

Expression Evaluation

Joseph Chuang-Chieh Lin (林莊傑)

Department of Computer Science & Engineering,
National Taiwan Ocean University

Fall 2024

Outline

1 Expressions

2 Infix to Postfix

Outline

1 Expressions

2 Infix to Postfix

Expressions

- Example: $a = (3 * (5 - 2))$;
 - Operators (運算子): $=$, $*$, $-$
 - Operands (運算元): a , 3, 5, 2
 - Parenthesis (括號): $(,)$

Expressions

- Example:

```
((rear+1 == front) || ((rear == MAX_QUEUE_SIZE-1) && !front))
```

- Operators (運算子): ==, +, -, ||, &&, !
- Operands (運算元): rear, front, MAX_QUEUE_SIZE
- Parenthesis (括號): (,)

Why expression evaluation is important?

- $9 + 3 * 5 = ?$
 - $9 + 3 * 5 = 24$
 - $9 + 3 * 5 = 60$

Why expression evaluation is important?

- $9 + 3 * 5 = ?$
 - $9 + 3 * 5 = 24$
 - $9 + 3 * 5 = 60$

- $9 - 3 - 2 = ?$
 - $9 - 3 - 2 = 4$
 - $9 - 3 - 2 = 8$

Why expression evaluation is important?

- $9 + 3 * 5 = ?$
 - $9 + 3 * 5 = 24$
 - $9 + 3 * 5 = 60$
 - Key: precedence rule (優先權)

- $9 - 3 - 2 = ?$
 - $9 - 3 - 2 = 4$
 - $9 - 3 - 2 = 8$

Why expression evaluation is important?

- $9 + 3 * 5 = ?$
 - $9 + 3 * 5 = 24$
 - $9 + 3 * 5 = 60$
 - Key: precedence rule (優先權)

- $9 - 3 - 2 = ?$
 - $9 - 3 - 2 = 4$
 - $9 - 3 - 2 = 8$
 - Key: associative rule (關聯性)

Why expression evaluation is important?

- $9 + 3 * 5 = ?$
 - $9 + 3 * 5 = 24$
 - $9 + 3 * 5 = 60$
 - Key: precedence rule (優先權)

- $9 - 3 - 2 = ?$
 - $9 - 3 - 2 = 4$
 - $9 - 3 - 2 = 8$
 - Key: associative rule (關聯性)

Within any programming language, there is a precedence hierarchy that determines the order in which we evaluate operators.



Precedence Hierarchy in C

Token	Operator	Precedence ¹	Associativity
0	function call	17	left-to-right
[]	array element		
>> ,	struct or union member		
-- ++	increment, decrement ²	16	left-to-right
-- ++	decrement, increment ³	15	right-to-left
!	logical not		
-	one's complement		
- +	unary minus or plus		
& *	address or indirection		
sizeof	size (in bytes)		
(type)	type cast	14	right-to-left
* / %	multiplicative	13	left-to-right
+ -	binary add or subtract	12	left-to-right
<< >>	shift	11	left-to-right
> >=	relational	10	left-to-right
< <=			
== !=	equality	9	left-to-right
&	bitwise and	8	left-to-right
^	bitwise exclusive or	7	left-to-right
	bitwise or	6	left-to-right
&&	logical and	5	left-to-right
	logical or	4	left-to-right
?:	conditional	3	right-to-left
= += -= /= *= %=	assignment	2	right-to-left
<=> >= &= ^= =			
,	comma	1	left-to-right

1. The precedence column is taken from Harbison and Steele.

2. Postfix form

3. Prefix form

- The associativity column indicates how we evaluate operators with the same precedence.

Infix & Postfix

Infix	Postfix
$2 + 3 * 4$	$234*+$
$a * b + 5$	$ab*5+$
$(1 + 2) * 7$	$12+7*$
$a * b / c$	$ab*c/$
$((a / (b - c + d)) * (e - a) * c$	$abc-d+/ea-*c*$
$a / b - c + d * e - a * c$	$ab/c-de*+ac*-$

Infix & Postfix

Infix	Postfix
$2 + 3 * 4$	$234*+$
$a * b + 5$	$ab*5+$
$(1 + 2) * 7$	$12+7*$
$a * b / c$	$ab*c/$
$((a / (b - c + d)) * (e - a) * c$	$abc-d+/ea-*c*$
$a / b - c + d * e - a * c$	$ab/c-de*+ac*-$

- Infix: the standard way we are used to.

