Lab 5: LLVM Pass

Software Testing 2021

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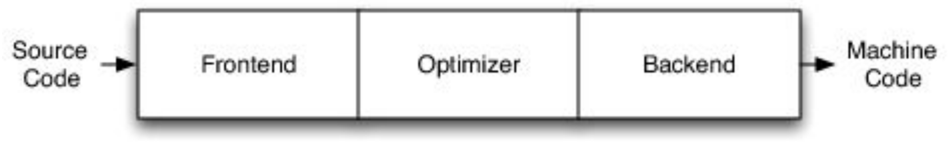
This lab will cover

- a little bit compiler concept
- llvm pass
- some assembly concept
- some C++ OOP concept

LLVM

Three-Phase Compiler

- Frontend, Optimizer, Backend
  - 解析、優化、輸出
  - source code -> IR -> machine code



Why LLVM?

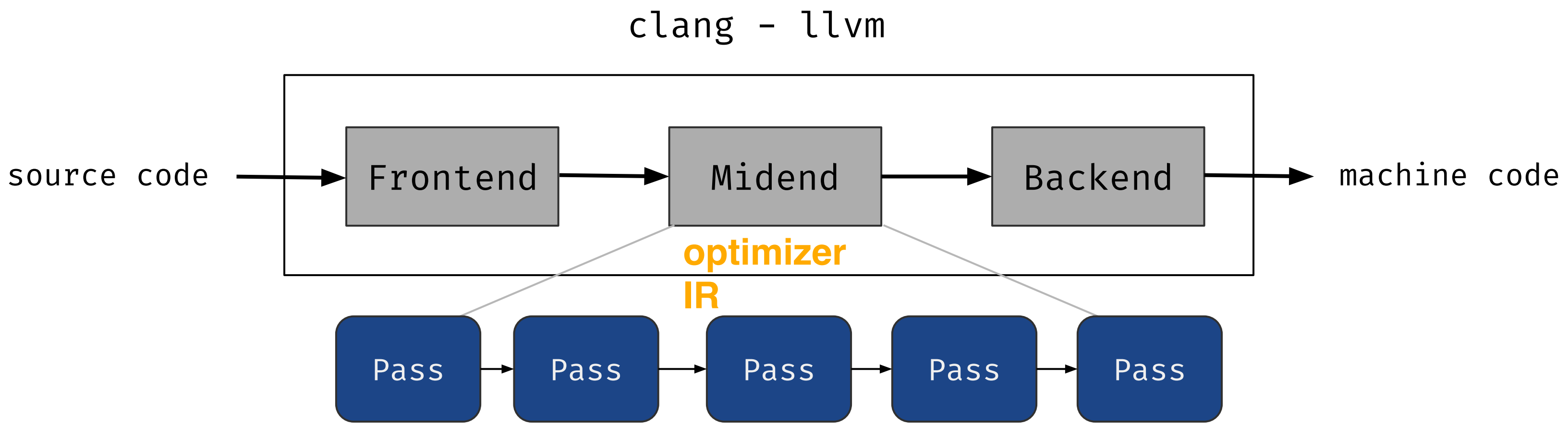
- Analysis
    - control flow graph
- Instrumentation
    - sanitizer

LLVM Pass

Caution!

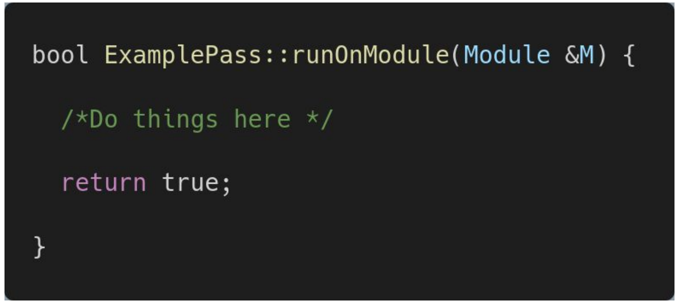
- All following content works on **llvm-11,** other versions are not guaranteed!
- All API can be found in **https://llvm.org/doxygen/index.html**

Pass

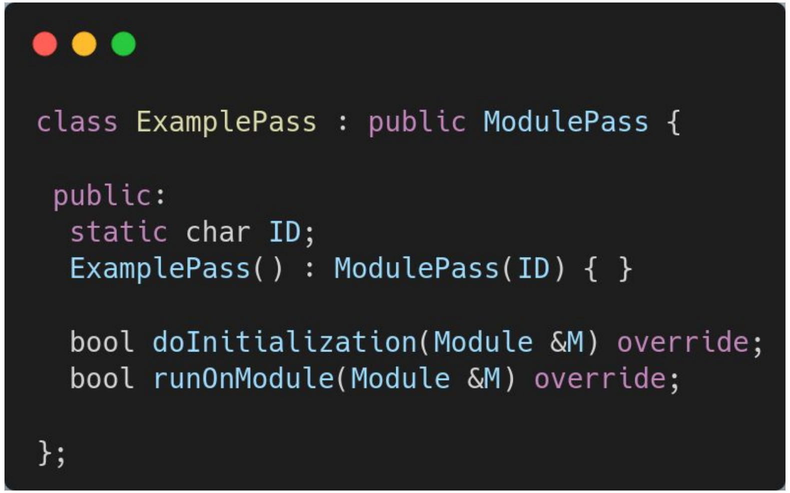

clang - llvm
source code
Frontend
Midend
Backend
machine code
optimizer
IR
Pass
Pass
Pass
Pass
Pass

Pass

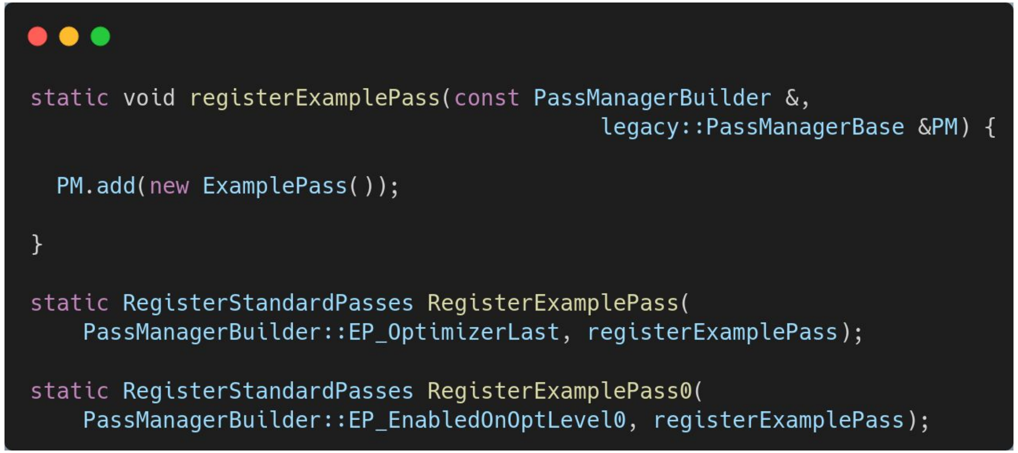
- inherit from Pass class
  - ModulePass
  - FunctionPass
  - …



```
bool ExamplePass::runOnModule(Module &M) {

  /*Do things here */

  return true;

}
```

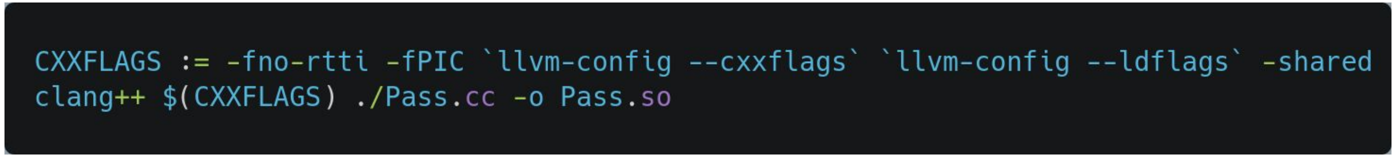


```
class ExamplePass : public ModulePass {

 public:
  static char ID;
  ExamplePass() : ModulePass(ID) { }

  bool doInitialization(Module &M) override;
  bool runOnModule(Module &M) override;

};
```



```
static void registerExamplePass(const PassManagerBuilder &,
                                legacy::PassManagerBase &PM) {

  PM.add(new ExamplePass());

}

static RegisterStandardPasses RegisterExamplePass(
    PassManagerBuilder::EP_OptimizerLast, registerExamplePass);

static RegisterStandardPasses RegisterExamplePass0(
    PassManagerBuilder::EP_EnabledOnOptLevel0, registerExamplePass);
```

