A Brief Introduction to LLVM

Nick Sumner

(with a few modifications by Matt Dwyer)

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  - Program analysis / optimization libraries
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- Easy to add / remove / change functionality

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  ./callcounter -static test.bc

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- Reporting properties of the program:

```
Function Counts
===============
b : 2
a : 1
printf : 3
```

What is LLVM Bitcode?

- A (Relatively) Simple IR

```
#include<stdio.h>

void
foo(unsigned e) {
  for (unsigned i = 0; i < e; ++i) {
    printf("Hello\n");
  }
}

int
main(int argc, char **argv) {
  foo(argc);
  return 0;
}
```

Code

clang -c -S -emit-llvm -O1 -g0

```
@str = private constant [6 x i8] c"Hello\00"

define void @foo(i32) {
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  %5 = phi i32 [ %7, %4 ], [ 0, %1 ]
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  %7 = add nuw i32 %5, 1
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IR

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clang -c -emit-llvm
(and llvm-dis)

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labels & predecessors

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branches & successors

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Instructions

Inspecting Bitcode

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```
Module& module = …;
for (Function& fun : module) {
  for (BasicBlock& bb : fun) {
    for (Instruction& i : bb) {

…
```

Iterate over the:

- Functions in a Module
- BasicBlocks in a Function
- Instructions in a BasicBlock

Inspecting Bitcode

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  - Easy to examine and/or manipulate
  - Many helpers (e.g. CallSite,)

```
Module& module = ...;
for (Function& fun : module) {
  for (BasicBlock& bb : fun) {
    for (Instruction& i : bb) {
      CallSite cs{&i};
      if (!cs.getInstruction()) {
        continue;
      }
...
```

CallSite helps you extract information from Call and Invoke instructions.

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      outs() << "Found a function call: " << i << "\n";
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```

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  - Easy to examine and/or manipulate
  - Many helpers (e.g. CallSite, outs(), dyn_cast)

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Module &module = ...;
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  for (BasicBlock& bb : fun) {
    for (Instruction& i : bb) {
      CallSite cs{&i};
      if (!cs.getInstruction()) {
        continue;
      }
      outs() << "Found a function call: " << i << "\n";
      Value* called = cs.getCalledValue()->stripPointerCasts();
      if (Function* f = dyn_cast<Function>(called)) {
        outs() << "Direct call to function: " << f->getName() << "\n";
...
```

dyn_cast() efficiently checks the runtime types of LLVM IR components.

Dealing with SSA

- You may ask where certain values came from
  - Useful for tracking dependencies
  - “Where was this variable defined?”

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- LLVM IR is in SSA form
  - How many acronyms can I fit into one line?
  - What does this mean?
  - Why does it matter?

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void foo()
  unsigned i = 0;
  while (i < 10) {
    i = i + 1;
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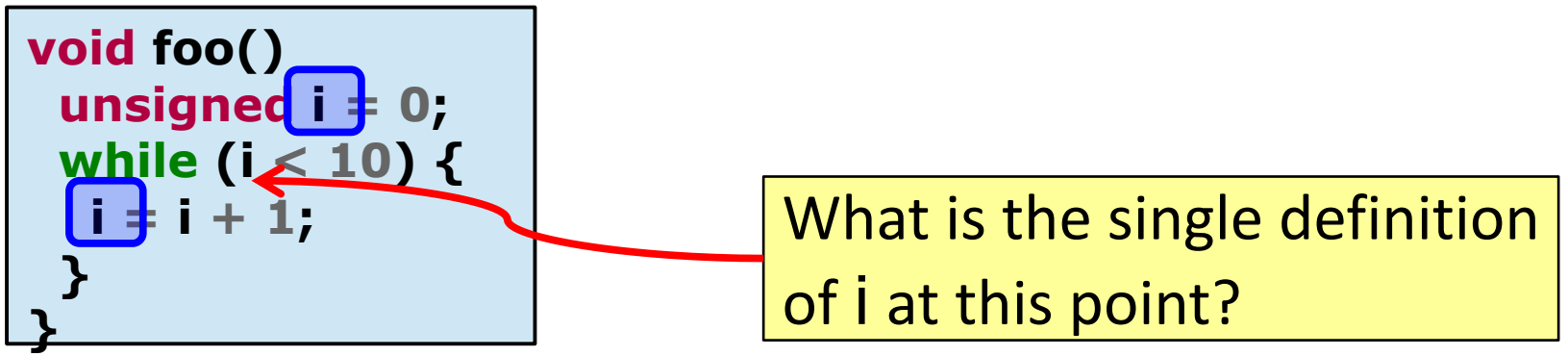

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- The phi instruction
  - It selects which of the definitions to use
  - Always at the start of a basic block

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```
void foo() {
  unsigned i = 0;
  while (i < 10) {
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  }
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```

```
define void @foo() {
  br label %1

; <label>:1                ; preds = %1, %0
  %i.phi = phi i32 [ 0, %0 ], [ %2, %1 ]
  %2 = add i32 %i.phi, 1
  %exitcond = icmp eq i32 %2, 10
  br i1 %exitcond, label %3, label %1

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  br i1 %exitcond, label %3, label %1

; <label>:3                ; preds = %1
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}
```

Dependencies in General

- You can loop over the values an instruction uses

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```

for %a = %b + %c:

[%b, %c]

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- You can loop over the values an instruction uses

```
for (Use& u : inst->operands()) {
  // inst uses the Value* u
}
```

- You can loop over the instructions that use a particular value

```
Instruction* inst = ...;
for (User* user : inst->users())
  if (auto* i = dyn_cast<Instruction>(user)) {
    // inst is used by Instruction i
  }
```

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```
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  ret i64 %1
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define i64 @trunc(i16 zeroext %a) {
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```

- Also types for pointers, arrays, structs, etc.
  - Strong typing means they take a bit more work

The `tipc` TIP compiler

- Compiles a TIP program into LLVM bitcode
- Consists of several phases
  - Parsing TIP (uses ANTLR4)
  - Builds an AST
  - Walks the AST to generate bitcode
  - Applies building LLVM optimizations
  - Emits bitcode to a .bc file
- To build an executable we link with libraries

The `tipc` TIP compiler

```
$ ./tipc --help
OVERVIEW: tipc - a TIP to llvm compiler

USAGE: tipc [options] <tip source file>

OPTIONS:

Generic Options:

  -help      - Display available options (-help-hidden for more)
  -help-list - Display list of available options (-help-list-hidden
for more)
  -version   - Display the version of this program

tipc Options:
Options for controlling the TIP compilation process.

  -d         - disable bitcode optimization
  -l         - pretty print with line numbers
  -p         - pretty print
```