LLVM for Open Shading Language

Larry Gritz
& Solomon Boulos, Alejandro Conty,
Chris Kulla, Cliff Stein

sony pictures imageworks

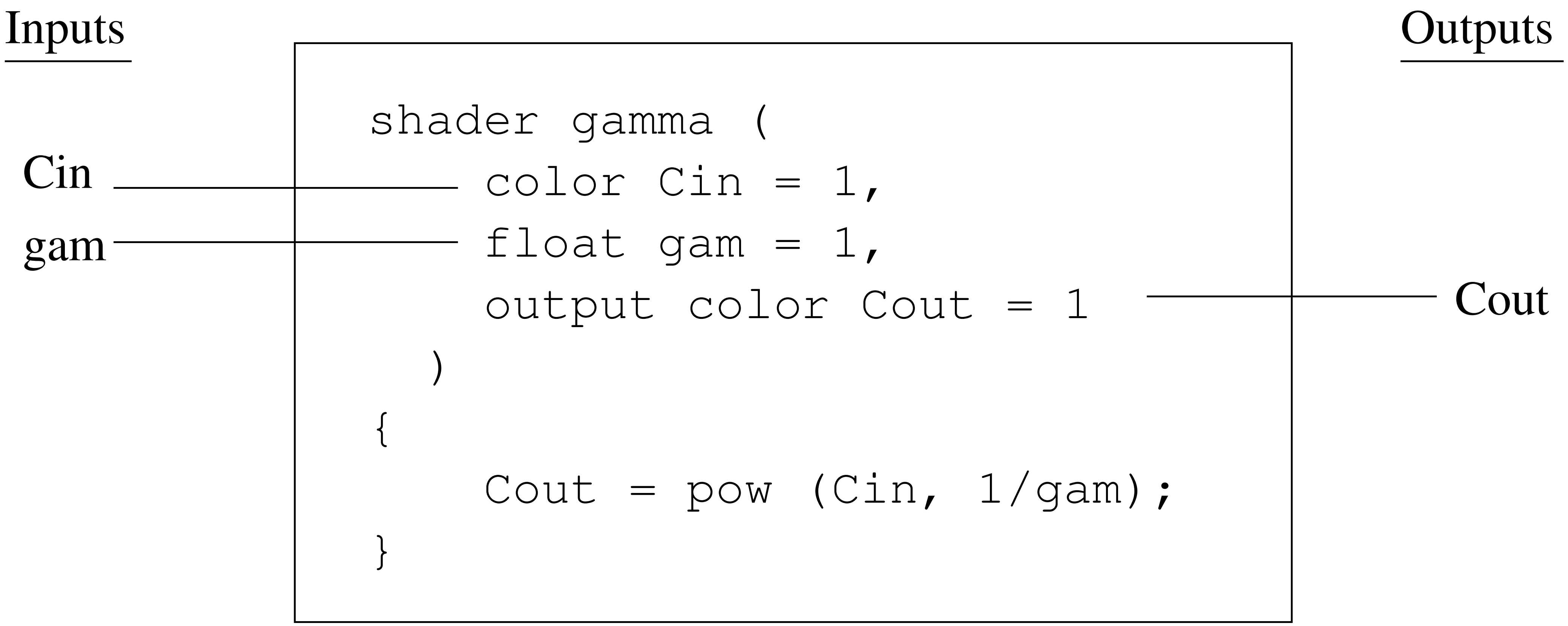
Open Shading Language (OSL)

- Film VFX-oriented DSL
- Ray-trace/GI-friendly
- Modular, generic, renderer-agnostic
- Open source (BSD)
- Uses LLVM

Production Rendering

- Huge scenes: 10+ GB geom, 200+ GB texture
- Quality is everything
- 4-10 hours/frame, peak 20-40+ hr (CPU time)
- Many thousands of cores
- No graphics hardware for final frames
- Shaders
  - describe materials, lights, displacements
  - huge: 50,000+ ops per shader group
  - important programmable tool when all else fails

