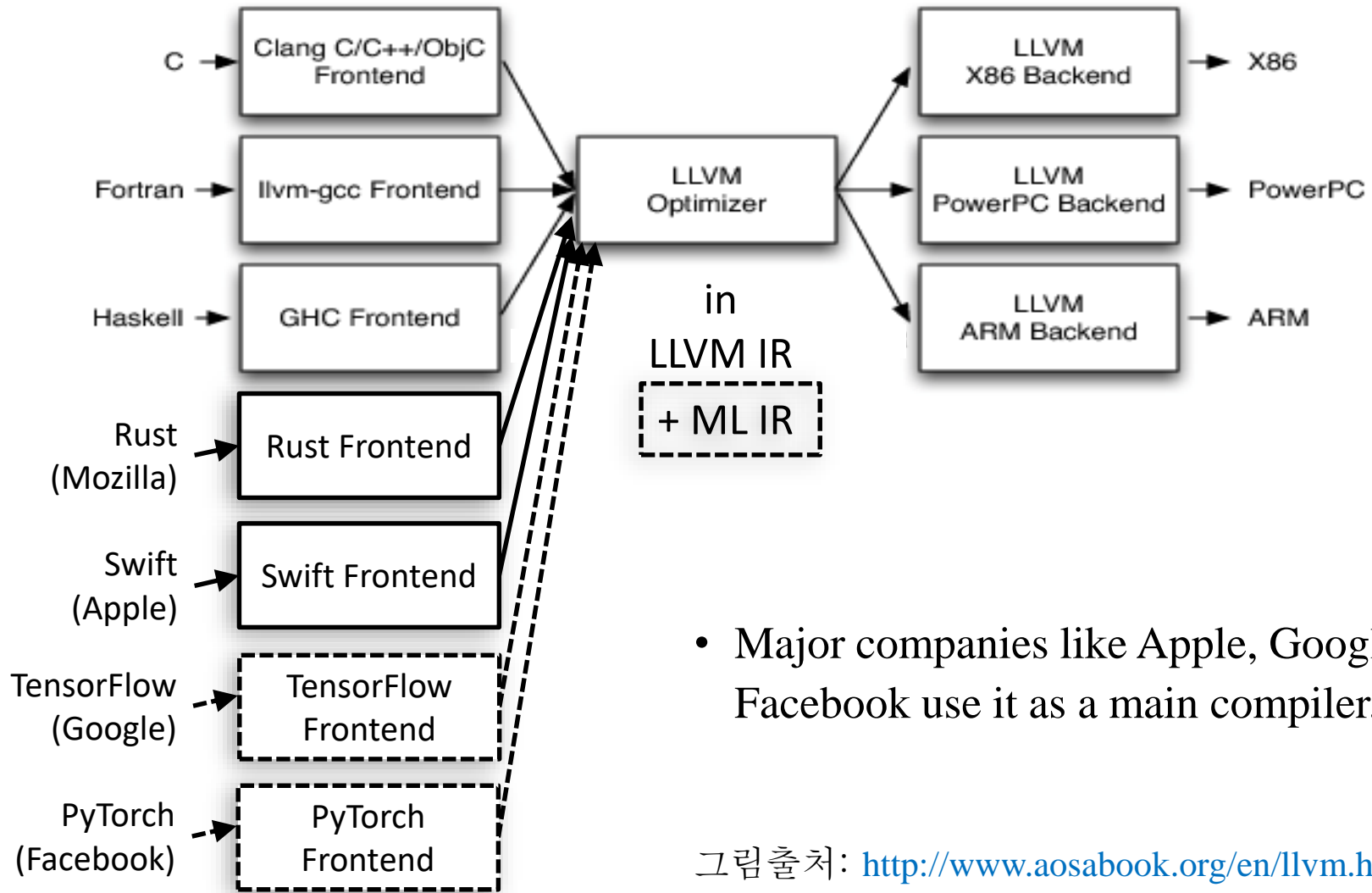


LLVM IR

Chung-Kil Hur

What is LLVM?



- Major companies like Apple, Google, Facebook use it as a main compiler.

