LLVM for OpenGL and other stuff

Chris Lattner
Apple Computer
clattner@apple.com

OpenGL JIT

OpenGL Vertex/Pixel Shaders

OpenGL Pixel/Vertex Shaders

- Small program, provided at run-time, to be run on each vertex/pixel:
  - Written in one of a few high-level graphics languages (e.g. GLSL)
  - Executed millions of times, extremely performance sensitive
- Ideally, these are executed on the graphics card:
  - What if hardware doesn't support some feature? (e.g. laptop gfx)
    - **Interpret or JIT on main CPU**

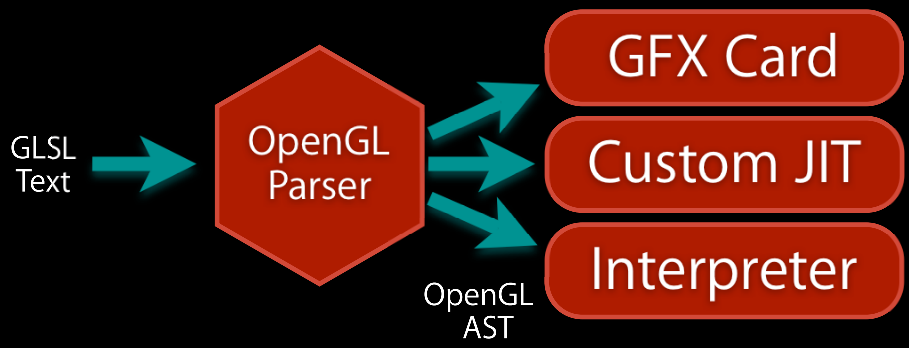
```
void main() {
 vec3 ecPosition = vec3(gl_ModelViewMatrix * gl_Vertex);
 vec3 tnorm      = normalize(gl_NormalMatrix * gl_Normal);
 vec3 lightVec   = normalize(LightPosition - ecPosition);
 vec3 reflectVec = reflect(-lightVec, tnorm);
 vec3 viewVec    = normalize(-ecPosition);
 float diffuse   = max(dot(lightVec, tnorm), 0.0);
 float spec      = 0.0;
 if (diffuse > 0.0) {
     spec = max(dot(reflectVec, viewVec), 0.0);
     spec = pow(spec, 16.0);
 }
 LightIntensity = DiffuseContribution * diffuse +
                  SpecularContribution * spec;
 MCposition     = gl_Vertex.xy;
 gl_Position    = ftransform();
}
```

GLSL Vertex Shader

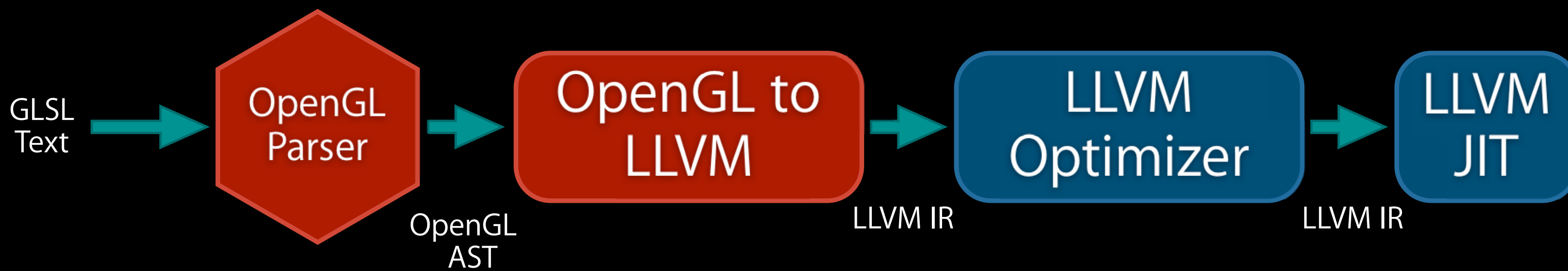
MacOS OpenGL Before LLVM

- Custom JIT for X86-32 and PPC-32:
  - Very simple codegen: Glued chunks of Altivec or SSE code
  - Little optimization across operations (e.g. scheduling)
  - Very fragile, hard to understand and change (hex opcodes)

