Power, Performance, and Diagnostics

What's new in GCD and XPC

Session 716

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Darwin Runtime Engineer

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Overview

Background

Quality of Service Classes

New QoS and GCD API

Propagation of QoS and Execution Context

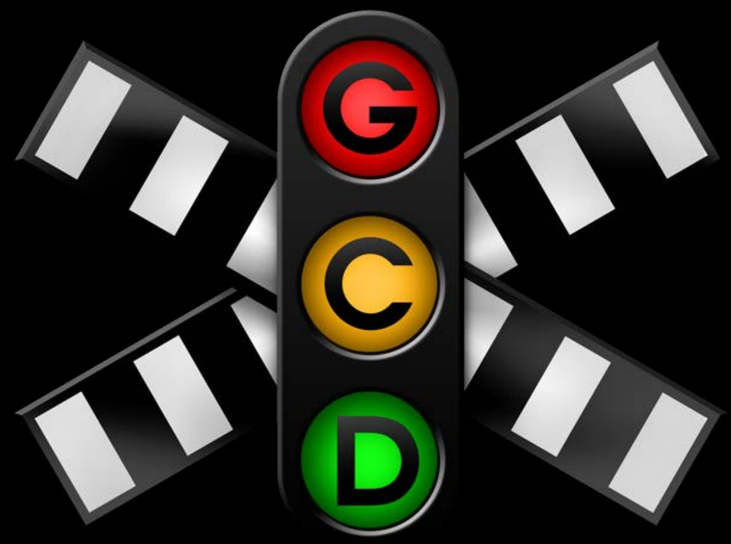
Diagnostics and Queue Debugging

Grand Central Dispatch

Asynchronous execution

Concurrent execution

Synchronization

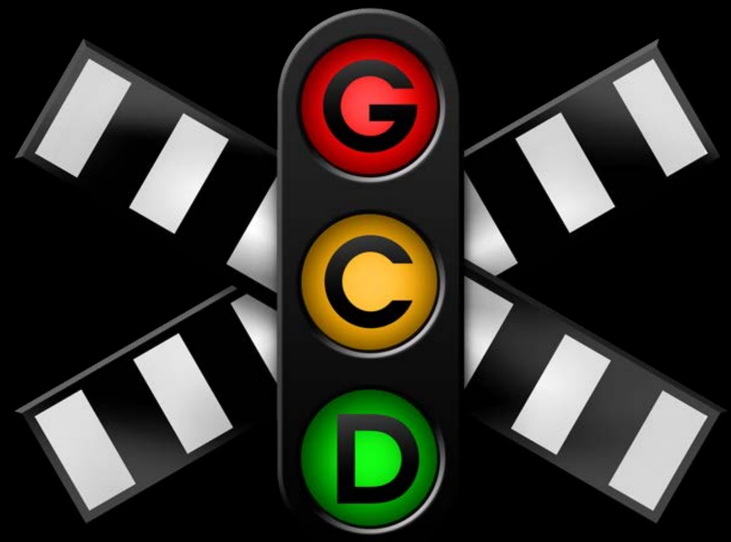


Asynchronous Execution

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

Primary Goal

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

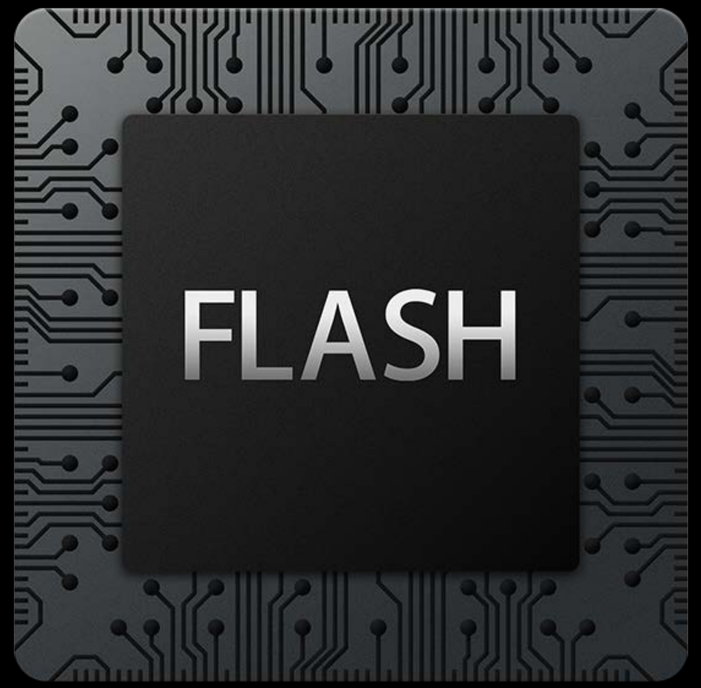
- High priorities get CPU first
- Low priorities
  - No restriction if no contention
  - May not run during UI activity

