Chapter 2

- Simple Programs
- Simple I/O
- Fundamental data types: Numbers, Strings
- Arithmetic operators
- **Memory concepts**
- “Decision-making”

C

- C is an **imperative** programming language
  — in a program, you “give orders to the computer”
- This is also called **procedural programming**
  — a program reflects the procedure how things are done
- Named (sub-)procedures are called **functions** in C
- Executing a program invokes its *main* function
- Comments /* … */ are code-level **documentation**
- The textbook **rightly promotes** **<u>commenting a lot</u>**

Read: Textbook Chapter 2

- Style conventions
- Comments!
- What is a keyword?
- Note: `int main()`
- `scanf(` *`format`*`,` ***`addresses`*** `);`
  e.g.: *scanf* ("%d", &*temp*);

Message Repetition Utility

```
#include <stdio.h>                      /* message.c */
int main () {
  char message[100];        /* Message to be displayed */
  int count;                /* Number of times message is to be displayed */
  int i;                    /* Loop counter */

  printf( "Enter count: " );          /* prompt */
  scanf( "%d", &count );              /* read an integer */
  printf( "Enter message: " );        /* prompt */
  scanf( "%s", message );             /* read the message */
  for ( i = 1; i ≤ count; i++ ) {     /* count times … */
    printf(message);                  /* print the message */
    printf( "\n" );
  }
  return 0;
}
```

Linux Output

```
$ ./message
Enter count: 2
Enter message: 5%rebate
5%rebate
5%rebate
$ ./message
Enter count: 2
Enter message: 10%discount
10-1073752496iscount
10-1073752496iscount
$ ./message
Enter count: 2
Enter message: ThisIs100%stupid
ThisIs100ThisIs100%stupidtupid
ThisIs100ThisIs100%stupidtupid
```


Read: Textbook Chapter 2 — Arithmetic

- Review **operator precedence**!
- Laws for integer division and modulo:

$$(n\ /\ k) * k + n \% k = n$$

$$abs(\ n \% k\ ) < abs(k)$$

  This is not a unique characterization!

  Exercise: Write a C program to test the behaviour of integer division and modulo.

  Run it on as many different platforms as you can!

  For each kind of behaviour you observe, provide additional laws that uniquely characterize that behaviour.

Read: Textbook Chapter 2

- Style conventions
- Comments!
- What is a keyword?
- Note: **`int`** `main()`
- `scanf(` *`format`*`,` ***`addresses`*** `);`

  e.g.: *scanf* ("%d", &*temp*);
- Format strings should be **string constants!**

  Otherwise, if values of variables are user-provided, **format string attacks** may become possible.

Floating Point Arithmetic

- **Associativity** of mathematical addition: $(a + b) + c = a + (b + c)$
- Floating point addition is **not associative**:

```
#include <stdio.h>                                  /* addAssoc.c */
int main () {                   /* x + (x + y) =?= (x + x) + y */
  float x = 1e–16, y = 1.0; xx = x+x, xy = x+y;
  printf ("%.18f =?= %.18f\n", x + xy, xx + y);
  double a = 1e–16, b = 1.0; aa = a+a, ab = a+b;
  printf ("%.18f =?= %.18f\n", a + ab, aa + b);
  return 0;
}
```

```
2S> gcc -std=c99 -pedantic -Wall -o addAssoc addAssoc.c
2S> ./addAssoc
1.000000000000000000 =?= 1.000000000000000222
1.000000000000000000 =?= 1.000000000000000222
2S> gcc -ansi -pedantic -Wall -O3 -o addAssoc addAssoc.c
2S> ./addAssoc
1.000000000000000000 =?= 1.000000000000000000
1.000000000000000000 =?= 1.000000000000000222
```

Chapter 3: Structured Program Development in C

- **Refinement**
- "single-selection statement": ***if*** … ***then*** …
- "double-selection statement": ***if*** … ***then*** … ***else*** …
- `while`-loops:
  - "counter-controlled repetition"
  - "sentinel-controlled repetition"
- Increment and decrement operators, updating assignment operators

Refinement Example

- Pseudocode can be written in a very abstract, high-level way

> – Read $r_0, \ldots, r_{2N-2}$
>
> – Construct the Toeplitz matrix
>
> – Print the Toeplitz matrix

Refinement Example

- Pseudocode can be written in a very abstract, high-level way
- Pseudocode can be **refined** by lowering the level of abstraction

> – Read $r_0, \ldots, r_{2N-2}$
>   - Prepare array with indices 0 to $2N - 2$
>   - For each index i of this array, obtain r_i from user
>
> – Construct the Toeplitz matrix
>   - …
>
> – Print the Toeplitz matrix

Refinement

- Pseudocode can be written in a very abstract, high-level way
- Pseudocode can be **refined** by lowering the level of abstraction
- **Stepwise refinement** is **good software engineering practice**
- Pseudocode at the *same level as C* is **dangerous**, since usually less precise.
- Refinement is usually performed on **specifications**
  — 2AA and more advanced courses.

