Adapted from slides by Sunjay Cauligi, and Dan Grossman
Today’s Agenda

• Building a MUPL Interpreter
  • Assume Correct Syntax
  • Check for Correct Semantics
  • Evaluating the AST

• MUPL “Macros”

• Eval, Quote, and Quasiquote

• RackUnit

• Variable Number of Arguments

• Apply
Building a MUPL Interpreter

- Skipping the parsing phase \(\leftarrow\) Do Not Implement
- Interpreter written in Racket
  - Racket is the “Metalanguage”
- MUPL code represented as an AST
  - AST nodes represented as Racket structs
- Can assume AST has valid syntax
- Can \textbf{NOT} assume AST has valid semantics
Correct Syntax Examples

Given this syntax:

(struct int (num) #:transparent)
(struct add (e1 e2) #:transparent)
(struct ifnz (e1 e2 e3) #:transparent)

We can need to evaluate these MUPL programs:

(int 34)
(add (int 34) (int 30))
(ifnz (add (int 5) (int 7)) (int 12) (int 1))
Incorrect Syntax Examples

Given this syntax:

```
(struct int (num) #:transparent)
(struct add (e1 e2) #:transparent)
(struct ifnz (e1 e2 e3) #:transparent)
```

We can assume we won’t see MUPL programs like:

```
(int "dan then dog")
(int (ifnz (int 0) (int 5) (int 7)))
(add (int 8) #t)
(add 5 4)
```

Illegal input ASTs may crash the interpreter - this is OK
Check for Correct Semantics

What if the program is a legal AST, but evaluation of it tries to use the wrong kind of value?

• For example, “add an integer and a function”

• You should detect this and give an error message that is not in terms of the interpreter implementation

• We need to check that the type of a recursive result is what we expect
  • No need to check if any type is acceptable
Evaluating the AST

• `eval-exp` should return a MUPL value
• MUPL values all evaluate to themselves
• Otherwise we haven’t interpreted far enough

\[
\text{(int 7)}; \text{ evaluates to (int 7)}
\]
\[
\text{(add (int 3) (int 4)}; \text{ evaluates to (int 7)}
\]
Macros Review

- Extend language syntax (allow new constructs)
- Written in terms of existing syntax
- Expanded before language is actually interpreted or compiled
MUPL “Macros”

- Interpreting MUPL using Racket as the metalanguage
- MUPL is represented as Racket structs
- In Racket, these are just data types
- Why not write a Racket function that returns MUPL ASTs?
MUPL “Macros”

If our MUPL Macro is a Racket function

```
(define (++ exp) (add (int 1) exp))
```

Then the MUPL code

```
(++) (int 7))
```

Expands to

```
(add (int 1) (int 7))
```
• Syntactically, Racket statements can be thought of as lists of tokens
• (+ 3 4) is a “plus sign”, a “3”, and a “4”
• quote-ing a parenthesized expression produces a list of tokens
quote  Examples

(+ 3 4) ; 7
(quote (+ 3 4)) ; '(+ 3 4)
(quote (+ 3 #t)) ; '(+ 3 #t)
(+ 3 #t) ; Error

• You may also see the single quote ` character used as syntactic sugar
quasiquote

• Inserts evaluated tokens into a quote
• Convenient for generating dynamic token lists
• Use \texttt{unquote} to escape a \texttt{quasiquote} back to evaluated Racket code
• A \texttt{quasiquote} and \texttt{quote} are equivalent unless we use an \texttt{unquote} operation
quasiquote  Examples

```
(quasiquote (+ 3 (unquote(+ 2 2)))) ; '(+ 3 4)
(quasiquote
  (string-append
   "I love CSE"
   (number->string
    (unquote (+ 3 338))))))
; '(string-append "I love CSE" (number->string 341))
```

• You may also see the backtick ` character used as syntactic sugar for `quasiquote`

• The comma character , is used as syntactic sugar for `unquote`
Self Interpretation

• Many languages provide an `eval` function or something similar
• Performs interpretation or compilation at runtime
  • Needs full language implementation during runtime
• It's useful, but there's usually a better way
• Makes analysis, debugging difficult
eval

• Racket's `eval` operates on lists of tokens
• Like those generated from `quote` and `quasiquote`
• Treat the input data as a program and evaluate it
eval examples

```
(define quoted (quote (+ 3 4)))
(eval quoted) ; 7
(define bad-quoted (quote (+ 3 #t)))
(eval bad-quoted) ; Error
(define qquoted (quasiquote (+ 3 (unquote(+ 2 2)))))
(eval qquoted) ; 7
(define big-qquoted
  (quasiquote
    (string-append
      "I love CSE"
      (number->string
        (unquote (+ 3 338))))))
(eval big-qquoted) ; "I love CSE341"
```
RackUnit

• Unit testing is built into the standard library
  • [http://docs.racket-lang.org/rackunit/](http://docs.racket-lang.org/rackunit/)

• Built in test functions to make testing your code easier
  • Test for equality, `check-eq?`
  • Test for True, `check-true`
  • Test for raised exception, `check-exn`
  • and many more
Variable Number of Arguments

• Some functions (like +) can take a variable number of arguments

• There is syntax that lets you define your own

```
(define fn-any
    (lambda xs ; any number of args
             (print xs)))

(define fn-1-or-more
    (lambda (a . xs) ; at least 1 arg
             (begin (print a) (print xs))))

(define fn-2-or-more
    (lambda (a b . xs) ; at least 2 args
             (begin (print a) (print a) (print xs))))
```
apply

• Applies a list of values as the arguments to a function in order by position

(define fn-any
  (lambda xs ; any number of args
    (print xs)))
(apply fn-any (list 1 2 3 4))

(apply + (list 1 2 3 4)) ; 10
(apply max (list 1 2 3 4)) ; 4