Compiler Design

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Intermediate-Code Generation

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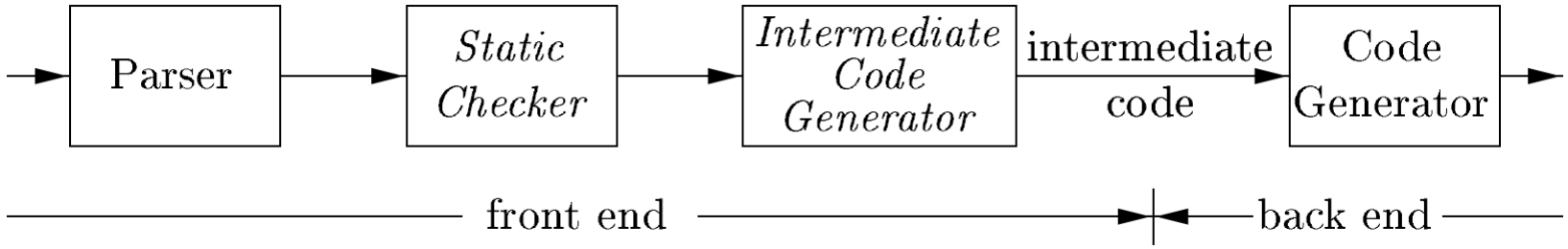
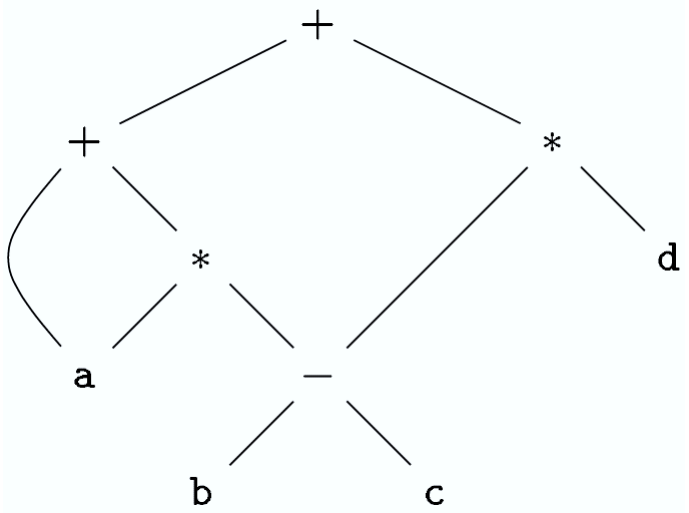
- $m * n$ compilers can be built by writing just m front ends and n back ends



- An intermediate representation may either be an actual language
- C is a programming language, yet it is often used as an intermediate form because **it is flexible**, **it compiles into efficient machine code**, and **its compilers are widely available**
  - The original C++ compiler consisted of a front end that generated C, treating a C compiler as a back end

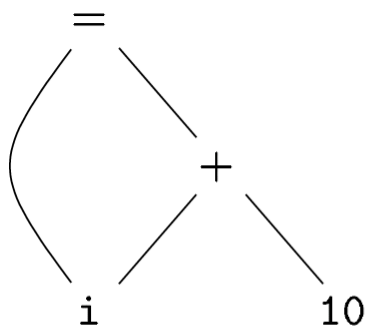
Directed Acyclic Graph

- A directed acyclic graph (DAG) for an expression identifies the **common subexpressions** of the expression
- DAGs can be constructed by using the same techniques that construct syntax trees
  - **A DAG has leaves corresponding to atomic operands and interior nodes corresponding to operators**
  - **A node N in a DAG has more than one parent if N represents a common subexpression**
- **Example**
  - $a + a * (b - c) + (b - c) * d$

