# Power, Performance, and Diagnostics

## What's new in GCD and XPC

Session 716

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Darwin Runtime Engineer

# Overview

Background

Quality of Service Classes

New QoS and GCD API

Propagation of QoS and Execution Context

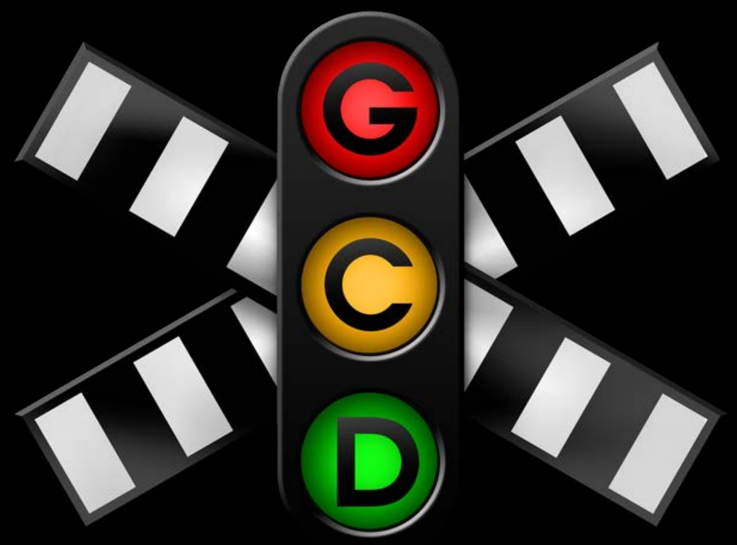
Diagnostics and Queue Debugging

# Grand Central Dispatch

Asynchronous execution

Concurrent execution

Synchronization

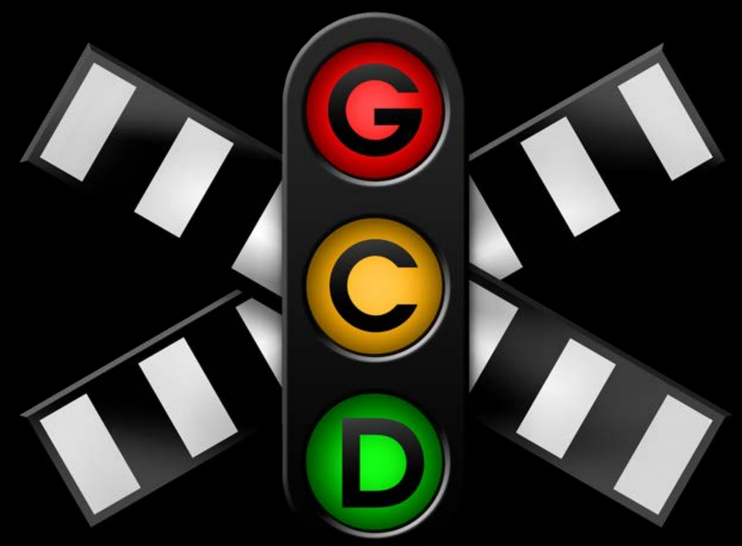


# Asynchronous Execution

# Asynchronous Execution

## GCD

Run code in separate environment
in same process

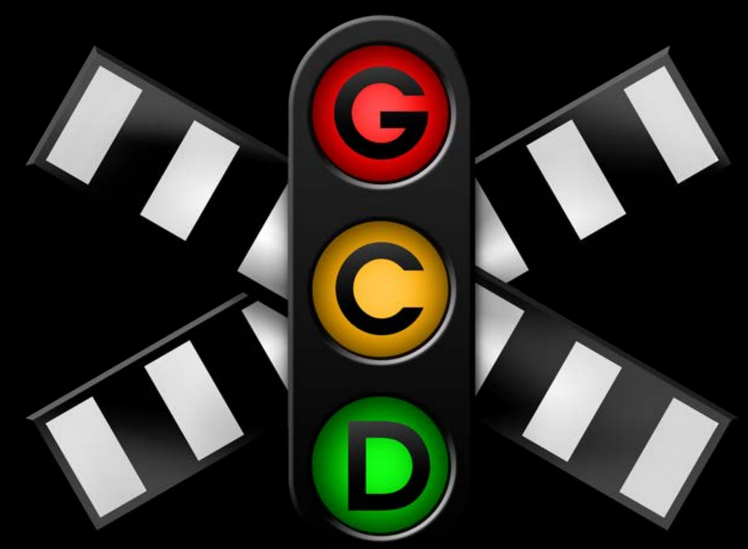


# Asynchronous Execution

## GCD

Run code in separate environment
in same process

- Avoid interfering with current thread
- Different priority level
- Coordination between multiple clients



# Asynchronous Execution

## XPC

Run code in separate process

# Asynchronous Execution

## XPC

Run code in separate process

- Avoid interfering with current process
- Different privilege level
- Coordination between multiple clients

# Previously…

## On developer.apple.com

| | |
|---|---|
| • Introducing Blocks and Grand Central Dispatch on iPhone | WWDC 2010 |
| • Simplifying iPhone App Development with Grand Central Dispatch | WWDC 2010 |
| • Introducing XPC | WWDC 2011 |
| • Blocks and Grand Central Dispatch in Practice | WWDC 2011 |
| • Mastering Grand Central Dispatch | WWDC 2011 |
| • Asynchronous Design Patterns with Blocks, GCD, and XPC | WWDC 2012 |
| • Efficient Design with XPC | WWDC 2013 |

# The Big Picture

# Primary Goal

Provide best user experience

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Provide best user experience

What is important to user?

# Primary Goal

Provide best user experience

What is important to user?

- Frontmost app
- Responsive user interface

# Responsive User Interface

# Responsive User Interface

Ensure resource availability for

- Main thread of frontmost app
  - UI event handling
  - UI drawing
- OS User Interface infrastructure

# Responsive User Interface

Other work should execute

- Off main thread
- Independently
- At lower priority

# Priorities

# Priorities

Resolving resource contention

# Priorities

Resolving resource contention

Under contention

- High priorities win

# Priorities

Resolving resource contention

Under contention

- High priorities win

No contention

- Low priorities have no restriction

# Scheduling Priority

Kernel scheduler

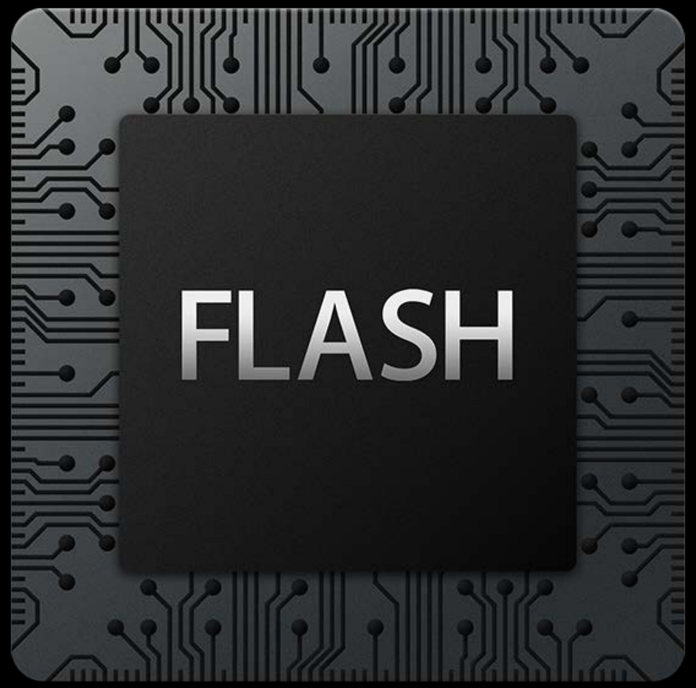
- High priorities get CPU first
- Low priorities
  - No restriction if no contention
  - May not run during UI activity

# I/O Priority

Background queue

Low priority I/O

- No restriction if no high priority I/O present
- Otherwise deprioritized



# Priorities

Many other resource controls

Complex configuration

No unified approach

No clear expression of intent

# Quality of Service Classes

# Quality of Service Classes

NEW

Communicate developer intent

Explicit classification of work

Single abstract parameter

- Move away from dictating specific configuration values

# Quality of Service Classes

## Effects

CPU scheduling priority

I/O priority

Timer coalescing

CPU throughput vs. efficiency

More…

# Quality of Service Classes

## Effects

CPU scheduling priority

I/O priority

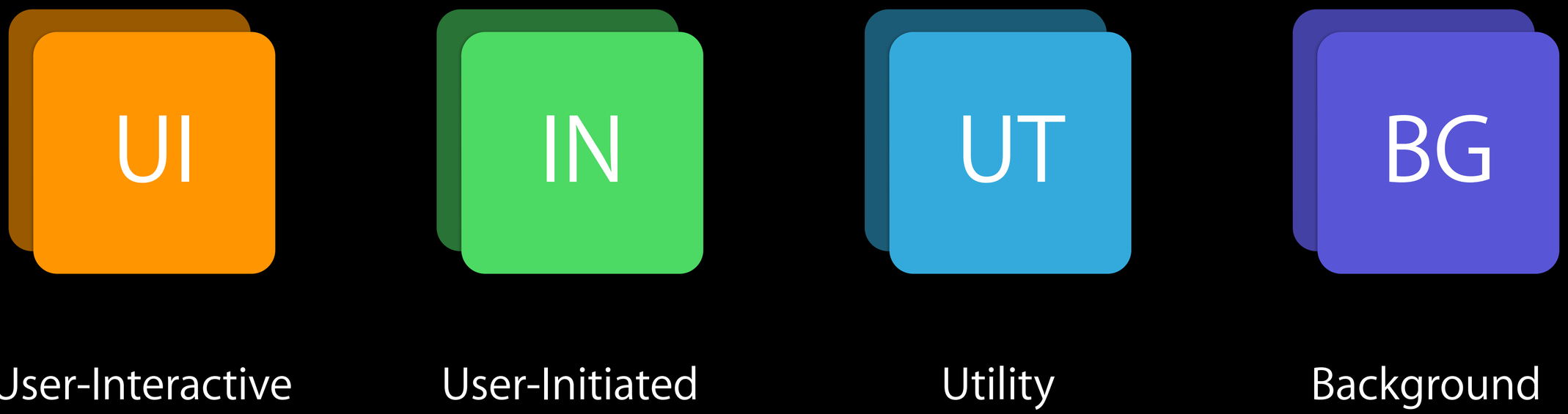
Timer coalescing

CPU throughput vs. efficiency

More…

Configuration values tuned for each platform/device

# QoS Classes


UI
IN
UT
BG
User-Interactive
User-Initiated
Utility
Background

# User-Interactive

UI thread

Directly involved in

- Event handling
- UI drawing

Small fraction of total work

# User-Initiated

Asynchronous to UI

Directly UI-initiated

User waiting for immediate results

Required to continue user interaction

# Utility

Long-running with user-visible progress

- Computation, I/O, networking

Ongoing data feed to UI

Getting ready for next UI request

Energy efficient

# Background

User is unaware work is occurring

Prefetching

Deferrable

Maintenance

# Choosing QoS Class

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| | | |
|---|---|---|
| UI | User Interactive | Is this work actively involved in updating the UI? |

