Introduction to LLVM

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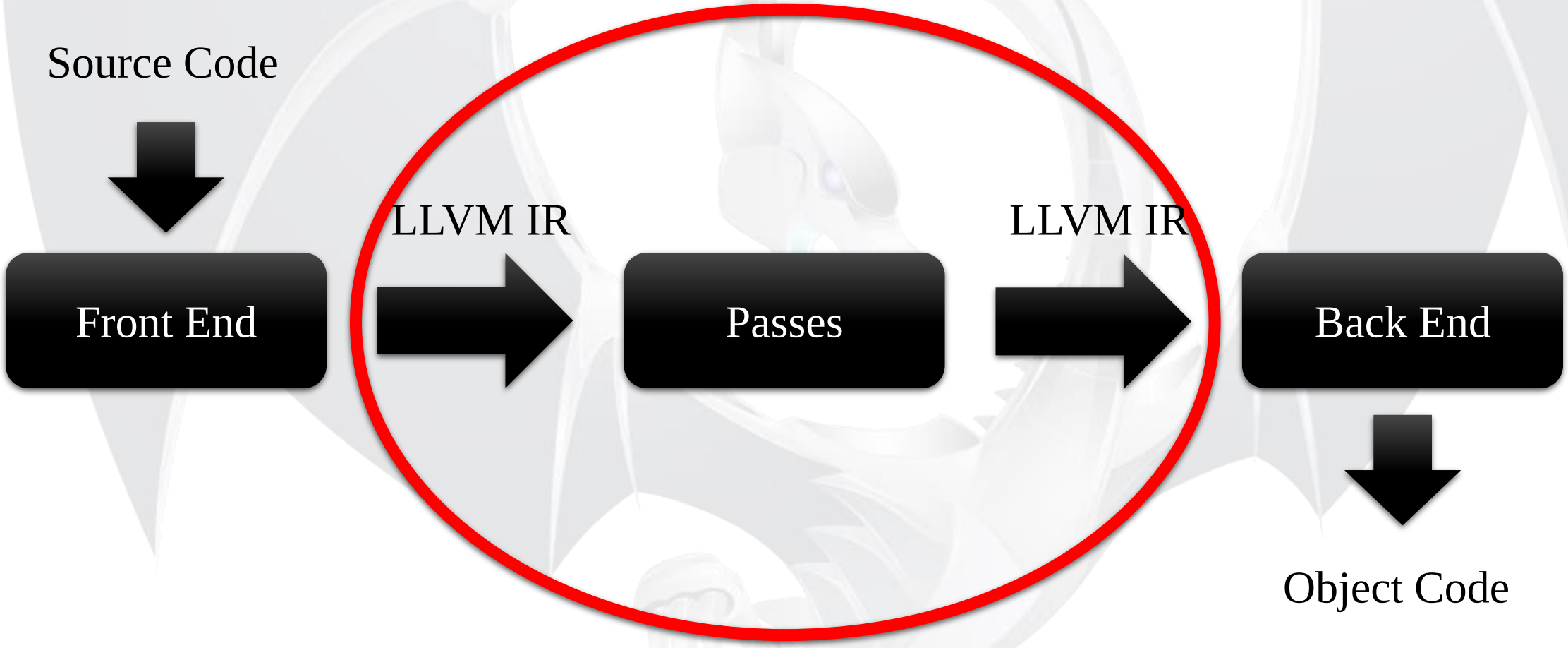
What you will need for Assignment 1 …

- LLVM: How to write a pass that **analyzes** and **transforms** (optimizes) Intermediate Representation (**IR**).

- C++ Fundamentals: **Public Inheritance (Abstract Class, Dynamic Casting)**, **Iterator**, **STL Data Structures**