Pass

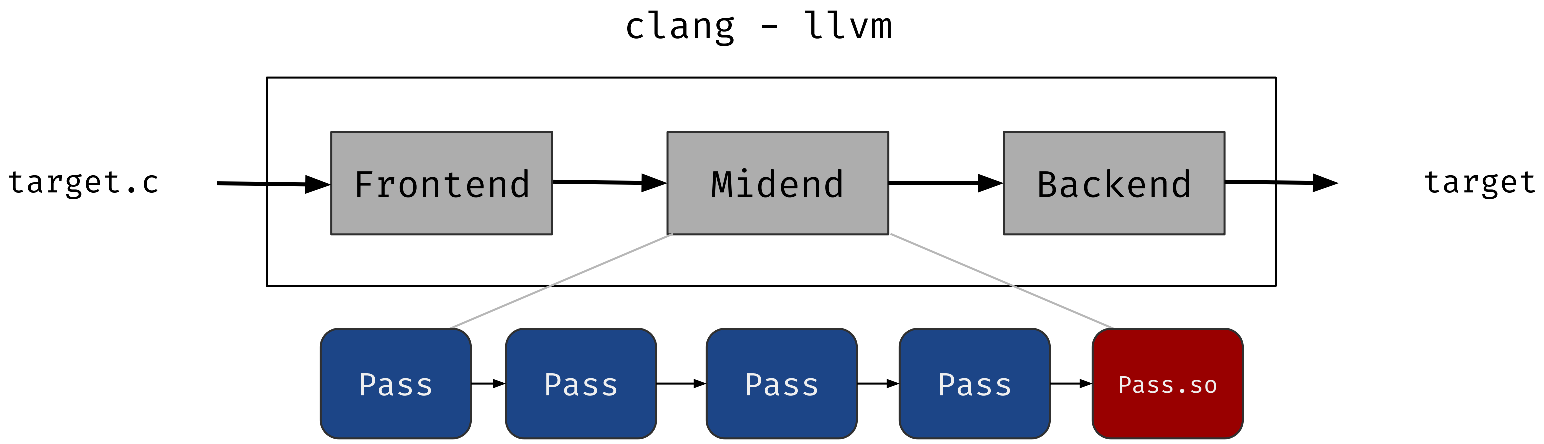


```
CXXFLAGS := -fno-rtti -fPIC `llvm-config --cxxflags` `llvm-config --ldflags` -shared
clang++ $(CXXFLAGS) ./Pass.cc -o Pass.so
```

Pass.cc
Pass.so

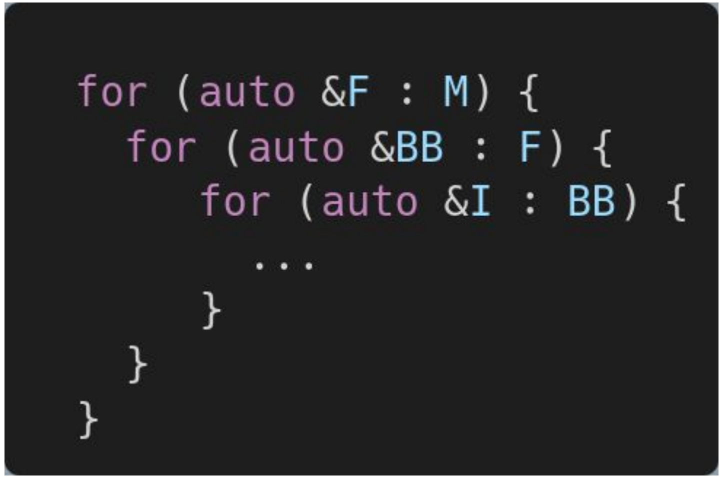
Pass

```
CFLAGS := `llvm-config --ldflags`
clang $(CFLAGS) -Xclang -load -Xclang Pass.so target.c -o target
```



LLVM Structure

- Module
- Function
- BasicBlock
- Instruction (IR)

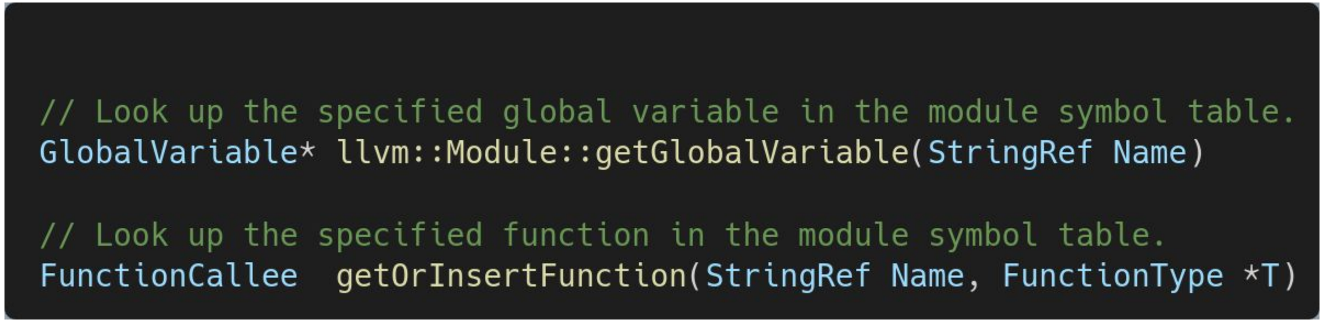


```
for (auto &F : M) {
  for (auto &BB : F) {
     for (auto &I : BB) {
       ...
     }
  }
}
```

https://llvm.org/docs/LangRef.html

LLVM Structure

- Module
  - top-level structure in an LLVM program

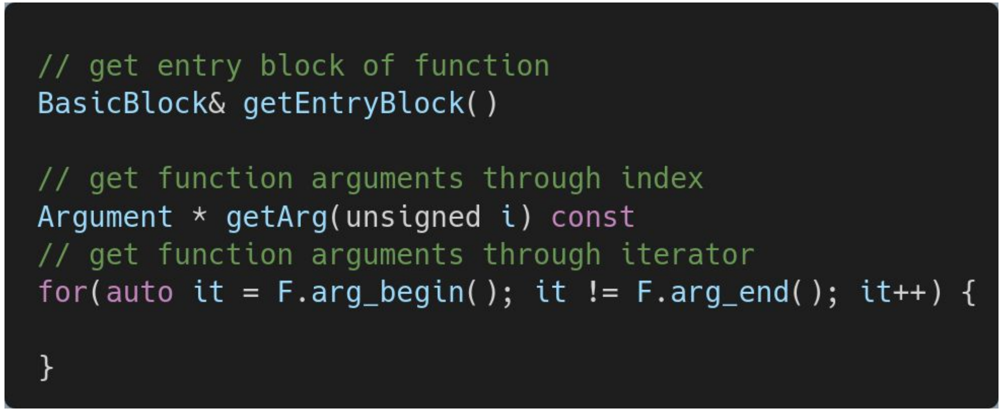


```
// Look up the specified global variable in the module symbol table.
GlobalVariable* llvm::Module::getGlobalVariable(StringRef Name)

// Look up the specified function in the module symbol table.
FunctionCallee  getOrInsertFunction(StringRef Name, FunctionType *T)
```

https://llvm.org/doxygen/classllvm_1_1Module.html

LLVM Structure

- Function

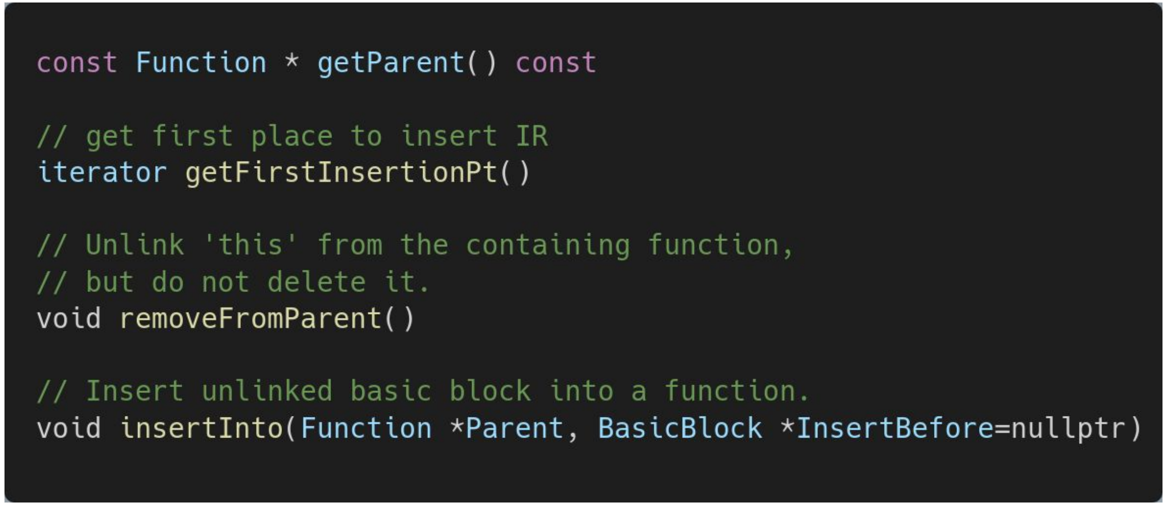


```
// get entry block of function
BasicBlock& getEntryBlock()

// get function arguments through index
Argument * getArg(unsigned i) const
// get function arguments through iterator
for(auto it = F.arg_begin(); it != F.arg_end(); it++) {

}
```

