C Expressions, Operators, and Flow of Control

C Programming and Software Tools

N.C. State Department of Computer Science

Computer Science
NC STATE UNIVERSITY

Outline

- Expressions
- Operators
  - Single operand
  - Two operands
  - Relational
  - Logical
  - Assignment
- Statement Separation
- C Operator Precedence and Order of Evaluation
- Flow of Control

Computer Science
NC STATE UNIVERSITY

Expressions

- Most statements in a C program are *expressions*
- *Evaluating* an expression means doing the computation according to the definition of the operations specified
- Results of expression evaluation
  - the value returned (and assigned); and/or
  - *side effects* (other changes to variables, or output, along the way)

```
j = k + 3 * m++;
```


Computer Science NC STATE UNIVERSITY

Comparison: C vs. Java Operators

Operator	Description	Associates
.	access class feature	left-to-right
a[]	array index	
fn()	function call	
++ --	**post**-inc/dec	
++ --	**pre**-inc/dec	right-to-left
~	bitwise not	
!	logical not	
- +	unary -/+	
& *	address/dereference	
(type)	cast	
new	object allocation	

Not in C

Operator	Description	Associates
* / %	multiplicative	left-to-right
+ -	additive	left-to-right
<< >> >>>	left, right shift	left-to-right
< <= > >=	relational	left-to-right
== != **instanceof**	equality/ineq. test object type	left-to-right
&	bitwise and	left-to-right
^	bitwise xor	left-to-right
|	bitwise or	left-to-right
&&	logical and	left-to-right
||	logical or	left-to-right
= += -= *= /= %= &= ^= |= <<= >>=	assignment	right-to-left

- C operators not found in Java:
  - pointer operations (`->`, `&`, `*`)
  - sizeof
  - sequential evaluation (`,`)

Computer Science NC STATE UNIVERSITY

What Are the C Operators?

- There are approximately 50 of them
- Most operators do the same thing in Java and C
- Categories of operators
  1. "other"
  2. arithmetic
  3. logical and relational
  4. assignment
  5. bit operators

Computer Science NC STATE UNIVERSITY

Other Operators (Discussed Later)

- *Array indexing (`x[]`)*
- *Function calls (`f()`)*
- *Address-of (`&x`) operator, and pointer dereferencing (`*x`)*
  - *and effect of other operators on pointers*
- *Member (of `struct`) specification*
  - *direct (`x.y`) and indirect (`x->y`)*
- *The `sizeof()` operator*
- *casting: `(type) operand` (already discussed)*

Computer Science NC STATE UNIVERSITY

Arithmetic: Ops on a Single Operand

Unary plus (+a): no effect

```
a = +b;
```

Unary minus (-b): change sign of operand

```
a = -b;
```

Increment (++) and decrement (--) operators

- operand type must be modifiable (not a constant)
- these operators have side effects!

```
a = ++b / c-- ;
```


Computer Science NC STATE UNIVERSITY

Single Operand... (cont'd)

prefix: side effect takes place first, then expression value is determined

```
int i = 1, j = 8;
printf("%d %d\n", ++i, --j);
printf("%d %d\n", i, j);
```

what is output?

postfix: expression uses old operand value first, then side effect takes place

```
int i = 1, j = 8;
printf("%d %d\n", i++, j--);
printf("%d %d\n", i, j);
```

what is output?

☠ common source of bugs ☠
difference between postfix and prefix

Arithmetic on Two Operands

- Multiply (*), Quotient (/), Remainder (%), Add (+), Subtract (-)
  - possibility of underflow and overflow during expression evaluation, or assignment of the results

common source of bugs
overflow in computations

- Divide by zero
  - causes program execution failure if the operands are integer type
  - generates a special value (inf) and continues execution if the operands are IEEE floating point

common source of bugs
divide by zero

Computer Science NC STATE UNIVERSITY

Arithmetic on Two Operands

- Modulus operator (%) operands must have type integer, should both be positive

```
printf("%d", (37 % 3));
```

results?

```
printf("%d", (-37 % 3));
```

- Result of a%b is program exception if b == 0

Computer Science NC STATE UNIVERSITY

Relational and Logical Operators

Used in evaluation conditions

```
if (expression evaluates to TRUE)
    ...do something...
```

What is TRUE (in C)?

