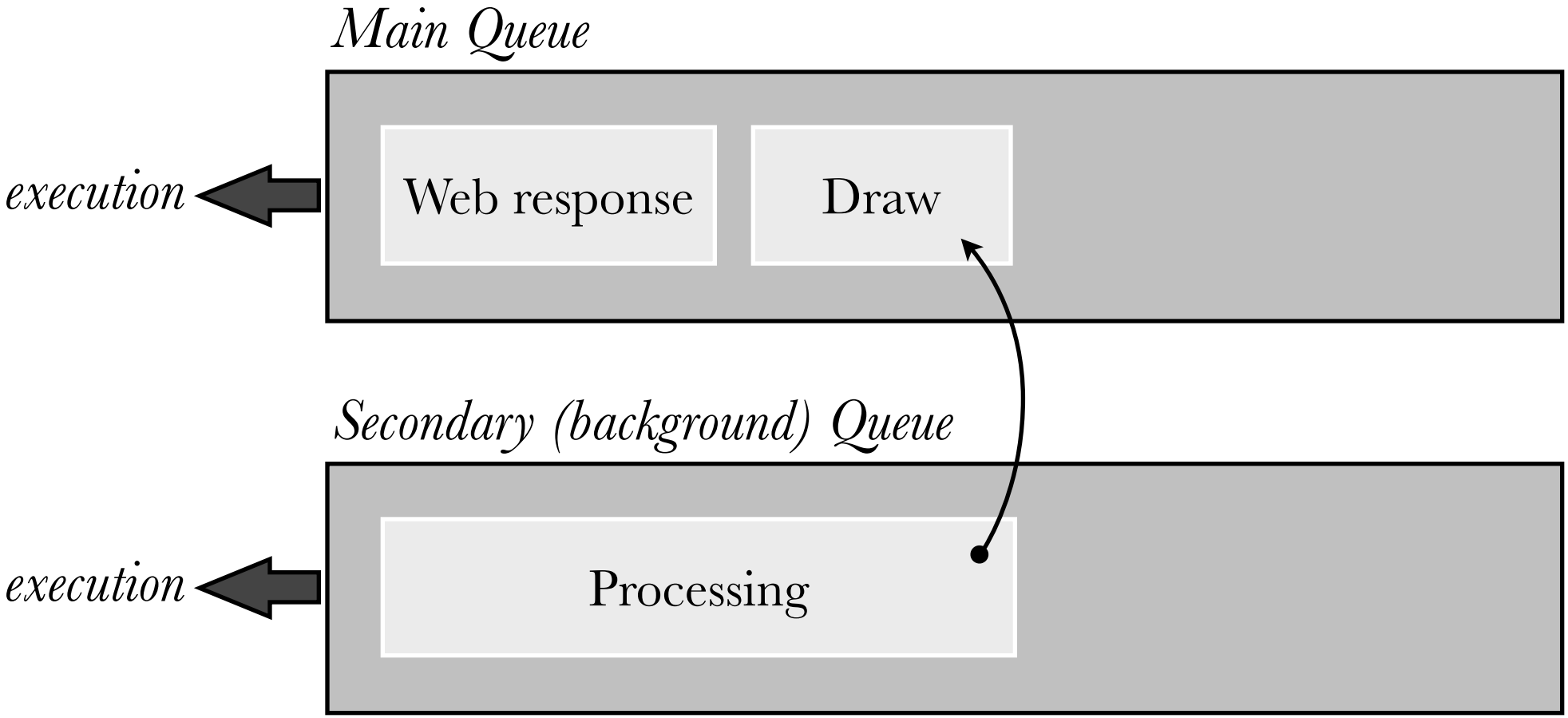
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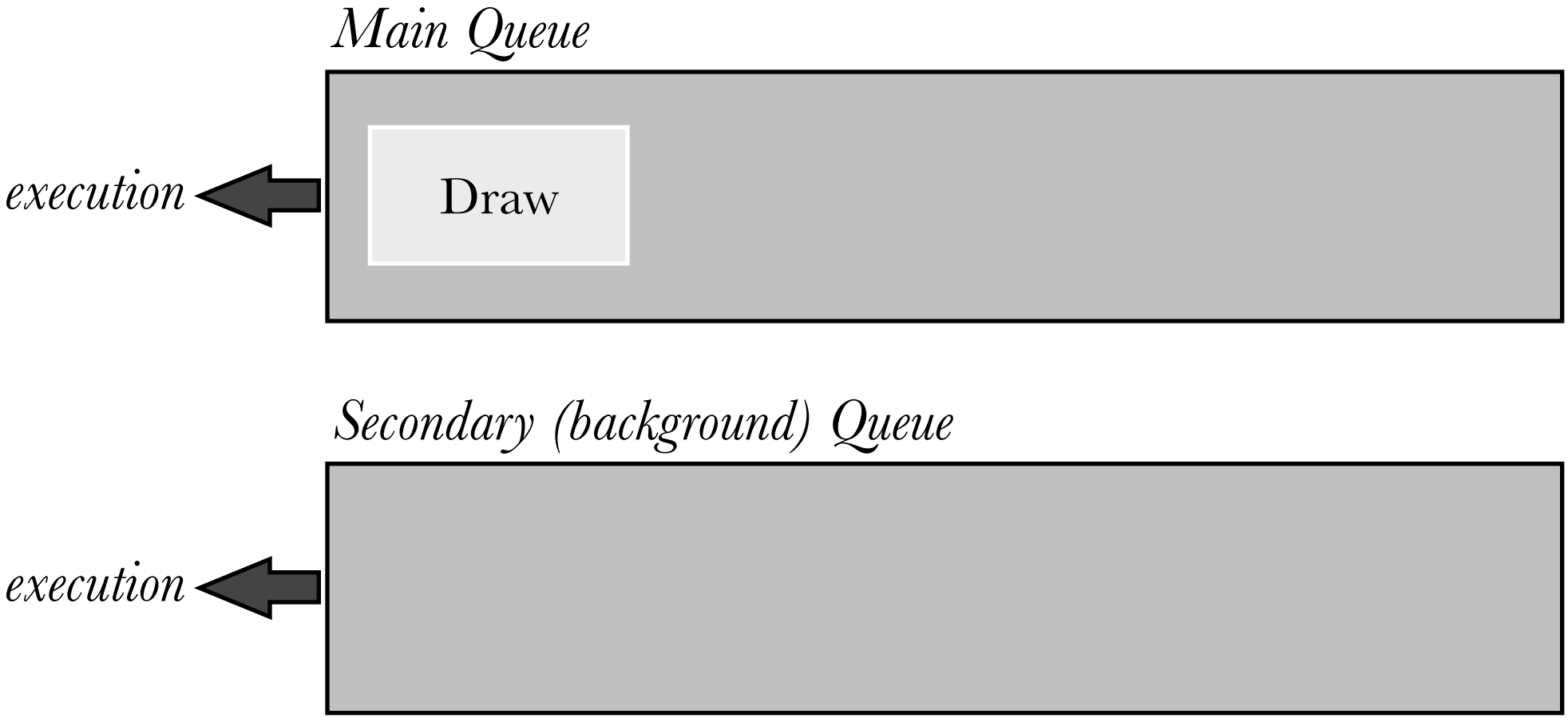
Main Queue
execution
Draw
Secondary (background) Queue
execution

