Test

The INFDEV team

Hogeschool Rotterdam
Rotterdam, Netherlands

Introduction

Lecture topics

- Course introduction
- Exam and practicum
- Semantics of traditional programming languages
- Basic lambda calculus

Course introduction

Course topics

- We will discuss a completely new paradigm for expressing programs
- This paradigm, functional programming, is based on different premises on computation
- It gives guarantees of correctness in complex places, like parallelism or separation of concerns
- It requires a radical conceptual shift in the way you think about programming

Course introduction

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Basic lambda calculus

Closing up

Course topics

- We will begin with a short discussion on traditional programming language extbfsemantics
- We will then show the extbflambda calculus, which is the foundation for functional languages

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- We will then bridge the gap between theory and practice

- We will translate the lambda calculus into two mainstream functional languages: F# and Haskell

- This will cover a huge chunk of possible applications in countless other languages and libraries, from C# LINQ to Java streams, to Scala, Scheme, Closure, etc.

Examination

Exam structure

- There is a theoretical exam, where you show understanding of the basic principles
- There is a practical exam, where you show understanding of their concrete applications

Theoretical exam

- One question on a lambda calculus program execution
- One question on the type system of a lambda calculus program, F# program, or Haskell program
- Both questions must be answered correctly to get a extbfvoldoende

Build, in groups of max four, any of the following applications in either Haskell or F#:

- A 2D simulation of a supermarket with customers, cash registers, and various aisles
- A 2D simulation of a supply chain with trucks, containers, and ships
- An interpreter for a Python-like language (with a parser for an extra challenge)
- An interpreter for the lambda calculus (with a parser for an extra challenge)

We will get together at the end of the course, and the teacher(s) will remove a few lines from each of your applications. **Individually** you will have to restore them within a few hours.

Semantics of traditional programming languages

Semantics of traditional programming languages

- Traditional, imperative programming languages are based on sharing memory through instructions
- This means that subsequent instructions are not independent from each other
- Any function call makes use of the available memory

For example, consider the semantic rules that describe the working of ";"

First we run s_1 with the initial memory, then we run s_2 with the modified memory.

Semantics of traditional programming languages

For example, consider the semantic rules that describe the working of ";"

First we run s_1 with the initial memory, then we run s_2 with the modified memory.

$$\frac{\langle s_1, S, H \rangle \rightarrow \langle S_1, H_1 \rangle \wedge \ \langle s_2, S_1, H_1 \rangle \rightarrow \langle S_2, H_2 \rangle}{\langle (s_1; s_2), S, H \rangle \rightarrow \langle S_2, H_2 \rangle}$$

What does "*first we run s_1 with the initial memory, then we run s_2 with the modified memory*" imply?.

What does "*first we run s_1 with the initial memory, then we run s_2 with the modified memory*" imply?.

- The same instructions, executed at different moments, will produce **different results**.
- Change the order of some method calls, and some weird dependence might cause bugs or break things.

Goals

- Our goal is to ensure that behaviour of code is consistent.
- Change the order of some method calls, and the results remain the same.
- This makes it easier to test, parallelize, and in general ensure correctness.

How do we achieve this?

How do we achieve this?

We give (shared) memory up: every piece of code is a function which output only depends on input.

This very important property is called **referential transparency**.

Basic lambda calculus

Basic lambda calculus

Introduction

- The (basic) lambda calculus is an alternative mechanism to Turing Machines and the Von Neumann architecture.
- It is very different, but has equivalent expressive power.
- It is the foundation of all functional programming languages.

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Substitution principle

- The (basic) lambda calculus is truly tiny when compared with its power.
- It is based on the substitution principle: calling a function with some parameters returns the function body with the variables replaced.
- There is no memory and no program counter: all we need to know is stored inside the body of the program itself.

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A lambda calculus program (just *program* from now on) is made up of three syntactic elements:

- Variables: x, y, ...
- Abstractions (function declarations with one parameter): $\lambda x \rightarrow t$ where x is a variable and t is the function body (a program).
- Applications (function calls with one argument): $t\ u$ where t is the function being called (a program) and u is its argument (another program).

A simple example would be the identity function, which just returns whatever it gets as input

$(\lambda x \rightarrow x)$

Basic lambda calculus

We can call this function with a variable as argument, by writing:

```
((λx→x) v)
```

A lambda calculus program is computed by replacing lambda abstractions applied to arguments with the body of the lambda abstraction with the argument instead of the lambda parameter:

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A lambda calculus program is computed by replacing lambda abstractions applied to arguments with the body of the lambda abstraction with the argument instead of the lambda parameter:

$$\overline{(\lambda x \to t)\ u \to_\beta t[x \mapsto u]}$$

$t[x \mapsto u]$ means that we change variable x with u within t

$((\lambda x \rightarrow x) \ v)$

Basic lambda calculus

$$((\lambda x \rightarrow x) \ v)$$

$$\underline{((\lambda x \rightarrow x) \ v)}$$

$((\lambda x \to x)\ v)$

Basic lambda calculus

```
((λx→x) v)
```

```
v
```

Multiple applications where the left-side is not a lambda abstraction are solved in a left-to-right fashion:

Multiple applications where the left-side is not a lambda abstraction are solved in a left-to-right fashion:

$$\frac{t \rightarrow_\beta t' \ \land \ u \rightarrow_\beta u' \ \land \ t' \ u' \rightarrow_\beta v}{t \ u \rightarrow_\beta v}$$

