VU Entwurf und Programmierung einer Rendering-Engine

Introduction

Examples rendering engines

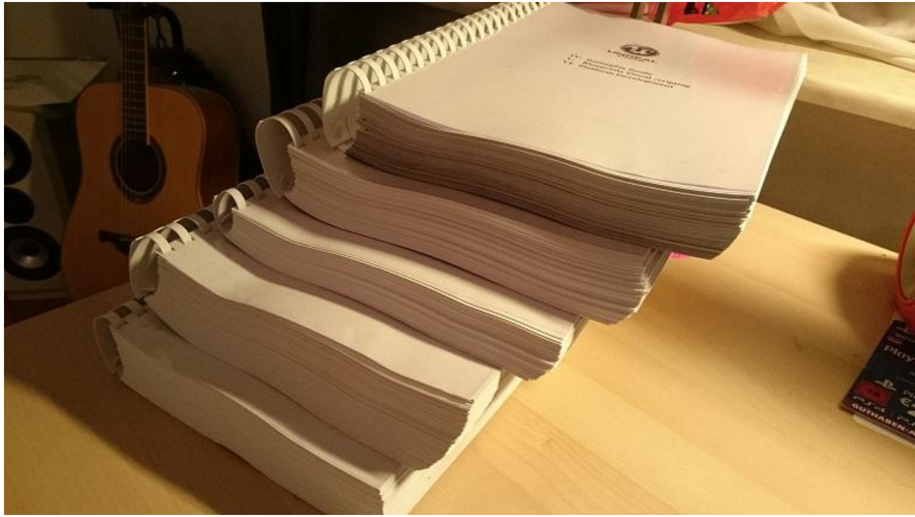
- Frostbite
- Effects, Level of Detail, Performance, Culling, Tooling,....

[image for copyright reasons ommited]

Examples rendering engines

- Unreal
- Level editor, strong tooling, runs on every console & hardware

[image for copyright reasons ommited]



https://forums.unrealengine.com/community/general-discussion/6602-pdf-for-ue4-documentation-available

Game engines

- Have physically based lighting & materials and strive for realism
- But also have artistic input and support movie-like design
- Algorithms often fake approximations of “realism” in order to achieve Real-time performance

- Make it fast & look good
- Challenge: high quality visuals with limited dynamism & real time
- Provide programmer interface (APIs, tooling)

Movie engines

- Physically based scene description and light
  - Advanced effects like dispersion, refraction ..
- Hacks and extensions to allow “unrealistic” artistic effects

- Make it exact & accurate & controllable
- Challenge: number of pixels/samples
- Toolchain integration instead of focus on APIs

