Adventures in

Dataflow Analysis

CSE 401 Section 9-ish

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Announcements

- Code Generation due 

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- Compiler Additions due next Thursday, 12/6
  - Involves revisiting all parts of the compiler

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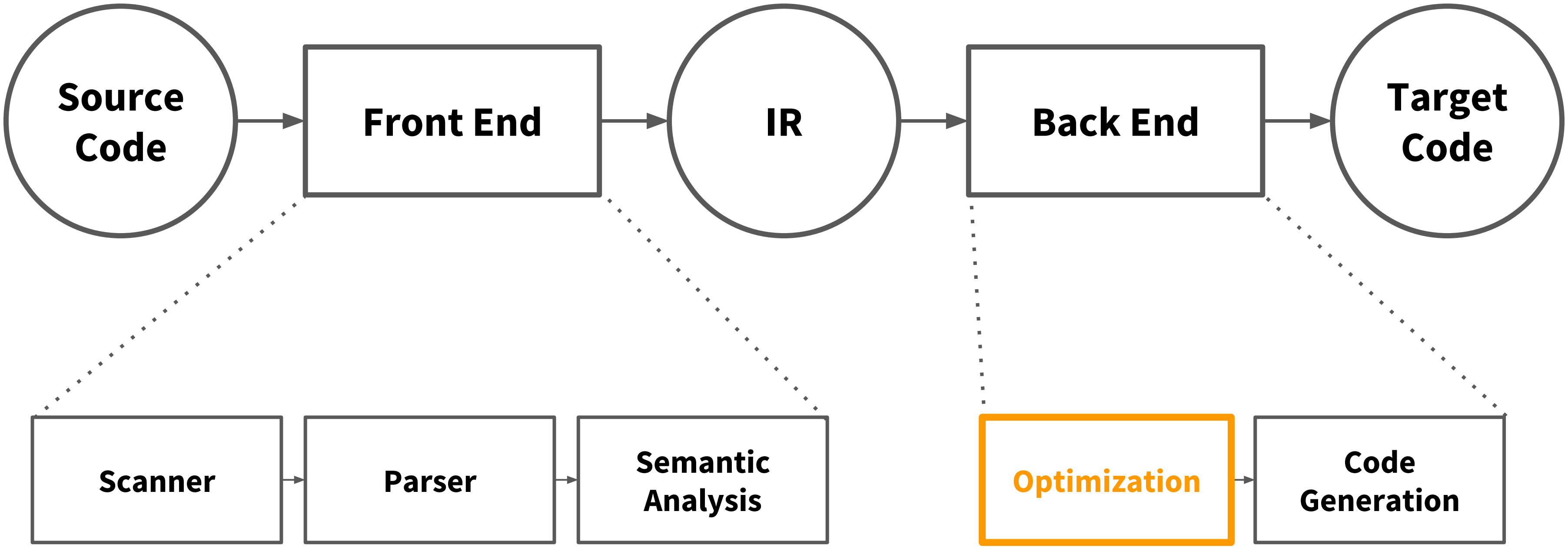
  - Involves revisiting all parts of the compiler

- Final Report due the following Saturday, 12/8
  - Ideally, also involves revisiting all parts of the compiler

