Impersonators and Chaperones:
Run-time Support for Higher-Order Contracts

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University of Utah

... This Talk ...

- It's about an **untyped** language

  ... in practice, though not in principle

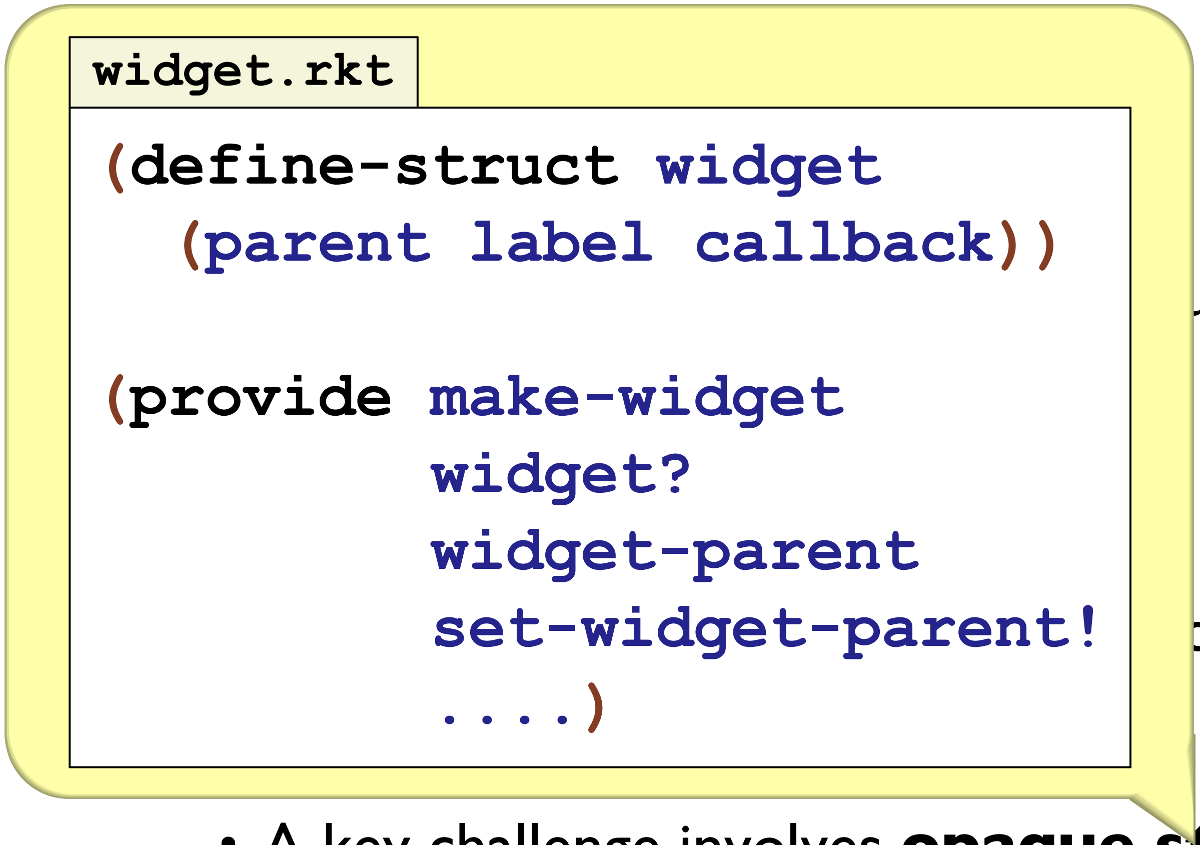
- It's about an **extensibile** language

  ... in the sense of implementing contracts as a layer

- A key challenge involves **opaque structures**

  ... not in Javascript, Ruby, or Python

... This Talk ...



widget.rkt

```
(define-struct widget
  (parent label callback))

(provide make-widget
         widget?
         widget-parent
         set-widget-parent!
         ....)
```

ugh not in principle

contracts as a layer

- A key challenge involves **opaque structures**

... not in Javascript, Ruby, or Python

... This Talk ...

- It’s about an **untyped** language

  ... in practice, though not in principle

- It’s about an **extensibile** language

  ... in the sense of implementing contracts as a layer

- A key challenge involves **opaque structures**

  ... not in Javascript, Ruby, or Python

Why This Talk is Relatively Racket-Specific

- It's about an **untyped** language

  ... in practice, though not in principle

- It's about an **extensibile** language

  ... in the sense of implementing contracts as a layer

- A key challenge involves **opaque structures**

  ... not in Javascript, Ruby, or Python

Contracts

```
make-gauge : nonnegative-integer? -> widget?

make-choice : (listof label-string?) -> widget?

make-button : label-string?
              (button-event? -> status?)
              -> widget?
```

Contracts

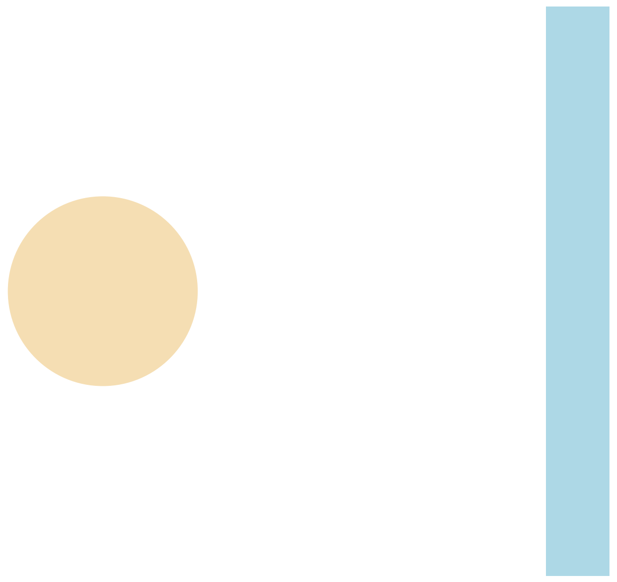
```
make-gauge : nonnegative-integer? -> widget?

make-choice : (listof label-string?) -> widget?

make-button : label-string?
              (button-event? -> status?)
              -> widget?
```

- Some contracts are not types
- Some contracts guard a typed–untyped boundary

Contracts and Boundaries



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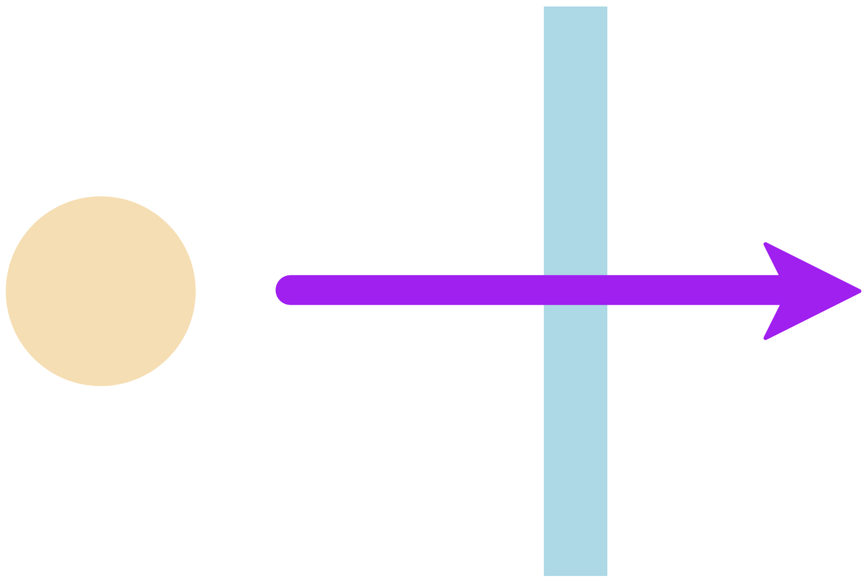

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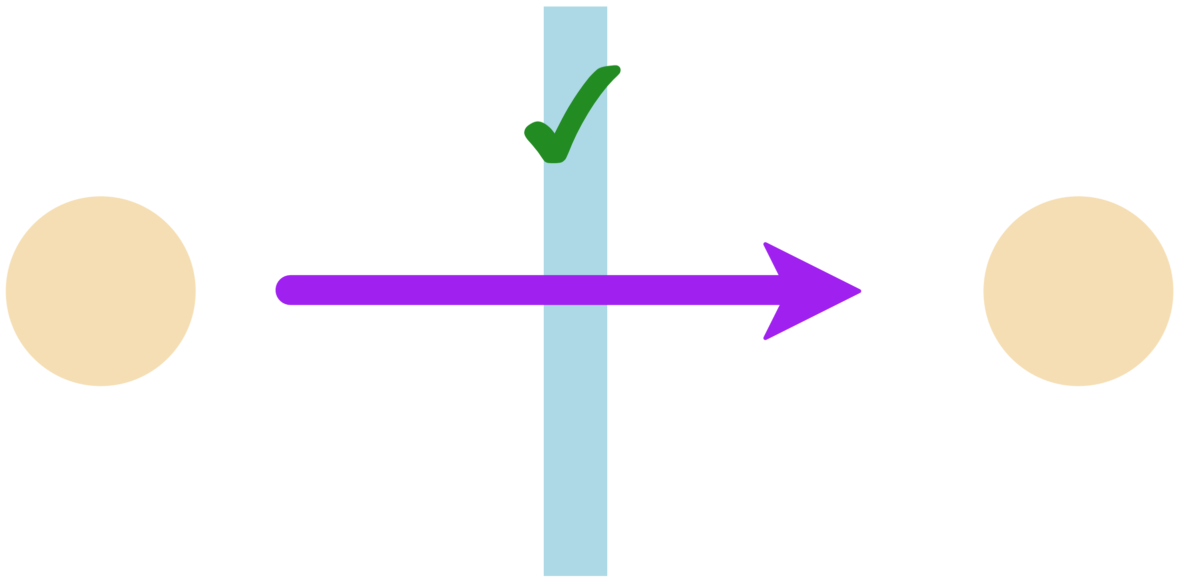

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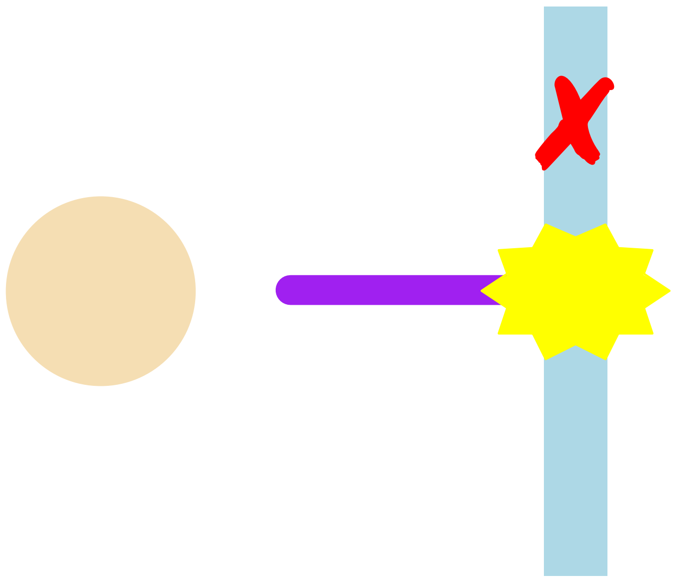

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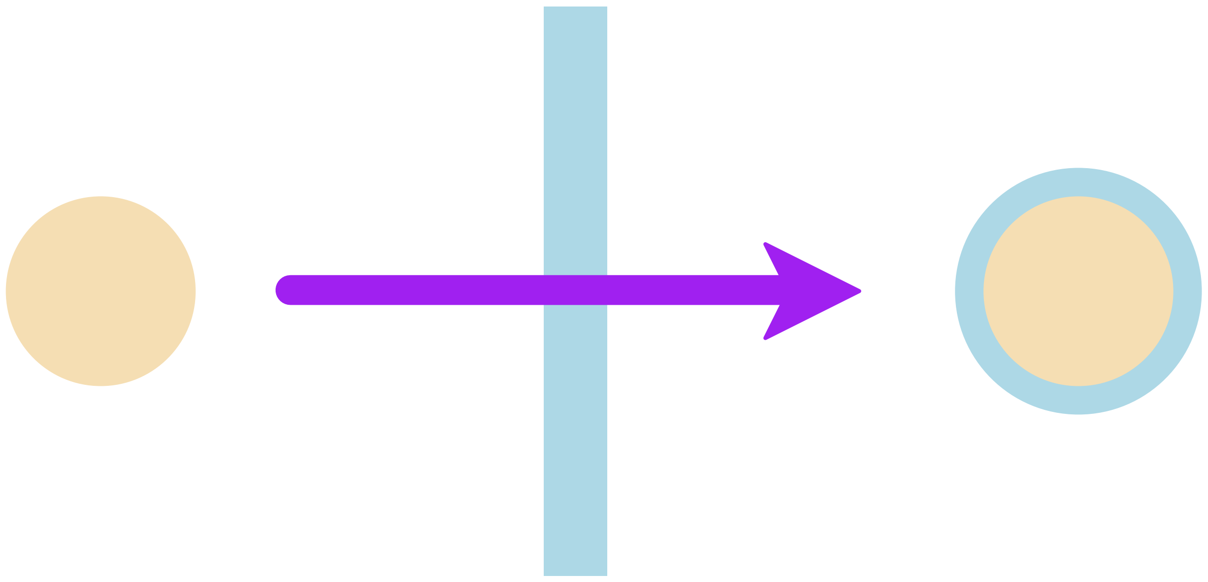

