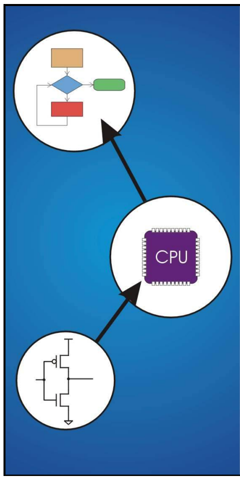


Chapter 12
Variables and Operators

Original slides from Gregory Byrd, North Carolina State University

Modified slides by Chris Wilcox, Colorado State University

Basic C Elements

- Variables
  - named, typed data items
- Operators
  - predefined actions performed on data items
  - combined with variables to form expressions, statements
- Rules and usage
- Implementation using LC-3 instructions

Data Types

- C has three basic data types

int	integer (at least 16 bits)
double	floating point (at least 32 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, LC-3 does not have **double**
  - **int** on a modern processor is usually 32 bits, **double** is usually 64 bits

Variable Names: Rules

- Any combination of letters, numbers, and underscore (_)
- Case matters
  - "sum" is different than "Sum", "printf" is not "Printf", and "while" is not "WHILE".
- Cannot begin with a number
  - usually variables beginning with underscore are used only in special library routines
- Restricted length?
  - compiler dependent, older implementations recognized as few as 31 characters

Variable Names: Customs

- Separate words with underscores (`big_dog`) or CamelCase (`bigDog`)
- Lowercase for variables (`buffer`)
- All caps for constants (`BUFFER_LENGTH`), whether via `#define` or `const`
- Capitalized for structures (`struct Packet`)

Examples

- *Legal*

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

same identifier

- *Illegal*

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

reserved keyword

Literals

- Integer

```
123         // decimal
-0123       // octal (leading 0)
0x123       // hexadecimal (0x)
```

- Floating point

```
6.023       // double
6.023e23    // double, 6.023 x 10^23
5E12f       // float, 5.0 x 10^12
```

- Character

```
'c'
'\n'  // newline
'\xA' // character code 10 (0xA)
```


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 in the program
  - 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 variables are declared outside all blocks

