VM Emulator Tutorial

This program is part of the software suite
that accompanies the book

The Elements of Computing Systems

by Noam Nisan and Shimon Schocken

MIT Press

www.idc.ac.il/tecs

This software was developed by students at the
Efi Arazi School of Computer Science at IDC

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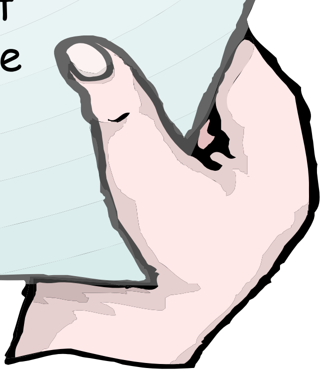
Background

The Elements of Computing Systems evolves around the construction of a complete computer system, done in the framework of a 1- or 2-semester course.

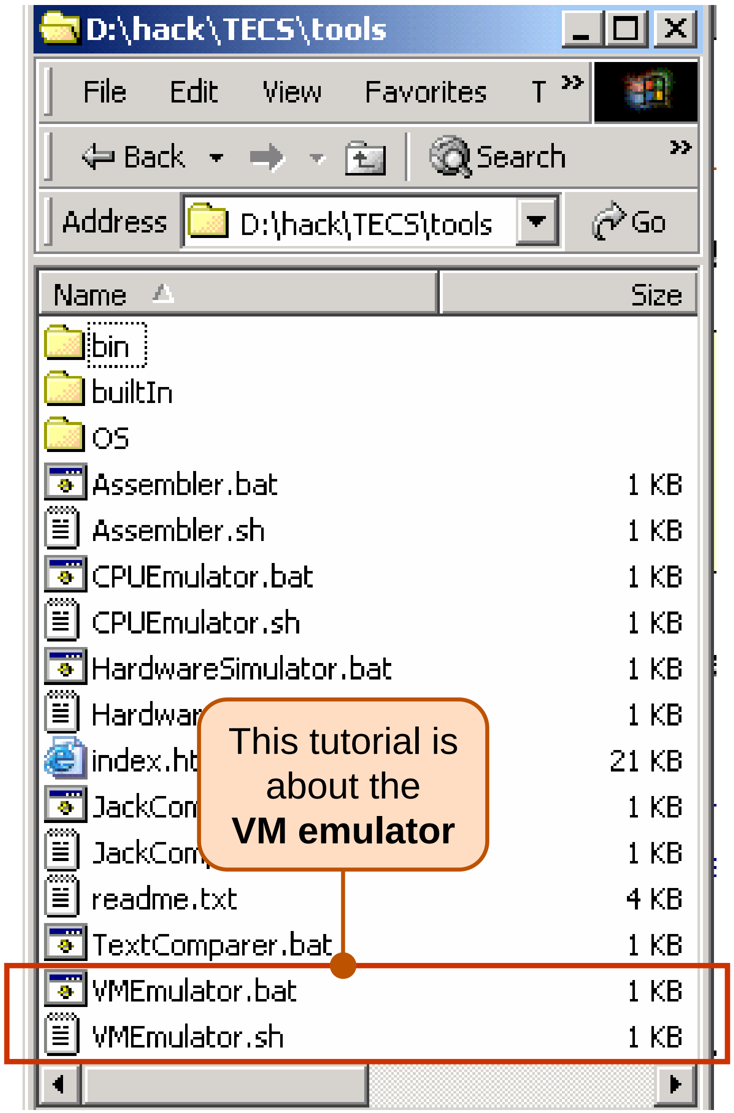
In the first part of the book/course, we build the hardware platform of a simple yet powerful computer, called Hack. In the second part, we build the computer's software hierarchy, consisting of an assembler, a virtual machine, a simple Java-like language called Jack, a compiler for it, and a mini operating system, written in Jack.

The book/course is completely self-contained, requiring only programming as a pre-requisite.

The book's web site includes some 200 test programs, test scripts, and all the software tools necessary for doing all the projects.



The Book's Software Suite



(All the supplied tools are dual-platform: **`Xxx.bat`** starts **`Xxx`** in Windows, and **`Xxx.sh`** starts it in Unix)

Simulators

(**`HardwareSimulator`**, **`CPUEmulator`**, **`VMEmulator`**):

- Used to build hardware platforms and execute programs;
- Supplied by us.

Translators (**`Assembler`**, **`JackCompiler`**):

- Used to translate from high-level to low-level;
- Developed by the students, using the book's specs; Executable solutions supplied by us.

Other

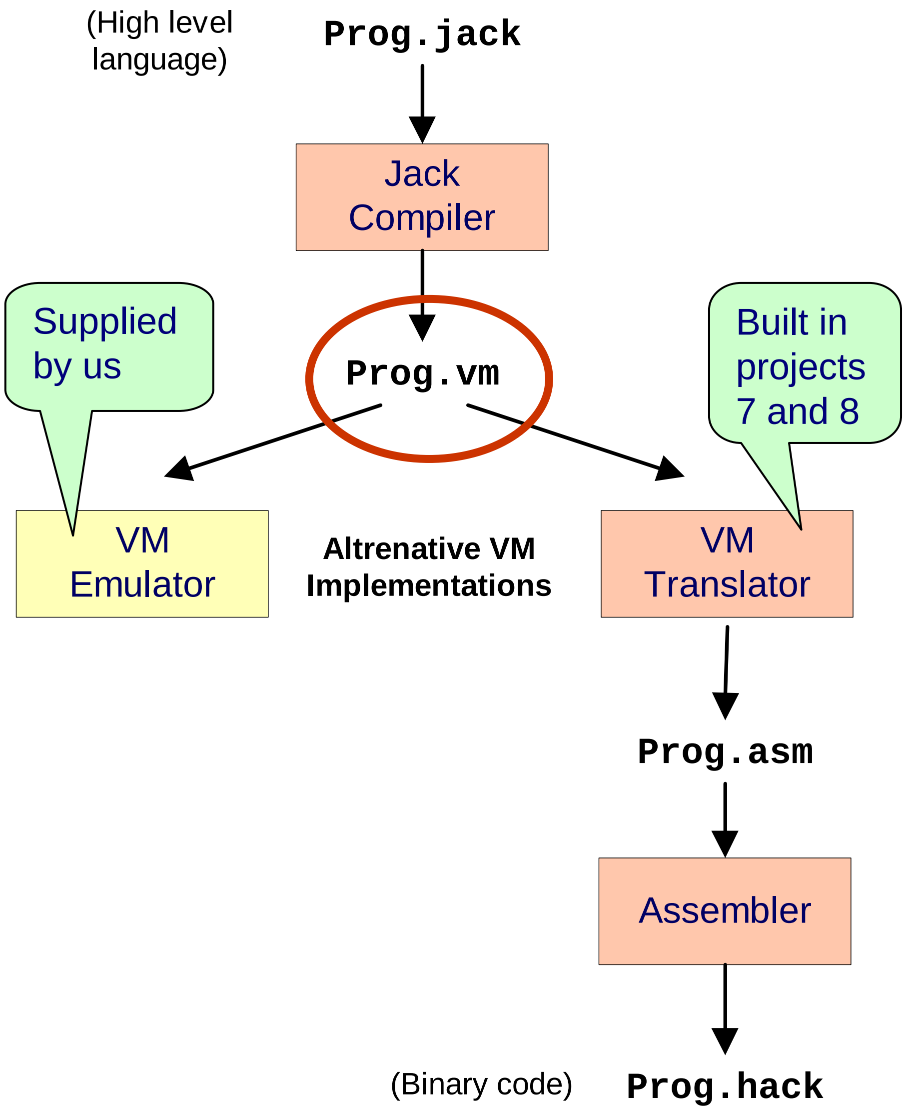
- **`Bin`**: simulators and translators software;
- **`builtIn`**: executable versions of all the logic gates and chips mentioned in the book;
- **`OS`**: executable version of the Jack OS;
- **`TextComparer`**: a text comparison utility.