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

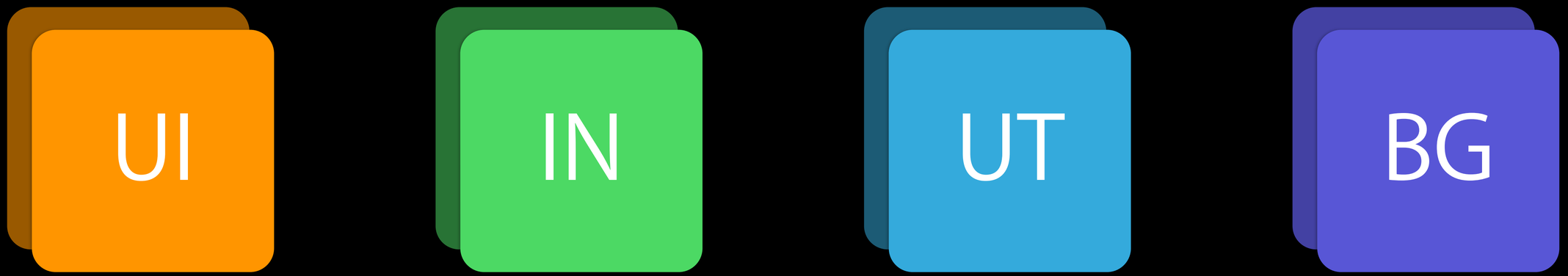
Timer coalescing

CPU throughput vs. efficiency

More…

Configuration values tuned for each platform/device

QoS Classes



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

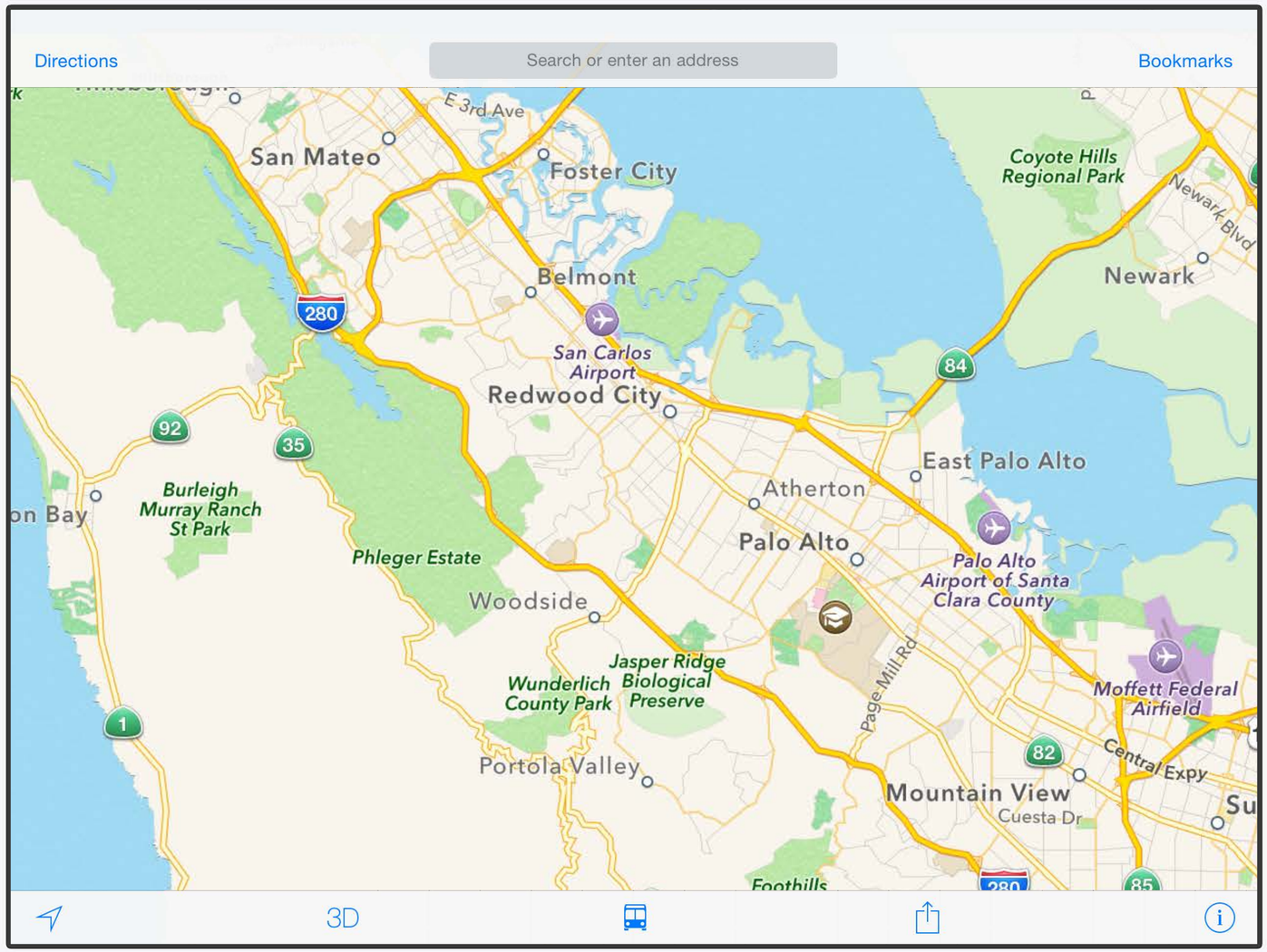
Background

User is unaware work is occurring

Prefetching

Deferrable

Maintenance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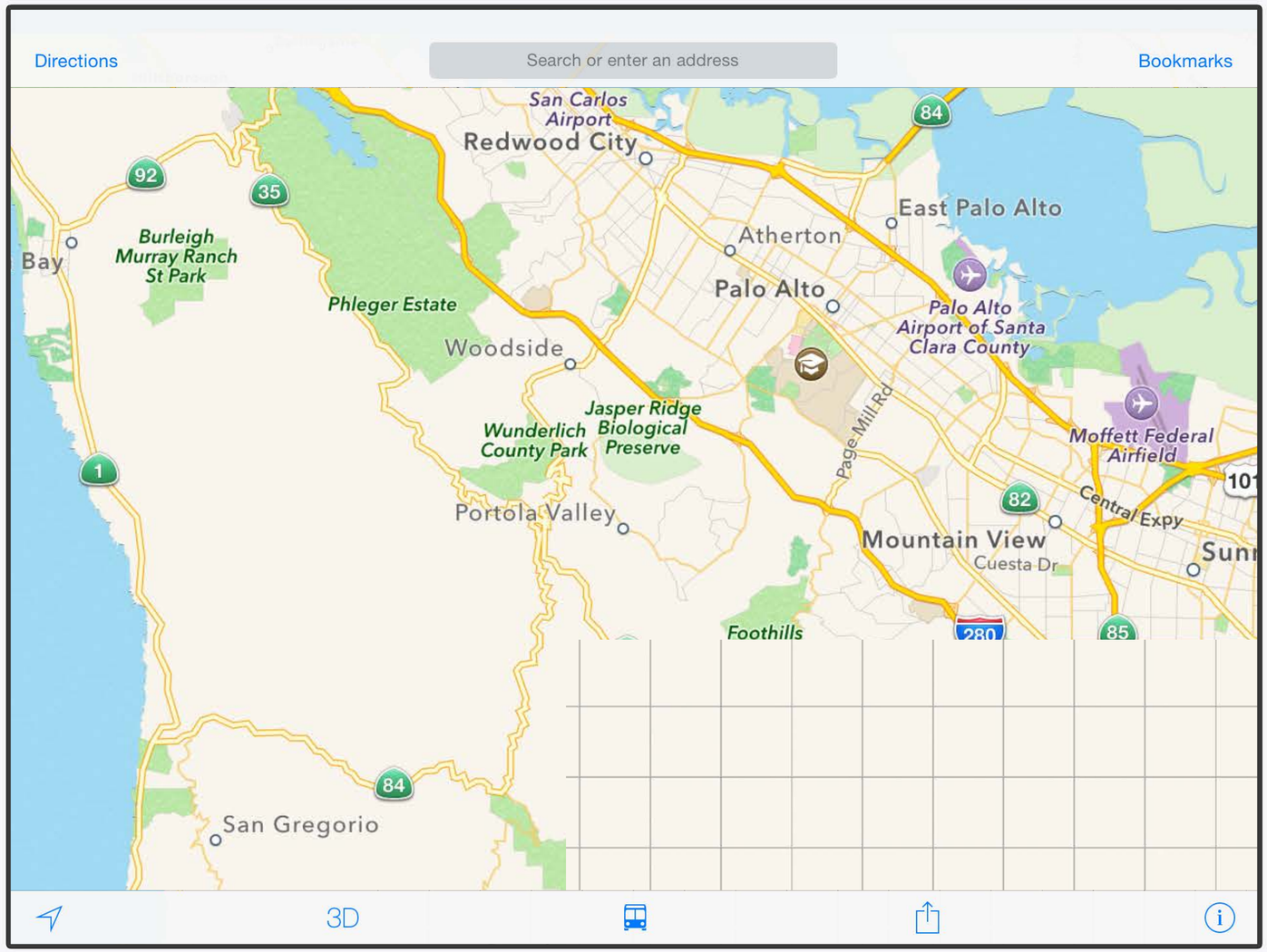
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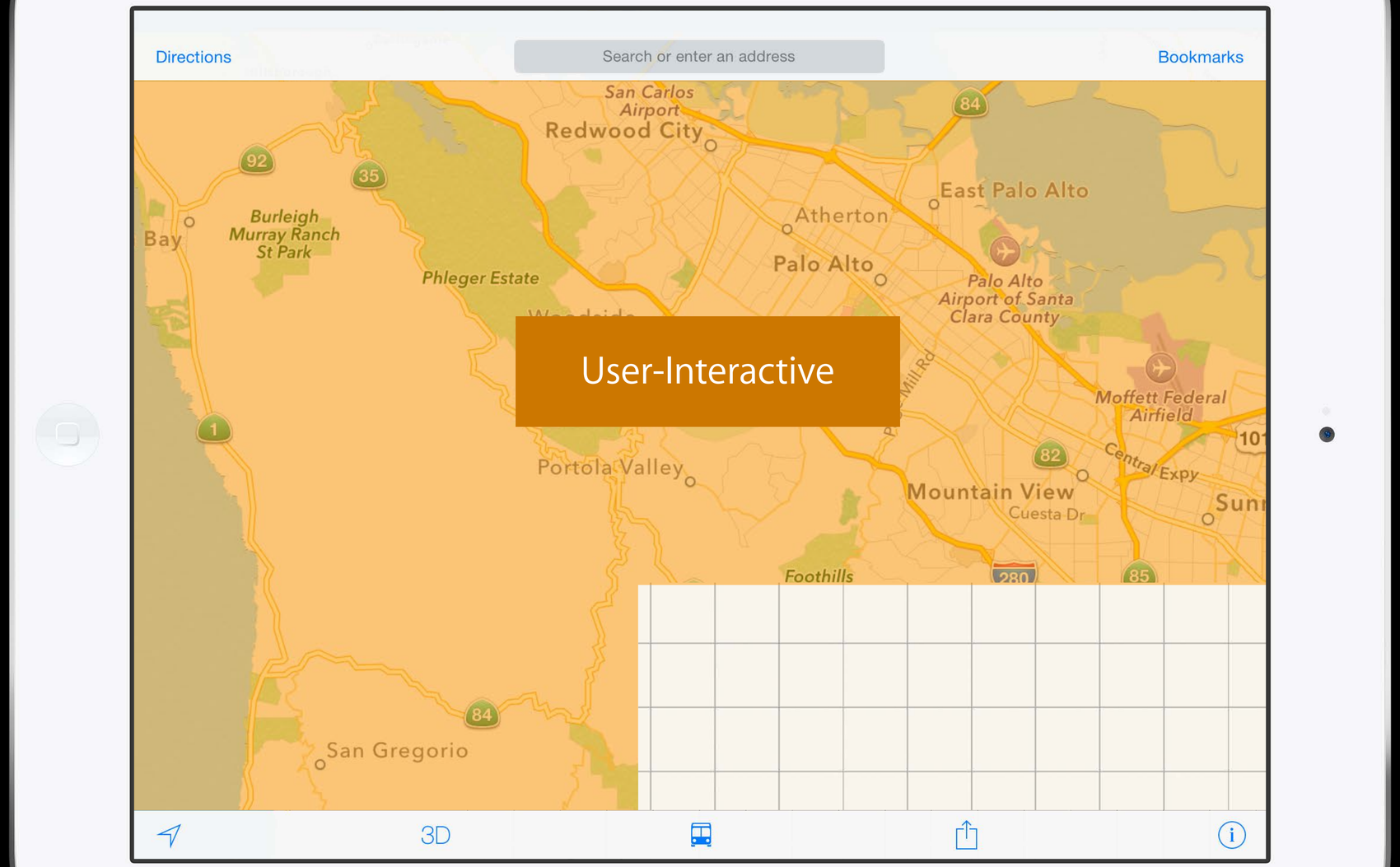
