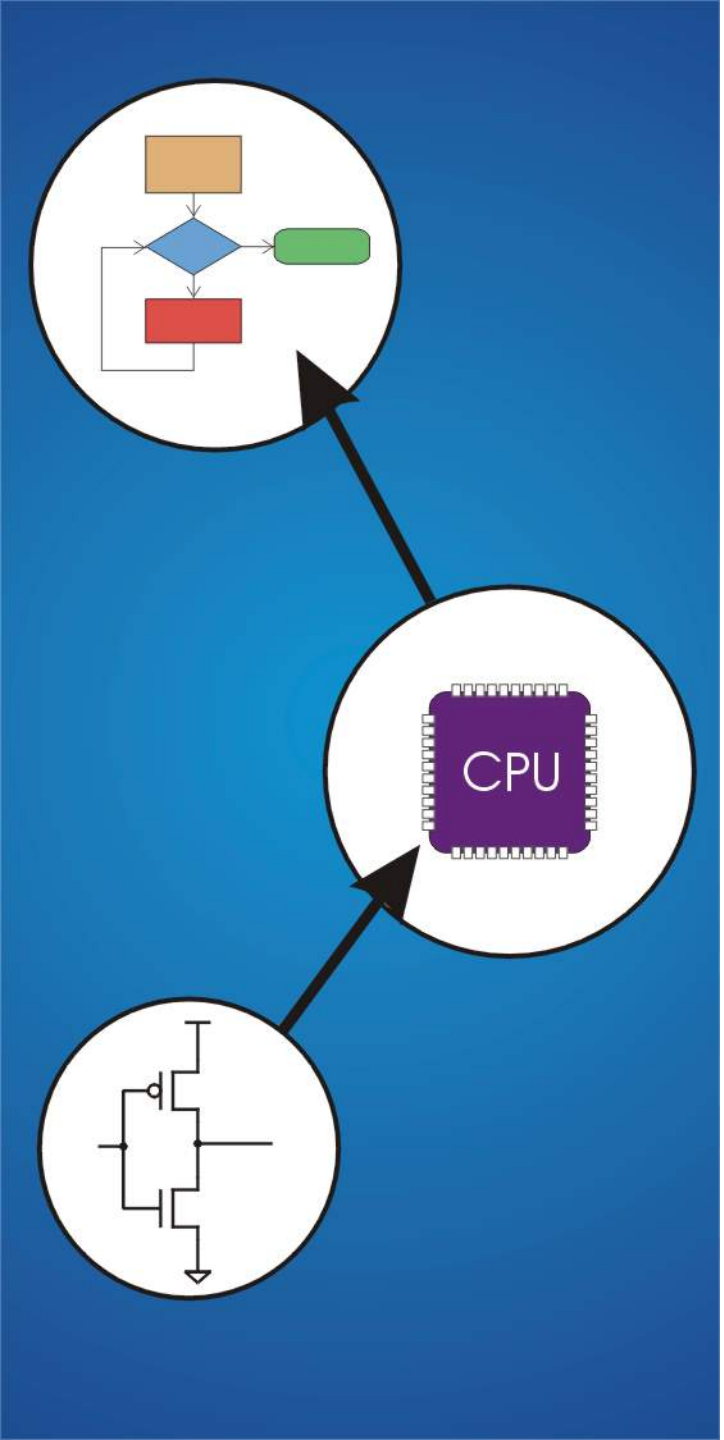


variable — type, initial value, scope

expression of { value / side-effect

statement

x+y++
x=y

Chapter 12
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

(_)로 시작 OS, Library에서 사용.

