Maxwell

NEXT LIMIT

Porting Maxwell to the GPU

Top Challenges

Juan Cañada
Head of Visualization
Next Limit Technologies

GPU TECHNOLOGY CONFERENCE

Maxwell

Agenda

- Maxwell overview
- Why porting to the GPU was challenging
- Performance considerations
- Using the CPU to improve the GPU engine
- Summary

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Maxwell Overview

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RealFlow

CaronteFX

Maxwell

Maxwell Overview

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MAXWELL

- First physically based render in the market (2004)
- Ground-truth reference render
- Predictive rendering tool
- Light analysis tool

Maxwell in use

- Animation & VFX
- Architecture
- Industrial Design
- Science
- Others

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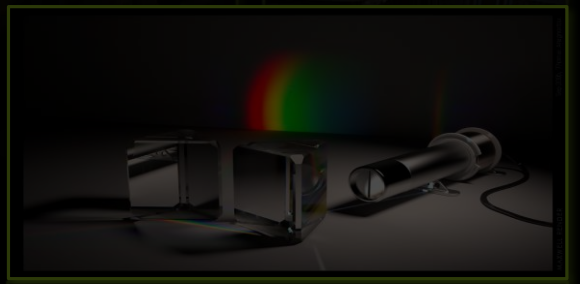


Maxwell in use

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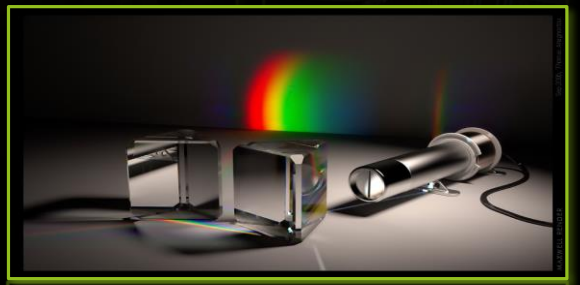

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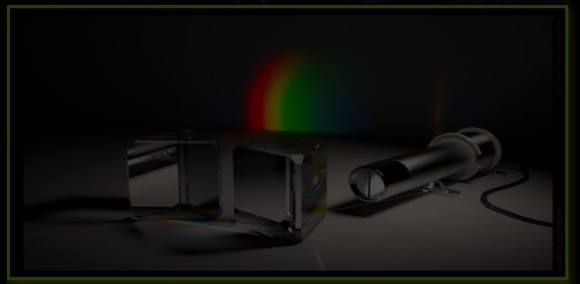


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Challenges

- Keep pixel accuracy
- Use GPU for predictive rendering
- Improve performance
- Spectral, unbiased, accurate PBR
- Support CPU & GPU resuming & merging
- …

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Predictive Rendering

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Photo.
Nikon D70. Focal lenght 24mm. CCD sensor size 23.7x15.6mm. Manual settings
ISO 200 / fStop 8 / Shutter speed 90 / WB set with 6500K lamp in Cornell box
Cornell box dimensions 50x50x50cm
Compact fluorescent lamp Philips Master PL electronic 865 (6500k daylight white)
27W / 1700 lumen / efficacy 62,96 lumen/W

Maxwell render 1.0
Maxwell camera. Focal lenght 24mm. Film size 23.7x15.6mm.
ISO 200 / fStop 8 / Shutter speed 90 / Burn 1 / Gamma 2.2
Scene box dimensions 50x50x50cm
Maxwell emitter 6500k / 27W / 1700 lumen / efficacy 62,96 lumen/W

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Correct → Fast ☺

Fast → Correct ☹


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Maxwell GPU Architecture

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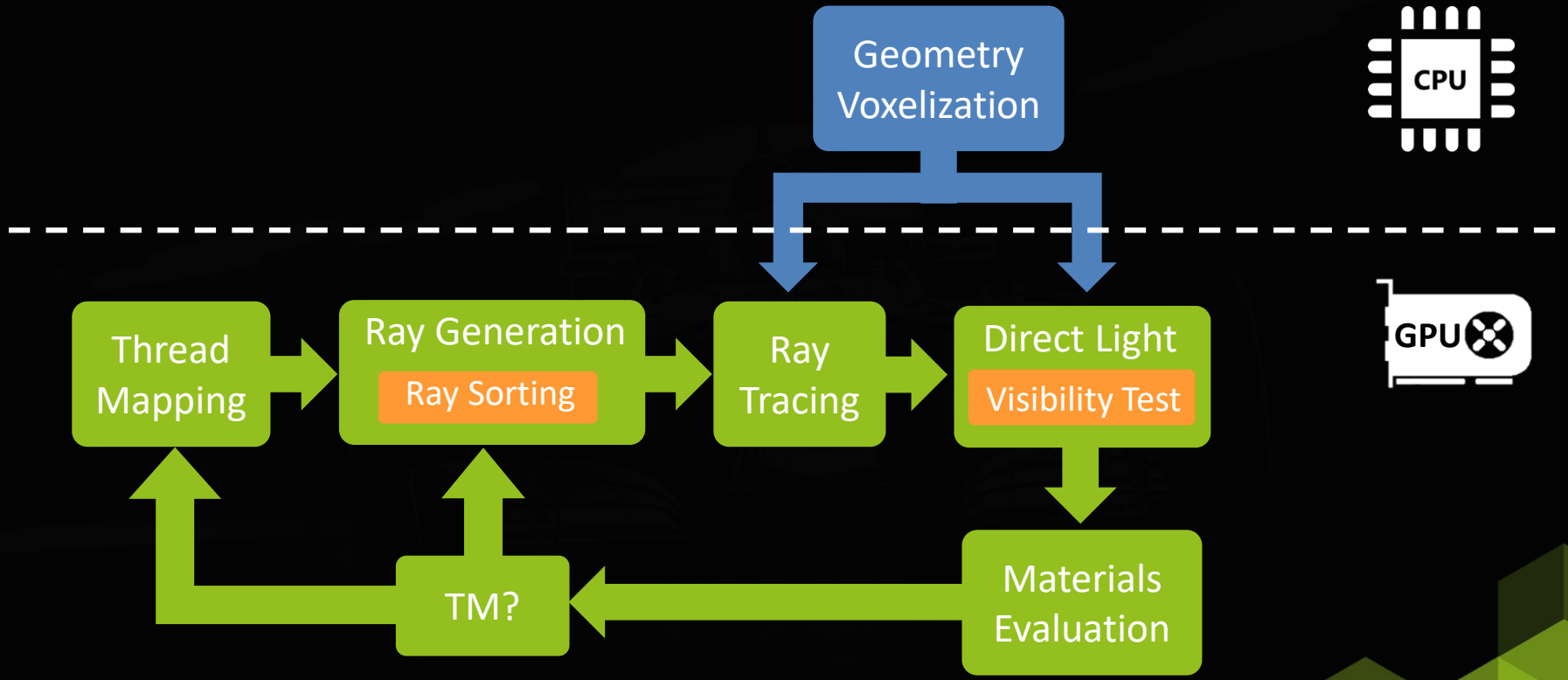

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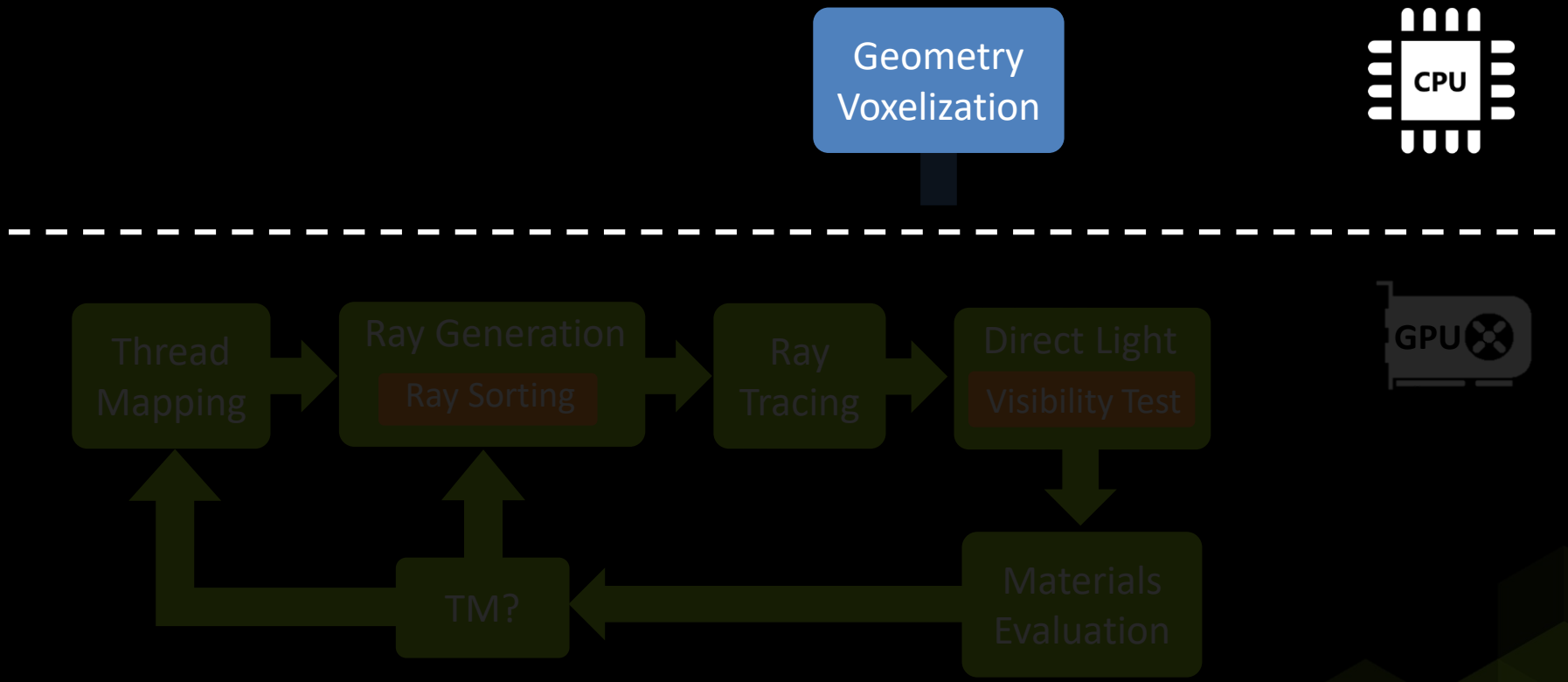

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- Voxelization
  - Same Voxelization system as the CPU render
  - Currently performed in CPU just once
  - BVH
    - Binary tree (each node has 2 childs)
    - Coherent traversal

- \+ All threads fetch same amount of data / node
- \+ Increase coherence in performance
- \- Trees become bigger

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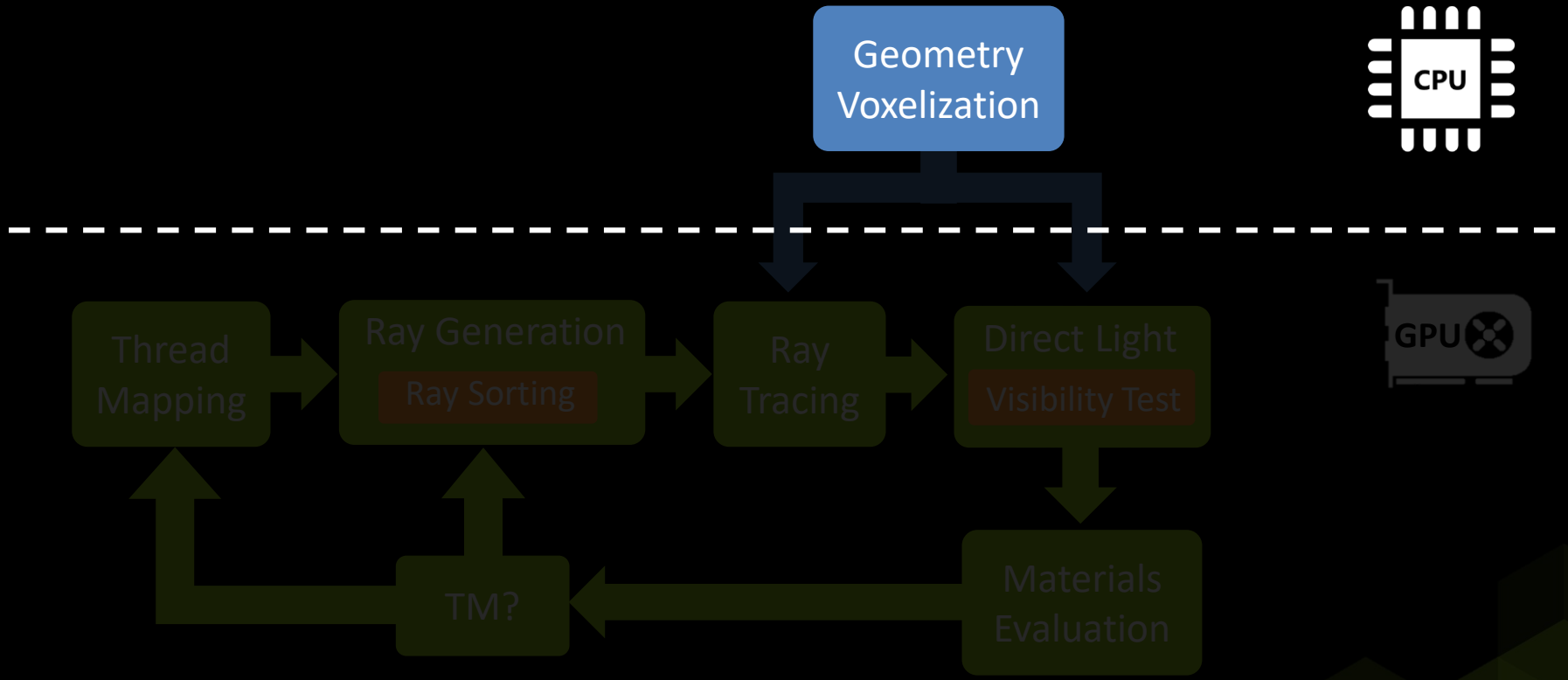

