The Basics of Programming

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Basic Notions

- Program: formal description of a method solving a problem.
  - Consists of instructions (also called commands or statements).
  - Operates on data (values like numbers, characters, text files, images, ...).

We will now investigate those elements of programming that are valid for (almost) any programming language.

Variables

Data are stored in variables.

- Variable: a labelled box holding some content.
  - The label is the name of the variable.
  - The content is the value of the variable.
- Example: variable named x with value 17:

  x: $\boxed{17}$
- Variables may hold different kinds of values.
  - Integer numbers: x: $\boxed{17}$
  - Characters: ch: $\boxed{\text{'+'}}$
  - Strings of characters: str: $\boxed{\text{“hello”}}$

Think of variables as boxes.

Changing Variable Values

A program operates on variables and changes its values.

- Variables before the execution of a program.

  x: 17
  ch: '+'
  str: "hello"

- Variables after the execution of the program.

  x: 18
  ch: '*'
  str: "world"

The name "variable" comes from "vary" (changing).

Variable Types

Variable types may not change arbitrarily

- Every variable has an associated type.
  - The set of values that it may hold during its whole life-time.
  - The type remains fixed during its life-time.
  - The type may be attached to the visual representation.

x: 17 *integer*
ch: '+' *character*
str: "hello" *string*

For the moment, we will only use variables of type "integer".

Variable Assignments

The simplest and most important instruction.

$$x \leftarrow E$$

- Read as "x becomes E".
  - Variable x.
  - Mathematical expression E.
- Compute value of E and store it in x.
  - Overwrites previous value of x.

Assignments change variable values.

Example

- x: $\boxed{5}$, y: $\boxed{1}$

  $y \leftarrow 2$

- x: $\boxed{5}$, y: $\boxed{2}$

  $y \leftarrow x + 1$

- x: $\boxed{5}$, y: $\boxed{6}$

  $x \leftarrow x + 1$

- x: $\boxed{6}$, y: $\boxed{6}$

  $x \leftarrow x * y$

- x: $\boxed{36}$, y: $\boxed{6}$

The execution of a program is a sequence of variable assignments.

Sequences

A program may consist of a sequence of commands:

- x: $\boxed{5}$, y: $\boxed{1}$

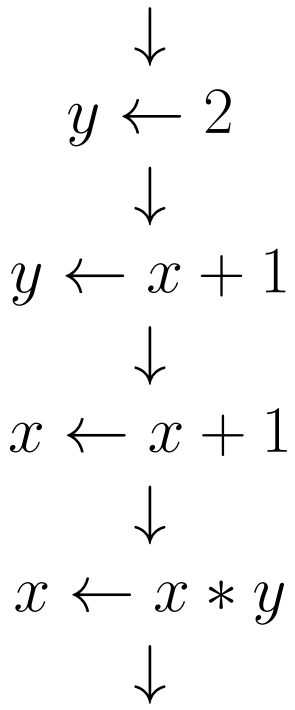
$$y \leftarrow 2$$
$$y \leftarrow x + 1$$
$$x \leftarrow x + 1$$
$$x \leftarrow x * y$$

- x: $\boxed{36}$, y: $\boxed{6}$

Multiple commands may be listed one after another.

Control Flow Diagrams

Arrows may indicate the order in which commands are executed.



Such diagrams will become important to visualize control structures.

Assertions

Diagrams may be annotated by assertions.

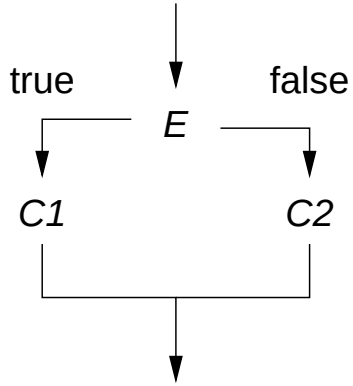
- Assertion: a proposition about the variable values.
  - Must hold at the denoted position of the program execution.

$$\downarrow$$
$$y \leftarrow 2 * x$$
$$\downarrow \text{ -- } y \text{ is even}$$
$$z \leftarrow y + 1$$
$$\downarrow \text{ -- } z \text{ is odd}$$

Dashed line -- indicates position of assertion in control flow.

Conditionals

A statement may be only executed if a condition holds.