그림출처: <http://www.aosabook.org/en/llvm.html>

A running example

C

```
int f(int x, int y) {  
    int z;  
    if (x == y) {  
        z = x + y;  
    } else {  
        z = x - y;  
    }  
    return z + z + z;  
}
```

->

LLVM IR

?

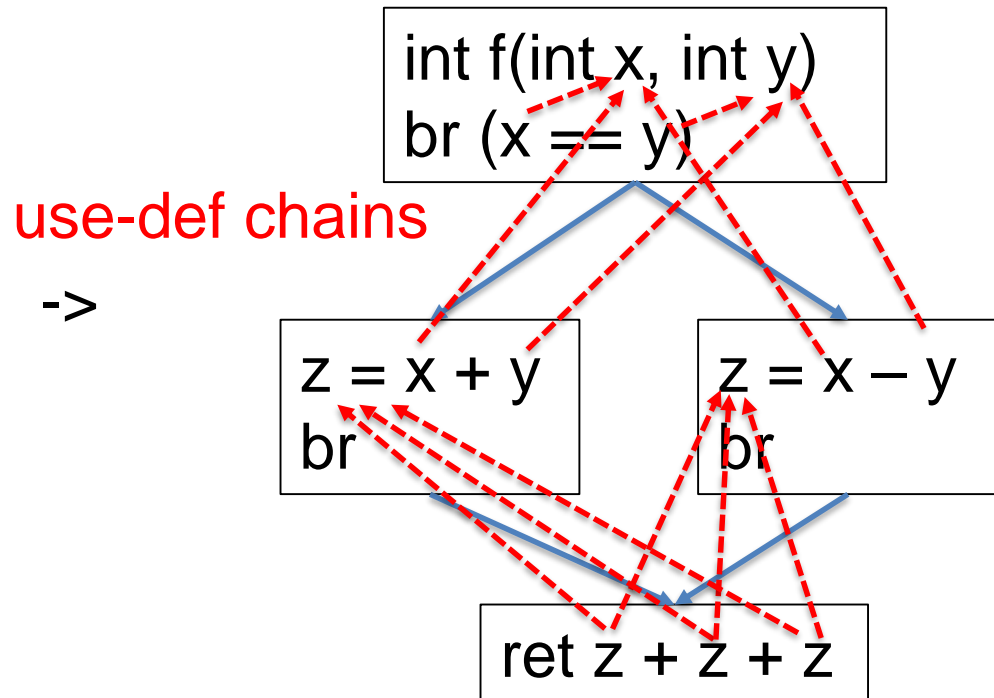
LLVM IR:

Control Flow Graph (CFG)

C

```
int f(int x, int y) {  
    int z;  
    if (x == y) {  
        z = x + y;  
    } else {  
        z = x - y;  
    }  
    return z + z + z;  
}
```

LLVM IR



LLVM IR:

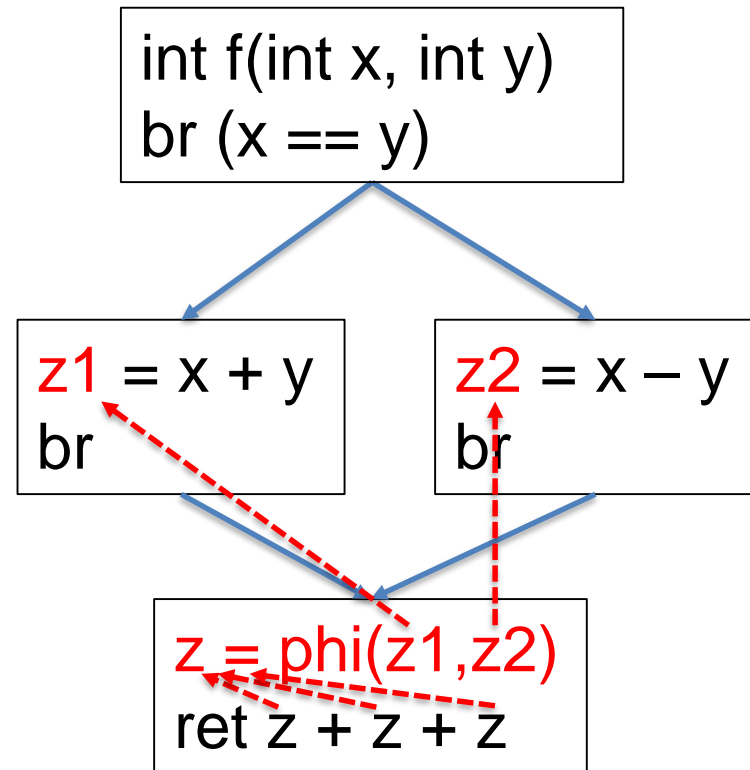
Static Single Assignment (SSA)