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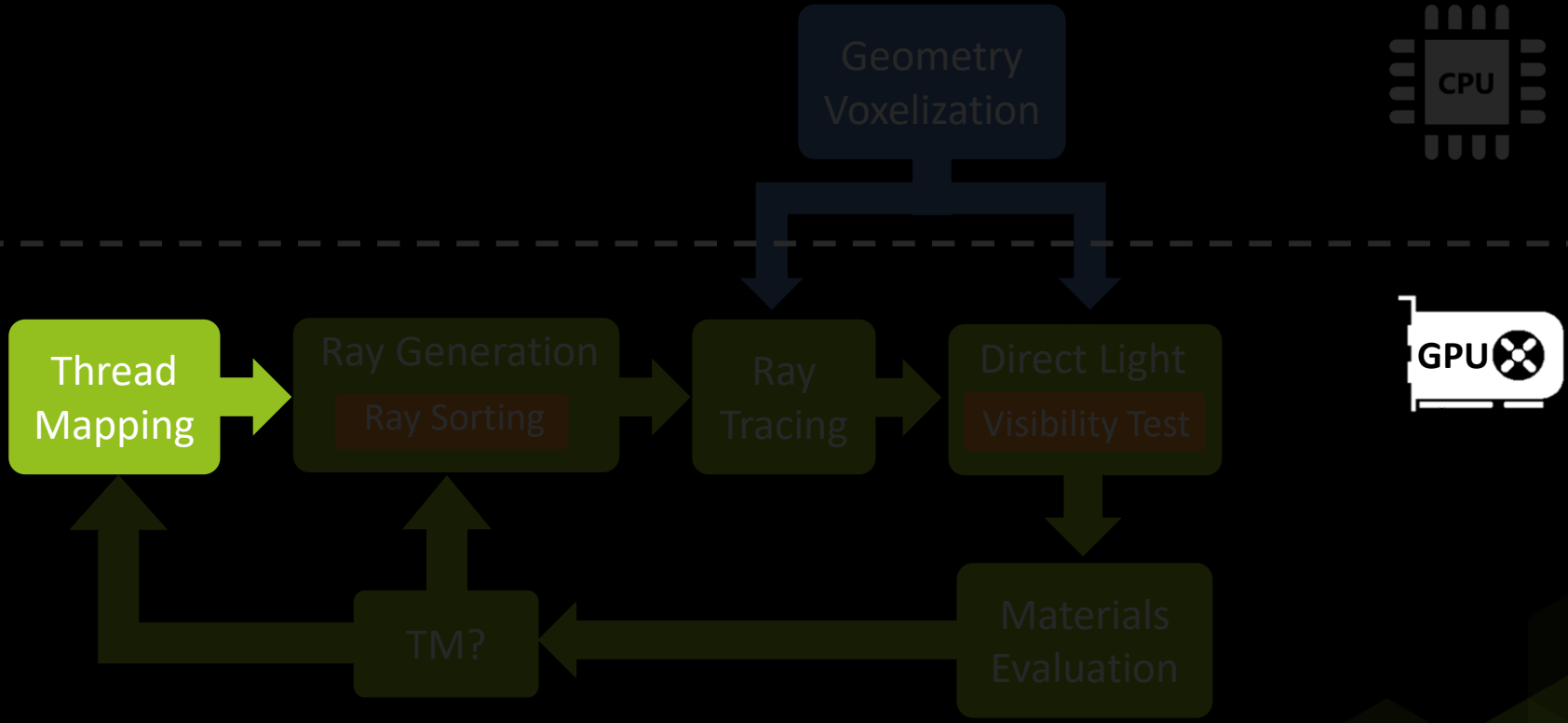
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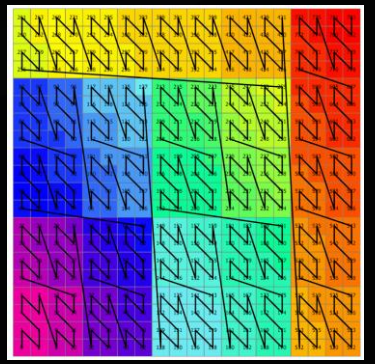
GPU Maxwell

Morton Curve



- Thread Mapping
  - Module that manages THREAD / PIXEL mapping
  - Sampling Level (SL)
    - Low Morton → Curve
    - Medium → Balances SPP
    - High → Uses Variance

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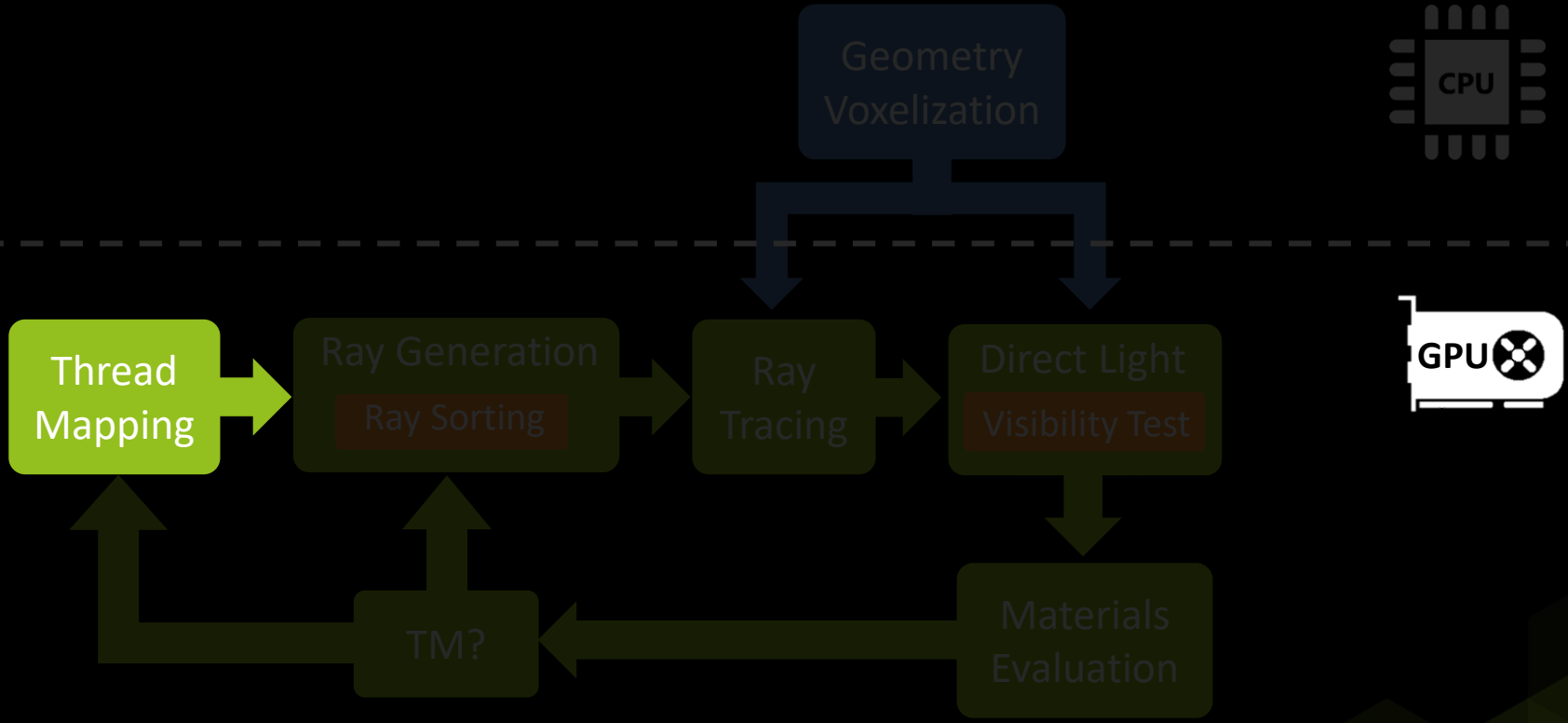
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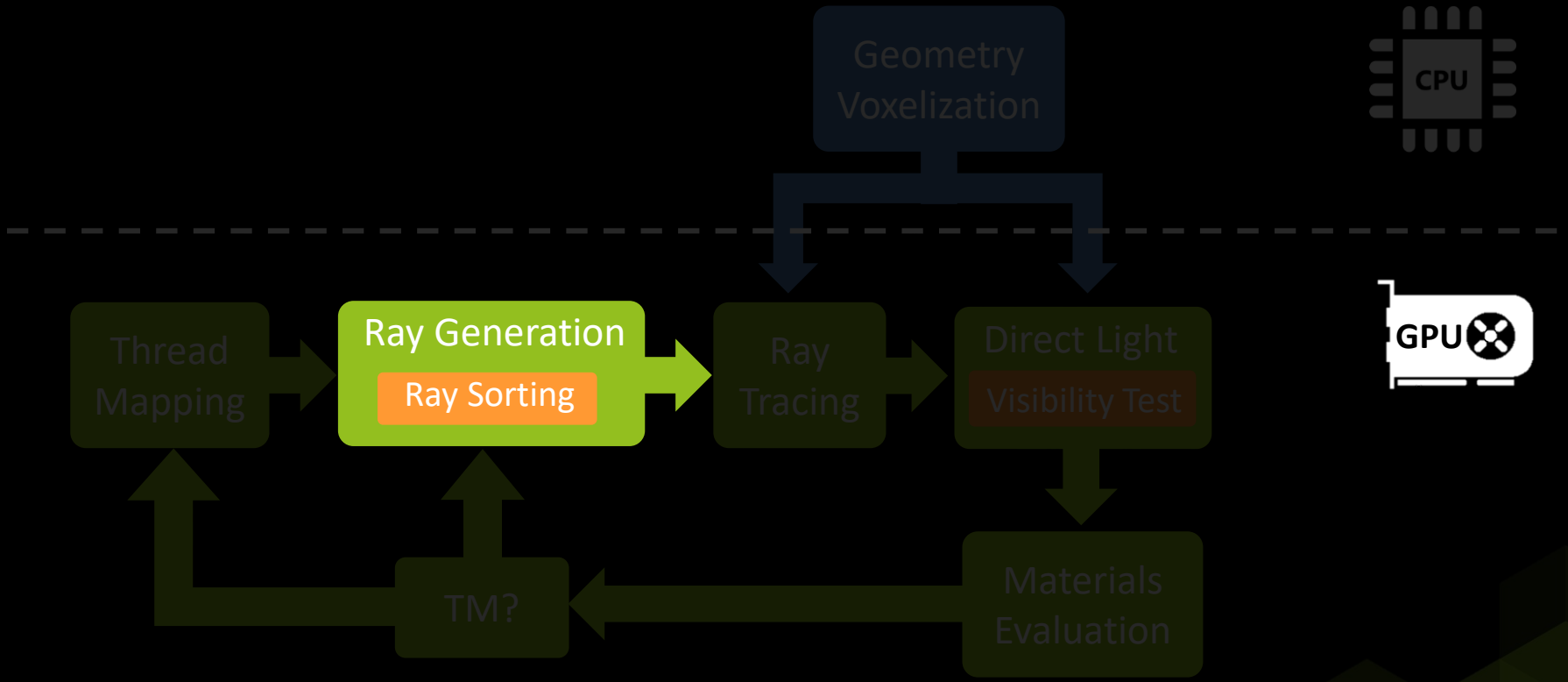
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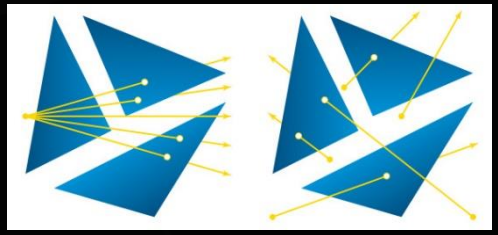
GPU TECHNOLOGY CONFERENCE

- Ray Generation Module



  - Primary Rays (PR)
    - Rays shot from camera
    - High degree of coherence
    - Two neighboring rays will hit nearby similar objects
  - Secondary Rays (SR)
    - Rays shot from surfaces
    - No coherence
    - Two neighbouring rays might hit different objects

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- Ray Generation Module
  - Thread blocks with just PR
    - High degree of coherence
    - Best performance situation
  - Thread blocks with just SR
    - All will take much more time than PR
    - The worst SR will drive the performance
  - Thread blocks with PR and SR
    - SR will hurt PR performance

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- Ray Generation Module
  - How do we handle it?
    - GPU Ray sorting by Ray Type

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GPU Maxwell

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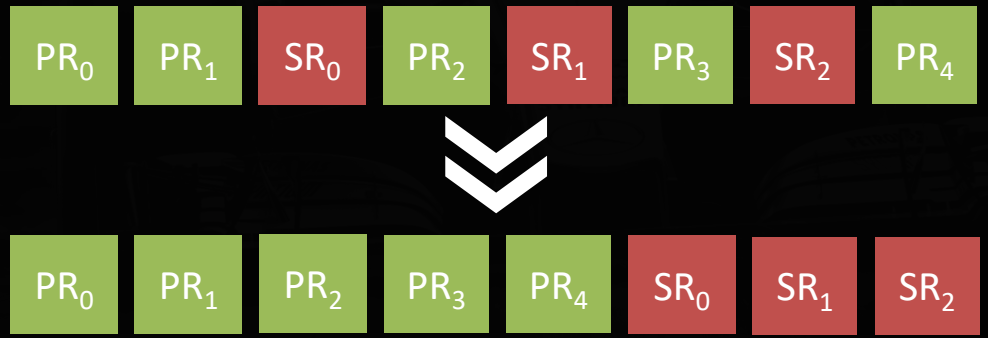

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- Ray Generation Module
  - How do we handle it?
    - GPU Ray sorting by Ray Type
      - Sorting is really fast
      - Simple, yet powerful
      - Do it just after 2nd bounce
        - Not needed for PR
      - Performance boost is scene dependant