Shader



Inputs

Outputs

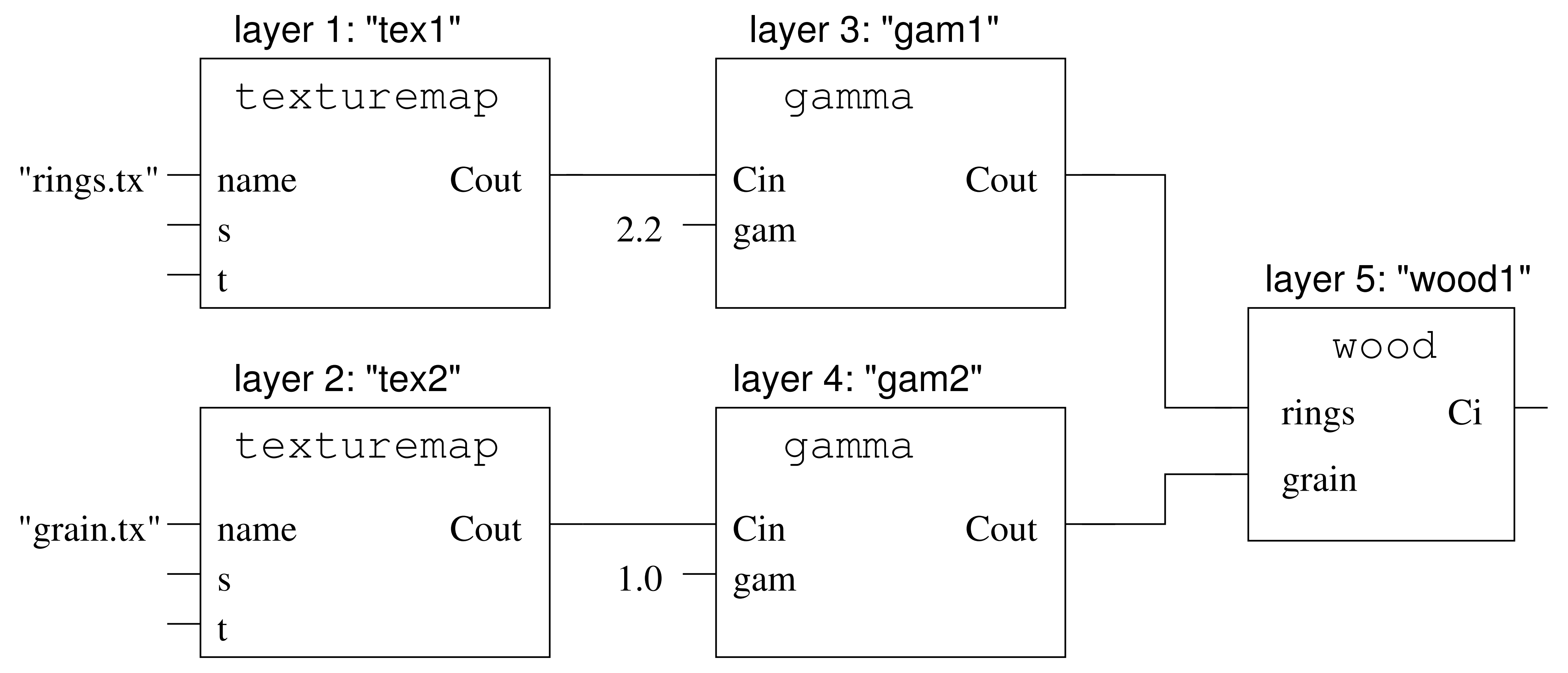
Cin

gam

Cout

```
shader gamma (
    color Cin = 1,
    float gam = 1,
    output color Cout = 1
  )
{
    Cout = pow (Cin, 1/gam);
}
```

Shader Group


layer 1: "tex1"

texturemap

"rings.tx" name Cout

s

t

layer 2: "tex2"

texturemap

"grain.tx" name Cout

s

t

layer 3: "gam1"

gamma

Cin Cout

2.2 gam

layer 4: "gam2"

gamma

Cin Cout

1.0 gam

layer 5: "wood1"

wood

rings Ci

grain

What's wrong with shaders

- C/C++ shaders:
    - can crash the renderer or leak memory
    - too much exposure of renderer internals
    - versionitis madness
    - hard to globally optimize
- Hardware dependence & limitations
- Black boxes: can't reason about them, sample, reorder, defer, etc.
- Suboptimal for a modern ray tracer

