Practical Dependently Typed Racket

Andrew M. Kent and Sam Tobin-Hochstadt
Indiana University

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A natural next step in program specification

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Once upon a time...

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developer

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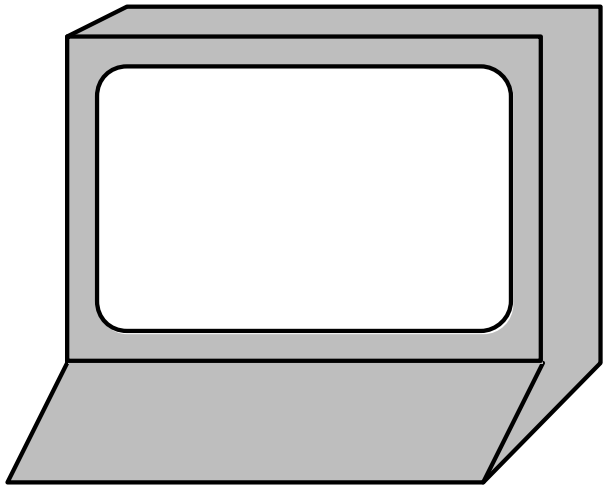
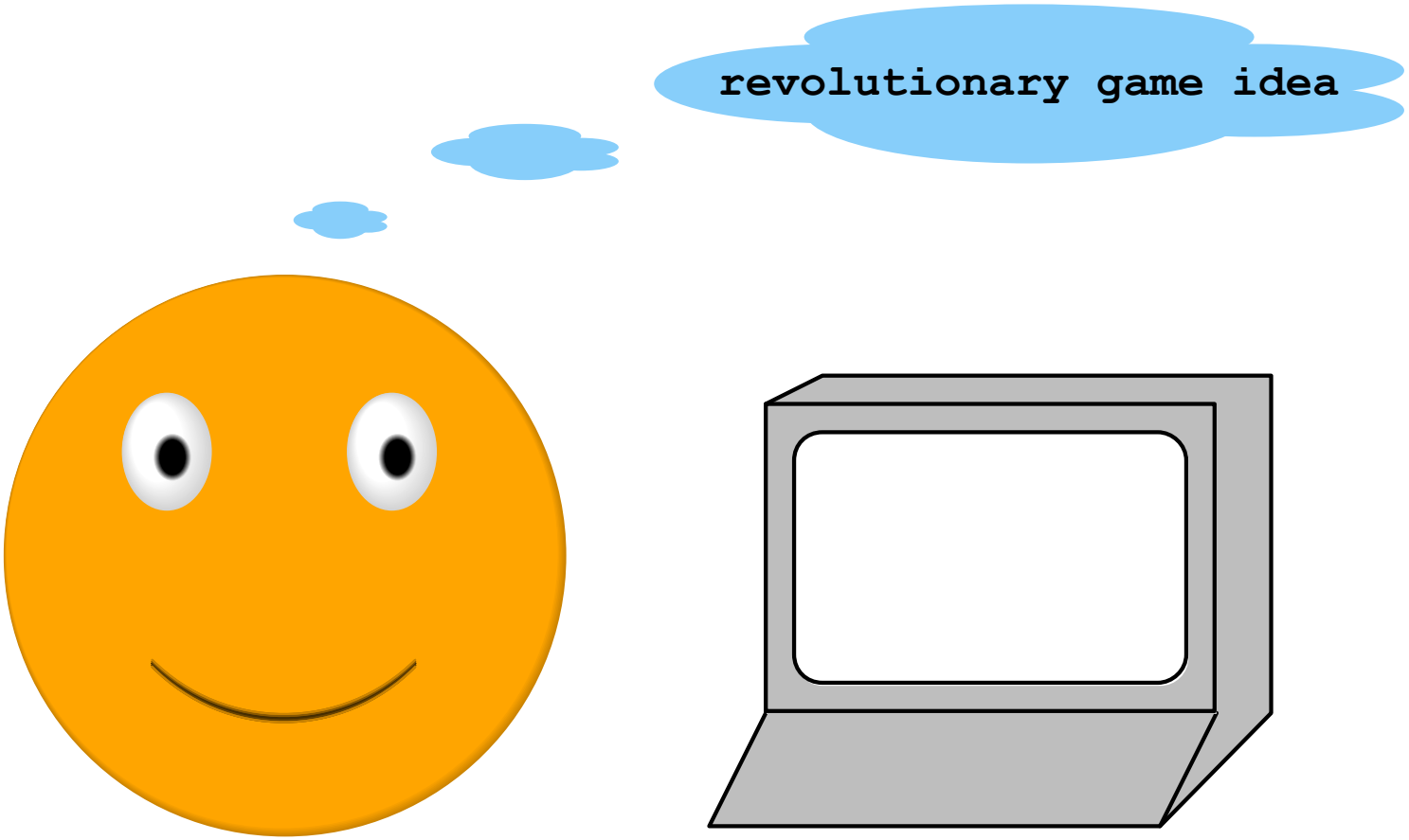
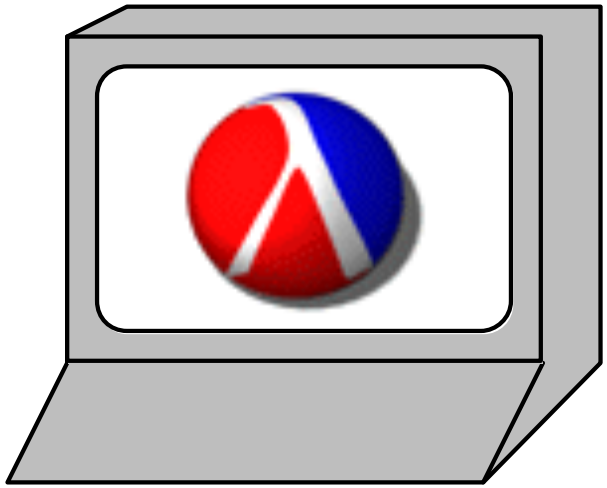
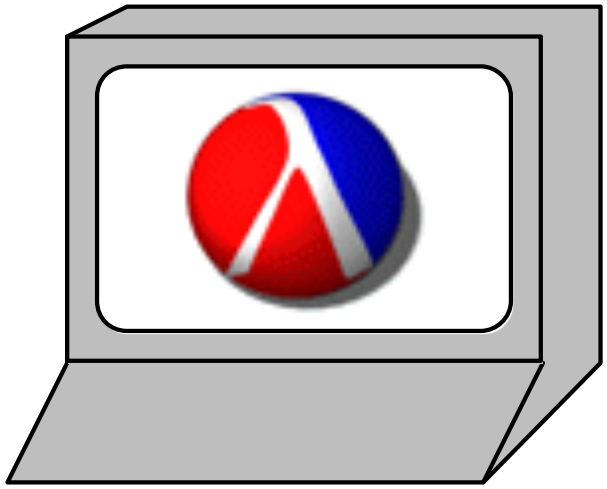
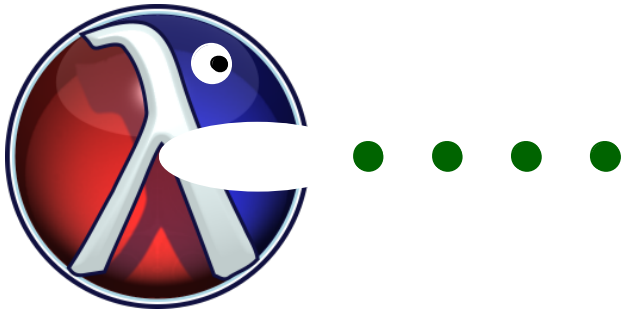
developer

