CSCI-344
Programming Language Concepts (Section 3)

Lecture 11

ML Overview

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September 26, 2016

Where we are

Done:

- Scheme
  - Lambda expressions, Closures, Currying, Algebraic Laws, Higher-order functions, Continuation-Passing Style

This session:

- ML: Overview

Lisp (Scheme)

- Lisp is the earliest representative of functional programming languages
- Lisp (and its dialects) pioneered many interesting ideas in programming languages
  - Higher-order functions
  - Recursion
  - Computation with symbols
- First is not always best
- Lisp (Scheme) isn't perfect:

  there are things that could be done better!

Compile time vs. run time errors

- Consider the `append` function

```
(define append (xs1 xs2)
  (if (null?  xs1) xs2
    (cons (car xs1) (append (cdr xs1) xs2))))
```

Compile time vs. run time errors

- Consider the `append` function

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  (if (null?  xs1) xs2
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```

- Assume we'd mistaken **`car`** with **`cdr`** and wrote append as following

```
(define append (xs1 xs2)
  (if (null?  xs1) xs2
    (cons (cdr xs1) (append (car xs1) xs2))))
```

- Scheme detects such errors dynamically (at run-time)
- When Scheme interpreter evaluates a function call to `append` it returns

  "error: `cdr` applied to non-pair"

- This error can be caught statically at an earlier stage

Type

- Type is a classification for a set of values that determines operations that can be done on values of that type

```
2                                integer?
#f                               boolean?
(lambda (x) (< x 5))     integer?  → boolean?
car                          pair?  → any
```

- Type error happens when program is not faithful to the intended semantics of type
  - e.g. applying **car** to a non-pair
- Scheme: run-time (dynamic) type checking
- Dynamic type checks slow down the program

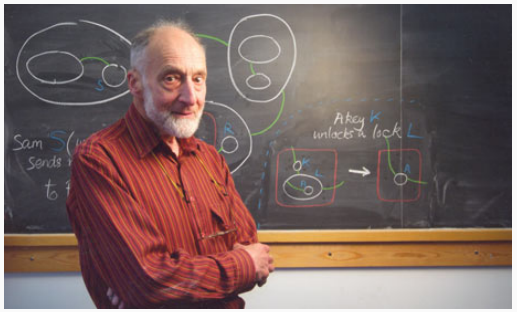
Scheme Syntax

LISP = (**L**ots of ((**I**rritating **S**purious) (**P**arentheses)))

– old hacker joke

- Not elegant syntax: it is sometimes unreadable due to lack of syntactic variety
  - Everything is parenthesized prefix notation

"Types are the leaven of computer programming: they make it digestible."



Sir Robin Milner
(1934 – 2010)

One of the world's leading computer scientists

Meta Language

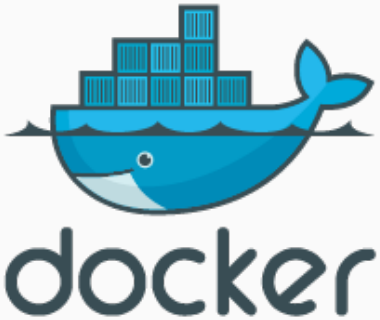
- **ML**: Functional programming language designed by Robin Milner in the 1970s
- It was originally designed as a Meta-Language:
  language to manipulate Theorems/Proofs

Several dialects:

- Standard ML (SML)
  - Has a formal specification and operational semantics ("The Definition of Standard ML")
- OCaml
  - French dialect with support for objects
  - State-of-the-art: applicable for large-scale software engineering
  - Extensive library, tool, user support
  - F# is a Microsoft .NET language based on OCaml

Companies using OCaml

http://ocaml.org/learn/companies.html



From μScheme to ML

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`(val x 1)`	`val x = 1;`

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`(define f(x) (+ x 1))`	`fun f(x) = x + 1;`

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`(define f(x) (+ x 1))`	`fun f(x) = x + 1;`
`(let (x e1) e2)`	`let val x = e1 in e2;`

