Implementing the Unimplementable

Bringing HLSL's Standard Library into Clang

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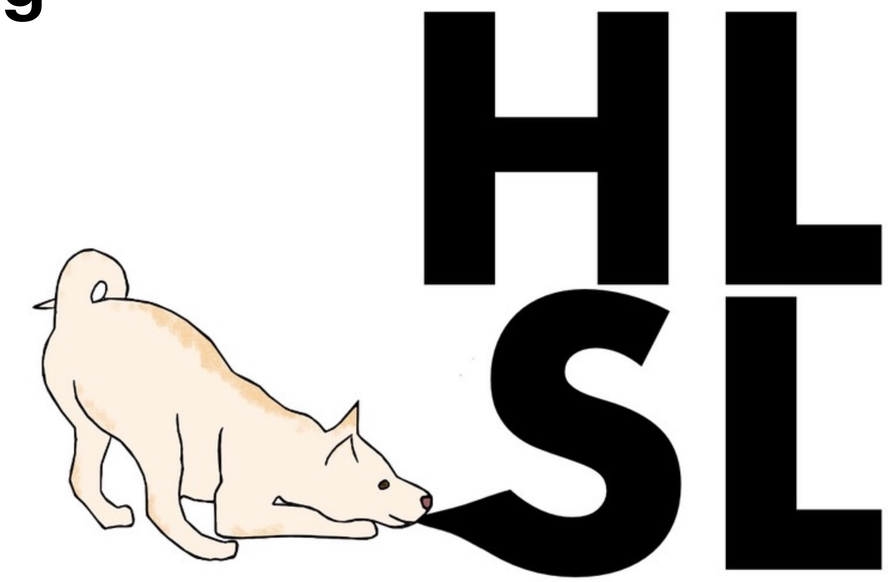
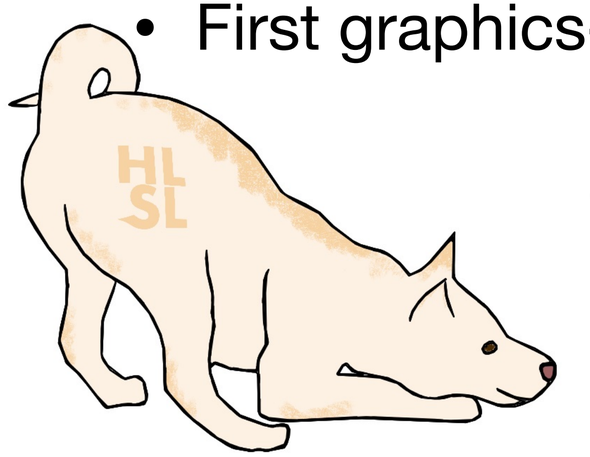


Introduction

- Who am I?
  - Long time LLVM contributor
  - HLSL team at Microsoft
- What am I talking about?
  - Ongoing effort to add HLSL support to Clang
- Where am I?