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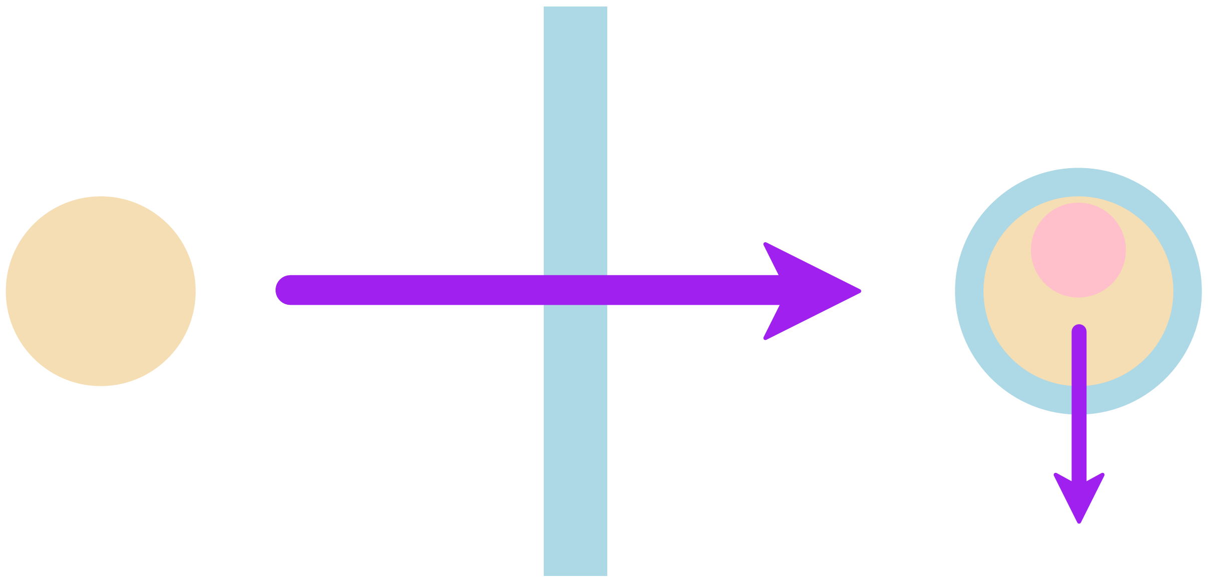

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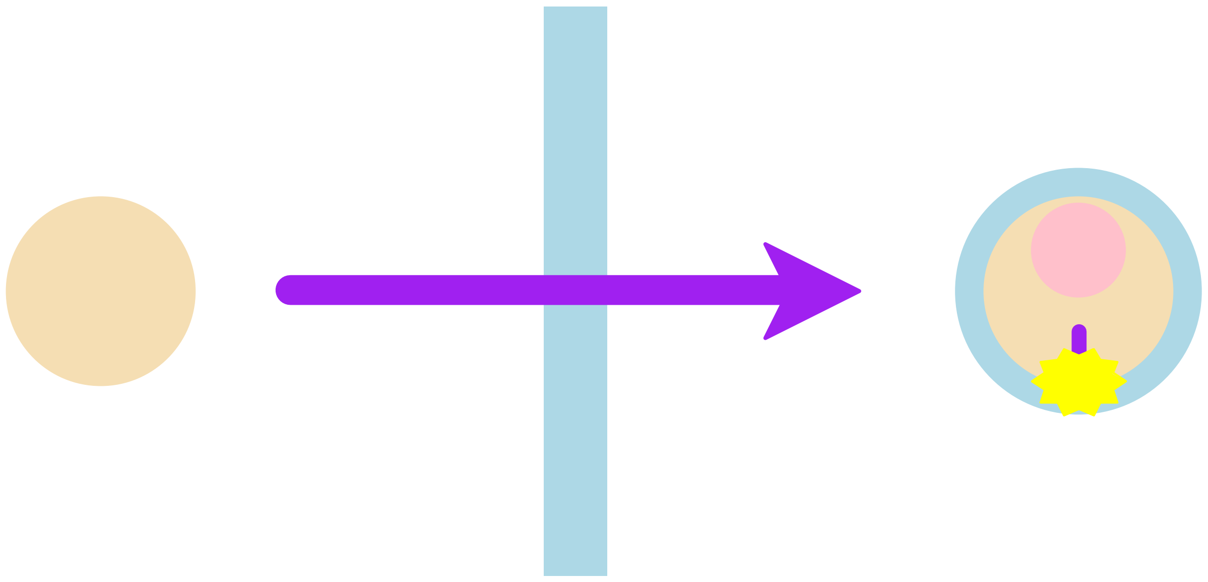

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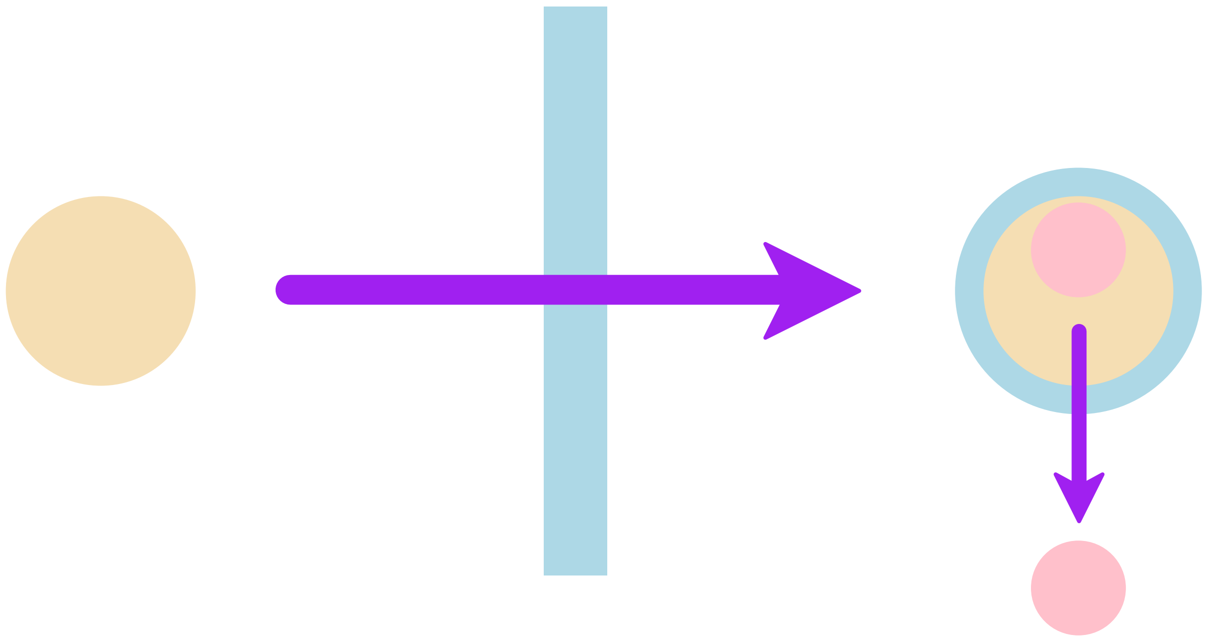

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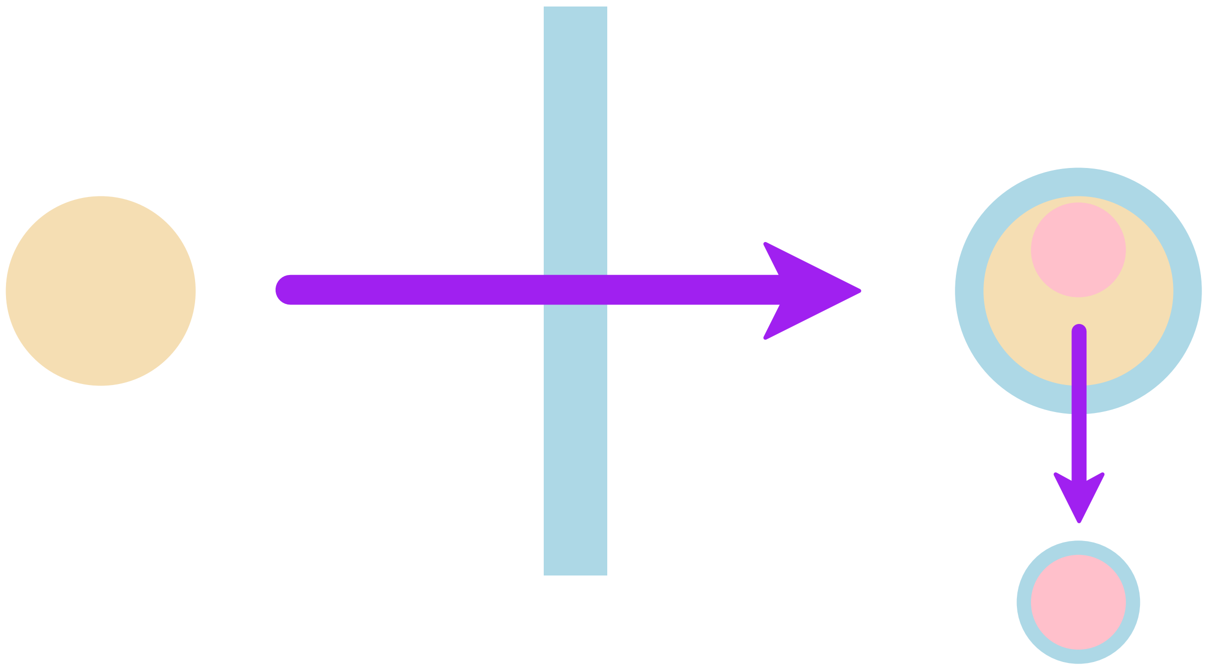

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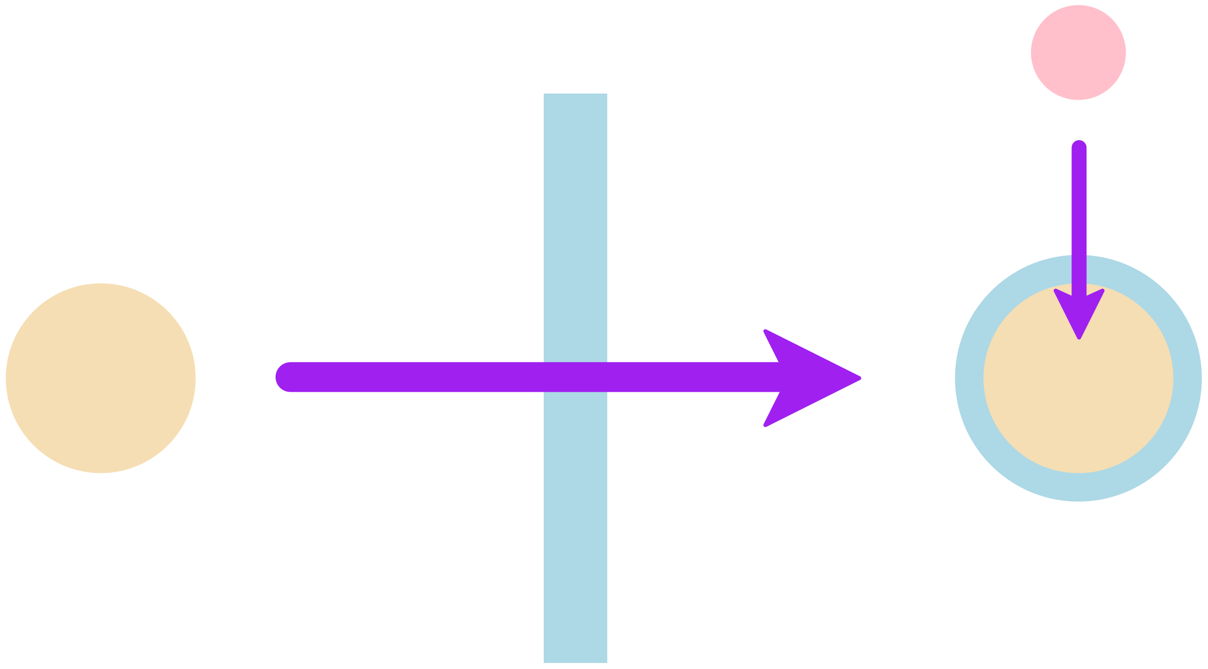

