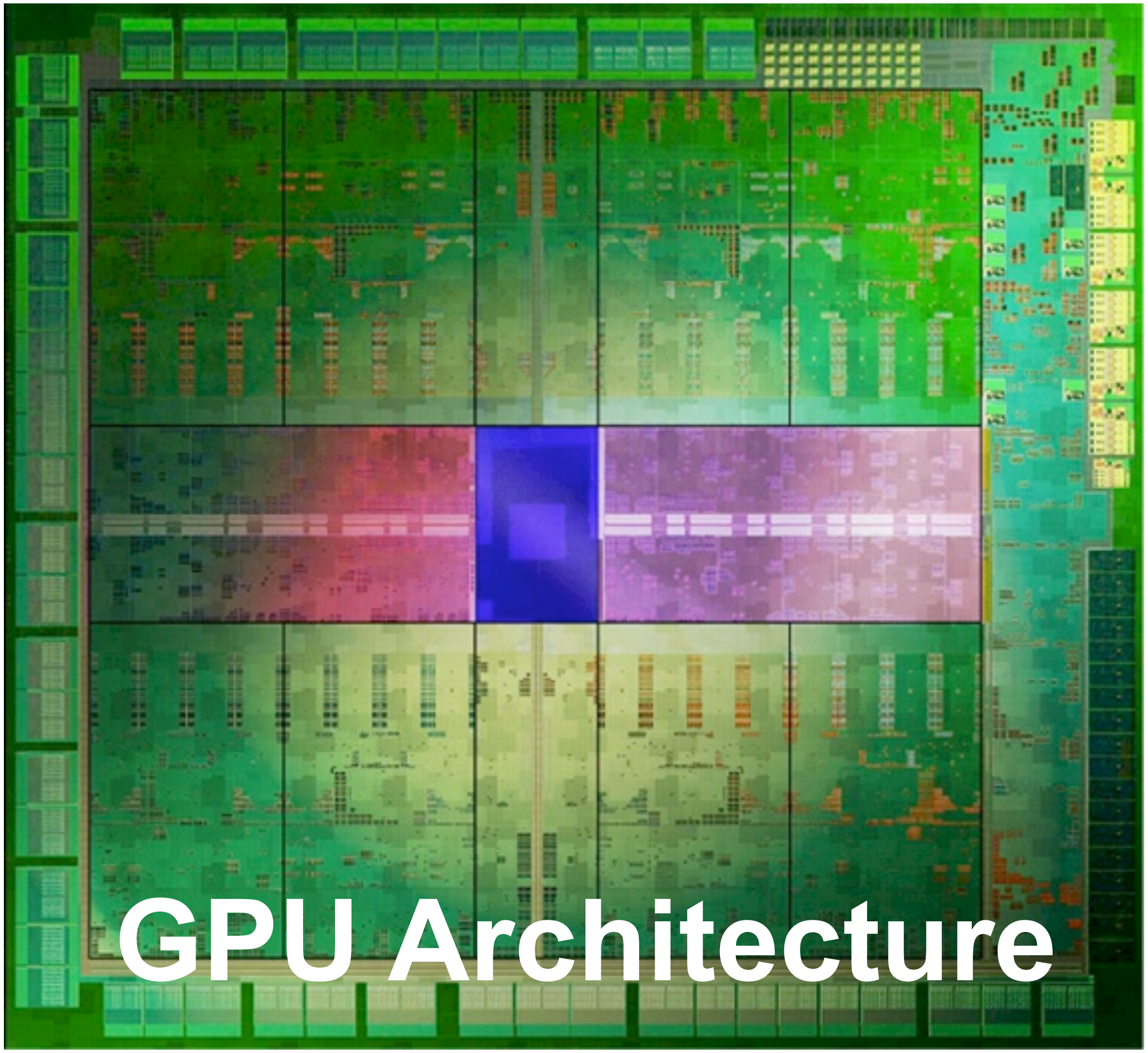


GPU Architecture

This Week: GPU Programming

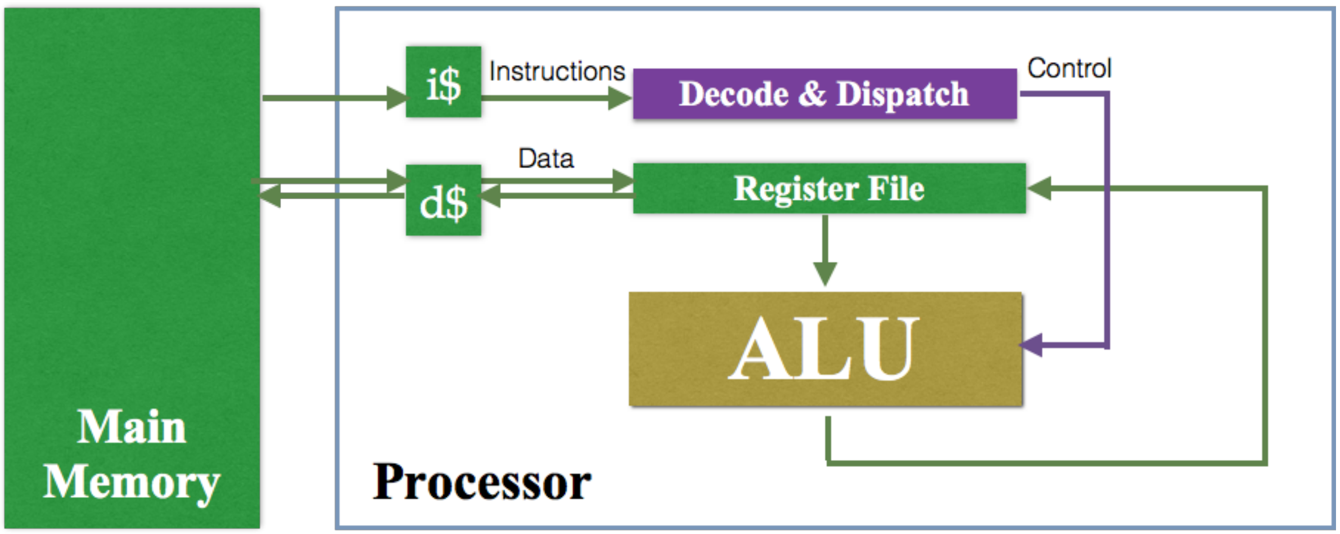
1. **Processor Architecture**
2. **GPU Register Model**
3. **Shader Launch**
4. **GLSL Language**
5. Implicit Surfaces
6. Sphere Tracing Algorithm
7. Leveraging Reference Frames
8. Procedural Texture

GPU ARCHITECTURE (++CS237)

State

