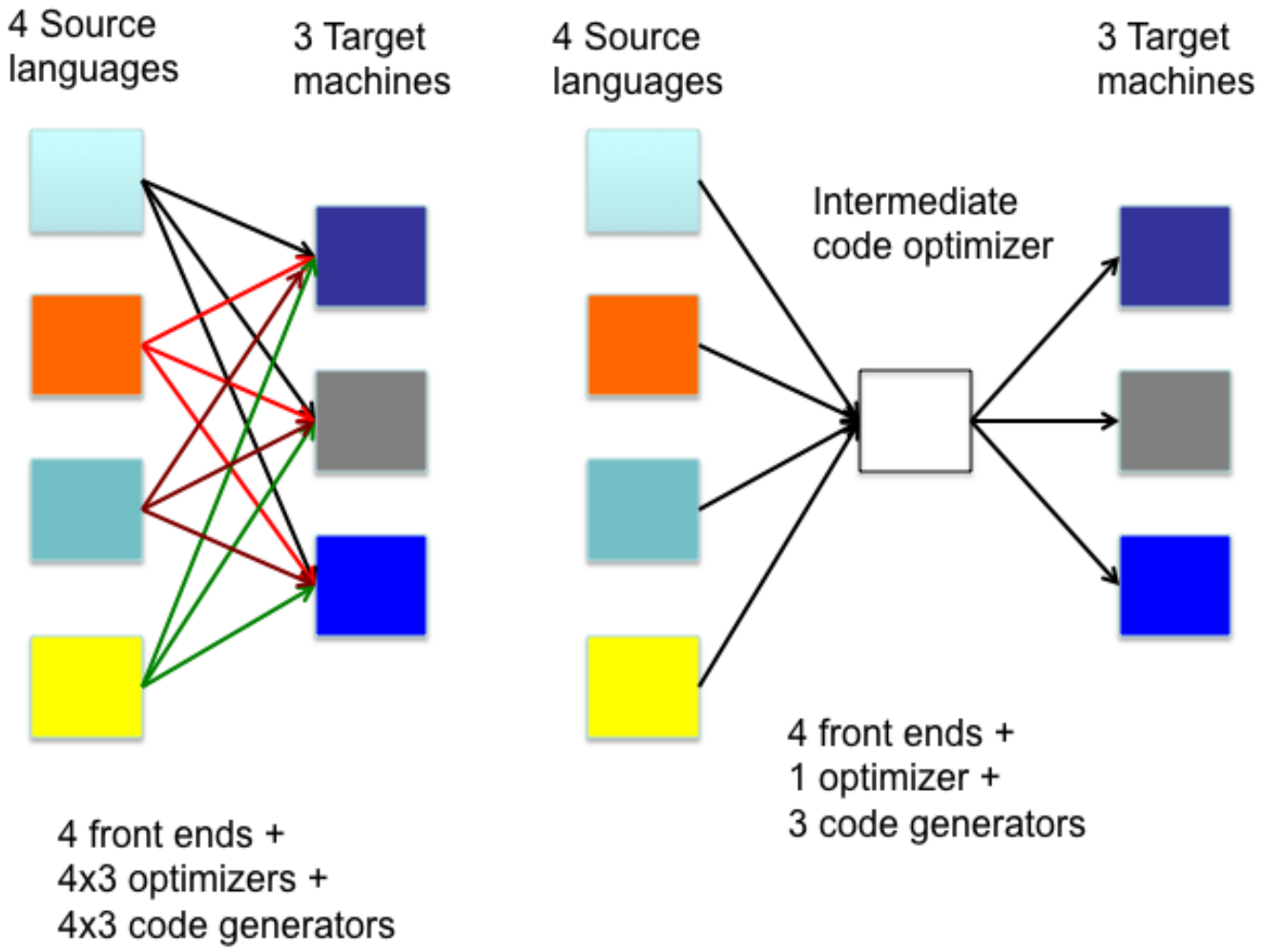
Intermediate Code Generation



Without Intermediate Code Optimizer

Why Intermediate Code?

Without intermediate code generator -

- For **m** languages and **n** target machines, we need to write **m** front-ends, **mxn** optimizers, and **mxn** code generators.
- Reuse is not possible.