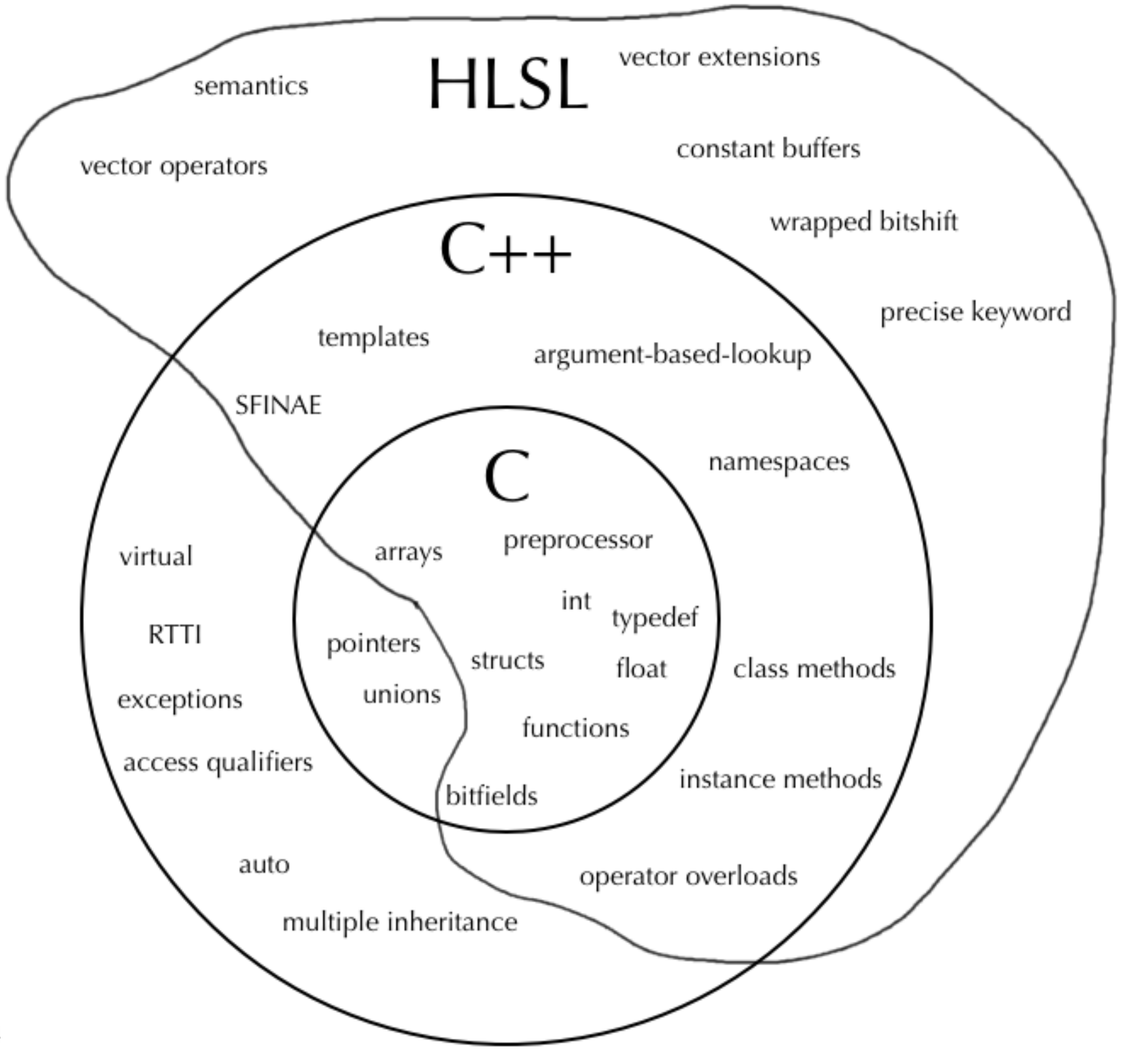
What is HLSL?

- High Level Shader Language was introduced with DirectX 9
- Initially supported vertex and pixel “shading”
- Started as a C-like language, but has evolved to be more C++-like
- Largely source compatible with other commonly used shader languages
- First graphics-focused language coming to Clang!