Infix & Postfix

Infix	Postfix
$2 + 3 * 4$	$234*+$
$a * b + 5$	$ab*5+$
$(1 + 2) * 7$	$12+7*$
$a * b / c$	$ab*c/$
$((a / (b - c + d)) * (e - a) * c$	$abc-d+/ea-*c*$
$a / b - c + d * e - a * c$	$ab/c-de*+ac*-$

- Infix: the standard way we are used to.
- The compilers typically use **postfix**!

Benefit of using Postfix Expression: Simpler!

Benefit of using Postfix Expression: Simpler!

- No parenthesis and precedence to consider.

Benefit of using Postfix Expression: Simpler!

- **No parenthesis and precedence to consider.**
- A single **left-to-right scan** of the expression suffices!

Benefit of using Postfix Expression: Simpler!

- **No parenthesis and precedence to consider.**
- A single **left-to-right scan** of the expression suffices!
- Evaluation of an expression can be done by using a **stack**.

Benefit of using Postfix Expression: Simpler!

- No parenthesis and precedence to consider.
- A single left-to-right scan of the expression suffices!
- Evaluation of an expression can be done by using a stack.

Token	Stack			Top
	[0]	[1]	[2]	
6	6			0
2	6	2		1
/	6/2			0
3	6/2	3		1
-	6/2-3			0
4	6/2-3	4		1
2	6/2-3	4	2	2
*	6/2-3	4*2		1
+	6/2-3+4*2			0

Outline

1 Expressions

2 Infix to Postfix

Postfix Evaluation

- Expression is represented as a character array.
 - Operators: +, -, *, / and %.
 - Operands: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9.
 - The operands are stored on a stack of type int.
 - The stack is represented by a global array accessed only through top.
- The declarations are:

```
#define MAX_STACK_SIZE 100 // maximum stack size
#define MAX_EXPR_SIZE 100 // max size of expression
typedef enum {
    lparen, rparen, plus, minus, times,
    divide, mod, eos, operand
} precedence;
int stack[MAX_STACK_SIZE]; // global stack
char expr[MAX_EXPR_SIZE]; // input string
```

To Get Tokens

```
precedence get_token(char *symbol, int *n) { // get the next token,
    *symbol = expr[(*n)++];
    switch (*symbol) {
        case '(':    return lparen;
        case ')':   return rparen;
        case '+':   return plus;
        case '-':   return minus;
        case '/':   return divide;
        case '*':   return times;
        case '%':   return mod;
        case '\0':  return eos; // end of string
        default:    return operand; /* no error checking,
                                         default: operand */
    }
}
```



```

int eval(void)
{
    /* evaluate a postfix expression, expr, maintained as a
    global variable. '\0' is the end of the expression.
    The stack and top of the stack are global variables.
    get_token is used to return the tokentype and
    the character symbol. Operands are assumed to be single
    character digits */
    precedence token;
    char symbol;
    int op1, op2;
    int n = 0; /* counter for the expression string */
    int top = -1;
    token = get_token(&symbol, &n);
    while (token != eos) {
        if (token == operand)
            push(symbol-'0');           /* stack insert */
        else {                         transform ASCII characters into numbers
            /* remove two operands, perform operation, and
            return result to the stack */
            op2 = pop();              /*stack delete */
            op1 = pop();
            switch(token) {
                case plus: push(op1+op2);
                break;
                case minus: push(op1-op2);
                break;
                case times: push(op1*op2);
                break;
                case divide: push(op1/op2);
                break;
                case mod: push(op1%op2);
            }
            token = get_token(&symbol, &n); → get next token
        }
        return pop();                  /* return result */
    }
}