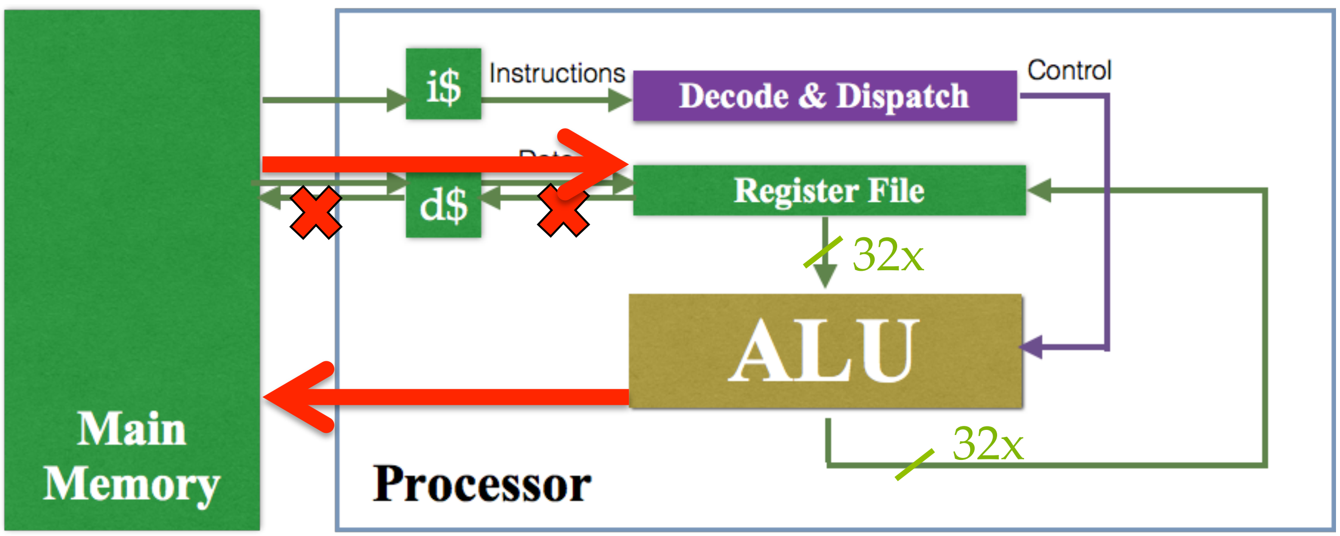
- **Program Counter** a.k.a. Instruction Pointer ("PC" or "IP")
- [Stack pointer ("SP"), Base pointer ("BP"), Condition codes]
- General-purpose **registers** ("reg" or "GPR")
- Fast, small **memory** (today: on-chip caches and local/shared memory)
- Slow, large **memory** (today: off-chip DRAM…and network and disk)