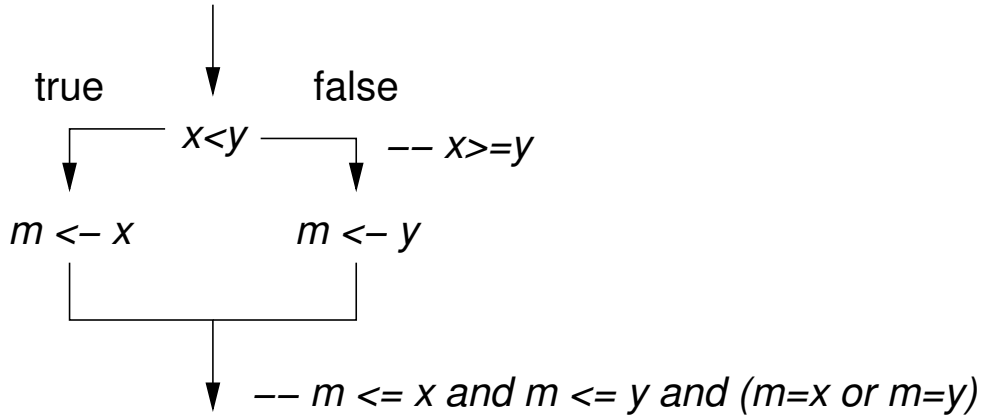


- Conditional statement
  - Condition E.
  - Commands C_1 and C_2 (the branches).
  - If E holds, then C_1 is executed, else C_2 is executed.

The control flow may branch.

Example

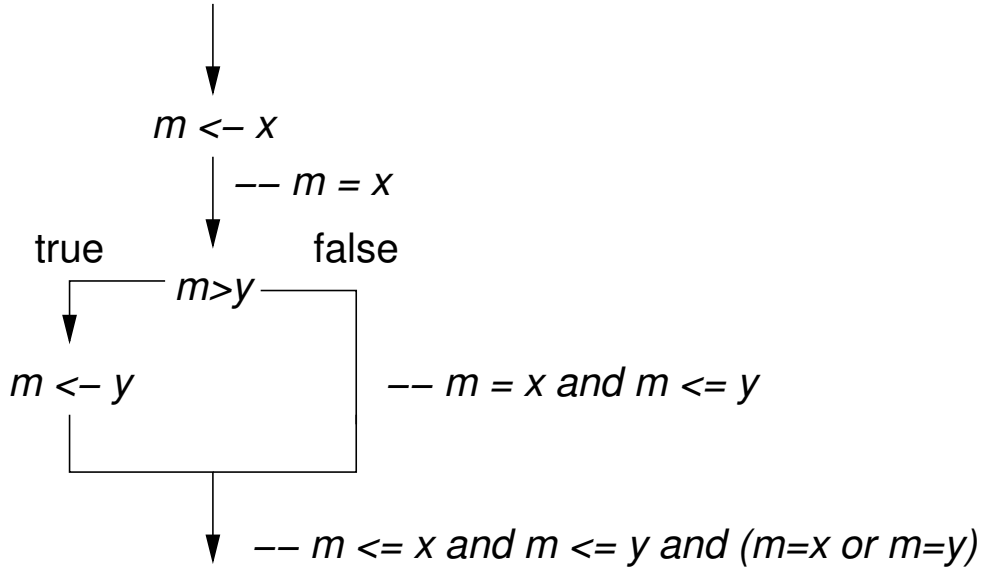
Computation of the minimum of two values.



Variable m is set to the smaller of the values of x and y.

Example

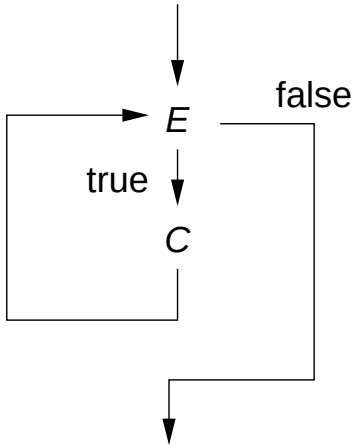
Alternative version of minimum computation.



A conditional may also have only one branch.

Loops

A statement may be repeatedly executed (iterated).

