COMPILER DESIGN

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INTERMEDIATE CODE GENERATION

- The front-end of the compiler translates a source program into an intermediate representation from which the back end generates target code.

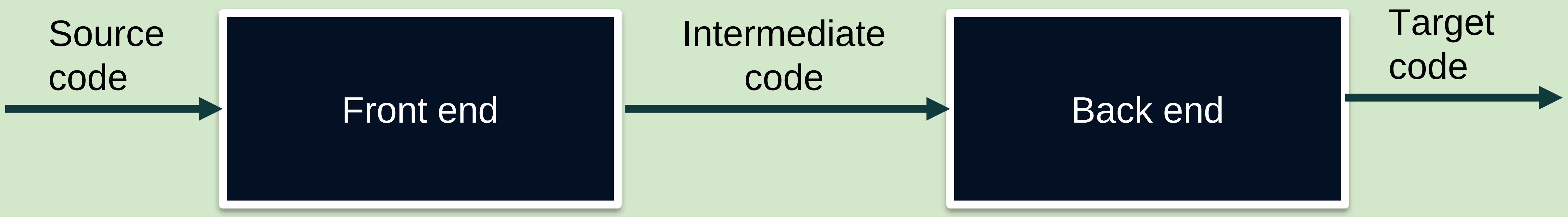
INTERMEDIATE CODE GENERATION

Need for ICC

1. If a compiler translates the source language to its target machine language without generating IC, then for each new machine, a full native compiler is required.
2. Synthesis part of back end depends on the target machine.
3. A machine Independent Code-Optimizer can be applied to the Intermediate Representation.

INTERMEDIATE CODE GENERATION

- IC Generation process should not be very complex.
- It shouldn’t be difficult to produce the target program from the intermediate code.



INTERMEDIATE LANGUAGES

- Abstract Syntax tree or Syntax Tree
- DAG (Directed Acyclic Graph)
- Postfix Notation
- Three Address Code

INTERMEDIATE LANGUAGES

Abstract Syntax tree or Syntax Tree

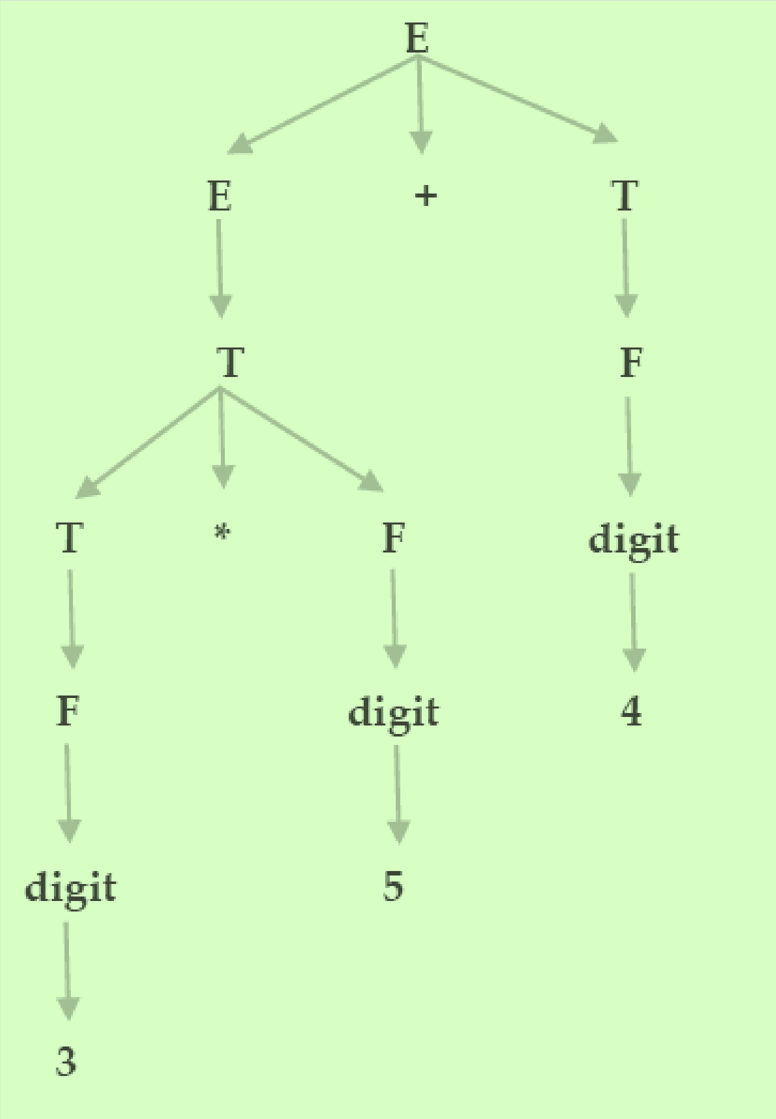
- ✓ Graphical Intermediate Representation.
- ✓ Syntax Tree depicts the hierarchical structure of a source program.
- ✓ Syntax tree (AST) is a condensed form of parse tree useful for representing language constructs.

Generate the parse tree and the syntax tree for 3 * 5 + 4.

