Tools

#WWDC14

Advanced Graphics and Animations for iOS Apps

Session 419

Axel Wefers
iOS Software Engineer

Michael Ingrassia
iOS Software Engineer

What You Will Learn

Core Animation pipeline

Rendering concepts

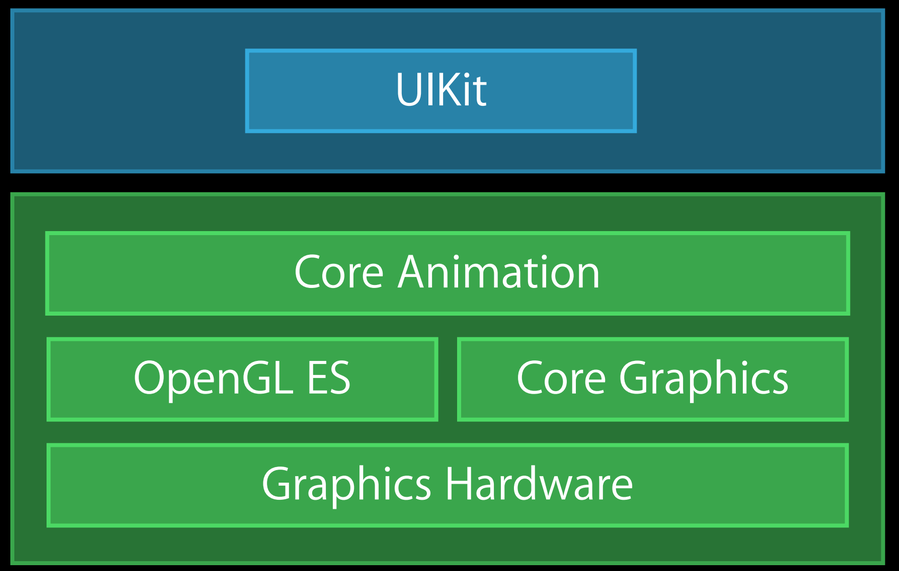
`UIBlurEffect`

`UIVibrancyEffect`

Profiling tools

Case studies

Technology Framework



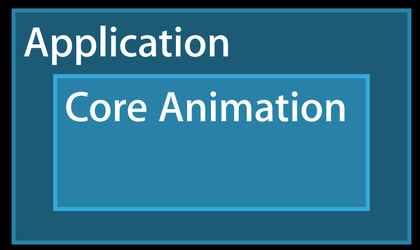
Core Animation Pipeline

Axel Wefers
iOS Software Engineer

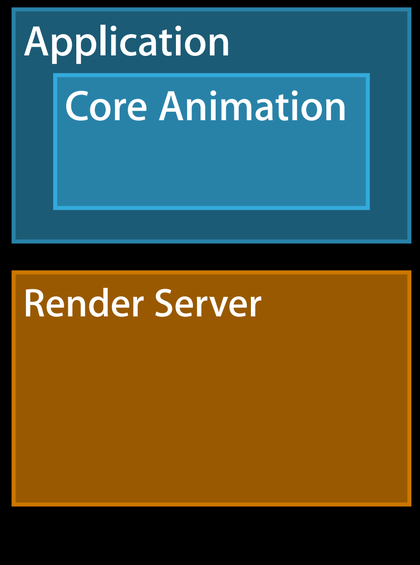
Core Animation Pipeline

Application

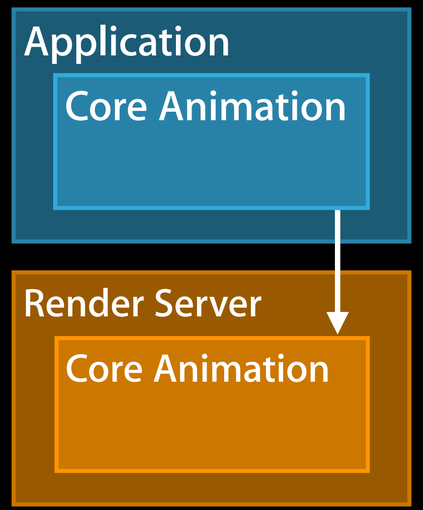
Core Animation Pipeline



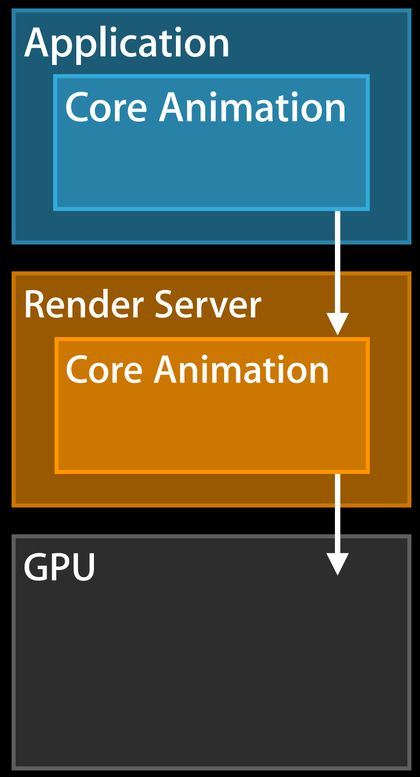
Core Animation Pipeline



Core Animation Pipeline



Core Animation Pipeline



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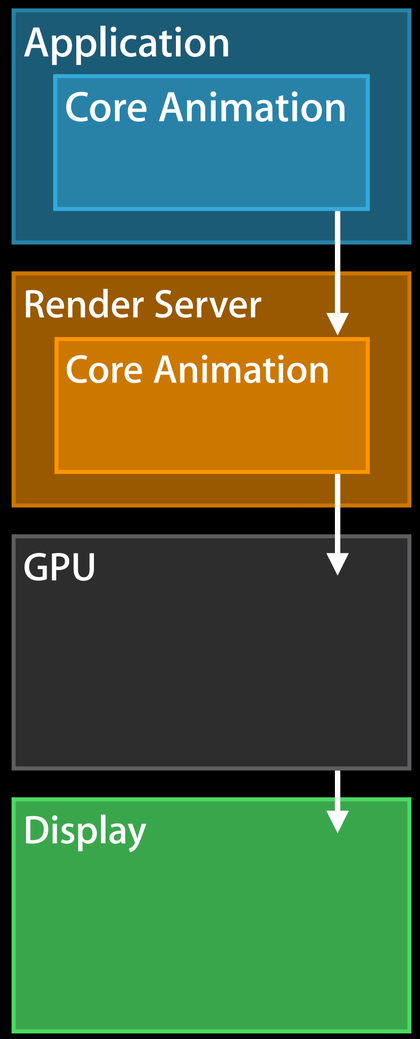
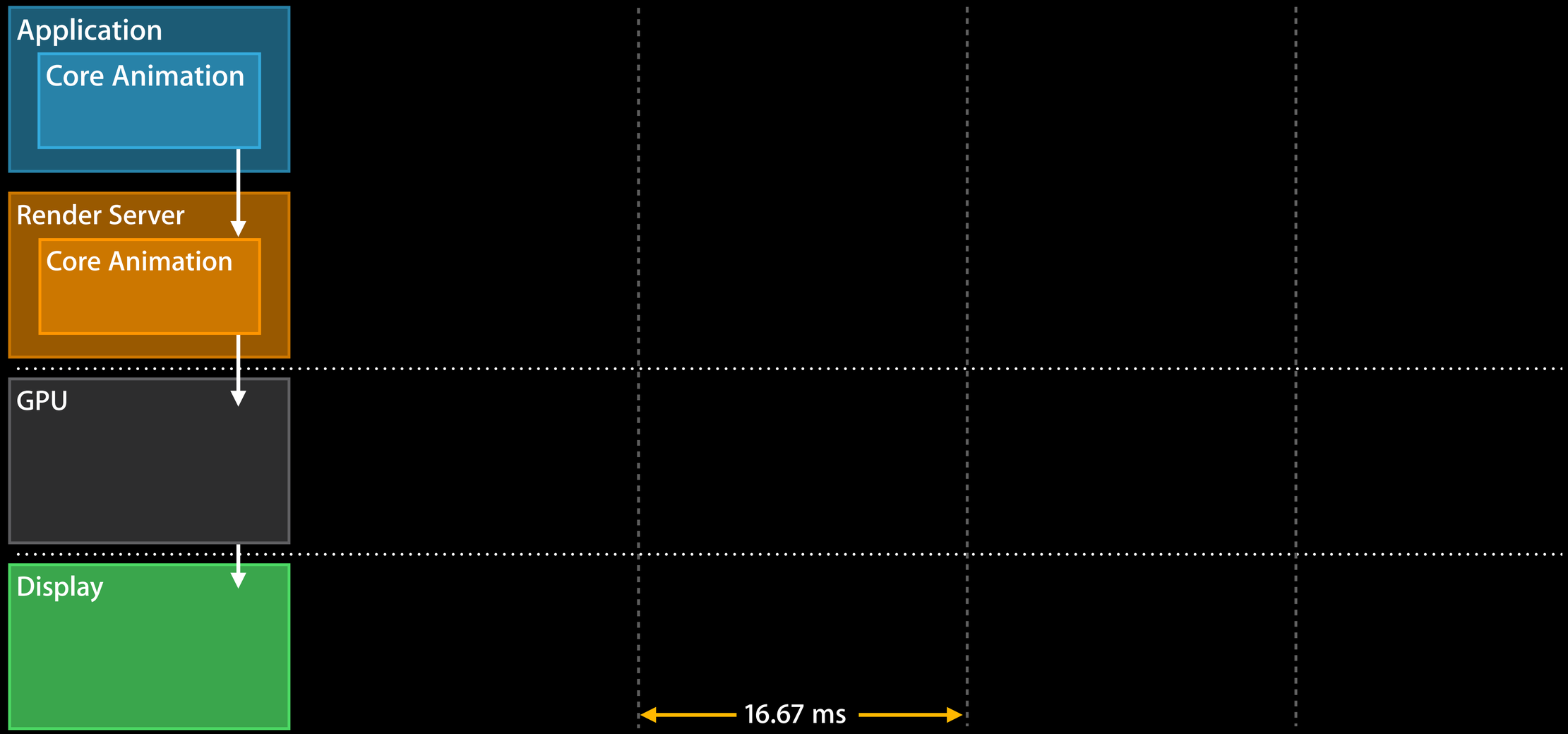
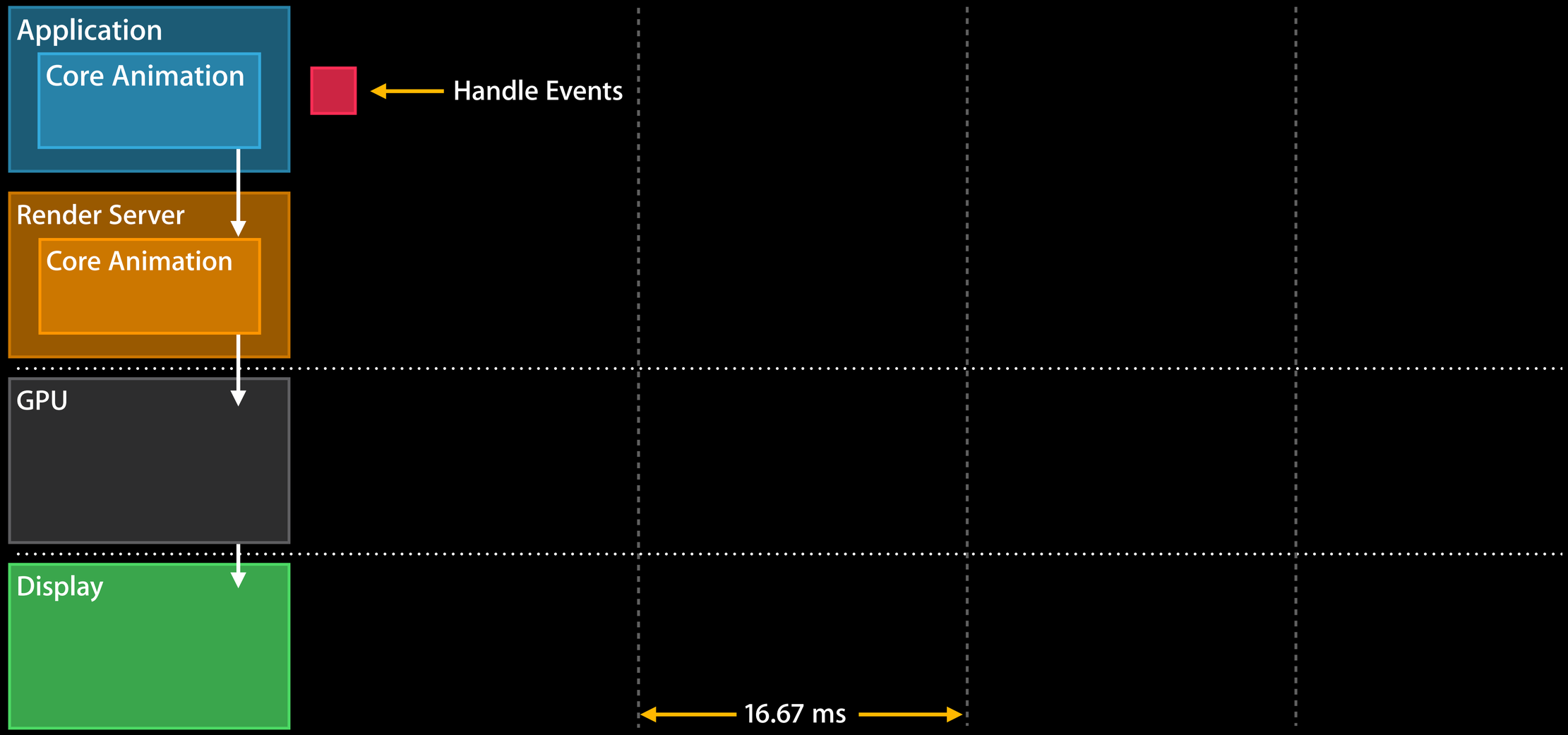


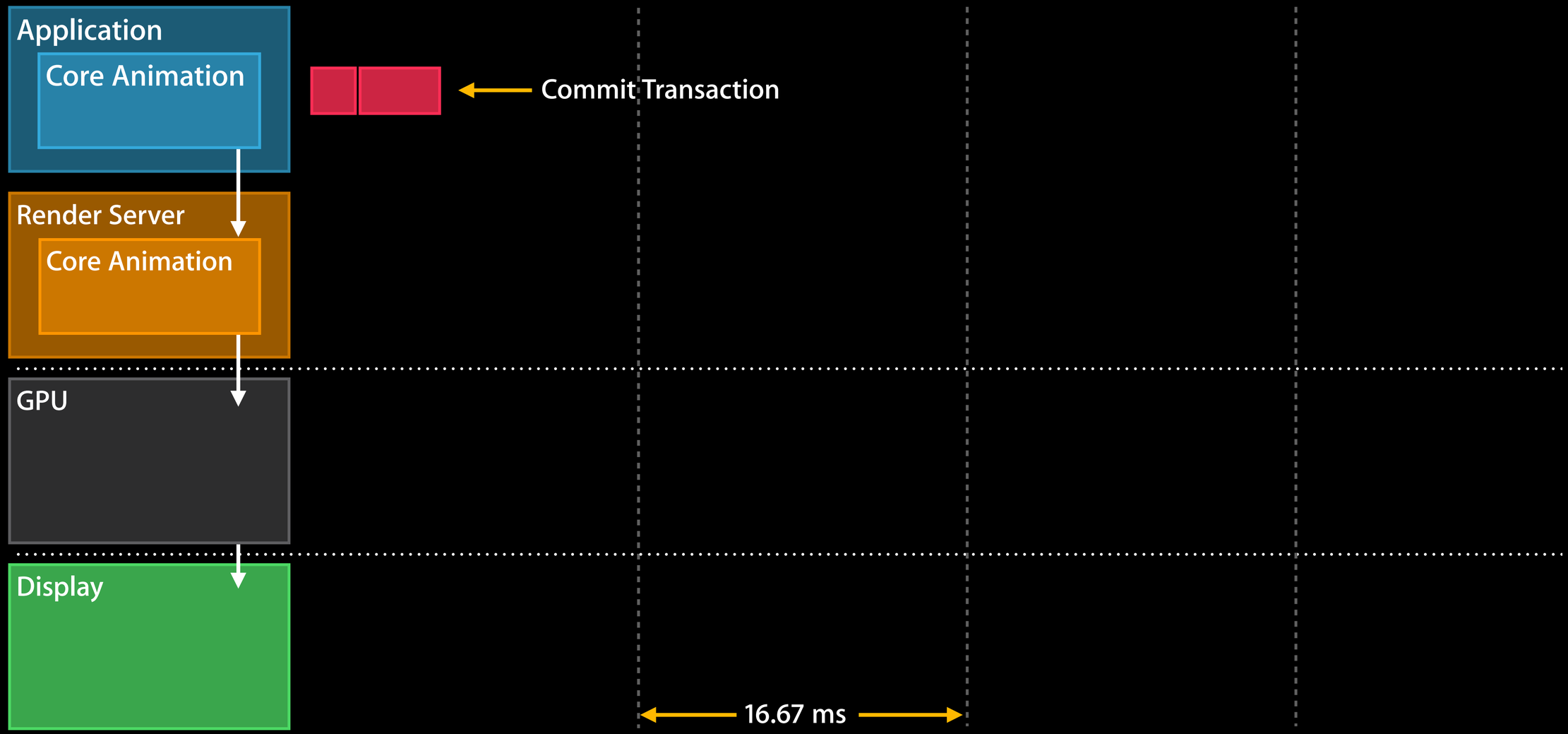
Core Animation Pipeline



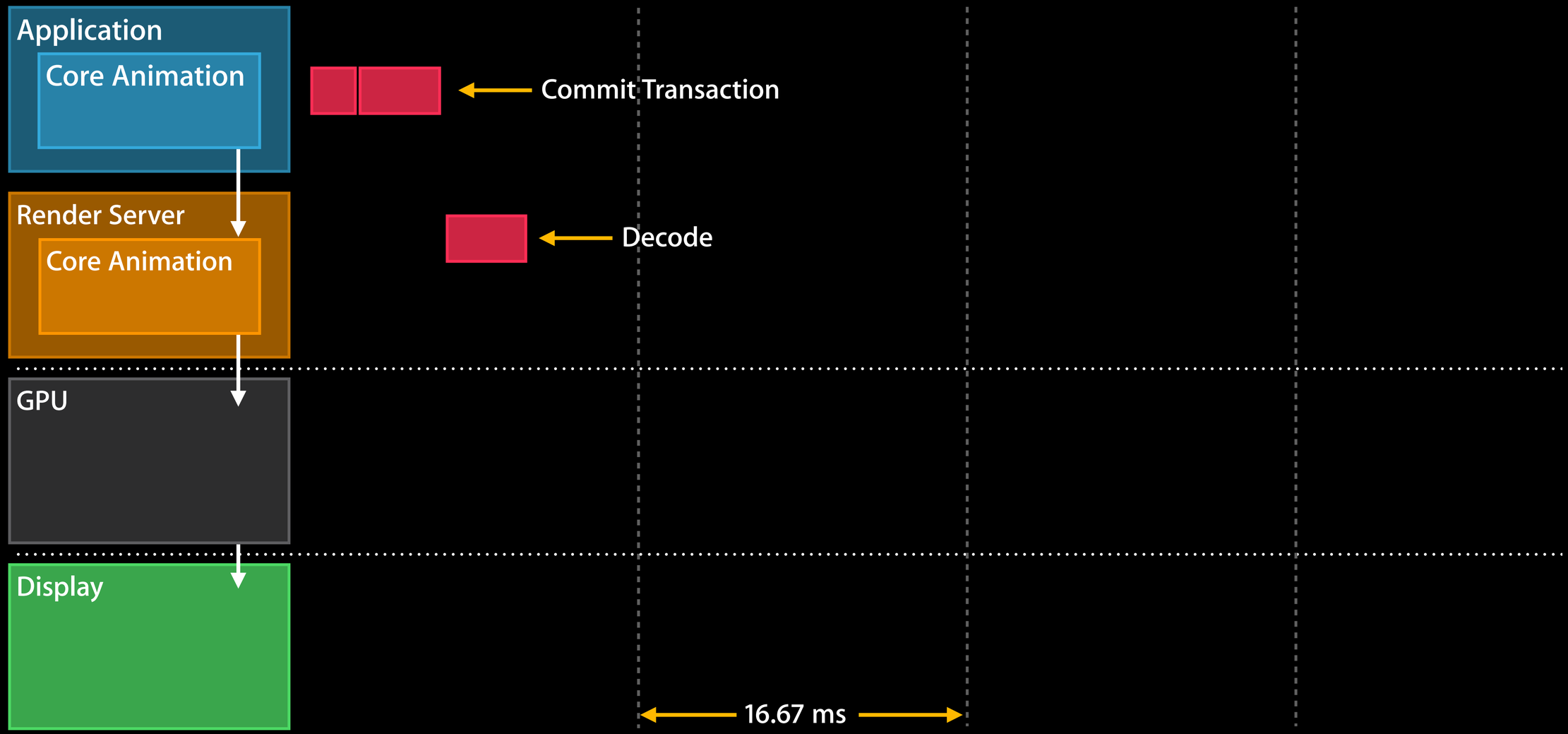
Core Animation Pipeline



Core Animation Pipeline



Core Animation Pipeline



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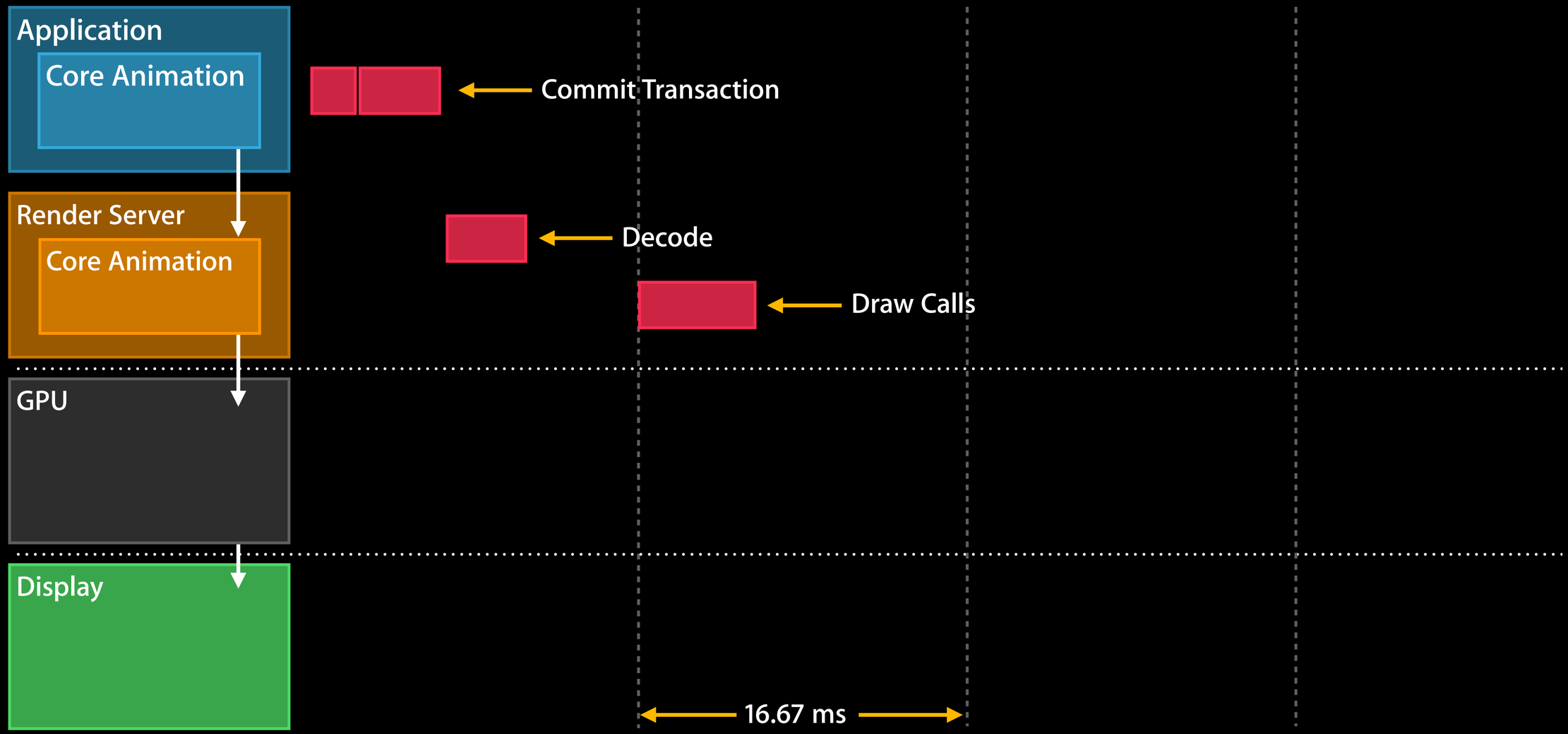

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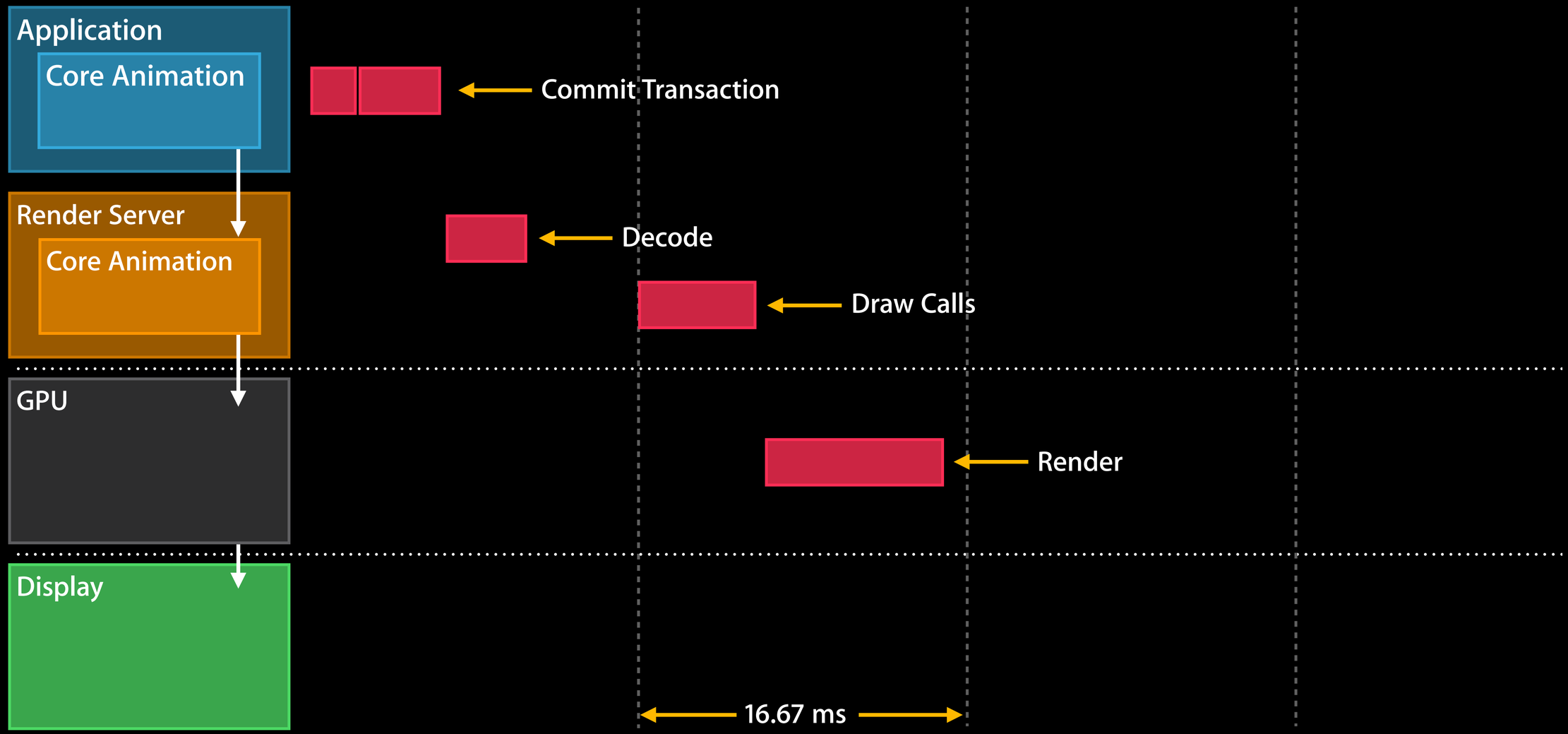

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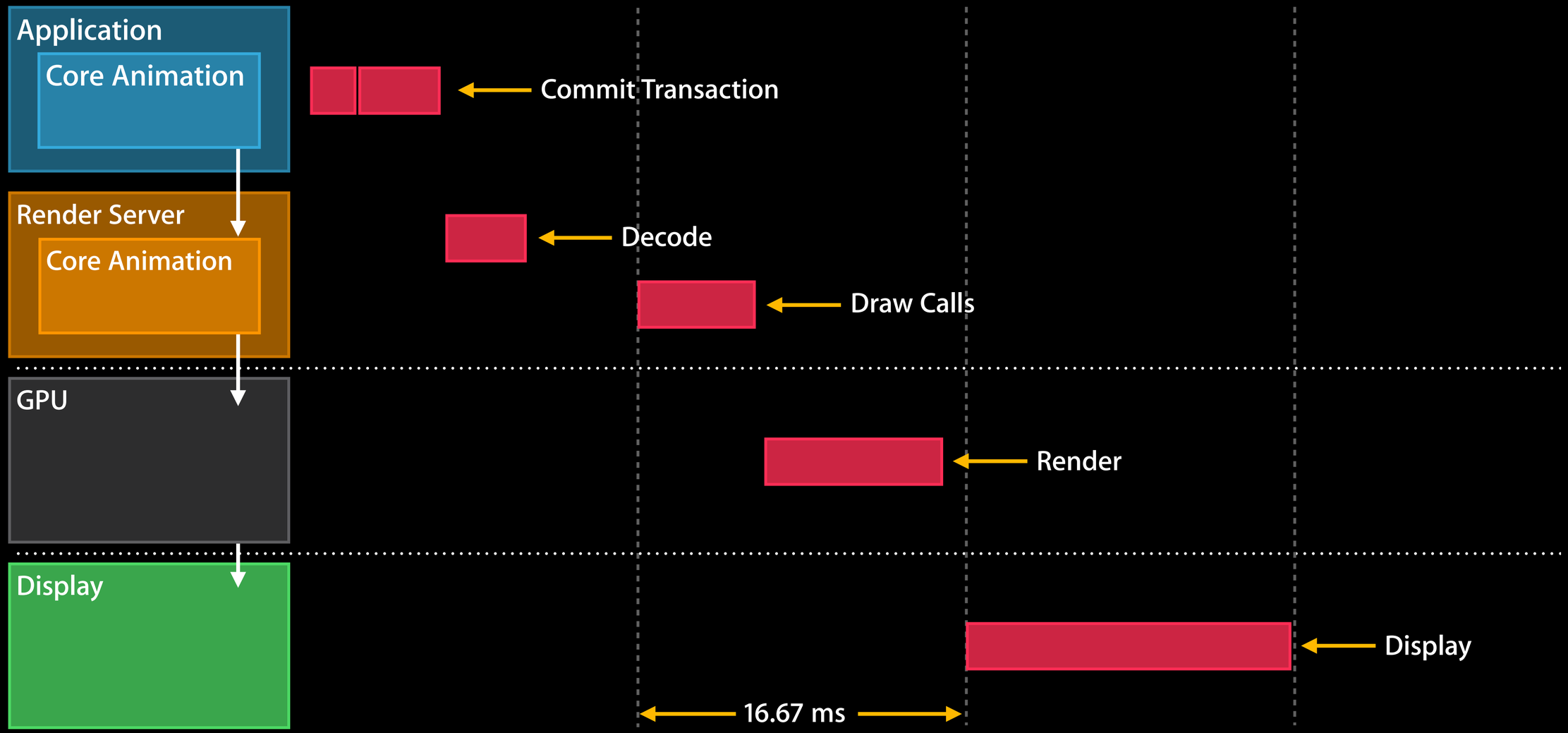

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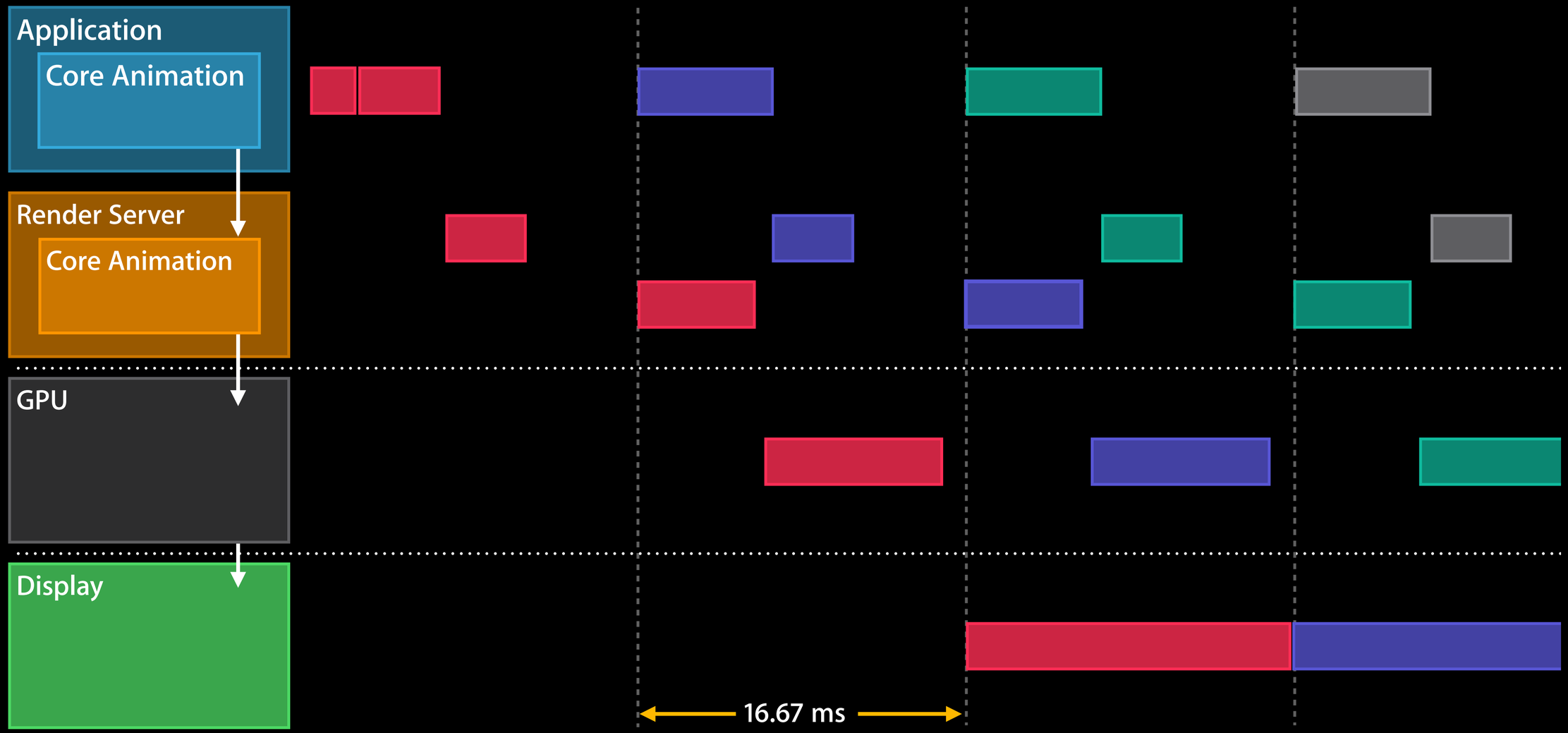

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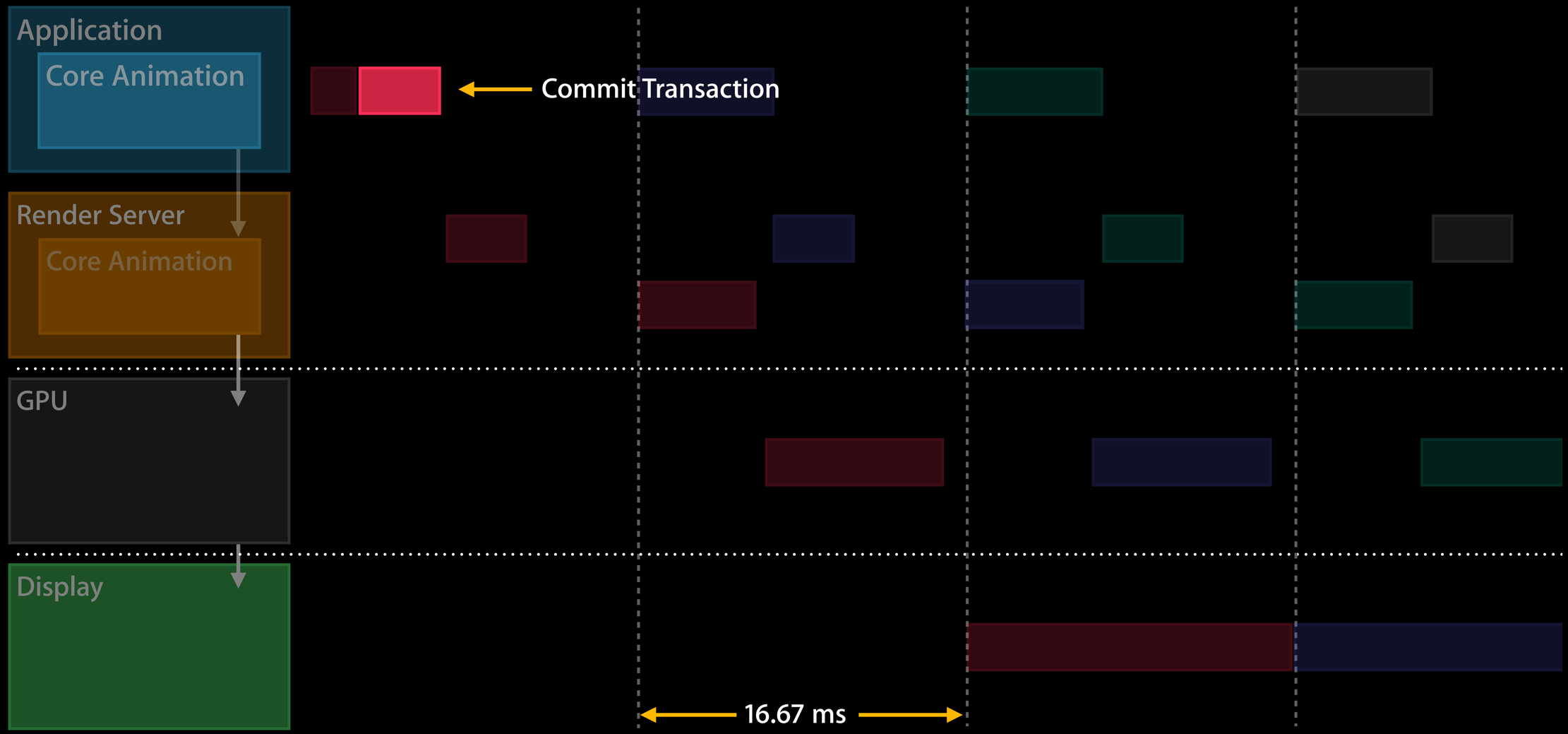


Commit Transaction

Commit Transaction

Layout

Set up the views

Commit Transaction

Layout | Display

Set up the views

Draw the views

Commit Transaction

Set up the views

Draw the views

Additional Core Animation work

Commit Transaction

Set up the views

Draw the views

Additional Core Animation work

Package up layers and send them to render server

Commit Transaction

Layout

Layout	Display	Prepare	Commit

`layoutSubviews` overrides are invoked

View creation, `addSubview:`

Populate content, database lookups

Usually CPU bound or I/O bound

Display

Layout | Display | Prepare | Commit

Draw contents via `drawRect:` if it is overridden

String drawing

Usually CPU or memory bound

Prepare Commit

Image decoding

Image conversion

Commit

Layout	Display	Prepare	Commit

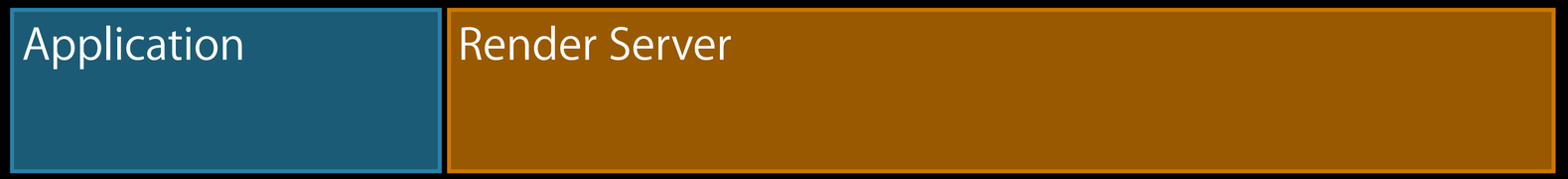
Package up layers and send to render server

Recursive

Expensive if layer tree is complex

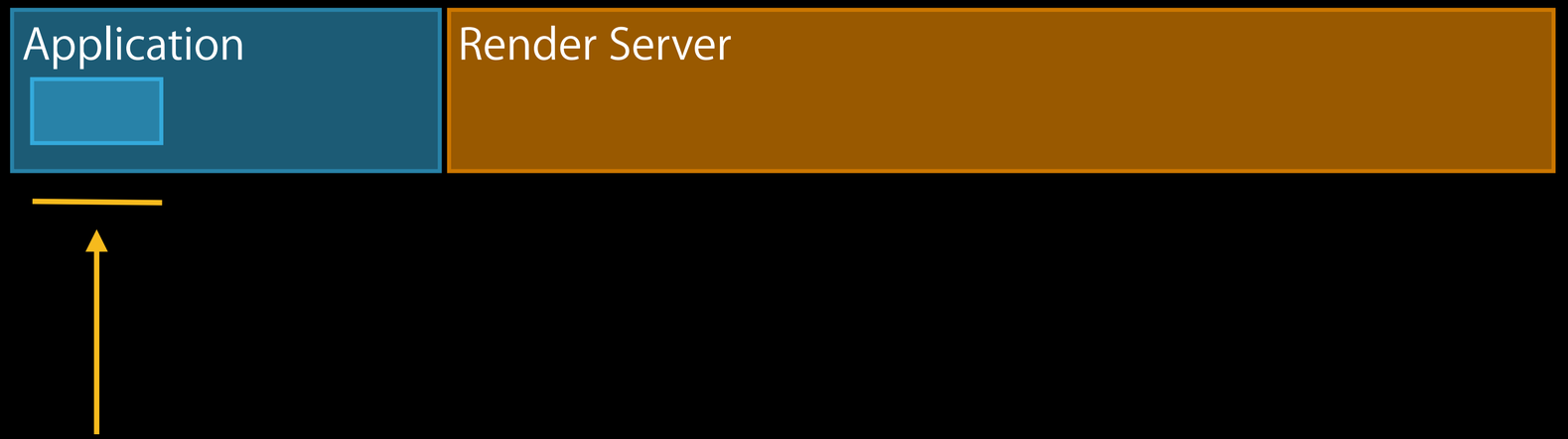
Animation

Three-stage process



Animation

Three-stage process



1. Create animation and update view hierarchy (`animateWithDuration:animations:`)

Animation

Three-stage process

Animation

Three-stage process

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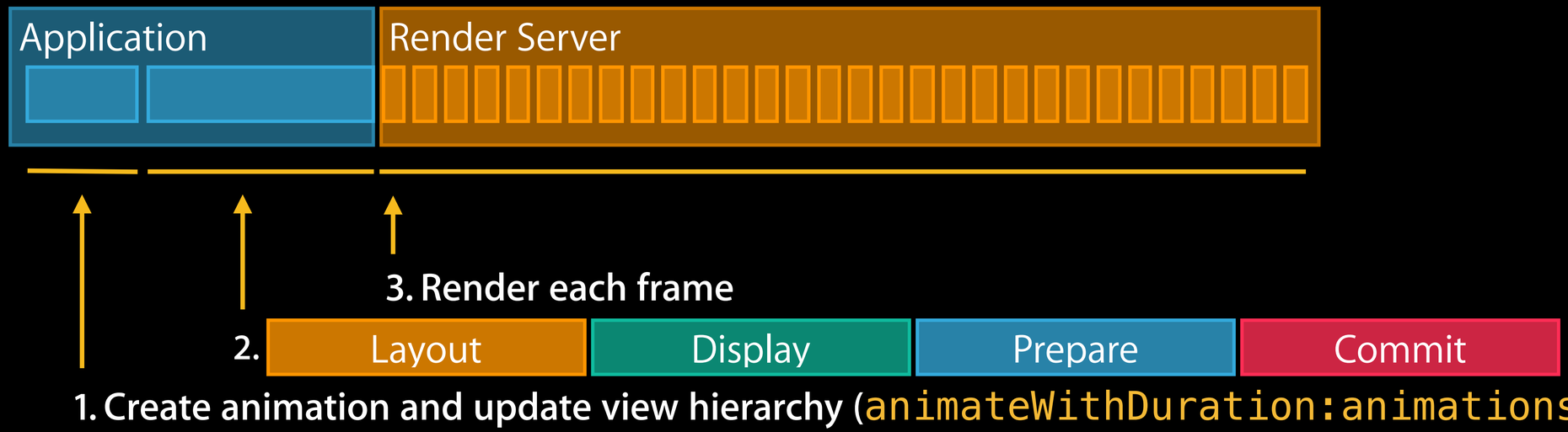
Animation

Three-stage process



Rendering Concepts

Axel Wefers
iOS Software Engineer

Rendering Concepts

Tile based rendering

Render passes

Example masking

Tile Based Rendering

Screen is split into tiles of NxN pixels

Each tile fits into the SoC cache

Geometry is split in tile buckets

Rasterization can begin after all geometry is submitted

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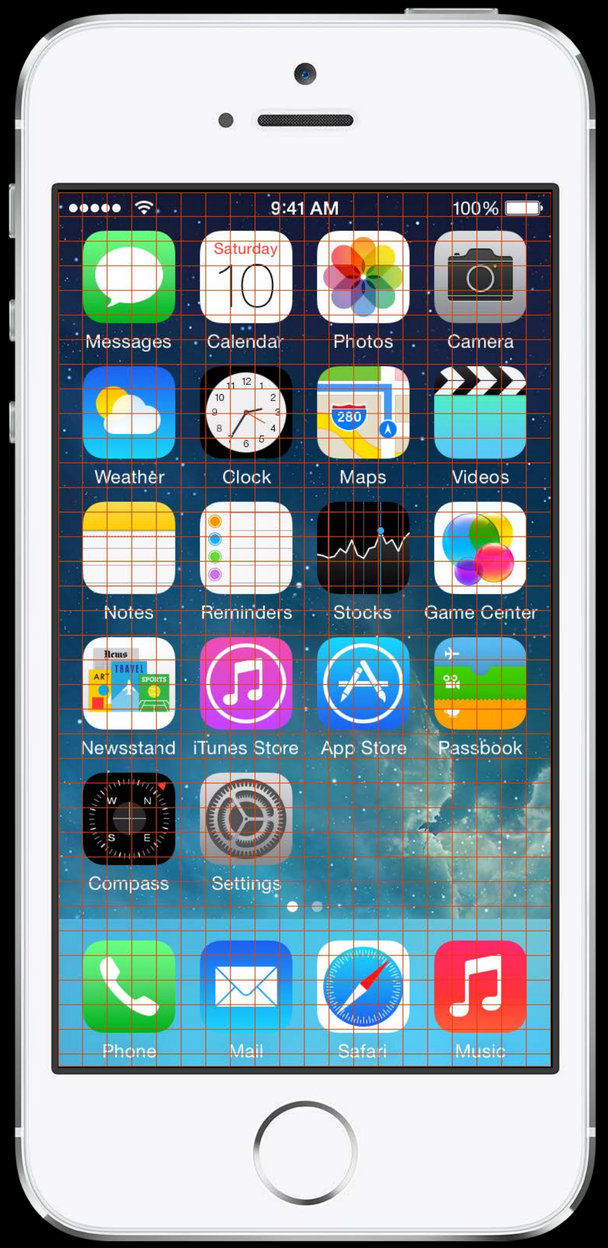

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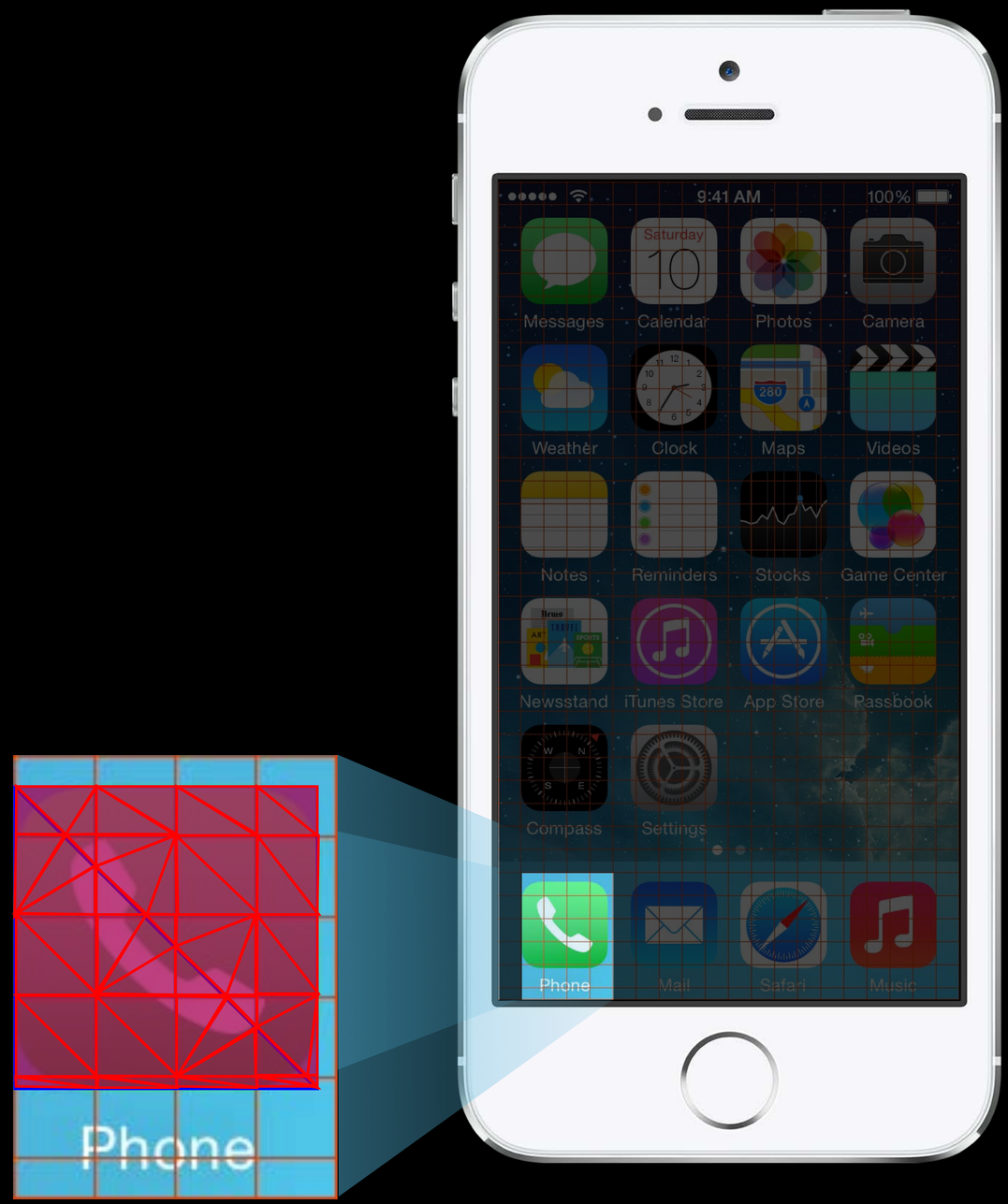
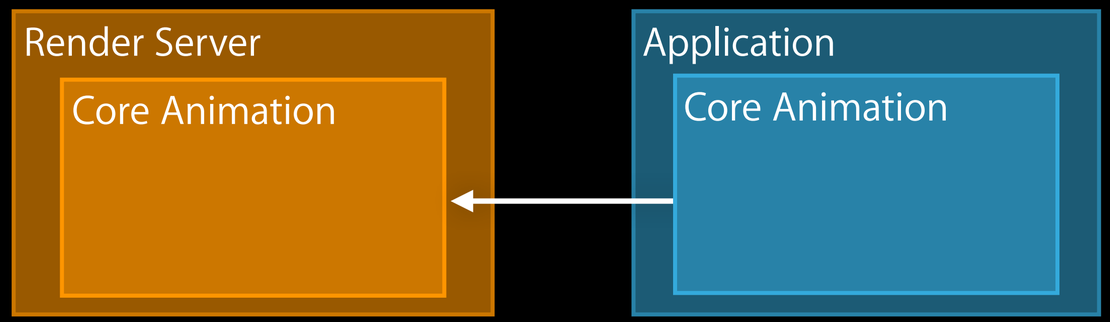


