Recursion, this time in the language

$\{\texttt{rec}\ \{\texttt{<id>}_1\ \texttt{<FAE>}_1\}$

$\texttt{<FAE>}_2\}$

like `with` but $\texttt{<id>}_1$ is bound in $\texttt{<FAE>}_2$ *and* $\texttt{<FAE>}_1$

Defining Recursion

Last time:

```
{rec {<id>₁ <FAE>₁}
     <FAE>₂}
```

could be parsed the same as

```
{with {mk-rec ...mk-rec-code...}
      {with {<id>₁ {mk-rec {fun {<id>₁}
                                 <FAE>₁}}}
            <FAE>₂}}
```

Defining Recursion

which is really

```
{{fun {mk-rec}
     {{fun {<id>1} <FAE>2}
       {mk-rec {fun {<id>1}
                    <FAE>1}}}}
  ...mk-rec-code...}
```

Defining Recursion

Another approach:

```
(local [(define fac
           (lambda (n)
             (if (zero? n)
                 1
                 (* n (fac (- n 1)))))))]
   (fac 10))
```

⟹

```
(let ([fac 42])
  (set! fac
        (lambda (n)
          (if (zero? n)
              1
              (* n (fac (- n 1))))))
  (fac 10))
```

Implementing Recursion

The `set!` approach to definition works only when the defined language includes `set!`.

But the `set!` approach to implementation requires only that the implementation language includes `set!`…

RCFAE Grammar

```
<RCFAE>  ::=  <num>
              |  {+ <RCFAE> <RCFAE>}
              |  {- <RCFAE> <RCFAE>}
              |  <id>
              |  {fun {<id>} <RCFAE>}
              |  {<RCFAE> <RCFAE>}
              |  {if0 <RCFAE> <RCFAE> <RCFAE>}
              |  {rec {<id> <RCFAE>} <RCFAE>}    NEW
```

RCFAE Datatype

```
(define-type RCFAE
  [num (n number?)]
  [add (lhs RCFAE?)
       (rhs RCFAE?)]
  [sub (lhs RCFAE?)
       (rhs RCFAE?)]
  [id (name symbol?)]
  [fun (param symbol?)
       (body RCFAE?)]
  [app (fun-expr RCFAE?)
       (arg-expr RCFAE?)]
  [if0 (test-expr RCFAE?)
       (then-expr RCFAE?)
       (else-expr RCFAE?)]
  [rec (name symbol?)
       (named-expr RCFAE?)
       (body RCFAE?)])
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    [num (n) (numV n)]
    [add (l r) (num+ (interp l ds) (interp r ds))]
    [sub (l r) (num- (interp l ds) (interp r ds))]
    [id (name) (lookup name ds)]
    [fun (param body-expr)
         (closureV param body-expr ds)]
    [app (fun-expr arg-expr)
         (local [(define fun-val
                   (interp fun-expr ds))]
           (interp (closureV-body fun-val)
                   (aSub (closureV-param fun-val)
                         (interp arg-expr ds)
                         (closureV-sc fun-val)))))]
    [if0 (test-expr then-expr else-expr)
         ...]
    [rec (bound-id named-expr body-expr)
         ...]))
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    [num (n) (numV n)]
    [add (l r) (num+ (interp l ds) (interp r ds))]
    [sub (l r) (num- (interp l ds) (interp r ds))]
    [id (name) (lookup name ds)]
    [fun (param body-expr)
         (closureV param body-expr ds)]
    [app (fun-expr arg-expr)
         (local [(define fun-val
                         (interp fun-expr ds))]
           (interp (closureV-body fun-val)
                   (aSub (closureV-param fun-val)
                         (interp arg-expr ds)
                         (closureV-sc fun-val)))))]
    [if0 (test-expr then-expr else-expr)
         ... (interp test-expr ds)
         ... (interp then-expr ds)
         ... (interp else-expr ds) ...]
    [rec (bound-id named-expr body-expr)
         ...])))
```

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RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    [num (n) (numV n)]
    [add (l r) (num+ (interp l ds) (interp r ds))]
    [sub (l r) (num- (interp l ds) (interp r ds))]
    [id (name) (lookup name ds)]
    [fun (param body-expr)
         (closureV param body-expr ds)]
    [app (fun-expr arg-expr)
         (local [(define fun-val
                   (interp fun-expr ds))]
           (interp (closureV-body fun-val)
                   (aSub (closureV-param fun-val)
                         (interp arg-expr ds)
                         (closureV-sc fun-val)))))]
    [if0 (test-expr then-expr else-expr)
         (if (numzero? (interp test-expr ds))
             (interp then-expr ds)
             (interp else-expr ds))]
    [rec (bound-id named-expr body-expr)
         ...]))
```

Testing For Zero

```
; numzero? : RCFAE-Value -> boolean
(define (numzero? n)
  (zero? (numV-n n)))
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    ...
    [rec (bound-id named-expr body-expr)
         ...]))
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    ...
    [rec (bound-id named-expr body-expr)
         ... (interp named-expr ds)
         ... (interp body-expr ds) ...]))
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    ...
    [rec (bound-id named-expr body-expr)
        (local [(define new-ds (aRecSub bound-id
                                        ...
                                        ds))]
          ... (interp named-expr new-ds)
          ... (interp body-expr new-ds) ...)]))
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    ...
    [rec (bound-id named-expr body-expr)
        (local [(define value-holder (box (numV 42)))
                (define new-ds (aRecSub bound-id
                                        value-holder
                                        ds))]
          ... (interp named-expr new-ds)
          ... (interp body-expr new-ds) ...)]))
```

RCFAE Interpreter

```
; interp : RCFAE DefrdSub -> RCFAE-Value
(define (interp a-rcfae ds)
  (type-case RCFAE a-rcfae
    ...
    [rec (bound-id named-expr body-expr)
        (local [(define value-holder (box (numV 42)))
                (define new-ds (aRecSub bound-id
                                        value-holder
                                        ds))]
          (begin
            (set-box! value-holder (interp named-expr new-ds))
            (interp body-expr new-ds)))]))
```

RCFAE DefrdSub

```
(define-type DefrdSub
  [mtSub]
  [aSub (name symbol?)
        (value RCFAE-Value?)
        (sc DefrdSub?)]
  [aRecSub (name symbol?)
           (value-box (box/c RCFAE-Value?))
           (sc DefrdSub?)])

(define-type RCFAE-Value
  [numV (n number?)]
  [closureV (param symbol?)
            (body RCFAE?)
            (sc DefrdSub?)])
```

RCFAE Lookup

```
; lookup : symbol DefrdSub -> num
(define (lookup name ds)
  (type-case DefrdSub ds
    [mtSub () (error 'lookup "free variable")]
    [aSub (sub-name val rest-sc)
          (if (symbol=? sub-name name)
              val
              (lookup name rest-sc))]
    [aRecSub (sub-name val-box rest-sc)
             (if (symbol=? sub-name name)
                 (unbox val-box)
                 (lookup name rest-sc))]))
```