C

```
int f(int x, int y) {  
    int z;  
    if (x == y) {  
        z = x + y;  
    } else {  
        z = x - y;  
    }  
    return z + z + z;  
}
```

->

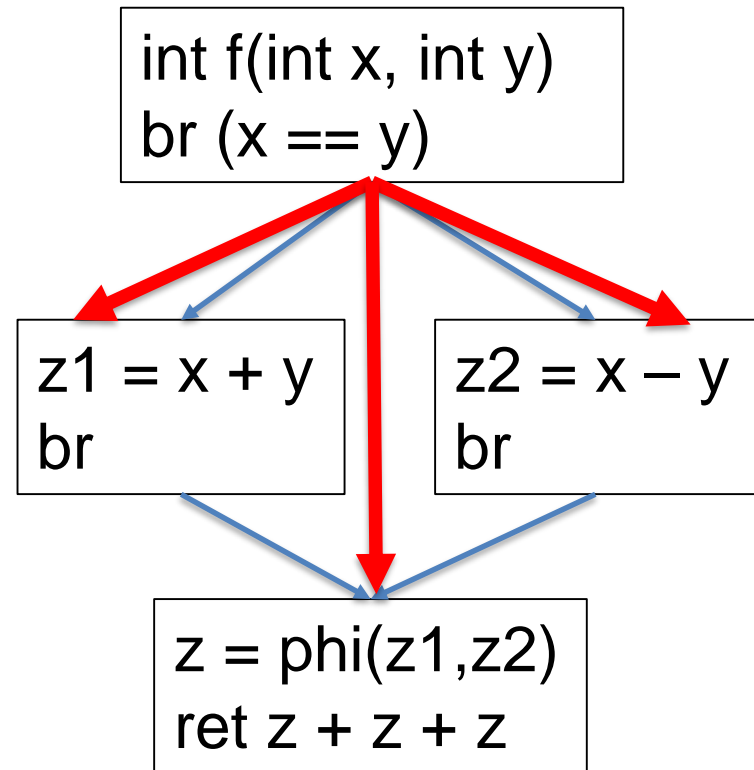
LLVM IR



LLVM IR: Domination Tree

A dominates B if A is always visited before visiting B

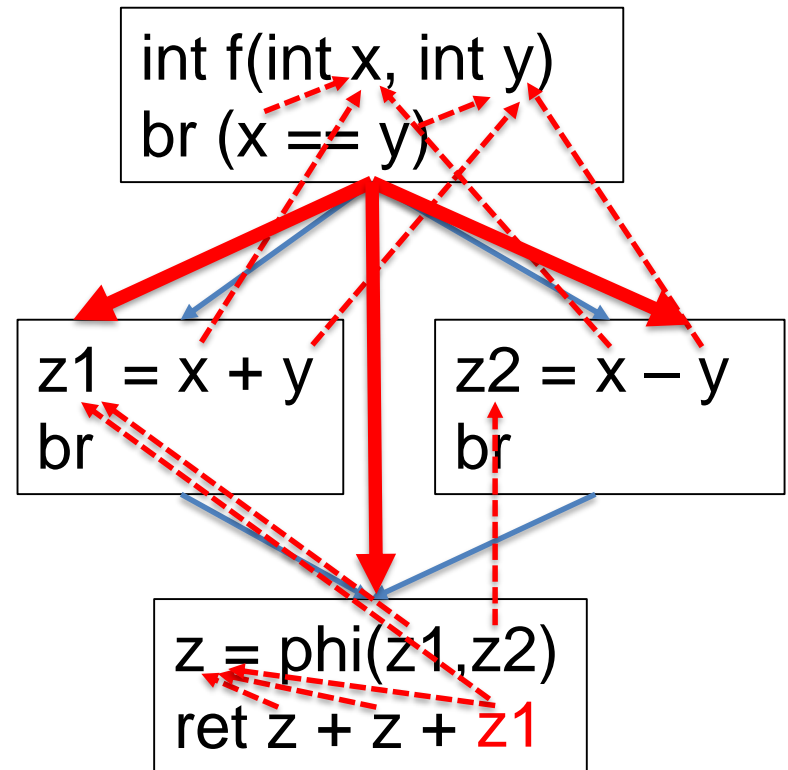
Domination Tree



LLVM IR:

Checking use-after-def

We can check whether a variable is used after it is defined using **use-def** and **dom tree**.