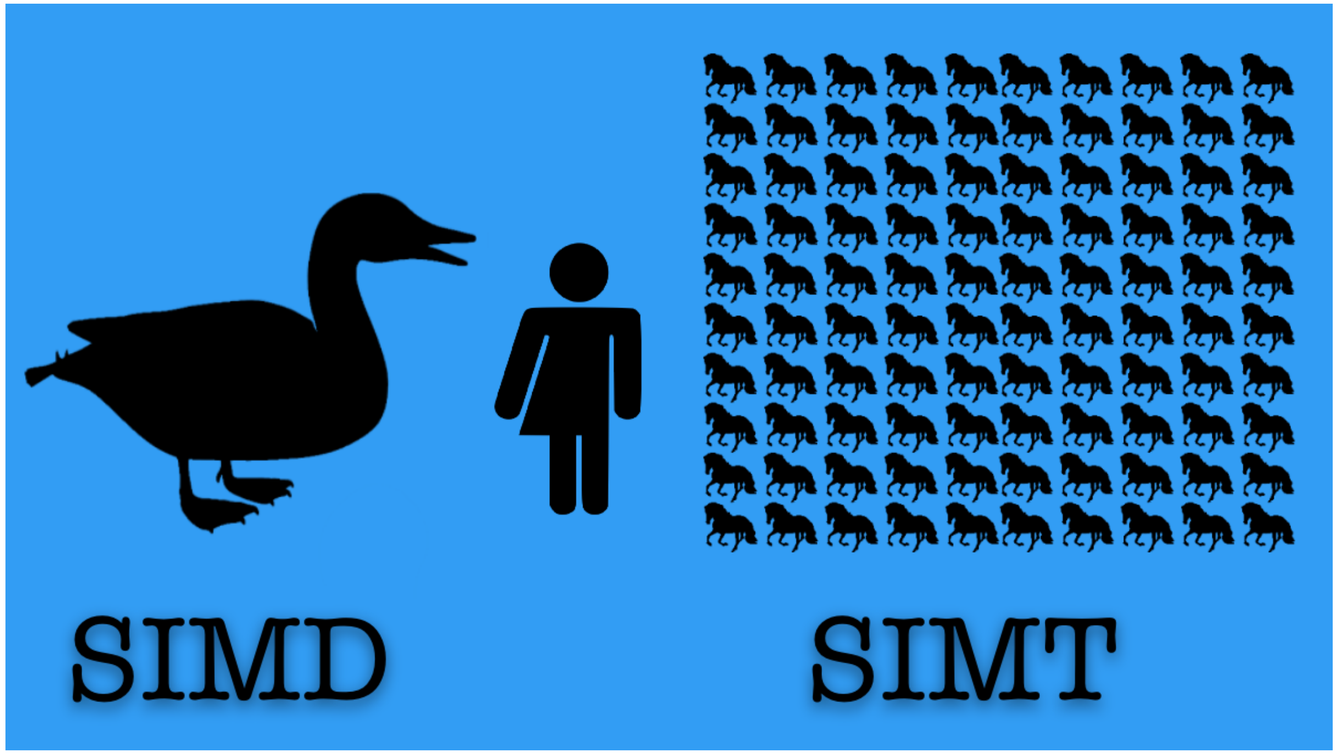
Language Features

- Supports enough C syntax to be familiar
- Has enough differences to be strange
- Implicitly parallel programming model
- Some C/C++ features just don’t make sense