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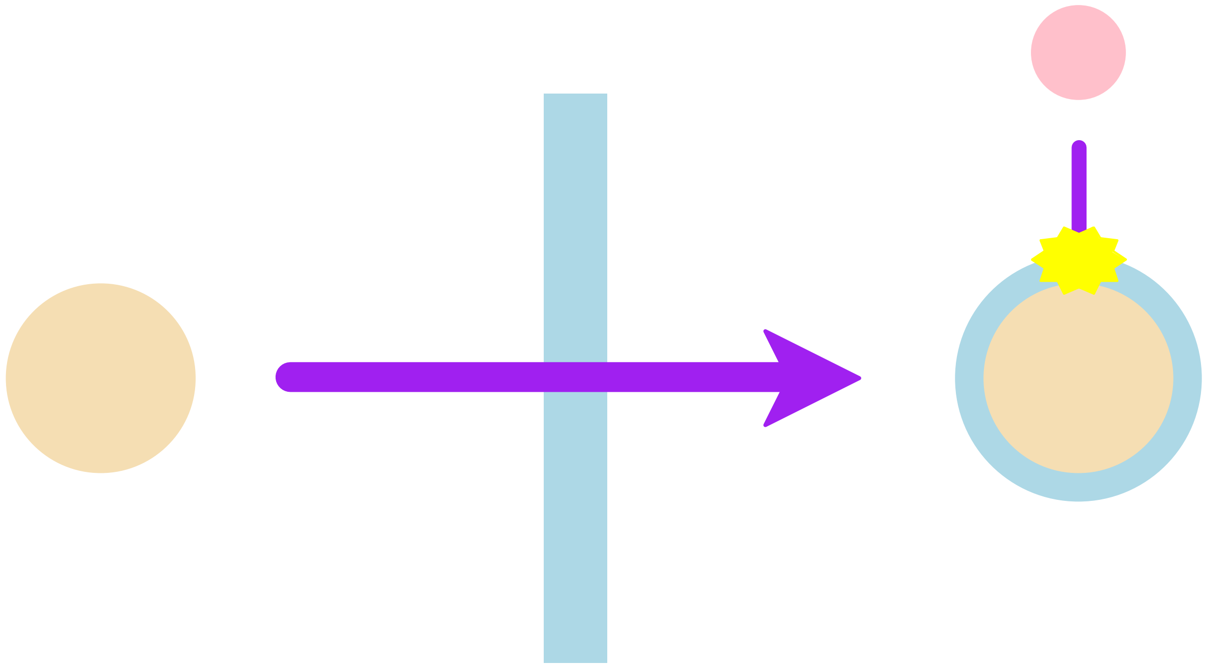

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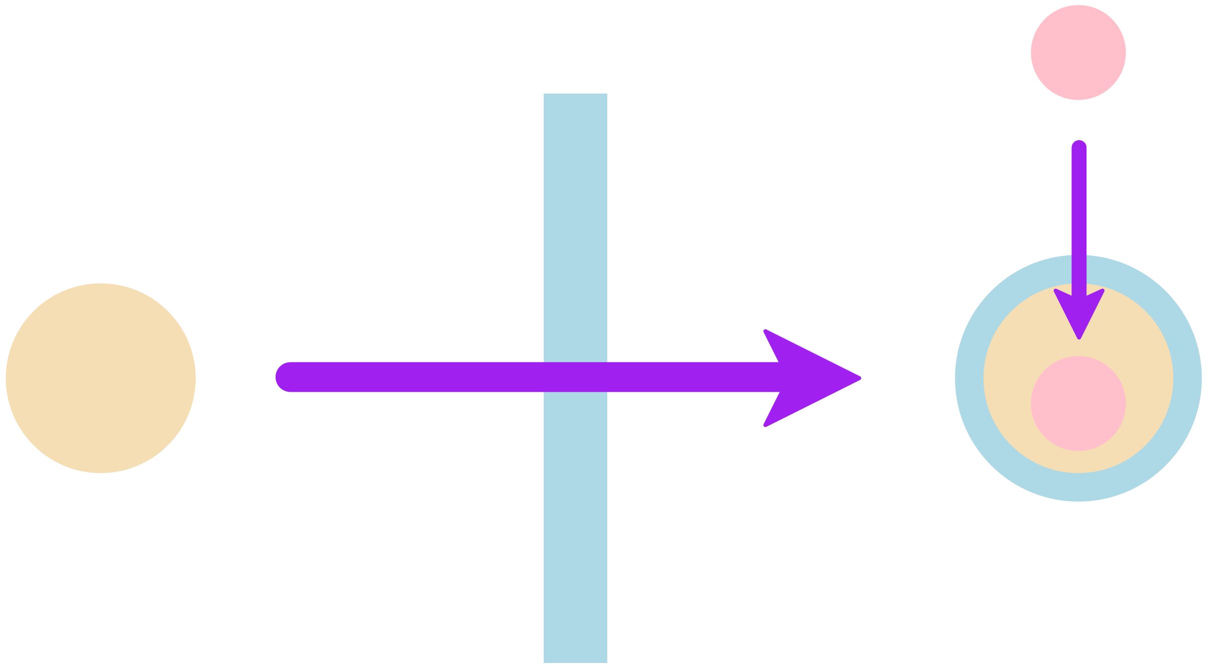

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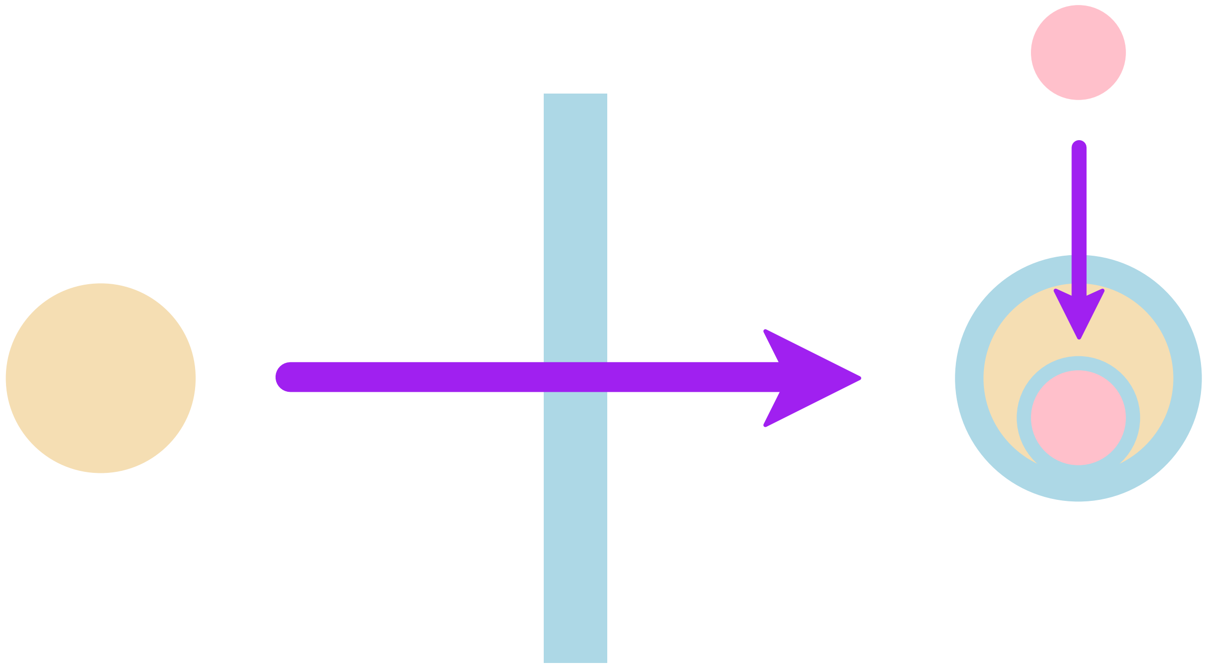
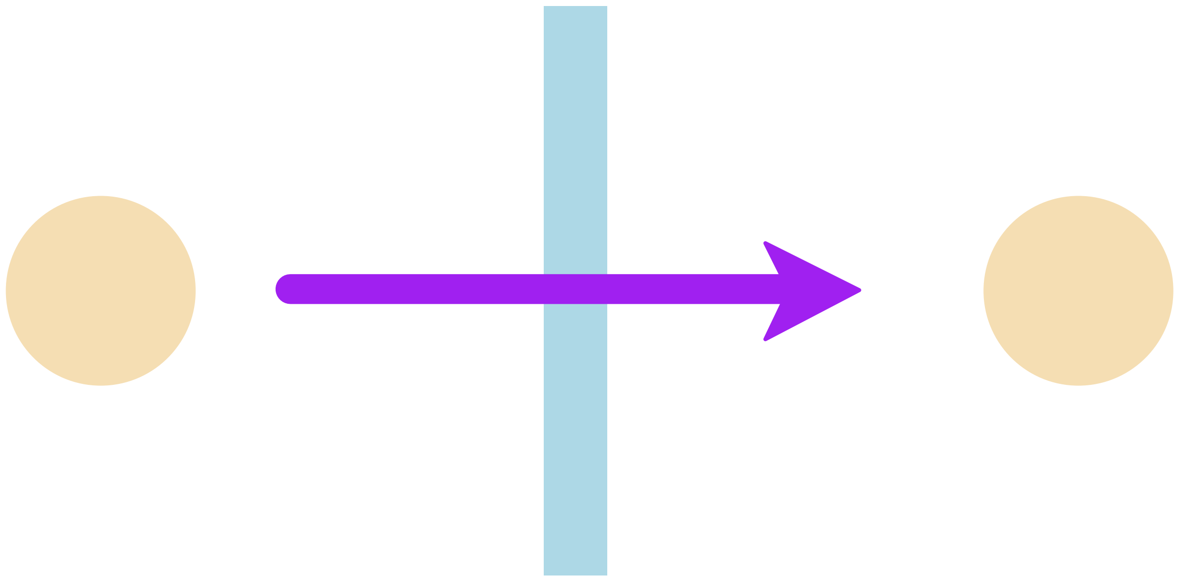


Contract Examples



math.rkt

```
(define pi 3.14)

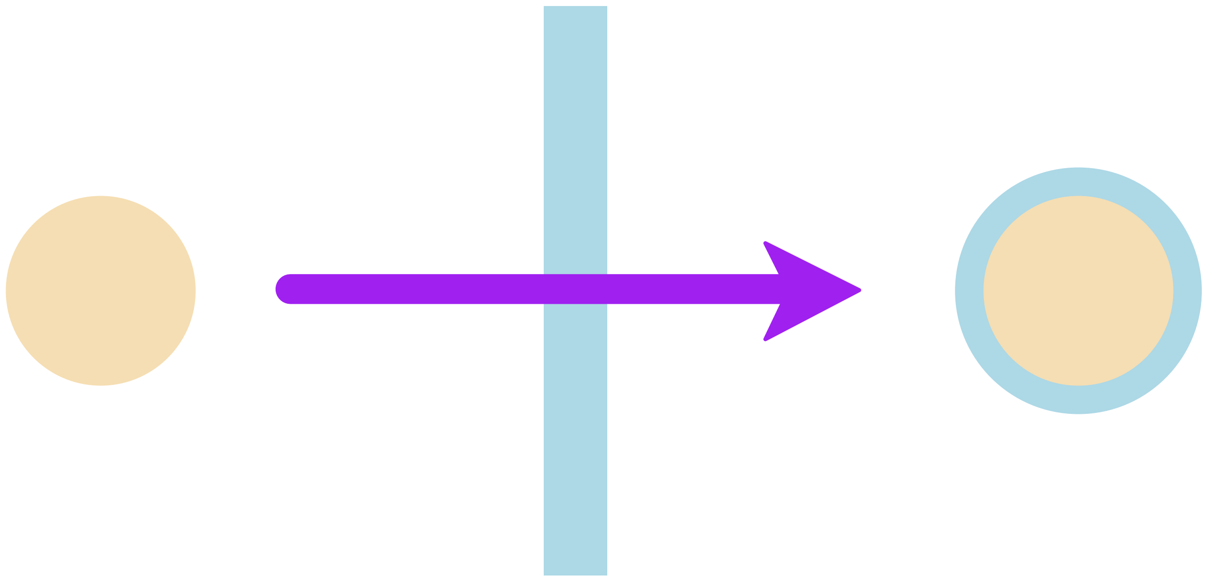
(provide/contract
 [pi real?])
```

circles.rkt

```
(require "math.rkt")

pi
```

Contract Examples



math.rkt

```
(define (sqr x) (* x x))

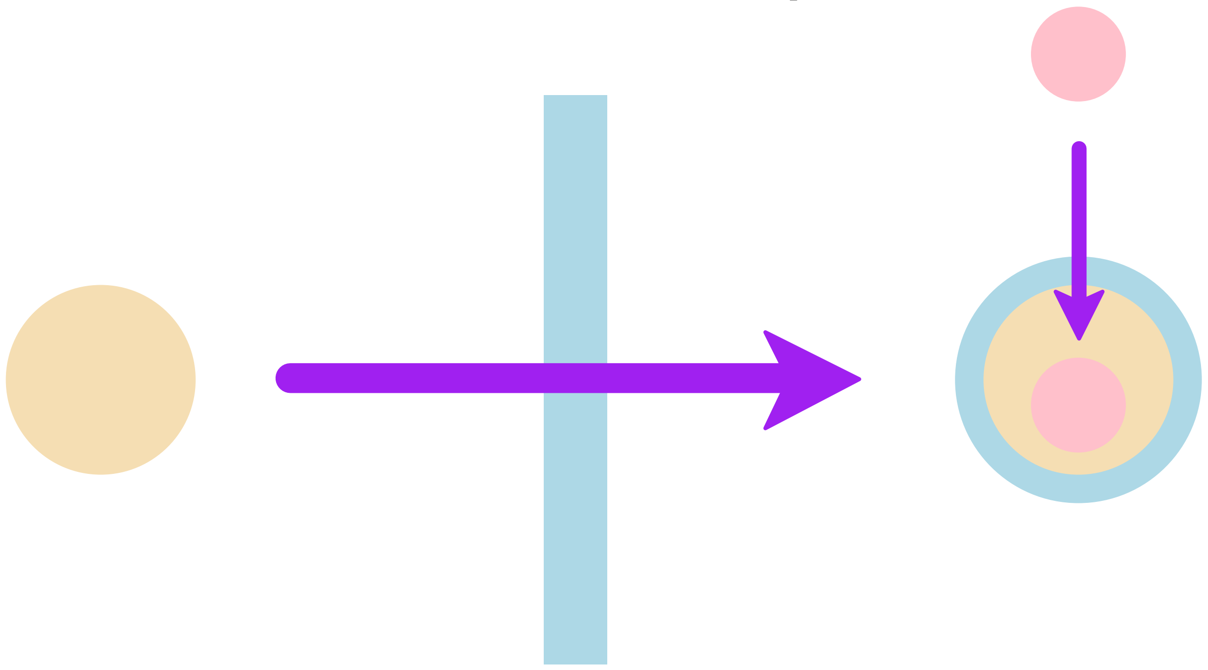
(provide/contract
 [sqr
  (real? . -> .
           nonnegative-real?)])
```