```



ASCII Code Table

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0 000	000	NUL (null)	32	20 040	000	 	Space	64	40 100	000	@	Ø	96	60 140	000	`	'
1	1 001	001	SOH (start of heading)	33	21 041	001	!	!	65	41 101	001	A	A	97	61 141	001	a	a
2	2 002	002	STX (start of text)	34	22 042	002	"	"	66	42 102	002	B	B	98	62 142	002	b	b
3	3 003	003	ETX (end of text)	35	23 043	003	#	#	67	43 103	003	C	C	99	63 143	003	c	c
4	4 004	004	EOT (end of transmission)	36	24 044	004	$	\$	68	44 104	004	D	D	100	64 144	004	d	d
5	5 005	005	ENQ (enquiry)	37	25 045	005	%	%	69	45 105	005	E	E	101	65 145	005	e	e
6	6 006	006	ACK (acknowledge)	38	26 046	006	&	&	70	46 106	006	F	F	102	66 146	006	f	f
7	7 007	007	BEL (bell)	39	27 047	007	'	'	71	47 107	007	G	G	103	67 147	007	g	g
8	8 010	010	BS (backspace)	40	28 050	010	({	72	48 110	010	H	H	104	68 150	010	h	h
9	9 011	011	TAB (horizontal tab)	41	29 051	011)	}	73	49 111	011	I	I	105	69 151	011	i	i
10	A 012	012	LF (NL line feed, new line)	42	2A 052	012	*	*	74	4A 112	012	J	J	106	6A 152	012	j	j
11	B 013	013	VT (vertical tab)	43	2B 053	013	+	+	75	4B 113	013	K	K	107	6B 153	013	k	k
12	C 014	014	FF (NP form feed, new page)	44	2C 054	014	,	,	76	4C 114	014	L	L	108	6C 154	014	l	l
13	D 015	015	CR (carriage return)	45	2D 055	015	-	-	77	4D 115	015	M	M	109	6D 155	015	m	m
14	E 016	016	SO (shift out)	46	2E 056	016	.	.	78	4E 116	016	N	N	110	6E 156	016	n	n
15	F 017	017	SI (shift in)	47	2F 057	017	/	/	79	4F 117	017	O	O	111	6F 157	017	o	o
16	10 020	020	DLE (data link escape)	48	30 060	020	0	0	80	50 120	020	P	P	112	70 160	020	p	p
17	11 021	021	DC1 (device control 1)	49	31 061	021	1	1	81	51 121	021	Q	Q	113	71 161	021	q	q
18	12 022	022	DC2 (device control 2)	50	32 062	022	2	2	82	52 122	022	R	R	114	72 162	022	r	r
19	13 023	023	DC3 (device control 3)	51	33 063	023	3	3	83	53 123	023	S	S	115	73 163	023	s	s
20	14 024	024	DC4 (device control 4)	52	34 064	024	4	4	84	54 124	024	T	T	116	74 164	024	t	t
21	15 025	025	NAK (negative acknowledge)	53	35 065	025	5	5	85	55 125	025	U	U	117	75 165	025	u	u
22	16 026	026	SYN (synchronous idle)	54	36 066	026	6	6	86	56 126	026	V	V	118	76 166	026	v	v
23	17 027	027	ETB (end of trans. block)	55	37 067	027	7	7	87	57 127	027	W	W	119	77 167	027	w	w
24	18 030	030	CAN (cancel)	56	38 070	030	8	8	88	58 130	030	X	X	120	78 170	030	x	x
25	19 031	031	EM (end of medium)	57	39 071	031	9	9	89	59 131	031	Y	Y	121	79 171	031	y	y
26	1A 032	032	SUB (substitute)	58	3A 072	032	:	:	90	5A 132	032	Z	Z	122	7A 172	032	z	z
27	1B 033	033	ESC (escape)	59	3B 073	033	;	:	91	5B 133	033	[[123	7B 173	033	{	[
28	1C 034	034	FS (file separator)	60	3C 074	034	<	<	92	5C 134	034	\	\	124	7C 174	034	|	\
29	1D 035	035	GS (group separator)	61	3D 075	035	=	=	93	5D 135	035]]	125	7D 175	035	})
30	1E 036	036	RS (record separator)	62	3E 076	036	>	>	94	5E 136	036	^	^	126	7E 176	036	~	~
31	1F 037	037	US (unit separator)	63	3F 077	037	?	?	95	5F 137	037	_	_	127	7F 177	037		DEL