Review of Optimizations



Review of Optimizations

Peephole

Local

Intraprocedural / Global

Interprocedural

Review of Optimizations

Peephole	A few Instructions
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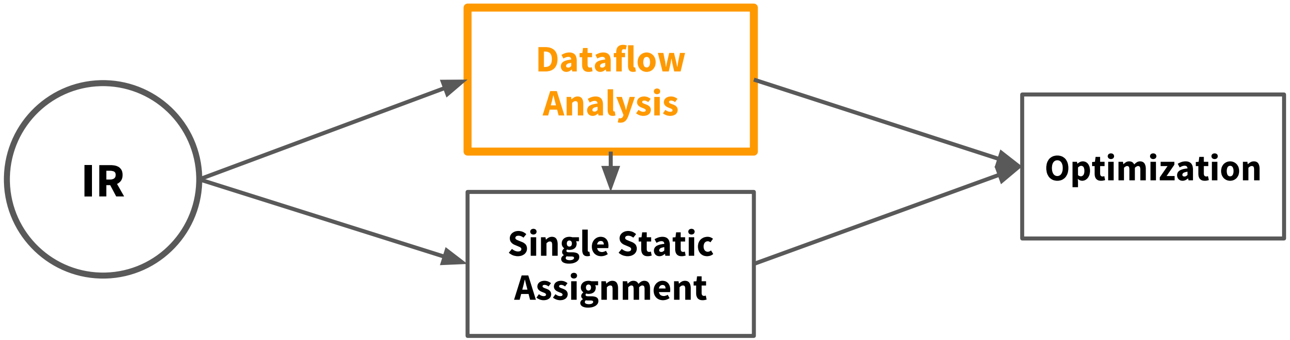
Interprocedural	A Program

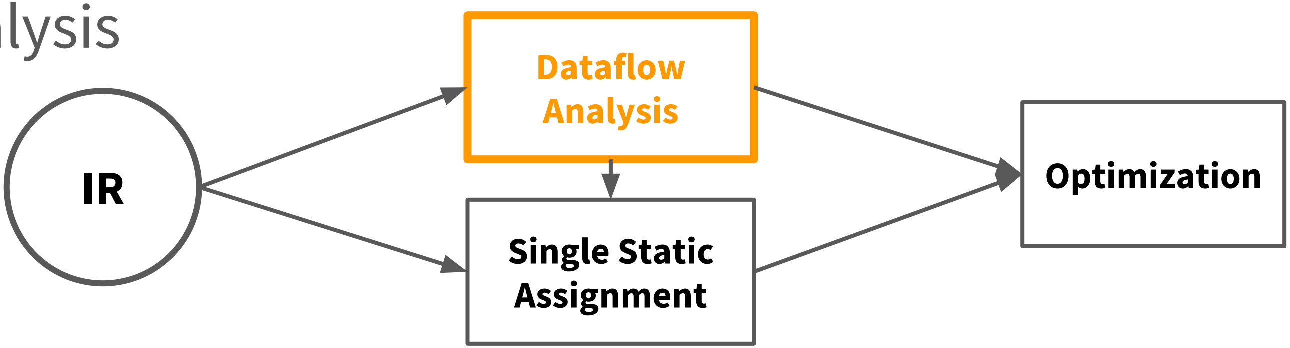
Overview of Dataflow Analysis

- A framework for exposing properties about programs
- Operates using sets of “facts”



Overview of Dataflow Analysis

- A framework for exposing properties about programs
- Operates using sets of “facts”
- Just the initial discovery phase
    - Changes can then be made to optimize based on the analysis



Overview of Dataflow Analysis

- Basic Framework of Set Definitions (for a Basic Block *b*):
  - `IN(`*b*`)`: facts true on entry to *b*
  - `OUT(`*b*`)`: facts true on exit from *b*
  - `GEN(`*b*`)`: facts created (and not killed) in *b*
  - `KILL(`*b*`)`: facts killed in *b*

Reaching Definitions (*A Dataflow Problem*)

"What definitions of each variable might reach this point"

- Could be used for:
  - Constant Propagation
  - Uninitialized Variables

```
int x;

if (y > 0) {
  x = y;
} else {
  x = 0;
}

System.out.println(x);
```

"x=y", "x=0"

Reaching Definitions (*A Dataflow Problem*)

"What definitions of each variable might reach this point"

- **Be careful**: Does not involve the *value* of the definition
  - The dataflow problem "Available Expressions" is designed for that

```
int x;

if (y > 0) {
  x = y;
} else {
  x = 0;
}

y = -1;
System.out.println(x);
```

still: "x=y", "x=0"

1 (a) & (b)