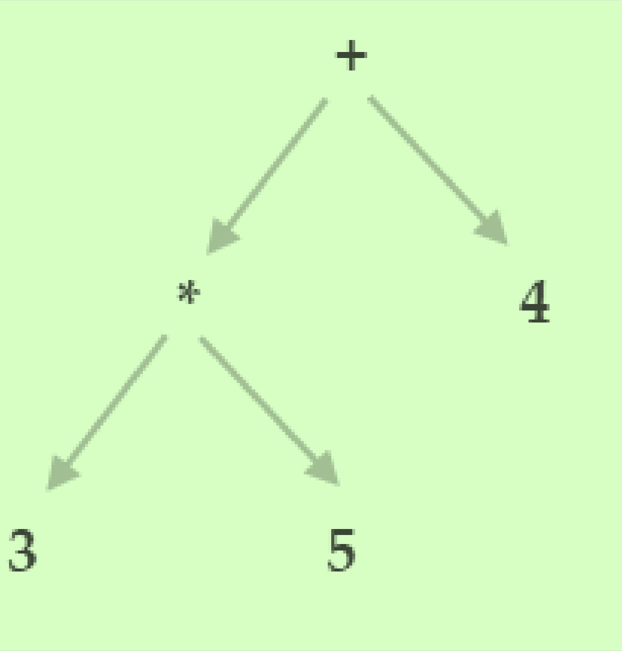
Grammar

E → E + T
E → E - T
E → T
T → T * F
T → F
F → digit

Parse Tree



Syntax Tree



Parse Tree	Syntax Tree
A parse tree is a graphical representation of a replacement process in a derivation	A syntax tree (AST) is a condensed form of parse tree
Each interior node represents a grammar rule	Each interior node represents an operator
Each leaf node represents a terminal	Each leaf node represents an operand
Parse tree represent every detail from the real syntax	Syntax tree does not represent every detail from the real syntax Eg : No parenthesis

INTERMEDIATE LANGUAGES

Constructing Syntax Tree for Expression

- ✓ Each node in a syntax tree can be implemented in a record with several fields.
- ✓ In the node of an operator, one field contains operator and remaining field contains pointer to the nodes for the operands.
- ✓ When used for translation, the nodes in a syntax tree may contain addition of fields to hold the values of attributes attached to the node.

INTERMEDIATE LANGUAGES

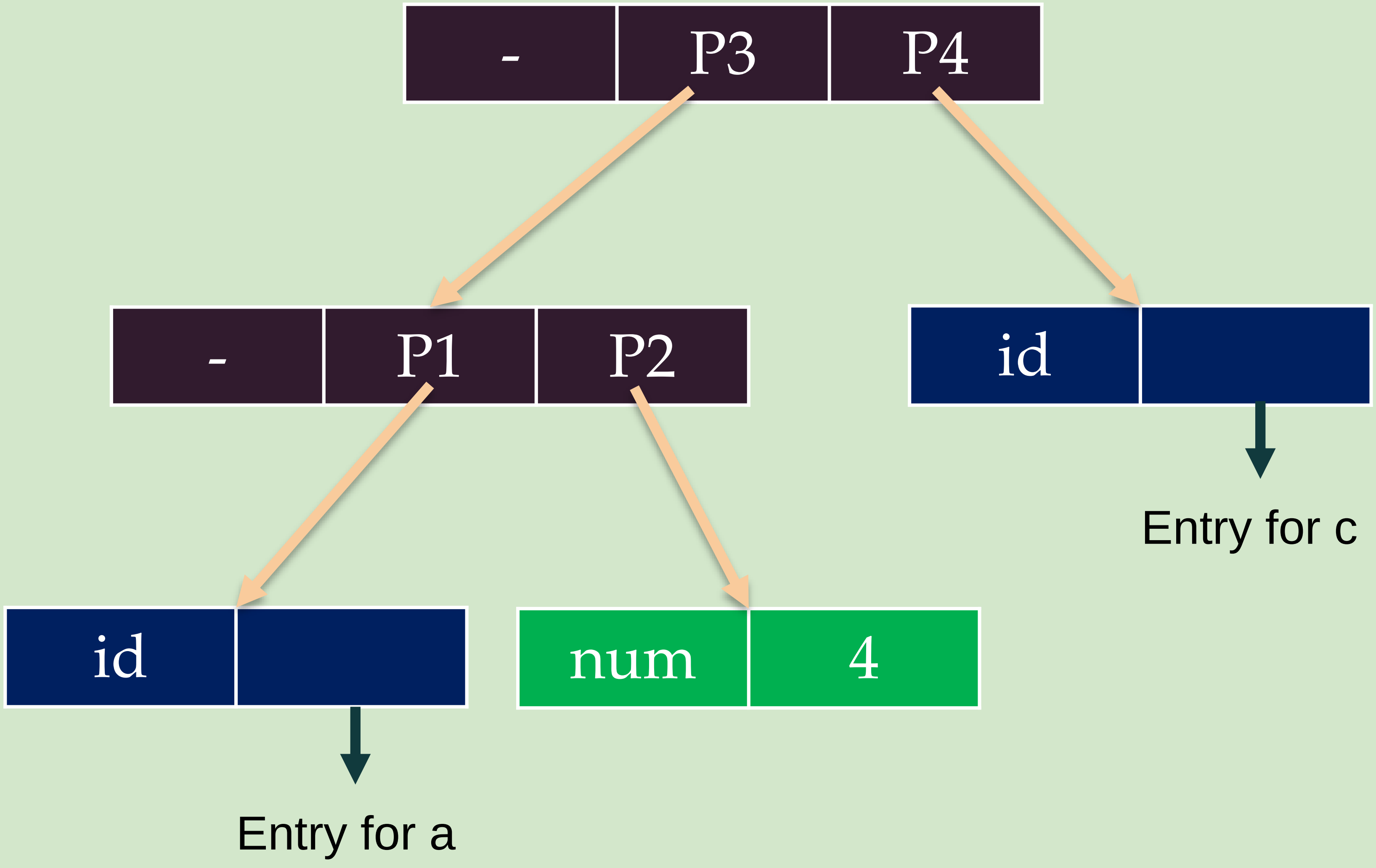
Constructing Syntax Tree for Expression

- ✓ **mknode(op,left,right)**: creates an operator node with label op and two fields containing pointers to left and right.
- ✓ **mkleaf(id,entry)**: creates an identifier node with label id and a field containing entry, a pointer to the symbol table entry for identifier.
- ✓ **mkleaf(num,val)**: creates a number node with label num and a field containing val, the value of the number.
- ✓ Such functions return a pointer to a newly created node.