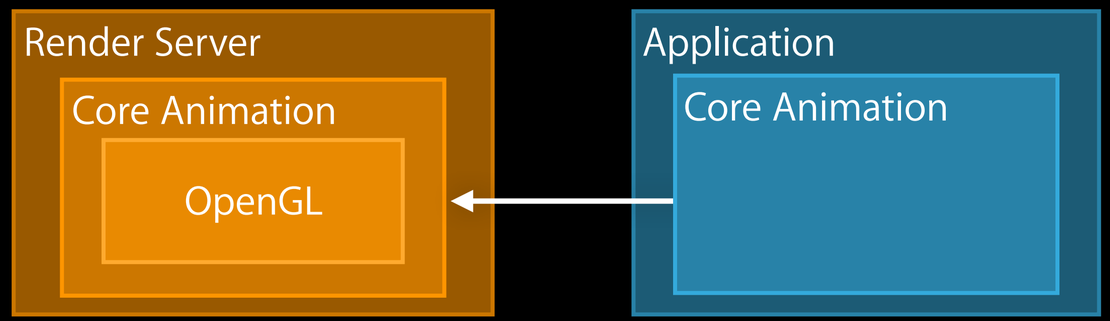
Tile Based Rendering

Rendering pass



Tile Based Rendering

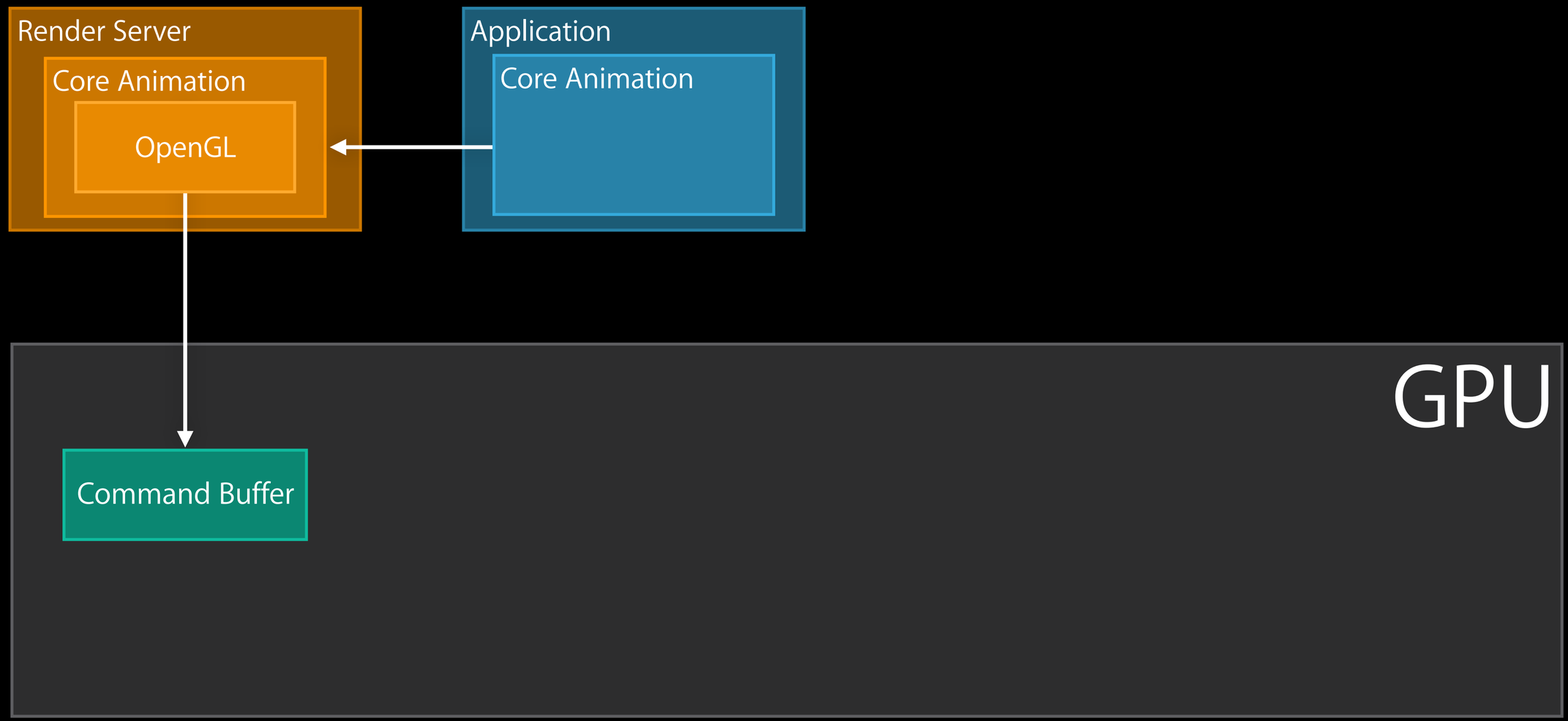
Rendering pass



GPU

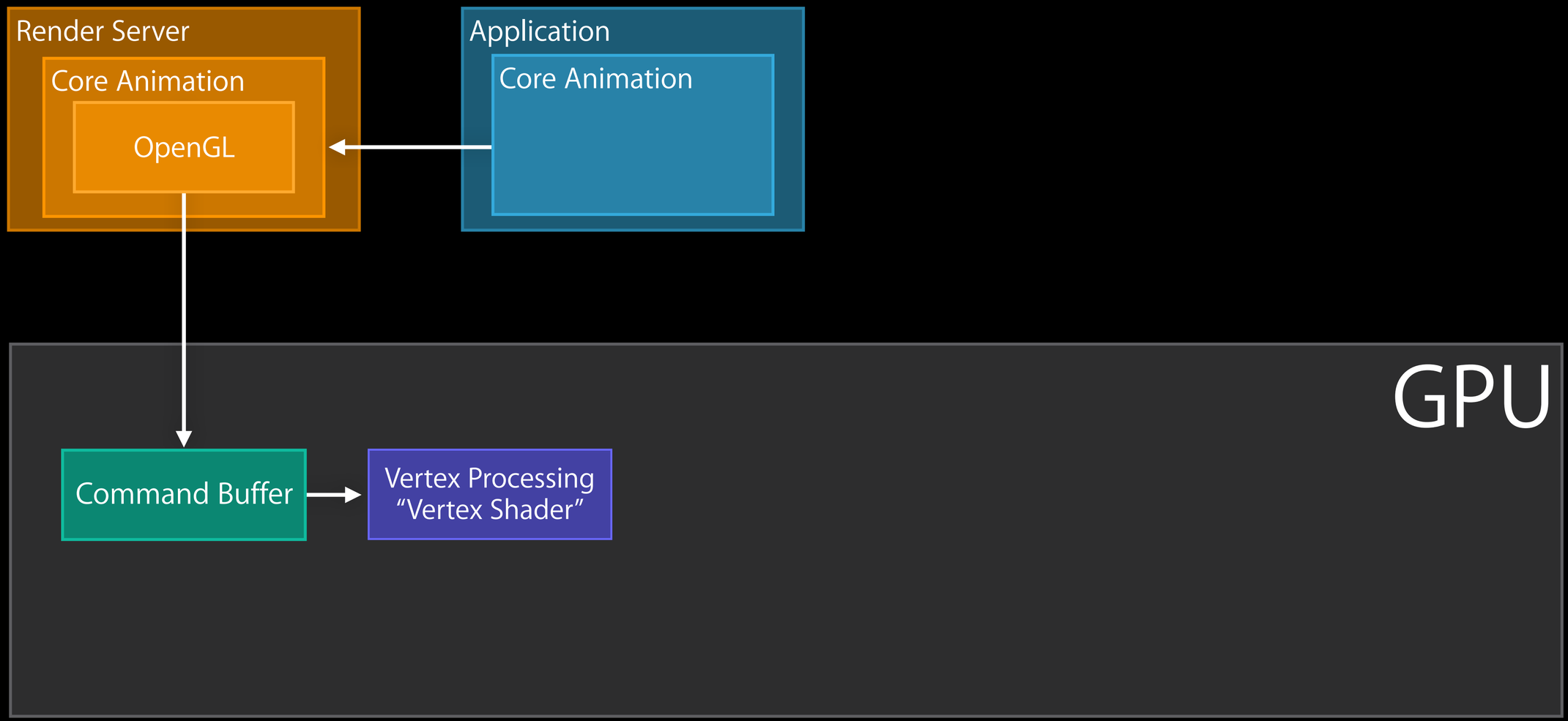
Tile Based Rendering

Rendering pass



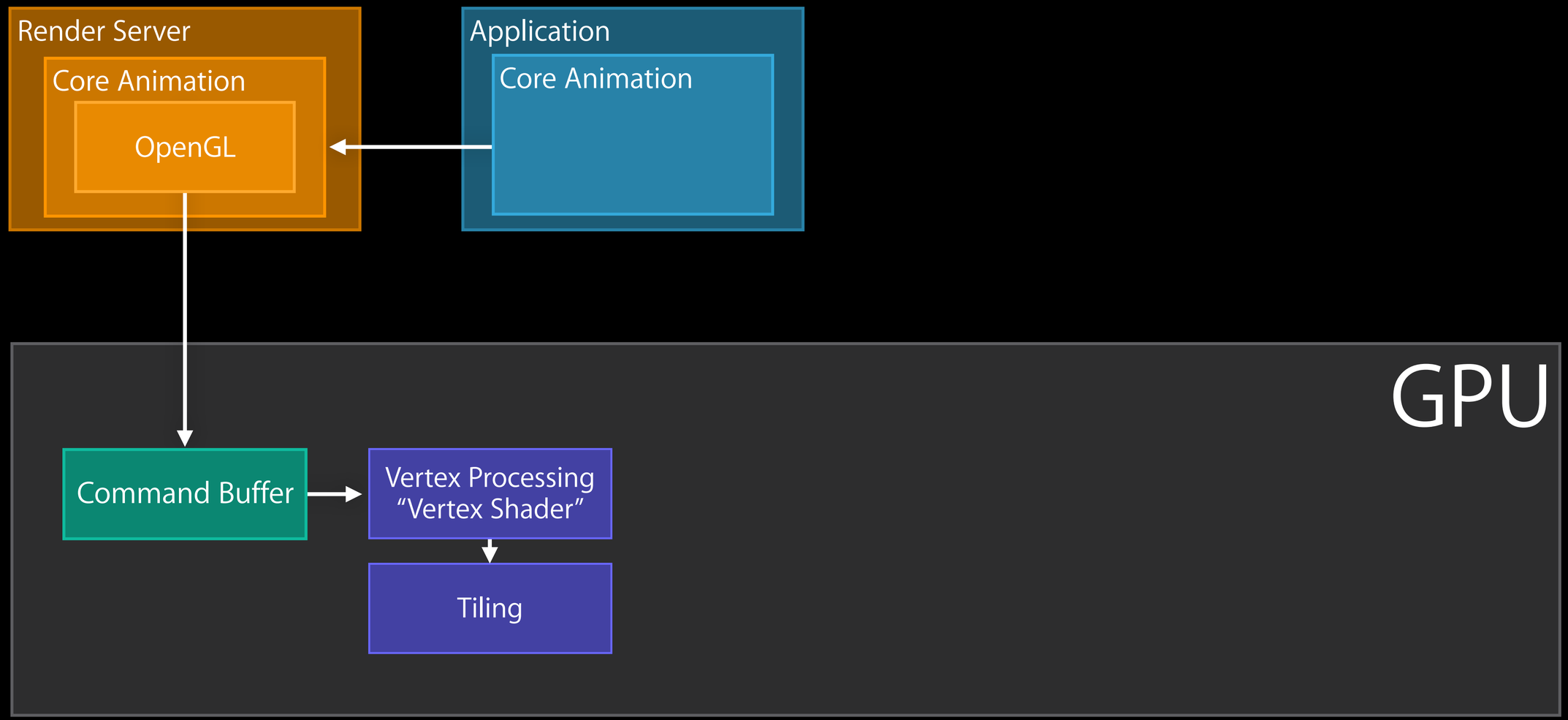
Tile Based Rendering

Rendering pass



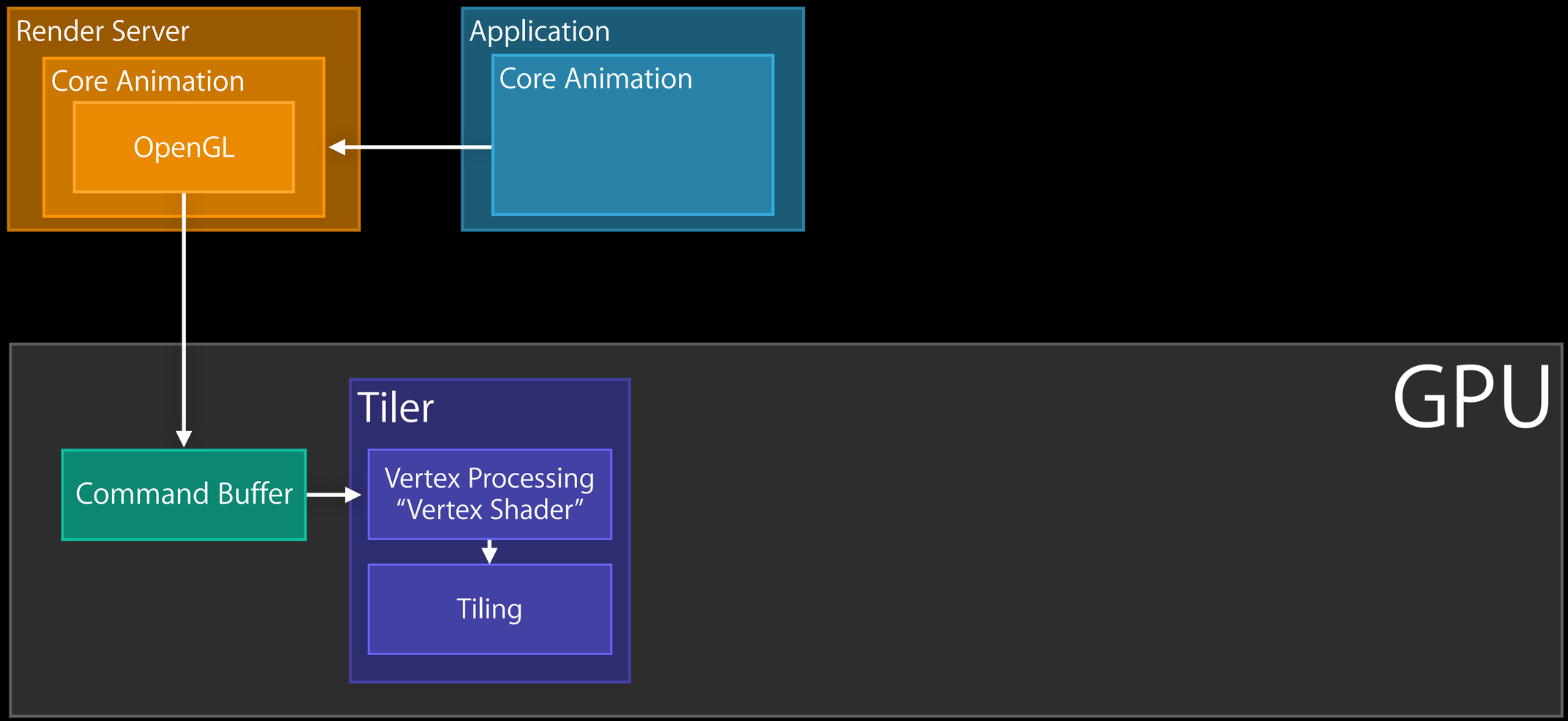
Tile Based Rendering

Rendering pass



Tile Based Rendering

Rendering pass



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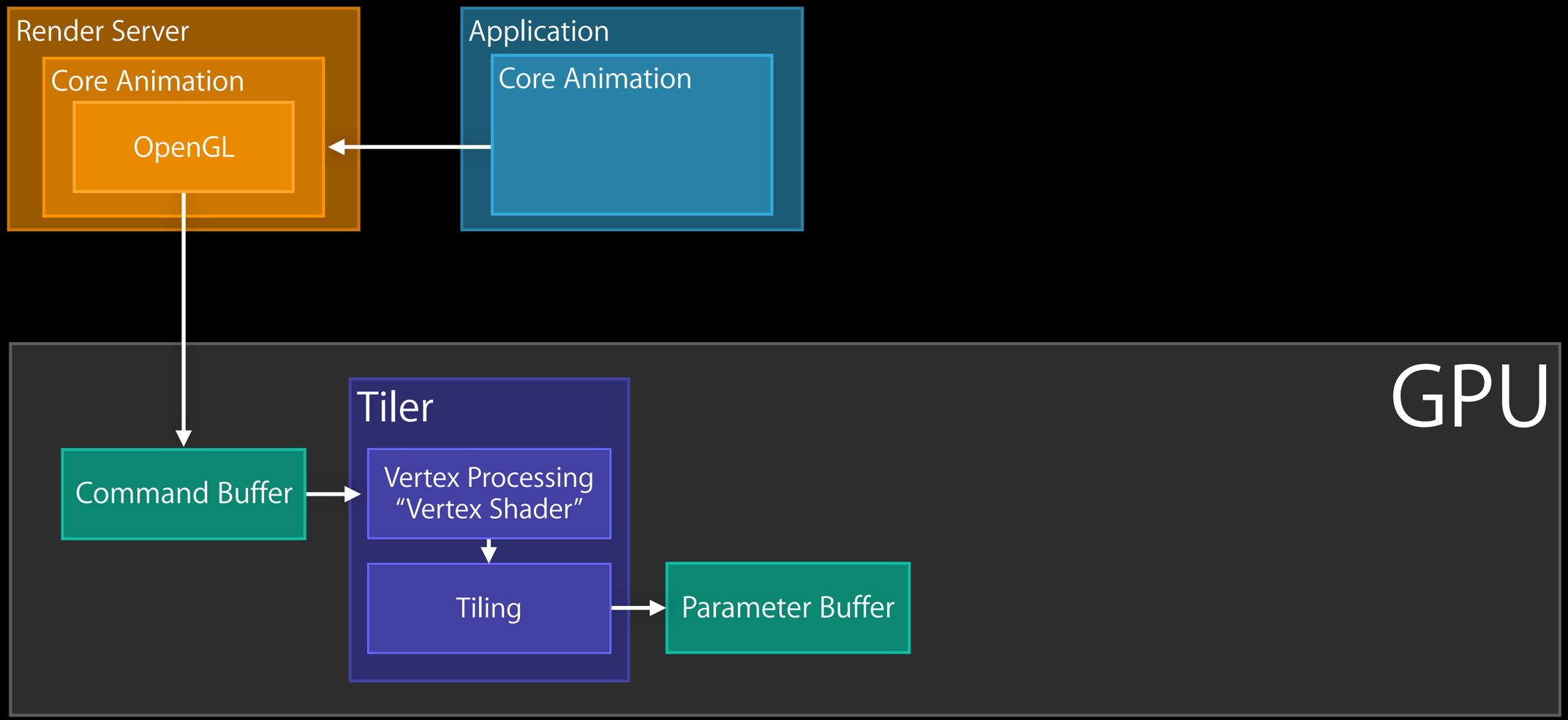

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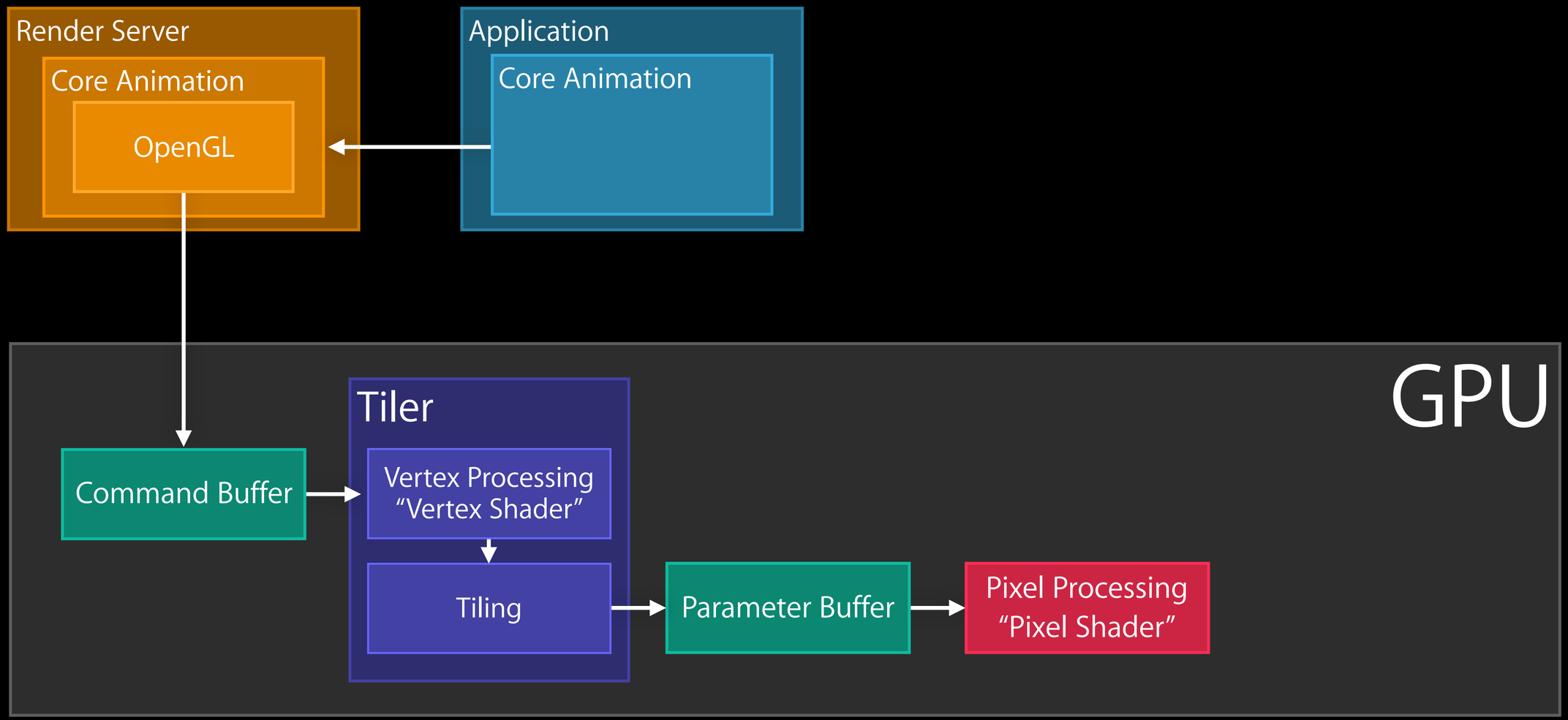

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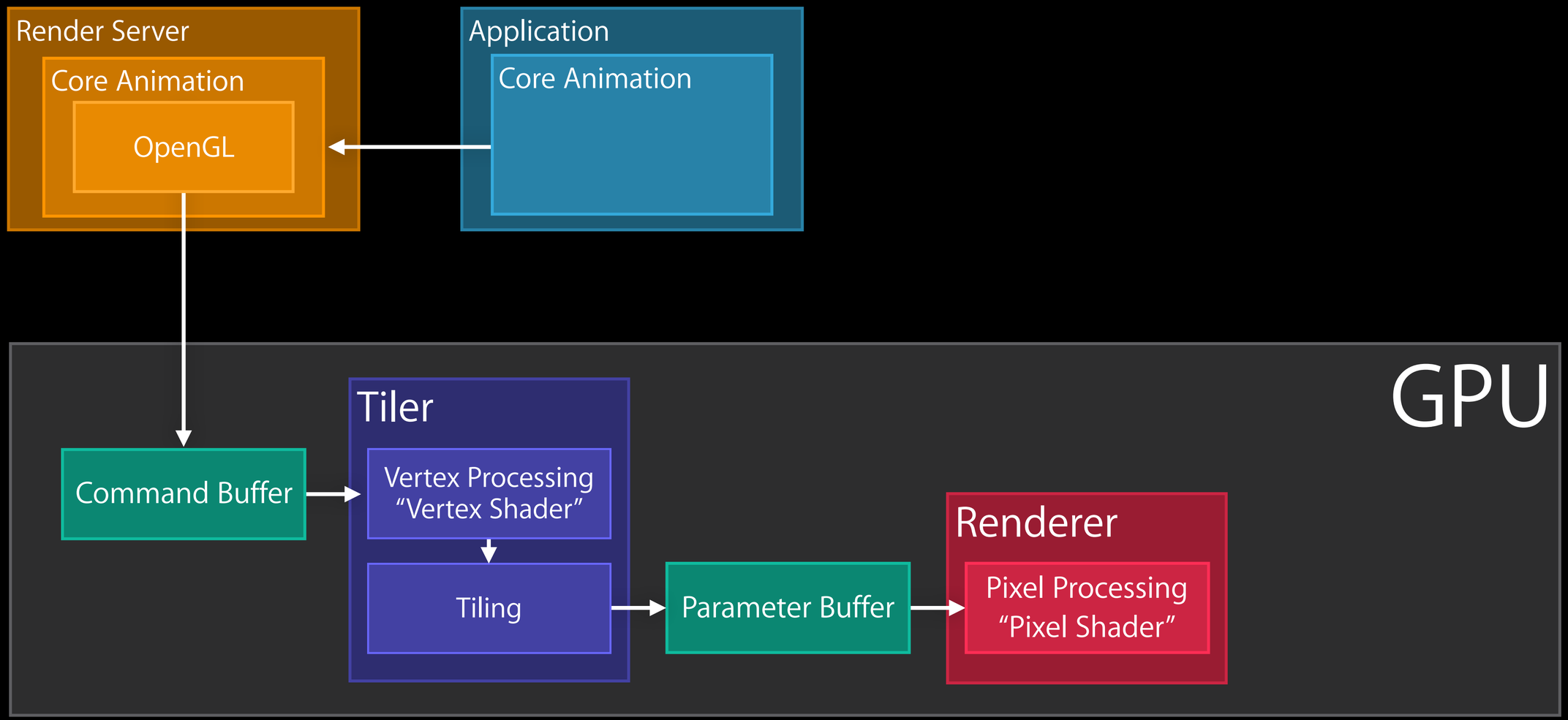
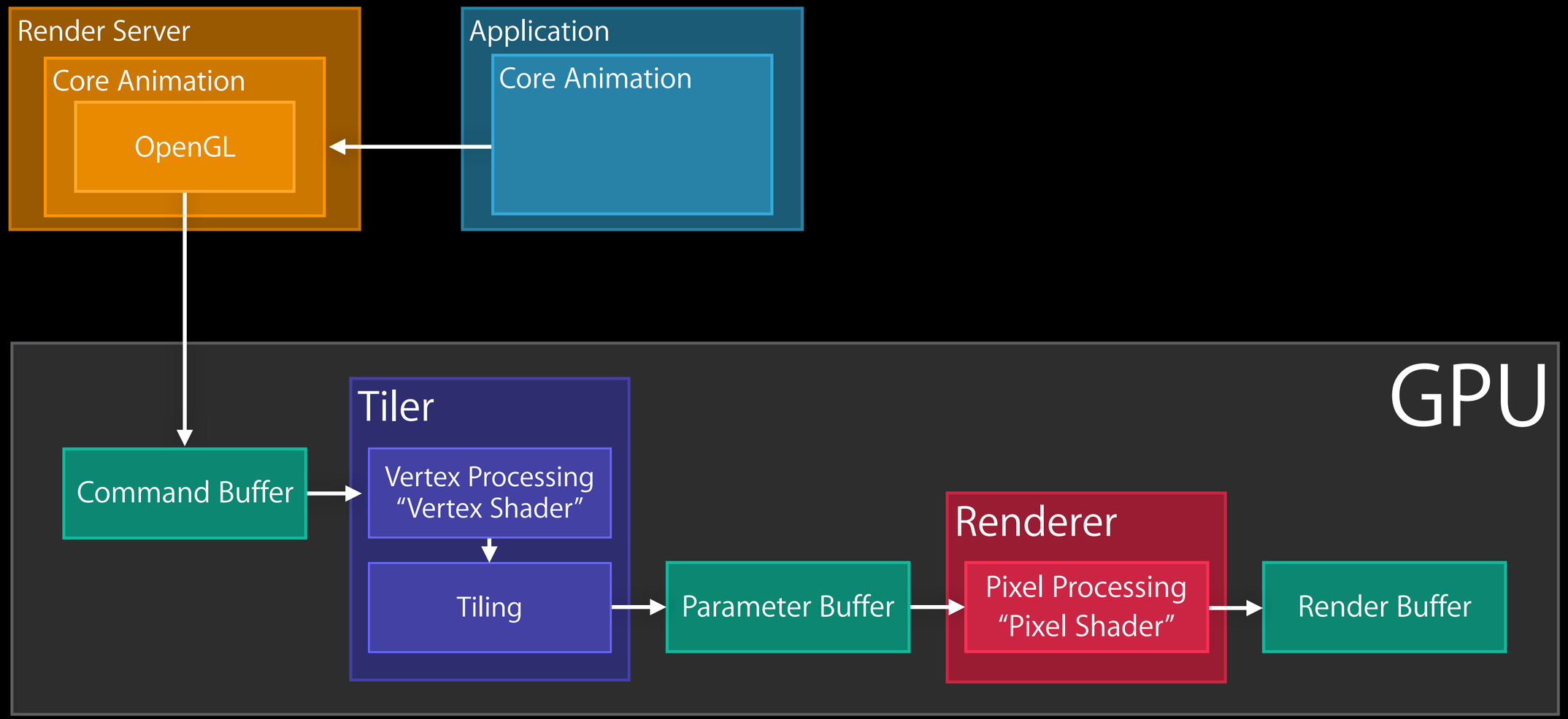


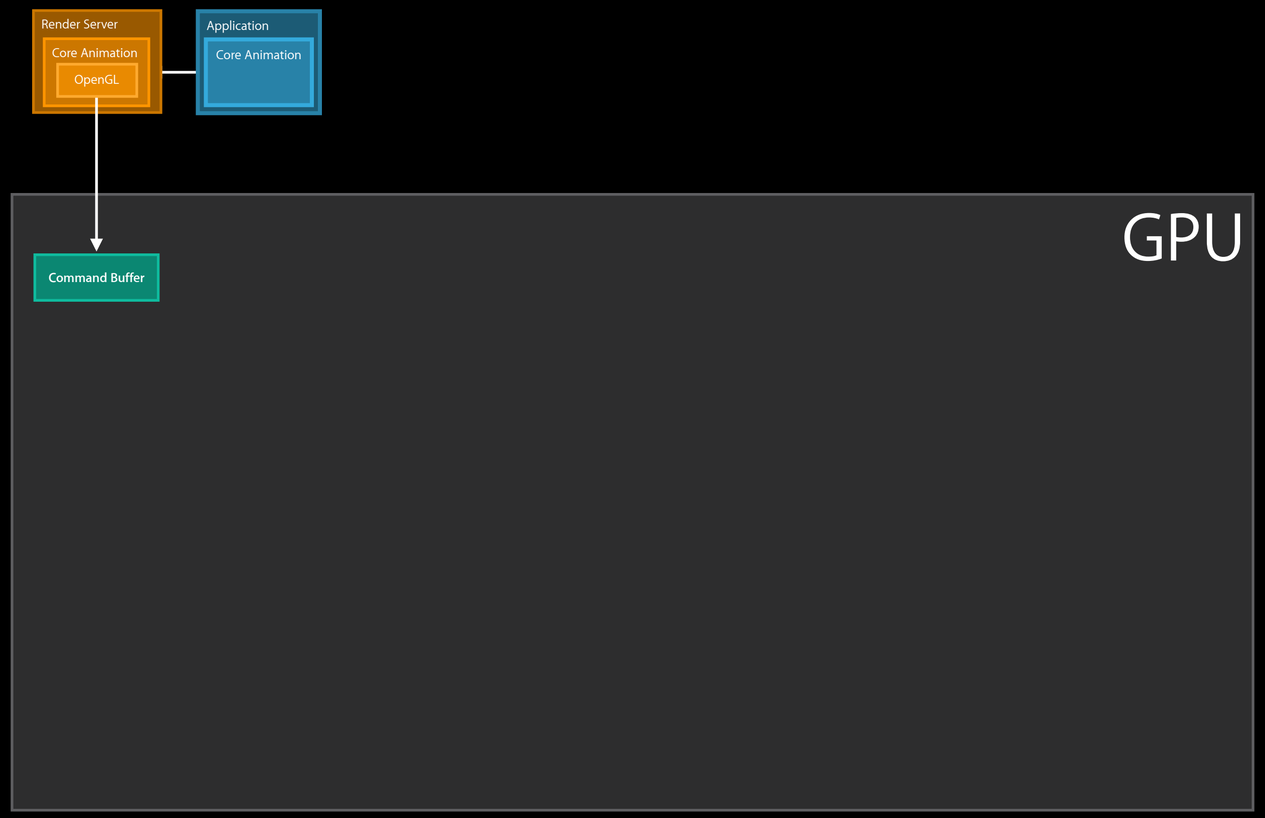
Tile Based Rendering

Rendering pass



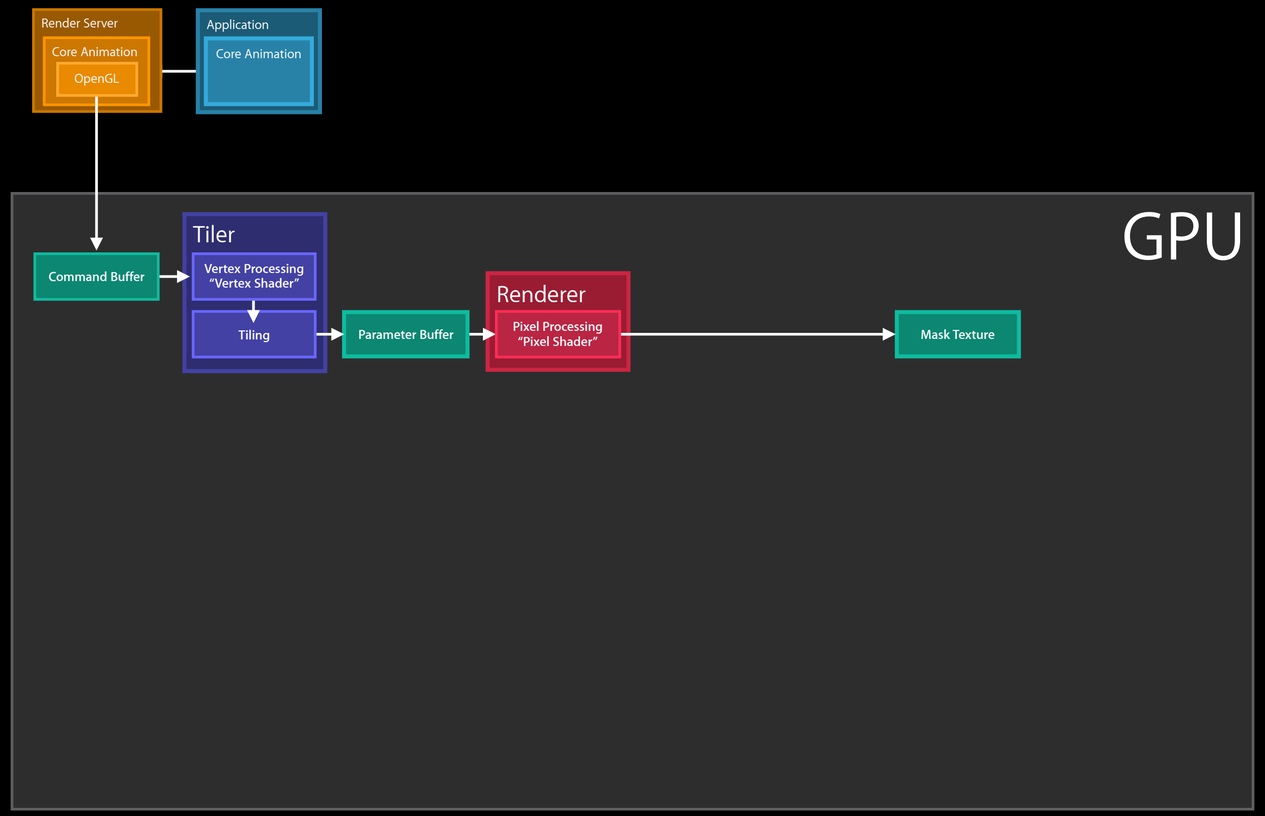
Masking

Rendering passes



Masking

Rendering passes

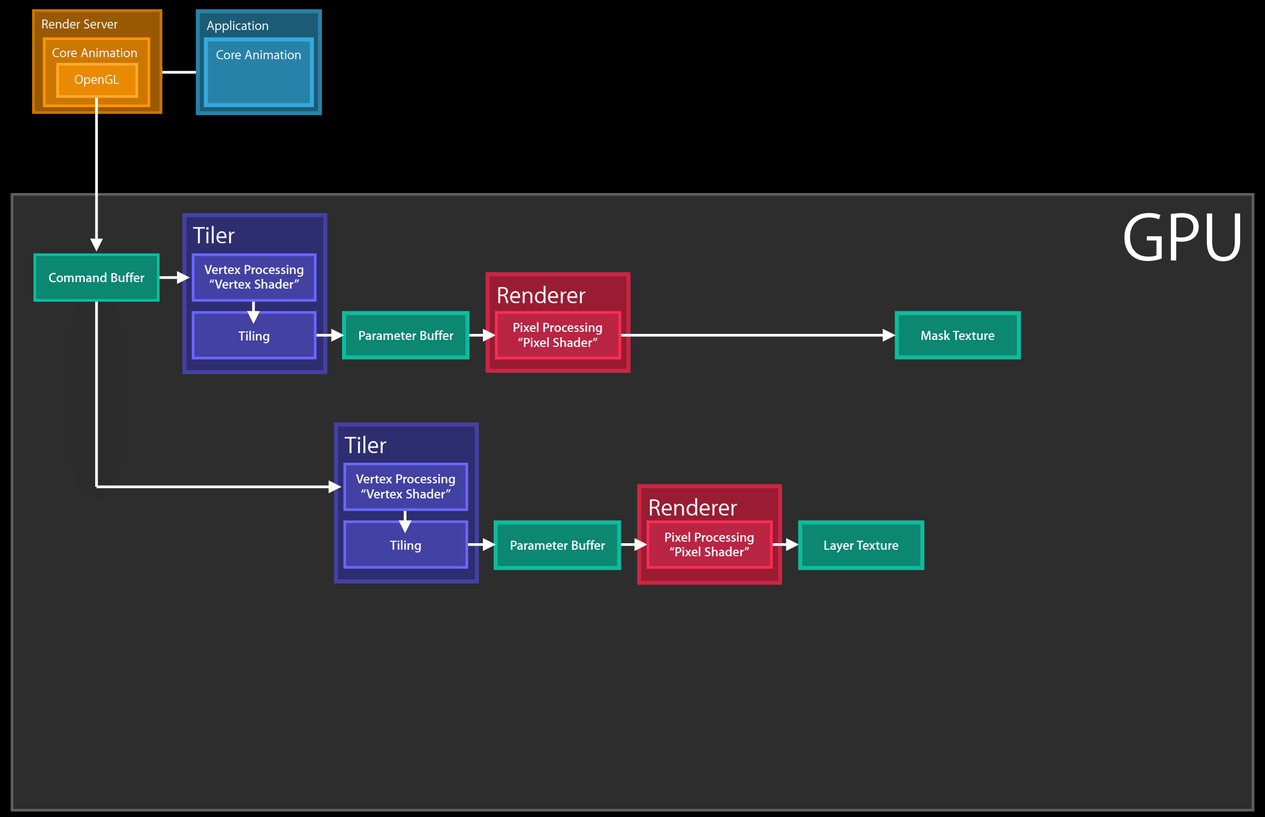


Pass 1

Render layer mask to texture

Masking

Rendering passes

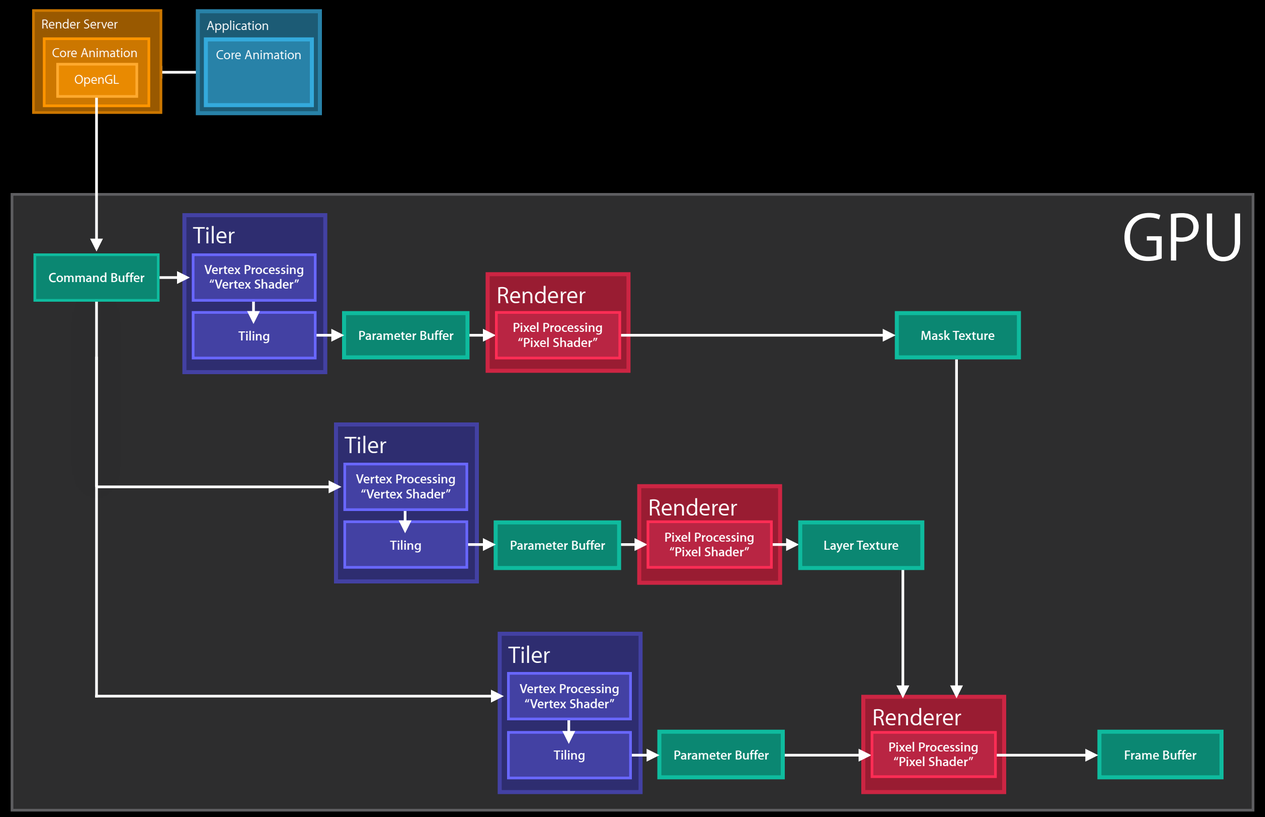


Pass 1
Render layer mask to texture

Pass 2
Render layer content to texture

Masking

Rendering passes



Pass 1
Render layer mask to texture

Pass 2
Render layer content to texture

Compositing pass
Apply mask to content texture

UIBlurEffect

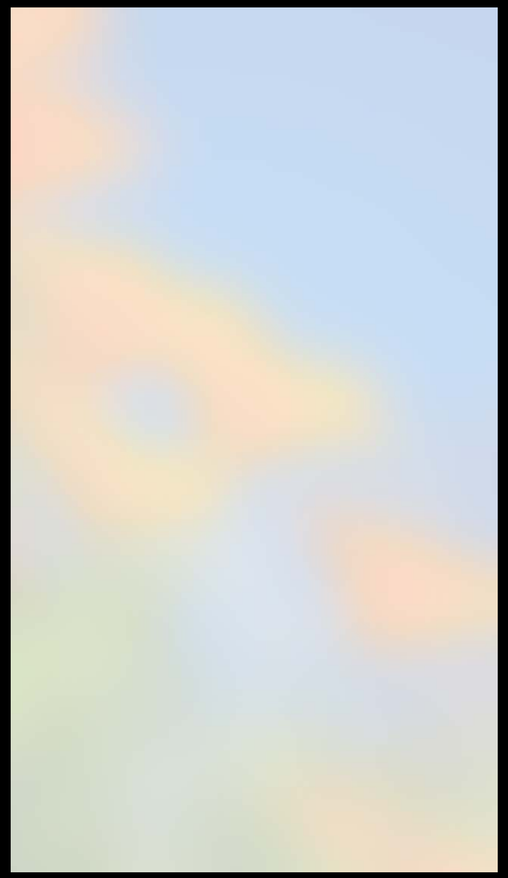
Axel Wefers
iOS Software Engineer

UIVisualEffectView with UIBlurEffect

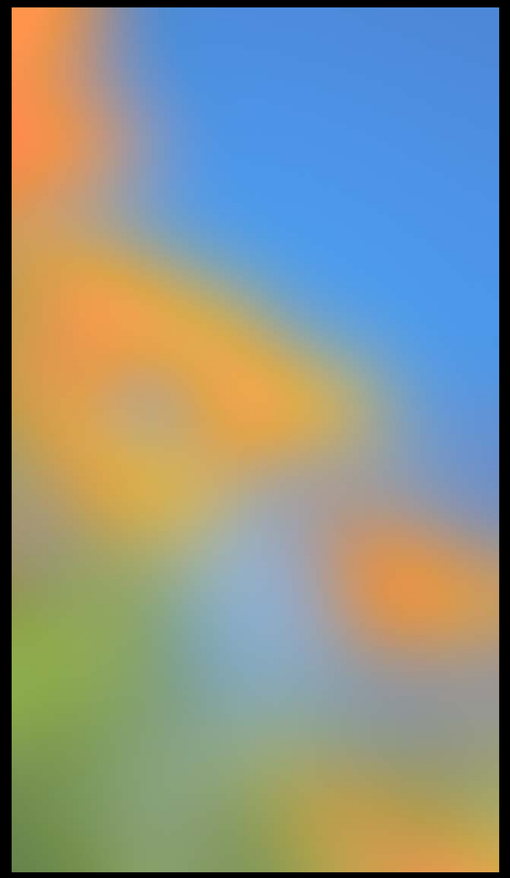
UIBlurEffect styles

No effect

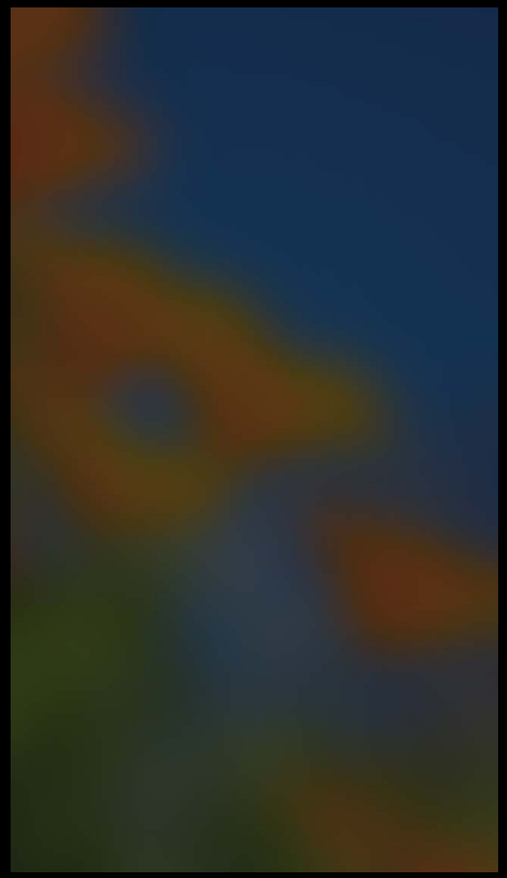
Extra light



Light

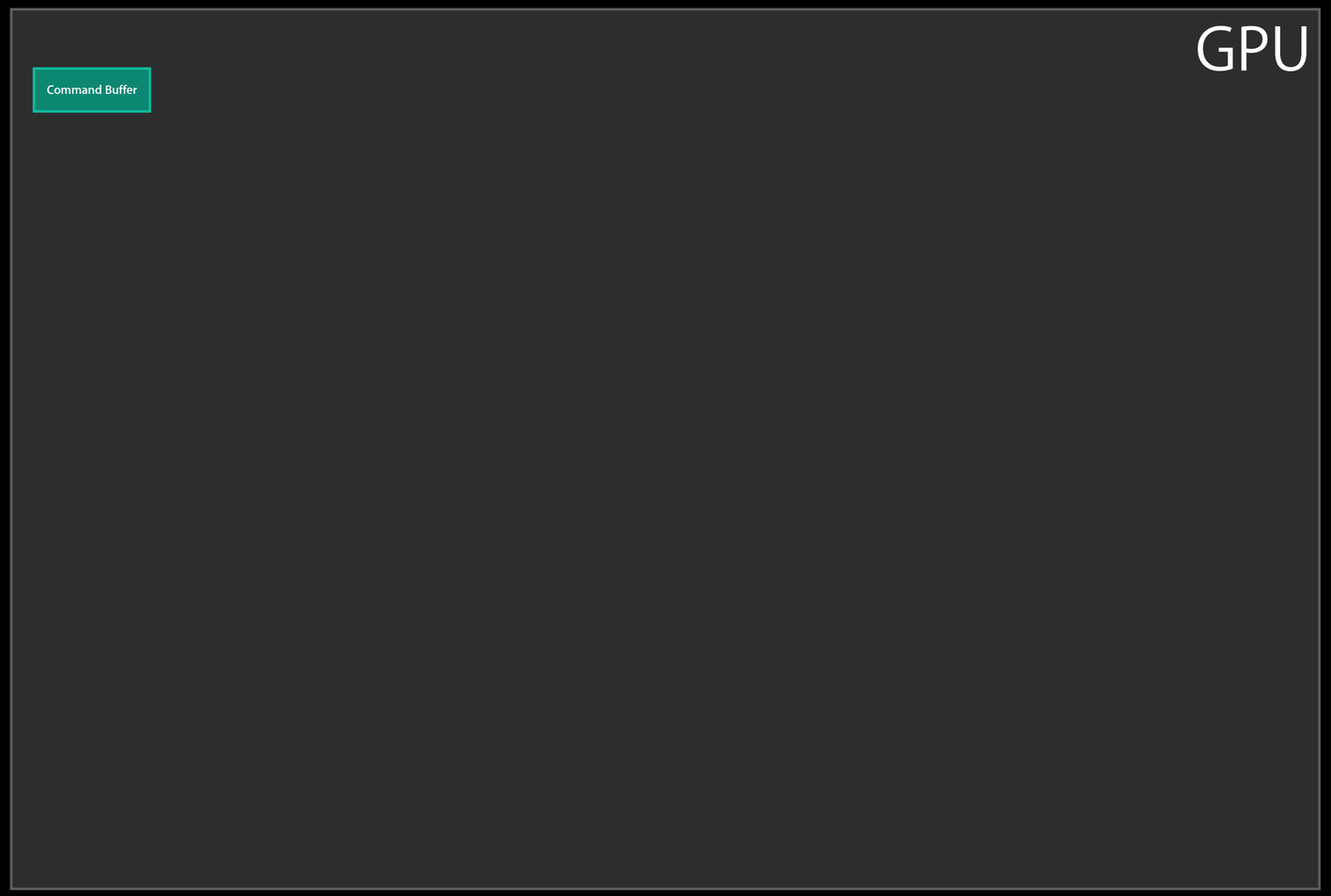


Dark



UIVisualEffectView with UIBlurEffect

Rendering passes (best case)



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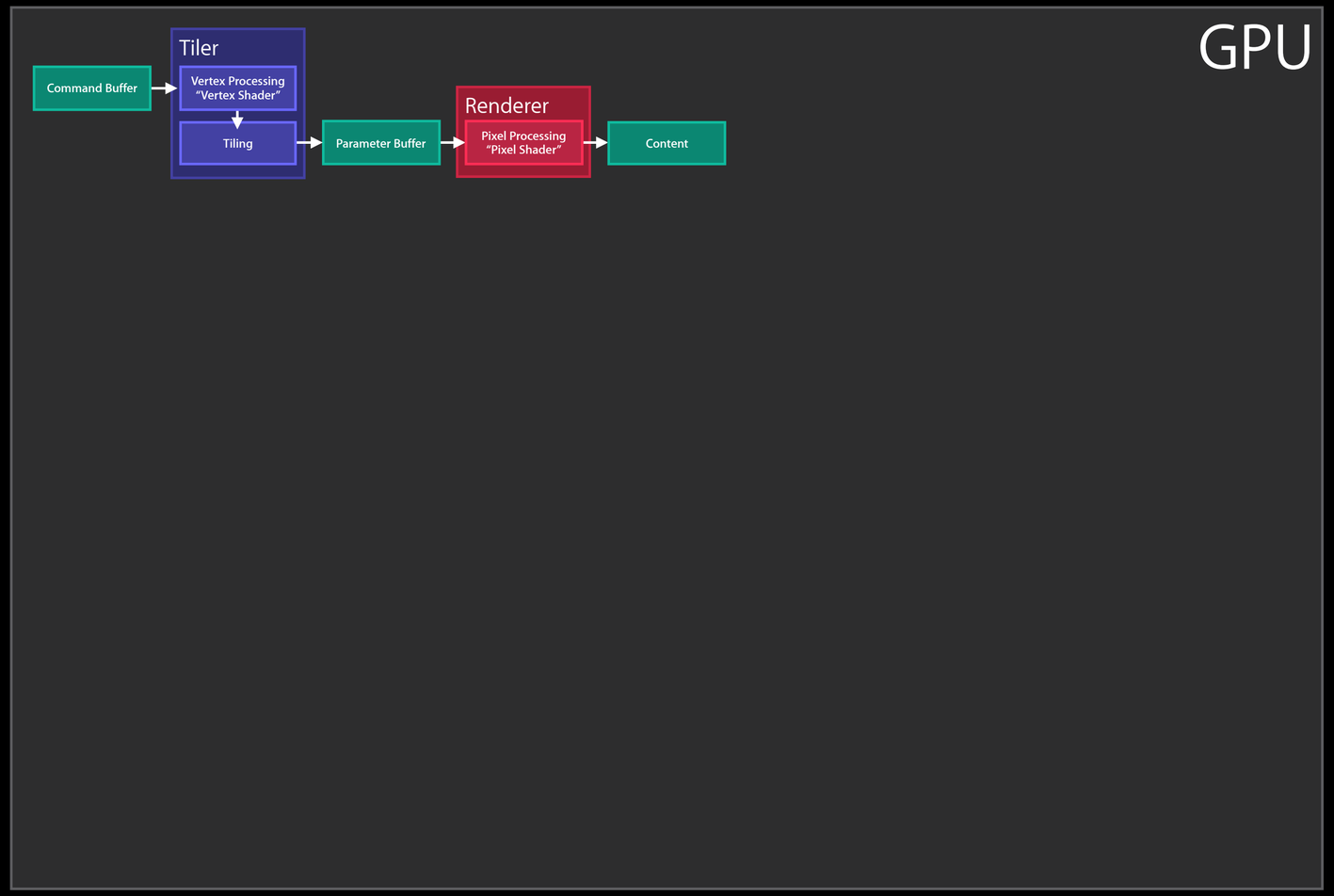
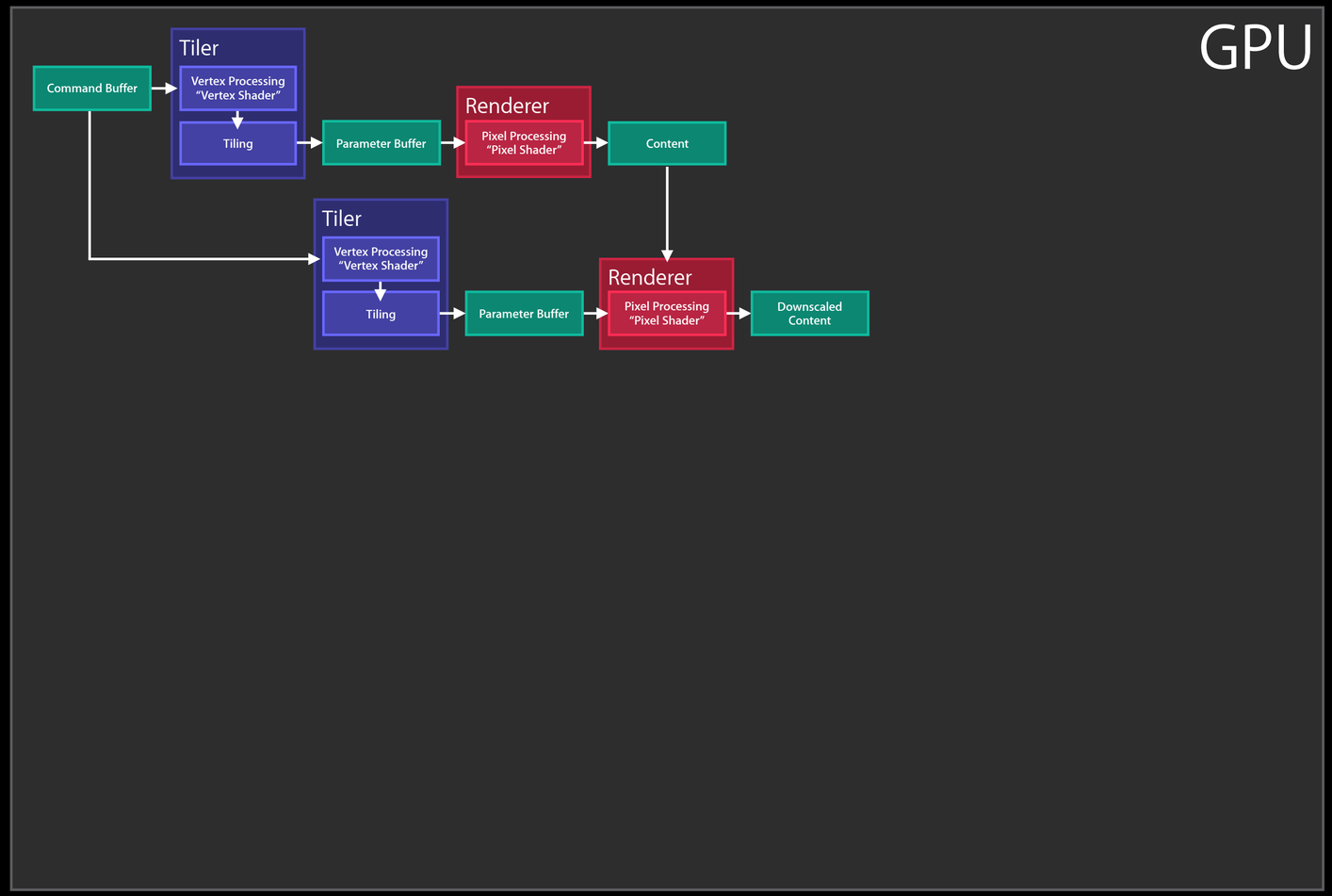


Pass 1
Render content

UIVisualEffectView with UIBlurEffect

Rendering passes (best case)



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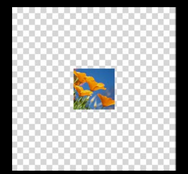
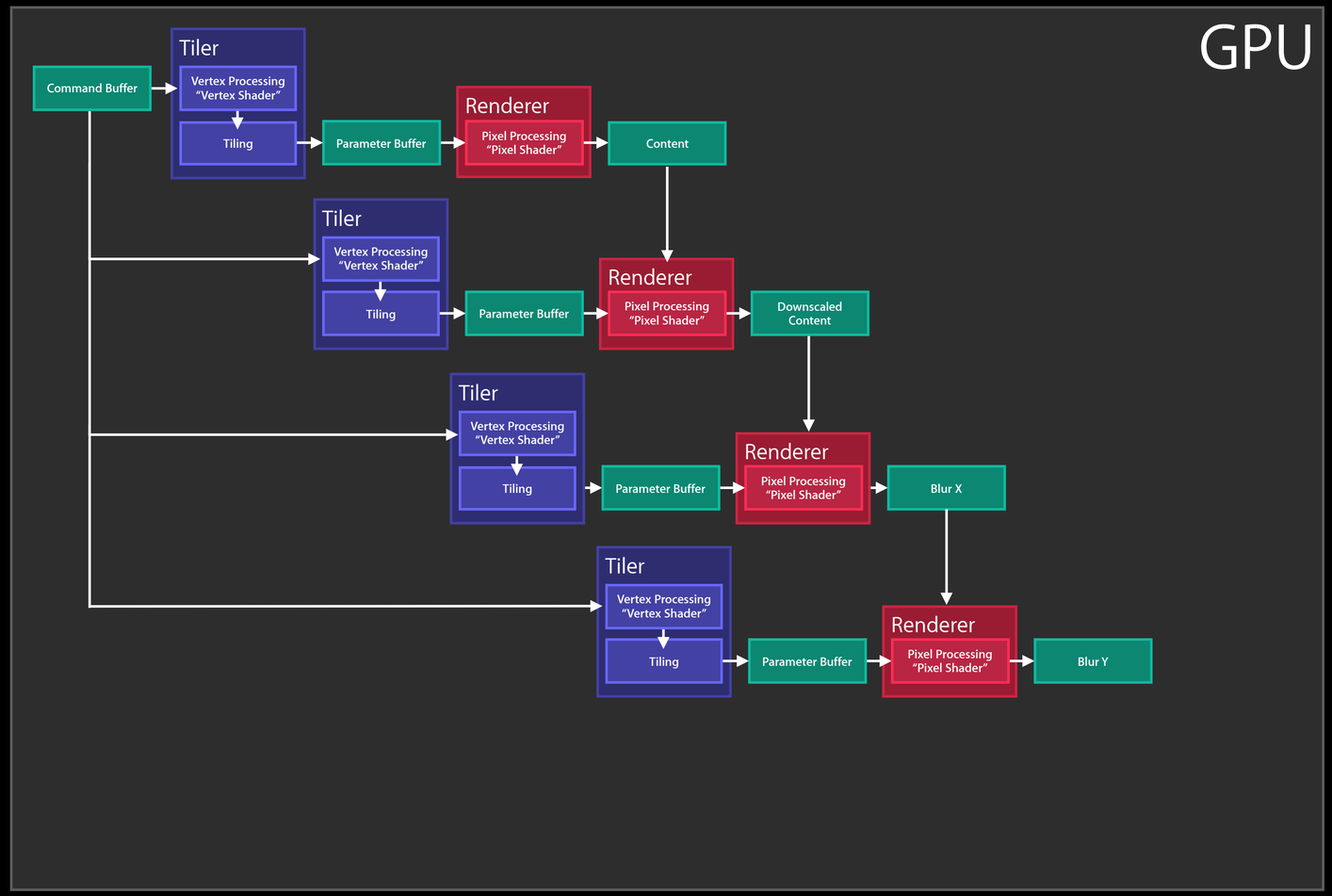
Render content



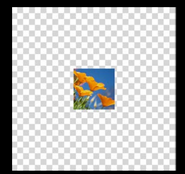
Pass 2
Capture content

UIVisualEffectView with UIBlurEffect

Rendering passes (best case)



Pass 1
Render content



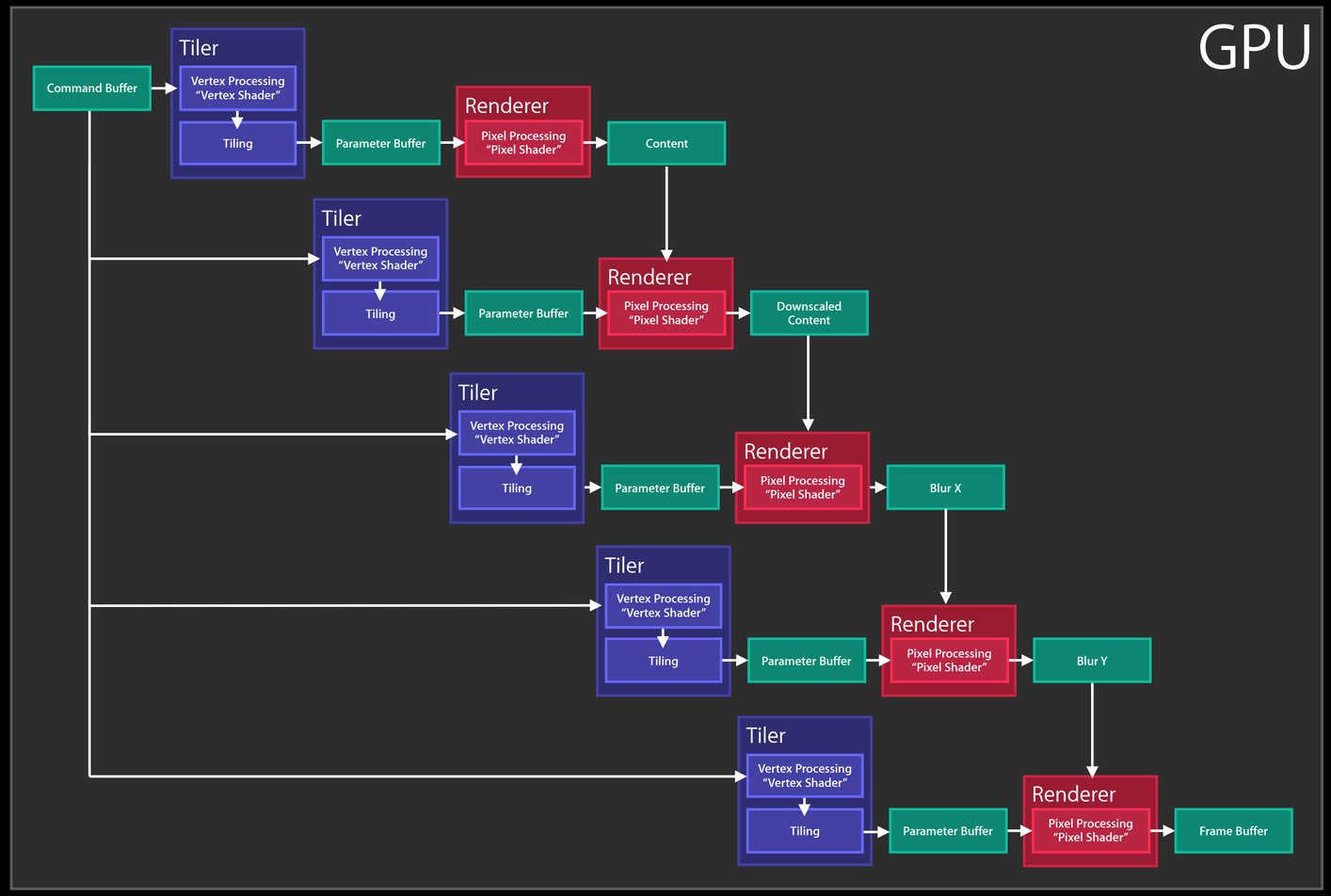
Pass 2
Capture content

Pass 3
Horizontal blur

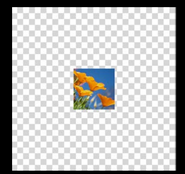
Pass 4
Vertical blur

UIVisualEffectView with UIBlurEffect

Rendering passes (best case)