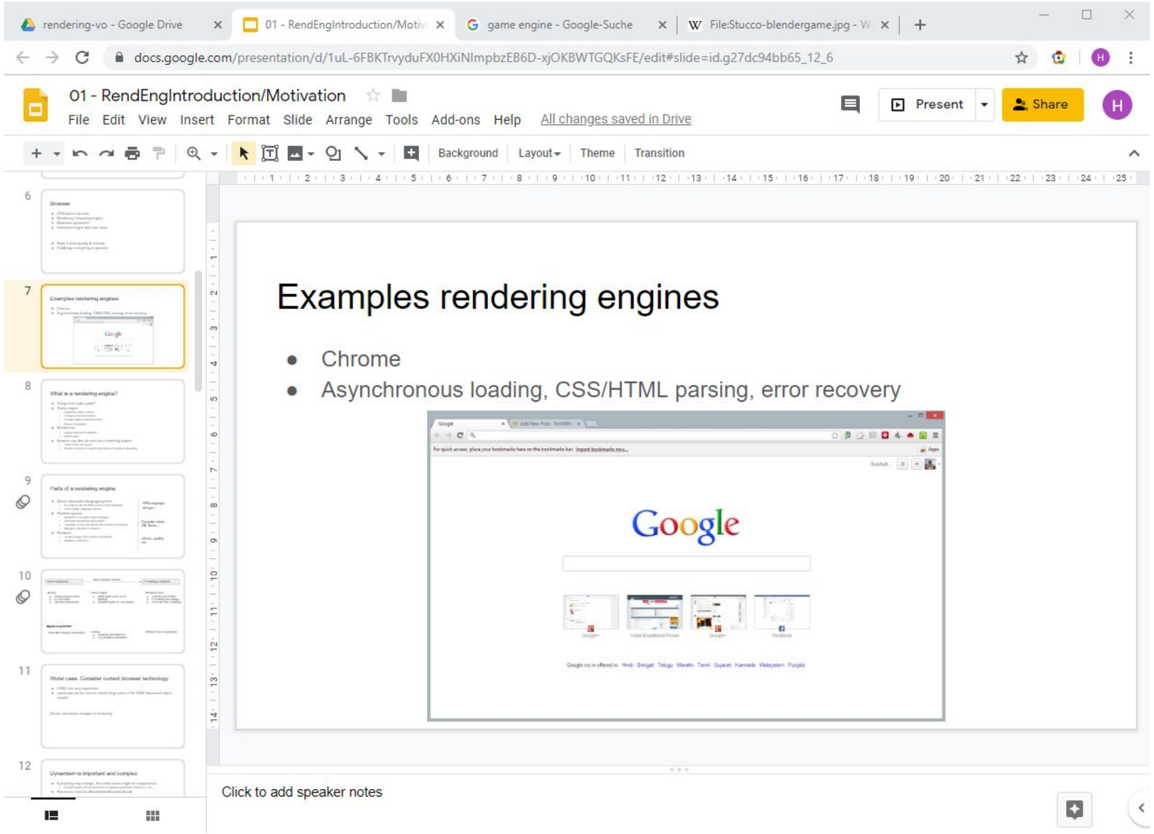
Browser

- CAD tool on steroids
- Rendering + layouting engine
- Maximum dynamism
- Execution engine with user input

- Make it work quickly & robustly
- Challenge: everything is dynamic

Examples rendering engines

- Chrome
- Asynchronous loading
- CSS/HTML parsing,
- error recovery



What is a rendering engine?

- Things that make pixels?
- Game engine
  - Dynamic & static content
  - Tooling & content creation
  - Complex light & material system
  - Physics simulation
- Renderman
  - Light & material description
  - Artistic input
- Browser can also be seen as a rendering engine
  - Turns HTML into pixels
  - Includes real time requirements such as responsive layouting

Parts of a rendering engine

- Scene description language/system
  - Developers can describe scenes in this language
  - Scene graph, language ruleset
- Runtime system
  - Interprets or compiles input language
  - Hardware dependent optimization
  - Translates scene description into renderer operations
  - Manages, allocates resources
- Renderer
  - Creates image from renderer operations
  - Raytracer, rasterizer

API/Language design...

Compiler tasks, OS Tasks,...

effects, quality etc.

Limited dynamism → More dynamic content → Everything is dynamic

Movies
- mostly preprocessed
- no user input
- only time dependent

Game engine:
- Static parts (level, level lighting)
- Dynamic parts (AI, user input)

Interactive tools
- CAD/Browser/Editor
- Everything can change
- User can edit everything

Degree of dynamism:

Often little real-time interaction

Limited
- Dynamic stuff baked in
- e.g. prebaked animation

Strong focus on dynamism

Worst case: Consider current browser technology

- HTML tree very expressive
- Javascript can be used to rewrite large parts of the DOM (document object model)

[Demo: interactive changes in browsers]

Dynamism is important and complex

- Everything may change. The entire scene might be swapped out.
    - Consider page refresh in browsers or dynamic javascript content (e.g. D3)
- Resources must be allocated/deallocated cleanly
- … while maintaining interactive performance