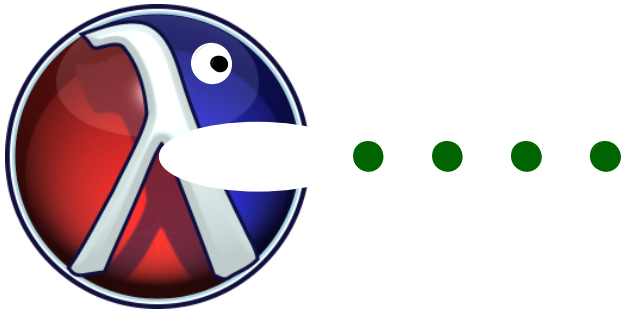


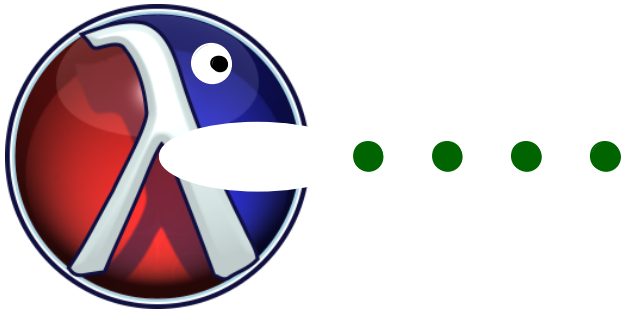

revolutionary game idea

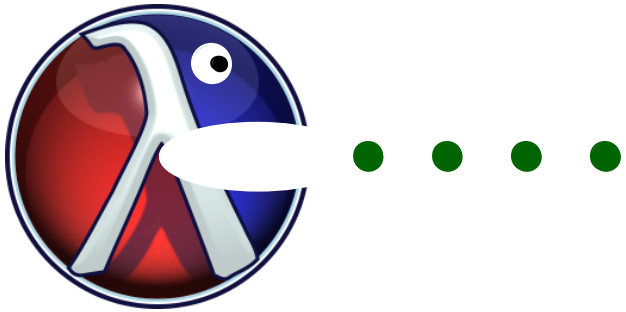


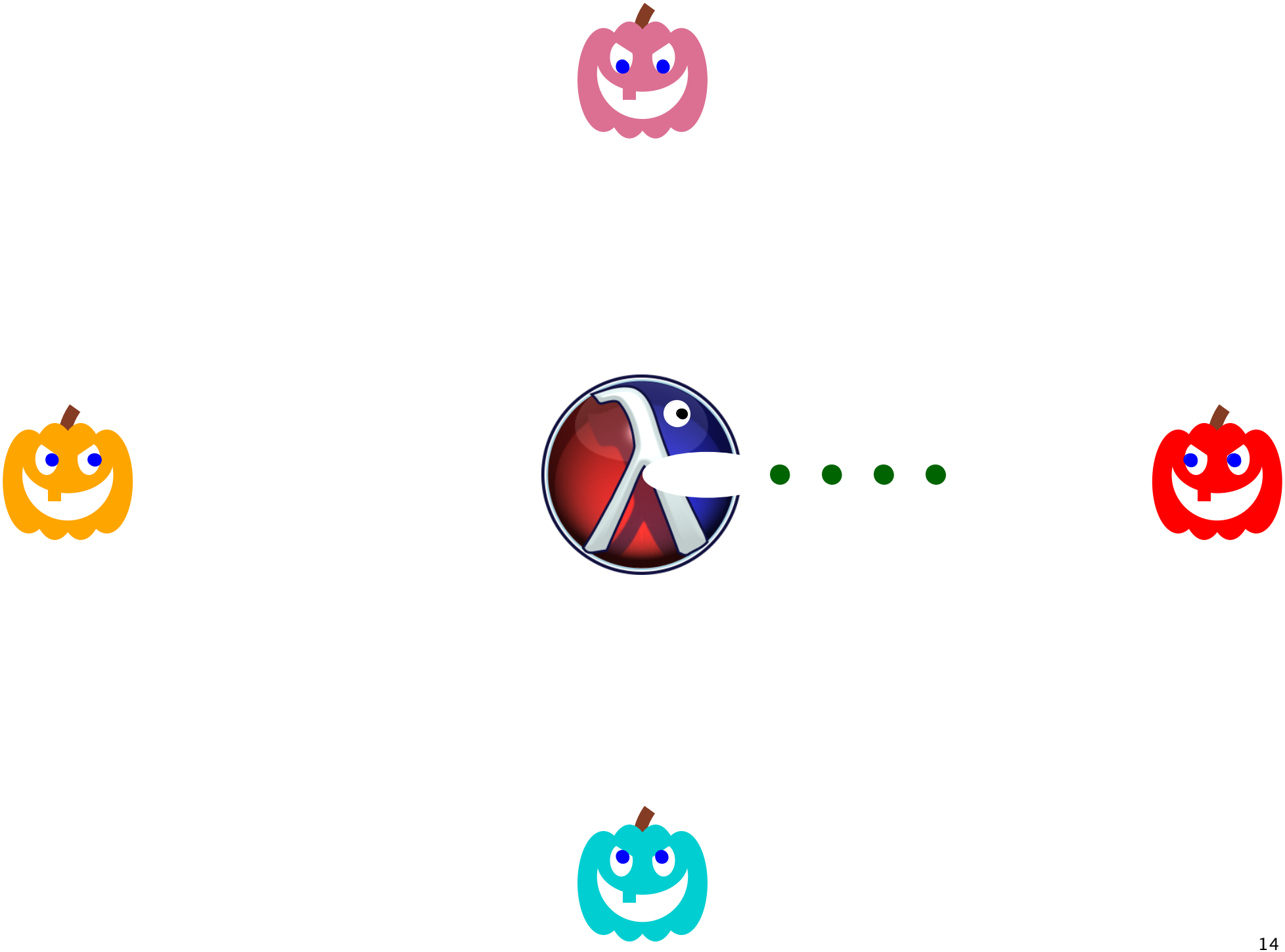




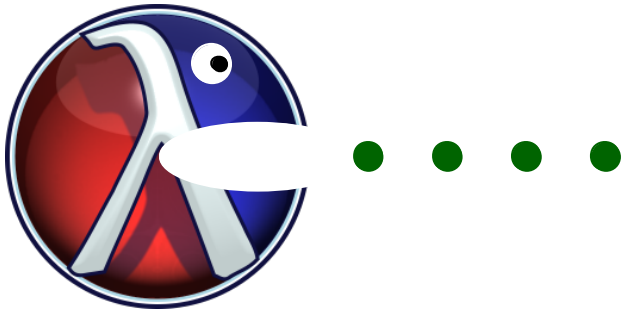


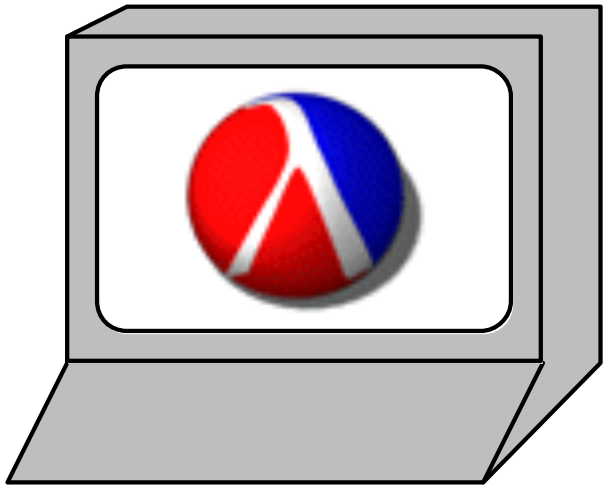