circles.rkt

```
(require "math.rkt")

(map sqr ....)
```

Contract Examples



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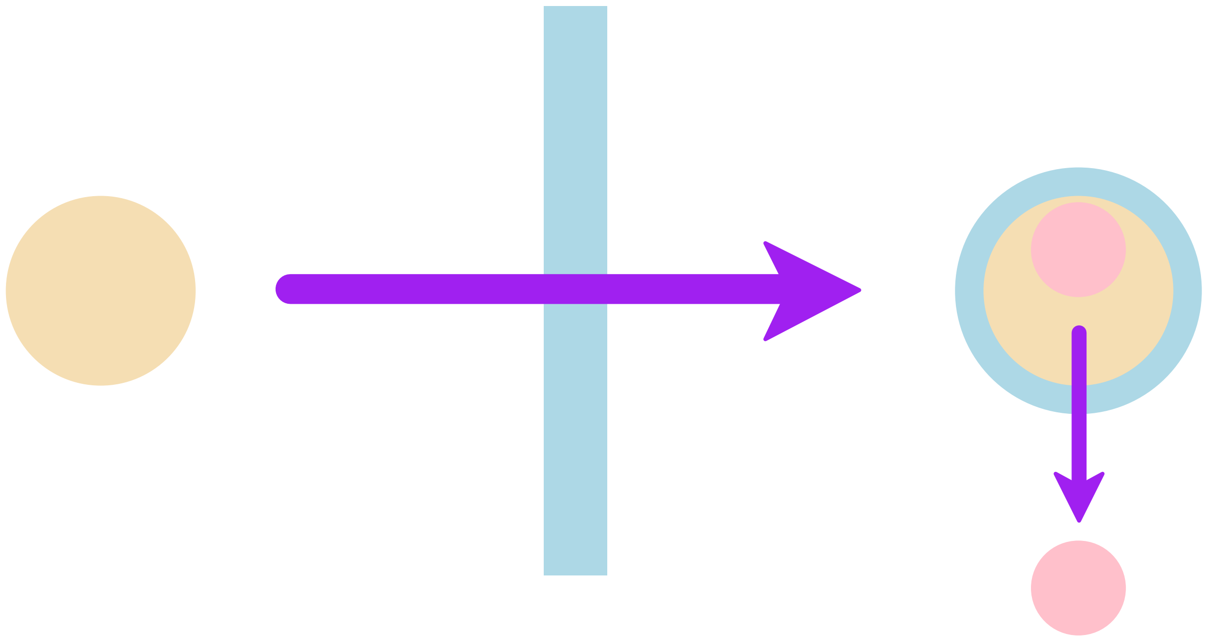
circles.rkt

```
(require "math.rkt")

(sqr 1.414)
```

Contract Examples



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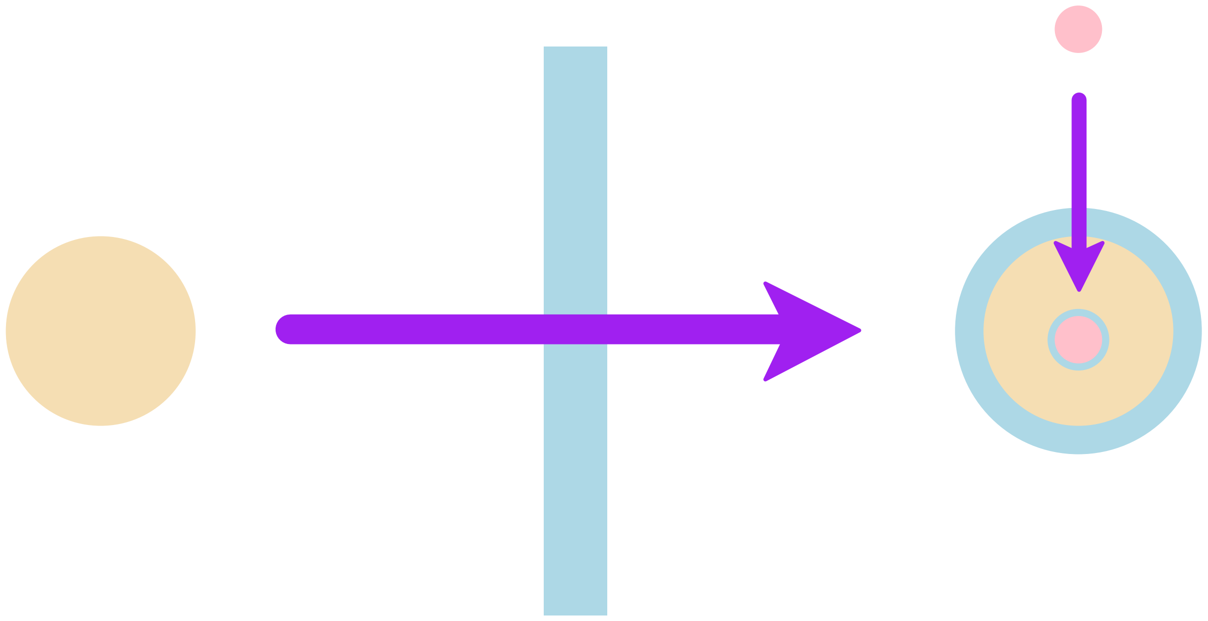
Contract Examples



math.rkt

```
(define (derivative f)
  ....)

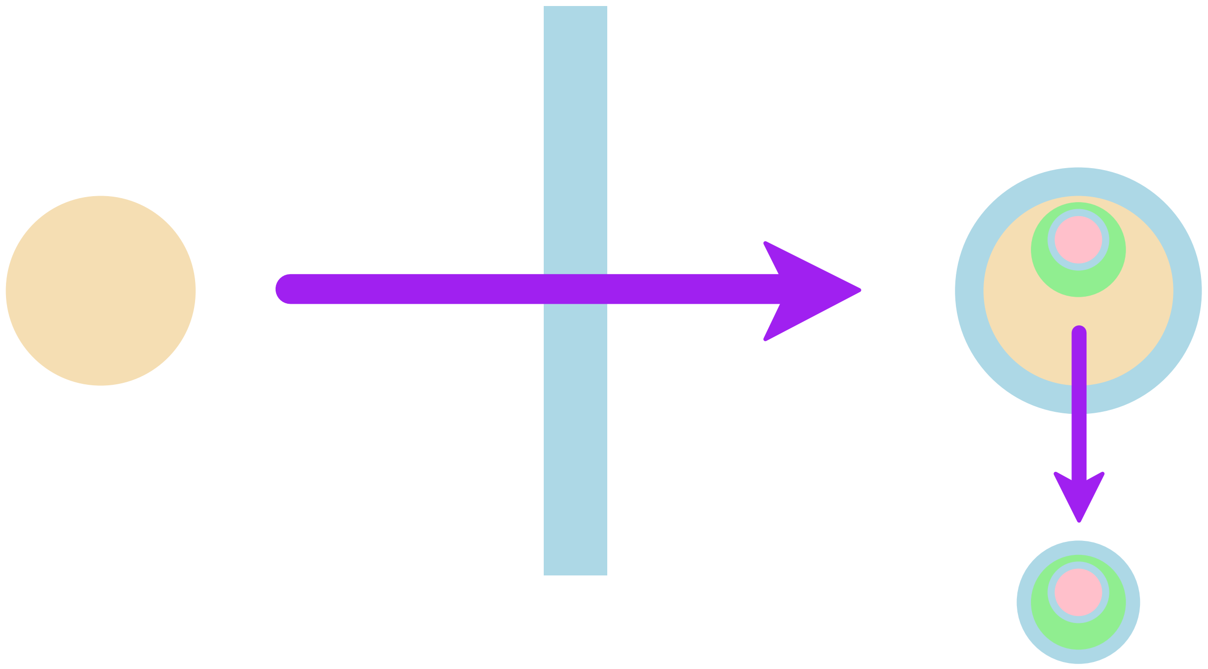
(provide/contract
 [derivative
  ((real? . -> . real?)
   . -> .
   (real? . -> . real?))])
```

circles.rkt

```
(require "math.rkt")

(derivative cos)
```

Contract Examples



math.rkt

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circles.rkt

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(require "math.rkt")

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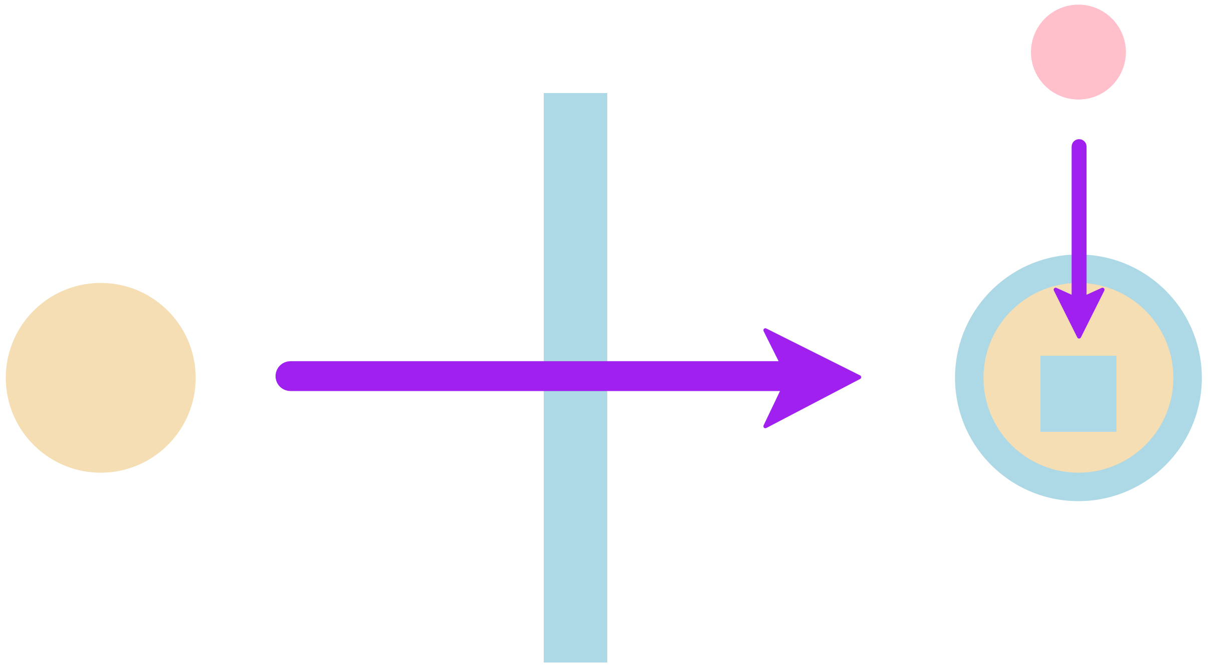
Contract Examples



vault.rkt

```
(define α (new-∀/c))
....

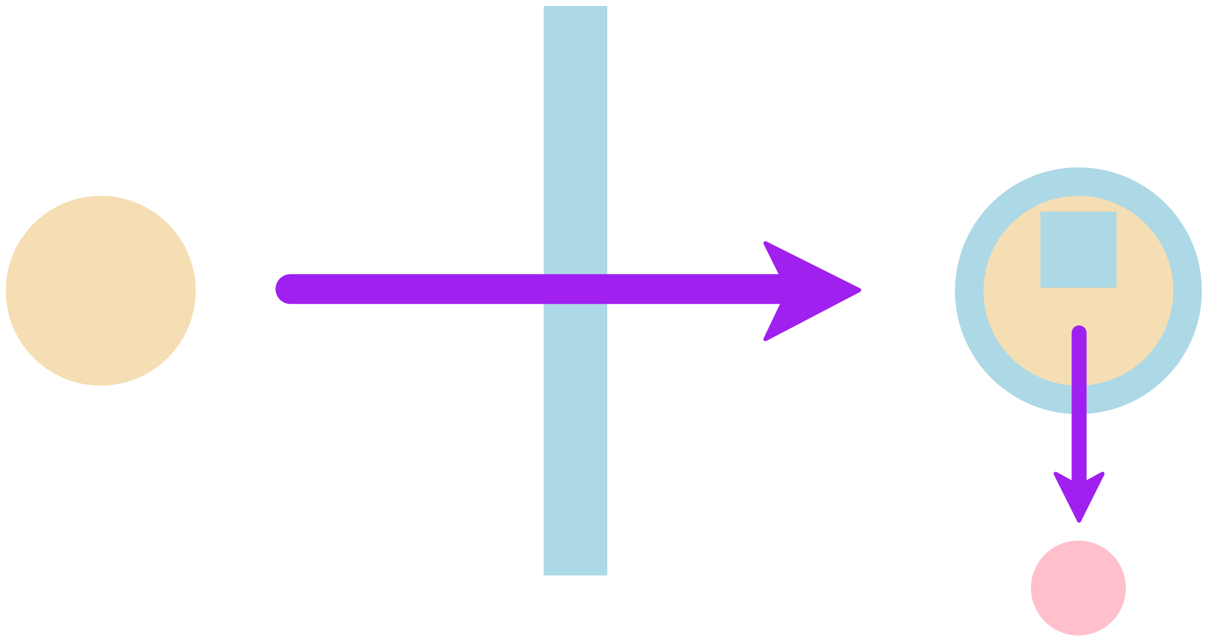
(provide/contract
 [put (α . -> . any)]
 [get (-> α)])
```

