Introduction to LLVM

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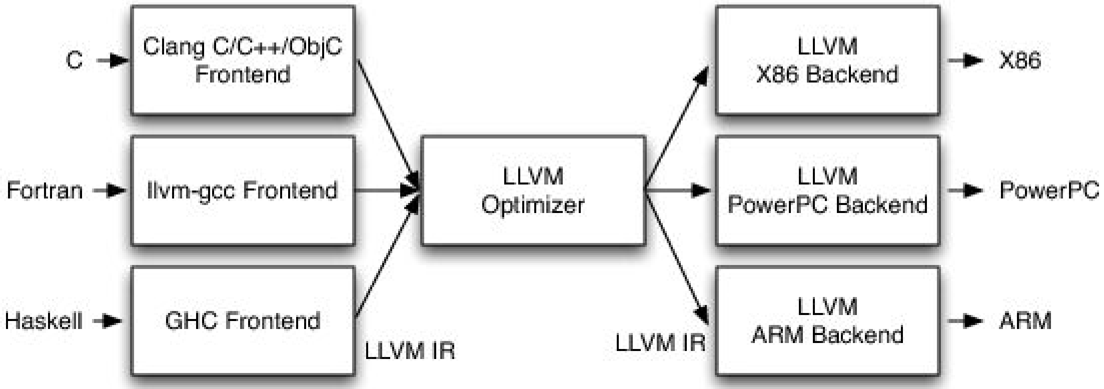
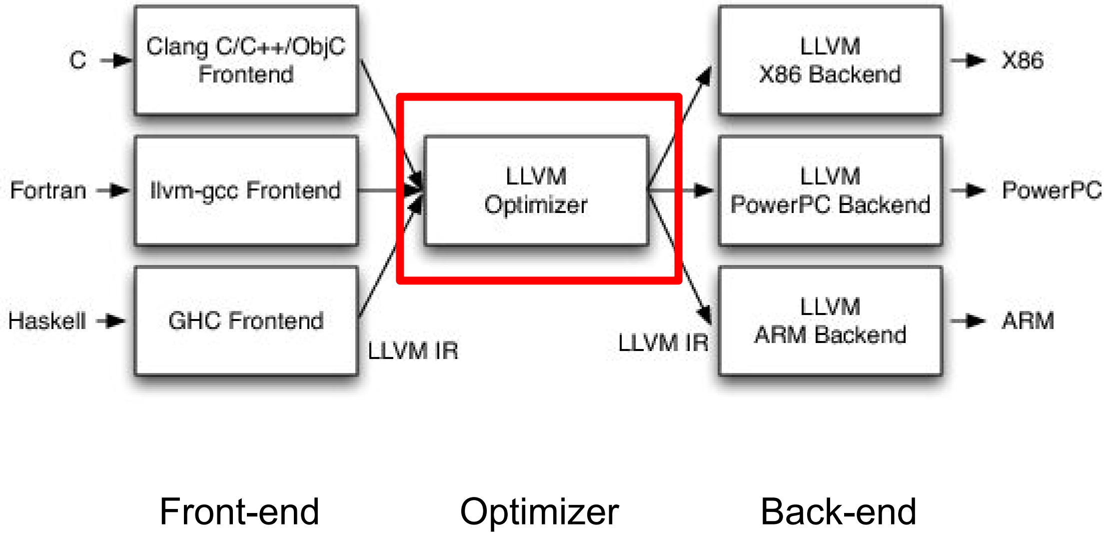
Architecture of LLVM



Front-end Optimizer Back-end

Architecture of LLVM



LLVM Optimizer

The optimizer analyzes, optimizes and secures programs.

The optimizer operates on LLVM Intermediate Representation (IR) code, which makes it source- and target-independent.

Functionalities are implemented as **passes**.

Optimizer Passes

A pass is an operation on a unit of LLVM Intermediate Representation (IR) code.