GPU Maxwell

- Ray Generation Module
  - How do we handle it?
    - GPU Ray sorting by Ray Type
      - **Considerations**
        - Not useful for medium to small-res images
        - Use an indirection buffer
          - Cleaner code
          - Avoids moving global data
          - Much better performance

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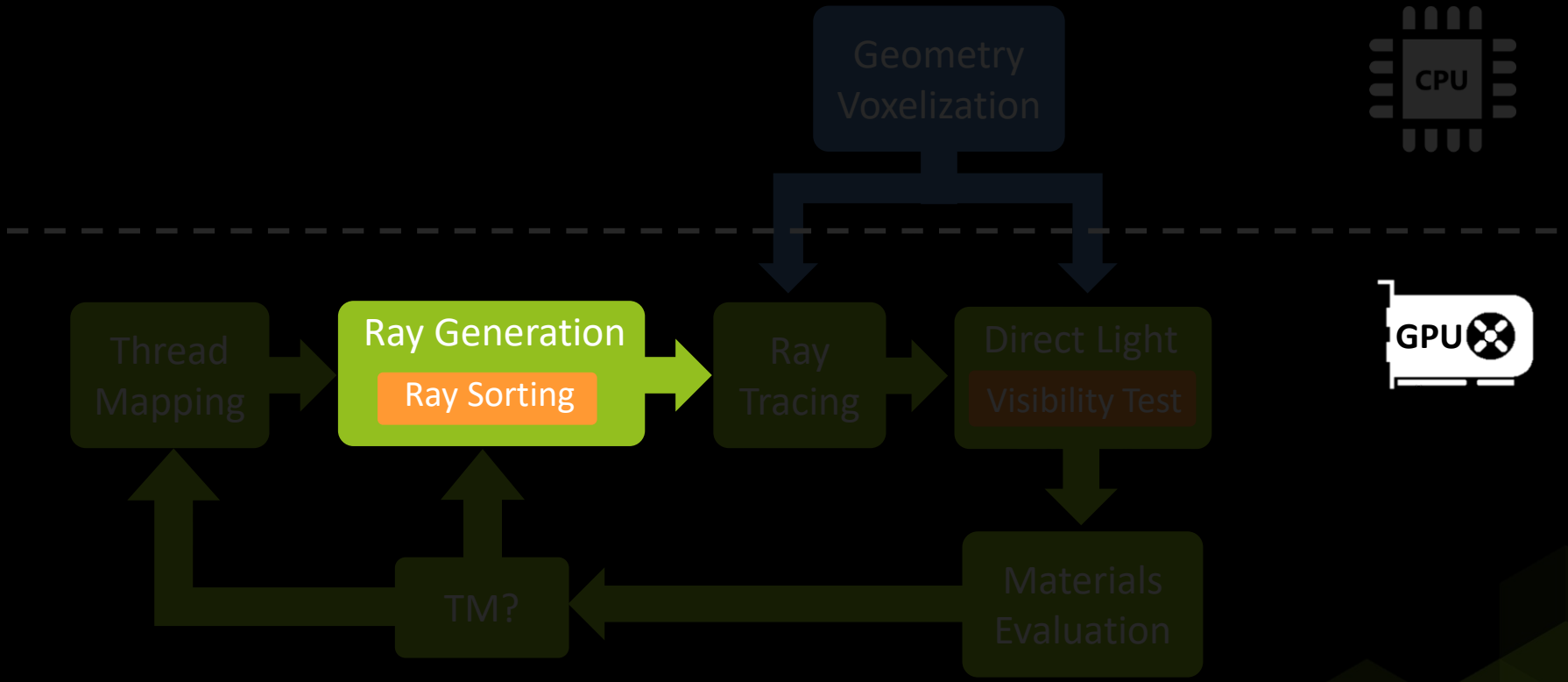
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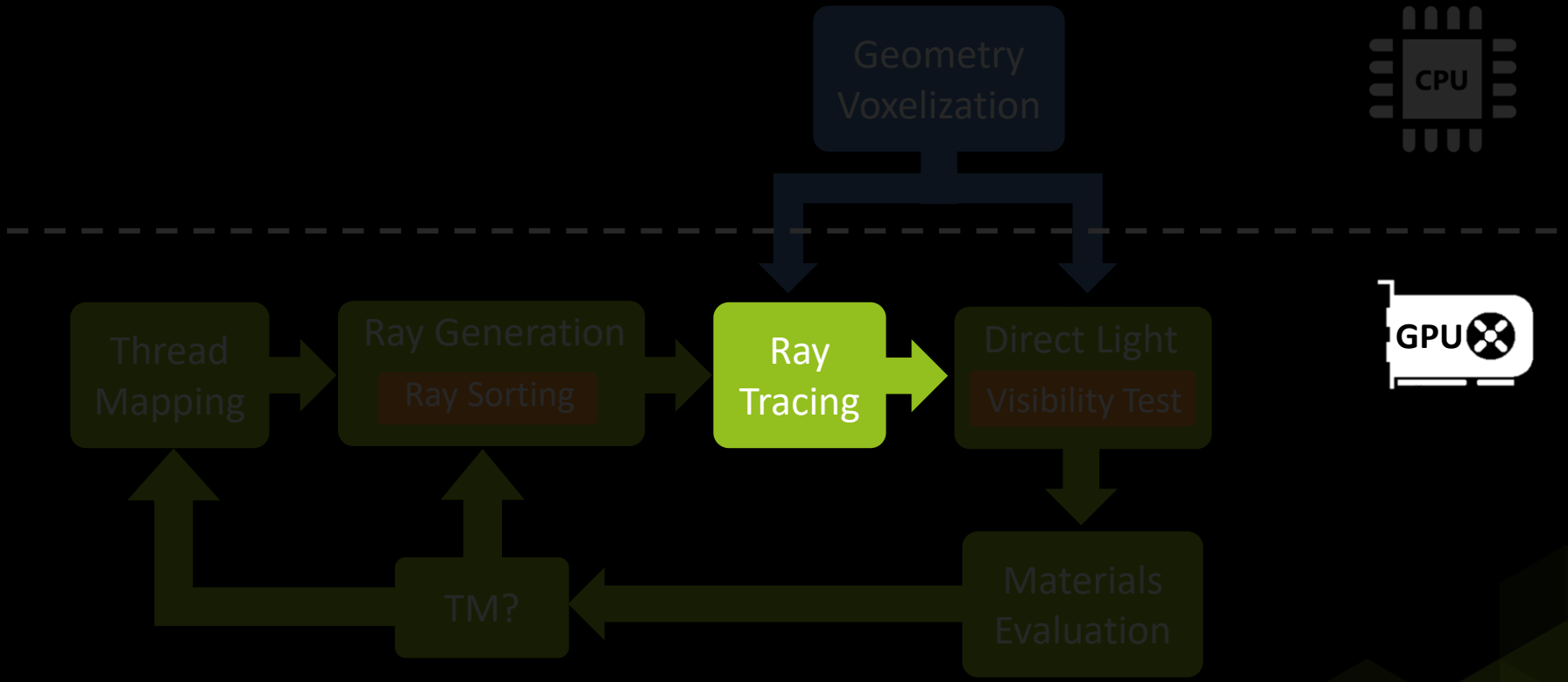
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- Ray Tracing Module
  - GPU architecture dependent kernels
    - Fermi, Kepler, Maxwell
    - Use every architecture strengths

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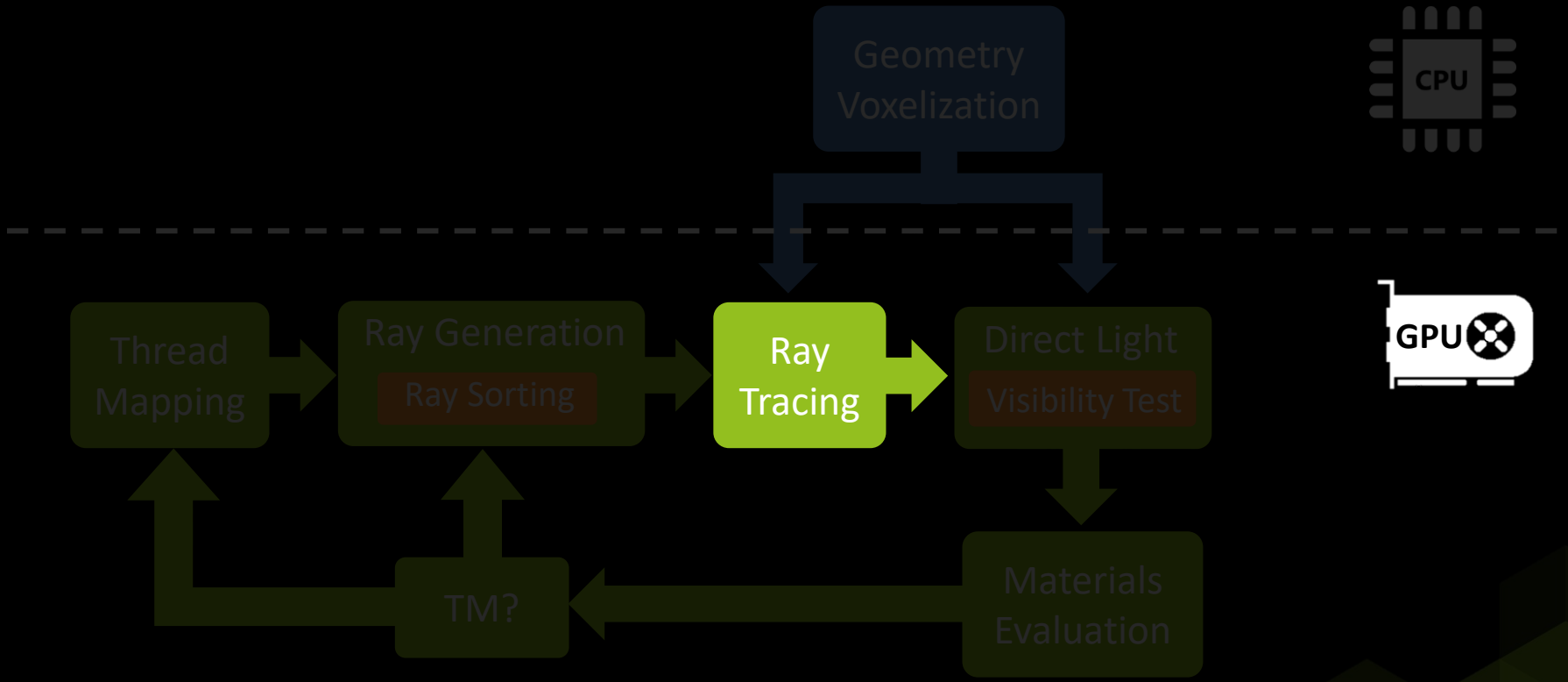
GPU Maxwell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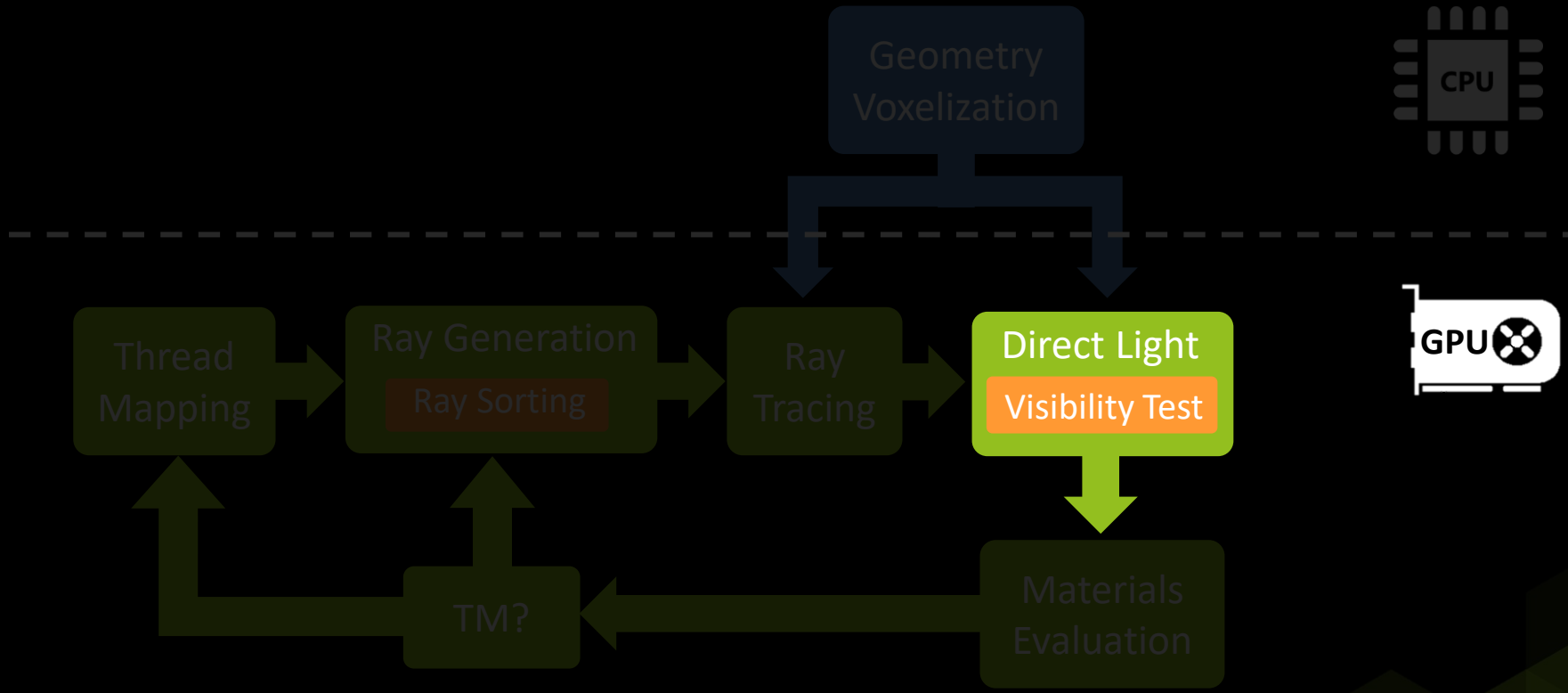
GPU Maxwell Render