Relevant reading (from *The Elements of Computing Systems*):

- Chapter 7: *Virtual Machine I: Stack Arithmetic*
- Chapter 8: *Virtual Machine II: Program Control*
- Appendix B: *Test Scripting Language, Section 4.*

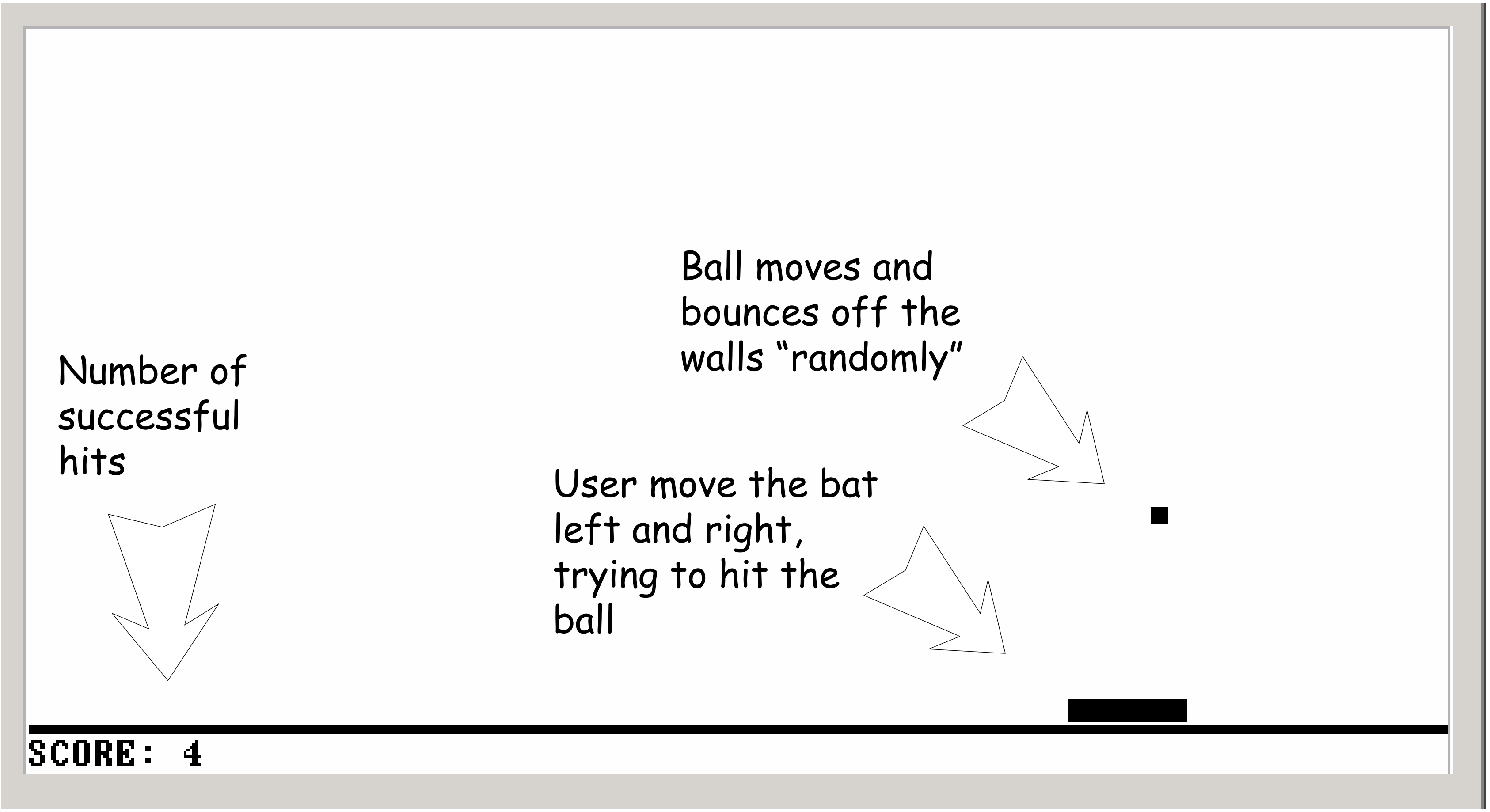

Part I:
Getting Started

The Typical Origin of VM Programs



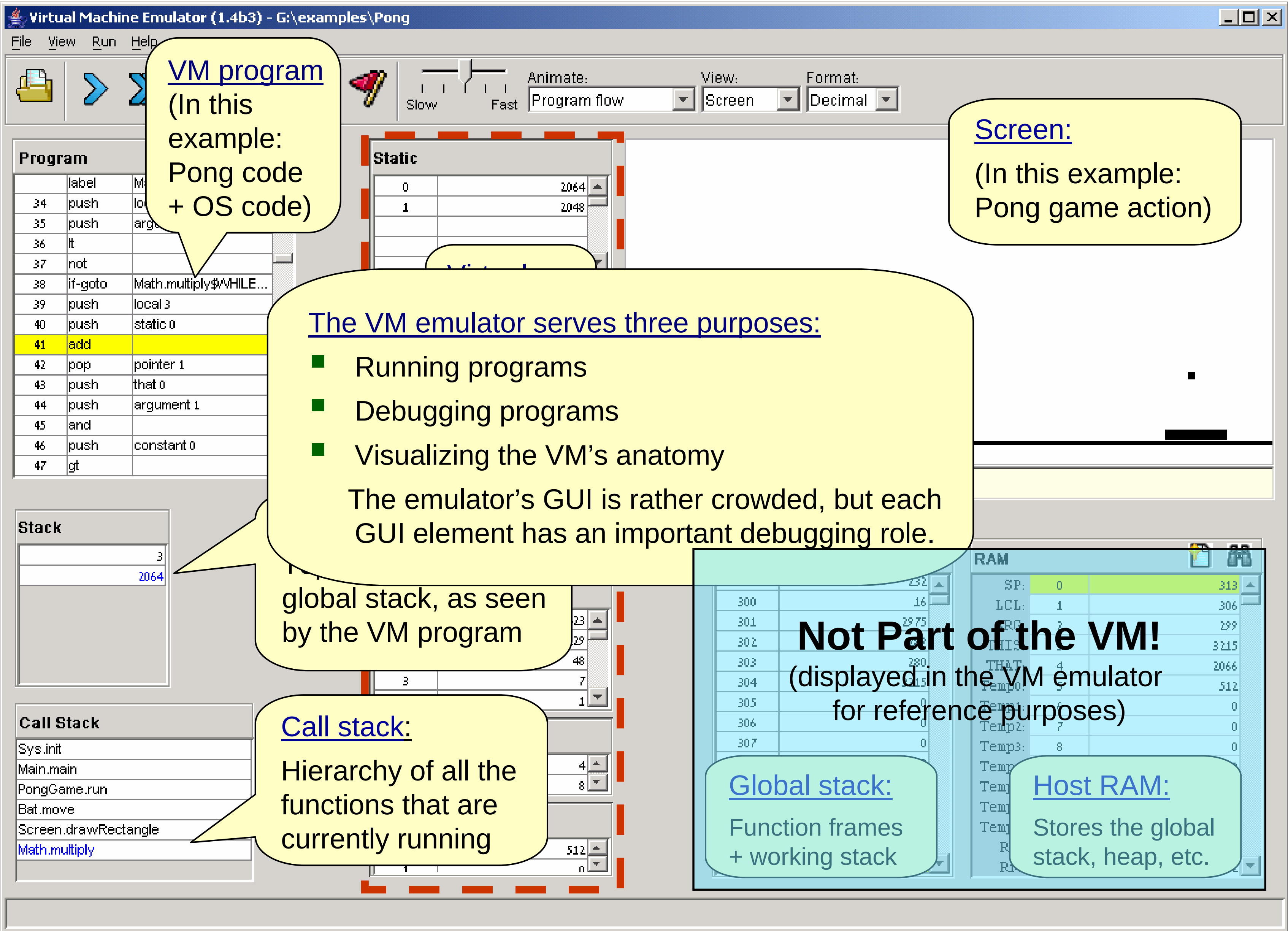
- VM programs are normally written by compilers
- For example, the Jack compiler (chapters 10-11) generates VM programs
- The VM program can be translated further into machine language, and then executed on a host computer
- Alternatively, the same VM program can be emulated as-is on a VM emulator.

