SCALABILITY FOR ALL: UNREAL ENGINE 4 ON INTEL

Jeff Rous, Senior Developer Relations Engineer, Intel
Rolando Caloca, Rendering Systems Lead, Epic Games
Agenda

Rationale (Why are we doing this?)
Understanding the Threading Model of Unreal Engine 4
CPU Optimizations
GPU Optimizations
Wrap up
Why Work Together?

Benefits all games that use the engine

UE4 runs on more hardware

Intel is 81% PC CPU share as of last Steam survey

Optimizations help everyone – high end to phone

Common goals

Scalability means more reach and available market

Leading edge APIs like DX12 are going to power tomorrow's games
UNDERSTANDING THE THREADING MODEL OF UNREAL ENGINE 4
UE4’s Threading Model

- **Game Thread**: Frame N, Frame N+1
- **Rendering Thread**: Frame N, Frame N+1
- **Physics Thread**: Frame N, Frame N+1
- **Audio Thread**: Frame N, Frame N+1

Time
UE4’s Threading Model: Game -> Rendering Thread

Game Thread

Frame N

Frame N

Frame N+1

Frame N+1

Rendering Thread

Time
UE4’s Threading Model: Game -> Rendering Thread

Game Thread

Rendering Thread

/**
 * Starts a new rendering frame. Called from the game thread
 */

void FViewport::EnqueueBeginRenderFrame(const bool bShouldPresent)
{
    AdvanceFrameRenderPrerequisite();
    FViewport* Viewport = this;
    ENQUEUE_RENDER_COMMAND(BeginDrawingCommand)(
        [Viewport](FRHICommandListImmediate& RHICmdList)
        {
            Viewport->BeginRenderFrame(RHICmdList);
        });
}
UE4’s Threading Model: Rendering

Rendering Thread

```c
void RenderingThread()
{
    // A
    AllocateRenderTarget(...);
}
```
UE4’s Threading Model: Rendering

Rendering Thread

```c
void RenderingThread()
{
    // A
    AllocateRenderTarget(...);
    RHI->BeginRenderPass(...);
}
```
UE4’s Threading Model: Rendering

Rendering Thread

```
void RenderingThread()
{
    // A
    AllocateRenderTargets(...);
    RHI->BeginRenderPass(...);
    // B
    CalculateViewUniformBuffer(...);
    RHI->SetUniformBuffer(...);
}
```
void RenderingThread()
{
    // A
    AllocateRenderTargets(...);
    RHI->BeginRenderPass(...);
    // B
    CalculateViewUniformBuffer(...);
    RHI->SetUniformBuffer(...);
    // C & D
    [...]
}
UE4’s Threading Model: RHI Command List

Rendering Thread

 void RenderingThreadCmdList()
{
   // A
   AllocateRenderTarget(...);
   RHICmdList.BeginRenderPass(...);
}

Enqueue

RHICmdList

Time

Rendering Command
D3D11 Command
RHI Command
UE4’s Threading Model: RHI Command List

Rendering Thread

A

B

Enqueue

void RenderingThreadCmdList()
{

    // A
    AllocateRenderTargets(...);
    RHICmdList.BeginRenderPass(...);
    // B
    CalculateViewUniformBuffer(...);
    RHICmdList.SetUniformBuffer(...);

    RHICmdList A B

Time
UE4’s Threading Model: RHI Command List

Rendering Thread

A  B  C  D

Enqueue

void RenderingThreadCmdList()
{
    // A
    AllocateRenderTarget(...);
    RHICmdList.BeginRenderPass(...);
    // B
    CalculateViewUniformBuffer(...);
    RHICmdList.SetUniformBuffer(...);
    // C & D
    [...]
}

Time

RHICmdList

Rendering Command
D3D11 Command
RHI Command
UE4’s Threading Model: RHI Command List

Rendering Thread: A B C D A

Translate:

void RenderingThreadCmdList() {
    [...]  // A
    RHI->BeginRenderPass(...);

RHICmdList: A B C D
UE4’s Threading Model: RHI Command List

Rendering Thread

A  B  C  D  A  B

Translate

Render Command
D3D11 Command
RHI Command

void RenderingThreadCmdList()
{
    [...]  // A
    RHI->BeginRenderPass(...);
    // B
    RHI->SetUniformBuffer(...);
}