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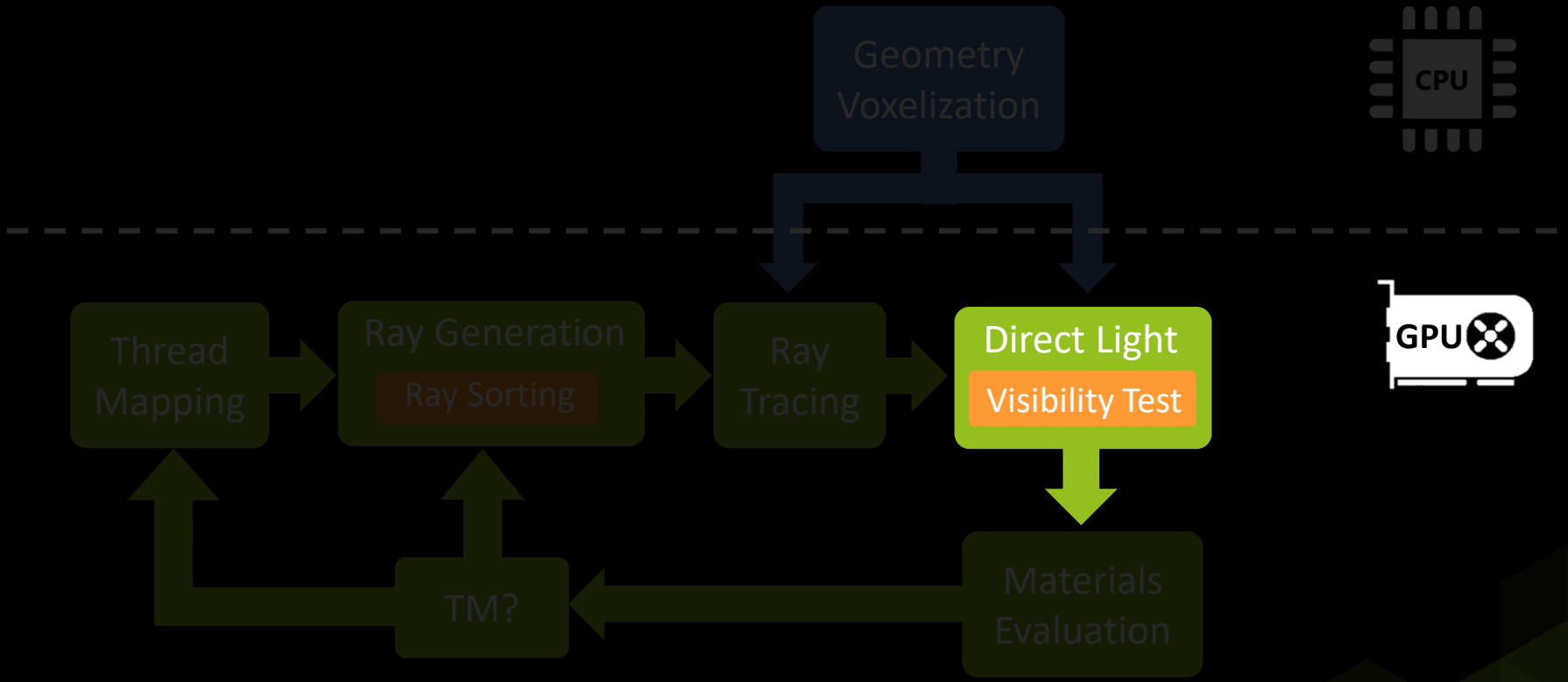
Direct Light Module

1. Sample scene emitters at each path node
   - Two strategies
     - Sample 1 random emitter / sample
     - Sample all emitters / sample

2. Visibility test
   - Trace shadow rays
   - Incoherent rays → Ray sorting does not help

3. Many other optimizations

GPU Maxwell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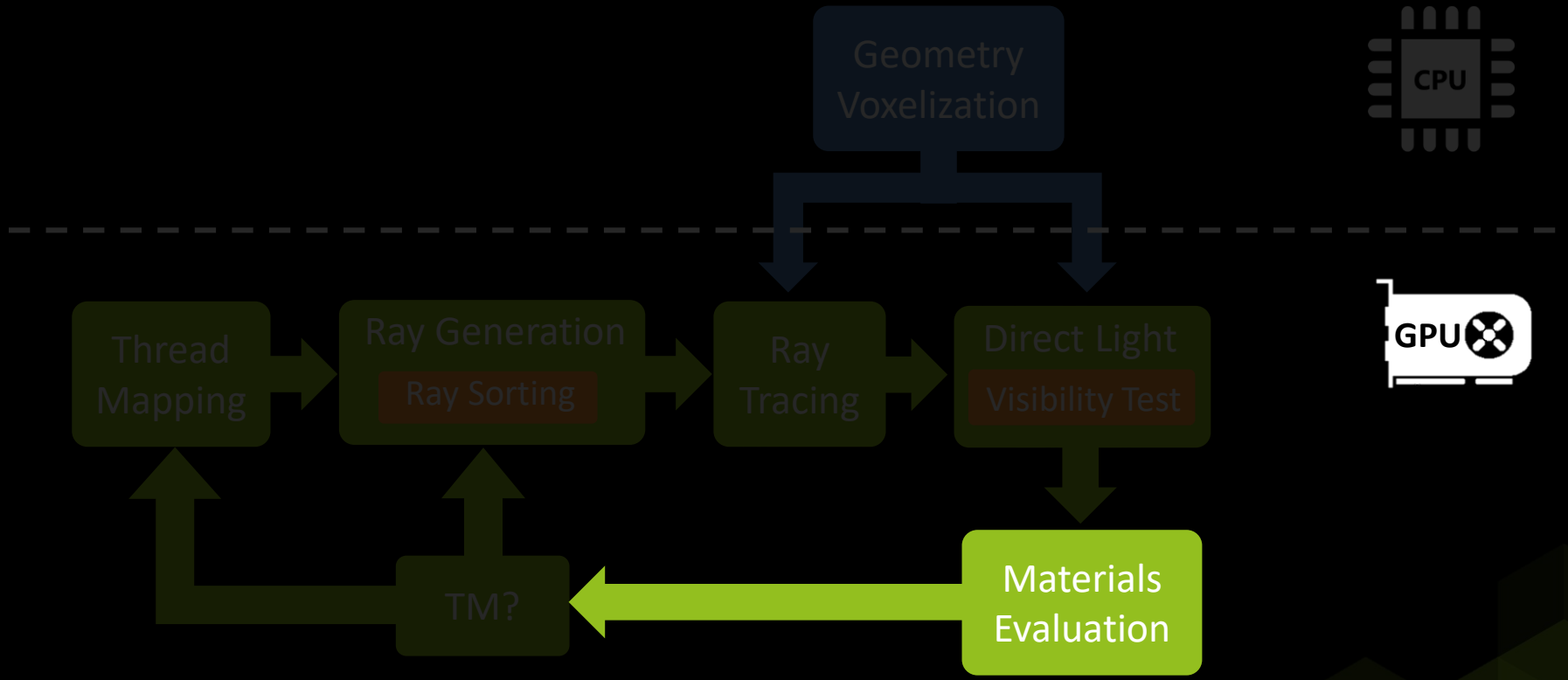
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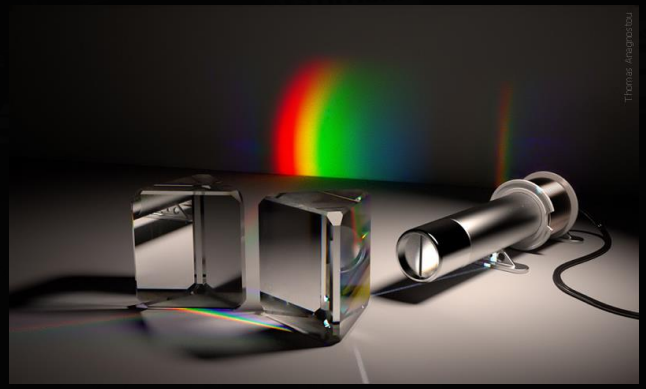
GPU Maxwell

- Materials Evaluation Module
  - Maxwell materials are complex
  - Many layers and many BSDFs / layer → very generic

GPU Maxwell

Materials Evaluation Module

- Bbig kernels are harmful
- Samples evaluating different materials
  - Access different data
  - Execute different code



GPU Maxwell

- Materials Evaluation Module
  - Materials Group Queue System (MGQS)
    1. Every material is assigned a Material Group ID
    2. Queue system for Material Groups (MG)
    3. Every queue has specific kernels
       - Avoid big kernels
    4. Samples are queued to the corresponding MG Queue
    5. All samples evaluating the same MG are executed together
       - Increased coherence in execution time
       - Increased coherence in data access