Rac-Man



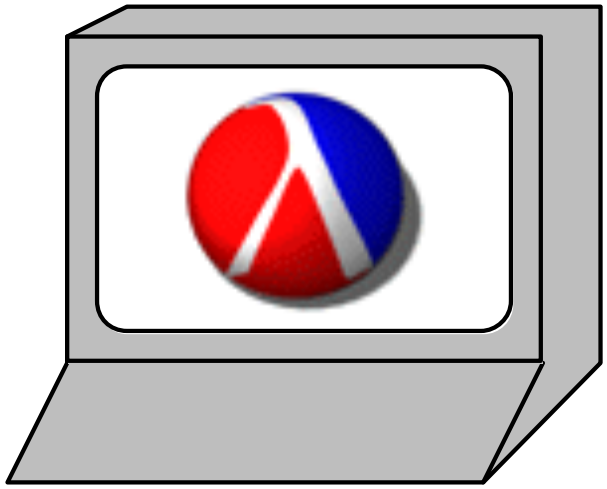


controls.rkt

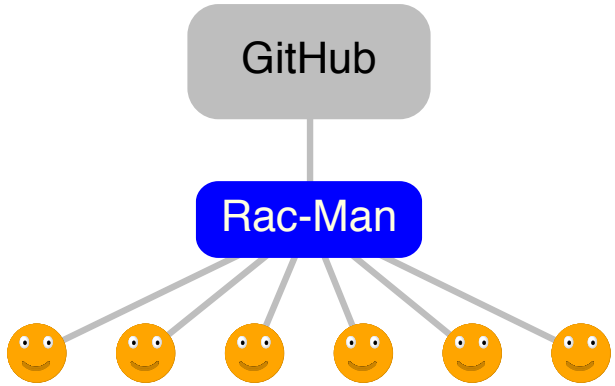
levels.rkt

render.rkt

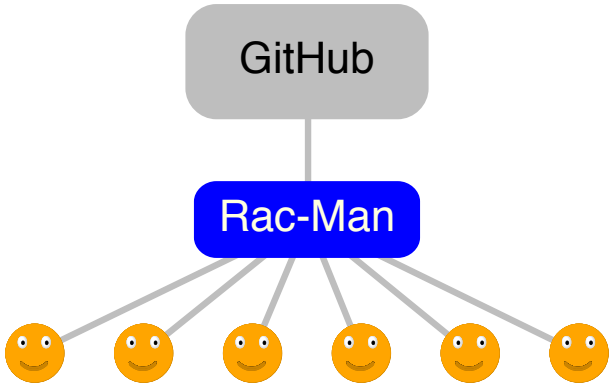
enemy-ai.rkt



1 week later...

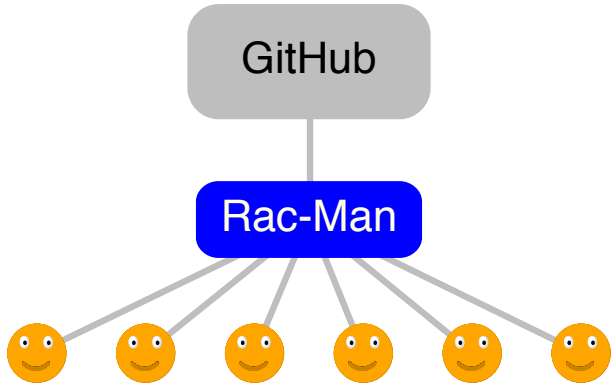

GitHub
Rac-Man

IDEA



IDEA

