Central Processing Unit Simulation
Version v2.5 (July 2005)

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1 Table of Contents

2 Overview

Purpose: Educational.

- Initiation to low-level programming and CPU principles.
- Explore various architectures of CPU through their programming and their step-by-step execution.
- Deliberate limitation: it supports elementary programs only.

Realization:

- Pure Tcl-Tk implementation.
- Requires Tcl-Tk, version 8.4 or better, and the BWidget ToolKit, version 1.7 or better.
- Tested on Window2000, Windows XP and Linux.

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Caveats: The look and Feel of the widgets is dependent on the operating system. The pictures given in this text are screen copies captured under Windows 2000, and have been generated by version 2.0 of the software.

3 Installation

Be sure that Tcl-Tk, version 8.4 or higher, and BWidget, version 1.7 or higher are installed.

1. If the environment variable **SOFTDIR** is defined, go to 5

2. Create a directory in which all software from C. André will be installed

3. Set the environment variable **SOFTDIR** to the path of this directory

4. Prepend your **PATH** environment variable with **$SOFTDIR/bin** (or **%SOFTDIR%\bin** for Windows)

5. Copy the distribution file **archi.2.x.tgz** in **$SOFTDIR** (replace **x** by the current minor version number)

6. Execute: **cd $SOFTDIR**

7. Execute: **gunzip -c archi.2.x.tgz | tar xvfp -** (overwrite existing files, if any)
   This creates (or updates) the Directory tree:
   $SOFTDIR
   - **bin**
   - **ARCHI**
     - **bin**
     - **TCL**
     - **doc**
     - **EXAMPLES**

8. For the first installation only:
   execute: **cd $SOFTDIR/bin**
   execute: **platform.tcl**
   This copies configuration files in your home directory depending on your OS

9) optional: in **$SOFTDIR/bin** make a symbolic link:
CPUSimulator to **../ARCHI/bin/CPUSimulator.tcl**

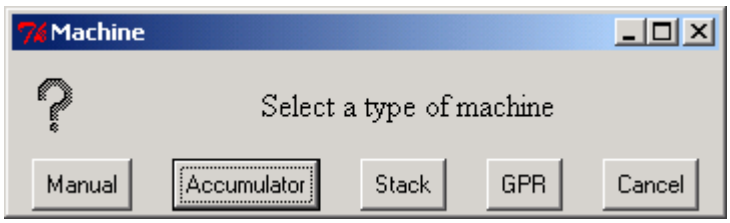
10) That's All Folks!

4 The CPU Simulator (v2.0)

4.1 Launching the application

Execute **`CPUSimulator`**. This is a symbolic link, present in the **`$SOFTDIR/bin`** directory and pointing to the actual application: **`$SOFTDIR/ARCHI/bin/CPUSimulator.tcl`**.

The dialog box below appears.



Four machines are proposed:

- **Manual**: not a programmable machine, just an ALU and a Memory. Data are fetched from and written to the memory by “drag-and-drop” moves. The operation performed by the ALU is selected by the user.
- **Accumulator**: an accumulator-based machine. Associated assembly language source files are suffixed by **`.amp`** (Accumulator Machine Program).
- **Stack**: a stack-based machine. Associated assembly language source files are suffixed by **`.smp`** (Stack Machine Program).
- **GPR**: a General-Purpose-Register machine, more precisely a register-register architecture: only load and store instructions access memory locations; arithmetic and logical instructions are performed only on registers. Associated assembly language source files are suffixed by **`.gmp`** (GPR Machine Program).

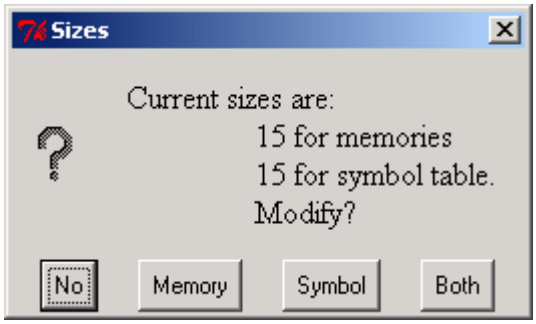
Remark: GPR machine are not yet implemented.

These machines are very small machines: They have tiny memories and a limited set of instructions. For simplicity, data memory and instruction memory are separated.

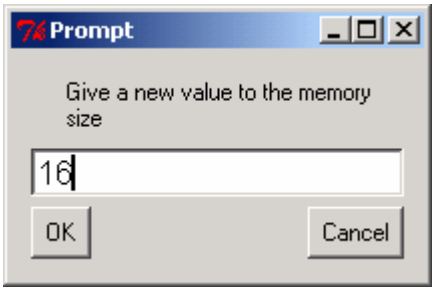
4.2 Selecting

Click on the corresponding button to select the desire machine type.

The default sizes of the (small) memories of the machines are stored in a configuration file (**`.CPUSimulator`**, in your home directory). This size is initially set to 15. A dialog box proposes to change these sizes. You can answer “No”, since the actual sizes could be enlarged later.