Dependencies: Incremental updates to the rescue

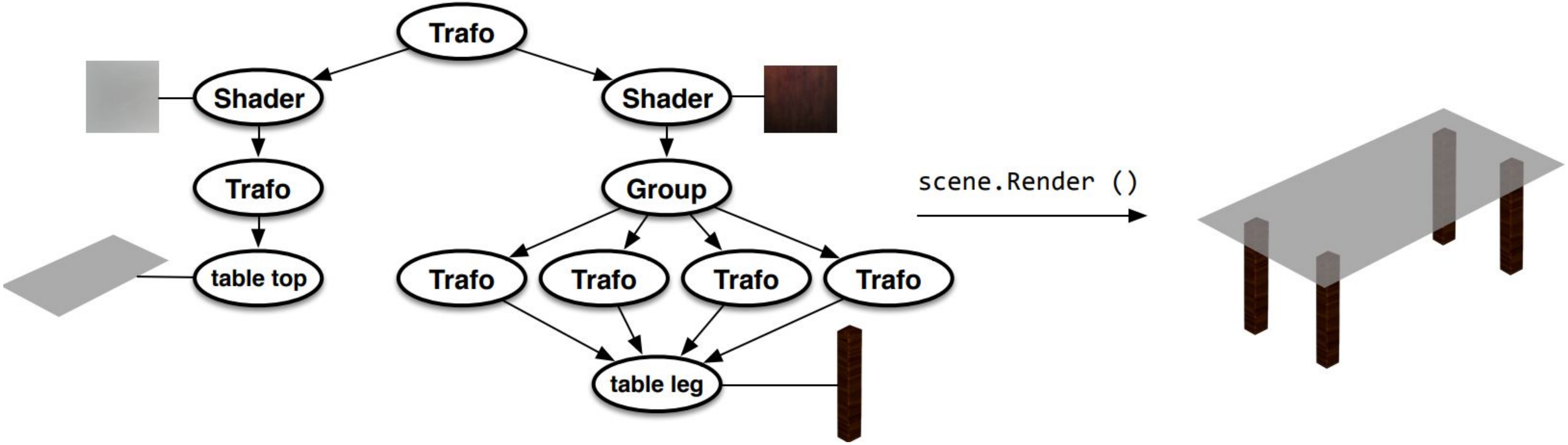
- Something changed -> refresh everything -> bad performance
- Smart Dependencies?
  - Every value becomes observable/change tracking system
  - Simple dependencies give rise to dependency graph
- Dependent change -> everything that depends on it
  - Incremental update
- Graph itself is dynamic
  - Structural change -> hard to handle, non-local effects

Abstraction

- Vulkan cube.cpp is 2900 lines of code
  - https://github.com/googlesamples/vulkan-basic-samples/blob/master/demos/cube.cpp
- Clearly, there is a need for abstraction
- Various types
  - macros
  - Reusable utility functions (e.g. createShader)
  - Notation for objects? Object list
  - Common abstraction: scene graph
    - e.g. HTML, Markdown, UI elements, scene entity tree

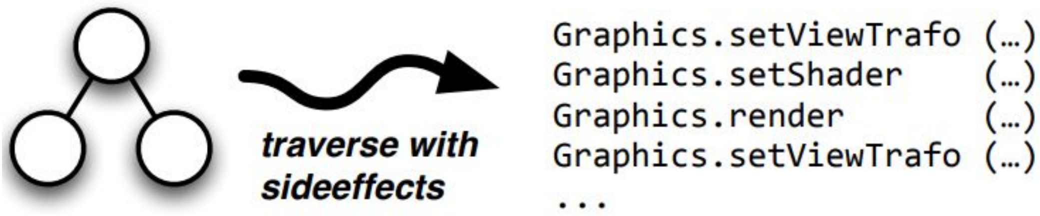
What is a scene graph

- Most general scene description
- At first glance: feel natural
- But also supports the level of dynamism & abstraction required
  - Not that easy, but we will see how….



Naive scene graph implementation

- Implementation -> traverse, allocate resources on the fly
  - OpenGL intermediate mode view