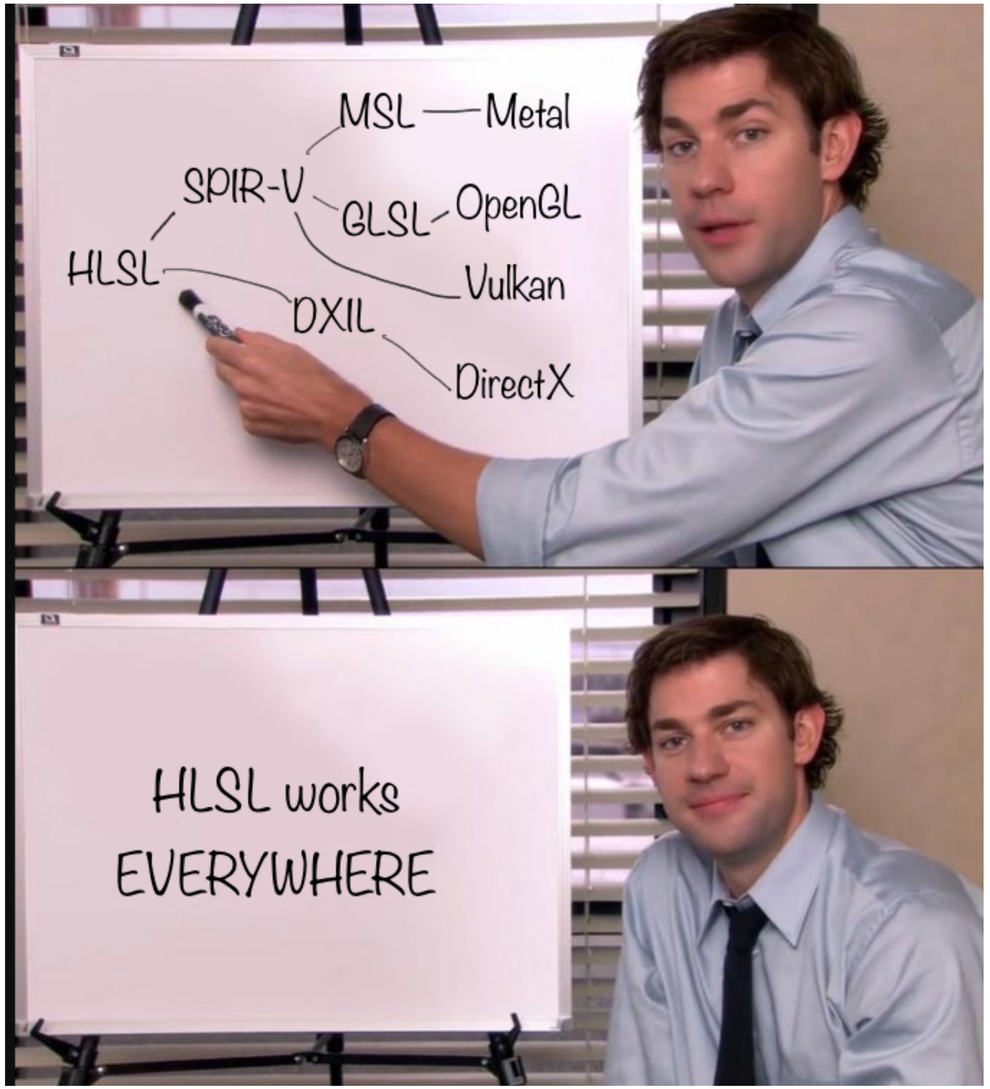
Implicit Parallelism

- GPU hardware is not all the same
  - Wide SIMD
- Implicit parallelism enables source portability
- Vectors are vectors of vectors



Where is HLSL used?

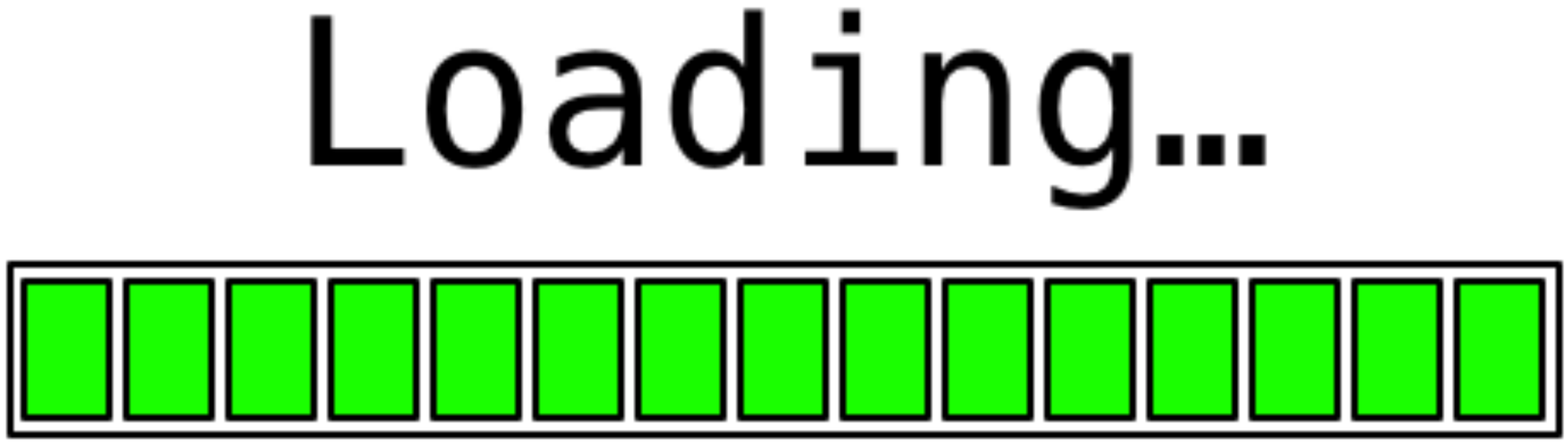
- HLSL has a rich ecosystem
- Can target every major graphics API
- Used everywhere modern 3d games run
- DXC is shipped in the DirectX and Vulkan SDKs



Missing Features

- Key C/C++ features are missing
- No support for pointers or references
- User defined templates were not supported until 2021
- No C++ 11 anything…
- Organic language growth led to gaps in features