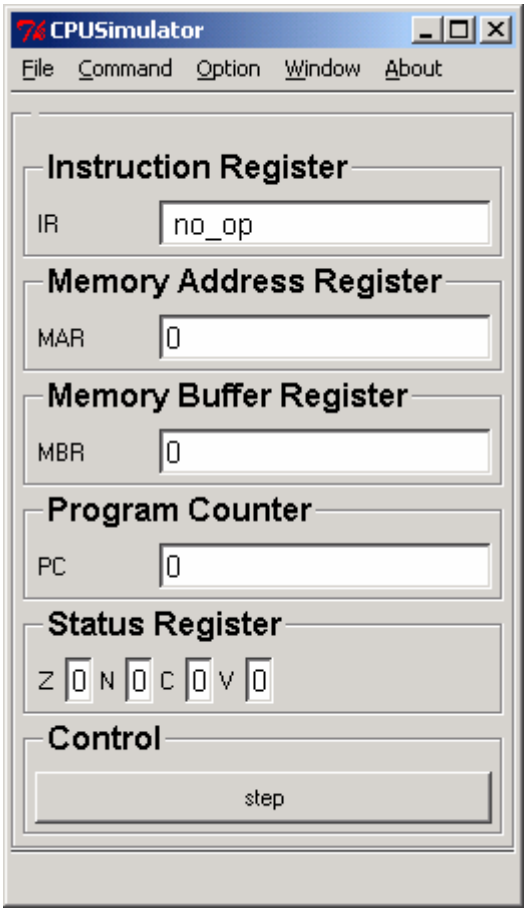
If a modification is selected, another dialog box pops up and asks for a new value. “Memory” applies only to Data and Instruction Memories; “Symbol” concerns the size of the Table of Symbols; “Both” applies to both. Prefer this latter option to the previous two choices.



4.3 The Control Window

The control window is the main panel. It offers

- a menu bar,
- various registers,
- and a control button



4.3.1 Menus

The menu bar presents a set of button-like menu entries to users. When you drag your mouse over the menu bar, the different menus are displayed. A click on a button posts (i.e., displays) the associated menu.

File

Load	open a browser for loading
Re-load	load the previously loaded file
Save	open a browser for saving
Exit	exit the application

Command

Reset	reset the simulation (memory and register cleanup)

Extend Memory	increment the size of the data and instruction memory by 1

Option

Preferences	configure your personal environment with a dialog box
----------	
Fonts	show and select fonts

Help font: 8pt	set the size of font in balloon to 8
Help font: 10pt	set the size of font in balloon to 10
Help font: 12pt	set the size of font in balloon to 12

Step running mode: step by step (a full instruction at a time)
Fetch/Execute running mode: separate instruction fetch and execution
Detail running mode: details (i-fetch, decode, d-fetch, operate, store)

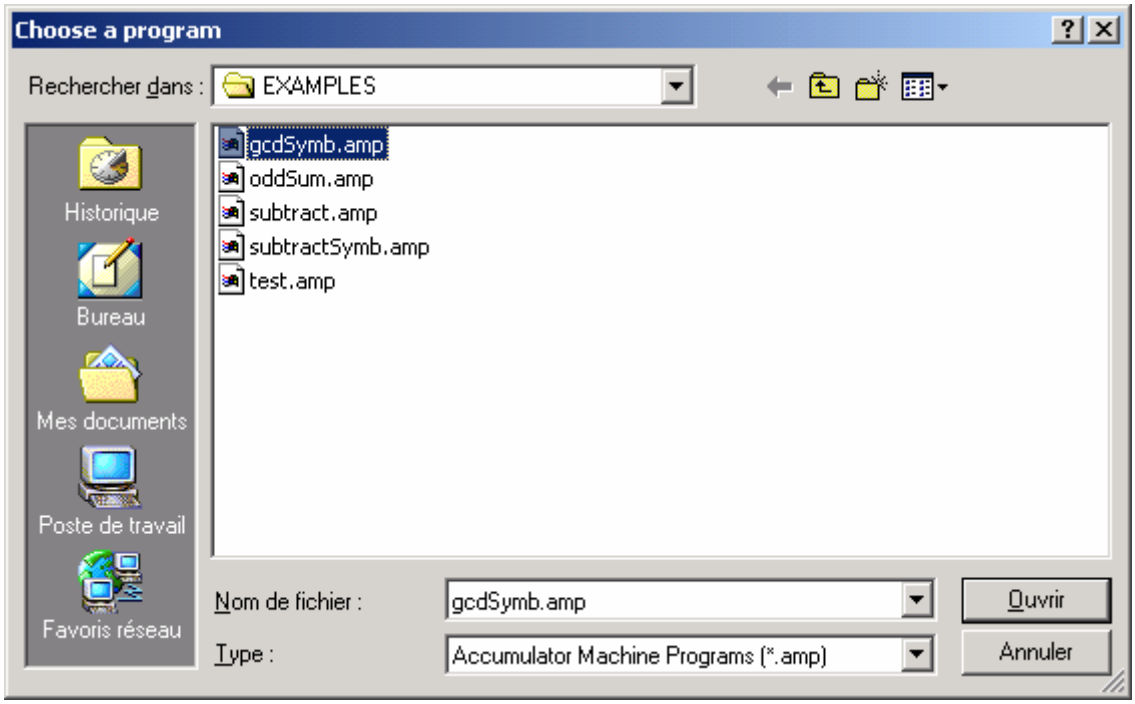
Window check buttons selecting windows to show/hide

- **Show ALU**
- **Show Symbol Table**
- **Show Pseudo Console**
- **Instruction Set**
- **Performances**
- **Raise Memory**

About miscellaneous information

- **Author**
- **Address**
- **Version**

File loading dialog box



File Saving Dialog Box

This dialog box is similar to the file loading dialog box. Contrary to the file loading box, creating a new file is possible.

4.3.2 Registers

Registers displayed in the control window are non user-programmable registers. They are useful for tracing program executions and understanding data paths.

