Chapter 12
Variables and Operators

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Basic C Elements

Variables

- A data item upon which the programmer performs an operation

Operators

- Predefined actions performed on data items
- Combined with variables to form expressions, statements

Statements and Functions

- Group together operations

Variable Properties

Identifier: variable name

Type: how data is interpreted, and how much space it needs

Scope: is the region of the program in which the variable is alive and accessible

Storage: how C compiler allocates storage and whether or not the variable loses its value when the block that contains it has completed execution

Identifier: Variable Names

Any combination of letters, numbers, and underscore (_)

Case sensitive

- "sum" is different than "Sum"

Cannot begin with a number

- Usually, variables beginning with underscore are used only in special library routines

Only first 31 characters are definitely used

- Implementations can consider more characters if they like

Identifier Examples

Legal

```
i
wordsPerSecond
words_per_second
_green
aReally_longName_moreThan31chars
aReally_longName_moreThan31characters
```

same identifier

Illegal

```
10sdigit
ten'sdigit
done?
double
```

reserved keyword

Types

C has several basic data types

`int`	integer (at least 16 bits, commonly 32 bits)
`long`	integer (at least 32 bits)
`float`	floating point (at least 32 bits)
`Double`	floating point (commonly 64 bits)
`char`	character (at least 8 bits)

Exact size can vary, depending on processor

- int is supposed to be "natural" integer size; for LC-3, that's 16 bits -- 32 bits for most modern processors

Signed vs unsigned:

- Default is 2's complement signed integers
- Use "**unsigned**" keyword for unsigned numbers

Additional to Data Type

Literal

- Unnamed constants that appear literally in source code.

Constants

- Variables whose values do not change during the execution of the program
- This done by appending 'const" before the type

Symbols

- Are values defined by using #define
- Values stay constant during single execution of the program but which might be different for different runs or from user to user

Literals

Integer

```
123   /* decimal */
-123
0x123 /* hexadecimal */
```

Floating point

```
6.023
6.023e23   /* 6.023 x 10^23 */
5E12       /* 5.0 x 10^12 */
```

Character

```
'c' or 'cat'
'\n'   /* newline */
'\xA' /* ASCII 10 (0xA) */
```

Constants vs. Symbol

#define RADIUS 15.0 → symbol

int main(){
 const double pi = 3.14159; (pi → constant; 3.14159 → literal)
 double area;
double circum;

area = pi * RADIUS * RADIUS;
 circum = 2 * pi * RADIUS;
}

Scope: Global and Local

Where is the variable accessible?
Global: accessed anywhere in program
Local: only accessible in a particular region

Compiler infers scope from where variable is declared
- Programmer doesn't have to explicitly state

Variable is local to the block in which it is declared
- Block defined by open and closed braces { }
- Can access variable declared in any "containing" block

Global variable is declared outside all blocks

Local vs. Global Example

```
#include <stdio.h>
int itsGlobal = 0;

int main()
{
 int itsLocal = 1;   /* local to main */
 printf("Global %d Local %d\n", itsGlobal, itsLocal);
 {
   int itsLocal = 2;   /* local to this block */
   itsGlobal = 4;      /* change global variable */
   printf("Global %d Local %d\n", itsGlobal, itsLocal);
 }
 printf("Global %d Local %d\n", itsGlobal, itsLocal);
}
```

Not the same as itsLocal

```
Output:
Global 0 Local 1
Global 4 Local 2
Global 4 Local 1
```


Storage Class of a Variable

- Indicates how the C compiler allocates storage
- Whether or not the variable loses its value when the block that contains it has completed execution

Two kinds:

Static
- Retain their values between invocations
- Global variables are static storage class

Automatic
- Lose their values when the their block terminates
- Local variables are automatic storage class by default
- Local variable can be made static by placing the keyword static before the variable
  - E.g. static int local

Tracking Variables

Tracking
- C compiler keeps tracks of variable name (along with additional information) in a symbol table
- This is similar to LC3 assembler's symbol table