Compiler Performance Concerns



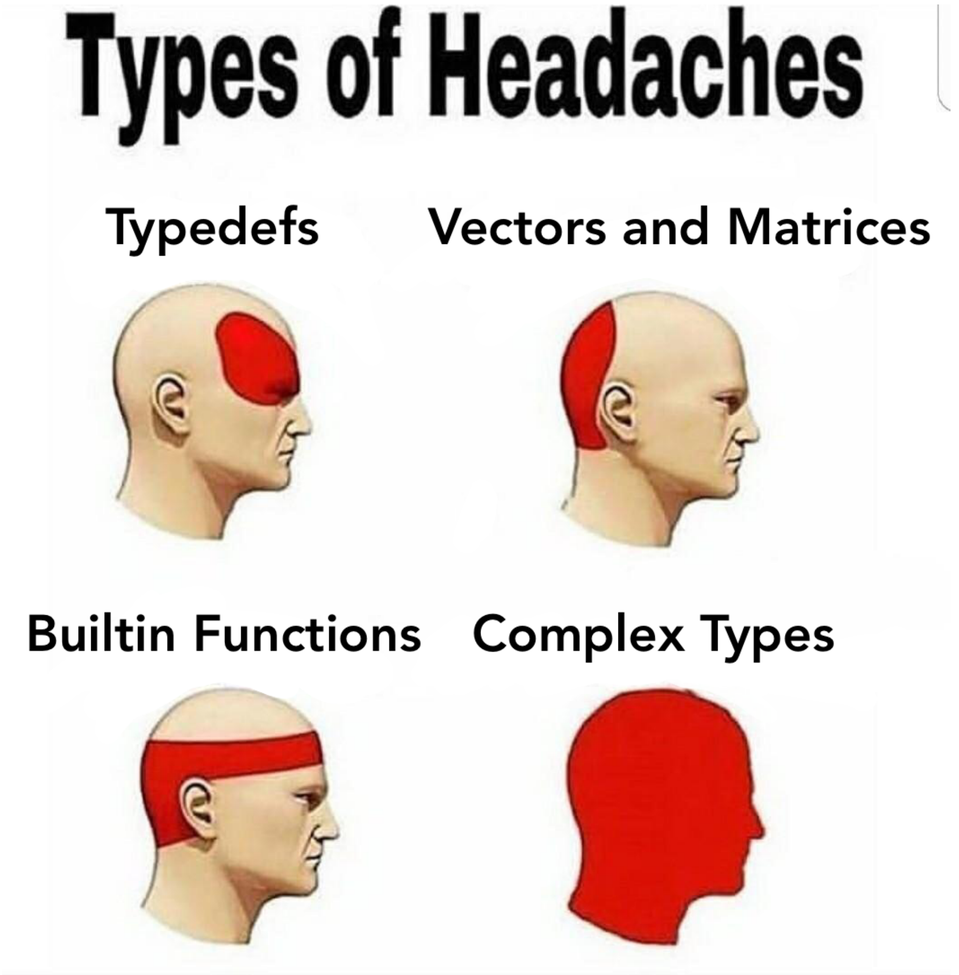
Compiler Performance Concerns

- Shader compilers sometimes run at runtime
- Re-parsing standard library headers can be slow
- Re-loading or initializing full serialized ASTs can be slow too
- Lazy AST initialization is a _big_ win

XKCD. *#303 - Compiling.* https://xkcd.com/303/

HLSL’s Library

- Pre-defined typedefs for common data types
- Built-in vector and matrix types
- Large collection of built-in functions
- Some complex data types

