# C Variables and Operators

# 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

# 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 -- 32 bits for most modern processors

# Variable Names

- Any combination of letters, numbers, and underscore (_)
- Case matters
  - "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 used

# 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
  - 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

# 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
```

# Operators

- Programmers manipulate variables
  using the operators provided by the high-level language.
- Variables and operators combine to form
  expressions and statements
  which 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 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.

# 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 the 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 |
| `+` | addition | `x + y` | 7 | l-to-r |
| `-` | subtraction | `x - y` | 7 | l-to-r |

All associate left to right.

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

# 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

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

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 is 1 (TRUE) or 0 (FALSE).

# 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).

Note: Don't confuse equality (==) with assignment (=).

# 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)

# 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.

# Symbol Table

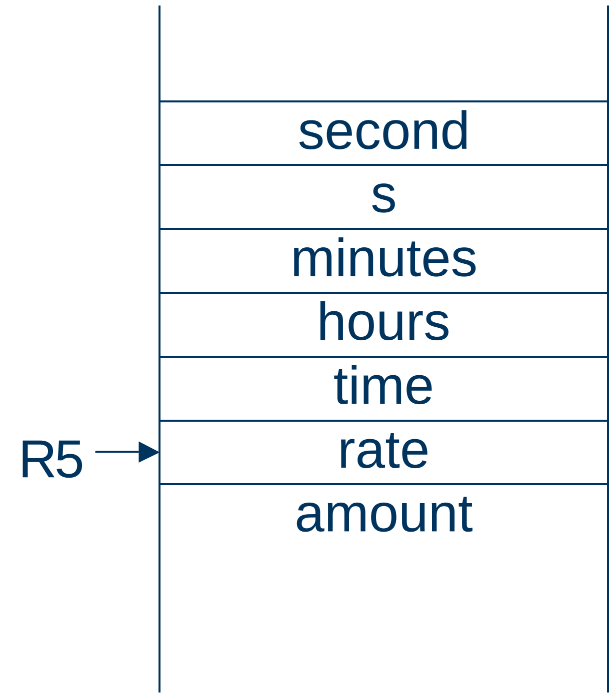
- Like assembler, compiler needs to know information associated with identifiers
  - in assembler, all identifiers were labels and information is address

- 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 |

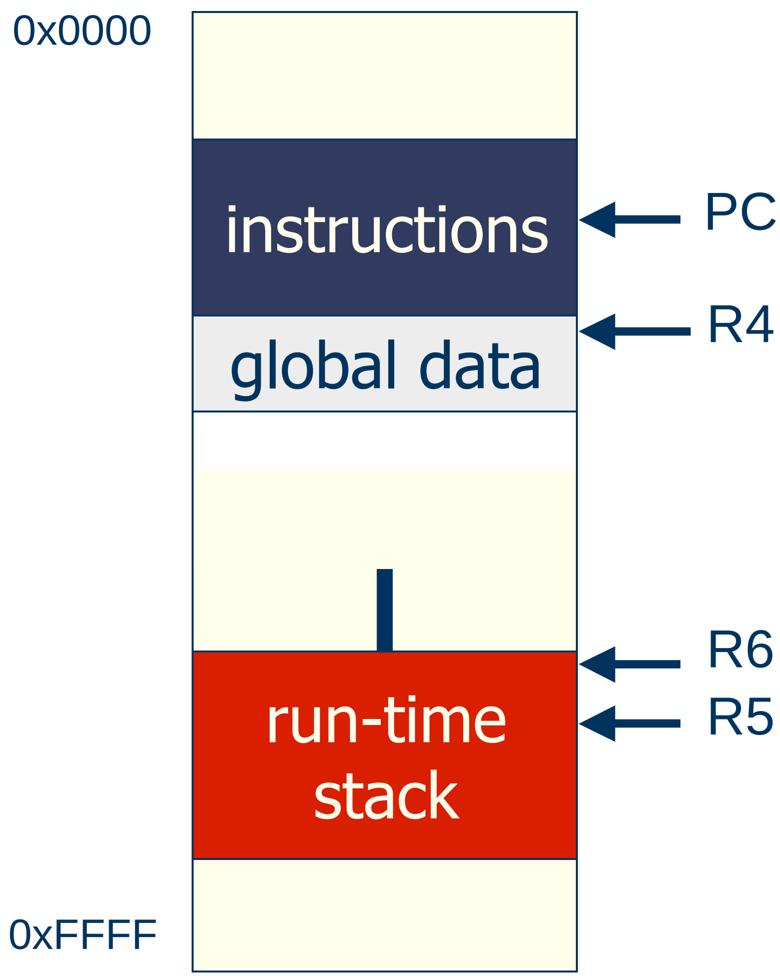
# Local Variable Storage

- 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.



# Allocating Space for Variables

- Global data section
  - All global variables stored here (actually all static variables)
  - 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`



# 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;
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` |

# Example: Code Generation

```
; main
; initialize variables
     AND R0, R0, #0
       ADD R0, R0, #5   ; inLocal = 5
       STR R0, R5, #0   ; (offset = 0)

       AND R0, R0, #0
       ADD R0, R0, #3   ; inGlobal = 3
       STR R0, R4, #0   ; (offset = 0)
```

# Example (continued)

```
; first statement:
; outLocalA = inLocal++ & ~inGlobal;
      LDR R0, R5, #0  ; get inLocal
        ADD R1, R0, #1  ; increment
        STR R1, R5, #0  ; store

        LDR R1, R4, #0  ; get inGlobal
        NOT R1, R1      ; ~inGlobal
        AND R2, R0, R1  ; inLocal & ~inGlobal
        STR R2, R5, #-1 ; store in outLocalA
                        ; (offset = -1)
```

## Example (continued)

```
; next statement:
; outLocalB = (inLocal + inGlobal)
  ;              - (inLocal - inGlobal);
     LDR R0, R5, #0  ; inLocal
       LDR R1, R4, #0  ; inGlobal
       ADD R0, R0, R1  ; R0 is sum
       LDR R2, R5, #0  ; inLocal
       LDR R3, R5, #0  ; inGlobal
       NOT R3, R3
       ADD R3, R3, #1
       ADD R2, R2, R3  ; R2 is difference
       NOT R2, R2      ; negate
       ADD R2, R2, #1
       ADD R0, R0, R2  ; R0 = R0 - R2
       STR R0, R5, #-2 ; outLocalB (offset = -2)
```

# 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 |

If x is TRUE (non-zero), result is y;
else, result is z.

Like a MUX, with x as the select signal.