- The **Instruction Register** (IR) contains, in a symbolic form, the instruction to be decoded and executed.
- The **Memory Address Register** (MAR) points either an Instruction Memory Cell (for i-fetch), or a Data Memory Cell (for d-fetch or store).
- The **Memory Buffer Register** (MBR) contains data from the memory (read-memory cycle) or to the memory (write-memory cycle).
- The **Program Counter** (PC) points to the current instruction. All programs start from address 0.
- The **Status Register** consists of 4 individual flags:
    - Zero (**Z**) set to 1 when the result of a logical or an arithmetic operation is 0
    - Negative (**N**) set to 1 when the most significant bit is 1
    - Carry (**C**) set to 1 by addition or subtraction overflows, and by logical shift operations.
    - oVerflow (**V**) set to 1 in case of an algebraic overflow.

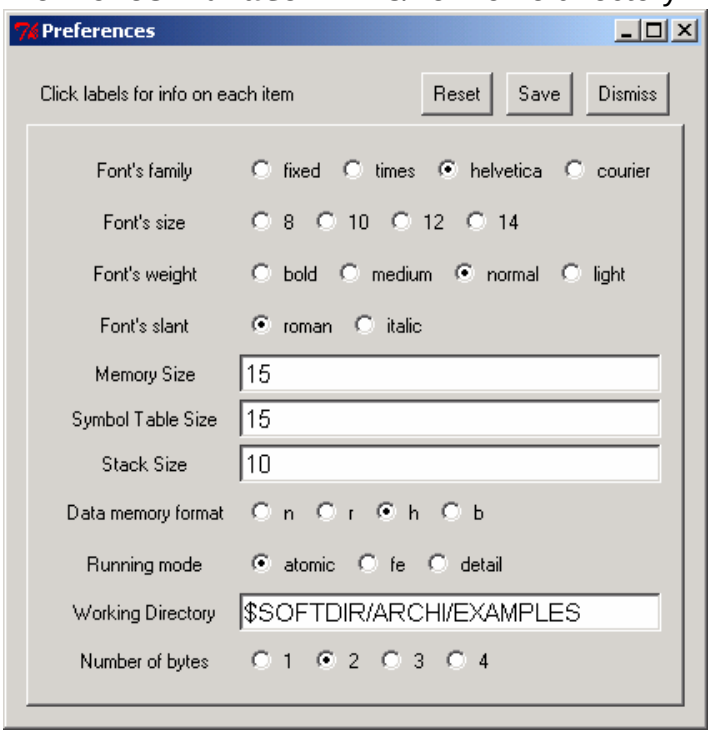
4.3.3 Control button

This button indicates what is the next thing to be done by the simulator. Its label depends on the current running mode.

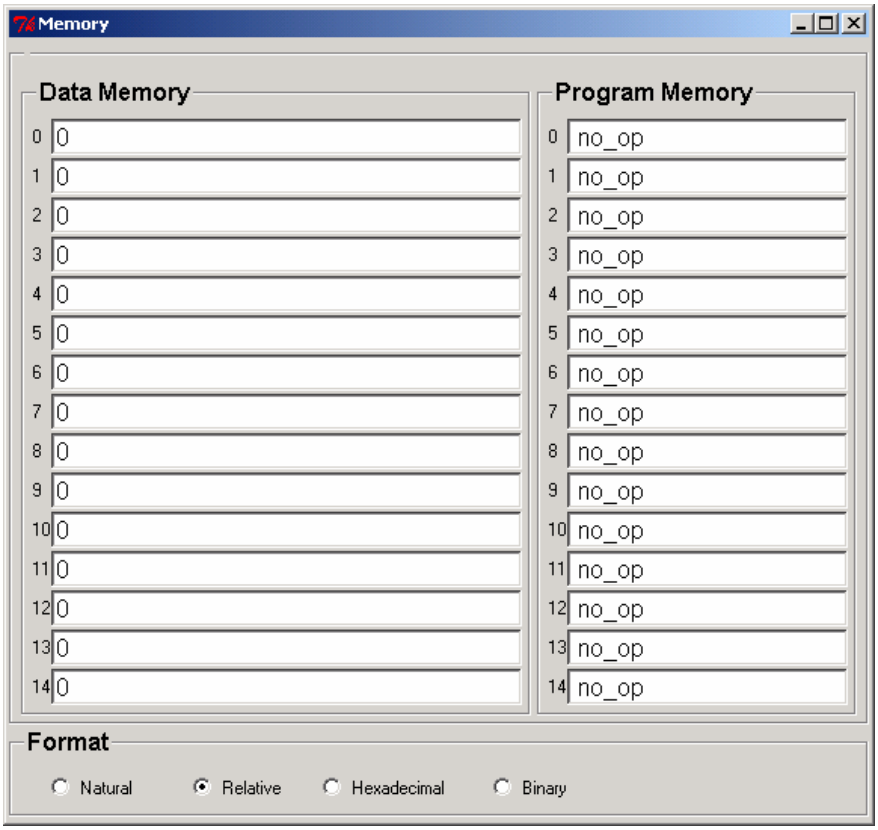
- In the step-by-step (or **Atomic**) mode, the label is always “Step”.
- In the **Fetch/Execute** (or fe) mode, the label alternates “i-fetch” and “Execute”.
- In the **Detail** mode, the label may be “i-fetch”, “decode”, “d-fetch”, “operate”, “d-write”. The exact succession depends on the instruction.

4.3.4 Preferences

This dialog box allows the user to customize its environment. His/her choices are saved in a hidden file: **`.CPUSimulator`** in his/her home directory.