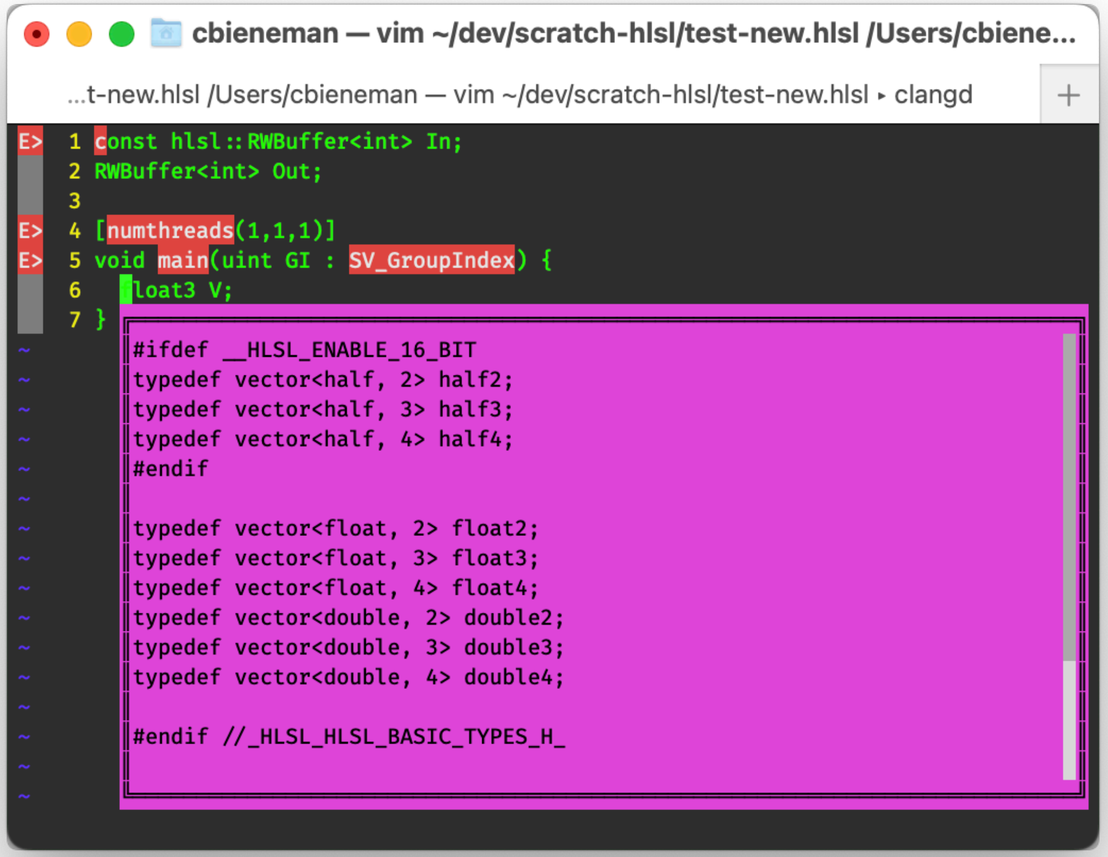


Balancing Priorities

- Scalability & Maintainability
- Compiler speed
- Robust Tooling

hlsl.h

- Header implementations are easy to write and test
- Re-parsing is slow
- Only typedefs and mapping functions to builtins
- Limited to older language features



Built-in `vector` Type

```
namespace hlsl {
template <typename element_type, int element_count>
using vector = element_type __attribute__((__ext_vector_type__(element_count)));

using float4 = vector<float, 4>;
} // namespace hlsl
```

- HLSL Vectors behave like clang's vector extension
- User-defined templates aren't supported in older language modes
  - HLSL 2018 can't parse this code

AST Initialization

- Define trivial types on AST initialization
  - Types with no methods
  - Types that are frequently used
- Makes the type available immediately
- Allows us to bypass parsing unsupported features

```
void HLSLExternalSemaSource::defineHLSLVectorAlias() {
  ASTContext &AST = SemaPtr->getASTContext();

  llvm::SmallVector<NamedDecl *> TemplateParams;

  auto *TypeParam = TemplateTypeParmDecl::Create(
      AST, HLSLNamespace, SourceLocation(), SourceLocation(), 0, 0,
      &AST.Idents.get("element", tok::TokenKind::identifier), false, false);
  TypeParam->setDefaultArgument(AST.getTrivialTypeSourceInfo(AST.FloatTy));

  TemplateParams.emplace_back(TypeParam);

  auto *SizeParam = NonTypeTemplateParmDecl::Create(
      AST, HLSLNamespace, SourceLocation(), SourceLocation(), 0, 1,
      &AST.Idents.get("element_count", tok::TokenKind::identifier), AST.IntTy,
      false, AST.getTrivialTypeSourceInfo(AST.IntTy));
  Expr *LiteralExpr =
      IntegerLiteral::Create(AST, llvm::APInt(AST.getIntWidth(AST.IntTy), 4),
                             AST.IntTy, SourceLocation());
  SizeParam->setDefaultArgument(LiteralExpr);
  TemplateParams.emplace_back(SizeParam);

  auto *ParamList =
      TemplateParameterList::Create(AST, SourceLocation(), SourceLocation(),
                                    TemplateParams, SourceLocation(), nullptr);

  IdentifierInfo &II = AST.Idents.get("vector", tok::TokenKind::identifier);

  QualType AliasType = AST.getDependentSizedExtVectorType(
      AST.getTemplateTypeParmType(0, 0, false, TypeParam),
      DeclRefExpr::Create(
          AST, NestedNameSpecifierLoc(), SourceLocation(), SizeParam, false,
          DeclarationNameInfo(SizeParam->getDeclName(), SourceLocation()),
          AST.IntTy, VK_LValue),
      SourceLocation());

  auto *Record = TypeAliasDecl::Create(AST, HLSLNamespace, SourceLocation(),
                                       SourceLocation(), &II,
                                       AST.getTrivialTypeSourceInfo(AliasType));
  Record->setImplicit(true);

  auto *Template =
      TypeAliasTemplateDecl::Create(AST, HLSLNamespace, SourceLocation(),
                                    Record->getIdentifier(), ParamList, Record);

  Record->setDescribedAliasTemplate(Template);
  Template->setImplicit(true);
  Template->setLexicalDeclContext(Record->getDeclContext());
  HLSLNamespace->addDecl(Template);
}
```

AST On Demand

`clang::ExternalASTSource`

- Forward declare types
- Populate definitions on use
- Solves exactly this problem!

