Currying and the Lambda Calculus

CS 350

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Overview

Objectives

- Learning Goals

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- Core Concepts
  - Currying
  - Lambda Calculus

Currying

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- How can we interpret a call to this function?
    - Evaluate the body with either
        - `x,y,z` replaced by concrete argument values (substitution)
        - `x,y,z` bound to concrete values in an environment

Achieving this: Currying

- We can achieve this with nested lambda expressions

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{let f {fun {x} {fun {y} {fun {z} {+ x {* y z}}}}}
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{{{f 1} 2} 3}
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- Step by step:

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  - `f 1` produces `{fun {y} {fun {z} {+ 1 {* y z}}}}`

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    - Calling that on 2 produces `{fun {z} {+ 1 {* 2 z}}}`

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  - `f 1` produces `{fun {y} {fun {z} {+ 1 {* y z}}}}`
  - Calling that on 2 produces `{fun {z} {+ 1 {* 2 z}}}`
  - Calling that on 3 produces `{+ 1 {* 2 3}}}`
    - Exactly what we want for `{f 1 2 3}`

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- The approach of simulating multiple-argument functions with nested single-argument functions is called **Currying**
    - Named after Haskell Curry, and American logician
        - Also the namesake of the Haskell programming language
- A function written in this style is *curried*

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- We can add multiple-argument functions to our Surface Language *without* changing the core language
  - Handle in `elab`
  - Doesn't matter if do substitution or environment-based version, translation is the exact same

AST for Multi-Argument Functions

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```
(define-type SurfExpr
....
 (SurfFun [xs : (Listof Symbol)]
          [body : SurfExpr]))
 (SurfCall [fun : SurfExpr]
           [args : (Listof SurfExpr)])
```

- Functions now take a list of variables

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- Functions now take a list of variables
- Calls now take a list of arguments

Elaborating Multi-Argument Functions

- Use recursion to iterate through the list

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```
(define (elab [surfExpr : SurfExpr])
  (type-case SurfExpr surfExpr
             ....
   [(SurfFun xs body)
     (type-case (Listof Symbol) xs
       [empty
         (elab body)]
       [(cons x rest)
         ;; Could also do with a helper fn
         (Fun x (elab (SurfFun rest body)))])]))
```

- No arguments: just produce the body

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- No arguments: just produce the body
- At least one argument: curry the rest of the arguments, and wrap the result in a lambda

Multi-Argument Calls with Tail Recursion

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```
(define (callHelper [args : (Listof SurfExpr)]
                    [accum : Expr]) : Expr
  (type-case (Listof SurfExpr) args
      [empty accum]
      [(cons arg rest)
         ;; tail recursion
         (callHelper rest (Call accum (elab arg)) )]))
```

- Given a list of argument to apply, build up one giant expression with nested calls

Building The Entire Call

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(define (elab [surfExpr : SurfExpr])
  (type-case SurfExpr surfExpr
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   [(SurfCall funExpr args)
      (callHelper args (elab funExpr))]))
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- A `0`-argument `(lambda () e)` is *NOT* the same as `e` in Plait
  - But it is in Curly, if we use this desugaring

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- Recall that `letvar` let us define a local variable to have the value of some expression, that we could then use to build another expression

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(define (elab [surfExpr : SurfExpr])
  (type-case SurfExpr surfExpr
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   [(SurfLetVar x xExpr body)
      (Call (Fun 'x (elab body))
            (elab xExpr))]))
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    - This does the exact same thing

Lambda The Ultimate

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  - Multi-argument functions
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- What else can se simulate?
- **NOTE** I won't ask about the following desugarings on an exam
  - But they're an important introduction to the “science” of computer science and the “mathematics” of informatics

The Smallest Language We Can Imagine

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```
(define-type UTLC
  ;; A variable
  (Var [x : Symbol])
  ;; Functiona application (call)
  (App [fun : UTLC]
       [arg : UTLC])
  ;; Anonymous function (lambda)
  (Lam [param : Symbol]
       [body : UTCL]))
```

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- Stands for “Un-Typed Lambda Calculus”
- All you can do is define an anonymous function (lambda) or call a function (application)
- **The Untyped Lambda Calculus is Turing Complete**
    - Any program you can write, you can write an equivalent UTLC Program

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```
(define (interpUTLC [e : UTLC] : UTLC)
  (type-case UTLC e
    [(App fun arg)
       (type-case (interpUTLC fun)
          [(Lam x body)
             (interpUTLC (subst x arg body))]
          [else (error 'x "Undefined variable")])]
    ;; Function and variables don't do any computation,
    ;; they just return themselves
    ;; Could have variables return an error,
    [else e]))
```

- Can also do with environments, like Curly-Lambda-Env

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```
(define True
  (Lam 'x (Lam 'y (Var 'x))))
(define False
  (Lam 'x (Lam 'y (Var 'y))))
;; curried (test thenCase elseCase)
(define (If test thenCase elseCase)
  (App (App test thenCase) elseCase))
```

- If we give `If` the boolean `True` it produces the then-case

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- If we give `If` the boolean `True` it produces the then-case
- If we give `If` the boolean `False` it produces the else-case

Numbers

- Define n to be the function that takes in another function and an argument, and applies it n times

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```
(define Zero
  (Lam 'f (Lam 'x (Var 'x)))) ;; Function that returns its argument
;; Add one to a number
(define (Add1 n)
  (Lam 'f (Lam 'x) (App (Var 'f) (App (App n f) x))))
(define (Plus m n)
  (Lam 'f (Lam 'x) (App m (App (App n f) x))))
```

Pairs

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```
(define (Pair x y)
  (Lam 'z (If (Var 'z) x y)))
(define (Fst pr)
  (App pr True))
(define (Snd pr)
  (App pr False))
```

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- Makes a new function where each call to `self` is replaced by a call to `f`
- You don't need to know the details of how this work, just that it's possible to do recursion in the UTLC
- Once we have recursion, we have loops