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# Choosing QoS Class

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|---|---|---|
| UI | User Interactive | Is this work actively involved in updating the UI? |
| IN | User Initiated | Is this work required to continue user interaction? |
| UT | Utility | Is the user aware of the progress of this work? |
| BG | Background | Can this work be deferred to start at a better time? |

# Choosing QoS Class

| | |
|---|---|
| UI | User Interactive |
| IN | User Initiated |
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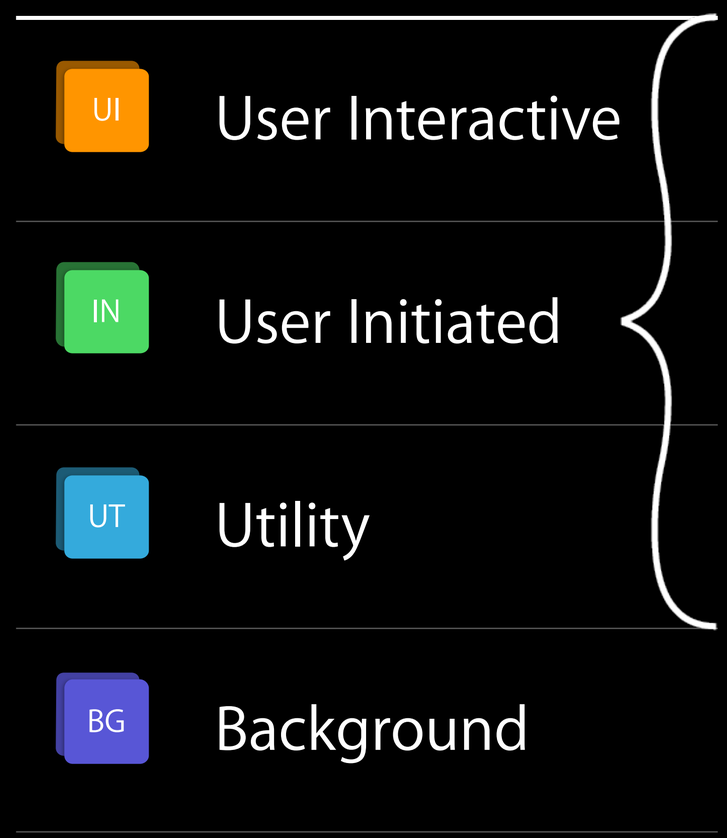
| BG | Background |

# Choosing QoS Class



# Choosing QoS Class

| | | |
|---|---|---|
| UI | User Interactive | Is it okay for User Interactive work to happen before my work? |
| IN | User Initiated | Is it okay for this work to compete with other User Initiated work? |
| UT | Utility | Is it okay for my work to take precedence over Utility work? |
| BG | Background | |

# Recap

Responsive User Interface

- Asynchronous execution at correct priority
- Had no unified way to express intent

Quality of Service Classes

- Explicit abstract classification of work
- Questions for choosing QoS

# QoS Class API

# QoS Class

## Can be specified on

Threads

Dispatch Queues

Dispatch Blocks

NSOperationQueue/NSOperation

Processes

# QoS Class Constants

| | sys/qos.h | Foundation.h |
|---|---|---|
| UI | QOS_CLASS_USER_INTERACTIVE | NSQualityOfServiceUserInteractive |
| IN | QOS_CLASS_USER_INITIATED | NSQualityOfServiceUserInitiated |
| UT | QOS_CLASS_UTILITY | NSQualityOfServiceUtility |
| BG | QOS_CLASS_BACKGROUND | NSQualityOfServiceBackground |

# QoS Class Constants

| | sys/qos.h | Foundation.h |
|---|---|---|
| UI | QOS_CLASS_USER_INTERACTIVE | NSQualityOfServiceUserInteractive |
| IN | QOS_CLASS_USER_INITIATED | NSQualityOfServiceUserInitiated |
| DF | QOS_CLASS_DEFAULT | |
| UT | QOS_CLASS_UTILITY | NSQualityOfServiceUtility |
| BG | QOS_CLASS_BACKGROUND | NSQualityOfServiceBackground |
| | QOS_CLASS_UNSPECIFIED | |

# Special QoS Class Values

`QOS_CLASS_DEFAULT`

- No specific QoS information was available
- Ordered between UI and non-UI QoS
- Thread and global queue default
- Not intended as a work classification

| | |
|---|---|
| UI | User Interactive |
| IN | User Initiated |
| DF | Default |
| UT | Utility |
| BG | Background |

# Special QoS Class Values

`QOS_CLASS_UNSPECIFIED`

- No QoS specification at given level
- QoS should be inferred from work origin
- Returned after legacy API QoS opt-out

# QoS Relative Priority

Relative position within a QoS Class band

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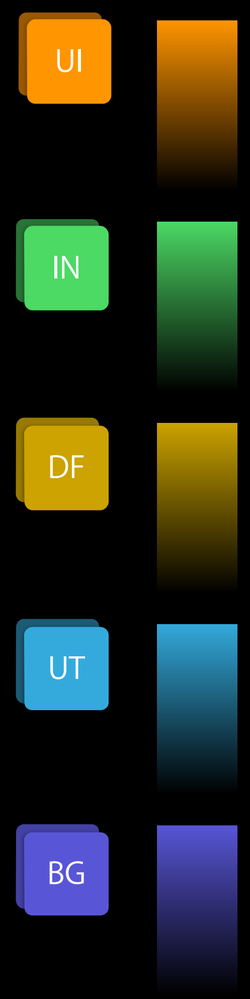

# QoS Relative Priority

Relative position within a QoS Class band

Lower than default

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Relative position within a QoS Class band

Lower than default

Intended for unusual situations

- Interdependent work within same QoS class with differing priority
- Producer/Consumer scenarios

# Thread QoS API

# Thread QoS Getters

QoS Class of current thread

```
qos = qos_class_self();
```

Initial QoS Class of main thread

```
qos = qos_class_main();
```

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| Process Type | Main QoS |
|---|---|
| App | User-Interactive |
| XPC Service | Default |

# GCD QoS API

# Global Queues

| Global Queue |
| --- |
| Main |
| High priority concurrent |
| Default priority concurrent |
| Low priority concurrent |
| Background priority concurrent |

# Global Queues

| | QoS Class | Global Queue |
|---|---|---|
| UI | User Interactive | Main |
| IN | User Initiated | High priority concurrent |
| DF | Default | Default priority concurrent |
| UT | Utility | Low priority concurrent |
| BG | Background | Background priority concurrent |

# Global Queues with QoS

Get a global concurrent queue with QoS Class

```
queue = dispatch_get_global_queue(QOS_CLASS_UTILITY, 0);
```

Get QoS Class of a queue

```
qos = dispatch_queue_get_qos_class(queue, &relative);
```

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Get a global concurrent queue with QoS Class

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```

# Queue QoS API

Get QoS queue attribute:

```
qos_attr = dispatch_queue_attr_make_with_qos_class(
                                                attr, QOS_CLASS_UTILITY, 0);
```

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# Queue QoS API

Get QoS queue attribute:

```
qos_attr = dispatch_queue_attr_make_with_qos_class(
                                                attr, QOS_CLASS_UTILITY, 0);

queue = dispatch_queue_create(“com.my.utility”, qos_attr);
```

# Dispatch Block Objects

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Configure properties of individual units of work on a queue

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Address individual workunits for

- Wait for completion
- Completion notification
- Cancellation

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Integrate with existing API

# Dispatch Block Objects

## Wrapper Block

Created from an existing GCD Block

- dispatch_block_t

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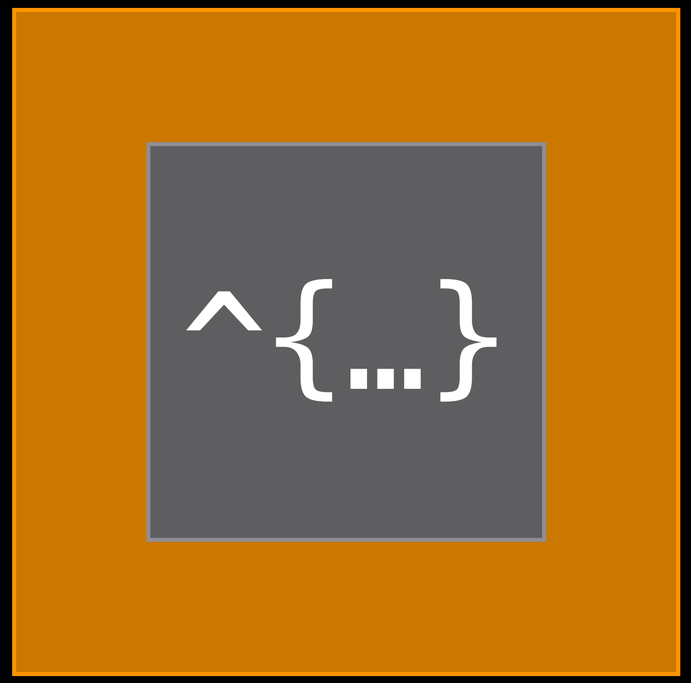
Created from an existing GCD Block