There are multiple types of passes:

- ModulePass, CallGraphSCCPass, FunctionPass, LoopPass, RegionPass, BasicBlockPass

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How to write a function pass:
http://releases.llvm.org/5.0.1/docs/WritingAnLLVMPass.html#writing-an-llvm-pass-basiccode

LLVM IR

- A low-level **strongly-typed** language-independent, SSA-based representation.
- Tailored for static analyses and optimization purposes.
- LLVM IR language reference: http://releases.llvm.org/5.0.1/docs/LangRef.html

LLVM IR

```c
int foo (int x) {

  int i = 0;
  volatile int count = 0;
  for (; i<x; i++) {
    count ++;
  }

  return count;
}
```

```llvm
define i32 @foo(i32) #0 {
  %2 = alloca i32, align 4
  %3 = alloca i32, align 4
  %4 = alloca i32, align 4
  store i32 %0, i32* %2, align 4
  store i32 0, i32* %3, align 4
  store volatile i32 0, i32* %4, align 4
  br label %5

; <label>:5:                                      ; preds = %12, %1
  %6 = load i32, i32* %3, align 4
  %7 = load i32, i32* %2, align 4
  %8 = icmp slt i32 %6, %7
  br i1 %8, label %9, label %15

; <label>:9:                                      ; preds = %5
  %10 = load volatile i32, i32* %4, align 4
  %11 = add nsw i32 %10, 1
  store volatile i32 %11, i32* %4, align 4
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  %14 = add nsw i32 %13, 1
  store i32 %14, i32* %3, align 4
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; <label>:15:                                     ; preds = %5
  %16 = load volatile i32, i32* %4, align 4
  ret i32 %16
}
```

Hierarchy of structures of IR programs

Module

Function

Basic Block

Instruction

A module == A compilation unit

gcc -c mytest.c -o mytest.o

The compilation unit consists of

- Code in mytest.c
- Code that is included in mytest.c (#include ...)

Project Part 1 overview

There are three sections:

- Count Static Instructions
- Count Dynamic Instructions
- Branch Profiling

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- Count Static Instructions: analysis pass
- Count Dynamic Instructions: transformation pass
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- **Count Static Instructions: analysis pass**
- Count Dynamic Instructions: transformation pass
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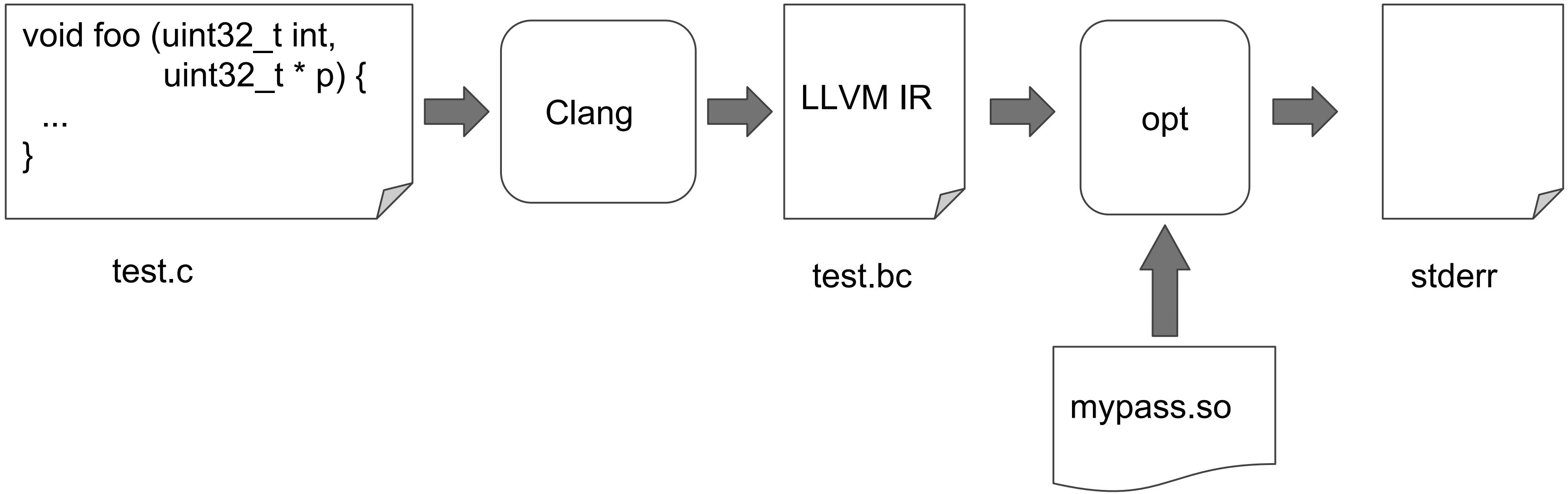
How an analysis pass works