Time

RHICmdList

A  B  C  D
UE4’s Threading Model: RHI Command List

Rendering Thread: A B C D A B C D

Translation:

```c
void RenderingThreadCmdList()
{
    [...]  // A
    RHI->BeginRenderPass(...);
    // B
    RHI->SetUniformBuffer(...);
    // C & D
    [...]  // C & D
}
```

RHICmdList: A B C D
UE4’s Threading Model: RHI Thread

Rendering Thread

A  B  C  D

RHI Thread

A

void RenderingThreadCmdList()
{
    [...]  
   // A
    RHI->BeginRenderPass(...);

Translate

RHICmdList  A  B  C  D

Time

Rendering Command
D3D11 Command
RHI Command
UE4’s Threading Model: RHI Thread

Rendering Thread

RHI Thread

```
void RenderingThreadCmdList()
{
    [...]  
    // A
    RHI->BeginRenderPass(...);
    // B
    RHI->SetUniformBuffer(...);
}
```

Translate

RHICmdList
UE4’s Threading Model: RHI Thread

Rendering Thread

RHI Thread

```cpp
void RenderingThreadCmdList()
{
    [...] // A
    RHI->BeginRenderPass(...);
    // B
    RHI->SetUniformBuffer(...);
    // C & D
    [...] // C & D
}
```

Time

Translate

RHICmdList
UE4’s Threading Model: Game -> Rendering -> RHI Thread

Game Thread

Frame N
Frame N+1
Frame N+2

Rendering Thread

Frame N
Frame N+1
Frame N+2

RHI Thread

Frame N
Frame N+1
Frame N+2

Time
UE4’s Threading Model: Parallel Frontend

Rendering Thread
Parallel Thread
Parallel Thread

Time

RHICmdList

Rendering Command
D3D11 Command
RHI Command
Parallel Command
UE4’s Threading Model: Parallel Frontend

Rendering Thread

Parallel Thread

Parallel Thread

Time

A

B

C

D

E

SubCmdList

SubCmdList

RHICmdList

A

B

C

D

E

Rendering Command
D3D11 Command
RHI Command
Parallel Command
UE4’s Threading Model: Parallel Frontend

- Rendering Thread
  - A
  - B

- Parallel Thread
  - C
  - D
  - E

- Parallel Thread
  - C
  - D

- Parallel Thread
  - E

- RHICmdList
  - A
  - B
  - C
  - D
  - E

- SubCmdList
  - C
  - D

- SubCmdList
  - E

- Rendering Command
- D3D11 Command
- RHI Command
- Parallel Command

Time
UE4’s Threading Model: Parallel Frontend

Rendering Thread

Parallel Thread

Parallel Thread

Time
UE4’s Threading Model: Parallel Frontend

- Rendering Thread
- Parallel Thread
- Parallel Thread
- RHI Thread

Time

Rendering Command
D3D11 Command
RHI Command
Parallel Command

RHICmdList

A B C D E F
CPU OPTIMIZATIONS
DirectX12 Optimizations

Problem: DX11 Render Thread Bottlenecks are starving the GPU but DX12 path is behind in performance. New Microsoft features (RTX, VRS) require DX12.

Driver and Engine investment to improve DX12 performance, from shader compilation to runtime efficiency.
Chaos Physics

- Brand new physics system unveiled at Epic’s GDC keynote.
- Worked closely with Epic to optimize low level solvers, data structures, and thread parallelism.
- Key learnings
  - C++ is bad at SIMD. Integrated Intel ISPC for ~3x gains in perf critical areas.
  - TSet is bad in high performance situations. Use TArray, Sort and RemoveSwap rather than guard dupes with TSet.Contains.
  - ParallelFor can be overused! Some oversubscription is good but don't go overboard with 1000s of jobs. Batch!
Intel SPMD Program Compiler (ISPC) Integration

• Problem: In perf critical code, C++ often doesn’t cut it. Usual solution is intrinsics. Not anymore!