E.g. Construct Syntax tree for a – 4 + c.

- ✓ The tree is constructed bottom up.

P1 = mkleaf(id,entry a)
P2 = mkleaf(num, 4)
P3 = mknode(-, P1, P2)
P4 = mkleaf(id,entry c)
P5 = mknode(+, P3, P4)



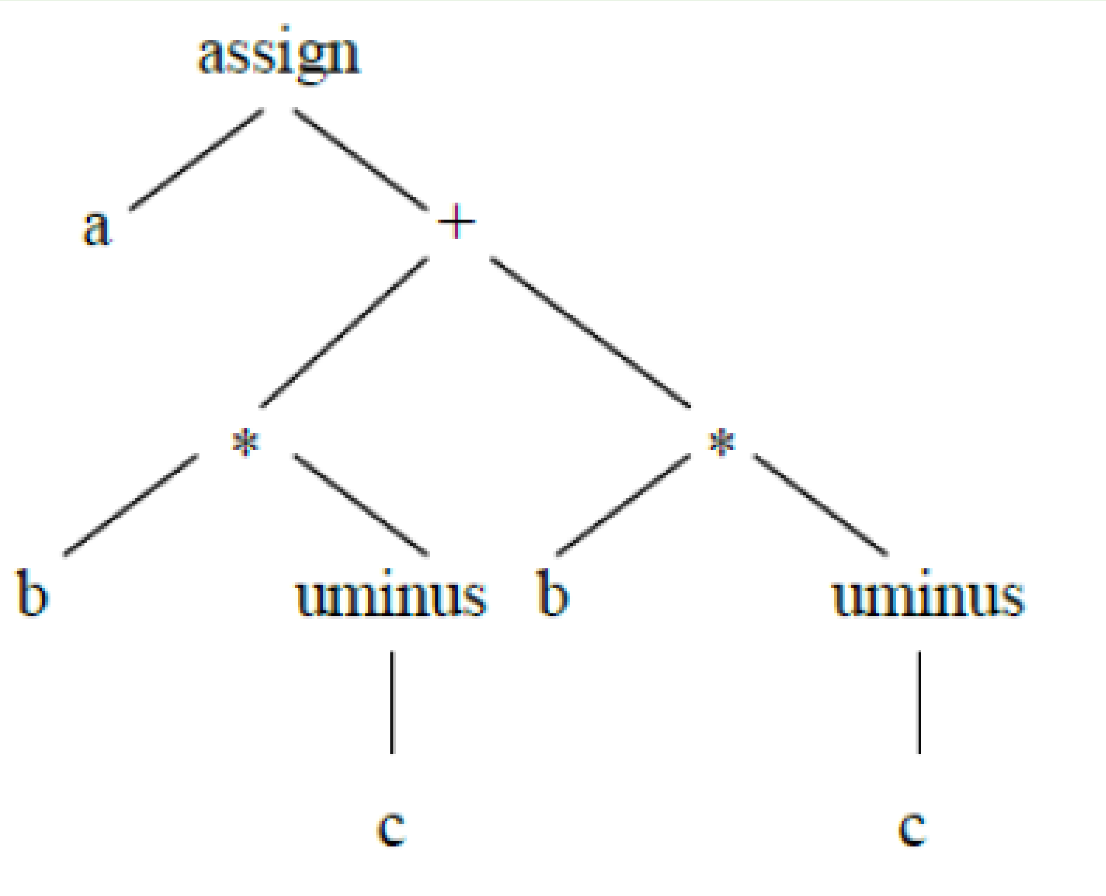
INTERMEDIATE LANGUAGES

Directed Acyclic Graph (DAG)

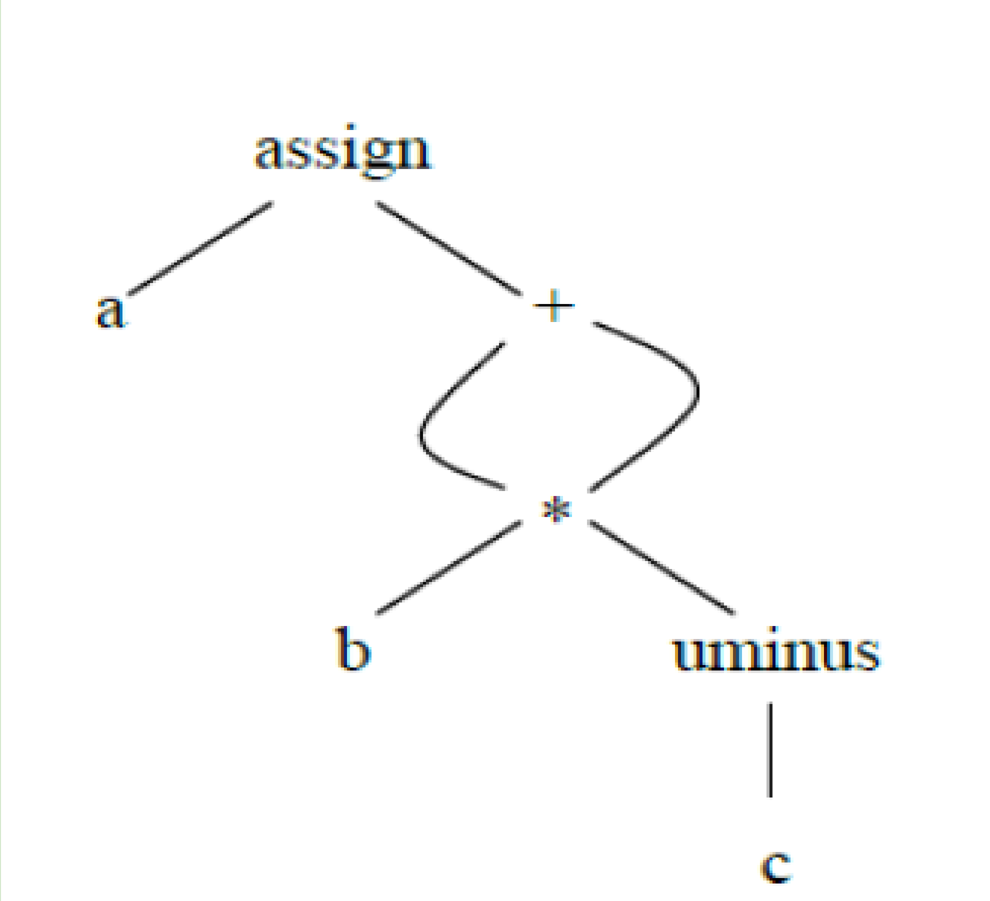
- ✓ Graphical Intermediate Representation.
- ✓ DAG also gives the hierarchical structure of source program but in a more compact way because common sub expressions are identified.