- `0` means FALSE
- anything else (`1`, `-96`, `1.414`, `'F'`, `inf`) means TRUE
- ???

```
float f = 9593.264;
if (f)
   ...do something...
```

Computer Science NC STATE UNIVERSITY

Relational Operators

Six comparison operators: `<`, `>`, `==`, `!=`, `>=`, `<=`

```
if (a < b) ...
if (x >= y) ...
if (q == r) ...
```

- Operands must be numbers (integer or floating point), result type is **`int`**
  - i.e., cannot use to compare structs, functions, arrays, etc.
- If relation is true, result is **`1`**, else result is **`0`**

```
float f = 9593.264;
if (f != 0)
   ...do something...
```

same meaning as previous slide

Computer Science NC STATE UNIVERSITY

Relational Operators (cont'd)

- Most common mistake in C (in my experience)
  - **==** is relational comparison for equality
  - **=** is assignment!

common source of bugs
confusion between = and ==

Example: some strategic defense code…

```
if (enemy_launch = confirmed)
    retaliate();
```

Oops… sorry!

Computer Science NC STATE UNIVERSITY

Logical Operators

Logical operators allow construction of complex (compound) conditions

Operands must be (or return) numbers (integer or floating point), result type is int

Logical NOT (**!**) operator

- result: **1** (TRUE) if operand was **0** (FALSE), otherwise **0**

```
int j = ...;
if (! j)
   ... do something ...
```

```
float f = ..., g = ...;
if (! (f < g) )
   ... do something ...
```

Logical … (cont'd)

- AND (**&&**):
  - evaluate first operand, if **0**, result is **0**; else,
  - evaluate second operand, if **0**, result is **0**; else,
  - result is **1**

```
if (x && (y > 32))
   ... do something ...
```


Logical... (cont'd)

- Condition evaluation stops as soon as truth value is known
  - i.e., order of the operands is significant
- Relied on by many programs!

☠ *common source of bugs* ☠
lack of understanding of significance of order in conditions

```
if ((b != 0) && ((a / b) > 5))
    printf("quotient greater than 5\n");
```

what's the difference???

```
if (((a / b) > 5) && (b != 0))
    printf("quotient greater than 5\n");
```

Logical… (cont'd)

- OR (**||**) operator
  - evaluate first operand, if not **0**, result is **1**;
  - otherwise, evaluate second operand, if not **0**, result is **1**;
  - otherwise, result is **0**
- There is no logical XOR in C
  - but (**a** XOR **b**) ➔ **(a && (! b)) || ((! a) && b)**

A Strange Idea?

- Mixing relational, bit-wise, and arithmetic operations into a single expression

```
unsigned char g, h;
int a, b;
float e, f;
…
if ((a < b) && (e * f || (g ^ h)))
    …do something here…
```

is condition true?

☠ common source of bugs ☠
mixing of operator types in a single expression

```
int a = -4;
char c = 'D';
float e = 0.0, f = 22.2, g;
…
g = (c == 'D') + (e || f) * a;
```

value of g?

Assignment Operators

- **a = b** assigns the value of **b** to **a**
  - **a** must be a reference and must be *modifiable* (not a function, not an entire array, etc.)
- Both **a** and **b** must be one of the following
  - numbers (integer or floating), or
  - structs or unions of the same type, or
  - pointers to variables of the same type

OK

```
float a;
int b = 25;
a = b;
```

Not OK

```
float a[2];
int b[2] = {25, 15};
a = b;
```


Assignment Operators (cont'd)

- **a *op*= b**
  - where ***op*** is one of ***,/,%,+,-,<<,>>,&,^,|**
  - "shorthand" for **a = a *op* b**

```
int i = 30, j = 40, k = 50;
i += j;  // same as i = i + j
k %= j;  // same as k = k % j
j *= k;  // same as j = j * k
```

Statement Termination and the "`,`"

- Normally, statements are executed sequentially and are separated by `;`
- Another separator: '`,`' (e.g., `j = k++, i = k;`):
  1. evaluate expressions left to right
  2. complete all side effects of left expression before evaluating right expression
  3. result is value of the right expression
- More shorthand?