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GPU Maxwell Render

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GPU Maxwell

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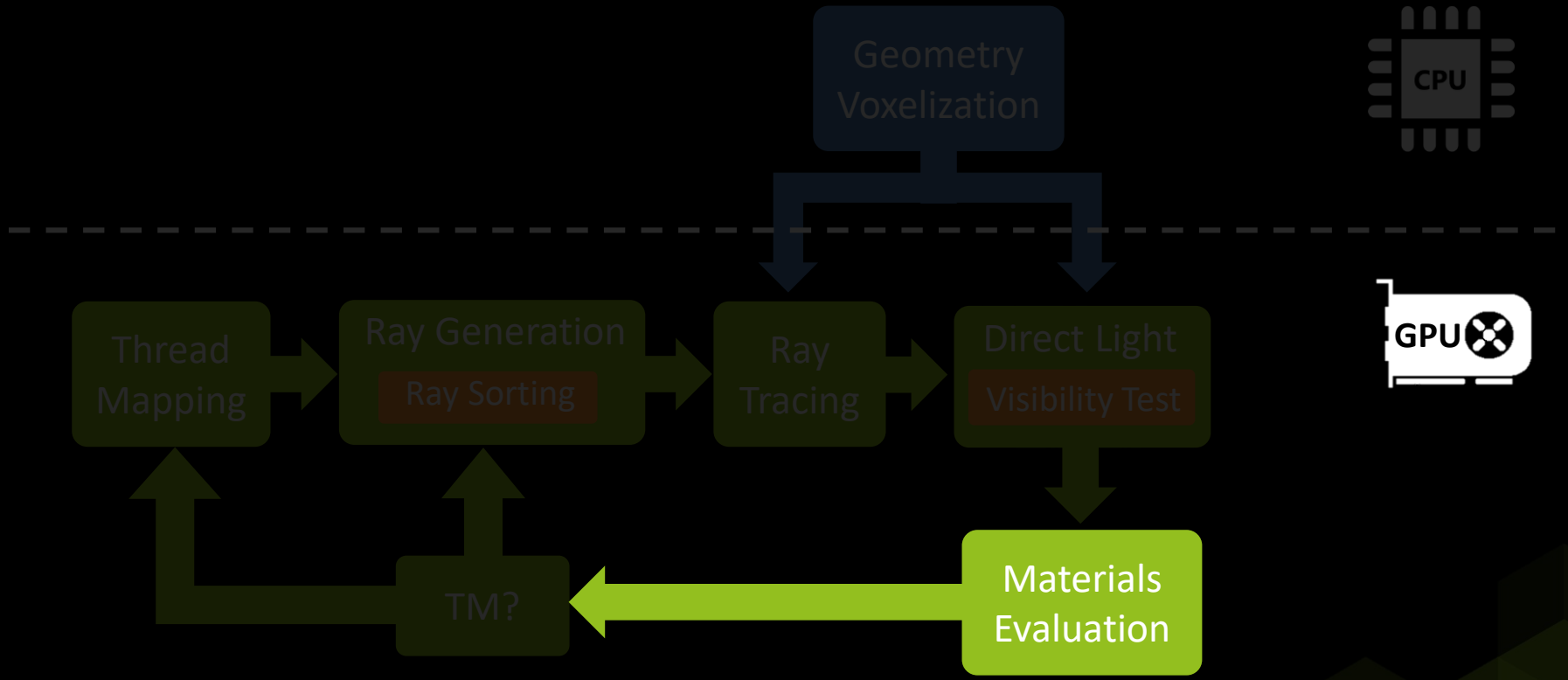
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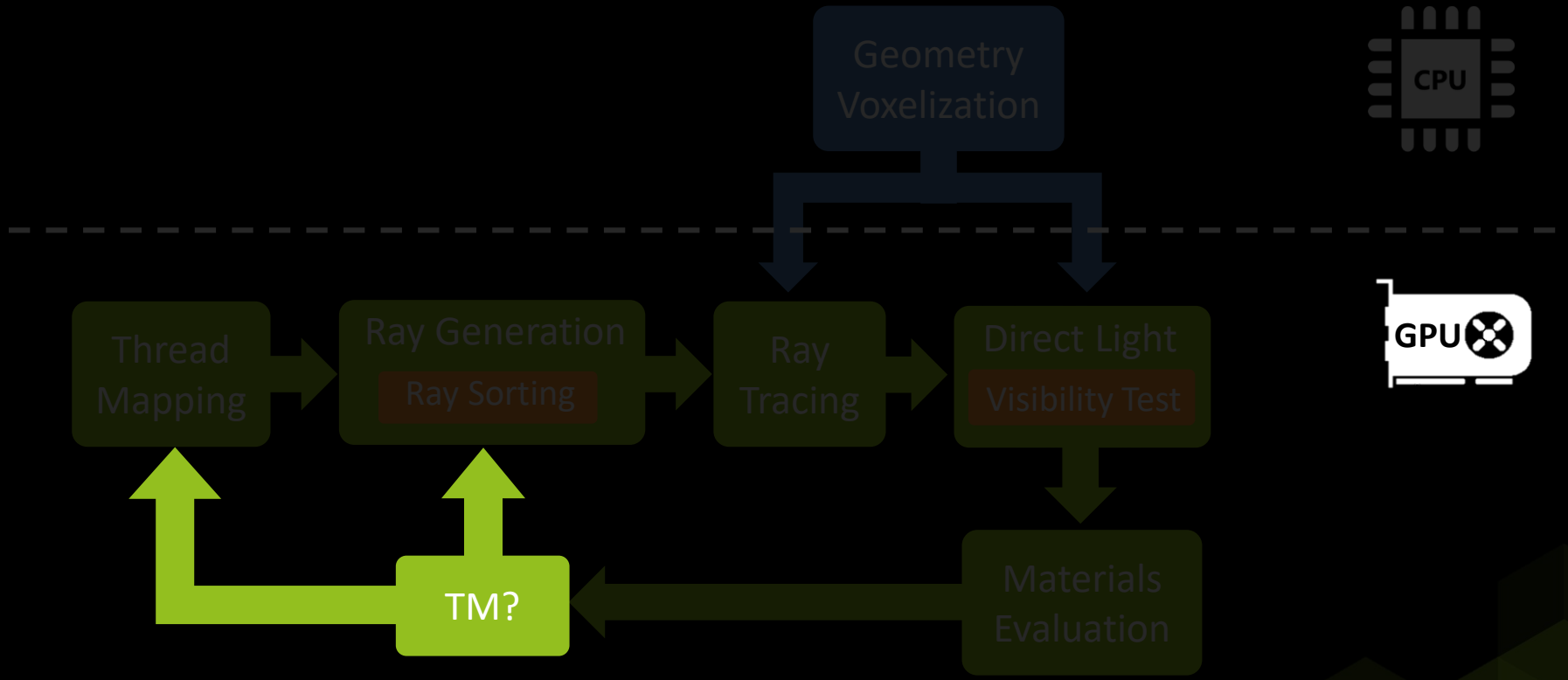
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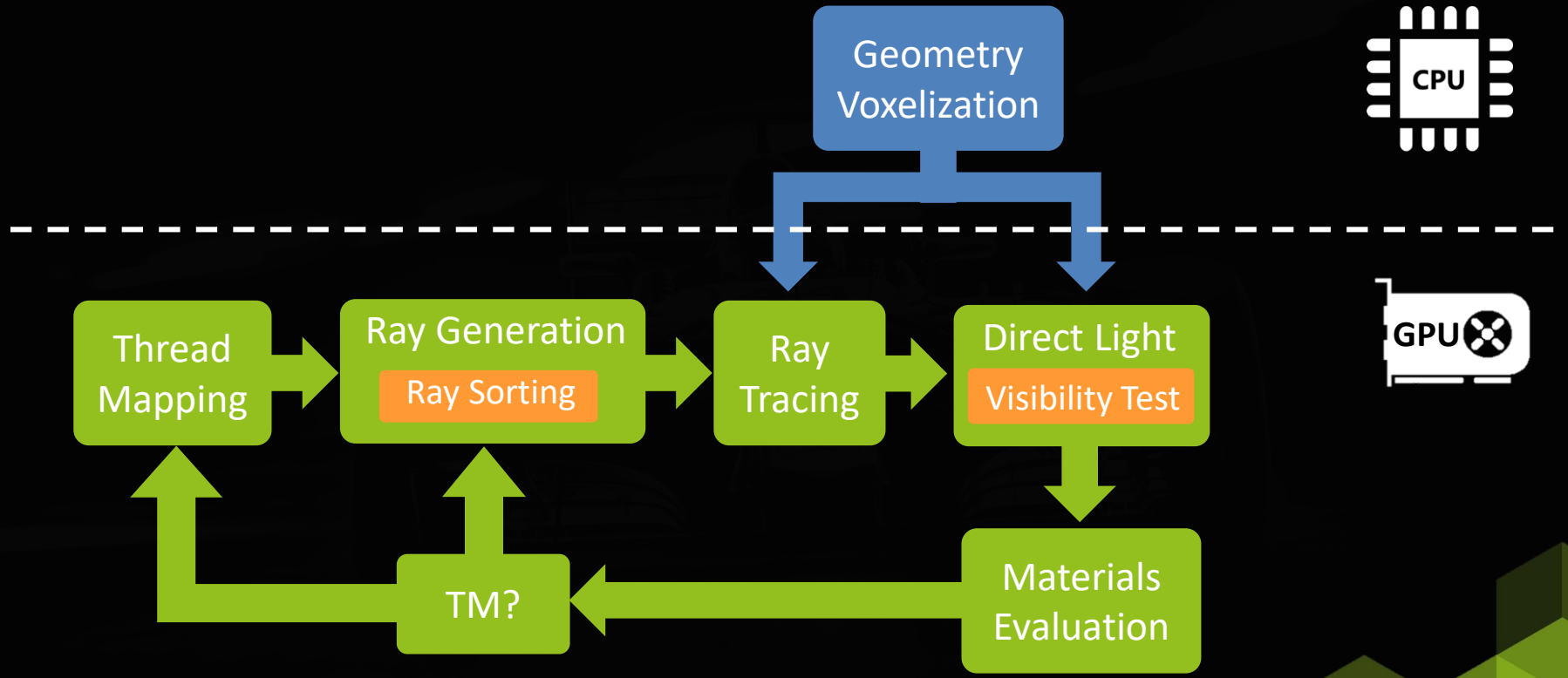

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Using the CPU to improve the GPU engine

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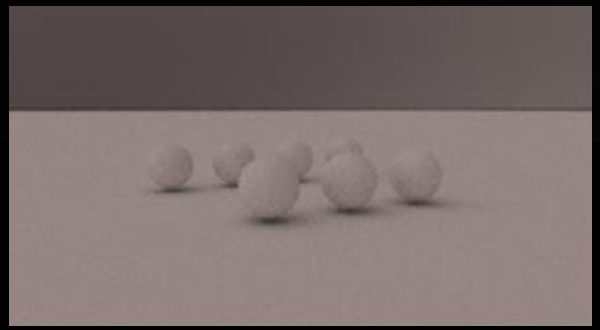
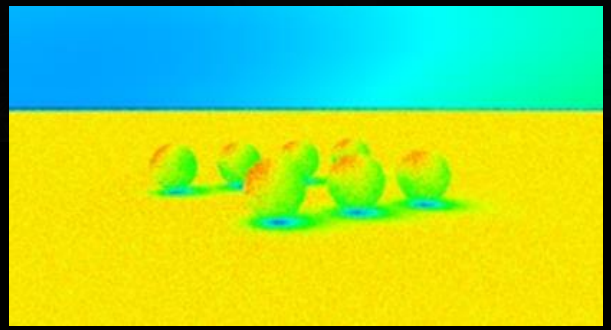
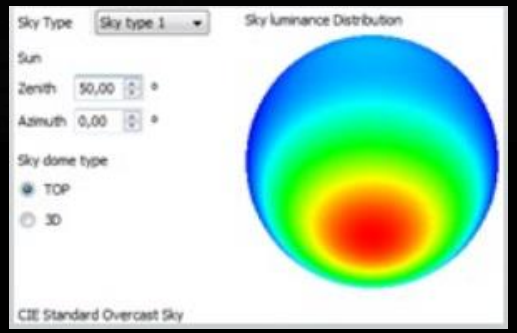
Why using our CPU engine as ground truth?

- 12 years old → Stable & Robust
- Used many times for validation purposes







CPU vs GPU Case Studies

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Guggenheim scene

Teapot scene

Maxwell

Guggenheim Scene

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Guggenheim Scene

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Guggenheim Scene

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ISSUES

- Slight differences in intensity
- Noise in some areas
- Subtle changes in glossy surfaces

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Guggenheim Scene

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STRATEGY

- Simplifying & Isolating (surprise :P)
- Automated numerical comparisons
    - -Raytracing text output
- Ray viewer

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Guggenheim Scene

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Guggenheim Scene

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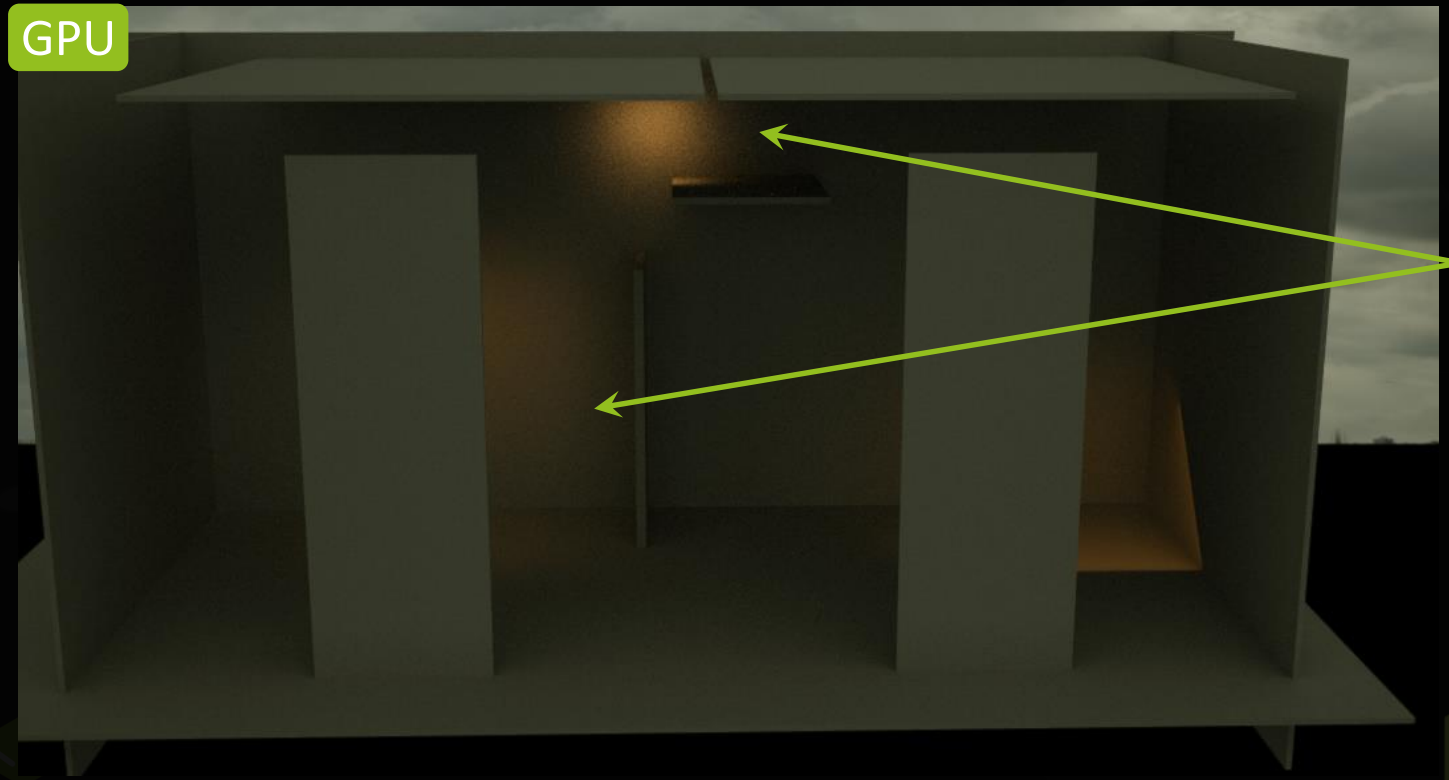
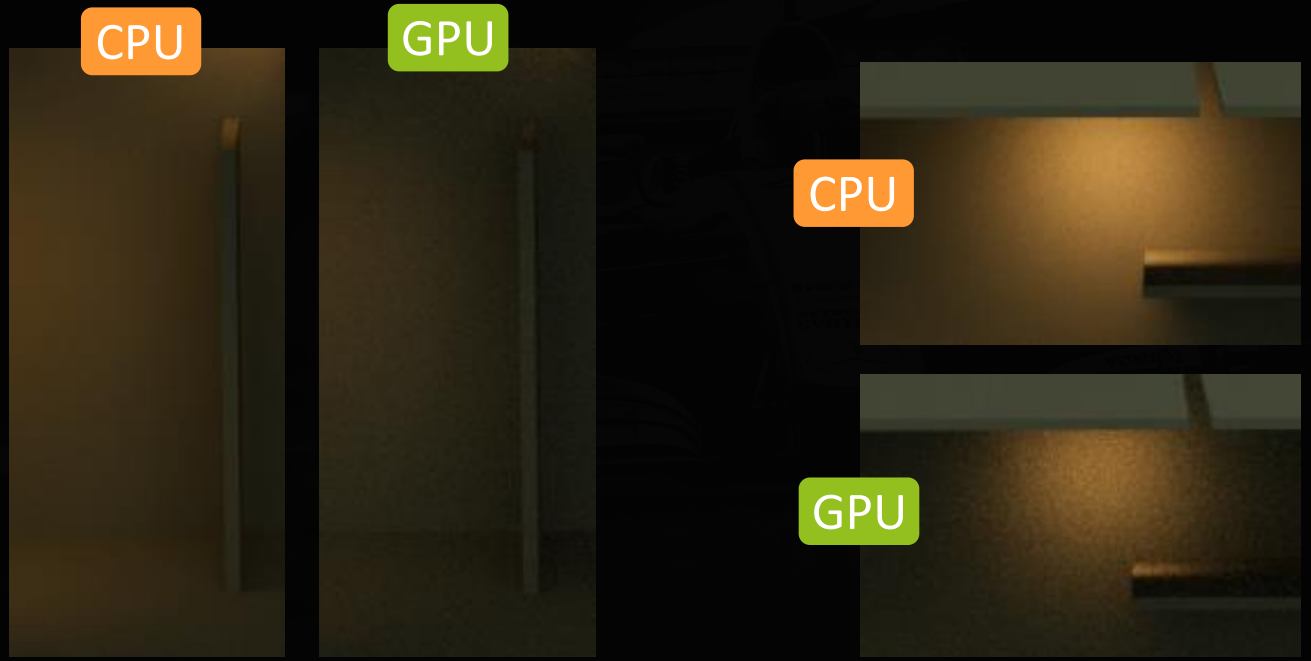