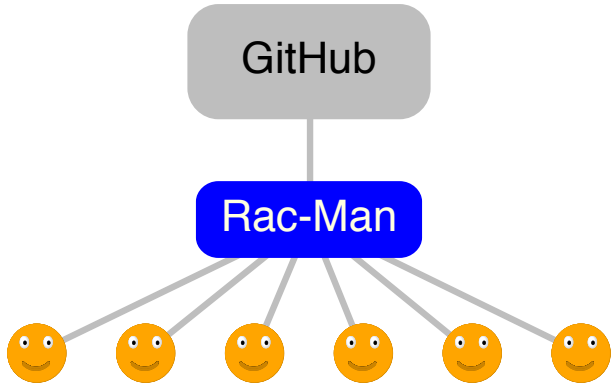
PULL REQUEST



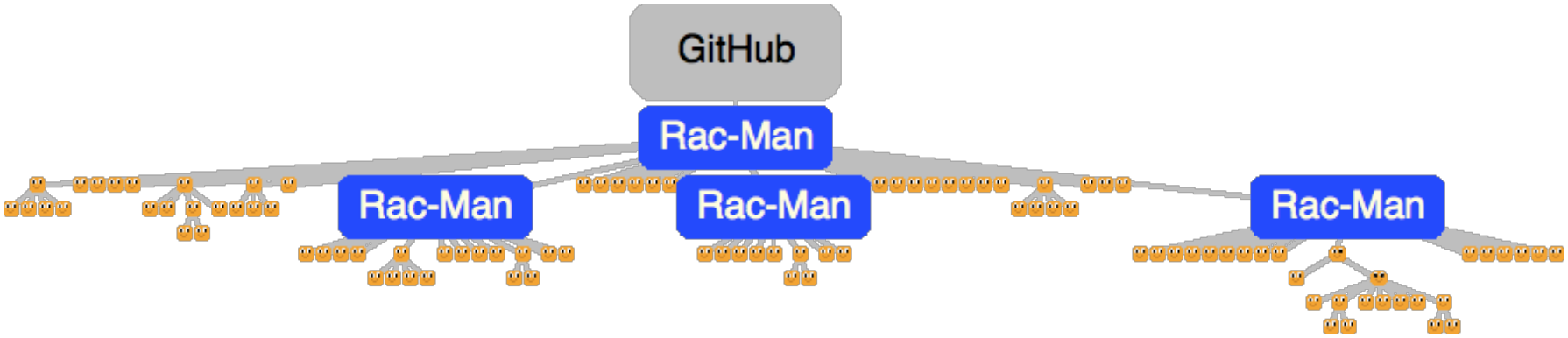
IDEA

NEW FEATURE

PULL REQUEST



more weeks later...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Rac-Man
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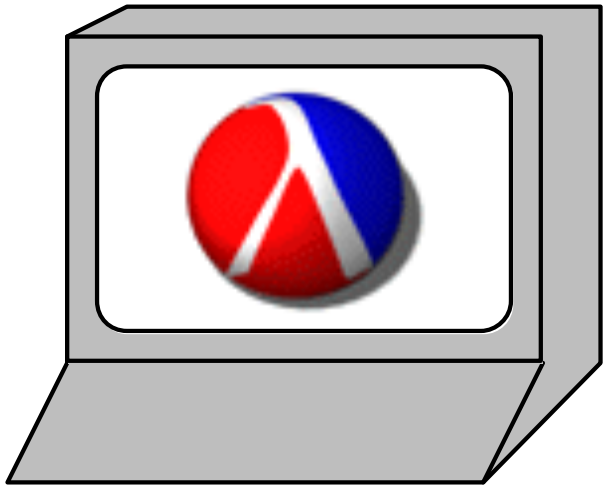

