

CS406: Compilers

Spring 2021

Week 7: 3 Address Codes, IR code for expressions, if-statement

3 Address Code (3AC)

- **What is it?** sequence of elementary program instructions

- Linear in structure (no hierarchy) unlike AST

- Format:

`op A, B, C` //means $C = A \text{ op } B$.

//op: ADDI, MULI, SUBF, DIVF, GOTO, STOREF etc.

- E.g.

program text

3-address code

<pre>INT x; FLOAT y, z; z:=x+y;</pre>	<pre>ADDF x y T1 STOREF T1 z</pre>
---	--

```
INT a, b, c, d;  
d = a-b/c;
```

```
DIVI b c T1  
SUBI a T1 T2  
STOREI T2 d
```

Comments:

$d = a - b/c$; is broken into:
 $t1 = b/c$;
 $t2 = a - t1$;
 $d = t2$;

3 Address Code (3AC)

- **Why is it needed?** To perform *significant* optimizations such as:
 - common sub-expression elimination
 - statically analyze possible values that a variable can take etc.

How?

Break the long sequence of instructions into “basic blocks” and operate on/analyze a graph of basic blocks

3 Address Code (3AC)

- **How is it generated?** Choices available:

1. Do a post-order walk of AST

- Generate/Emit code as a string/data_object when you visit a node
- Pass the code to the parent node

Parent generates code for self after the code for children is generated. The generated code is appended to code passed by children and passed up the tree

```
data_object generate_code() {  
    //preprocessing code  
    data_object lcode=left.generate_code();  
    data_object rcode=right.generate_code();  
    return generate_self(lcode, rcode);  
}
```

2. Can generate directly in semantic routines or after building AST

3 Address Code (3AC)

- Generating 3AC directly in semantic routines.



```
INT x;  
x:=3*4+5+6+7;
```

```
MULI 3 4 T1  
ADDI T1 5 T2  
ADDI T2 6 T3  
ADDI T3 7 T4  
STOREI T4 x
```

Comments:

$x = 3*4+5+6+7$ is broken into:

$t1 = 3*4;$

$t2 = 5+t1;$

$t3 = 6+t2;$

$t4 = 7+t3;$

$x = t4$

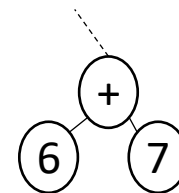
- Walk the AST in post-order and infer at an internal node (labelled op) that it computes a constant expression



```
INT x;  
x:=3*4+5+6+7;
```

```
STOREI 30 x
```

Comments:



L-values and R-values

- Need to distinguish between meaning of identifiers appearing on RHS and LHS of an assignment statement

```
i := 5;      } //RHS specifies data that is computed/read.  
i := i + 1; } LHS specifies address where data is stored.
```

- **L-values**: addresses which can be loaded from or stored into
- **R-values**: data often loaded from address
 - Expressions produce R-values
- Assignment statements: **L-value := R-value;**

→ a := a;
a refers to memory location named a. We are storing into that memory location (L-value)

a := a;
← a refers to data stored in the memory location named a. We are loading from that memory location to produce R-value

Temporaries

- Earlier saw the use of temporaries e.g.

```
INT x;          ADDF x y T1
FLOAT y, z;    STOREF T1 z
z:=x+y;
```

- Think of them as unlimited pool of registers with memory to be allocated later
- Optionally declare them in 3AC. Name should be unique and should not appear in program text

```
INT x
FLOAT y z T1
ADDF x y T1
STOREF T1 z
```

- Temporary can hold L-value or R-value

Temporaries and L-value

- Yes, a temporary can hold L-value. Consider:

```
a := &b; //& is address-of operator. R-value  
of a is set to L-value of b.  
//expression on the RHS produces data that is  
an address of a memory location.
```

Recall: L-Value = address which can be loaded from or stored into, R-Value = data (often) loaded from addresses.