https://llvm.org/doxygen/classllvm_1_1Function.html

LLVM Structure

- BasicBlock

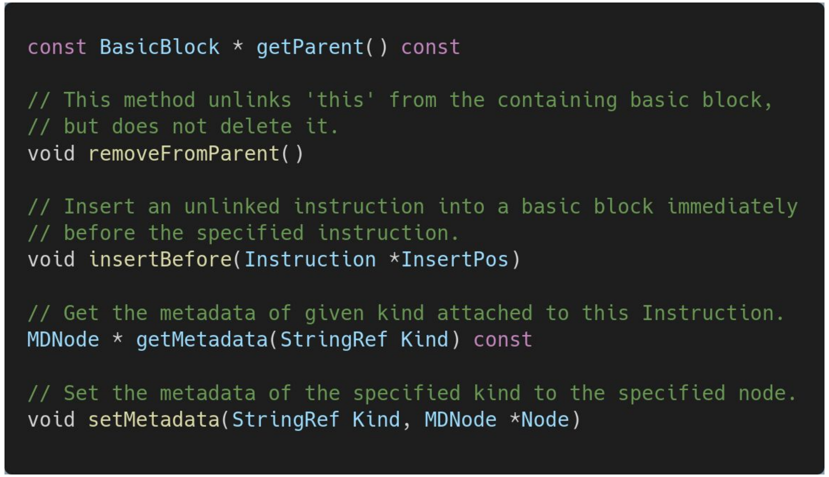


```
const Function * getParent() const

// get first place to insert IR
iterator getFirstInsertionPt()

// Unlink 'this' from the containing function,
// but do not delete it.
void removeFromParent()

// Insert unlinked basic block into a function.
void insertInto(Function *Parent, BasicBlock *InsertBefore=nullptr)
```

https://llvm.org/doxygen/classllvm_1_1BasicBlock.html

LLVM Structure

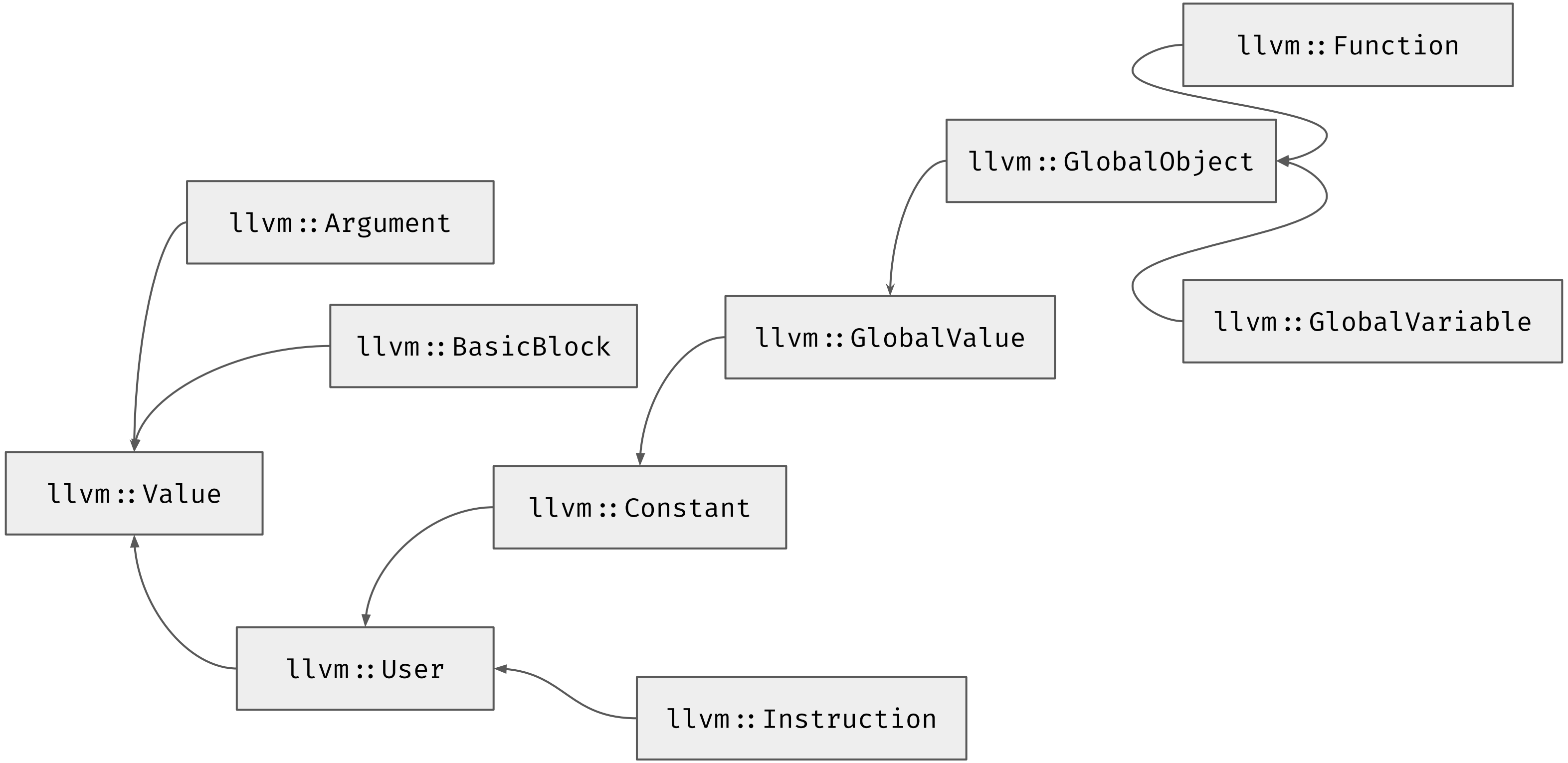
- Instruction (IR)



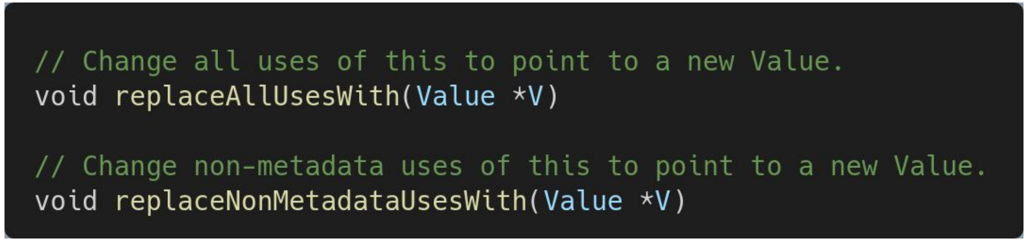
```
const BasicBlock * getParent() const

// This method unlinks 'this' from the containing basic block,
// but does not delete it.
void removeFromParent()

// Insert an unlinked instruction into a basic block immediately
// before the specified instruction.
void insertBefore(Instruction *InsertPos)

// Get the metadata of given kind attached to this Instruction.
MDNode * getMetadata(StringRef Kind) const

// Set the metadata of the specified kind to the specified node.
void setMetadata(StringRef Kind, MDNode *Node)
```

https://llvm.org/doxygen/classllvm_1_1Instruction.html

Value


llvm::Function
llvm::GlobalObject
llvm::Argument
llvm::GlobalValue
llvm::GlobalVariable
llvm::BasicBlock
llvm::Value
llvm::Constant
llvm::User
llvm::Instruction

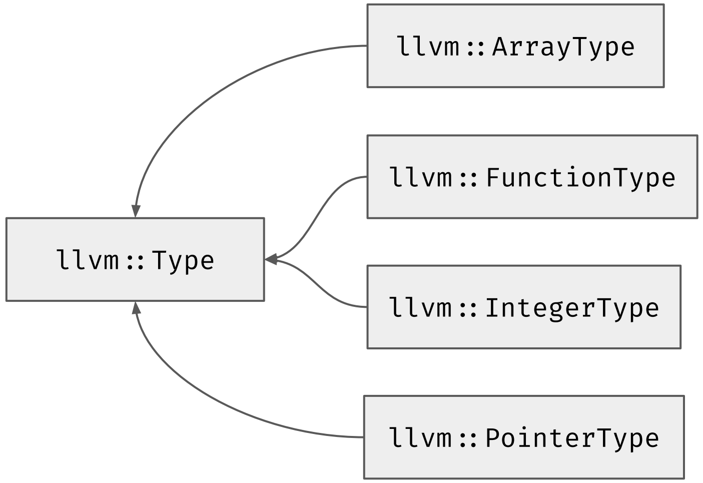
Value



```
// Change all uses of this to point to a new Value.
void replaceAllUsesWith(Value *V)

// Change non-metadata uses of this to point to a new Value.
void replaceNonMetadataUsesWith(Value *V)
```