bank.rkt

```
(require "vault.rkt")

(put 199.99)
(get)
```

Contract Examples



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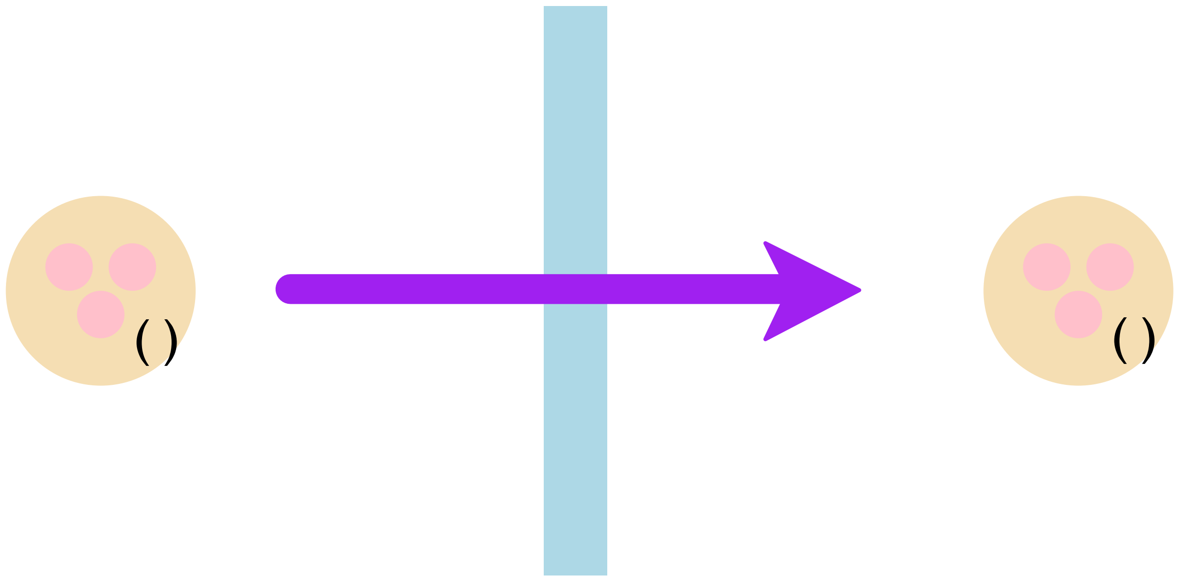
Contract Examples



math.rkt

```
(define constants
  (list 299000000.0
        6.67e-11
        6.63e-34))

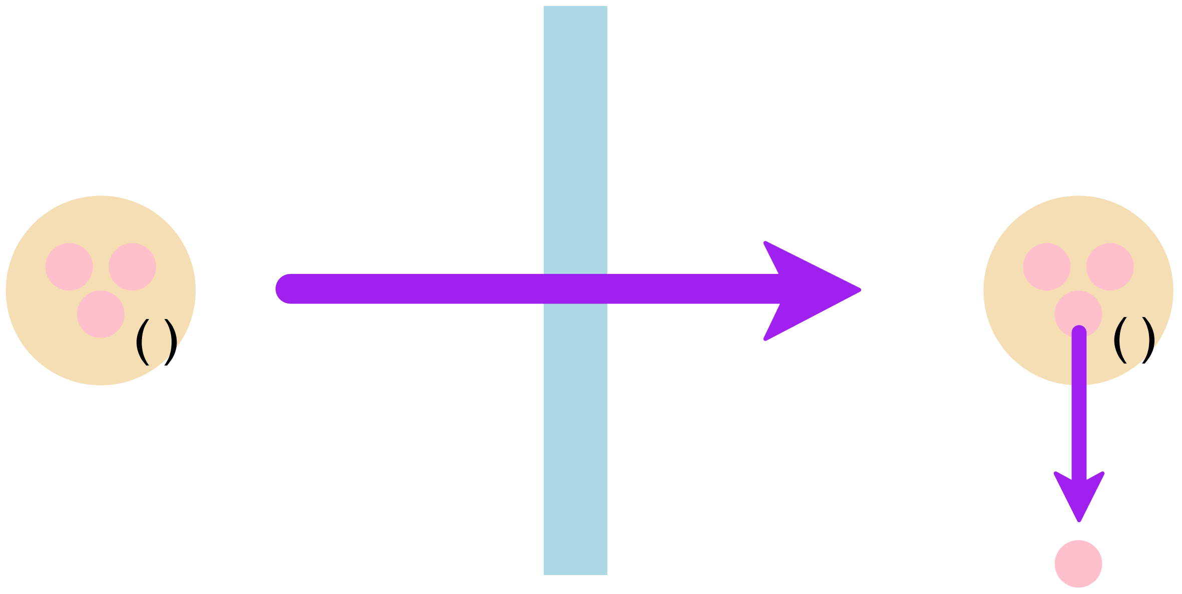
(provide/contract
 [constants
  (listof nonnegative-real?)])
```

circles.rkt

```
(require "math.rkt")

constants
```

Contract Examples



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  (list 299000000.0
        6.67e-11
        6.63e-34))

(provide/contract
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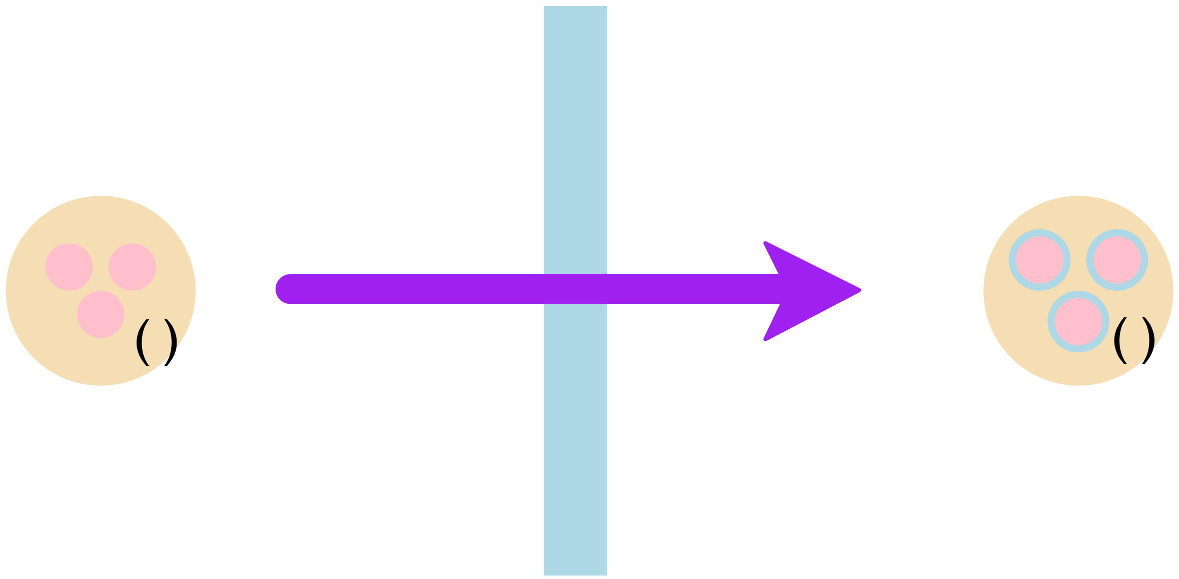
  (listof nonnegative-real?)])
```

circles.rkt

```
(require "math.rkt")

(first constants)
```

Contract Examples



math.rkt

```
(define transforms
  (list identity sqr sqrt))

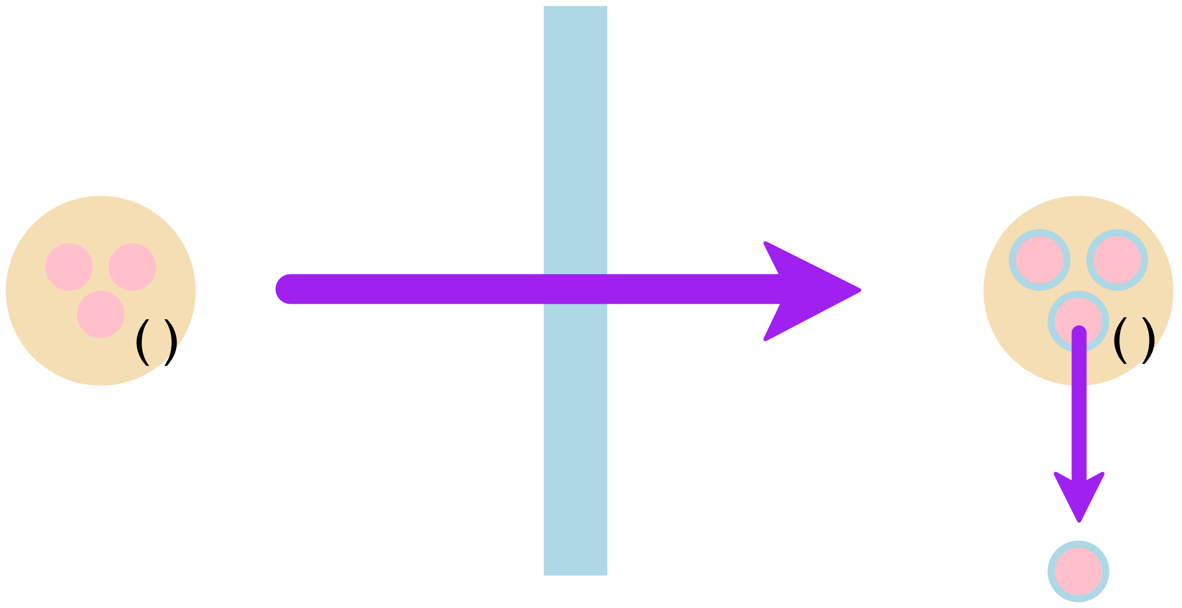
(provide/contract
 [constants
  (listof
   (nonnegative-real?
    . -> . nonnegative-real?))])
```

circles.rkt

```
(require "math.rkt")

transforms
```

Contract Examples



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(define transforms
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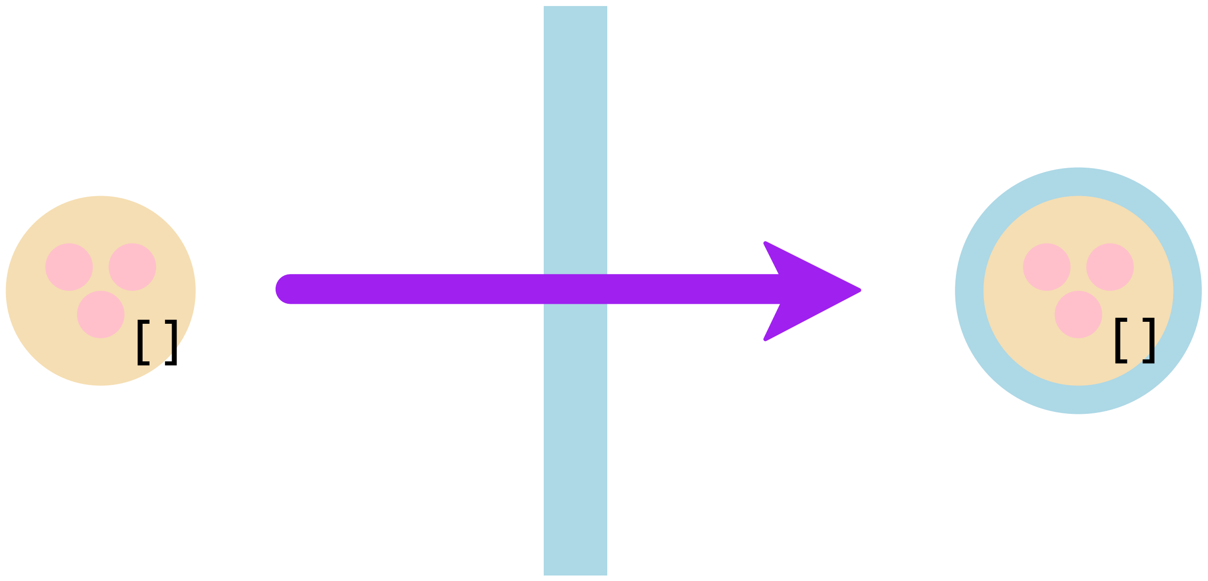
(provide/contract
 [constants
  (listof
   (nonnegative-real?
    . -> . nonnegative-real?))])
```

