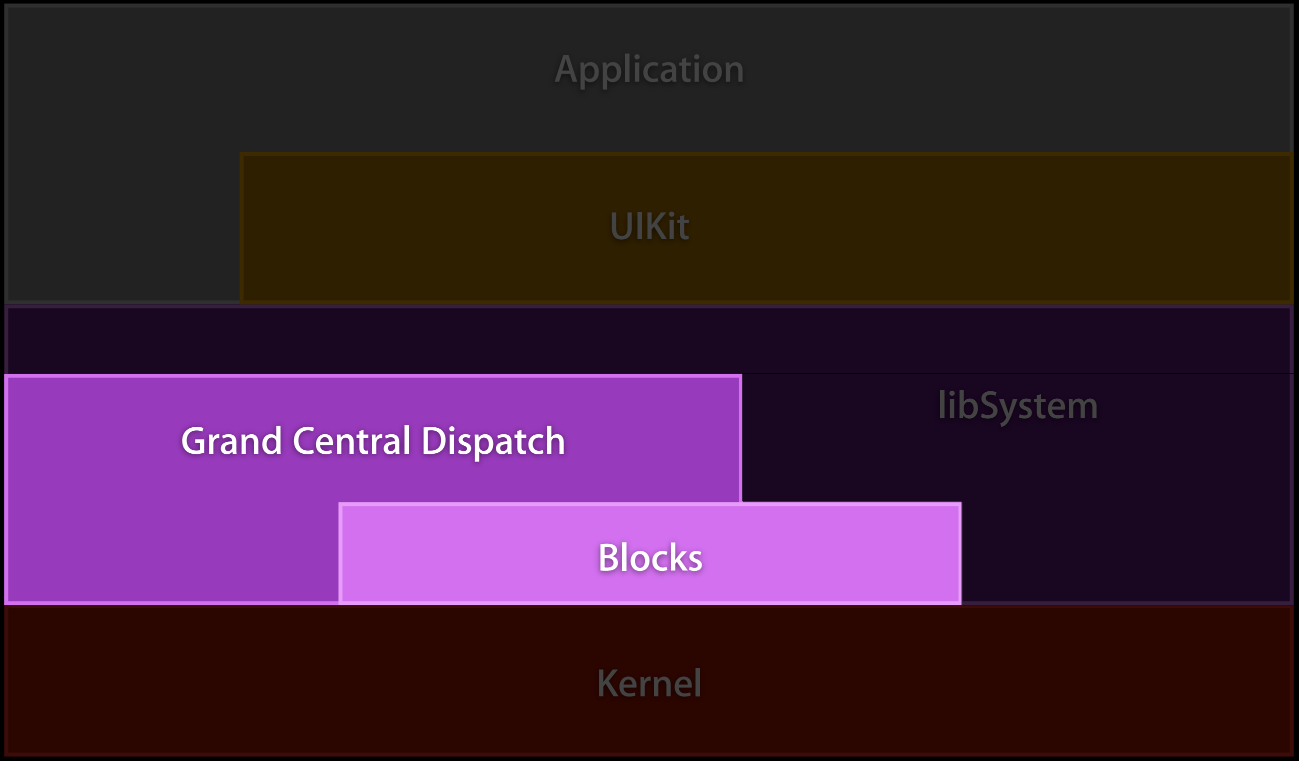
Blocks and Grand Central Dispatch in Practice