Equations for Reaching Definitions

- $\texttt{IN}(b)$: the definitions reaching upon entering block b
- $\texttt{OUT}(b)$: the definitions reaching upon exiting block b
- $\texttt{GEN}(b)$: the definitions assigned and not killed in block b
- $\texttt{KILL}(b)$: the definitions of variables overwritten in block b

$$\texttt{IN}(b) = \bigcup_{p \in \texttt{pred}(b)} \texttt{OUT}(p)$$

$$\texttt{OUT}(b) = \texttt{GEN}(b) \cup (\texttt{IN}(b) - \texttt{KILL}(b))$$

Another *Equivalent* Set of Equations (from Lecture):

- Sets:
  - `DEFOUT(b)`: set of definitions in b that reach the end of b (i.e., not subsequently redefined in b)
  - `SURVIVED(b)`: set of all definitions not obscured by a definition in b
  - `REACHES(b)`: set of definitions that reach b
- Equations:
  - $$\text{REACHES}(b) = \bigcup_{p \in \text{preds}(b)} \text{DEFOUT}(p) \cup (\text{REACHES}(p) \cap \text{SURVIVED}(p))$$

1 (c) & (d)

```
L0:  a = 0
L1:  b = a + 1
L2:  c = c + b
L3:  a = b * 2
L4:  if a < N goto L1
L5:  return c
```

