UMass Boston Computer Science

CS450 High Level Languages (section 2)

Variables and Environments

Wednesday, November 15, 2023

Logistics

- HW 7 out
  - due: Sun 11/19 11:59 pm EST
  - Really due: Wed 11/22 11:59 pm EST
  - (no hw over Thanksgiving)
- Reminder: **Pass/Fail & Course Withdraw Deadline**
  - tomorrow Thurs 11/16

Last Time

Introducing: The "CS450JS" Programming Lang!

Programmer writes:

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

parse450js

```
;; A 450jsAST is one of:
;; - (num Number)
;; - (str String)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)

(struct num [val])
(struct str [val])
(struct add [lft rgt])
(struct sub [lft rgt])
```

"eval450js"

```
;; A 450jsResult is one of:
;; - Number
;; - String
;; - NaN
```

"meaning" of the program

run450js

(JS semantics)

“CS450JS” Examples

Programmer writes:

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

“eval450js”

```
;; A 450jsResult is one of:
;; - Number
;; - String
;; - NaN
```

```
(check-equal? (eval450js 100) 100)
(check-equal? (eval450js “one”) “one”)
(check-equal? (eval450js '(+ 100 200)) 300)
(check-equal? (eval450js '(+ “cs” 450)) “cs450”)
```

```
(check-equal? (eval450js '(+ 1 2 3 4))  ???  )
```

```
match: no matching clause for '(+ 1 2 3 4)
```

Dynamic Errors (e.g, Exceptions)

When: **a function argument:**

1. **Comes from arbitrary users**
2. **Has a sufficiently complex data definition**
   - (So that signature and contracts are not enough)

Then: **dynamic errors** may be needed

Parsing: “CS450JS” Programs

```
;; parse450js: 450jsExpr -> 450jsAST
;; Converts a CS450js Lang surface program to its AST
```

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

```
(define (450jsexpr? s)
  (or (number? s)
      (string? s)
      (cons? s)))
```

```
(define/contract (parse450js s)
  (-> 450jsexpr? 450jsAST?)
  (match s
   [(? number?) (num s)]
   [(? string?) (str s)]
   [`(+ ,x ,y)  (add (parse450js x) (parse450js y))]
   [`(- ,x ,y)  (sub (parse450js x) (parse450js y))]))
```

???

```
;; A 450jsAST is one of:
;; - (num Number)
;; - (str String)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)

(struct num [val])
(struct str [val])
(struct add [lft rgt])
(struct sub [lft rgt])
```

???

```
(define (450jsAST? s)
  (or (num? s) (str? s)
      (add? s) (sub? s)))
```

Interlude: Inheritance and "Super" Structs

```
;; A 450jsAST is one of:
;; - (num Number)
;; - (str String)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)

(struct num [val])
(struct str [val])
(struct add [lft rgt])
(struct sub [lft rgt])
```

```
;; A 450jsAST is one o
;; - (num Number)
;; - (str String)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)
(struct 450jsAST [])
(struct num 450jsAST [val])
(struct str 450jsAST [val])
(struct add 450jsAST [lft rgt])
(struct sub 450jsAST [lft rgt])
```

"abstract" struct (implicitly defines **450jsAST?** predicate)

"super" struct declaration

Alternatively …

```
(define (450jsAST? s)
  (or (num? s) (str? s)
      (add? s) (sub? s)))
```

e.g., if `p = (sub (num 1) (num 2))` then **both** `(sub? P) = true` and `(450jsAST? p) = true`

Interlude: Inheritance and "Super" Structs

This kind of "polymorphic" "abstract" data definition is what we've been creating all semester!

"super" structs are just a convenience for the same thing (when all itemizations are structs)

```
;; A 450jsAST is one o
;; - (num Number)
;; - (str String)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)
(struct 450jsAST [])
(struct num 450jsAST [val])
(struct str 450jsAST [val])
(struct add 450jsAST [lft rgt])
(struct sub 450jsAST [lft rgt])
```

"abstract" struct (implicitly defines `450jsAST?` predicate)

WAIT, I thought "Inheritance is bad"???