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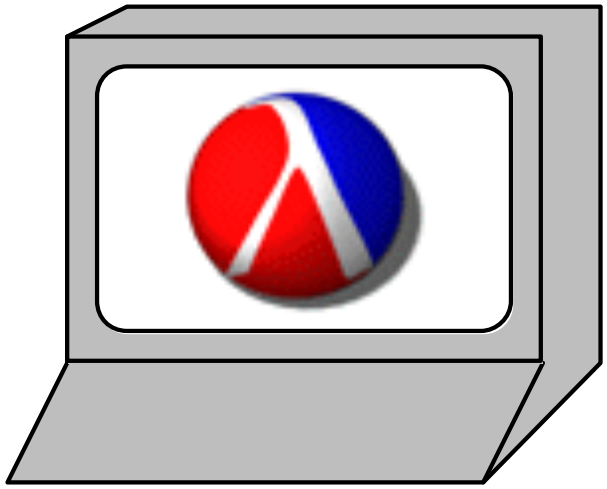

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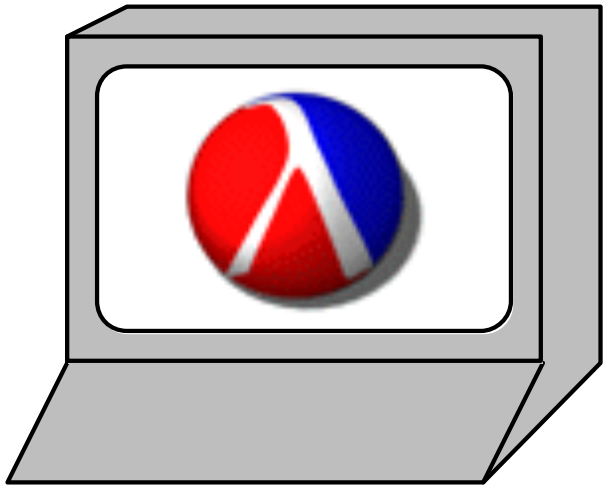

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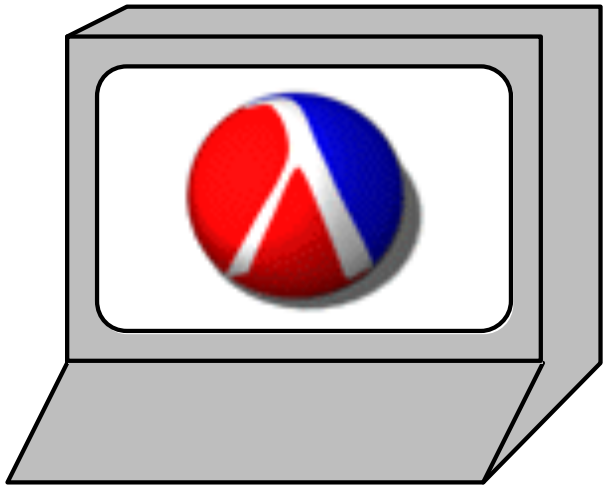

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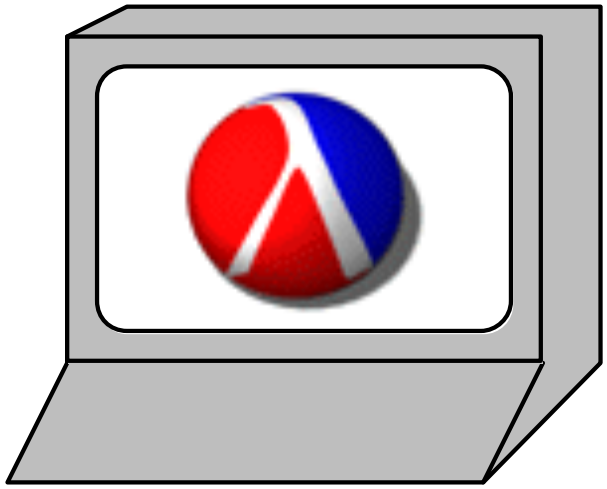

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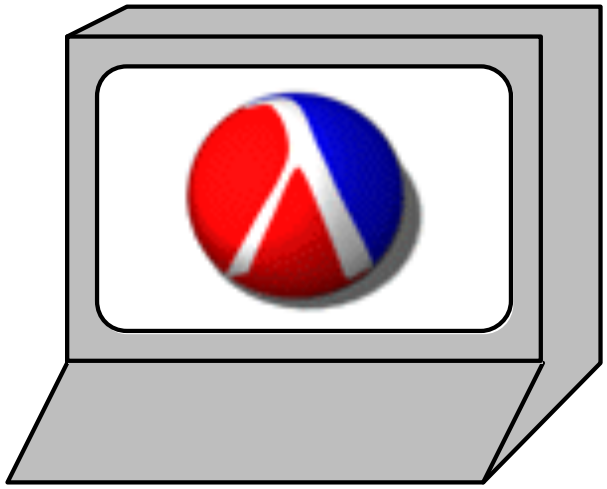