Session 308

Dave Zarzycki
Developer Technologies

Technology Stack

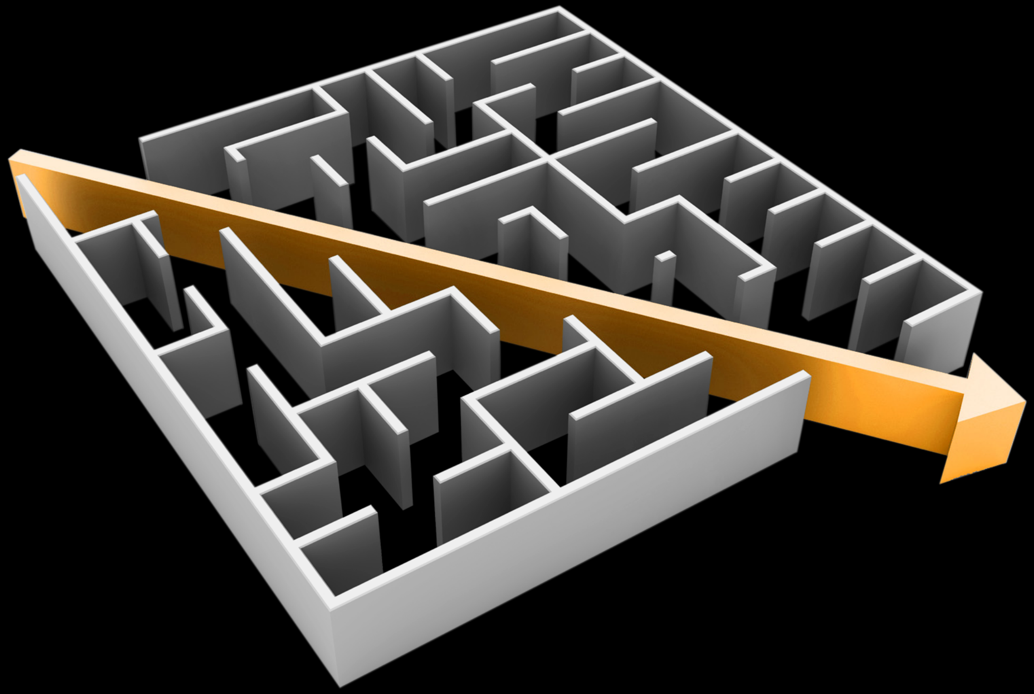


Agenda

- Introduction
  - Blocks
  - Grand Central Dispatch
- Memory management
  - What blocks automate
  - What blocks do not automate

Blocks

Blocks Simplify Function Callbacks



Functions

```
// body of code
{
    return a - b;
}
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Functions

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}
```

Blocks

```
// body of code
{
    return a - b;
}
```

*   ^

Functions

```
// body of code
{
    return a - b;
}

// pointer to a function
     *
```

Blocks

```
// body of code
{
    return a - b;
}

// pointer to a block
     ^
```

Functions

```
// body of code
{
    return a - b;
}

// pointer to a function
int (*cmpr)(int, int);
```

Blocks

```
// body of code
{
    return a - b;
}

// pointer to a block
int (^cmpr)(int, int);
```

Functions

```
// body of code
{
    return a - b;
}

// pointer to a function
int (*cmpr)(int, int);

// better style
typedef int (*func_t)(int, int);
```

Blocks

```
// body of code
{
    return a - b;
}

// pointer to a block
int (^cmpr)(int, int);

// better style
typedef int (^block_t)(int, int);
```

Functions

```
// body of code
{
    return a - b;
}

// pointer to a function
int (*cmpr)(int, int);

// better style
typedef int (*func_t)(int, int);
func_t cmpr = arg;
```

Blocks

```
// body of code
{
    return a - b;
}

// pointer to a block
int (^cmpr)(int, int);

// better style
typedef int (^block_t)(int, int);
block_t cmpr = arg;
```

Functions

```
// body of code
{
    return a - b;
}

// pointer to a function
int (*cmpr)(int, int);

// better style
typedef int (*func_t)(int, int);
func_t cmpr = arg;
cmpr(x, y);
```

Blocks

```
// body of code
{
    return a - b;
}

// pointer to a block
int (^cmpr)(int, int);

// better style
typedef int (^block_t)(int, int);
block_t cmpr = arg;
cmpr(x, y);
```

Functions

```
// body of code
{
    return a - b;
}
```

Blocks

```
// body of code
{
    return a - b;
}
```

Functions

```
// body of code
                         {
    return a - b;
}
```