Pass 1
Render content



Pass 2
Capture content

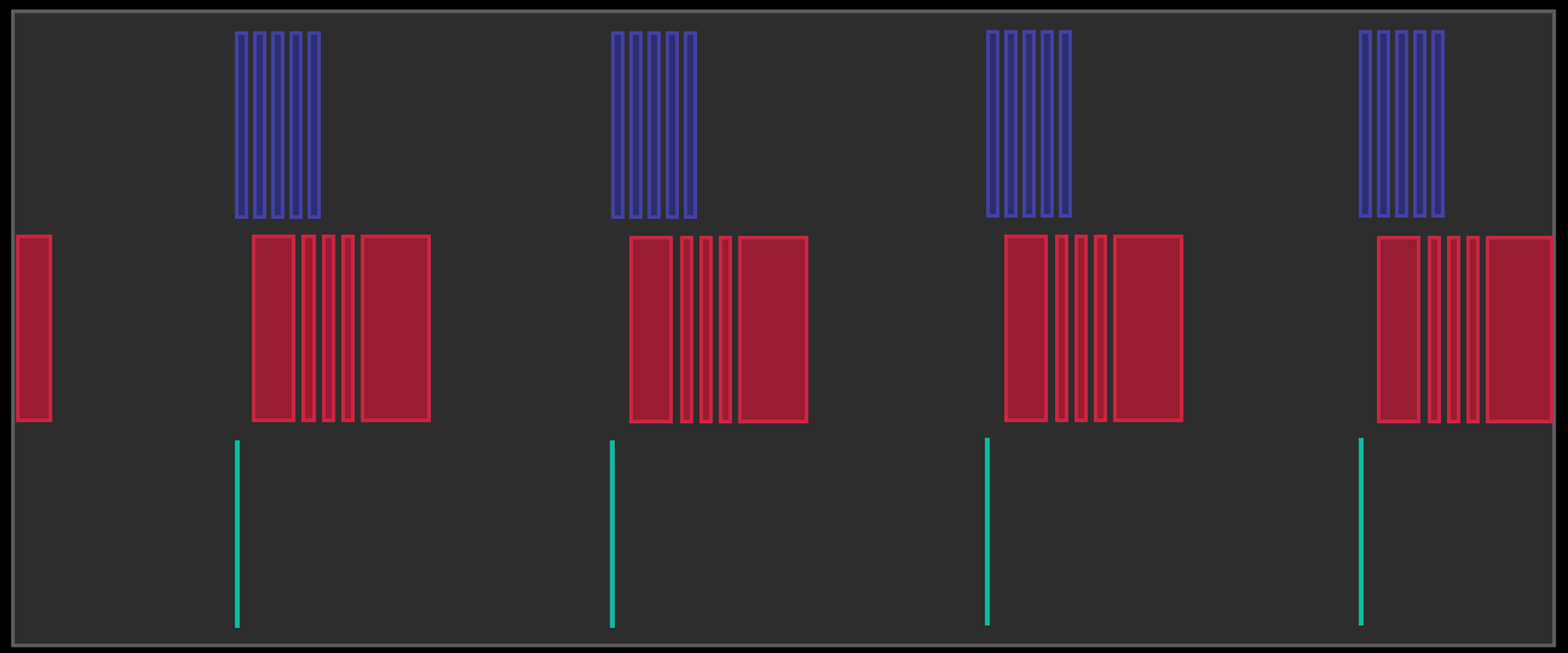
Pass 3
Horizontal blur

Pass 4
Vertical blur

Compositing pass
Upscale and tint

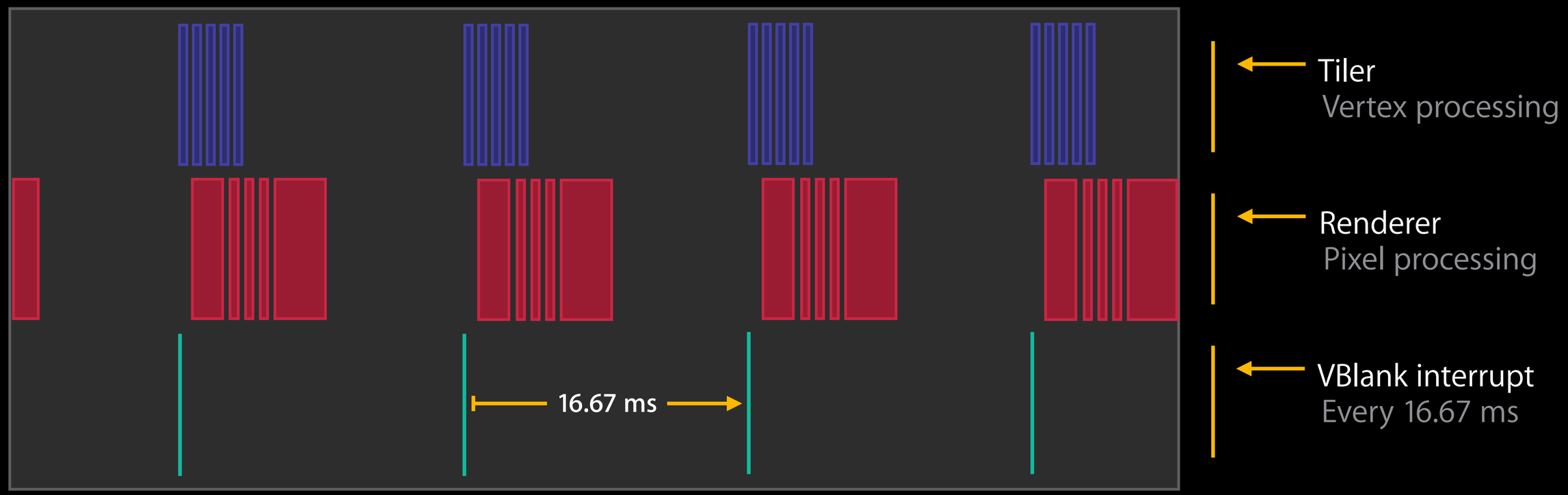
UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air



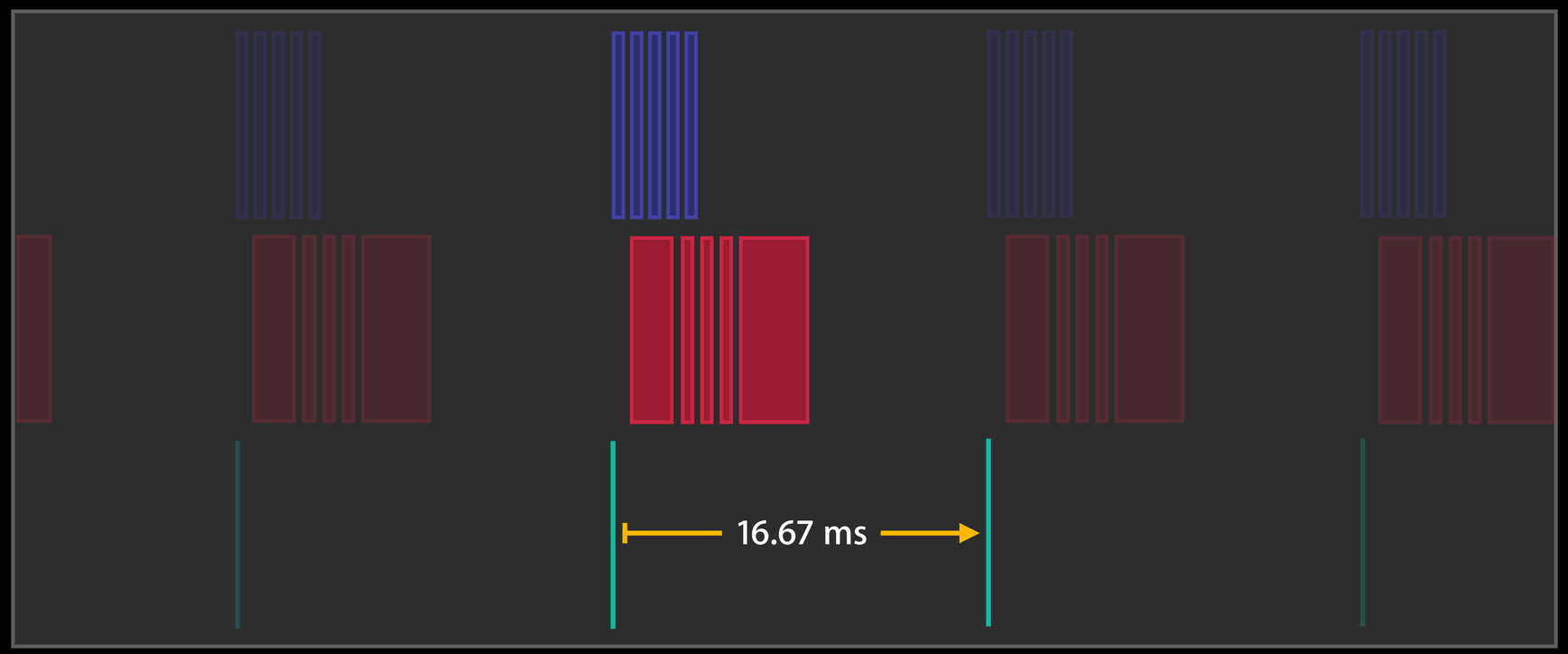
UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air



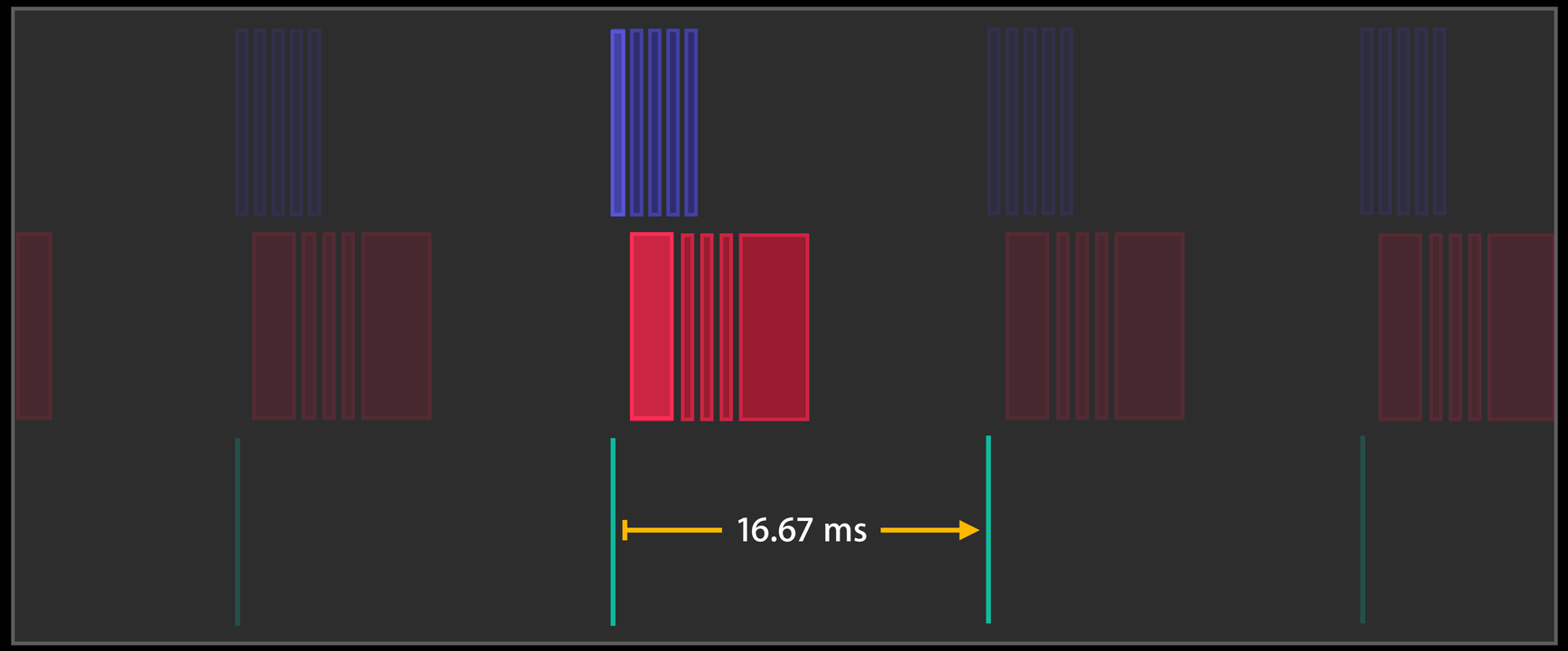
UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air



UIVisualEffectView with UIBlurEffect

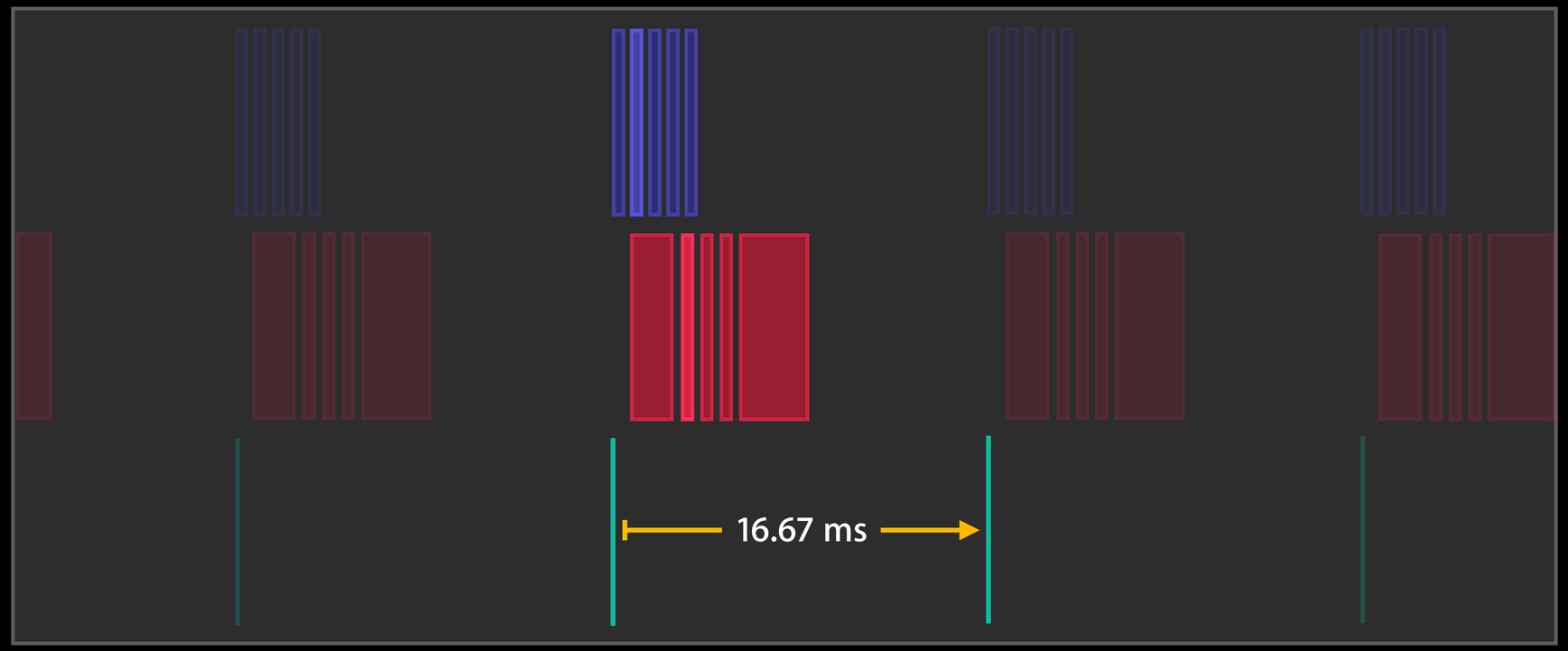
GPU utilization, fullscreen, iPad Air



Pass 1

UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air

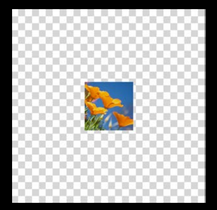


Tiler
Vertex processing

Renderer
Pixel processing

VBlank interrupt
Every 16.67 ms

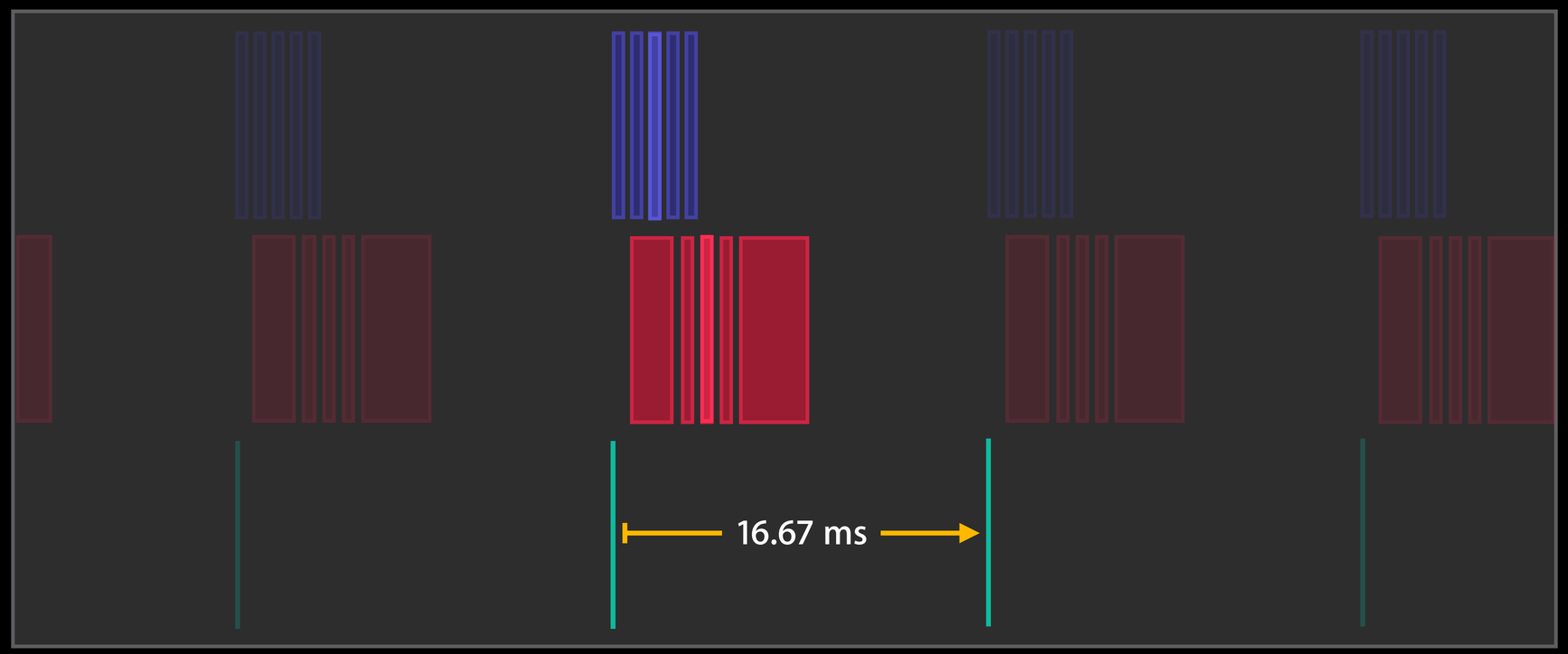
Pass 1



Pass 2

UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air

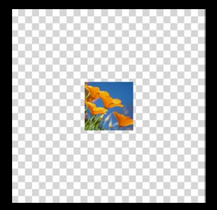


Tiler
Vertex processing

Renderer
Pixel processing

VBlank interrupt
Every 16.67 ms

Pass 1

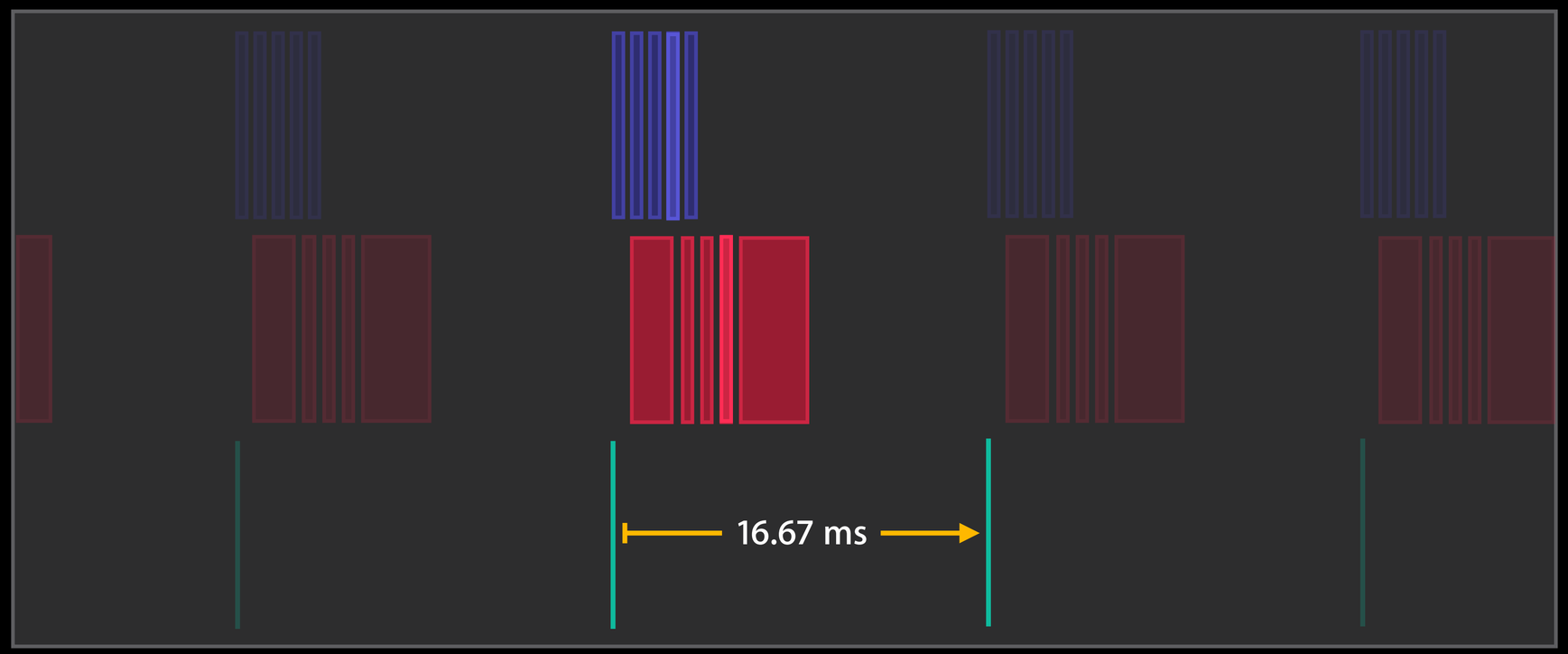


Pass 2

Pass 3

UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air

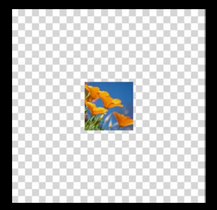


Tiler
Vertex processing

Renderer
Pixel processing

VBlank interrupt
Every 16.67 ms


Pass 1

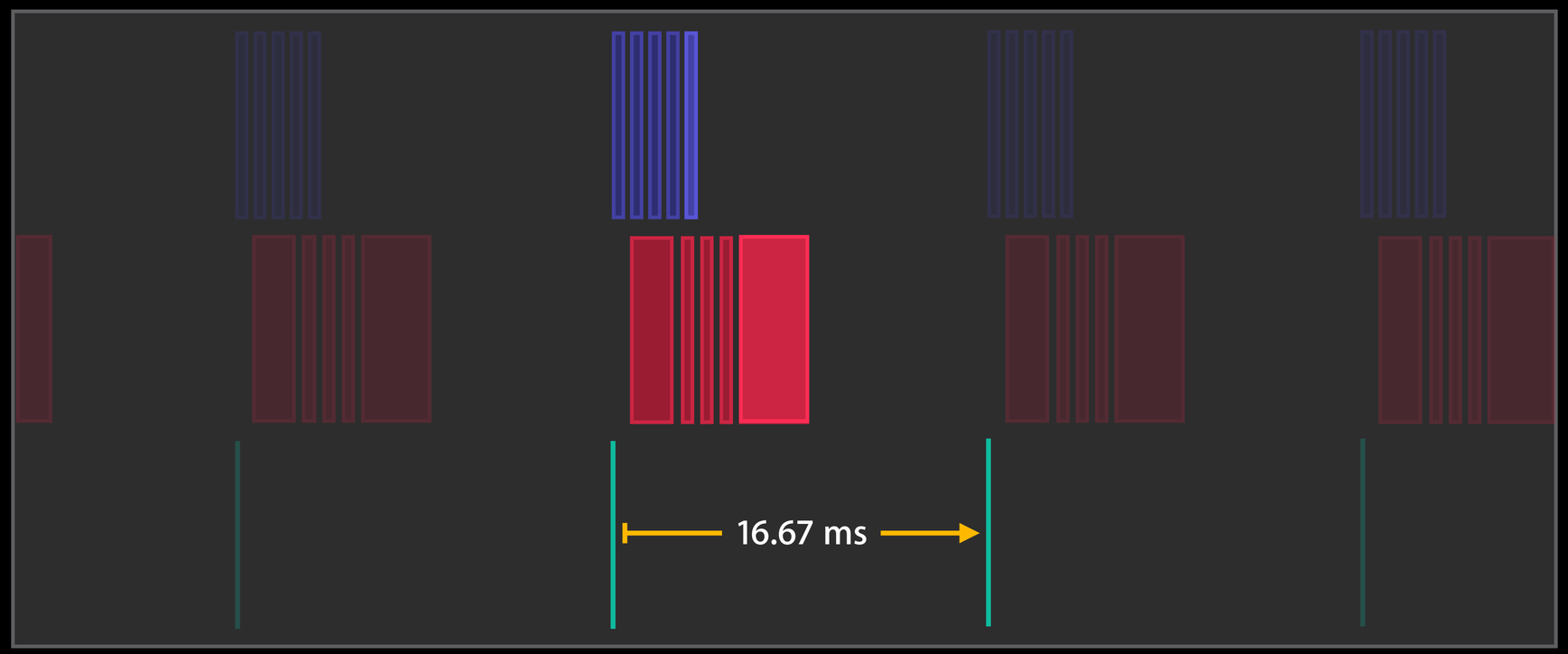

Pass 2


Pass 3


Pass 4

UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air

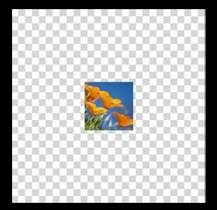


Tiler
Vertex processing

Renderer
Pixel processing

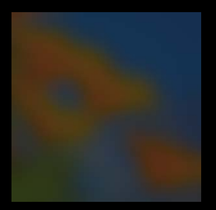
VBlank interrupt
Every 16.67 ms


Pass 1


Pass 2

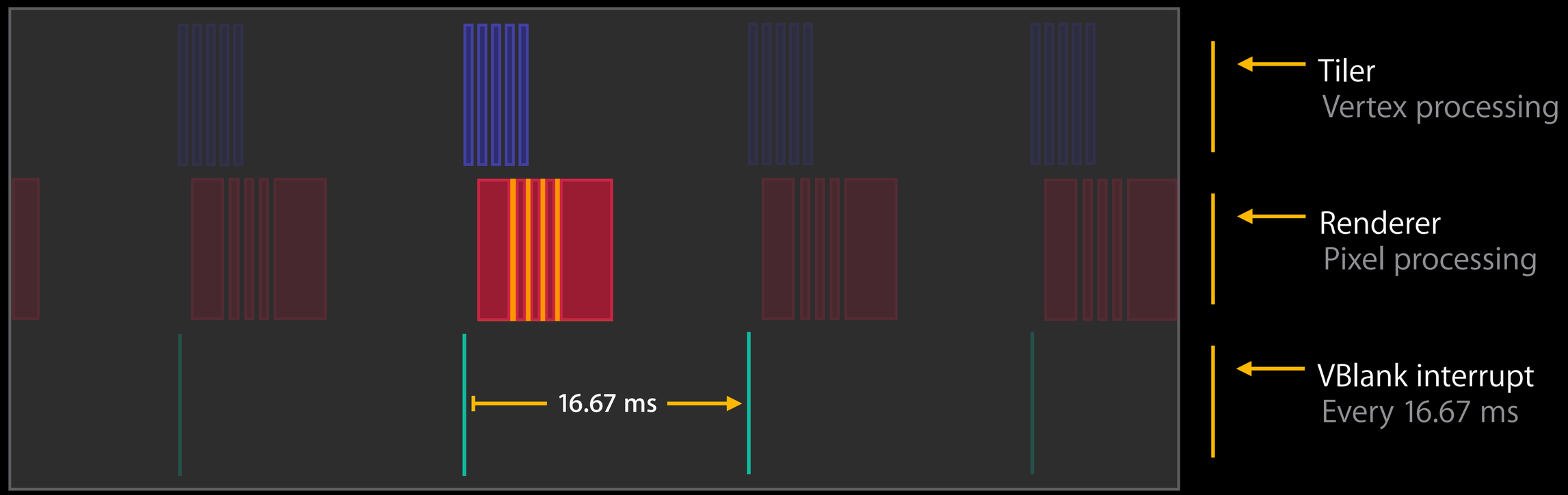

Pass 3


Pass 4


Pass 5

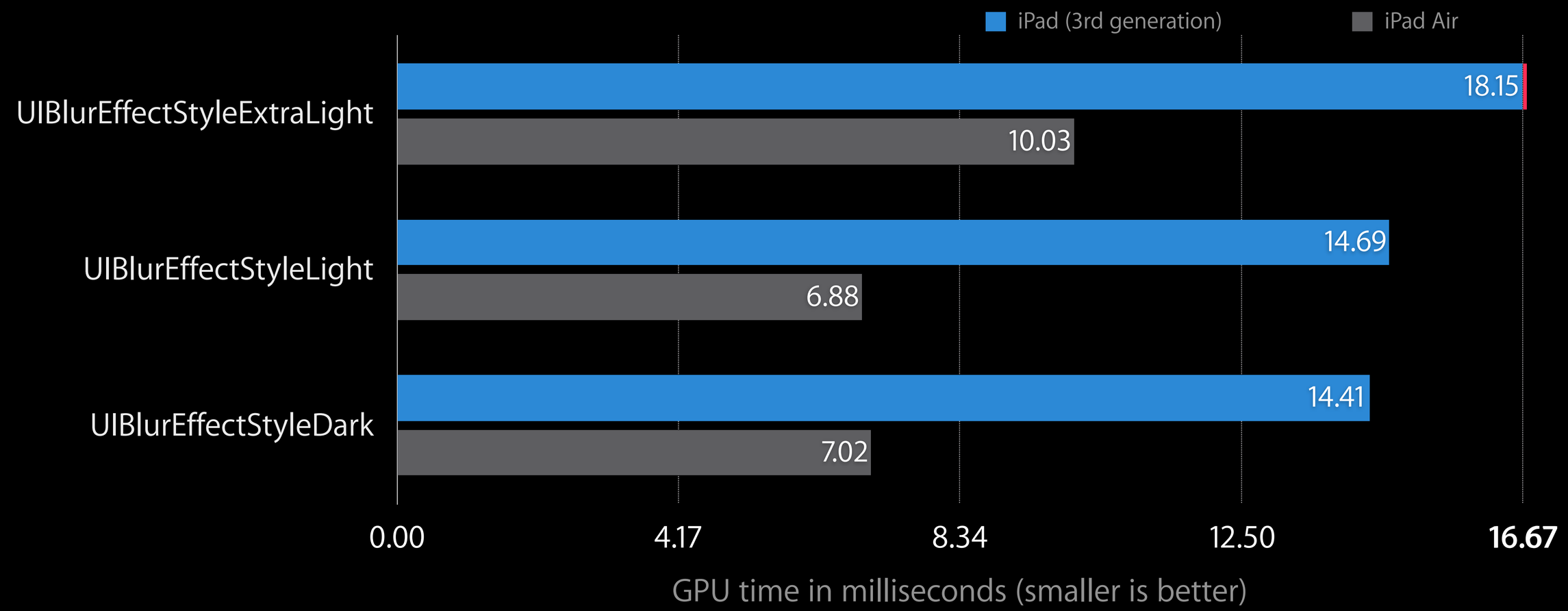
UIVisualEffectView with UIBlurEffect

GPU utilization, fullscreen, iPad Air



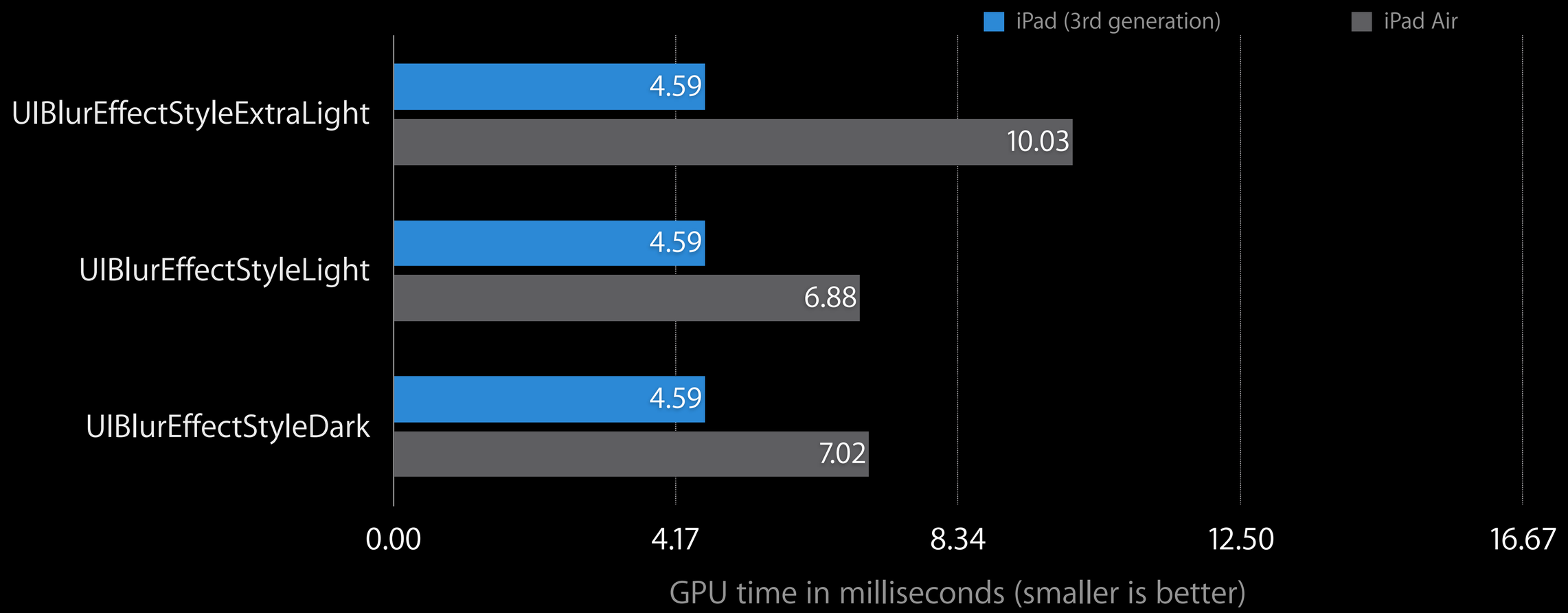
UIVisualEffectView with UIBlurEffect

Fullscreen performance



UIVisualEffectView with UIBlurEffect

Fullscreen performance



UIVisualEffectView with UIBlurEffect

UIBlurEffect support

Device	Blur	Tint
iPad 2	✗	✓
iPad (3rd generation)	✗	✓
iPad (4th generation)	✓	✓
iPad Air	✓	✓
iPad mini	✓	✓
iPad mini Retina display	✓	✓
All iPhones	✓	✓
iPod touch	✓	✓

UIVisualEffectView with UIBlurEffect

Performance considerations

`UIBlurEffect` adds multiple offscreen passes depending on style

Only dirty regions are redrawn

Effect is very costly

→ UI can easily be GPU bound

→ Keep bounds of view as small as possible

→ Make sure to budget for effect

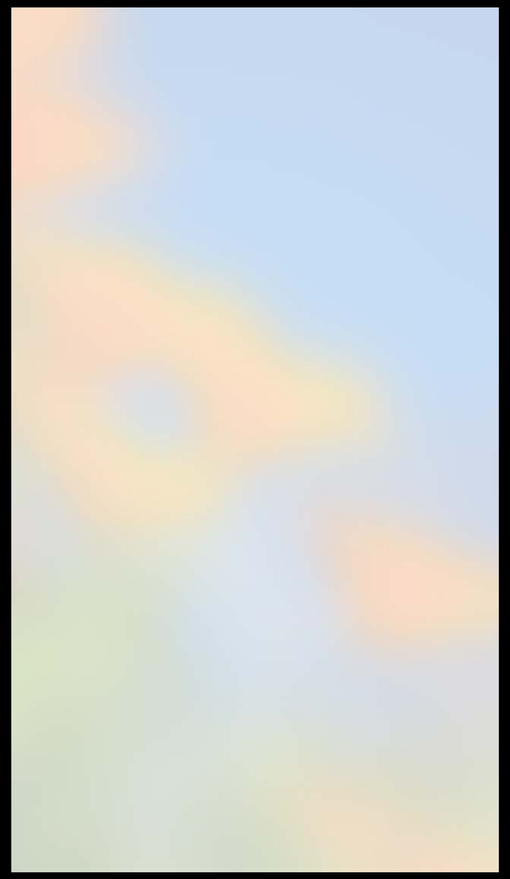
UIVibrancyEffect

Axel Wefers
iOS Software Engineer

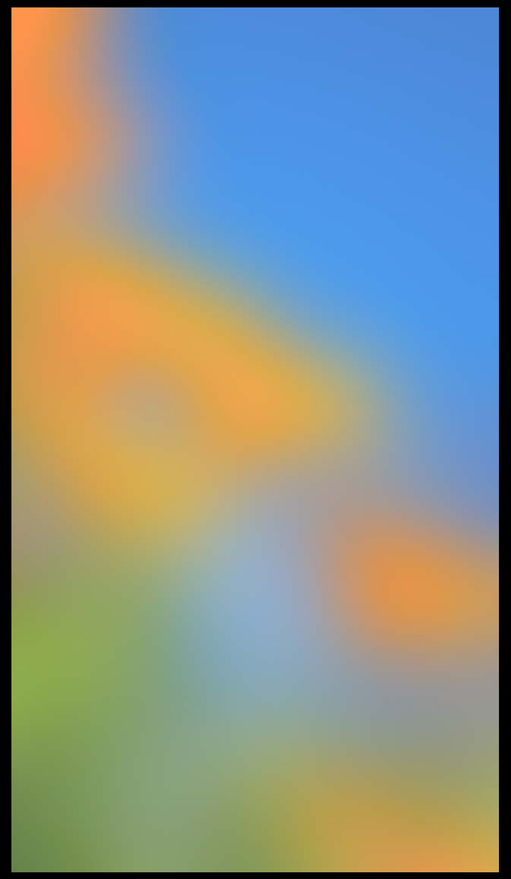
UIVisualEffectView with UIVibrancyEffect

UIVibrancyEffect styles

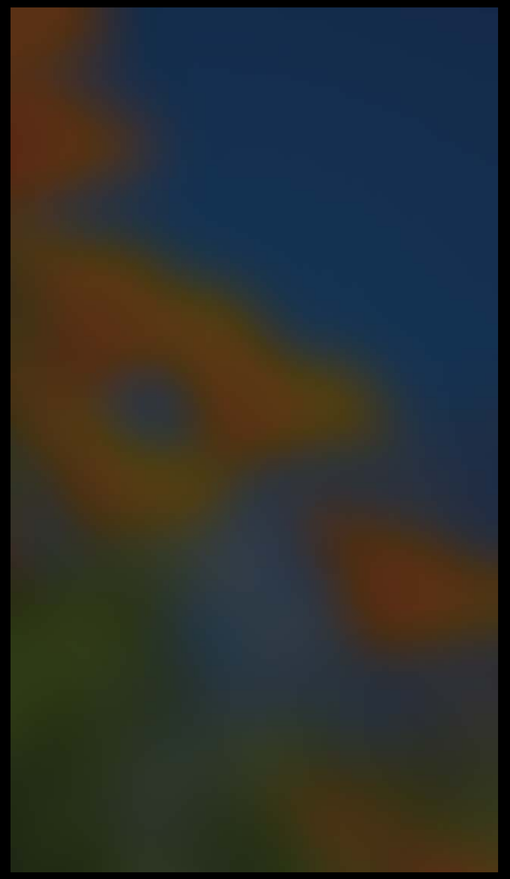
Extra light



Light



Dark

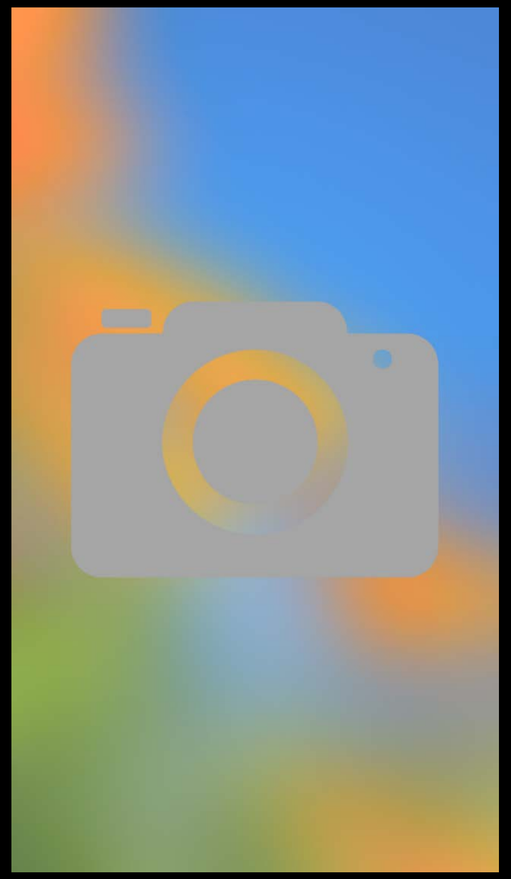


UIVisualEffectView with UIVibrancyEffect

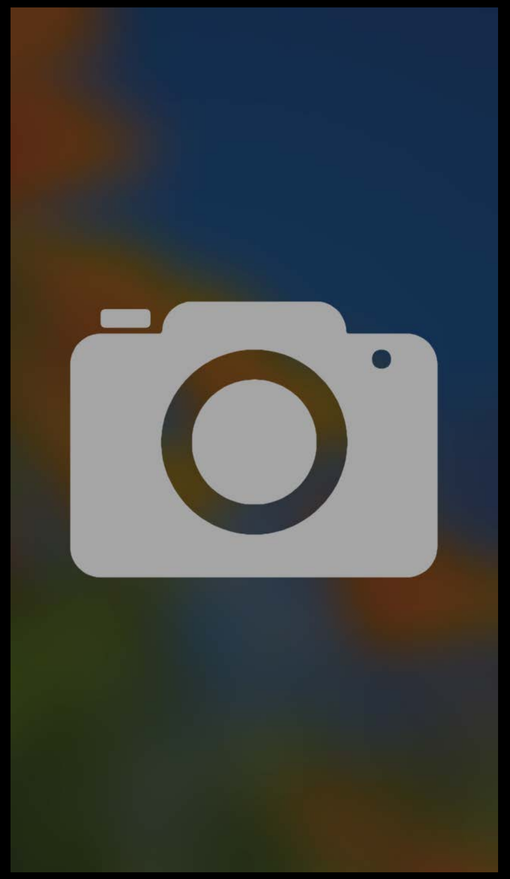
UIVibrancyEffect styles

Extra light

Light



Dark



UIVisualEffectView with UIVibrancyEffect

UIVibrancyEffect styles

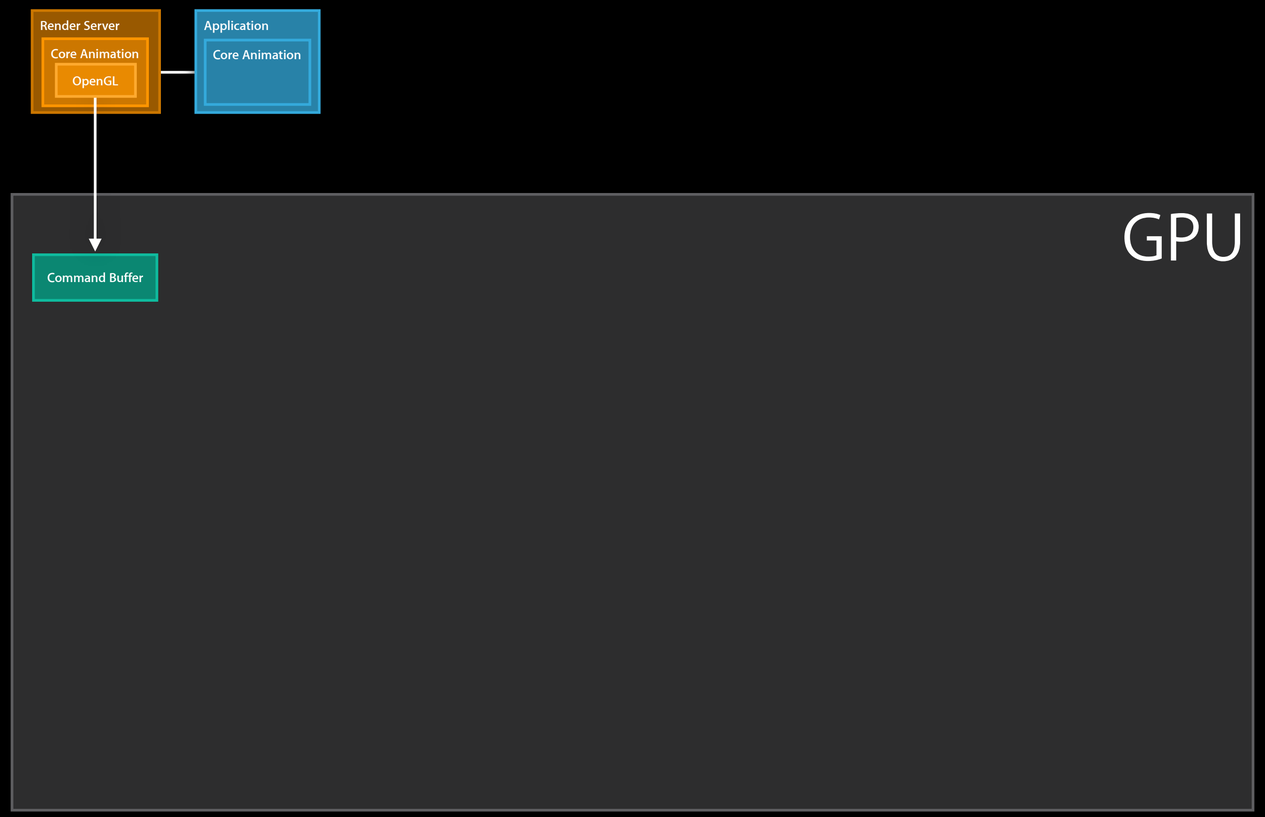
Extra light

Light

Dark

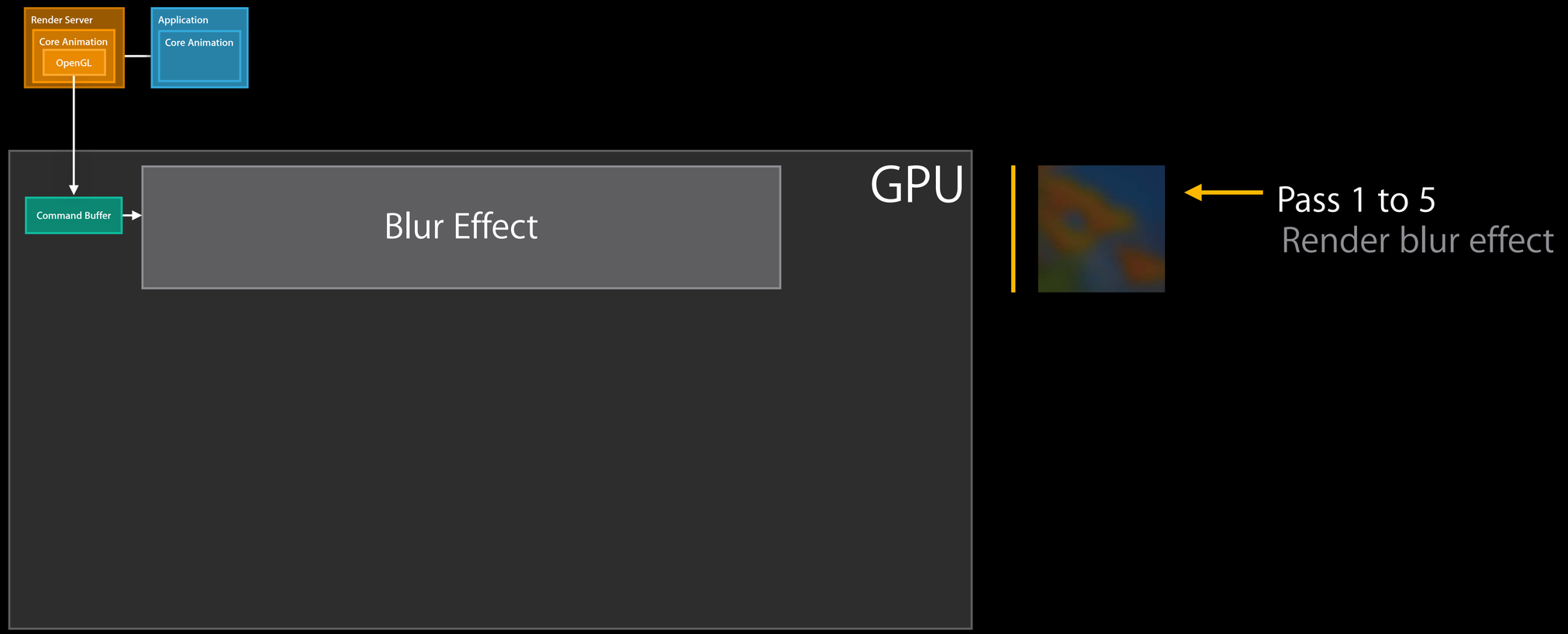
UIVisualEffectView with UIVibrancyEffect

Rendering passes



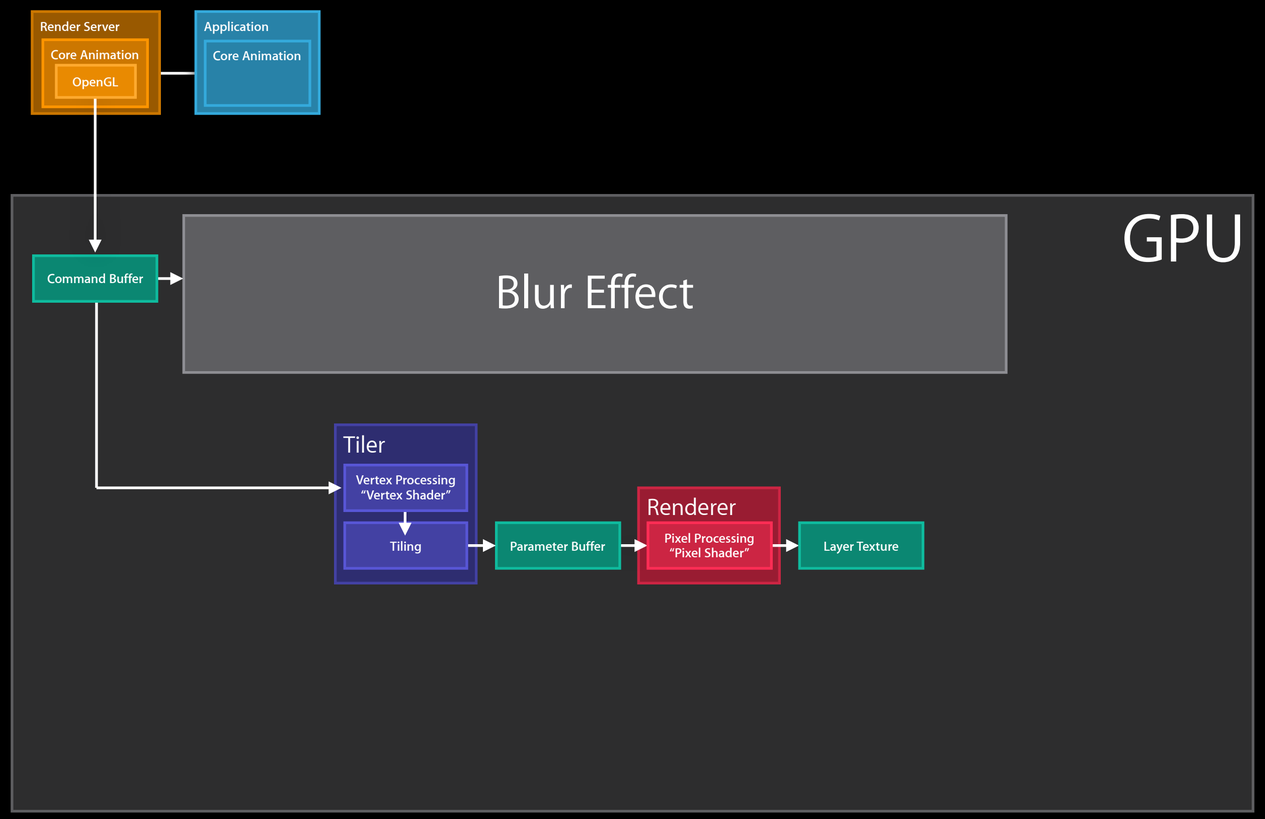
UIVisualEffectView with UIVibrancyEffect