Example: Pong game (user view)

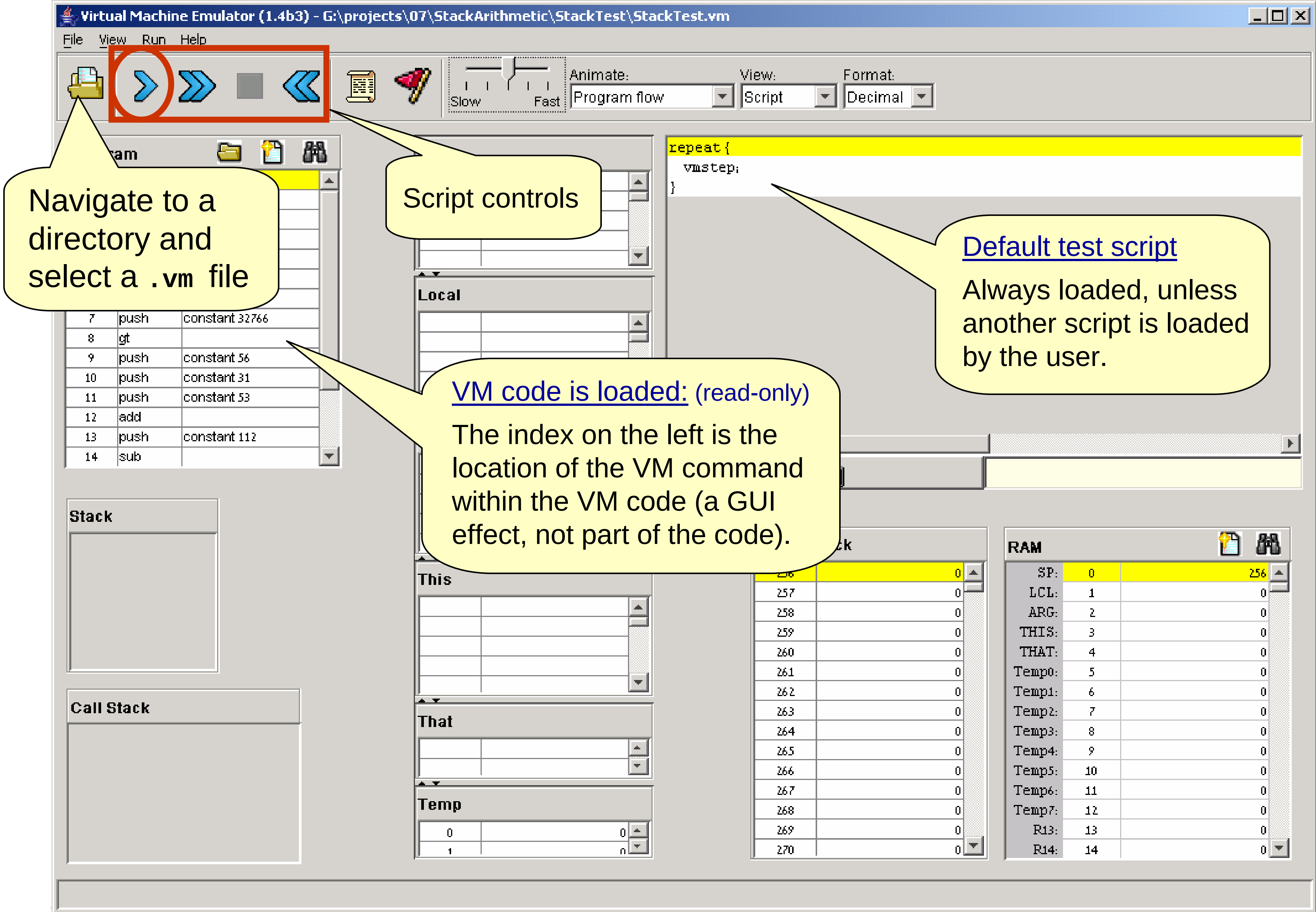


Now let's go behind the scene ...

