



CSCI 742 - Compiler Construction

Lecture 34
Control Flow Graphs
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Recap: Optimizations

- **Optimizations:** code transformations that improve the program
 - Usually to improve execution time
 - Sometimes to reduce program size or power usage
- Can be done at high-level or low-level
 - e.g. constant folding
- Optimizations must preserve the original behavior of program
- Execution of transformed code must yield same result as the original code for every possible input

Optimization Correctness: Dead Code Elimination

- What statements are dead and can be removed?

```
x = y - 1;
```

```
y = z * 2;
```

```
x = y - z;
```

```
z = 10;
```

```
z = x;
```

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- Is `x` dead at first statement?
- Need to know if values assigned to `x` is never used later
- Obvious for this simple example (with no control flow)
- Not obvious for complex flow of control

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- Is x dead at first statement?
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Optimization Correctness: Dead Code Elimination


- Add control flow to example
- Is $x = y - 1$ dead code? Is $z = 10$ dead code?

```
x = y - 1;  
y = z * 2;  
if (c1) x = y - z;  
z = 10;  
z = x;
```

Optimization Correctness: Dead Code Elimination

- Add control flow to example
- Is $x = y - 1$ dead code? Is $z = 10$ dead code?

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x = y - 1;  
y = z * 2;  
if (c1) x = y - z;  
z = 10;  
z = x;
```



- Statement $x = y - 1$ is not dead code anymore
- On some executions, value is used later

Optimization Correctness: Dead Code Elimination

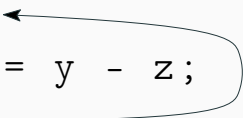
- Add more control flow to example
- Is $x = y - 1$ dead code? Is $z = 10$ dead code?

```
while (c2) {  
    x = y - 1;  
    y = z * 2;  
    if (c1) x = y - z;  
    z = 10; }  
z = x;
```


Optimization Correctness: Dead Code Elimination

- Add more control flow to example
- Is $x = y - 1$ dead code? Is $z = 10$ dead code?

```
while (c2) {  
    x = y - 1;  
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```

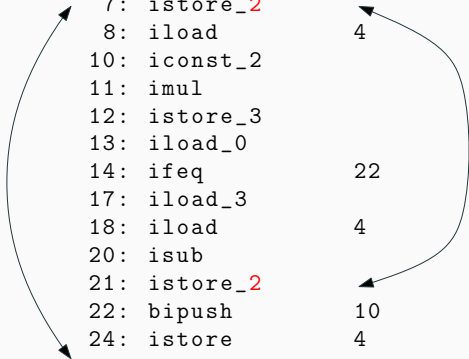


- Statement $x = y - 1$ not dead anymore
- Statement $z = 10$ not dead either
- On **some** executions, value from $z = 10$ is used later

Low-level Code

- Harder to eliminate dead code in low-level code

0:	iload_1	
1:	ifeq	32
4:	iload_3	
5:	iconst_1	
6:	isub	
7:	istore_2	
8:	iload	4
10:	iconst_2	
11:	imul	
12:	istore_3	
13:	iload_0	
14:	ifeq	22
17:	iload_3	
18:	iload	4
20:	isub	
21:	istore_2	
22:	bipush	10
24:	istore	4
26:	iload_2	
27:	istore	4
29:	goto	0



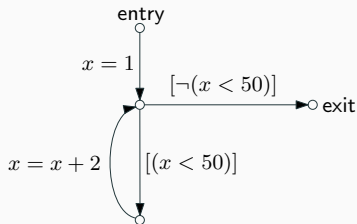
Optimizations and Control Flow

- Application of optimizations requires information
 - e.g. dead code elimination needs to know if variables are dead when assigned values
- Required information are not usually explicit in the program
- We must compute it statically (at compile-time)
- Must characterize all dynamic (run-time) executions
- Control flow makes it hard to extract information
 - Branches and loops in the program
 - Different executions =
different branches taken,
different number of loop iterations executed

Control Flow Graphs

- **Control Flow Graph:** graph representation of computation and control flow in the program
- Specifies all possible execution paths

```
x = 1
while (x < 50)
{
  x = x + 2
}
```



Generating Control-Flow Graphs

- Control-Flow graph is similar to AST
- Start with graph that has one **entry** and one **exit** node
- Draw an edge from entry to exit and label it with the entire program