- **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**

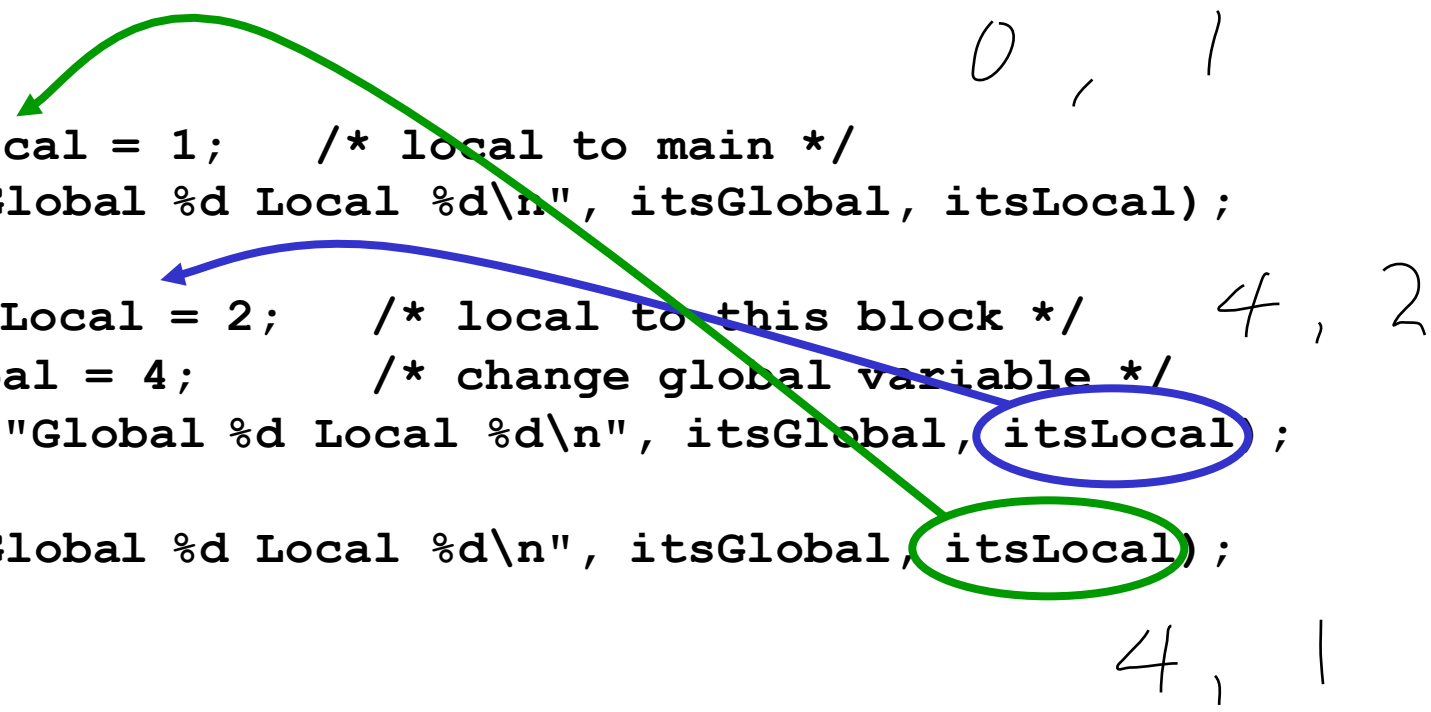
Variable is local to the block in which it is declared