Structured Programming (in C)

Composing programs from

- **expressions** and
- **primitive statements** (assignments, procedure calls)

using **control structures** at the level of:

- **sequencing**: P_1`;` P_2
- **conditional** (**selection**): `if (` *condition* `)` S_1 `else` S_2
- **while-loops**: `while (` *condition* `)` S_1
- **for-loops**: `for (` S_1 `;` *condition* `;` S_2 `)` S_3
- **blocks** (**compound statements**): `{` P_1 `}`

Flowcharts — Control Flow Graphs

- **Many decades ago**, flowcharts were used in software design.
- A flowchart has **less structure** than the corresponding structured C program
- Therefore, flowcharts are **not useful** in design and refinement
- The flowcharts given in the book serve as **visualizations** of the control flow — they are **control flow graphs** derived from the programs

Unstructured Programming

`goto`

The Simplest Statement

The Simplest Program

/* empty.c */

void *main* () {}

`if`

Conditional statement (“**double-selection statement**”):

if *condition* ***then*** S_1 ***else*** S_2

In C:

`if (` *condition* `)` S_1 `else` S_2

The “**single-selection statement**”

`if (` *condition* `)` S_1

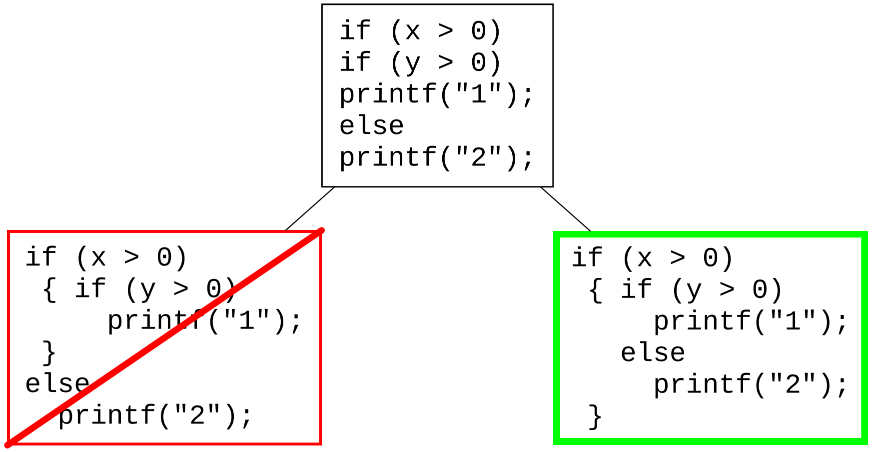
is an abbreviation for:

`if (` *condition* `)` S_1 `else {}`

It is good style to make this explicit!

Dangling `else`

What is the structure of the following “nested `if`”?



Every `else` belongs to the “***closest possible***” `if`.

The Use of the Conditions in Conditionals

```
float floatMax(float x, float y) {
 if (x > y) {
       assert (x > y);        // the if-condition is true here!
   return x;
 }
 else {
       assert ( !(x > y) );   // the negation of the if-condition is true here!
       assert ( x ≤ y );      // equivalent assertion
       assert ( y ≥ x );      // equivalent assertion, showing that y is maximum
   return y;
 }
}
```

- Assertions are used as machine-checkable **documentation**
- “*assert* ($x > y$);” reads “$x > y$ is true here”

The Use of the Conditions in Conditionals (ctd.)

Integer comparison function $intcmp(x,y) = \begin{cases} 1 & \text{if} \quad x > y \\ 0 & \text{if} \quad x = y \\ -1 & \text{if} \quad x < y \end{cases}$

```
int intcmp(int x, int y) {
  if (x > y) {
        assert (x > y);        // the if-condition is true here!
    return 1; }
  else {
        assert ( !(x > y) );   // the negation of the if-condition is true here!
        assert ( x ≤ y );      // equivalent assertion
     if (x == y) {
        assert (x == y);       // the inner if-condition is true here!
      return 0;
     }
     else {
        assert ( x ≤ y  &&  x ≠ y ); // both if-conditions are false here!
        assert ( x < y );      // equivalent assertion
      return –1; } }
}
```


Conditional Expressions (p. 62)

