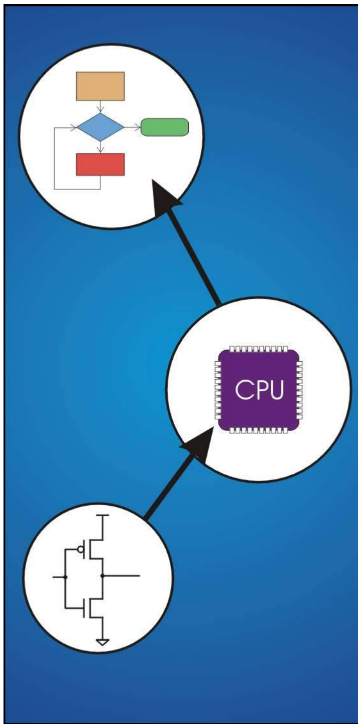


# Chapter 12
# **Variables and Operators**

Original slides from Gregory Byrd, North Carolina State University

Modified slides by C. Wilcox, S. Rajopadhye
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



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# Variable Names

- Any combination of letters, numbers, and underscore (_)
- **Case matters**
  - "sum" is different from "Sum", this is also true of function names
- **Cannot begin with a number**
  - usually variables beginning with underscore are used only in special library routines
- **Only first 31 characters are used**
  - actually that's compiler dependent, so be careful not to create ambiguous variables!

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

- Floating point

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

- Character

```
'c'
'\n'   /* newline */
'\xA' /* ASCII 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



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# Example

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

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
```

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# 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) Function
  - 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 float and result is float
- 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 assignment)

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

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





# Practice with Precedence

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

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

- same as:

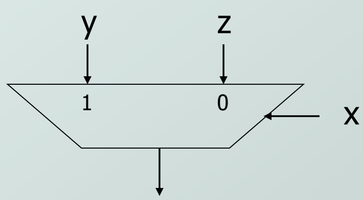
```
x = (a * b) + ((c * d) / 2);
```

- 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.








# 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

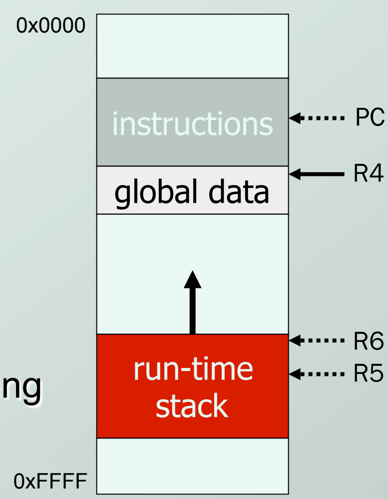
| Name | Type | Offset | Scope |
|---|---|---|---|
| amount | int | 0 | main |
| hours | int | -3 | main |
| minutes | int | -4 | main |
| rate | int | -1 | main |
| seconds | int | -5 | main |
| time | int | -2 | main |





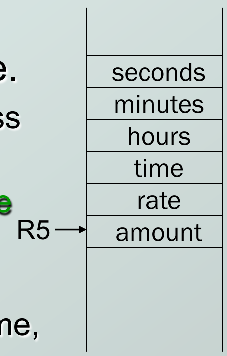
# Allocating Space for Variables

- **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?**