circles.rkt

```
(require "math.rkt")

(first transforms)
```

Contract Examples



math.rkt

```
(define state
  (vector 0.1
          0.4
          7.9))

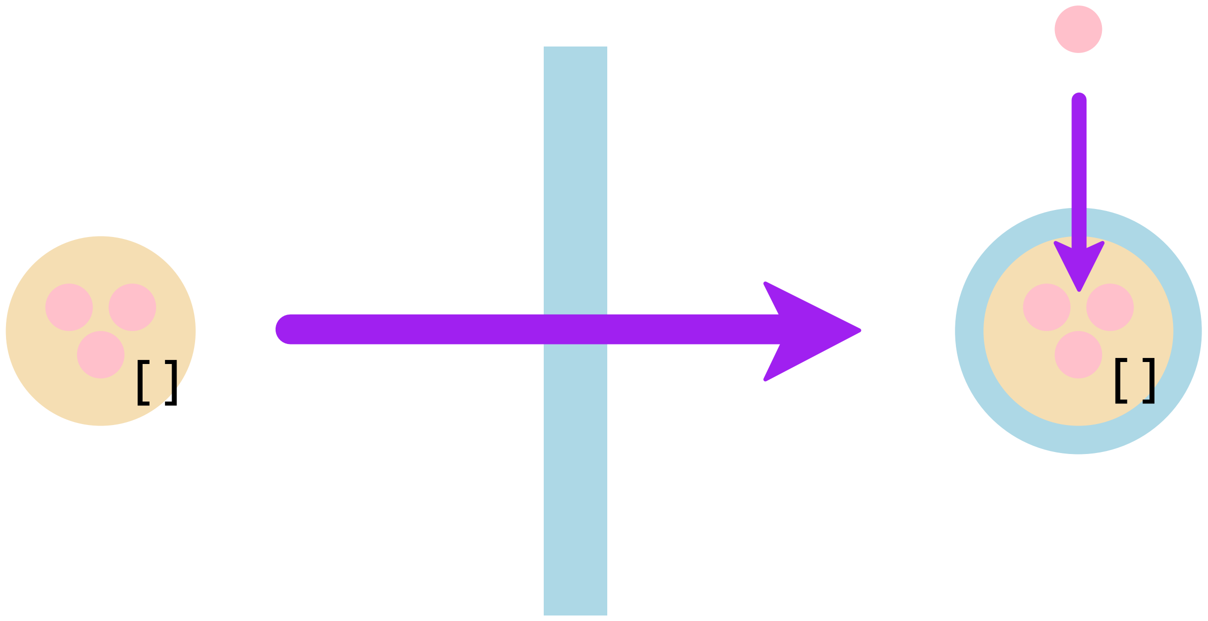
(provide/contract
 [state
  nonnegative-real?])
```

circles.rkt

```
(require "math.rkt")

state
```

Contract Examples



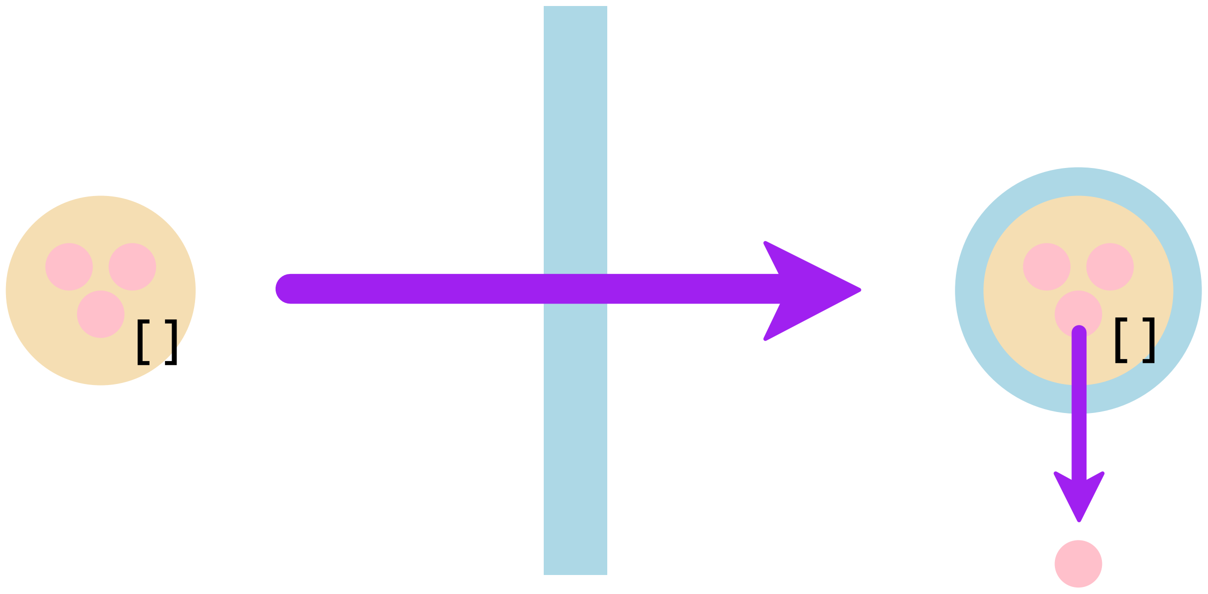
math.rkt
```
(define state
  (vector 0.1
          0.4
          7.9))

(provide/contract
 [state
  nonnegative-real?])
```

circles.rkt
```
(require "math.rkt")

(vector-set! state 0 0.5)
```

Contract Examples



math.rkt

```
(define state
  (vector 0.1
          0.4
          7.9))

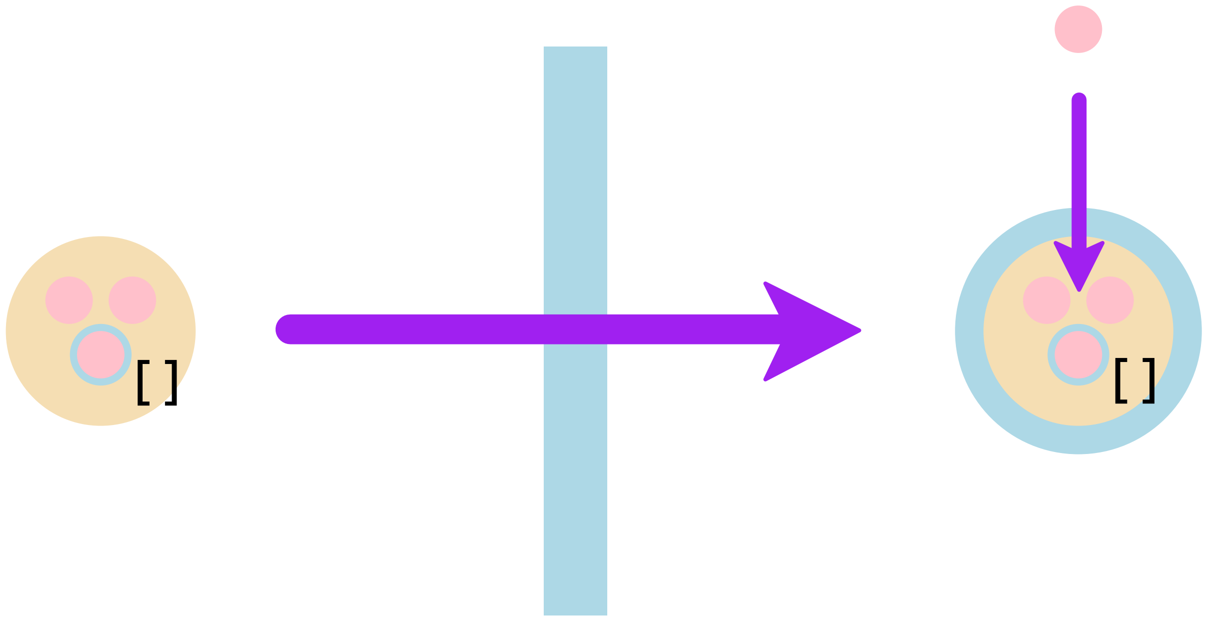
(provide/contract
 [state
  nonnegative-real?])
```

circles.rkt

```
(require "math.rkt")

(vector-ref state 0)
```

Contract Examples



math.rkt

```
(define transforms
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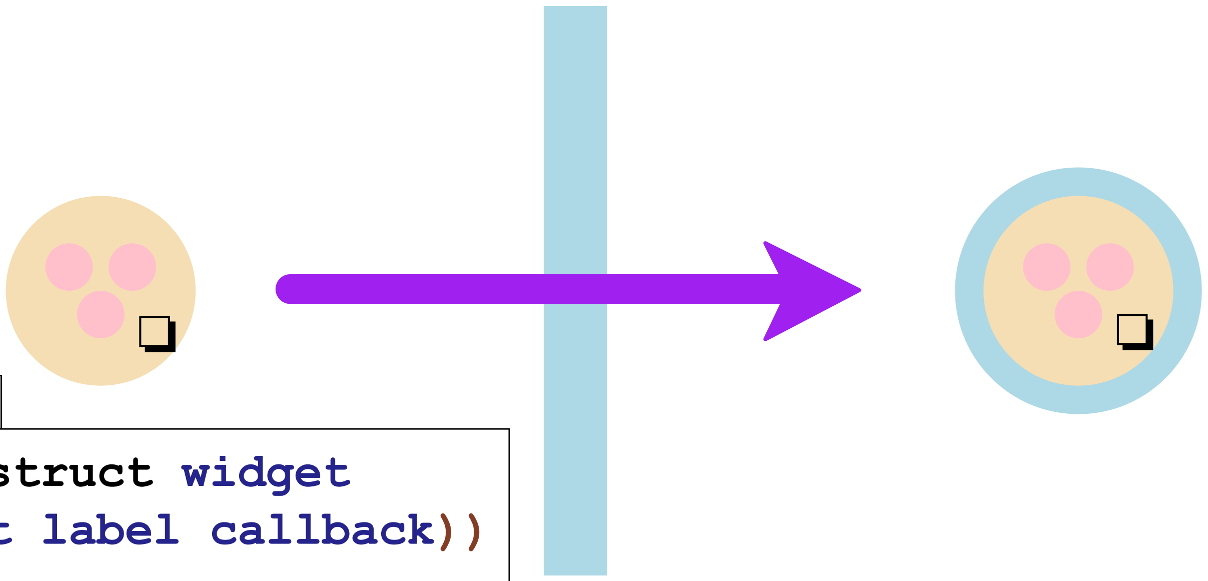
(provide/contract
 [state
  (vectorof
   (nonnegative-real?
    . -> . nonnegative-real?))])
```

circles.rkt

```
(require "math.rkt")

(vector-set! transforms
             0
             abs)
```

Contract Examples



widget.rkt

```
(define-struct widget
  (parent label callback))
....
```

scene.rkt

```
(require "widget.rkt")

(define plot
  (make-button parent "Draw"
               draw-callback))

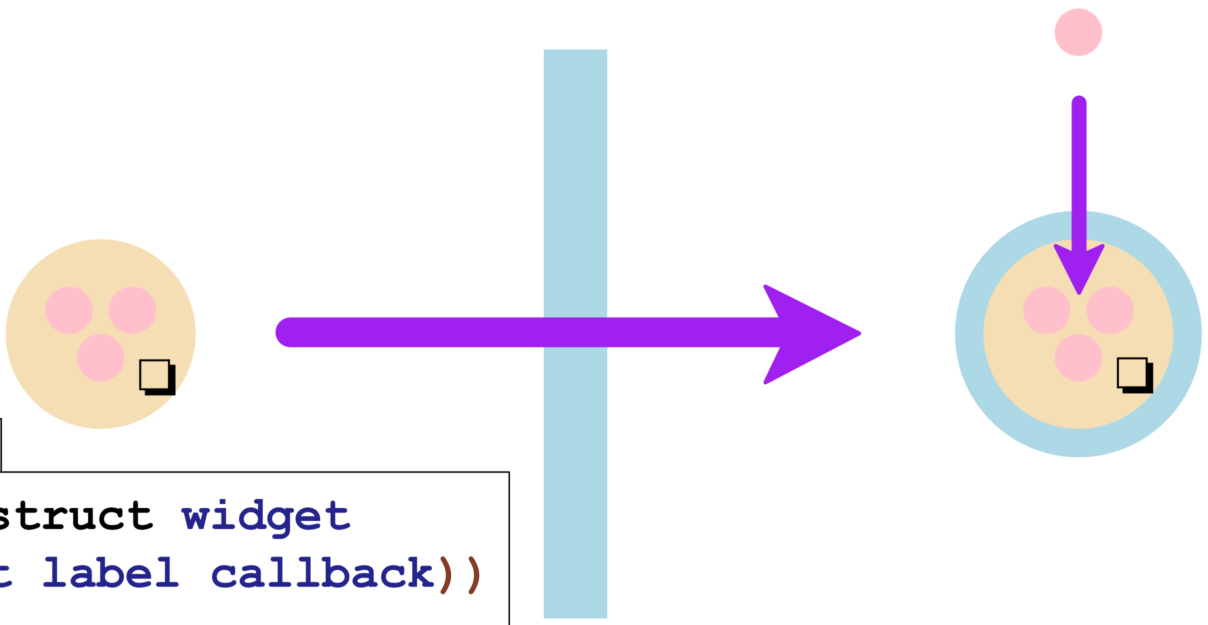
(provide/contract
 [plot (struct/c widget gl-window?
                 ....)])
```