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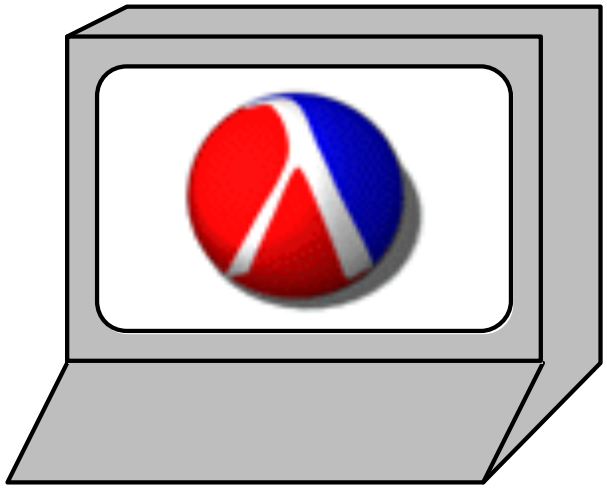

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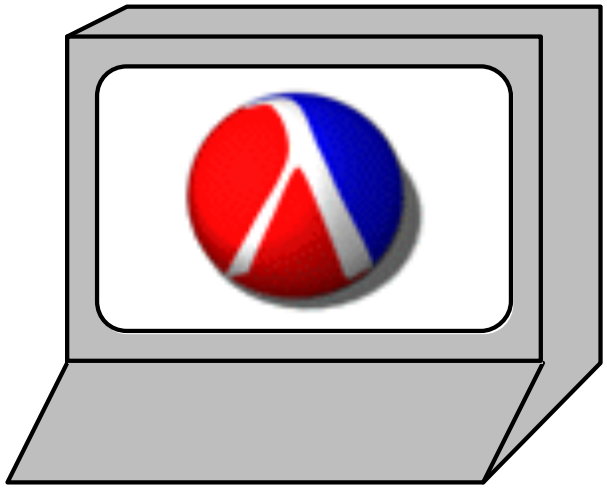

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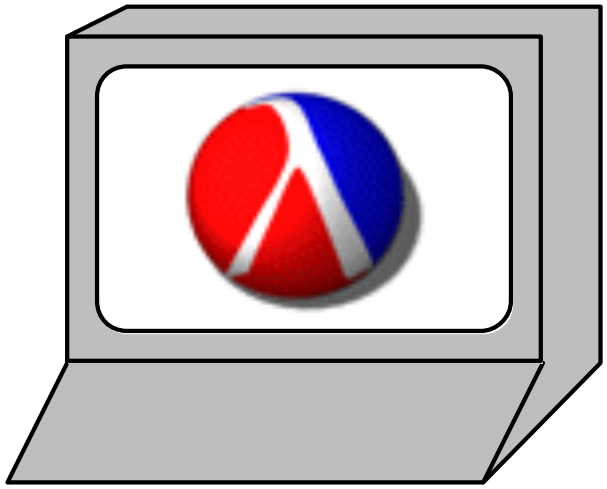

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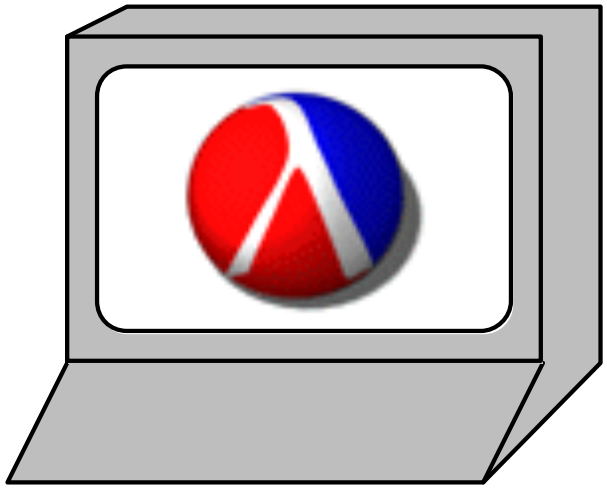

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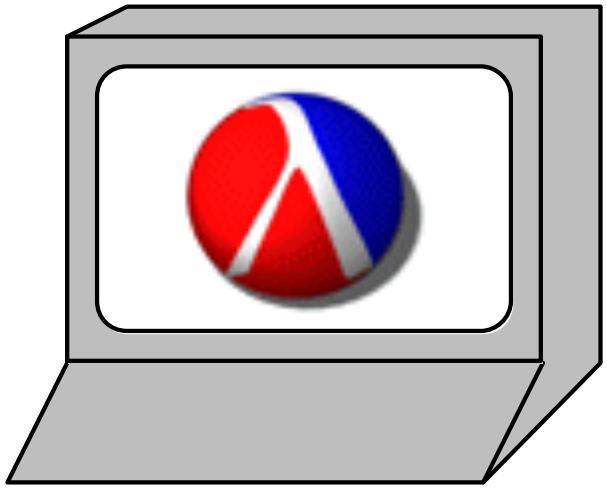

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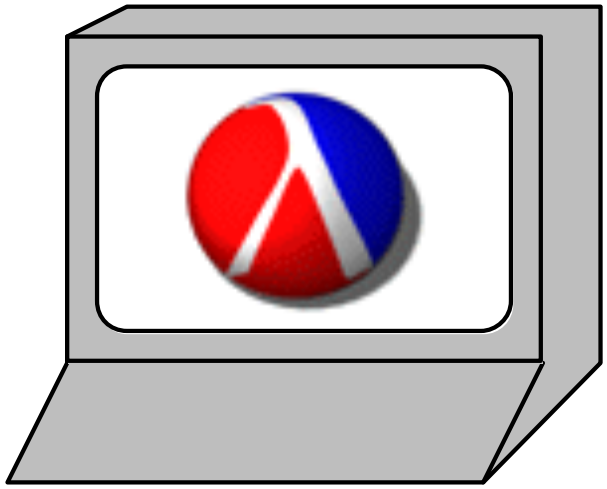