Rendering passes



UIVisualEffectView with UIVibrancyEffect

Rendering passes

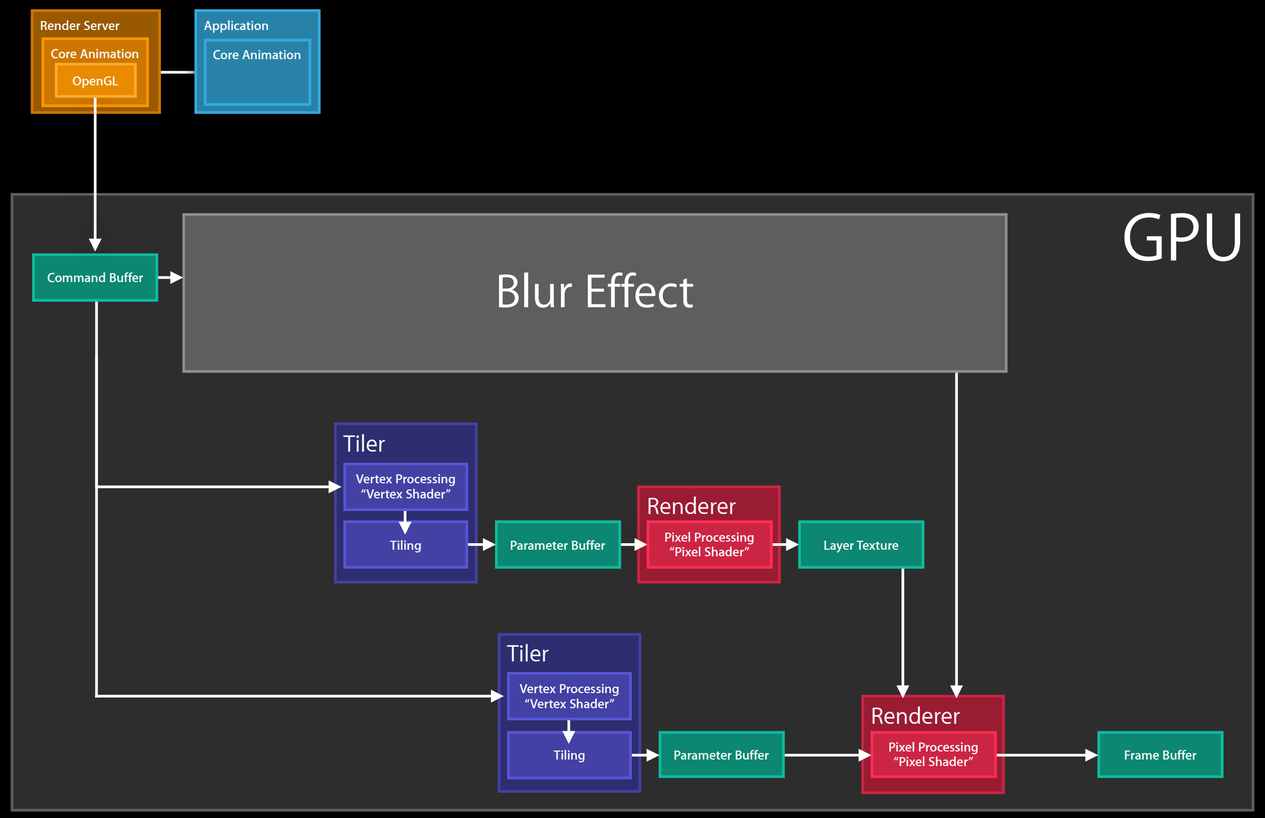


Pass 1 to 5
Render blur effect

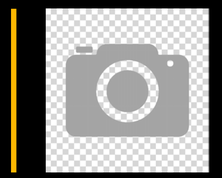
Pass 6
Render layer content to texture

UIVisualEffectView with UIVibrancyEffect

Rendering passes



Pass 1 to 5
Render blur effect

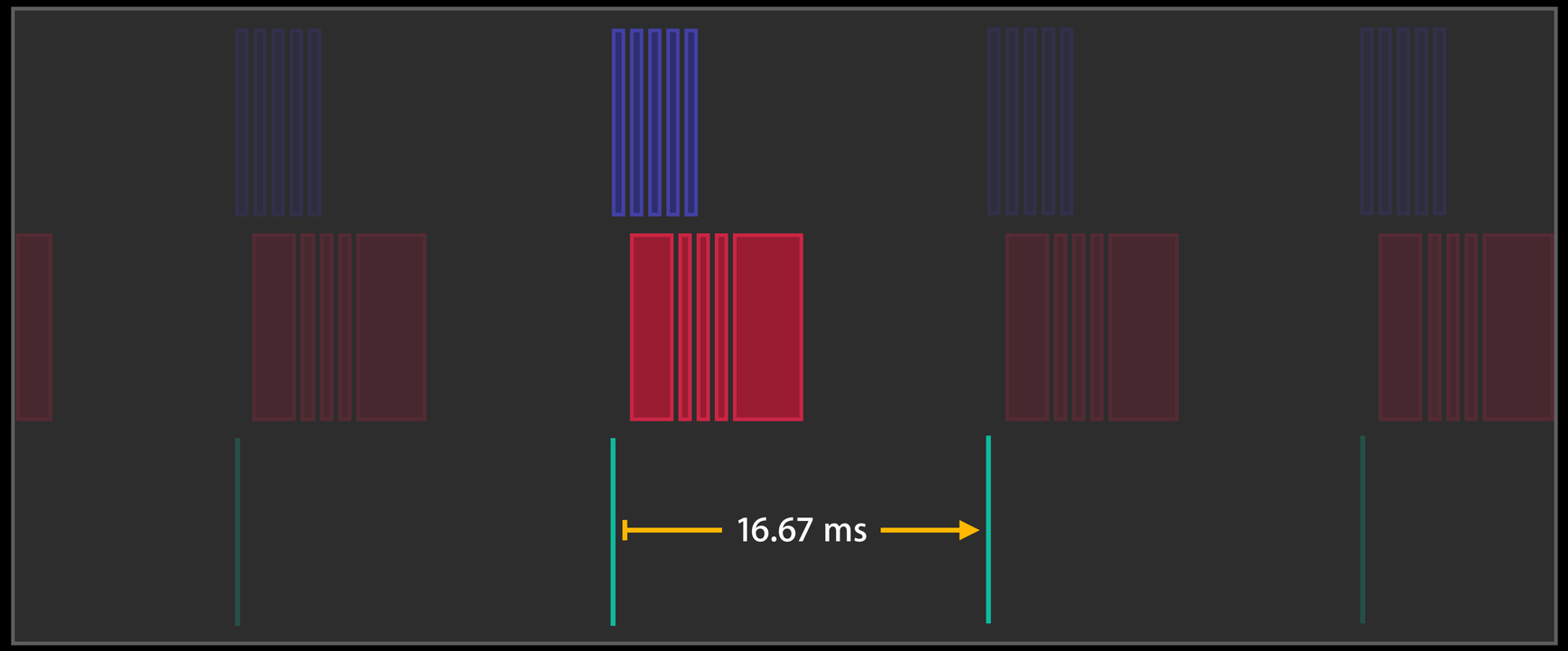


Pass 6
Render layer content to texture

Compositing pass
Apply filter to content texture

UIVisualEffectView with UIVibrancyEffect

GPU utilization, fullscreen, iPad Air

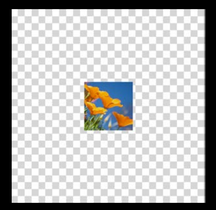


Tiler
Vertex processing

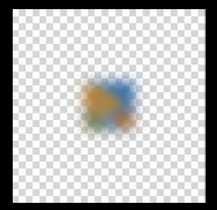
Renderer
Pixel processing

VBlank interrupt
Every 16.67 ms


Pass 1


Pass 2

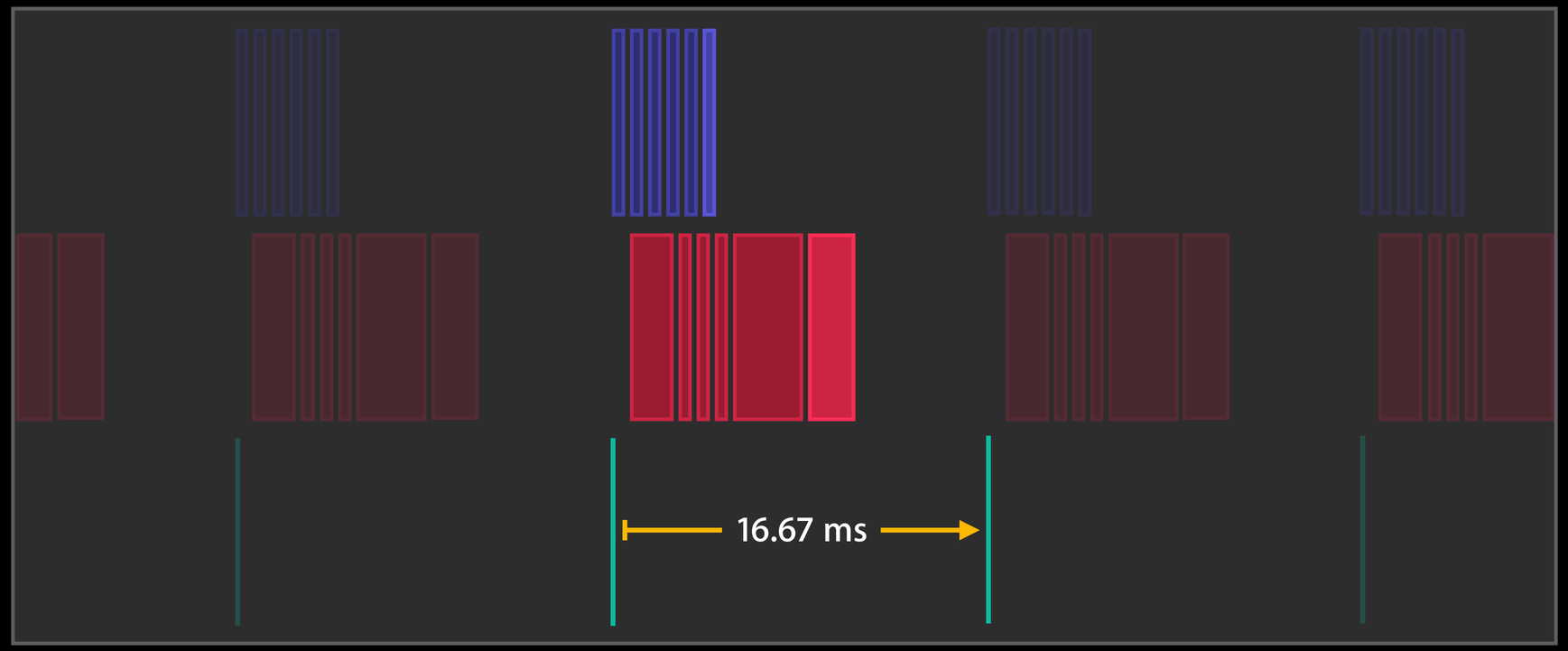

Pass 3


Pass 4


Pass 5

UIVisualEffectView with UIVibrancyEffect

GPU utilization, fullscreen, iPad Air

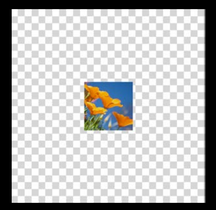


Tiler
Vertex processing

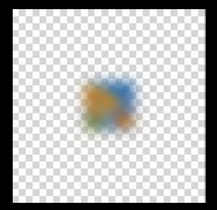
Renderer
Pixel processing

VBlank interrupt
Every 16.67 ms


Pass 1


Pass 2


Pass 3

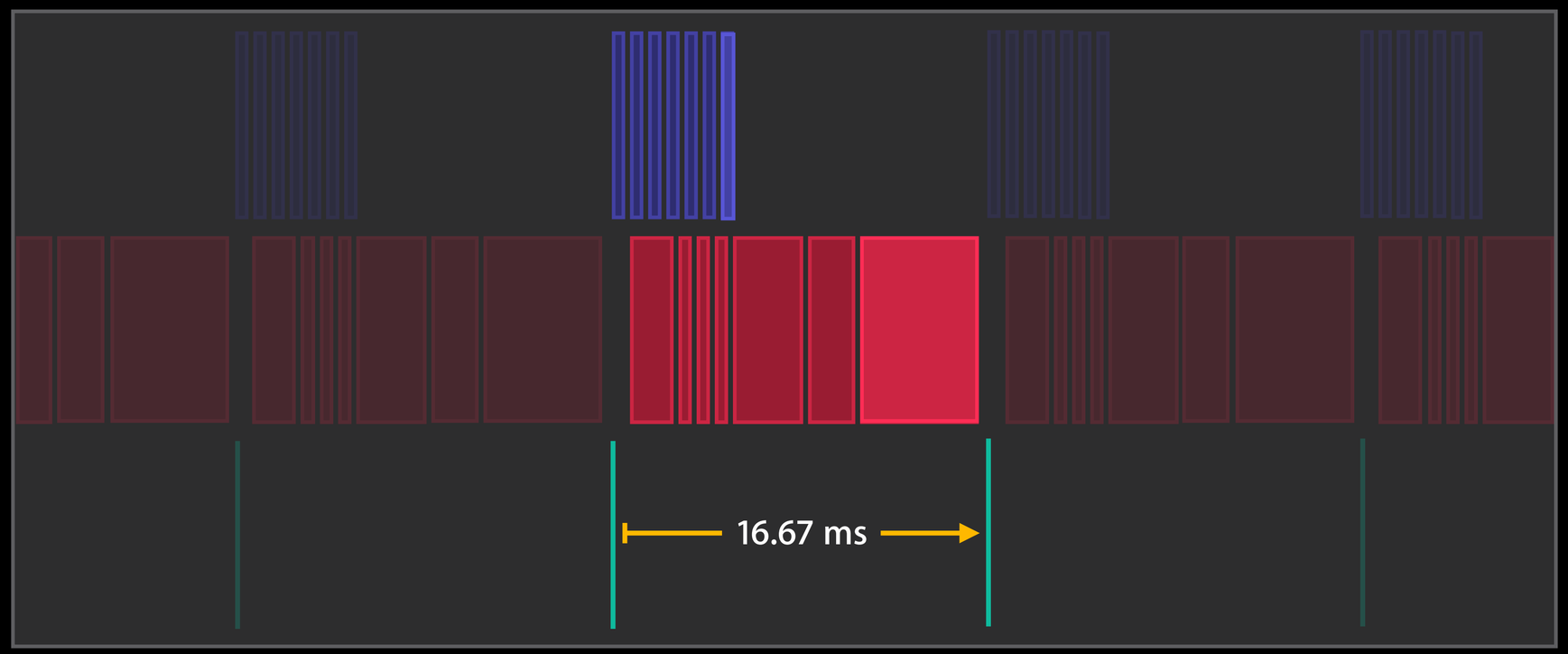

Pass 4


Pass 5


Pass 6

UIVisualEffectView with UIVibrancyEffect

GPU utilization, fullscreen, iPad Air

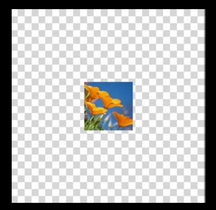


Tiler
Vertex processing

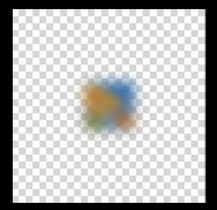
Renderer
Pixel processing

VBlank interrupt
Every 16.67 ms


Pass 1


Pass 2


Pass 3


Pass 4

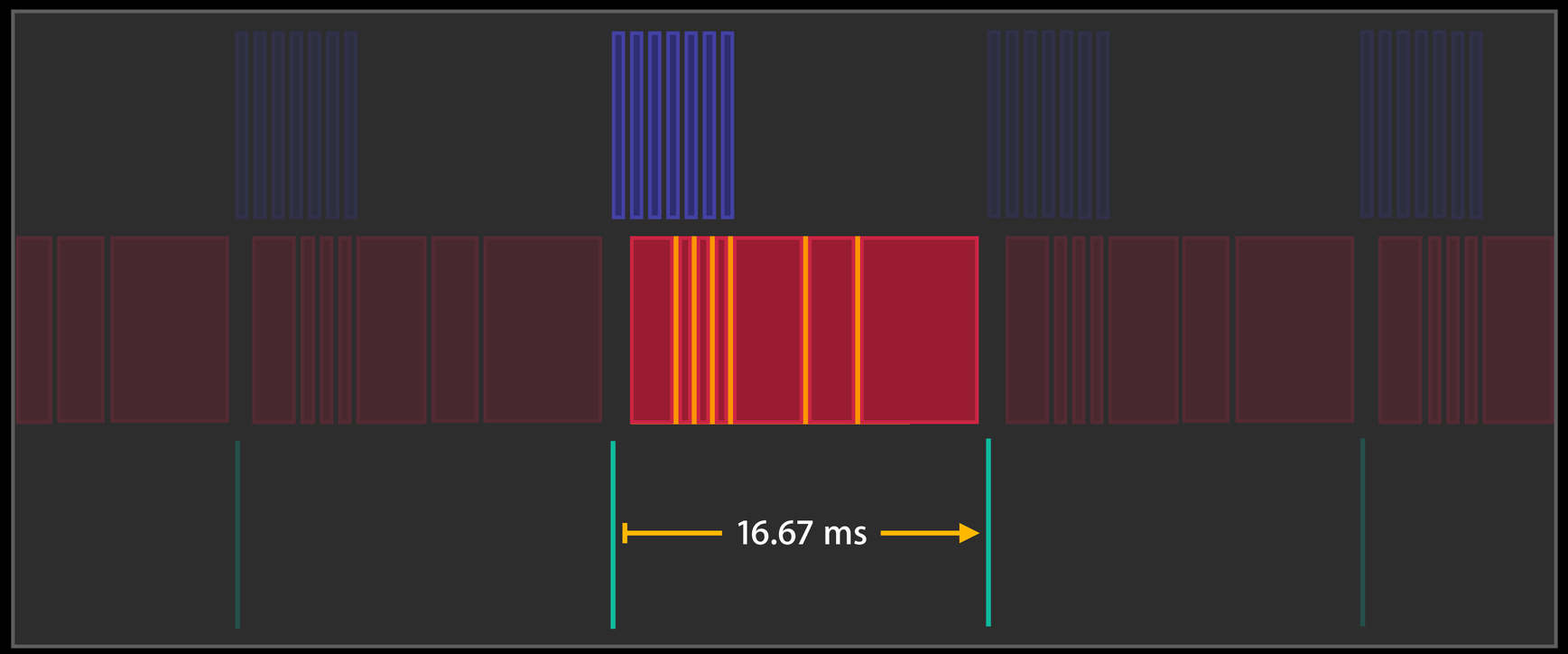

Pass 5


Pass 6


Pass 7

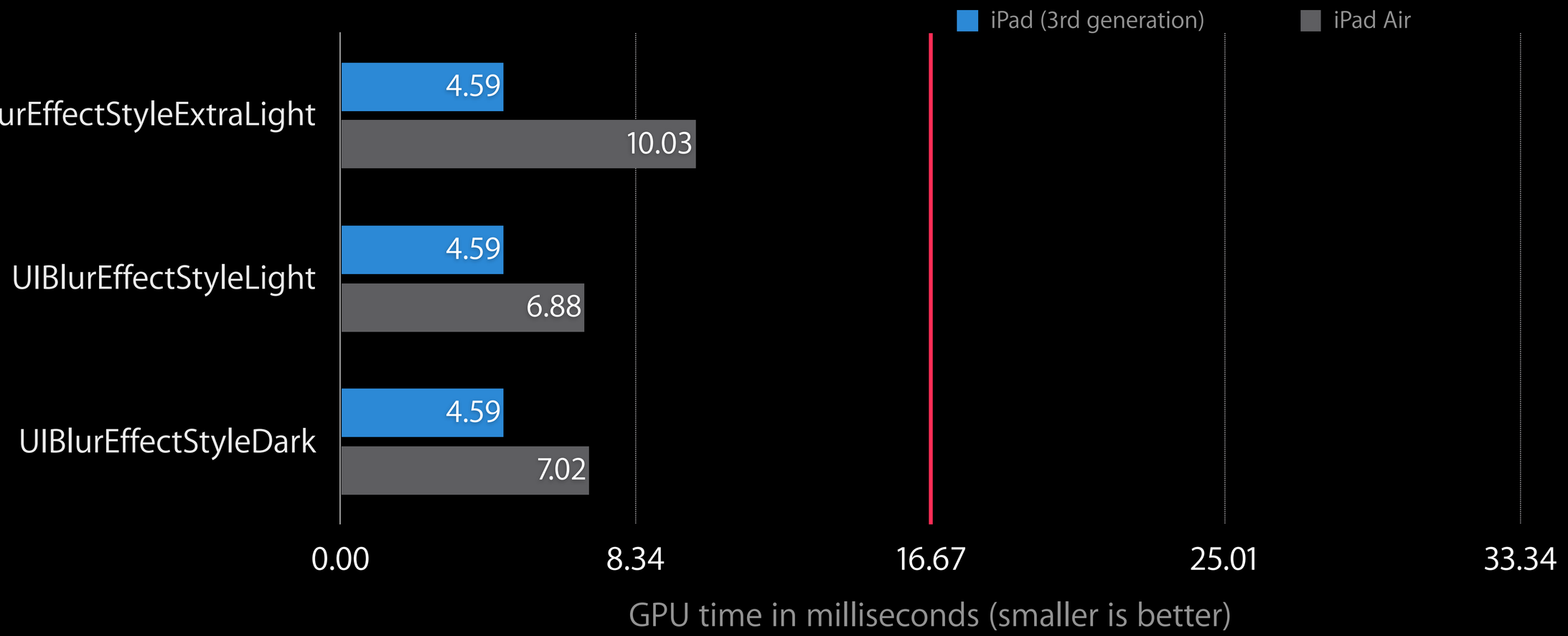
UIVisualEffectView with UIVibrancyEffect

GPU utilization, fullscreen, iPad Air



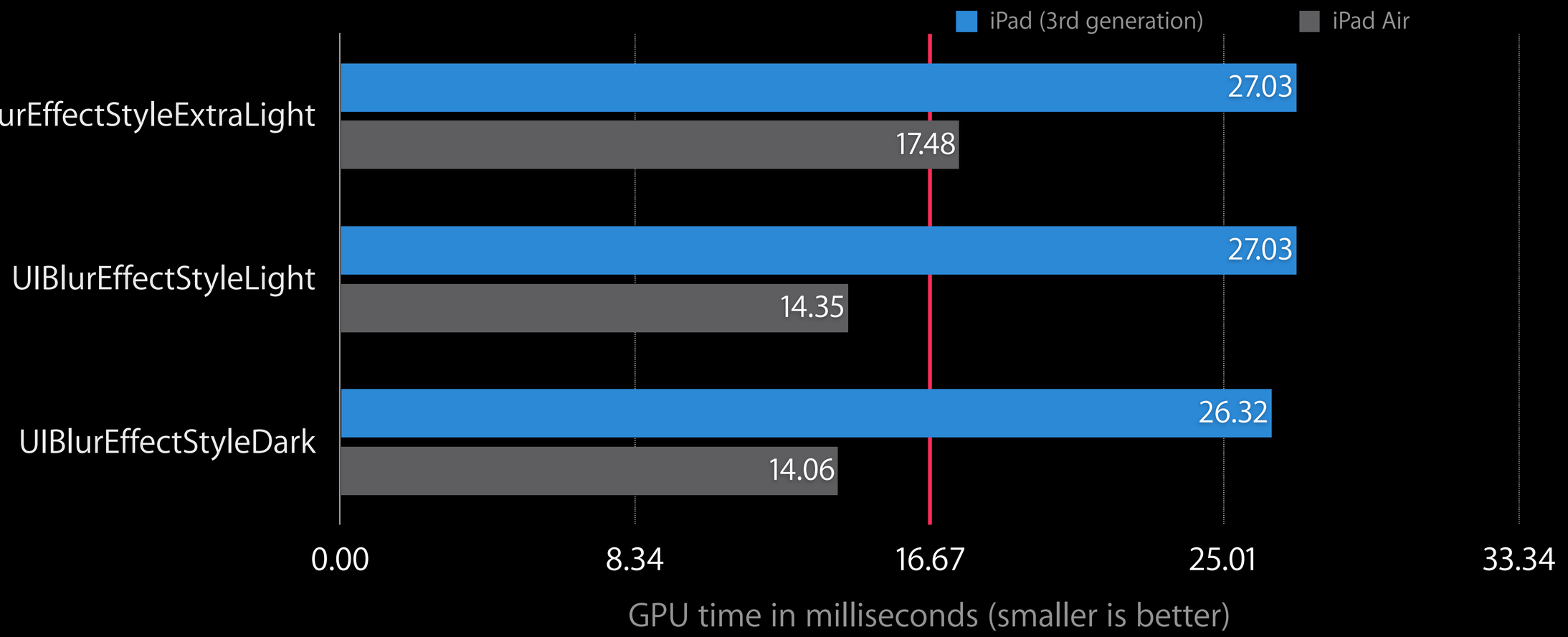
UIVisualEffectView with UIVibrancyEffect

Fullscreen performance



UIVisualEffectView with UIVibrancyEffect

Fullscreen performance



UIVisualEffectView with UIVibrancyEffect

Performance considerations

`UIVibrancyEffect` adds two offscreen passes

`UIVibrancyEffect` uses expensive compositing filter for content

Use `UIVibrancyEffect` on small regions

Only dirty regions are redrawn

`UIVibrancyEffect` is very costly on all devices

- → UI can easily be GPU bound
- → Keep bounds of view as small as possible
- → Make sure to budget for effects

Rasterization

Performance considerations

Use to composite to image once with GPU

Enable with `shouldRasterize` property on `CALayer`

Extra offscreen passes when updating content

Do not overuse, cache size is limited to 2.5x of screen size

Rasterized images evicted from cache if unused for more than 100ms

Rasterization

Typical use cases

Avoid redrawing expensive effects for static content

Avoid redrawing of complex view hierarchies

Group Opacity

Performance considerations

Disable with `allowsGroupOpacity` property on `CALayer`

Will introduce offscreen passes:

- If layer is not opaque (`opacity` != 1.0)
- And if layer has nontrivial content (child layers or background image)

  → Sub view hierarchy needs to be composited before being blended

Always turn it off if not needed

Tools

Michael Ingrassia
iOS Software Engineer

Performance Investigation Mindset

Performance Investigation Mindset

What is the frame rate?	Goal is always 60 frames per second

Performance Investigation Mindset

What is the frame rate?	Goal is always 60 frames per second
CPU or GPU bound?	Lower utilization is desired and saves battery

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Performance Investigation Mindset

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Too many offscreen passes?	Fewer is better
Too much blending?	Less is better

Performance Investigation Mindset

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Performance Investigation Mindset

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Any expensive views or effects?	Understand the cost of what is in use

Performance Investigation Mindset

What is the frame rate?	Goal is always 60 frames per second
CPU or GPU bound?	Lower utilization is desired and saves battery
Any unnecessary CPU rendering?	GPU is desirable but know when CPU makes sense
Too many offscreen passes?	Fewer is better
Too much blending?	Less is better
Any strange image formats or sizes?	Avoid on-the-fly conversions or resizing
Any expensive views or effects?	Understand the cost of what is in use
Anything unexpected in hierarchy?	Know the actual view hierarchy