Different Intensity
+
Noise Problems

Guggenheim Scene – Intensity & Noise



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Guggenheim Scene

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FINDINGS

- Emitters intensity
  - Hidden property of emitters was not working properly
  - Non-visible emitters were causing occlusions
  - Loss of energy
- Noise
  - QMC had some problems for higher dimensions

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Guggenheim Scene

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FIXED

Guggenheim Scene

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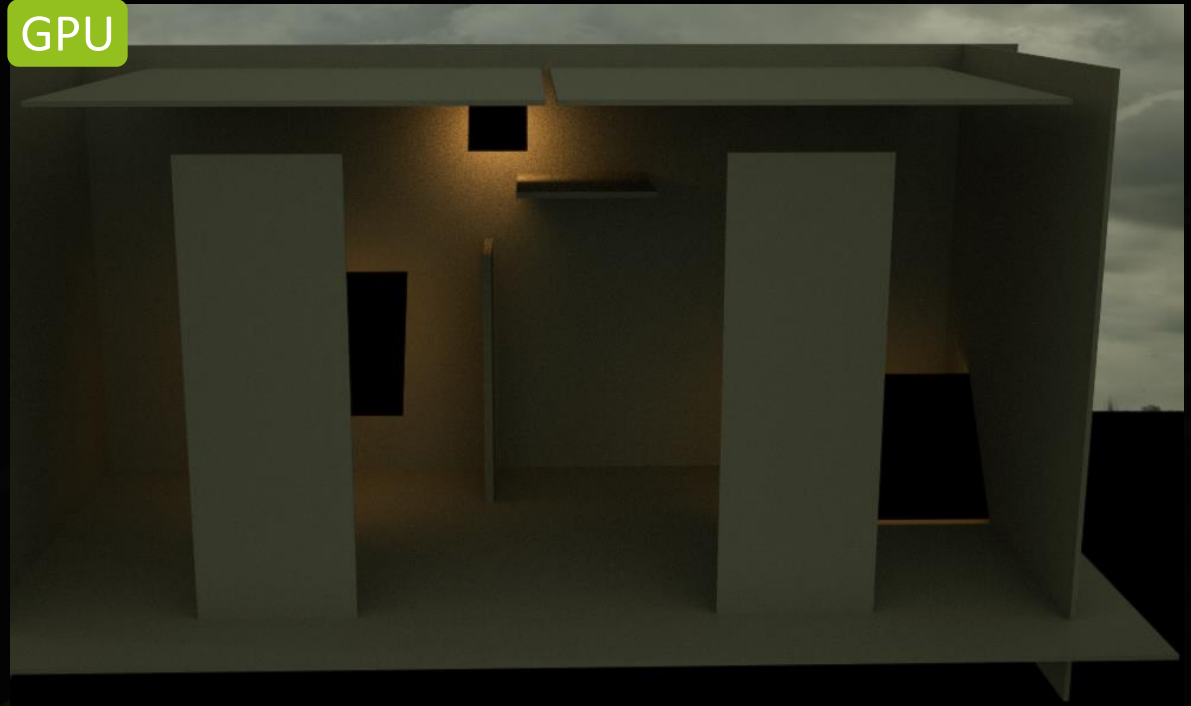

FIXED

Guggenheim Scene

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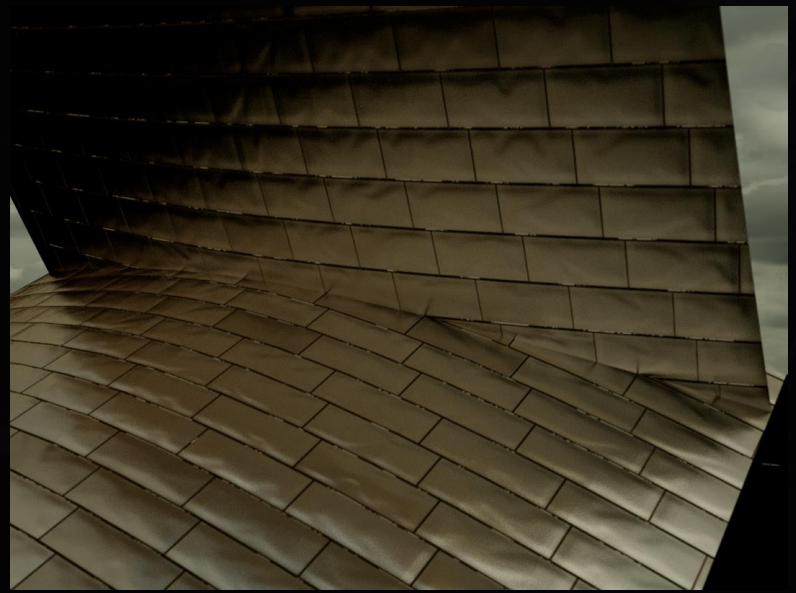
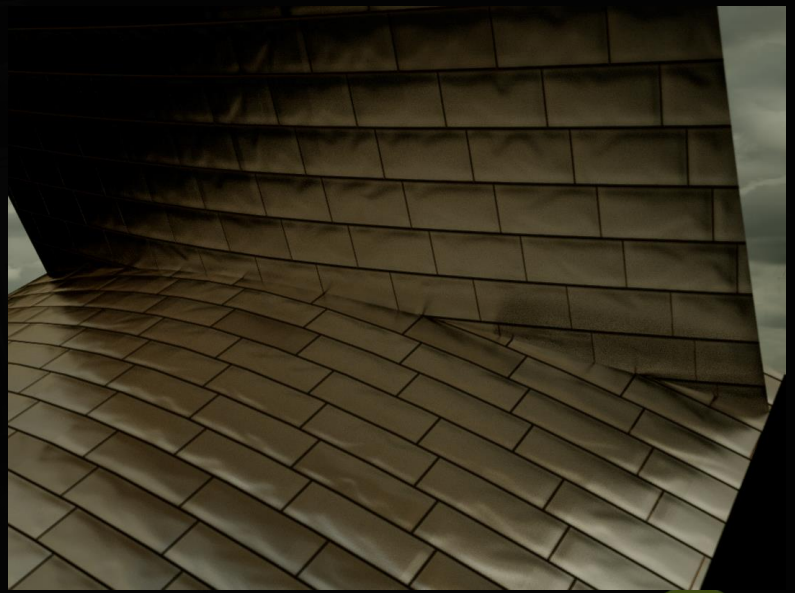
Guggenheim Scene – Differences in glossies





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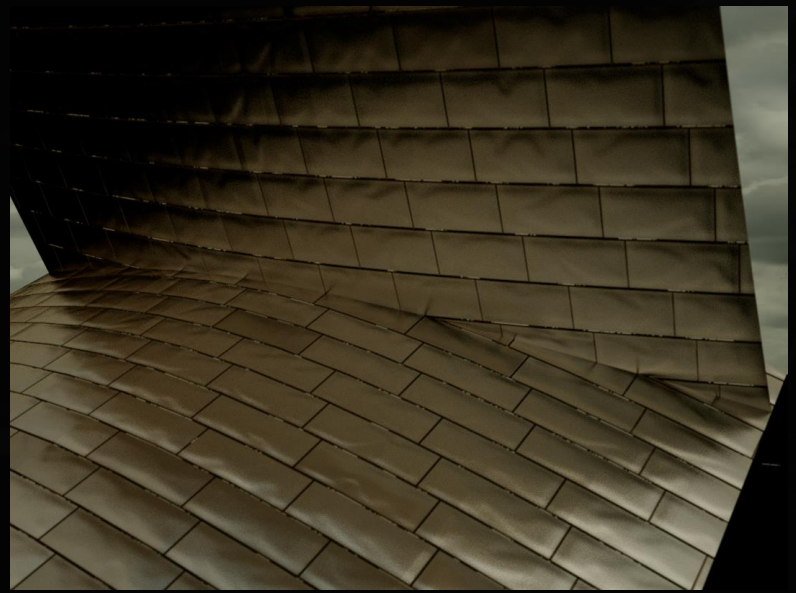
Guggenheim Scene – Differences in glossies



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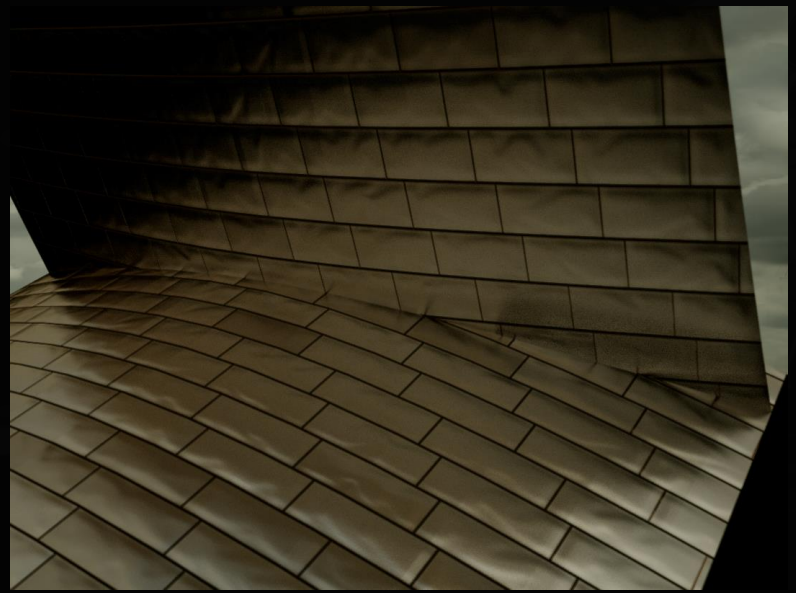

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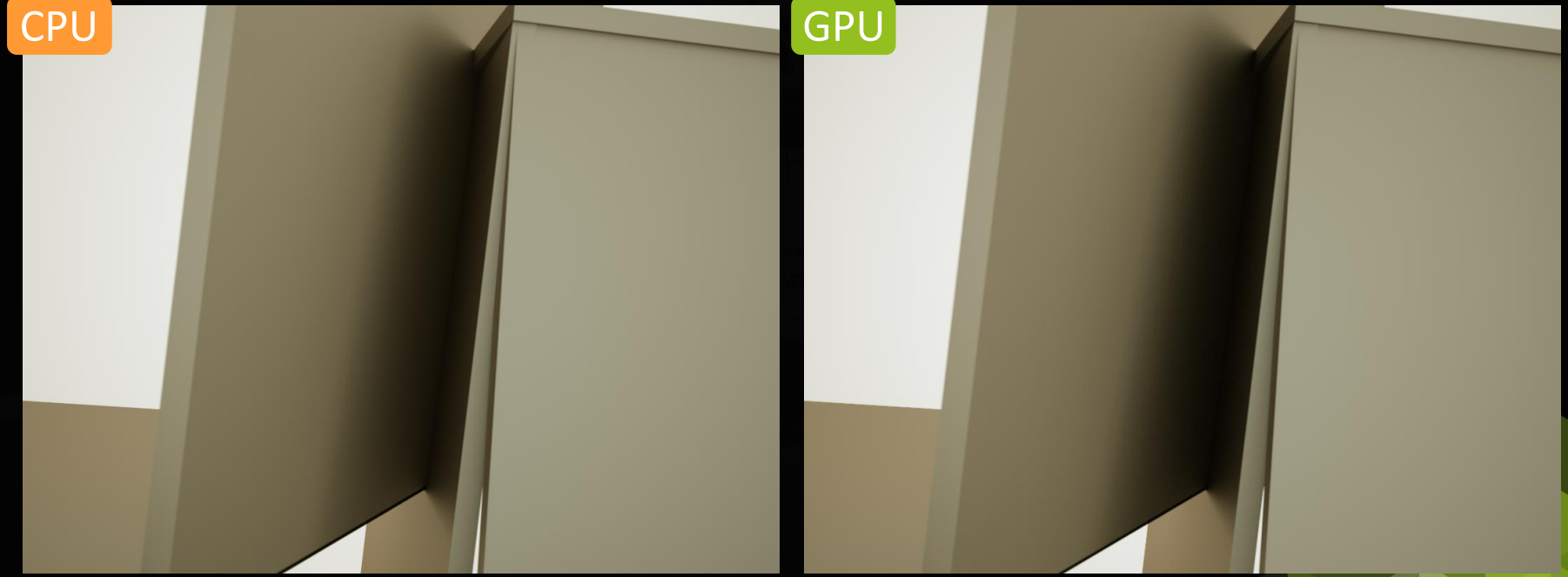

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Guggenheim Scene – Differences in glossies

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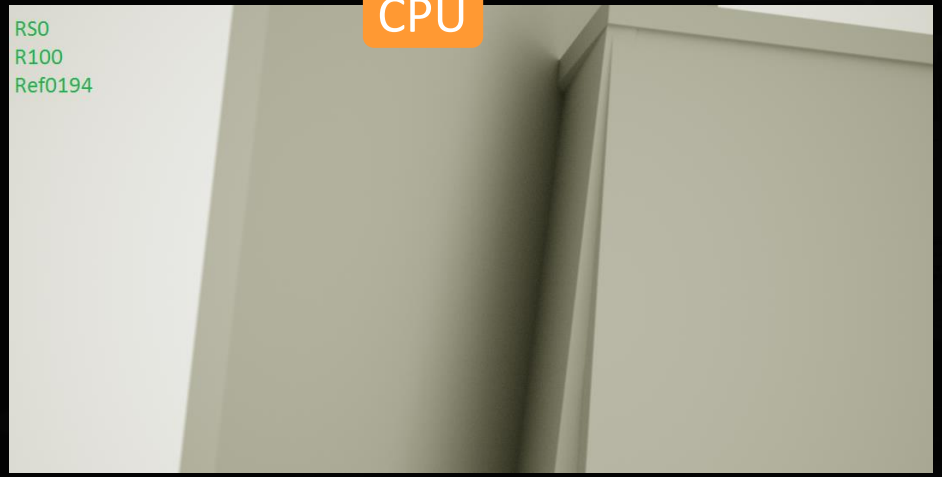
CPU