Identifier	Type	Location (offset)	Scope	Other Info

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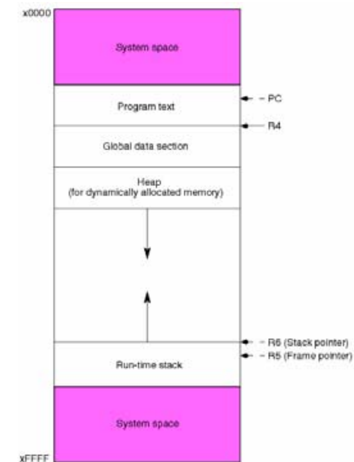
Memory Allocation in C for Variables

- Global Data section for global variables
- Run-time stack section for local variables
- Heap section for dynamically allocated memory
- Will go in detail how the Memory allocation works in chp 14. But for now skip section 12.5.2…



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Expression

Expression
- Any combination of variables, constants, operators, and function calls
- Every expression has a type, derived from the types of its components (according to C typing rules)

Examples:

```
counter >= STOP
x + sqrt(y)
x & z + 3 || 9 - w-- % 6
```

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Statement

Expresses a complete unit of work
- Executed in sequential order

Simple statement ends with semicolon (note: ";" is not a comment in C)

```
z = x * y; /* assign product to z */
y = y + 1; /* update y */
 ;  /* null statement */
```

Compound statement formed with braces
- Syntactically equivalent to a simple statement

```
{ z = x * y; y = y + 1; }
```

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Operators

Three things to know about each operator

(1) Function

- What does it do?

(2) Precedence

- In which order are operators combined?
- Example:
  "a * b + c * d" is the same as "(a * b) + (c * d)"
  because multiply (*) has a higher precedence than addition (+)

(3) Associativity

- In which order are operators of the same precedence combined?
- Example:
  "a - b - c" is the same as "(a - b) - c"
  because add/sub associate left-to-right

Assignment Operator

Changes the value of a variable

```
x = x + 4;
```

1. Evaluate right-hand side.

2. Set value of left-hand side variable to result.

LC3 code:

```
;assume addr of variable x is in R5 for now
LDR R0, R5, #0
ADD R0, R0, #4
STR R0, R5, #0
```


Assignment Operator (contd..)

All expressions evaluate to a value (even ones with the assignment operator i.e. y = x = 3)

For assignment, the result is the value assigned

- Usually (but not always) the value of the right-hand side
  - Type conversion might make assigned value different than computed value e.g. int x = 15.6/3 = 5

Assignment associates right to left.

```
y = x = 3;
```

y gets the value 3, because (x = 3) evaluates to the value 3

```
y = (x = 3);
```


Arithmetic Operators

Symbol	Operation	Usage	Precedence	Assoc
*	multiply	x * y	6	l-to-r
/	divide	x / y	6	l-to-r
%	modulo	x % y	6	l-to-r
+	addition	x + y	7	l-to-r
-	subtraction	x - y	7	l-to-r

All associate left to right

`* / %` have higher precedence than `+ -`

Example

- 2 + 3 * 4 vs. (2 + 3) * 4
- 2 * 4 % 5

Arithmetic Expressions

If mixed types, smaller type is "promoted" to larger

- Example: `x + 4.3`
- if x is int, converted to double and result is double

Integer division -- fraction is dropped

- Example: `x / 3`
- if x is int and x=5, result is 1 (not 1.666666...)

Modulo -- result is remainder

- Example: `x % 3`
- if x is int and x=5, result is 2

Bitwise Operators

Symbol	Operation	Usage	Precedence	Assoc
`~`	bitwise NOT	`~x`	4	r-to-l
`<<`	left shift	`x << y`	8	l-to-r
`>>`	right shift	`x >> y`	8	l-to-r
`&`	bitwise AND	`x & y`	11	l-to-r
`^`	bitwise XOR	`x ^ y`	12	l-to-r
`|`	bitwise OR	`x | y`	13	l-to-r

Operate on variables bit-by-bit

- Like LC-3 AND and NOT instructions

Shift operations

- Operate on *values* -- neither operand is changed
- `x = y << 1` same as `x = y+y`