circles.rkt

```
(require "widget.rkt"
         "scene.rkt")


widget
```

Contract Examples



widget.rkt
```
(define-struct widget
  (parent label callback))
....
```

scene.rkt
```
(require "widget.rkt")

(define plot
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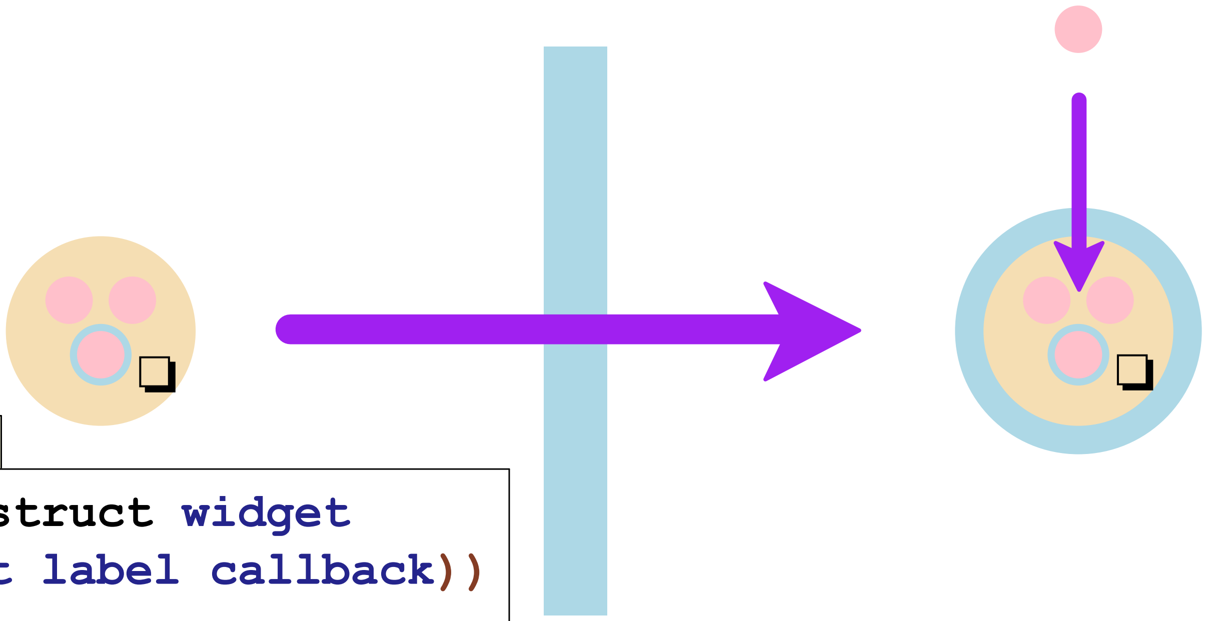
                draw-callback))

(provide/contract
 [plot (struct/c widget gl-window?
                      ....)])
```

circles.rkt
```
(require "widget.rkt"
         "scene.rkt")

(set-widget-parent!
 plot
 other-window)
```

Contract Examples



widget.rkt

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....
```

scene.rkt

```
(require "widget.rkt")

(define plot
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               draw-callback))

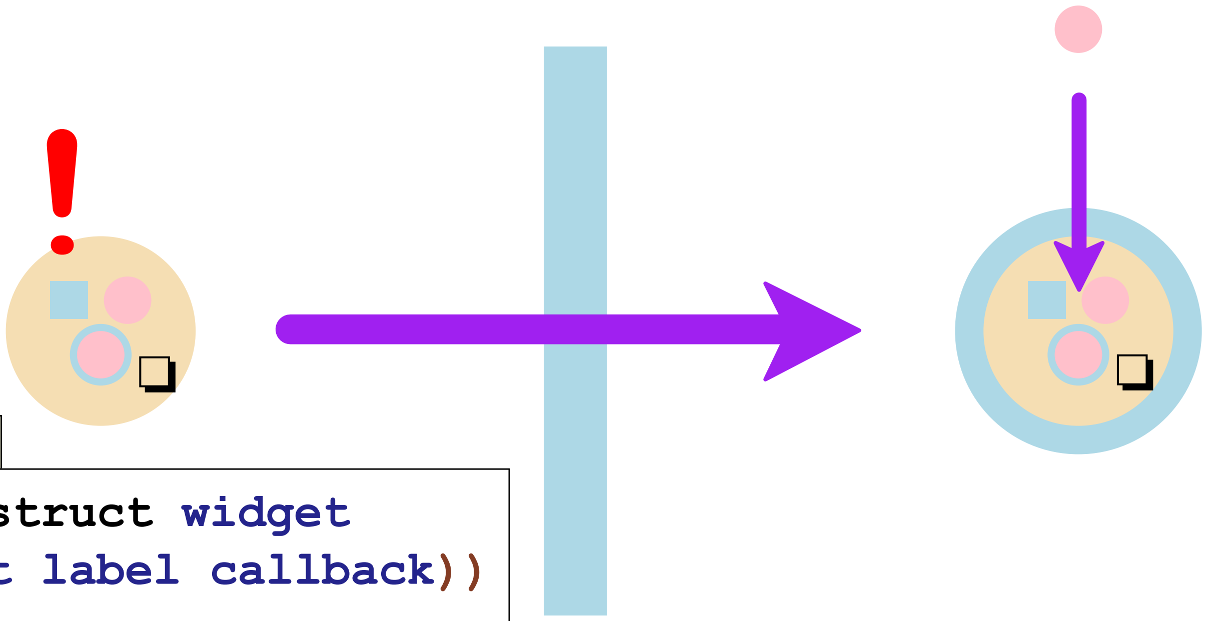
(provide/contract
 [plot (struct/c widget gl-window?
                 ....)])
```

circles.rkt

```
(require "widget.rkt"
         "scene.rkt")

(set-widget-callback!
 plot
 save-file)
```

Contract Examples



widget.rkt

```
(define-struct widget
   (parent label callback))
....
```

scene.rkt

```
(require "widget.rkt")

(define plot
   (make-button parent "Draw"
                draw-callback))

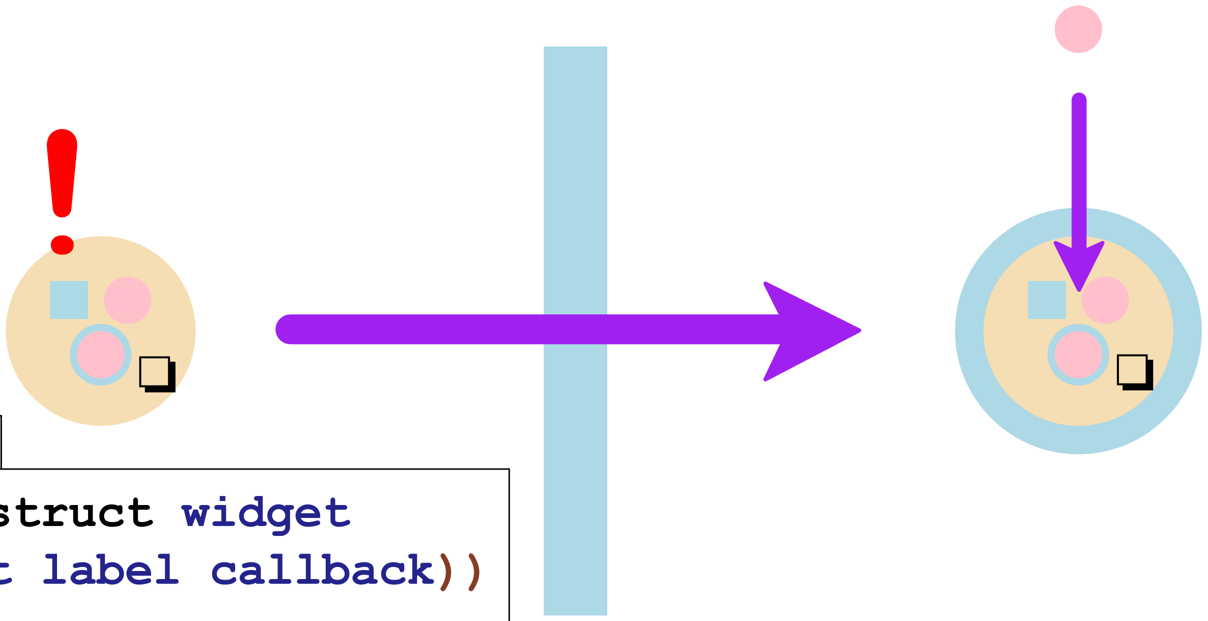
(provide/contract
 [plot (struct/c widget α
                ....)])
```

circles.rkt

```
(require "widget.rkt"
         "scene.rkt")

(set-widget-parent!
 plot
 other-window)
```

Contract Examples



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(require "widget.rkt")

(define plot
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               draw-callback))

(provide/contract
 [plot (struct/c widget α
                 ....)])
```

```
                       .rkt"
                       .rkt")

(set-widget-parent!
 plot
 other-window)
```

originator might assume invariants that are enforced by constructor

Contract Hierarchy

flat contracts $\subset$ chaperone contracts $\subset$ impersonator contracts

Contract Hierarchy

flat: all checks are immediate

$\boxed{\text{flat contracts}} \subset$ chaperone contracts $\subset$ impersonator contracts

```
positive-integer?

  (listof char?)
```

Contract Hierarchy

chaperone: checks may be delayed

$$\text{flat contracts} \subset \boxed{\text{chaperone contracts}} \subset \text{impersonator contracts}$$

```
(positive-integer? . -> . negative-integer?)

(number? (real? . -> . real?) . -> . number?)
```

Contract Hierarchy

impersonator: checks may substitute alternatives

flat contracts $\subset$ chaperone contracts $\subset$ $\boxed{\text{impersonator contracts}}$

```
(α α . -> . α)
```

Contract Hierarchy

chaperone: checks may be delayed

$$\text{flat contracts} \subset \boxed{\text{chaperone contracts}} \subset \text{impersonator contracts}$$

consistent with opacity and immutability

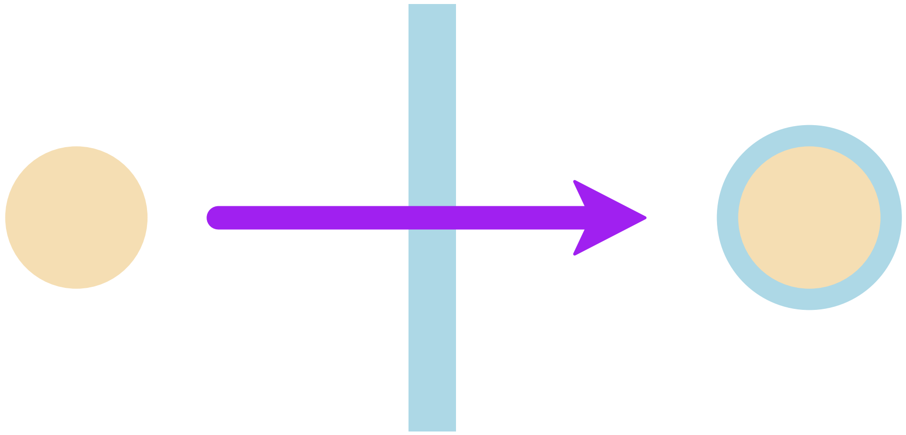
Contract Hierarchy

impersonator: checks may substitute alternatives

flat contracts $\subset$ chaperone contracts $\subset$ impersonator contracts

inconsistent with opacity and immutability

Implementing Contracts

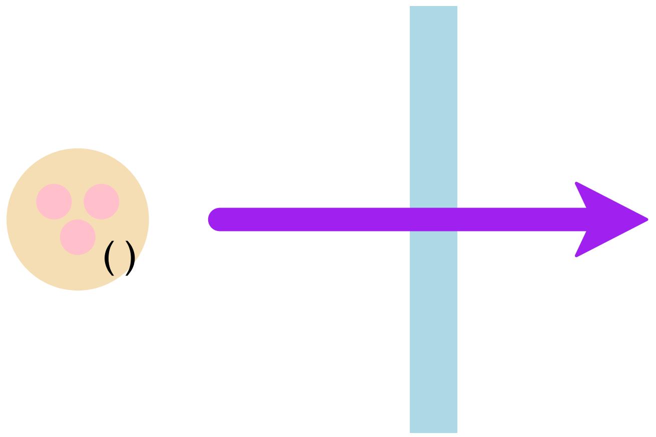


```
(λ (x) (* x x))
```

$\longrightarrow$

```
(lambda (x)
  (unless (real? x)
    (contract-failure))
  (let ([v ((λ (x) (* x x)) x)])
    (unless (nonnegative-real? v)
      (contract-failure))
    v))
```

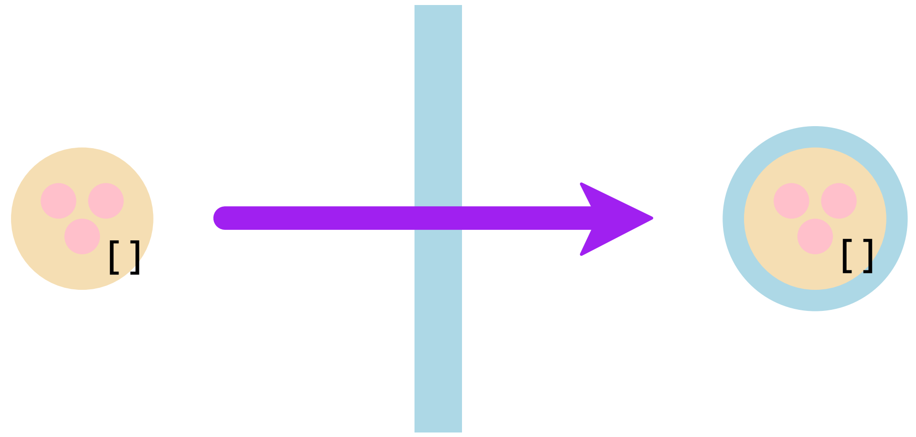
Implementing Contracts



```
(list identity
      sqr
      sqrt)
```

```
(map
 (lambda (transform)
   (lambda (x)
     (unless (nonnegative-real? x)
       (contract-failure))
     (let ([v (transform x)])
       (unless (nonnegative-real? v)
         (contract-failure))
      v)))
 (list identity
       sqr
       sqrt))
```