https://llvm.org/doxygen/classllvm_1_1Value.html

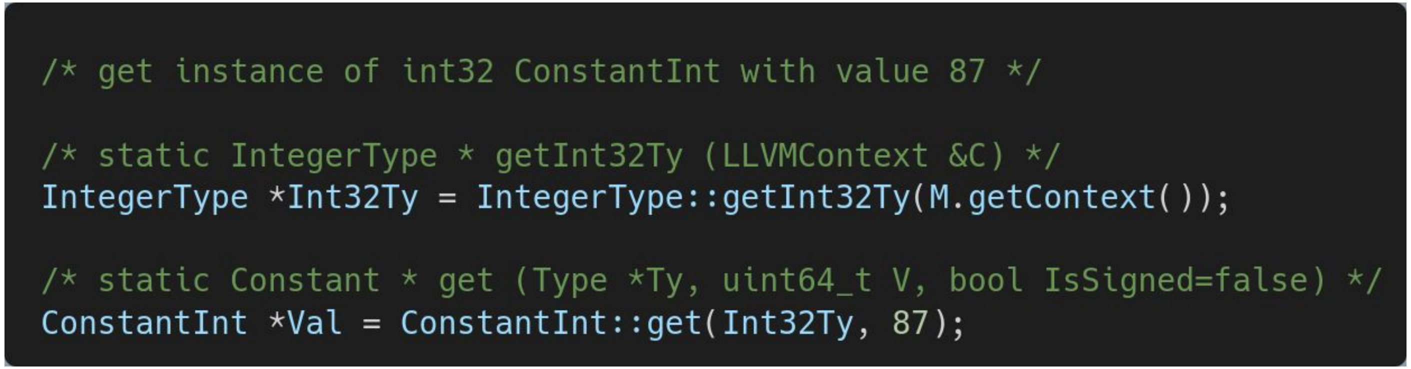
Type



https://llvm.org/doxygen/classllvm_1_1Type.html

ConstantInt

- get instance of int32 ConstantInt



```
/* get instance of int32 ConstantInt with value 87 */

/* static IntegerType * getInt32Ty (LLVMContext &C) */
IntegerType *Int32Ty = IntegerType::getInt32Ty(M.getContext());

/* static Constant * get (Type *Ty, uint64_t V, bool IsSigned=false) */
ConstantInt *Val = ConstantInt::get(Int32Ty, 87);
```

https://llvm.org/doxygen/classllvm_1_1ConstantInt.html

getOrInsertFunction

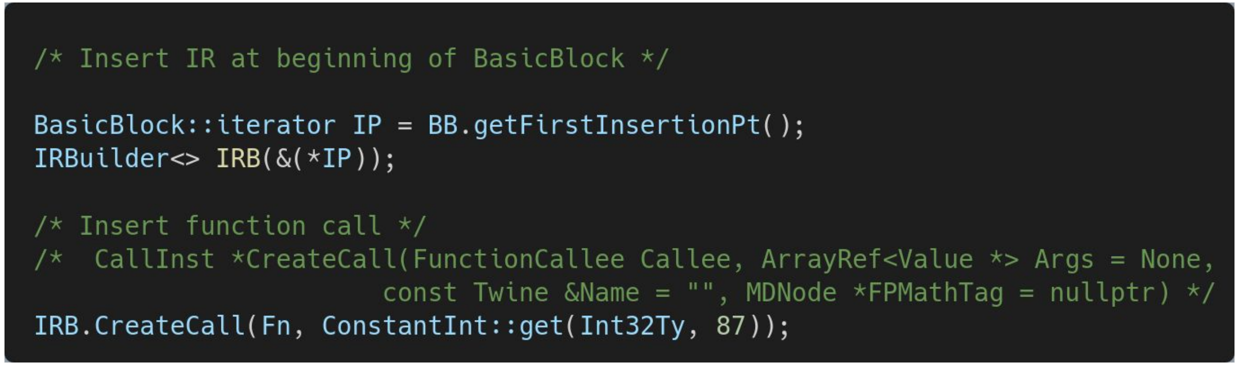
```c
// used for debug
void debug(int id) {

  if (id == 9527)
    fprintf(stderr, "debug mode\n");
  else
    fprintf(stderr, "bad id !\n");
}
```

```cpp
/* Insert a debug function into Module M */

/* static FunctionType * get (Type *Result, ArrayRef< Type * > Params, bool isVarArg) */
std::vector<Type *>FnArgs;
FnArgs.push_back(Int32Ty);

FunctionType *FnTy = FunctionType::get(VoidTy, FnArgs, false);
// or
FunctionType *FnTy = FunctionType::get(VoidTy, {Int32Ty}, false);

/// Look up the specified function in the module symbol table. If it does not
/// exist, add a prototype for the function and return it.
/* FunctionCallee getOrInsertFunction(StringRef Name, FunctionType *T) */
FunctionCallee Fn = M.getOrInsertFunction("debug", FnTy);
```

https://llvm.org/doxygen/classllvm_1_1Module.html

IRBuilder

- insert new IR at specific position

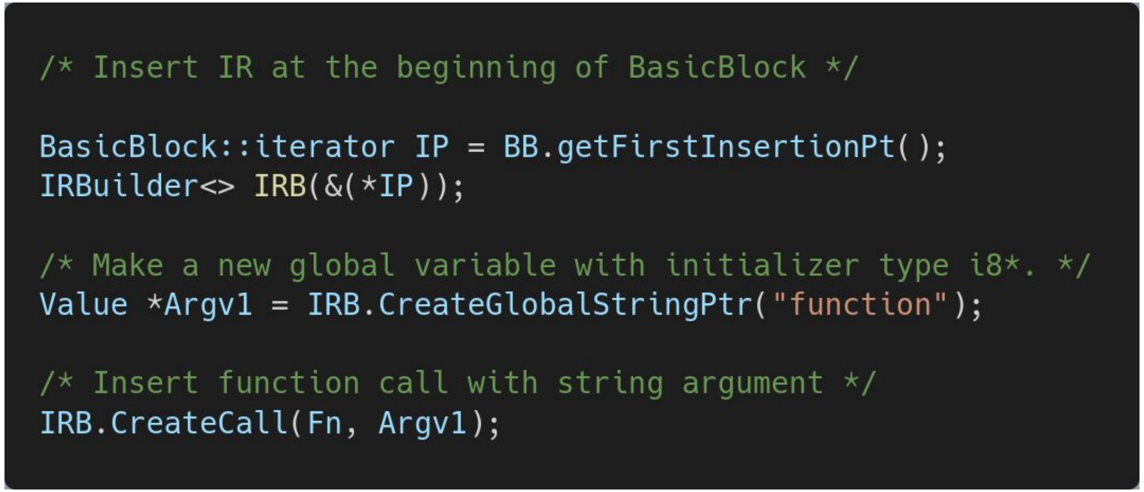


```
/* Insert IR at beginning of BasicBlock */

BasicBlock::iterator IP = BB.getFirstInsertionPt();
IRBuilder<> IRB(&(*IP));

/* Insert function call */
/*  CallInst *CreateCall(FunctionCallee Callee, ArrayRef<Value *> Args = None,
                         const Twine &Name = "", MDNode *FPMathTag = nullptr) */
IRB.CreateCall(Fn, ConstantInt::get(Int32Ty, 87));
```

https://llvm.org/doxygen/classllvm_1_1IRBuilderBase.html

IRBuilder

- insert new IR at specific position

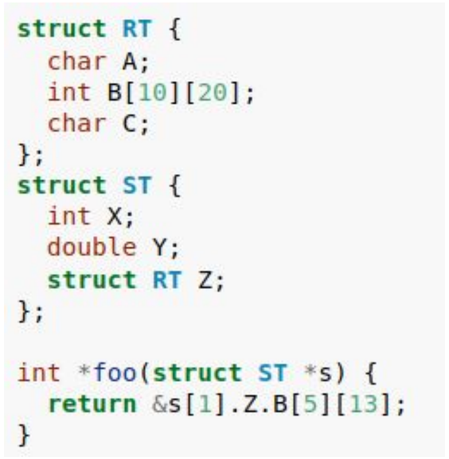


```
/* Insert IR at the beginning of BasicBlock */

BasicBlock::iterator IP = BB.getFirstInsertionPt();
IRBuilder<> IRB(&(*IP));

/* Make a new global variable with initializer type i8*. */
Value *Argv1 = IRB.CreateGlobalStringPtr("function");

/* Insert function call with string argument */
IRB.CreateCall(Fn, Argv1);
```

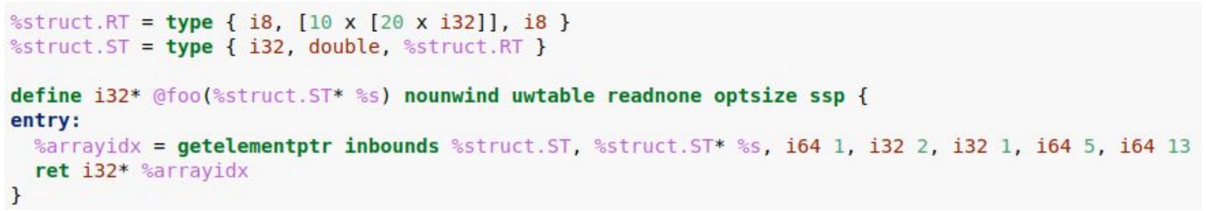
https://llvm.org/doxygen/classllvm_1_1IRBuilderBase.html