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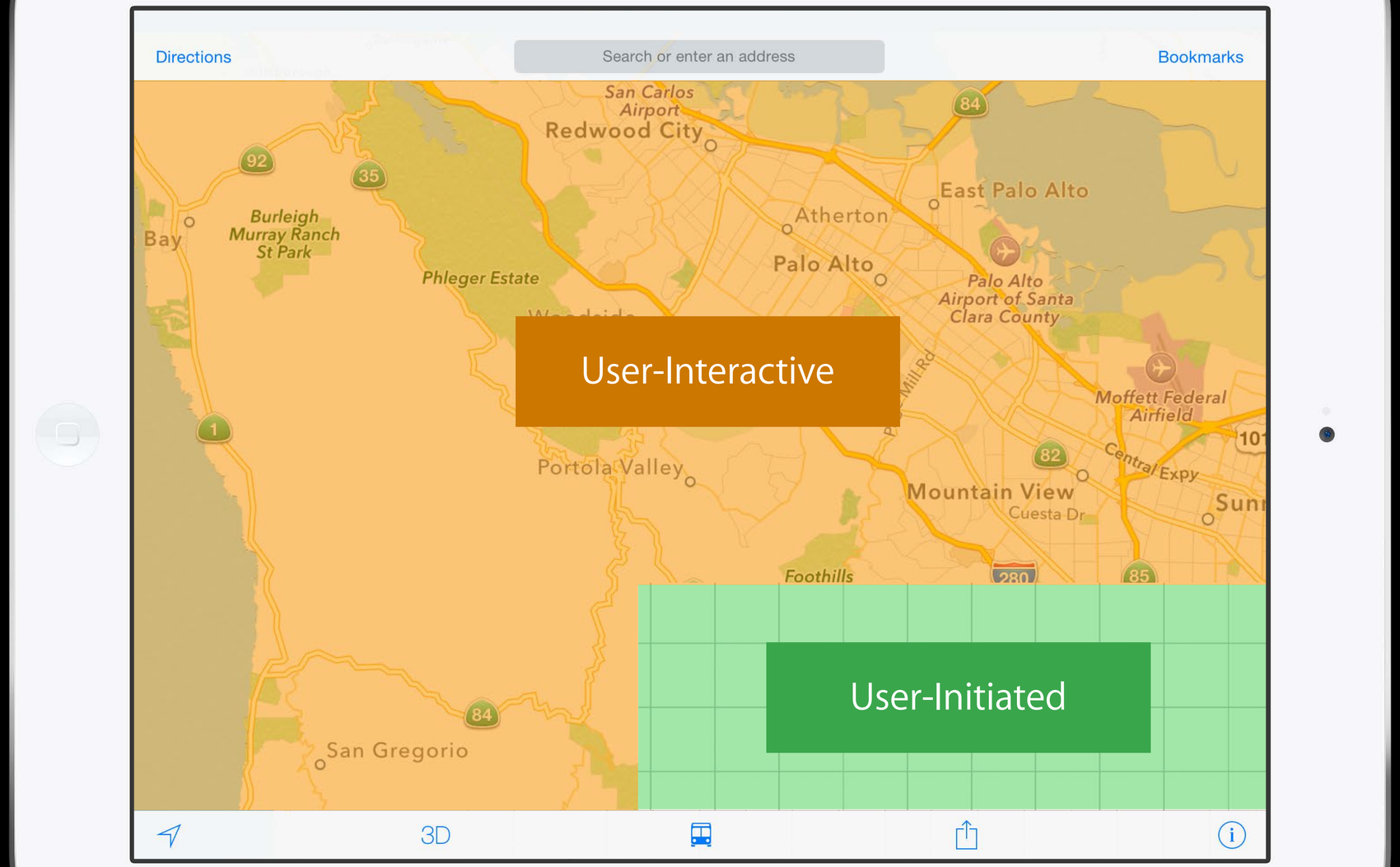
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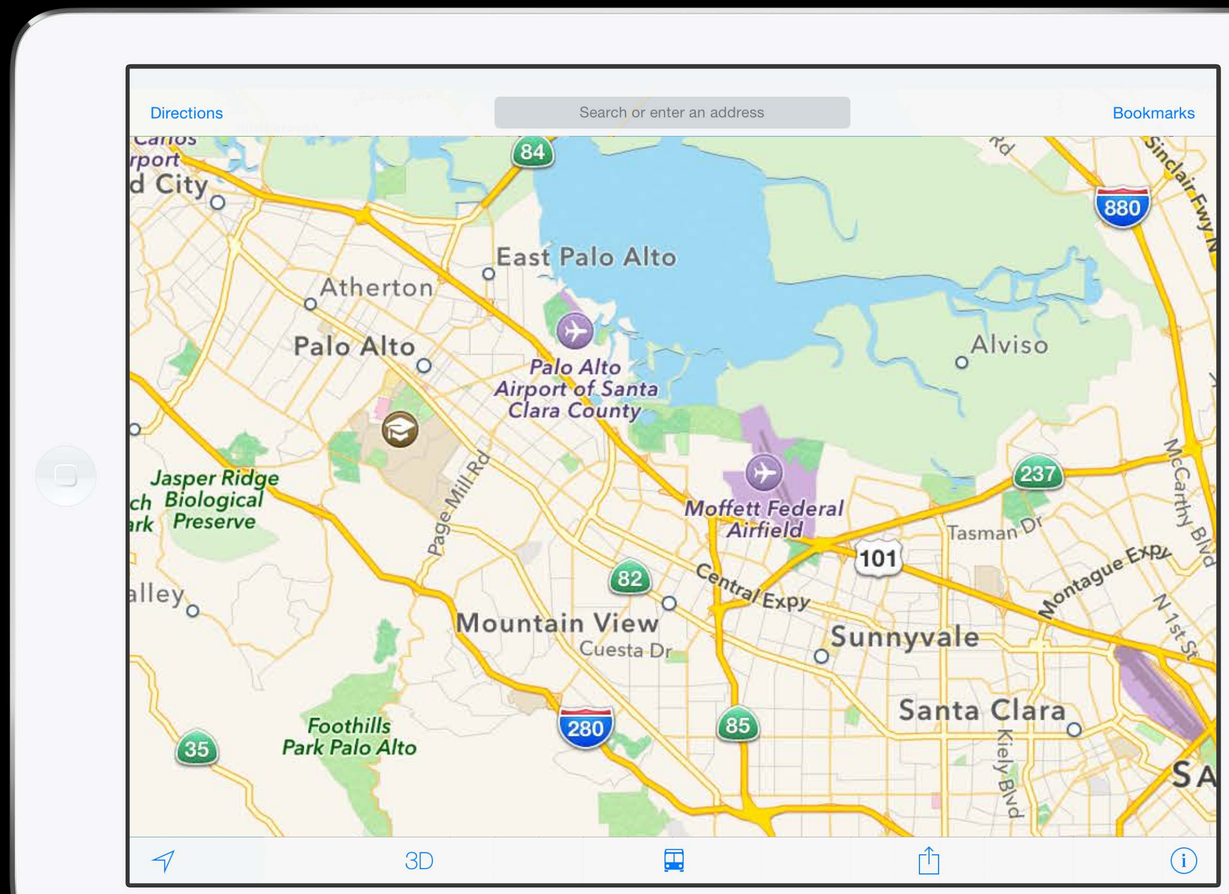
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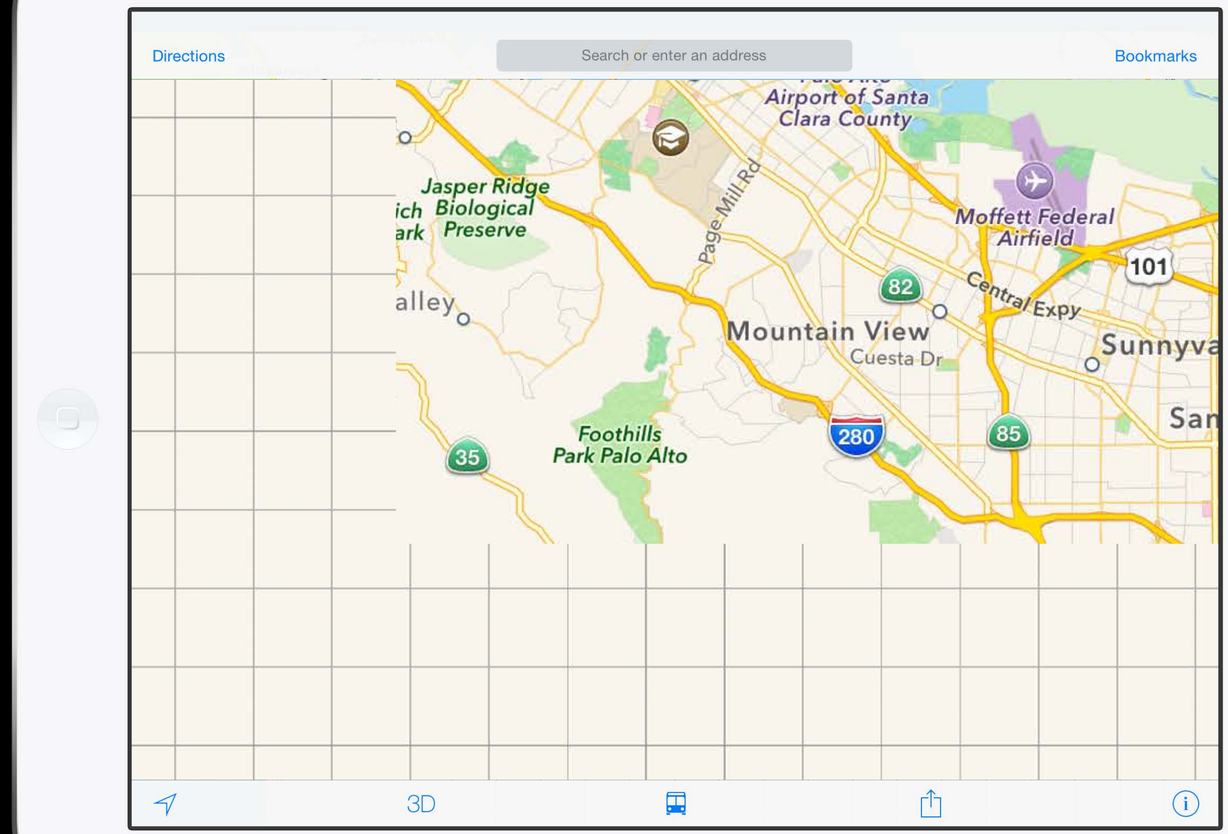
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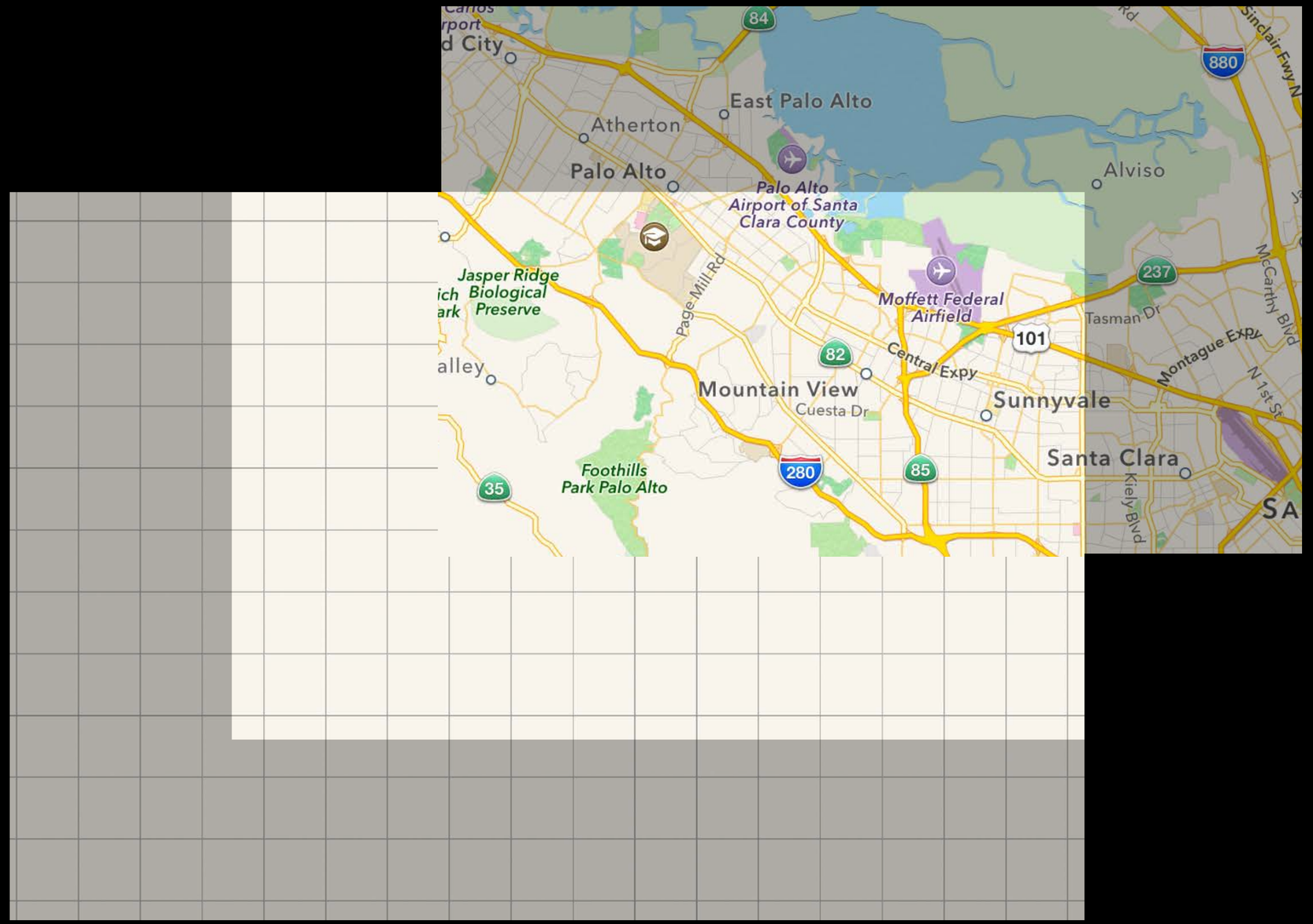
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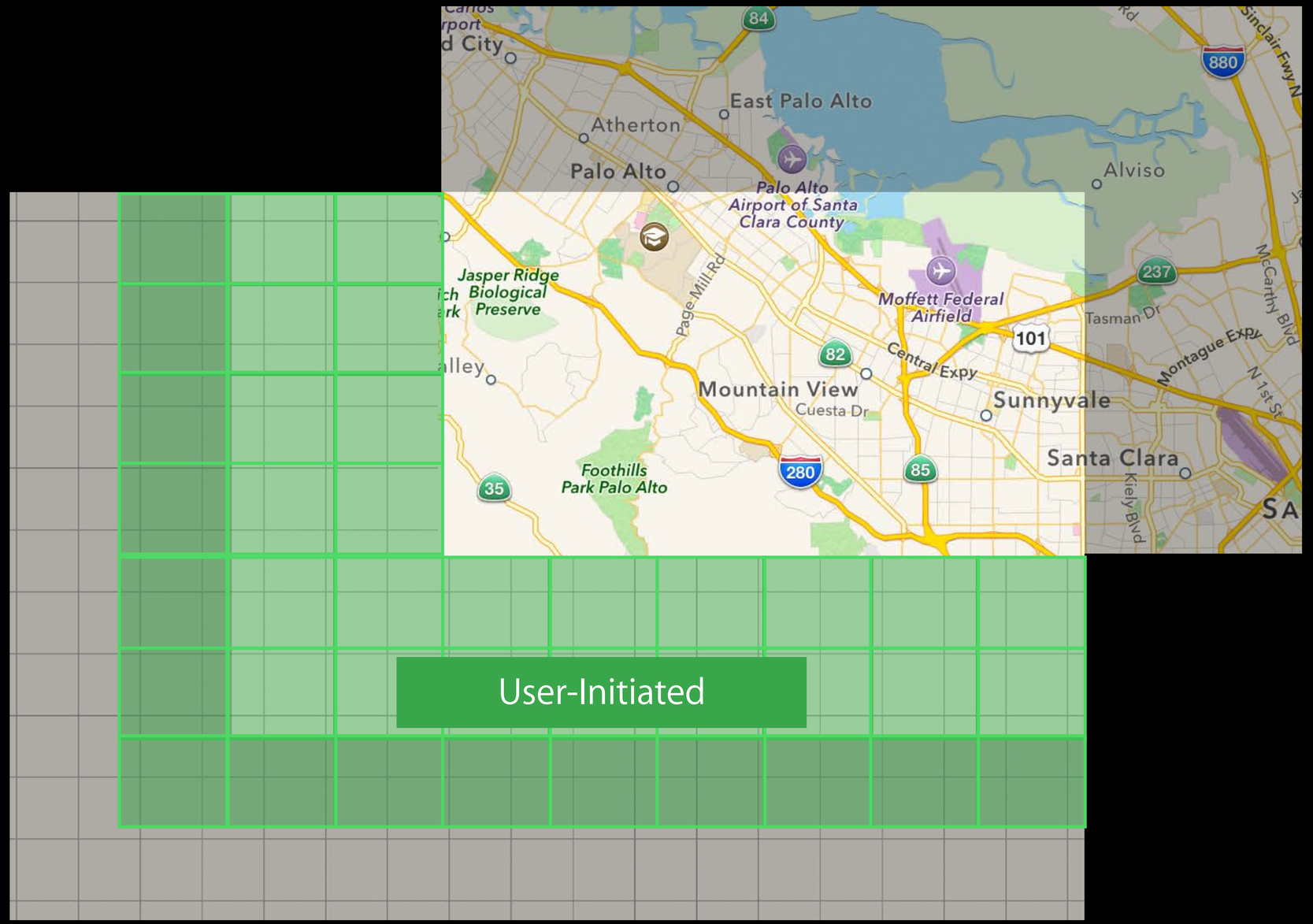
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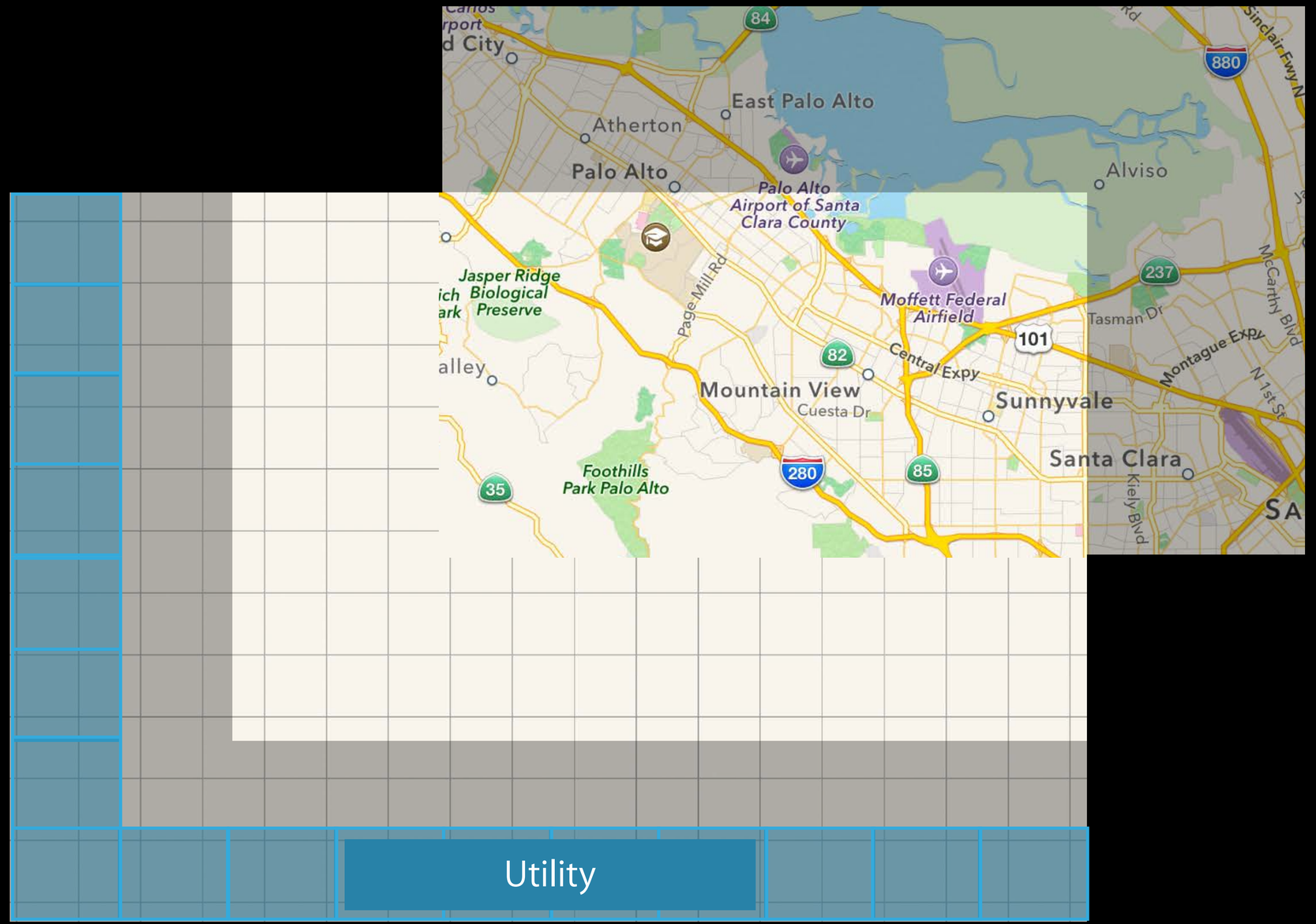
User-Initiated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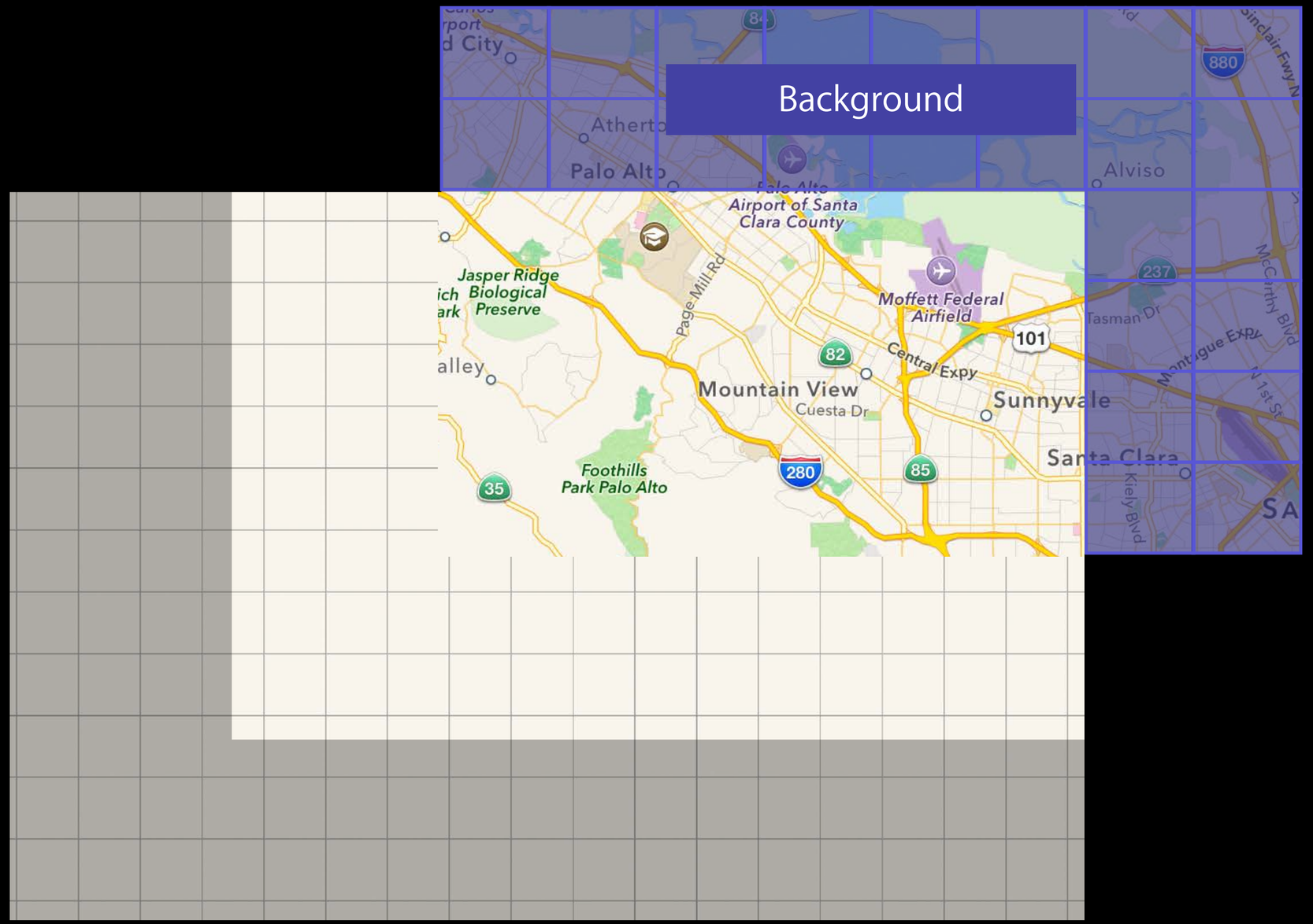
Utility