Block	GEN	KILL	IN (1)	OUT (1)	IN (2)	OUT (2)
L0	L0					
L1	L1					
L2	L2					
L3	L3					
L4						
L5						

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Block	GEN	KILL	IN (1)	OUT (1)	IN (2)	OUT (2)
L0	L0	L3				
L1	L1					
L2	L2					
L3	L3	L0				
L4						
L5						

```
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```

Block	GEN	KILL	IN (1)	OUT (1)	IN (2)	OUT (2)
L0	L0	L3				
L1	L1		L0			
L2	L2		L0, L1			
L3	L3	L0	L0, L1, L2			
L4			L1, L2, L3			
L5			L1, L2, L3			

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L0:  a = 0
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Block	GEN	KILL	IN (1)	OUT (1)	IN (2)	OUT (2)
L0	L0	L3		L0		
L1	L1		L0	L0, L1		
L2	L2		L0, L1	L0, L1, L2		
L3	L3	L0	L0, L1, L2	L1, L2, L3		
L4			L1, L2, L3	L1, L2, L3		
L5			L1, L2, L3	L1, L2, L3		

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```

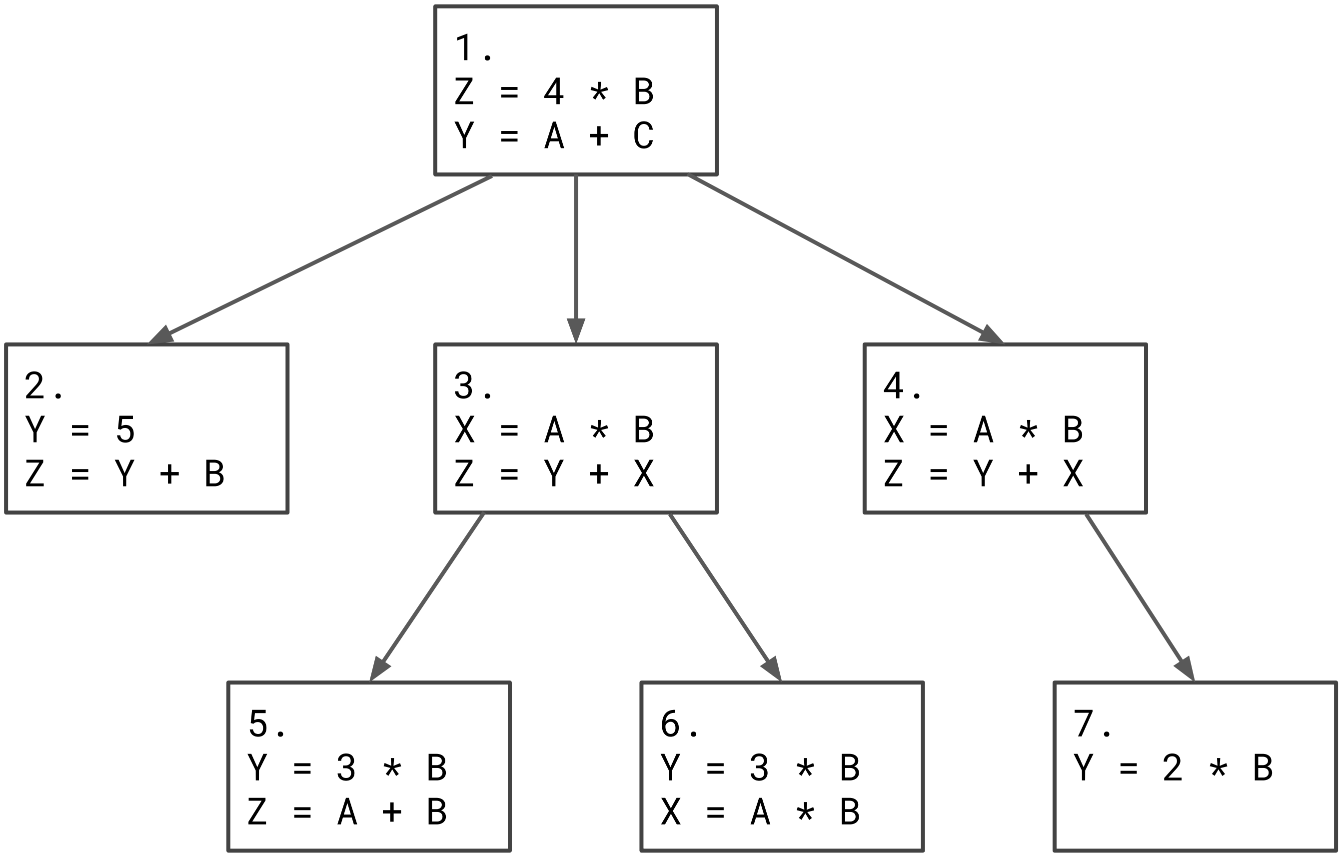
Block	**GEN**	**KILL**	**IN (1)**	**OUT (1)**	**IN (2)**	**OUT (2)**
L0	L0	L3		L0		L0
L1	L1		L0	L0, L1	L0, L1, L2, L3	L0, L1, L2, L3