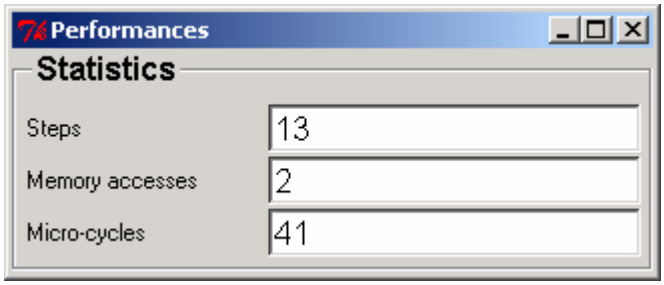
4.4 The Memory Window



The left side of the window represents the Data Memory, the right side the Program Memory. The addresses are written on the left of each memory entry.
The bottom frame, entitled “Format”, allows the user to select a display format.

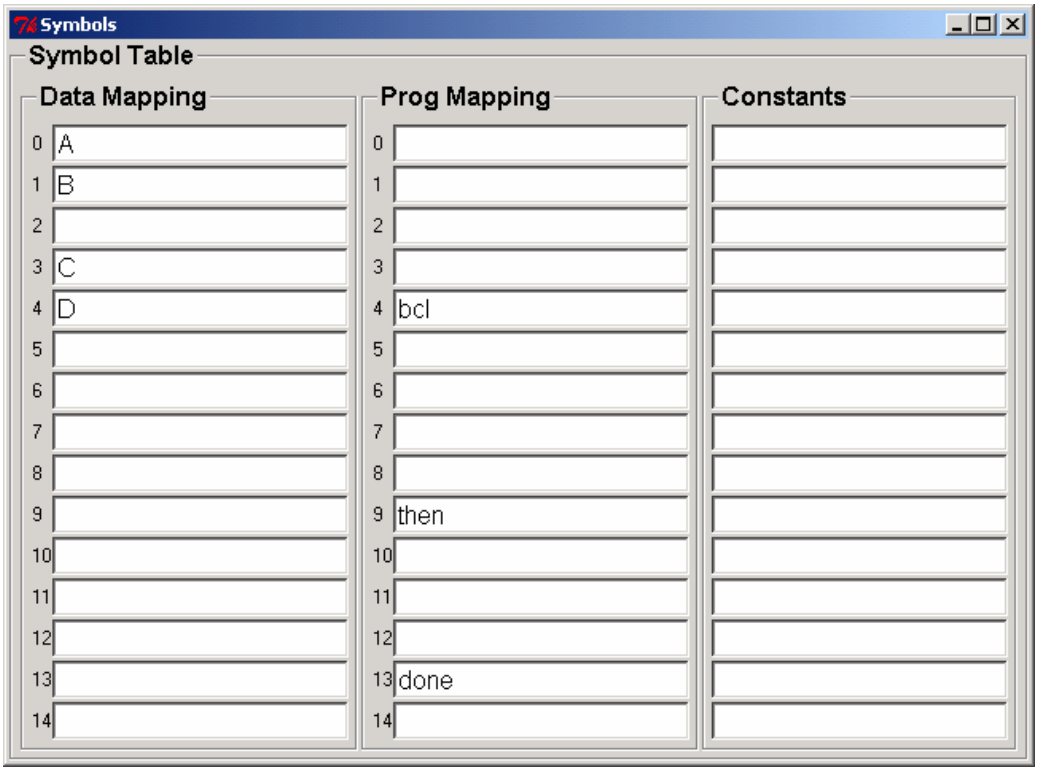
4.5 The Performance Windows

While a program is executed, statistics are computed. The number of steps (i.e., the number of executed instructions), the number of Memory Accesses, and the number of microcycles are automatically updated. All the counters are reset to 0 by the Reset command, or by a new program loading.
The number of microcycles by instruction is computed by taking one unit for each phase: i-fetch, decode, d-fetch, operate, d-write. This is a coarse approximation. With modern fast CPUs, external accesses should be given a relative cost much higher than 1.



4.6 Symbol Table Window

When your program uses symbolic names, you have to fill up the symbol table (You do what is usually done by an assembler!).