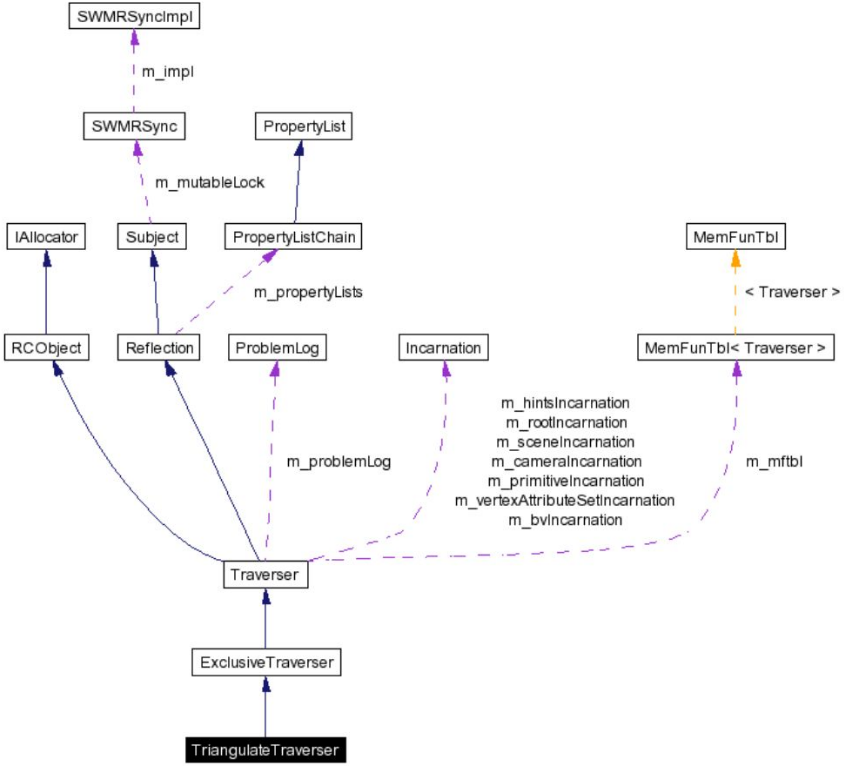
  - Command-buffer implementation possible.

- What happens if scene is dynamic: simple -> traverse again (cache resource allocations)
  - Question: when to free resources: garbage collection
  - Question: when to retraverse?
  - Answer: don’t know -> always

Better scene graph implementation

- Finding appropriate abstraction is challenging.
- Abstraction in combination with dynamism is even harder.
- How to provide expressive/easy to use APIs?

Try to combine those with optimal performance / best hardware utilization!



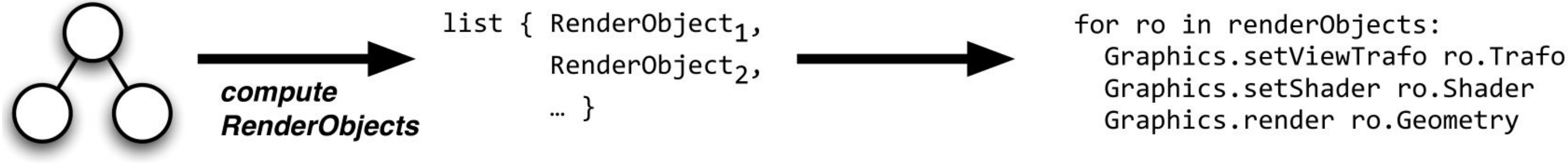
[nvidia, scenix documentation]

Scene graph rendering (evaluating the graph)

Translating scene graph input structure directly (in one step) into graphics instructions is hard. Can we approach the problem differently?

Comparison: it is hard to translate c++ directly into machine code. Most compilers use appropriate intermediate representation

- Is there a common intermediate representation in our domain?
- We focus on rasterizer-specific features
    - Materials/BRDFs in ray tracer VS cullmode stencil in GL



Requirements for Rendering Engines

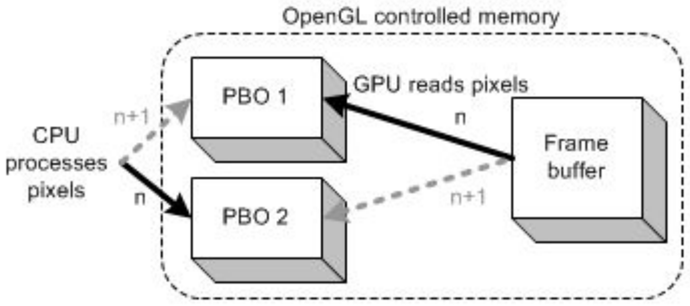
- Easy to use and extend
- Translation of scene description into graphics commands

- **Performance**
  - Utilize graphics hardware as best as possible!!!
  - Responsiveness
  - High-frequency changes

Graphics API Insights required

- In OpenGL there are dozens of ways to solve a problem inefficiently.