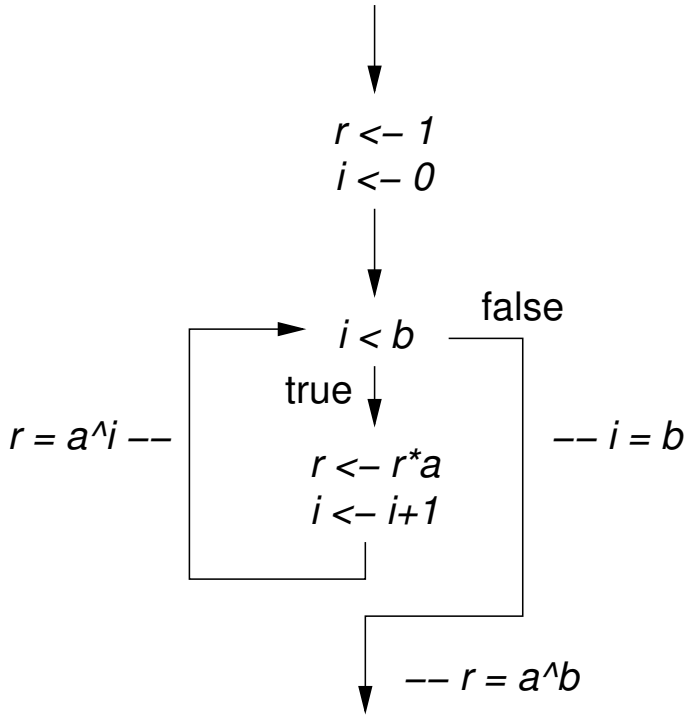


- Loop statement
  - Condition E (the loop condition).
  - Command C (the loop body).
  - While E holds, C is executed.

The control flow may form loops.

Example

The computation of an exponentiation value.

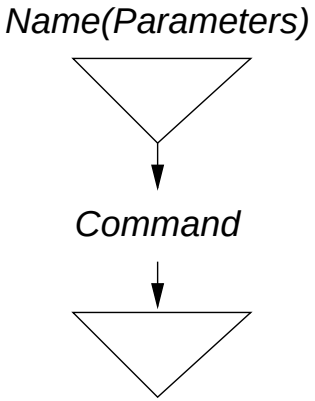


	r	i
Before first iteration	1	0
After first iteration	4	1
After second iteration	16	2
After third iteration	64	3

The variable r is set to a^b.

Algorithm Descriptions

Format for describing algorithms.

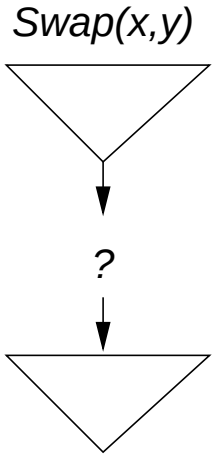


- Every algorithm has a name and parameters.
  - Parameters: variables provided by the user.
  - Algorithm may use these variables and internal ones.
- Triangles initiate and terminate the control flow.

Swapping two Variables

Exchange the values of two variables.

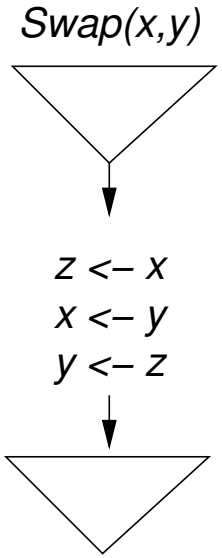
$$x\colon \boxed{3},\ y\colon \boxed{5} \rightsquigarrow x\colon \boxed{5},\ y\colon \boxed{3}$$



We have to develop the body of the algorithm skeleton.

Swapping two Variables

Algorithm needs an auxiliary variable.