- dispatch_block_t

Additional configuration

- QoS Class
- Flags



# Dispatch Block Objects

## Wrapper Block

Created from an existing GCD Block

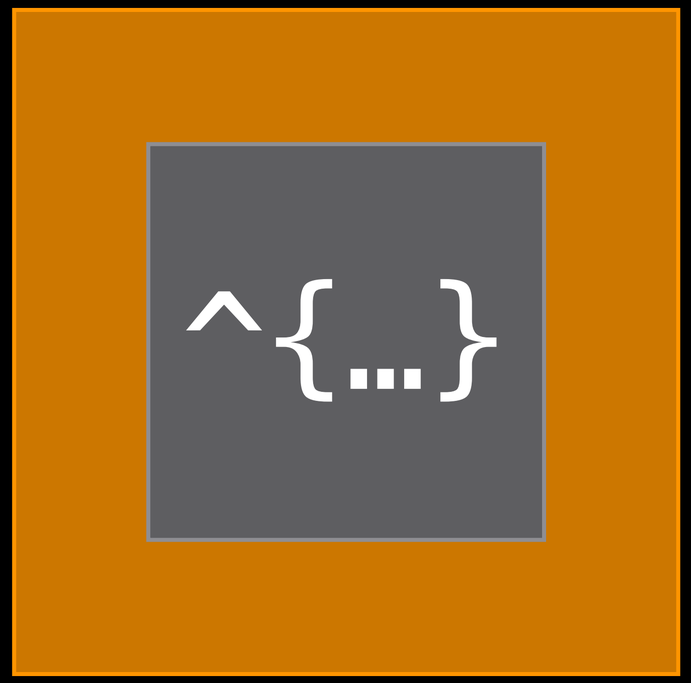
- dispatch_block_t

Additional configuration

- QoS Class
- Flags

Heap object

- Block_release()



# GCD Block API

```
dispatch_block_t block;

block = dispatch_block_create(0, ^{
    NSLog(@“Hello World!”);
});

dispatch_async(queue, block);

// Do some work

dispatch_wait(block, DISPATCH_TIME_FOREVER);

Block_release(block);
```

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# GCD Block API

```
dispatch_block_t block;

block = dispatch_block_create_with_qos_class(
              0, QOS_CLASS_UTILITY, -8, ^{…});

dispatch_async(queue, block);

// Do some work
// Change your mind

dispatch_cancel(block);

Block_release(block);
```