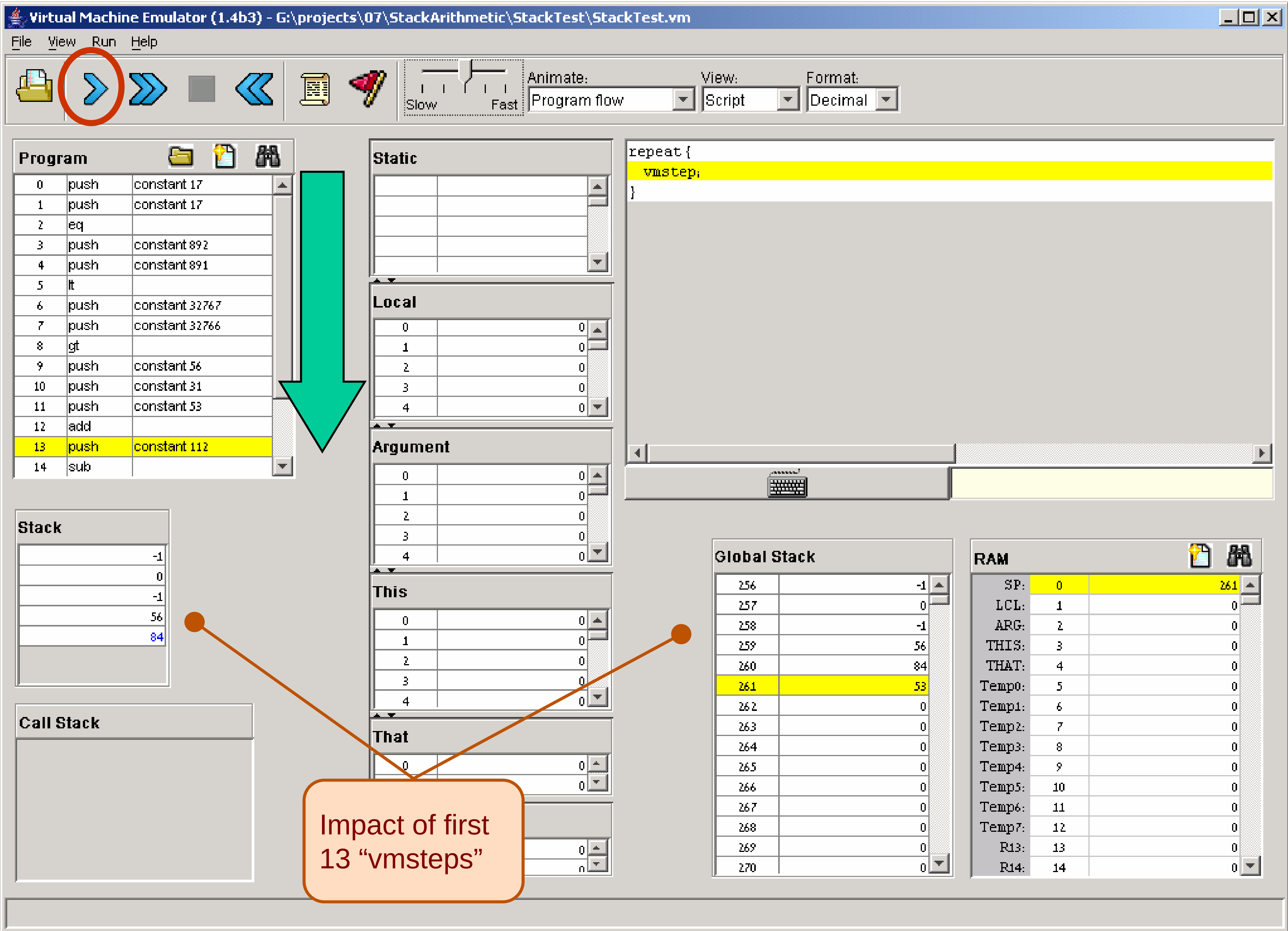
VM Emulator at a Glance



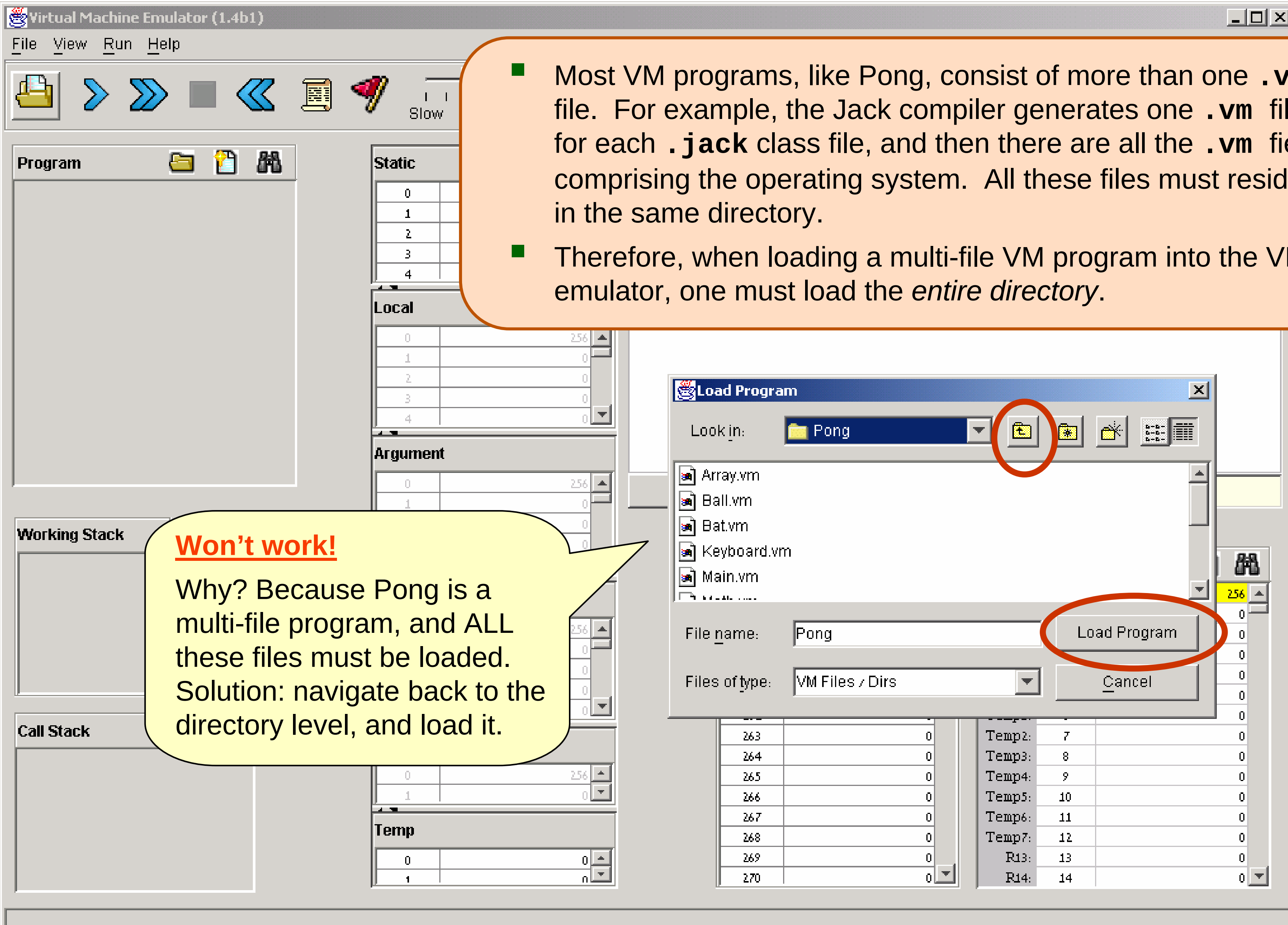
Running a Program



Running a Program



Loading a Multi-File Program

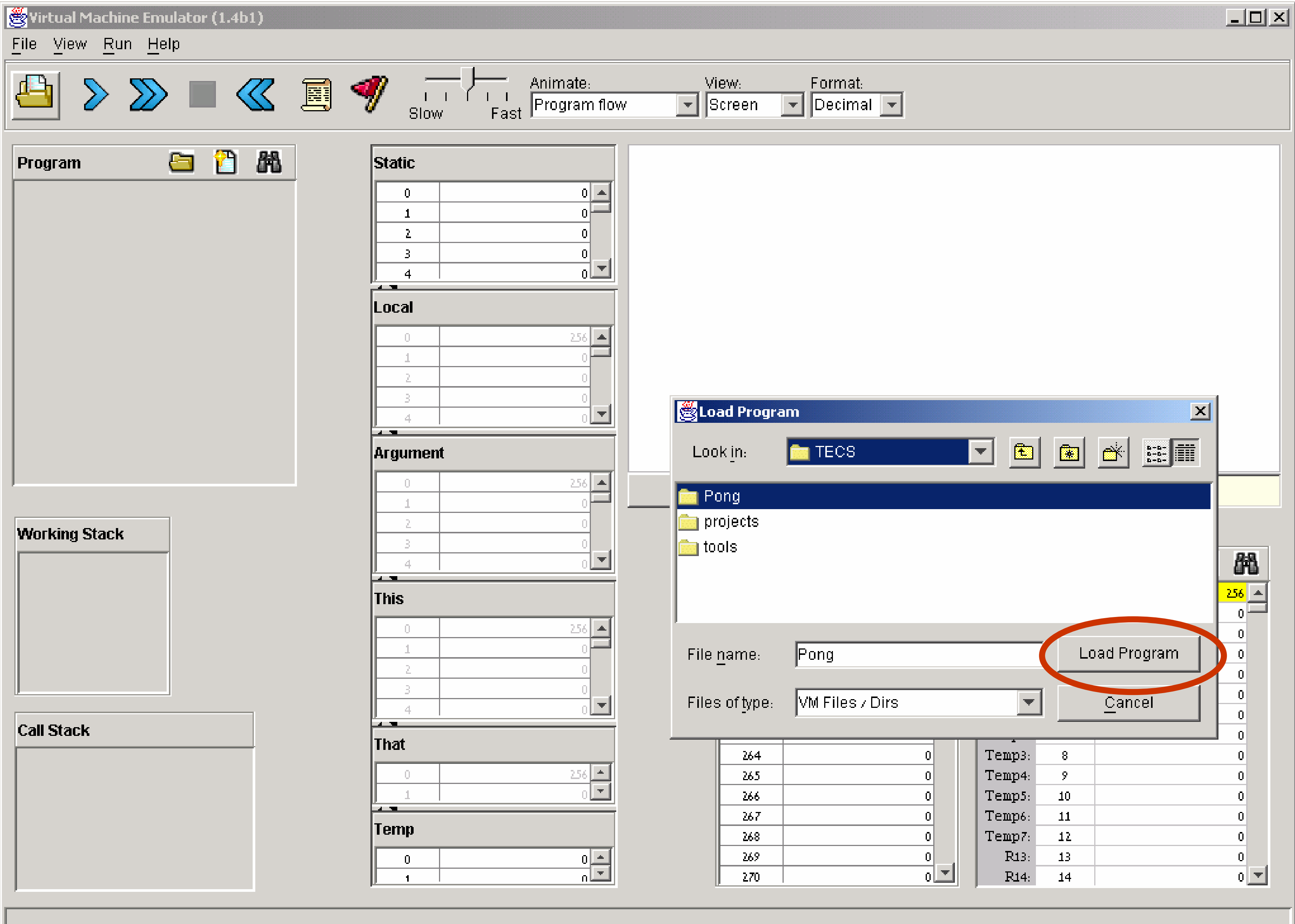


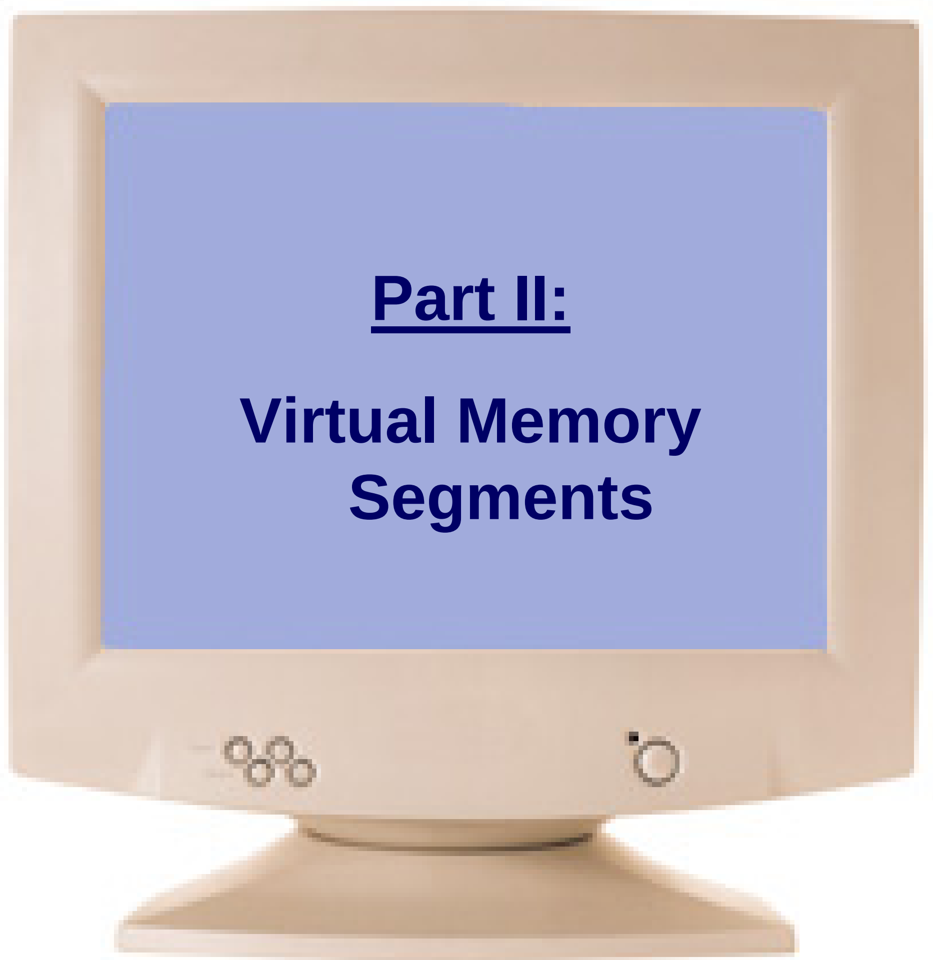
- Most VM programs, like Pong, consist of more than one **.vm** file. For example, the Jack compiler generates one **.vm** file for each **.jack** class file, and then there are all the **.vm** fies comprising the operating system. All these files must reside in the same directory.
- Therefore, when loading a multi-file VM program into the VM emulator, one must load the *entire directory*.