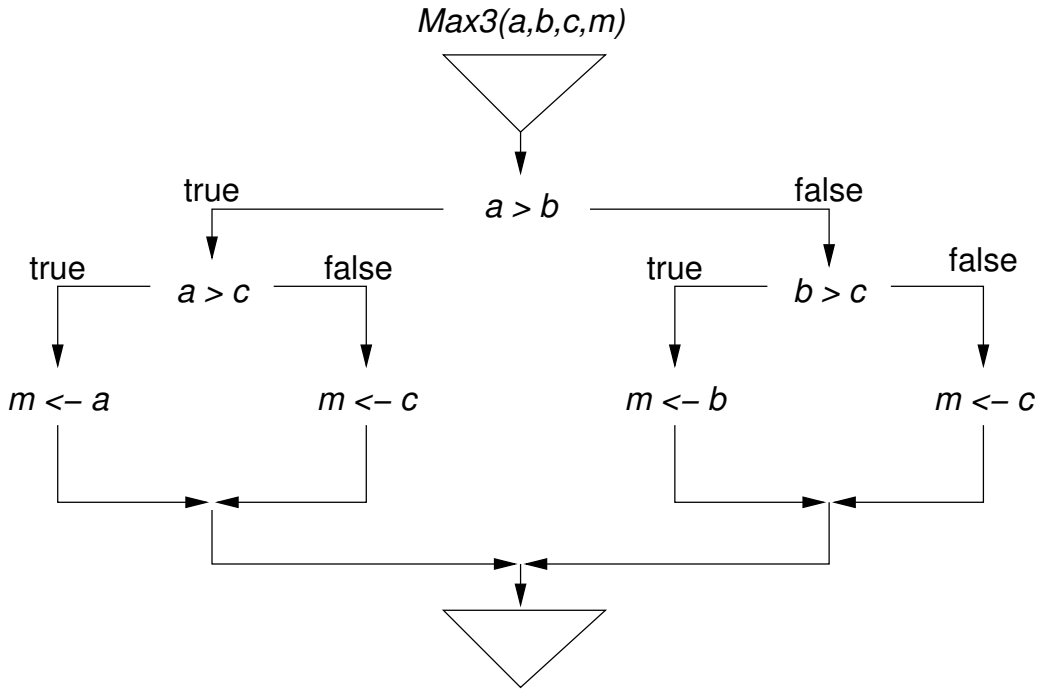


x	y	z	
$\not{B}$	$\not{b}$		Initial Situation
		3	After $z \leftarrow x$
5			After $x \leftarrow y$
	3		After $y \leftarrow z$

Every algorithm can be simulated with paper and pencil.

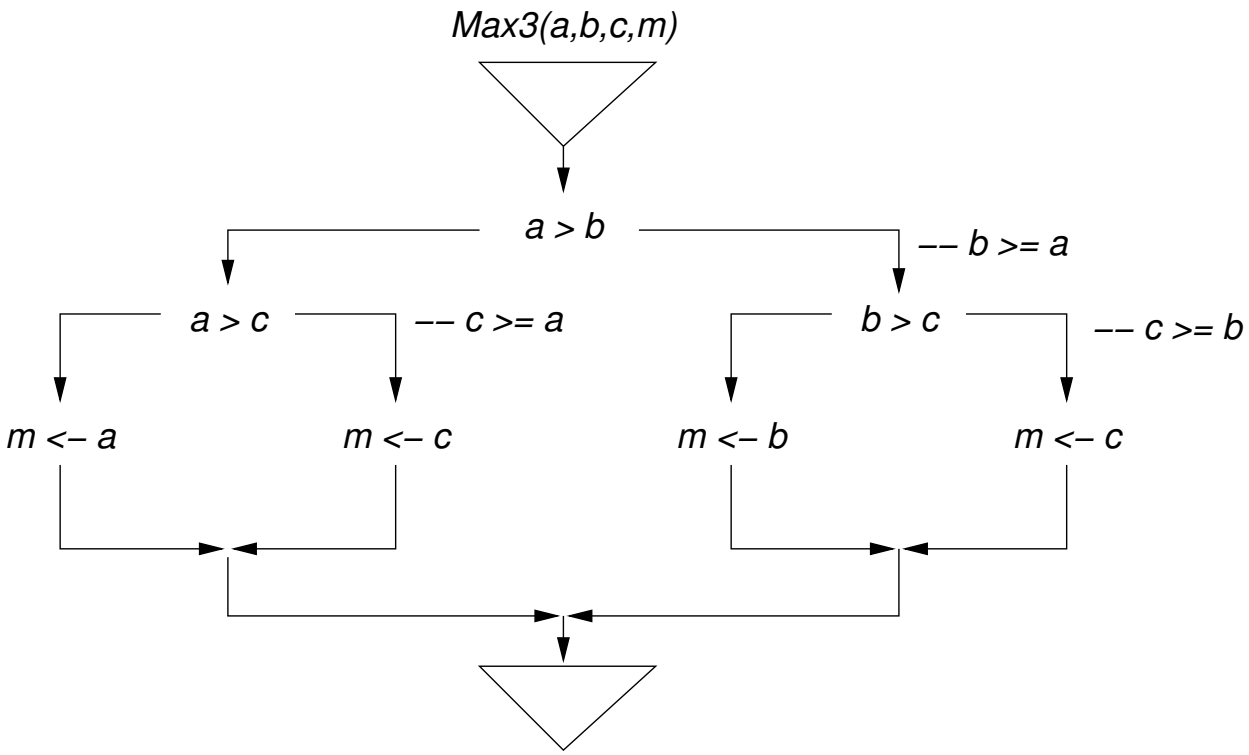
Maximum of Three Numbers

Find the largest of three numbers.



How to verify the correctness of the algorithm?

Maximum of Three Numbers



Use assertions to support the reasoning.

Primality Test

Test whether a given natural number n is a prime number.

- Prime number: a natural number n such that
  - n is greater than 1 and
  - n is only divisible by 1 and itself.
    - n is divisible by m (written as $m|n$) if and only if $n = m \cdot o$ for some natural number o.
    - For example, 10 is divisible by 5 ($5|10$) because $10 = 5 \cdot 2$.
- Prime numbers: $2, 3, 5, 7, 11, 13, 17, \ldots$
  - 2 is the only even prime number (why?).

Signal success by setting a variable p to "true" or "false".

Primality Test