- **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
```

side effect (?)

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)**

bitwise
&, |

logical
&&, ||

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 우선순위

- 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 결합법칙

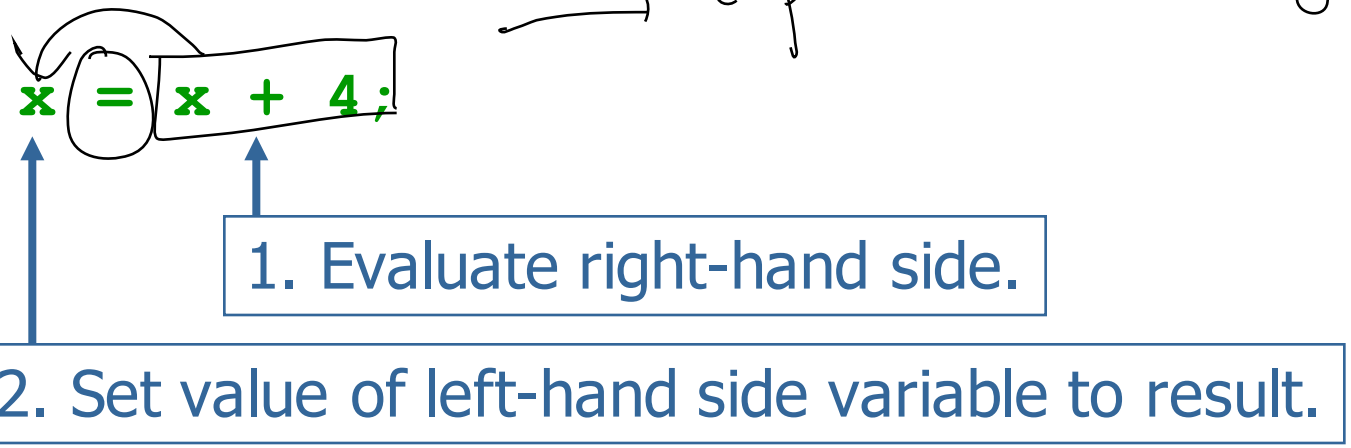
- in which order are operators of the same precedence combined?
- Example:
  "a - b - c" is the same as "(a - b) - c"
  because add/sub associate left-to-right

Assignment Operator

side-effect???

Changes the value of a variable.

expression = assign되는 값.



Assignment Operator

연산자의 오른쪽에 있는 값을 연산자의 왼쪽에 있는 변수에 넣는 것을 나타내는 연산자

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

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 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**

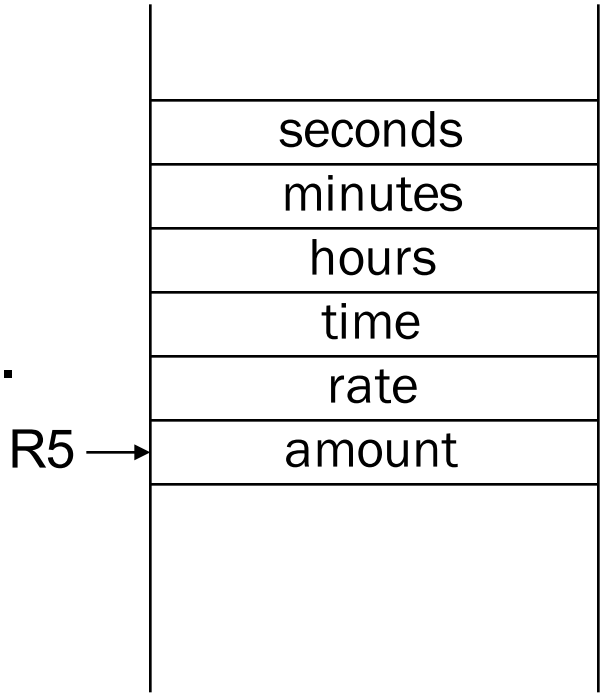
Name	Type	Offset	Scope
amount	int	0	main
hours	int	-3	main
minutes	int	-4	main
rate	int	-1	main
seconds	int	-5	main
time	int	-2	main

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

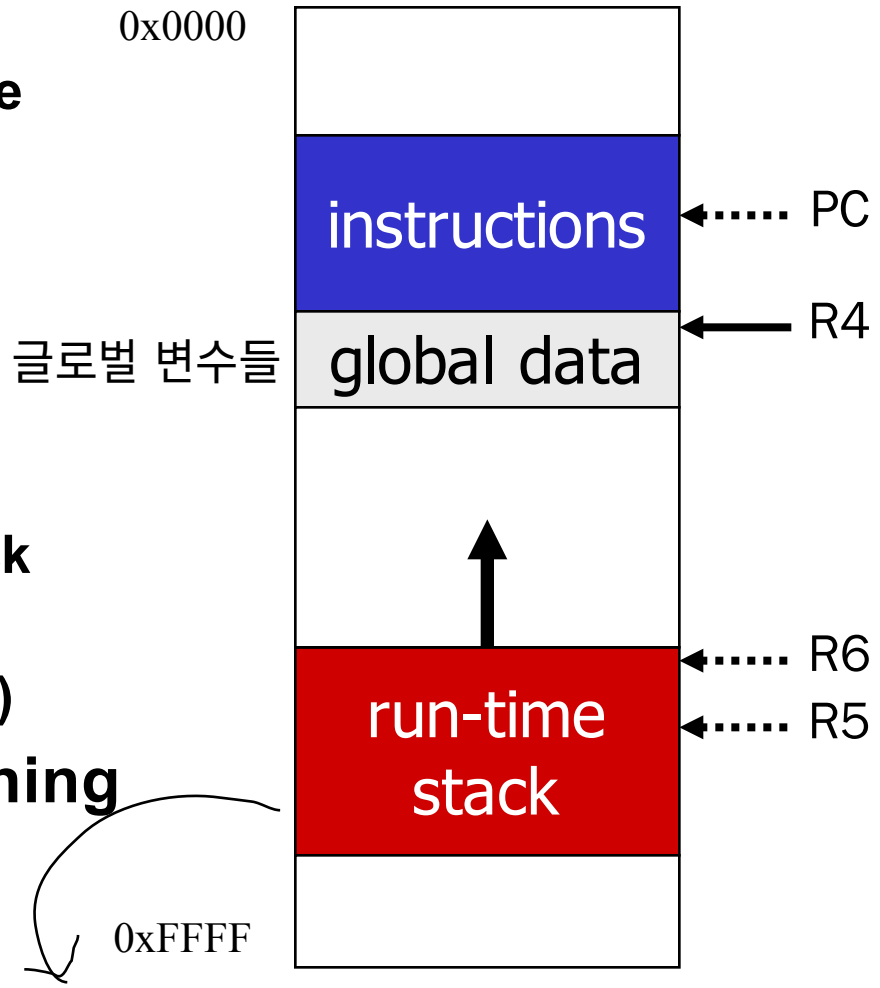
- All global variables stored here (actually all static variables)