Won't work!

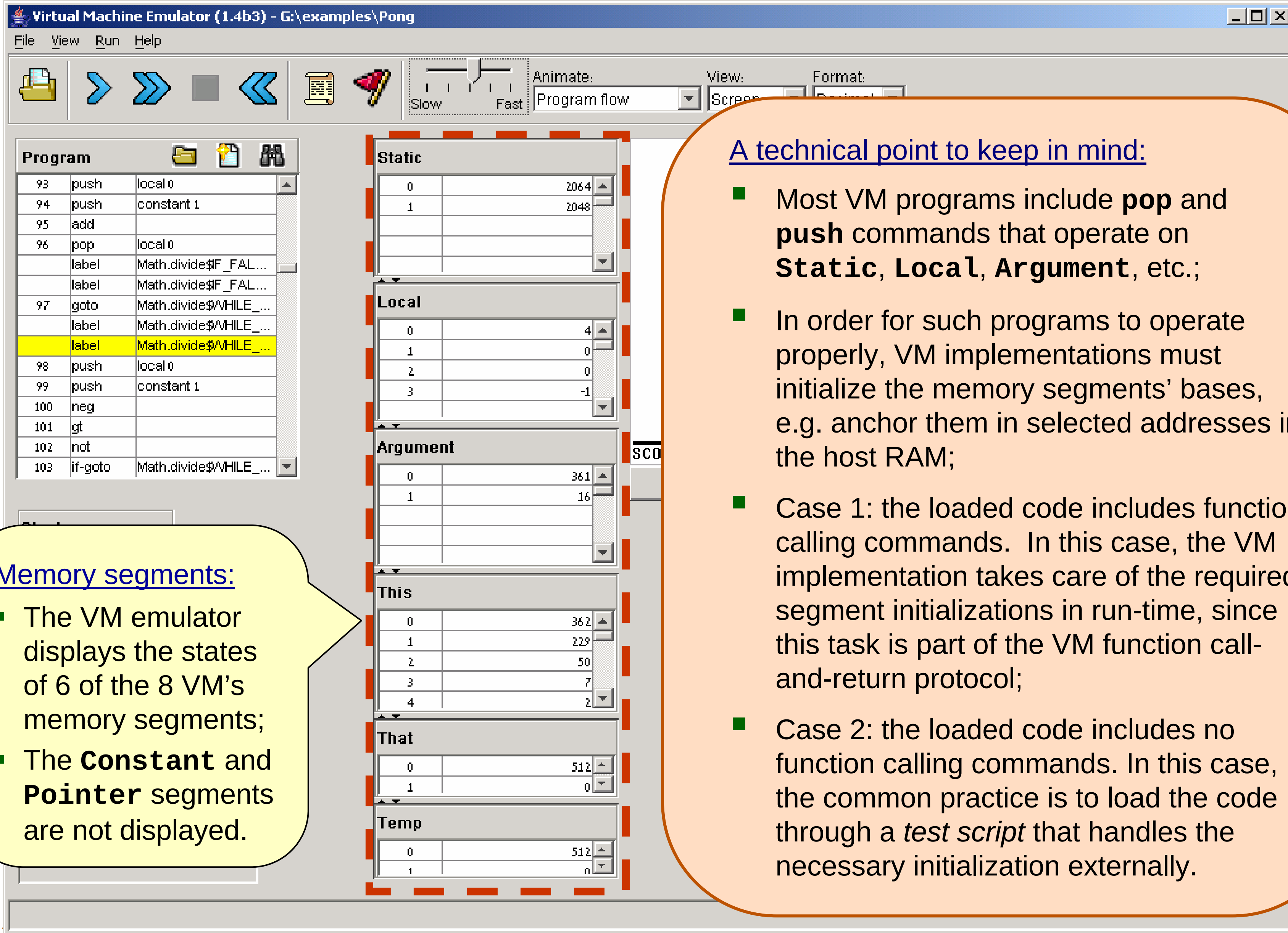
Why? Because Pong is a multi-file program, and ALL these files must be loaded. Solution: navigate back to the directory level, and load it.

Loading a Multi-File Program




Part II:
Virtual Memory
Segments

Virtual Memory Segments



Memory segments:

- The VM emulator displays the states of 6 of the 8 VM's memory segments;
- The **`Constant`** and **`Pointer`** segments are not displayed.

A technical point to keep in mind:

- Most VM programs include **`pop`** and **`push`** commands that operate on **`Static`**, **`Local`**, **`Argument`**, etc.;
- In order for such programs to operate properly, VM implementations must initialize the memory segments' bases, e.g. anchor them in selected addresses in the host RAM;
- Case 1: the loaded code includes function calling commands. In this case, the VM implementation takes care of the required segment initializations in run-time, since this task is part of the VM function call-and-return protocol;
- Case 2: the loaded code includes no function calling commands. In this case, the common practice is to load the code through a *test script* that handles the necessary initialization externally.


Part II:
Using Scripts

Typical VM Script

Simulation step (a series of script commands ending with a semicolon)

```
load BasicTest.vm,
output-file BasicTest.out,
compare-to BasicTest.cmp,
output-list RAM[256]%D1.6.1
       RAM[300]%D1.6.1 RAM[401]%D1.6.1
       RAM[402]%D1.6.1 RAM[3006]%D1.6.1
       RAM[3012]%D1.6.1
       RAM[3015]%D1.6.1 RAM[11]%D1.6.1;
```

Typical "script setup" commands

Next simulation step

```
set sp 256,
set local 300,
set argument 400,
set this 3000,
set that 3010;
```