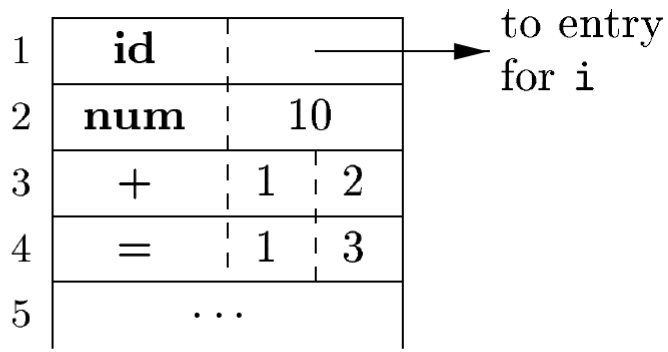


The Value-Number Method for Constructing DAGs

- Often, the nodes of a syntax tree or DAG are stored in an array of records



(a) DAG



(b) Array.

- In this array, we refer to nodes by giving the **integer index of the record for that node within the array**, which called the **value number** for the node or for the expression represented by the node

The Value-Number Method for Constructing DAGs

Algorithm 6.3: The value-number method for constructing the nodes of a DAG.

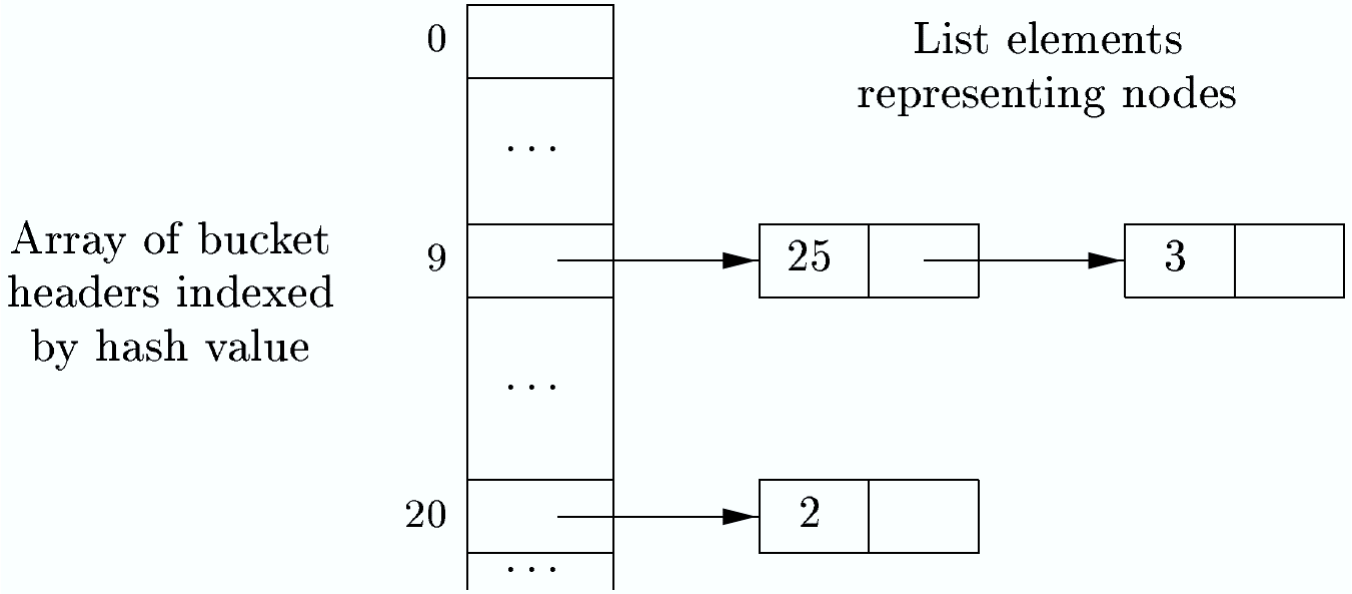
INPUT: Label op, node l, and node r.

OUTPUT: The value number of a node in the array with signature $\langle op, l, r \rangle$.