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}
```

Count Static Instructions

How to traverse a function (and how to write to stderr)

http://releases.llvm.org/5.0.1/docs/ProgrammersManual.html#basic-inspection-and-traversal-routines

Project Part 1 overview

There are three sections:

- Count Static Instructions: analysis pass
- **Count Dynamic Instructions: transformation pass**
- Branch Profiling: transformation pass

LLVM IR

```c
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  int i = 0;
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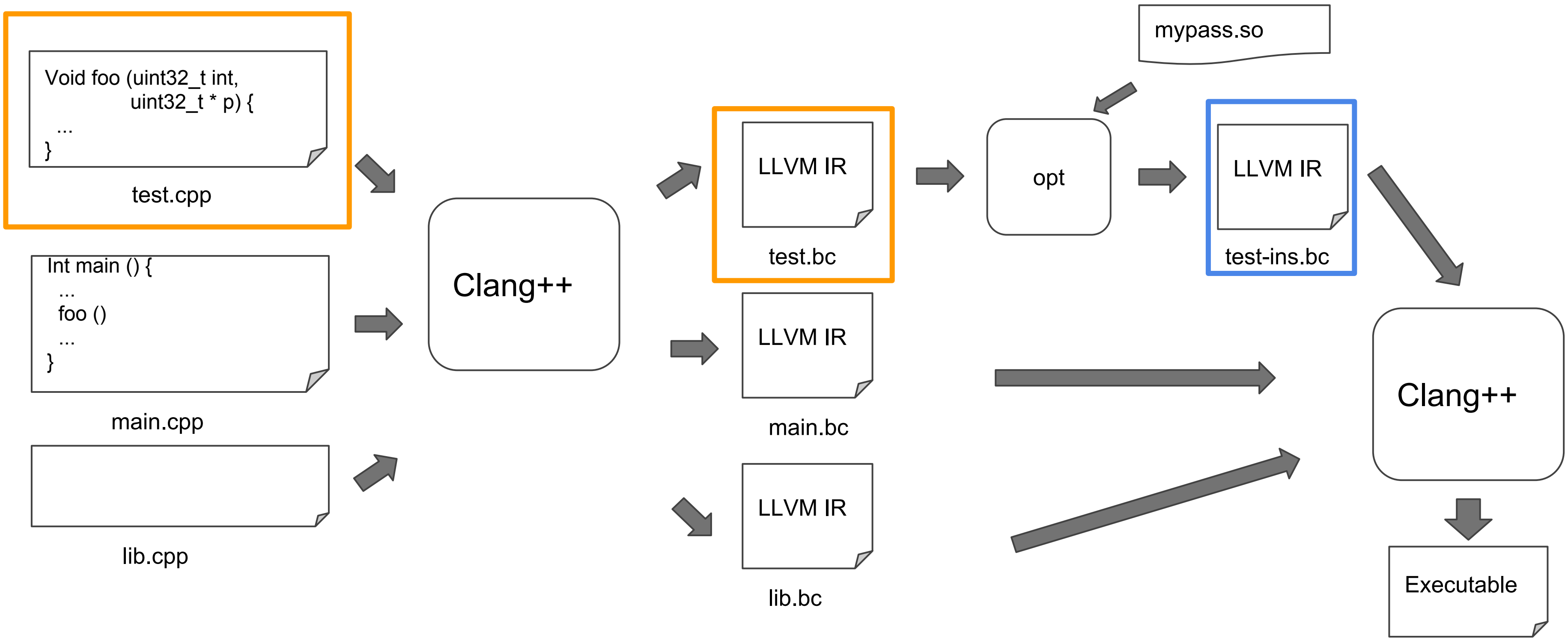
How a transformation pass works



How to insert a function call to IR code

First of all, we need to find the function we want to call.

- **Class Function** represents functions in IR programs
- How can we get a handle of the function?

