Abstract Machines

Turing, LLVM, Lambda, SECD, Semantics

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Lecture #5 out of 10 90 minutes

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Who Are Abstract Machines?

Turing Machine

 λ -calculus

SECD Machine(s)

Semantic

Chapter #1:

Who Are Abstract Machines?

[Definition Purpose Virtual Machines LLVM]

Definition

An abstract machine is a theoretical model of computation.

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

Abstract machines are "machines" because they allow <u>step-by-step</u> execution of programmes. (really?)

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

An abstract machine is an <u>intermediate language</u> with a small-step operational semantics.

[Definition Purpose Virtual Machines LLVM]

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 <u>semantic</u> of a program.

[Definition Purpose Virtual Machines LLVM]

Virtual Machines

An abstract machine implemented in software is termed a <u>virtual machine</u>, 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 (<u>intermediate representation</u>) is used internally by a compiler or virtual machine to represent source code. An <u>intermediate language</u> is the language of an abstract machine.

Machines Turing λ SECD Semantic

[Definition Purpose Virtual Machines 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, ...)

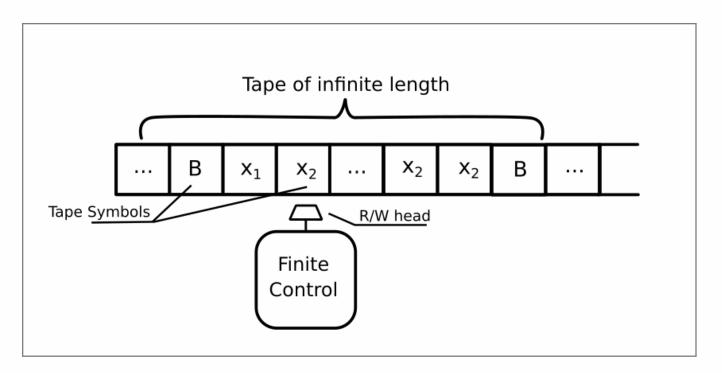
define i32 @main(i32 %argc, ptr %argv) nounwind {
  entry:
    %tmp1 = getelementptr [14 x i8], ptr @.str, i32 0, i32 0
    %tmp2 = call i32 (ptr, ...) @printf( ptr %tmp1 ) nounwind
    ret i32 0
}
```

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Chapter #2:

Turing Machine

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



For example, Emil Post's Machine is simpler.

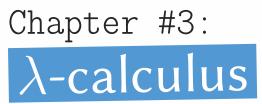
[Proof]

Proof

The <u>Church-Turing thesis</u>: 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. — <u>here</u>.

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Abstraction:

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

Application:

$$(ts)$$
 e.g. $(f 16) = 4$

In lambda calculus, <u>functions</u> are taken to be "first class values," so functions may be used as the inputs, or be returned as outputs from other functions.

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Chapter #4:

SECD Machine(s)

There are SECD (stack, environment, control, dump), CESK, CEK, CS, and maybe other abstract machines.

I like the CRM (control stack, result stack, memory) machine explained by Michael Pradel in his YouTube course about program analysis: $\langle c, r, m \rangle$.

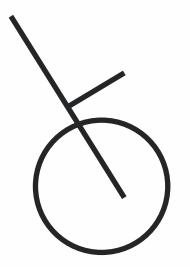
$$\langle \mathbf{x} := 2 \times 3, \mathbf{nil}, \{\} \rangle \longrightarrow \langle \mathbf{x} \circ 2 \times 3 \circ :=, \mathbf{nil}, \{\} \rangle$$
$$\longrightarrow \langle 2 \times 3 \circ :=, \mathbf{x} \circ \mathbf{nil}, \{\} \rangle$$
$$\longrightarrow \langle :=, 6 \circ \mathbf{x} \circ \mathbf{nil}, \{\} \rangle$$
$$\longrightarrow \langle \mathbf{nil}, \mathbf{nil}, \{\mathbf{x} \mapsto 6\} \rangle$$

Chapter #5:

Semantic

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

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;
```