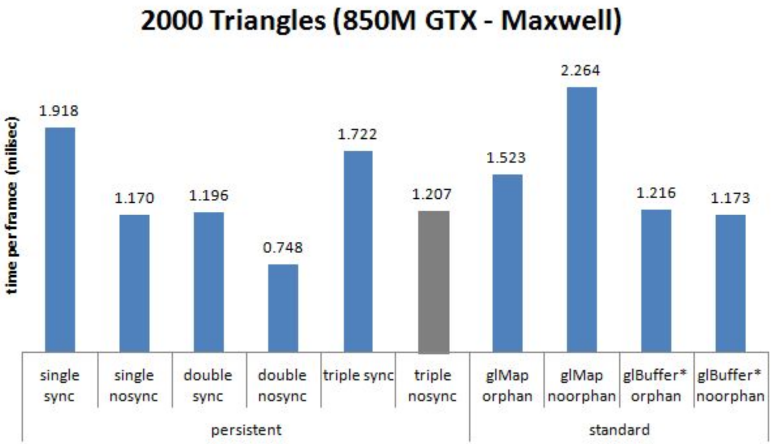
```
index = (index + 1) % 2;
nextIndex = (index + 1) % 2;


glReadBuffer(GL_FRONT);

glBindBufferARB(GL_PIXEL_PACK_BUFFER_ARB, pboIds[index]);
glReadPixels(0, 0, WIDTH, HEIGHT, GL_BGRA, GL_UNSIGNED_BYTE, 0);
glBindBufferARB(GL_PIXEL_PACK_BUFFER_ARB, pboIds[nextIndex]);
GLubyte* ptr = (GLubyte*)glMapBufferARB(GL_PIXEL_PACK_BUFFER_ARB,
                                        GL_READ_ONLY_ARB);
if(ptr)
{
    processPixels(ptr, ...);
    glUnmapBufferARB(GL_PIXEL_PACK_BUFFER_ARB);
}

glBindBufferARB(GL_PIXEL_PACK_BUFFER_ARB, 0);
```



http://www.songho.ca/opengl/gl_pbo.html

Graphics API Insights required

- There are a many approaches for uploading data to OpenGL. Even on single hardware there are significant differences…
- Dozens talks, forum discussions, e.g.:
    - Beyond Porting - How Modern OpenGL can radically Reduce Driver Overhead, [Everitt, https://www.slideshare.net/CassEveritt/beyond-porting]



http://www.bfilipek.com/2015/01/persistent-mapped-buffers-benchmark.html

Low level optimizations

- For high performance, we need to know the cost of abstraction:
- Examples:
  - Loop overhead in image processing: memcpy vs copying pixel by pixel
  - Allocation overhead: e.g. accidental allocations in scene graph traversal
  - Virtual calls in performance critical code?
  - How is multiple inheritance implemented? What are the costs

Our OpenGL renderer has a custom AMD64 assembler...

```
member x.Mov(target : Register, value : uint32) =
    if target < Register.XMM0 then
        let tb = target |> byte
        if tb >= 8uy then
            let tb = tb - 8uy
            let rex = 0x41uy
            writer.Write(rex)
            writer.Write(0xB8uy + tb)
        else
            writer.Write(0xB8uy + tb)


        writer.Write value


    else
        x.Mov(Register.Rax, value)
        x.Mov(target, Register.Rax, false)
```