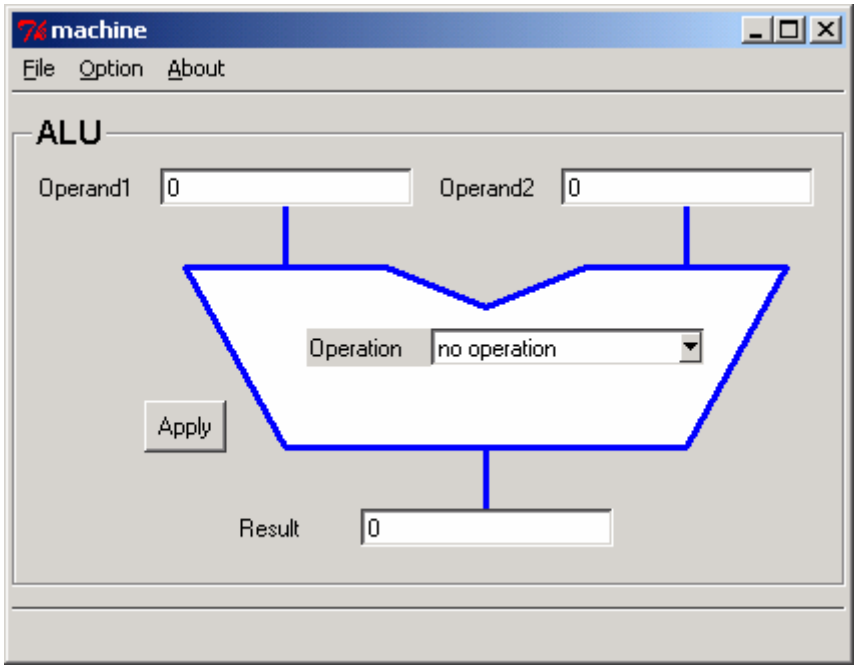


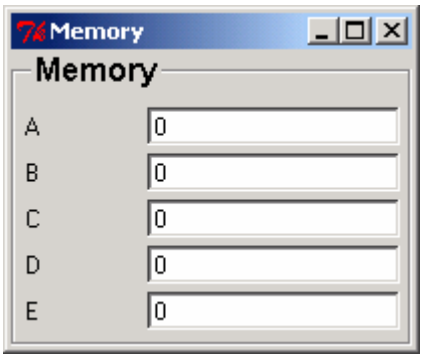
The above table corresponds to a program that makes reservation for variables A, B, gcd, C, and D at the respective addresses 0, 1, 2, 3, 4 in the Data memory. The program uses symbolic labels “bcl:”, “then:”, “done:” at respective locations 2, 4, and 13 in the Program Memory.
Aliases are possible: each entry may contain a space-separated list of identifiers.

Syntactic Remark: symbolic labels are followed by a colon in their definition; the colon is omitted in the table and in the branch instructions.

5 Manual Execution

As explained above, this is not a programmable machine. The user has to drag and drop the data, select the operation of the ALU, apply the operation and collect the result.

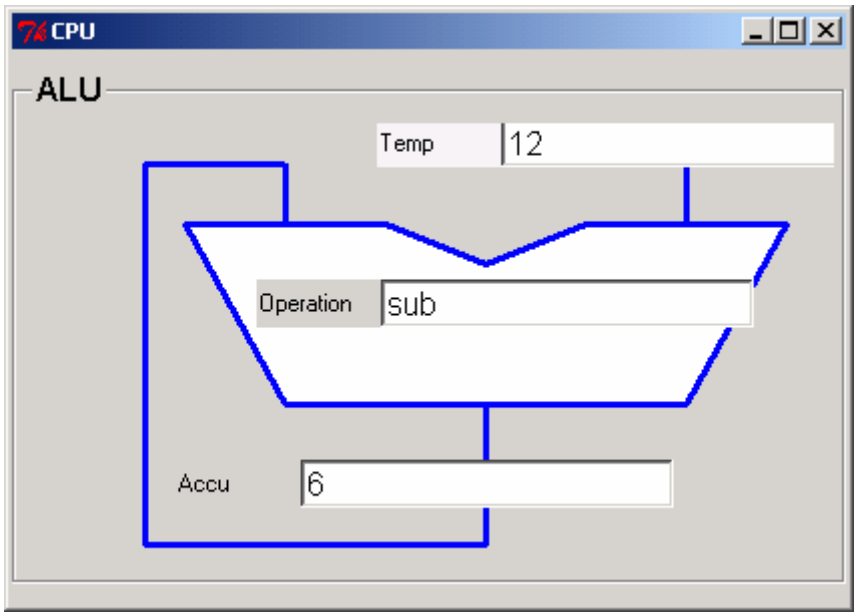




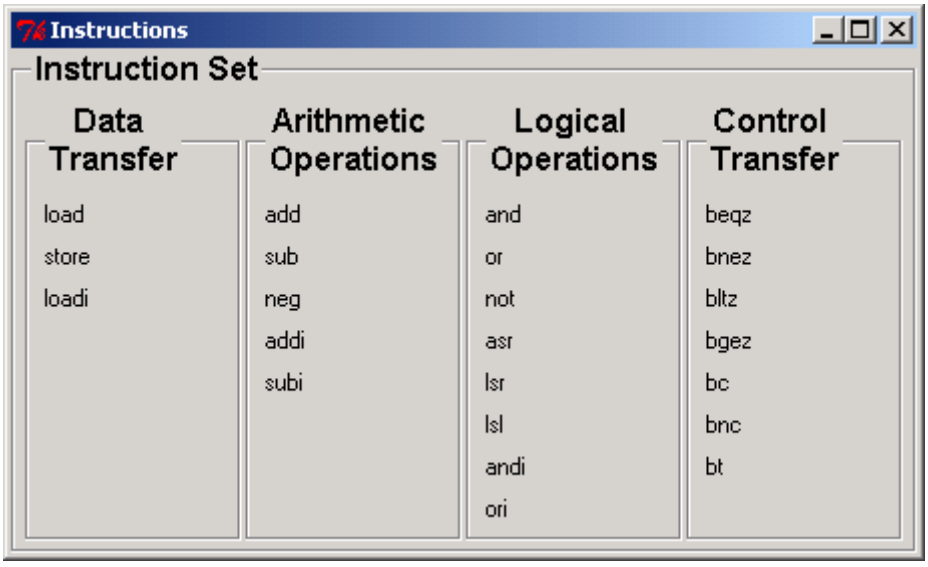
6 Accumulator-based Machine

6.1 Arithmetic and Logical Unit

This machine has an accumulator, used as both the first operand of the operation performed by the ALU, and the result of the operation. The second operand, if any, comes from the Memory or the Instruction Register (for immediate operations). The entry named “Temp” shows the value of this operand.
The operation entry is set during the decode phase according to the contents of the Instruction Register.