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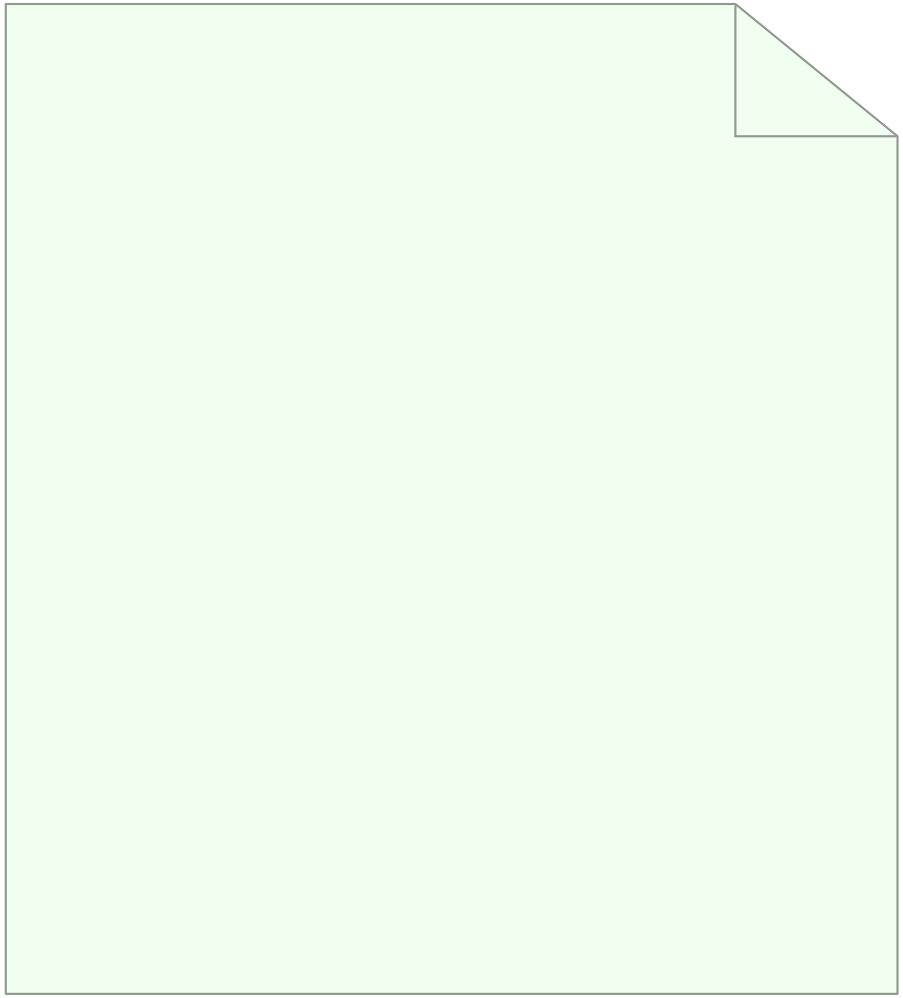

Technical Debt Repayment Plan

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+ Refactor spaghetti code

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+ Write additional tests

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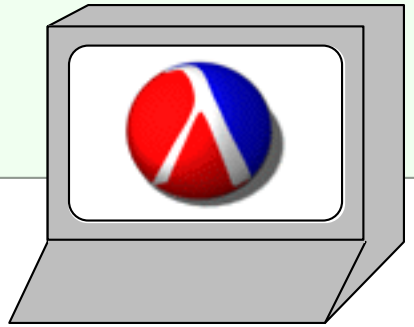
Help me help you!



Enforcing Specifications/Invariants

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- Assertions within code.

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- Use Racket's contract system.

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(provide/contract
 [my-function (-> Int Int)])
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- Use Racket's contract system.

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(provide/contract
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- Use Typed Racket.

Enforcing Specifications/Invariants

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```
(define (render sprites locs)
  ...)
```

Enforcing Specifications/Invariants

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(define (render sprites locs)
  (for ([i (in-range (vector-length sprites))])
    ...))
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Enforcing Specifications/Invariants

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(define (render sprites locs)
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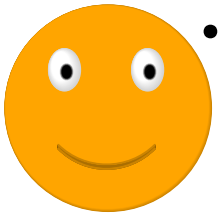

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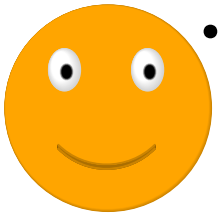

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(render (vector racman baddy1 baddy2)
        (list   loc1   loc2   loc3))
```

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```

Enforcing Specifications/Invariants

- Use Typed Racket.

```
(render (vector racman baddy1 baddy2)
        (list   loc1   loc2   loc3)) Not a vector!
```

```
(: render :
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(define (render sprites locs)
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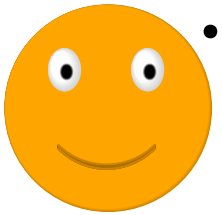

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- Use Typed Racket.

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(render (vector racman baddy1 baddy2)
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No type errors! ...

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(: render :
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Enforcing Specifications/Invariants

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Enforcing Specifications/Invariants

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Enforcing Specifications/Invariants

```
(: render :
   ([v1 : (Vectorof Sprite)]
    [_  : (Vectorof Loc)])
   ~> Void)
```

Enforcing Specifications/Invariants

```
(: render :
   ([v1 : (Vectorof Sprite)]
    [_  : (Refine [v : (Vectorof Loc)]
                  ...)])
   ~> Void)
```

Enforcing Specifications/Invariants

```
(: render :
   ([v1 : (Vectorof Sprite)]
    [_  : (Refine [v : (Vectorof Loc)]
                  LOGICAL-PROPOSITION)])
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```

A logical proposition?

