Csmith Paper

Transformation from SSA Form

Proposal

- Restore original variable names (*i.e.*, drop subscripts)
- Delete all ϕ-functions

Complications

- What if versions get out of order? (simultaneously live ranges)

```
x0 =
x1 =
   = x0
   = x1
```

Alternative

- Perform dead code elimination (to prune ϕ-functions)
- Replace ϕ-functions with copies in predecessors
- Rely on register allocation coalescing to remove unnecessary copies

Revisiting Data-flow Analyses in SSA Form

How do our various data-flow analyses change, if at all?

– Liveness
– Available expressions
– Common sub-expression elimination
– Reaching definitions

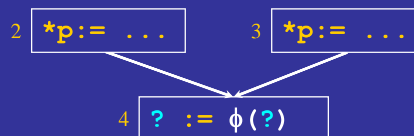
LLVM

Partial SSA form

– Top-level variables are in SSA from
– Address-taken variables are not

Why does LLVM do this?

– Pointers are difficult in SSA form



SSA in LLVM

SSA form

- Everything that starts with % or @ is in SSA
  - Once initialized, they become immutable
  - Every definition has to dominate all of its uses
  - "Virtual register" or "top-level variable"
- Use fresh names %1, %2 rather than subscripts to rename variables

```
int f(int a)
{
  a = a * 2;
  a = a + 1;
  return a;
}
```

```
define i32 @f(i32 %a) {
  %1 = mul nsw i32 %a, 2
  %2 = add nsw i32 %a, 1
  ret i32 %2
}
```

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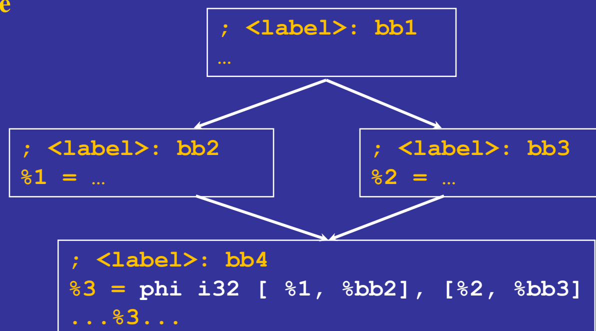
LLVM (cont)

ϕ-function in LLVM

- Both the incoming value and the incoming block have to be specified

Example



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LLVM (cont)

Mutable variables

- Partial SSA
  - Values that reside in memory are "address-taken variables"
  - These variables are mutable

Memory operations

- Alloca for stack allocation
- Load & store for memory read/write

LLVM (cont)

Example

```
int f()
{
  int a = 5;
  int b = a - 3;
  b = 42;
  return b;
}
```

```
define i32 @f() {
  %a = alloca i32
  %b = alloca i32
  store i32 5, %i32* %a
  %1 = load i32* %a
  %2 = sub nsw i32 %1, 3
  store i32 %2, %i32* %b
  store i32 42 i32* %b
  %3 = load i32* %b
  ret i32 %3
}
```

In the IR, what do variable a and b in the source language get translated to?

LLVM (cont)

In C/C++, every variable is mutable

- By default, clang will generate one memory allocation for every single C variable
- But this is wasteful!

Mem2reg to the rescue

- LLVM has a highly-tuned optimization pass called “mem2reg”
  - promotes allocas into virtual registers
  - inserts ϕ-node as appropriate
- This pass is essentially a dominance-frontier finder already written for you

LLVM (cont)

Mem2reg example

Before

```
define i32 @f() {
  %a = alloca i32
  %b = alloca i32
  store i32 5, %i32* %a
  %1 = load i32* %a
  %2 = sub nsw i32 %1, 3
  store i32 %2, %i32* %b
  store i32 42 i32* %b
  %3 = load i32* %b
  ret i32 %3
}
```

After

```
define i32 @f() {
  %1 = sub nsw i32 5, 3
  ret i32 42
}
```

LLVM (cont)

Summary

- In LLVM, values can be stored in virtual registers or memory
- Virtual register values are required to be in SSA form
- Memory values can be mutable
- Use –mem2reg to eliminate unnecessary allocations

Concepts

Data dependences

- Three kinds of data dependences
- du-chains

Alternate representations

SSA form

Conversion to SSA form

- ϕ-function placement
  - Dominance frontiers
- Variable renaming
  - Dominance trees

Conversion from SSA form

LLVM and partial SSA form

Next Time

Lecture

– Reuse optimizations

Reading

– Wegman and Zadeck paper due Tuesday February 24th at 5:00pm