METHOD: Search the array for a node M with label op, left child l, and right child r. If there is such a node, return the value number of M. If not, create in the array a new node N with label op, left child l, and right child r, and return its value number. $\square$

The Value-Number Method for Constructing DAGs

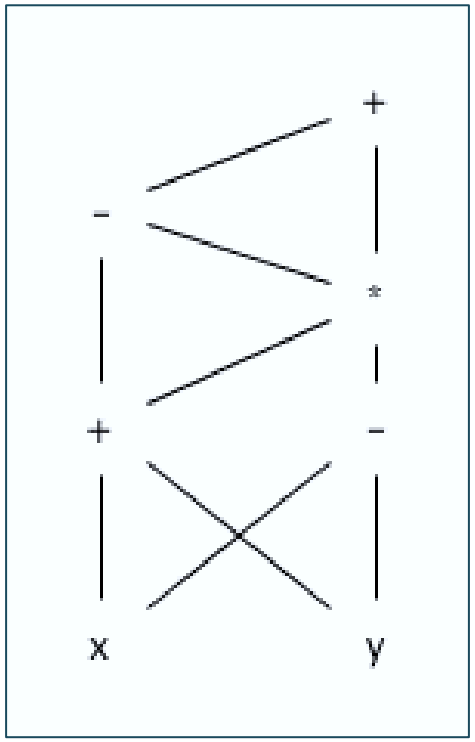
- **Searching the entire array every time we are asked to locate one node is expensive**
- A more efficient approach is to use a **hash table**, in which the nodes are put into buckets, each of which typically will have only a few node



Directed Acyclic Graph

Exercise 6.1.1 : Construct the DAG for the expression

$$((x + y) - ((x + y) * (x - y))) + ((x + y) * (x - y))$$



Directed Acyclic Graph

- **Example**

a+b+(a+b)

1	id	a	
2	id	b	
3	+	1	2
4	+	3	3

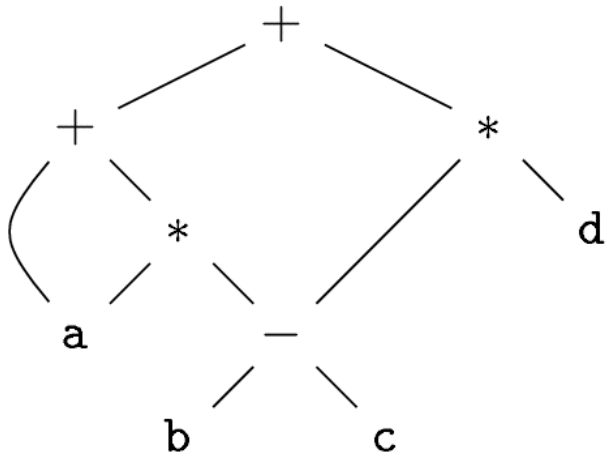
a+b+a+b

1	id	a	
2	id	b	
3	+	1	2
4	+	3	1
5	+	4	2

Three-Address Code

- In three-address code, there is at most one operator on the right side of an instruction
- **Example**
  - $x + y * z$

```
t1 = y * z
t2 = x + t1
```



```
t1 = b - c
t2 = a * t1
t3 = a + t2
t4 = t1 * d
t5 = t3 + t4
```

Three-Address Code

- Three-address code is built from two concepts: **addresses** and **instructions**
- **An address can be one of the following**
  - ***Name***
    - We allow source-program names to appear as addresses in three-address code
  - ***Constant***
    - A compiler must deal with many different types of constants and variables
  - ***Compiler-generated temporary***
    - It is useful, especially in optimizing compilers, to create a distinct name each time a temporary is needed