Enforcing Specifications/Invariants

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(: render :
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Enforcing Specifications/Invariants

A logical proposition?

```
#lang typed/racket
```

```
Welcome to DrRacket, version 6.2.900.17--2015-
Language: typed/racket; memory limit: 1024 MB.
> number?
- : (-> Any Boolean : Number)
#<procedure:number?>
>
```

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(: render :
   ([v1 : (Vectorof Sprite)]
    [_  : (Refine [v : (Vectorof Loc)]
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Enforcing Specifications/Invariants

```
(: render :
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    [_  : (Refine [v : (Vectorof Loc)]
                  (= (vector-length v)
                     (vector-length v1)))])
   ~> Void)
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                  (= (vector-length v)
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(define (render sprites locs)
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Enforcing Specifications/Invariants

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Enforcing Specifications/Invariants

```
(: vector-ref :
   (∀ (T)
      (Vectorof T)
      Int
      -> T))
```

Enforcing Specifications/Invariants

```
(: safe-vector-ref :
   (∀ (T)
      ([v : (Vectorof T)]
       [_ : (Refine [i : Int]
                    ...)])
      -> T))
```

Enforcing Specifications/Invariants

```
(: safe-vector-ref :
   (∀ (T)
      ([v : (Vectorof T)]
       [_ : (Refine [i : Int]
                    (≤ 0 i)
                    (< i (vector-length v)))])
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(define safe-vector-ref unsafe-vector-ref)
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Enforcing Specifications/Invariants

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What have we added to Typed Racket?

Enforcing Specifications/Invariants

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What have we added to Typed Racket?

- Dependent Function Types

Enforcing Specifications/Invariants

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What have we added to Typed Racket?

- Dependent Function Types
- Refinement Types (allow dependencies)

Enforcing Specifications/Invariants

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What have we added to Typed Racket?

- Dependent Function Types
- Refinement Types (allow dependencies)
- New Propositions! Linear inequalities (over integers)

Enforcing Specifications/Invariants

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What does this buy us?

Enforcing Specifications/Invariants

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What does this buy us?

- ✓ More detailed specifications

Enforcing Specifications/Invariants

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What does this buy us?

- ✔ More detailed specifications
- ✔ Safe removal of things like integer bounds checks

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- ✔ Dependently typed data structures

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What does this buy us?

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  - e.g. Red Black Tree

Enforcing Specifications/Invariants

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(unless (= (vector-length A)
           (vector-length B))
  (error "invalid lengths"))
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```
(unless (= (vector-length A)
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```
(: render :
   (Vector of Sprite)
   [v1 : (Vector of Sprite)]
   [_  : (Refine [v : (Vector of Loc)]
                 (= (vector-length v)
                    (vector-length v1)))]
   ~> Void)
```

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(unless (= (vector-length A)
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```
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   (Vector of Sprite)
   [_ : (Refine [v : (Vector of Loc)]
                (= (vector-length v)
                   (vector-length A)))]
   [_ : (Refine [v : (Vector of Sprite)]
                (= (vector-length v)
                   (vector-length B)))]
   ~> Void)
```

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(unless (= (vector-length A)
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We're not ready for that specific a type!

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Are these dependent types *infectious*?

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(: render :
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(define (render sprites locs)
  (unless (= (vector-length sprites)
             (vector-length locs))
    (error 'render "unequal number of items"))
  (for ([i (in-range (vector-length sprites))])
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Have it your way!

Are these *really* dependent types?

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- A *true* dependently typed language can _____.

Are these *really* dependent types?

- A *true* dependently typed language can fully type **`quicksort`**

Are these *really* dependent types?

- A *true* dependently typed language can typecheck `printf`

Are these *really* dependent types?

- A *true* dependently typed language supports theorem proving.

Are these *really* dependent types?

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- ✓ Typed Racket check types with dependencies

Are these *really* dependent types?

- Typed Racket check types with dependencies

```
Program Fixpoint quicksort
      (l:list nat)
      {measure (length l)} :
      {sl : list nat |
        Permutation l sl
        /\ StronglySorted le sl} :=
match l with
| nil => nil
| x :: xs =>
    match partition (gtb x) xs with
    | (lhs, rhs) =>
      (quicksort lhs) ++ x :: (quicksort rhs)
    end
end.
```

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```
quicksort has type-checked, generating 3 obligation(s)
Solving obligations automatically...
quicksort_obligation_3 is defined
2 obligations remaining
Obligation 1 of quicksort:
forall l : list nat,
(forall l0 : list nat, length l0 < length l -> list nat) ->
forall (x : nat) (xs : list nat),
x :: xs = l ->
let filtered_var := partition (leb x) xs in
forall rhs lhs : list nat, (rhs, lhs) = filtered_var ->
                  length lhs < length l.

Obligation 2 of quicksort:
forall l : list nat,
(forall l0 : list nat, length l0 < length l -> list nat) ->
forall (x : nat) (xs : list nat),
x :: xs = l ->
let filtered_var := partition (leb x) xs in
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This is not VeriRacket

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Thank you