6.2 Instruction Set

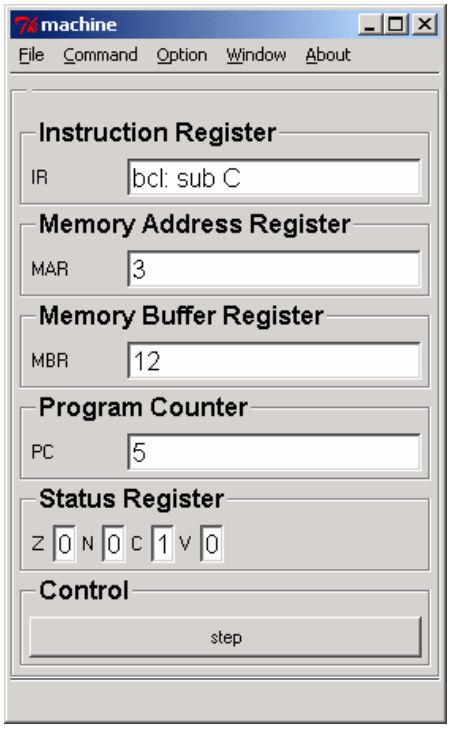


The (simplified) instruction set is available in the Instruction Set Window. The semantics of each instruction is popped-up when the mouse stays over the label for a while.

6.3 Example of the gcd computation

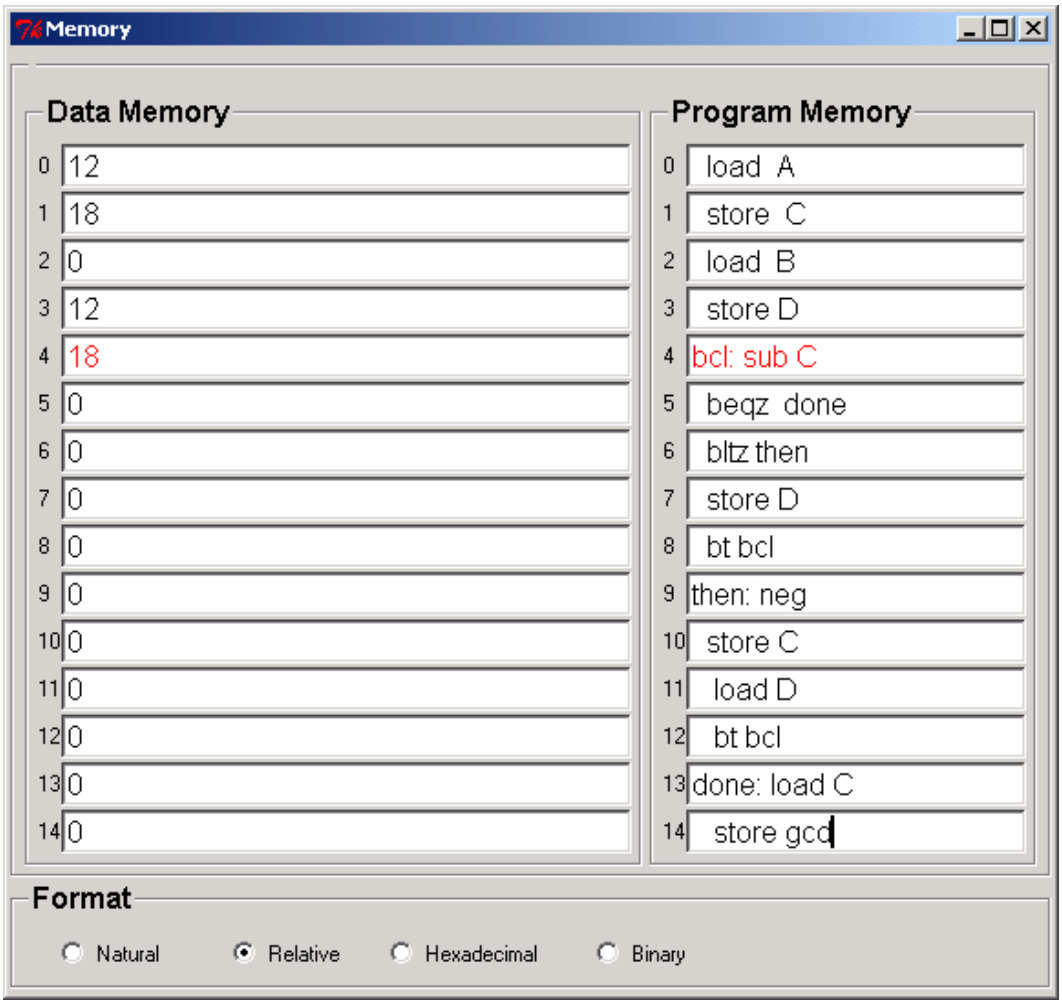
This program computes the Greatest Common Divider of two positive integers A and B. This algorithm is the original one, using only subtraction, not the remainder of the integer division.
Gcd is the result, A and B are the input data preserved during the computation. C and D are auxiliary variables.

```
        load    A
        store   C       ;   C is the dynamic value of A
        load    B
        store   D       ;   D is the dynamic value of B
bcl:    sub     C       ;   D - C
        beqz    done    ;   If Z then go to done
        bltz    then    ;   If D < C then go to then
        store   D       ;   D > C => B <- B - A
        bt      bcl     ;   iterate
then:   neg             ;   C > D; take the opposite of D - C
        store   C       ;   C <- C - A
        load    D       ;   Before looping, put D in the accumulator
        bt      bcl     ;   iterate
done:   load    C       ;   Here C=D=gcd
        store   gcd
```