External ASTs

- Basis for precompiled headers and modules
- Designed to enable lazy deserialization of bitcode ASTs
- Also used by lldb and Tooling APIs

```
class ExternalASTSource : public RefCountedBase<ExternalASTSource> {
public:
  ExternalASTSource() = default;
  virtual ~ExternalASTSource();

  /// Gives the external AST source an opportunity to complete
  /// an incomplete type.
  virtual void CompleteType(TagDecl *Tag);
};
```

Lazily Building Decls

BuiltinTypeDeclBuilder

- Forward declare on initialization
- Hook through `ExternalSemaSource::CompleteType`
  - Called whenever the language requires completed types

```
void HLSLExternalSemaSource::forwardDeclareHLSLTypes() {
  CXXRecordDecl *Decl;
  Decl = BuiltinTypeDeclBuilder(*SemaPtr, HLSLNamespace, "RWBuffer")
             .addTemplateArgumentList()
             .addTypeParameter("element_type", SemaPtr->getASTContext().FloatTy)
             .finalizeTemplateArgs()
             .Record;
  if (!Decl->isCompleteDefinition())
    Completions.insert(
        std::make_pair(Decl->getCanonicalDecl(),
                       std::bind(&HLSLExternalSemaSource::completeBufferType,
                                 this, std::placeholders::_1)));
}

void HLSLExternalSemaSource::completeBufferType(CXXRecordDecl *Record) {
  BuiltinTypeDeclBuilder(Record)
      .addHandleMember()
      .addDefaultHandleConstructor(*SemaPtr, ResourceClass::UAV)
      .addArraySubscriptOperators()
      .annotateResourceClass(HLSLResourceAttr::UAV,
                             HLSLResourceAttr::TypedBuffer)
      .completeDefinition();
}
```

Everything in the AST

- Extending HLSL with internal attributes
- Complete ASTs for methods
- Minimize codegen changes
- Better tooling experience!

```
namespace hlsl {

template <typename element_type>
[[hlsl::resource(UAV, TypedBuffer)]] struct RWBuffer {
  element_type *h;
  RWBuffer() {
    h = reinterpret_cast<element_type *>(__builtin_hlsl_create_handle());
  }

  RWBuffer(const RWBuffer &) = default;

  RWBuffer &operator=(const RWBuffer &) = default;

  element_type operator[](size_t Idx) { return h[Idx]; }
};

} // namespace hlsl
```

Internal Attributes

- Attributes have no spelling
- Never string-match type names
- Model special behaviors of built-in types
  - Special code generation
  - Initialization behavior

```
!llvm.ident = !{!0}
!dx.version = !{!1}
!dx.valver = !{!2}
!dx.shaderModel = !{!3}
!dx.resources = !{!4}
!dx.entryPoints = !{!12}

!0 = !{!"dxc(private) 1.7.0.3682"}
!1 = !{i32 1, i32 0}
!2 = !{i32 1, i32 7}
!3 = !{!"cs", i32 6, i32 0}
!4 = !{!5, !8, null, null}
!5 = !{!6}
!6 = !{i32 0, %"class.Texture2D<float>"* undef, !"", i32 0,
       i32 0, i32 1, i32 2, i32 0, !7}
!7 = !{i32 0, i32 9}
!8 = !{!9, !11}
!9 = !{i32 0, %"class.RWBuffer<int>"* undef, !"", i32 0, i32 1,
       i32 1, i32 10, i1 false, i1 false, i1 false, !10}
!10 = !{i32 0, i32 4}
!11 = !{i32 1, %"class.RWBuffer<int>"* undef, !"", i32 0, i32 0,
        i32 1, i32 10, i1 false, i1 false, i1 false, !10}
!12 = !{void ()* @CSMain, !"CSMain", null, !4, !13}
!13 = !{i32 4, !14}
!14 = !{i32 8, i32 8, i32 1}
```

Future Directions

Even more in the AST

- Moving IR-based analysis to AST & Clang CFG
  - Augment with internal attributes
- Provide higher quality diagnostics
  - earlier & more consistently

```
namespace hlsl {

template <typename element_type>
[[hlsl::resource(UAV, TypedBuffer)]] struct RWBuffer {
  element_type *h;
  [[hlsl::uninitialized]] RWBuffer() {
    h = reinterpret_cast<element_type *>(__builtin_hlsl_create_handle());
  }

  [[hlsl::initializer]] RWBuffer(const RWBuffer &) = default;

  [[hlsl::initializer]] RWBuffer &operator=(const RWBuffer &) = default;

  element_type operator[](size_t Idx) { return h[Idx]; }
};

} // namespace hlsl
```

Are we yolo yet?