Three-Address Code

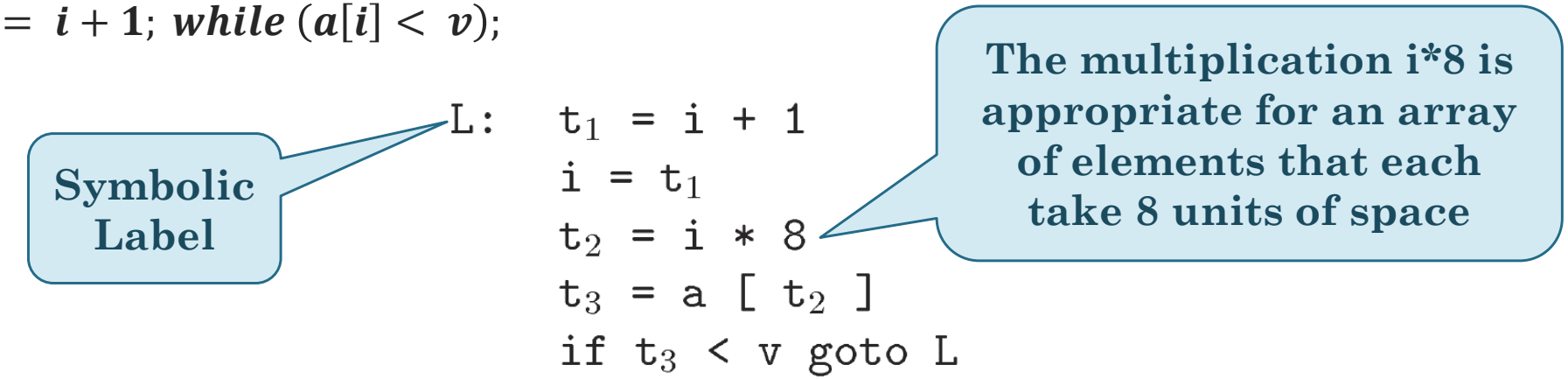
- **A list of the common three-address instruction forms**
  1. Assignment instructions of the form **x = y op z**
  2. Assignments of the form **x = op y**, where op is a unary operation
  3. Copy instructions of the form **x = y**
  4. An unconditional jump **goto L**
  5. Conditional jumps of the form **if x goto L** and **if False x goto L**
  6. Conditional jumps such as **if x relop y goto L**
  7. Procedure (Function) calls and returns

```
param x1
param x2
...
param xn
call p, n
```

  8. Indexed copy instructions of the form **x = y[i]** and **x[i]=y**
  9. Address and pointer assignments of the form **x = &y**, **x = *y**, and ***x = y**

Three-Address Code

- **Example**
  - ***do*** $i = i + 1$; ***while*** $(a[i] < v)$;



- **Three representations for three-address code are as follows**
  - Quadruples
  - Triples
  - Indirect triples

Three-Address Code

- **Quadruples**
  - A quadruple has four fields, which we call **op, arg1, arg2, and result**
  - **Some exceptions**
    - Instructions with unary operators like x = minus y or x = y do not use arg2
      - Note that for a copy statement like x = y, op is =, while for most other operations, the assignment operator is implied
    - Operators like param use neither arg2 nor result
    - Conditional and unconditional jumps put the target label in result
- **Example**
  - $a = b * -c + b * -c;$

```
t1 = minus c
t2 = b * t1
t3 = minus c
t4 = b * t3
t5 = t2 + t4
 a = t5
```

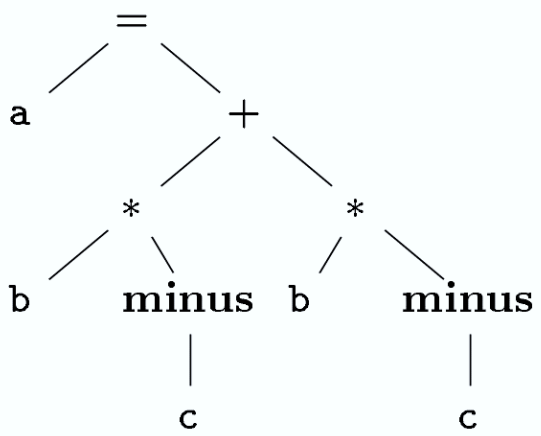
(a) Three-address code

	op	arg_1	arg_2	*result*
0	minus	c		t_1
1	*	b	t_1	t_2
2	minus	c		t_3
3	*	b	t_3	t_4
4	+	t_2	t_4	t_5
5	=	t_5		a
		...		

