CS520 Theory of Programming Languages

Introduction

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How to analyze programming languages (their constructs, type systems, implementations, etc) formally?

We will study mathematical tools for doing such analysis.

Preview 1: Abstract syntax

- What is a program? What kind of syntactic object is it?

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- Bad answer: a sequence of characters.

Preview 1: Abstract syntax

- What is a program? What kind of syntactic object is it?

- Bad answer: a sequence of characters.

- Our answer: an instance of an abstract syntax.

- Mathematically, an element of an initial algebra.

Preview 2: Domain theory

```
>>> def F(g): return g
...
```

- Which mathematical object does the program F denote?

Preview 2:
Domain theory

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```

- Which mathematical object does the program F denote?

- Identity function in [D→D] for some D.

Preview 2: Domain theory

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>>> def F(g): return g
...
>>> F(F)
<function F at 0x10c573410>
```

- Which mathematical object does the program F denote?

- Identity function in [D→D] for some D.

- But D should include [D→D]. Impossible if D is a set.

Preview 2: Domain theory

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>>> def F(g): return g
...
>>> F(F)
<function F at 0x10c573410>
```

- Which mathematical object does the program F denote?

- Identity function in [D→D] for some D.

- But D should include [D→D]. Impossible if D is a set.

- Possible if D is a domain & [D→D] has only continuous fns.

Preview 3: Evaluation order

```
>>> def f(x): return (x+x)
...
>>> f(f(3))
12
```

- Should we compute f(3) before applying f to f(3)?

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- Should we compute f(3) before applying f to f(3)?

- Yes. Eager evaluation. Python, OCaml, Scheme, etc.

- No. Normal-order evaluation or lazy evaluation. Haskell.

Preview 3:
Evaluation order

```
>>> def f(x): return 3
...
>>> f(f(3))
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```

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- Yes. Eager evaluation. Python, OCaml, Scheme, etc.

- No. Normal-order evaluation or lazy evaluation. Haskell.

Preview 3:
Evaluation order

```
>>> def f(x): return 3
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```

- Should we compute f(3) before applying f to f(3)?

- Yes. Eager evaluation. Python, OCaml, Scheme, etc.

- No. Normal-order evaluation or lazy evaluation. Haskell.

- To be analysed via operational and denotational semantics.

Preview 4:
Type system

```
import typing
from typing import Callable

def twice(f : Callable[[int],int], x : int) -> int:
  return(f(f(x)))
```

- Types help develop correct programs.

Preview 4:
Type system

```
import typing
from typing import Callable

def twice(f : Callable[[int],int], x : int) -> int:
  return(f(f(x)))
```

- Types help develop correct programs.

- Can we infer types automatically?

- What mathematical objects do types denote?

Preview 4:
Type system

```
import typing
from typing import Callable

def twice(f : Callable[[int],int], x : int) -> int:
  return(f(f(x)))
```

- Types help develop correct programs.

- Can we infer types automatically? Type inference algo.

- What mathematical objects do types denote? Partial equivalence relation.

- Predicate Logic (Ch1).

- The Simple Imperative Language (Ch2).

- Program Specification and Their Proofs (Ch3).

- Failure, Input-Output, and Continuation (Ch5).

- Transition Semantics (Ch6).

- An Introduction to Category Theory (Tennent Ch8).

- Recursively-Defined Domains (Tennent Ch10).

- The Lambda Calculus (Ch10).

- An Eager Functional Language (Ch11).

- Continuation in a Functional Language (Ch12).

- A Normal-Order Language (Ch14).

- The Simple Type System (Ch15).

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Imperative Languages

- Predicate Logic (Ch1).

- The Simple Imperative Language (Ch2).

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Math tools

- An Introduction to Category Theory (Tennent Ch8).

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Functional Languages

Course webpage

https://github.com/hongseok-yang/graduatePL19

- Primary source of information about the course.

Blackboard lectures

- Nearly all the lectures will use blackboard, not slides.

- My handwritten notes will be available in the course webpage.

Evaluation

- Final exam — 40%.

- Homework (4 problem sheets) — 30%.

- Two critical reviews — 30%.

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Critical reviews

- Read an assigned book chapter or research papers.

- Write a review (up to 3 pages).

- Try to go beyond simple summary.

- Your own thoughts. Connection with other PL concepts. Or further in-depth study.

Review assignment 1

- Deadline: 1 Nov (Friday). By midnight.

- Material: Chapter 8 of our textbook.

- Topic: Shared-variable concurrency.

Review assignment 2

- Deadline: 9 Dec (Monday). By midnight.

- Material: "A Modern Eye on ML Type Inference" and "Principal Type-Schemas for Functional Programs".

- Topic: Type inference.

Teaching staffs

- Prof Hongseok Yang (Lecturer). <u>hongseok00@gmail.com</u>. Office hour: 6pm-7pm on Tue at 3403 in E3-1.

- Mr Hyoungjin Lim (TA1). <u>lmkmkr@kaist.ac.kr</u>

- Mr Jungmin Park (TA2). <u>qkrclrl701@kaist.ac.kr</u>

- TAs' office hours will be announced shortly.