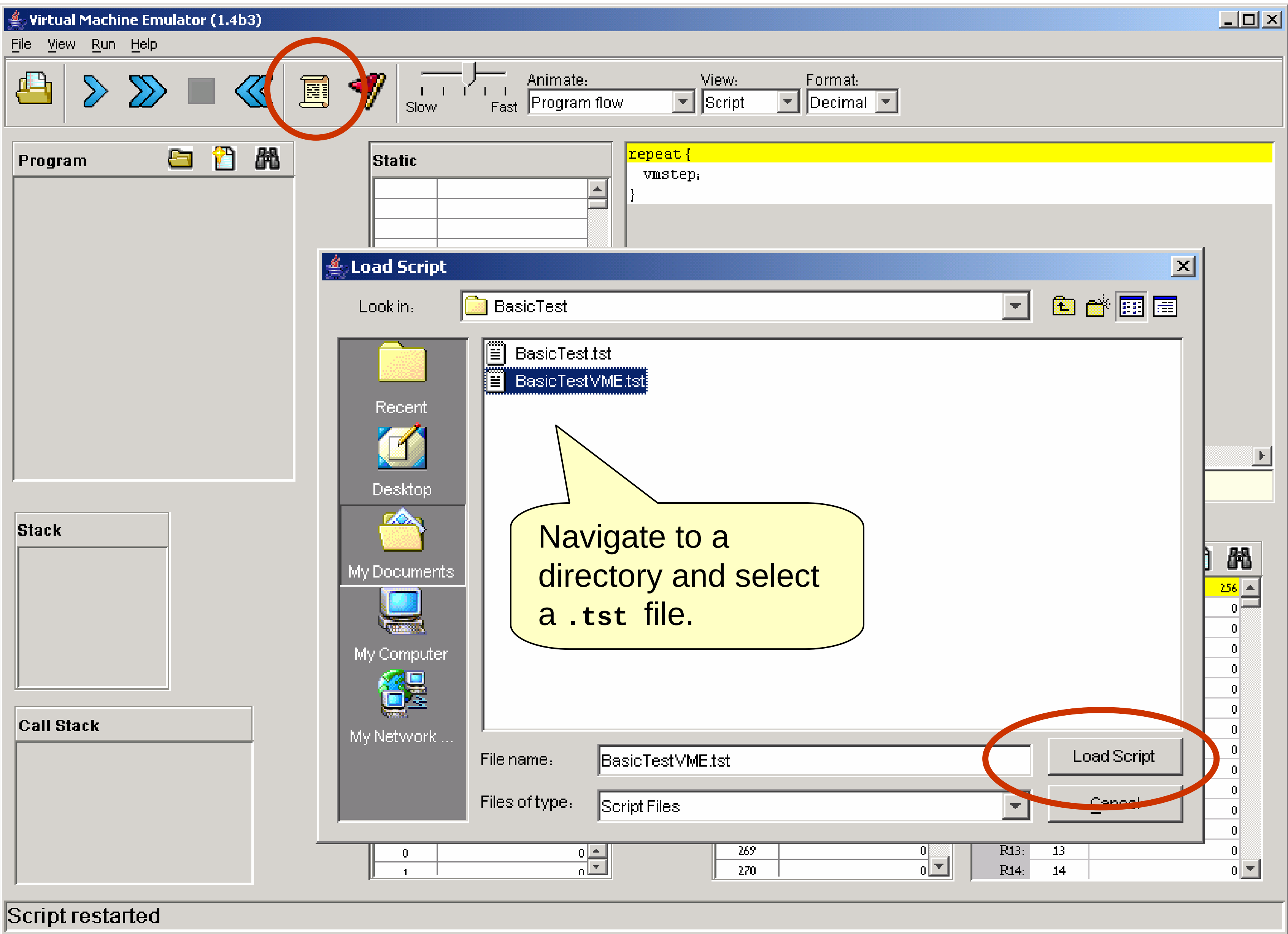
Typical memory segments initialization commands

Repeated simulation step

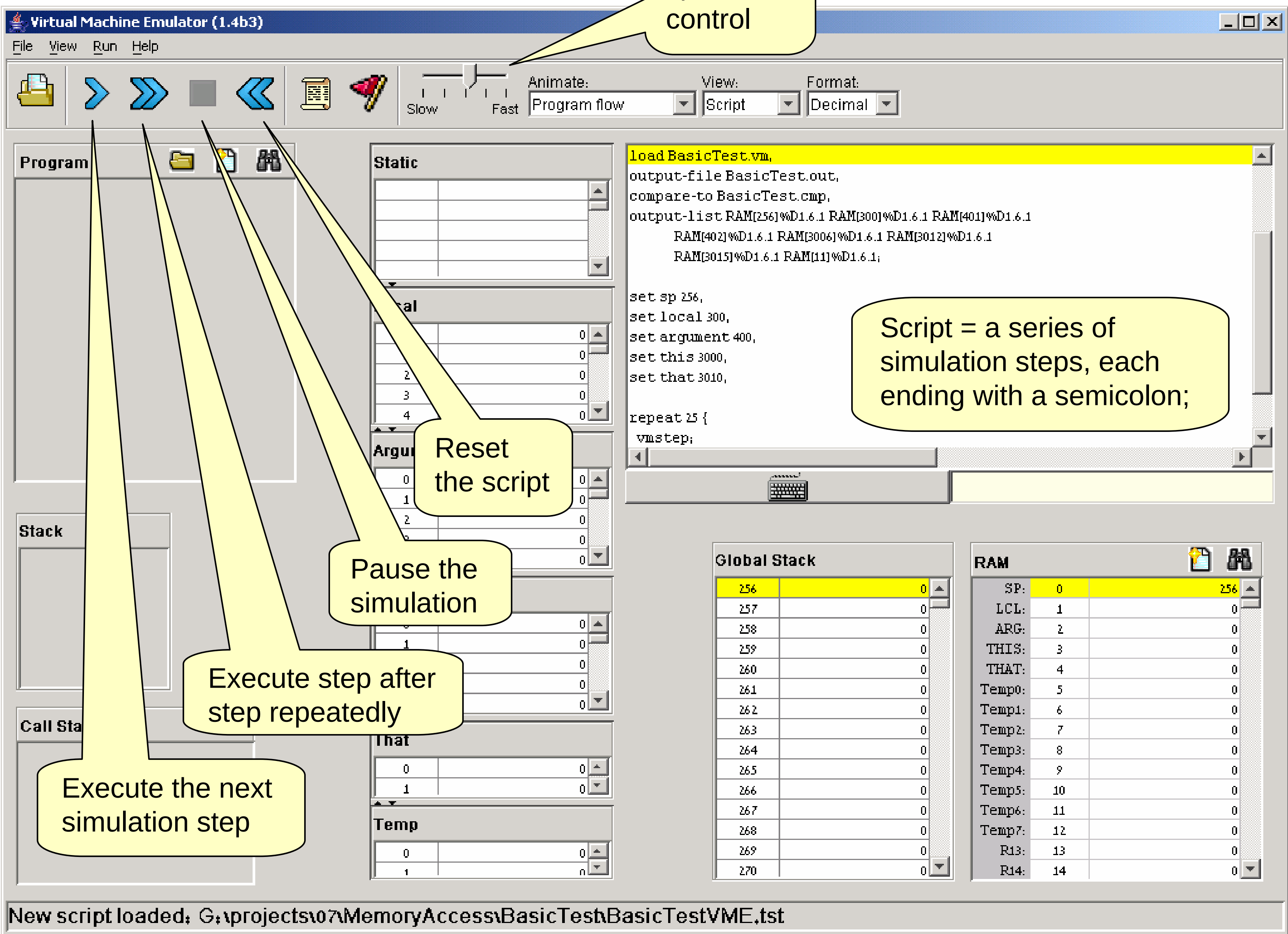
```
repeat 25 {
  vmstep,
  output;
}
```