- OpenGL Interpreter:
  - JIT didn't support all OpenGL features: fallback to interpreter
  - Interpreter was very slow, 100x or worse than JIT



OpenGL JIT built with LLVM Components



- At runtime, build LLVM IR for program, optimize, JIT:
  - Result supports any target LLVM supports (+ PPC64, X86-64 in MacOS 10.5)
  - Generated code is as good as an optimizing static compiler
- Other LLVM improvements to optimizer/codegen improves OpenGL
- Key question: How does the "OpenGL to LLVM" stage work?

http://llvm.org/

Structure of an Interpreter

- Simple opcode-based dispatch loop:

```
while (...) {
  ...
  switch (cur_opcode) {
  case dotproduct:      result = opengl_dot(lhs, rhs); break;
  case texturelookup: result = opengl_texlookup(lhs, rhs); break;
  case ...
```

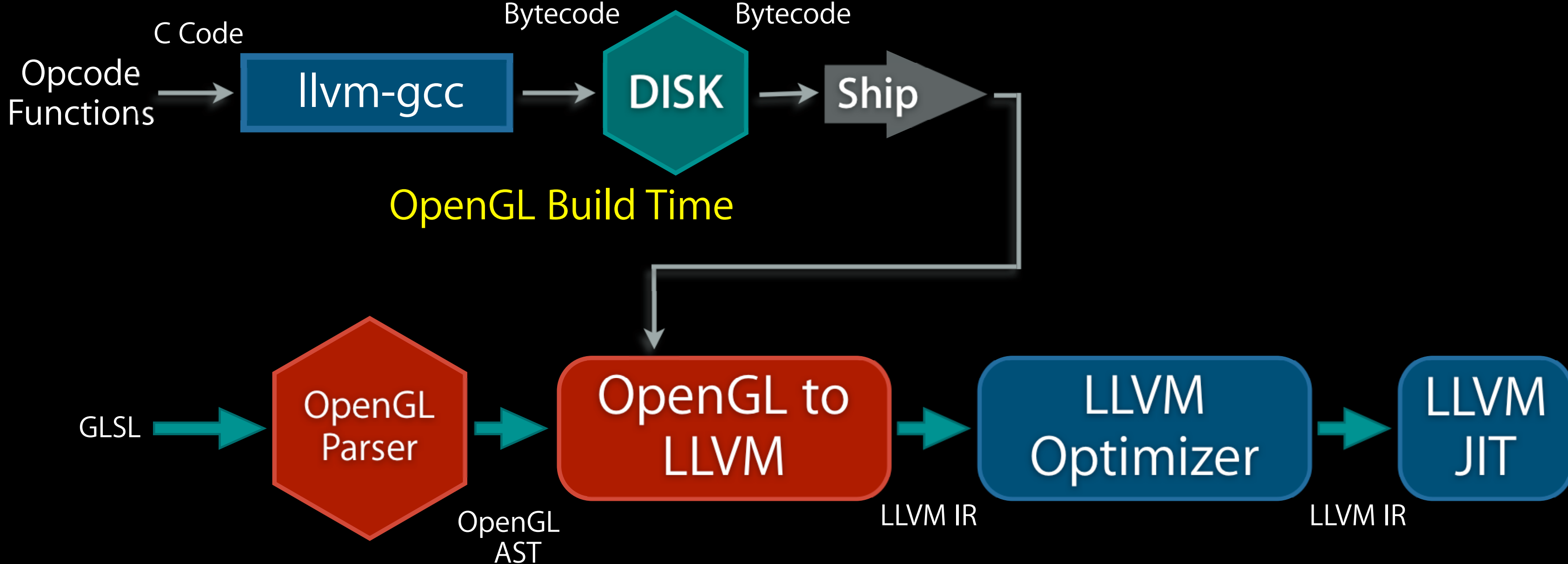
- One function per operation, written in C:

```
double opengl_dot(vec3 LHS, vec3 RHS) {
 #ifdef ALTIVEC
   ... altivec intrinsics ...
 #elif SSE
   ... sse intrinsics ...
 #else
   ... generic c code ...
  #endif
}
```