• Implicit parallelism: SIMD lanes act similar to GPU shader invocations

• Write Once, Compile to many vectorized instruction sets (SSE4, AVX, AVX2)

• Used in Chaos, available in UE4 soon!
  • Include ISPC module in your build.cs
  • Add ispc files to your project
  • Include a generated C++ header
  • Unreal build tool handles the rest

Scalar and vectorized loop versions with Intel® SSE, AVX and AVX-512.
When to use ISPC?

- Good for dense compute-bound workloads. Heavy math like physics intersection testing, cloth or CPU vertex transformations
- Best with contiguous memory load, manipulate, store ie TArray
- Best when no data dependencies between operations. Especially useful when combined with ParallelFor and batching

```c
export void rgb2grey(uniform int N, uniform float r[], uniform float g[], uniform float b[], uniform float grey[])
{
    foreach (idx = 0 ... N) {
        grey[idx] = 0.3f * r[idx] + 0.59f * g[idx] + 0.11f * b[idx];
    }
}
```

... 

```c
vmulps (%rdx,%rax), %ymm1, %ymm3
vfmadd231ps (%rsi,%rax), %ymm0, %ymm3
vfmadd231ps (%rcx,%rax), %ymm2, %ymm3
vmovups %ymm3, (%r8,%rax)
...
```
Cascade CPU Particles

For enhanced realism (level lighting, bouncing, complex interactions).

- Legacy physics engine had issue with locking scene on reads, causing serialization through a critical section.
- No exiting support for ticking CPU particles in parallel.
- Fixing both gave up to 4x throughput improvement per frame
- Patch available for 4.19+
Intel® VTune™ Amplifier

Intel® Vtune™ Amplifier enables deep profiling and problem identification. Hotspots, locks, syncs, multithreading, even GPU data!

With 4.19, new support for event based CPU sampling using itt_notify framework.

Use –VTune on the command line and stat NamedEvents on the console.

Vtune™ is now free!
Embree enables fast light baking for breathtaking visuals.

“Intel Embree is pretty good. 4x faster Lightmass ray tracing which results in 2.4x faster lighting builds” – Daniel Wright, Technical Director, Graphics, Epic Games

Embree is fully enabled for multicore
Used by default in static light builds
ISPC Texture Compression

Unreal Engine 4 now has support in the public engine release for Intel’s fast texture compressor

Unreal needs multiple industry standard formats (BC6H/BC7/ASTC)

44x average speed improvement, making this the fastest in the industry on Intel

Epic found SunTemple texture compression time drop from 68 min to 35 secs on a Macbook Pro!
ASTC Quality Comparison

Zoomed in portion of a 2048x2048 normal map

Original: 12 MB
ETC1: 2 MB
ASTC 6x6: 1.8 MB
GPU OPTIMIZATIONS
Masked Occlusion Culling

CPU-based alternative Hi-Z buffer representation for fast, low-latency occlusion queries.

- Much less memory to read/write than full res z-buffer.
- Updates use bitmasks – can process many pixels in parallel (i.e. SSE4.1/AVX2).
- No need for conservative art assets (although faster if so).
- Integrated into UE4 threading systems.
- Compatible with LLVM/Clang for cross platform support.

### Intel Castle Sample, Performance Comparison

<table>
<thead>
<tr>
<th></th>
<th>Draw All</th>
<th>Frustum culling only</th>
<th>AVX2 Threaded (10C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPS</td>
<td>143</td>
<td>194</td>
<td>650</td>
</tr>
<tr>
<td>MS</td>
<td>6.9</td>
<td>5.14</td>
<td>1.53</td>
</tr>
<tr>
<td>Drawcalls</td>
<td>20801</td>
<td>6518</td>
<td>1512</td>
</tr>
</tbody>
</table>
MOC Binned rendering

• Transform triangles into screen space.
• Bin by screen-space tiles.
• Use ScissorRect to clip contents.
• 1 active tile per TaskGraph thread.
Problem: GPU cost varies over time

• In general, more content means longer frames
• If last frame was slow, potentially current one will be too:
  • Particles/fog/smoke
  • More draw calls
  • Higher density objects
  • ... etc!
Dynamic Resolution

- Available since 4.21!
- Adjusts the primary screen percentage according to the previous frames' GPU workload and/or game control