Generic Processor



$ = "cache"
ALU = Arithmetic Logic Unit

Streaming Vector Processor



Simplify
- No out-of-order, branch prediction, etc.
- *Many* ALUs and registers in saved space

Fast context switch
- 100,000s of threads
- Swap during memory latency

Special stream in/out path
- Bypass cache
- Self-synchronized by scheduling

Vectorize instructions
- Execute each 32x
- Amortize instruction fetch & decode

Streaming Vector Processor

Implications:

- Explicit memory **load is slow**
- Explicit memory **store is *very* slow** (and unsafe)
- **Stack is slow** (affects context swap)
- **Pointers are slow** (most data are in registers!)
- Computed **array indexing is slow** (same as above)
- **Divergence is slow** (splits vectors)
- Everything else is *very* fast!

Simplify

- No out-of-order, branch prediction, etc.
- *Many* ALUs and registers in saved space

Fast context switch

- 100,000s of threads
- Swap during memory latency

Special stream in/out path

- Bypass cache
- Self-synchronized by scheduling

Vectorize instructions

- Execute each 32x
- Amortize instruction fetch & decode

HLSL/GLSL

- **Designed to prevent writing slow programs**
  - Stack is slow → no recursion, fully-inlined program
  - Pointers are slow → no pointers
  - Memory store is slow → hard to use
  - Memory load is slow → abstract through "texture" functions
  - Abstractions might hide slow code → only C-level features

- **Result**: awkward, but fast

- You *can* use other languages for GPU programming (CUDA, OpenCL, C++ -> SPIRV, etc.)