NO, accepted OO principles says:

Inheritance of implementations is bad ☒

Interfaces and abstract classes are ok ☑

Parsing: “CS450JS” Programs

```
;; parse450js: 450jsExpr -> 450jsAST
;; Converts a CS450js Lang surface program to its AST
```

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

function argument:

1. Comes from arbitrary users
2. Has sufficiently complex data definition where contracts are insufficient

```
(define/contract (parse450js s)
  (-> 450jsexpr? 450jsAST?)
  (match s
   [(? number?) (num s)]
   [(? string?) (str s)]
   [`(+ ,x ,y)  (add (parse450js x) (parse450js y))]
   [`(- ,x ,y)  (sub (parse450js x) (parse450js y))]
   [_ (error … )]))
```

Interlude: Racket exceptions

Exceptions are just special structs

Super struct (enables using exception API)

```
(struct exn:fail:syntax:cs450js exn:fail:syntax [])
```

```
(define/contract (parse450js s)
  (-> 450jsexpr? 450jsAST?)
  (match s
   [(? number?) (num s)]
   [(? string?) (str s)]
   [`(+ ,x ,y)  (add (parse450js x) (parse450js y))]
   [`(- ,x ,y)  (sub (parse450js x) (parse450js y))]
   [_ (raise-syntax-error
        'parse450js "not a valid CS450js program" s
       #:exn exn:fail:syntax:cs450js)]))
```

“CS450js” Examples

Programmer writes:

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

“eval450js”

```
;; A 450jsResult is one of:
;; - Number
;; - String
;; - NaN
```

```
(check-equal? (eval450js '(+ 1 2 3 4))  ???  )
```

~~match: no matching clause for '(+ 1 2 3 4)~~

```
parse450js: not a valid CS450js program in: (+ 1 2 3 4)
```

```
(check-exn exn:fail:syntax:cs450js?
           (λ () (eval450js '(+ 1 2 3 4))))
```

HW7: Let's Get Started Early

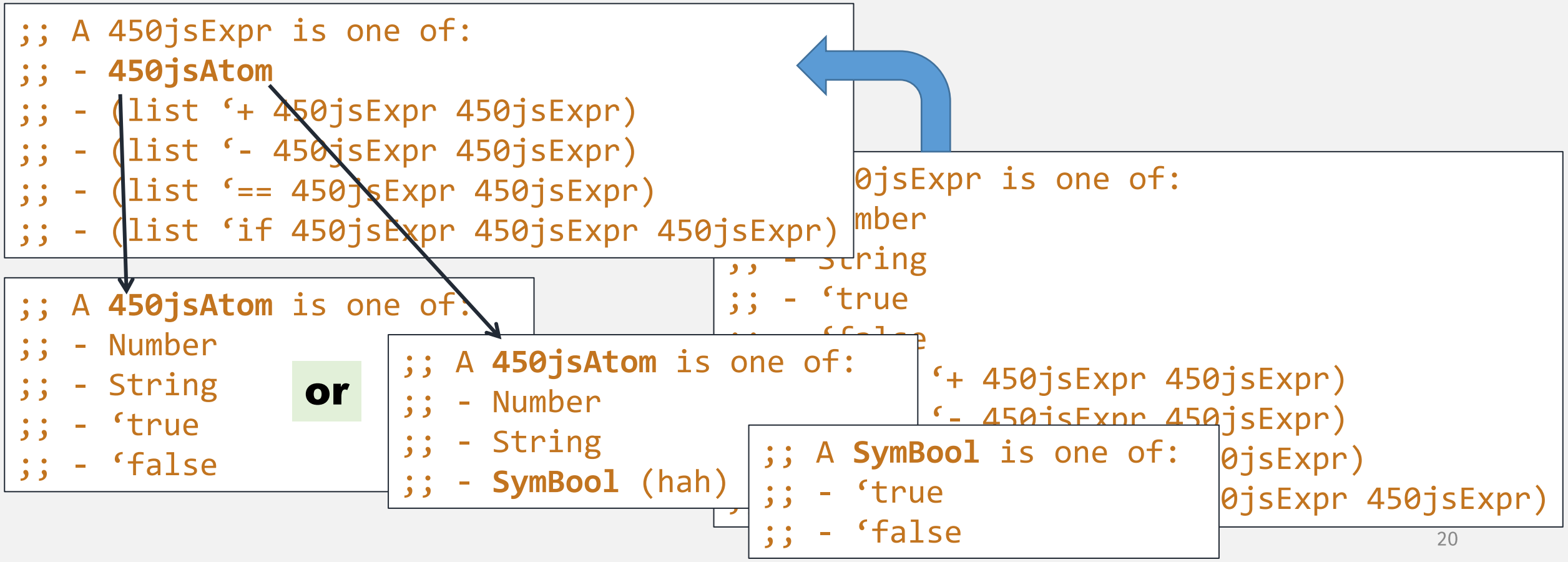
- Add some boolean constructs:
  - true / false literal values
  - "loose equality" comparator (look it up)
  - If-then-else, with "truthy" true / false (look it up)