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# GCD Block API

```
dispatch_block_t block;

block = dispatch_block_create(DISPATCH_BLOCK_DETACHED, ^{
    // Clean caches
});

dispatch_async(queue, block);

dispatch_notify(block, dispatch_get_main_queue(), ^{
    // Cleanup complete
});

Block_release(block);
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# Interaction of QoS Specifications

# Interaction of Multiple QoS Specifications

## Asynchronous Blocks

Default to QoS class of queue

- Or inherited from immediate global target queue

# Interaction of Multiple QoS Specifications

## Asynchronous Blocks

Default to QoS class of queue

- Or inherited from immediate global target queue

If neither are specified

- Use Block QoS class
- Or QoS inferred from submitting thread

# Interaction of Multiple QoS Specifications

## Inferred QoS

QoS captured at the time of block submission

- User Interactive translated to User Initiated

# Interaction of Multiple QoS Specifications

## Inferred QoS

QoS captured at the time of block submission

- User Interactive translated to User Initiated

Intended for use on queues

- Without specific identity or single purpose
- Mediating between many different clients

# Interaction of Multiple QoS Specifications

## Synchronous Blocks

Default to QoS class of Block

- Or current thread
- Will only raise QoS

# Interaction of Multiple QoS Specifications

## Explicit control

`DISPATCH_BLOCK_INHERIT_QOS_CLASS`

- Prefer queue/thread QoS

`DISPATCH_BLOCK_ENFORCE_QOS_CLASS`

- Prefer Block QoS
- Only if higher than queue/thread QoS

# Interaction of Multiple QoS Specifications

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# Priority Inversions

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Progress of high-priority work depends on

- Results of low-priority work
- Resource held by low-priority work

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- Results of low-priority work
- Resource held by low-priority work

High-priority threads are

- Blocking
- Spinning/polling

Waiting for low-priority threads

# Priority Inversion

## Synchronous

High QoS thread waiting on lower QoS work

# Priority Inversion

## Synchronous

High QoS thread waiting on lower QoS work

System will attempt to automatically resolve inversion for

- `dispatch_sync()` and `dispatch_wait()` of blocks on serial queues
- `pthread_mutex_lock()`

QoS of work is raised for the duration of the wait

# Priority Inversion

## Asynchronous

High QoS Block submitted to serial queue

- Created with lower QoS
- Containing Blocks with lower QoS

# Priority Inversion

## Asynchronous

High QoS Block submitted to serial queue

- Created with lower QoS
- Containing Blocks with lower QoS

System will attempt to automatically resolve inversion

QoS of queue is raised until high QoS Block is reached

# Avoiding Priority Inversions

Decouple shared data as much as possible

- Use finer grained synchronization
- Move work outside of lock/serial queue

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# Avoiding Priority Inversions

Decouple shared data as much as possible

- Use finer grained synchronization
- Move work outside of lock/serial queue

Prefer asynchronous execution over synchronous waiting

Avoid spinning/polling

- Look out for timer-based “synchronization”

# Recap

QoS Class constants

QoS relative priority

Thread and queue QoS API

Dispatch Block API

Interaction of multiple QoS specifications

Priority Inversions

# Propagation of Execution Context

# Execution Context

Thread-local attributes maintained by system

- Activity ID
- Properties of current IPC request
  - Originator
  - Importance
  - More…

# Execution Context

## Automatic propagation

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Propagated across threads

- GCD
- NSOperationQueue
- Foundation

# Execution Context

## Automatic propagation

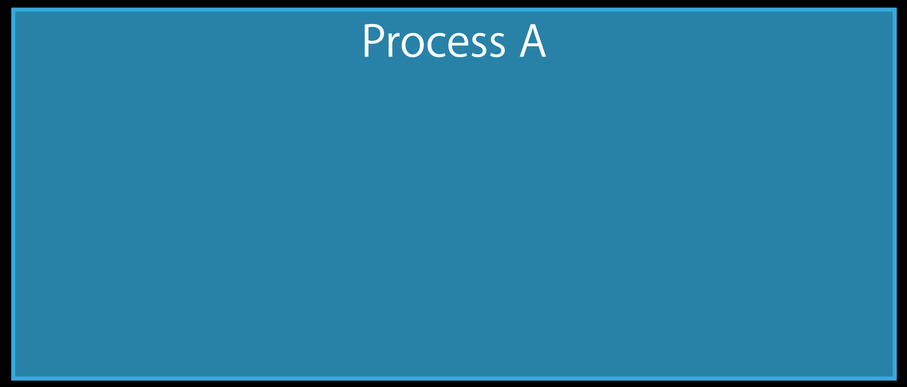
Propagated across threads

- GCD
- NSOperationQueue
- Foundation

Propagated across processes

- XPC
- MIG
- CFMachPort

# Automatic Propagation



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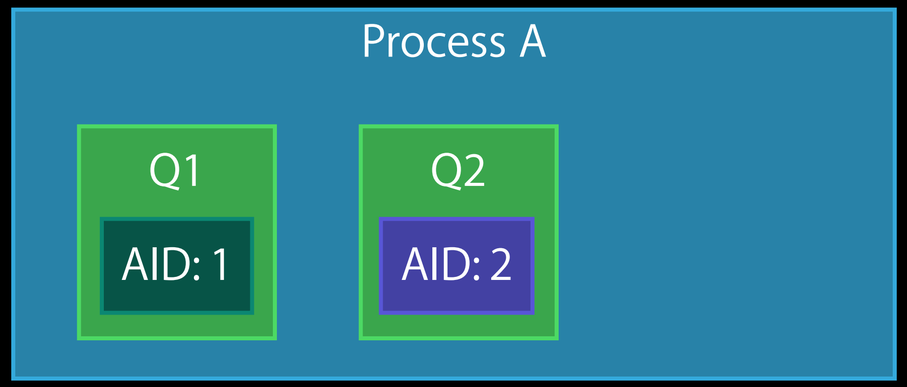

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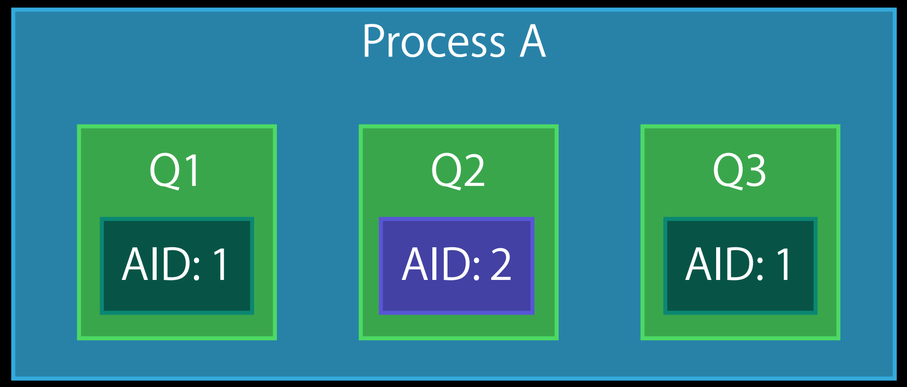

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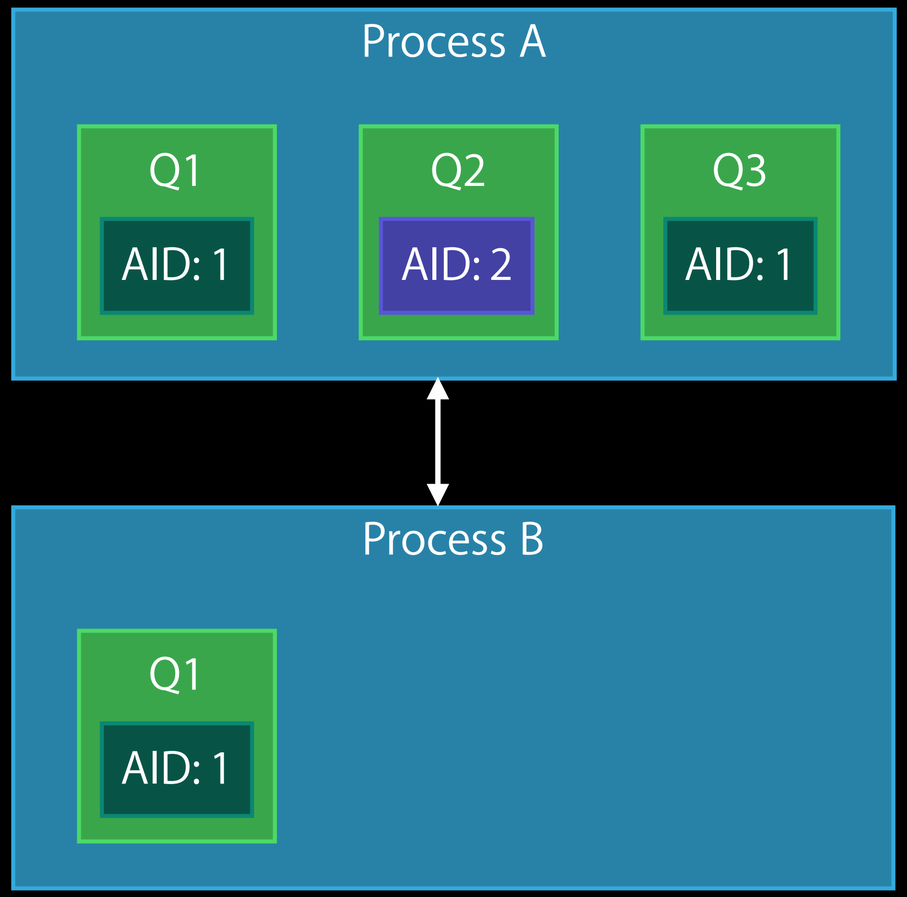