(b) Quadruples

Three-Address Code

- **Triples**
  - A triple has only three fields, which we call op, arg1, and arg2
  - We refer to the result of an operation x op y by its position, rather than by an explicit temporary name
- **Example**
  - $a = b * -c + b * -c;$



(a) Syntax tree

	op	arg_1	arg_2
0	minus	c	
1	*	b	(0)
2	minus	c	
3	*	b	(2)
4	+	(1)	(3)
5	=	a	(4)
	...		

(b) Triples

Three-Address Code

- **Indirect triples**
  - A benefit of quadruples over triples can be seen in an optimizing compiler, where instructions are often moved around
    - With triples, moving an instruction may require us to change all references to that result
  - **Indirect triples** consist of a listing of pointers to triples, rather than a listing of triples themselves
    - With indirect triples, an optimizing compiler can move an instruction by reordering the instruction list
- **Example**
  - $a = b * -c + b * -c;$

	instruction
35	(0)
36	(1)
37	(2)
38	(3)
39	(4)
40	(5)
	...

	op	arg_1	arg_2
0	minus	c	
1	*	b	(0)
2	minus	c	
3	*	b	(2)
4	+	(1)	(3)
5	=	a	(4)
	...		

Three-Address Code

- **Example**
  - $a + -(b + c)$
  - **Quadruple**

	on	arg1	arg2	result
0	+	b	c	t1
1	minus	t1		t2
2	+	a	t2	t3

  - **Triple**

	on	arg1	arg2
0	+	b	c
1	minus	(0)	
2	+	a	(1)

Indirect triples

	on	arg1	arg2
0	+	b	c
1	minus	(0)	
2	+	a	(1)

	instruction
0	(0)
1	(1)
2	(2)

Three-Address Code

- **Example**
  - $a = b[i] + c[j]$
  - **Quadruple**

```
0) =[]   b    i    t1
1) =[]   c    j    t2
2) +     t1   t2   t3
3) =     t3        a
```

  - **Triple**

```
0) =[]   b    i
1) =[]   c    j
2) +     (0)  (1)
3) =     a    (2)
```

Three-Address Code

- **Example**
  - $a[i] = b * c - b * d$
  - **Quadruple**

```
0) *    b    c    t1
1) *    b    d    t2
2) -    t1   t2   t3
3) []=  a    i    t4
4) =    t3        t4
```

  - **Triple**

```
0) *    b    c
1) *    b    d
2) -    (0)  (1)
3) []=  a    i
4) =    (3)  (2)
```

Three-Address Code

- **Example**
  - $x = f(y + 1) + 2$
  - **Quadruple**

```
0) +        y    1    t1
1) param    t1
2) call     f    1    t2
3) +        t2    2   t3
4) =        t3        x
```

  - **Triple**

```
0) +        y     1
1) param    (0)
2) call     f     1
3) +        (2)   2
4) =        x     (3)
```

Translation of Expressions

- **Goal**
  - Translation of expressions and statements into three-address code
- **Example**
  - Attributes ***S.code*** and ***E.code*** denote the three-address code for ***S*** and ***E***, respectively
  - Attribute ***E.addr*** denotes the address that will hold the value of ***E***
    - **Recall that an address can be a name, a constant, or a compiler-generated temporary**

PRODUCTION	SEMANTIC RULES
$S \rightarrow \textbf{id} = E\ ;$	$S.code = E.code \mid\mid gen(top.get(\textbf{id}.lexeme)\ '='\ E.addr)$
$E \rightarrow E_1 + E_2$	$E.addr = \textbf{new}\ Temp()$ $E.code = E_1.code \mid\mid E_2.code \mid\mid gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$
$\mid\ - E_1$	$E.addr = \textbf{new}\ Temp()$ $E.code = E_1.code \mid\mid gen(E.addr\ '='\ '\textbf{minus}'\ E_1.addr)$
$\mid\ (\ E_1\ )$	$E.addr = E_1.addr$ $E.code = E_1.code$
$\mid\ \textbf{id}$	$E.addr = top.get(\textbf{id}.lexeme)$ $E.code = ''$

Let *top* denote the current symbol table.