Constructing DAG for Expression

$$a = b * -c + b * -c$$



Syntax Tree



DAG

INTERMEDIATE LANGUAGES

Postfix

- ✓ Linearized representation of syntax tree.
- ✓ In postfix notation, each operator appears immediately after its last operand.
- ✓ Operators can be evaluated in the order in which they appear in the string.

INTERMEDIATE LANGUAGES

Postfix rules

- ✓ If E is a variable or constant, then the postfix notation for E is E itself.
- ✓ If E is an expression of the form E1 op E2 then postfix notation for E is E1′ E2′ op, here E1′ and E2′ are the postfix notations for E1and E2, respectively.
- ✓ If E is an expression of the form (E), then the postfix notation for E is the same as the postfix notation for E.
- ✓ For unary operation –E the postfix is E-
- ✓ Postfix notation of an infix expression can be obtained using stack.

Find the postfix of 9-(5+2)

952+-

INTERMEDIATE LANGUAGES

Three Address Code

- ✓ The reason for the term “three address code” is that each statement contains 3 addresses at most. Two for the operands and one for the result.

INTERMEDIATE LANGUAGES

General form of Three Address Code

- **a = b op c**
  - **a, b, c** are the operands that can be names, constants or compiler generated temporaries.
  - **op** represents operator, such as fixed or floating point arithmetic operator or a logical operator on Boolean valued data.

INTERMEDIATE LANGUAGES

General form of Three Address Code

- ✓ A source language expression like **x + y * z** might be translated into a sequence

  t1 = y*z

  t2 = x+t1 where, **t1** and **t2** are compiler generated temporary names.

INTERMEDIATE LANGUAGES

Advantages of Three Address Code

- ✓ The unraveling of complicated arithmetic expressions and of nested flow-of-control statements makes three-address code desirable for target code generation and optimization.
- ✓ The use of names for the intermediate values computed by a program allows three-address code to be easily rearranged - unlike postfix notation.

Types of Three Address Statements

- ✓ Assignment statements

  x = y op z, where op is a binary arithmetic or logical operation.
- ✓ Unary operations

  x = ***op*** **y**, where op is a unary operation . Essential unary operations include unary minus, logical negation, shift operators, and conversion operators that for example, convert a fixed-point number to a floating-point number.

Types of Three Address Statements

- ✓ Copy statements

  x = y where the value of y is assigned to x.
- ✓ Unconditional jump

  goto L The three-address statement with label L is the next to be executed.

Types of Three Address Statements

- ✓ Conditional jump

  if x relop y goto L This instruction applies a relational operator **(<, =, =, etc,)** to **x** and y, and executes the statement with label **L** next if x stands in relation **relop** to **y.** If not, the three-address statement following if **x relop y goto L** is executed next, as in the usual sequence.

Types of Three Address Statements

- ✓ Procedure call and return

  param x and **call p, n** for procedure calls and **return y**, where **y** representing a returned value is optional.
  Their typical use is as the sequence of three-address statements
  param x_1
  param x_2
  ……….
  param x_n
  call p,n
  generated as part of the call procedure **p(x_1 , x_2, . . . , x_n)**
  The integer **n** indicates the number of actual-parameters.

Types of Three Address Statements

- ✓ Indexed Assignments

  Indexed assignments of the form **x = y[i] or x[i] = y**
- ✓ **Address and pointer assignments**

  Address and pointer operator of the form **x = &y**, **x = *y** and ***x = y**

Implementation of Three Address Statements

- ✓ In a compiler, three address statements can be implemented as records with fields for the operator and the operands. Three such, representations are
  - ✓Quadruples
  - ✓Triples
  - ✓Indirect triples

Implementation of Three Address Statements

- ✓ Quadruples
  - A quadruple is a record structure with four fields, which are ***op, ag1, arg2*** and ***result.***
  - The op field contains an internal code for the operator. The three address statement **x = y op z** is represented by placing **y** in ***arg1,*** **z** in ***arg2*** and **x** in ***result***.
  - The contents of ***arg1, arg2***, and ***result*** are normally pointers to the symbol table entries for the names represented by these fields. If so temporary names must be entered into the symbol table as they are created.

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Implementation of Three Address Statements

- ✓ Quadruples
  - The statement **x := op y**, where op is a unary operator is represented by placing **op** in the operator field, **y** in the argument field & n in the result field. The ***arg2*** is not used.
  - A statement like **param t1** is represented by placing **param** in the operator field and t1 in the arg1 field. Neither ***arg2*** nor result field is used.
  - Unconditional & Conditional jump statements are represented by placing the target in the result field.