Tools

Instruments

- Core Animation instrument
- OpenGL ES Driver instrument

Simulator

- Color debug options

Xcode

- View debugging

Instruments

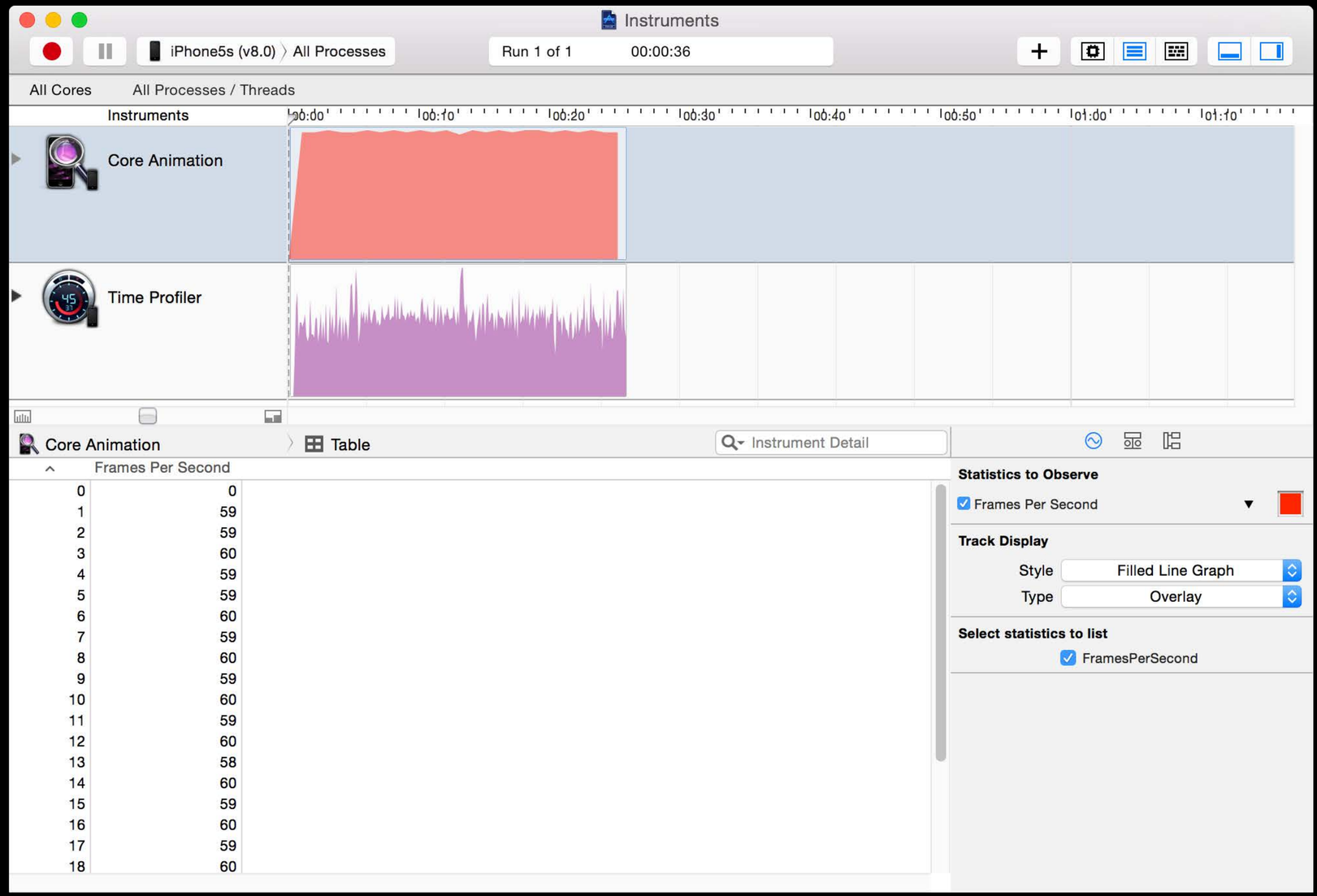
Core Animation template

Instruments

Core Animation template

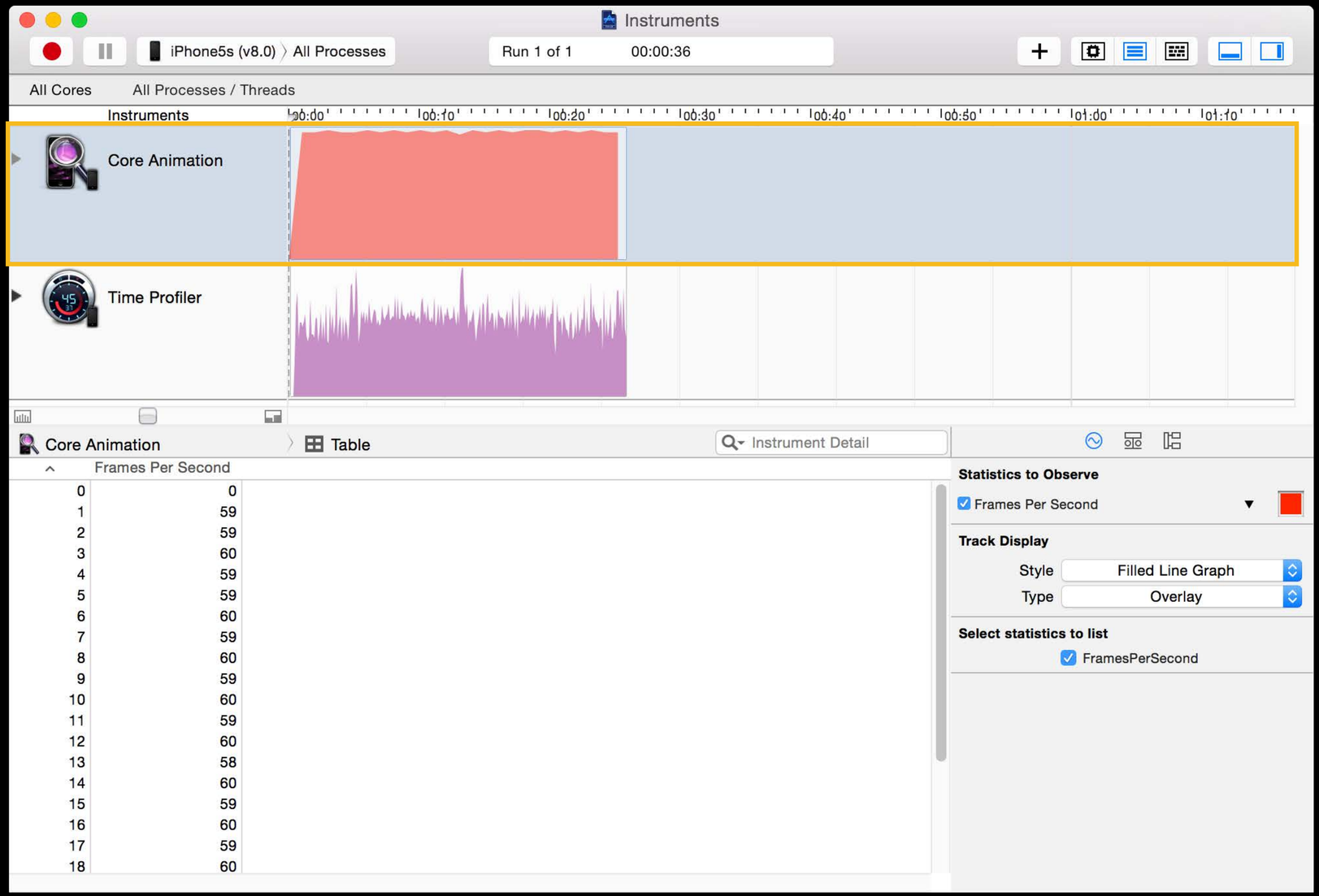
Core Animation Instrument

Measuring frame rate



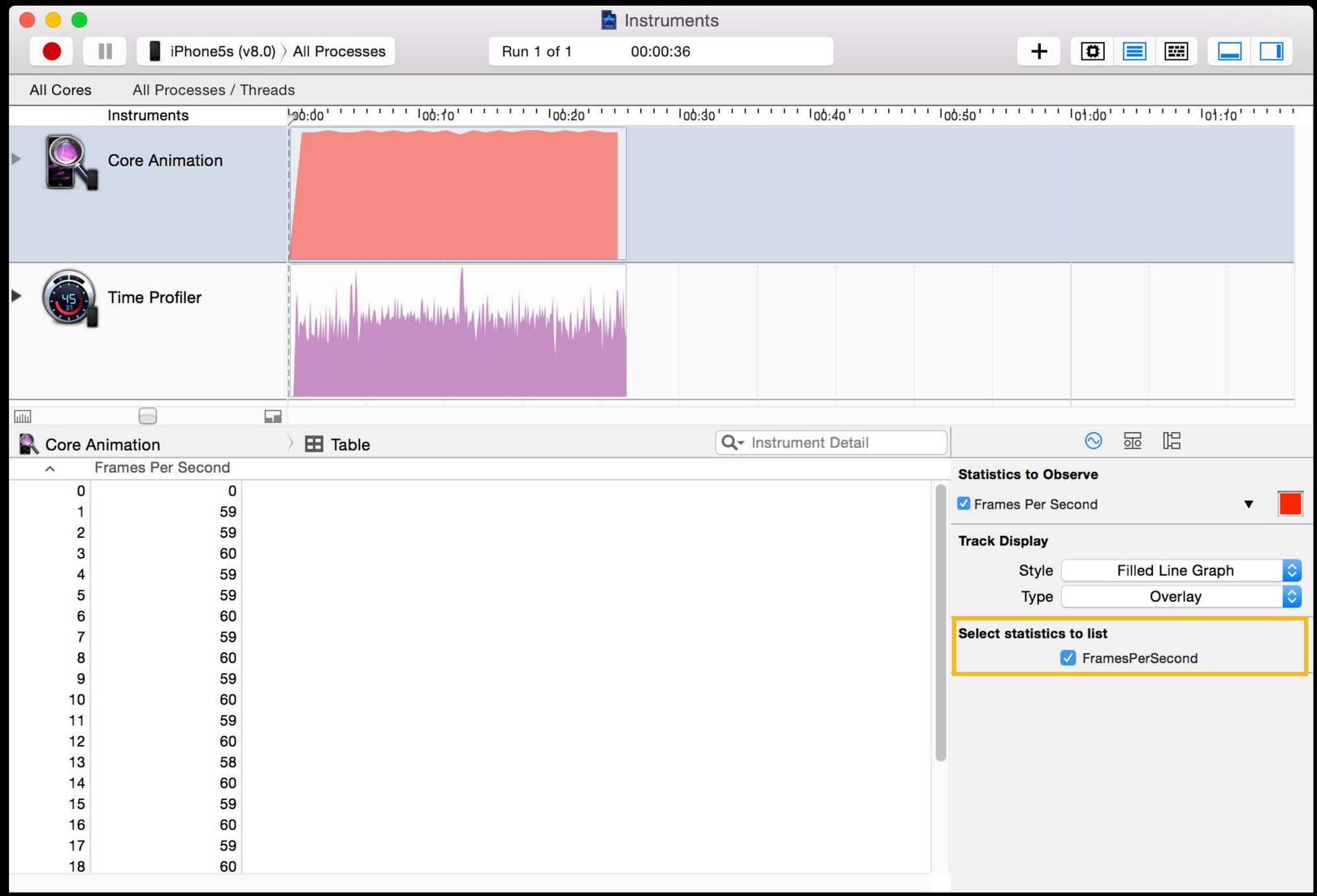
Core Animation Instrument

Measuring frame rate



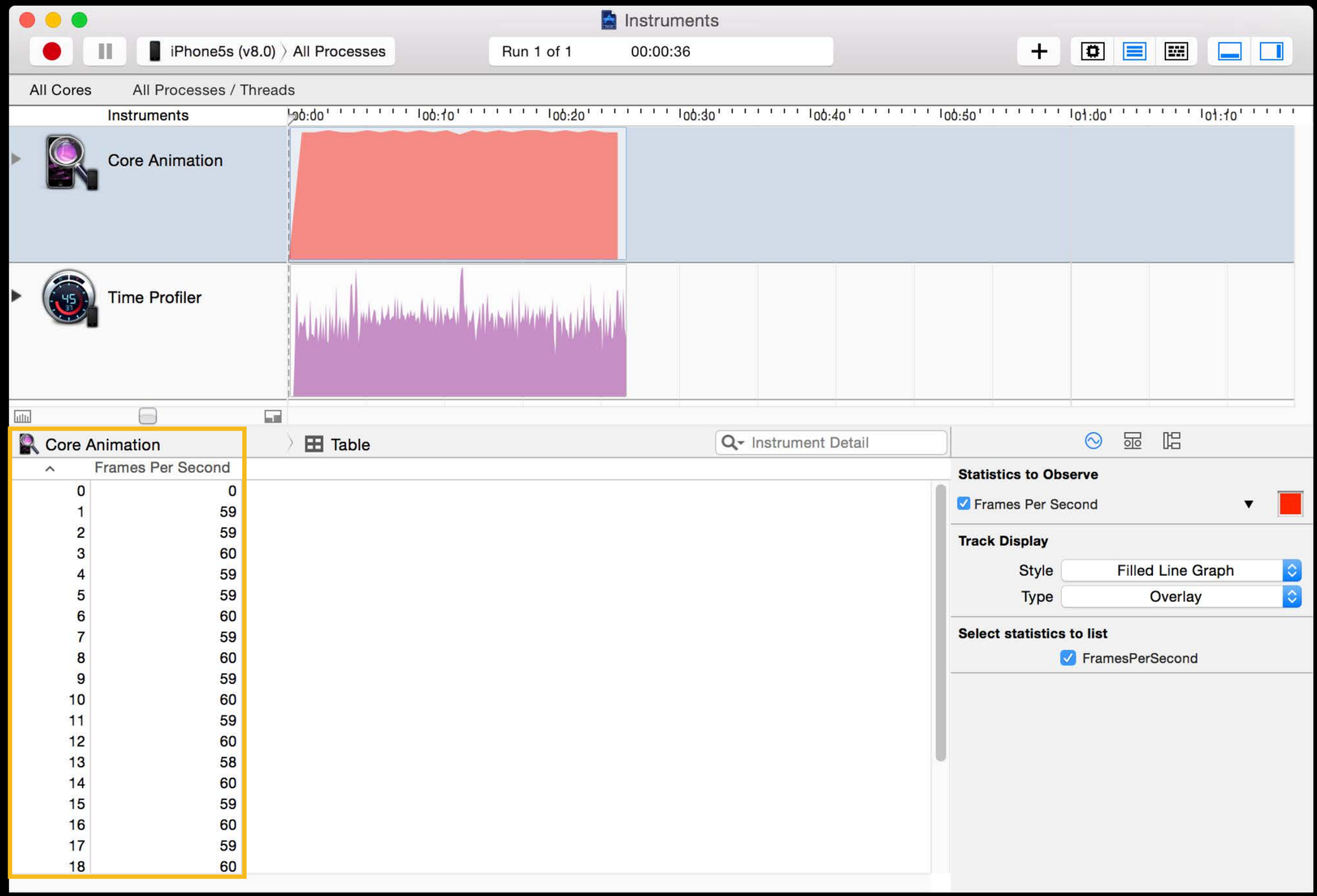
Core Animation Instrument

Measuring frame rate



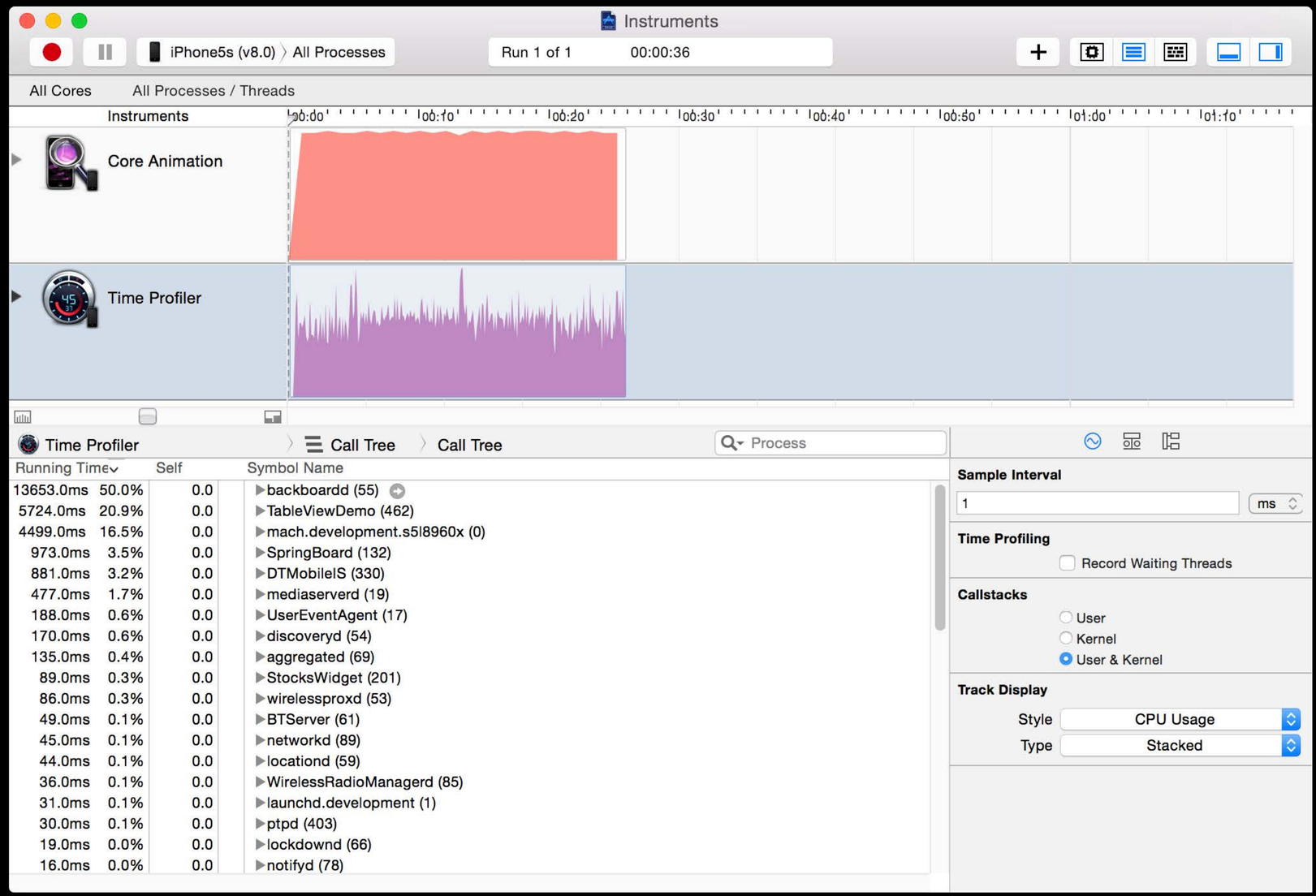
Core Animation Instrument

Measuring frame rate



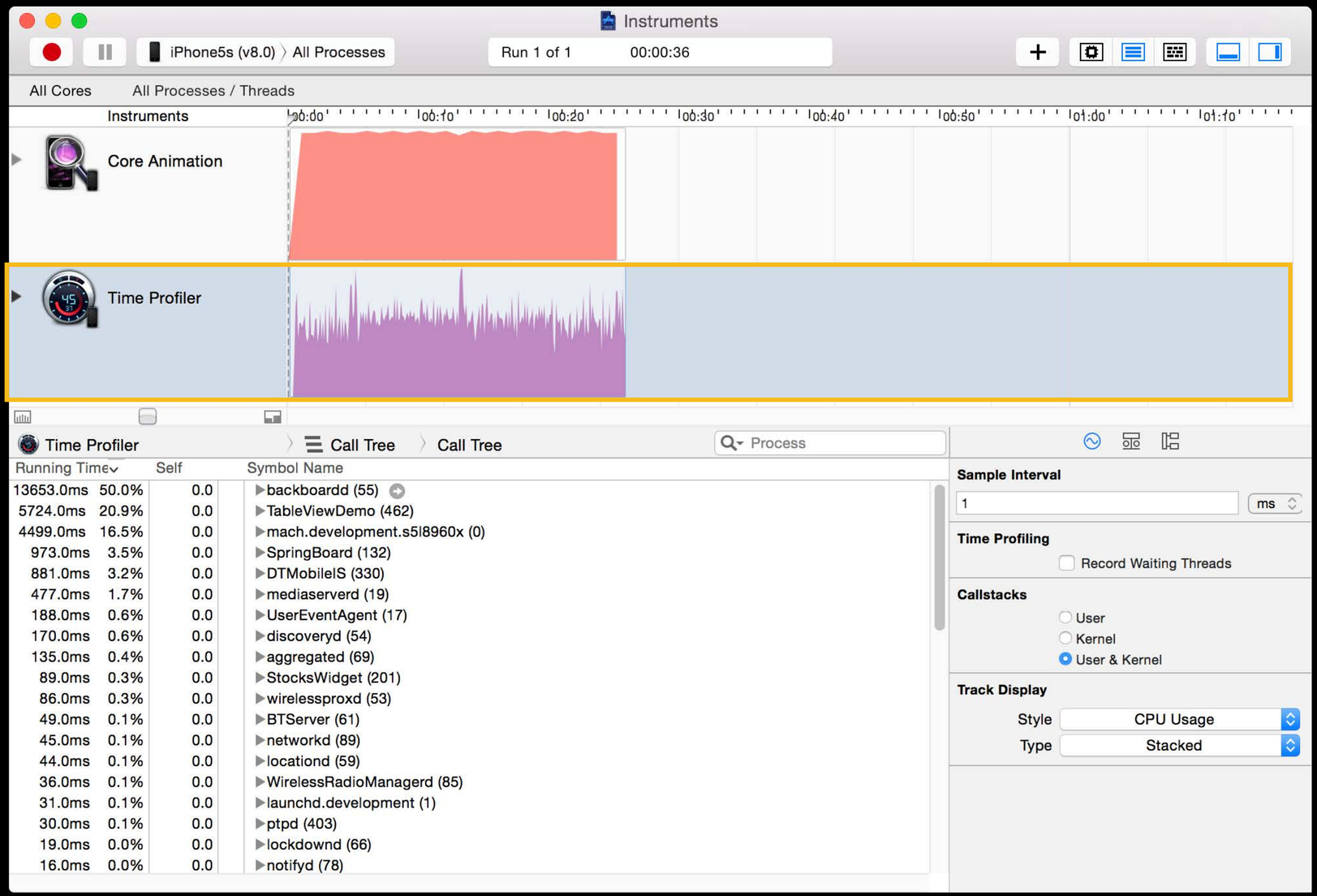
Time Profiler Instrument

CPU utilization



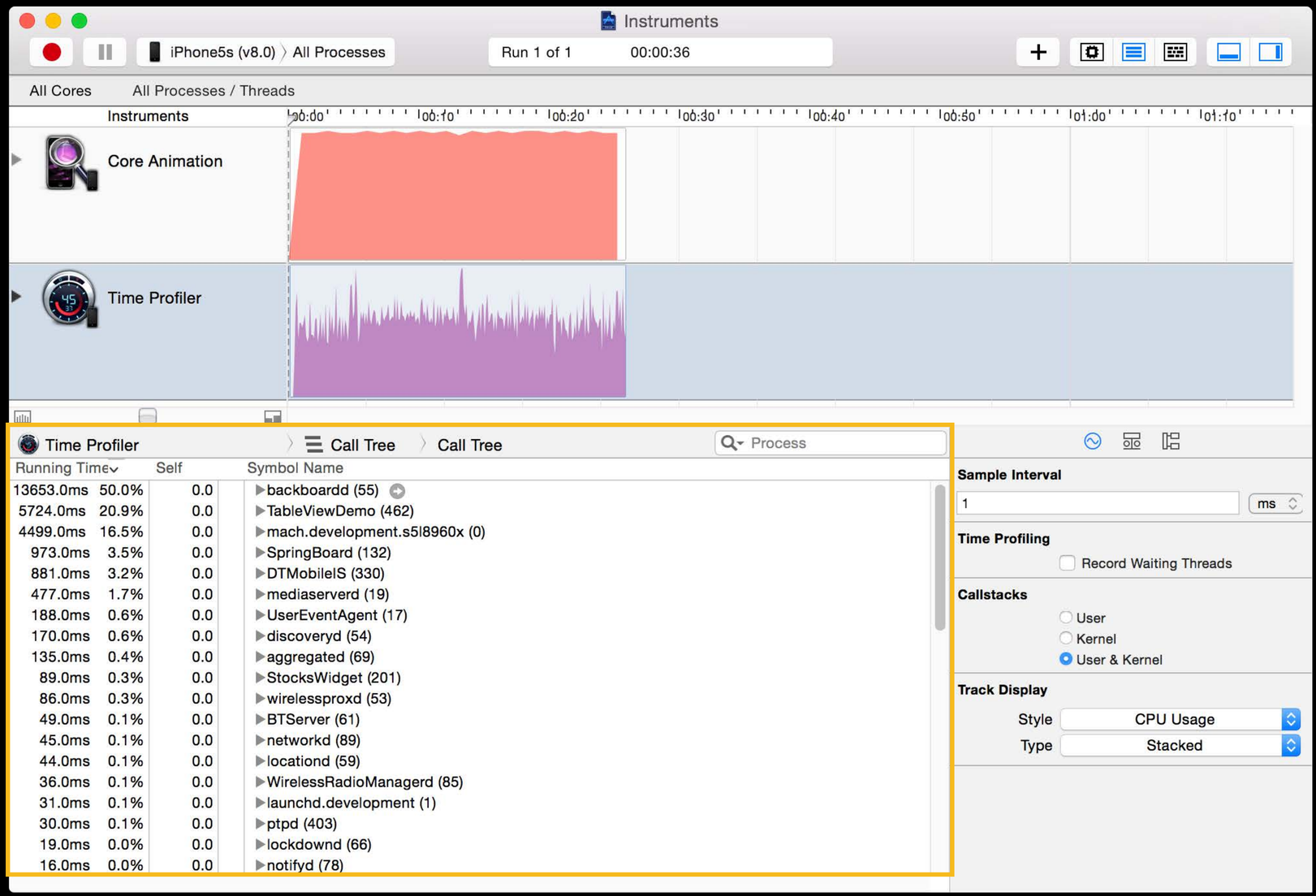
Time Profiler Instrument

CPU utilization



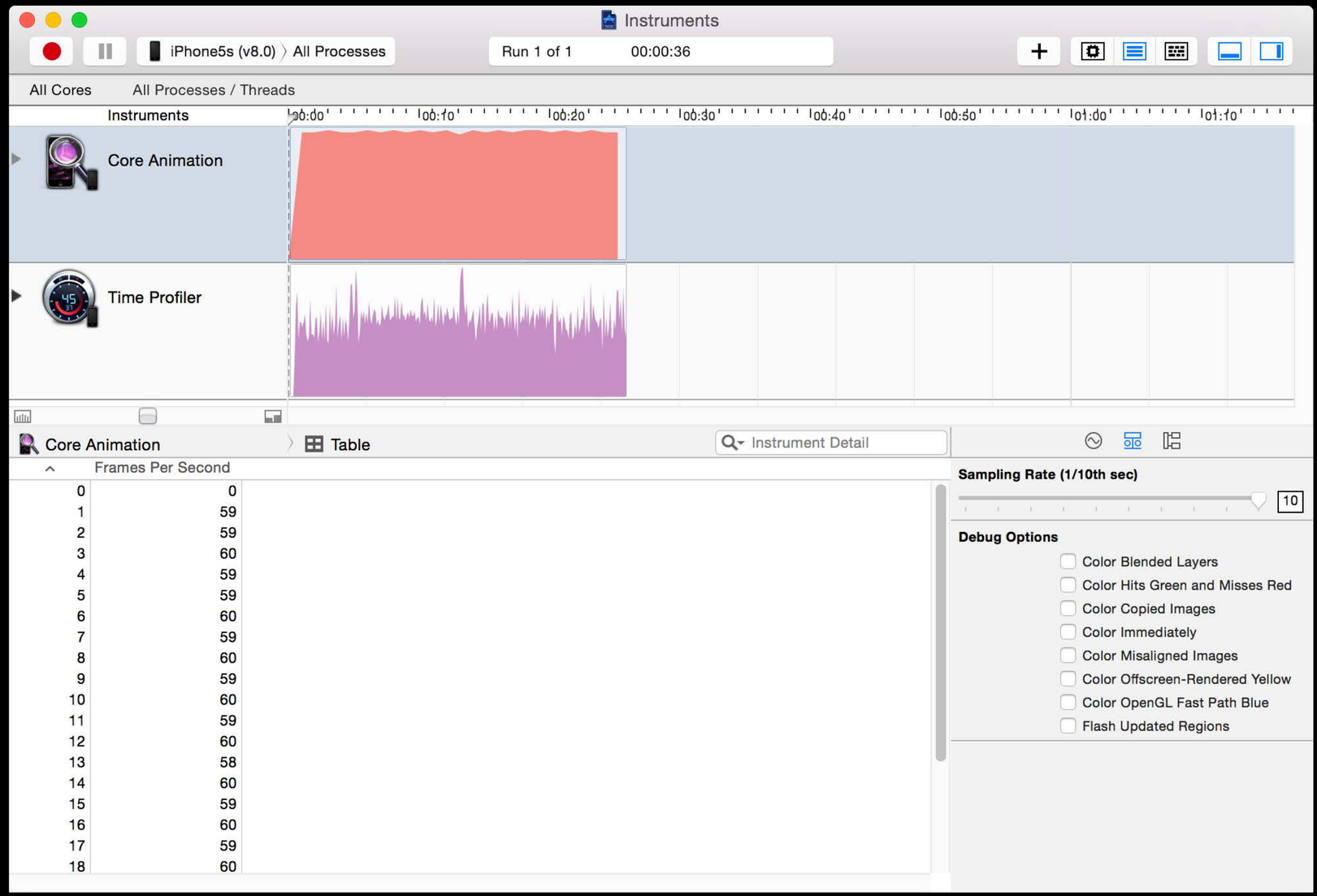
Time Profiler Instrument

CPU utilization



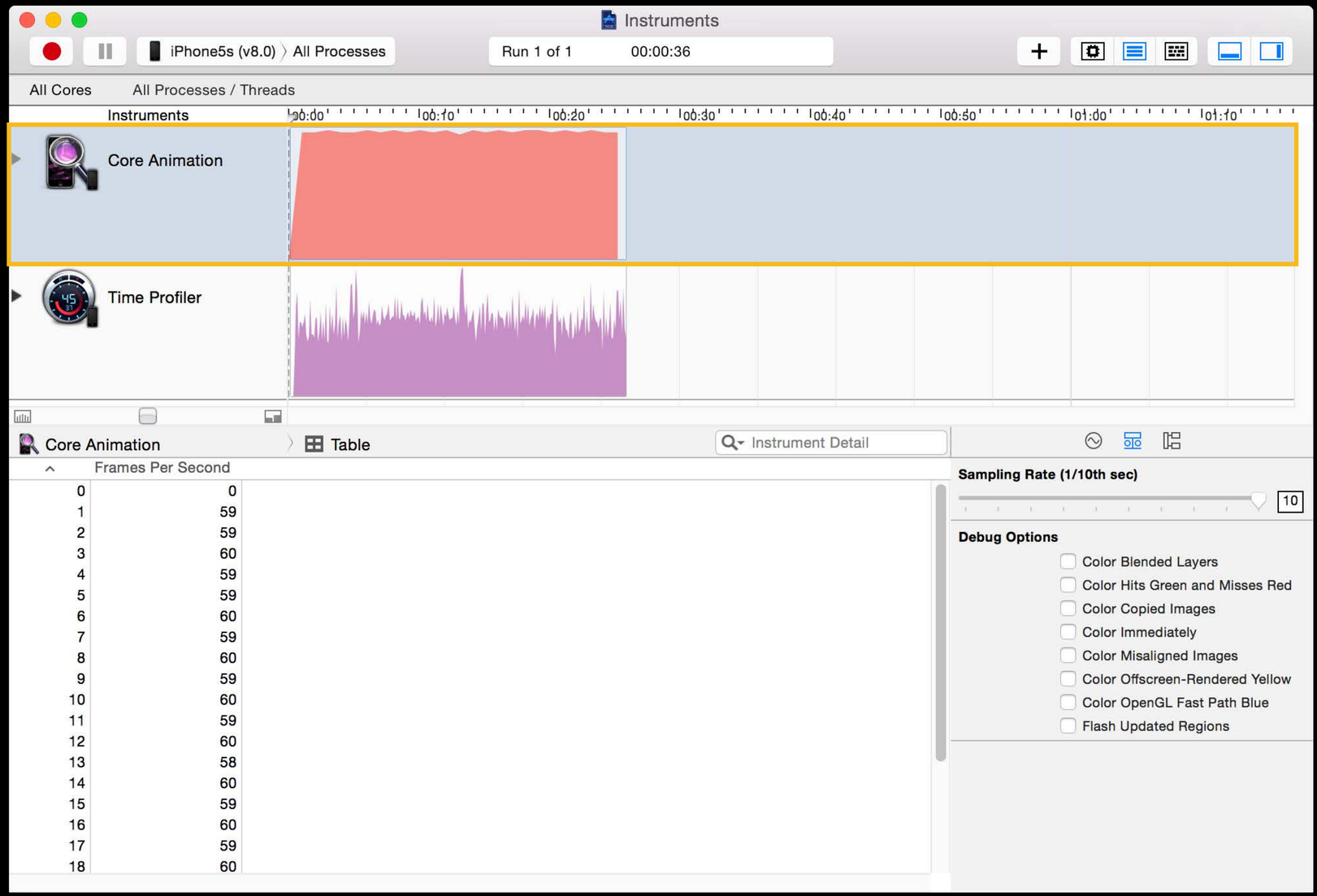
Core Animation Instrument

Color debug options



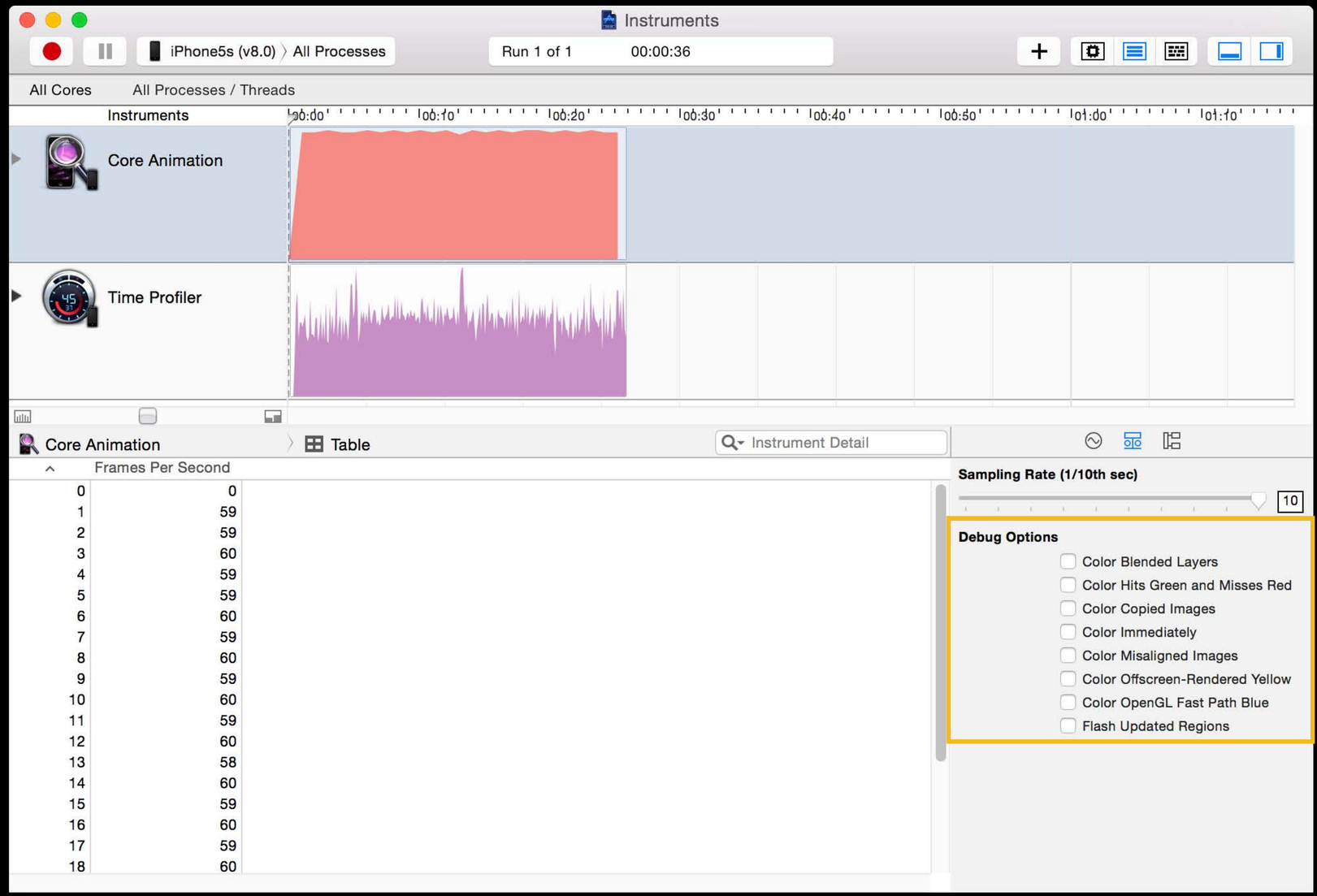
Core Animation Instrument

Color debug options



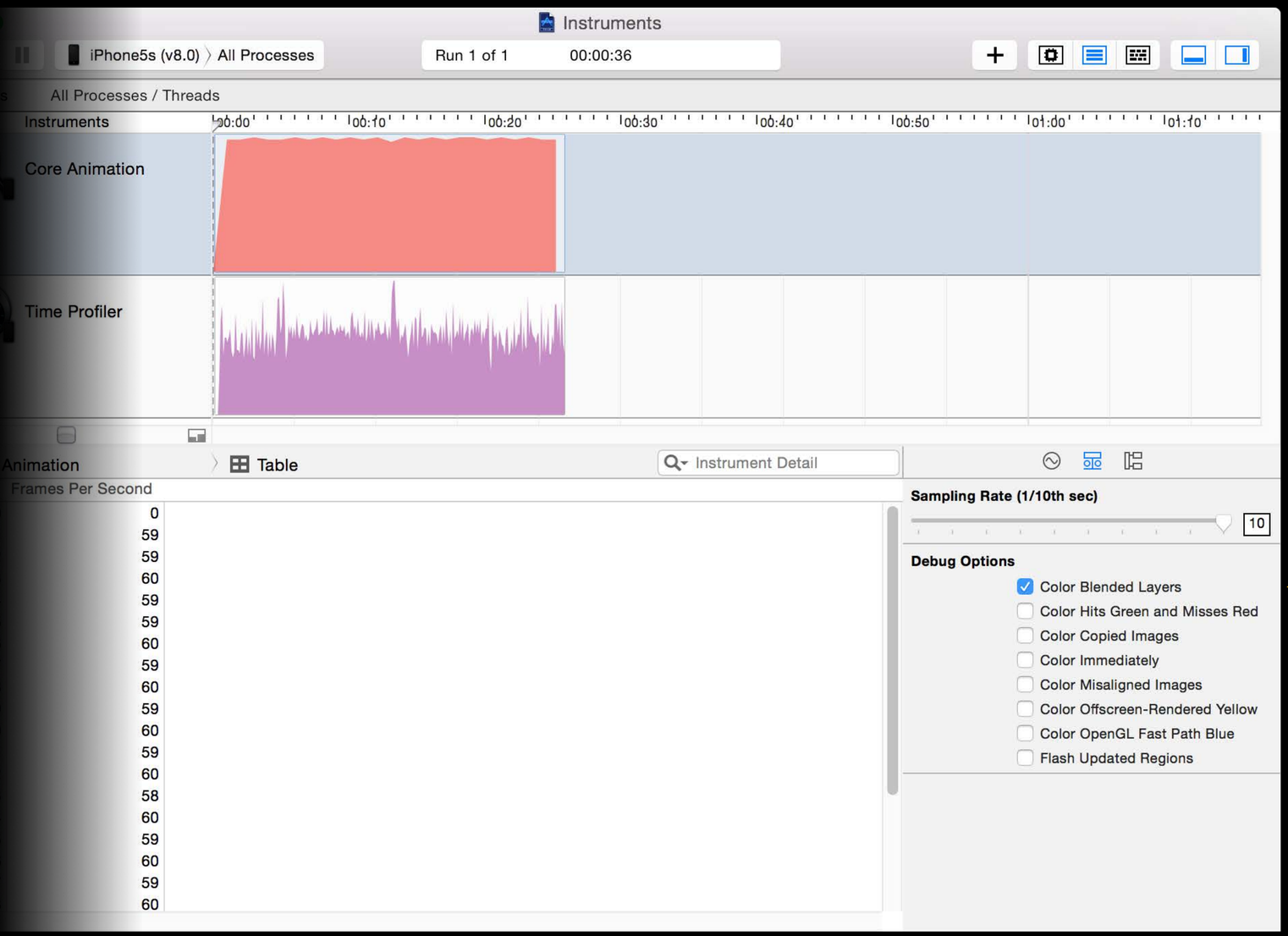
Core Animation Instrument

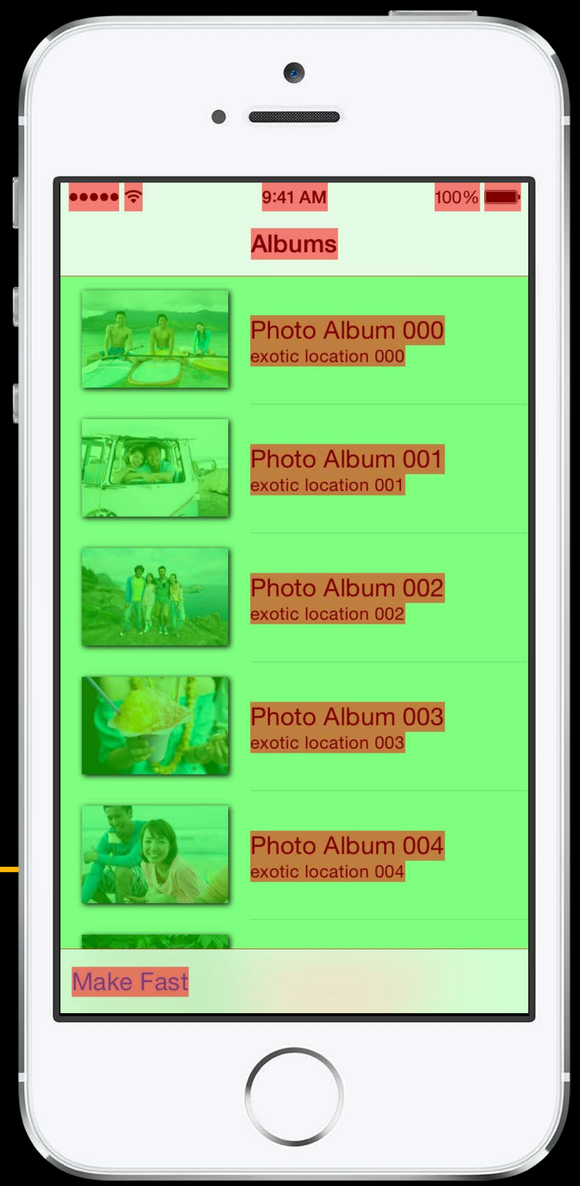
Color debug options



Core Animation Instrument

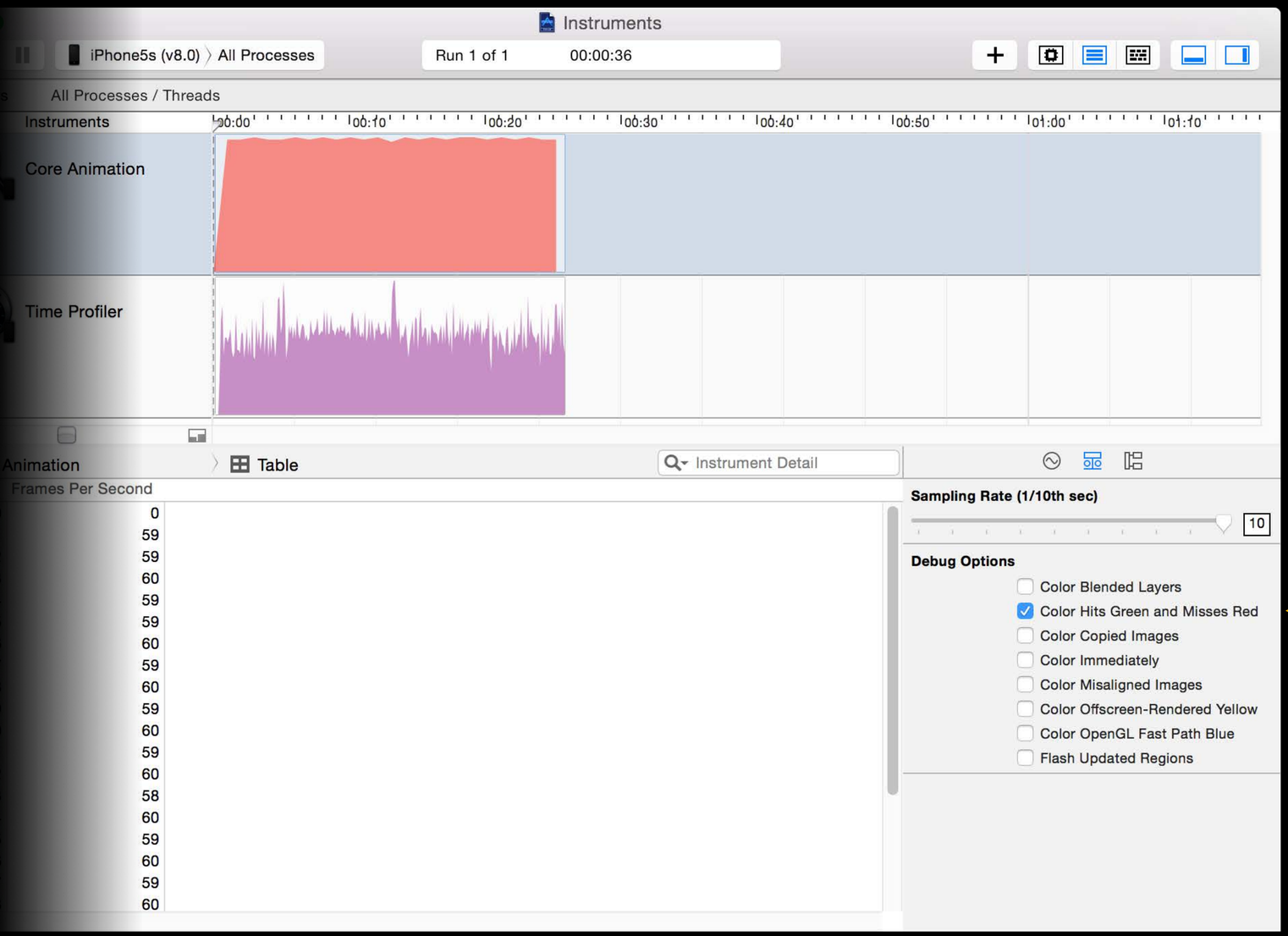
Color blended layers





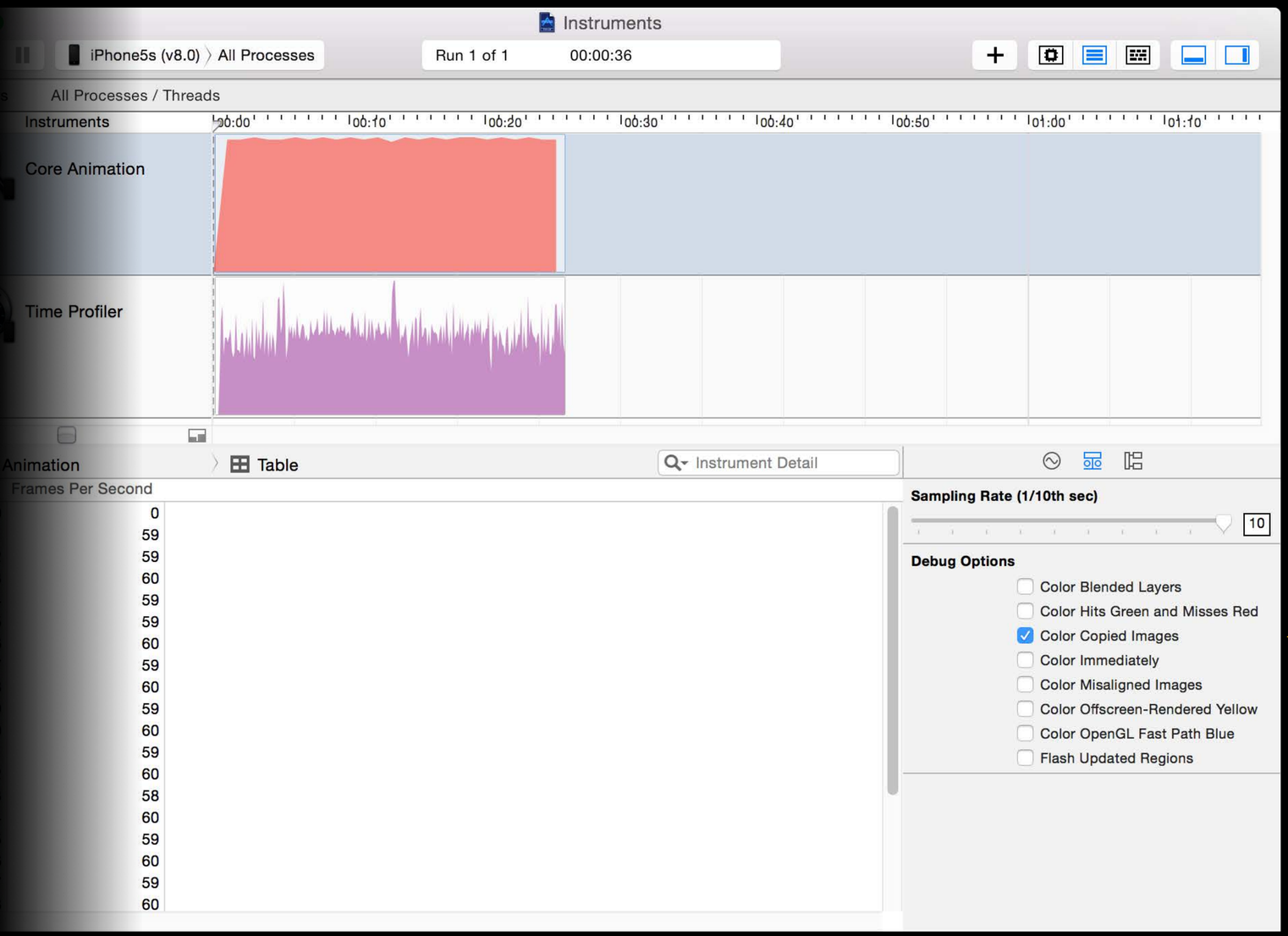
Core Animation Instrument

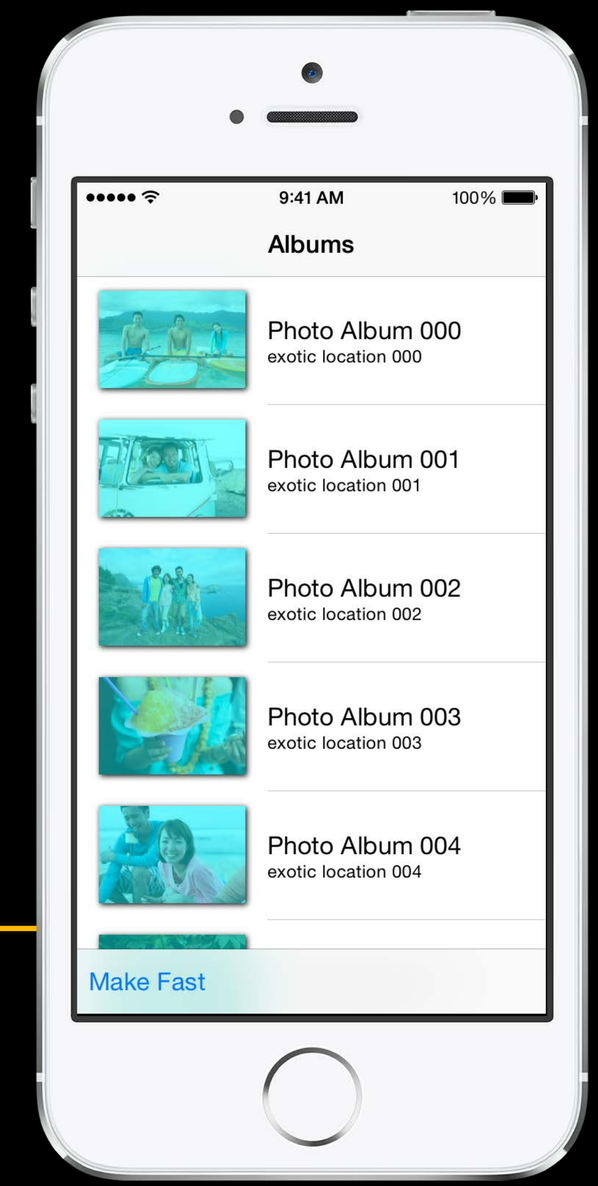
Color hits green and misses red



Core Animation Instrument

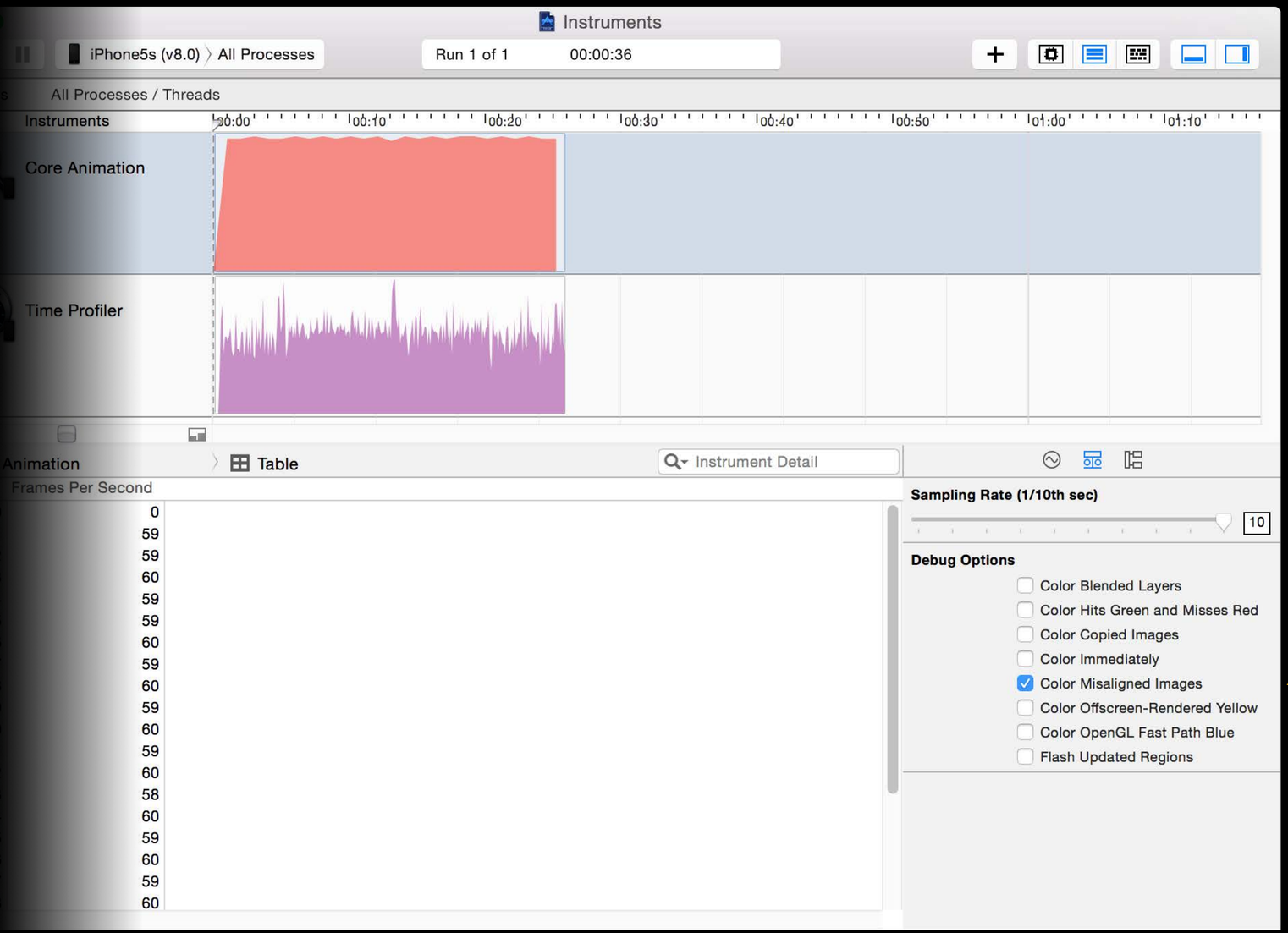
Color copied images

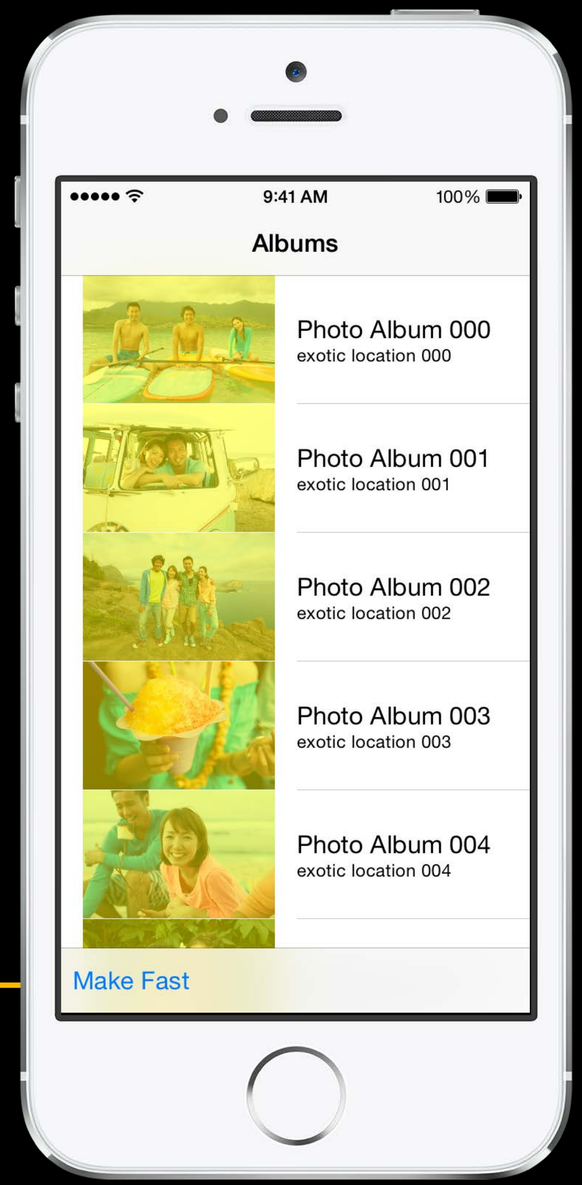




Core Animation Instrument

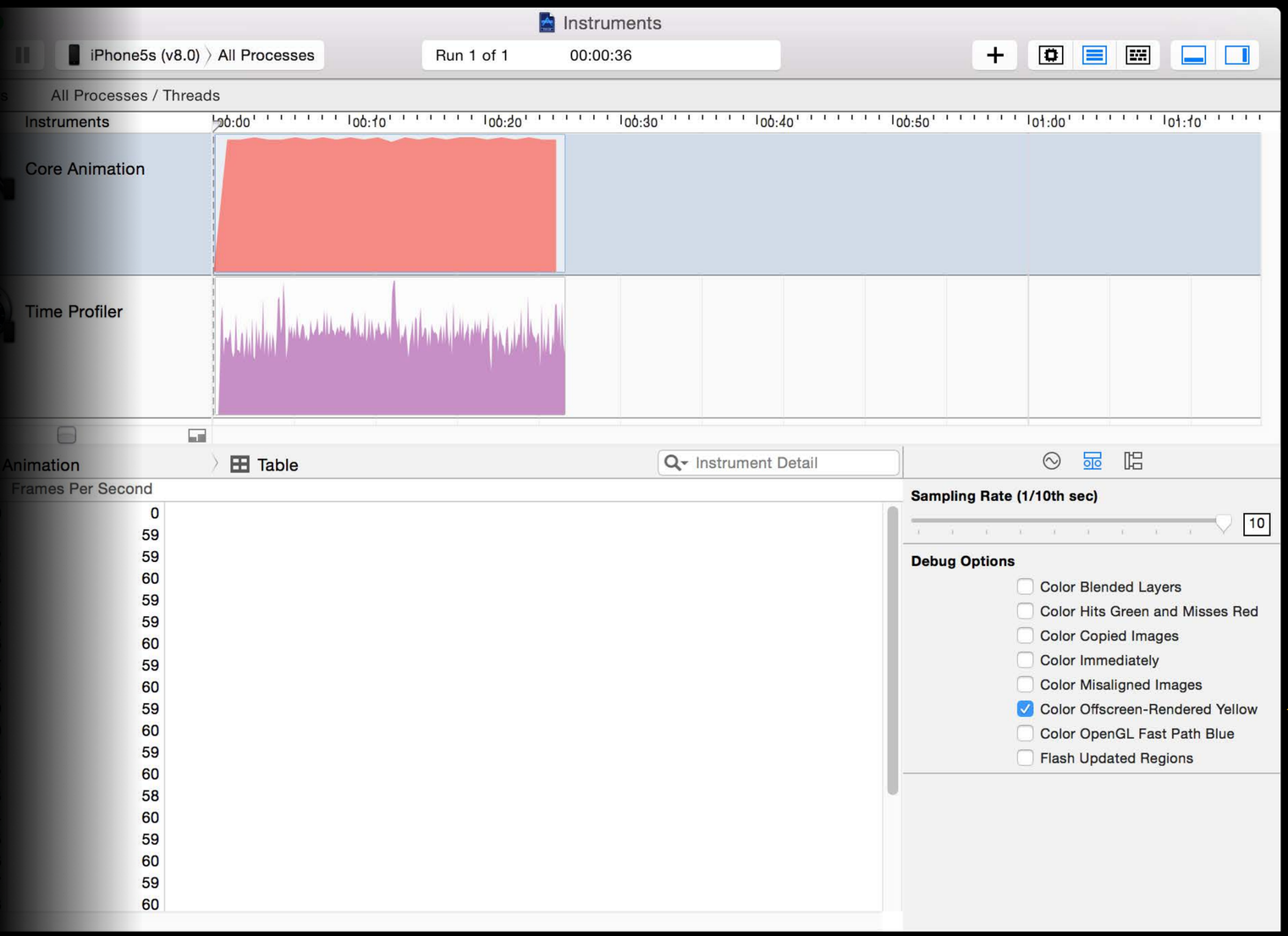
Color misaligned images





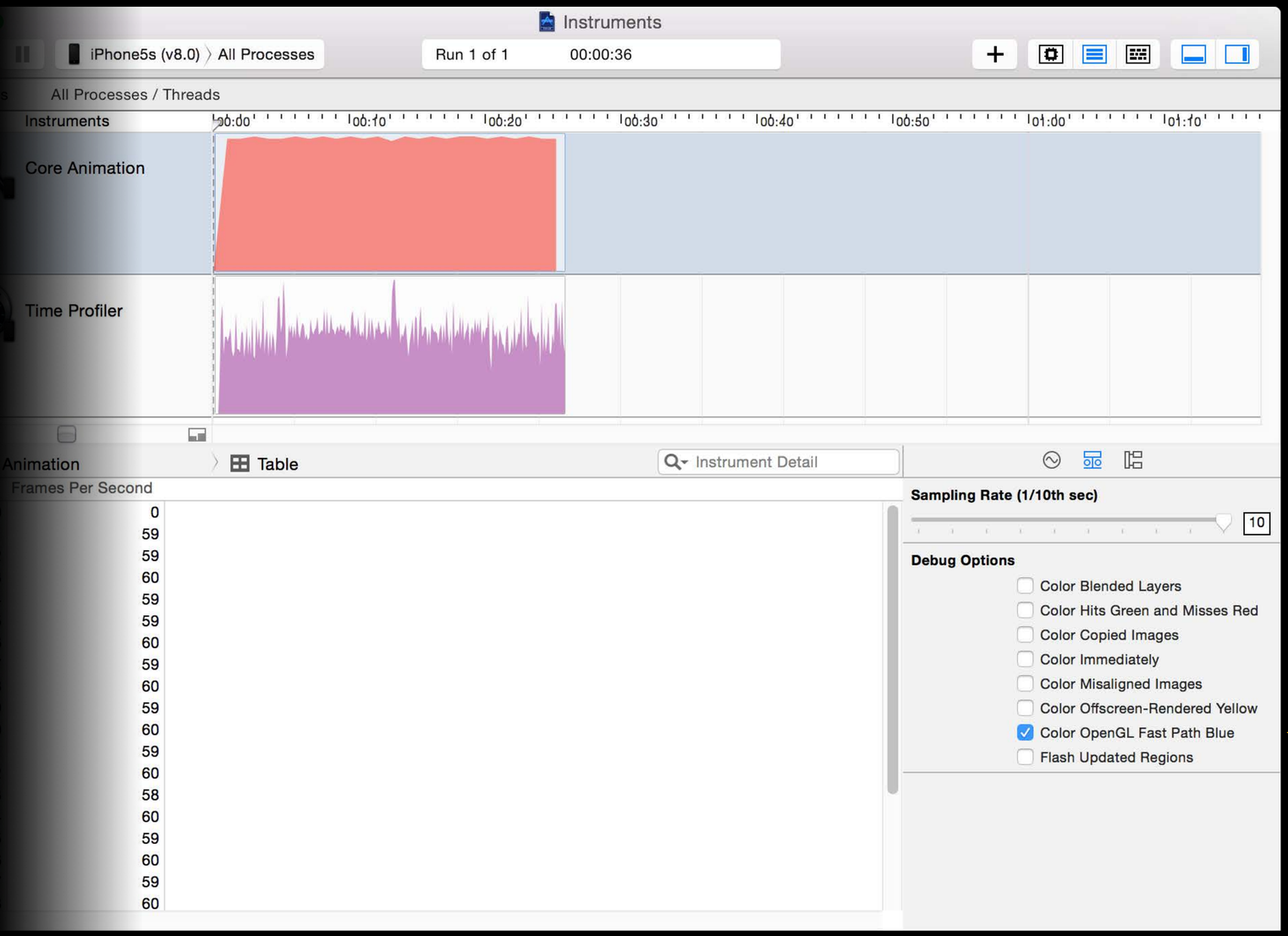
Core Animation Instrument

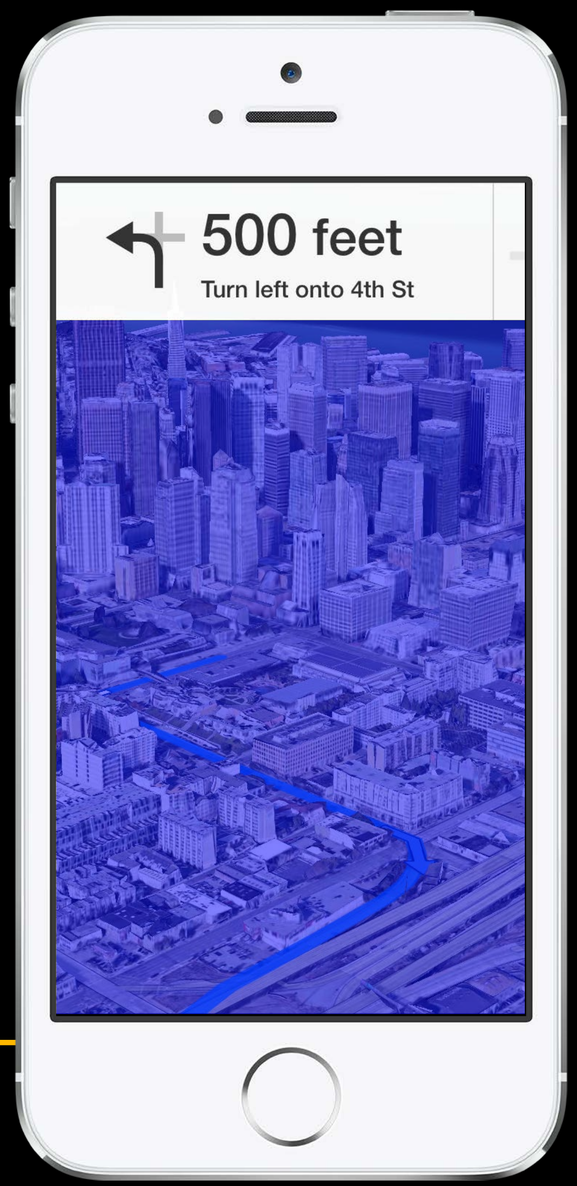
Color offscreen-rendered yellow



Core Animation Instrument

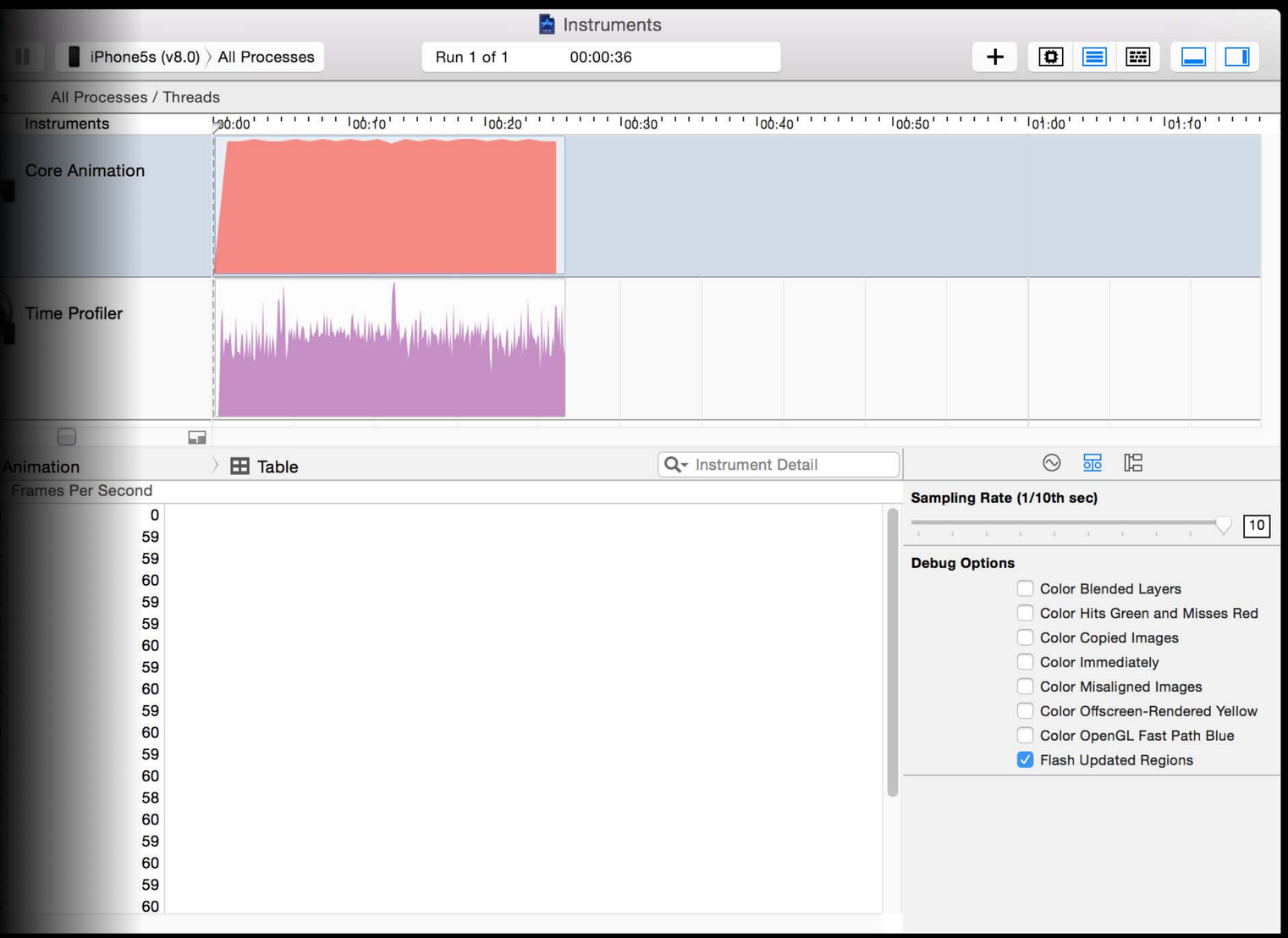
Color OpenGL fast path blue

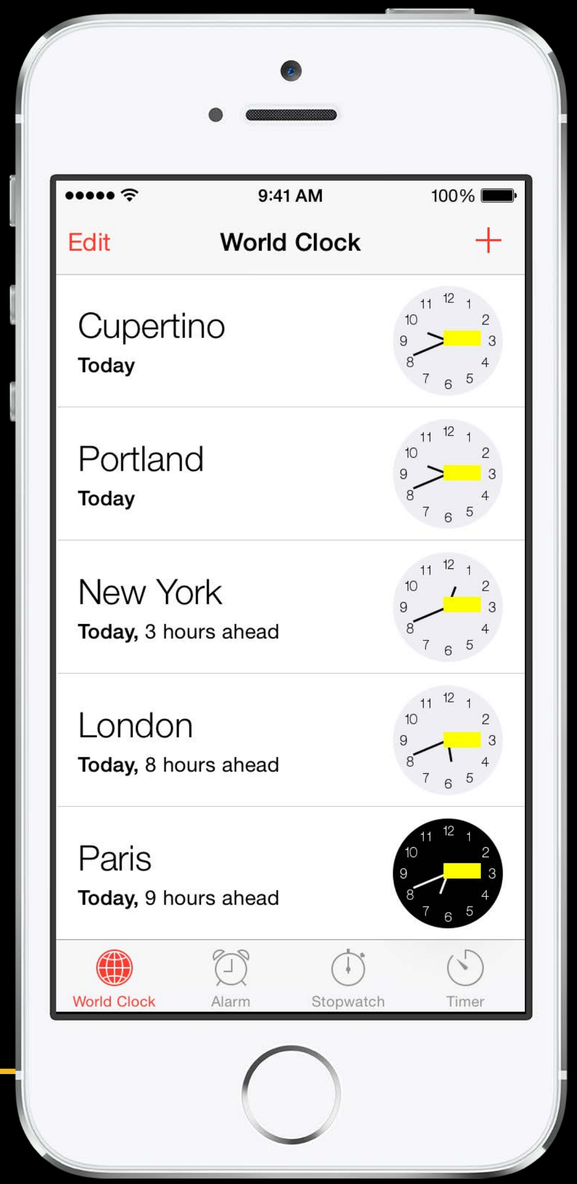




Core Animation Instrument

Flash updated regions



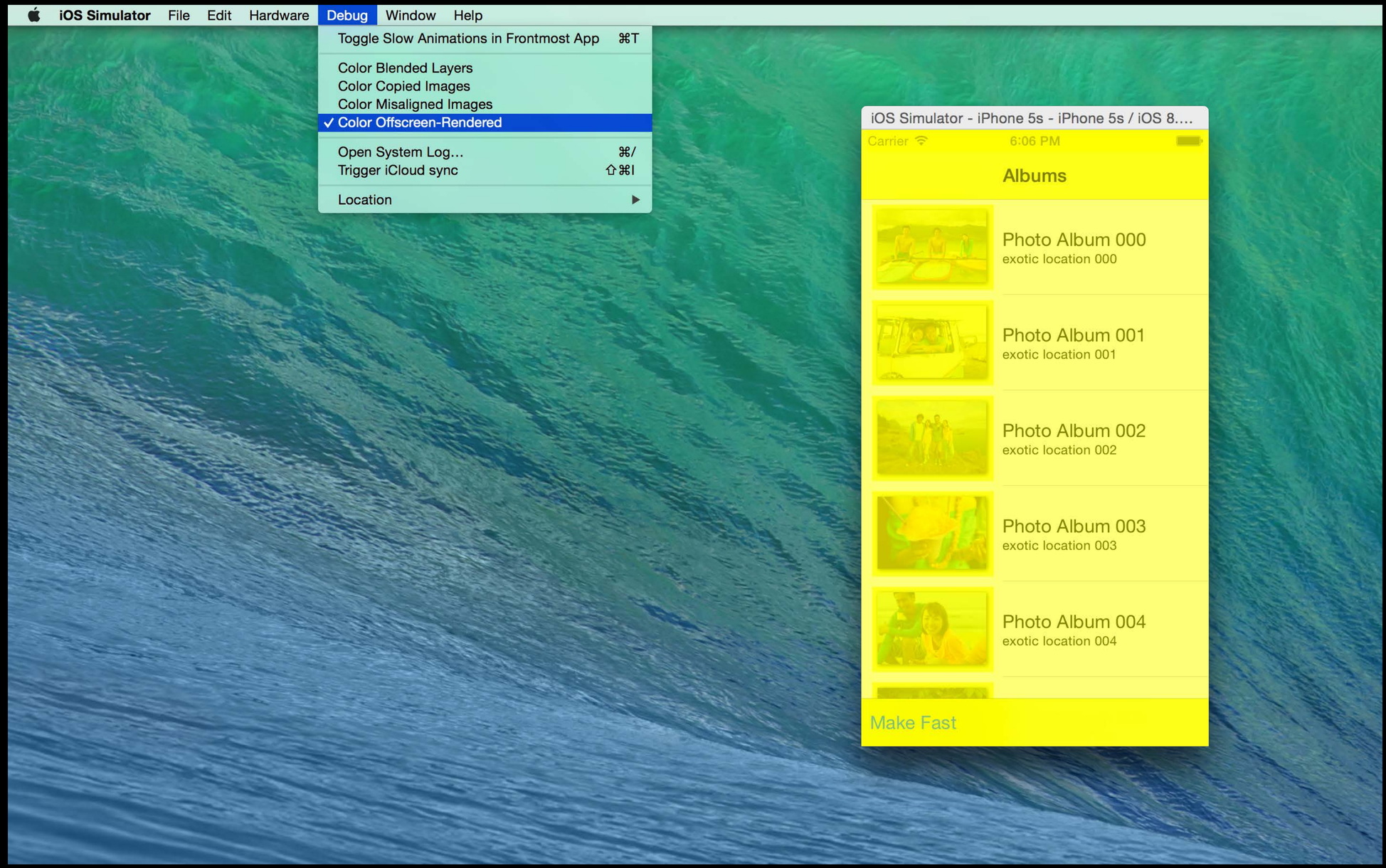


Performance Investigation Mindset

Core Animation instrument summary

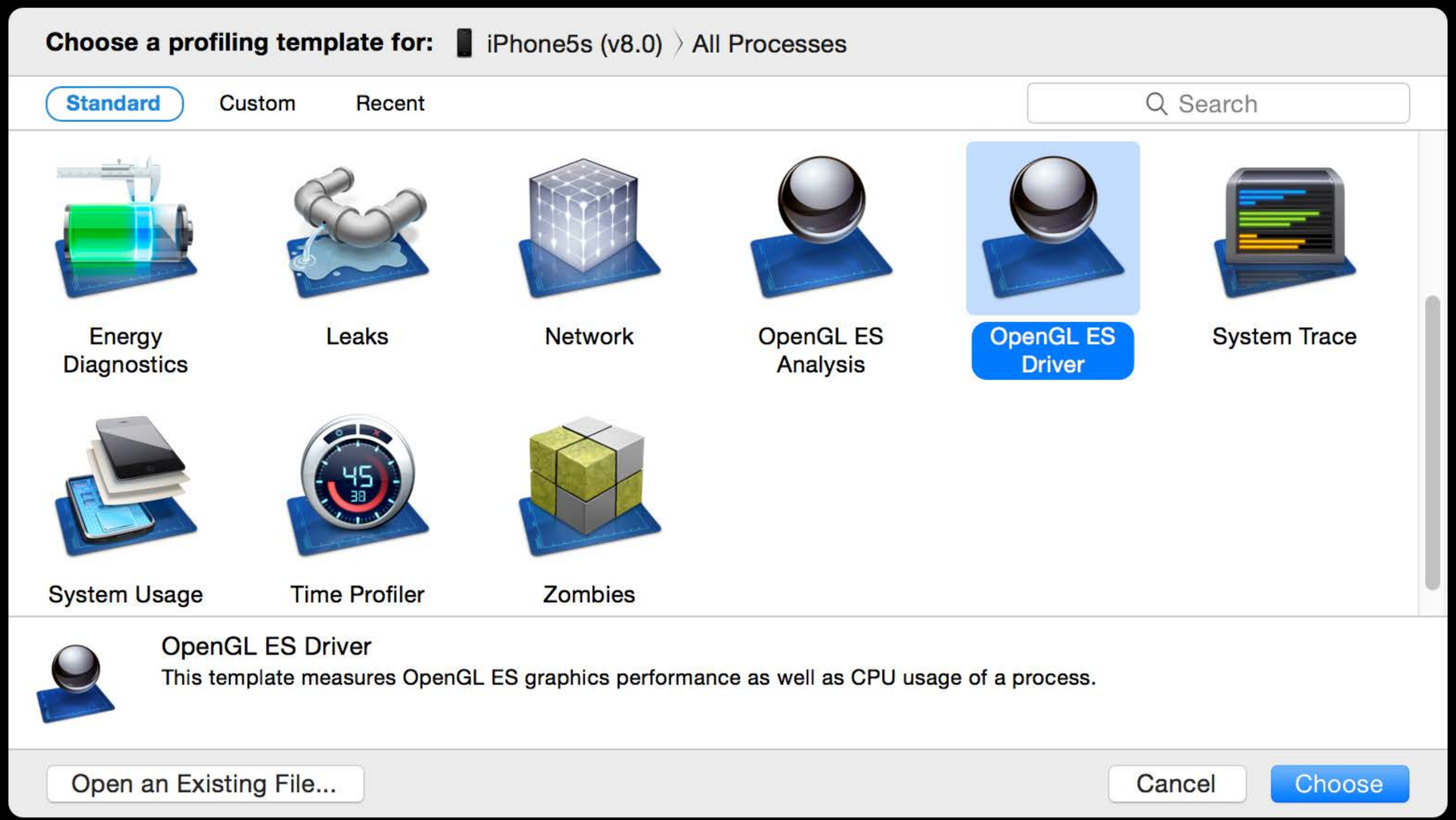
What is the frame rate?	Goal is always 60 frames per second
Any unnecessary CPU rendering?	GPU is desirable but know when CPU makes sense
Too many offscreen passes?	Fewer is better
Too much blending?	Less is better
Any strange image formats or sizes?	Avoid on-the-fly conversions or resizing