The figure above shows the control window *before* executing the instruction at location 5 (i.e., the contents of PC). In the Program Memory Window, the last

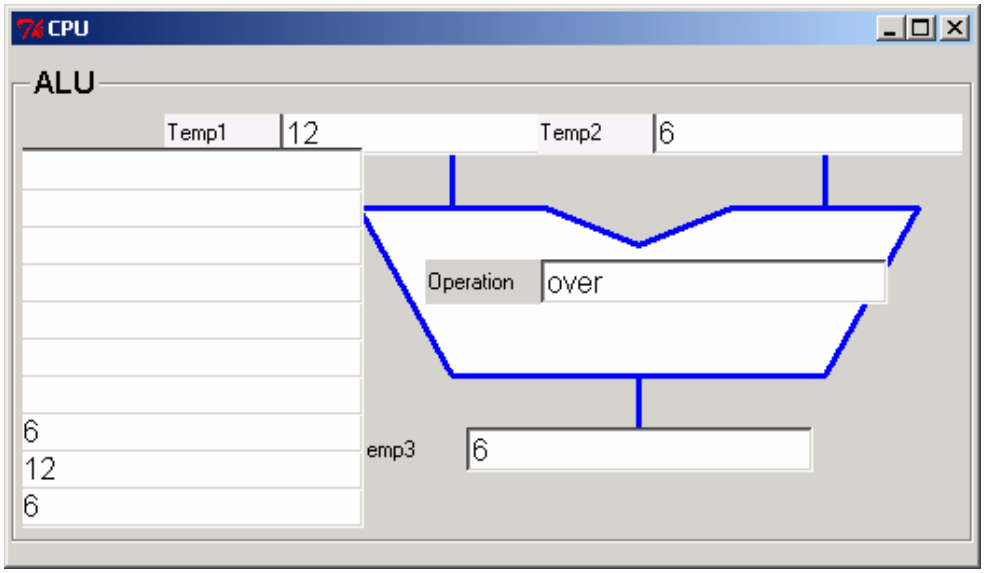
executed instruction (`bcl: sub C`) is highlighted (painted red) and still present in the Instruction Register. The Memory Address Register points to (data) memory cell 3 (i.e., the location of C, the last accessed memory cell). The Memory Buffer Register contains the value of C (i.e., 12).
The highlighted Data Memory cell is the more recently written memory cell (Here, the cell that stores the value of D).
Remind that correspondences between memory locations and symbolic names are given by the Table of Symbols.



7 Stack-based Machine

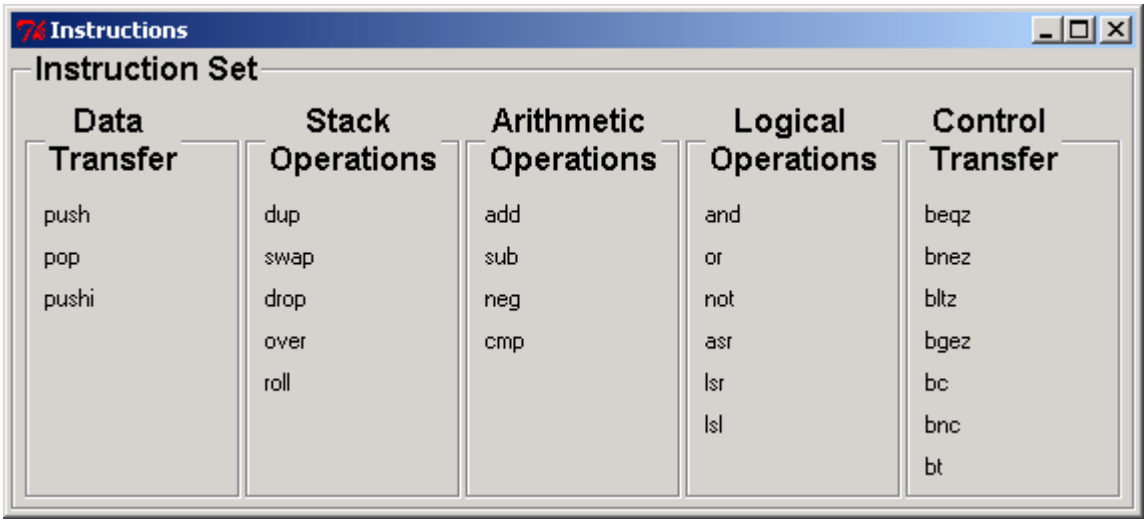
7.1 Arithmetic and Logical Unit

The UAL has two operands and a result. Sources and destination are the stack. The stack itself is represented on the left of the picture. The stack grows upwards.