- Many (functional) programming languages have **conditional expressions**:

```
max (x,y)  =  if x > y then x else y
fact n  =  if n == 0 then 1 else n * fact (n-1)
```

- C has conditional expressions, too, but with a strange syntax:

$$condition \; ? \; expr_1 : expr_2$$

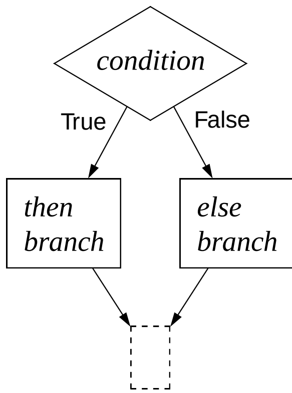
(There can be no one-way version of conditional **expressions**!)

Example:

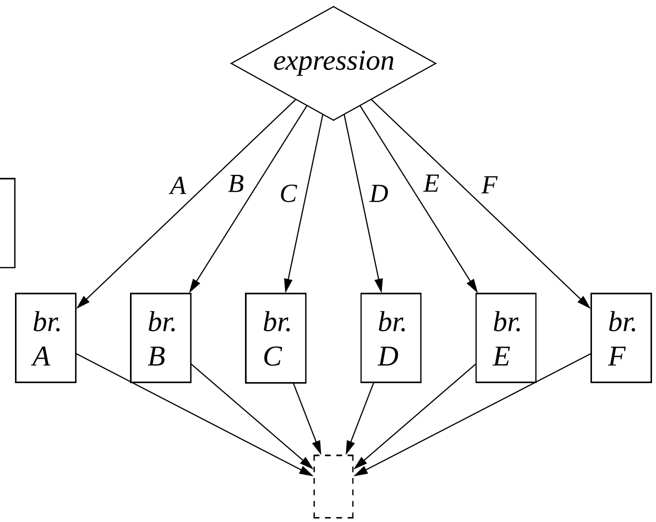
```
float floatMax(float x, float y)
{
  return x > y ? x : y ;
}
```


Multiple Selection

Double Selection

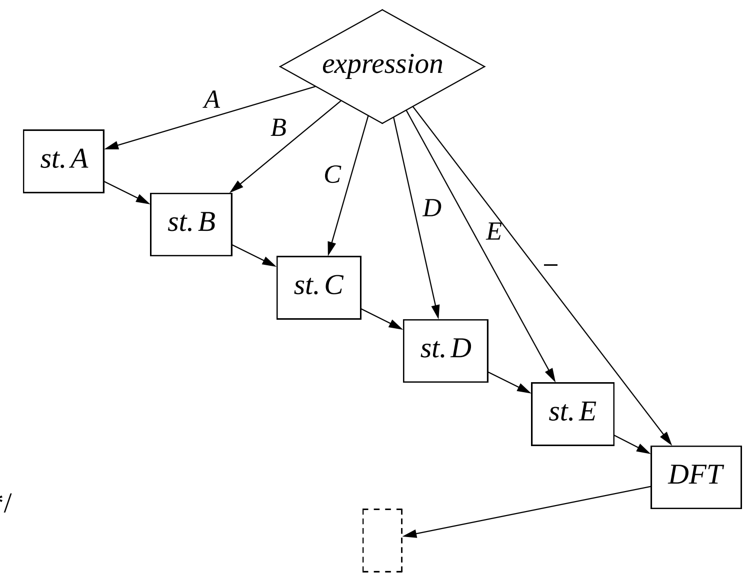


Multiple Selection



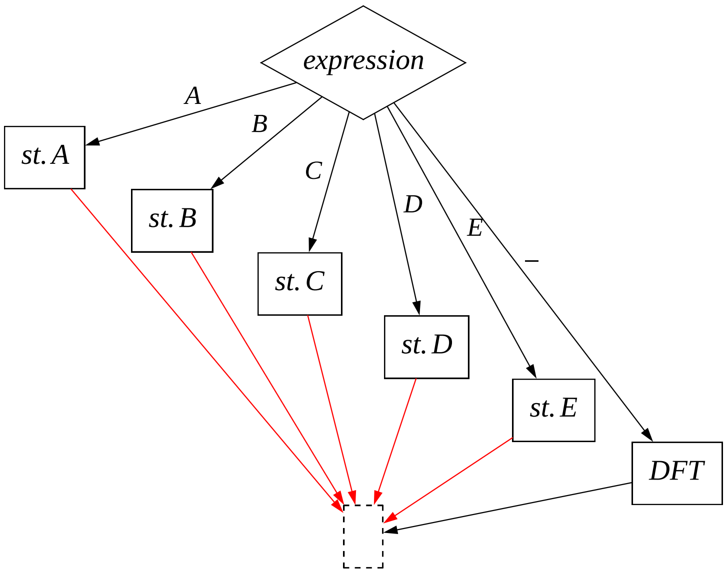
`switch` Statement

```
switch (expr) {
  case A:
    stmtsA;
  case B:
    stmtsB;
  case C:
    stmtsC;
  case D:
    stmtsD;
  case E:
    stmtsE;
  default:
    stmtsDFT;
} /* end switch */
```