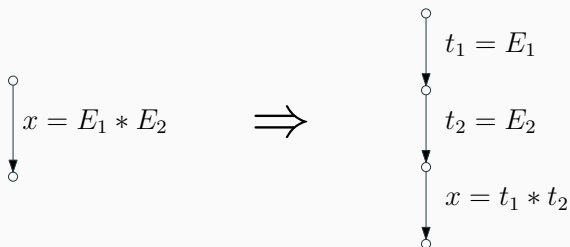
- Recursively decompose the program to have more edges with simpler labels
- When labels cannot be decomposed further, we are done

Flattening Expressions

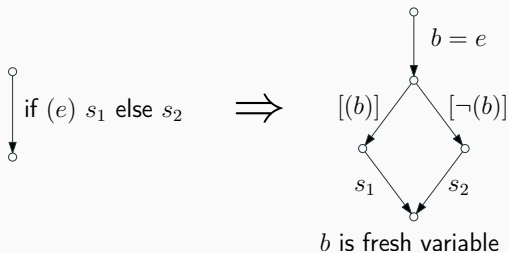
- Label flattening: simplify a label, make an order on the side effects

E_1, E_2 : complex expressions

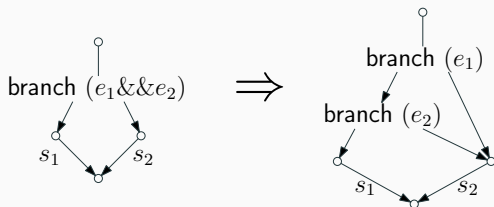
t_1, t_2 : fresh variables



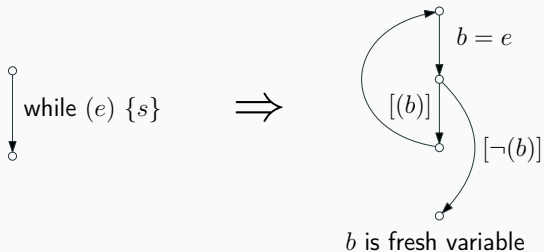
Conditional Statement



- Translation using `branch` instruction with two destinations



while Statement



- Translation using the `branch` instruction

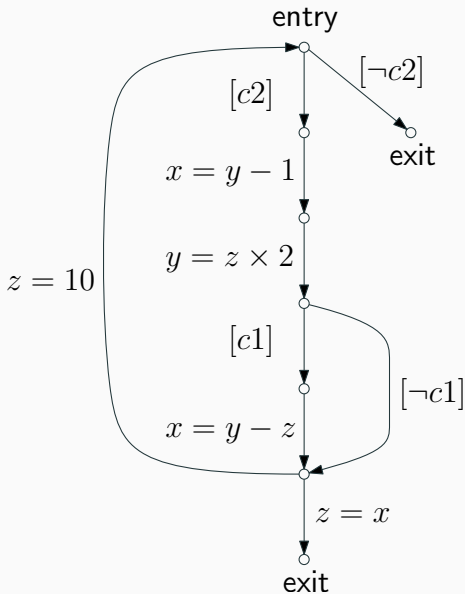


Exercise 1: Convert to CFG

```
while(c2) {  
    x = y - 1;  
    y = z * 2;  
    if (c1) x = y - z;  
    z = 10;  
}  
z = x;
```

Exercise 1: Convert to CFG

```
while (c2) {  
  x = y - 1;  
  y = z * 2;  
  if (c1) x = y - z;  
  z = 10;  
}  
z = x;
```



Exercise 2: Convert to CFG

```
int i = n;
while (i > 1) {
    println(i);
    if (i % 2 == 0) {
        i = i / 2;
    } else {
        i = 3*i + 1;
    }
}
```

Control Flow Graph Construction

$$\begin{aligned} [s_1; s_2] v_{source} v_{target} = \\ [s_1] v_{source} v_{fresh} \\ [s_2] v_{fresh} v_{target} \end{aligned}$$

$$\mathbf{insert}(v_s, \text{stmt}, v_t) = \mathit{cfg} + (v_s, \text{stmt}, v_t)$$

$$[x = y + z] v_s v_t = \mathbf{insert}(v_s, x = y + z, v_t)$$

where y, y are constants or variables

$$[\text{branch}(x < y)] v_{source} v_{true} v_{false} =$$

$$\mathbf{insert}(v_{source}, [x < y], v_{true});$$

$$\mathbf{insert}(v_{source}, [!(x < y)], v_{false})$$