Variables cannot be further reduced, that is they stay the same:

Basic lambda calculus

Variables cannot be further reduced, that is they stay the same:

$$\overline{x \rightarrow_\beta x}$$

We can encode functions with multiple parameters by nesting lambda abstractions:

```
(λx→y→(x y))
```

The parameters are then given one at a time:

```
(((λx→y→(x y)) A) B)
```

Basic lambda calculus

```
(((λx→y→(x y)) A) B)
```

Basic lambda calculus

$$(((\lambda x \rightarrow y \rightarrow (x\ y))\ A)\ B)$$

$$(((\underline{\lambda x \rightarrow y \rightarrow (x\ y))\ A})\ B)$$

$(((\lambda x \rightarrow y \rightarrow (x\ y))\ A)\ B)$

Basic lambda calculus

```
(((λx→y→(x y)) A) B)
```

```
((λy→(A y)) B)
```

```
((λy→(A y)) B)
```

$((\lambda y \rightarrow (A\ y))\ B)$

$\underline{((\lambda y \rightarrow (A\ y))\ B)}$

$((\lambda y \rightarrow (A\ y))\ B)$

```
((λy→(A y)) B)
```

```
(A B)
```

Closing up

Example executions of (apparently) nonsensical programs

- We will now exercise with the execution of various lambda programs.
- Try to guess what the result of these programs is, and then we shall see what would have happened.

What is the result of this program execution?

```
(((λx→y→(x y)) (λz→(z z))) A)
```

$$(((\lambda x \rightarrow y \rightarrow (x\ y))\ (\lambda z \rightarrow (z\ z)))\ A)$$

```
(((λx→y→(x y)) (λz→(z z))) A)
```

```
(((λx→y→(x y)) (λz→(z z))) A)
```

$(((\lambda x \to y \to (x\ y))\ (\lambda z \to (z\ z)))\ A)$

```
(((λx→y→(x y)) (λz→(z z))) A)
```

```
((λy→((λz→(z z)) y)) A)
```

```
((λy→((λz→(z z)) y)) A)
```

$((\lambda y \rightarrow ((\lambda z \rightarrow (z\ z))\ y))\ A)$

$\underline{((\lambda y \rightarrow ((\lambda z \rightarrow (z\ z))\ y))\ A)}$

$((\lambda y \rightarrow ((\lambda z \rightarrow (z\ z))\ y))\ A)$

```
((λy→((λz→(z z)) y)) A)
```

```
((λz→(z z)) A)
```

$$((\lambda z \to (z\ z))\ A)$$

```
((λz→(z z)) A)
```

```
((λz→(z z)) A)
```

$((\lambda z \rightarrow (z\ z))\ A)$

```
((λz→(z z)) A)
```

```
(A A)
```

What is the result of this program execution? Watch out for the scope of the two "x" variables!

```
(((λx→x→(x x)) A) B)
```

```
(((λx→x→(x x)) A) B)
```

$(((\lambda x \to x \to (x\ x))\ A)\ B)$

$(((\underline{\lambda x \to x \to (x\ x))\ A})\ B)$

$(((\lambda x \rightarrow x \rightarrow (x\ x))\ A)\ B)$

```
(((λx→x→(x x)) A) B)
```

```
((λx→(x x)) B)
```

```
((λx→(x x)) B)
```

((λx→(x x)) B)

((λx→(x x)) B)

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$((\lambda x \rightarrow (x\ x))\ B)$

$((\lambda x \rightarrow (x\ x))\ B)$

(B B)

The first "x" gets replaced with "A", but the second "x" shadows it!

```
(((λx→x→(x x)) A) B)
```

A better formulation, less ambiguous, would turn:

```
(((λx→x→(x x)) A) B)
```

...into:

```
(((λy→x→(x x)) A) B)
```

```
(((λy→x→(x x)) A) B)
```

$(((\lambda y \rightarrow x \rightarrow (x \ x)) \ A) \ B)$

$(((\lambda y \rightarrow x \rightarrow (x \ x)) \ A) \ B)$

$(((\lambda y \rightarrow x \rightarrow (x\ x))\ A)\ B)$

```
(((λy→x→(x x)) A) B)
```

```
((λx→(x x)) B)
```

```
((λx→(x x)) B)
```

```
((λx→(x  x))  B)
```

```
((λx→(x  x))  B)
```

$((\lambda x \rightarrow (x\ x))\ B)$

```
((λx→(x x)) B)
```

```
(B B)
```

What is the result of this program execution? Is there even a result?

```
((λx→(x x)) (λx→(x x)))
```

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x \ x)) \ (\lambda x \rightarrow (x \ x)))$

$\underline{((\lambda x \rightarrow (x \ x)) \ (\lambda x \rightarrow (x \ x)))}$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$\underline{((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))}$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

$((\lambda x \rightarrow (x\ x))\ (\lambda x \rightarrow (x\ x)))$

```
((λx→(x x)) (λx→(x x)))
```

It never ends! Like a `while true:   ...`!

Ok, I know what you are all thinking: what is this for sick joke?
This is no real programming language!

- We have some sort of functions and function calls
- We do not have booleans and if's
- We do not have integers and arithmetic operators
- We do not have a lot of things!

Surprise!

With nothing but lambda programs we will show how to build all of these features and more.

Closing up

Stay tuned.

This will be a marvelous voyage.

The best of luck, and thanks for the attention!