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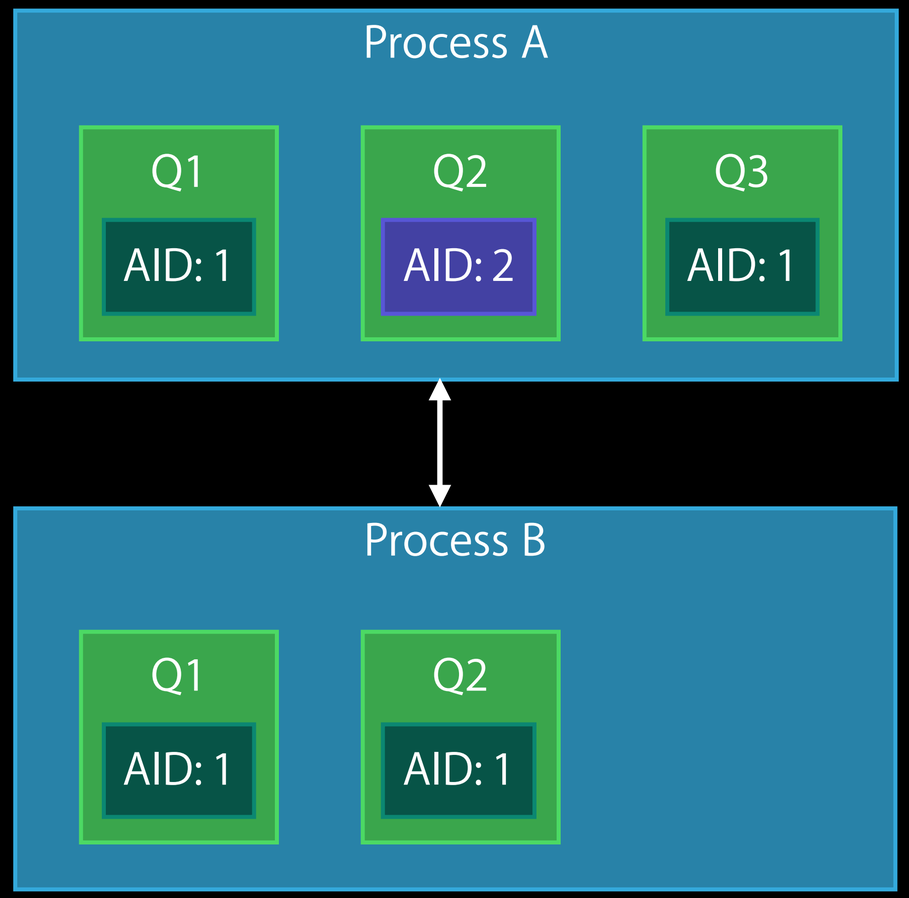

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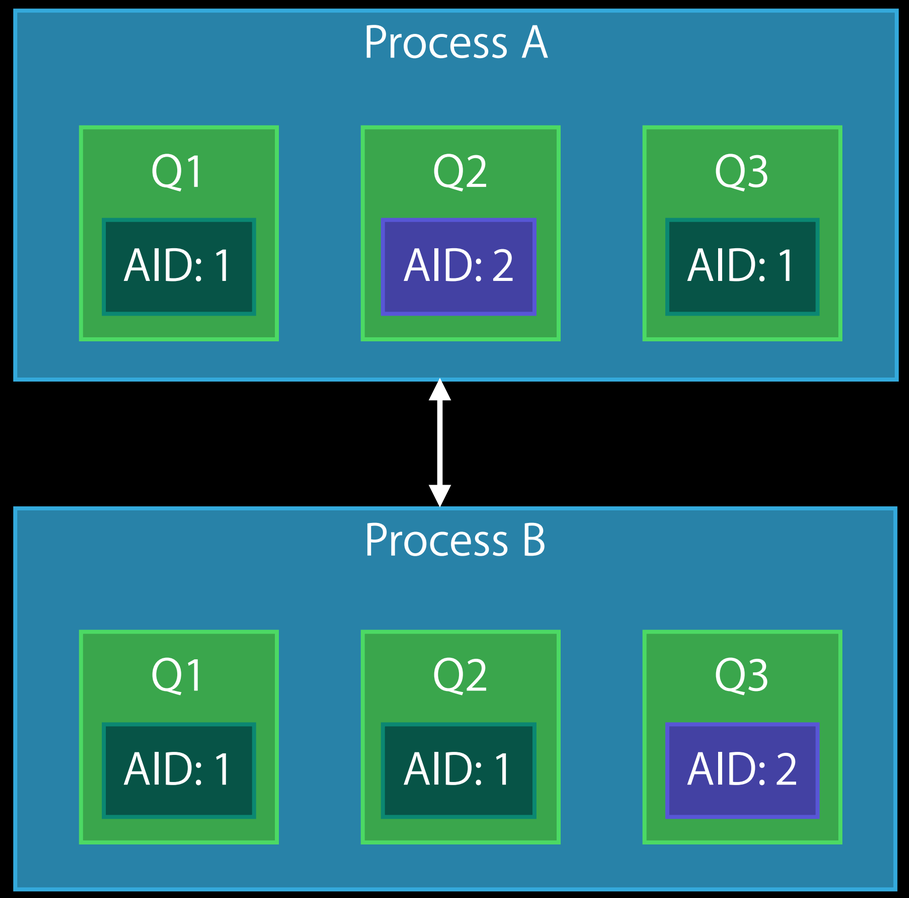


# Propagation Control

## Prevent propagation

`DISPATCH_BLOCK_DETACHED`

Work disassociated from principal activity

- Asynchronous, long-running cleanup

# Propagation Control

## Prevent propagation

`DISPATCH_BLOCK_DETACHED`

Work disassociated from principal activity

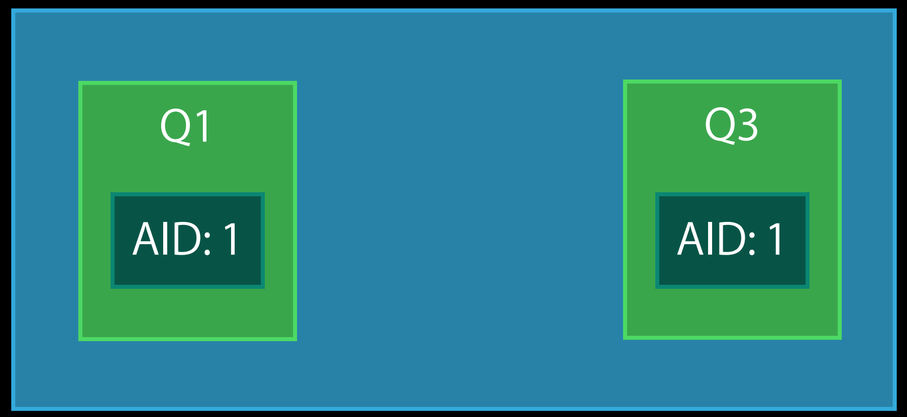
- Asynchronous, long-running cleanup

Detached by default

- Dispatch source handlers
- `dispatch_after()`

# Detached Block

# Detached Block



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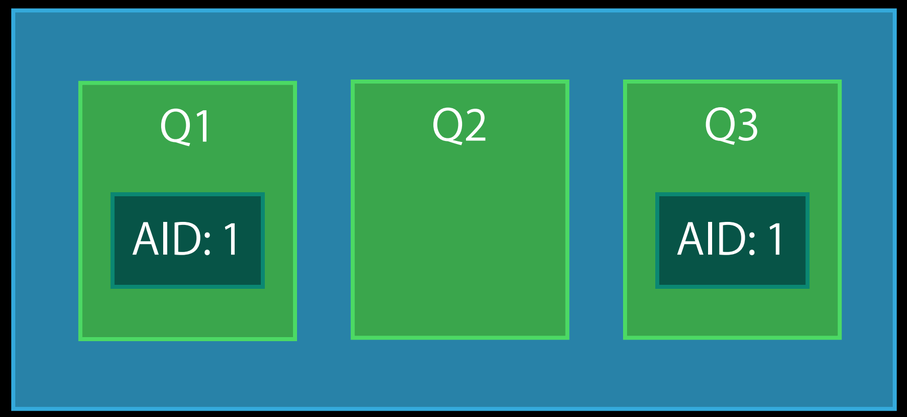
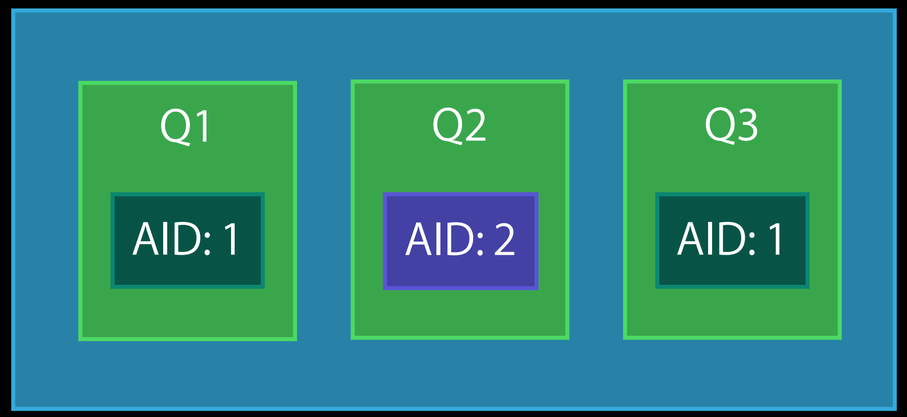


# Detached Block



# Propagation Control

## Manual propagation

`DISPATCH_BLOCK_ASSIGN_CURRENT`

- Assigns current QoS Class and Execution Context

# Propagation Control

## Manual propagation

`DISPATCH_BLOCK_ASSIGN_CURRENT`

- Assigns current QoS Class and Execution Context

Store Block for later execution

- Direct call on manually created pthread
- Submission to dispatch queue

# XPC

## Propagation

XPC connections automatically propagate

- QoS Class
- Execution Context

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Capture of current state on sending thread

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XPC connections automatically propagate

- QoS Class
- Execution Context

Capture of current state on sending thread

XPC handlers prefer propagated QoS over queue QoS

# XPC Service

## Importance boosting

Initially clamped to Background QoS

Clamp removed during IPC with UI

# XPC Service

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Initially clamped to Background QoS

Clamp removed during IPC with UI

Boost lifetime automatically handled by XPC

- Until reply is sent
- While using message

# XPC Service

## Importance boosting

Initially clamped to Background QoS

Clamp removed during IPC with UI

Boost lifetime automatically handled by XPC

- Until reply is sent
- While using message
- While asynchronous work submitted from handler context is ongoing
  - Ensure unrelated work is detached

# Recap

Execution Context attributes

Automatic propagation of Execution Context and QoS

Manual propagation control

XPC propagation and importance boosting

# Diagnostics and Queue Debugging

Xcode 6 CPU Report

---

Xcode 6 Queue Debugging

---

Activity Tracing

# Diagnostics and Queue Debugging

Xcode 6 CPU Report

Xcode 6 Queue Debugging

Activity Tracing

MyApplication 〉 My Mac 64–bit

Running MyApplication : MyApplication

CPU Report

**MyApplication**
PID 7632, Paused

| | |
|---|---|
| **CPU** | 7% |
| **Memory** | 12.7 MB |
| **Energy Impact** | Low |
| **Disk** | Zero KB/s |
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**Thread 1**
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- 12 main
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- 19 main
- 20 start

**Thread 7**

**Thread 9**

**Thread 10**

## Percentage Used

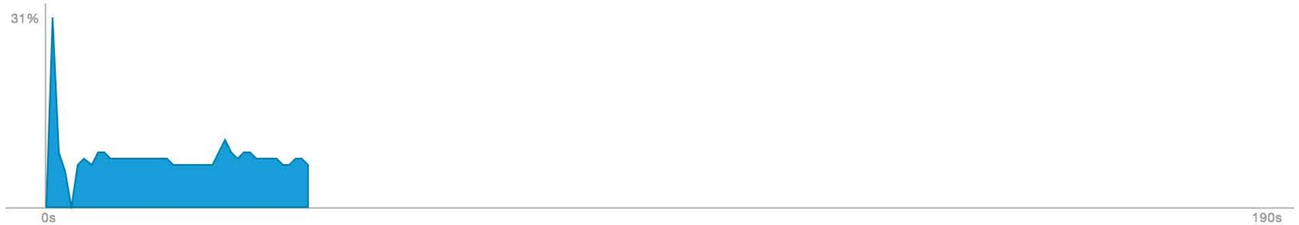

7%

## Usage Comparison

- **MyApplication** 7%
- **Other Processes** 70%
- **Free** 323%

## Usage over Time

Duration: 45 sec
High: 31%
Low: 0%

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MyApplication 〉 Thread 5 〉 0 __semwait_signal

(lldb)

Auto

All Output

MyApplication 〉 My Mac 64–bit

Running MyApplication : MyApplication

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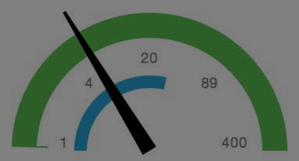


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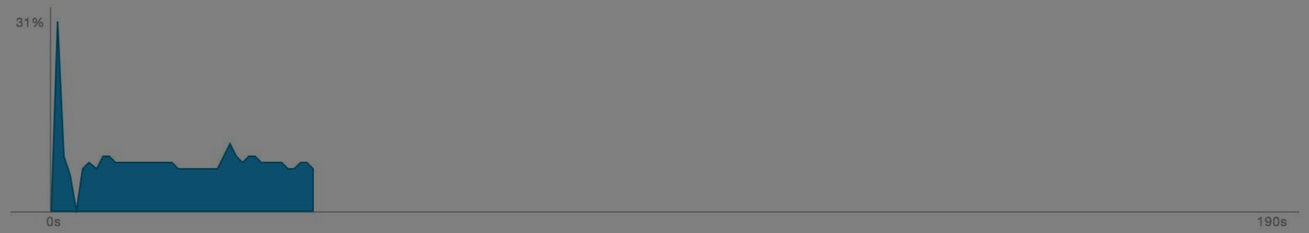


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(lldb)
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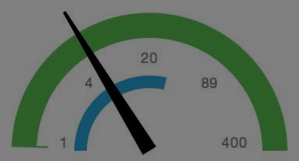


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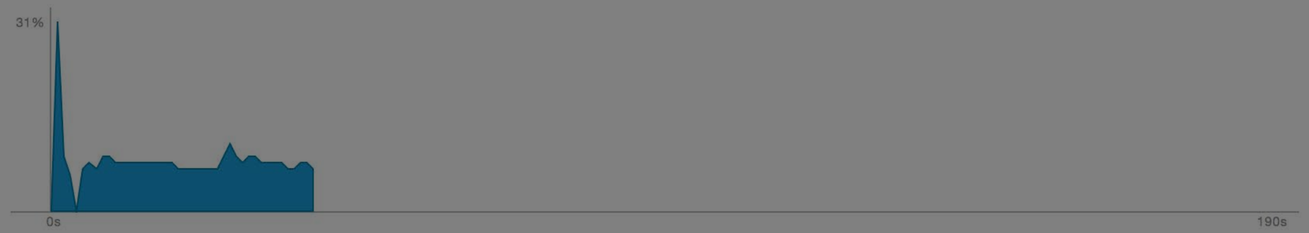


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(lldb)
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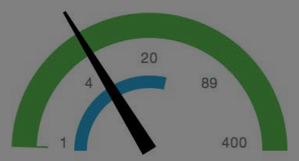


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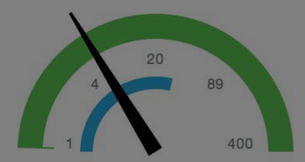


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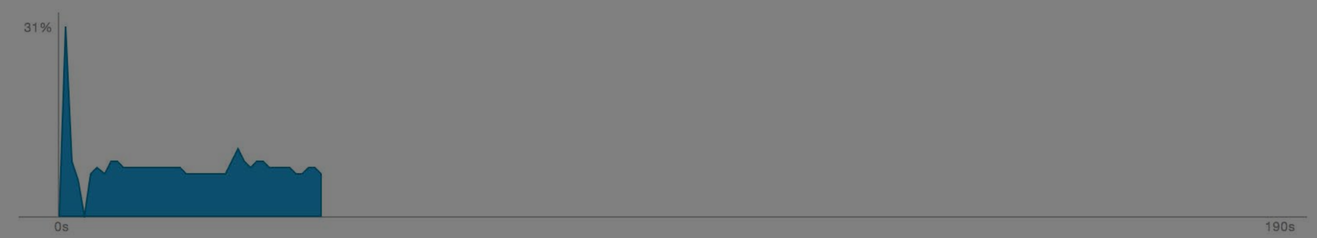


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```
(lldb)
```