Implementation of Three Address Statements

- ✓ Triples
  - In triples representation, the use of temporary variables is avoided & instead reference to instructions are made to three address statements can be represented by records with only there fields OP, arg1 & arg2.
  - Since, there fields are used this intermediated code formal is known as triples.
  - Advantages
    - No need to use temporary variable which saves memory as well as time.

Implementation of Three Address Statements

- ✓ Triples
  - Disdvantages
    - Triple representation is difficult to use for optimizing compilers. Because for optimization statements need to be shuffled.
    - E.g., statement 1 can come down or statement 2 can go up etc.
    - So the reference we used in the representation will change.

Translate a + b * c / e ^ f + b * a to qudruple and triple.

First construct the three address code.

t1 = e ^ f
t2 = b * c
t3 = t2 / t1
t4 = b * a
t5 = a + t3
t6 = t5 + t4

Location	OP	arg1	arg2	Result
(0)	^	e	f	t1
(1)	*	b	c	t2
(2)	/	t2	t1	t3
(3)	*	b	a	t4
(4)	+	a	t3	t5
(5)	+	t3	t4	t6

Translate a + b * c | e ^ f + b * a to qudruple and triple.

First construct the three address code.

t1 = e ^ f

t2 = b * c

t3 = t2 / t1

t4 = b * a

t5 = a + t3

t6 = t5 + t4

Location	OP	arg1	arg2
(0)	^	e	f
(1)	*	b	c
(2)	/	(1)	(0)
(3)	*	b	a
(4)	+	a	(2)
(5)	+	(4)	(3)

A ternary operation like x[i] = y requires two entries in the triple structure while x = y[i] is naturally represented as two operations.

Location	op	arg1	arg2
(0)	[ ]=	x	i
(1)	assign	(0)	y

x[i] = y

Location	op	arg1	arg2
(0)	=[ ]	y	i
(1)	assign	x	(0)

x = y[i]

Implementation of Three Address Statements

- ✓ Indirect Triples
  - In triples representation, the use of temporary variables is avoided & instead reference to instructions are made to three
  - This representation is an enhancement over triple representation.
  - It uses an additional instruction array to led the pointer to the triples in the desired order.
  - It allows the optimizers to easily reposition the sub-expression for producing the optimized code.

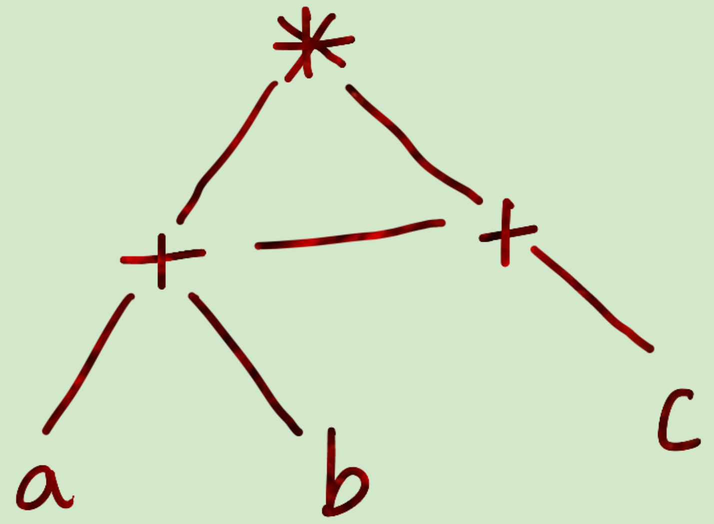
	Statement
35	(0)
36	(1)
37	(2)
38	(3)
39	(4)
40	(5)

Location	op	arg1	arg2
(0)	^	E	f
(1)	*	B	c
(2)	/	(1)	(0)
(3)	*	B	a
(4)	+	A	(2)
(5)	+	(4)	(3)

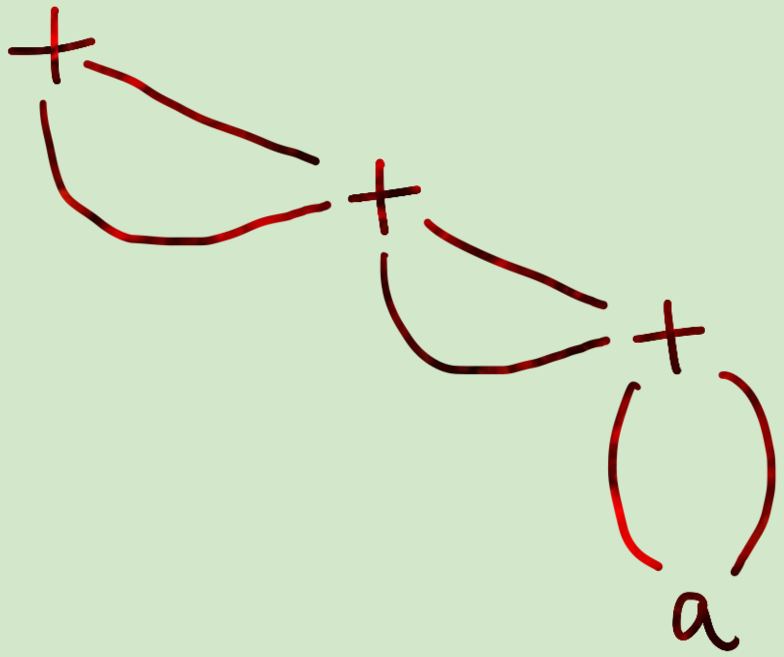
Construct DAG for the following

- (a+b)*(a+b+c)
- (((a+a)+(a+a))+((a+a)+(a+a)))
- a+a*(b-c)+(b-c)*d
- a= b+c
  b=a-d
  c=b+c
  d=a-d
- a= b+c
  b=b-d
  c=c+d
  e=b+c