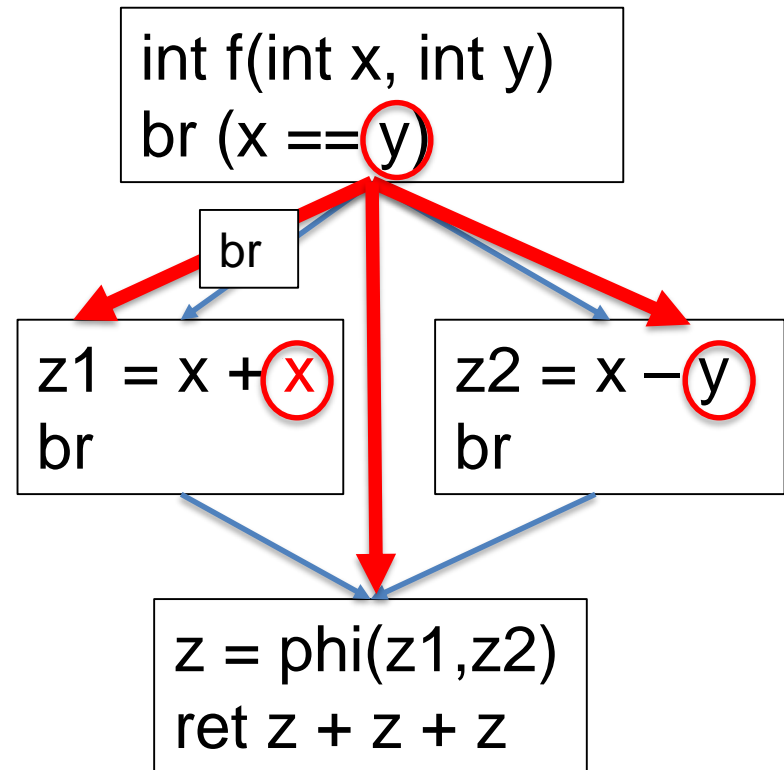
An example optimization

Goal

- replace y by x when $x == y$

Algorithm

- Insert a dummy block between $x == y$ and its left successor (called critical edge splitting)
- Replace all uses of y that are dominated by the dummy block



LLVM Syntax

```
define i32 @f(i32 %x, i32 %y) {  
entry:  
    %0 = icmp eq i32 %x, %y  
    br i1 %0, label %btrue, label %bfalse
```

```
btrue:
```

```
    %z1 = add nsw i32 %x, %y  
    br label %end
```