Blocks

```
// body of code
                {
    return a - b;
}
```

Functions

```
// body of code
          (int a, int b) {
    return a - b;
}
```

Blocks

```
// body of code
 (int a, int b) {
    return a - b;
}
```

Functions

```
// body of code
int my_cmp(int a, int b) {
    return a - b;
}
```

Blocks

```
// body of code
^(int a, int b) {
    return a - b;
}
```

Functions

```
// body of code
int my_cmp(int a, int b) {
    return a - b;
}

// callee
void sort(int *, int, func_t);
```

Blocks

```
// body of code
^(int a, int b) {
    return a - b;
}

// callee
void sort(int *, int, block_t);
```

Functions

```
// body of code
int my_cmp(int a, int b) {
    return a - b;
}

// callee
void sort(int *, int, func_t);

// usage
sort(array, 10, my_cmp);
```

Blocks

```
// body of code
^(int a, int b) {
    return a - b;
}

// callee
void sort(int *, int, block_t);
```

Functions

```
// body of code
int my_cmp(int a, int b) {
    return a - b;
}

// callee
void sort(int *, int, func_t);

// usage
sort(array, 10, my_cmp);
```

Blocks

```
// body of code
^(int a, int b) {
    return a - b;
}

// callee
void sort(int *, int, block_t);

// usage
sort(array, 10, ^(int a, int b) {
    return a - b;
});
```

Trivial Blocks vs. Nontrivial Functions

Implementing a Configurable Sort

Functions

Blocks

Functions

Blocks

```
sort(array, 10, ^(int a, int b) {
    return a - b;
});
```

Functions

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    return a - b;
});
```

Functions

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
bool rev = arg;

sort(array, 10, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s d = { arg };

sort(array, 10, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s d = { arg };

sort(array, 10, &d, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s d = { arg };

sort(array, 10, &d, my_cmp);




//////////////////////////////////////
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s {
    bool rev;
};
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

```
/////////////////////////////////////
struct data_s d = { arg };
sort(array, 10, &d, my_cmp);
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(int a, int b)
{
    return a - b;
}


/////////////////////////////////////
struct data_s d = { arg };
sort(array, 10, &d, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(            int a, int b)
{



        return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, 10, &d, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, 10, &d, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, 10, &d, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, 10, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Extracting Results

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, &d, my_cmp);
```

Blocks

```
bool rev = arg;

sort(array, ^(int a, int b) {
    if (rev) return b - a;
    else return a - b;
});
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, &d, my_cmp);
```

Blocks

```
bool rev = arg;
        int cnt = 0;

sort(array, ^(int a, int b) {
    cnt++;
    if (rev) return b - a;
    else return a - b;
});

log(“Count: %d”, cnt);
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, &d, my_cmp);
```

Blocks

```
bool rev = arg;
__block int cnt = 0;

sort(array, ^(int a, int b) {
    cnt++;
    if (rev) return b - a;
    else return a - b;
});

log("Count: %d", cnt);
```

Functions

```
struct data_s {
    bool rev;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
struct data_s d = { arg };
sort(array, &d, my_cmp);
```

Blocks

```
bool rev = arg;
__block int cnt = 0;

sort(array, ^(int a, int b) {
    cnt++;
    if (rev) return b - a;
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});

log(“Count: %d”, cnt);
```

Functions

```
struct data_s {
    bool rev;

};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;

    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////

struct data_s d = {
    arg,

};
sort(array, &d, my_cmp);
```

Blocks

```
bool rev = arg;
__block int cnt = 0;

sort(array, ^(int a, int b) {
    cnt++;
    if (rev) return b - a;
    else return a - b;
});

log(“Count: %d”, cnt);
```

Functions

```
struct data_s {
    bool rev;
    int *out_count;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    (*d->out_count)++;
    if (d->rev) return b - a;
    else return a - b;
}
////////////////////////////////////
int cnt = 0;
struct data_s d = {
    arg,
    &cnt
};
sort(array, &d, my_cmp);

log(“Count: %d”, cnt);
```

Blocks

```
bool rev = arg;
__block int cnt = 0;