LLVM IR

- **getelementptr** Instruction
  - used to get the address of a subelement of an **aggregate** data structure.



```c
struct RT {
  char A;
  int B[10][20];
  char C;
};
struct ST {
  int X;
  double Y;
  struct RT Z;
};

int *foo(struct ST *s) {
  return &s[1].Z.B[5][13];
}
```



```llvm
%struct.RT = type { i8, [10 x [20 x i32]], i8 }
%struct.ST = type { i32, double, %struct.RT }

define i32* @foo(%struct.ST* %s) nounwind uwtable readnone optsize ssp {
entry:
  %arrayidx = getelementptr inbounds %struct.ST, %struct.ST* %s, i64 1, i32 2, i32 1, i64 5, i64 13
  ret i32* %arrayidx
}
```

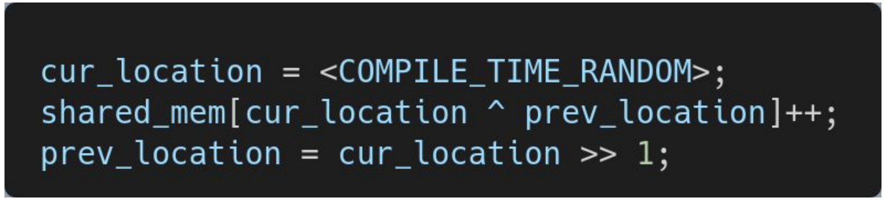
https://llvm.org/docs/LangRef.html

Example 1: AFL LLVM Pass

https://github.com/google/AFL/blob/master/llvm_mode/afl-llvm-pass.so.cc

Coverage Instrumentation

- Instrument following code into each BasicBlock



```
cur_location = <COMPILE_TIME_RANDOM>;
shared_mem[cur_location ^ prev_location]++;
prev_location = cur_location >> 1;
```

Coverage Instrumentation

- Get Global Variable shared_mem, prev_loc

```
cur_location = <COMPILE_TIME_RANDOM>;
shared_mem[cur_location ^ prev_location]++;
prev_location = cur_location >> 1;
```

In afl-llvm-rt.o.c

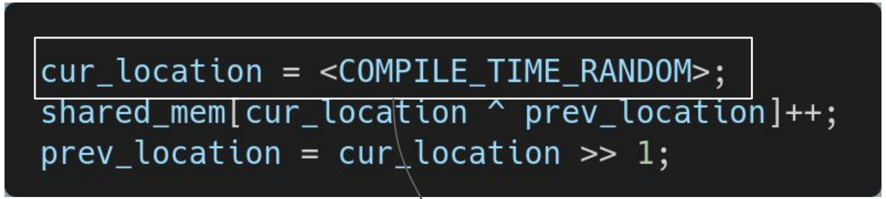
```
u8* __afl_area_ptr = __afl_area_initial;

__thread u32 __afl_prev_loc;
```

Pass.cc

```
/* Get globals for the SHM region and the previous location. Note that
    __afl_prev_loc is thread-local. */

 GlobalVariable *AFLMapPtr =
     new GlobalVariable(M, PointerType::get(Int8Ty, 0), false,
                        GlobalValue::ExternalLinkage, 0, "__afl_area_ptr");

 GlobalVariable *AFLPrevLoc = new GlobalVariable(
     M, Int32Ty, false, GlobalValue::ExternalLinkage, 0, "__afl_prev_loc",
     0, GlobalVariable::GeneralDynamicTLSModel, 0, false);
```

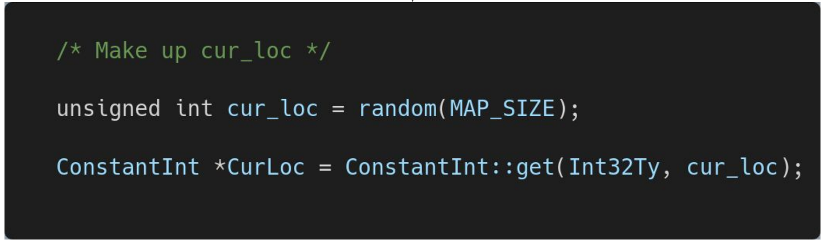
Coverage Instrumentation

- Make up cur_loc
-



```
cur_location = <COMPILE_TIME_RANDOM>;
shared_mem[cur_location ^ prev_location]++;
prev_location = cur_location >> 1;
```

Pass.cc



```
/* Make up cur_loc */

unsigned int cur_loc = random(MAP_SIZE);

ConstantInt *CurLoc = ConstantInt::get(Int32Ty, cur_loc);
```

Coverage Instrumentation

- Load prev_loc

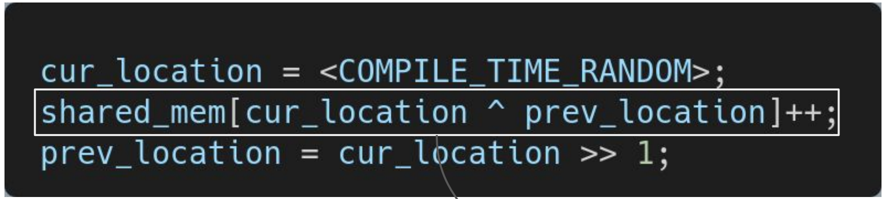
-
  ```
  cur_location = <COMPILE_TIME_RANDOM>;
  shared_mem[cur_location ^ prev_location]++;
  prev_location = cur_location >> 1;
  ```

Pass.cc

```
/* Load prev_loc */

LoadInst *PrevLoc = IRB.CreateLoad(AFLPrevLoc);

/* The ‘zext’ instruction zero extends its operand to type ty2. */
Value *PrevLocCasted = IRB.CreateZExt(PrevLoc, IRB.getInt32Ty());
```

In LLVM, to access global variable value or pointer value, we need to use LoadInst

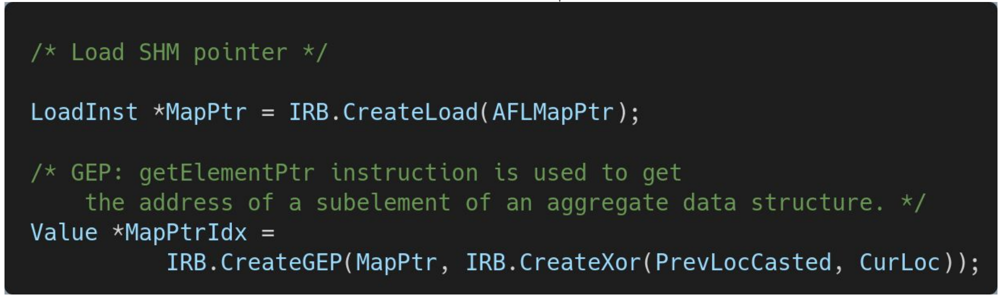
Coverage Instrumentation

- Load SHM pointer
- 

```
cur_location = <COMPILE_TIME_RANDOM>;
shared_mem[cur_location ^ prev_location]++;
prev_location = cur_location >> 1;
```

In LLVM, getElementPtr only calculates address, it does not access memory

Pass.cc



```
/* Load SHM pointer */

LoadInst *MapPtr = IRB.CreateLoad(AFLMapPtr);

/* GEP: getElementPtr instruction is used to get
    the address of a subelement of an aggregate data structure. */
Value *MapPtrIdx =
          IRB.CreateGEP(MapPtr, IRB.CreateXor(PrevLocCasted, CurLoc));
```

Coverage Instrumentation

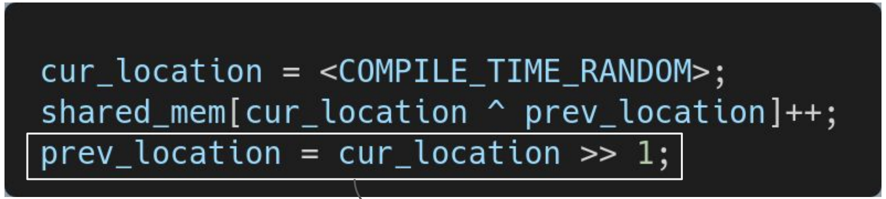
- Update bitmap
-

```
cur_location = <COMPILE_TIME_RANDOM>;
shared_mem[cur_location ^ prev_location]++;
prev_location = cur_location >> 1;
```