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);
}
```

Output

```
Global 0 Local 1
Global 4 Local 2
Global 4 Local 1
```


Operators

- Programmers manipulate variables using the **operators** provided by the high-level language.
- Variables and operators combine to form **expressions** and **statements**.
- These constructs denote the work to be done by the program.
- Each operator may correspond to many machine instructions.
  - Example: The multiply operator (`*`) typically requires multiple LC-3 ADD instructions.

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`

Statement

- Expresses a complete unit of work
  - executed in sequential order
- Simple statement ends with semicolon
  - `z = x * y; /* assign product to z */`
  - `y = y + 1; /* after multiplication */`
  - `; /* null statement */`
- Compound statement groups simple statements using braces.
  - syntactically equivalent to a simple statement
  - `{ z = x * y; y = y + 1; }`

Operators

Three things to know about each operator:

- **(1) Functionality**
  - what does the operator do?
- **(2) Precedence**
  - in which order are operators combined?
  - Example: a * b + c * d is the same as (a * b) + (c * d) since multiply has 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 and subtract 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.

Assignment Operator

- All expressions evaluate to a value, even ones with the assignment operator.
- **For assignment, the result is the value assigned.**
  - usually (but not always) the value of right-hand side
  - type conversion might make assigned value different than computed value
- **Assignment associates right to left.**

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

  - y gets the value 3, because (x = 3) evaluates to the value 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
+	add	`x + y`	7	l-to-r
-	subtract	`x - y`	7	l-to-r

- All associate left to right.
- `* / %` have higher precedence than `+ -`.
- Full precedence chart on page 602 of textbook

Arithmetic Expressions

- **If mixed types, smaller type is "promoted" to larger.**
  - `x + 4.3`
    - if x is int, converted to double and result is double
- **Integer division—fraction is dropped.**
  - `x / 3`
    - if x is int and x=5, result is 1 (not 1.666666...)
- **Modulo—result is remainder.**
  - `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 are logical (not arithmetic).
  - Operate on *values* -- neither operand is changed.

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 of a logcial operation is always either TRUE (1) or FALSE (0).

Relational Operators

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

- Result is 1 (TRUE) or 0 (FALSE).
- **Note: Don't confuse equality (==) with assignment (=)!**

Special Operators: ++ and --

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

- Changes value of variable before (or after) its value is used in an expression.
  - 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 yielding a value)

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

- Results: x = 5, y = 5
  (x is incremented before yielding a value)

Practice with Precedence

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

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

- same as:

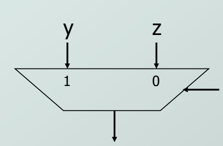
```
x = (a * b) + ((c * d) / 2);
```

- For long or confusing expressions, use parentheses, because reader might not have memorized precedence table.
- Note: Assignment operator has lowest precedence, so operations on the right-hand side are evaluated before assignment.

Special Operator: Conditional

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

- If x is TRUE (non-zero), result is y; else, result is z.
- Like a MUX, with x as the select signal.



Undefined Behavior

- int a;
- int b=5, c = b * ++b;
- int d=8, e = d++ * d++;
- int f=7; f = f++;
- int g=3; printf("%d %d\n", ++g, ++g);
- int alpha() { printf("alpha"); return 1; }
  int beta() { printf("beta"); return 1; }
  int gamma = alpha()+beta();

Experimentation proves *nothing*!

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.

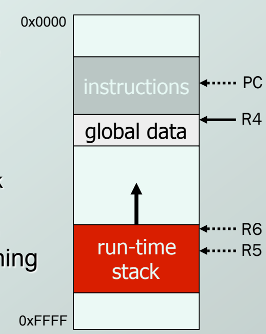
Symbol Table

- Like assembler, compiler needs to know information associated with identifiers
  - in assembler, all identifiers were labels and information is address
- Compiler keeps more information
  - Name (identifier)
  - Type
  - Location in memory
  - Scope

Name	Type	Offset	Scope
amount	int	0	main
hours	int	-3	main
minutes	int	-4	main
rate	int	-1	main
seconds	int	-5	main
time	int	-2	main

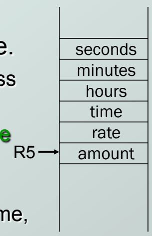
Allocating Space for Variables

- **Global data section**
  - All global variables stored here
    R4 points to beginning
- **Run-time stack**
  - Used for local variables
  - R6 points to top of stack
  - R5 points to top frame on stack
  - New frame for each block
    (goes away when block exited)
- Offset = distance from beginning of storage area
  - Global: `LDR R1, R4, #4`
  - Local: `LDR R2, R5, #-3`



Local Variable Storage

- Local variables are stored in an *activation record*, also known as a *stack frame*.
- Symbol table "offset" gives the distance from the base of the frame.
  - R5 is the frame pointer – holds address of the base of the current frame.
  - A new frame is pushed on the run-time stack each time a block is entered.
  - Because stack grows downward, base is the highest address of the frame, and variable offsets are <= 0.



Variables and Memory Locations

- In our examples, a variable is always stored in memory.
- When assigning to a variable, must <u>store</u> to memory location.
- A real compiler would perform code optimizations that try to keep variables allocated in registers.

Why?

Example: Compiling to LC-3

```
#include <stdio.h>
int inGlobal;

int main()
{
  int inLocal;   /* local to main */
  int outLocalA;
  int outLocalB;

  /* initialize */
  inLocal = 5;
  inGlobal = 3;

  /* perform calculations */
  outLocalA = inLocal++ & ~inGlobal;
  outLocalB = (inLocal + inGlobal) - (inLocal -
   inGlobal);

  /* print results */
  printf("The results are: outLocalA = %d, outLocalB
   = %d\n", outLocalA, outLocalB);
}
```


Example: Symbol Table

Name	Type	Offset	Scope
inGlobal	int	0	global
inLocal	int	0	main
outLocalA	int	-1	main
outLocalB	int	-2	main