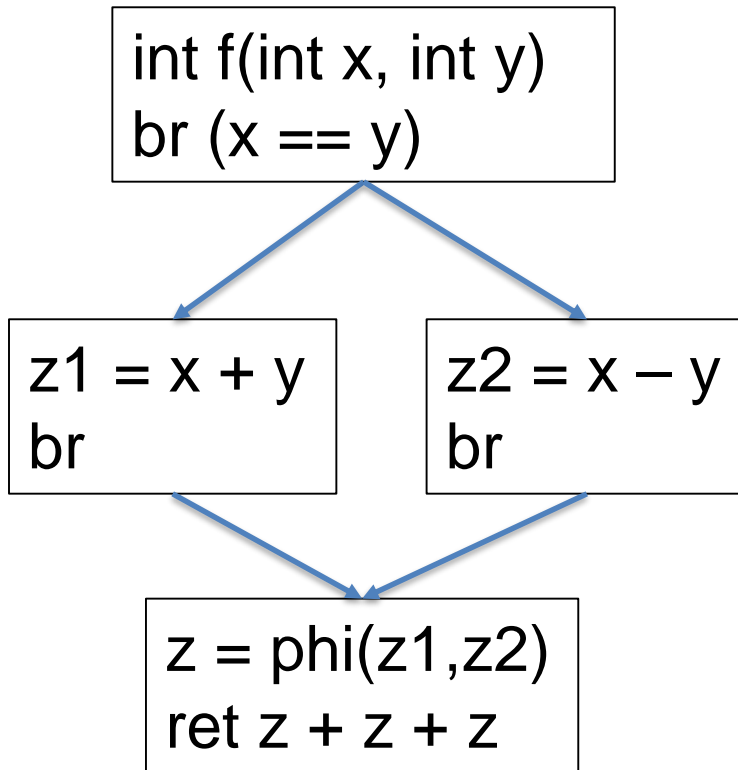
```
bfalse:
```

```
    %z2 = sub nsw i32 %x, %y  
    br label %end
```

```
end:
```

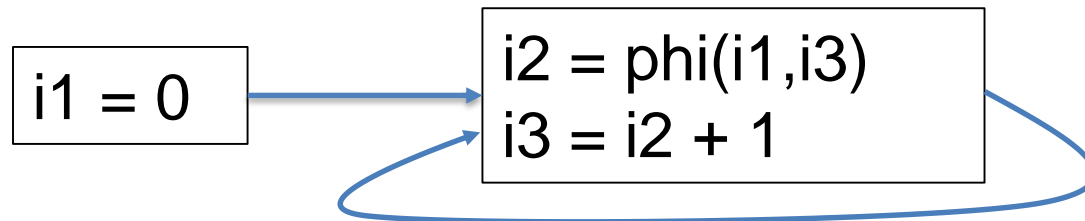
```
    %z = phi i32 [ %z1, %btrue ],  
              [ %z2, %bfalse ]  
    %1 = add nsw i32 %z, %z  
    %2 = add nsw i32 %1, %z  
    ret i32 %2
```

```
}
```



Registers

- Registers
 - Syntax: %0, %x, %gil, ...
 - Can use an unbounded number of registers (ie, infinitely many)
 - Each register has a type: i1, i32, i64, f32, f64, i32*, ...
 - Define: write a value (of the right type) into a register
 - Use: read the stored value from it
 - Q: Can a register be updated multiple times?
A: Yes, in the presence of loop (ie, cycle in CFG)



- Q: What's difference between LLVM registers and C variables?
A: C variables reside in memory (ie, have addresses, sharable)
but registers do not (ie, have no addresses, unsharable)

Memory: Stack vs. Heap

// Stack Allocation

```
int f() {  
    int x;  
    x = 42;  /*(&x) = 42    =>  
    g(&x);  
    return x; // *(&x)  
}
```

// Heap Allocation

```
int f() {  
    int* xptr;  
    xptr = malloc(4);  
    *xptr = 42;  
    g(xptr);  
    int r = *xptr;  
    free(xptr);  
    return r;  
}
```

```
define i32 @f() {
```

```
entry:
```

```
    %xptr = alloca i32
```

```
    store i32 42, i32* %xptr
```

```
    call void @g(i32* %xptr)
```

```
    %0 = load i32, i32* %xptr
```

```
    ret i32 %0
```

```
}
```

```
define i32 @f() {
```

```
entry:
```

```
    %xptr = call i32* @malloc(i64 4)
```

```
    store i32 42, i32* %xptr
```

```
    call void @g(i32* %xptr)
```

```
    %0 = load i32, i32* %xptr
```

```
    call void @free(%xptr)
```

```
    ret i32 %0
```

```
}
```