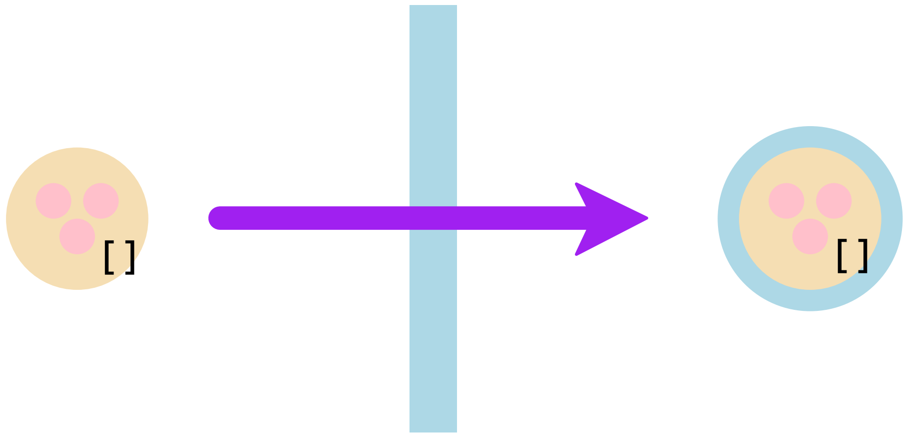
Implementing Contracts



```
(vector 0.1
        0.4
        7.9)
```

```
??? (vector 0.1
            0.4
            7.9)
```

Implementing Contracts



```
(vector 0.1
        0.4
        7.9)
```

$\longrightarrow$

```
??? (vector 0.1
            0.4
            7.9)
```

need a `???` that works with all vector operations

Implementing Contracts

Before adding run-time support:

	flat contracts	higher-order contracts
procedures	✓	✓
immutable data	✓	✓
mutable data	~	✗
opaque structures	~	✗
objects	✓*	✓*

* all objects incur cost

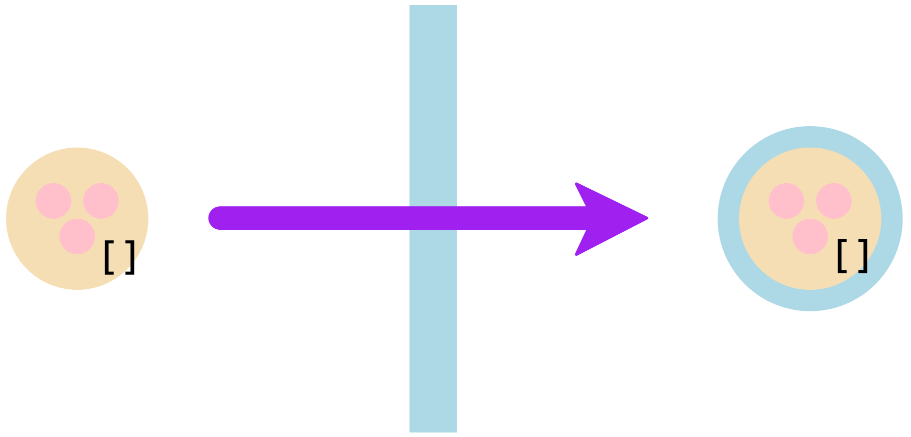
Implementing Contracts

After adding run-time support:

	flat contracts	chaperone contracts	impersonator contracts
procedures	✓	✓	✓
immutable data	✓	✓	✗*
mutable data	✓	✓	✓
opaque structures	✓	✓	✗*
objects	✓	✓	✓

* not sensible

Implementing Contracts



```
(vector 0.1
        0.4
        7.9)
```

```
??? (vector 0.1
            0.4
            7.9)
```

need a ??? that works with all vector operations

Implementing Contracts

- **Proxies**
    - *Proxies: Design Principles for Robust Object-oriented Intercession APIs*, Van Cutsem and Miller, DLS'10
- **Aspects**
    - *Harmless Advice*, Dantas and Walker, POPL'06

Implementing Contracts

- ▶ **Proxies**
  - *Proxies: Design Principles for Robust Object-oriented Intercession APIs*, Van Cutsem and Miller, DLS'10
- **Aspects**
  - *Harmless Advice*, Dantas and Walker, POPL'06

Chaperones and Impersonators

Chaperone constructors:

```
(chaperone-procedure proc alt-apply)

(chaperone-vector vec alt-vec-ref alt-vec-set!)

(chaperone-struct struct
                  accessor alt-accessor ...
                  mutator alt-mutator ...)
```

Impersonator constructors:

```
(impersonate-procedure proc alt-apply)

(impersonate-vector vec alt-vec-ref alt-vec-set!)
```

mutable vectors only

```
(impersonate-struct struct
                    accessor alt-accessor ...
                    mutator alt-mutator ...)
```

mutable fields only

Chaperones and Im

Alternate arguments/results must chaperone originals

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Chaperones and Im

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                  mutator alt-m
```

Alternate arguments/results are unconstrained

Impersonator constructors:

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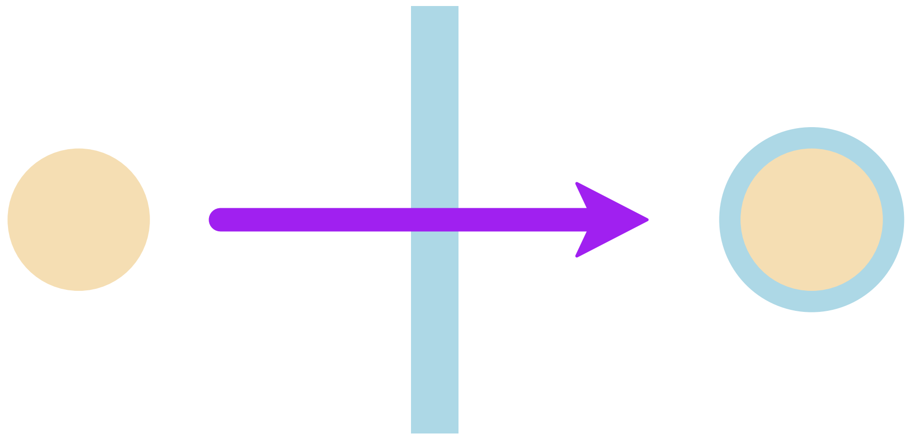
mutable fields only

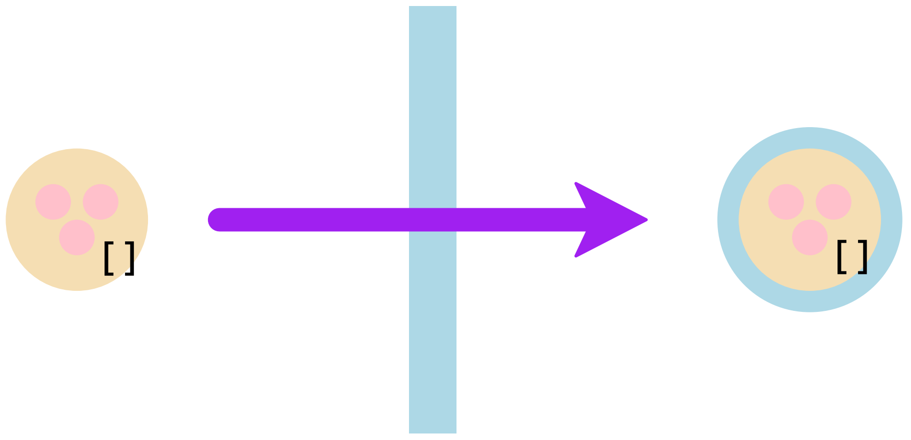
Chaperones and Impersonators



```
(λ (x) (* x x))
```

```
(chaperone-procedure
 (λ (x) (* x x))
 (lambda (x)
   (unless (real? x)
     (contract-failure))
   (values
    x
    (lambda (v)
      (unless (nonnegative-real? v)
        (contract-failure))
     v))))
```

Chaperones and Impersonators

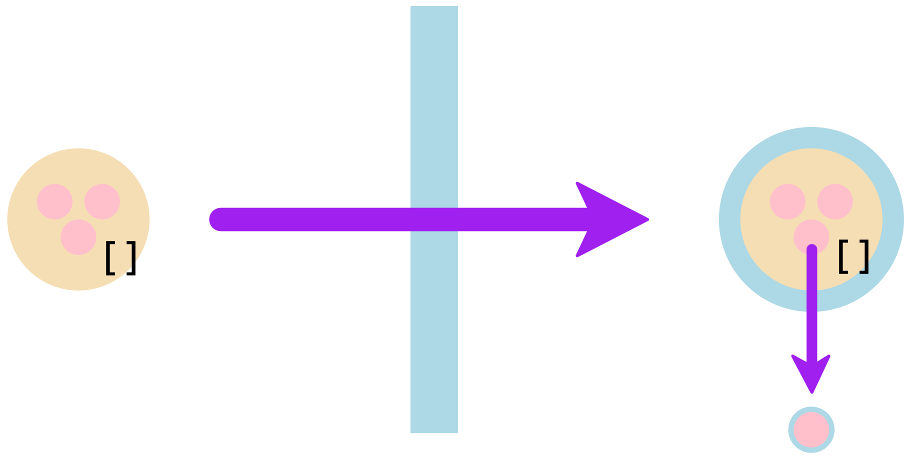


```
(vector 0.1
        0.4
        7.9)
```

→

```
(chaperone-vector
 (vector 0.1
         0.4
         7.9)
 (lambda (vec i val) ; ref
   (unless (nonnegative-real? val)
     (contract-failure))
   val)
 (lambda (vec i val) ; set
   (unless (nonnegative-real? val)
     (contract-failure))
   val))
```

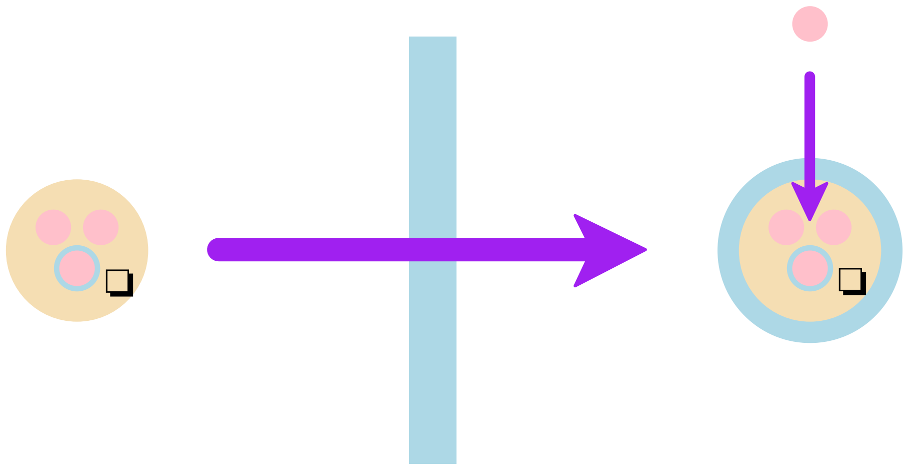
Chaperones and Impersonators



```
(vector identity
        sqr
        sqrt)
```

```
(chaperone-vector
 (vector identity sqr sqrt)
 (lambda (vec i val)
   (unless (procedure? val)
     (contract-failure))
   (chaperone-procedure
    val
    (lambda (x)
      (unless (nonnegative-real? x)
        (contract-failure))
      ....)))
 ....)
```

Chaperones and Impersonators



```
(make-widget parent label
             callback)
```

```
(chaperone-struct
 (make-widget parent label
              callback)
 widget-parent
 (lambda (w val)
   (unless (gl-window? val)
     (contract-failure))
   val)
 set-widget-callback!
 (lambda (w val)
   (chaperone-procedure
    val ....)))
```

Results

	flat contracts	chaperone contracts	impersonator contracts
procedures	✓	✓	✓
immutable data	✓	✓	✗*
mutable data	✓	✓	✓
opaque structures	✓	✓	✗*
objects	✓	✓	✓

* not sensible

Results

	flat contracts	chaperone contracts	impersonator contracts
procedures	✓	✓	✓
immutabl			✗*
mutable data	✓	✓	✓
opaque structures	✓	✓	✗*
objects	✓	✓	✓

1. Closes known holes in Typed Racket

* not sensible

Results

	flat contracts	chaperone contracts	impersonator contracts
procedures	✓	✓	✓
immutable data	✓	✓	✗*
mutable data	✓	✓	✓
opaque structu			
objects	✓	✓	✓

2. Object contracts supported without penalty

* not sensible

Results

	flat contracts	chaperone con acts	impersonator contracts
proce			
immutable			
mutable data	✓	✓	✓
opaque structures	✓	✓	✗*
objects	✓	✓	✓

3. Claim:

No failures in chaperones ⇒

erasing chaperones produces the same result

* not sensible

Results

	flat contracts	chaperone contracts	impersonator contracts
procedures	✓	✓	✓
immutable data	✓	✓	✗*
mutable data	✓	✓	✓
opaque structures	✓	✓	✗*
objects	✓	✓	✓

* not sensible