- R4 points to beginning

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`



함수, 변수들은 스택에 들어간다.

Variables and Memory Locations

In our examples,
a variable is always stored in memory.

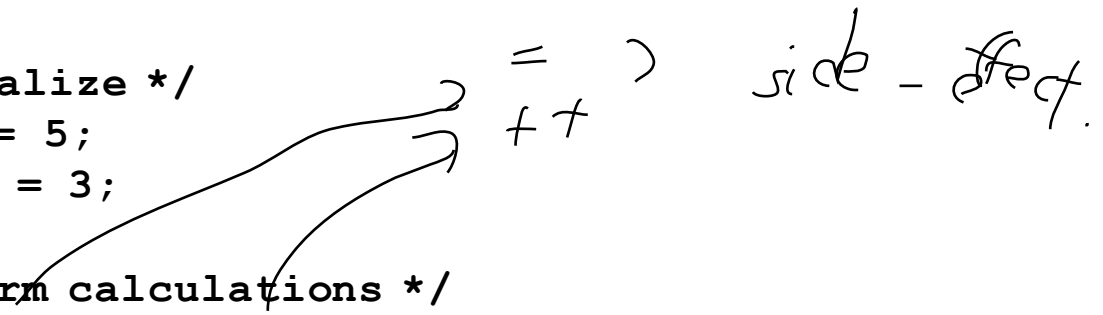
When assigning to a variable,
must store to memory location.

A real compiler would perform code optimizations that try to keep variables allocated in registers.

Why?

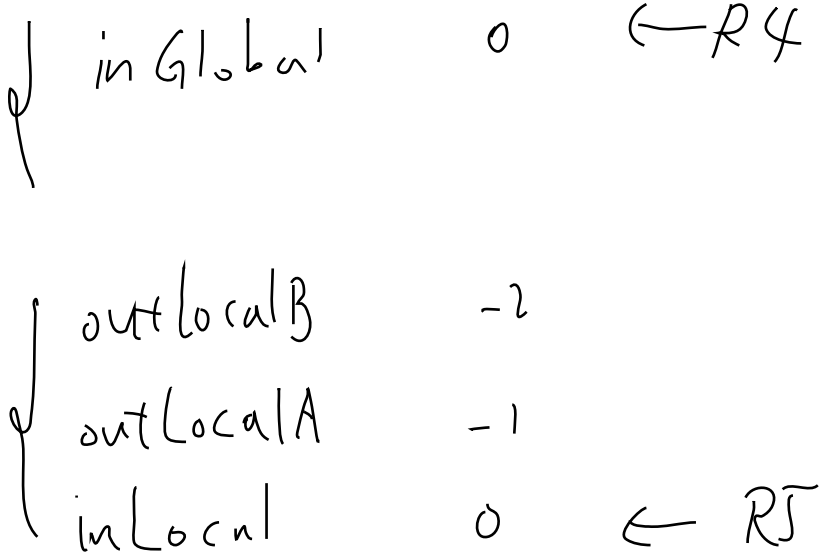
Example: Compiling to LC-3

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

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)
```

Local

global

Example (continued)

```
; first statement:
; outLocalA = inLocal  & ~inGlobal;
        LDR R0, R5, #0   ; get inLocal
        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 (inLocal + inGlobal)
      LDR R2, R5, #0   ; inLocal
      LDR R3, R4, #0   ; inGlobal
      NOT R3, R3
      ADD R3, R3, #1
      ADD R2, R2, R3   ; R2 is diff (inLocal - inGlobal)
      NOT R2, R2       ; negate
      ADD R2, R2, #1
      ADD R0, R0, R2   ; (inLocal + inGlobal) - inLocal - inGlobal)
      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.