iOS Simulator Coloring Options



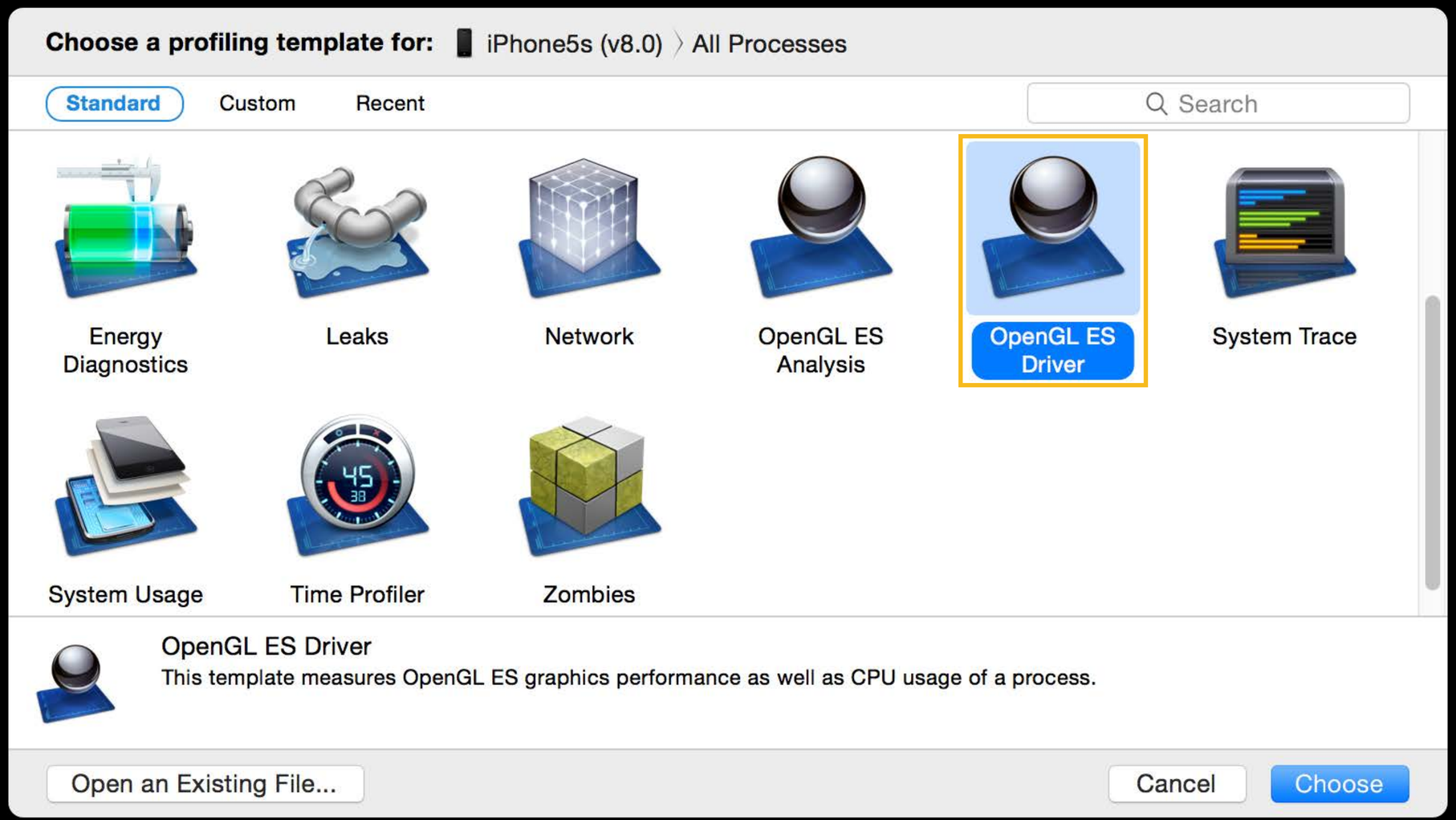
Instruments

OpenGL ES Driver template



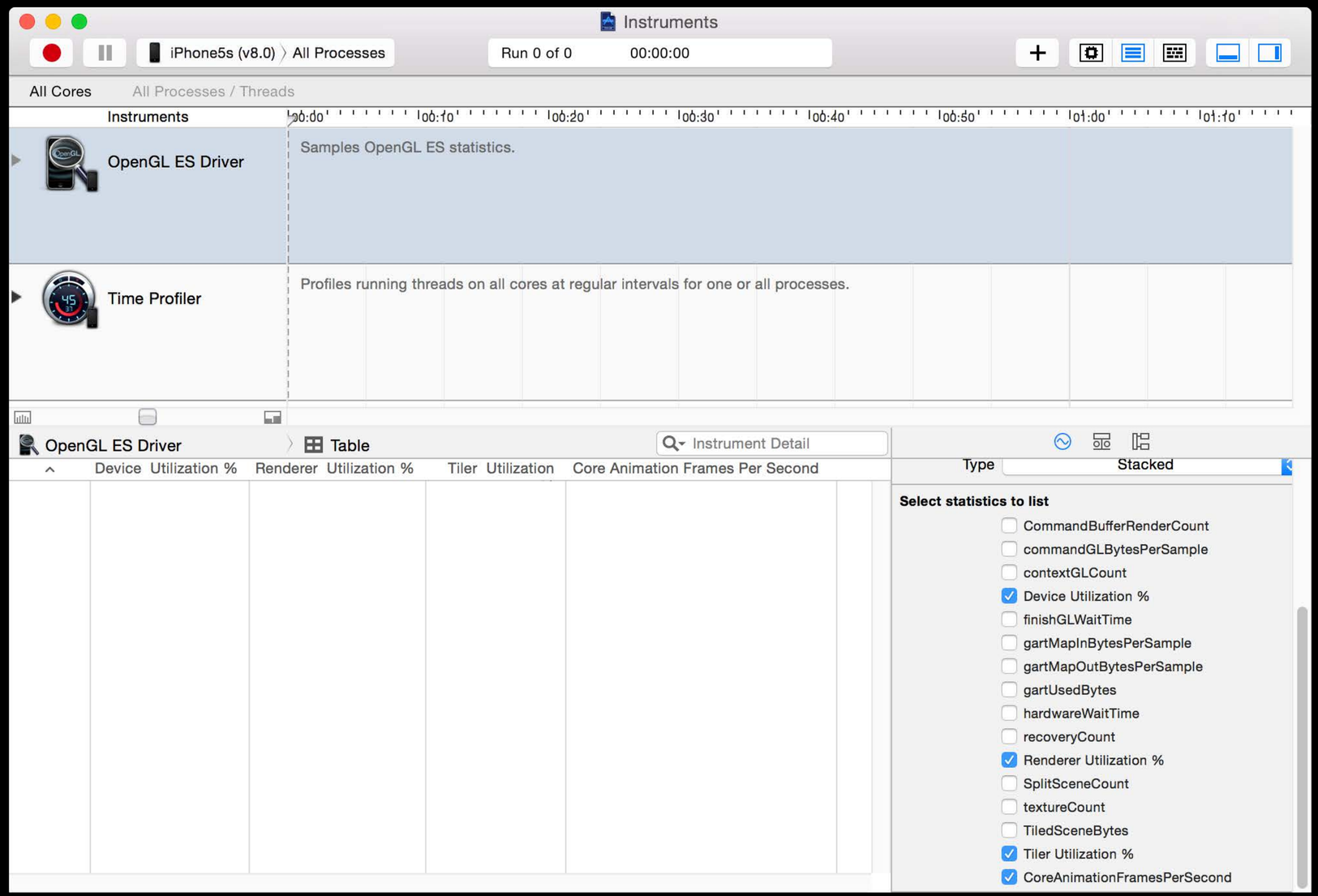
Instruments

OpenGL ES Driver template



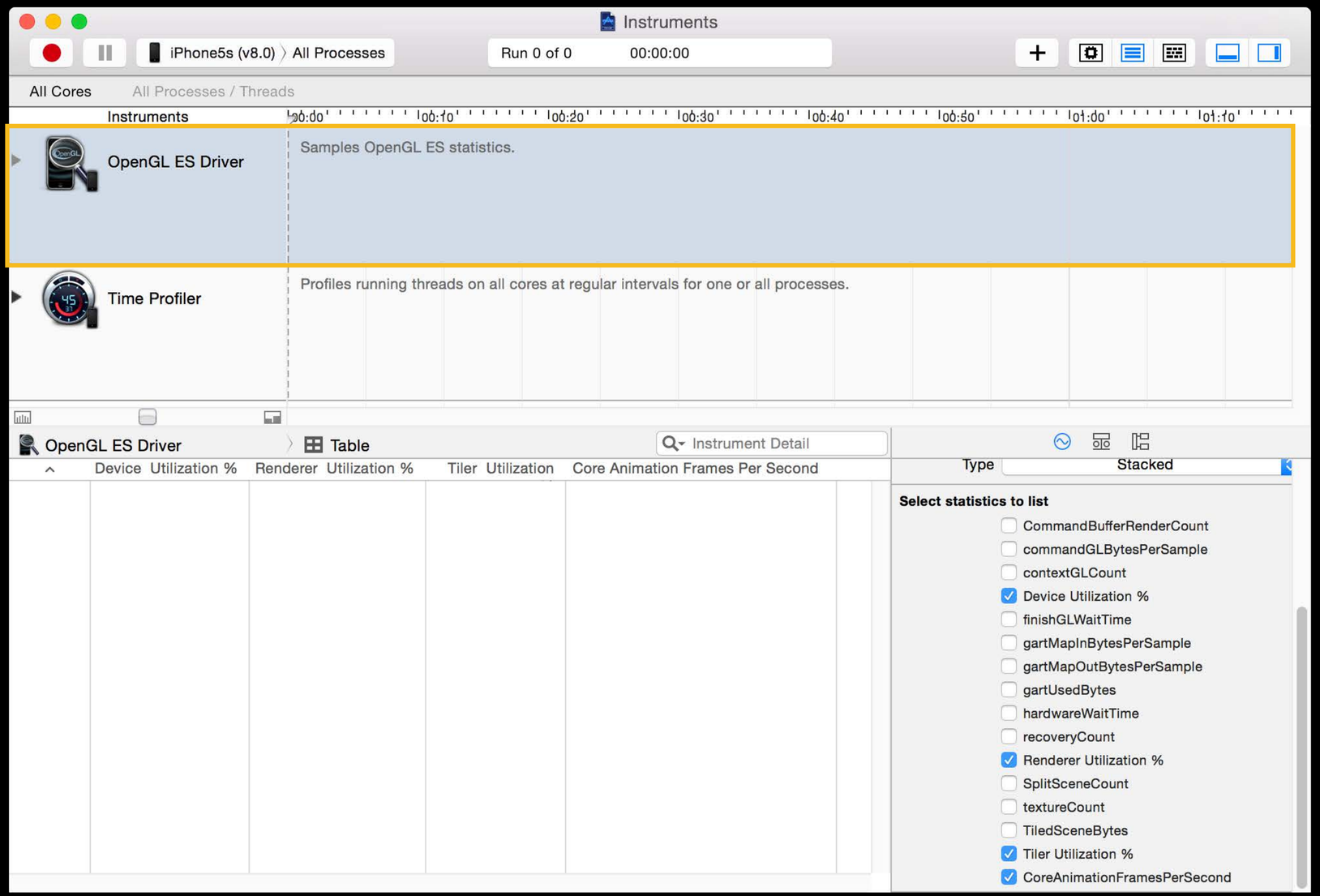
OpenGL ES Driver Instrument

Selecting statistics to list



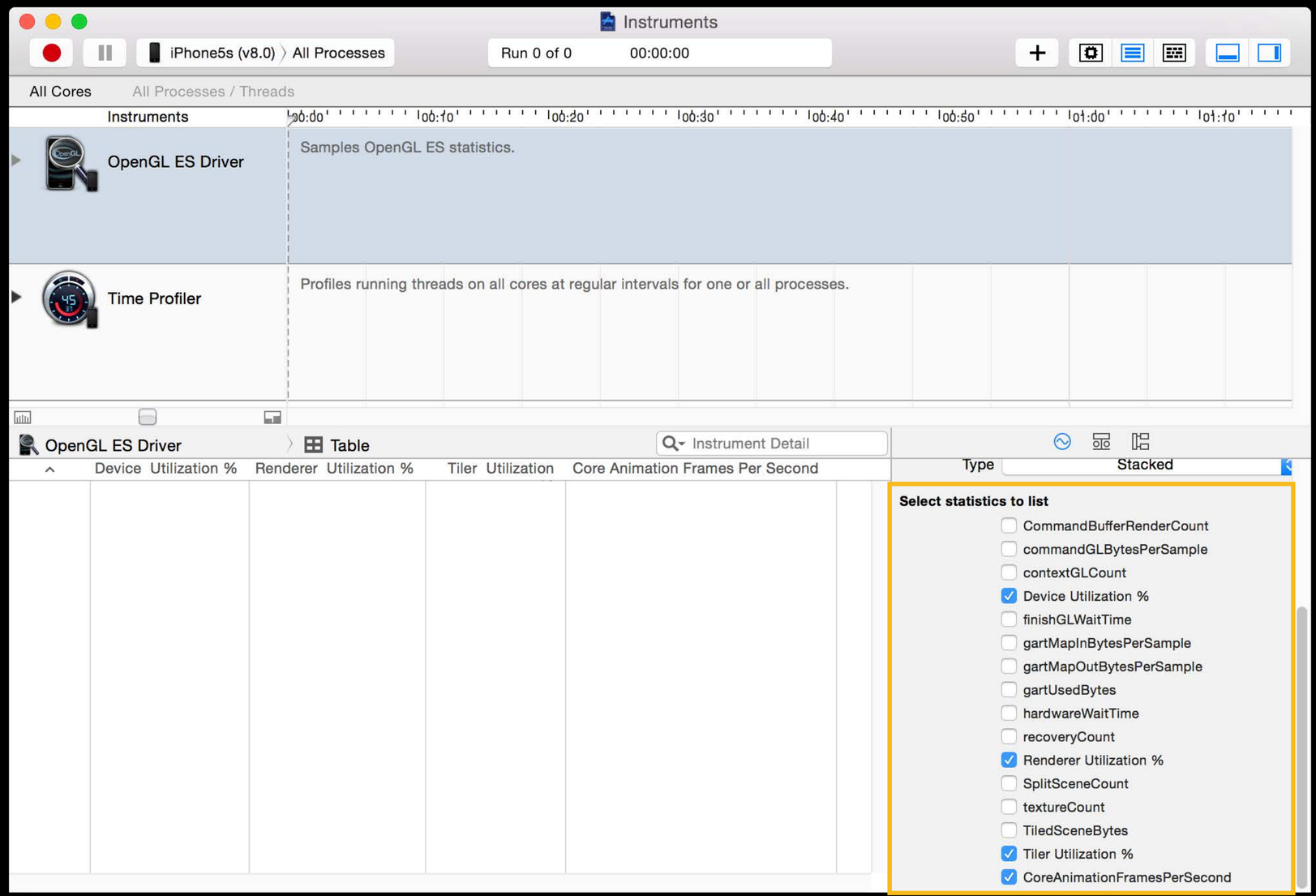
OpenGL ES Driver Instrument

Selecting statistics to list



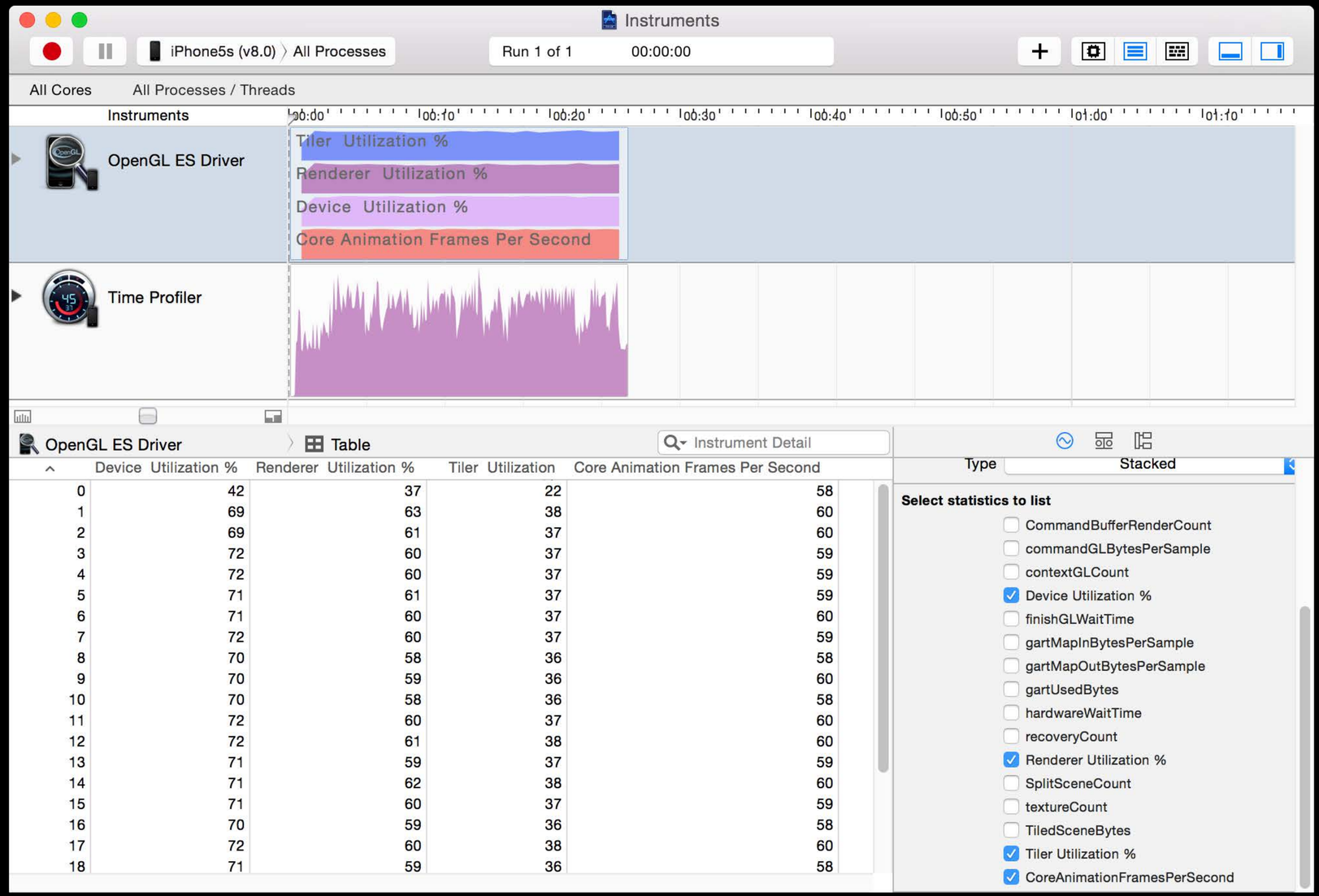
OpenGL ES Driver Instrument

Selecting statistics to list



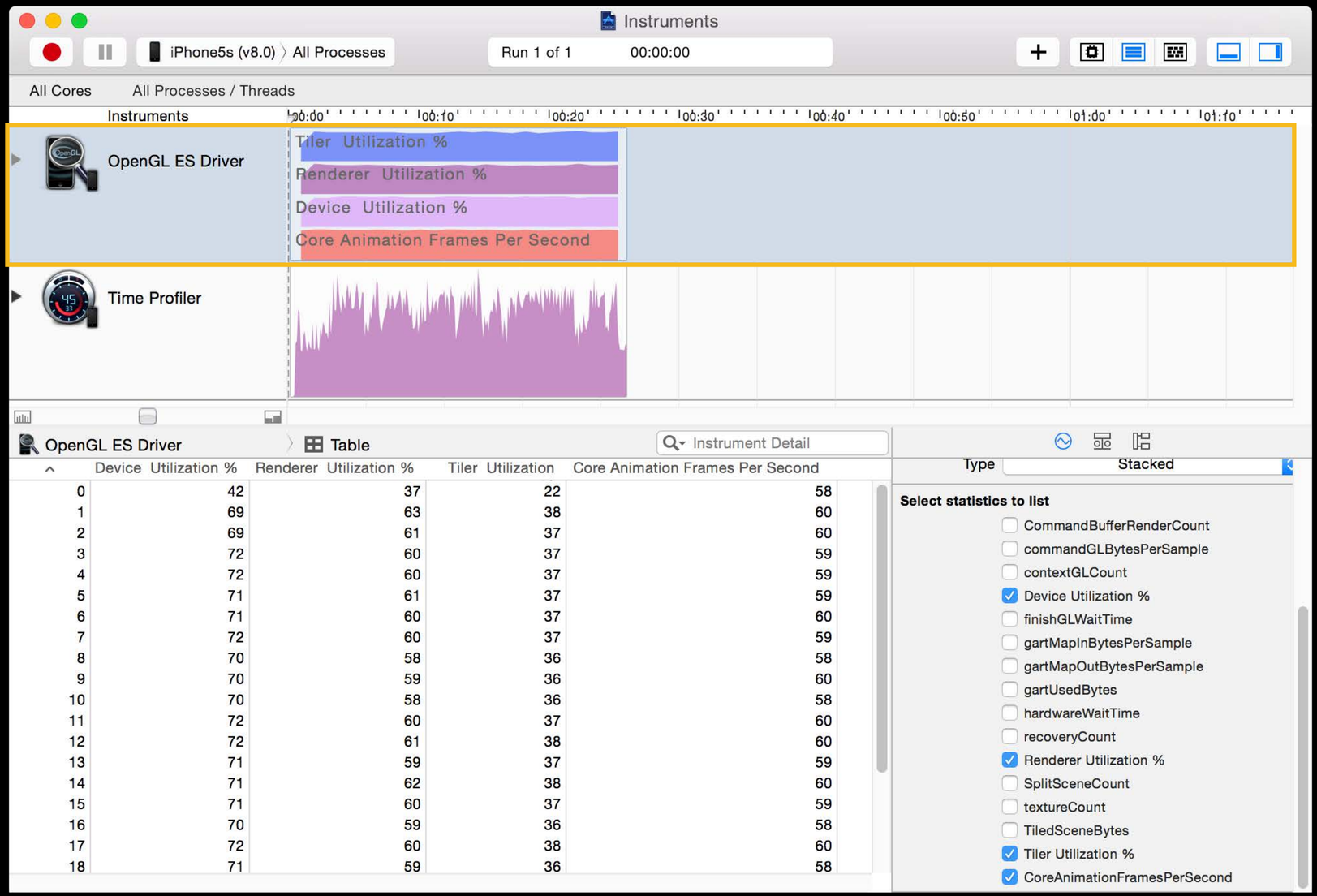
OpenGL ES Driver Instrument

GPU utilization



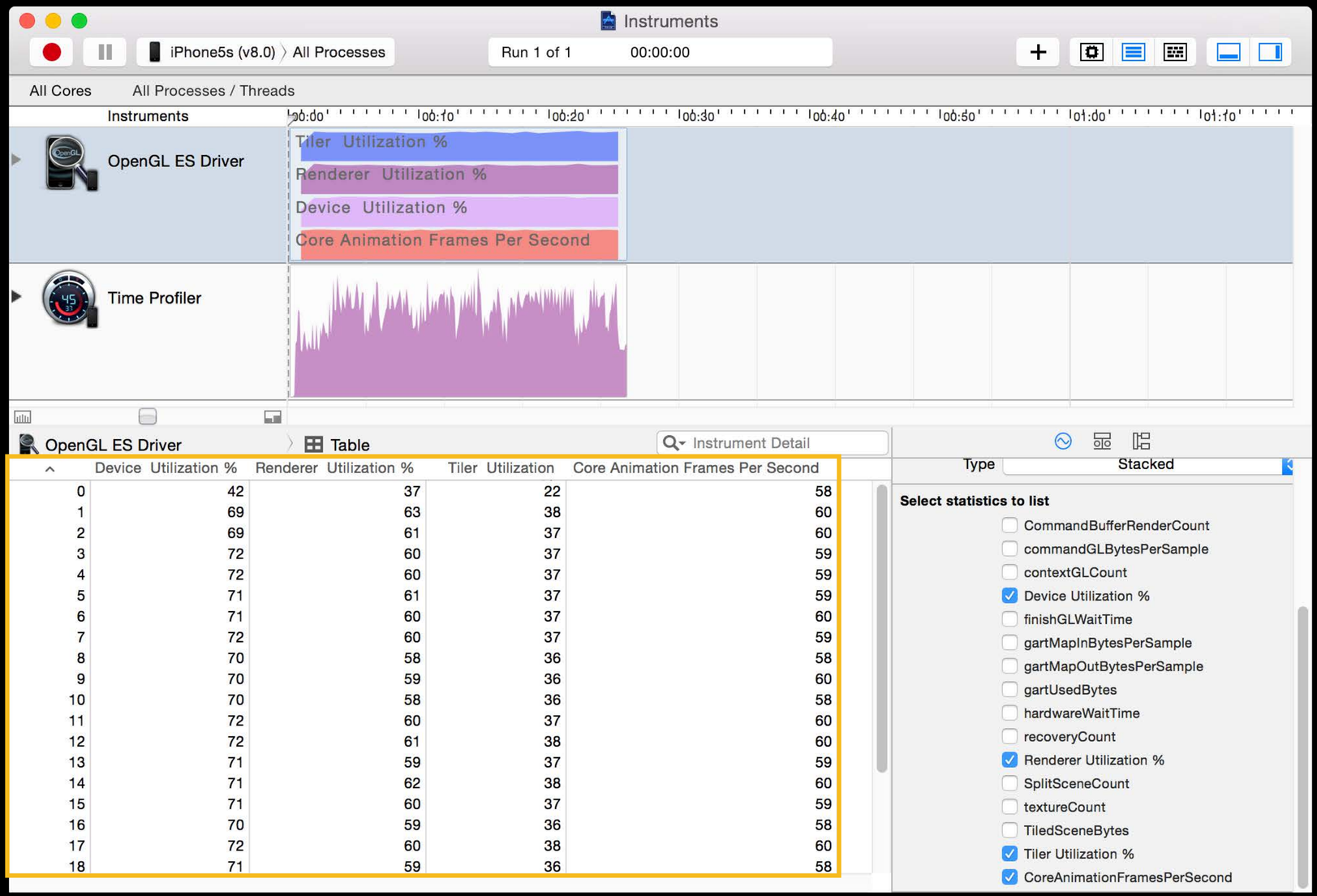
OpenGL ES Driver Instrument

GPU utilization



OpenGL ES Driver Instrument

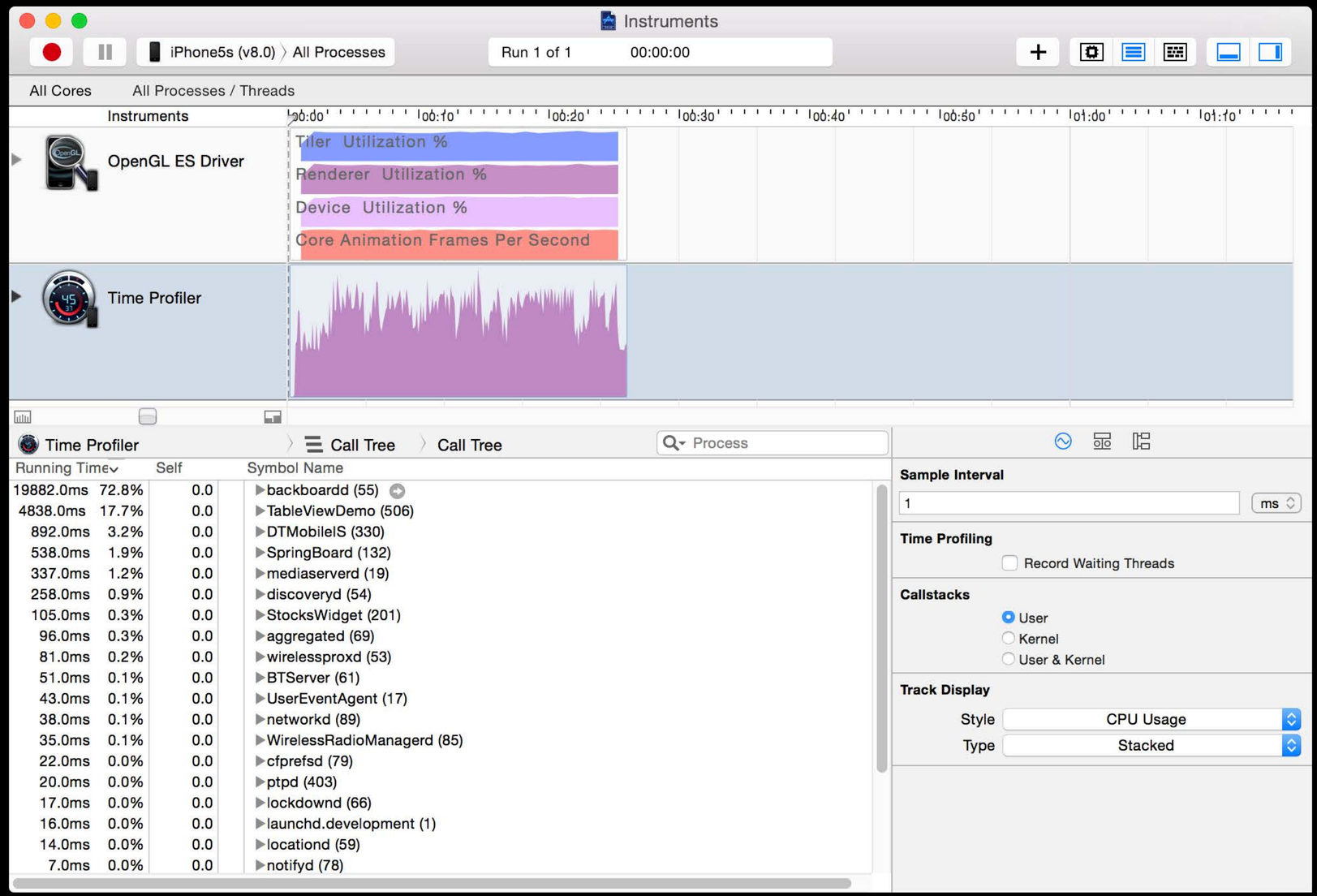
GPU utilization



	Device Utilization %	Renderer Utilization %	Tiler Utilization	Core Animation Frames Per Second
0	42	37	22	58
1	69	63	38	60
2	69	61	37	60
3	72	60	37	59
4	72	60	37	59
5	71	61	37	59
6	71	60	37	60
7	72	60	37	59
8	70	58	36	58
9	70	59	36	60
10	70	58	36	58
11	72	60	37	60
12	72	61	38	60
13	71	59	37	59
14	71	62	38	60
15	71	60	37	59
16	70	59	36	58
17	72	60	38	60
18	71	59	36	58

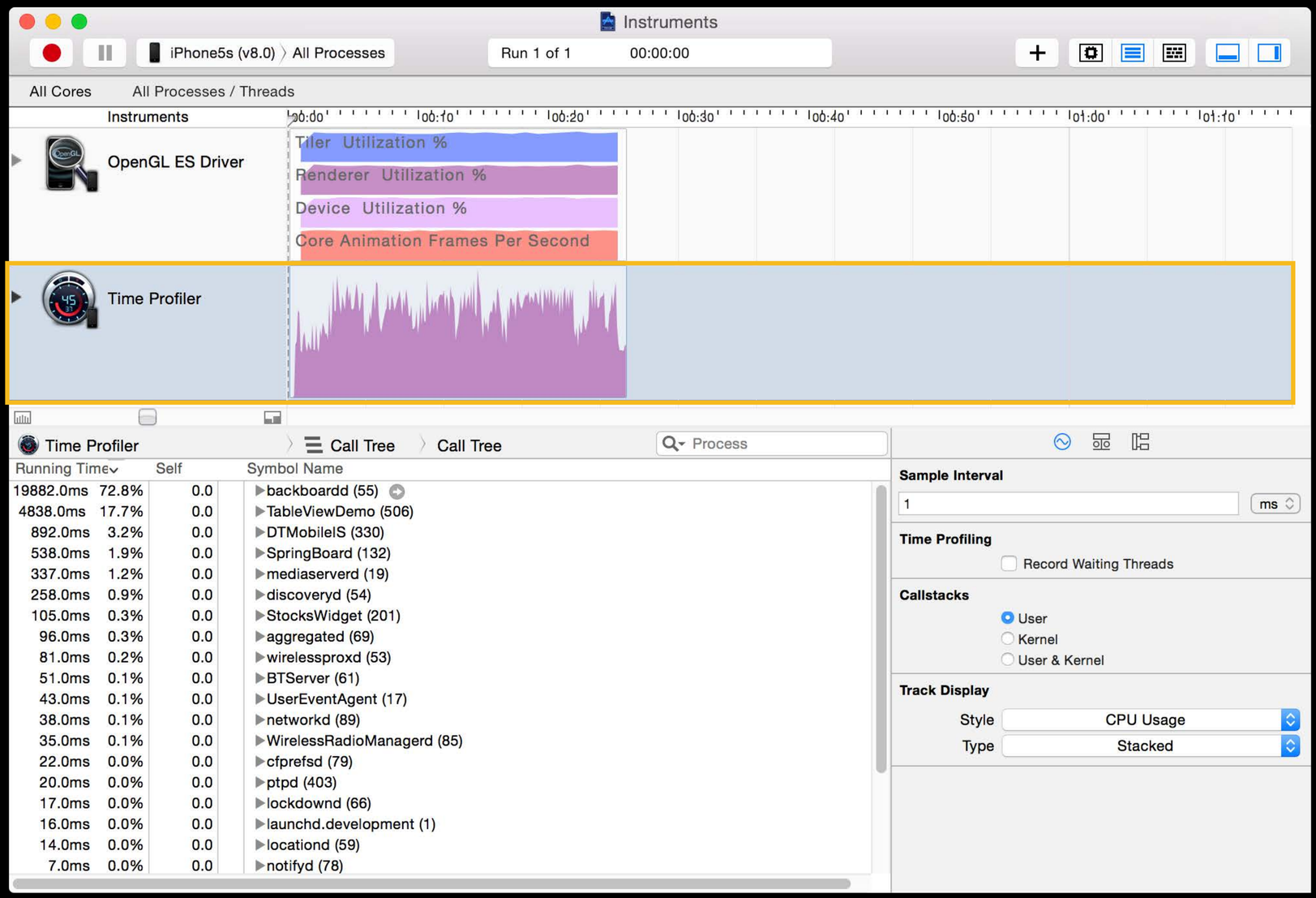
Time Profiler Instrument

CPU utilization



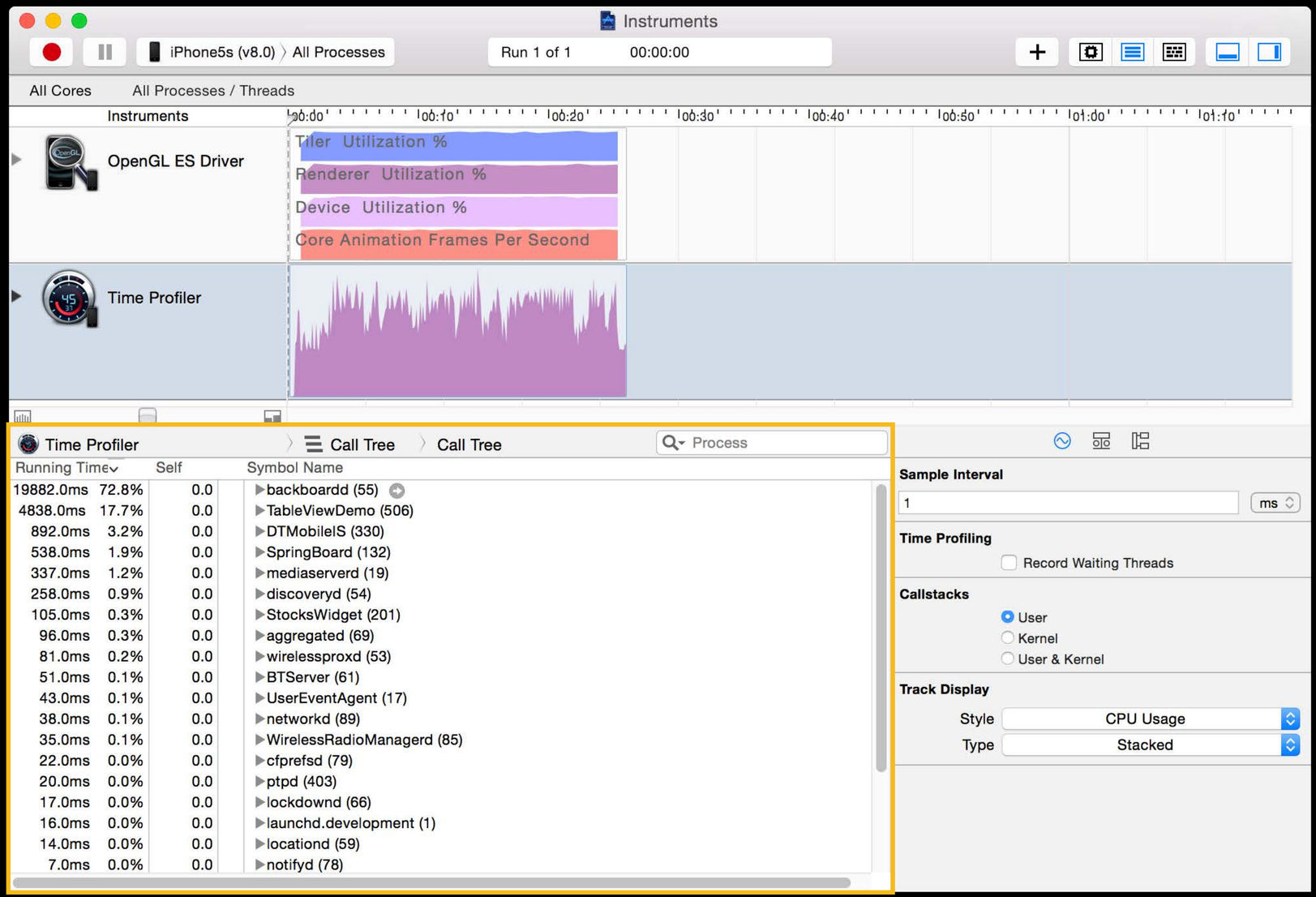
Time Profiler Instrument

CPU utilization



Time Profiler Instrument

CPU utilization



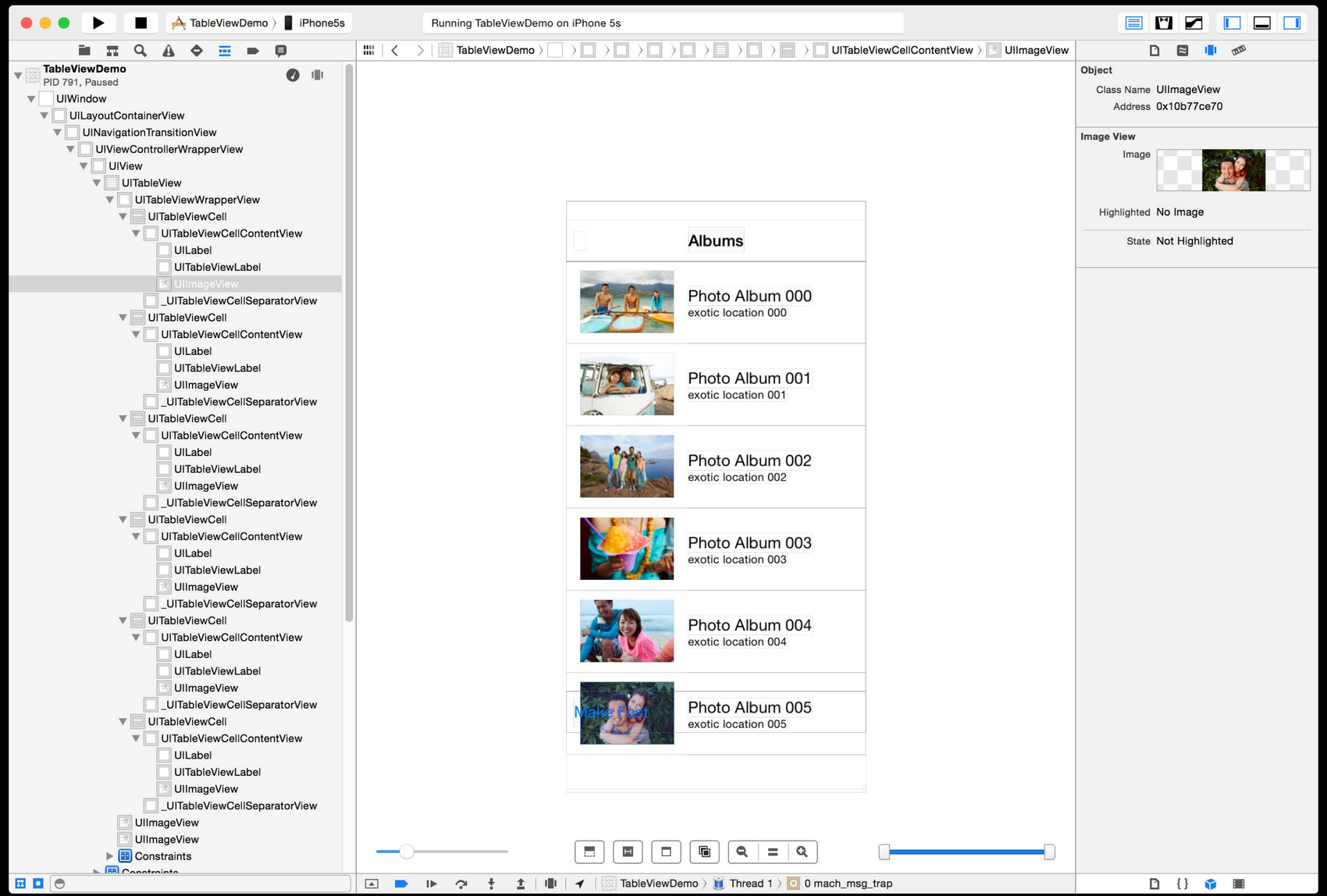
Performance Investigation Mindset

OpenGL ES Driver instrument summary

What is the frame rate?	Goal is always 60 frames per second
CPU or GPU bound?	Lower utilization is desired and saves battery
Any unnecessary CPU rendering?	GPU is desirable but know when CPU make sense

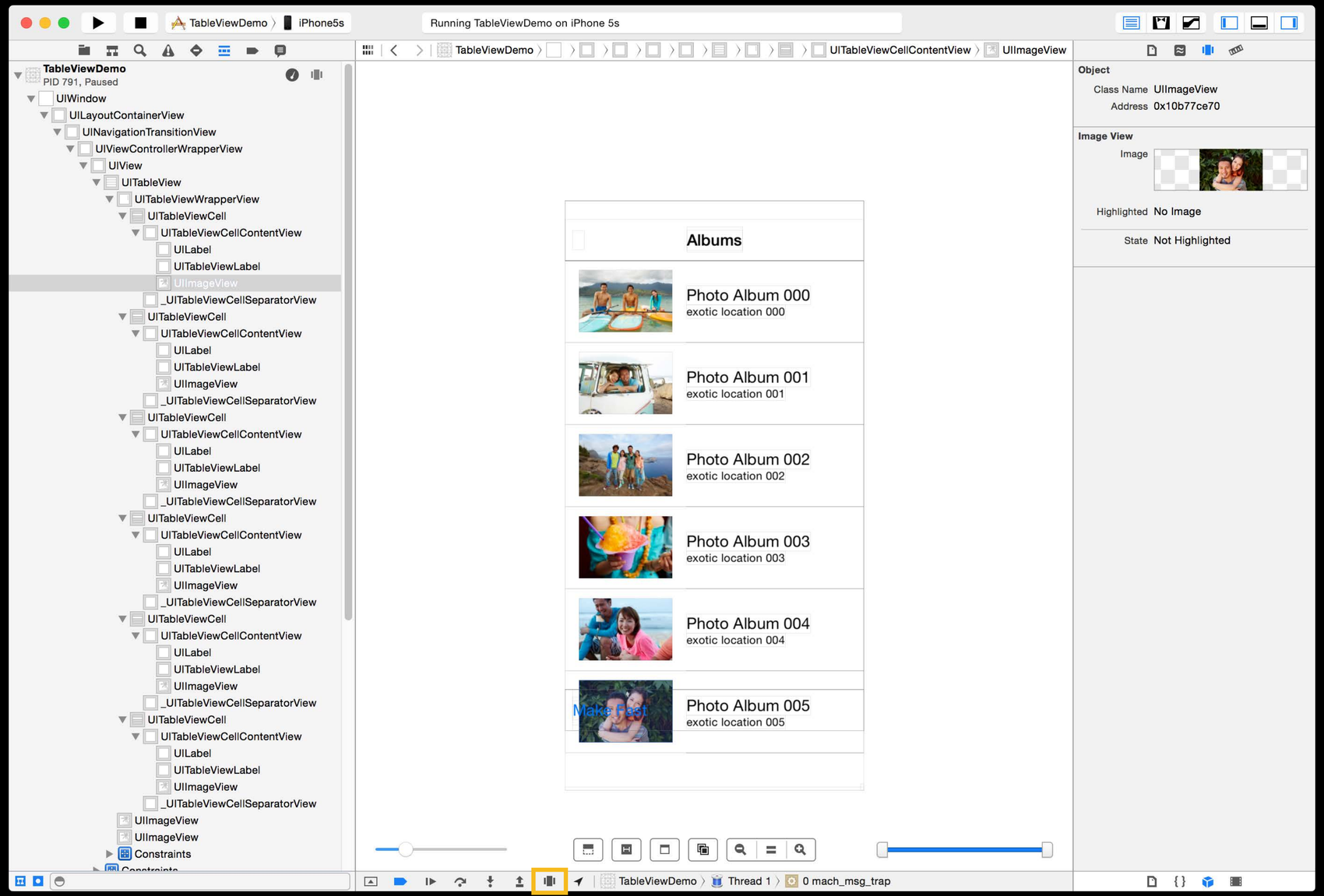
Xcode

View debugging



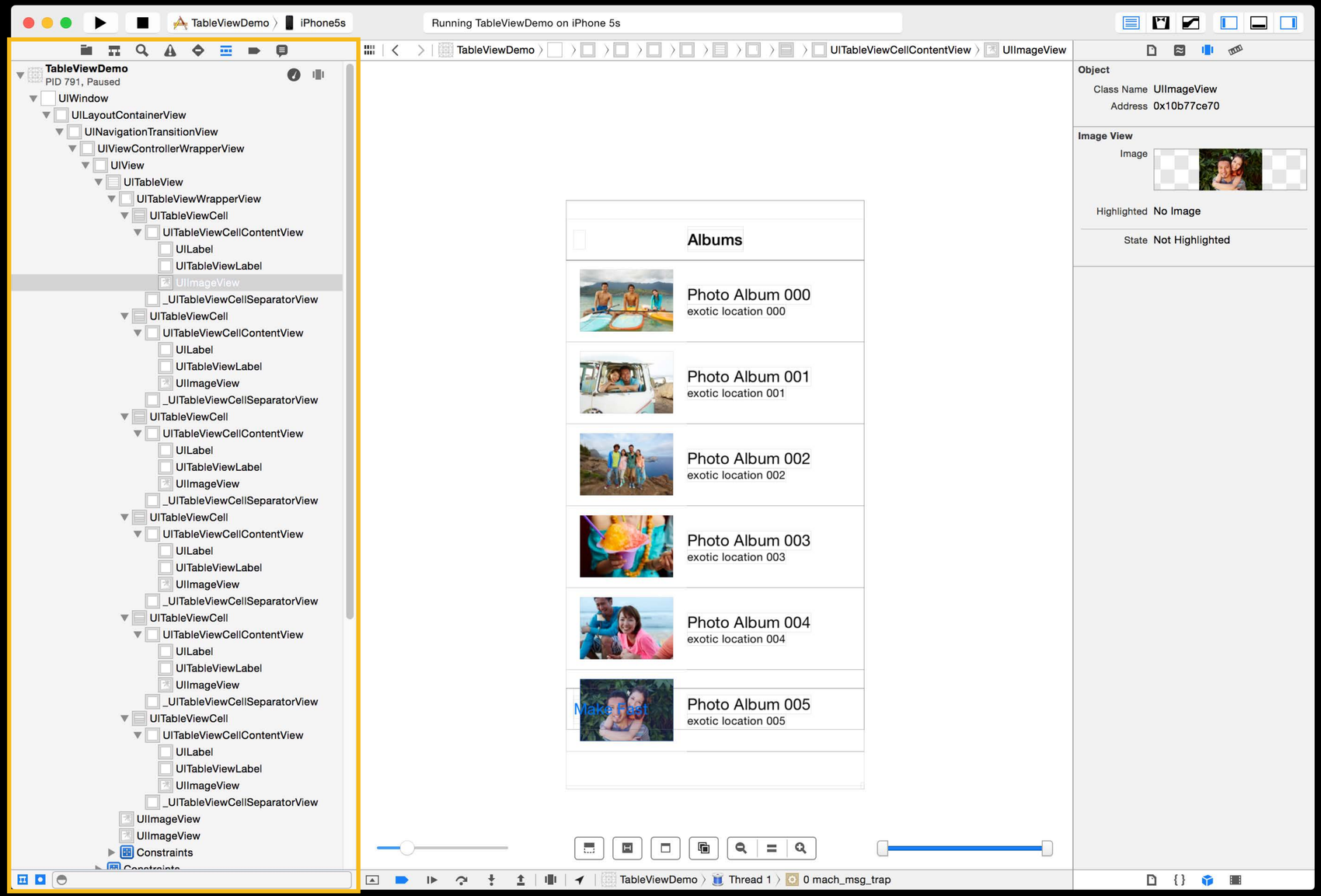
Xcode

View debugging



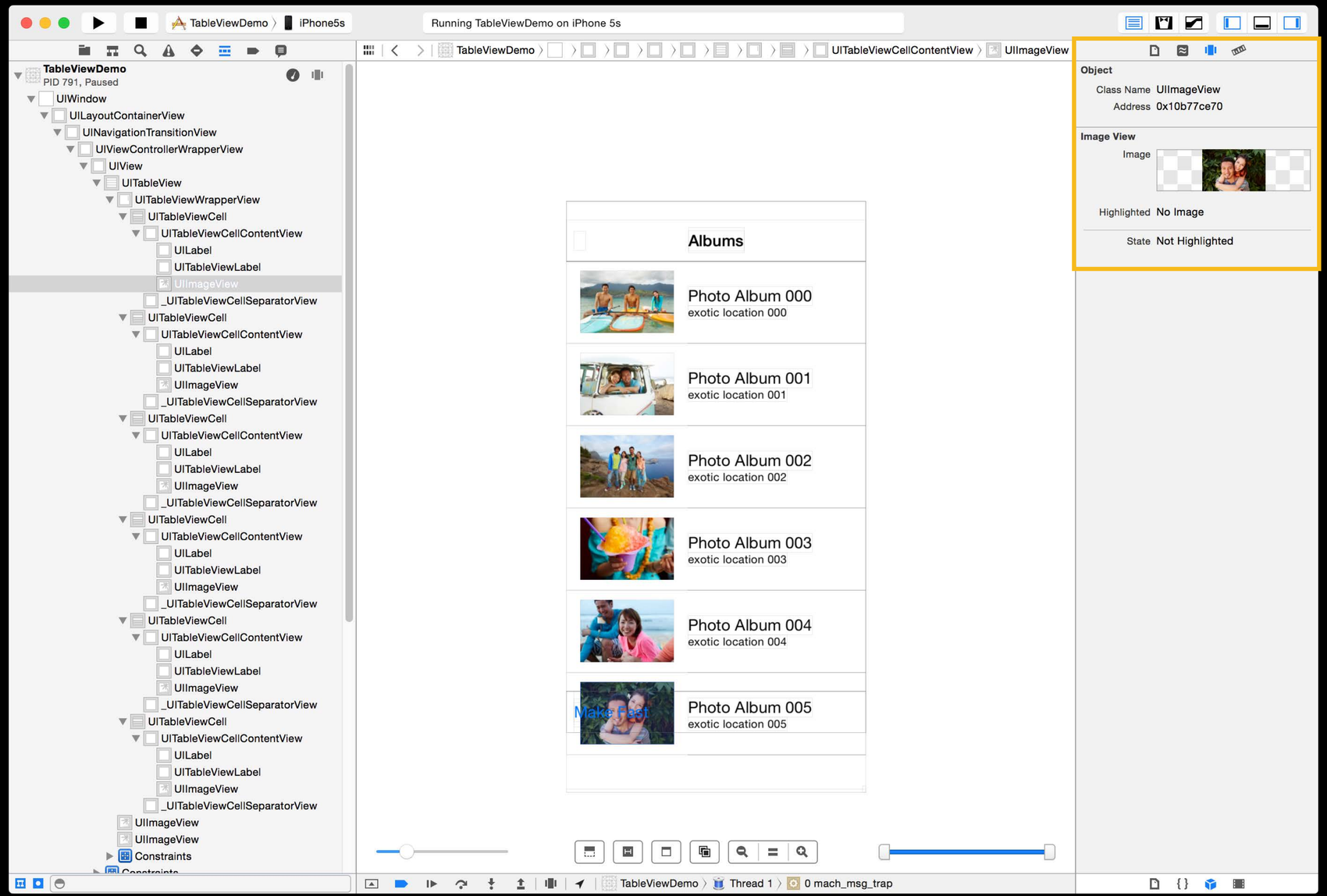
Xcode

View debugging



Xcode

View debugging



Performance Investigation Mindset

Xcode view debugging summary

Any expensive views or effects?	Understand the cost of what is in use
Anything unexpected in hierarchy?	Know the actual view hierarchy

Case Studies

Michael Ingrassia
iOS Software Engineer

Case Studies

Explore several scenarios

Measure performance on different devices

Keep the same appearance with better performance

Fictitious Photo Application

Case study

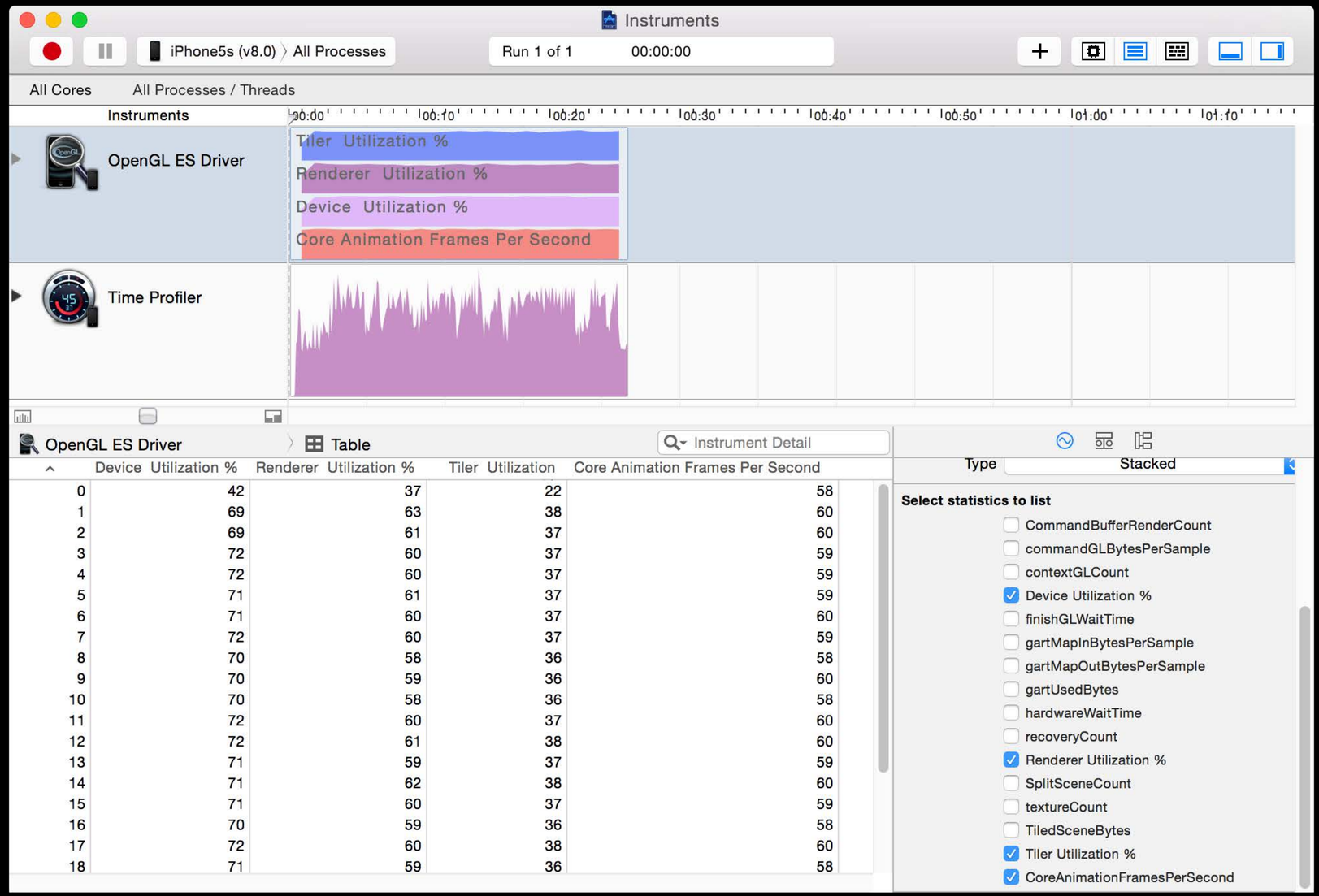
Simple table view

Each cell shows a photo thumbnail and some text

Each photo has a small shadow

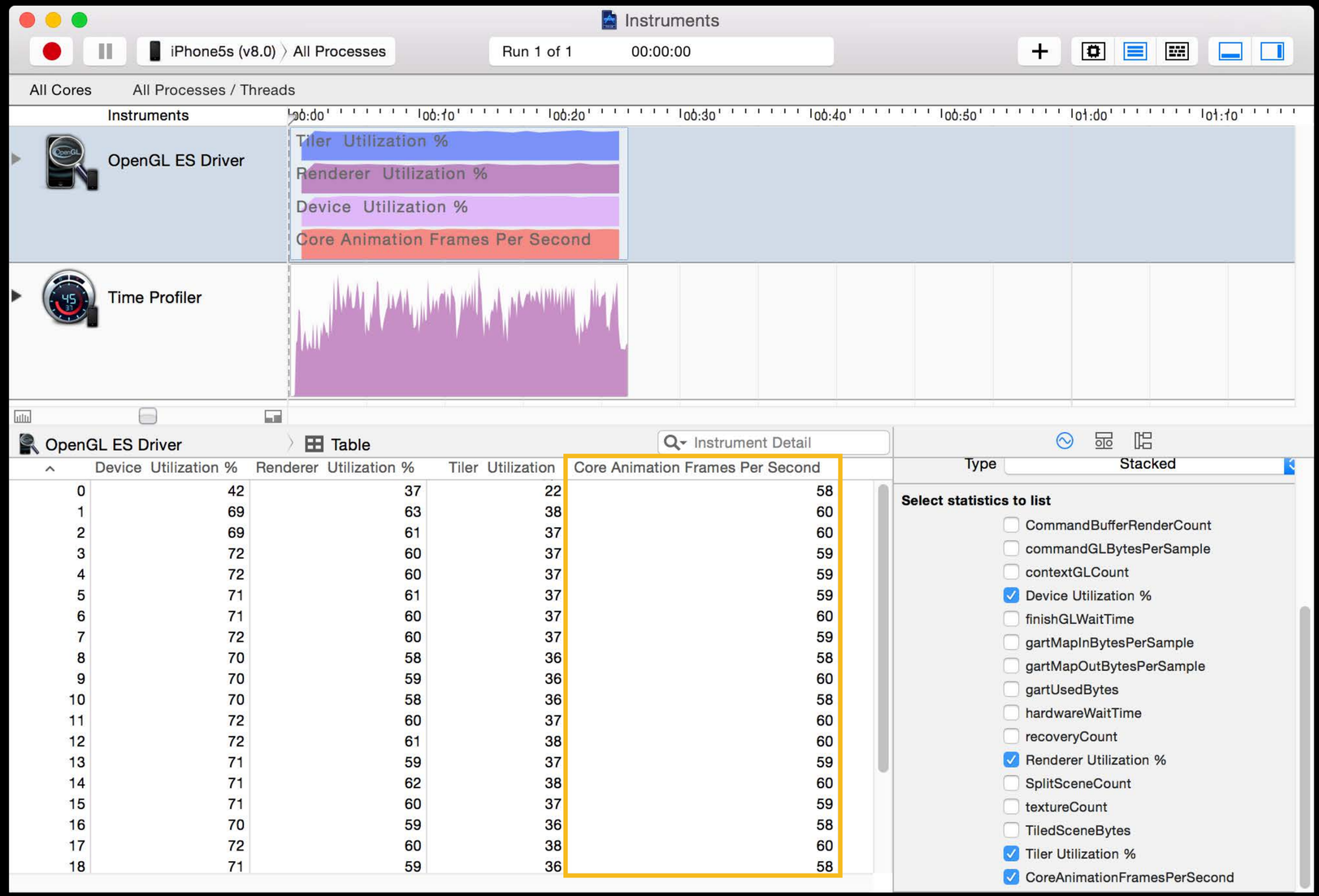
Measure Frame Rate on iPhone 5s

OpenGL ES Driver instrument



Measure Frame Rate on iPhone 5s

OpenGL ES Driver instrument



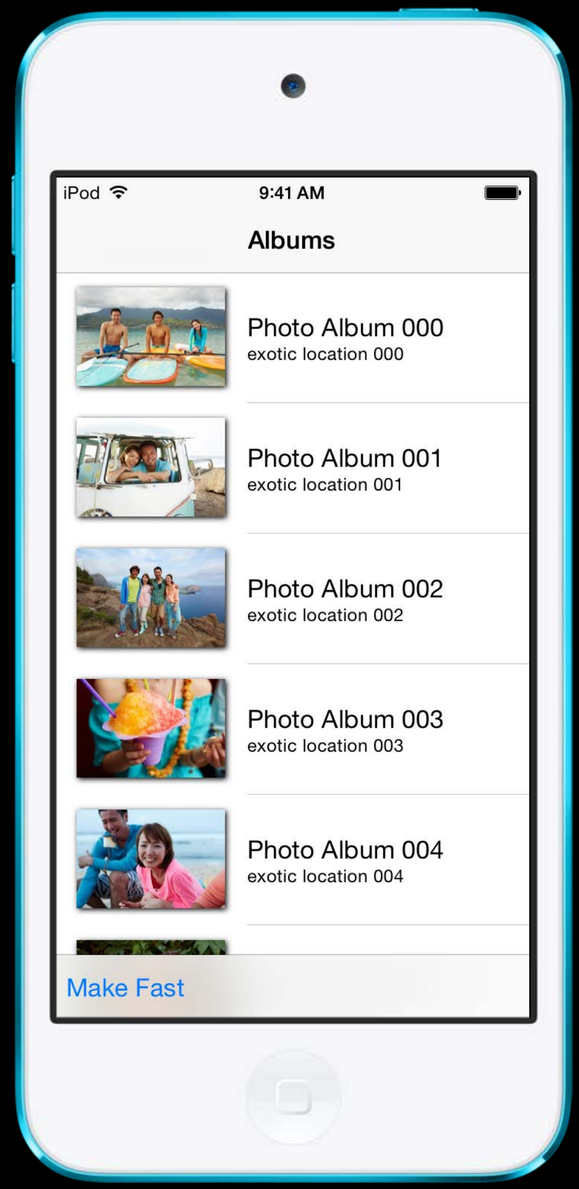
Awesome

Ship it?

Fictitious Photo Application

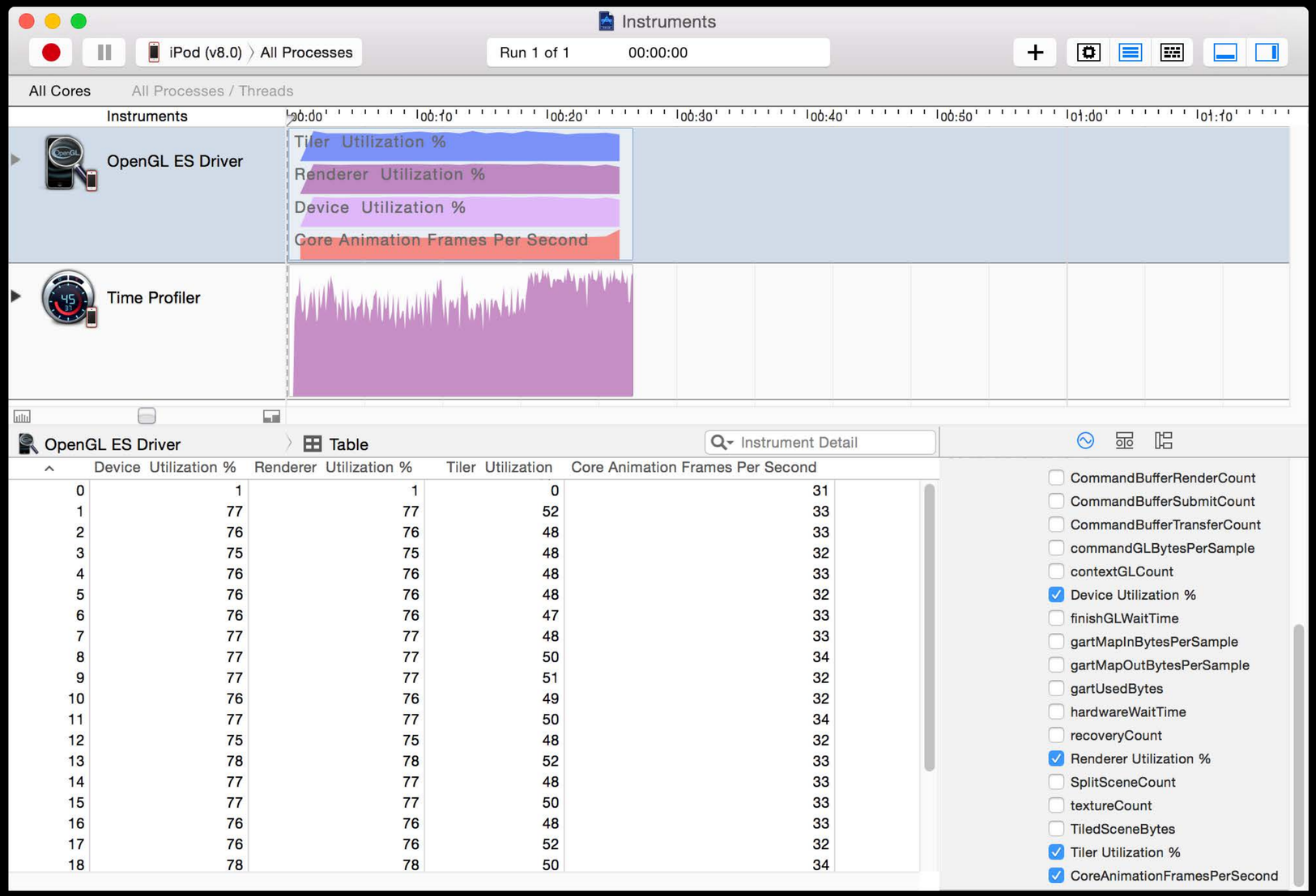
iPod touch scrolling performance

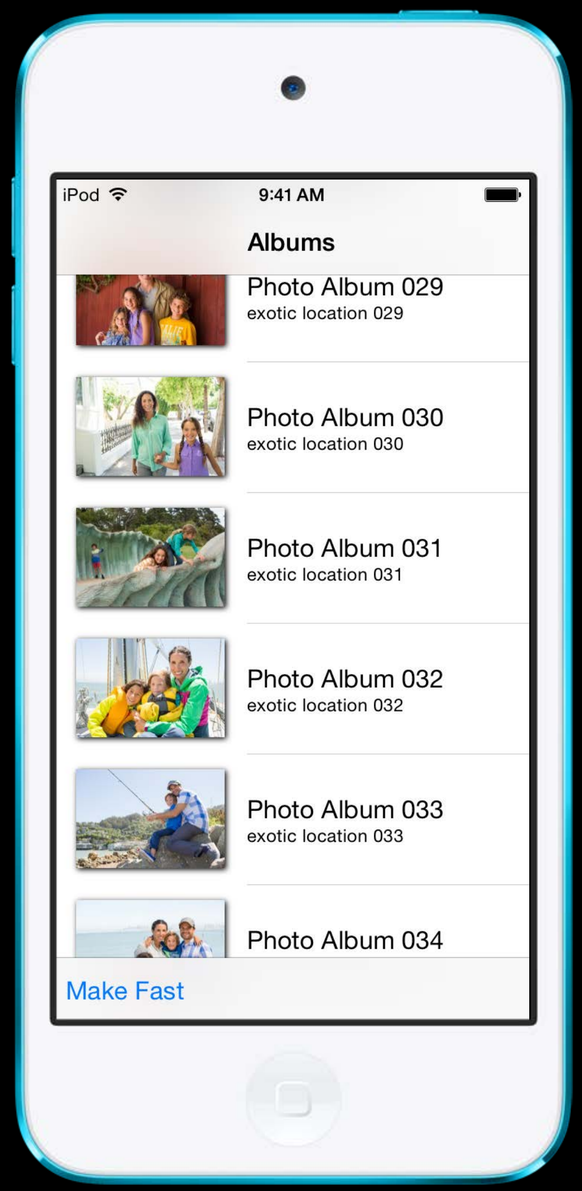
What about the performance on other devices?