Computer Science NC STATE UNIVERSITY

Constant Expressions

- Constant-valued expressions are used in…
  - case statement labels
  - array bounds
  - bit-field lengths
  - values of enumeration constants
  - initializers of static variables

all evaluated at compile time, not run time

```
static int a = 35 + (16 % (4 | 1));
```

(`static`: variable's value is initialized only once, no matter how many times the block in which it is defined is executed)

Computer Science NC STATE UNIVERSITY

Constant Expressions… (cont'd)

- Cannot contain assignments, increment or decrement operators, function calls, …
  - see a C reference manual for all the restrictions
  - basically: nothing that has to be evaluated at run-time

```
static int b = a++ - sum();
```

Computer Science NC STATE UNIVERSITY

C Operator Precedence

Tokens	Operator	Class	Prec.	Associates
`a[k]`	subscripting	postfix	16	left-to-right
`f(...)`	function call	postfix		left-to-right
`.`	direct selection	postfix		left-to-right
`->`	indirect selection	postfix		left to right
`++ --`	increment, decrement	**postfix**		left-to-right
`++ --`	increment, decrement	**prefix**	15	right-to-left
`sizeof`	size	unary		right-to-left
`~`	bit-wise complement	unary		right-to-left
`!`	logical NOT	unary		right-to-left
`- +`	negation, plus	unary		right-to-left
`&`	address of	unary		right-to-left
`*`	Indirection (*dereference*)	unary		right-to-left

C Operator Precedence (cont'd)

`(type)`	casts	unary	**14**	right-to-left
`* / %`	multiplicative	binary	**13**	left-to-right
`+ -`	additive	binary	**12**	left-to-right
`<< >>`	left, right shift	binary	**11**	left-to-right
`< <= > >=`	relational	binary	**10**	left-to-right
`== !=`	equality/ineq.	binary	**9**	left-to-right
`&`	bitwise and	binary	**8**	left-to-right
`^`	bitwise xor	binary	**7**	left-to-right
`|`	bitwise or	binary	**6**	left-to-right
`&&`	logical AND	binary	**5**	left-to-right
`||`	logical OR	binary	**4**	left-to-right
`?:`	conditional	ternary	**3**	right-to-left
`= += -= *= /= %= &= ^= |= <<= >>=`	assignment	binary	**2**	right-to-left
`,`	sequential eval.	binary	**1**	left-to-right

Order of Evaluation in Compound Expressions

- Which operator has higher precedence?
- If two operators have equal precedence, are operations evaluated left-to-right or right-to-left?
- Ex:

```
a += b = q - ++ r / s && ! t == u ;
```

what gets executed first, second, ...?

One solution: use parentheses to force a specific order

```
t = (u + v) * w;
```


Computer Science NC STATE UNIVERSITY

Order of Evaluation in Compound Expressions

- Common mistake: overlooking precedence and associativity (l-to-r or r-to-l)

```
t = u+v * w;
```

common source of bugs
failure to use parentheses to enforce precedence

Advice: either…

- force order of evaluation when in doubt by using parentheses
- or (even better) write one large expression as sequence of several smaller expressions

Computer Science NC STATE UNIVERSITY

Ex: A Ridiculous Expression

- (all type **`unsigned char`**)
  - **`a+=b=q-++r/(s^!t==u);`**

1. subexpression in parentheses evaluated first
2. ! has highest precedence (15)
3. == has next highest precedence (9)
4. ^ has lowest precedence in subexpression (7)
5. Outside parens, ++ has highest precedence (15)
6. / has next highest precedence (13)
7. - has next highest precedence (12)
8. += and = have lowest precedence (2), evaluate r-to-l

Result

```
a+=(b=(q-((++r)/(s^((!t)==u)))));
  8  7  6 5  5  1  3 2  2   3 1 6 7 8
```

Evaluating Expressions… (cont'd)

- Instead of…

☠ common source of bugs ☠
expressions that are too complex

```
a+=b=q-++r/(s^!t==u);
```

Or…

```
a+=(b=(q-((++r)/(s^((!t)==u)))));
```

Better:

```
tmp1 = s ^ ( (!t) == u );
tmp2 = (++r) / tmp1;
b = q - tmp2;
a += b;
```