`switch` used as Multiple-Selection Statement

switch (*expr*) {
  case *A*:
    stmtsA;
    break;
  case *B*:
    stmtsB;
    break;
  case *C*:
    stmtsC;
    break;
  case *D*:
    stmtsD;
    break;
  case *E*:
    stmtsE;
    break;
  default:
    stmtsDFT;
} /* end switch */



`switch` — Mixed Style

switch (*c*) {
  case 'A':
  case 'a':
    stmtsA;
    break;
  case 'B':
  case 'b':
    stmtsB;
    break;
  ...
  case ' ':
  case '\n':
  case '\t':
    stmtsS;
    break;
  ...
  default:
    stmtsDFT;
} /* end switch */

Attention: it is easy to get mixed up here!

- indent carefully
- document case groups

The `while` Repetition Statement

`while (` *condition* `)` *body*

A single **statement** has to be given as *body*; often, *body* is a block,i.e., a sequence of statements enclosed in braces `{ }`.

Intuitive meaning:

"While *condition* evaluates to true, execute *execute*."

More precisely — **operational semantics**:

(1) Evaluate *condition*

(2) If result is false, execution of the `while` statement is finished

(3) Otherwise, execute *body*

(4) Resume from step (1)

Loop Design

- Most loops are intended to terminate (at least in SE2S…)
- Each iteration **makes progress** towards termination

- Loops start in a **controlled situation**
- Each iteration **expands the scope** of this control — ***progress***
- Each iteration **<u>maintains</u> this control** on the current scope — ***loop invariant***

- Keywords: **the loop "maintains", "keeps", "remembers", …**

- Formalisation into a C *assert*() is not always easy.

Quiz 2005, Program Execution with Assertions

```
#include <stdio.h>
#include <assert.h>                    // See Textbook 13.10
int square(int k) { return k * k; }
void main(void) {
  int n = 22;
  int k = 0, d = 1, s = 1;
  while ( s ≤ n ) {    //  Loop invariant:
                 assert( d == 2 * k + 1      &&  s == square(k + 1) );
    d = d + 2;

    s = s + d;

    k = k + 1;
                 assert( d == 2 * k + 1      &&  s == square(k + 1) );
    printf("k = %d\t d = %d\t s = %d\n", k, d, s);
  }
  printf("The result is %d.\n", k);
}
```


Quiz, Question 2 — Factorial

```
#include <stdio.h>

int fact(int n) { if n == 0 return 1; else return n * fact(n–1); }

void main ( void ) {
  int n = 5, r;
      int n0 = n;              // Initial value n0 only used in assertions
  for (r = 1; n > 0; n––) {
      assert(fact(n) * r = fact(n0));        // Invariant:  n! * r = n0!
   printf("n = %d\tr = %d\n", n, r);
   r = r * n;
  }
      assert(n == 0 && r = fact(n0));         // Result:  r = n0!
  printf("The result is %d.\n", r);
}
```


Quiz, Question 3 — Last Occurrence of Maximum

- **Keep** maximum-seen-so-far and its largest index in local variables — this is the **loop invariant**
- Only **keeping** the index would be sufficient, too.

```
int locate_max ( int n, int array[] ) {
 assert(n > 0);                    // n is positive
 int m = array[0];                 // legal since array non-empty
 int ind = 0;                      // last time we have seen m
 int i;
 for ( i = 1; i < n; i++ ) {       // start at 1 since we already looked at 0
   if ( array[i] ≥ m ) {
     // found new maximum or later occurrence
     m = array[i];
     ind = i;
   }
 }
 return ind; }
```


"Sentinel-Controlled Repetition"

The Canadian Oxford Dictionary:

> **sentinel** *n.* a sentry or lookout; a guard. *v.tr.* **1** station sentinels at or in **2** *literary* keep guard over or in.

