# Concrete model of computation

The INFDEV Team @ HR

Hogeschool Rotterdam
Rotterdam, Netherlands

# Introduction

## Lecture topics

- We discuss a formal way to define computation
- We discuss the fundamental elements of a concrete computer
- We bridge what we have seen in the previous lecture with concrete descriptions

# Introduction

## Semantics

- Any language has **semantics**
- **Semantics** describe the *meaning* of sentences in the language
- Programming languages have **formal semantics**
- **Formal semantics** are expressed in a very logical, unambiguous format

Consider this program from the previous lecture:

```
1 take 3 steps forward
2 sit on the chair
3 turn left
4 slide 3 steps forward
```

What do you implicitly assume by performing each of the instructions? **Try to guess and discuss!**

# Introduction

## Semantics of `stdNt`

- We start with a *current instruction* and a *student state*:
  - The current instruction (often called *instruction pointer* (`IP`) or *program counter* (`PC`)) is just the index of the current instruction;
  - the student state (usually just called *state*, or `S`, or $\sigma$) is whatever relevant attributes we track about the student (for example, his position and orientation in the room and whether or not he is sitting).
- Each instruction changes the `PC` and the `S`.

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 1 | Standing | Forward | (0,0) |

```
1 take 3 steps forward
2 sit on the chair
3 turn left
4 slide 3 steps forward
```

what changes while running the current instruction? **Try to guess and discuss!**

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 2 | Standing | Forward | (0,3) |

```
1 take 3 steps forward
2 sit on the chair
3 turn left
4 slide 3 steps forward
```

what changes while running the current instruction? **Try to guess and discuss!**

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 3 | Sitting | Forward | (0,3) |

```
1 take 3 steps forward
2 sit on the chair
3 turn left
4 slide 3 steps forward
```

what changes while running the current instruction? **Try to guess and discuss!**

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 4 | Sitting | Left | (0,3) |

```
1 take 3 steps forward
2 sit on the chair
3 turn left
4 slide 3 steps forward
```

what changes while running the current instruction? **Try to guess and discuss!**

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| END | Sitting | Left | (-3,3) |

```
1 take 3 steps forward
2 sit on the chair
3 turn left
4 slide 3 steps forward
```

what do we do now? **Try to guess and discuss!**

# Introduction

## A slight formalization

- We say that an instruction `I` is a *function* that, given a pair of `PC` and `S`, returns a new pair of `PC` and `S`

# Introduction

## A slight formalization

- We say that an instruction `I` is a *function* that, given a pair of `PC` and `S`, returns a new pair of `PC` and `S`
- Do not panic now, math..y symbols incoming!

# Introduction

## A slight formalization

- We say that an instruction `I` is a *function* that, given a pair of `PC` and `S`, returns a new pair of `PC` and `S`
- Do not panic now, math..y symbols incoming!
- $(PC, S) \overset{Instr}{\rightarrow} (PC', S')$

# Introduction

## A slight formalization

- Consider instruction `sit on the chair` (we will shorten it to `sit`)
- *How do we change the current instruction?*
- *How do we change the position of the resulting state depending on the orientation of the input state?*

# Introduction

## A slight formalization

- Consider instruction `sit on the chair` (we will shorten it to `sit`)
  - $(PC, S) \xrightarrow{sit} (PC + 1, S[Pose \mapsto Sitting])$
- We increment the current instruction index by one
- We change the pose of the resulting state independent on the input state
  - $S[Pose \mapsto Sitting]$ is read as *"S, where pose is sitting"*

# Introduction

## A slight formalization

- Consider instruction `stand up` (we will shorten it to `stand`)
- *How do we change the current instruction?*
- *How do we change the position of the resulting state depending on the orientation of the input state?*

## A slight formalization

- Consider instruction `stand up` (we will shorten it to `stand`)

# Introduction

## A slight formalization

- Consider instruction `stand up` (we will shorten it to `stand`)
  - $(PC, S) \overset{stand}{\rightarrow} (PC + 1, S[Pose \mapsto Standing])$
- We increment the current instruction index by one
- We change the pose of the resulting state independent on the input state

# Introduction

## A slight formalization

- Consider instruction `take 3 steps forward` (we will shorten it to `fwd 3`)
- *How do we determine the next instruction index?*
- *How do we change the position of the resulting state?*
  - Are there dependencies from the input state?