Typical execution loop

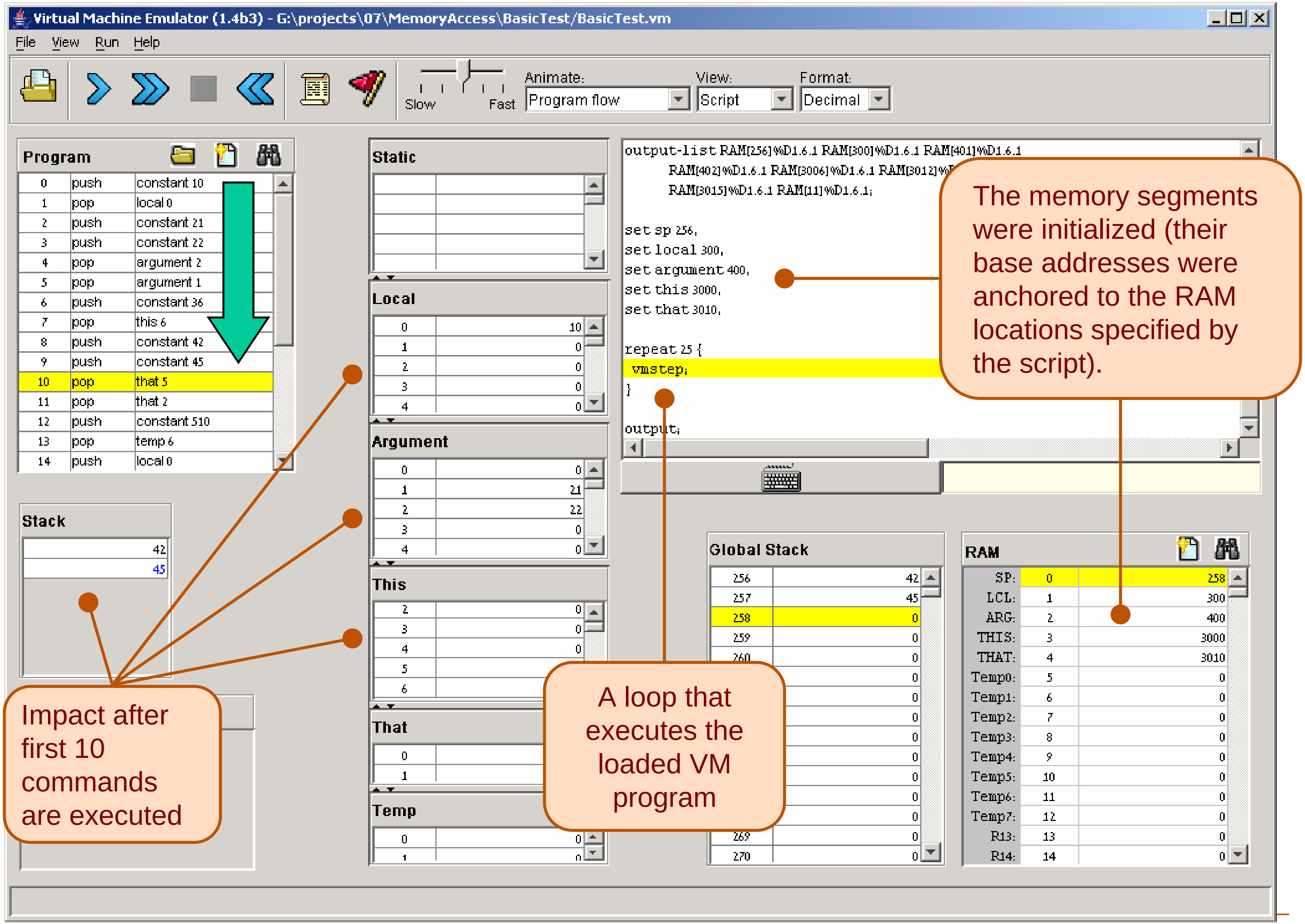
Loading a Script



Script Controls

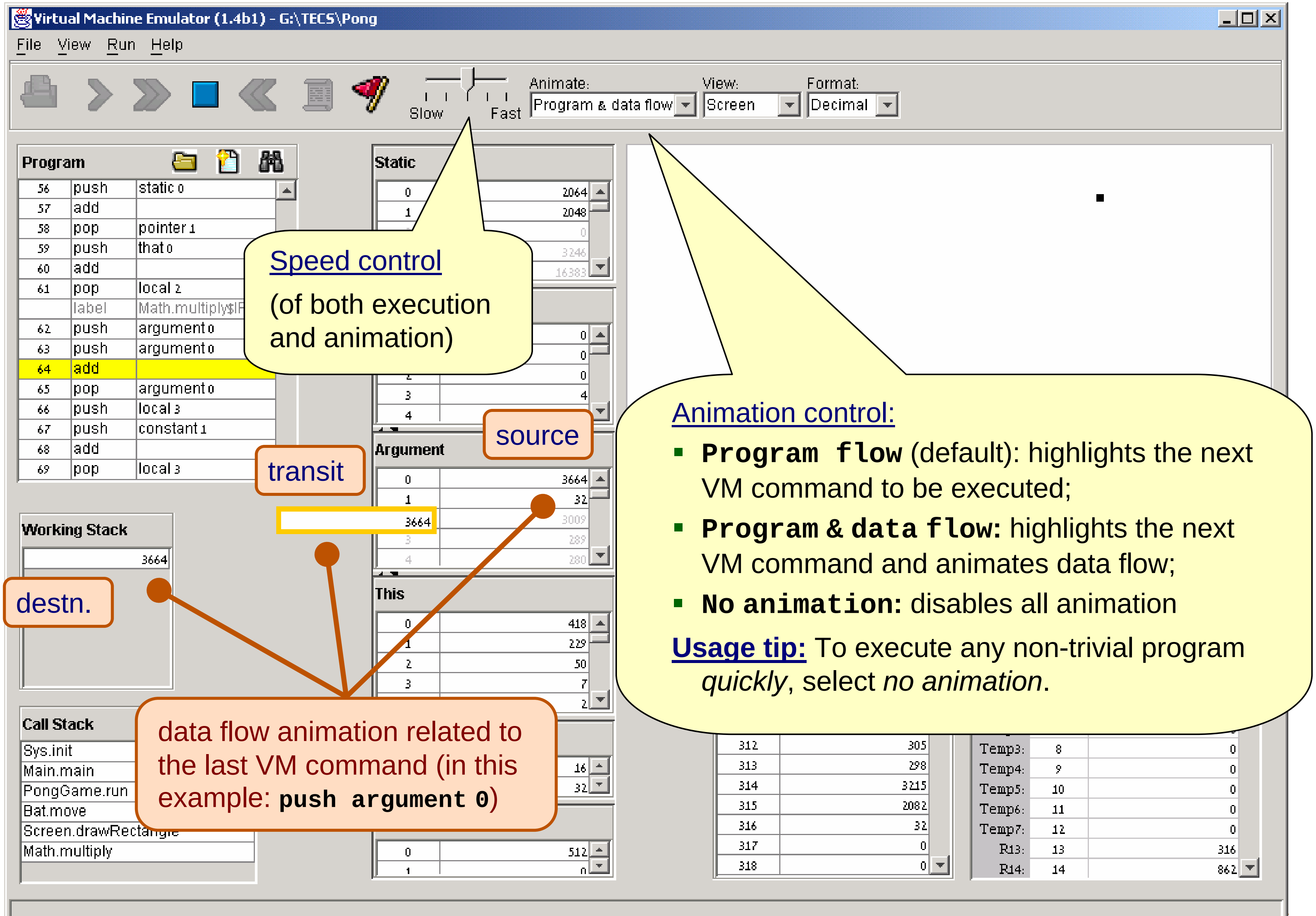


Running the Script




Part III:
Debugging

Animation Options



Breakpoints: a Powerful Debugging Tool

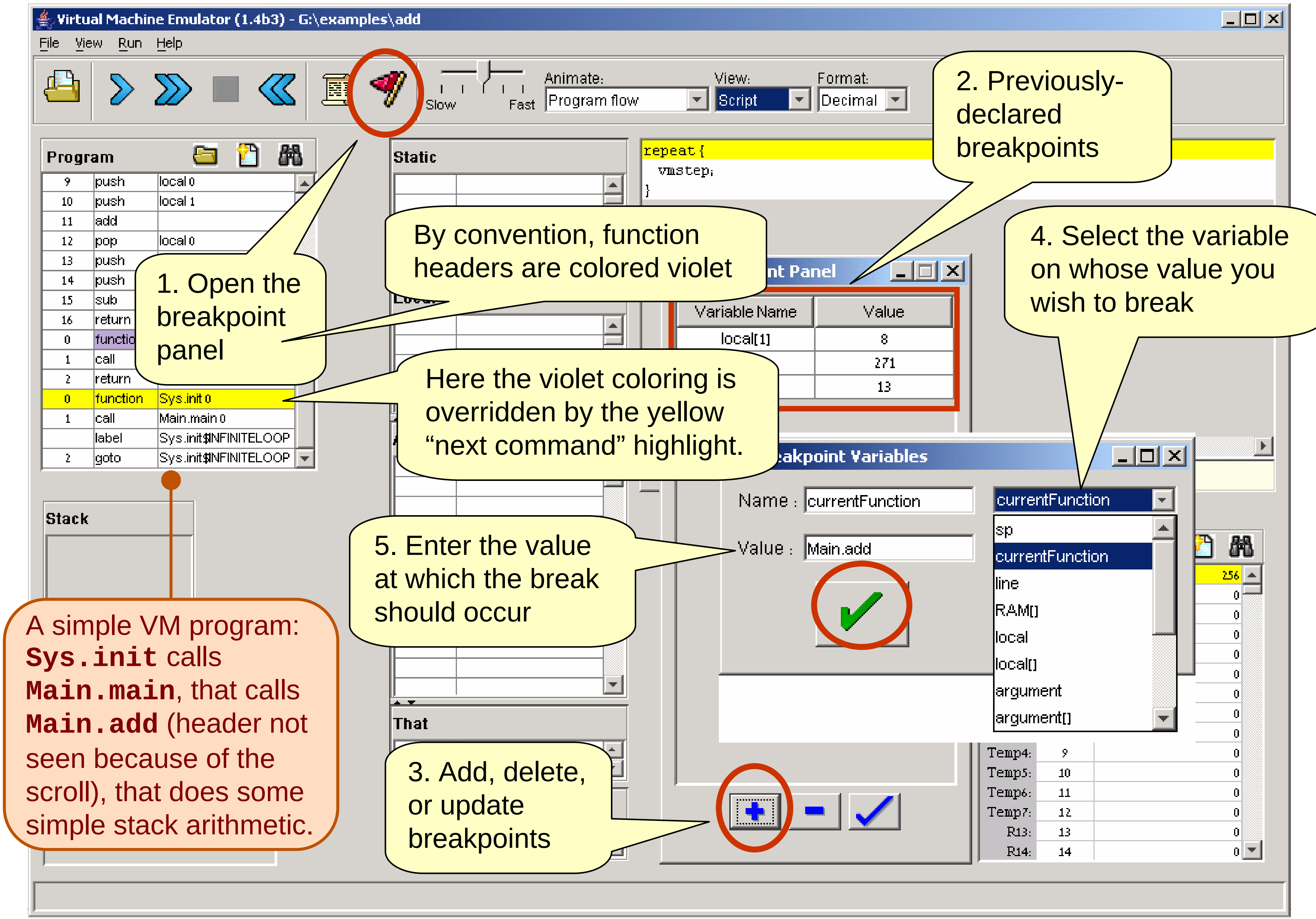
The VM emulator keeps track of the following variables:

- **`segment[i]`**: Where segment is either **`local`**, **`argument`**, **`this`**, **`that`**, or **`temp`**
- **`local`**, **`argument`**, **`this`**, **`that`**: Base addresses of these segments in the host RAM
- **`RAM[i]`**: Value of this memory location in the host RAM
- **`sp`**: Stack pointer
- **`currentFunction`**: Full name (inc. fileName) of the currently executing VM function
- **`line`**: Line number of the currently executing VM command

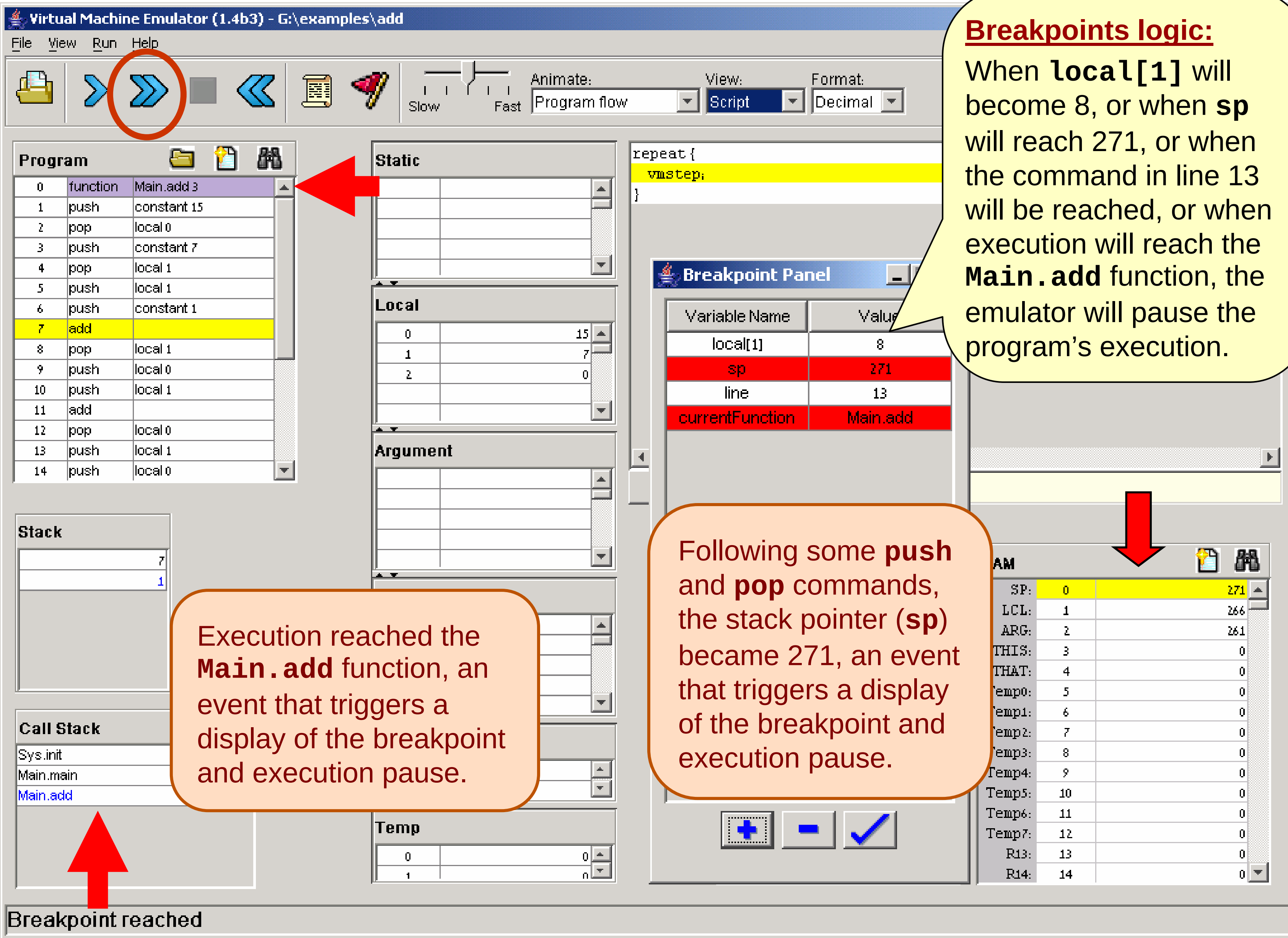
Breakpoints:

- A breakpoint is a pair <*variable*, *value*> where *variable* is one of the labels listed above (e.g. **`local[5]`**, **`argument`**, **`line`**, etc.) and *value* is a valid value
- Breakpoints can be declared either interactively, or via script commands
- For each declared breakpoint, when the *variable* reaches the *value*, the emulator pauses the program's execution with a proper message.

Setting Breakpoints



Breakpoints in Action



Breakpoints logic:

When **`local[1]`** will become 8, or when **sp** will reach 271, or when the command in line 13 will be reached, or when execution will reach the **`Main.add`** function, the emulator will pause the program's execution.

Execution reached the **`Main.add`** function, an event that triggers a display of the breakpoint and execution pause.

Following some **push** and **pop** commands, the stack pointer (**sp**) became 271, an event that triggers a display of the breakpoint and execution pause.

Breakpoints in Scripts

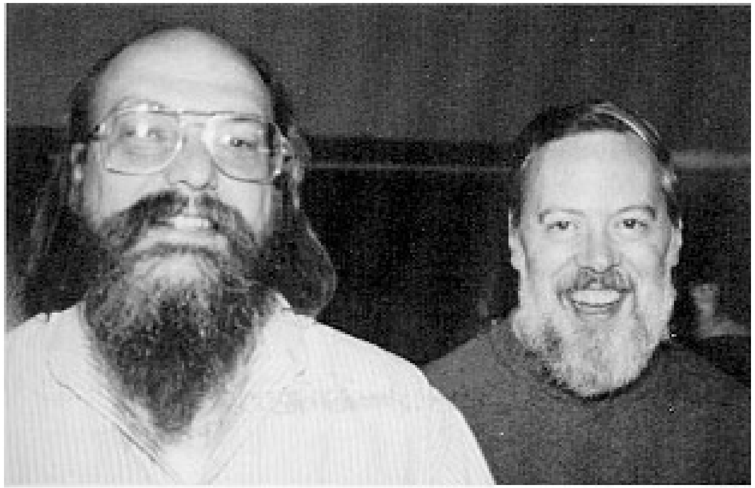
```
load myProg.vm,
output-file myProg.out,
output-list sp%D2.4.2
            CurrentFunction%S1.15.1
            Argument[0]%D3.6.3
            RAM[256]%D2.6.2;

breakpoint currentFunction Sys.init,

set RAM[256] 15,
set sp 257;

repeat 3 {
  vmStep,
}
output;

while sp < 260 {
  vmstep;
}
output;

clear-breakpoints;

// Etc.
```

- For systematic and replicable debugging, use scripts
- The first script commands usually load the **.vm** program and set up for the simulation
- The rest of the script may use various debugging-oriented commands:
  - Write variable values (output)
  - Repeated execution (while)
  - Set/clear Breakpoints
  - Etc. (see Appendix B.)

End-note on Creating Virtual Worlds

"It's like building something where you don't have to order the cement. You can create a world of your own, your own environment, and never leave this room."

(Ken Thompson,
1983 Turing Award lecture)



Ken Thompson (L) and Dennis Ritchie (R)