Background



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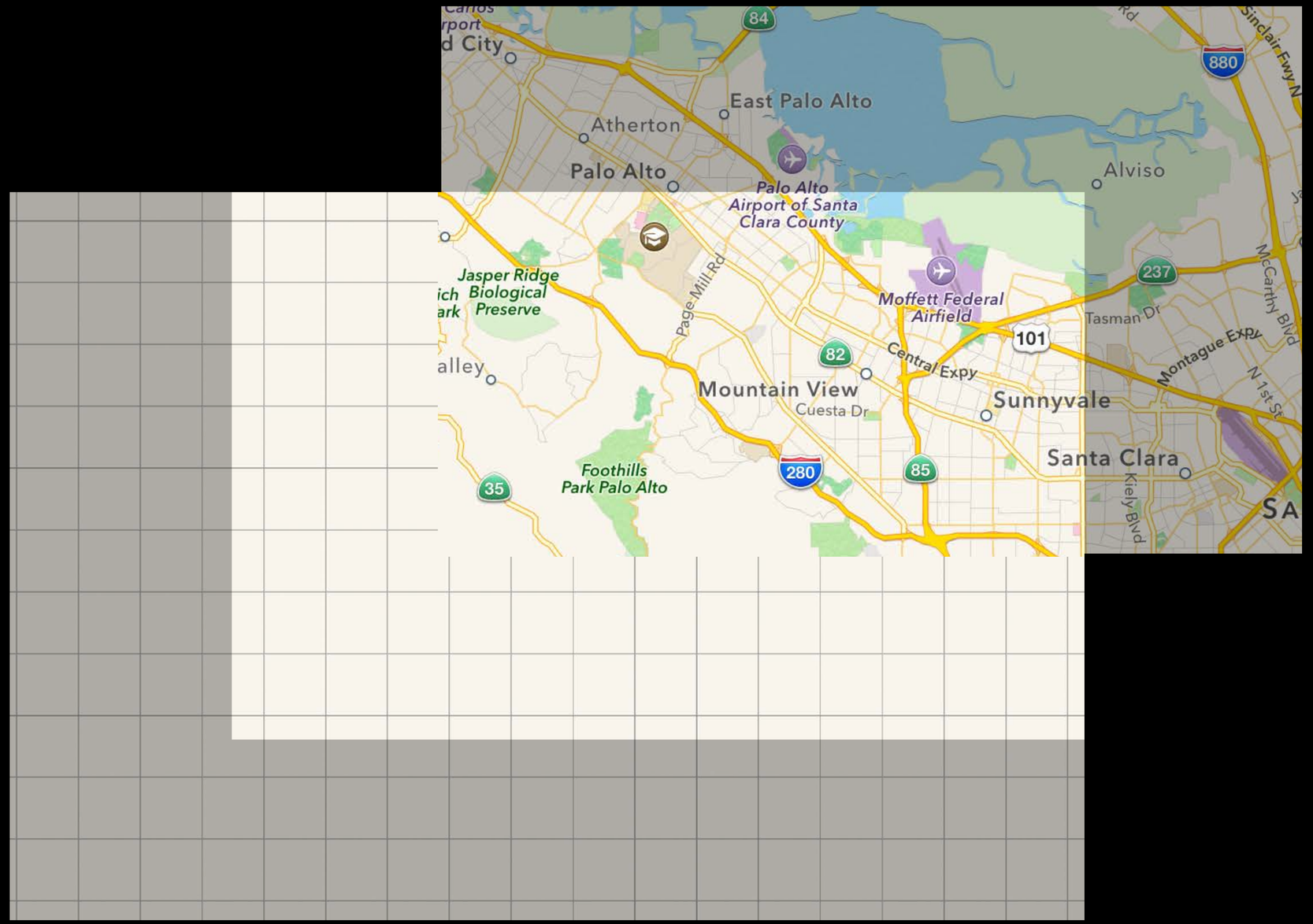
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Choosing QoS Class

Choosing QoS Class

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

Choosing QoS Class

	User Interactive	Is this work actively involved in updating the UI?
	User Initiated	Is this work required to continue user interaction?

Choosing QoS Class

	User Interactive	Is this work actively involved in updating the UI?
	User Initiated	Is this work required to continue user interaction?
	Utility	Is the user aware of the progress of this work?

Choosing QoS Class

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

Choosing QoS Class

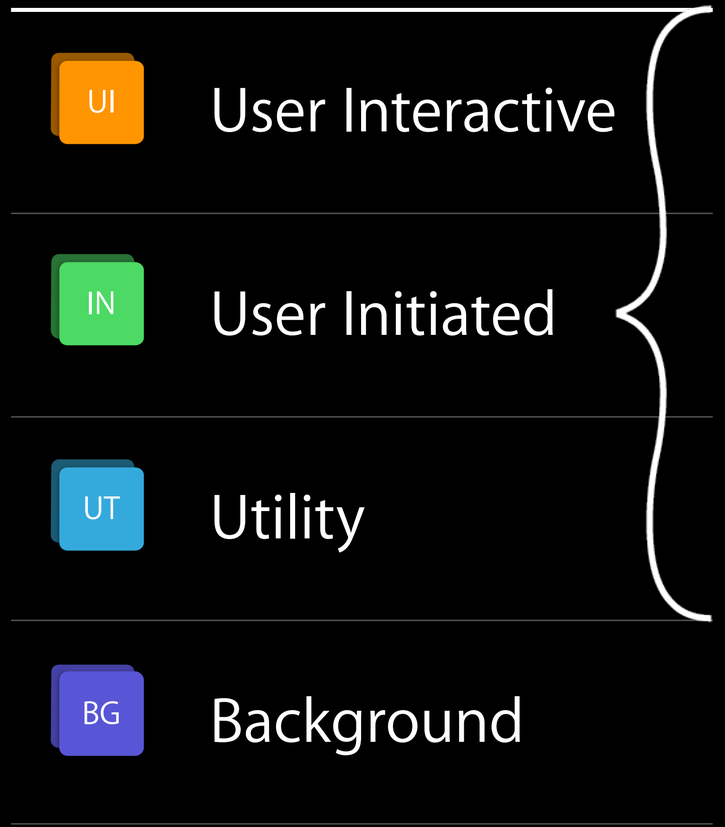
User Interactive

User Initiated

Utility

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

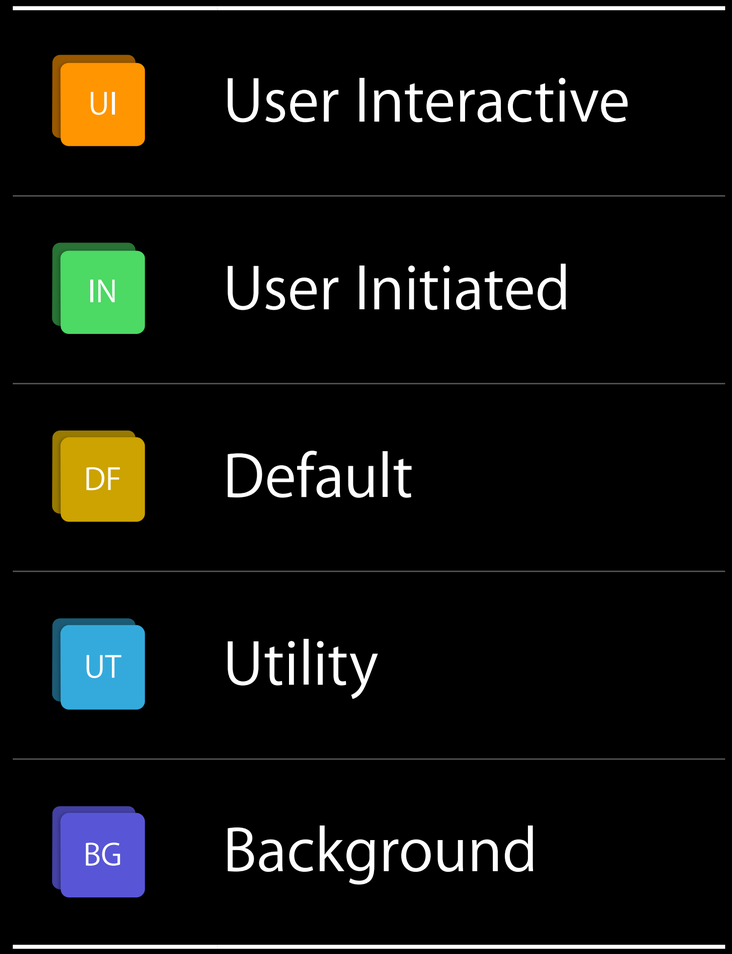
QoS Class Constants

	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



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

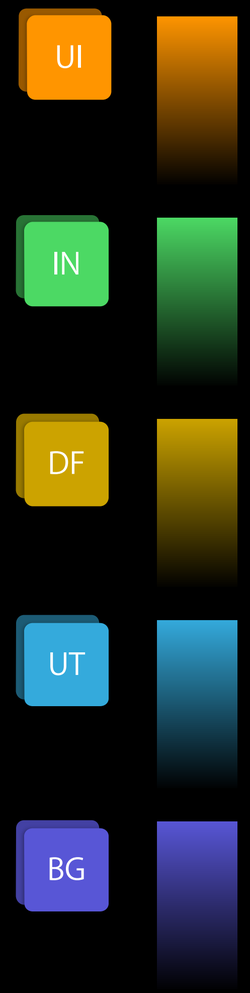
Relative position within a QoS Class band

QoS Relative Priority

Relative position within a QoS Class band

QoS Relative Priority

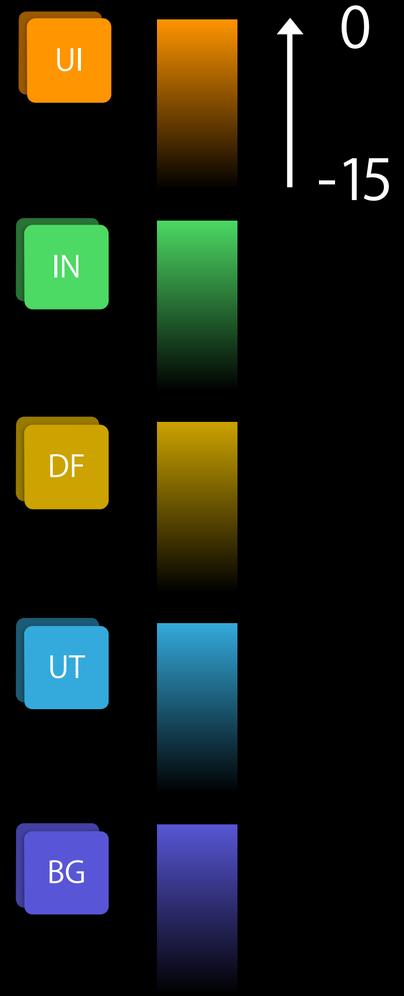
Relative position within a QoS Class band



QoS Relative Priority

Relative position within a QoS Class band

Lower than default



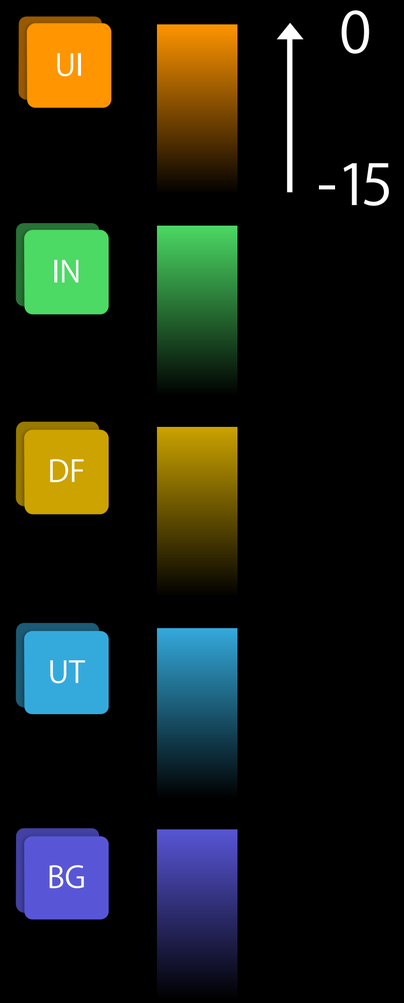
QoS Relative Priority

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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Initial QoS Class of main thread