Auto

All Output

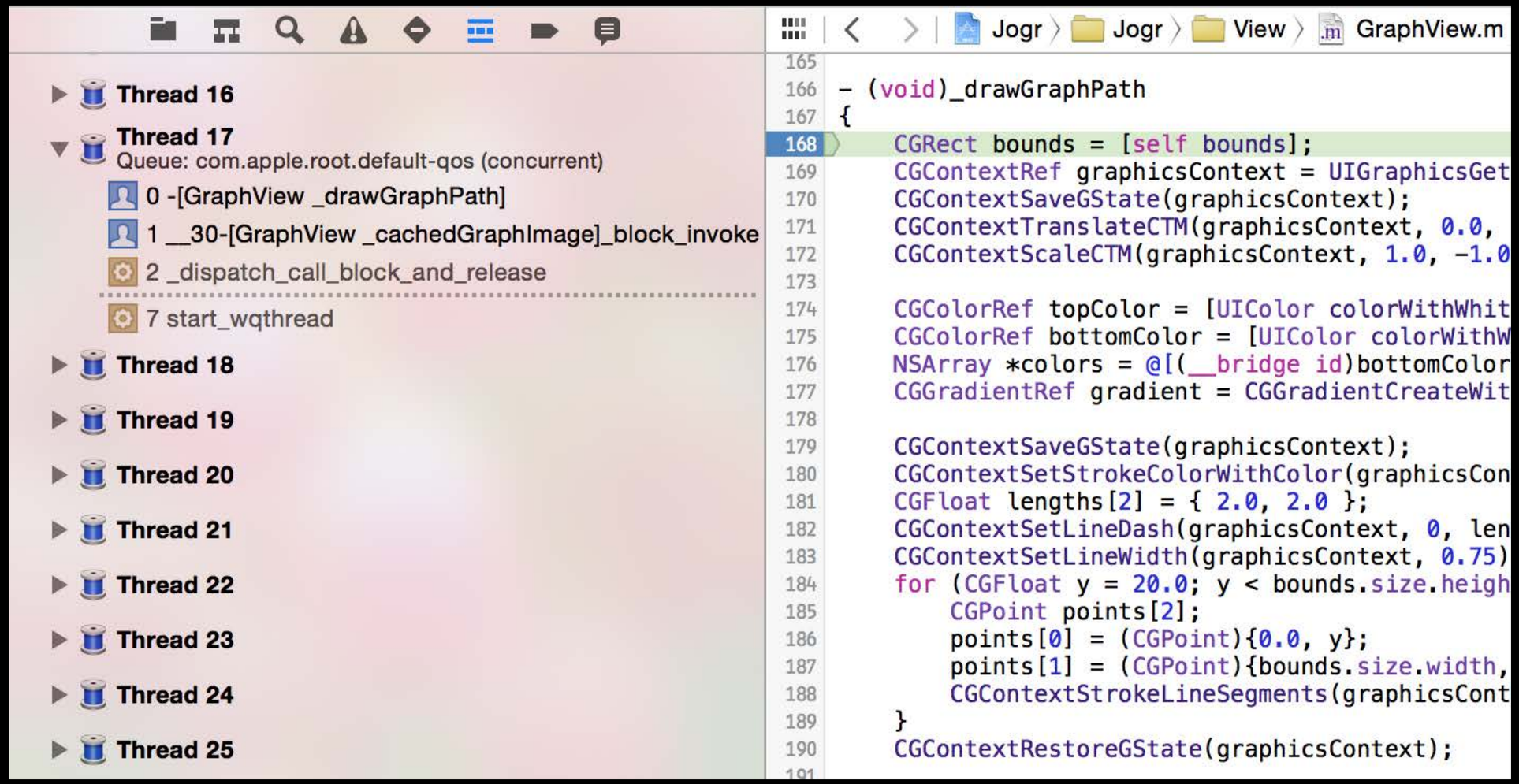
# Diagnostics and Queue Debugging

Xcode 6 CPU Report

Xcode 6 Queue Debugging

Activity Tracing

# Logical Backtraces



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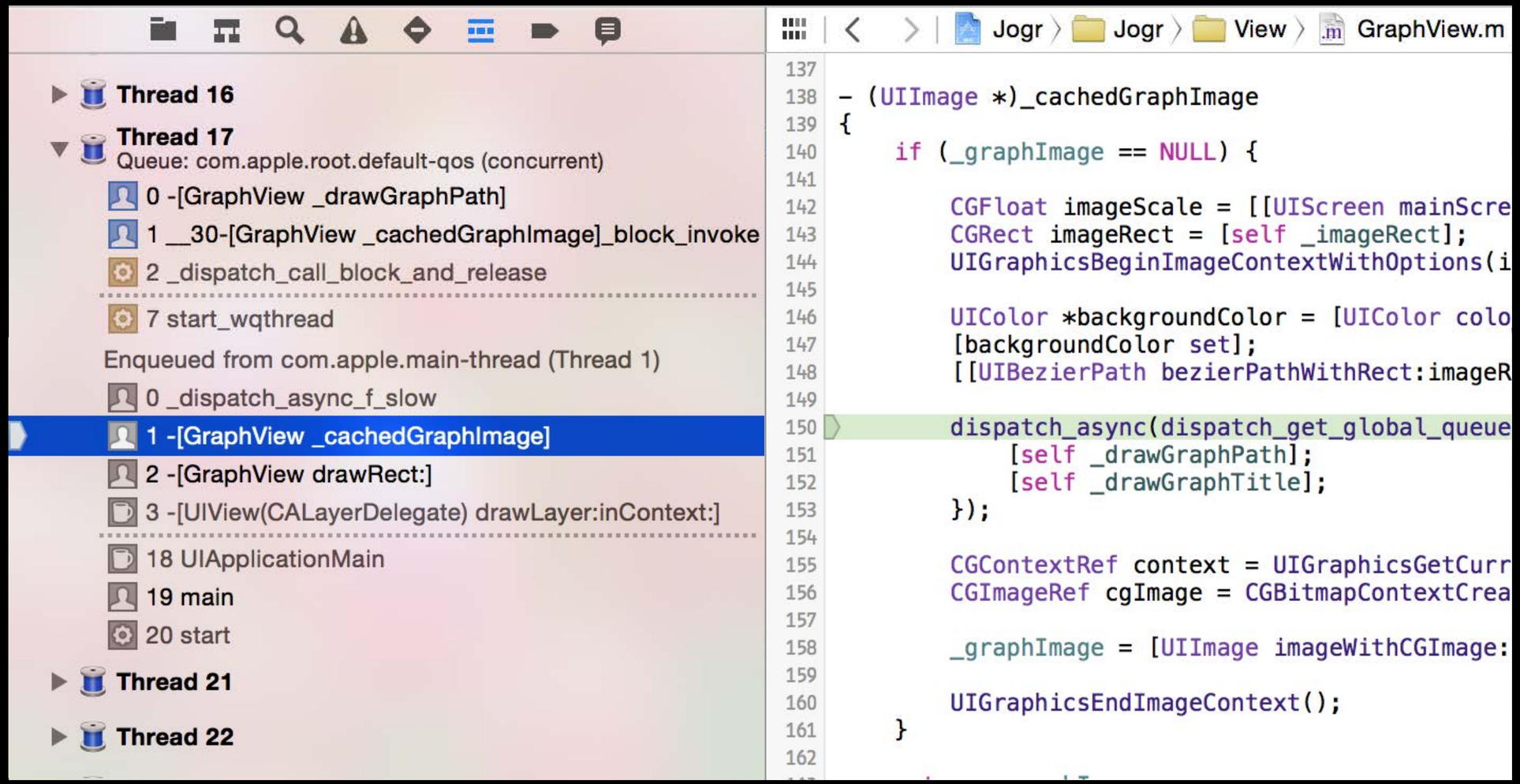

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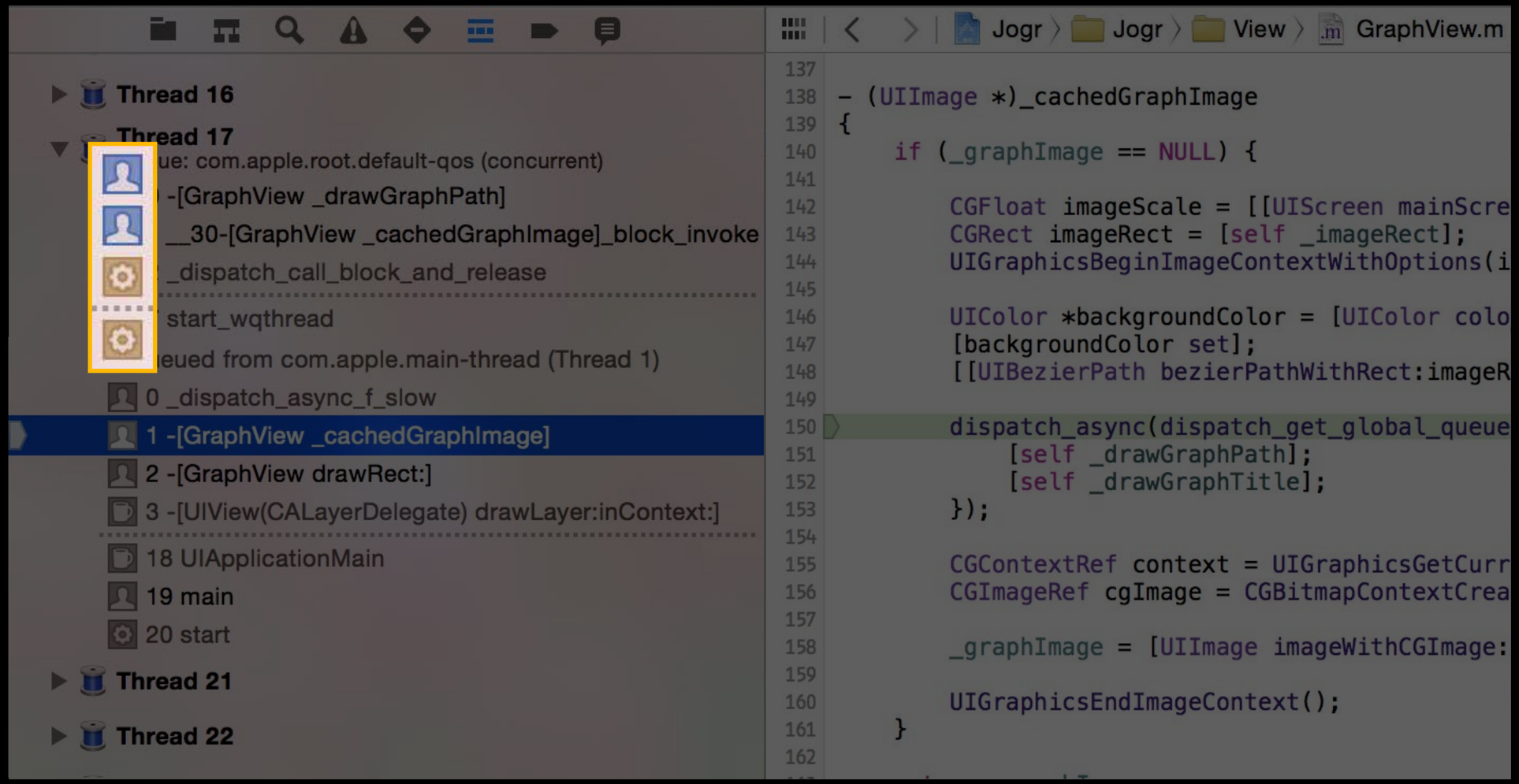