sort(array, ^(int a, int b) {
    cnt++;
    if (rev) return b - a;
    else return a - b;
});

log(“Count: %d”, cnt);
```

Functions

```
struct data_s {
    bool rev;
    int *out_count;
};

int my_cmp(void *ctxt, int a, int b)
{
    struct data_s *d = ctxt;
    (*d->out_count)++;
    if (d->rev) return b - a;
    else return a - b;
}
/////////////////////////////////////
int cnt = 0;
struct data_s d = {
    arg,
    &cnt
};
sort(array, &d, my_cmp);

log(“Count: %d”, cnt);
```

Blocks

```
bool rev = arg;
__block int cnt = 0;

sort(array, ^(int a, int b) {
    cnt++;
    if (rev) return b - a;
    else return a - b;
});

log(“Count: %d”, cnt);
```

Blocks and Apple

Many APIs use them

Examples

Enumeration

```
[dict enumerateKeysAndObjectsUsingBlock: ^(id key, id obj, BOOL *stop) {
    NSLog(@"%@ = %@", key, object);
}];

[array enumerateObjectsUsingBlock: ^(id obj, NSUInteger idx, BOOL *stop) {
    NSLog(@"%lu = %@", idx, object);
}];

// and more!
```

Examples

Callbacks

```
^(void) { ... }
```

Examples

Callbacks

```
^(void) { ... }
```

```
^{ ... }
```

Grand Central Dispatch

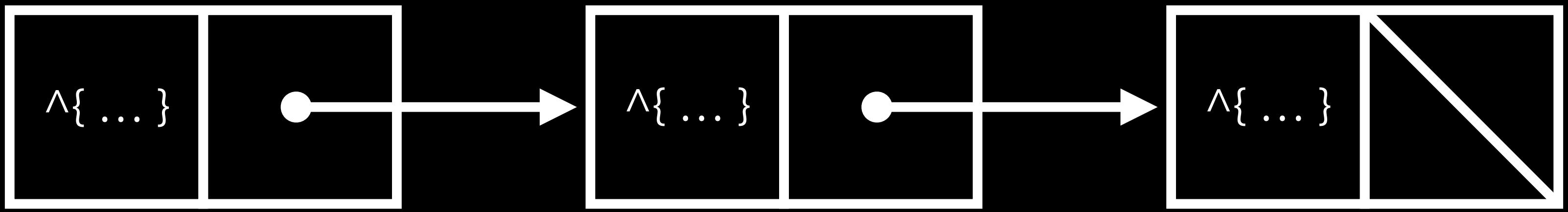
Kevin Van Vechten
Core OS

Grand Central Dispatch

- Execute blocks on queues
  - Serialized
  - Concurrent
  - Asynchronous

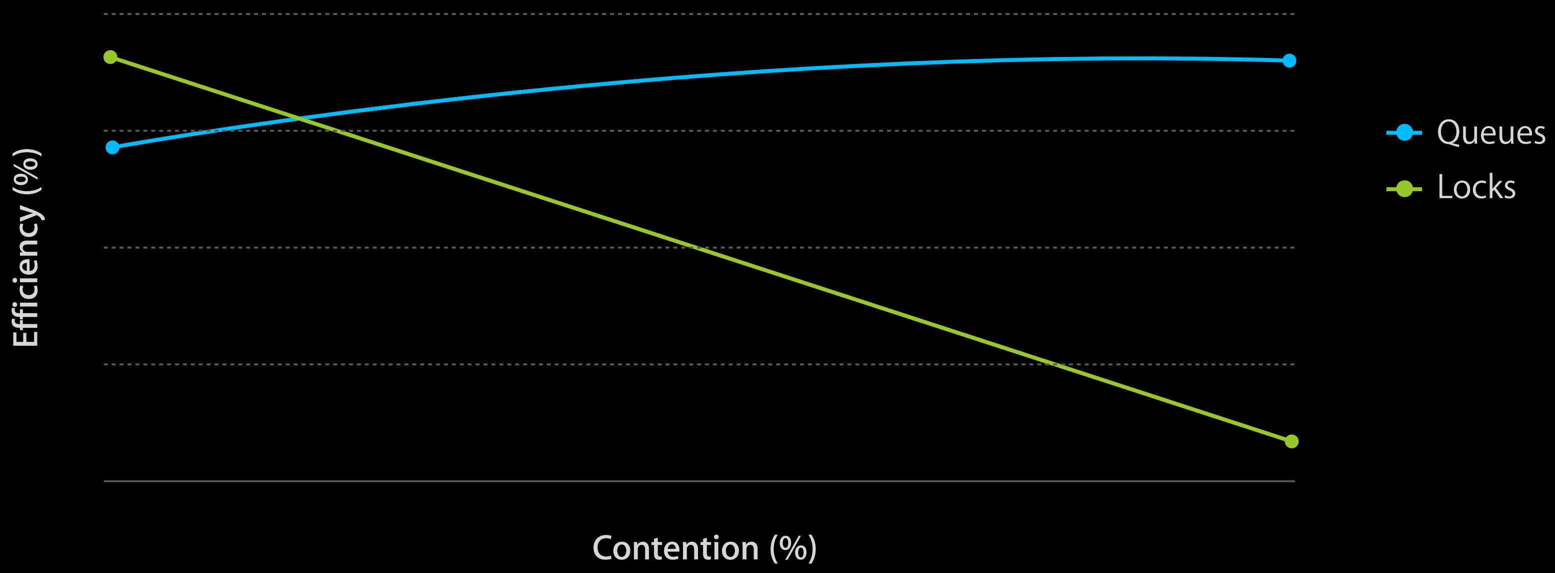
Queues

- FIFO
- Atomic enqueue
- Automatic dequeue



Throughput

Throughput efficiency vs. contention



Scaleability

From one to many cores

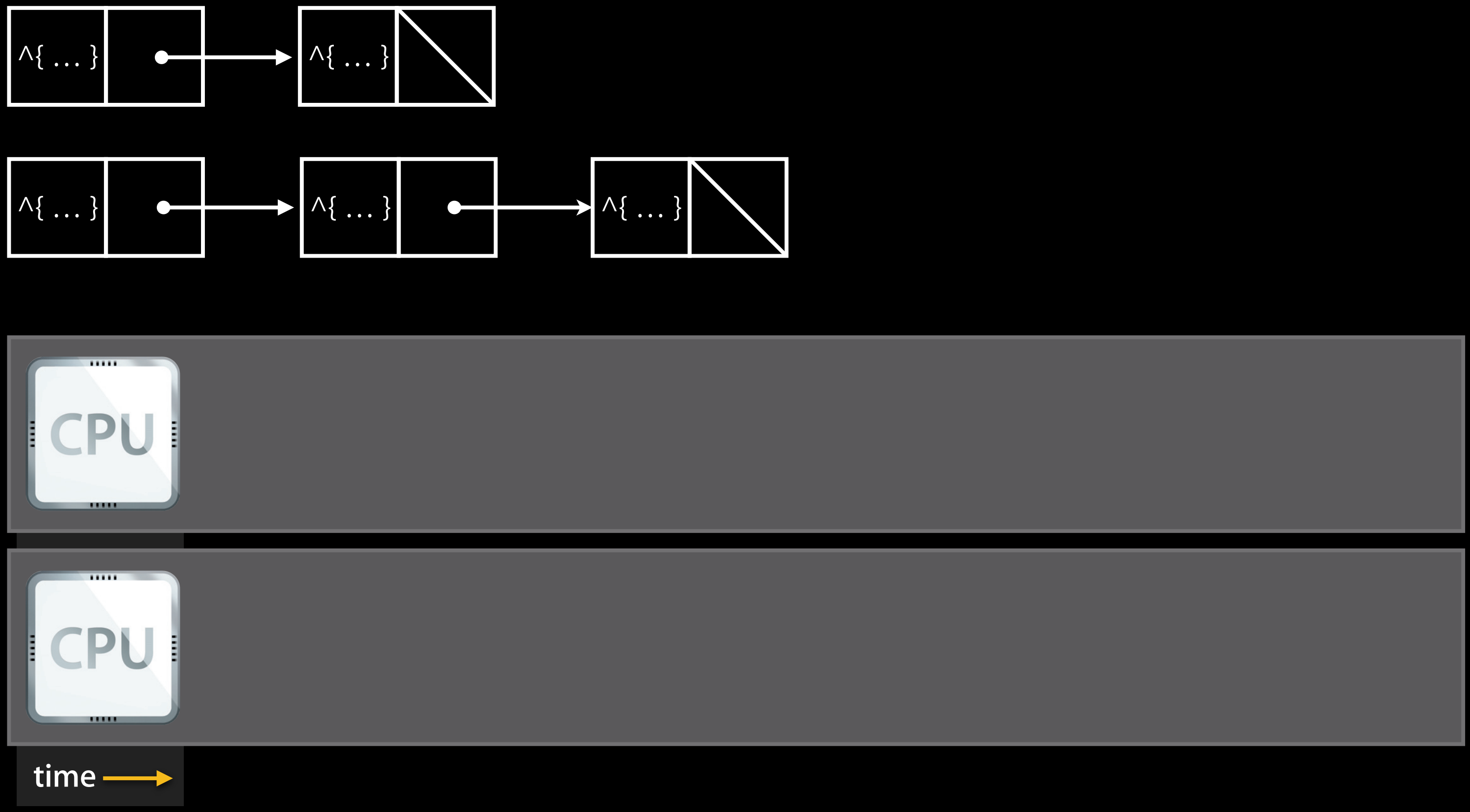
Scaleability

From one to many cores

Scaleability

From one to many cores

Automatic Threads



Dispatch Fundamentals

- dispatch_queue_t
- dispatch_sync
- dispatch_apply
- dispatch_async

dispatch_queue_t

A dispatch queue object

- Standard create/retain/release semantics