Computer Science NC STATE UNIVERSITY

★ you try it ★
operators

Exercise

1. What does the following output?

```
int a = 32, b = 5;
printf("%d %d\n", a--, ++b);
printf("%d %d\n", --a, --b);
```

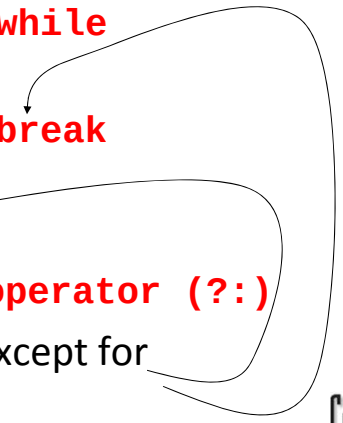
2. What is the value of a after executing the following, and is the condition TRUE or FALSE?

```
int a = 32, b = 5, c = 8, d = 4, e = 12;
if (a -= ((b > c) || (e / d)) + 6)
    ...do something...
```


Computer Science NC STATE UNIVERSITY

Flow of control

- Flow-of-control statements in C
  - **`if-then-else`**
  - **`while`** and **`do-while`**
  - **`for`**
  - **`continue`** and **`break`**
  - **`switch-case`**
  - **`goto`**
  - **`conditional operator (?:)`**
- Same set in java, except for



The C Conditional Operator

- A terse way to write if-then-else statements

```
c = (a > b) ? d : e;
```

- This is equivalent to (shorthand for)

```
if (a > b)
   c = d;
else
   c = e;
```

common source of bugs
complex conditional statements

Combining Assignment and Condition Checking

Why write this…

```
c = getchar();
while (c != '\n') {
    …do something…
    c = getchar();
}
```

does the same thing!

…when you can write this instead?

```
while ( (c = getchar()) != '\n' ) {
    …do something…
}
```


for

- The value of the counter after the loop is exited is valid and can be tested or used
  - C99: you can declare your counter in the for loop

```
for ( i = 0; i < 10; i++ )
   b *= 2;
printf("b was doubled %d times\n", i);
```

- Some parts of the expression can be missing; default to null statement

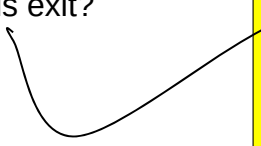
no initialization, i's value determined before the loop is executed

```
for (  ; i < 10; i++ )
   b *= 2;
```

`break` Statement

- Terminates execution of closest enclosing **`for`**, **`while`**, **`do`**, or **`switch`** statement

which loop(s) does this exit?



```
b = 0;
for ( i = 0; i < 10; i++ ) {
   for (j = 0; j < 5; j++) {
      if (a[i][j] > 100)
         break;
      b += a[j];
   }
   printf("b = %d\n", b);
}
```

Unlike Java, there is no labeled **`break`**

See: http://download.oracle.com/javase/tutorial/java/nutsandbolts/branch.html for example of a labeled break in Java.

`continue` Statement

- For bypassing 1 iteration of the innermost loop
  - but not exiting the loop altogether
- Example

```
b = 0;
for ( i = 0; i < 10; i++ ) {
   for (j = 0; j < 5; j++) {
      if (a[i][j] > 100)
         continue;
      b += a[i][j];
   }
   printf("b = %d\n", b);
}
```

The `goto`

- Add symbolic labels (`thisisalabel:`)to arbitrary points in your program
- `goto <label>;` transfers control to that point

`goto`… (cont'd)

- General consensus: avoid using `goto`'s

```
label6: …code here…
        if (something) goto label4;
label3: …code here…
        if (something) goto label2;
label4: ….code here…
        if (something) goto label3;
label2: …code here…
        if (something) goto label5;
…
```

goto… (cont'd)

- Common exception: use for global exits (program termination)

```
for (…)
   for (…)
      for (…) {
         …
         if (disaster)
            goto whoops;
      }
…
whoops:
   /* clean up the mess here
      and abort execution */
```


Exercise

★ you try it ★
Flow of control

1. What are d and g equal to after...
   - Relate it to other variables

```
int a = 2, b = 3;
int x = 40, y = 30;
if (a < b)
{
    d = e;
if (x > y)
    g = h;
}
else
    d = f;
```

2. Write an equivalent switch statement

```
unsigned int a;...
if ((a > 1) && (a <= 3))
    printf("process now\n");
else if (a == 5)
    printf("defer til later\n");
else if (a < 7)
    ;
else
    printf("invalid code\n");
```