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - 'true
;; - 'false
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
;; - (list '== 450jsExpr 450jsExpr)
;; - (list 'if 450jsExpr 450jsExpr 450jsExpr)
```

HW7: Let's Get Started Early

- **Refactor data definitions?** (your design choice)



- Repo: **cs450f23/lecture20-inclass**
- File: **cs450js-tests-**<*your last name*>**.rkt**

In-class Coding 11/20: **write hw7 tests**

```
;; parse450js: 450jsExpr -> 450jsAST
;; Parses "CS450js Lang" program to AST
```

```
;; run450js: 450jsAST -> 450jsResult
;; Computes result of running CS450js AST
```

```
(define eval450js (compose run450js parse450js))
```

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - 'true
;; - 'false
;; - (list '+ 450jsExpr 450jsE
;; - (list '- 450jsExpr 450jsE
;; - (list '== 450jsExpr 450js
;; - (list 'if 450jsExpr 450jsExpr 450jsExpr)
```

```
;; "adding" bools
(check-equal? (eval450js '(+ true false)) 1)
```

```
;; weird ==
(check-true (eval450js '(== (+ 10 90) (+ "10" "0"))))
```

```
;; js "truthy true"
(check-equal? (eval450js '(if 10 100 200)) 100)
;; js "truthy false"
(check-equal? (eval450js '(if (- 100 100) "a" "b")) "b")
```

- For ==: Look into JavaScript "loose equality"
- For if: look into JavaScript "truthy" values
- I will collect so all can use for hw (even if it's wrong!)

```
;; - Number
;; - String
;; - Boolean
;; - NaN
```

Last Time

Introducing: The "CS450JS" Programming Lang!

Programmer writes:

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

"eval450js"

```
;; A 450jsResult is one of:
;; - Number
;; - String
;; - NaN
```

Next Feature: **Variables?**

parse450js

```
;; A 450jsAST is one of:
;; - (num Number)
;; - (str String)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)

(struct num [val])
(struct str [val])
(struct add [lft rgt])
(struct sub [lft rgt])
```

run450js

(JS semantics)

NOTE: not needed for hw7

Adding Variables

```
;; A Variable is a Symbol
```

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - Variable
;; - (list '+ 450j
;; - (list '- 450j
```

```
;; A 450jsResu
;; - Number
;; - String
;; - NaN
```

parse450js

run450js

```
;; A 450jsAST is one of:
;;  (num Number)
;;  (str String)
;;  (var Symbol)
;;  (add 450jsAST 450jsAST)
;;  (  450jsAST 450jsAST)