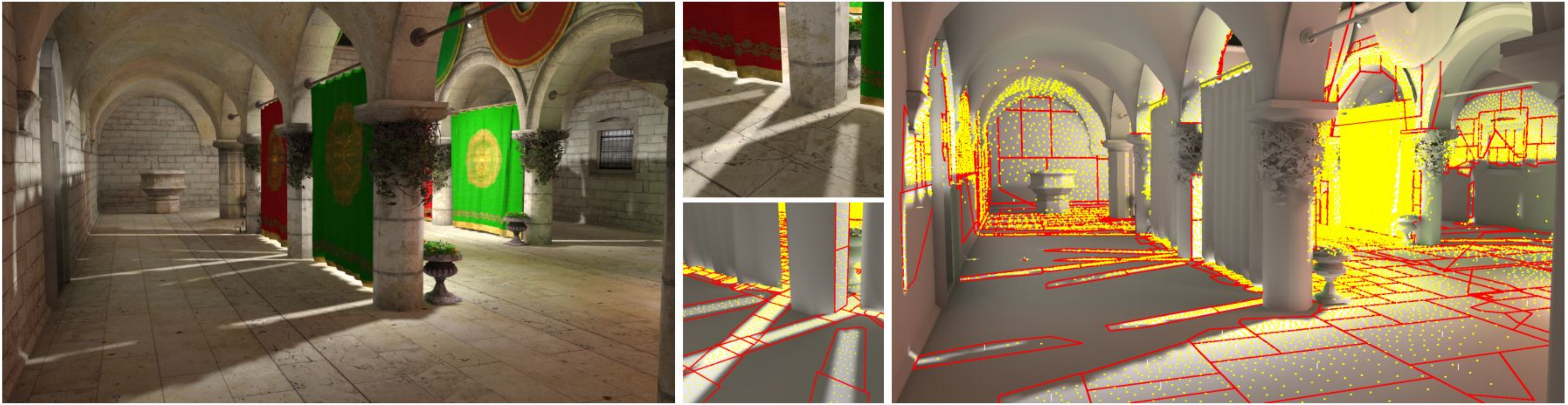
Towards interactive lighting systems

Armed with technical tools for

- Abstraction
- Mechanisms for handling dynamism
- Algorithms and datastructures
- Low level understanding and techniques

We turn shift our focus towards tooling for real-world interactive lighting simulation….

Later in this lecture we return to more traditional rendering techniques again...



Images © VRVis

Two lectures by Christian Luksch. Topics:

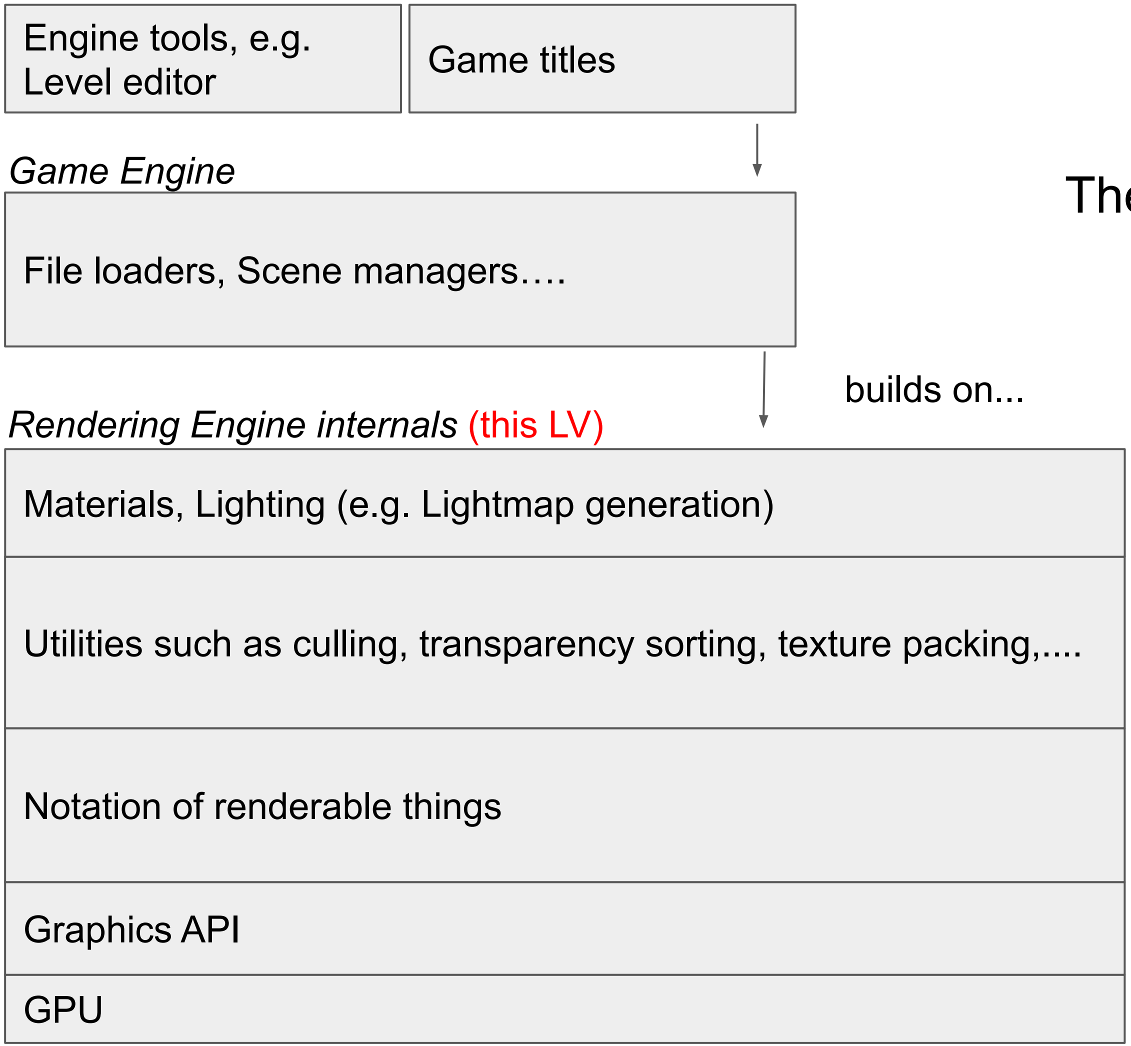
- Material systems
- Instant radiosity
- Deferred Rendering
- Physically based shading