Logical Operators

Symbol	Operation	Usage	Precedence	Assoc
`!`	logical NOT	`!x`	4	r-to-l
`&&`	logical AND	`x && y`	14	l-to-r
`||`	logical OR	`x || y`	15	l-to-r

Treats entire variable (or value) as

- TRUE (non-zero), or
- FALSE (zero)

Result is 1 (TRUE) or 0 (FALSE)

- `x = 15; y = 0; printf("%d", x || y);`

Bit-wise vs Logical

- 1 & 8 = 0 (000001 AND 001000 = 000000)
- 1 && 8 = 1 (True & True = True)

…C and the Right Shift Operator (>>)

Does right shift sign extend or not?

- Answer: Yes and No

Unsigned values: zero extend

- `unsigned int x = ~0;`
- Then, `(x >> 10)` will have 10 leading zeros

Signed values:

- "Right shifting a *signed* quantity will fill with sign bits ("arithmetic shift") *on some machines* and with 0-bits ("logical shift") *on others*." - Kernighan and Ritchie
- In practice, it does sign extend
  - `int x = ~0; /* signed */`
  - Then, `(x >> 10)` will still be all 1s

Relational Operators

Symbol	Operation	Usage	Precedence	Assoc
>	greater than	`x > y`	9	l-to-r
>=	greater than or equal	`x >= y`	9	l-to-r
<	less than	`x < y`	9	l-to-r
<=	less than or equal	`x <= y`	9	l-to-r
==	equal	`x == y`	10	l-to-r
!=	not equal	`x != y`	10	l-to-r

Result is 1 (TRUE) or 0 (FALSE)

Assignment vs. Equality

Don't confuse equality (==) with assignment (=)

```
int x = 9;
int y = 10;
if (x == y) {
  printf("not executed\n");
}
if (x = y) {
  printf("x = %d y = %d", x, y);
}
```

Result: "x = 10 y = 10" is printed. Why?

Compiler will not stop you! (What happens in Java?)

Special Operators: ++ and --

Changes value of variable before (or after) its value is used in an expression

Symbol	Operation	Usage	Precedence	Assoc
++	postincrement	`x++`	2	r-to-l
--	postdecrement	`x--`	2	r-to-l
++	preincrement	`++x`	3	r-to-l
--	predecrement	`--x`	3	r-to-l

Pre: Increment/decrement variable before using its value

Post: Increment/decrement variable after using its value

Using ++ and --

```
x = 4;
y = x++;
```

Results: x = 5, y = 4
(because x is incremented after assignment)

```
x = 4;
y = ++x;
```

Results: x = 5, y = 5
(because x is incremented before assignment)

Special Operators: +=, *=, etc.

Arithmetic and bitwise operators can be combined with assignment operator

Statement	Equivalent assignment
`x += y;`	`x = x + y;`
`x -= y;`	`x = x - y;`
`x *= y;`	`x = x * y;`
`x /= y;`	`x = x / y;`
`x %= y;`	`x = x % y;`
`x &= y;`	`x = x & y;`
`x |= y;`	`x = x | y;`
`x ^= y;`	`x = x ^ y;`
`x <<= y;`	`x = x << y;`
`x >>= y;`	`x = x >> y;`

All have same precedence and associativity as = and associate right-to-left.

Special Operator: Conditional

Symbol	Operation	Usage	Precedence	Assoc
`?:`	conditional	`x?y:z`	16	l-to-r

x ? y : z

- If x is non-zero, result is y
- If x is zero, result is z

Seems useful, but don't use it

- A normal "if" is almost always more clear
- You don't need to use every language feature

Practice with Precedence

Assume a=1, b=2, c=3, d=4

```
x = a * b + c * d / 2;   /* x = 8 */
```

same as:

```
x = (a * b) + ((c * d) / 2);
```

For long or confusing expressions, use parentheses, because reader might not have memorized precedence table

Note: Assignment operator has lowest precedence, so all the arithmetic operations on the right-hand side are evaluated first