From μScheme to ML

ML = μScheme + pattern matching + exceptions + static types

Pattern Matching

- We have used **pattern matching** before in operational semantics
  - When applying inference rules
  - Example: We match the pattern $\langle \mathrm{Literal}(3), \varnothing, \varnothing \rangle$ with the pattern on the left hand-side of conclusion:

$$\frac{}{\langle \mathrm{Literal}(v), \rho, \sigma \rangle \Downarrow \langle v, \sigma \rangle} \text{ (Literal)}$$

- A **pattern** is an expression containing variables for which other expressions may be substituted (informal definition)
- Matching a pattern against an expression:
  find suitable substitution that makes pattern identical to expression

Pattern Matching

Example:

- Consider the De Morgan's Law in Boolean algebra:

$$\neg(\alpha \wedge \beta) = \neg(\alpha) \vee \neg(\beta)$$

- We can use pattern matching to apply De Morgan's law
  $\neg(\neg p \wedge \neg\neg q) = \neg\neg p \vee \neg\neg\neg q$ (p and q are Boolean variables)
- Here we substituted meta-variables α and β with $\neg p$ and $\neg\neg q$

Pattern Matching

- Pattern matching offers a powerful alternative to define functions

μScheme

```
(define length (xs)
  (if (null? xs) 0 (+ 1 (length (cdr xs)))))
```

ML

```
fun length xs =
  if xs = nil then 0 else 1 + length(tl(xs));
```

ML (Pattern Matching)

```
fun length [] = 0
  | length (x::xs) = 1 + length xs;
```

length

```
fun length [] = 0
  | length (x::xs) = 1 + length xs;
```

- More readable syntax (fewer parentheses than μScheme)
- Function application by juxtaposition
- Function application has higher precedence than any infix operator
- Compiler (interpreter) checks all the cases

map

```
fun map f [] = []
  | map f (x::xs) = (f x) :: (map f xs);
```

- `map length [[1],[],[6,7,8]]`
  reduces to
- `[1, 0, 3]`

filter

```
fun filter pred [] = []
  | filter pred (x::xs) =
      let val rest = filter pred xs in
        if pred x
           then (x::rest)
           else rest
      end;
```

- `filter (fn x => (x mod 2) <> 0) [1,2,3,4,5,6,7]` reduces to
- `[1, 3, 5, 7]`
- The convention of using a question mark in the names of predicates doesn't work in SML

exists

```
fun exists pred [] = false
  | exists pred (x::xs) =
      (pred x) orelse (exists pred xs);
```

- `exists (fn x => (x mod 2) <> 0) [2,4,6,8,10]` reduces to
- `false`

takewhile

```
fun takewhile p [] = []
  | takewhile p (x::xs) =
    if p x then (x::(takewhile p xs)) else [];
```

- `takewhile (fn x => (x <= 5)) [1,3,5,7,9]` reduces to
- `[1, 3, 5]`

fold

```
fun foldr f base [] = base
  | foldr f base (x::xs) = f (x, (foldr f base xs));
fun foldl f base [] = base
  | foldl f base (x::xs) = foldl f (f(x,base)) xs;
```

- `foldr (op +) 0 [1,2,3,4,5]`
  reduces to `15`

- `foldl (op -) 0 [1,2,3,4,5]`
  reduces to `3`

- Note: `op` converts an infix operator into a function

Exceptions

- ML was one of the earliest languages to include exceptions at the language level
- Exceptions factor out error handling as "exceptional" code from the "normal" code

```
exception Empty;
fun hd (x::xs) = x
  | hd [] = raise Empty;
```

- Handling Exceptions:

```
fun inc_head (xs) = hd xs + 1
handle Empty => (print "error";0);
```

ML – The Five Questions

- **Syntax:** expressions, definitions, patterns, types
- **Values:** num/string/bool, record/tuple, algebraic data
- **Environments:** names stand for values (and types)
- **Evaluation:** μScheme + case and pattern matching
- **Initial Basis:** medium size; emphasizes lists

(Question Six: type system - will talk about it later)

Summary

- ML: general-purpose functional programming language
- Static Type Checking
- Pattern Matching

Next Lecture

- Algebraic Data Types