Pass.cc

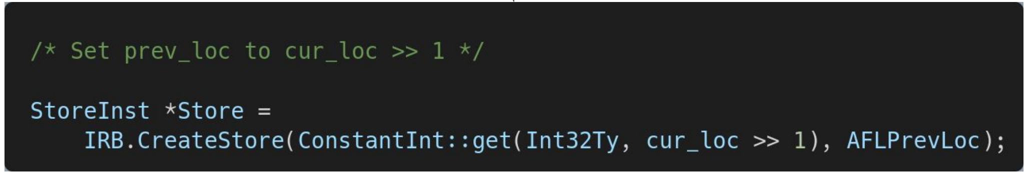
```
/* Update bitmap */

/* actually access memory */
LoadInst *Counter = IRB.CreateLoad(MapPtrIdx);

/* increase 1 */
Value *Incr = IRB.CreateAdd(Counter, ConstantInt::get(Int8Ty, 1));

/* Store counter back to bitmap */
IRB.CreateStore(Incr, MapPtrIdx);
```

Coverage Instrumentation

- Set prev_loc to cur_loc >> 1
- 

```
cur_location = <COMPILE_TIME_RANDOM>;
shared_mem[cur_location ^ prev_location]++;
prev_location = cur_location >> 1;
```

Pass.cc



```
/* Set prev_loc to cur_loc >> 1 */

StoreInst *Store =
    IRB.CreateStore(ConstantInt::get(Int32Ty, cur_loc >> 1), AFLPrevLoc);
```

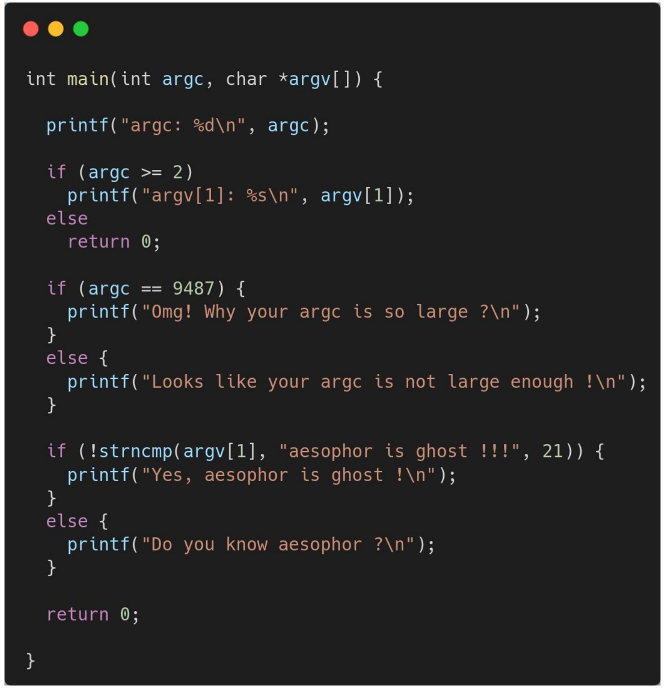
Lab

Lab

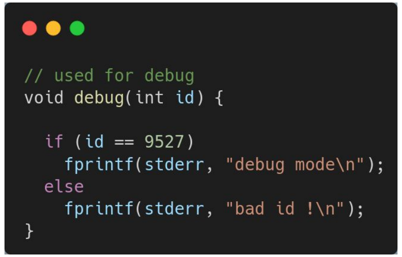
1. Given a target.c file, write a llvm pass to satisfy following requirements **without modifying** source code.
    a. **Invoke debug function** with the first argument is **9527** in main function. (40%)
    b. Let **argv[1] = "aesophor is ghost !!!"** before checking. (30%)
    c. Let **argc = 9487** before checking. (30%)
2. Upgrade your llvm-lab-pass.cc to new e3.
    a. We will compile your code and use it to instrument target.c.
    b. We will execute ./target 1 and see the output result.
    c. We may modify the output message after checking, so do not just instrument the output message.
3. We provide Pass.cc template, Makefile, and a docker file as testing environment.

Do not compress the files and plagiarism.

target.c

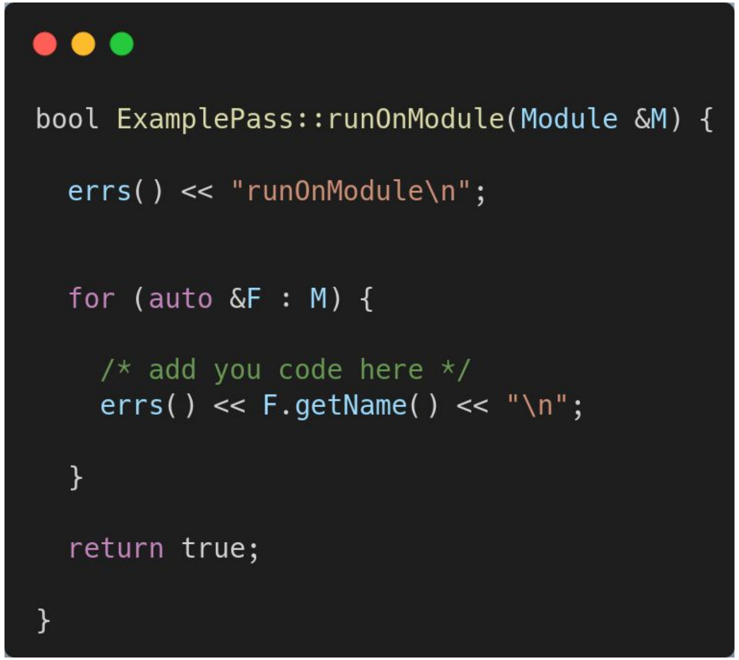


```c
int main(int argc, char *argv[]) {

  printf("argc: %d\n", argc);

  if (argc >= 2)
    printf("argv[1]: %s\n", argv[1]);
  else
    return 0;

  if (argc == 9487) {
    printf("Omg! Why your argc is so large ?\n");
  }
  else {
    printf("Looks like your argc is not large enough !\n");
  }

  if (!strncmp(argv[1], "aesophor is ghost !!!", 21)) {
    printf("Yes, aesophor is ghost !\n");
  }
  else {
    printf("Do you know aesophor ?\n");
  }

  return 0;

}
```



```c
// used for debug
void debug(int id) {

  if (id == 9527)
    fprintf(stderr, "debug mode\n");
  else
    fprintf(stderr, "bad id !\n");
}
```

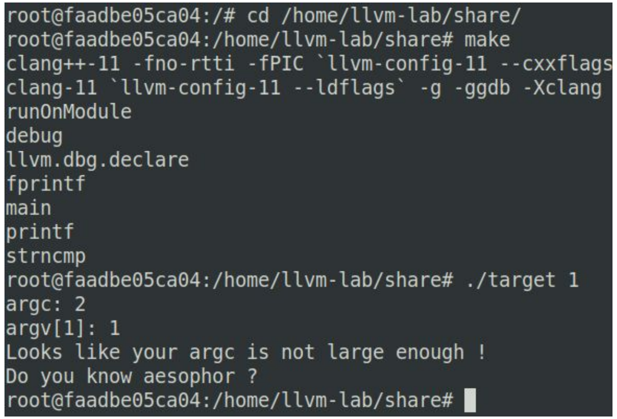
llvm-pass.cc



```
bool ExamplePass::runOnModule(Module &M) {

  errs() << "runOnModule\n";


  for (auto &F : M) {

    /* add you code here */
    errs() << F.getName() << "\n";

  }

  return true;

}
```

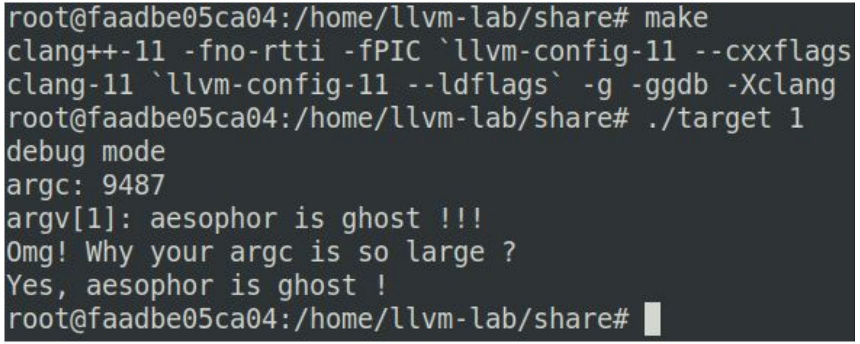
Demo

Original



```
root@faadbe05ca04:/# cd /home/llvm-lab/share/
root@faadbe05ca04:/home/llvm-lab/share# make
clang++-11 -fno-rtti -fPIC `llvm-config-11 --cxxflags
clang-11 `llvm-config-11 --ldflags` -g -ggdb -Xclang
runOnModule
debug
llvm.dbg.declare
fprintf
main
printf
strncmp
root@faadbe05ca04:/home/llvm-lab/share# ./target 1
argc: 2
argv[1]: 1
Looks like your argc is not large enough !
Do you know aesophor ?
root@faadbe05ca04:/home/llvm-lab/share# 
```