Key Advantage of an Interpreter:
Easy to understand and debug, easy to write each operation (each operation is just C code)

- In a high-level language like GLSL, each op can be hundreds of LOC

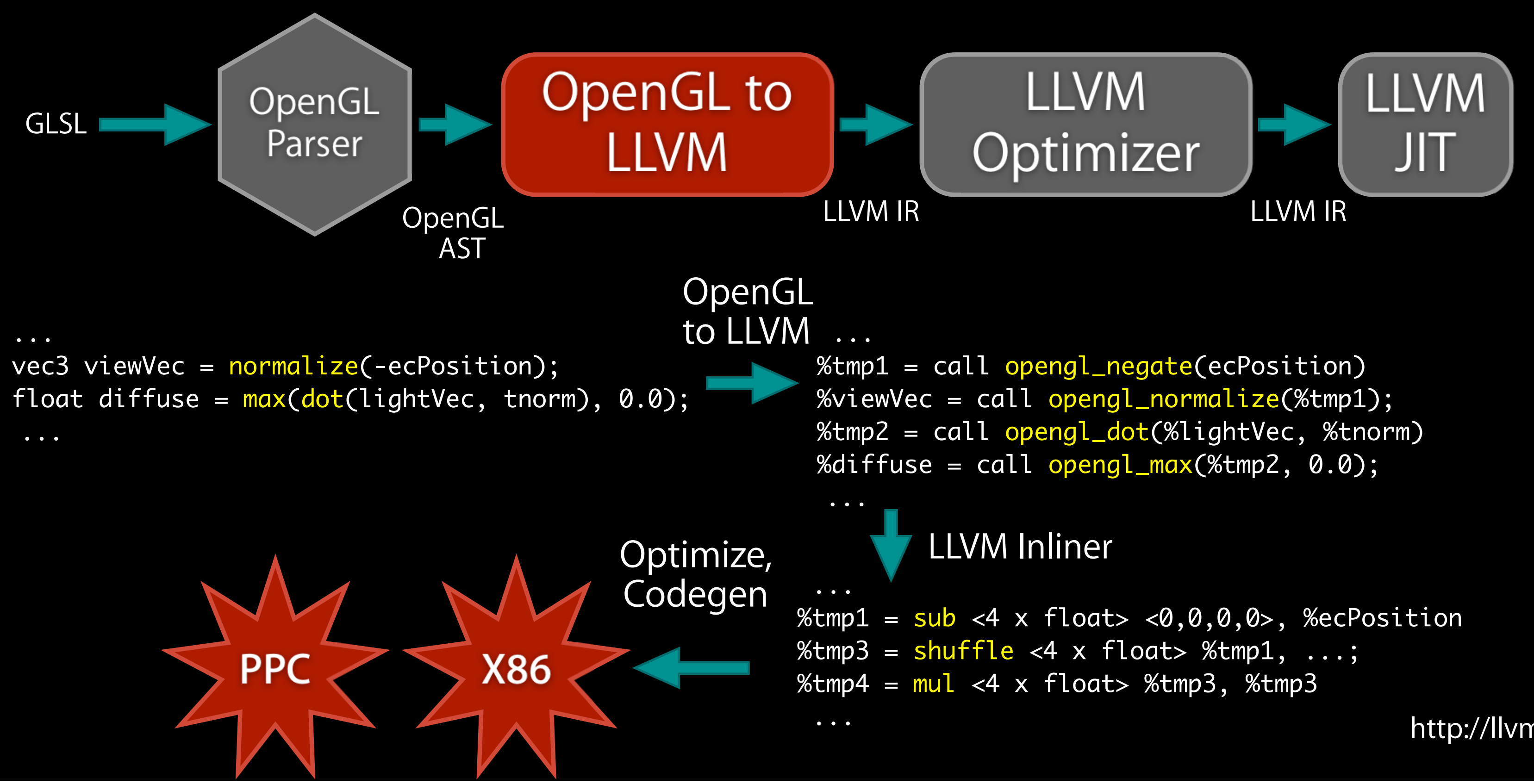
OpenGL to LLVM Implementation



- At OpenGL build time, compile each opcode to LLVM bytecode:
  - Same code used by the interpreter: easy to understand/change/optimize

OpenGL to LLVM: At runtime

1. Translate OpenGL AST into LLVM call instructions: one per operation
2. Use the LLVM inliner to inline opcodes from precompiled bytecode
3. Optimize/codegen as before



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Benefits of this approach

- Key features of this approach:
  - Each opcode is written/debugged for a simple interpreter, in standard C
    - Retains all advantages of an interpreter: debugability, understandability, etc
    - Easy to make algorithmic changes to opcodes
  - OpenGL runtime is independent of opcode implementation

- Primary contributions to Mac OS:
  - Support for PPC64/X86-64
  - Much better performance: optimizations, regalloc, scheduling, etc
    - No fallback to interpreter needed!
  - OpenGL group doesn't maintain their own JIT!

Another Example: Colorspace Conversion

- Code to convert from one coordinate system to another:
  - e.g. BGRA 444R -> RGBA 8888
  - Hundreds of combinations, importance depends on input

```
for each pixel {
  switch (infmt) {
  case RGBA 5551:
    R = (*in >> 11) & C
    G = (*in >> 6) & C
    B = (*in >> 1) & C
  ... }
  switch (outfmt) {
  case RGB888:
    *outptr = R << 16 |
              G << 8 ...
  }
}
```

Run Time
Specialize

```
for each pixel {
  R = (*in >> 11) & C;
  G = (*in >> 6) & C;
  B = (*in >> 1) & C;
  *outptr = R << 16 |
            G << 8 ...
}
```

Compiler optimizes
shifts and masking

LLVM + Dynamic Languages