Deitel & Deitel:

> […] *sentinel value* (also called a *signal value*, a *dummy value*, or a *flag value*)

General Situation:

- An operation can either **succeed**, producing a **result** of type *t*, or **fail**.
- Not all elements of type *t* are possible "good" results of the operation
- One element (or a class of elements) of type *t* is defined to indicate failure of the operation.

do … while

For loops where the body needs to be executed once **before** the condition is first tested:

`do`
  body
`while` (*condition*)
	≡	*body*
		`while` (*condition*)
		  body

body has to be a single *statement.*

It is recommended

- to enclose *body* in braces, even when it is a primitive statement
- to **indent** the *body*

The **invariant** needs to hold **only at the end of the body**, not necessarily at the beginning of the first iteration

for Loops

- **Counter-controlled repetition** occurs frequently
  – Variations: length or direction of step
- ***Specialised syntax*** for counter-controlled repetition:

  > "A **for** statement specifies the repeated execution of a statement sequence while a progression of values is assigned to an integer variable called the ***control variable*** of the **for** statement."

- In "real" for loops,
  – the iteration bounds are calculated once, before the body is first executed
  – the body is not allowed to change the control variable

  Such **restricted** for **loops**
  – always terminate, if their body always terminates, but
  – have *less expressive power* than while loops
- for statements in C are abbreviations for a certain kind of while loop.

Counter-Controlled Repetition

```
int k;   /* Variable declaration at beginning of scope */

...

k = 0;       /* Variable initialisation immediately preceeding loop */
while ( k ≤ 10 ) /* Here, condition includes upper bound */
{
  ...
  printf("k = %d\n", k);
  ...
  k++;          /* Incrementing the loop counter */
}
```

Writing the loop body as a block even when it is a single primitive statement is **good practice**.

for Statements in C

First explanation:

`for` (*init* ; *condition* ; *step*)
  body
	≡	*init*;
		`while` (*condition*)
		 {
		  body;
		  step
		 }

Typical use — "proper `for` loop":

```
for ( k = start ; k ≤ end ; k++ )
   body
```

One kind of **atypical** use — `while` loop:

```
for ( ; condition ; )
   body
```

Chapter 4: C Program Control

- `for`, `do` ... `while`
- `switch`
- `break`, `continue`
- logical operators

"C-Truth"

- Modern languages have a predefined datatype for truth values, also called **Boolean** values
- C allows values of any integral type (including characters and pointers) to be used in conditions.

Truth-value use of integral values:

Integral	— *interpretation* →	**Truth**	— *translation* →	**Integral**
0		False		0
non-zero		True		1

Recommended:

#include <stdbool.h>
/* provides bool, true, false */
/* only in C99 */

Better than nothing:

#define bool int
#define true 1
#define false 0

Truth Tables

x	y	$x \wedge y$	$x \vee y$
False	False	False	False
False	True	False	True
True	False	False	True
True	True	True	True

"C-Truth" Tables

Integral	— *interpretation* →	**Truth**	— *translation* →	**Integral**
0		False		0
non-zero		True		1

x	y	*x* && *y*	*x* || *y*
`0`	`0`	`0`	`0`
`0`	non-zero	`0`	`1`
non-zero	`0`	`0`	`1`
non-zero	non-zero	`1`	`1`

Conditional Evaluation

"An expression containing && or || operators is evaluated only until truth or falsehood is known."

$x \mathbin{\&\&} y \quad \equiv \quad IF\ x\ THEN\ y\quad ELSE\ FALSE\ ENDIF$

$x \mathbin{||} y \quad \equiv \quad IF\ x\ THEN\ TRUE\ ELSE\ y\quad ENDIF$

Therefore the following is safe:

```
if (x ≠ 0 && 12 / x < q)
{
  k = 7 / x;
}
else
{
  fprintf(stderr, "There is a problem.\n")
}
```


Updating Assignment Operators

var += *expr*;	*abbreviates*	*var* = *var* + *expr*;
var –= *expr*;	*abbreviates*	*var* = *var* – *expr*;
var *= *expr*;	*abbreviates*	*var* = *var* * *expr*;
var /= *expr*;	*abbreviates*	*var* = *var* / *expr*;
var %= *expr*;	*abbreviates*	*var* = *var* % *expr*;

Compare readability:

```
myArray[3*k+i][j–5] += d + 2 * k;

myArray[3*k+i][j–5] = myArray[3*k+i][j–5] + d + 2 * k;
```


Increment and Decrement Operators

Used as **statements**,

var++;	and	++*var*;	abbreviate	*var* += 1;
var––;	and	––*var*;	abbreviate	*var* –= 1;

Assignment used as expression returns the assigned value:

```
float x, y = 3.5; int k;
x = 4.2 + (k = y);          /* k == 3  &&  x = 7.2 */
```

Used as **expressions**,

++*var*	abbreviates	(*var* = *var* + 1)
var++	abbreviates	(*var0* = *var*, *var* += 1, *var0*)

where *var0* is a "new" variable.