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- How can we get a handle of the function?

```
// getOrInsertFunction - Look up the specified function in the module symbol
// table.  If it does not exist, add a prototype for the function and return it.
// This version of the method takes a null terminated list of function
// arguments, which makes it easier for clients to use.
```

```
Module::getOrInsertFunction
```

How to use getOrInsertFunction

```
void helper (uint32_t x, uint32_t * p);
```

```
Function * myHelper =
        cast<Function>(Mod.getOrInsertFunction("helper",
                                                Type::getVoidTy(context),
                                                Type::getInt32Ty(context),
                                                Type::getInt32PtrTy(context)));
```

How to prepare arguments for a function call

If you need a constant integer

- **ConstantInt** represents boolean and integer constants
- From **Class ConstantInt**

```
/// Return a ConstantInt with the specified integer value for the specified
/// type. If the type is wider than 64 bits, the value will be zero-extended
/// to fit the type, unless isSigned is true, in which case the value will
/// be interpreted as a 64-bit signed integer and sign-extended to fit
/// the type.
/// @brief Get a ConstantInt for a specific value.
static ConstantInt *get(IntegerType *Ty, uint64_t V,
                        bool isSigned = false);
```

How to prepare arguments for a function call

If you need a constant integer

```
static ConstantInt *get(IntegerType *Ty, uint64_t V,
                        bool isSigned = false);
```

- How to get the type of the constant integer?

```
class Type
```

```
IntegerType *Type::getInt1Ty(LLVMContext &C) { return &C.pImpl->Int1Ty; }
IntegerType *Type::getInt8Ty(LLVMContext &C) { return &C.pImpl->Int8Ty; }
IntegerType *Type::getInt16Ty(LLVMContext &C) { return &C.pImpl->Int16Ty; }
IntegerType *Type::getInt32Ty(LLVMContext &C) { return &C.pImpl->Int32Ty; }
IntegerType *Type::getInt64Ty(LLVMContext &C) { return &C.pImpl->Int64Ty; }
IntegerType *Type::getInt128Ty(LLVMContext &C) { return &C.pImpl->Int128Ty; }
```

How to prepare arguments for a function call

If you need a pointer to a constant array

- Allocate the array somewhere in the address space

The easiest way to do it is to put the array in the static region.

Class GlobalVariable represents static and global variables of a program.

How to prepare arguments for a function call

Class GlobalVariable represents static and global variables of a program.

```
GlobalVariable(Module &M, Type *Ty, bool isConstant,
               LinkageTypes Linkage, Constant *Initializer,
               const Twine &Name = "", GlobalVariable *InsertBefore = nullptr,
               ThreadLocalMode = NotThreadLocal, unsigned AddressSpace = 0,
               bool isExternallyInitialized = false);
```

This constructor has quite a few parameters but luckily many of them have a default value that we don’t need to change.

How to prepare arguments for a function call

Class GlobalVariable represents static and global variables of a program.

```
GlobalVariable(Module &M, Type *Ty, bool isConstant,
               LinkageTypes Linkage, Constant *Initializer,
               const Twine &Name = "", GlobalVariable *InsertBefore = nullptr,
               ThreadLocalMode = NotThreadLocal, unsigned AddressSpace = 0,
               bool isExternallyInitialized = false);
```

```
GlobalVariable* VG = new GlobalVariable(*(F.getParent()),
                                        ArrayTy,
                                        true,
                                        GlobalValue::InternalLinkage,
                                        ConstantDataArray::get(context, values),
                                        "value global");
```

How to prepare arguments for a function call

Class GlobalVariable represents static and global variables of a program.

“Because GlobalValues are memory objects, they are always referred to by their address. As such, the Type of a global is always a pointer to its contents.”

http://releases.llvm.org/5.0.1/docs/ProgrammersManual.html#the-globalvariable-class

How to insert a function call

Now that we have the function handle and the arguments, we can finally insert a function call.

Class IRBuilder can be used for insert instructions into a basic block.

- First, we need to specify where we want to insert the instruction

Either use function **SetInsertPoint** or specify the insert point in the constructor of **IRBuilder** (which will call **SetInsertPoint**).

How to insert a function call

Now that we have the function handle and the arguments, we can finally insert a function call.

Class IRBuilder can be used for insert instructions into a basic block.

- First, we need to specify where we want to insert the instruction
- Second, we need to create the IR call instruction

Use **IRBuilder::CreateCall**

```
Builder.CreateCall(processBBFunction, args);
```

Tips

- Learn from other use cases of the API in the code base
- Read the comments above the definition/declaration of the function you want to use
- Use an IDE (“Open Declaration” and “Open Call Hierarchy”)
- Read the code of the function you want to use

Links

- How to write a basic function pass

  http://releases.llvm.org/5.0.1/docs/WritingAnLLVMPass.html

- Developer Tutorial: covering many common operations

  http://releases.llvm.org/5.0.1/docs/ProgrammersManual.html

- Our tutorial

  https://ucsd-pl.github.io/cse231/wi18/tutorials/part1.html