PAUL G. ALLEN SCHOOL
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CSE341: Programming Languages

Lecture 16
Datatype-Style Programming With Lists or Structs

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The Goal

In ML, we often define datatypes and write recursive functions over them – how do we do analogous things in Racket?

- First way: With lists
- Second way: With structs [a new construct]
  - Contrast helps explain advantages of structs

Life without datatypes

Racket has nothing like a datatype binding for one-of types

No need in a dynamically typed language:

- Can just mix values of different types and use primitives like **`number?`**, **`string?`**, **`pair?`**, etc. to "see what you have"
- Can use cons cells to build up any kind of data

Mixed collections

In ML, cannot have a list of “ints or strings,” so use a datatype:

```
datatype int_or_string = I of int | S of string

fun funny_sum xs = (* int_or_string list -> int *)
   case xs of
        [] => 0
      | (I i)::xs’ => i + funny_sum xs’
      | (S s)::xs’ => String.size s + funny_sum xs’
```

In Racket, dynamic typing makes this natural without explicit tags

- Instead, every value has a tag with primitives to check it
- So just check car of list with **`number?`** or **`string?`**

Recursive structures

More interesting datatype-programming we know:

```
datatype exp = Const of int
             | Negate of exp
             | Add of exp * exp
             | Multiply of exp * exp
```

```
fun eval_exp e =
   case e of
        Const i => i
      | Negate e2 => ~ (eval_exp e2)
      | Add(e1,e2) => (eval_exp e1) + (eval_exp e2)
      | Multiply(e1,e2)=>(eval_exp e1)*(eval_exp e2)
```

Change how we do this

- Previous version of **`eval_exp`** has type **`exp -> int`**
- From now on will write such functions with type **`exp -> exp`**
- Why? Because will be interpreting languages with multiple kinds of results (ints, pairs, functions, …)
  - Even though much more complicated for example so far
- How? See the ML code file:
  - Base case returns entire expression, e.g., **`(Const 17)`**
  - Recursive cases:
    - Check variant (e.g., make sure a **`Const`**)
    - Extract data (e.g., the number under the **`Const`**)
    - Also return an **`exp`** (e.g., create a new **`Const`**)

New way in Racket

See the Racket code file for coding up the same new kind of "**`exp -> exp`**" *interpreter*

- Using lists where car of list encodes "what kind of exp"

Key points:

- Define our own constructor, test-variant, extract-data functions
  - Just better style than hard-to-read uses of **`car`**, **`cdr`**
- Same recursive structure without pattern-matching
- With no type system, no notion of "what is an exp" except in documentation
  - But if we use the helper functions correctly, then okay
  - Could add more explicit error-checking if desired

Symbols

Will not focus on Racket *symbols* like **`'foo`**, but in brief:

- Syntactically start with quote character
- Like strings, can be almost any character sequence
- Unlike strings, compare two symbols with **`eq?`** which is fast

New feature

```
(struct foo (bar baz quux) #:transparent)
```

Defines a new kind of thing and introduces several new functions:

- **`(foo e1 e2 e3)`** returns “a foo” with **`bar`**, **`baz`**, **`quux`** fields holding results of evaluating **`e1`**, **`e2`**, and **`e3`**
- **`(foo? e)`** evaluates **`e`** and returns **`#t`** if and only if the result is something that was made with the **`foo`** function
- **`(foo-bar e)`** evaluates **`e`**. If result was made with the **`foo`** function, return the contents of the **`bar`** field, else an error
- **`(foo-baz e)`** evaluates **`e`**. If result was made with the **`foo`** function, return the contents of the **`baz`** field, else an error
- **`(foo-quux e)`** evaluates **`e`**. If result was made with the **`foo`** function, return the contents of the **`quux`** field, else an error

An idiom

```
(struct const (int) #:transparent)
(struct negate (e) #:transparent)
(struct add (e1 e2) #:transparent)
(struct multiply (e1 e2) #:transparent)
```

For “datatypes” like exp, create one struct for each “kind of exp”

- structs are like ML constructors!
- But provide constructor, tester, and extractor functions
  - Instead of patterns
  - E.g., **`const`**, **`const?`**, **`const-int`**
- Dynamic typing means “these are the kinds of exp” is “in comments” rather than a *type system*
- Dynamic typing means “types” of fields are also “in comments”

All we need

These structs are all we need to:

- Build trees representing expressions, e.g.,

```
(multiply (negate (add (const 2) (const 2)))
          (const 7))
```

- Build our **`eval-exp`** function (see code):

```
(define (eval-exp e)
  (cond [(const? e) e]
        [(negate? e)
         (const (- (const-int
                     (eval-exp (negate-e e)))))]
        [(add? e) …]
        [(multiply? e) …]…
```

Attributes

- `#:transparent` is an optional attribute on struct definitions
  - For us, prints struct values in the REPL rather than hiding them, which is convenient for debugging homework

- `#:mutable` is another optional attribute on struct definitions
  - Provides more functions, for example:

```
(struct card (suit rank) #:transparent #:mutable)
; also defines set-card-suit!, set-card-rank!
```

  - Can decide if each struct supports mutation, with usual advantages and disadvantages
    - As expected, we will avoid this attribute
  - `mcons` is just a predefined mutable struct

Contrasting Approaches

```
(struct add (e1 e2) #:transparent)
```

Versus

```
(define (add e1 e2) (list 'add e1 e2))
(define (add? e) (eq? (car e) 'add))
(define (add-e1 e) (car (cdr e)))
(define (add-e2 e) (car (cdr (cdr e))))
```

This is *not* a case of syntactic sugar

The key difference

```
(struct add (e1 e2) #:transparent)
```

- The result of calling **`(add x y)`** is *not* a list
  - And there is no list for which **`add?`** returns **`#t`**

- **`struct`** makes a new kind of thing: extending Racket with a new kind of data

- So calling **`car`**, **`cdr`**, or **`mult-e1`** on "an add" is a run-time error

List approach is error-prone

```
(define (add e1 e2) (list 'add e1 e2))
(define (add? e) (eq? (car e) 'add))
(define (add-e1 e) (car (cdr e)))
(define (add-e2 e) (car (cdr (cdr e))))
```

- Can break abstraction by using **`car`**, **`cdr`**, and list-library functions directly on “add expressions”
  - Silent likely error:

```
(define xs (list (add (const 1)(const 4)) …))
(car (car xs))
```

- Can make data that **`add?`** wrongly answers **`#t`** to

```
(cons 'add "I am not an add")
```

Summary of advantages

Struct approach:

- Is better style and more concise for *defining* data types

- Is about equally convenient for *using* data types

- But much better at timely errors when *misusing* data types
  - Cannot use accessor functions on wrong kind of data
  - Cannot confuse tester functions

More with abstraction

Struct approach is even better combined with other Racket features not discussed here:

- The *module system* lets us hide the constructor function to enforce invariants
  - List-approach cannot hide cons from clients
  - Dynamically-typed languages can have abstract types by letting modules define new types!

- The *contract system* lets us check invariants even if constructor is exposed
  - For example, fields of “an add” must also be “expressions”

Struct is special

Often we end up learning that some convenient feature could be coded up with other features

Not so with struct definitions:

- A function cannot introduce multiple bindings
- Neither functions nor macros can create a new kind of data
  - Result of constructor function returns **`#f`** for *every* other tester function: **`number?`**, **`pair?`**, other structs' tester functions, etc.