*Take L-value of b, **don't load from it**, treat it as an R-value and store the resulting data in a temporary*

Dereference operator

- Consider:

```
*a := b; // * is dereference operator. R-value  
of a is set to R-value of b.  
// expression on the LHS produces address data  
that is an address of a memory location.
```

a appearing on LHS is loaded from to produce R-value. That R-value is treated as an address that can be stored into.

Take R-value of a, treat it as an L-value (address of a memory location) and then store RHS data

*Summary: pointer operations & and * mess with meaning of L-value and R-values*

Observations

- Identifiers appearing on LHS are (normally) treated as L-values. Appearing on RHS are treated as R-values.
 - So, when you are visiting an `id` node in an AST, you cannot generate code (load-from or store-into) until you have seen how that identifier is used. => until you visit the parent.
- Temporaries are needed to store result of current expression
- a `data_object` should store:
 - Code
 - L-value or R-Value or constant
 - Temporary storing the result of the expression

Simple cases

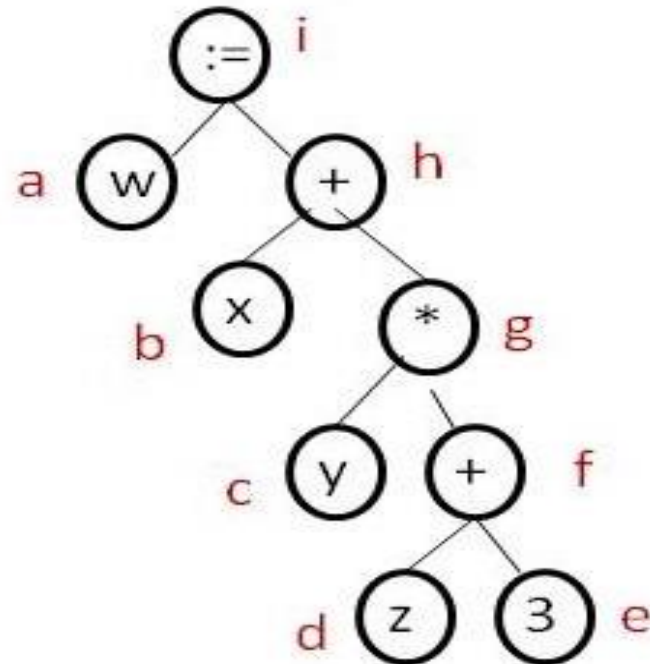
- Generating code for constants/literals
 - Store constant in temporary
 - Optional: pass up flag specifying this is a constant
- Generating code for identifiers
 - Generated code depends on whether identifier is used as L-value or R-value
 - Is this an address? Or data?
 - One solution: just pass identifier up to next level
 - Mark it as an L-value (it's not yet data!)
 - Generate code once we see how variable is used

Generating code for expressions

- Create a new temporary for result of expression
- Examine data-objects from subtrees
- If temporaries are L-values, load data from them into new temporaries
 - Generate code to perform operation
 - In project, no need to explicitly load (variables can be operands)
- If temporaries are constant, can perform operation immediately
 - No need to perform code generation!
- Store result in new temporary
 - Is this an L-value or an R-value?
- Return code for entire expression

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node a:

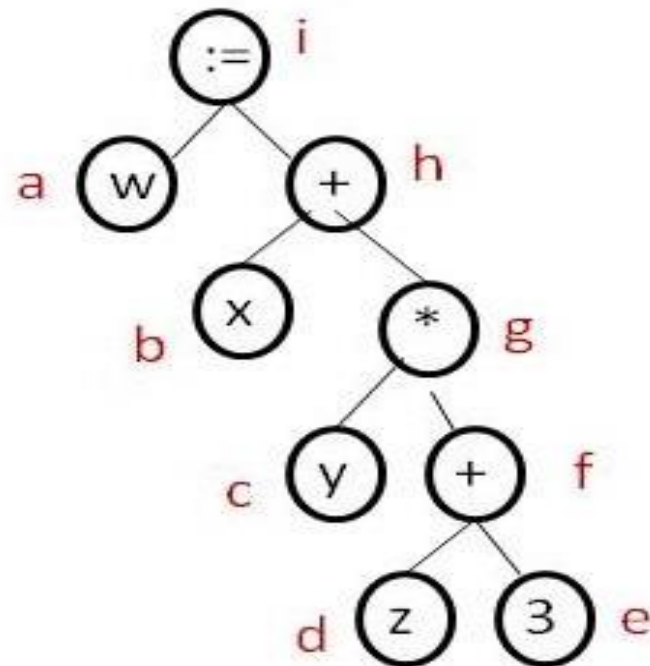
Temp: w

Type: l-value

Code: --

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node b:

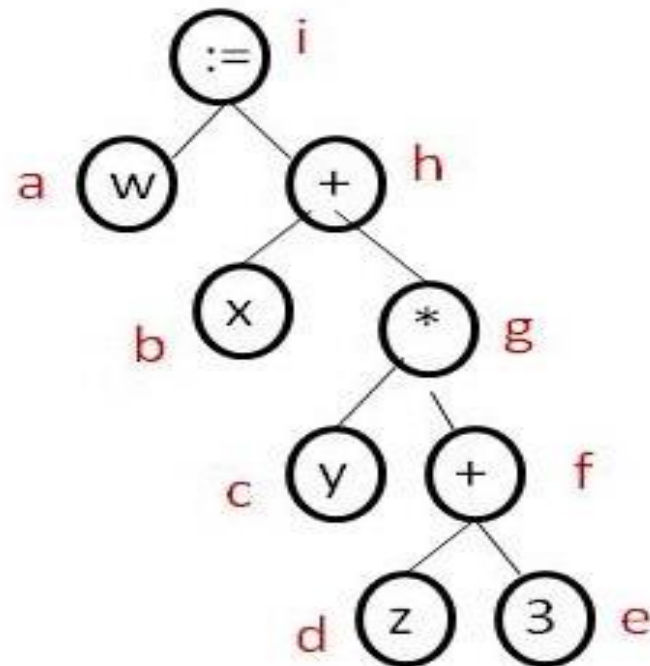
Temp: x

Type: l-value

Code: --

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node c:

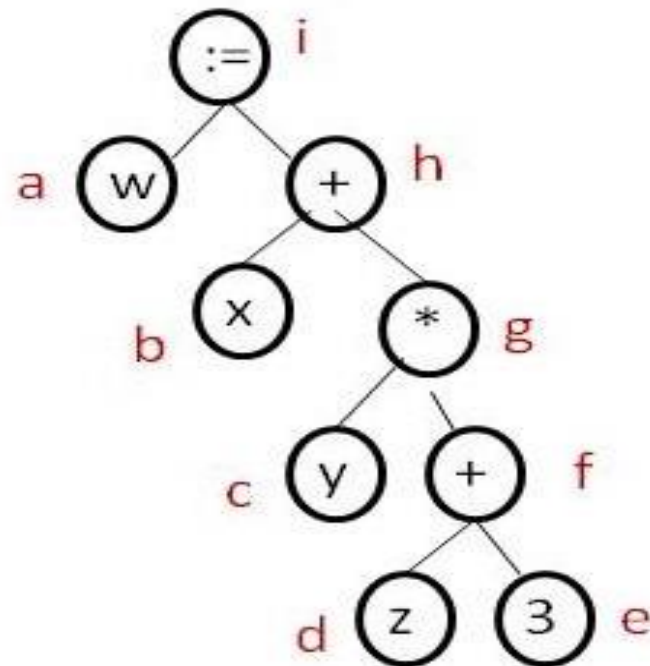
Temp: y

Type: l-value

Code: --

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node d:

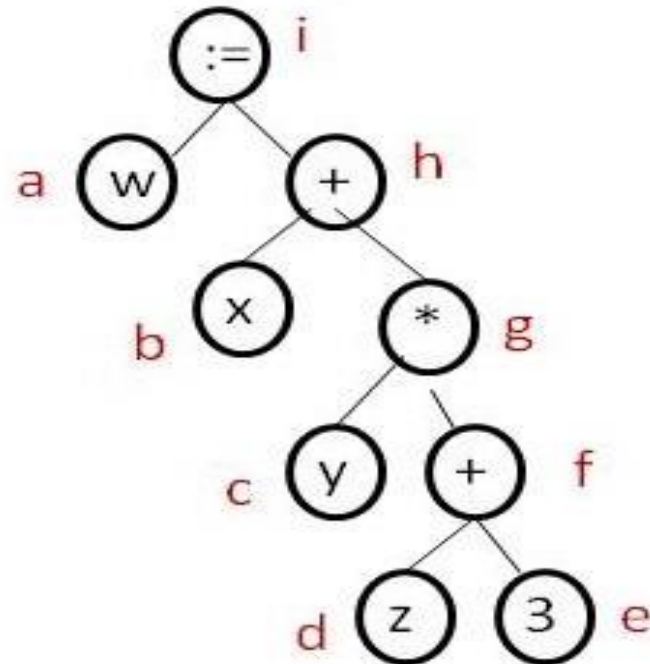
Temp: z

Type: l-value

Code: --

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node e:

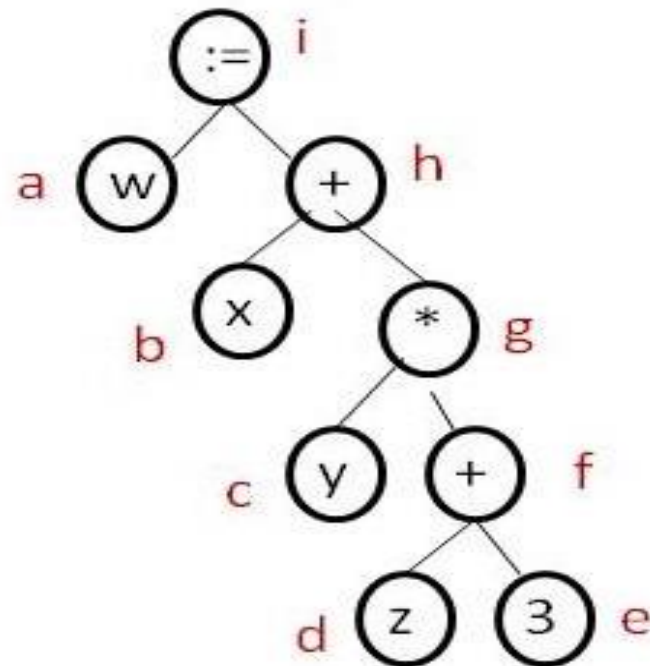
Temp: 3

Type: constant

Code: --

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node f:

Temp: T1

Type: R-value

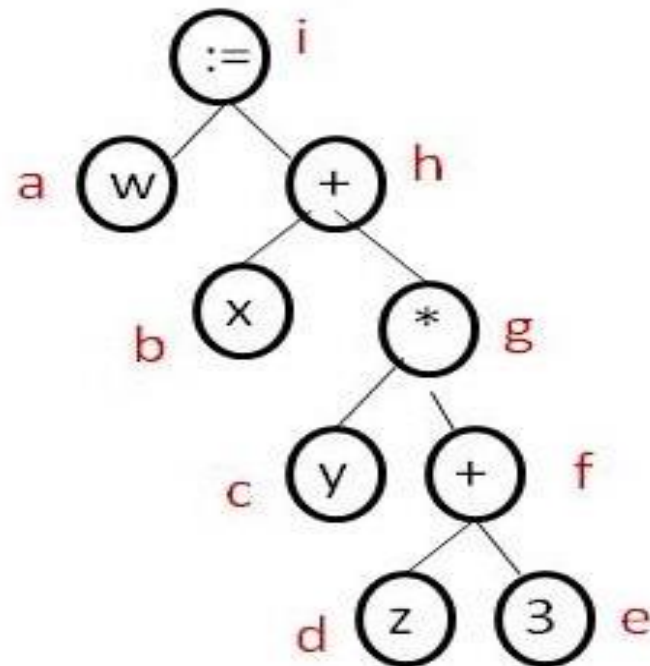
Code:

LD z T2

ADD T2 3 T1

Example - assignment statement

AST for $w := x + y * (z + 3);$ \Rightarrow



Visit Node g :

Temp: T3

Type: R-value

Code:

LD y T4

LD z T2

ADD T2 3 T1

MUL T4 T1 T3

Example - assignment statement

AST for $w := x + y * (z + 3);$

Visit Node h:

Temp: T5

Type: R-value

Code:

LD x T6

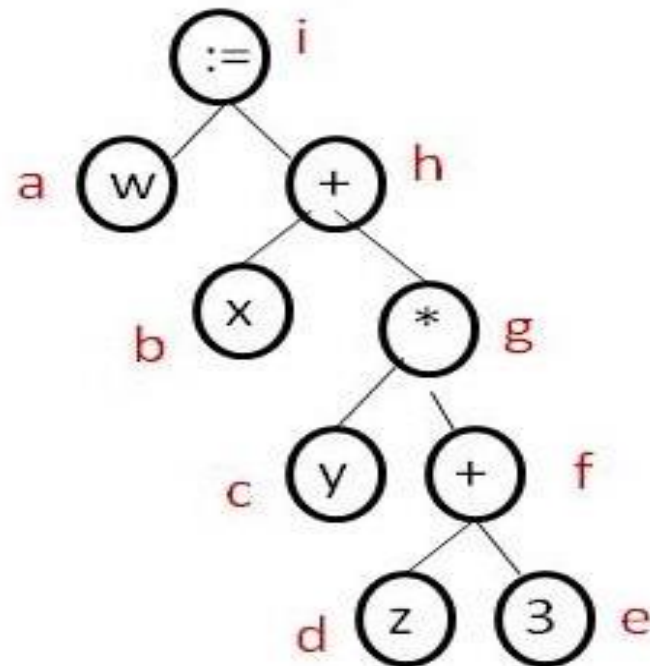
LD y T4

LD z T2

ADD T2 3 T1

MUL T4 T1 T3

ADD T6 T4 T5



Example - assignment statement

AST for $w := x + y * (z + 3);$

Visit Node i:

Temp: NA

Type: NA

Code:

LD x T6

LD y T4

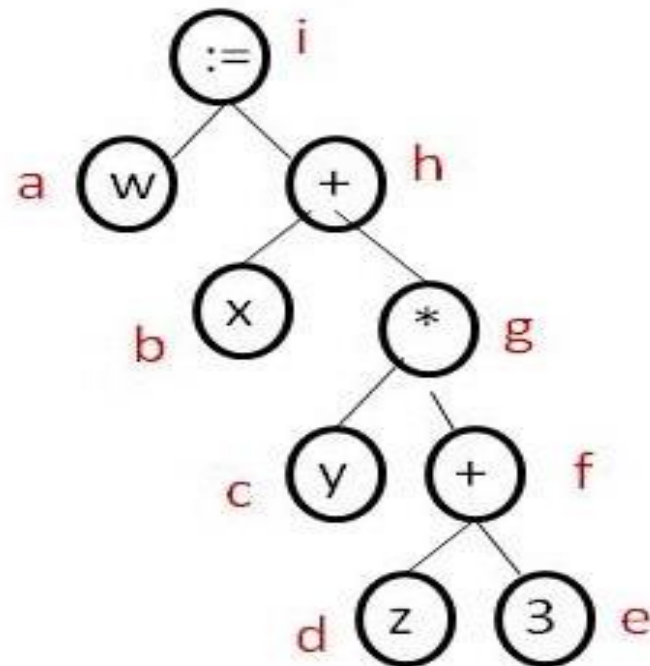
LD z T2

ADD T2 3 T1

MUL T4 T1 T3

ADD T6 T4 T5

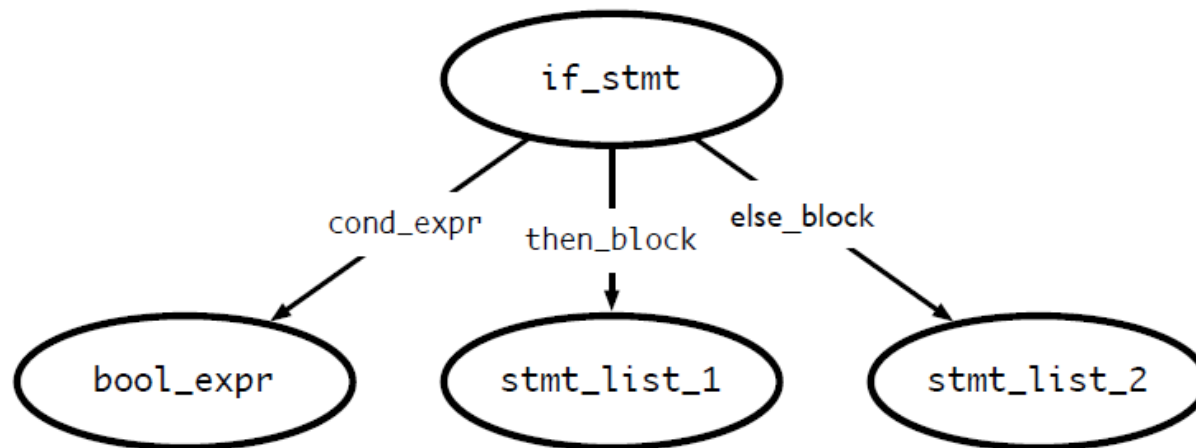
ST T5 w



If statements

```
if <bool_expr_1>  
    <stmt_list_1>  
else  
    <stmt_list_2>  
endif
```

If statements



Generating code for ifs

```
if <bool_expr_1>  
  <stmt_list_1>  
else  
  <stmt_list_2>  
endif
```

```
<code for bool_expr_1>  
j<!op> ELSE_1  
<code for stmt_list_1>  
jmp OUT_1  
ELSE_1:  
  <code for stmt_list_2>  
OUT_1:
```


Notes on code generation

- The `<op>` in `j<!op>` is dependent on the type of comparison you are doing in `<bool_expr>`
- When you generate JUMP instructions, you should also generate the appropriate LABELS
- Remember: labels have to be unique!

Code-generation – if-statement

Program text	3AC
INT a, b;	STOREI 2 T1 //a := 2
a := 2;	STOREI T1 a
IF (a = 1)	STOREI 1 T2 //a = 1?
b := 1;	NE a T2 label1
ELSIF (TRUE)	STOREI 1 T3 //b := 1
b := 2;	STOREI T3 b
ENDIF	JUMP label2 //to out label
	LABEL label1 //elsif label
	STOREI 1 T4 //TRUE can be handled by checking 1 = 1?
	STOREI 1 T5
	NE T4 T5 label3 //jump to the next elsif label
	STOREI 2 T6 //b := 2
	STOREI T6 b
	JUMP label2 //jump to out label
	LABEL label2 //out label

Suggested Reading

- Alfred V. Aho, Monica S. Lam, Ravi Sethi and Jeffrey D. Ullman: Compilers: Principles, Techniques, and Tools, 2/E, AddisonWesley 2007
 - Chapter 2 (2.8), Chapter 6(6.2, 6.3, 6.4)
- Fisher and LeBlanc: Crafting a Compiler with C
 - Chapter 7 (7.1, 7.3), Chapter 11 (11.2)