Three-Phase Design – From Source to Binary



Three-Phase Design – From Source to Binary

C/C++ Source

```
int main()
{
    return 0;
}
```

LLVM IR

```
define i32 @main() … {
    ret i32 0
}
```

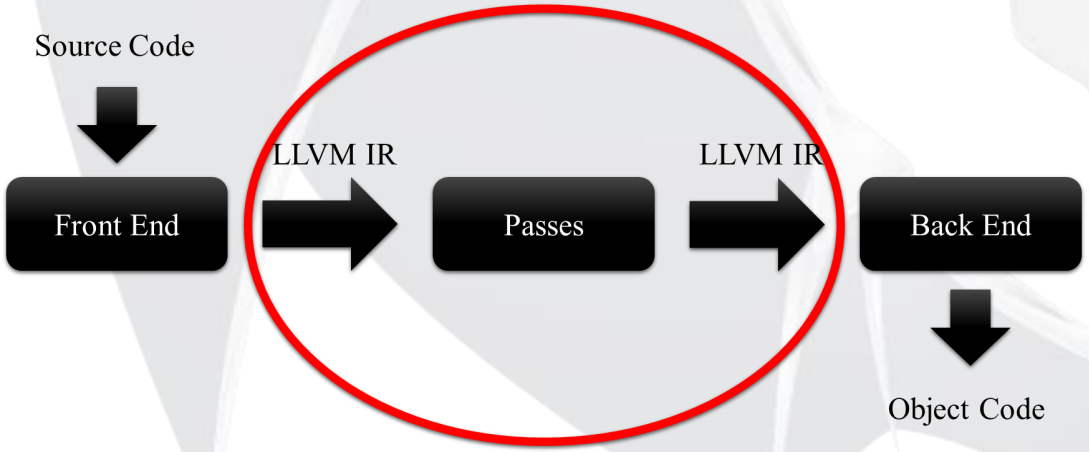
Example – IR Optimization

- Suppose that we are hoping to replace every $x \times 2^N$ statement in our code with $x \ll N$. How can we achieve this?
- Write a **Pass** that does the followings:
  1. **Analyzes** whether there are statements of the form $\%p = \mathbf{mul}\ \%q, 2^N$ in our code or not, and where are those statements located.
  2. **Transforms** those instructions with $\%p = \mathbf{shl}\ \%q, N$.

IR Optimization

- The IR optimizations consist of many optimization passes.
- LLVM itself also has passes for analysis or transformations: https://llvm.org/docs/Passes.html
- In this assignment, we will be making use of the **mem2reg** pass.
  - Please **DON'T** use the LLVM passes unless otherwise told to.

Questions?



- Keywords:
  - Intermediate Representation (IR)
  - Optimization Pass
  - Analysis & Transformation