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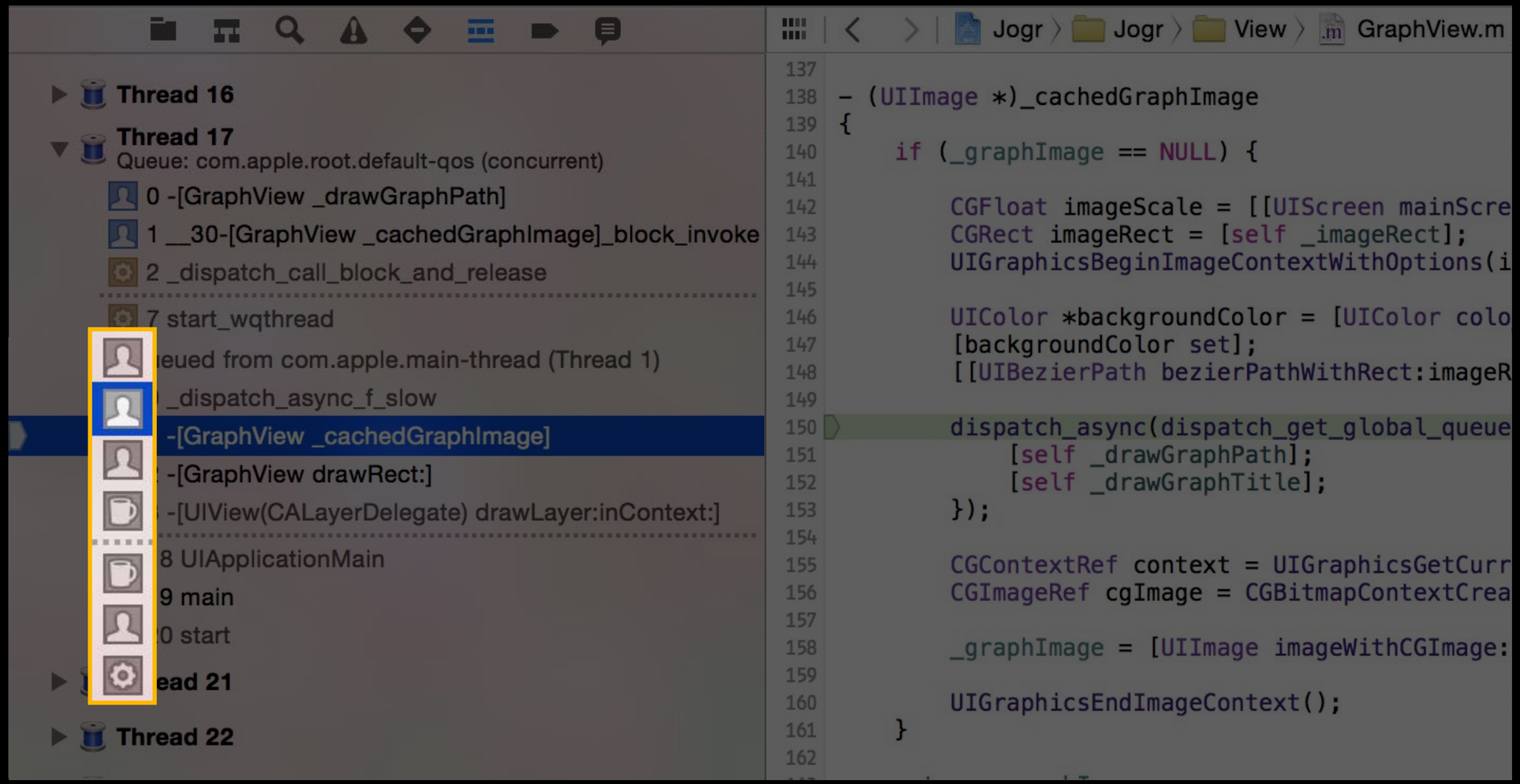

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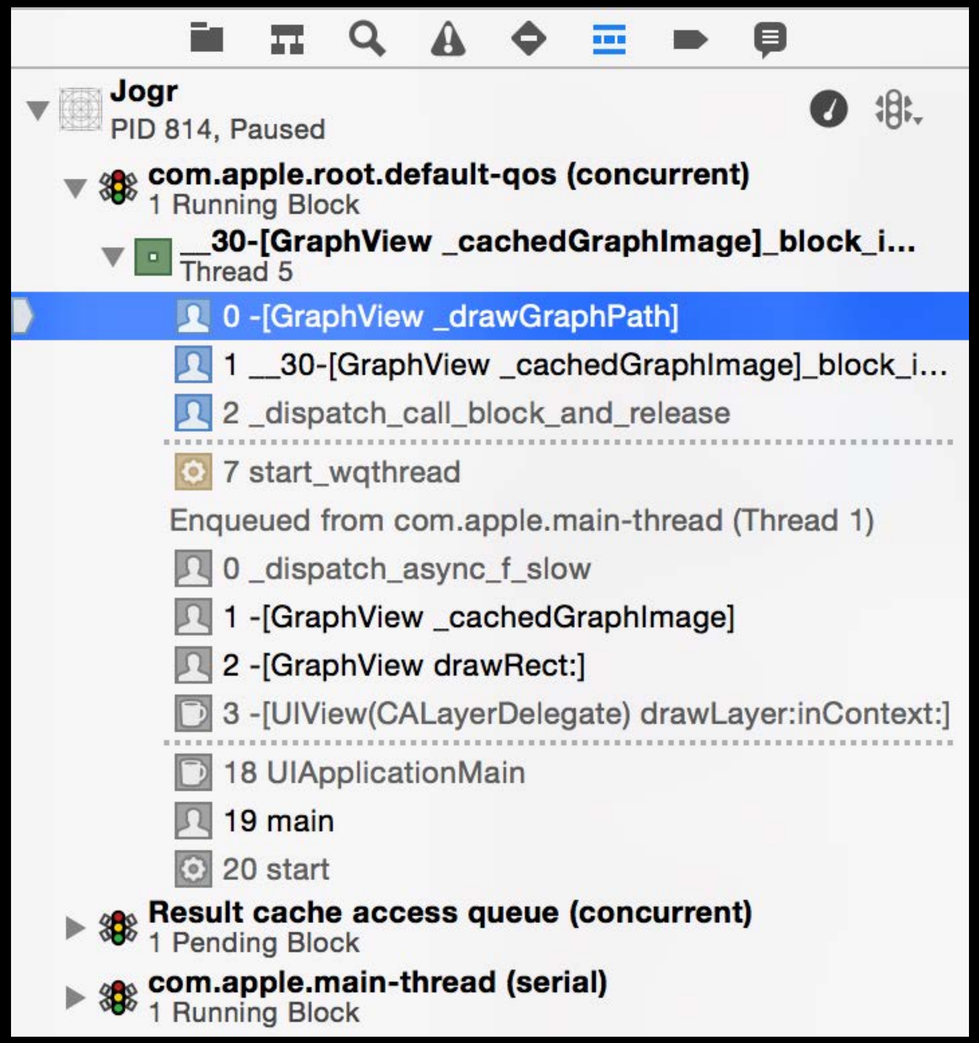

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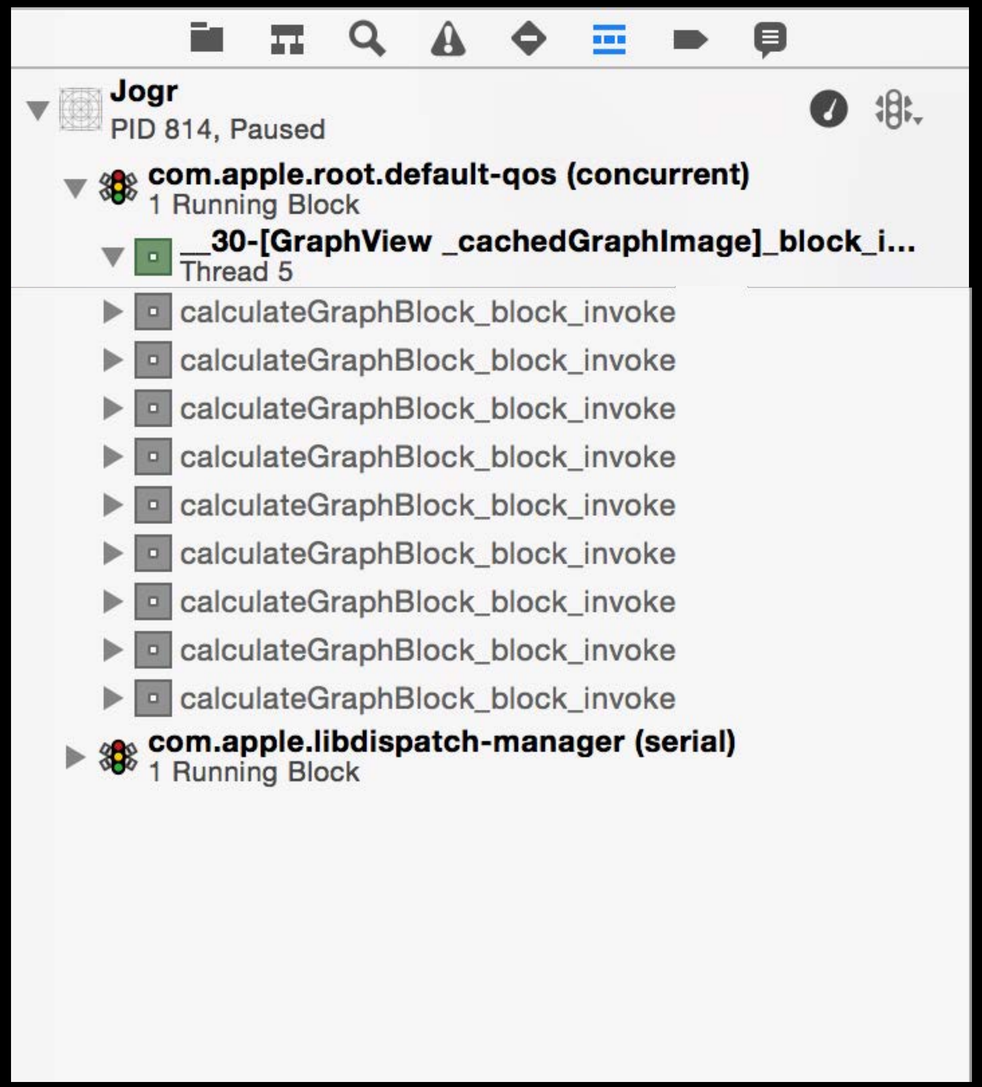