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Disabled (Default)</td>
</tr>
<tr>
<td>1</td>
<td>Enabled based on the setting used in GameUserSettings.</td>
</tr>
<tr>
<td>2</td>
<td>Enabled regardless of the setting used by GameUserSettings.</td>
</tr>
</tbody>
</table>
## Dynamic Resolution

<table>
<thead>
<tr>
<th>Console Variable</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>r.DynamicRes.MinScreenPercentage</td>
<td>50</td>
<td>Sets the minimum screen percentage to use.</td>
</tr>
<tr>
<td>r.DynamicRes.MaxScreenPercentage</td>
<td>100</td>
<td>Sets the maximum primary screen percentage that is used to allocate render targets.</td>
</tr>
<tr>
<td>r.DynamicRes.FrameTimeBudget</td>
<td>33.3</td>
<td>Sets the budget of the frame (in milliseconds).</td>
</tr>
</tbody>
</table>
Dynamic Resolution

• *stat unit* to show if it’s enabled

• *When on, X% by Y%

• *For more info:* https://docs.unrealengine.com/en-us/Engine/Rendering/DynamicResolution

• *Or Google “Unreal Engine Dynamic Resolution” ;)*
Dynamic Resolution

- **stat unitgraph**
  - 1- Timings (filtered or raw)
  - 2- Target Frame Time
  - 3- Dyn Res Max Screen %
  - 4- Dyn Res Screen % curve

- Originally supported only on consoles...
Dynamic Resolution

• Intel added driver API support to Unreal to access low level hardware counters

• Why isn’t this a solved problem using API timestamps?

• Timestamp = GPU + CPU time. Want just GPU time to avoid CPU bubbles.

• Feature previously only available on console now on PC
Variable Rate Shading

Problem: Spending pixel shading time on far away/motion-blurred objects.
Variable Rate Shading

1.33x Speedup
CPS Constant 2x2
Problem: Anti-Aliasing Performance v. Quality

Tradeoff between extremes: temporal blurring or unreadable text?

Source  | FXAA 3.11  | SMAA  | CMAA2  | CMAA2-ExtraSharp
Sharpness vs anti-aliasing
Conservative Morphological Anti-Aliasing 2.0
Final Thoughts

• We’ve talked about a bunch of things that improve performance and help developer quality of life both on CPU and GPU

• Go try out the things we’ve worked on!

• Give us feedback on what we can work on next. Tell us about your pain points.

Talk back to us! Twitter handles @jeff_rous and @rcalocao
QUESTIONS?
Questions?
Unreal Engine 4 Samples and Whitepapers


Optimization Guide (software.intel.com/en-us/articles/unreal-engine-4-optimization-tutorial-part-1)

CPU Optimizations for Cloth Simulations (software.intel.com/en-us/articles/unreal-engine-4-blueprint-cpu-optimizations-for-cloth-simulations)

Setting up Destructive Meshes (software.intel.com/en-us/articles/unreal-engine-4-setting-up-destructive-meshes)

CPU Scaling Sample (github.com/GameTechDev/RCRaceland)
Legal Notices and Disclaimers

No license (express or implied, by estoppel or otherwise) to any intellectual property rights is granted by this document.

Intel disclaims all express and implied warranties, including without limitation, the implied warranties of merchantability, fitness for a particular purpose, and non-infringement, as well as any warranty arising from course of performance, course of dealing, or usage in trade.

You may not use or facilitate the use of this document in connection with any infringement or other legal analysis concerning Intel products described herein. You agree to grant Intel a non-exclusive, royalty-free license to any patent claim thereafter drafted which includes subject matter disclosed herein.

The products and services described may contain defects or errors known as errata which may cause deviations from published specifications. Current characterized errata are available on request.

Intel technologies' features and benefits depend on system configuration and may require enabled hardware, software or service activation. Performance varies depending on system configuration. No computer system can be absolutely secure. Check with your system manufacturer or retailer or learn more at intel.com.

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more complete information visit www.intel.com/benchmarks.

Optimization Notice: Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Results have been estimated or simulated using internal Intel analysis or architecture simulation or modeling, and provided to you for informational purposes. Any differences in your system hardware, software or configuration may affect your actual performance.

Intel, Core and the Intel logo are trademarks of Intel Corporation in the U.S. and/or other countries.

*Other names and brands may be claimed as the property of others

© Intel Corporation.