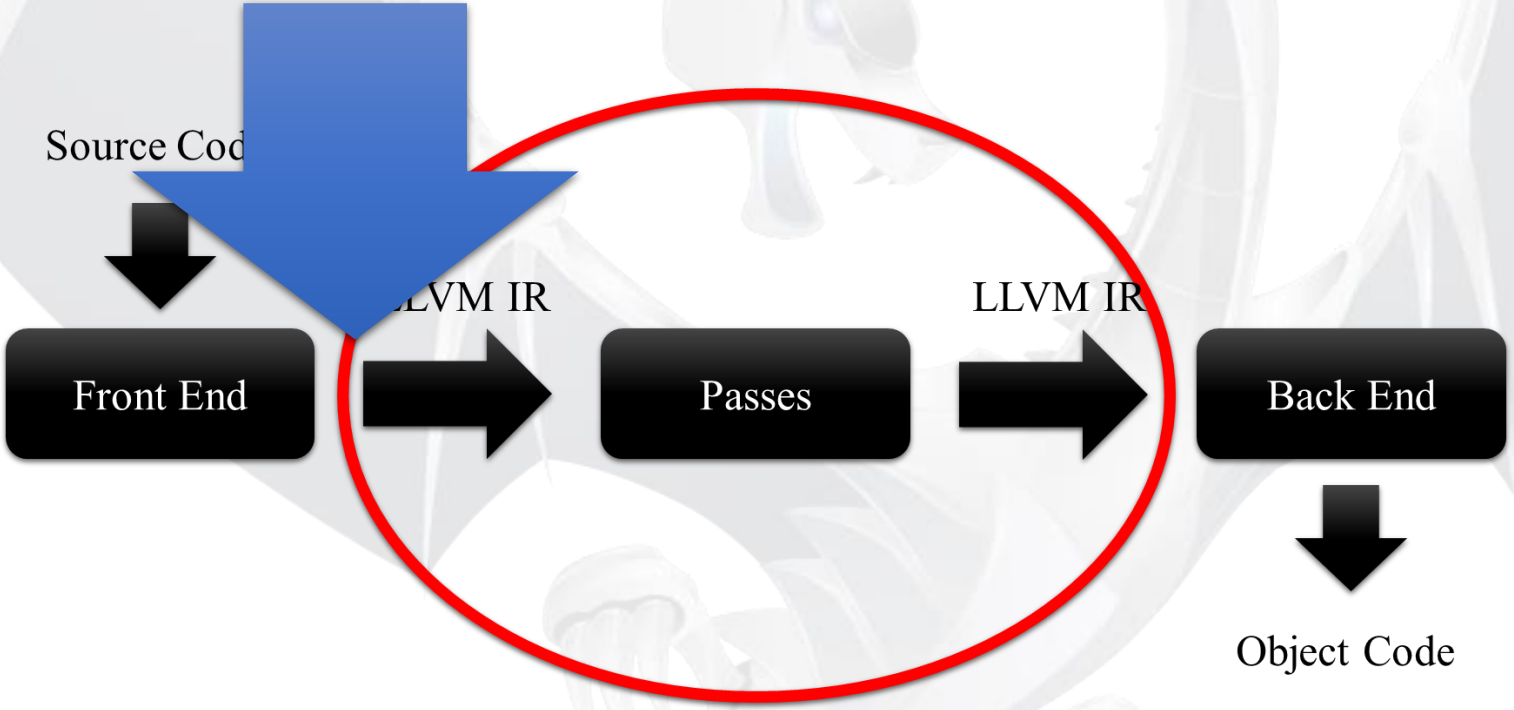
Analysis

How to write an **analysis** pass?

- We need to understand the following three things:
  - **Program Structure**: How is our program represented in LLVM?
  - **Iterators**: How to traverse through such structures?
  - **Downcasting**: How to retrieve more information from iterators?
  - **LLVM Pass Interface**: Implement LLVM interface.

Program Structure

- It is important that we understand how our programs are represented after being translated by the LLVM frontend clang:



Program Structure

C/C++ Source

- Source File
- Function
- Code Block
- Statement

LLVM IR

- **Module** contains **Functions** and Global Variables.
- **Function** contains **Basic Blocks** and Arguments.
- **Basic Block** contains a list of **Instructions**.
- **Instruction** is an Opcode plus vector of **Operands**.

Program Structure

- A Simplified View (for Understanding **ONLY**):

```
typedef std::vector < Function > Module;
typedef std::vector < BasicBlock > Function;
typedef std::vector < Instruction > BasicBlock;
typedef std::vector < Operand > Instruction;
```

How to iterate through the Structures?

- **Iterators!**
- Recall how you traverse through `std::vector`

```
std::vector < unsigned > vec;

for (auto iter  = vec.begin();
          iter != vec.end(); ++iter)
{/* do something */}
```

How to iterate through the Structures?

- Similarly, …

```
Module M;

for (auto iter  = M.begin();
          iter != M.end(); ++iter)
{/* do something */}
```

Downcasting – Getting More Details

- Suppose that we have an instruction, how can we know whether it is an unary instruction? a binary instruction? a call instruction? …
- **Dynamic Casting!**
  - Consider the statement `UnaryInstruction * unary_inst = dyn_cast < UnaryInstruction > (inst);`

LLVM Pass Interface

LLVM Interface

```
class ModulePass
{
    bool runOnModule
(Module & M) = 0;
};
```

Implementation

```
class MyModulePass : public
ModulePass
{
    bool runOnModule
(Module & M)
    {
        for (iter = …
    }
};
```

Questions?

- Keywords:
  - Program Structure
  - Iterators
  - Downcasting
  - LLVM Pass Interface

Transformations

Insert/Remove/Move/Replace Instructions

- Three Options
  - **`Instruction`** class methods:
    - `insertBefore()`, `insertAfter()`, `moveBefore()`, `moveAfter()`, `eraseFromParent()`, `removeFromParent()`, …
  - Ask parent (**`BasicBlock`**) to do this:
    - `inst.getParent()->getInstList()` `.insert/erase/remove/…()`
  - Make use of **`BasicBlockUtils`** (defined in header `llvm/Transforms/Utils/BasicBlockUtils.h`):
    - `ReplaceInstWithValue()`, `ReplaceInstwithInst()`