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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);
```

Global Queues with QoS

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Get QoS Class of a queue

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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 QoS API

Get QoS queue attribute:

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

Dispatch Block Objects

Dispatch Block Objects

Configure properties of individual units of work on a queue

Dispatch Block Objects

Configure properties of individual units of work on a queue

Address individual workunits for

- Wait for completion
- Completion notification
- Cancellation

Dispatch Block Objects

Configure properties of individual units of work on a queue

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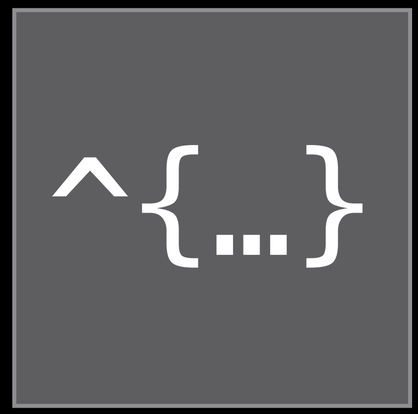
Integrate with existing API

Dispatch Block Objects

Wrapper Block

Created from an existing GCD Block

- dispatch_block_t



Dispatch Block Objects

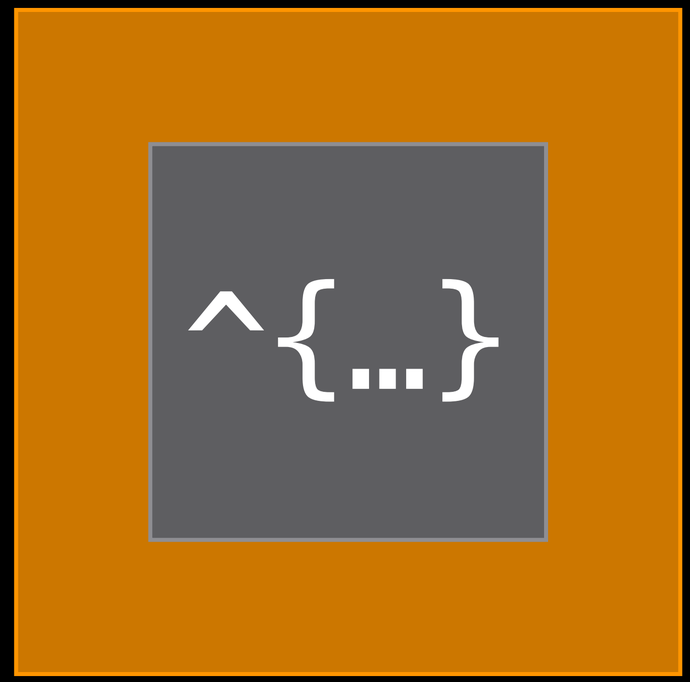
Wrapper Block

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

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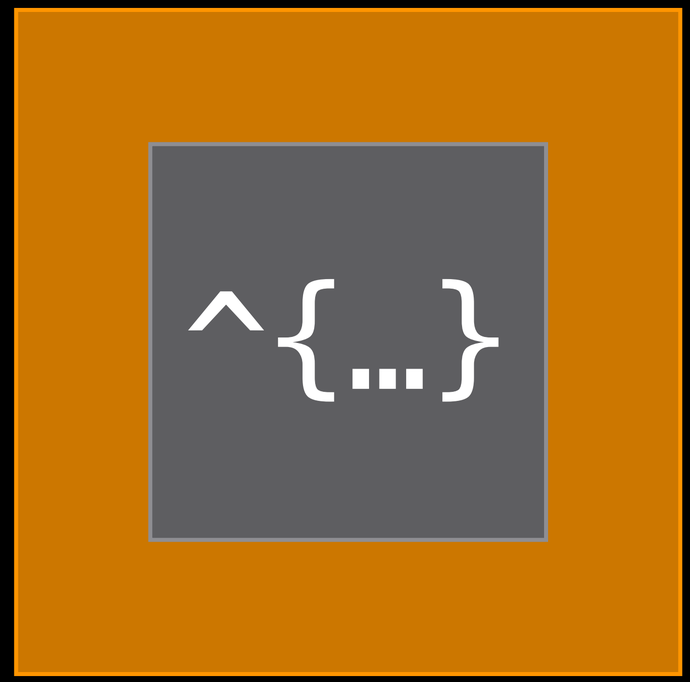
Additional configuration

- 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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dispatch_async(queue, block);

// Do some work

dispatch_wait(block, DISPATCH_TIME_FOREVER);

Block_release(block);
```