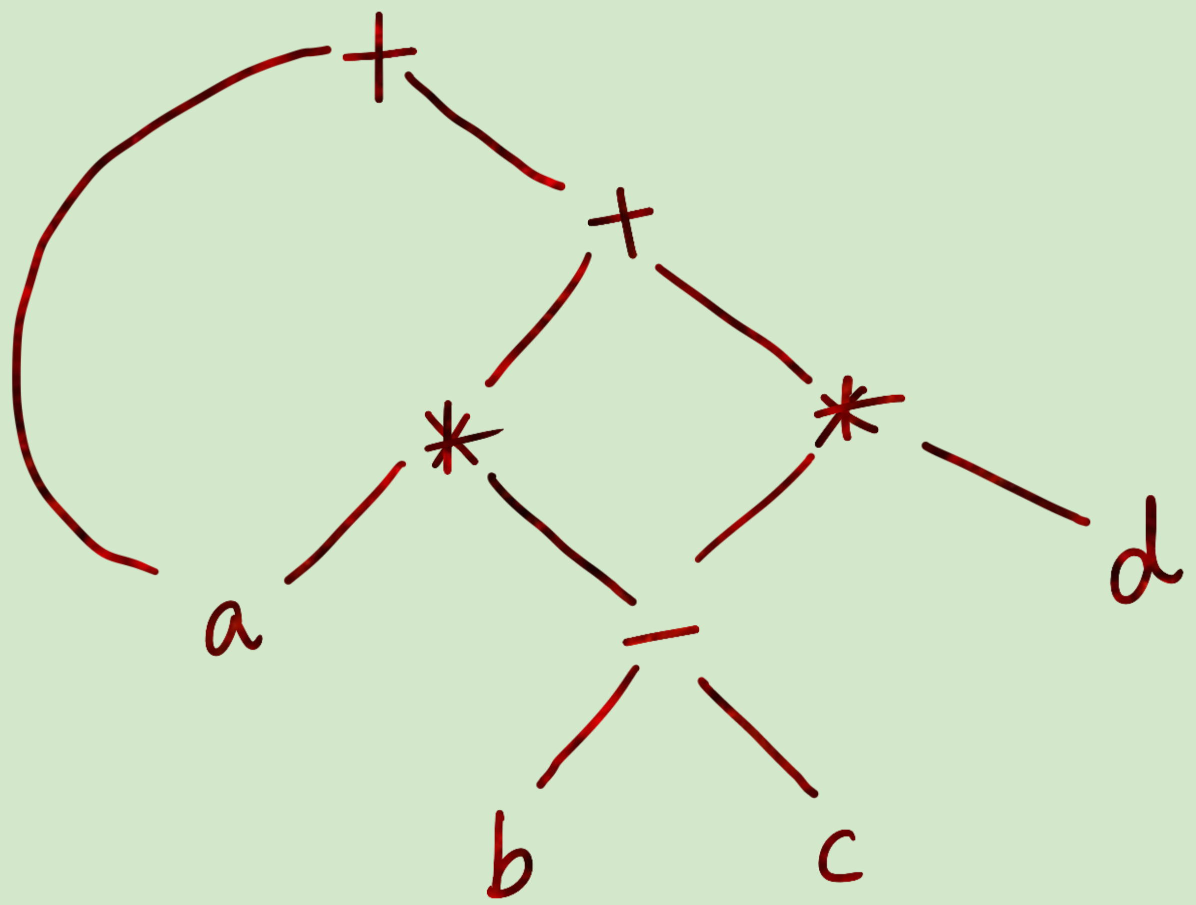
- a=(a*b+c)-(a*b+c)



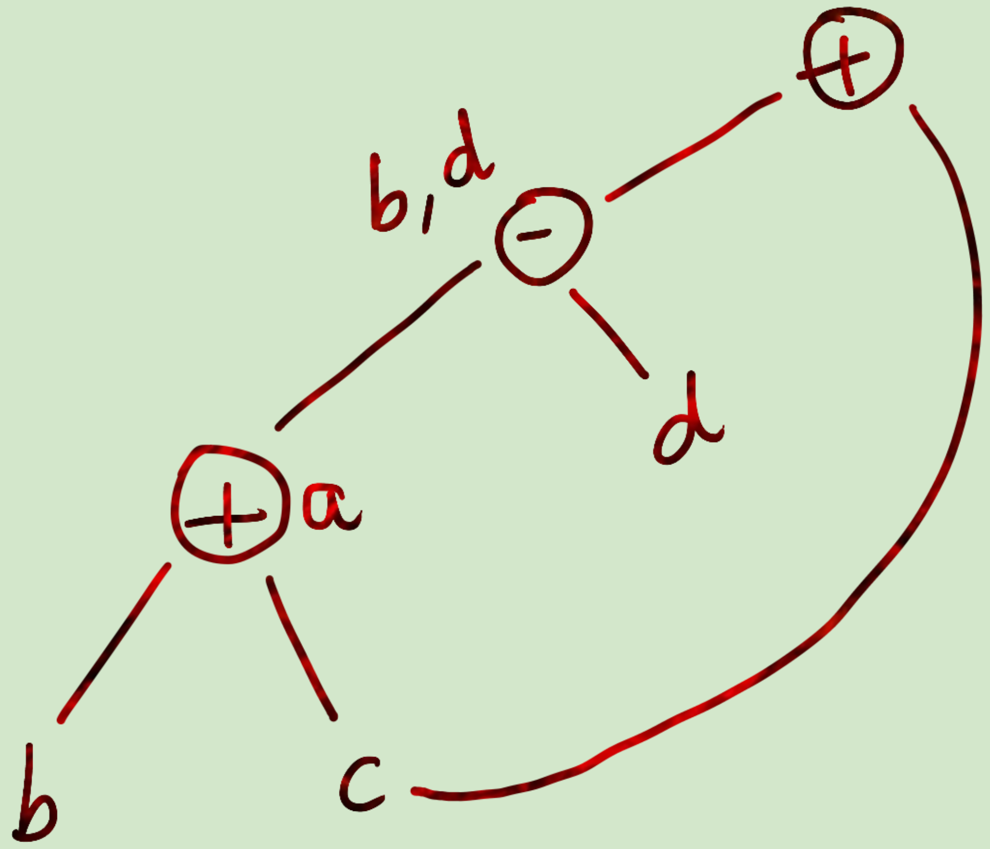
DAG for (a+b) * (a+b+c)