Topics of this LV

- Render scenes efficiently using graphics hardware
  - Graphics Hardware and API (recap)
  - Common infrastructure for rasterizer-based rendering backend (intermediate language)
  - Scene description
  - Optimization techniques

- Rendering scenes nicely
  - Using lighting and material systems
  - Concrete techniques such as shadow mapping is part of other lectures
  - Here we focus on practical implementations thereof

The big picture…..



Rendering Engine internals

Materials, Lighting (e.g. lightmap generation)

Utilities such as culling, transparency sorting, texture packing,....

Notation of renderable things

Graphics API

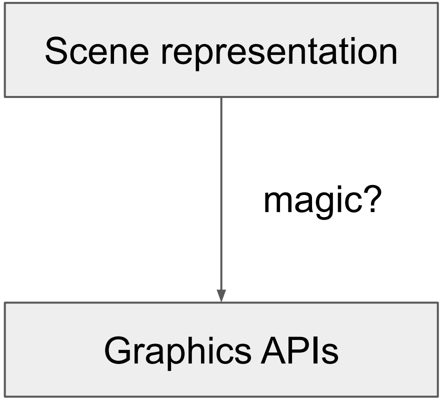
GPU

High-level Abstraction:
Graphics scenes, Shaders...

efficient mapping?

High-level Abstraction:
Graphics scenes, Shaders...

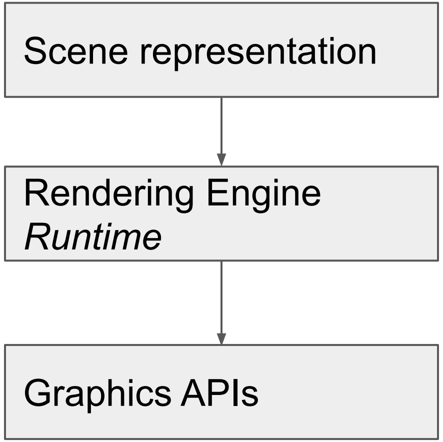
Bridging the gap



Two approaches:

- Condense scene to minimal representation and then map it to hardware
- Given hardware, what utilities can we expose to build more powerful tools?

Bridging the gap



Two approaches:

- Condense scene to minimal representation and then map it hardware
- Given hardware, what utilities can we expose to build more powerful tools?

Upcoming topics I

- Top down: Traditional scene graph systems
  - Implementation techniques
  - Advantages and disadvantages
- Bottom up: Hardware capabilities and their implications
- Bridging the gap: Towards a rendering engine runtime system
  - How to model scene data in order to map it to graphics hardware efficiently.
- Low-level optimizations for efficient graphics programming
  - Towards adaptive optimizations
- Algorithmic optimizations
  - Algorithms and data structures for rendering engines

Upcoming topics II

- Practical topics for rendering engines
  - Performance considerations
  - Precision considerations
- Domain specific languages for
  - Dynamic data
  - Scene representation (in presence of dynamic data)
  - Shader programming
- Towards real-time high quality lighting
  - Global Illumination, Material models
  - Physically based shading
  - Deferred Shading
  - Instant radiosity, Texture packing

Videos

- Siggraph 2016: Surface-only liquids
  - offline-rendering
  - https://www.youtube.com/watch?v=9gUSmYRl8B8
- Battlefield 1 gameplay
  - User input
  - https://www.youtube.com/watch?v=-NxAzWAM9Hc
- Unity game dev speed-up
  - Scene description & scripting languages
  - https://www.youtube.com/watch?v=fiHRxD1yE4Y