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);
```

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);

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    // 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

Explicit control

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Priority Inversions

Priority Inversion

Progress of high-priority work depends on

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

Priority Inversion

Progress of high-priority work depends on

- 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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Prefer asynchronous execution over synchronous waiting

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

Execution Context

Automatic propagation

Propagated across threads

- GCD
- NSOperationQueue
- Foundation

Execution Context

Automatic propagation

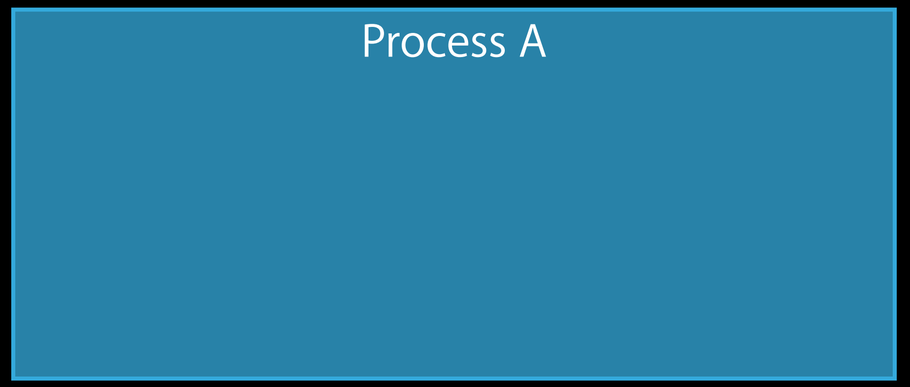
Propagated across threads

- GCD
- NSOperationQueue
- Foundation

Propagated across processes

- XPC
- MIG
- CFMachPort

Automatic Propagation



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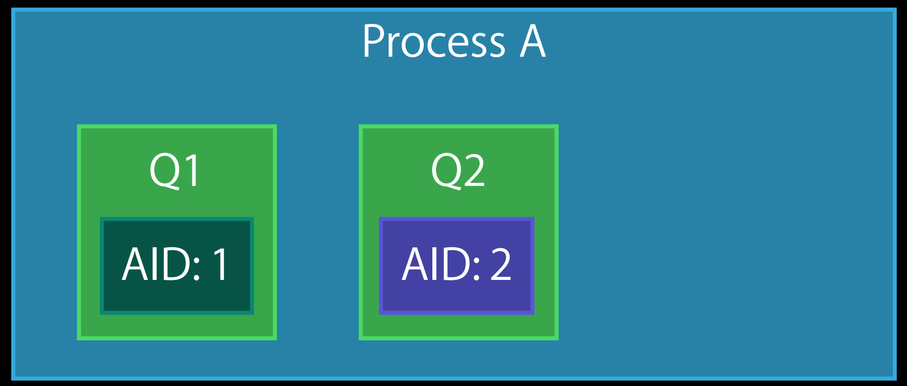

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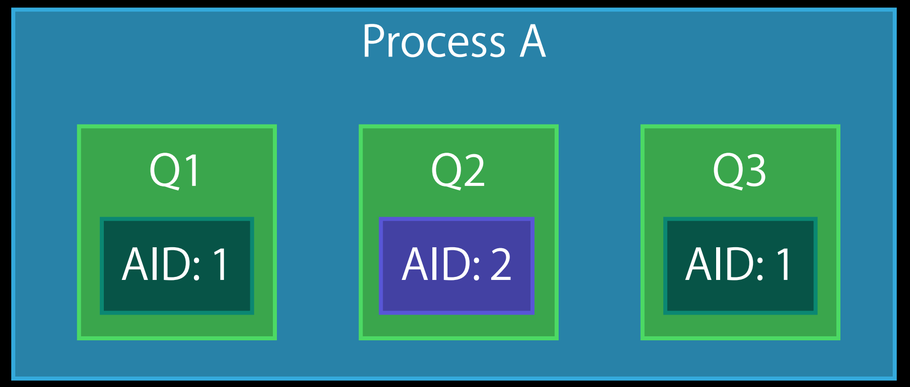

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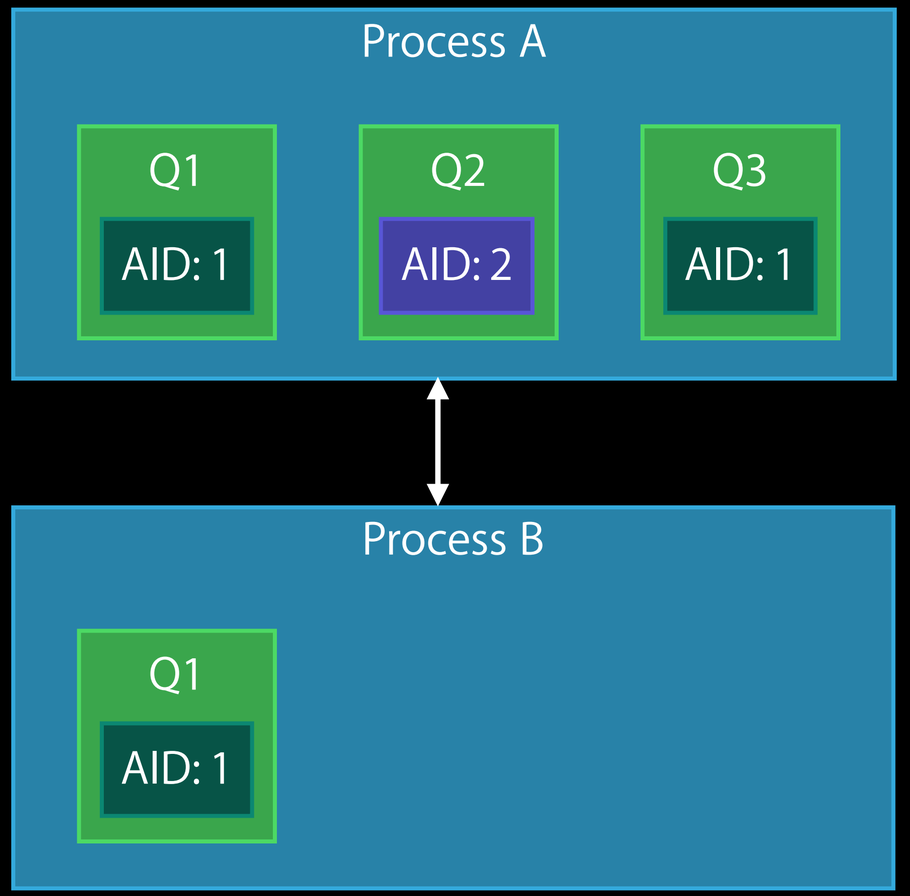

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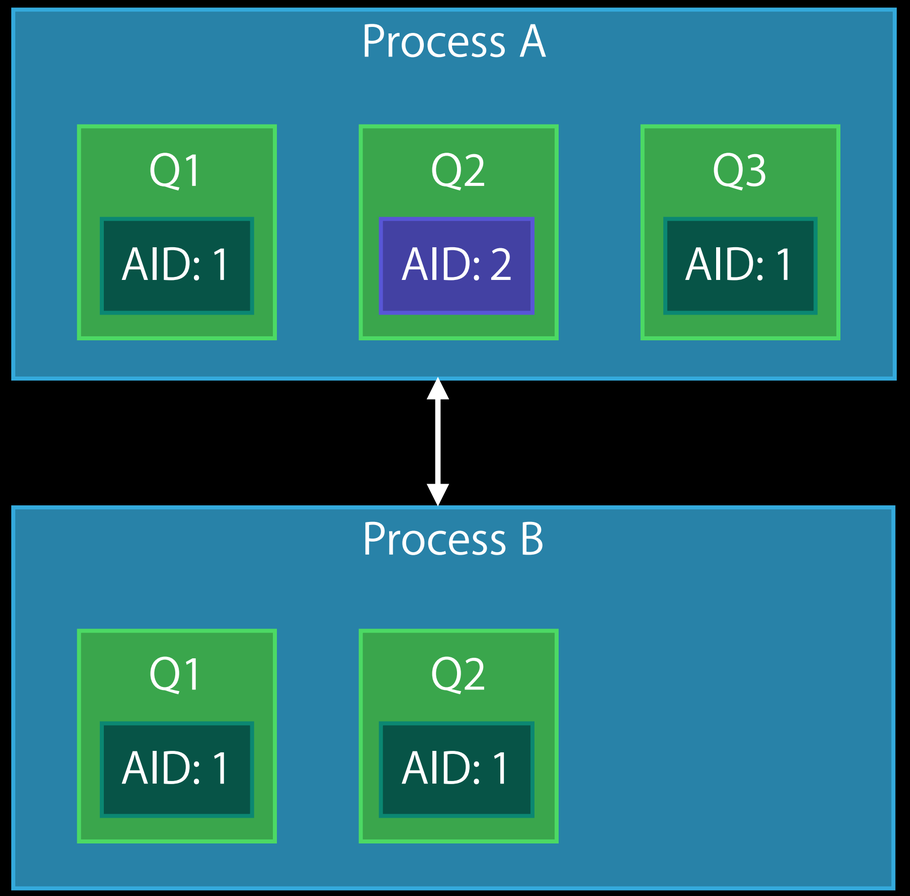

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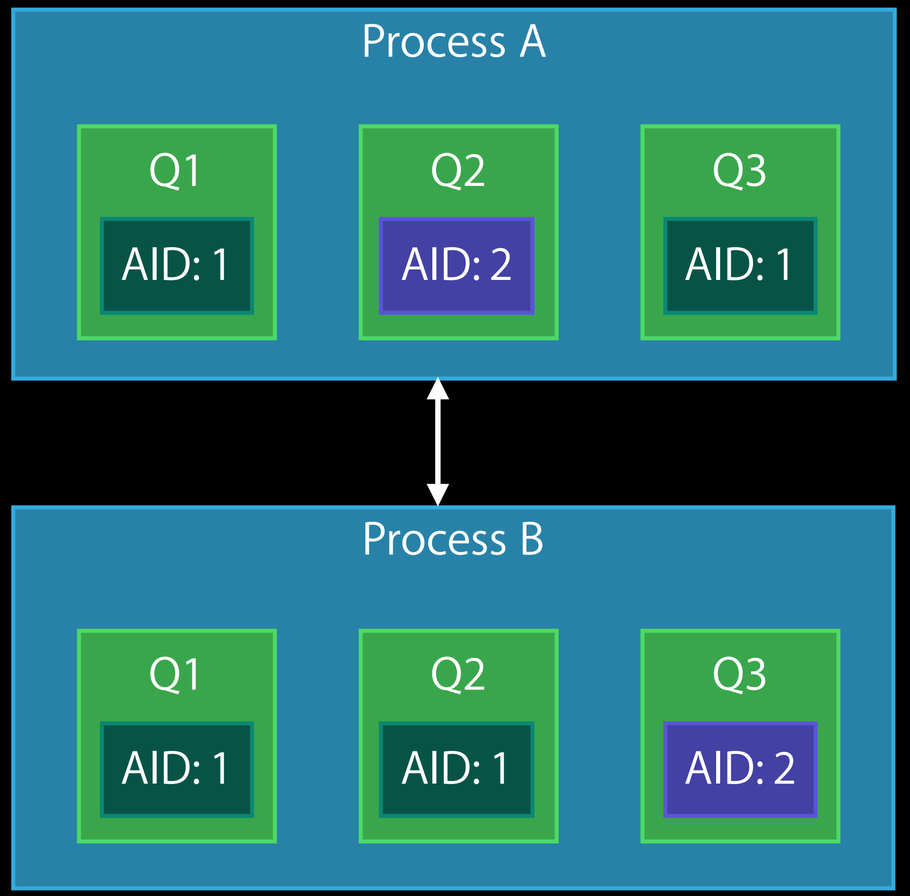


Propagation Control

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

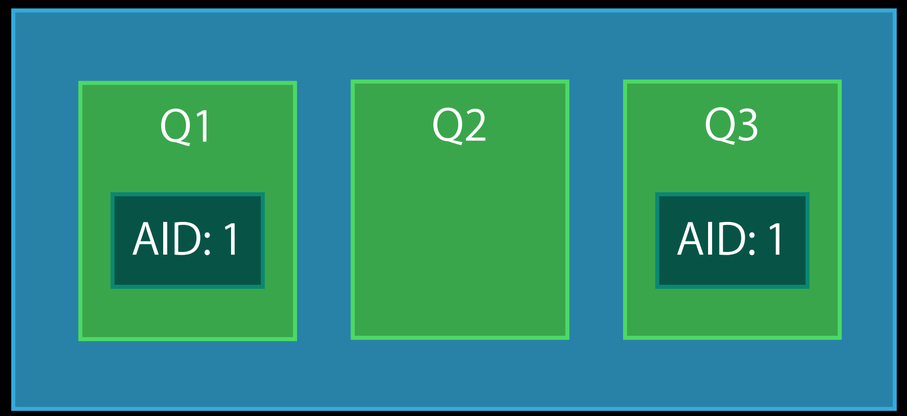
Detached by default

- Dispatch source handlers
- `dispatch_after()`

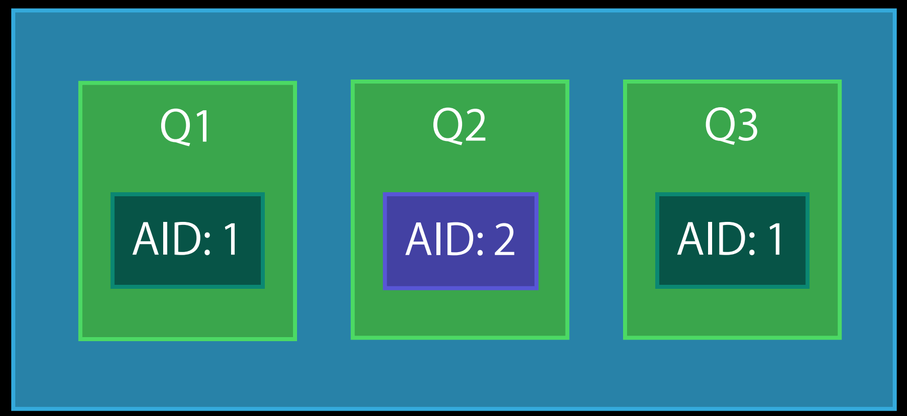
Detached Block

Detached Block

Detached Block



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

XPC

Propagation

XPC connections automatically propagate

- QoS Class
- Execution Context

Capture of current state on sending thread

XPC

Propagation

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

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

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