Measure Frame Rate on iPod touch

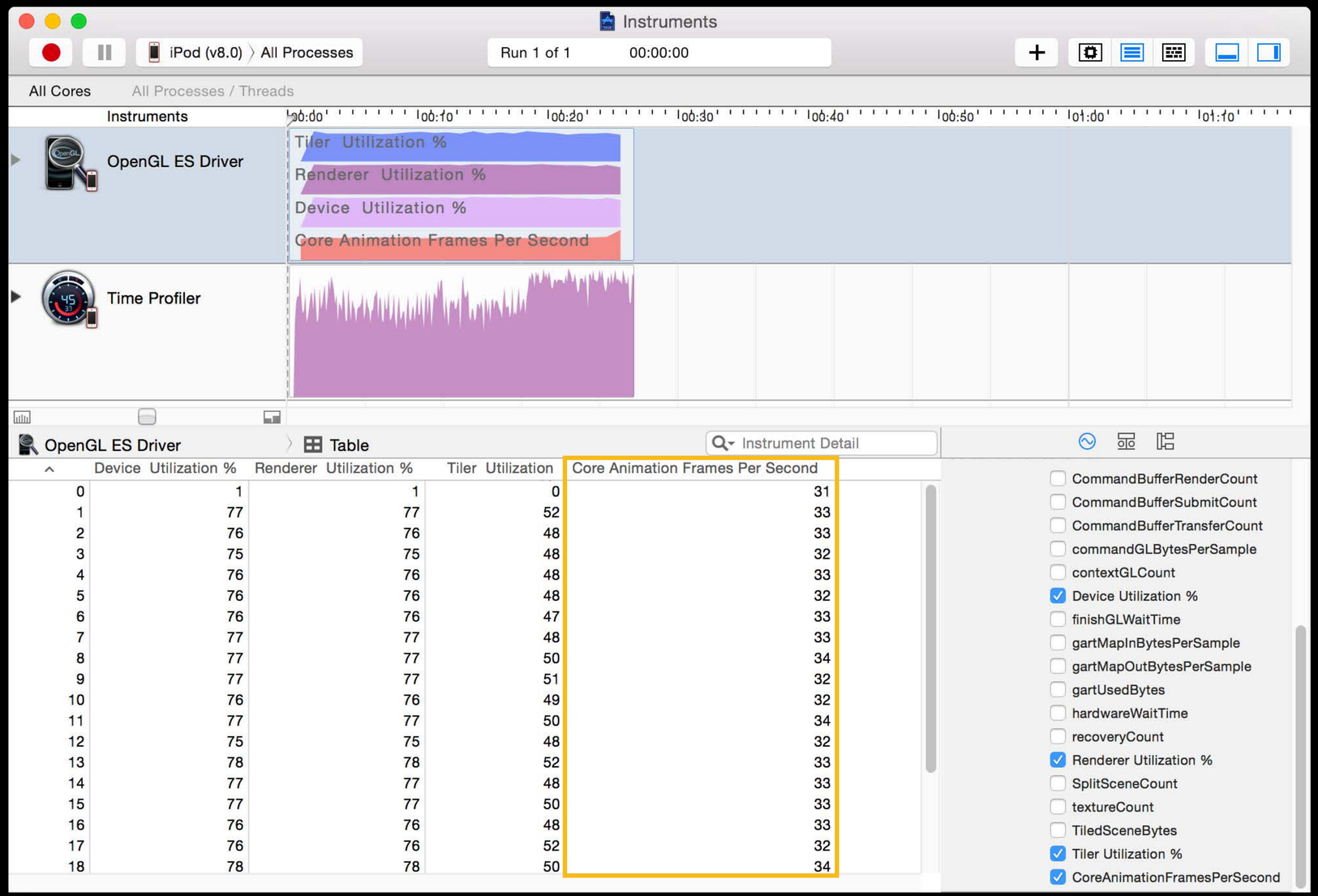
OpenGL ES Driver instrument

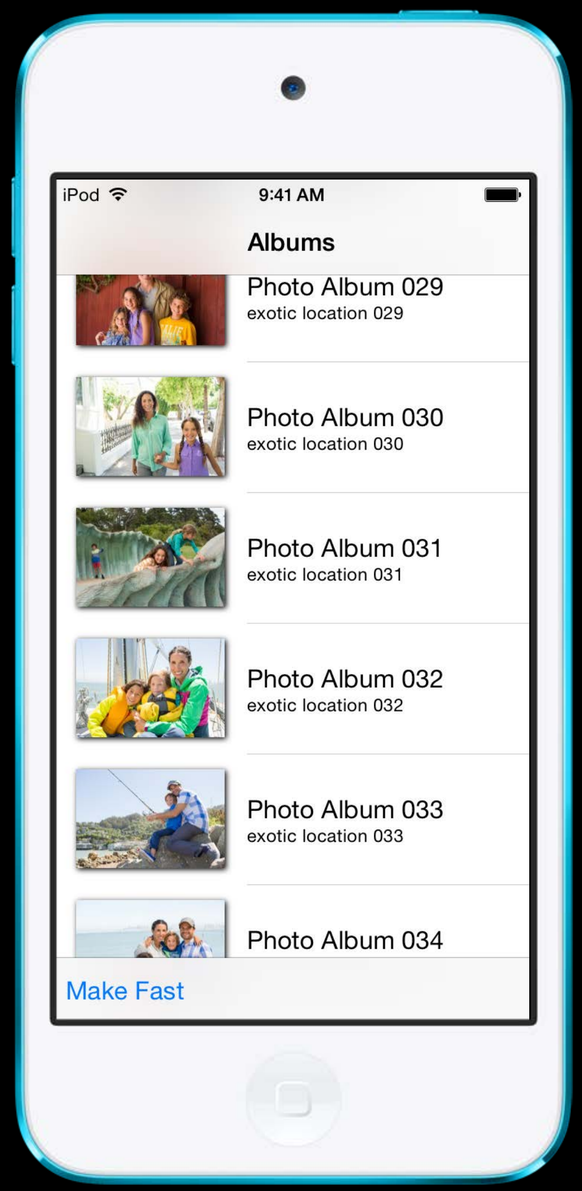




Measure Frame Rate on iPod touch

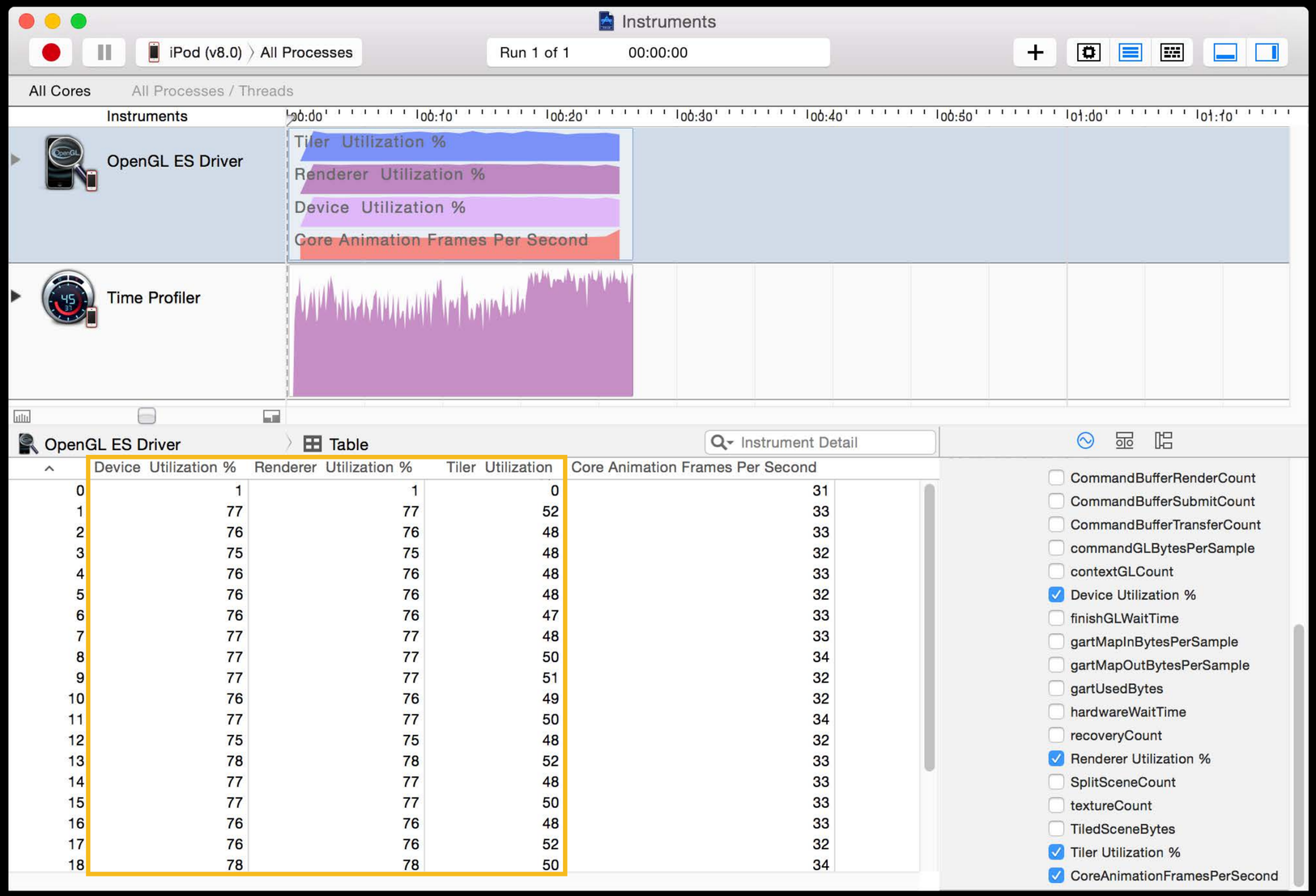
OpenGL ES Driver instrument

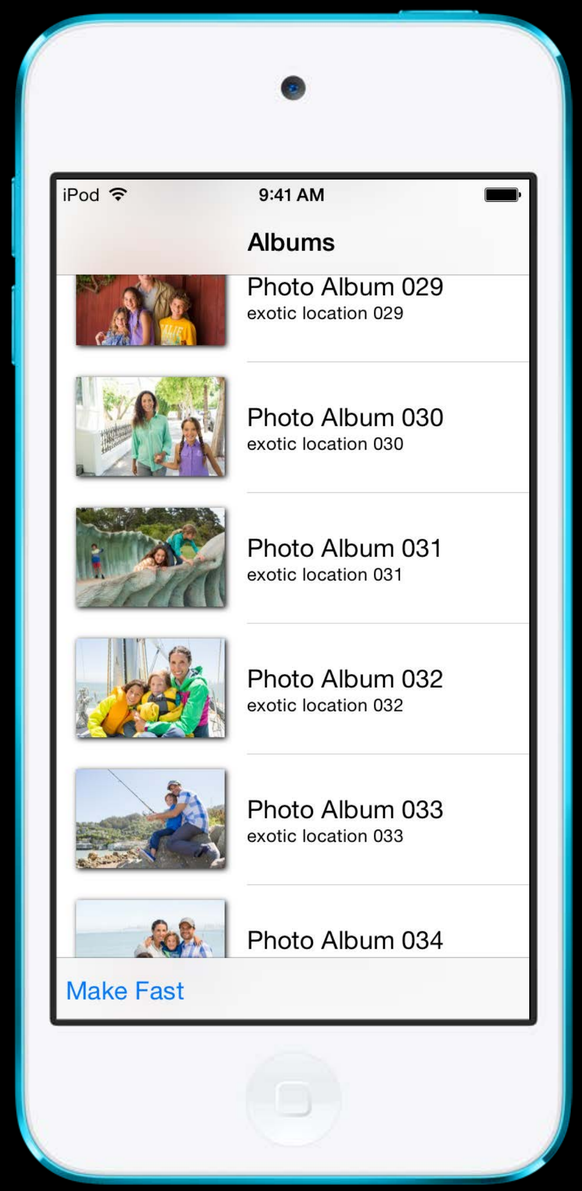




Measure Frame Rate on iPod touch

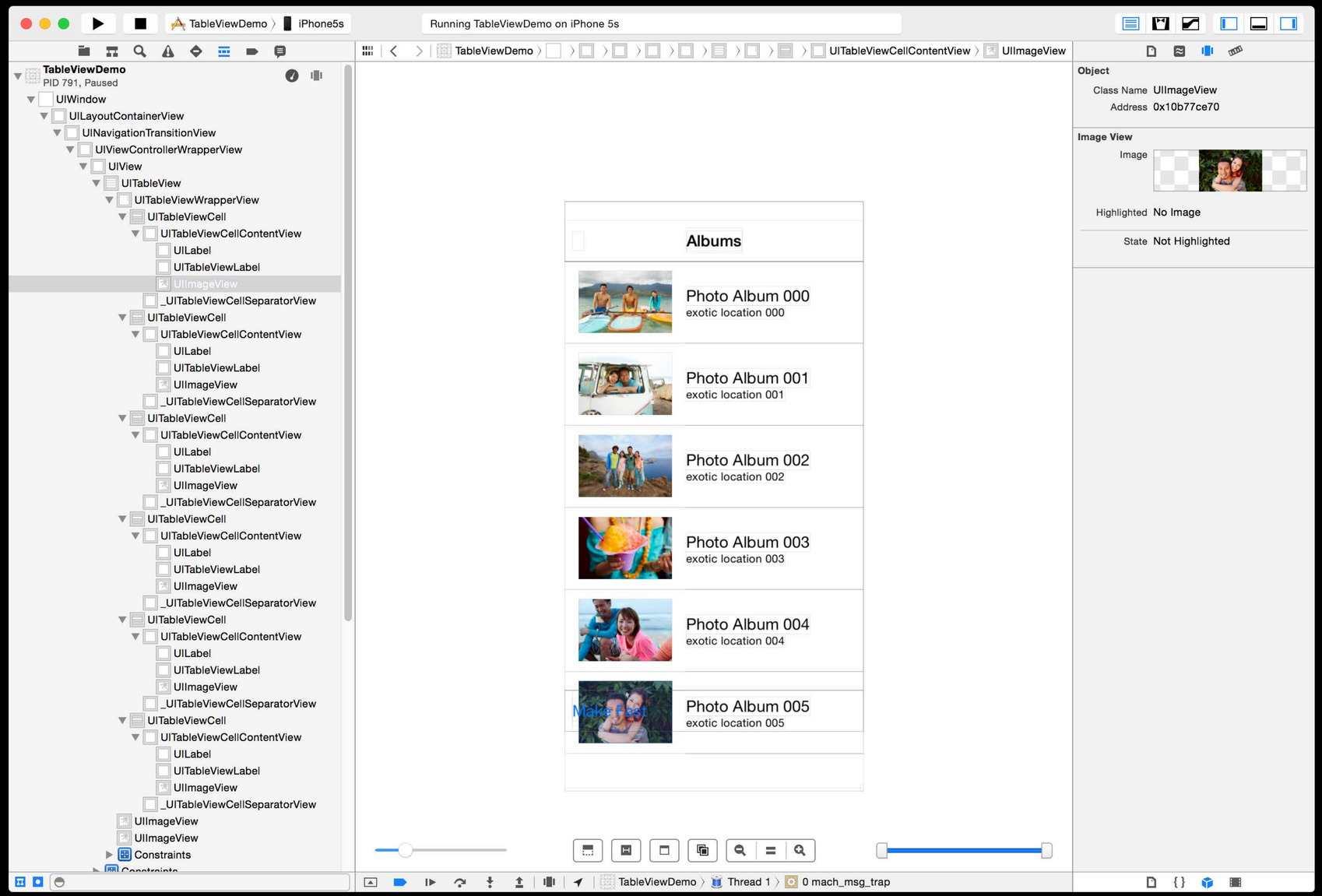
OpenGL ES Driver instrument

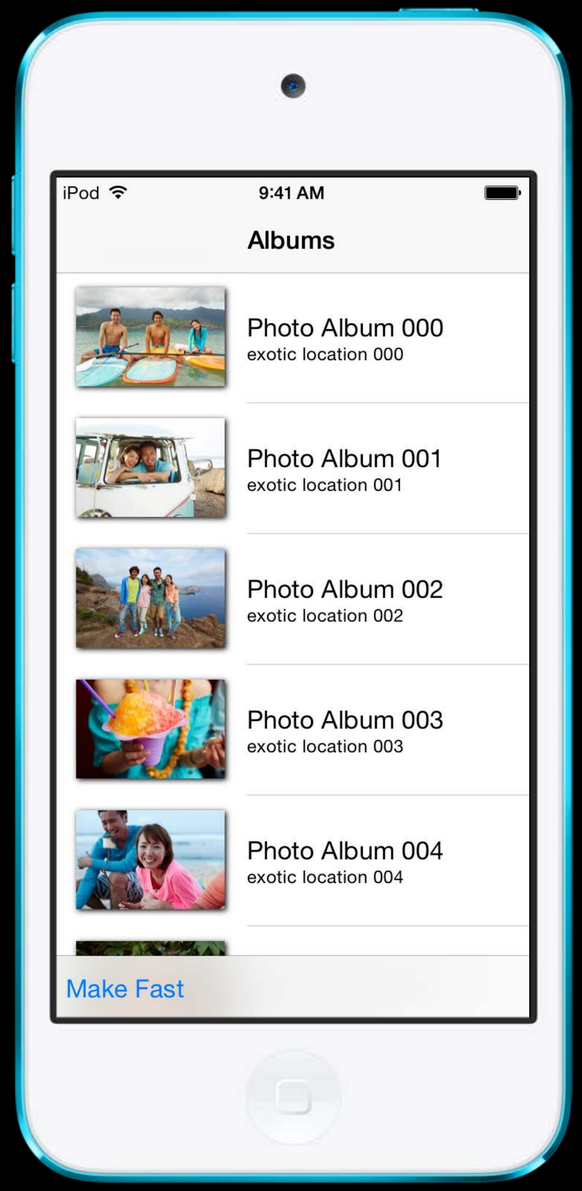




Analyzing View Hierarchy on iPod touch

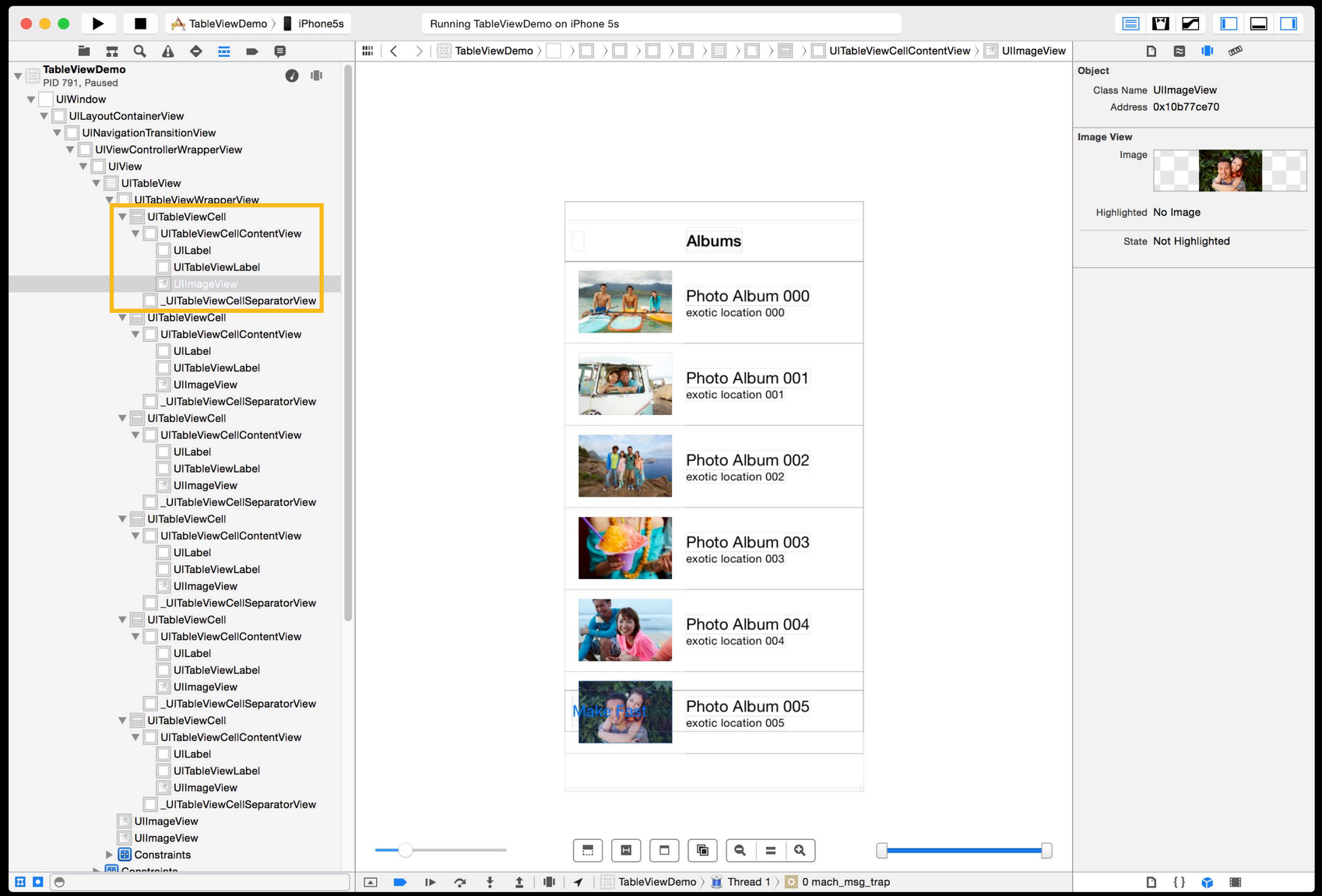
Xcode view debugging

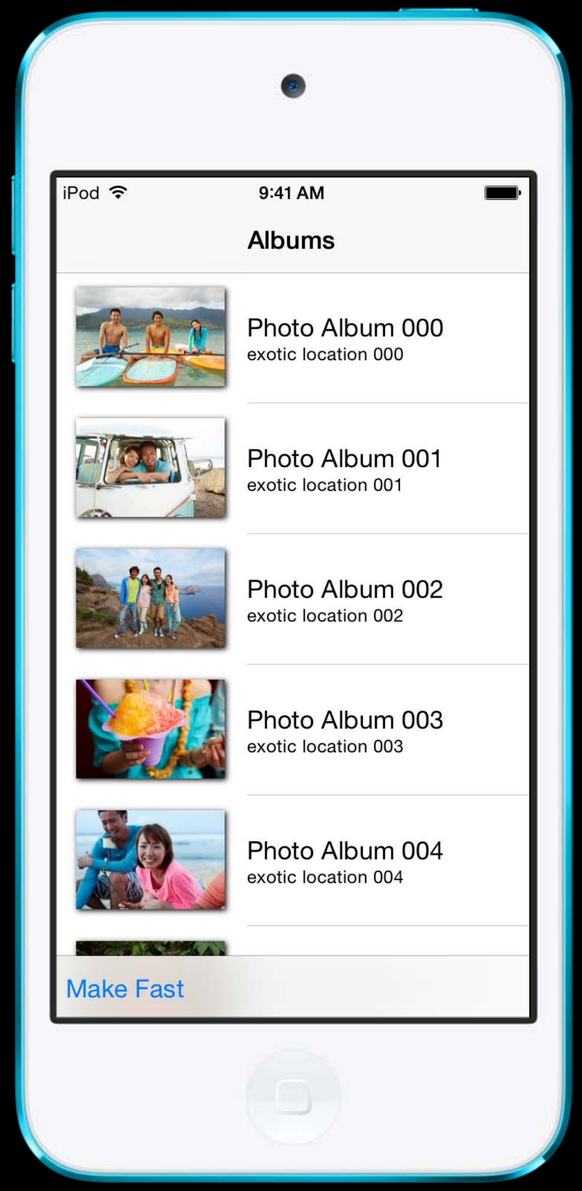




Analyzing View Hierarchy on iPod touch

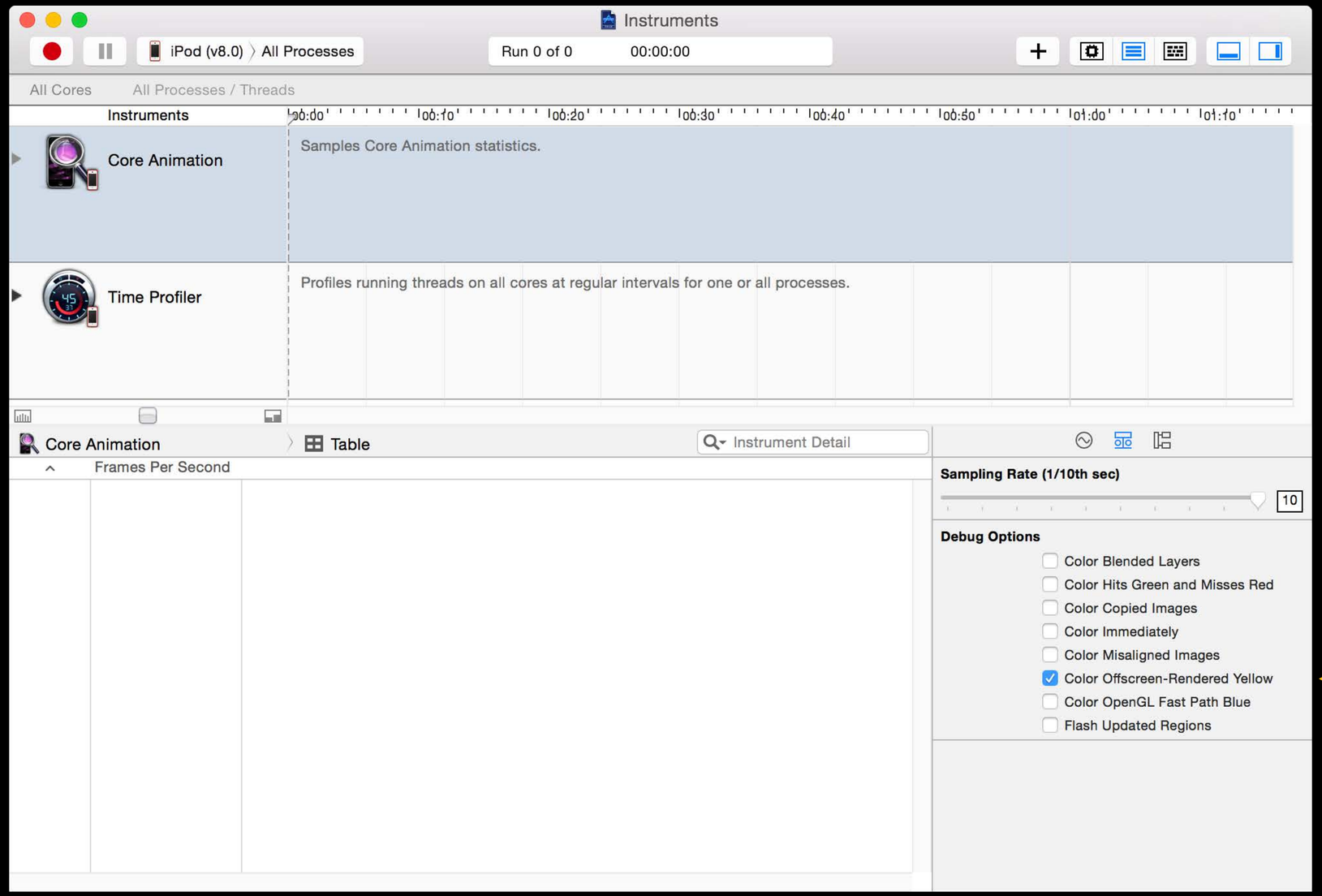
Xcode view debugging





Color Offscreen-Rendered Yellow

Core Animation instrument



How Are We Setting up the Shadow?

How Are We Setting up the Shadow?

We are asking Core Animation to generate the shadow

```
CALayer *imageViewLayer = cell.imageView.layer;
imageViewLayer.shadowColor = [UIColor blackColor].CGColor;
imageViewLayer.shadowOpacity = 1.0;
imageViewLayer.shadowRadius = 2.0;
imageViewLayer.shadowOffset = CGSizeMake(1.0, 1.0);
```

How Are We Setting up the Shadow?

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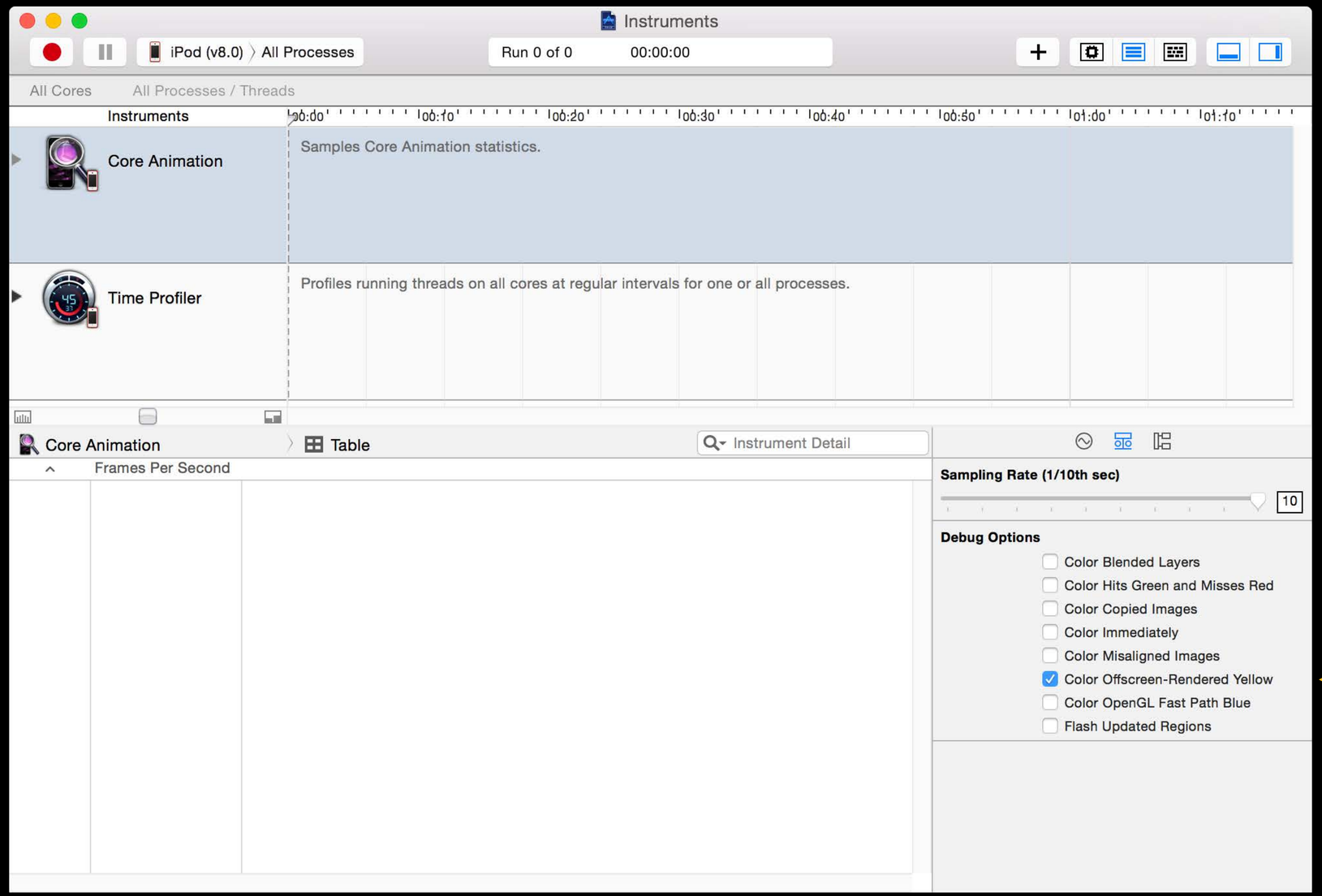
imageViewLayer.shadowRadius = 2.0;
imageViewLayer.shadowOffset = CGSizeMake(1.0, 1.0);
```

Perhaps there is a more efficient way