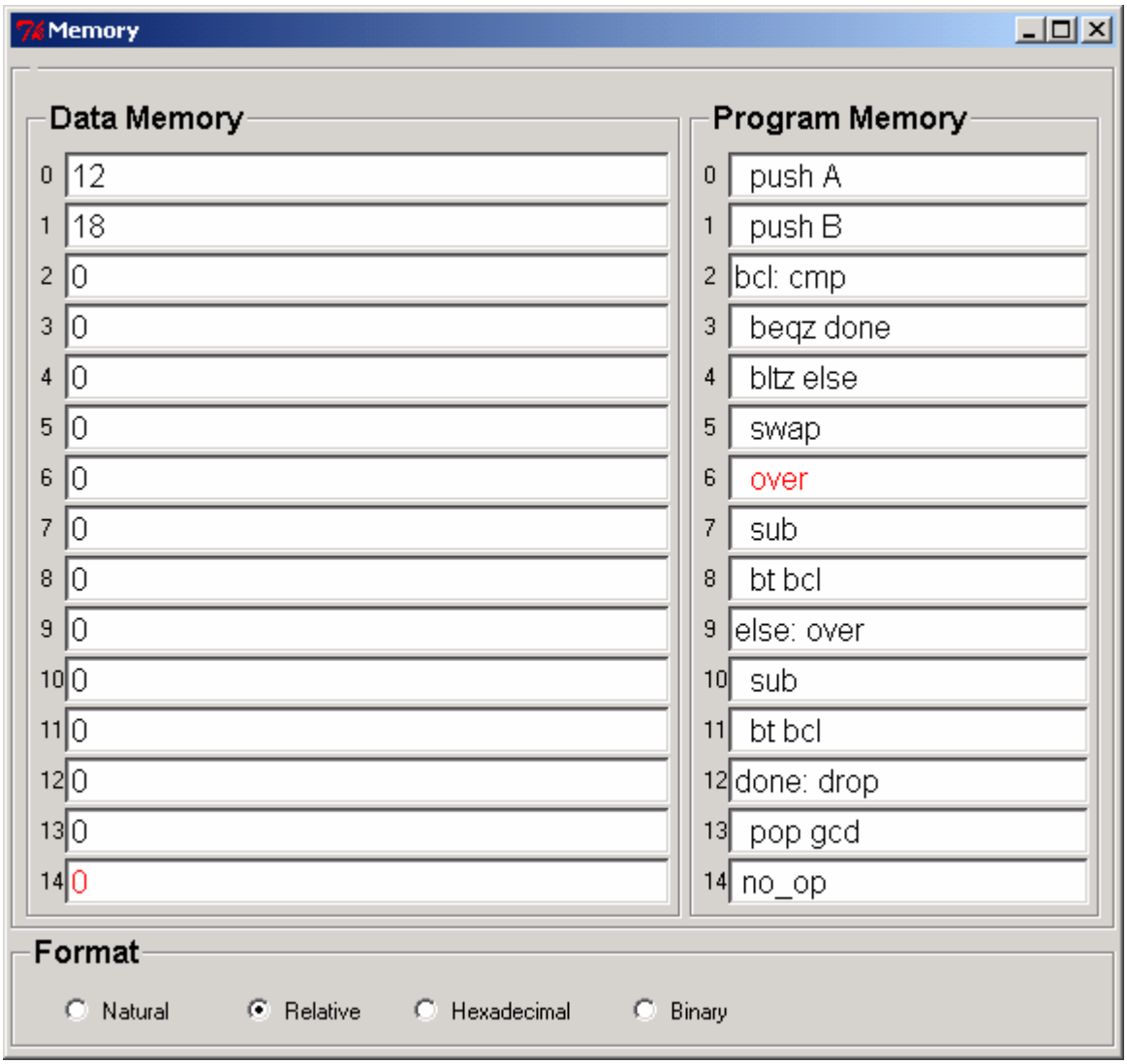
7.2 Instruction Set

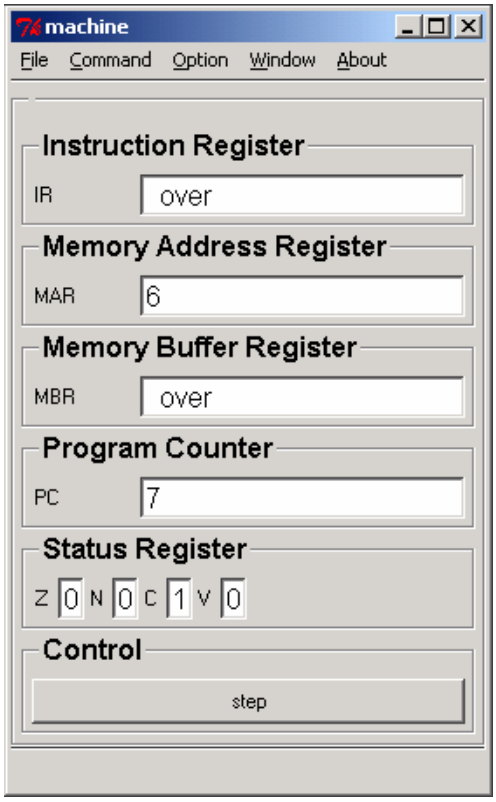
The instruction set is available in the Instruction set Window. The semantics of each instruction is popped-up when the mouse stays over the label for a while.



7.2.1 Example of the gcd computation

```
        push    A       ;   A       -
        push    B       ;   A       B       -
bcl :   cmp             ;   A       B       -       Set N and Z
        beqz    done    ;   Branch to done if A == B
        bltz    else    ;   Branch to else if A < B
        swap            ;   B       A       -
        over            ;   B       A       B       -
        sub             ;   B       A-B     -
        bt      bcl     ;   Branch to bcl with new A and old B
else:   over            ;   A       B       A       -
        sub             ;   A       B-A     -
        bt      bcl     ;   Branch to bcl with new B and old A
done:   drop            ;   A       -               Discard B
        pop     gcd     ;   -
```




machine
File Command Option Window About
Instruction Register
IR over
Memory Address Register
MAR 6
Memory Buffer Register
MBR over
Program Counter
PC 7
Status Register
Z 0 N 0 C 1 V 0
Control
step