1

CPU Report

MyApplication
PID 7632, Paused

CPU	7%
Memory	12.7 MB
Energy Impact	Low
Disk	Zero KB/s
Network	Zero KB/s

- **Thread 1** Queue: com.apple.main-thread (serial)
  - 0 mach_msg_trap
  - 11 NSApplicationMain
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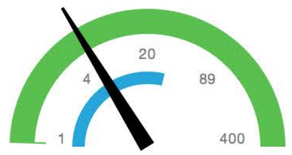
Percentage Used



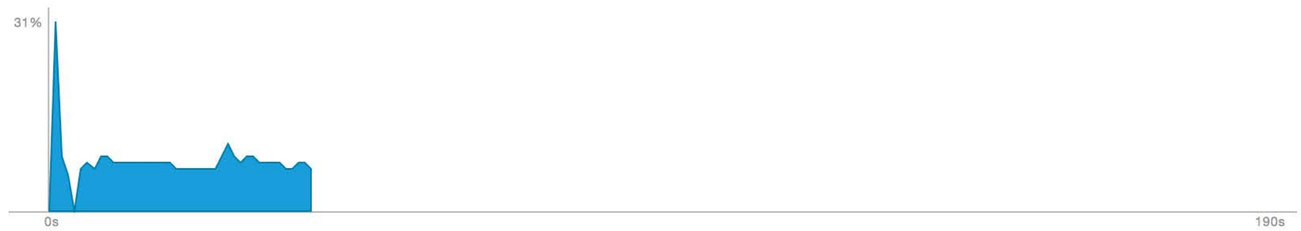
7%

Usage Comparison

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

Usage over Time

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



Threads

MyApplication 〉 Thread 5 〉 0 __semwait_signal

(lldb)

Auto

All Output

MyApplication 〉 My Mac 64–bit

Running MyApplication : MyApplication

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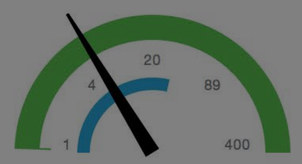

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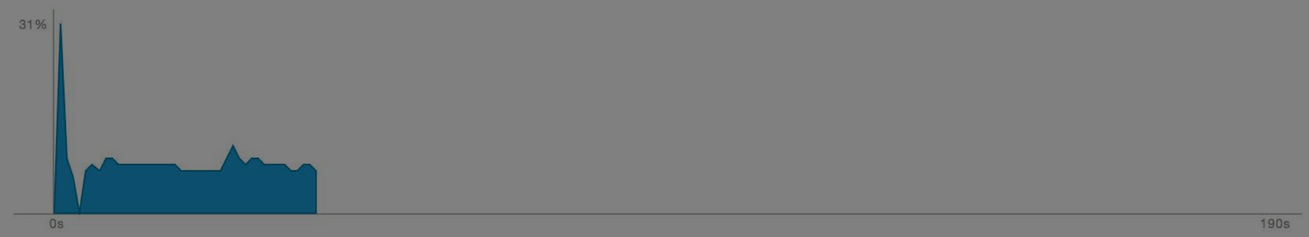

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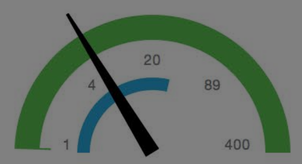

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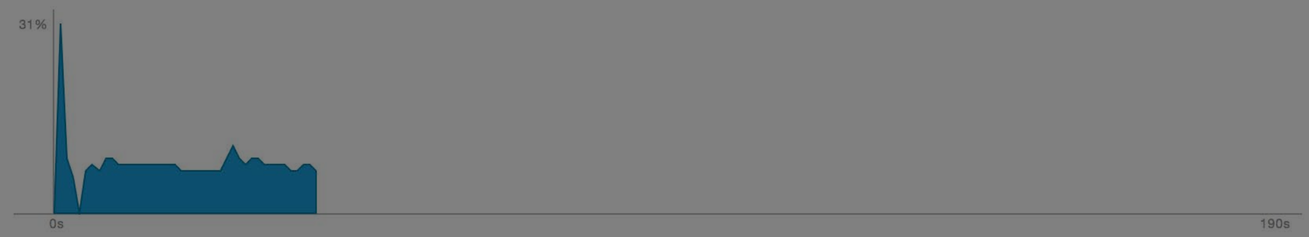

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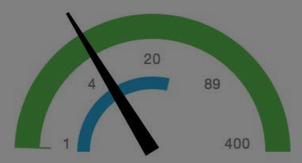

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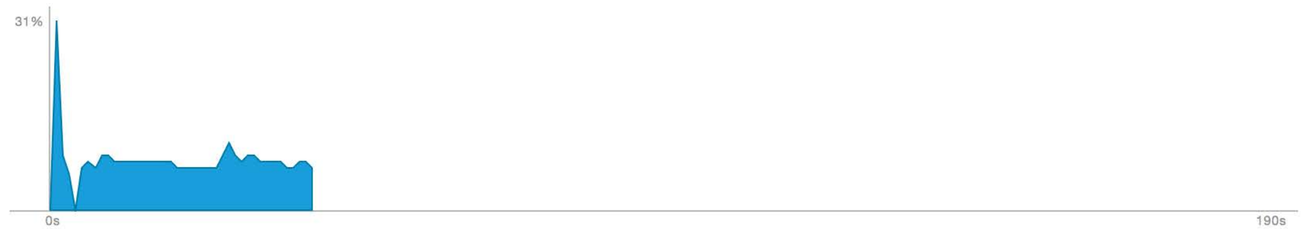

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(lldb)

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All Output

MyApplication 〉 My Mac 64–bit

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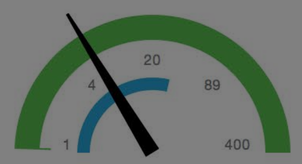

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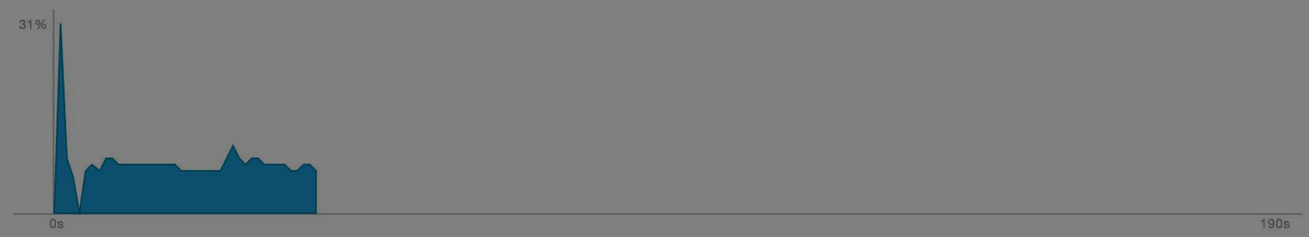


Threads

Thread 1	User Interactive
Thread 2	User Interactive
Thread 3	QoS Unavailable
Thread 5	Utility
Thread 7	User Interactive
Thread 9	Default

MyApplication 〉 Thread 5 〉 0 __semwait_signal

(lldb)

Auto

All Output

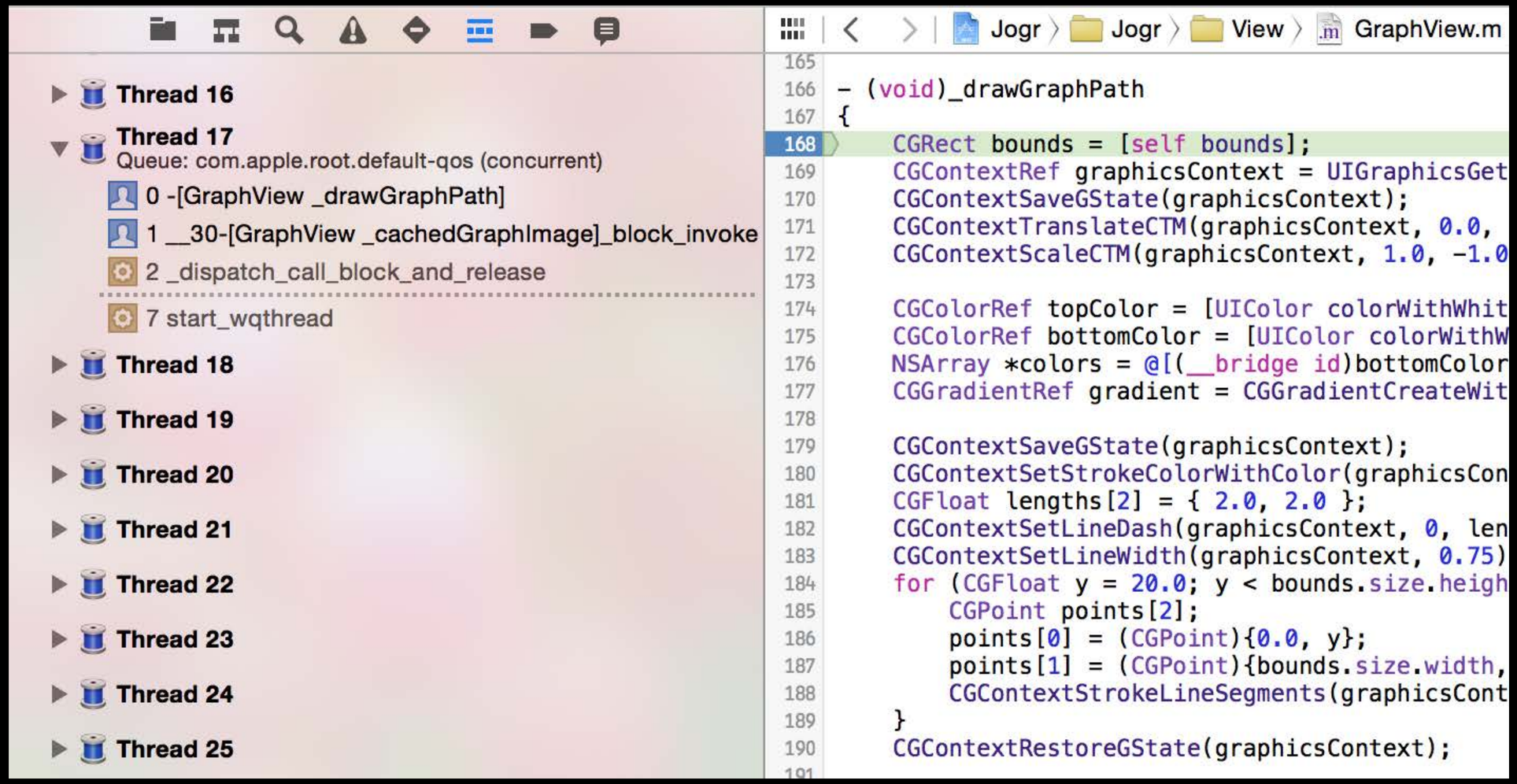
Diagnostics and Queue Debugging

Xcode 6 CPU Report

Xcode 6 Queue Debugging

Activity Tracing

Logical Backtraces



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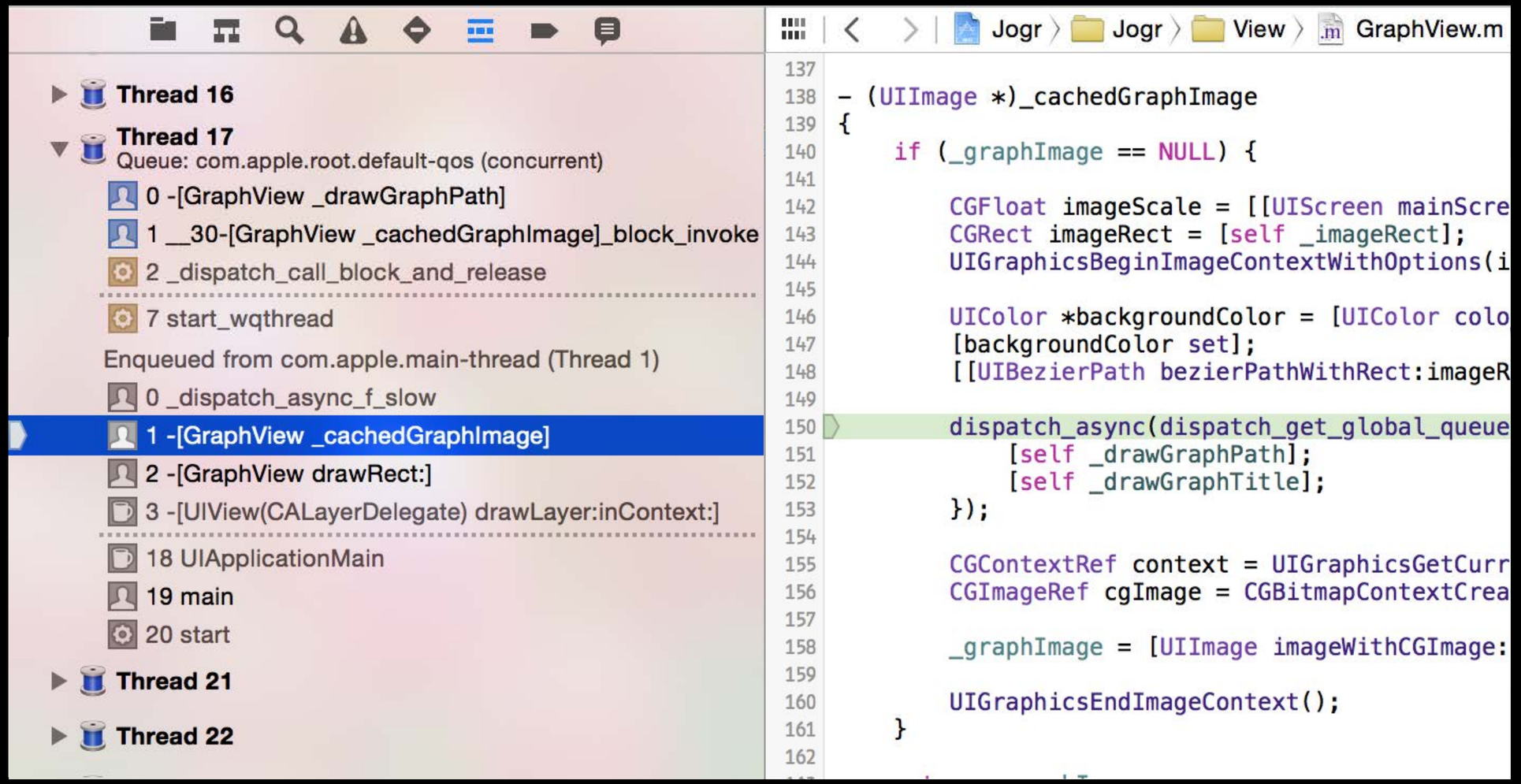

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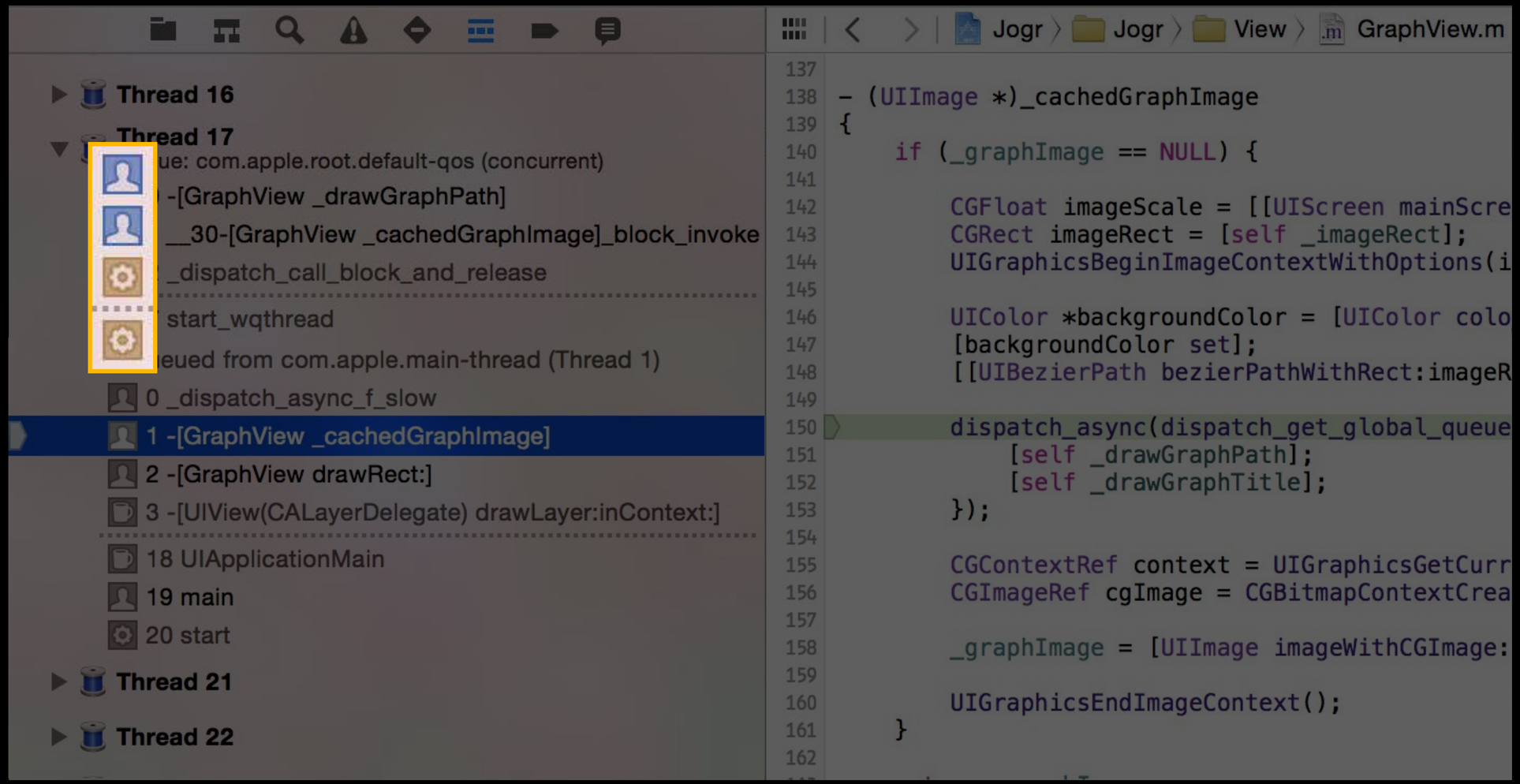