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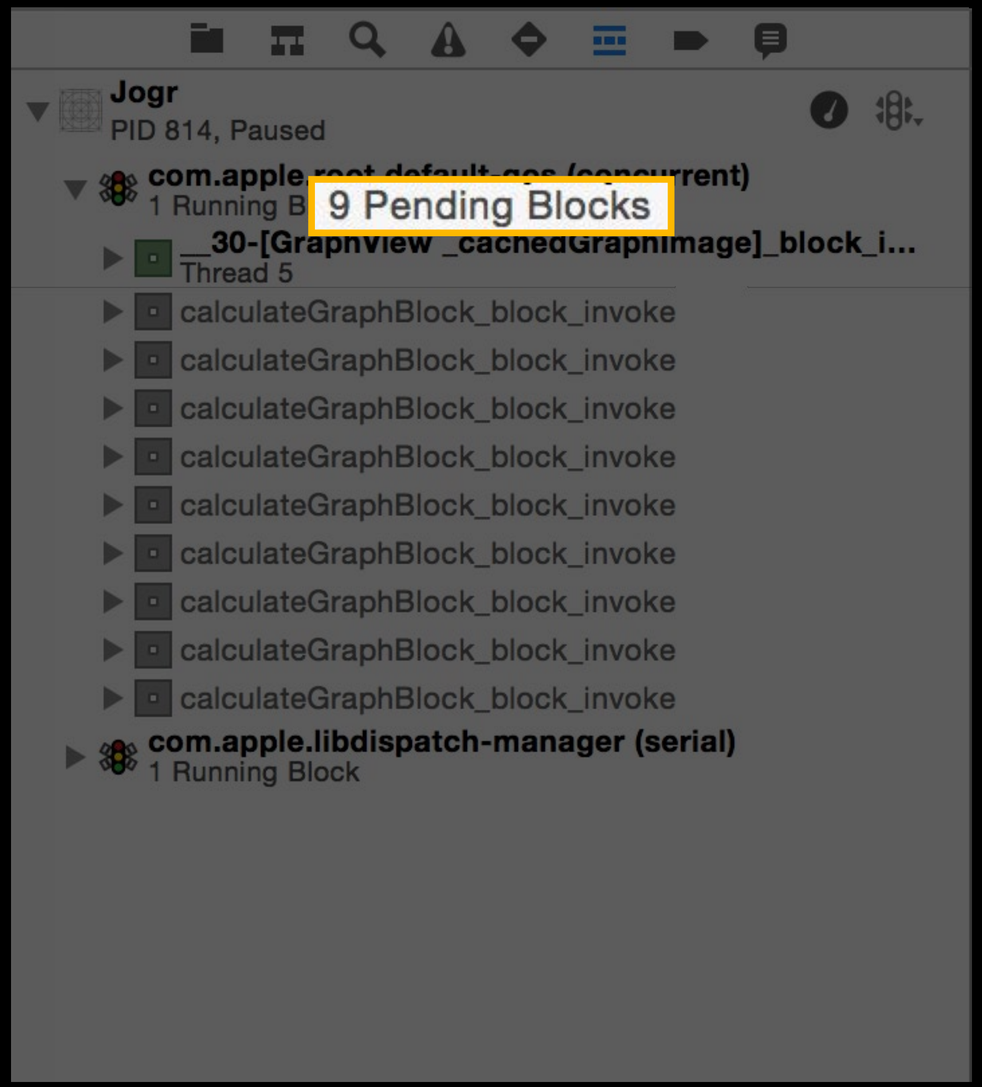

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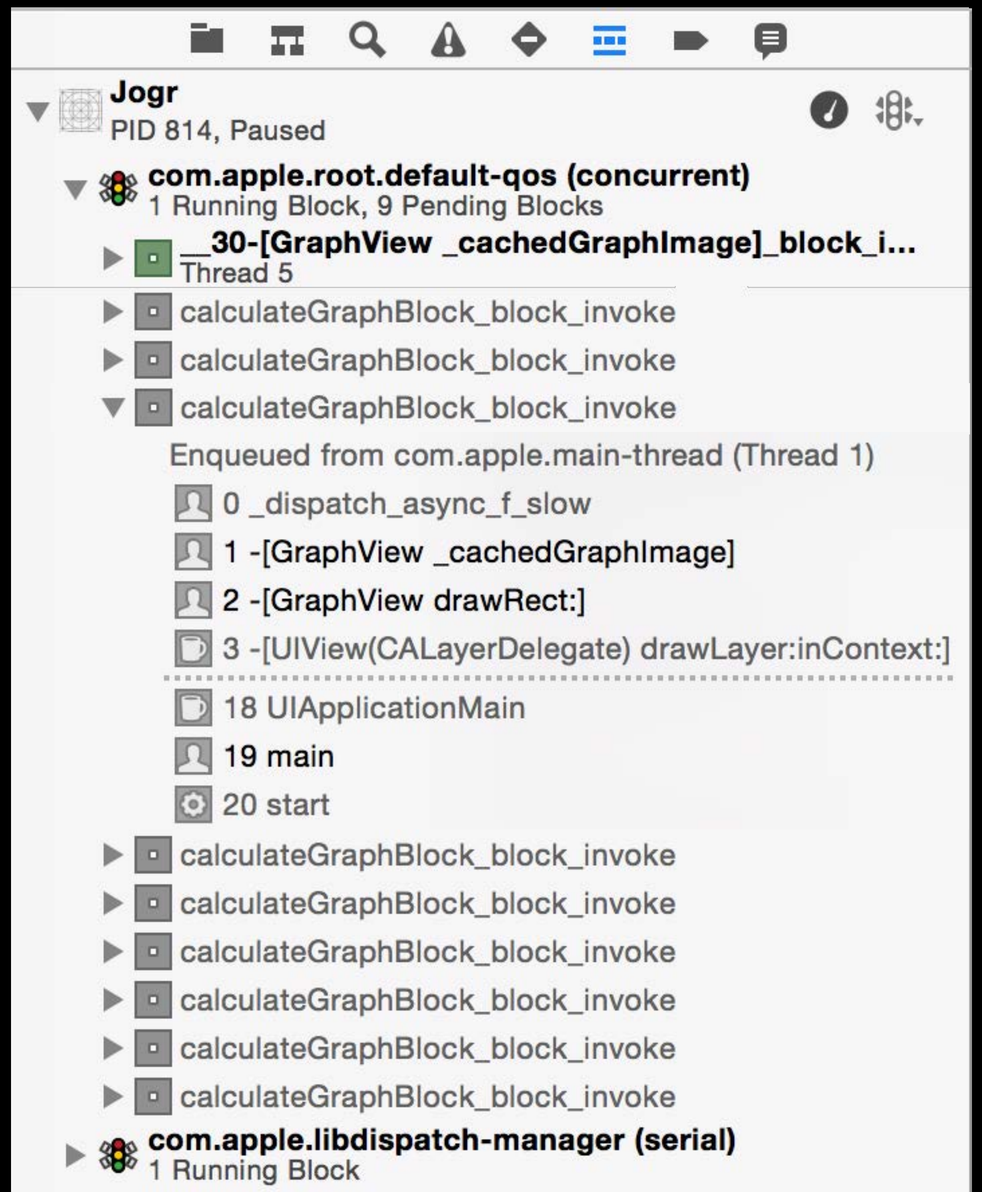

# Diagnostics and Queue Debugging

Xcode 6 CPU Report

Xcode 6 Queue Debugging

Activity Tracing

# Activities in Crash Reports

```
Crashed Thread:        0  Dispatch queue: com.apple.main-thread

Exception Type:        EXC_CRASH (SIGABRT)
Exception Codes:       0x0000000000000000, 0x0000000000000000
```

Additional info about key events leading up to crash

```
Thread 0 Crashed:: Dispatch queue: com.apple.main-thread
0   com.apple.Query-Directory       0x00000001000027ea -[QDAppDelegate query:foundResults:error:] + 554
1   com.apple.OpenDirectory         0x00007fff9066ec88 __delegate_callback + 388
2   com.apple.CFOpenDirectory       0x00007fff84750bed _query_perform + 568
3   com.apple.CoreFoundation        0x00007fff8964e1f1 __CFRUNLOOP_IS_CALLING_OUT_TO_A_SOURCE0_PERFORM_FUNCTION__ + 17
. . .
16  com.apple.AppKit                0x00007fff83c01a9e NSApplicationMain + 1778
17  com.apple.Query-Directory       0x0000000100001a82 main + 34
18  libdyld.dylib                   0x00007fff874af5c9 start + 1
```

Detailed messages associated with the crash point

# Activities in Crash Reports

```
Crashed Thread:        0  Dispatch queue: com.apple.main-thread

Exception Type:        EXC_CRASH (SIGABRT)
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```

**Breadcrumb Trail (reverse chronological seconds):**
**6 Query directory using NSRunLoop (Activity ID: 0x0000008f00000002)**
**15 Query directory using NSRunLoop**

```
0   com.apple.Query-Directory      0x0000000100002 7ea -[QDAppDelegate query:foundResults:error:] + 334
1   com.apple.OpenDirectory        0x00007fff9066ec88 __delegate_callback + 388
2   com.apple.CFOpenDirectory      0x00007fff84750bed _query_perform + 568
3   com.apple.CoreFoundation       0x00007fff8964e1f1 __CFRUNLOOP_IS_CALLING_OUT_TO_A_SOURCE0_PERFORM_FUNCTION__ + 17
• • •
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Activity ID:            0x0000008f00000002
Activity Name:          sendAction:
Activity Breadcrumb:    Query directory using NSRunLoop
Activity Running Time:  6.028601 sec
Activity Failure Reason: none detected

Trace Messages (reverse chronological seconds):
5.866399    Query Directory            0x0000000100000000 IPC send
5.866463    Query Directory            0x00000001000027e0 aborting test due to no results
5.866529    Query Directory            0x0000000100000000 IPC send
5.866564    Query Directory            0x0000000100002243 skipping record with UID 210 (not member of 'admin')
5.866583    opendirectoryd             0xffffffff00000000 IPC send
5.866596    opendirectoryd             0xffffffff00021c21 request completed, delivered 1 results
• • •
5.866803    opendirectoryd             0xffffffff00021640 UID: 4129, EUID: 4129, GID: 11, EGID: 11
5.866863    opendirectoryd             0xffffffff00000000 IPC receive
5.866883    Query Directory            0x0000000100000000 IPC send
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# Activities in Crash Reports

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# Using lldb

```
(lldb) thread info
thread #1: tid = 0x1c93, 0x00007fff9452a37a
libsystem_kernel.dylib`__pthread_kill + 10, queue = 'com.apple.main-thread',
activity = 'sendAction:', 5 messages, stop reason = signal SIGABRT

  Activity 'sendAction:', 0x4d00000002

  Current Breadcrumb: Query directory using NSRunLoop

  5 trace messages:
    aborting test due to no results
    skipping record with UID 210 (not member of 'admin')
    IPC send
    issued query
    canceling previous query for mode: 0
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# Using lldb

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# Summary

Background

Quality of Service Classes

New QoS and GCD API

Propagation of QoS and Execution Context

Diagnostics and Queue Debugging

# More Information

Paul Danbold
Core OS Technologies Evangelist
danbold@apple.com

Documentation
Grand Central Dispatch (GCD) Reference
Concurrency Programming Guide
http://developer.apple.com/

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

# Related Sessions

| | | |
|---|---|---|
| Improving Your App with Instruments | Nob Hill | Tuesday 4:30PM |
| Writing Energy Efficient Code, Part 1 | Russian Hill | Wednesday 10:15AM |
| Debugging in Xcode 6 | Marina | Wednesday 10:15AM |
| Writing Energy Efficient Code, Part 2 | Russian Hill | Wednesday 11:30AM |
| Fix Bugs Faster using Activity Tracing | Russian Hill | Thursday 11:30AM |

# Labs

| | | |
|---|---|---|
| • Power and Performance Lab | Core OS Lab A | Thursday 3:15PM |
| • Core OS Lab Open Hours | Core OS Lab A and B | Friday 2:00PM |

WWDC14