With intermediate code generator -

- A machine independent code optimizer can be written
- **m** front ends, **n** code generators and 1 optimizer

Three Address Code

- Simple instructions
- LHS is the target and RHS has at most two operands and one operator
- RHS operands can be either variables or constants

Example:
a+b*c-d/(b*c)

3-address code

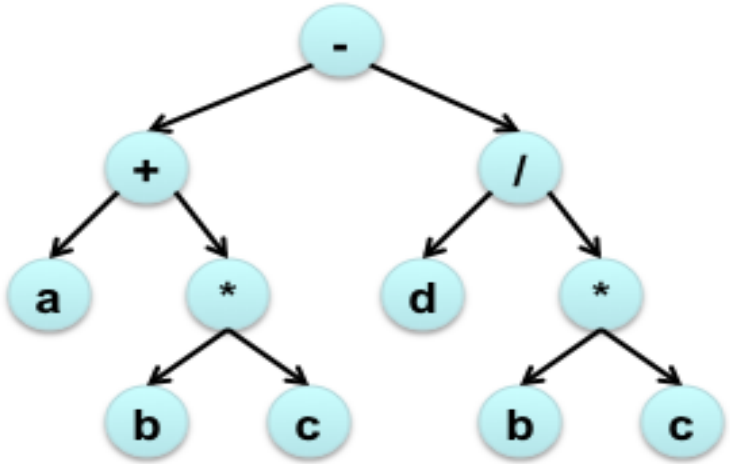
```
1  t1 = b*c
2  t2 = a+t1
3  t3 = b*c
4  t4 = d/t3
5  t5 = t2-t4
```

Quadruples

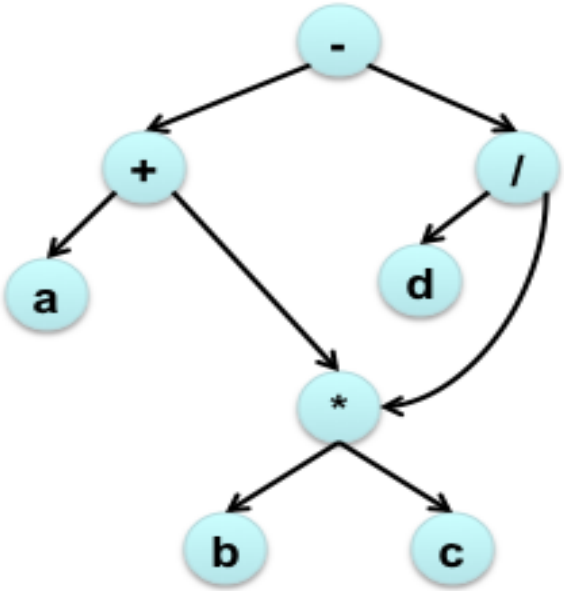
op	arg_1	arg_2	result
*	b	c	t1
+	a	t1	t2
*	b	c	t3
/	d	t3	t4
-	t2	t4	t5

Triples

	op	arg_1	arg_2
0	*	b	c
1	+	a	(0)
2	*	b	c
3	/	d	(2)
4	-	(1)	(3)



Syntax tree



DAG

Three Address Code

- Assignment instructions:

a = b biop c

a = uop b

  - biop is any binary arithmetic, logical, or relational operator
  - uop is any unary arithmetic (-, shift, conversion) or logical operator (~)

- Copy instruction:

a = b

- Jump instructions:

goto L

if t goto L

- L is the label of the next three-address instruction to be executed, t is a boolean variable, a and b are either variables or constants

Three Address Code

- **Functions:**

```
func begin <name>          //beginning of the function
func end                   //end of a function
param p                    //place a value parameter p on stack
refparam p                 //place a reference parameter p on stack
call f, n                  //call a function f with n parameters
return                     //return from a function
return a                   //return from a function with a value a
```

Three Address Code

- Indexed copy instructions:

a = b[i] //a is set to contents(contents(b)+contents(i))

a[i] = b //i th location of array a is set to b

- Pointer assignments:

a = &b //a is set to the address of b, i.e., a points to b

*a = b //contents(contents(a)) is set to contents(b)

a = *b //a is set to contents(contents(b))

Three Address Code

- C-Program

```
int a[10], b[10], dot_prod, i;
dot_prod = 0;
for (i=0; i<10; i++) dot_prod += a[i]*b[i];
```

```
        dot_prod = 0;
        i = 0;
L1:     T1 = i>10
        T2 =  i= =10
        T3 = T1 && T2
        if T3 goto L2
        T4 = addr(a)
        T5 = i*4
        T6 = T4[T5]
        T7 = addr(b)
        T8 = i*4
        T9 = T7[T8]
        T10 = T6*T9
        T11 = dot_prod+T10
        dot_prod = T11
        T12 = i+1
        i = T12
        goto L1
L2:
```

Single-Static-Assignment (SSA)

- Another intermediate representation
- Facilitates certain code optimizations
- All assignments are to variables with distinct names