Instrumentation



```
root@faadbe05ca04:/home/llvm-lab/share# make
clang++-11 -fno-rtti -fPIC `llvm-config-11 --cxxflags
clang-11 `llvm-config-11 --ldflags` -g -ggdb -Xclang
root@faadbe05ca04:/home/llvm-lab/share# ./target 1
debug mode
argc: 9487
argv[1]: aesophor is ghost !!!
Omg! Why your argc is so large ?
Yes, aesophor is ghost !
root@faadbe05ca04:/home/llvm-lab/share# 
```

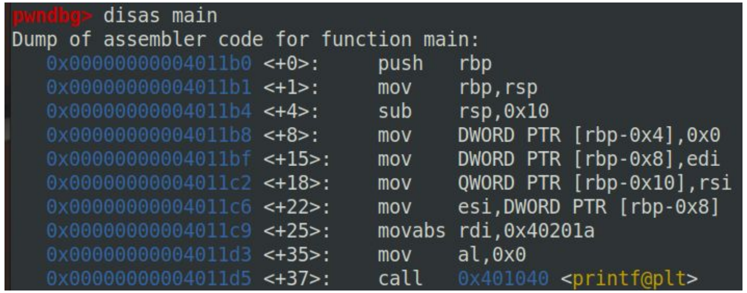
Environment

1. environment in docker file:
   a. Download llvm-lab.zip from github
   b. unzip and cd to distribute
   c. sudo docker build -t llvm-lab . --no-cache
   d. sudo docker run -v $PWD/share:/home/llvm-lab/share -it llvm-lab /bin/bash
   e. cd /home/llvm-lab/share
   f. make
   g. ./target 1

Debug

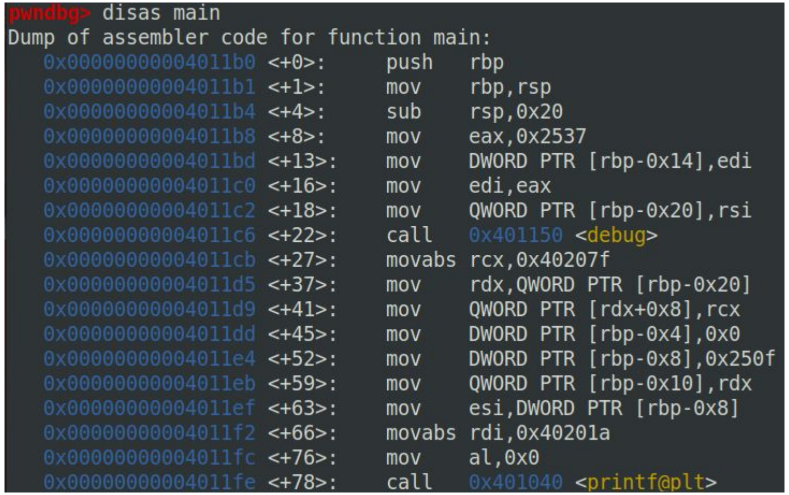
- compile error
  - clang error message
- Instrumentation debug
  - target output
  - gdb

Original



```
pwndbg> disas main
Dump of assembler code for function main:
   0x00000000004011b0 <+0>:     push   rbp
   0x00000000004011b1 <+1>:     mov    rbp,rsp
   0x00000000004011b4 <+4>:     sub    rsp,0x10
   0x00000000004011b8 <+8>:     mov    DWORD PTR [rbp-0x4],0x0
   0x00000000004011bf <+15>:    mov    DWORD PTR [rbp-0x8],edi
   0x00000000004011c2 <+18>:    mov    QWORD PTR [rbp-0x10],rsi
   0x00000000004011c6 <+22>:    mov    esi,DWORD PTR [rbp-0x8]
   0x00000000004011c9 <+25>:    movabs rdi,0x40201a
   0x00000000004011d3 <+35>:    mov    al,0x0
   0x00000000004011d5 <+37>:    call   0x401040 <printf@plt>
```

Instrumentation

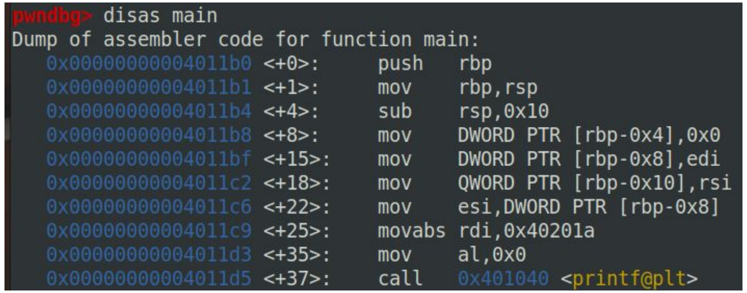


```
pwndbg> disas main
Dump of assembler code for function main:
   0x00000000004011b0 <+0>:     push   rbp
   0x00000000004011b1 <+1>:     mov    rbp,rsp
   0x00000000004011b4 <+4>:     sub    rsp,0x20
   0x00000000004011b8 <+8>:     mov    eax,0x2537
   0x00000000004011bd <+13>:    mov    DWORD PTR [rbp-0x14],edi
   0x00000000004011c0 <+16>:    mov    edi,eax
   0x00000000004011c2 <+18>:    mov    QWORD PTR [rbp-0x20],rsi
   0x00000000004011c6 <+22>:    call   0x401150 <debug>
   0x00000000004011cb <+27>:    movabs rcx,0x40207f
   0x00000000004011d5 <+37>:    mov    rdx,QWORD PTR [rbp-0x20]
   0x00000000004011d9 <+41>:    mov    QWORD PTR [rdx+0x8],rcx
   0x00000000004011dd <+45>:    mov    DWORD PTR [rbp-0x4],0x0
   0x00000000004011e4 <+52>:    mov    DWORD PTR [rbp-0x8],0x250f
   0x00000000004011eb <+59>:    mov    QWORD PTR [rbp-0x10],rdx
   0x00000000004011ef <+63>:    mov    esi,DWORD PTR [rbp-0x8]
   0x00000000004011f2 <+66>:    movabs rdi,0x40201a
   0x00000000004011fc <+76>:    mov    al,0x0
   0x00000000004011fe <+78>:    call   0x401040 <printf@plt>
```

Debug

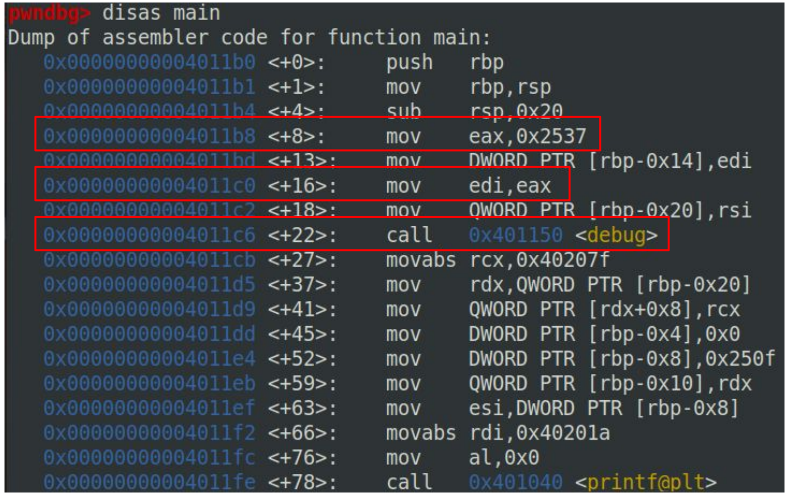
- call debug with arg1=9527=0x2537
- x64 calling convention
  - **arg1, arg2, arg3** will be set in **rdi, rsi, rdx**

Original



```
pwndbg> disas main
Dump of assembler code for function main:
   0x00000000004011b0 <+0>:     push   rbp
   0x00000000004011b1 <+1>:     mov    rbp,rsp
   0x00000000004011b4 <+4>:     sub    rsp,0x10
   0x00000000004011b8 <+8>:     mov    DWORD PTR [rbp-0x4],0x0
   0x00000000004011bf <+15>:    mov    DWORD PTR [rbp-0x8],edi
   0x00000000004011c2 <+18>:    mov    QWORD PTR [rbp-0x10],rsi
   0x00000000004011c6 <+22>:    mov    esi,DWORD PTR [rbp-0x8]
   0x00000000004011c9 <+25>:    movabs rdi,0x40201a
   0x00000000004011d3 <+35>:    mov    al,0x0
   0x00000000004011d5 <+37>:    call   0x401040 <printf@plt>
```