i.e., event processing is outsourced to secondary threads (via run loop); UI updates are performed in the main thread (via main run loop)

Convenience APIs for accessing the main thread / run loop:

```
interface NSThread : NSObject
+ (NSThread *)mainThread;
@end


@interface NSRunLoop : NSObject
+ (NSRunLoop *)mainRunLoop;
@end


@interface NSObject (NSThreadPerformAdditions)
- (void)performSelectorOnMainThread:(SEL)aSelector
                         withObject:(id)arg
                      waitUntilDone:(BOOL)wait;
@end
```

```
- (IBAction)action:(id)sender forEvent:(UIEvent *)event
{
    // outsource event handling to background thread
    [self performSelector:@selector(processEvent:)
                 onThread:processingThread
               withObject:event
            waitUntilDone:NO];
}

- (void)processEvent:(UIEvent *)event
{
    // process event (in background thread)
    id result = lengthyProcessing(event);

    // queue UI update with result in main run loop
    [self performSelectorOnMainThread:@selector(updateUI:)
                           withObject:result
                        waitUntilDone:NO];
}

- (void)updateUI:(id)result
{
    // update the UI (happens in the main thread)
    self.label.text = [result description];
}
```

important: run loops are *not thread safe*!

i.e., don't access other threads' run loops directly (use `performSelector...`)

but manual threading is *old school*!

a host of issues:

- reusing threads (thread pools)
- interdependencies & synchronization
- ideal number of threads?

Grand Central Dispatch is a facility that abstracts away thread-level concurrency with a *queue-based* API

C API for system-managed concurrency

(note: GCD is open sourced by Apple!)