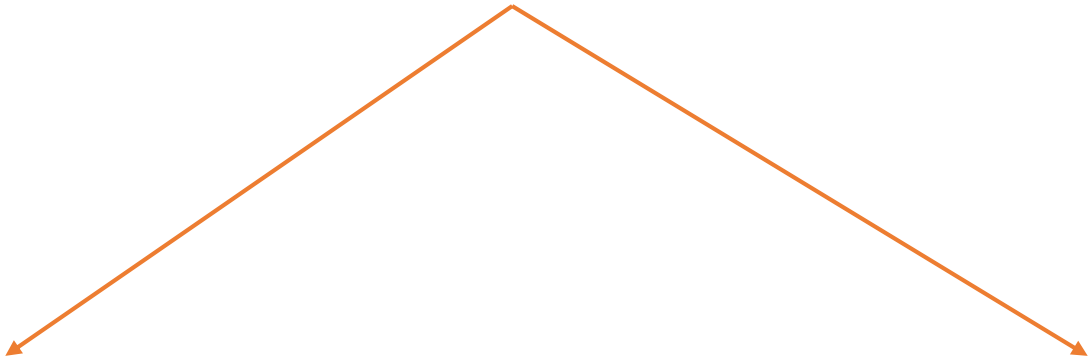
```
p = a + b
q = p - c
p = q * d
p = e - p
q = p + q
```

(a) Three-address code.

$$
\begin{aligned}
p_1 &= a + b \\
q_1 &= p_1 - c \\
p_2 &= q_1 * d \\
p_3 &= e - p_2 \\
q_2 &= p_3 + q_1
\end{aligned}
$$

(b) Static single-assignment form.

Translations of Statements and Expressions



- Syntax-Directed Definition (SDD)
- Syntax-Directed Translation (SDT)

Three Address Code for Expressions

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

Stores address of E
(e.g. temp variable etc.)

Stores three-address code
For E

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

Builds an instruction

Returns a temporary variable

Current Symbol Table

An example: a = b + c + (d)

Top of stack

Stack	*Production Rule*	*Semantic Rules*	*Action*	*'gen' Output*
id = id	*E -> id*	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$	*E.addr = b*	
id = E_1 + id	*E -> id*	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$	*E.addr = c*	
id = E_1 + E_2	*E -> E_1 + E_2*	$E.addr = \mathbf{new}\ Temp()$ $E.code = E_1.code \mid\mid E_2.code \mid\mid gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$	*E.addr = t1*	*t1 = b + c*
id = E + (id	*E -> id*	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$	*E.addr = d*	
id = E + (E_1)	*E -> (E_1)*	$E.addr = E_1.addr$ $E.code = E_1.code$	*E.addr = d*	*t1 = b + c*

An example: a = b + c + (d)

Top of stack

Stack	Production Rule	Semantic Rules	Action	'gen' Output
id = id	E -> id	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$	E.addr = b	
id = E_1 + id	E -> id	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$	E.addr = c	
id = E_1 + E_2	E -> E_1 + E_2	$E.addr = \mathbf{new}\ Temp()$ $E.code = E_1.code \mid\mid E_2.code \mid\mid gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$	E.addr = t1	t1 = b + c
id = E + (id	E -> id	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$	E.addr = d	
id = E + (E_1)	E -> (E_1)	$E.addr = E_1.addr$ $E.code = E_1.code$	E.addr = d	t1 = b + c

b

c

t1

t1 d

An example: a = b + c + (d)

Top of stack

Stack	*Production Rule*	*Semantic Rules*	*Action*	*'gen' Output*
id = E_1 + E_2	*E -> E_1 + E_2*	$E.addr = \text{new } Temp()$ $E.code = E_1.code \mid\mid E_2.code \mid\mid gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$	*E.addr = t2*	*t2 = t1 + d*
id = E	*S -> id = E*	$S.code = E.code \mid\mid gen(top.get(\text{id}.lexeme)\ '='\ E.addr)$	*top.get returns a*	*a = t2*

Final Code

t1 = b + c
t2 = t1 + d
a = t2

Incremental Translation

$$
\begin{array}{lll}
S \rightarrow \mathbf{id} = E\ ; & \{\ gen(\ top.get(\mathbf{id}.lexeme)\ '='\ E.addr);\ \} \\
E \rightarrow E_1 + E_2 & \{\ E.addr = \mathbf{new}\ Temp\,();\ gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr);\ \} \\
\mid\ -\ E_1 & \{\ E.addr = \mathbf{new}\ Temp\,();\ gen(E.addr\ '='\ '\mathbf{minus}'\ E_1.addr);\ \} \\
\mid\ (\ E_1\ ) & \{\ E.addr = E_1.addr;\ \} \\
\mid\ \mathbf{id} & \{\ E.addr = top.get(\mathbf{id}.lexeme);\ \}
\end{array}
$$

gen() does two things:

1. generate three address instruction
2. append it to the sequence of instructions generated so far

Three Address Code Generation

- Problems:

1. Change the semantic rules to generate three-address codes for arithmetic expressions (binary operators + and -) involving one-dimensional array variables on the right hand side.
   - Note that no array element will appear on the left hand side of an expression.
   - All variables used are integers of 4 byte length.

Write a program in any of your preferred language to generate the three-address code.