```
dispatch_queue_t q = dispatch_queue_create(“com.example.myqueue”, NULL);

// must pair retain & release
dispatch_retain(q);
dispatch_release(q);

// last release deallocates
dispatch_release(q);
```

dispatch_sync

dispatch_sync

Enqueue a block for synchronous execution

- Useful to implement critical sections

```
bool debit_account(Account *account, Transaction *transaction)
{
  dispatch_sync(account->queue, ^{
      account->balance -= transaction->amount;
  });
  return true;
}
```

dispatch_sync

Advanced patterns

- Use __block to modify enclosing scope
- Use return to safely leave critical section

```
bool debit_account(Account *account, Transaction *transaction)
{
  __block bool result = false;
  dispatch_sync(account->queue, ^{
     if (transaction->amount > account->balance) return;
     account->balance -= transaction->amount;
     result = true;
  });
  return result;
}
```

dispatch_sync

Caveat

- Queues are strictly FIFO therefore nested dispatch_sync *will* deadlock

```
dispatch_sync(queue, ^{
  dispatch_sync(queue, ^{
     // NOT REACHED: DEADLOCK
  });
});
```

dispatch_apply

dispatch_apply

Data-level parallelism with blocks

- Scales with number of cores and concurrent dispatch_apply operations

```
// for (index = 0; index < count; index++) {
dispatch_apply(count, queue, ^(size_t index) {
  outputs[index] = perform_computation(inputs[index]);
});
```

```
dispatch_apply(count, queue, ^(size_t index) { … });
```

CPU
CPU
time

dispatch_apply

Caveat

- Watch out for hidden locks that negate performance benefits

```
dispatch_apply(count, queue, ^(size_t index) {
  printf(“%lu\n”, index);
});
```

dispatch_apply

Striding

- Amortize costs for tiny operations
- Avoid false cache sharing