GPU

- Simplify the material → Lambert

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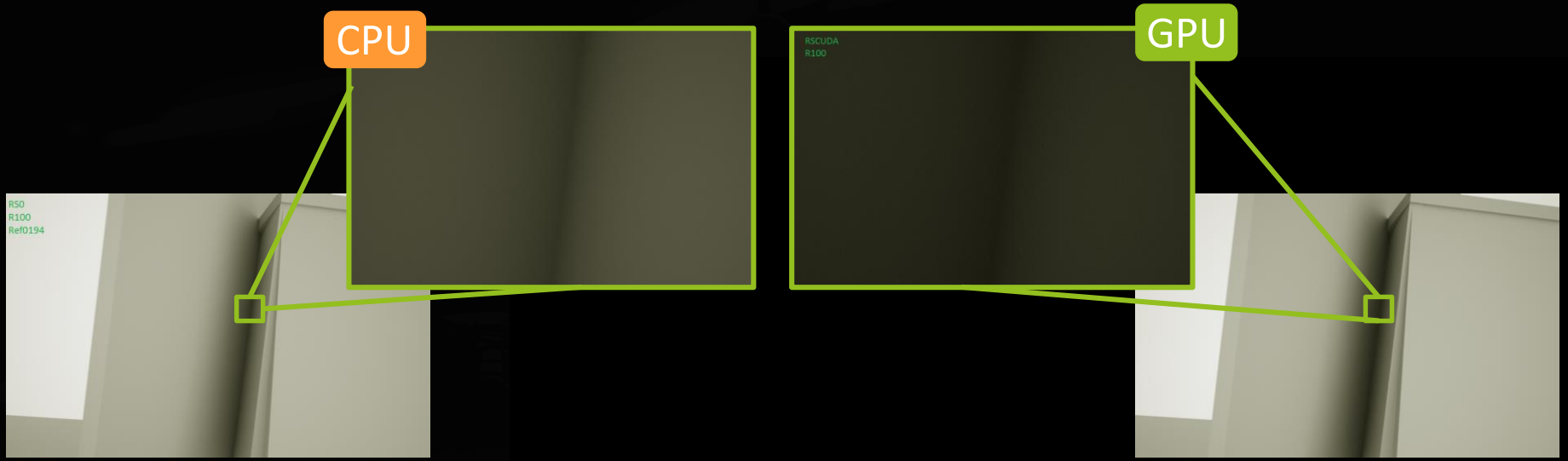
Guggenheim Scene – Differences in glossies



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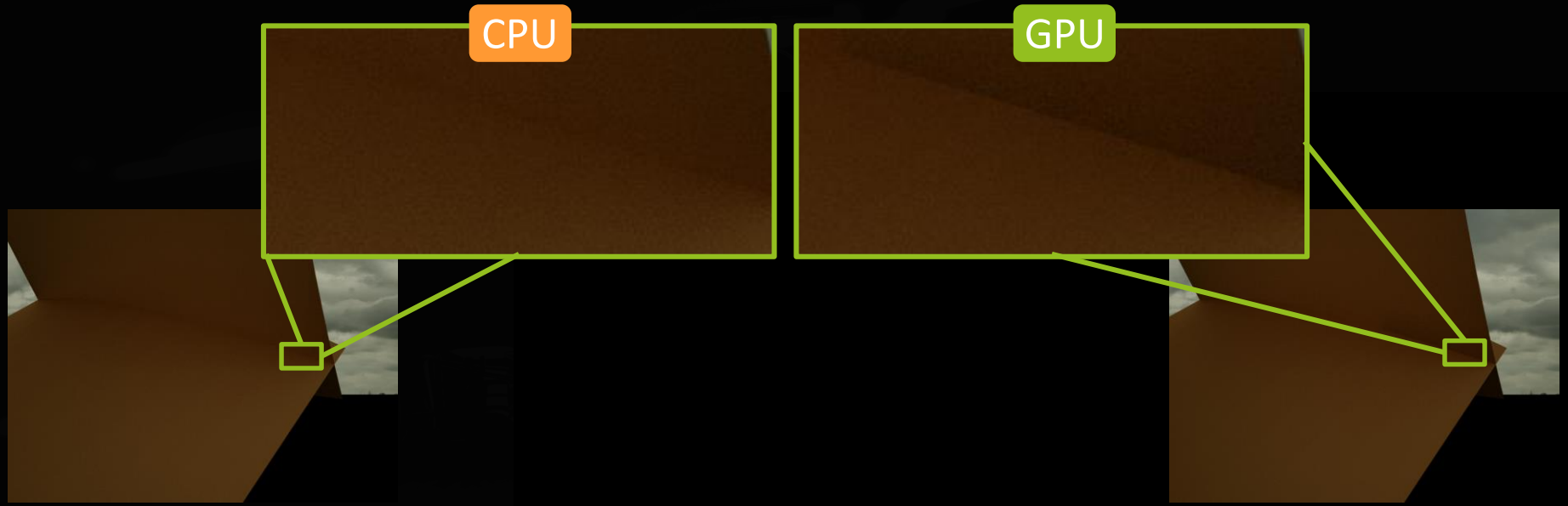

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- It turned out it was not related to materials
  - Both glossy and lambert have the same problem
  - Difficult to isolate

- Possible problems
  - QMC numbers bug?
  - Russian Roulette bug?
  - Ray / triangle intersection issues with indirect bounces?
  - Energy accumulation problem?
  - Precision issues?
  - …

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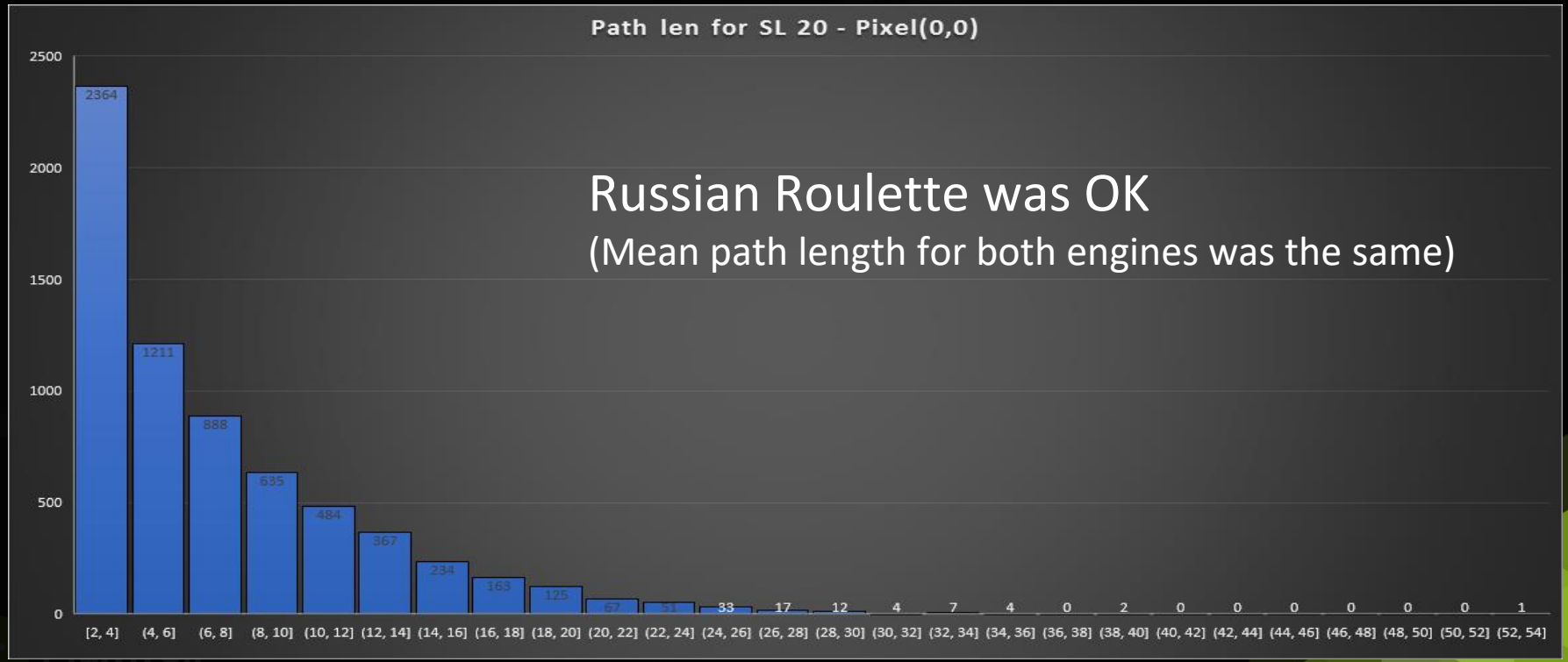
Guggenheim Scene – Differences in glossies



Russian Roulette was OK

(Mean path length for both engines was the same)

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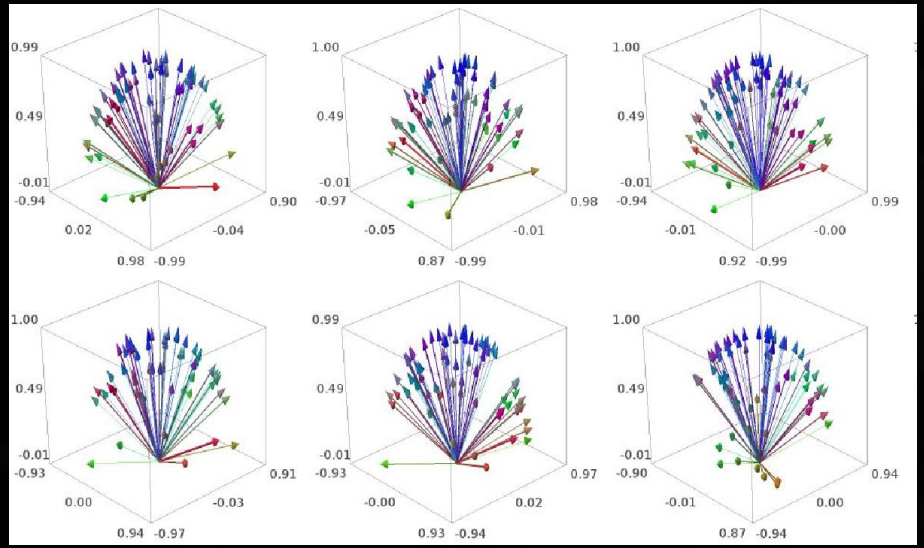
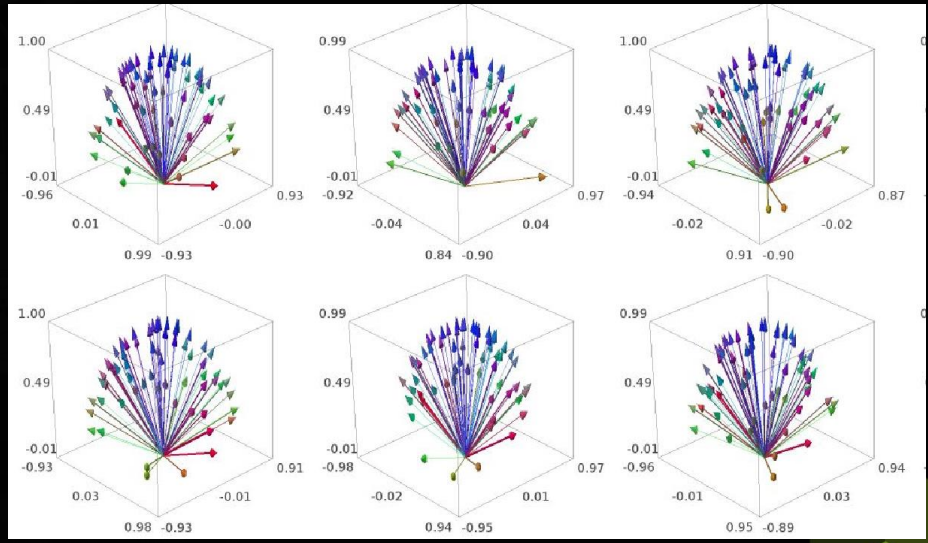
CPU – QMC Distributions



GPU – QMC Distributions



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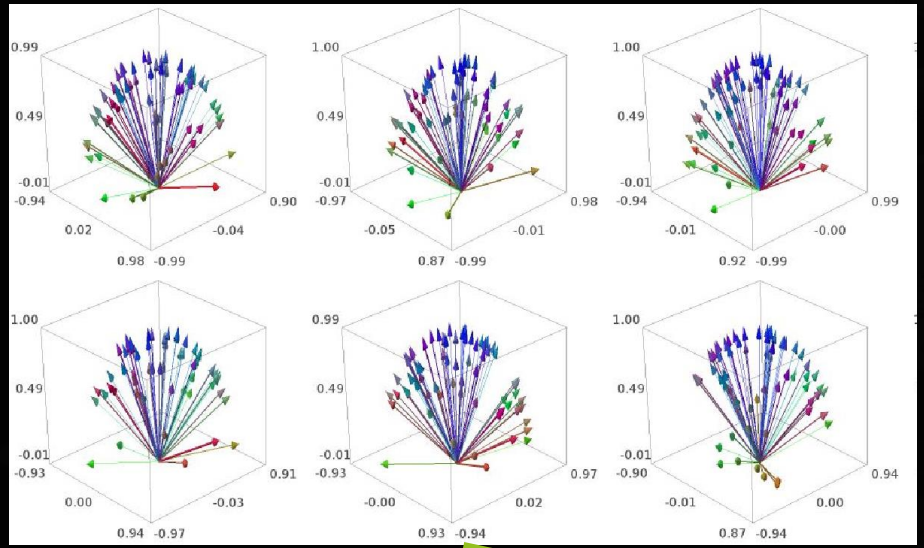
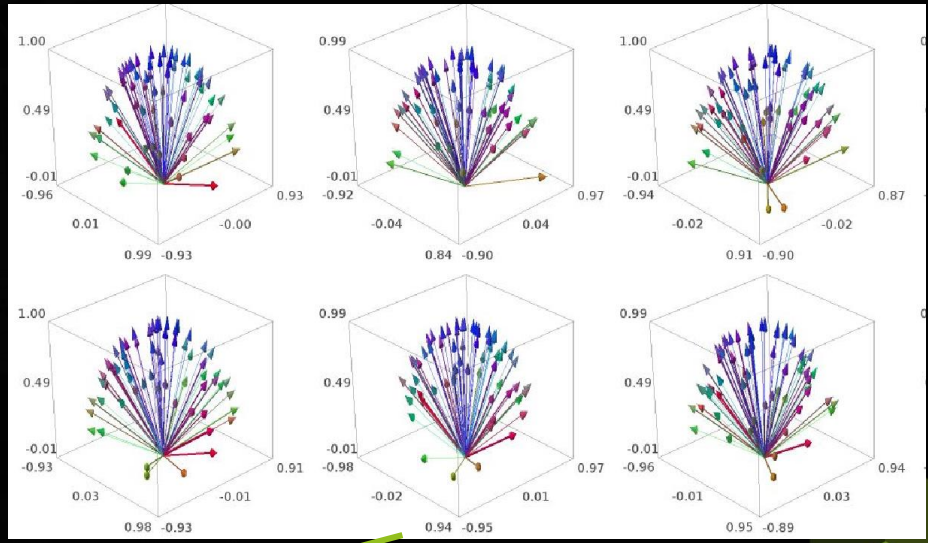
CPU – QMC Distributions



GPU – QMC Distributions



Automated tests detected differences!