LLVM and Dynamic Languages

- Dynamic languages are very different than C:
  - Extremely polymorphic, reflective, dynamically extensible
  - Standard compiler optzns don’t help much if “+” is a dynamic method call

- Observation: in many important cases, dynamism is eliminable
  - Solution: Use dataflow and static analysis to infer types:

‘i’ starts as an integer

++ on integer returns integer

```
var i;
for (i = 0; i < 10; ++i)
   ... A[i] ...
```

i isn’t modified anywhere else

  - We proved “i” is always an integer: change its type to integer instead of object
  - Operations on “i” are now not dynamic
    - Faster, can be optimized by LLVM (e.g. loop unrolling)

Advantages and Limitations of Static Analysis

- Works on unmodified programs in scripting languages:
  - No need for user annotations, no need for sub-languages
- Many approaches for doing the analysis (with cost/benefit tradeoffs)
- Most of the analyses could work with many scripting languages:
  - Parameterize the model with info about the language operations
- Limitation: cannot find all types in general!
  - That's ok though, the more we can prove, the faster it goes

Scripting Language Performance

- Ahead-of-Time Compilation provides:
  - Reduced memory footprint (no ASTs in memory)
  - Eliminate (if no 'eval') or reduce use of interpreter at runtime (save code size)
  - Much better performance if type inference is successful
- JIT compilation provides:
  - Full support for optimizing eval'd code (e.g. json objects in javascript)
  - Runtime "type profiling" for speculative optimizations

- LLVM provides:
  - Both of the above, with one language -> llvm translator
  - Install-time codegen
  - Continuously improving set of optimizations and targets
  - Ability to inline & optimize code from different languages
    - inline your runtime library into the client code?