- Are HLSL features valuable to C++?
- New attributes might enable expressing API constraints
- HLSL matrix syntax might be nice for C++

```
class TaggedValue {
  enum Kind {
    Uninitialized = 0,
    Integer,
    Float
  };
  Kind VK = Uninitialized;

  union {
    int I;
    float F;
  };
public:

  [[clang::yolo]]
  TaggedValue() = default;

  TaggedValue(TaggedValue&) = default;

  void hasValue() { return VK == Uninitialized; } // always safe

  [[clang::woot("FloatSet"]] // Marks as safe for functions with matching kaboom arguments
  void set(float V) {
    VK= Float;
    F = V;
  }

  [[clang::woot("IntSet")]] // Marks as safe for functions with matching kaboom arguments
  void set(int V) {
    VK= Integer;
    I = V;
  }

    [[clang::woot]] // Marks as safe for all kaboom functions (because I'm sad)
   void zero() {
     VK= Integer;
     I = 0;
   }

  [[clang::kaboom("FloatSet"]]
  operator float() {
    return F;
  }

  [[clang::kaboom("IntSet")]]
  operator int() {
    return I;
  }
};
```

Balancing Priorities

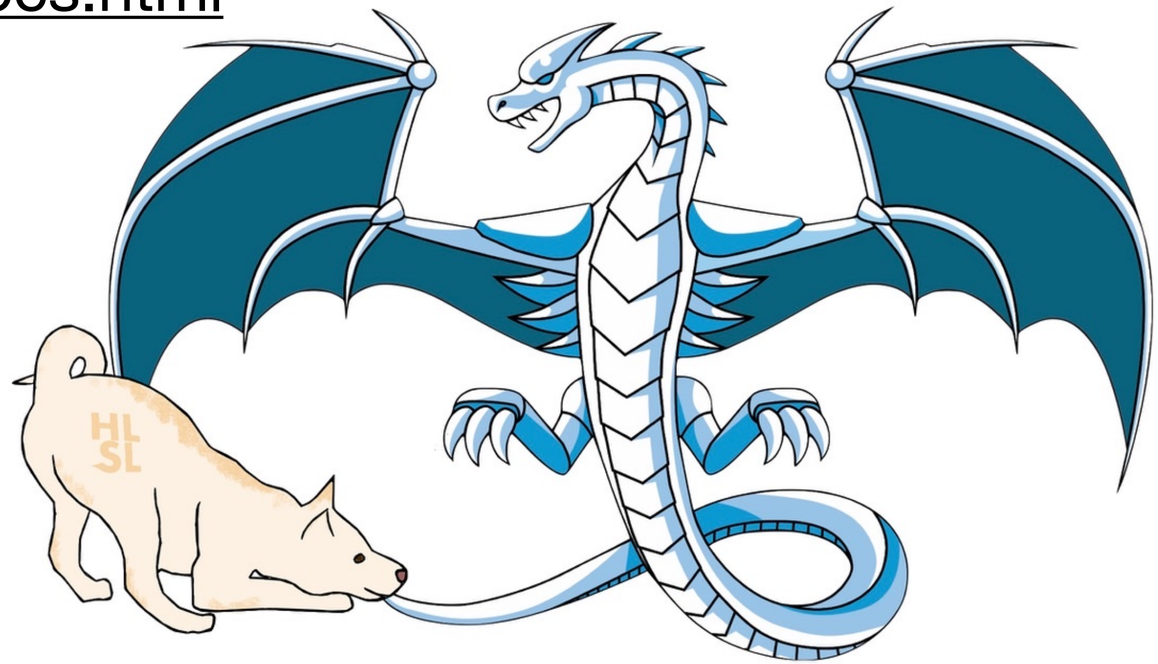
- Scalability & Maintainability
  - Do as much as possible in HLSL
- Compiler speed
  - Lazy AST population
  - Works with PCH
- Robust Tooling
  - Complete ASTs
  - Source available

HLSL Future Directions

- Working hard on HLSL Support in Clang
- Want to have clangd support in clang-16
- Public language design process
  - https://github.com/microsoft/hlsl-specs
  - Actively working to make HLSL more like C++

More Resources

- Join the monthly HLSL Working Group meetings
- https://github.com/orgs/llvm/projects/4
- https://clang.llvm.org/docs/HLSL/HLSLDocs.html
- Find us on Discord, Discourse and IRC



Consolation Prize