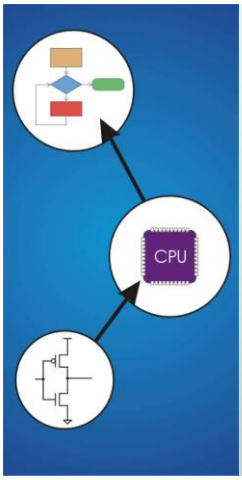



# Chapter 12
# Variables and Operators

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.



Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

## 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)



Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

## 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.

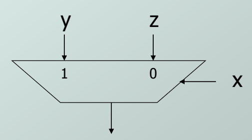


Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

## 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

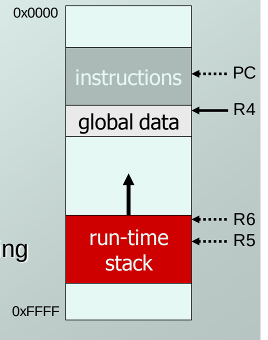
| Name | Type | Offset | Scope |
|---|---|---|---|
| amount | int | 0 | main |
| hours | int | -3 | main |
| minutes | int | -4 | main |
| rate | int | -1 | main |
| seconds | int | -5 | main |
| time | int | -2 | main |





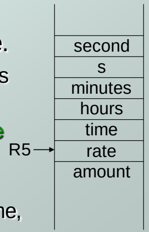
## Allocating Space for Variables

- 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 store 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 |