L2	L2		L0, L1	L0, L1, L2	L0, L1, L2, L3	L0, L1, L2, L3
L3	L3	L0	L0, L1, L2	L1, L2, L3	L0, L1, L2, L3	L1, L2, L3
L4			L1, L2, L3	L1, L2, L3	L1, L2, L3	L1, L2, L3
L5			L1, L2, L3	L1, L2, L3	L1, L2, L3	L1, L2, L3

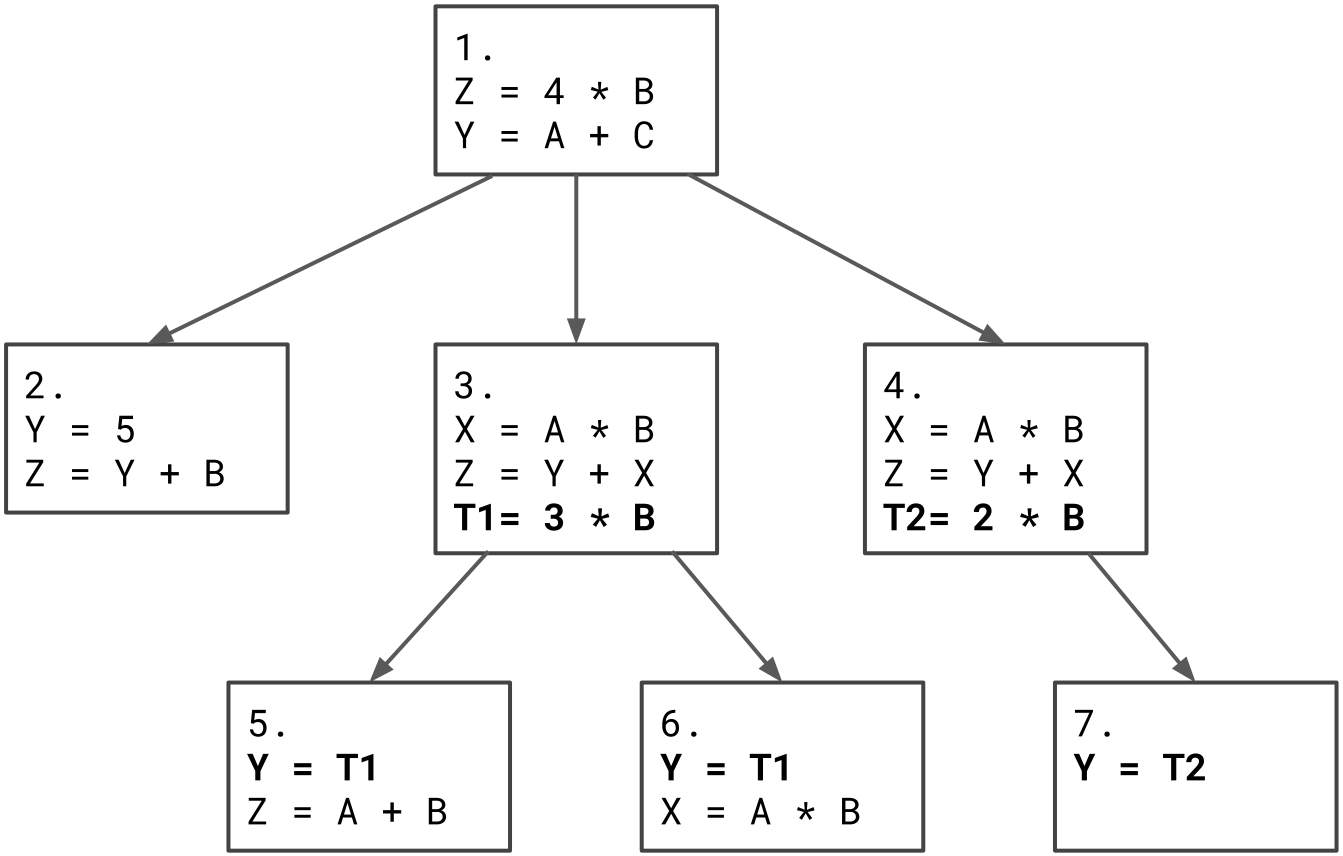
```
L0:  a = 0
L1:  b = a + 1
L2:  c = c + b
L3:  a = b * 2
L4:  if a < N goto L1
L5:  return c
```

Convergence!

Block	GEN	KILL	IN (1)	OUT (1)	IN (2)	OUT (2)
L0	L0	L3		L0		L0
L1	L1		L0	L0, L1	L0, L1, L2, L3	L0, L1, L2, L3
L2	L2		L0, L1	L0, L1, L2	L0, L1, L2, L3	L0, L1, L2, L3
L3	L3	L0	L0, L1, L2	L1, L2, L3	L0, L1, L2, L3	L1, L2, L3
L4			L1, L2, L3	L1, L2, L3	L1, L2, L3	L1, L2, L3
L5			L1, L2, L3	L1, L2, L3	L1, L2, L3	L1, L2, L3

2 (a) & (b)


1.
Z = 4 * B
Y = A + C
2.
Y = 5
Z = Y + B
3.
X = A * B
Z = Y + X
4.
X = A * B
Z = Y + X
5.
Y = 3 * B
Z = A + B
6.
Y = 3 * B
X = A * B
7.
Y = 2 * B


1.
Z = 4 * B
Y = A + C
2.
Y = 5
Z = Y + B
3.
X = A * B
Z = Y + X
T1= 3 * B
4.
X = A * B
Z = Y + X
T2= 2 * B
5.
Y = T1
Z = A + B
6.
Y = T1
X = A * B
7.
Y = T2