(struct num [val])
(struct str [val])
(struct var [name])
(struct add [lft rgt])
```

Q_1: What is the "meaning" of a variable?

A_1: Whatever "value" it is bound to

Q_2: Where do these "values" come from?

A_2: Other parts of the program

The run function needs to "remember" these values (with an **accumulator**!)

`run450js`, with an accumulator

```
;; run: 450jsAST -> 450jsResult
;; Computes result of running CS450js AST
(define (run p)
  ;; accumulator acc : Environment
  ;; invariant: Contains variable+result pairs that are currently in-scope
  (define (run/acc p acc)
    (match p
     [(num n) n]
     [(add x y) (450+ (run x) (run y))]))
 (run/acc p  ???  ))
```

Environments

- A data structure that “associates” two things together
  - E.g., maps, hashes, etc
  - For simplicity, let’s use list-of-pairs

```
;; An Environment is one of:
;; - empty
;; - (cons (list Var 450jsResult) Environment)
```

```
;; interpretation: a runtime environment for
;; (ie gives meaning to) cs450js-lang variables
```

```
;; if there are duplicates,
;; vars at front of list shadow those in back
```

Environments

- A data structure that “associates” two things together
  - E.g., `maps`, `hashes`, etc
  - For simplicity, let’s use list-of-pairs
- Needed operations:
  - `add : Env Var Result -> Env`
  - `Lookup : Env Var -> Result`

`run450js`, with an Environment

TODO:
- When are variables “added” to environment
- Initial environment?

```
;; run: 450jsAST -> 450jsResult
;; Computes result of running CS450js AST
(define (run p)
  ;; accumulator env : Environment
  ;; invariant: Contains variable+result pairs that are in-scope
  (define (run/acc p env)
    (match p
     [(num n) n]
     [(var x) (lookup env x)]
     [(add x y) (450+ (run x env) (run y env))]))
 (run/acc p  ???  ))
```

NOTE: not needed for hw7

Adding Variables

```
;; A 450jsExpr is one of:
;; - Number
;; - String
;; - Variable
;; - `(bind [x ,450jsExpr] ,450jsExpr)
;; - (list '+ 450jsExpr 450jsExpr)
;; - (list '- 450jsExpr 450jsExpr)
```

parse450js

```
;; A 450jsAST is one of:
;; - (num Number)
;; - (str String)
;; - (var Symbol)
;; - (bind Symbol 450jsAST 450jsAST)
;; - (add 450jsAST 450jsAST)
;; - (sub 450jsAST 450jsAST)

(struct num [val])
(struct str [val])
(struct var [name])
(struct bind [var expr body])
(struct add [lft rgt])
(struct sub [lft rgt])
```

`run450js`, with an Environment

```
;; run: 450jsAST -> 450jsResult
(define (run p)
  ;; accumulator env : Environment
  ;; invariant: Contains variable:result pairs that are in scope
  (define (run/acc p env)
    (match p
     [(num n) n]
     [(var x) (lookup env x)]
     [(bind x e body) (run body (add env x (run e env)))]
     [(add x y) (450+ (run x env) (run y env))]))
 (run/acc p  ???  ))
```

3. run body with that new environment

2. add variable x to environment

1. Compute `450jsResult` that variable x represents

- Repo: **cs450f23/lecture20-inclass**
- File: **env-**<*your last name*>**.rkt**

In-class Coding 11/20: **write env ops**

- Needed operations:
  - `add : Env Var Result -> Env`
  - `Lookup : Env Var -> Result`

```
;; An Environment is one of:
;; - empty
;; - (cons (list Var 450jsResult) Environment)
```

```
;; interpretation: a runtime environment for
;; (ie gives meaning to) cs450js-lang variables
```

```
;; if there are duplicates,
;; vars at front of list shadow those in back
```

Think about examples where this happens!

No More Quizzes!

but push your in-class work to:
Repo: **`cs450f23/lecture20-inclass`**