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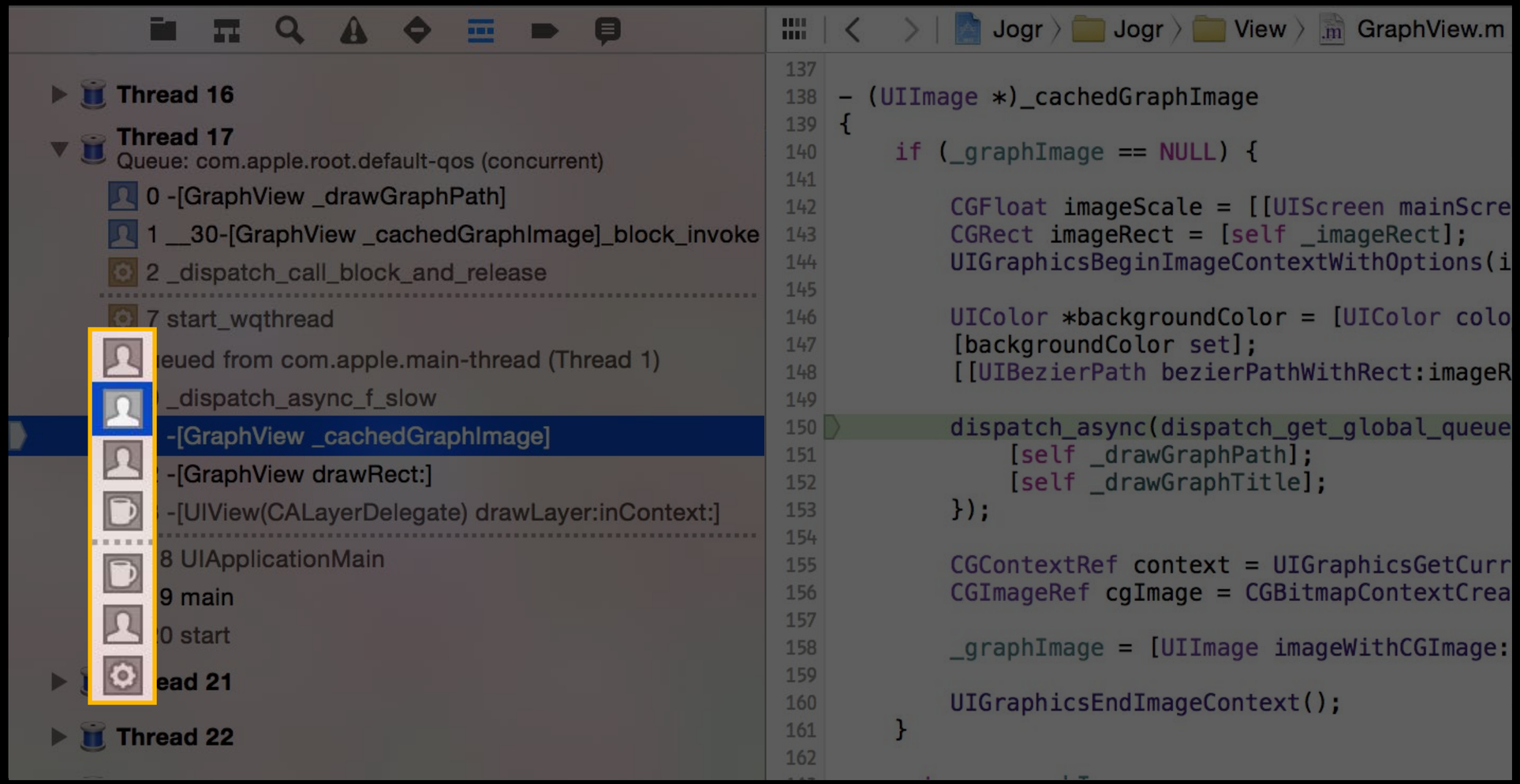
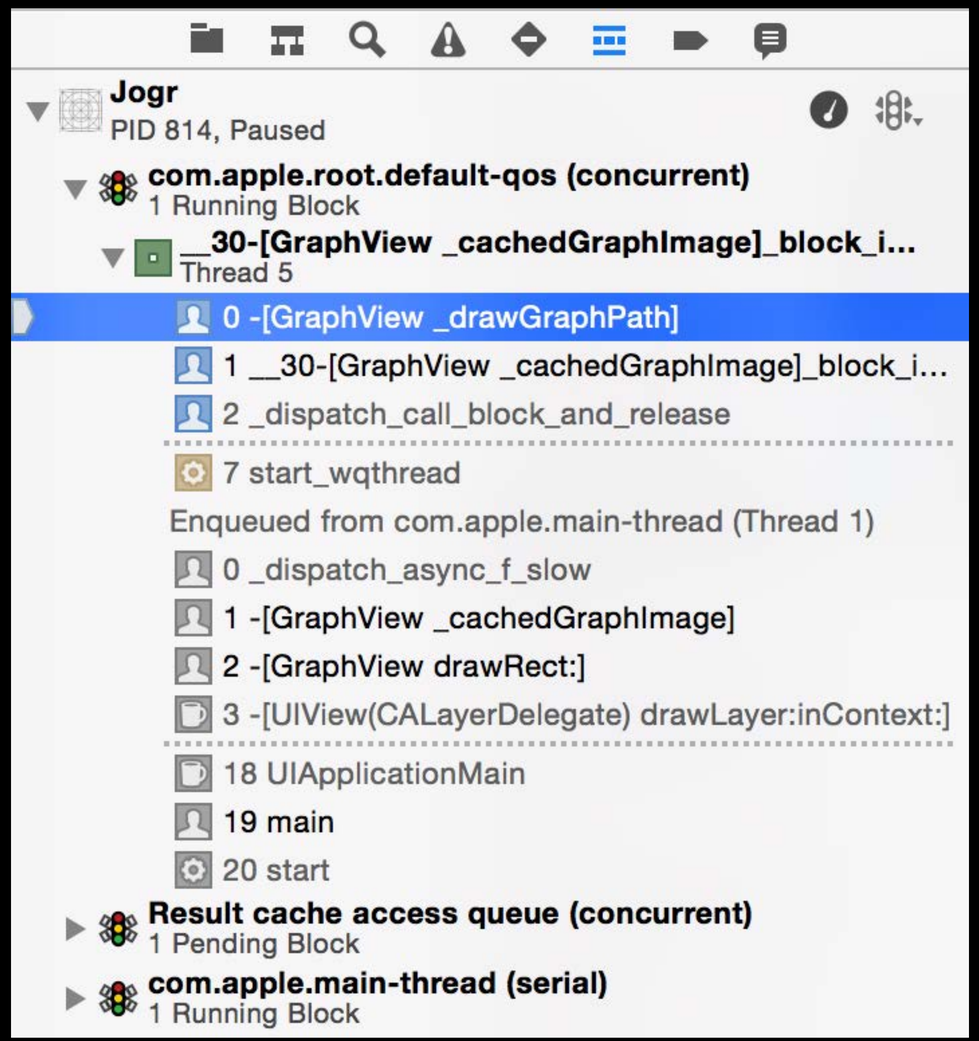
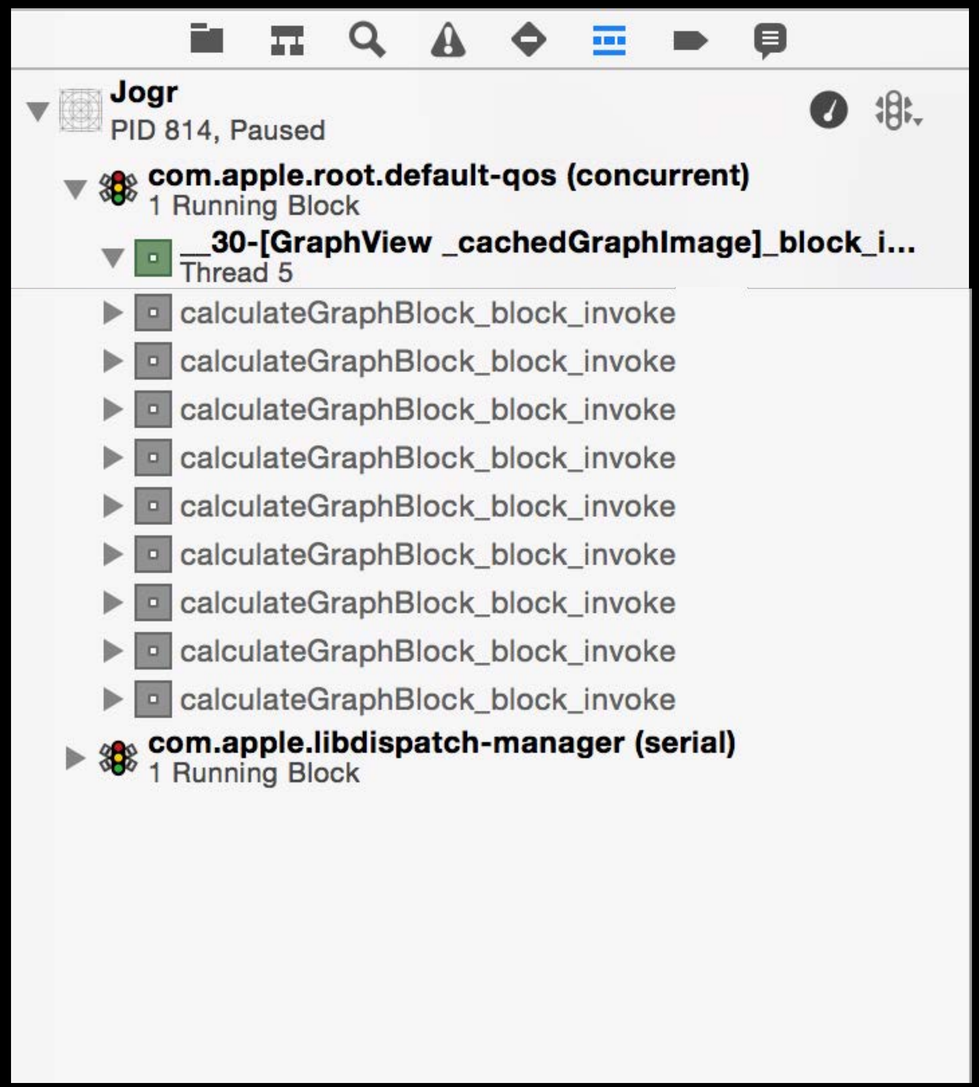


Pending Blocks



Pending Blocks



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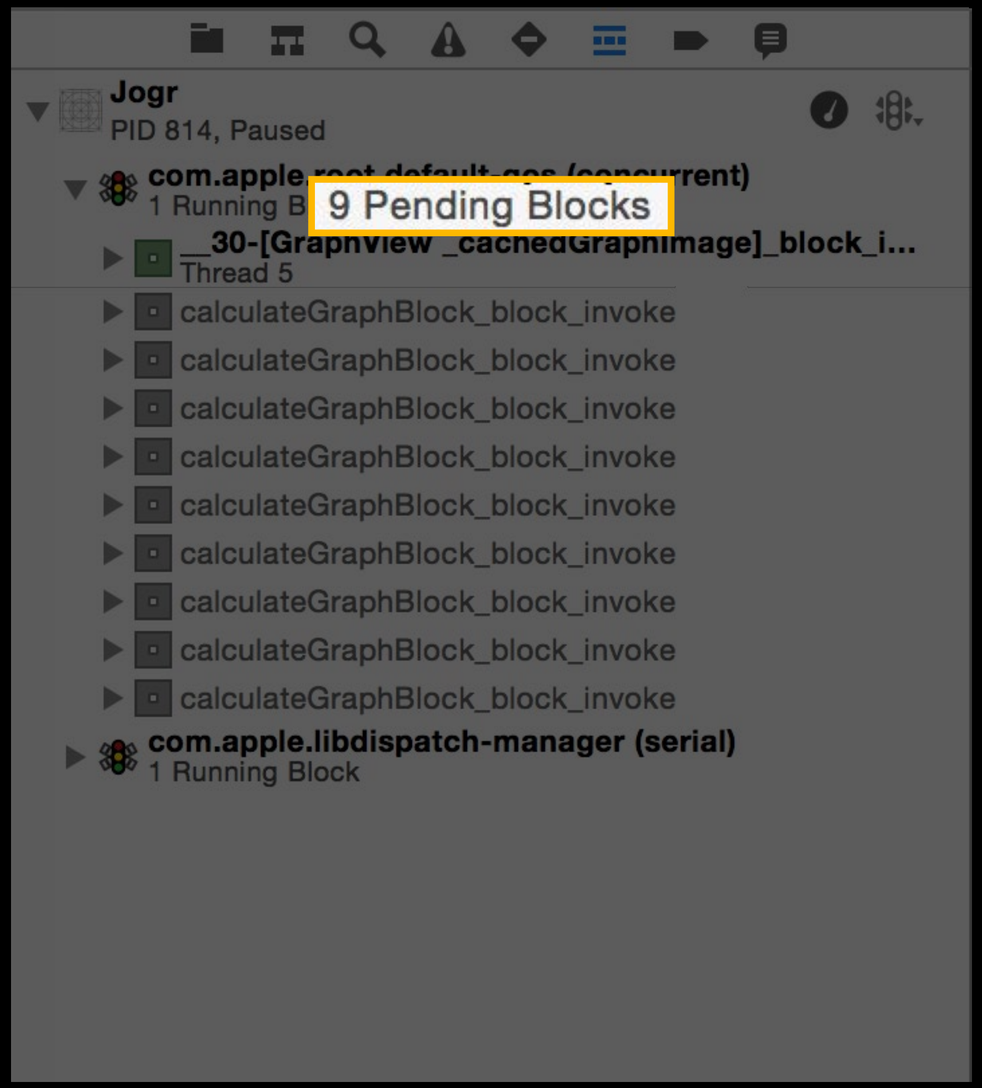

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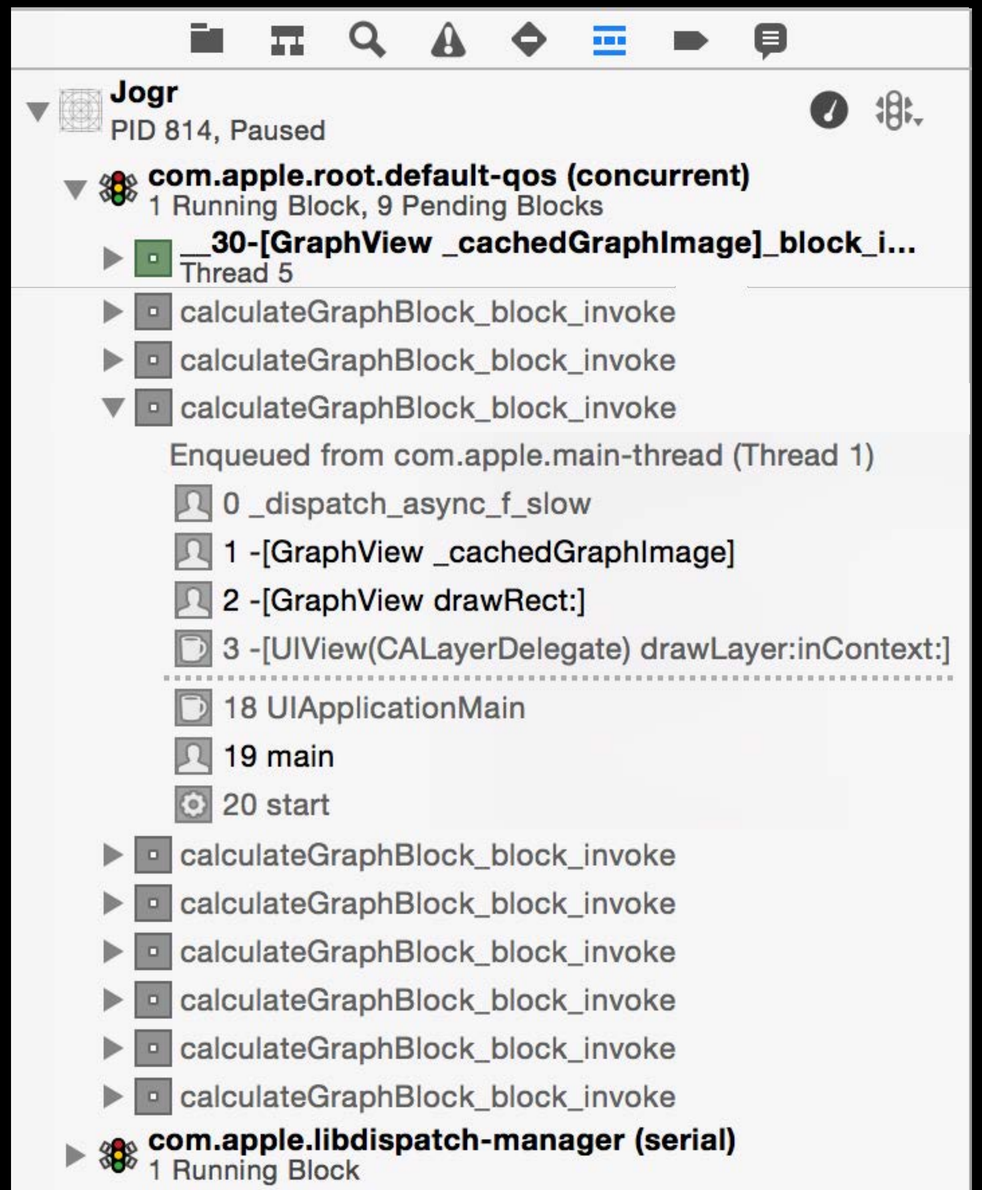

Diagnostics and Queue Debugging

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)
Exception Codes:       0x0000000000000000, 0x0000000000000000

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

0   com.apple.Query-Directory       0x0000000100002[illegible] -[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
• • •
16  com.apple.AppKit                0x00007fff83c01a9e NSApplicationMain + 1778
17  com.apple.Query-Directory       0x0000000100001a82 main + 34
18  libdyld.dylib                   0x00007fff874af5c9 start + 1

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
```

Activities in Crash Reports

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

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

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

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

```
Activity ID:                0x0000008f00000002
Activity Name:              sendAction:
Activity Breadcrumb:        Query directory using NSRunLoop
Activity Running Time:      6.028601 sec
Activity Failure Reason:    none detected
```

```
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
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5.866863     opendirectoryd               0xffffffff00000000 IPC receive
5.866883     Query Directory              0x0000000100000000 IPC send
```

Activities in Crash Reports

```
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   Activity Running Time:   6.028601 sec
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   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
```

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
```

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
```

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

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