Instrumentation

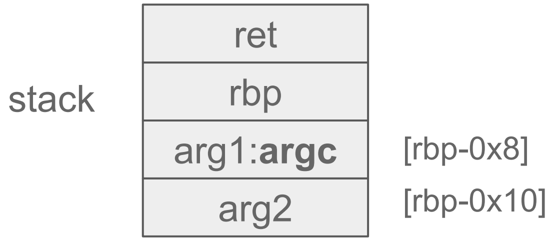


```
pwndbg> disas main
Dump of assembler code for function main:
   0x00000000004011b0 <+0>:     push   rbp
   0x00000000004011b1 <+1>:     mov    rbp,rsp
   0x00000000004011b4 <+4>:     sub    rsp,0x20
   0x00000000004011b8 <+8>:     mov    eax,0x2537
   0x00000000004011bd <+13>:    mov    DWORD PTR [rbp-0x14],edi
   0x00000000004011c0 <+16>:    mov    edi,eax
   0x00000000004011c2 <+18>:    mov    QWORD PTR [rbp-0x20],rsi
   0x00000000004011c6 <+22>:    call   0x401150 <debug>
   0x00000000004011cb <+27>:    movabs rcx,0x40207f
   0x00000000004011d5 <+37>:    mov    rdx,QWORD PTR [rbp-0x20]
   0x00000000004011d9 <+41>:    mov    QWORD PTR [rdx+0x8],rcx
   0x00000000004011dd <+45>:    mov    DWORD PTR [rbp-0x4],0x0
   0x00000000004011e4 <+52>:    mov    DWORD PTR [rbp-0x8],0x250f
   0x00000000004011eb <+59>:    mov    QWORD PTR [rbp-0x10],rdx
   0x00000000004011ef <+63>:    mov    esi,DWORD PTR [rbp-0x8]
   0x00000000004011f2 <+66>:    movabs rdi,0x40201a
   0x00000000004011fc <+76>:    mov    al,0x0
   0x00000000004011fe <+78>:    call   0x401040 <printf@plt>
```

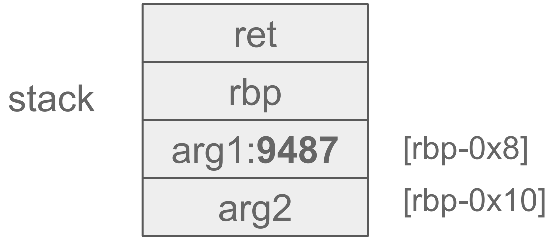
Debug

- let argc=9487=0x250f
-

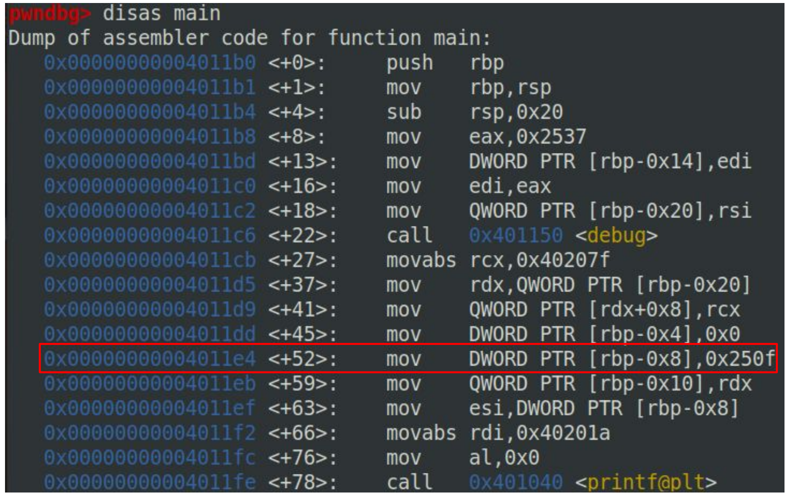
Original



Instrumentation



Instrumentation

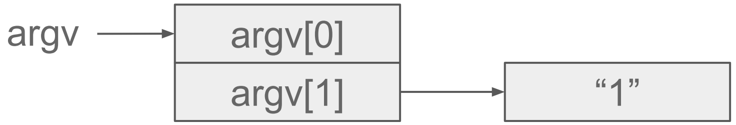


```
pwndbg> disas main
Dump of assembler code for function main:
   0x00000000004011b0 <+0>:     push   rbp
   0x00000000004011b1 <+1>:     mov    rbp,rsp
   0x00000000004011b4 <+4>:     sub    rsp,0x20
   0x00000000004011b8 <+8>:     mov    eax,0x2537
   0x00000000004011bd <+13>:    mov    DWORD PTR [rbp-0x14],edi
   0x00000000004011c0 <+16>:    mov    edi,eax
   0x00000000004011c2 <+18>:    mov    QWORD PTR [rbp-0x20],rsi
   0x00000000004011c6 <+22>:    call   0x401150 <debug>
   0x00000000004011cb <+27>:    movabs rcx,0x40207f
   0x00000000004011d5 <+37>:    mov    rdx,QWORD PTR [rbp-0x20]
   0x00000000004011d9 <+41>:    mov    QWORD PTR [rdx+0x8],rcx
   0x00000000004011dd <+45>:    mov    DWORD PTR [rbp-0x4],0x0
   0x00000000004011e4 <+52>:    mov    DWORD PTR [rbp-0x8],0x250f
   0x00000000004011eb <+59>:    mov    QWORD PTR [rbp-0x10],rdx
   0x00000000004011ef <+63>:    mov    esi,DWORD PTR [rbp-0x8]
   0x00000000004011f2 <+66>:    movabs rdi,0x40201a
   0x00000000004011fc <+76>:    mov    al,0x0
   0x00000000004011fe <+78>:    call   0x401040 <printf@plt>
```

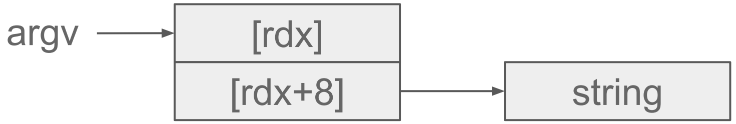
Debug

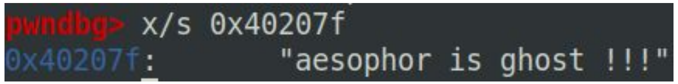
- let argv[1]="aesophor is ghost !!!"

Original



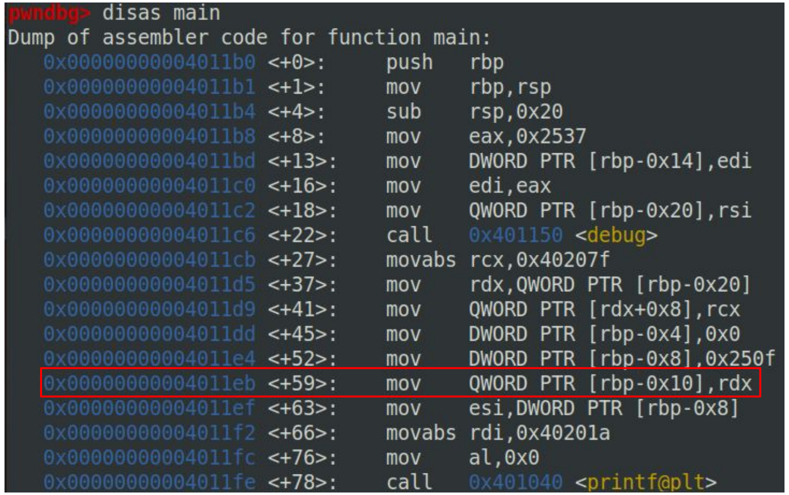
Instrumentation





```
pwndbg> x/s 0x40207f
0x40207f:       "aesophor is ghost !!!"
```

Instrumentation



```
pwndbg> disas main
Dump of assembler code for function main:
   0x00000000004011b0 <+0>:     push   rbp
   0x00000000004011b1 <+1>:     mov    rbp,rsp
   0x00000000004011b4 <+4>:     sub    rsp,0x20
   0x00000000004011b8 <+8>:     mov    eax,0x2537
   0x00000000004011bd <+13>:    mov    DWORD PTR [rbp-0x14],edi
   0x00000000004011c0 <+16>:    mov    edi,eax
   0x00000000004011c2 <+18>:    mov    QWORD PTR [rbp-0x20],rsi
   0x00000000004011c6 <+22>:    call   0x401150 <debug>
   0x00000000004011cb <+27>:    movabs rcx,0x40207f
   0x00000000004011d5 <+37>:    mov    rdx,QWORD PTR [rbp-0x20]
   0x00000000004011d9 <+41>:    mov    QWORD PTR [rdx+0x8],rcx
   0x00000000004011dd <+45>:    mov    DWORD PTR [rbp-0x4],0x0
   0x00000000004011e4 <+52>:    mov    DWORD PTR [rbp-0x8],0x250f
   0x00000000004011eb <+59>:    mov    QWORD PTR [rbp-0x10],rdx
   0x00000000004011ef <+63>:    mov    esi,DWORD PTR [rbp-0x8]
   0x00000000004011f2 <+66>:    movabs rdi,0x40201a
   0x00000000004011fc <+76>:    mov    al,0x0
   0x00000000004011fe <+78>:    call   0x401040 <printf@plt>
```

Questions

- **tl455047.cs09@nycu.edu.tw**

Reference

- https://llvm.org/docs/LangRef.html
- https://llvm.org/doxygen/index.html
- https://github.com/google/AFL