```
#define STRIDE (10 * (CACHE_LINE_SIZE / sizeof(double))) // measure & tune!
dispatch_apply(count / STRIDE, queue, ^(size_t index) {
  size_t j = index * STRIDE;
  size_t j_stop = j + STRIDE;
  do {
      outputs[index] = perform_computation(inputs[index]);
  } while (j < j_stop);
});
```

dispatch_async

dispatch_async

Enqueue a block for *asynchronous* execution

- Useful to implement deferred critical sections
- Returns immediately

```
void calculate_interest(Account *account)
{
    dispatch_async(account->queue, ^{
        account->balance += account->balance * INTEREST_RATE;
    });
}
```

dispatch_async

- Move work off the main thread
  - Stay responsive to UI events
- Deferred execution of tasks
  - Automatic concurrency

dispatch_async

Nested invocations provide asynchronous callbacks

- Communication between subsystems
- Useful pattern to avoid blocking the main thread

```
-(IBAction)onClick:(NSButton *)sender
{
  dispatch_async(account->queue, ^{
     NSImageRep *image = renderAccountStatement(account);
     dispatch_async(dispatch_get_main_queue(), ^{
        [image draw];
     });
  });
}
```

dispatch_async

Advanced patterns

- Use queue—block callback pair as last arguments to async functions

```
void renderAccountStatementAsync(Account *account,
  dispatch_queue_t queue, my_callback_t block);

-(IBAction)onClick:(NSButton *)sender
{
  renderAccountStatementAsync(account, dispatch_get_main_queue(),
  ^(NSImageRep *image) {
     [image draw];
  });
}
```

dispatch_async

Caveat

- dispatch_queue_t must be retained in nested blocks
- C dynamic allocations must be manually copied/retained

```
void myAsync(dispatch_queue_t queue, my_callback_t block)
{
  dispatch_retain(queue);
  dispatch_async(background_queue, ^{
      dispatch_async(queue, ^{
          block();
      });
      dispatch_release(queue);
  });
}
```

Blocks and Memory Management

Dave Zarzycki
Developer Technologies

Functions

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

Blocks

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

Functions

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

Blocks

```
void dispatch_async(
    dispatch_queue_t queue,
    dispatch_block_t block)
{
    dispatch_async_f(queue,
        Block_copy(block),
        _static_helper);
}
```

Functions

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

Blocks

```
void dispatch_async(
    dispatch_queue_t queue,
    dispatch_block_t block)
{
    dispatch_async_f(queue,
        Block_copy(block),
        _static_helper);
}
void _static_helper(void *ctxt) {
    dispatch_block_t b = ctxt;
    b();
    Block_release(b);
}
```

Functions

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

Blocks

```
void dispatch_async(
    dispatch_queue_t queue,
    dispatch_block_t block)
{
    dispatch_async_f(queue,
        Block_copy(block),
        _static_helper);
}
void _static_helper(void *ctxt) {
    dispatch_block_t b = ctxt;
    b();
    Block_release(b);
}
```

Blocks Trivially Wrap Traditional APIs

What Does Block_copy() Do?

- Automatically copies values
  - Integers, floats, pointers, etc
  - Shared variables are forced with __block
- Automatically copies and releases other blocks
- Automatically retains and releases Objective-C objects
- Automatically calls C++ copy constructors and destructors
  - Use the Apple LLVM 3.0 Compiler

What Does Block_copy() Not Do?

Read your mind…

```
dispatch_async(queue, ^{



    [_ivar doSomething];
});
```

What Does Block_copy() Not Do?

Read your mind…

```
dispatch_async(queue, ^{
    // implicitly: self->_ivar
    // therefore: self is automatically retained
    [_ivar doSomething];
});
```

What Does Block_copy() Not Do?

Read your mind…

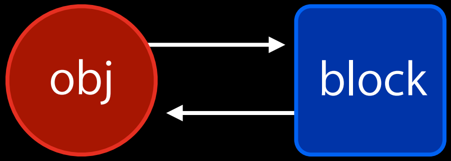
```
dispatch_async(queue, ^{
    // implicitly: self->_ivar
    // therefore: self is automatically retained
    [_ivar doSomething];
});

