

Abstract Machines

Turing, LLVM, Lambda, SECD, Semantics

YEGOR BUGAYENKO

Lecture #5 out of 10

90 minutes

All videos are in [this YouTube playlist](#).

All visual and text materials presented in this slidedeck are either originally made by the author or taken from public Internet sources, such as website. Copyright belongs to their respected authors.

Who Are Abstract Machines?

Turing Machine

λ -calculus

SECD Machine(s)

Semantic

Chapter #1:

Who Are Abstract Machines?

Definition

An abstract machine is a theoretical model of computation.

Similar to a function, a machine receives inputs and produces outputs based on predefined rules.

Abstract machines are “machines” because they allow step-by-step execution of programmes. (really?)

They are “abstract” because they ignore many aspects of actual (hardware) machines.

An abstract machine is an intermediate language with a small-step operational semantics.

Purpose

“The implementation of a programming language consists of two stages. The implementation of the compiler and the implementation of the abstract (virtual?) machine. This is a typical divide-and-conquer approach. From a pedagogical point of view, this simplifies the presentation and teaching of the principles of programming language implementations. From a software engineering point of view, the introduction of layers of abstraction increases maintainability and portability.” (1999)

We are interested in using abstract machines to explain the semantic of a program.

Virtual Machines

An abstract machine implemented in software is termed a virtual machine, and one implemented in hardware is called simply a “machine.”

JVM (for Java) and CLR (for .NET) are among most notable examples of virtual machines.

IR (intermediate representation) is used internally by a compiler or virtual machine to represent source code. An intermediate language is the language of an abstract machine.

LLVM

LLVM (Low Level Virtual Machine) is a standard de-facto.

```
@.str = internal constant [14 x i8] c"hello, world\0A\00"

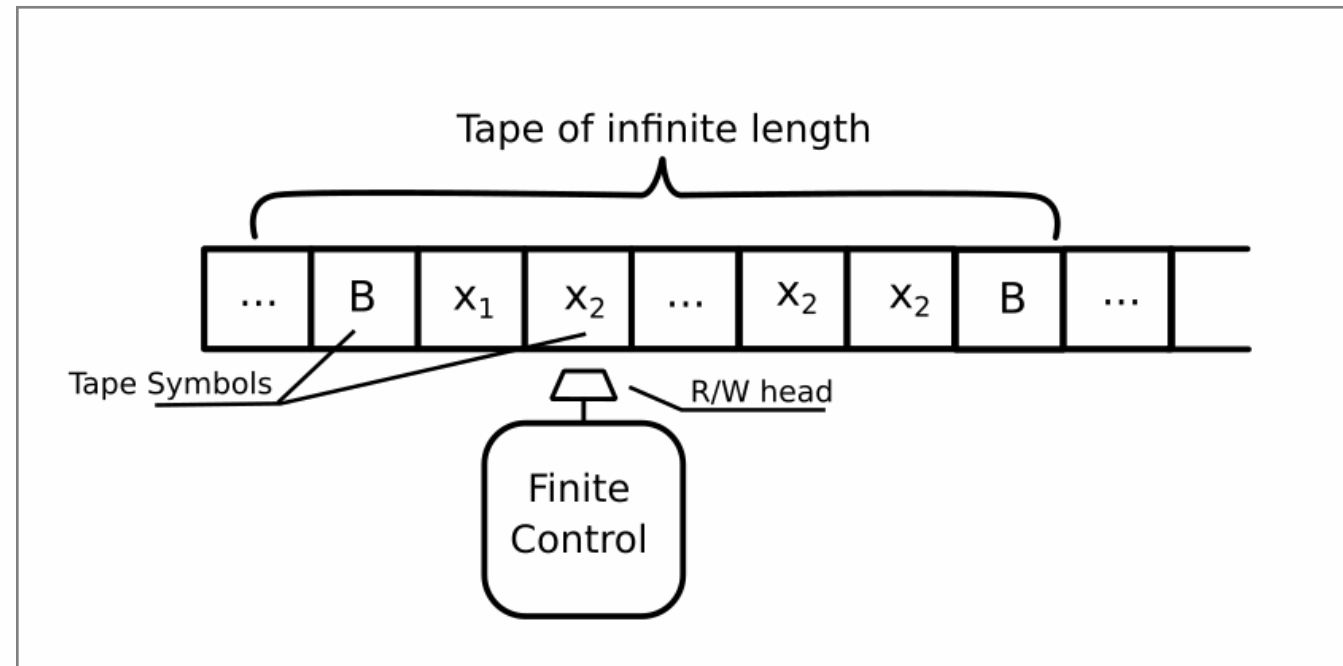
declare i32 @printf(ptr, ...)

define i32 @main(i32 %argc, ptr %argv) nounwind {
entry:
    %tmp1 = getelementptr [14 x i8], ptr @.str, i32 0, i32 0
    %tmp2 = call i32 (ptr, ...) @printf( ptr %tmp1 ) nounwind
    ret i32 0
}
```

Chapter #2:

Turing Machine

Turing Machine was the first (1936) ... but not the simplest.



For example, Emil Post's Machine is simpler.

Proof

The Church-Turing thesis: Anything that can be computed can be computed by some Turing machine.

There **has never been a proof**, but the evidence for its validity comes from the fact that every realistic model of computation, yet discovered, has been shown to be equivalent. — here.

Chapter #3:

λ -calculus

Abstraction:

$$(\lambda x.t) \quad \text{e.g. } f = \lambda x.\sqrt{x}$$

Application:

$$(ts) \quad \text{e.g. } (f \ 16) = 4$$

In lambda calculus, functions are taken to be “first class values,” so functions may be used as the inputs, or be returned as outputs from other functions.

Chapter #4:

SECD Machine(s)

There are SECD (**s**tack, **e**nvironment, **c**ontrol, **d**ump), CESH, CEK, CS, and maybe other abstract machines.

I like the CRM (**c**ontrol stack, **r**esult stack, **m**emory) machine explained by [Michael Pradel](#) in [his YouTube course](#) about program analysis: $\langle c, r, m \rangle$.

$$\begin{aligned} \langle x := 2 \times 3, \text{nil}, \{\} \rangle &\longrightarrow \langle x \circ 2 \times 3 \circ :=, \text{nil}, \{\} \rangle \\ &\longrightarrow \langle 2 \times 3 \circ :=, x \circ \text{nil}, \{\} \rangle \\ &\longrightarrow \langle :=, 6 \circ x \circ \text{nil}, \{\} \rangle \\ &\longrightarrow \langle \text{nil}, \text{nil}, \{x \mapsto 6\} \rangle \end{aligned}$$

Chapter #5: Semantic

This is our programming language that helps us draw on a canvas:

```
L 10, 20, 15, 23;
C 13, 13, 35;
L 5, 28, 15, 12;
```

Its semantic may be explained by the abstract machine with the following instruction set, which semantic is **obvious** to a reader:

```
DRAW x, y;
LOOP; IF t THEN BREAK; END LOOP;
x > y; x + y; x - y; x / y;
x := y;
1600; 900.
```



This is what "L x1, y1, x2, y2" means:

```
dx := x2 - x1;
dx := dx / 1600;
dy := y2 - y1;
dy := dy / 900;
LOOP;
DRAW x1, y1;
IF x1 > x2 THEN BREAK;
IF y1 > y2 THEN BREAK;
x1 := x1 + dx;
y1 := y1 + dy;
END LOOP;
```