Source: www.LookupTables.com

The First Algorithm

- Consider the following example:

$$a / b - c + d * e - a * c$$

The First Algorithm

- Consider the following example:

$$a / b - c + d * e - a * c$$

- fully parenthesize the expression. (將運算式加上括號).
 - $((((a / b) - c) + (d * e)) - (a * c))$



The First Algorithm

- Consider the following example:

$$a / b - c + d * e - a * c$$

- fully parenthesize the expression. (將運算式加上括號).
 - $((((a / b) - c) + (d * e)) - (a * c))$
- move all binary operators so that they replace their corresponding right parentheses. (將運算符號取代其相對應的右括號)
 - $((((a b /c - (d e * + a c * -$

The First Algorithm

- Consider the following example:

$$a / b - c + d * e - a * c$$

- fully parenthesize the expression. (將運算式加上括號).
 - $((((a / b) - c) + (d * e)) - (a * c))$
- move all binary operators so that they replace their corresponding right parentheses. (將運算符號取代其相對應的右括號)
 - $((((a b / c - (d e * + a c * -$
- delete all parentheses.
 - $a b / c - d e * + a c * -$

The Second Algorithm

- Scan string from left to right.
- Operands are taken out immediately.
- Operators are taken out of the stack as long as their in-stack precedence (isp) is \geq the incoming precedence (icp) of the new operator.
- If the token is the right parenthesis ')', unstack tokens until we reach the corresponding left parenthesis '('.

Algorithm 2 (Example 1)

$a + b * c$

Token	Stack			top	output
	[0]	[1]	[2]		
a				-1	a
+	+			0	a
b	+			0	ab
*	+	*		1	ab
c	+	*		1	abc
eos				-1	abc*+

op	isp	icp
(0	20
)	19	19
+	12	12
-	12	12
*	13	13
/	13	13
%	13	13
eos	0	0

Algorithm 2 (Example 2)

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

token	Stack			top	output
	[0]	[1]	[2]		
a				-1	a
*	*			0	a
(*	(1	a
b	*	(1	ab
+	*	(+	2	ab
c	*	(+	2	abc
)	*			0	abc+
*	*			0	abc+*
d	*			0	abc+*d
eos				-1	abc+*d*

op	isp	icp
(0	20
)	19	19
+	12	12
-	12	12
*	13	13
/	13	13
%	13	13
eos	0	0



The Postfix Algorithm

```
void postfix(void)
{
    /* output the postfix of the expression. The expression
       string, the stack, and top are global */
    char symbol;
    precedence token;
    int n = 0;
    int top = 0;    /* place eos on stack */
    stack[0] = eos;
    for (token = get_token(&symbol, &n); token != eos;
         token = get_token(&symbol,&n)) {
        if (token == operand)
            printf("%c",symbol); directly print out the operand
        else if (token == rparen) { If it's the right parenthesis '
            /* unstack tokens until left parenthesis */
            while (stack[top] != lparen)
                print_token(delete(&top));
            delete(&top); /* discard the left parenthesis */
        } delete the left parenthesis ' (
        else {
            /* remove and print symbols whose isp is greater
               than or equal to the current token's icp */
            while(isp[stack[top]] >= icp[token])
                print_token(delete(&top));
            add(&top, token);
        }
    }
    while ( (token=delete(&top)) != eos)
        print_token(token);
    printf("\n"); Print out the token when the end of string is reached
}
```

Time Complexity of the Postfix Algorithm

- Total time: $\Theta(n)$.

Time Complexity of the Postfix Algorithm

- Total time: $\Theta(n)$.
 - The number of stacked tokens that get stacked: $O(n)$
 - The total number of unstacked tokens: $O(n)$.
 - $\Omega(n)$: at least scanning over the input once.

Discussions