```
imageViewLayer.shadowPath = CGPathCreateWithRect(imageRect, NULL);
```

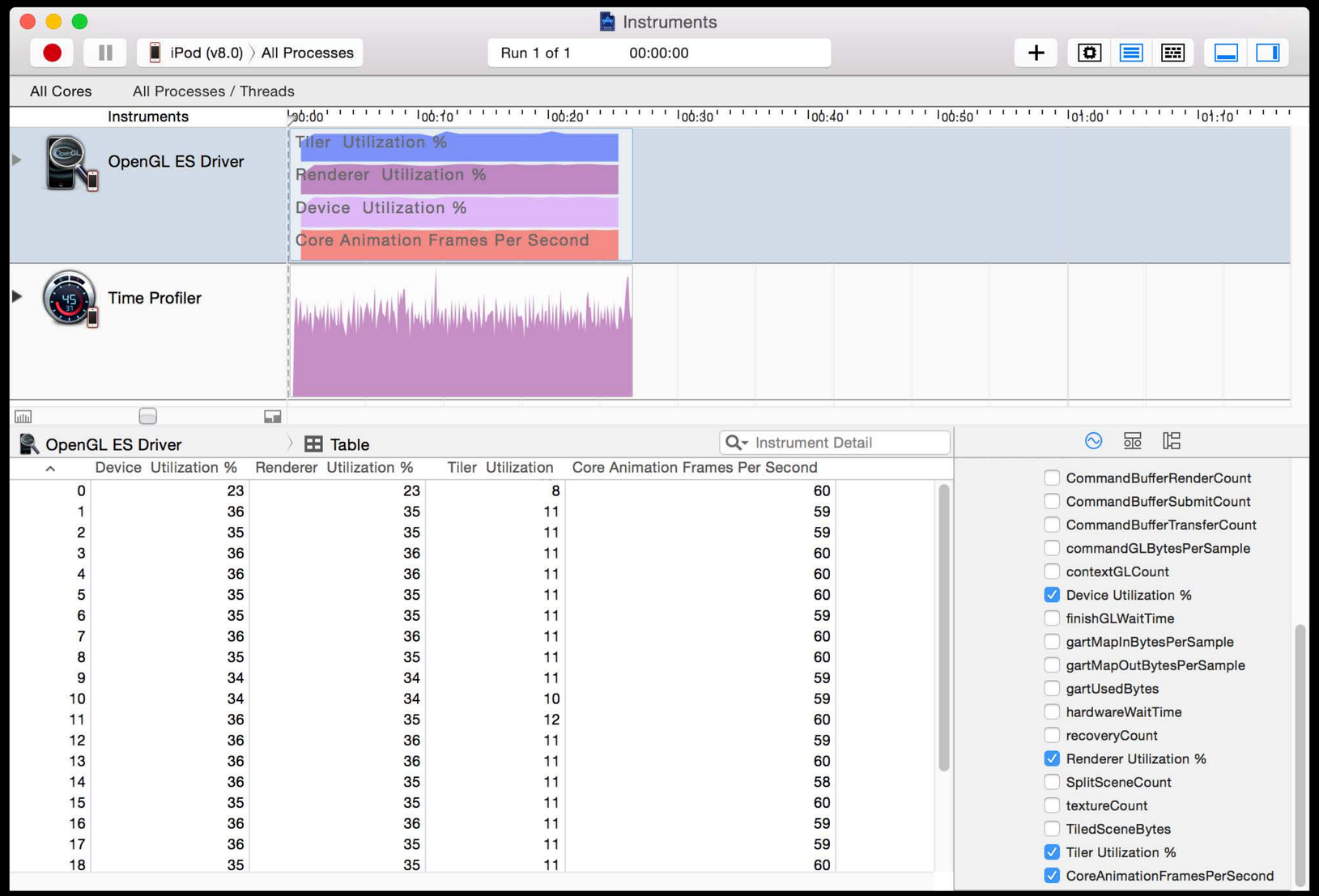
Color Offscreen-Rendered Yellow

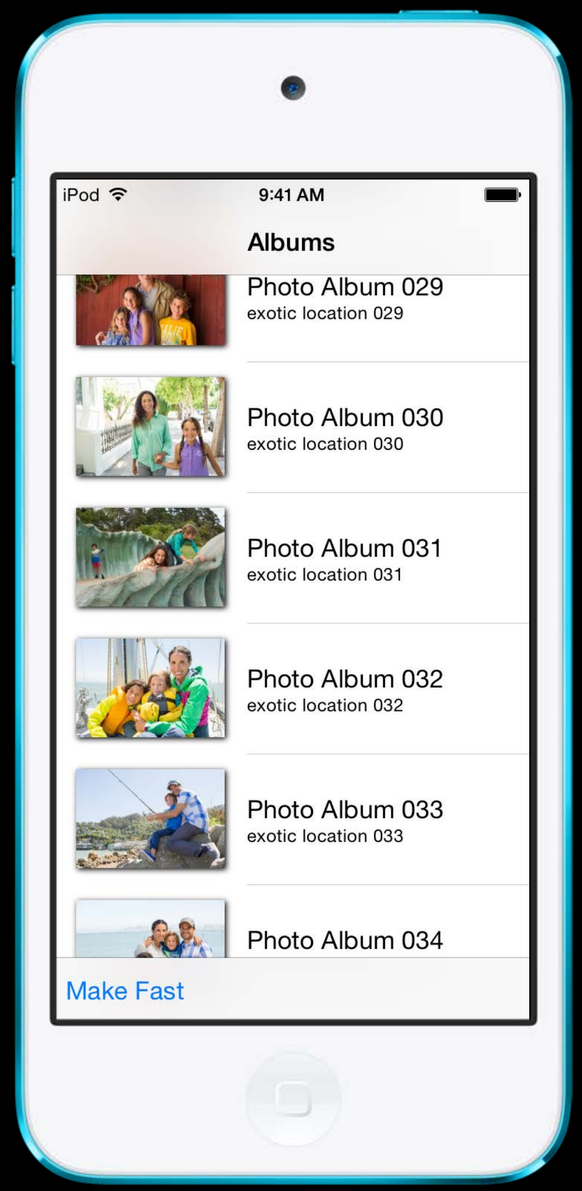
Core Animation instrument



Measure Frame Rate on iPod touch

OpenGL ES Driver instrument





Measure Frame Rate on iPod touch

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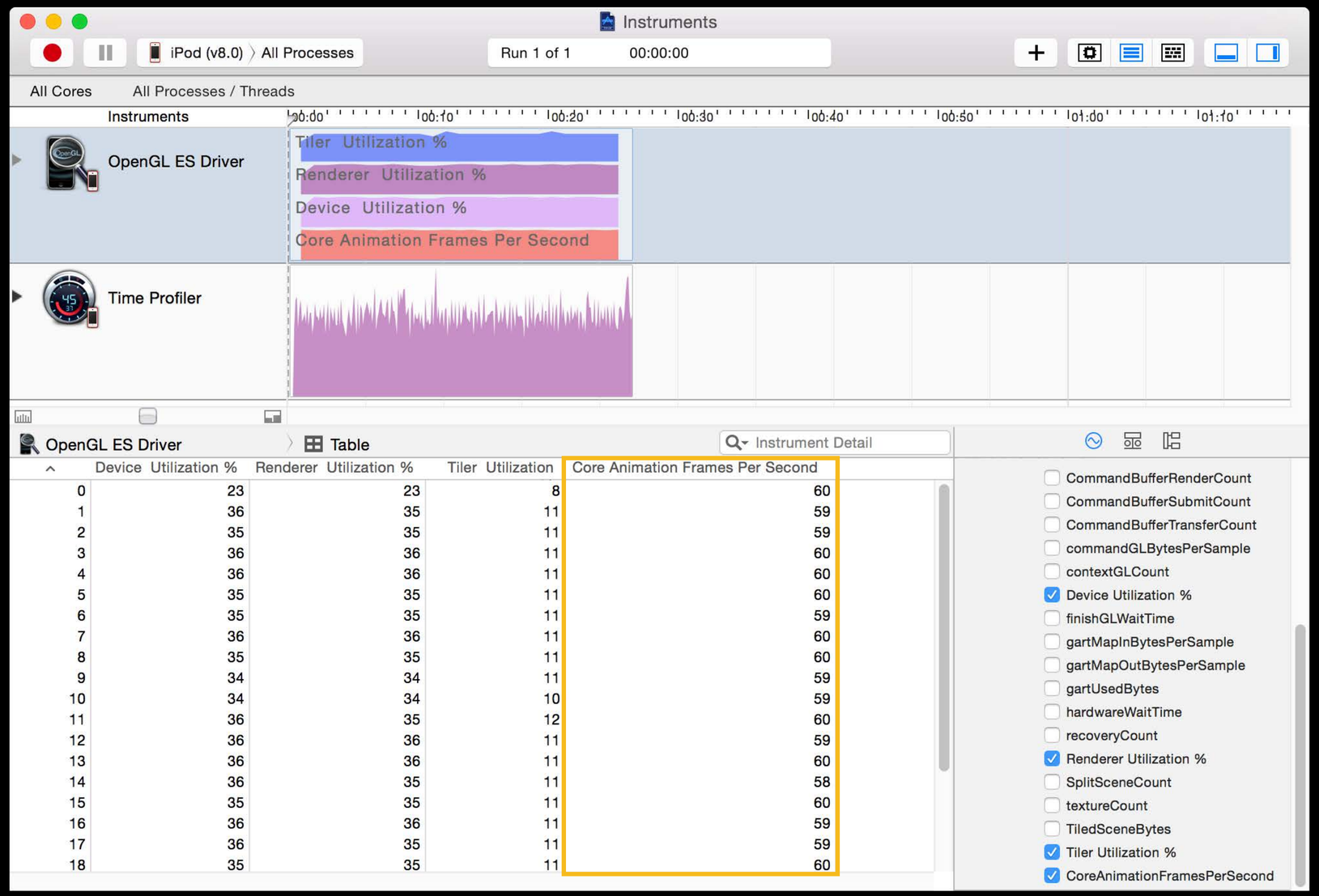
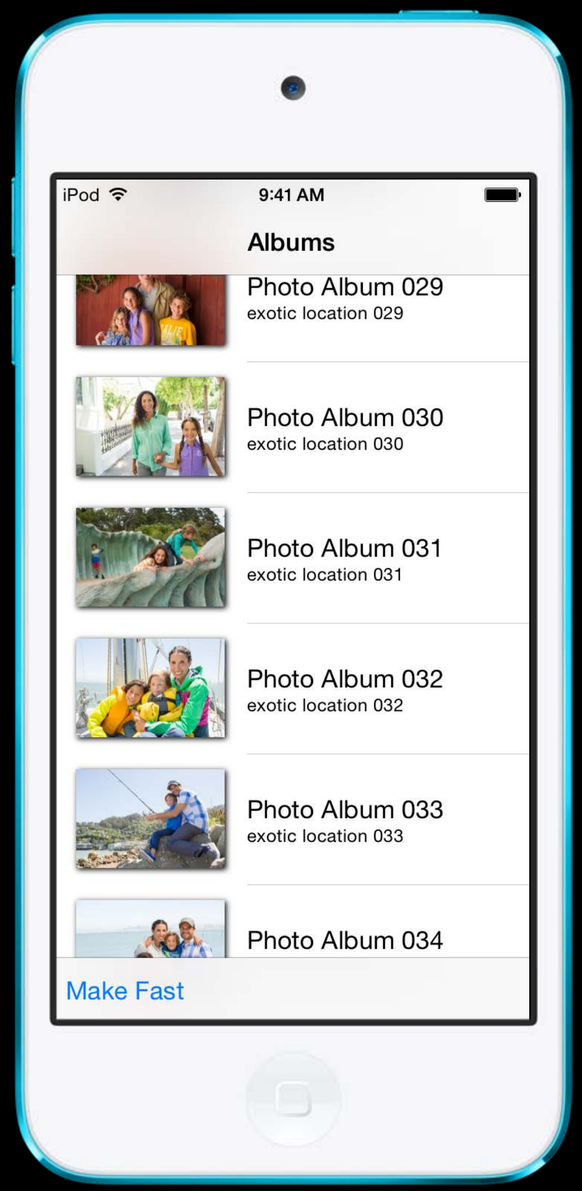
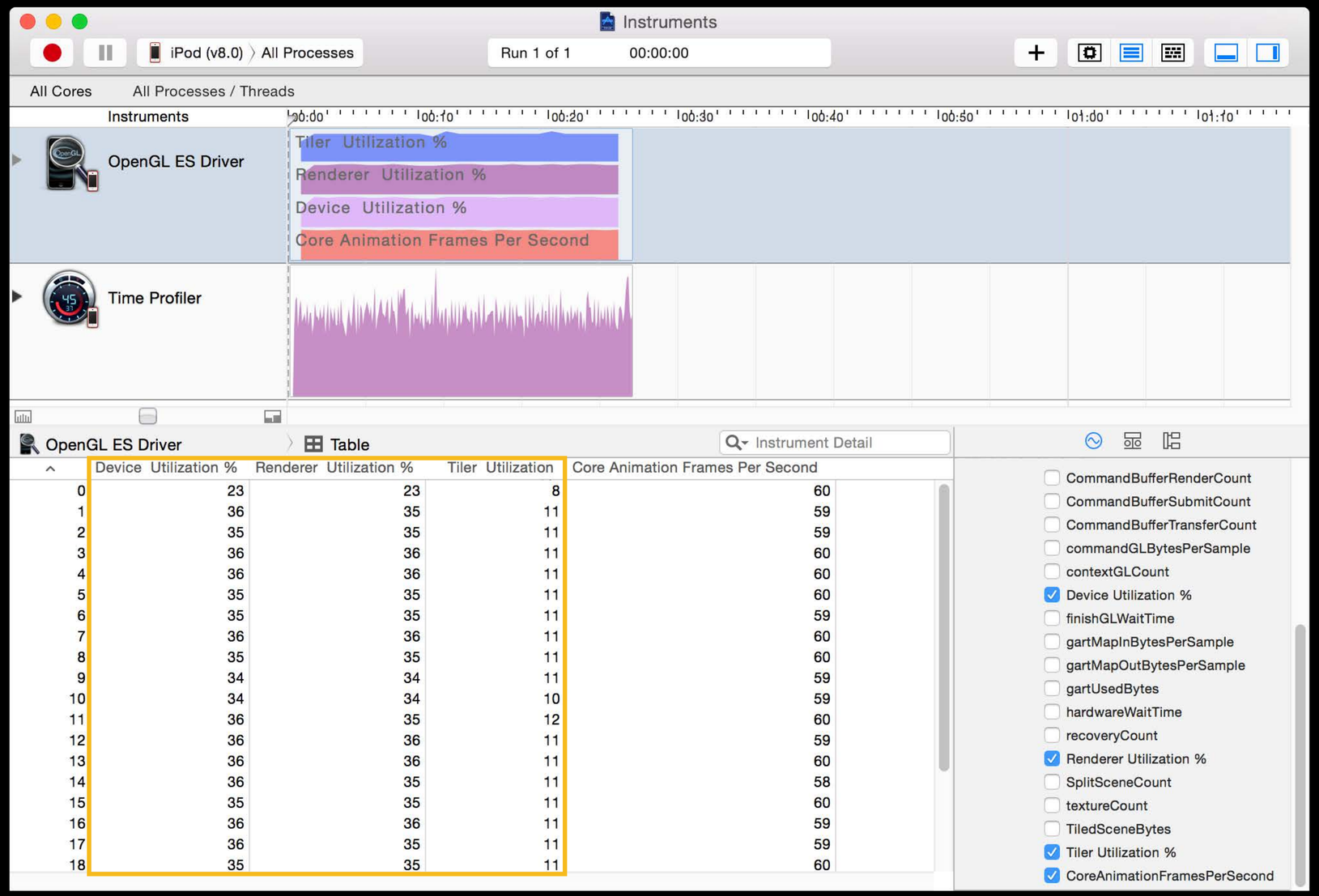
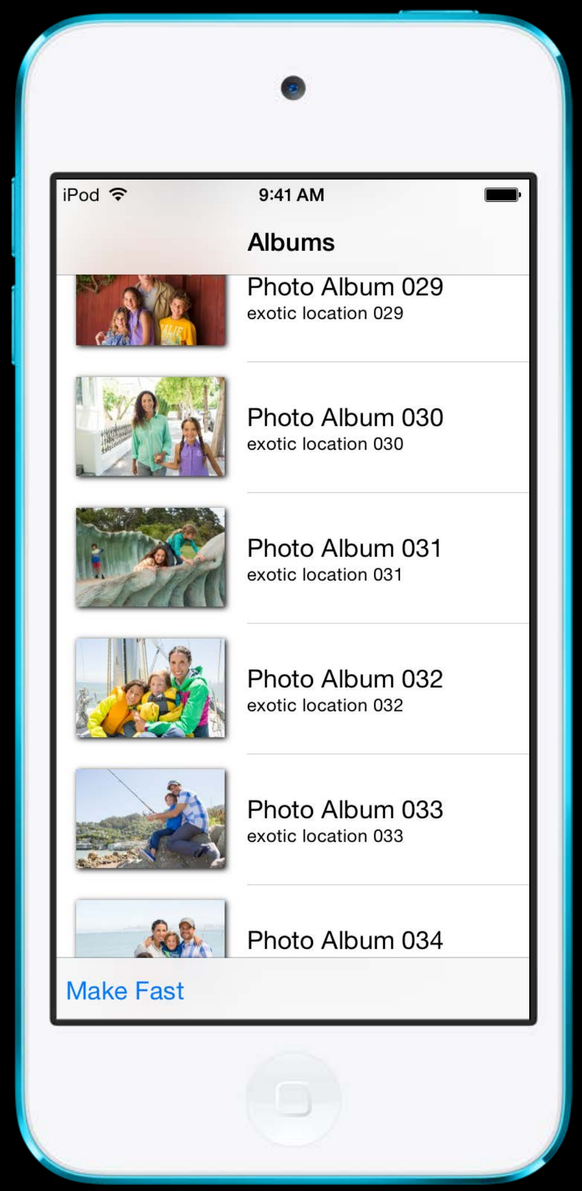




Measure Frame Rate on iPod touch

OpenGL ES Driver instrument



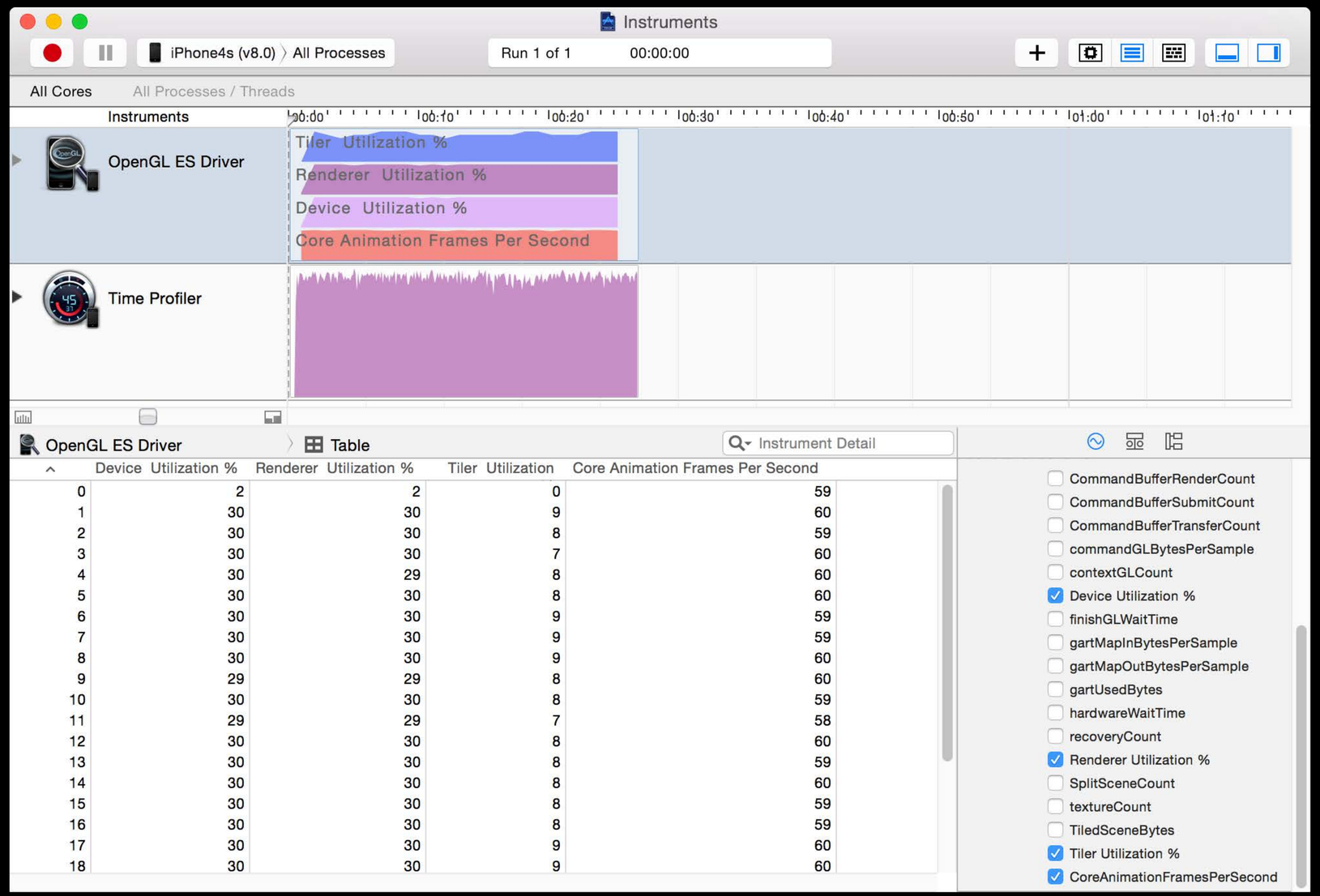


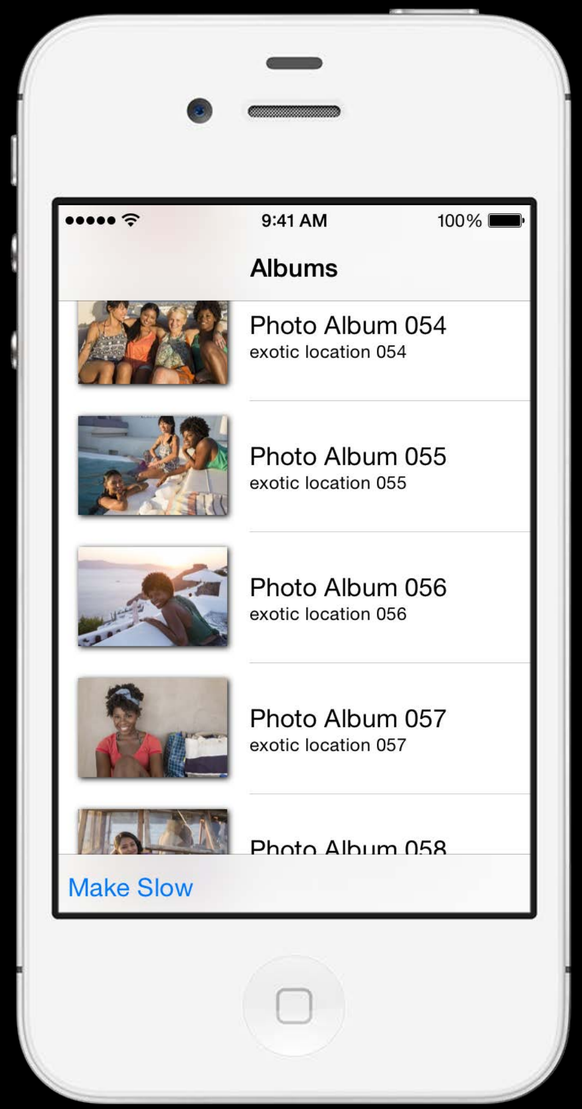
Awesome

Can we ship it now?

Measure Frame Rate on iPhone 4s

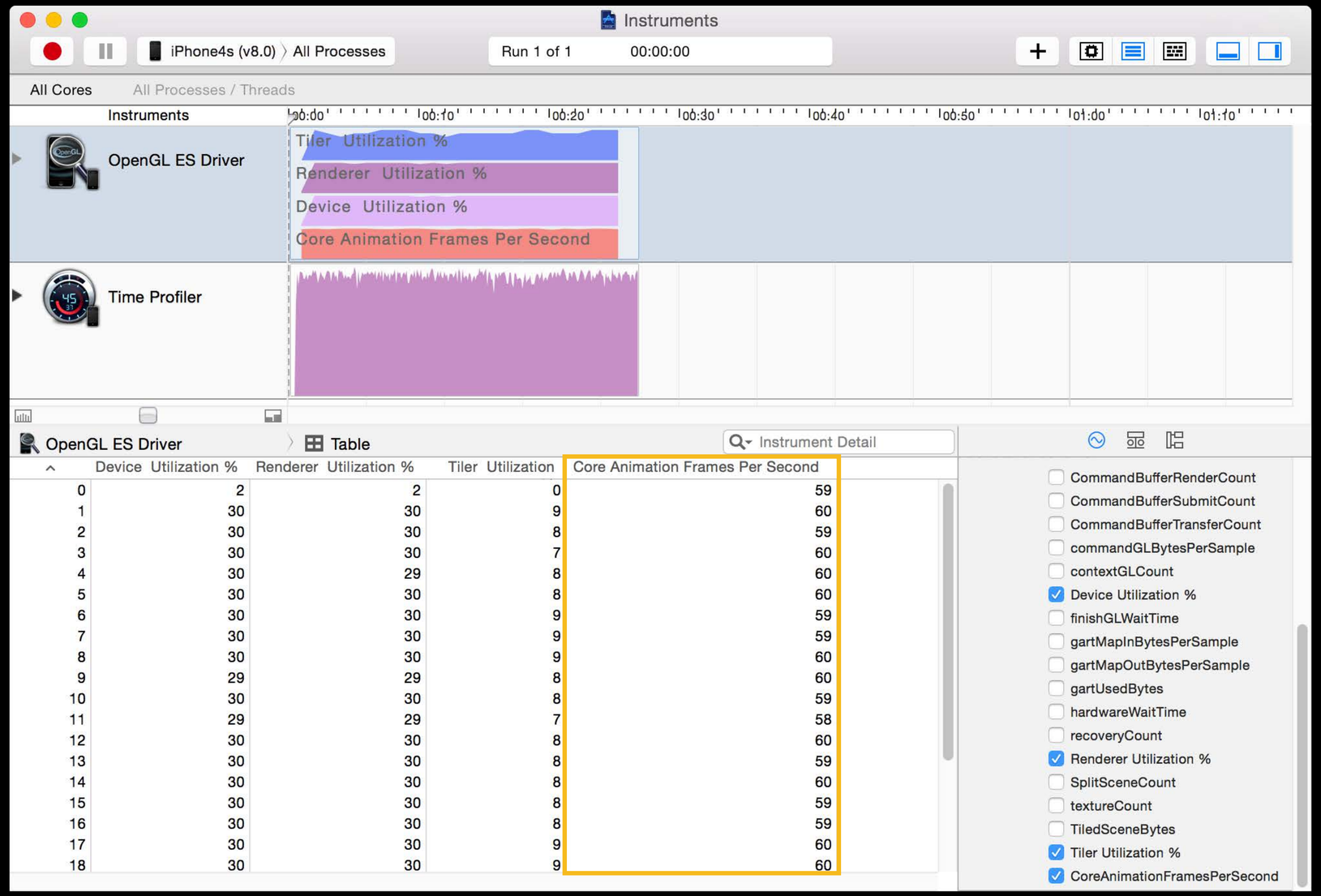
OpenGL ES Driver instrument

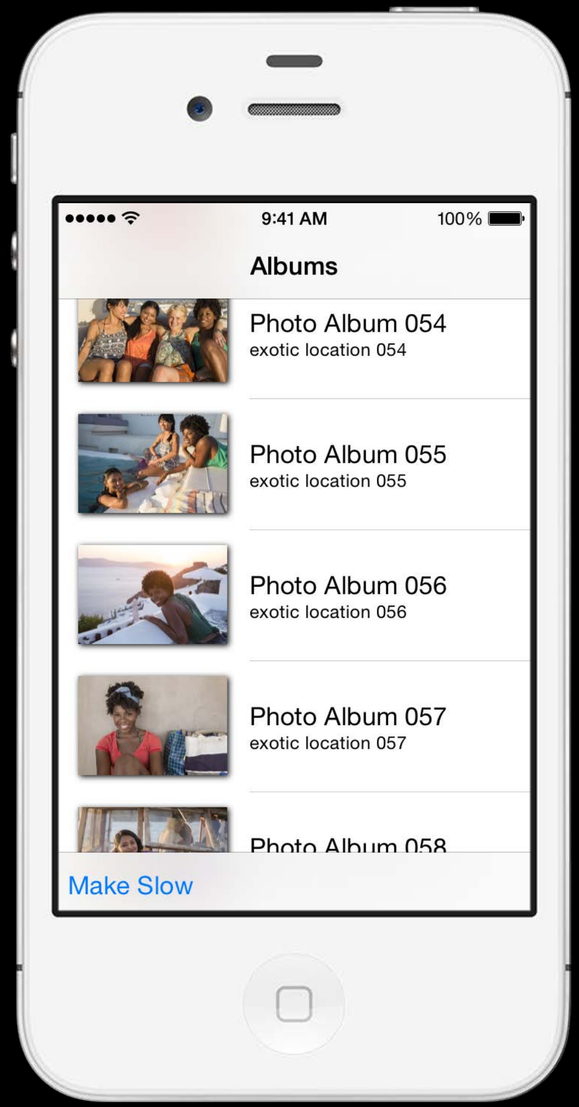




Measure Frame Rate on iPhone 4s

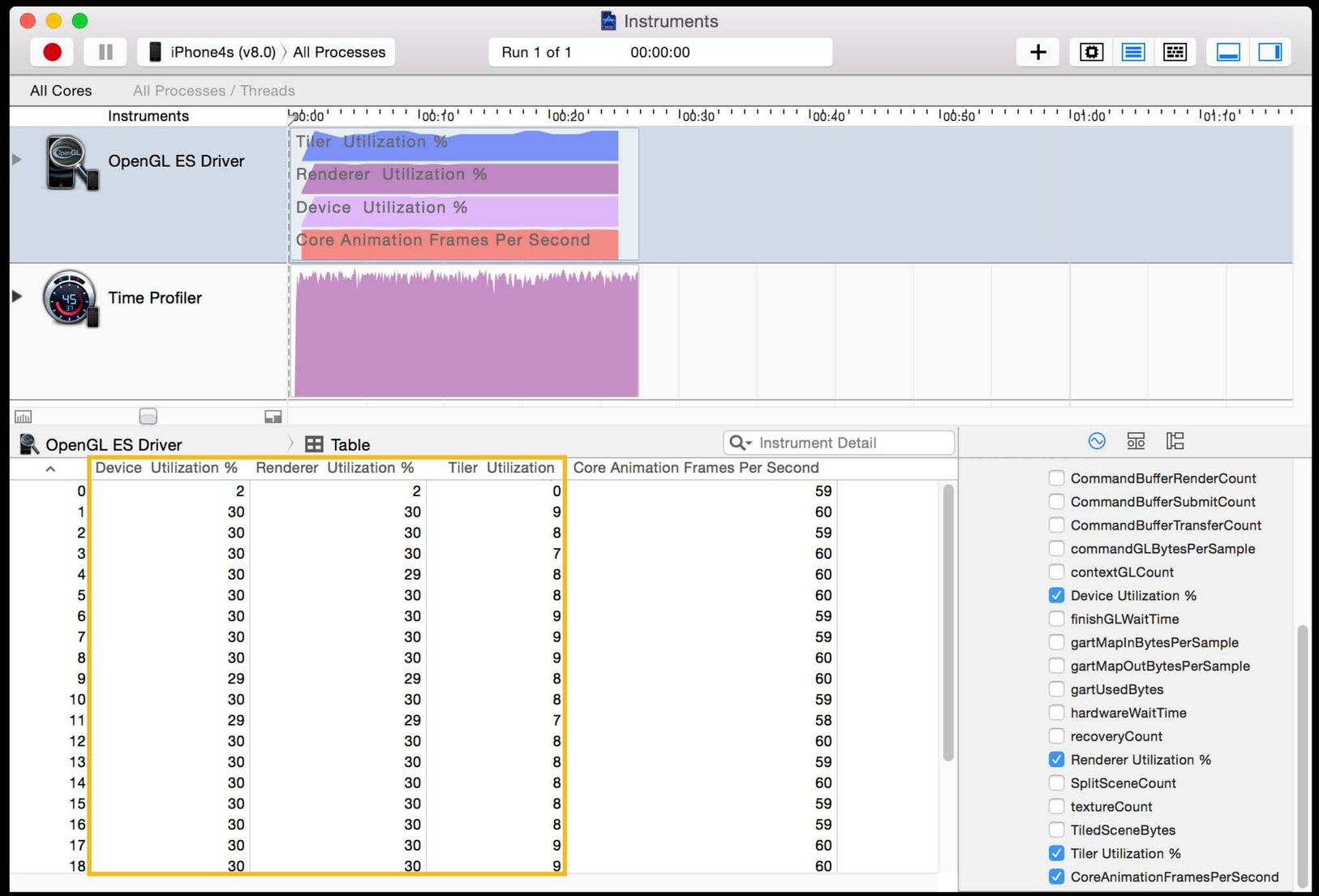
OpenGL ES Driver instrument

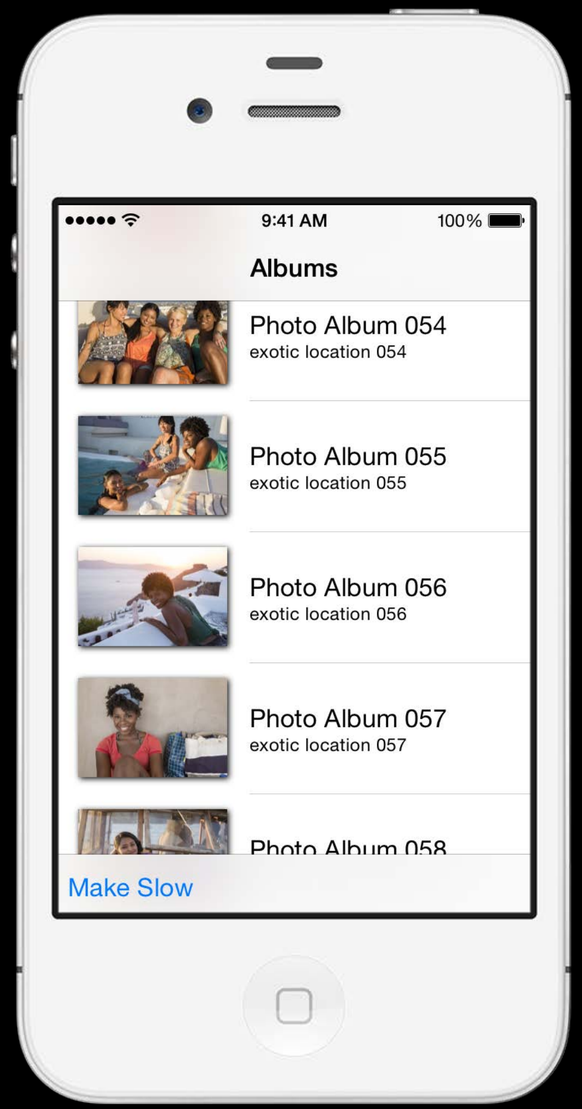




Measure Frame Rate on iPhone 4s

OpenGL ES Driver instrument





Fictitious Photo Application

Performance across devices

Awesome

Ship it!

Fictitious Photo Application

Summary

Offscreen passes are expensive

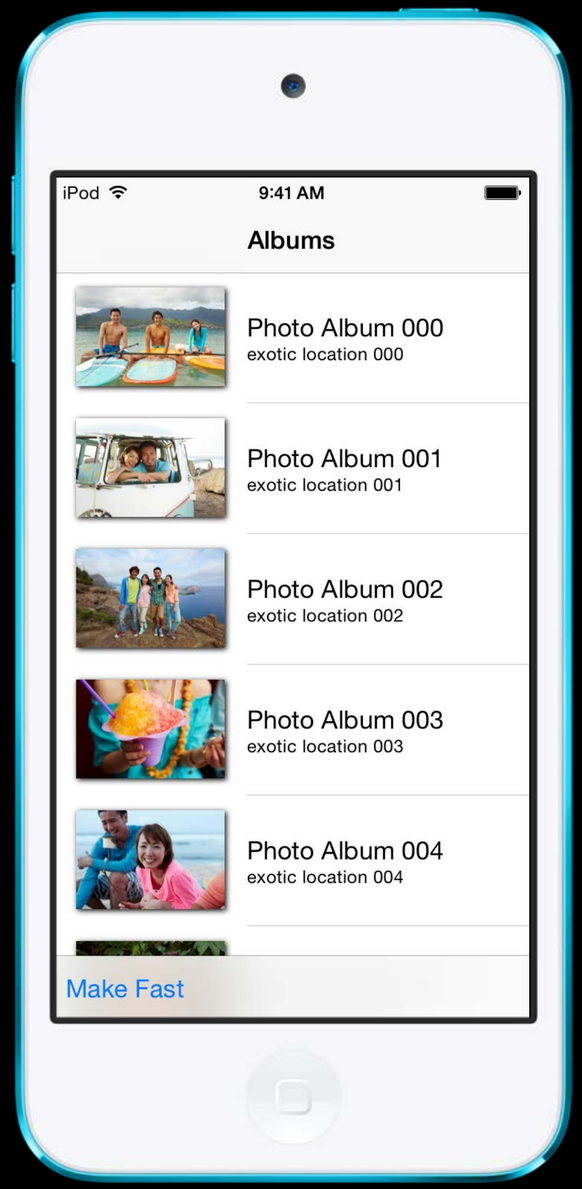
- Use Core Animation instrument to find them
- Know what you can do to avoid them

Measure performance across different devices

- Use OpenGL ES Driver instrument for GPU time
- Use Time Profiler instrument for CPU time

Know your view hierarchy and any hidden costs

- This is especially true for table cells and scrolling

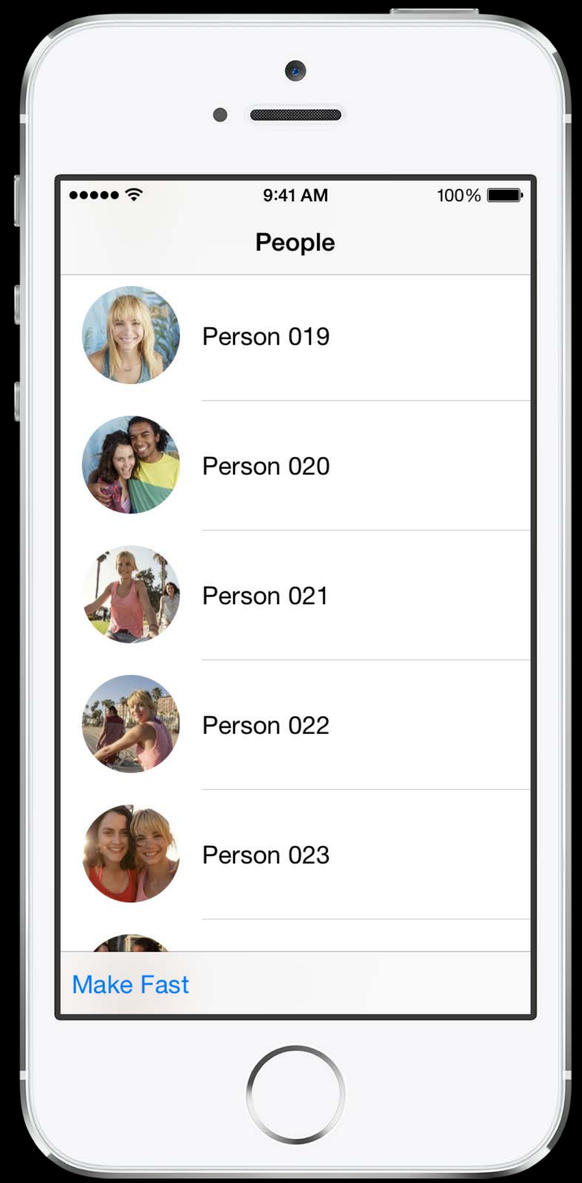


Fictitious Contacts Application

Case study

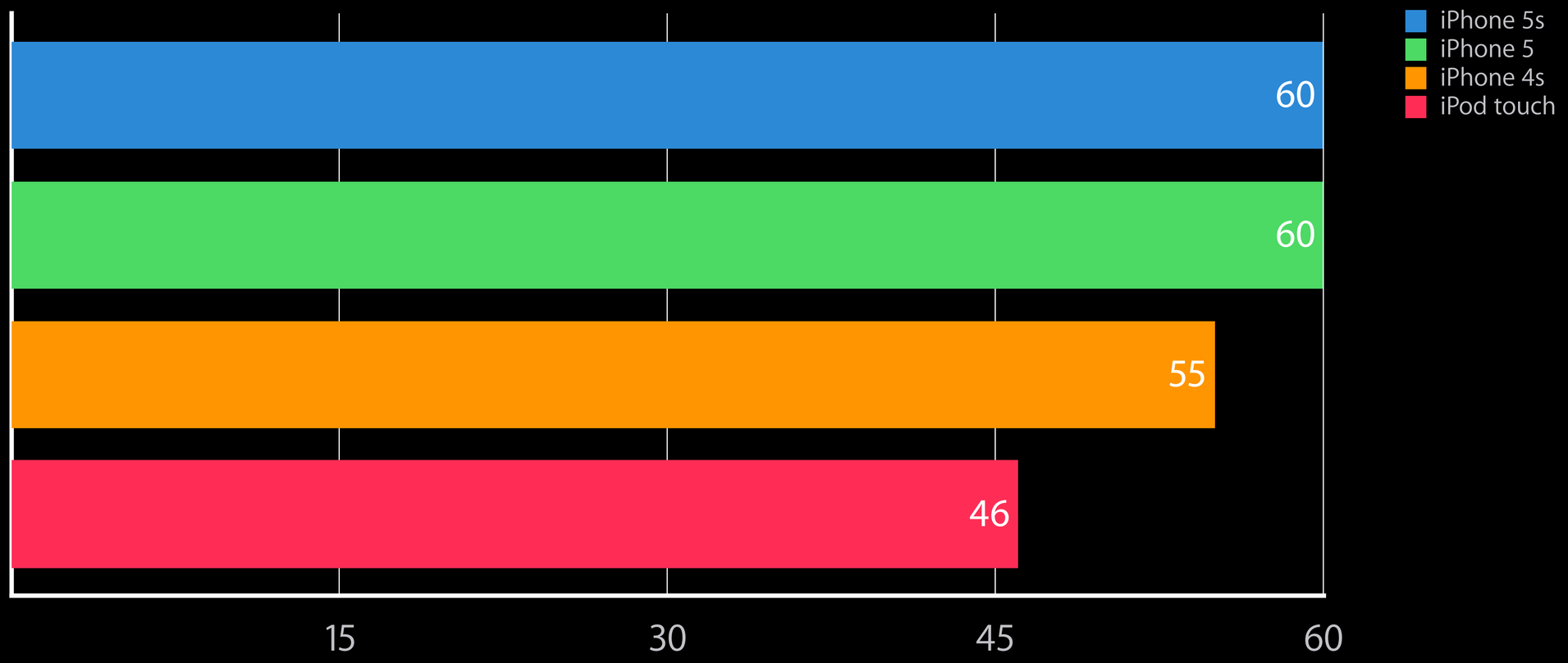
Simple table view

Each cell shows a round thumbnail and some text



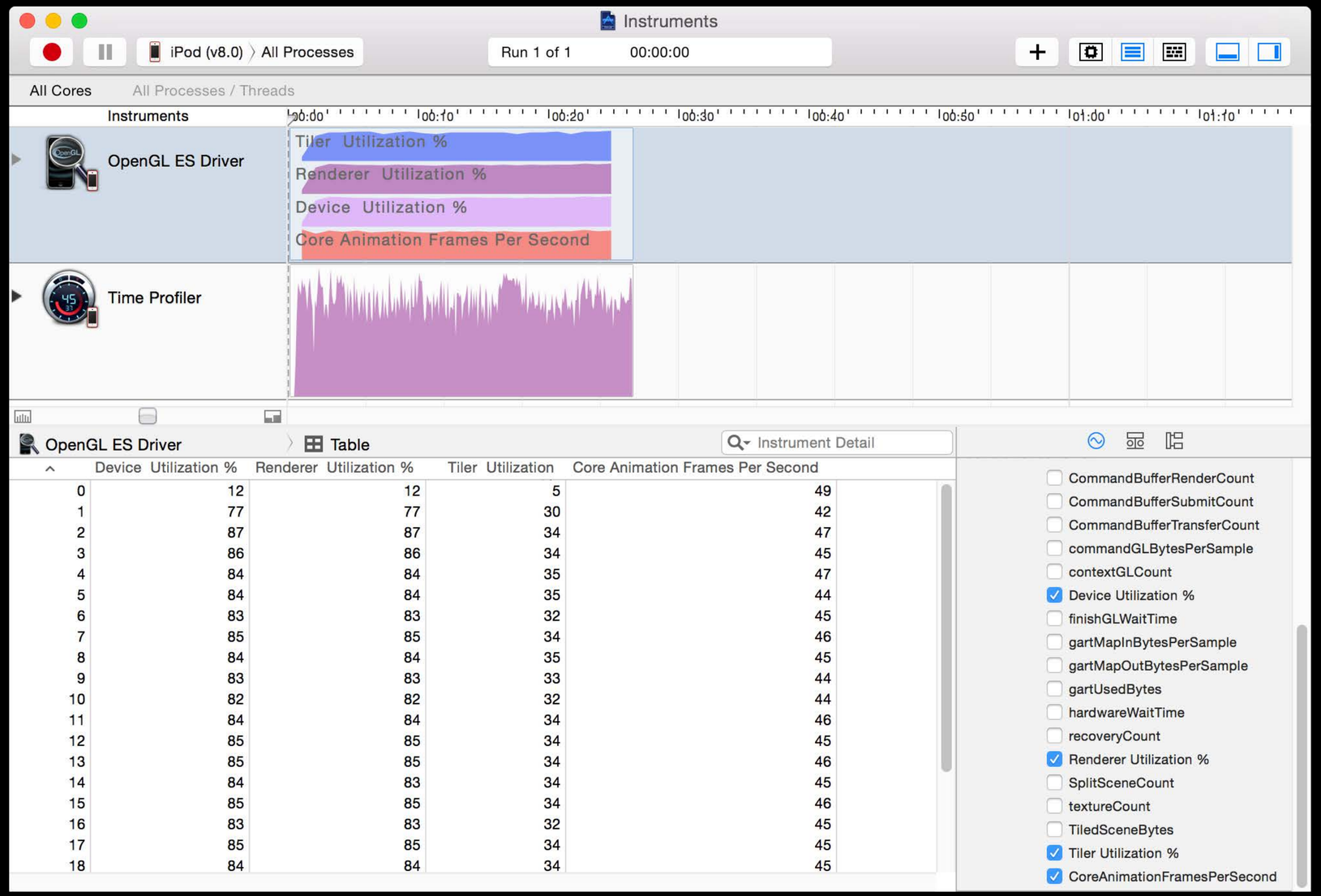
Fictitious Contacts Application

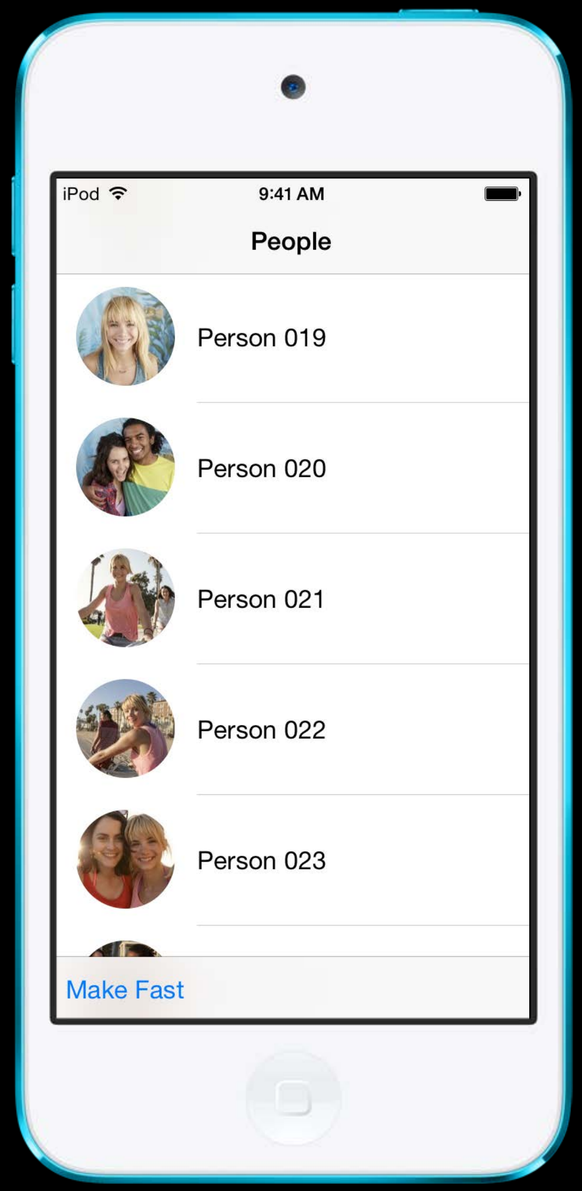
Performance across devices



Measure Frame Rate on iPod touch

OpenGL ES Driver instrument





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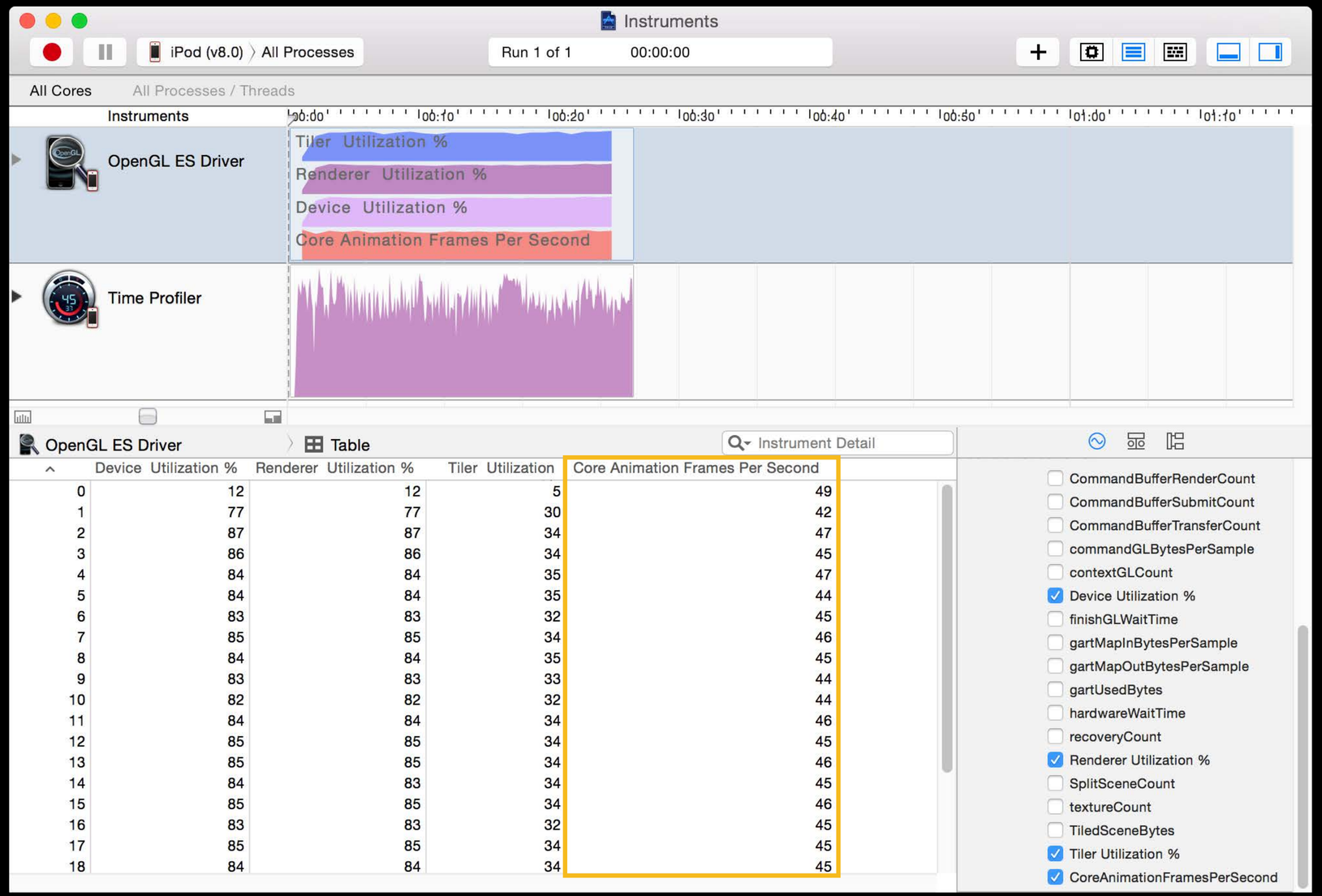

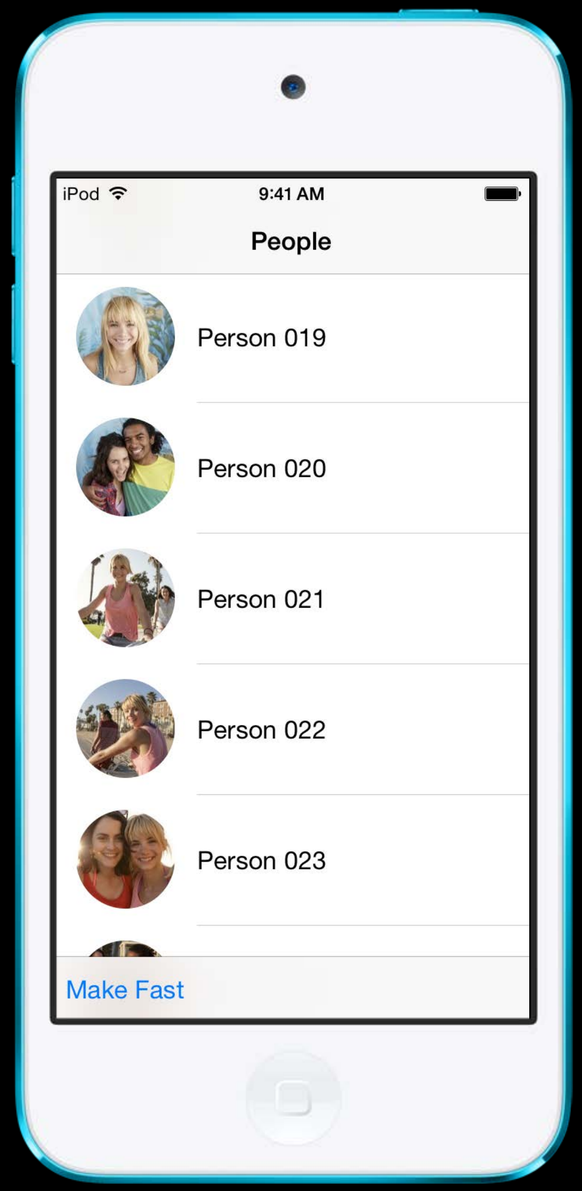

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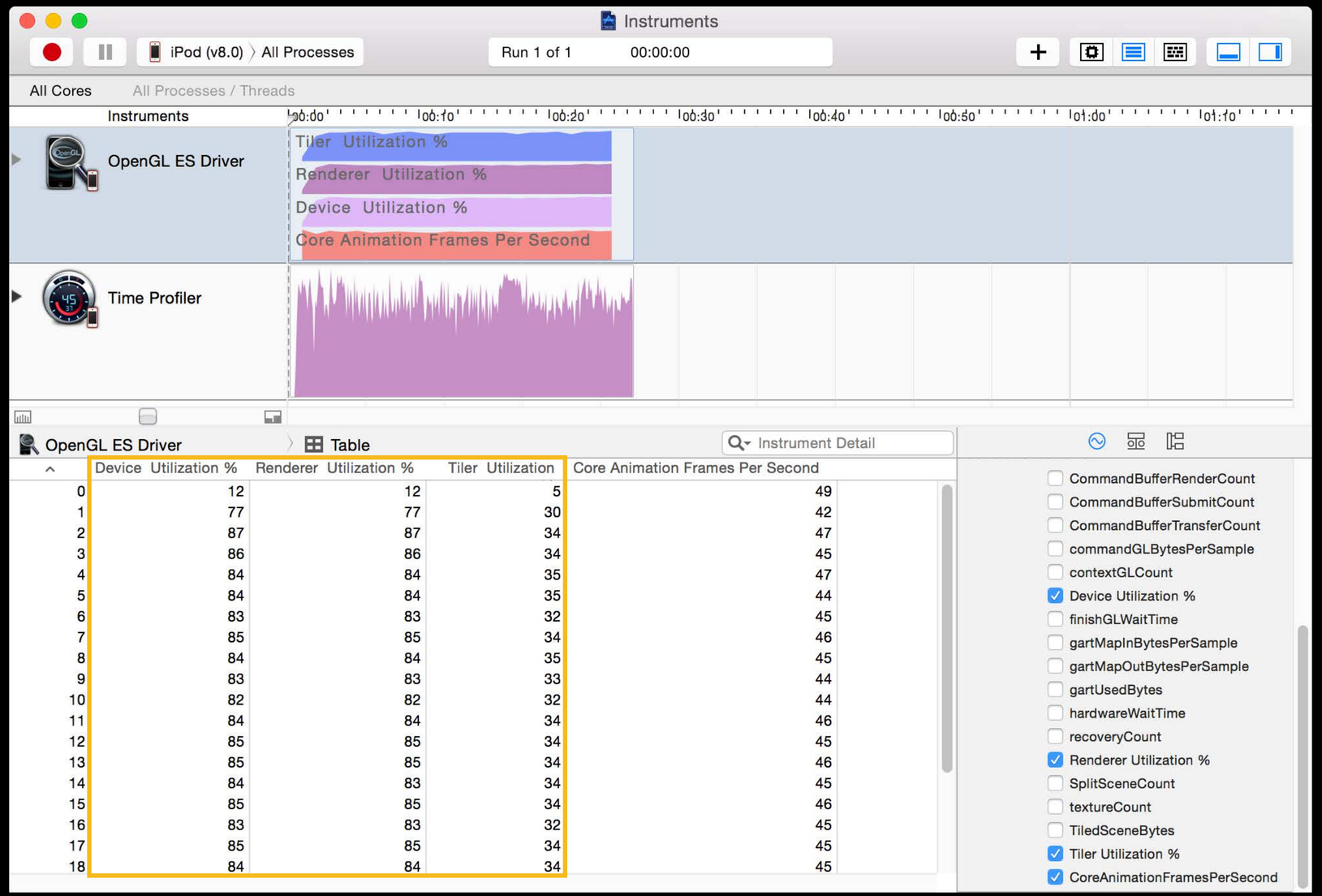
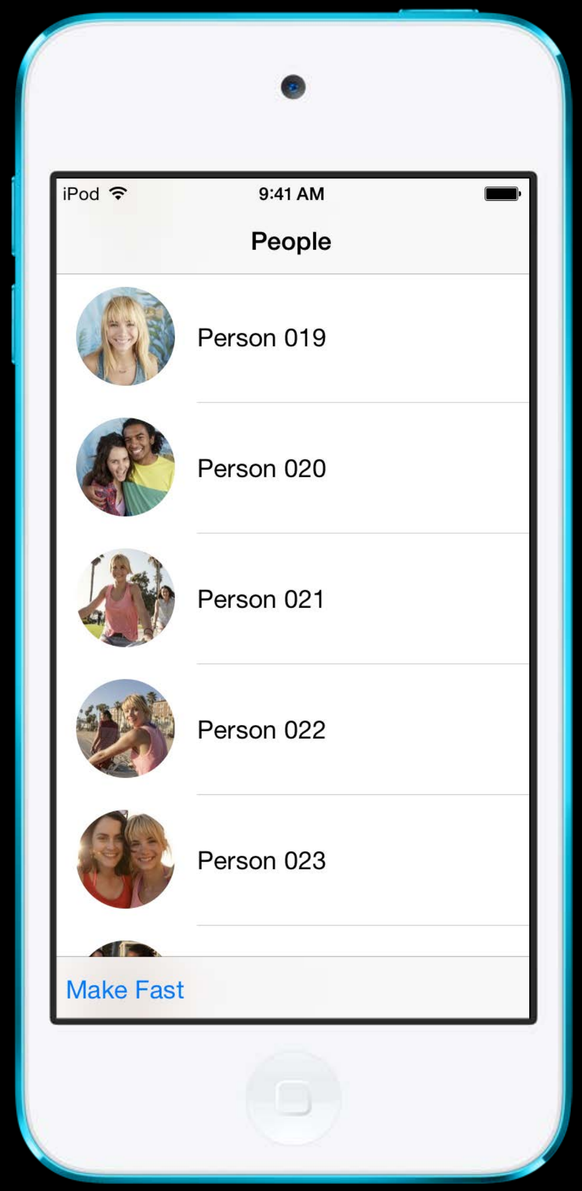
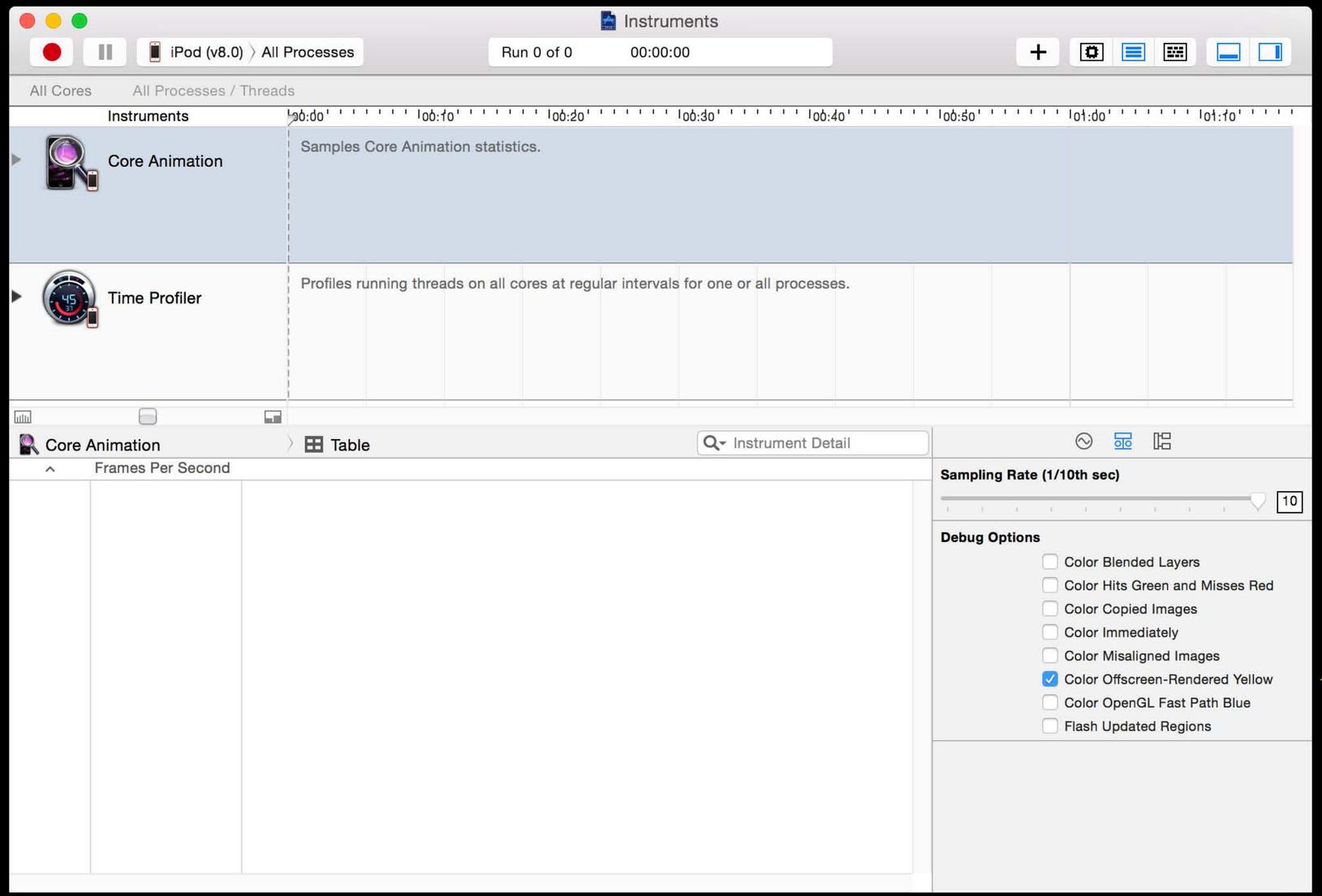
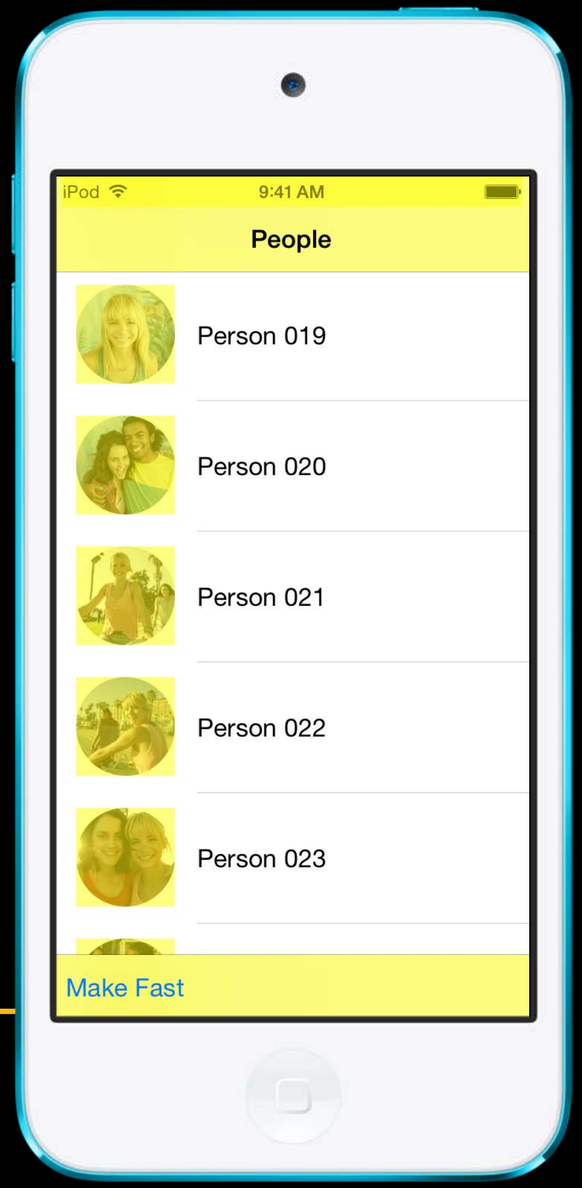




Color Offscreen-Rendered Yellow

Core Animation instrument





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We are asking Core Animation to mask the image

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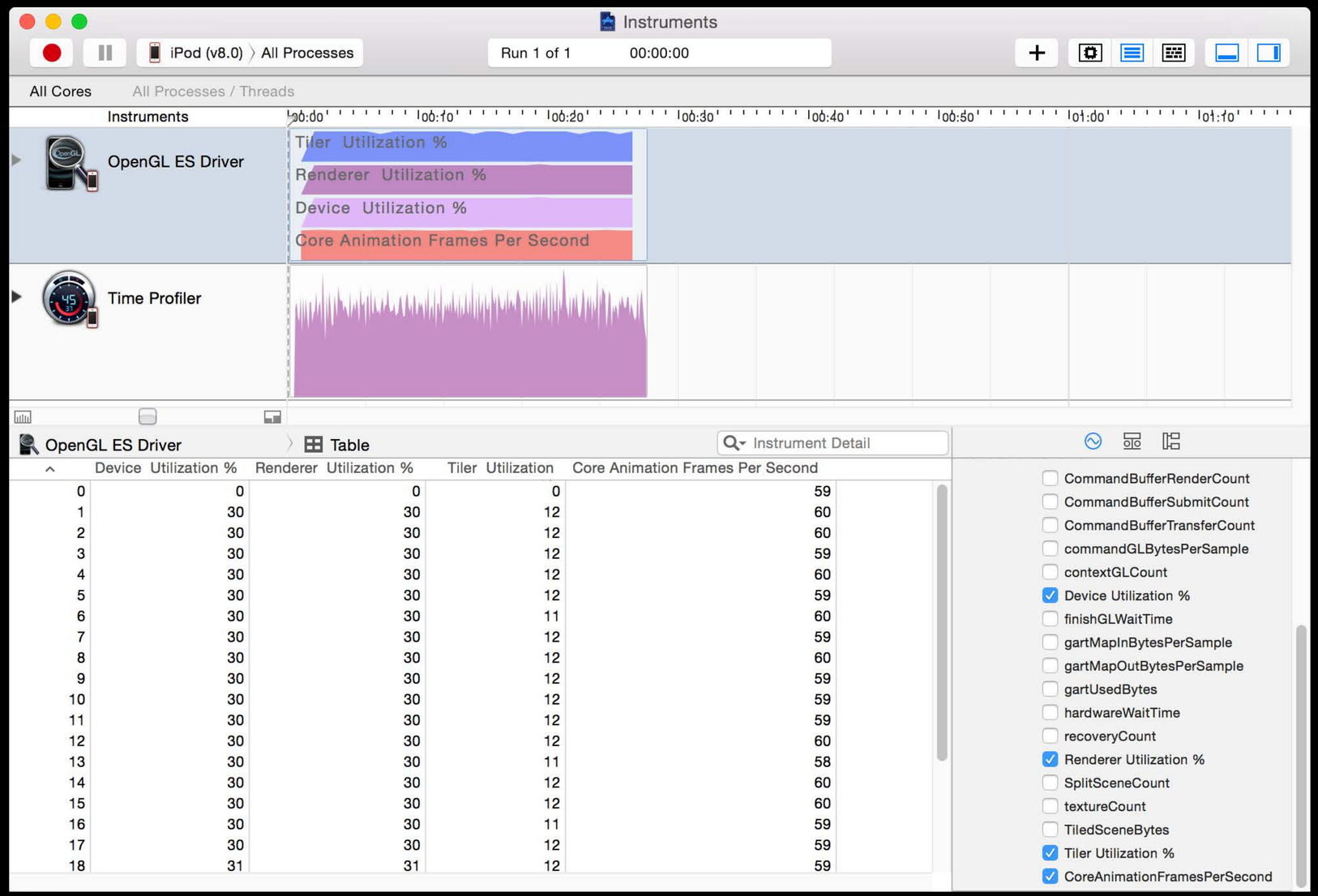
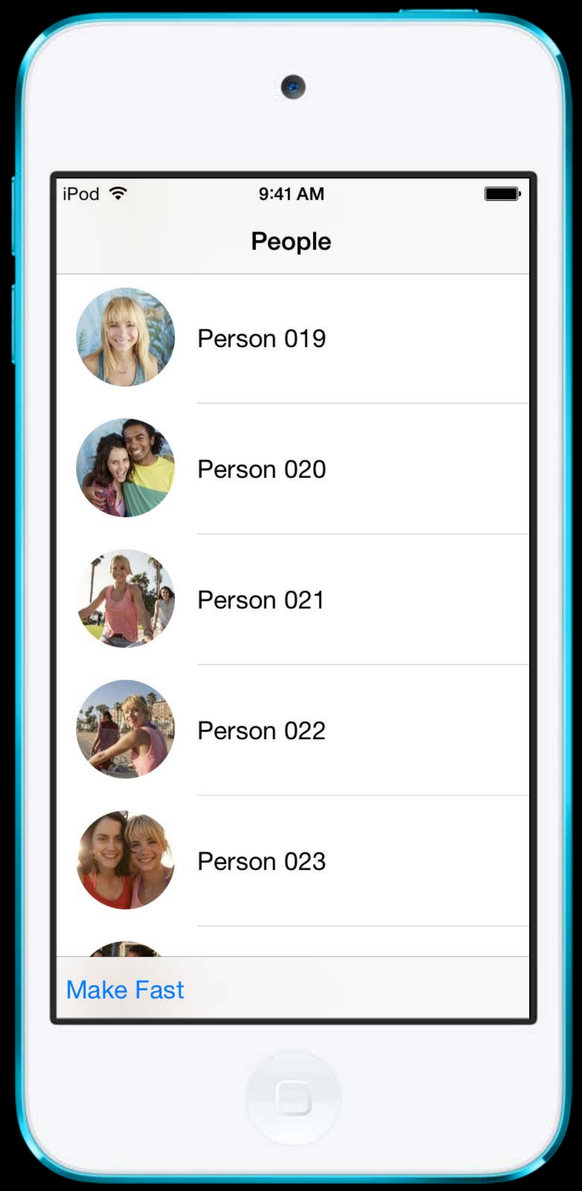
Perhaps there is a more efficient way

- Don’t mask on the fly, pre-generate thumbnails as round, or
- If that is not possible, fake it
  - Table background is solid white
  - Render a white inverted circle on top of square thumbnail asset
  - Reducing offscreen passes but increasing blending, still a net performance win

Measure Frame Rate on iPod touch

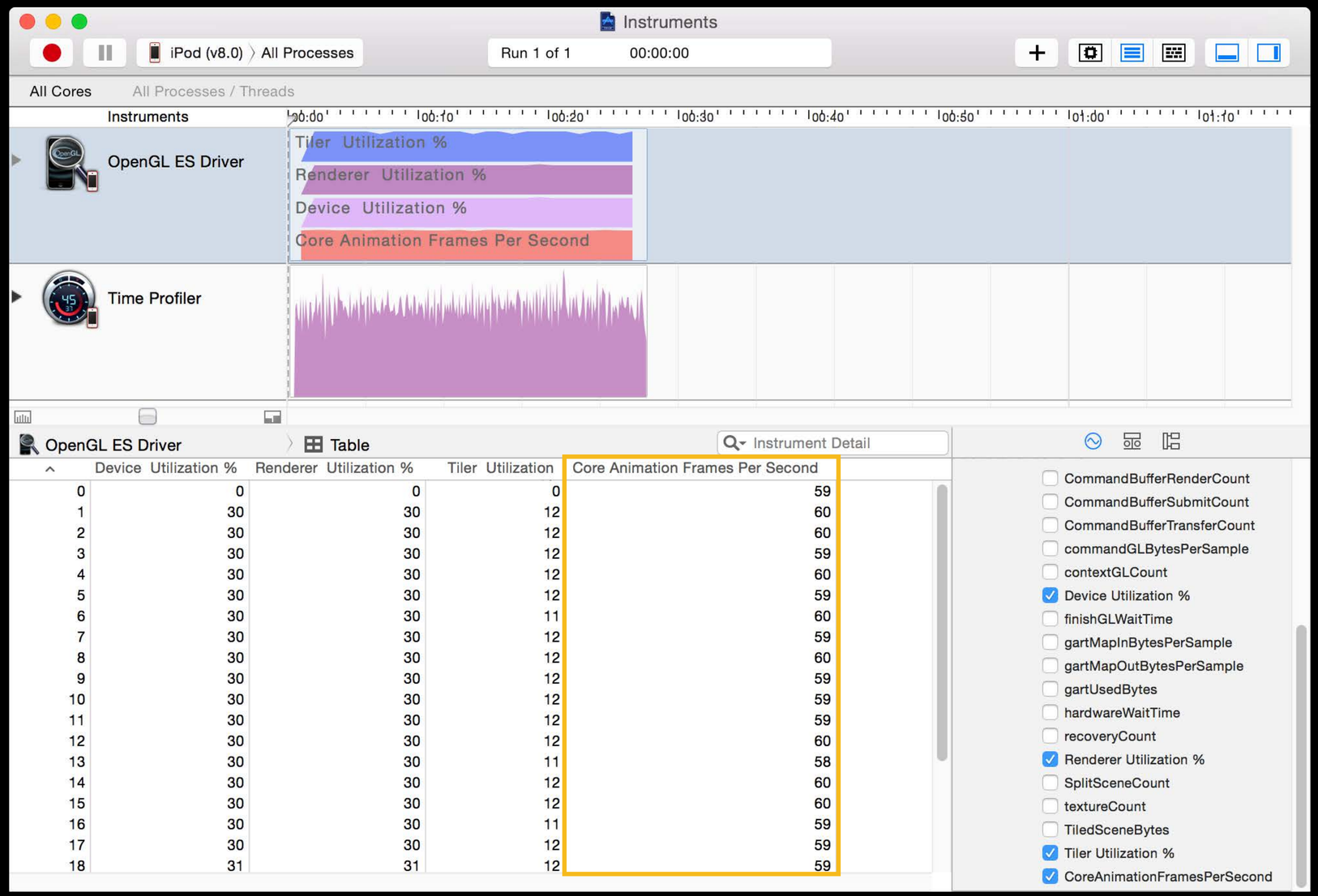
OpenGL ES Driver instrument

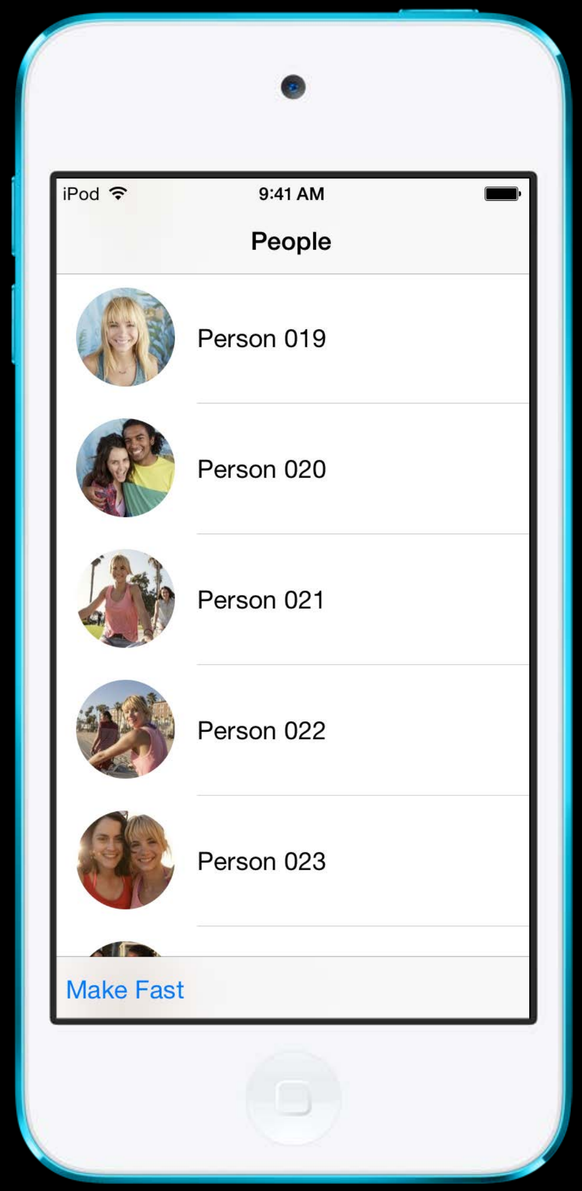




Measure Frame Rate on iPod touch

OpenGL ES Driver instrument





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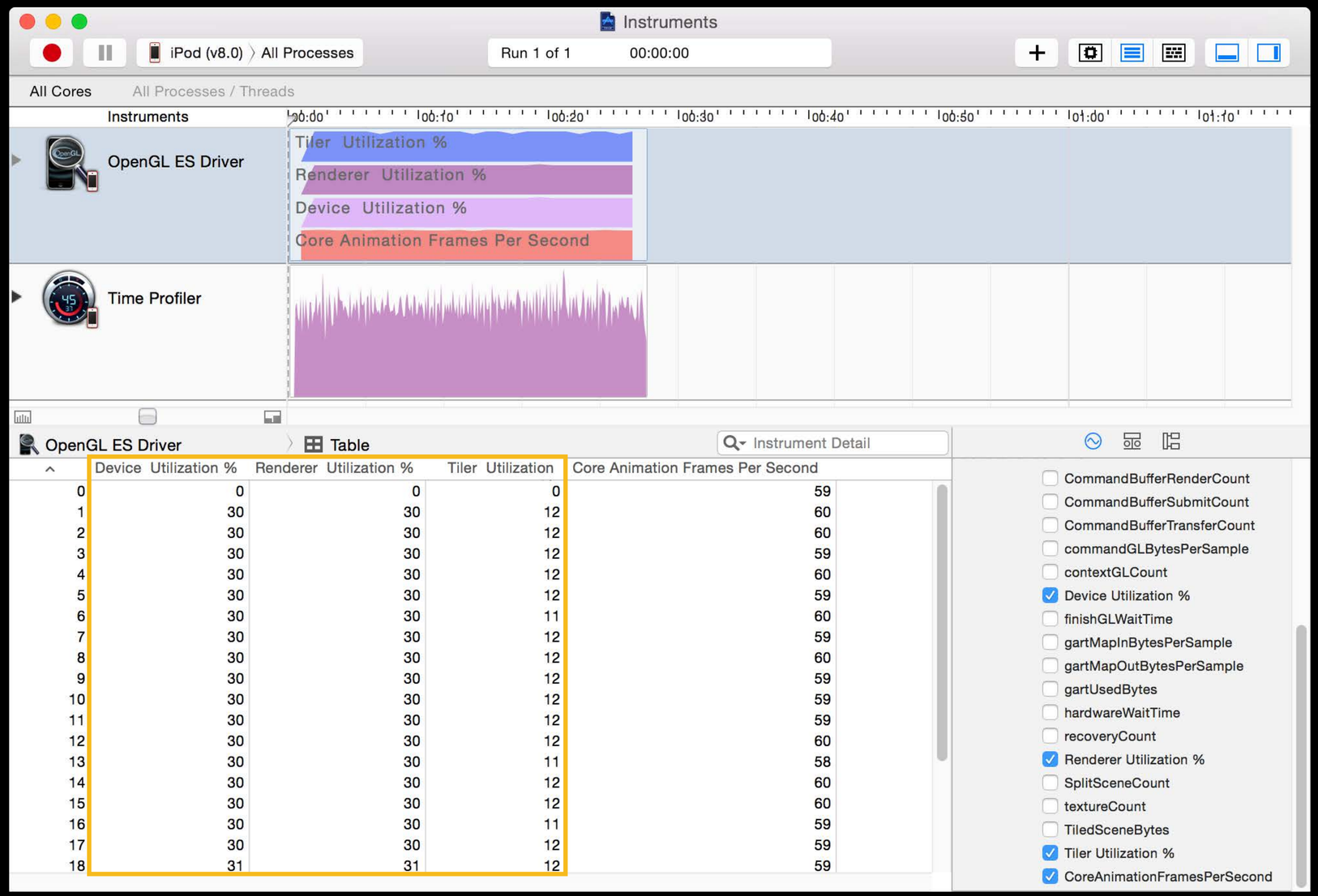
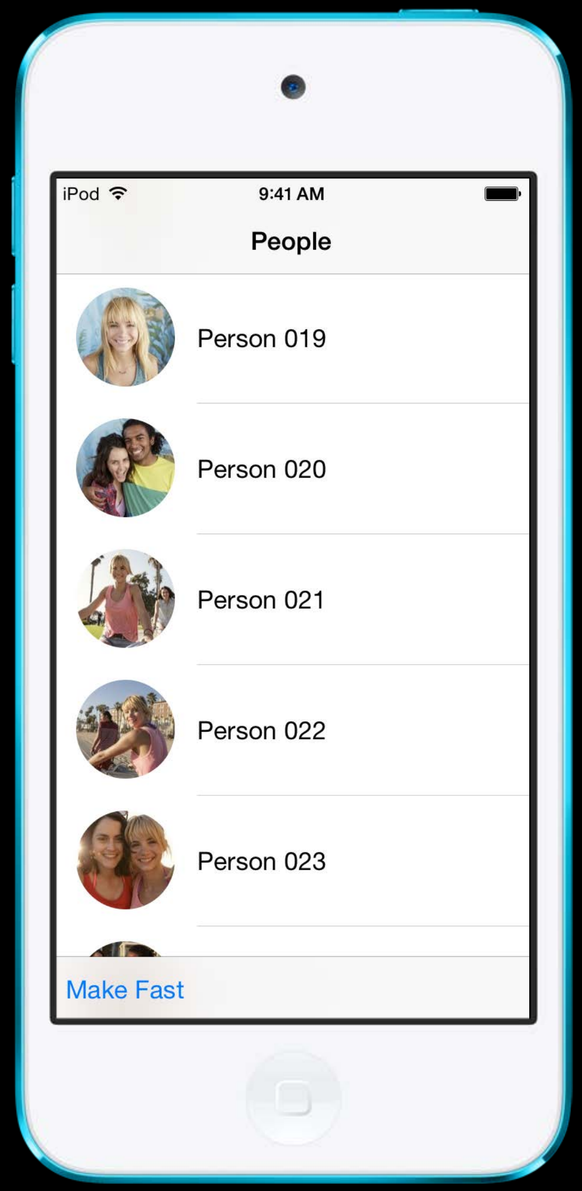
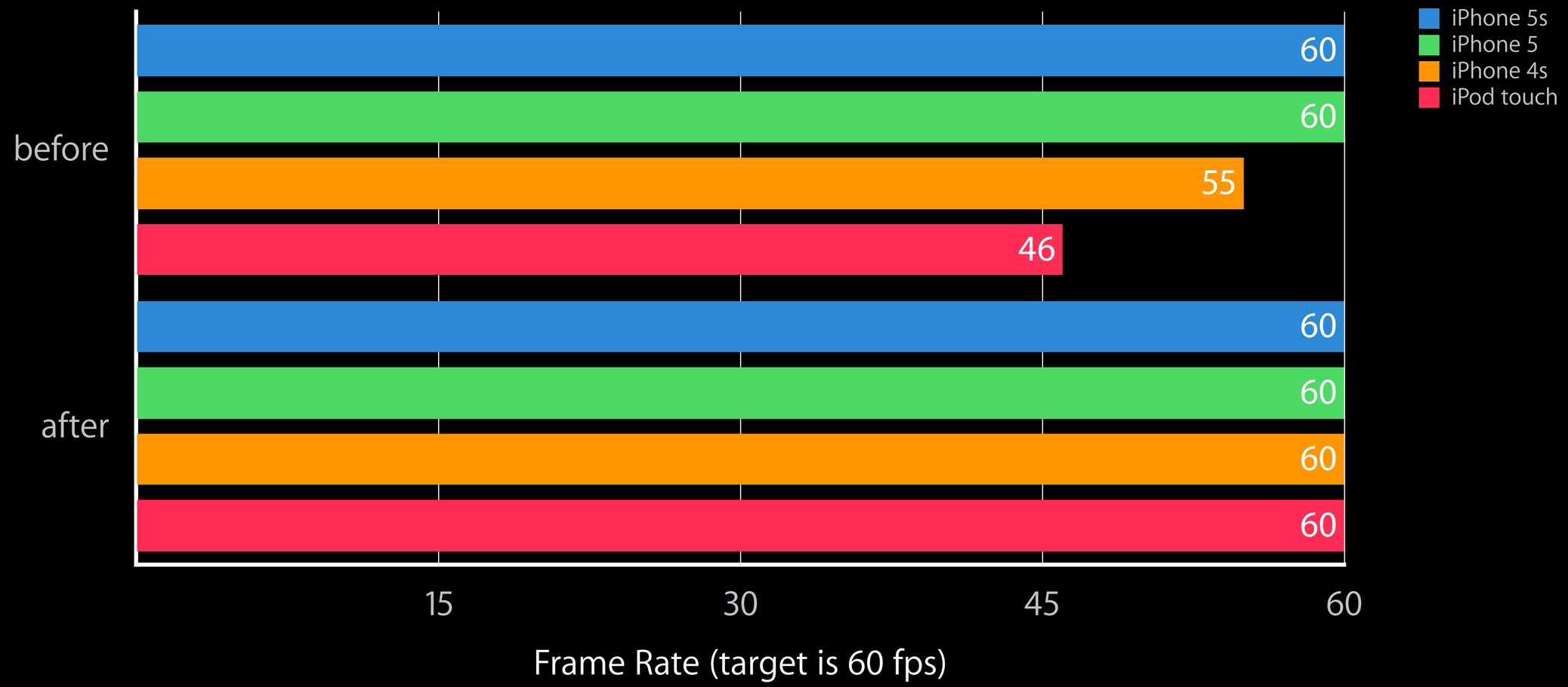




Fictitious Contacts Application

Performance across devices



Fictitious Contacts Application

Summary

Offscreen passes are expensive

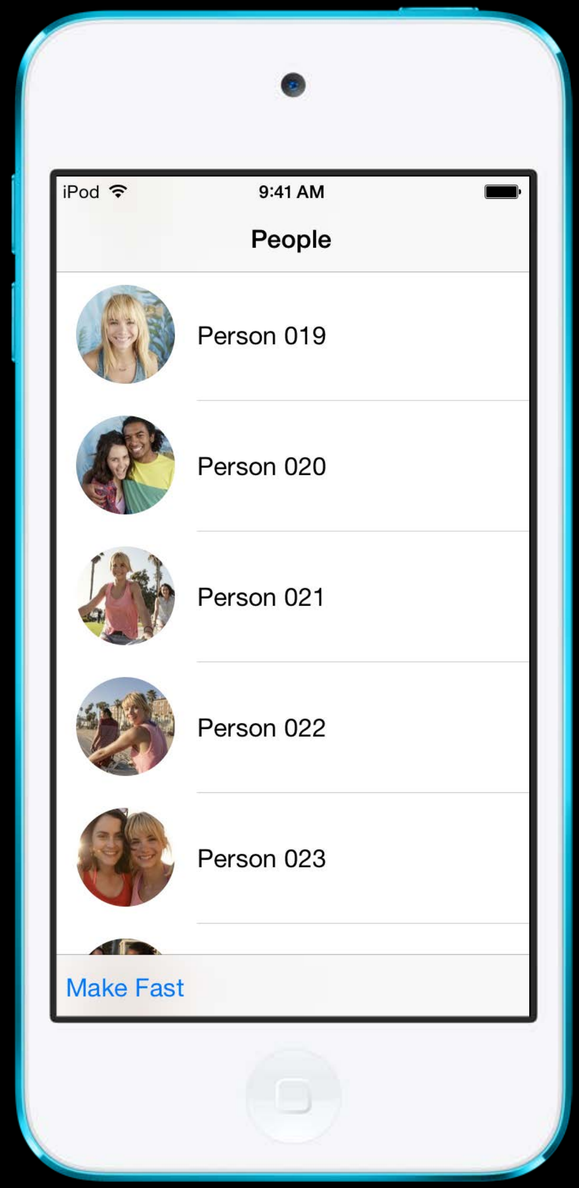
- Use Core Animation instrument to find them
- Know what you can do to avoid them

Measure performance across different devices

- Use OpenGL ES Driver instrument for GPU time
- Use Time Profiler instrument for CPU time

Know your view hierarchy and any hidden costs

- This is especially true for table cells and scrolling



Performance Investigation Mindset

Summary

What is the frame rate?	Core Animation or OpenGL ES Driver instrument
CPU or GPU bound?	OpenGL ES Driver and Time Profiler instrument
Any unnecessary CPU rendering?	Time Profiler instrument
Too many offscreen passes?	Core Animation instrument
Too much blending?	Core Animation instrument
Any strange image formats or sizes?	Core Animation instrument
Any expensive views or effects?	Xcode View Debugger
Anything unexpected in hierarchy?	Xcode View Debugger

Summary

Core Animation pipeline

Rendering concepts

`UIBlurEffect`

`UIVibrancyEffect`

Profiling tools

Case studies

More Information

Jake Behrens
App Frameworks Evangelist
behrens@apple.com

Dave DeLong
Developer Tools Evangelist
delong@apple.com

Documentation
Core Animation
http://developer.apple.com/library/IOs/documentation/Cocoa/Conceptual/CoreAnimation_guide/Introduction/Introduction.html

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

Related Sessions

Improving Your App with Instruments	Marina	Tuesday 4:30PM
Debugging in Xcode 6	Marina	Wednesday 10:15AM
Writing Energy Efficient Code, Part 1	Russian Hill	Wednesday 10:15AM
Writing Energy Efficient Code, Part 2	Russian Hill	Wednesday 11:30AM
Creating Custom iOS User Interfaces	Marina	Wednesday 3:15PM
Building Interruptible and Responsive Interactions	Presidio	Friday 11:30AM

Labs

Core Animation and Quartz 2D Lab	Graphics and Games Lab A	Tuesday 2:00PM
Interface Builder and Live Views Lab	Tools Lab C	Wednesday 9:00AM
Power and Performance Lab	Core OS Lab B	Wednesday 2:00PM
Dynamics, View Animations, and Core Animation Lab	Frameworks Lab A	Thursday 9:00AM
Power and Performance Lab	Core OS Lab A	Thursday 3:15PM
Visual Effects and Appearance Customization Lab	Frameworks Lab A	Friday 9:00AM

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