New Language Goals

- Similar to RSL/GSL, but evolved & easier
- Separate description vs implementation
  - End versionitis nightmare
  - Late-stage optimization
  - No crashing, NaNs, etc.
  - Allow multiple back ends
- Renderer control of rays / more physical shading
- Lazy running of layers
- Closures describe materials/lights
- Automatic differentiation

First: Bytecode Interpreter

```
for (ip = beginop;  ip < endop && beginpoint < endpoint;  ++ip) {
    Opcode &op (code[ip]);
    op.implementation (op.nargs, args+op.firstarg);
}

OP_add (...) {
    Symbol &Result (exec->sym (args[0])), &A(...), &B(...);
    if (Result.is_uniform())
        Result[0] = A[0] + B[0];
    else {   // varying case
        for (int i = beginpoint; i < endpoint; ++i)
            if (runflags[i])
                Result[i] = A[i] + B[i];
    }
}
```

Bytecode interpreter

- Extensive runtime specialization
- Interpreter performance pretty good
  - Interpreter overhead amortized over batches
  - Uniforms make up the difference
- Hinges on large enough batch sizes...
  - Hard for GI ray tracer to keep batches big enough
  - Lots of renderer-side overhead from batching
  - Performance about 1/5 what we needed for real-world batch sizes
- Next plan: LLVM

LLVM: first try

- Compile existing batch shadeops with llvm-gcc
- JIT code that makes the calls in succession
- Inline and hope for the best
- Not unlike the Apple OpenGL interpreter
- Results:
  - Tricky static initialization problems
  - Huge memory bloat
  - Not good performance
  - Didn't work correctly for all cases. Now what?
  - But, inspiring proof of concept

LLVM: Plan B

- Bytecode → LLVM IR → JIT
  - LLVM IR for control flow and many ops
  - Some ops C++ compiled with llvm-gcc/clang
  - Some ops IR function calls to renderer internals
- Still do extensive folding, specialization, deriv analysis on the bytecode first
- Single point execution only
  - Greatly simplifies & optimizes renderer side

First "Real" Result

- About 40 man-hours to implement Plan B for a subset of the language necessary to run a small math benchmark
- 16x faster vs 1-point-at-a-time interpreter
- Next step: Plan B for full language

Final Results

- Full team worked ~3 months
- Greatly simplified internals & renderer
- Exceed perf of hand-coded C shaders
  - Our runtime specialization + LLVM optimization
  - Inter-layer optimization and pruning
  - No batching overhead on renderer side
- We recently removed the interpreter!
- Continuing to add features & optimize
- First shows going into production now

Issues we're running into with LLVM

Issues: Optimization

- Full C++ optimizations not a good tradeoff
- Laborious process of picking LLVM passes
- Trial and error
- Still something to go back to
- Lingering bugs?
  - Lots of time fighting LLVM crashes with certain pass combinations
  - Still poorly understood
  - May be related to reusing EE

Issues: Parallelization

- We have many threads
- New shader groups to JIT at any time
- WBN: allow multiple threads to JIT without separate LLVM context per thread (for memory reasons)
- WBN: parallel JIT examples that share a global Module of shared code but can JIT independent code.

Issue: Memory

- Thousands of shader groups to JIT
- New ones coming along all the time
- Add to existing module/EE? (Bugs?)
- New module per group? (memory!)
- Once JITted, we only need machine code
- Planned: custom JITMemoryManager?
  - But would be great to be an LLVM feature

Issue: Hardware parallelism

- How to take advantage of SSE/AVX?
- PTX back end?
- LLVM vector support
  - avoid manually using intrinsics?
  - how to get better LLVM vector support?

LLVM wish list

- More working examples, especially for JIT (versus static compilation)
- Many static codepath tools useless for JIT
- No good metadata-for-debugging docs
- Better multithread JIT
- Return JIT code and free everything else

Future work

- Optimize performance
- Memory/speed issues as we scale to thousands of shaders
- Allow BSDF prims & integrators to be expressed in OSL itself
- Alternate back ends (PTX)
- SSE/AVX
- Conquer the world

Q&A and Reminders

- lg@imageworks.com
- http://code.google.com/p/openshadinglanguage

- Acknowledgements:
    - OSL Coathors: Cliff Stein, Chris Kulla, Alejandro Conty, Solomon Boulos
    - SPI: Adam Martinez, Jay Reynolds, John Monos, Rene Limberger, Rob Bredow
    - Images: Sony Pictures, Disney