NSThingy *tmp = _ivar;    // workaround
dispatch_async(queue, ^{
    [tmp doSomething];
});
```

What Does Block_copy() Not Do?

Fix retain cycles…

```
[obj setHandler: ^{
    [obj doSomething];
}];
```

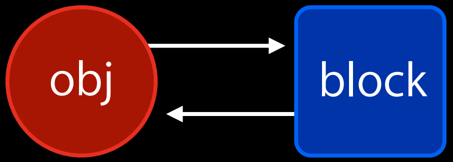


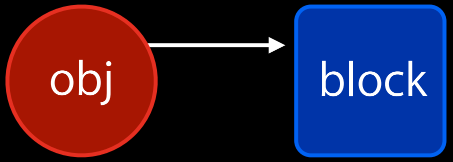
What Does Block_copy() Not Do?

Fix retain cycles…

```
[obj setHandler: ^{
    [obj doSomething];
}];

// workaround via __block which
// does not implicitly retain
__block NSThingy *tmp = obj;
[obj setHandler: ^{
    [tmp doSomething];
}];
```


$$\begin{tikzcd} \text{obj} \arrow[r, shift left] & \text{block} \arrow[l, shift left] \end{tikzcd}$$


$$\begin{tikzcd} \text{obj} \arrow[r] & \text{block} \end{tikzcd}$$

What Does Block_copy() Not Do?

Retain non-objects…

```
dispatch_async(queue, ^{
    xyz();
    dispatch_async(other_queue, ^{
        abc();
    });
});
```

What Does Block_copy() Not Do?

Retain non-objects…

```
dispatch_retain(other_queue);
dispatch_async(queue, ^{
    xyz();
    dispatch_async(other_queue, ^{
        abc();
    });
    dispatch_release(other_queue);
});
```

What Does Block_copy() Not Do?

Retain non-objects…

```
CFRetain(foo);
dispatch_async(queue, ^{
    CFFooDoSomethingAwesome(foo);
    CFRelease(foo);
});
```

What Does Block_copy() Not Do?

Not implicitly called by non-blocks…

```
block_t array[10];

for (i = 0; i < 10; i++) {
    // the block is only valid inside the loop!
    array[i] = ^{ ... };
}
```

What Does Block_copy() Not Do?

Not implicitly called by non-blocks…

```
block_t array[10];

for (i = 0; i < 10; i++) {
    // the block is only valid inside the loop!
    array[i] = ^{ ... };
}

return ^{ ... };

// code must Block_copy() to outlive scope!
```

Better Blocks

Automatic reference counting

- Many of these challenges are solved by ARC
- Some are not
  - Retain and release of non-objects
- See the ARC talks for more information

Conclusion

- Blocks and Grand Central Dispatch
    - Simpler
    - Safer
- Already patterns you use today
    - Enumeration
    - Callbacks
    - Synchronization
    - Asynchronous code

More Information

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Documentation
Concurrency Programming Guide
http://developer.apple.com

Open Source
Mac OS Forge > libdispatch
http://libdispatch.macosforge.org

Apple Developer Forums
http://devforums.apple.com

Related Sessions

Developer Tools Kickoff	Pacific Heights Monday 3:15PM
Introducing Automatic Reference Counting	Presidio Tuesday 4:30PM
Mastering Grand Central Dispatch	Pacific Heights Thursday 10:15AM
Objective-C Advancements In–Depth	Mission Friday 11:30AM

Labs

Grand Central Dispatch Lab	Core OS Lab A Thursday 2:00PM
Xcode 4 Lab	Developer Tools Lab A Wednesday 11:30AM
Xcode 4 Lab	Developer Tools Lab A Thursday 11:30AM
LLVM Lab	Developer Tools Lab A Wednesday 2:00PM
Objective–C and Automatic Reference Counting Lab	Developer Tools Lab B Thursday 2:00PM

Q&A

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