DAG for (((a+a)+(a+a))+(((a+a)+(a+a)))



DAG for a+a*(b-c)+(b-c)*d

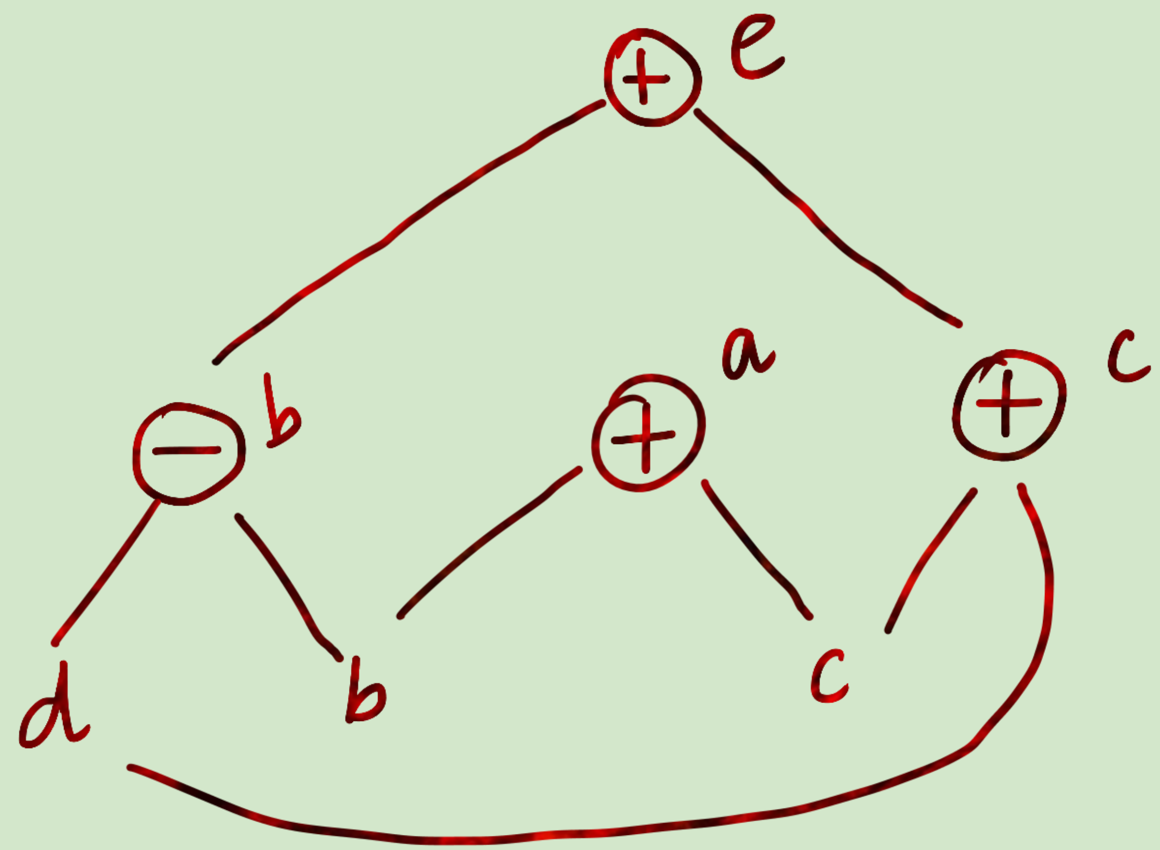


DAG for $a = b + c$

$b = a - d$

$c = b + c$

$d = a - d$

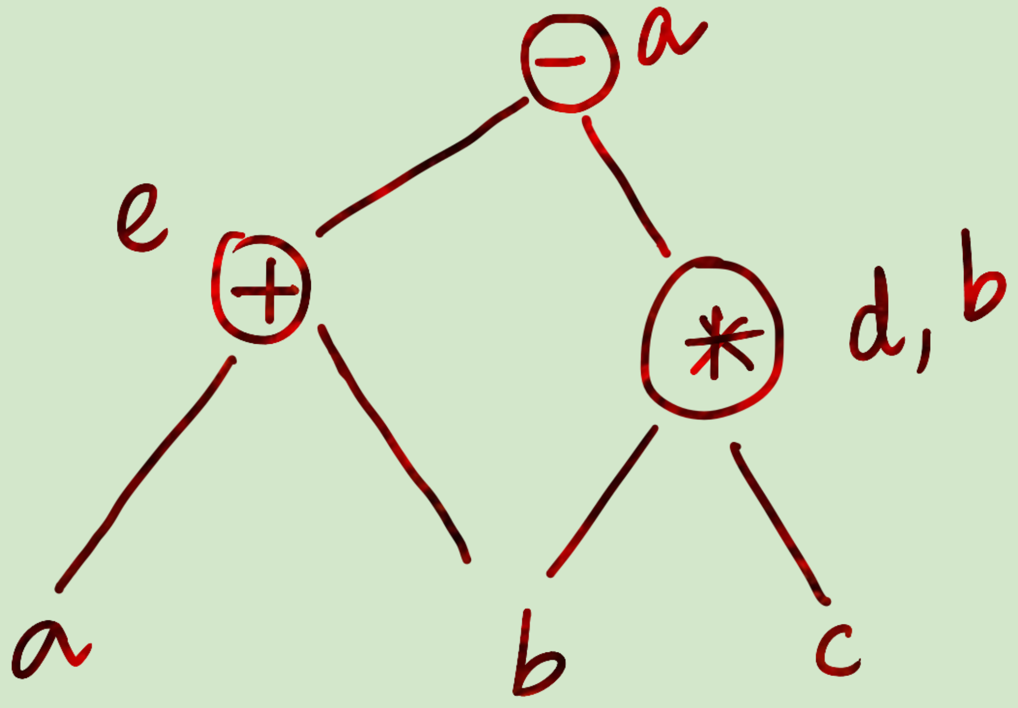


DAG for a = b+c

b = b−d

c = c+d

e = b+c

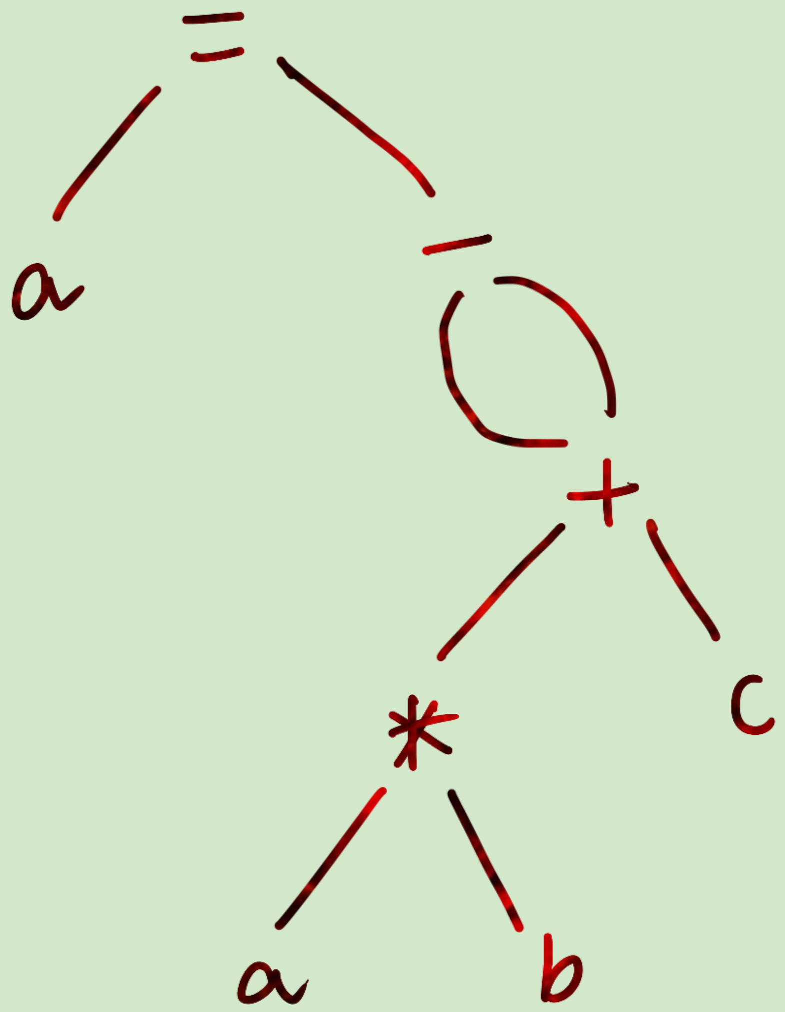


DAG for $d = b*c$

$e = a+b$

$b = b*c$

$a = e-d$



DAG for $a = (a*b+c)-(a*b+c)$

Construct quadruples, triples and indirect triples

A=-B*(C/D)

Three address codes are
T1 = -B
T2 = C/D
T3 = T1 * T2
A = T3

Location	op	arg1	arg2	result
(0)	uminus	B		T1
(1)	/	C	D	T2
(2)	*	T1	T2	T3
(3)	=	T3		A

Quadruple

Construct quadruples, triples and indirect triples

A=-B*(C/D)

Three address codes are
T1 = -B
T2 = C/D
T3 = T1 * T2
A = T3

Location	op	arg1	arg2
(0)	uminus	B	
(1)	/	C	D
(2)	*	(0)	(1)
(3)	=	A	(2)

Triple

Construct quadruples, triples and indirect triple

A=-B*(C/D)

	Statement
21	(0)
22	(1)
23	(2)
24	(3)

Location	op	arg1	arg2
(0)	uminus	B	
(1)	/	C	D
(2)	*	(0)	(1)
(3)	=	A	(2)

Indirect Triple

Construct quadruples, triples and indirect triples

(a+b)*(c+d)-(a+b+c)

Three address codes are
t1 = a+b
t2 = c+d
t3 = t1*t2
t4 = t1+c
t5 = t3–t4

Location	op	arg1	arg2	result
(0)	+	a	b	t1
(1)	=	c	d	t2
(2)	*	t1	t2	t3
(3)	+	t1	c	T4
(4)	-	t3	t4	t5

Quadruple

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Construct quadruples, triples and indirect triples

(a+b)*(c+d)-(a+b+c)

Three address codes are
t1 = a+b
t2 = c+d
t3 = t1*t2
t4 = t1+c
t5 = t3–t4

Location	op	arg1	arg2
(0)	+	a	b
(1)	=	c	d
(2)	*	(0)	(1)
(3)	+	(0)	c
(4)	-	(2)	(3)

Triple