1. Dispatch queues
2. Dispatch sources

```
void dispatch_async(dispatch_queue_t queue,
                    dispatch_block_t block);

void dispatch_async_f(dispatch_queue_t queue,
                      void *context,
                      dispatch_function_t work);

void dispatch_sync(dispatch_queue_t queue,
                   dispatch_block_t block);

void dispatch_sync_f(dispatch_queue_t queue,
                     void *context,
                     dispatch_function_t work);

void dispatch_apply(size_t iterations,
                    dispatch_queue_t queue,
                    void (^block)(size_t));
```

```
// serially process work items
for (int i=0; i<N_WORK_ITEMS; i++) {
    results[i] = process_data(data[i]);
}

summarize(results, N_WORK_ITEMS);
```

```
dispatch_queue_t queue = dispatch_get_global_queue(
                            DISPATCH_QUEUE_PRIORITY_HIGH, 0);

// process work items in blocks added to queue
dispatch_apply(N_WORK_ITEMS, queue, ^(size_t i){
    // block code automagically run in threads
    results[i] = process_data(data[i]);
});

summarize(results, N_WORK_ITEMS);
```

(mini map-reduce)

dispatch queues are backed by threads (# threads determined by system)

main & global queues created for every application; can create more if needed

dispatch sources automatically *monitor* different input sources (e.g., timers, file descriptors, system events)

… and *schedule* blocks on dispatch queues

```
dispatch_queue_t  queue = dispatch_get_global_queue(
                              DISPATCH_QUEUE_PRIORITY_HIGH, 0);

dispatch_source_t timer = dispatch_source_create(
                              DISPATCH_SOURCE_TYPE_TIMER, 0, 0, queue);

dispatch_source_set_timer(timer, DISPATCH_TIME_NOW, 1 * NSEC_PER_SEC, 0.0);

dispatch_source_set_event_handler(timer, ^{ NSLog(@"Beep!"); });

dispatch_resume(timer);
```

```
12:28:55.184 QueueTest[72282:1303] Beep!
12:28:56.184 QueueTest[72282:1a03] Beep!
12:28:57.184 QueueTest[72282:1a03] Beep!
12:28:58.184 QueueTest[72282:1a03] Beep!
12:28:59.184 QueueTest[72282:1a03] Beep!
```

but we rarely use GCD directly

- low level (ugly) C API
- source creation is especially irritating

Operation Queue

(Cocoa wrapper for GCD)

`NSOperationQueue`

manages operation execution, prioritization, and inter-dependencies

Tasks = `NSOperation`

concrete subclasses:

- `NSInvocationOperation`
- `NSBlockOperation`

```
NSOperationQueue *queue = [[NSOperationQueue alloc] init];
[queue setMaxConcurrentOperationCount:2];  // amount of concurrency

NSInvocationOperation *op;
op = [[NSInvocationOperation alloc] initWithTarget:self
                                          selector:@selector(taskMethod:)
                                            object:nil];

NSBlockOperation *bop = [NSBlockOperation blockOperationWithBlock:^{
    // task body
}];

[bop addExecutionBlock:^{
    // can have multiple concurrent blocks in this operation!
}];

[bop setCompletionBlock:^{
    // this is run when all execution blocks complete
}];

[bop addDependency:op]; // bop needs op to complete first (beware cycles!)

[queue addOperation:op];
[queue addOperation:bop];

[queue addOperationWithBlock:^{
    // easier way to schedule a single block as an operation
}];
```

but we run into the same issue as before:

- operation queues are backed by 1+ thread(s), and only the main thread can perform UI updates
- how to return control to main thread from operation queues?

as with run loops, `currentQueue`, `mainQueue` access specific op-queues

— backed by current and main *threads*

solution:

- schedule background operations in secondary queues
- background operations schedule UI updates in main queue

```
- (IBAction)action:(id)sender forEvent:(UIEvent *)event
    [operationQueue addOperationWithBlock:^{
        // process event (in background thread)
        id result = lengthyProcessing(event);
        [[NSOperationQueue mainQueue] addOperationWithBlock:^{
            // update the UI (happens in the main thread)
            self.label.text = [result description];
        }];
    }];
}
```

(compare to:)

```
- (IBAction)action:(id)sender forEvent:(UIEvent *)event
{
    // outsource event handling to background thread
    [self performSelector:@selector(processEvent:)
                 onThread:processingThread
               withObject:event
            waitUntilDone:NO];
}

- (void)processEvent:(UIEvent *)event
{
    // process event (in background thread)
    id result = lengthyProcessing(event);

    // queue UI update with result in main run loop
    [self performSelectorOnMainThread:@selector(updateUI:)
                           withObject:result
                        waitUntilDone:NO];
}

- (void)updateUI:(id)result
{
    // update the UI (happens in the main thread)
    self.label.text = [result description];
}
```

Hands-on

- Projects: *DominantColors*
- Concurrency with NSOperationQueue
- Incorporating a C library

§Bonus: Node.js & Event-Driven Programming