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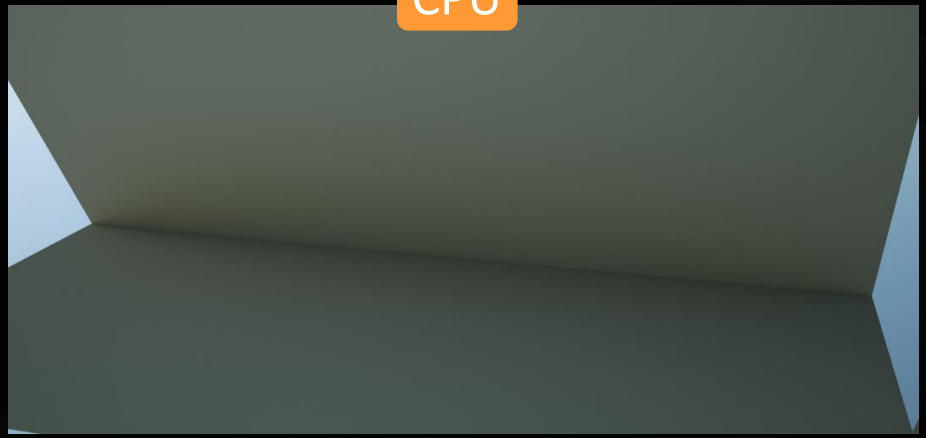
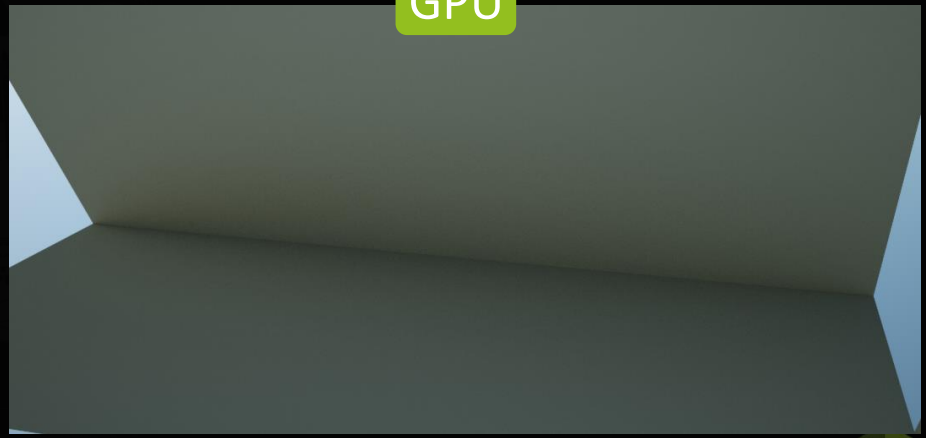
CPU



GPU



SOLVED

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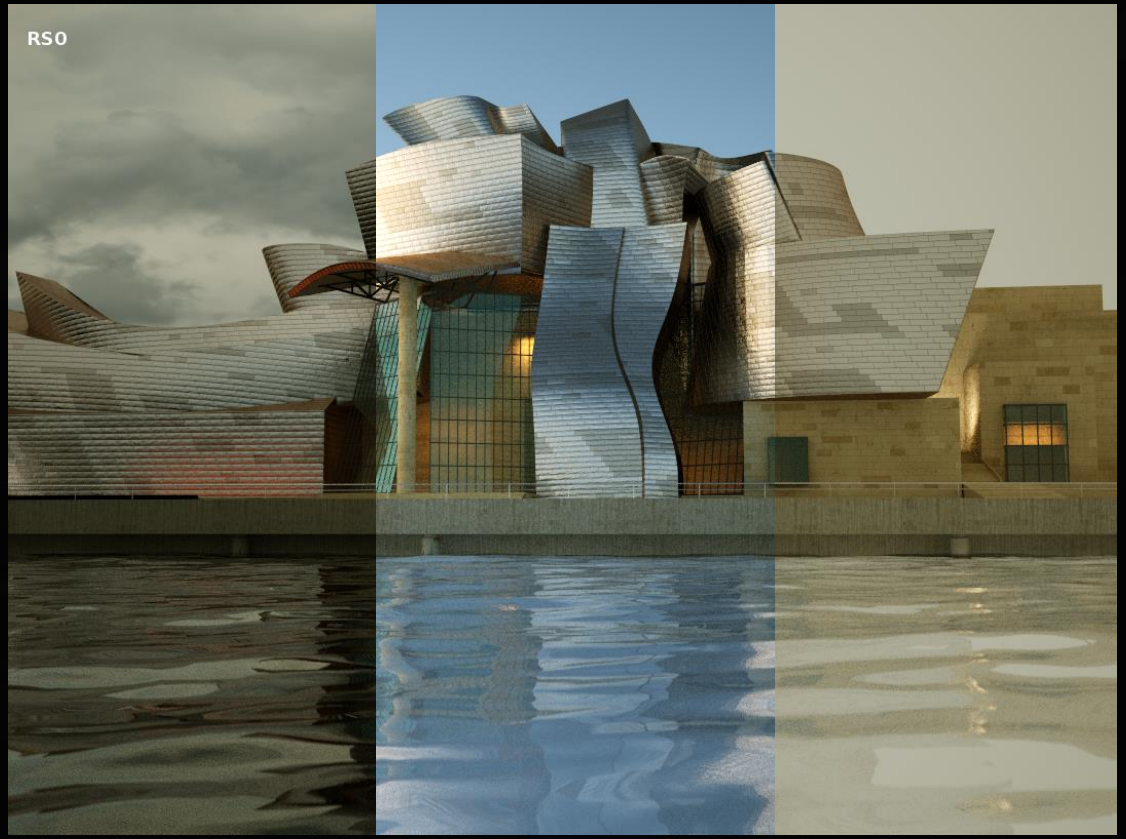

CPU == GPU ☺

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ISSUES

- Subtle differences in bump/normal mapping
- Differences in materials with many layers/bsdfs
- Small changes in intensity

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Use cases where CPU Maxwell helped… A LOT!!!

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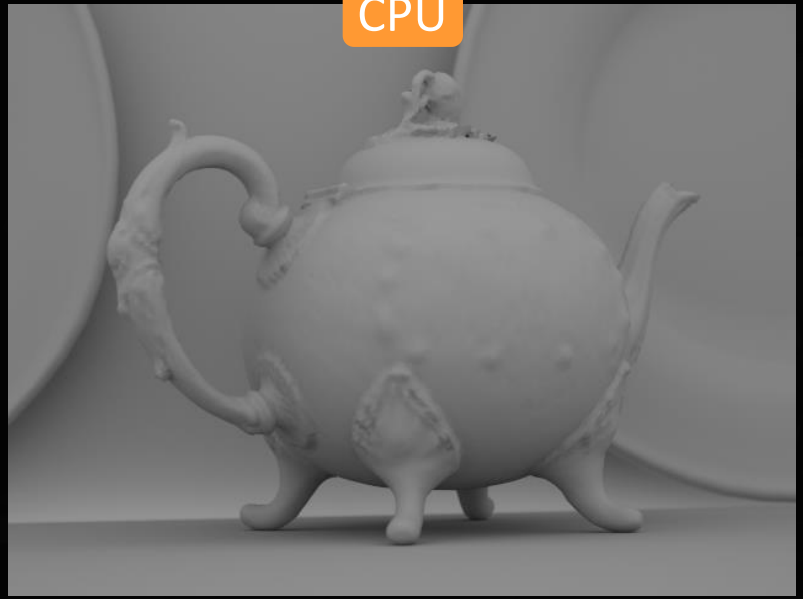

Test 1 : Lambert materials + Constant Sky → OK

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Test 2 : Added textures + Normal maps → WRONG

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Test 3 : Added multilayered materials → WRONG

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FINDINGS

- Automated CPU vs GPU numerical comparisons were **key**
  - Rays reaching IBL were not accumulating energy properly
  - Multilayered weights were not properly computed
    - Bug introduced when porting CPU **optimized** code
  - Precision issues creating TBN bases (Affected bump/normal mapping)

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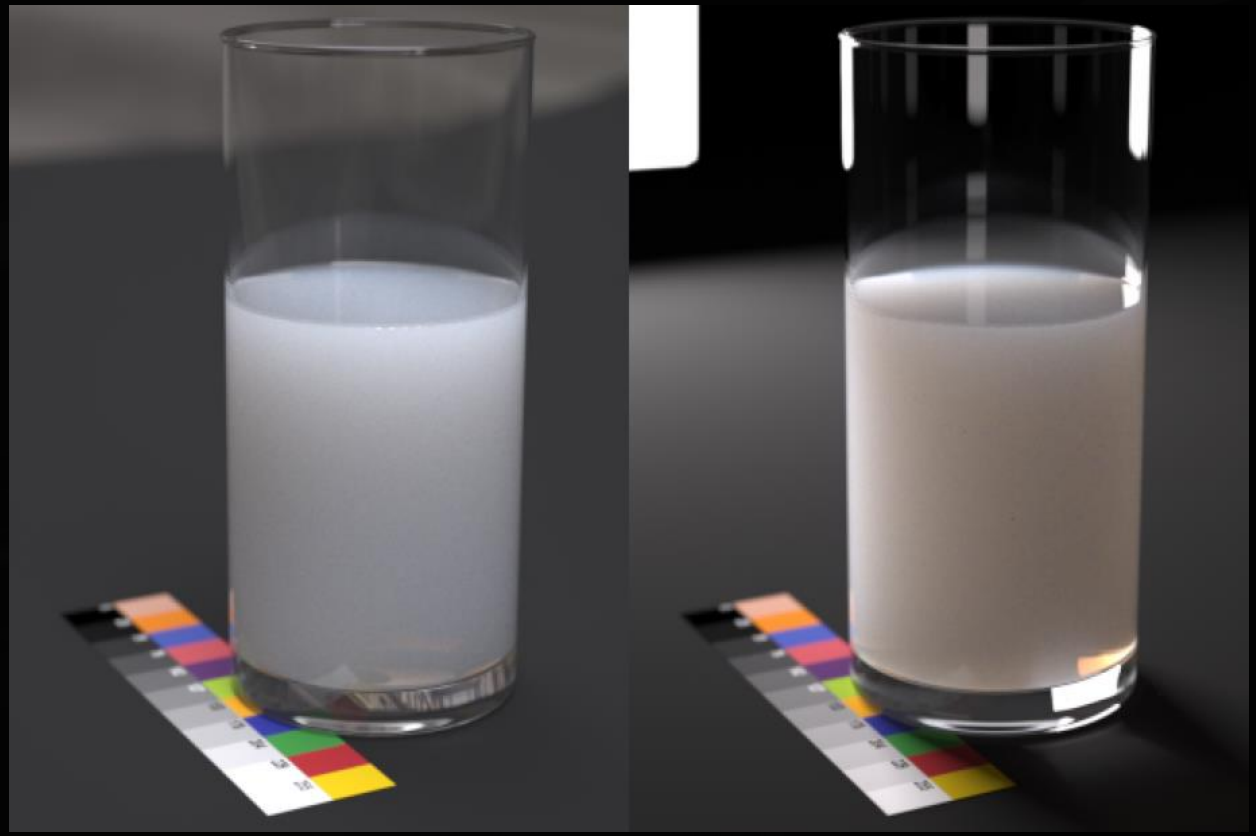
Next Steps Unbiased, GPU friendly SSS



Agenda

- Maxwell Render overview
- Why porting to the GPU was challenging
- Performance considerations
- Using the CPU to improve the GPU engine
- Summary

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Summary

Main sources of bugs:

- CPU optimized code not easy to port
- Refactoring to make code GPU friendly
- Precision issues with some math operators

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Summary

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- **90% of the complexity of Maxwell already ported**
  - -Very happy with the results: Speed boost: 5x-15x
  - - CUDA made it possible
- **Validating using a ground truth renderer**
  - - Was painful
  - - 100% worth in the long run (quality first, speed second)

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NEXT LIMIT

Thanks!

Juan Cañada
Head of Visualization
Next Limit Technologies

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