GLSL Syntax Tips

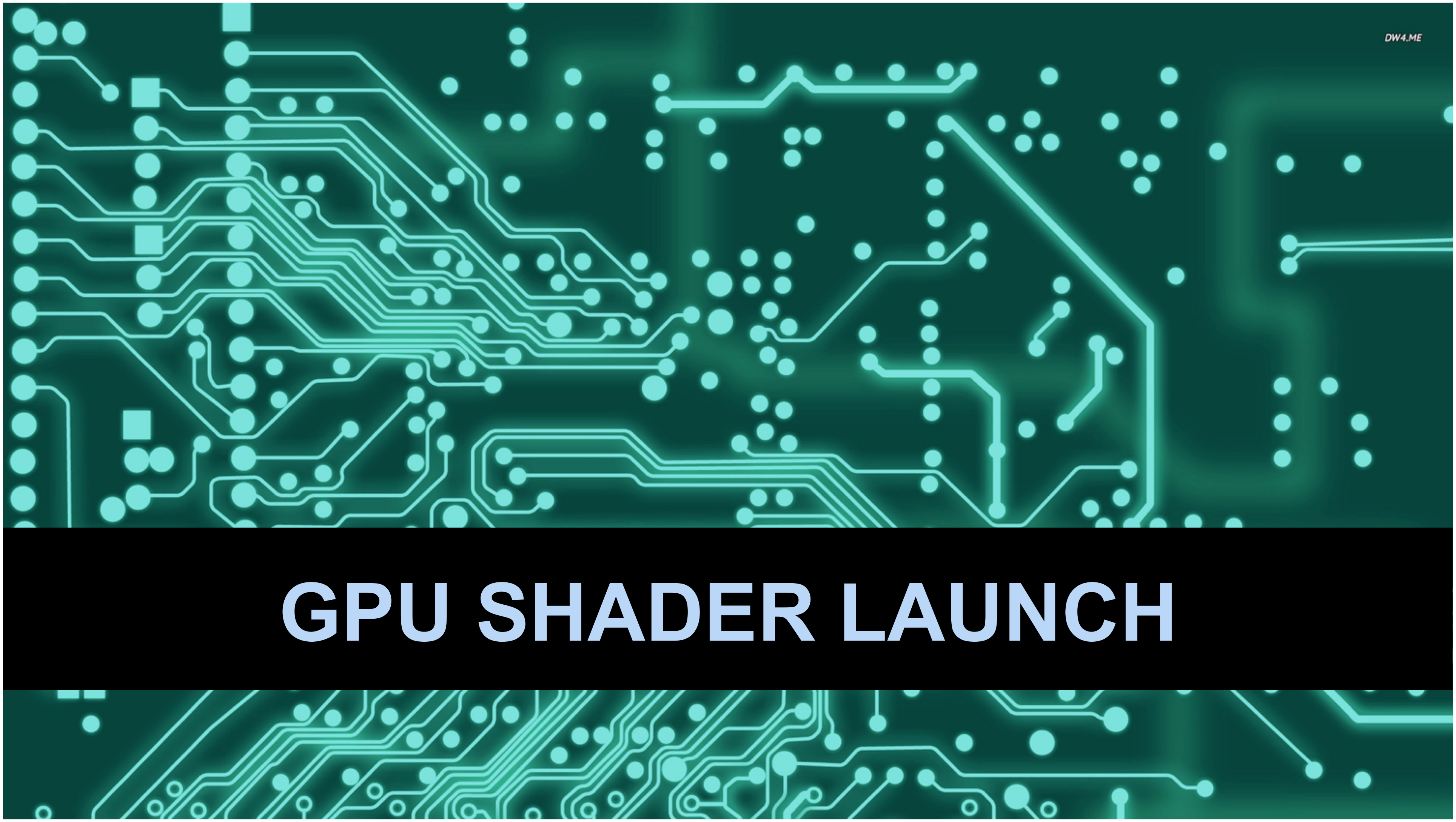
- “in out” = C++ &
- “const” = C++ “static const”…must be compile-time evaluable
- Use #define instead of typedef
- Maximum single-precision float and int (no double or long)
- No heap allocation
- No Doxygen support

GLSL Inlines Everything

- Small, fixed-length loops unroll completely
- Branches on *compile*-time constants are free
- Dead code is free
- No pointers
- No exceptions
- No recursion allowed (but you can build your own slow stack)
- No function pointers (and no classes or methods, but you can use switch)
- No pointers + no recursion = no data structures except fixed-length array and struct

GLSL Hidden Performance

- More registers = fewer threads = slower
- Float is much faster than int!
- Some intrinsics are very fast:
  - normalize()
  - dot()
- Multiply-add is a single operation
- Branches and loops have high overhead *and* create divergence
  - But conditional assignment is inexpensive!
- Computed array indices force the array out of registers into cache (slow!)



GPU SHADER LAUNCH

Shader Launch Modes

- “**Compute**” mode
  - Iterate over 1D, 2D, or 3D rectangular bounds
  - Like G3D::Thread::runConcurrently on CPU

- “**Graphics**” mode
  - Iterate over an indexed triangle list’s **vertices**, **geometry**, and **pixels**
  - Special **depth test** support for pixels
  - Automatic clipping to 3D frustum
  - Some other exotic cases (tessellated patches, stencils, paths, axis-aligned rectangles)

G3D Syntax

for a pixel shader on a full-screen rectangle in "Graphics" mode

```
// Prepare for the 2D rectangle
rd->push2D();

// Pass arguments from the CPU to the GPU
Args args;
args.setUniform("center", Point3(x, y, z));
args.setUniform("environmentMap", environmentMap, Sampler::cubeMap());
…

// Set the indexed triangle list to two triangles covering the near plane
args.setRect(rd->viewport());

LAUNCH_SHADER("mycode.pix", args);
rd->pop2D();
```

THE RASTERIZER