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 104 | Standing | Left | (10,20) |

```
103 ...
104 take 3 steps forward
105 ...
```

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 105 | Standing | Left | (7,20) |

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 104 | Standing | Right | (10,20) |

```
103 ...
104 take 3 steps forward
105 ...
```

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 105 | Standing | Right | (13,20) |

# Introduction

## A slight formalization

- Consider instruction `take 3 steps forward` (we will shorten it to `fwd 3`)

$$\begin{cases} (PC, S) \overset{fwd3}{\rightarrow} (PC + 1, S[Position \mapsto S.Position + (0, 3)]) \\ when\ S.Orientation = Forward \\ (PC, S) \overset{fwd3}{\rightarrow} (PC + 1, S[Position \mapsto S.Position - (0, 3)]) \\ when\ S.Orientation = Backward \\ (PC, S) \overset{fwd3}{\rightarrow} (PC + 1, S[Position \mapsto S.Position + (3, 0)]) \\ whenS.Orientation = Right \\ (PC, S) \overset{fwd3}{\rightarrow} (PC + 1, S[Position \mapsto S.Position - (3, 0)]) \\ whenS.Orientation = Left \end{cases}$$

- We always increment the instruction by one
- We change the position of the resulting state depending on the orientation of the input state

# Introduction

## A slight formalization

- Consider instruction `if A then B else C`
- *How do we determine the next instruction index?*
- *How do we change the state?*

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 24 | Standing | Right | (10,20) |

```
23  ...
24  if A is ‘‘black’’ then
25    turn left by 90 * B degrees
26  otherwise
27    turn left by 90 * C degrees
28  ...
```

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 25[1] | Standing | Right | (10,20) |

[1] Assuming student's shirt is black

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 24 | Standing | Right | (10,20) |

```
23  ...
24  if A is ‘‘black’’ then
25    turn left by 90 * B degrees
26  otherwise
27    turn left by 90 * C degrees
28  ...
```

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 27[2] | Standing | Right | (10,20) |

[2] Assuming student's shirt is not black

# Introduction

## A slight formalization

- Consider instruction `if A then B else C` (shortened by as $if_{ABC}$)

# Introduction

## A slight formalization

- Consider instruction `if A then B else C` (shortened by as $if_{ABC}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`

# Introduction

## A slight formalization

- Consider instruction `if A then B else C` (shortened by as $if_{ABC}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`
- We jump to the first instruction of the `C` block if the condition evaluates to `FALSE`

# Introduction

## A slight formalization

- Consider instruction `if A then B else C` (shortened by as $if_{ABC}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`
- We jump to the first instruction of the `C` block if the condition evaluates to `FALSE`
- We leave the state unchanged

# Introduction

## A slight formalization

- Consider instruction `if A then B else C` (shortened by as $if_{ABC}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`
- We jump to the first instruction of the `C` block if the condition evaluates to `FALSE`
- We leave the state unchanged

$$\begin{cases} (PC, S) \overset{if_{ABC}}{\rightarrow} (loc(B), S) & when \quad (PC, S) \overset{A}{\rightarrow} \texttt{TRUE} \\ (PC, S) \overset{if_{ABC}}{\rightarrow} (loc(C), S) & when \quad (PC, S) \overset{A}{\rightarrow} \texttt{FALSE} \end{cases}$$

# Introduction

## A slight formalization

- Consider instruction `while A do B`
- *How do we determine the next instruction index?*
- *How do we change the state?*

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 24 | Standing | Right | (10,20) |

```
23 ...
24 while A is ‘‘sunny’’ do
25   order another beer
26   enjoy the day for another hour
27 go back to work
28 ...
```

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 25[3] | Standing | Right | (10,20) |

[3] As long as it is sunny

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 24 | Standing | Right | (10,20) |

```
23  ...
24  while A is ‘‘sunny’’ do
25    order another beer
26    enjoy the day for another hour
27  go back to work
28  ...
```

| PC | S.Pose | S.Orientation | S.Position |
|---|---|---|---|
| 27[4] | Standing | Right | (10,20) |

[4] When it stops being sunny

# Introduction

## A slight formalization

- Consider instruction `while A do B` (shortened by as $while_{AB}$)

# Introduction

## A slight formalization

- Consider instruction `while A do B` (shortened by as $while_{AB}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`

# Introduction

## A slight formalization

- Consider instruction `while A do B` (shortened by as $while_{AB}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`
- We jump to after the last instruction of the `B` block if the condition evaluates to `FALSE`

# Introduction

## A slight formalization

- Consider instruction `while A do B` (shortened by as $while_{AB}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`
- We jump to after the last instruction of the `B` block if the condition evaluates to `FALSE`
- We leave the state unchanged

# Introduction

## A slight formalization

- Consider instruction `while A do B` (shortened by as $while_{AB}$)
- We jump to the first instruction of the `B` block if the condition evaluates to `TRUE`
- We jump to after the last instruction of the `B` block if the condition evaluates to `FALSE`
- We leave the state unchanged

$$\begin{cases} (PC, S) \overset{while_{AB}}{\rightarrow} (loc(B), S) \; when \; (PC, S) \overset{A}{\rightarrow} \texttt{TRUE} \\ (PC, S) \overset{while_{AB}}{\rightarrow} (lastloc(B) + 1, S) \; when \; (PC, S) \overset{A}{\rightarrow} \texttt{FALSE} \end{cases}$$

# This is it!

The best of luck, and thanks for the attention!