Optimization Coaching

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PLT

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```
#lang typed/racket/base
(require racket/match racket/math racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         "flonum.rkt"
         "flomap-struct.rkt")
(provide flomap-flip-horizontal flomap-flip-vertical flomap-transpose
         flomap-cw-rotate flomap-ccw-rotate
         (struct-out invertible-2d-function) Flomap-Transform
         transform-compose rotate-transform whirl-and-pinch-transform
         flomap-transform)
(: flomap-flip-horizontal (flomap -> flomap))
(define (flomap-flip-horizontal fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- w-1 x) y)))))
(define (flomap-flip-vertical fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k x (fx- h-1 y))))))
(define (flomap-transpose fm)
  (match-define (flomap vs c w h) fm)
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y x)))))
(define (flomap-cw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- h-1 y) x)))))
(define (flomap-ccw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y (fx- w-1 x))))))
(struct: invertible-2d-function ([f : (Flonum Flonum -> (values Flonum Flonum))]
                                 [g : (Flonum Flonum -> (values Flonum Flonum))]))
(define-type Flomap-Transform (Integer Integer -> invertible-2d-function))
(: transform-compose (Flomap-Transform Flomap-Transform -> Flomap-Transform))
(define ((transform-compose t1 t2) w h)
  (match-define (invertible-2d-function f1 g1) (t1 w h))
  (match-define (invertible-2d-function f2 g2) (t2 w h))
  (invertible-2d-function (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (f2 x y)])
                              (f1 x y)))
                          (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (g1 x y)])
                              (g2 x y)))))
(: flomap-transform (case-> (flomap Flomap-Transform -> flomap)
                            (flomap Flomap-Transform Real Real Real Real -> flomap)))
(define flomap-transform
  (case-lambda
    [(fm t)
     (match-define (flomap vs c w h) fm)
     (match-define (invertible-2d-function f g) (t w h))
     (define x-min +inf.0)
     (define x-max -inf.0)
     (define y-min +inf.0)
     (define y-max -inf.0)
     (let: y-loop : Void ([y : Integer  0])
       (when (y . fx< . h)
         (let: x-loop : Void ([x : Integer  0])
           (cond [(x . fx< . w)
                  (define-values (new-x new-y) (f (+ 0.5 (fx->fl x)) (+ 0.5 (fx->fl y))))
                  (when (new-x . < . x-min) (set! x-min new-x))
                  (when (new-x . > . x-max) (set! x-max new-x))
                  (when (new-y . < . y-min) (set! y-min new-y))
                  (when (new-y . > . y-max) (set! y-max new-y))
                  (x-loop (fx+ x 1))]
                 [else
                  (y-loop (fx+ y 1))])))))
     (flomap-transform fm t x-min x-max y-min y-max)]
    [(fm t x-min x-max y-min y-max)
     (let ([x-min  (real->double-flonum x-min)]
           [x-max  (real->double-flonum x-max)]
           [y-min  (real->double-flonum y-min)]
           [y-max  (real->double-flonum y-max)])
       (match-define (flomap vs c w h) fm)
       (match-define (invertible-2d-function f g) (t w h))
       (define int-x-min (fl->fx (floor x-min)))
       (define int-x-max (fl->fx (ceiling x-max)))
       (define int-y-min (fl->fx (floor y-min)))
       (define int-y-max (fl->fx (ceiling y-max)))
       (define new-w (- int-x-max int-x-min))
       (define new-h (- int-y-max int-y-min))
       (define x-offset (+ 0.5 (fx->fl int-x-min)))
       (define y-offset (+ 0.5 (fx->fl int-y-min)))
       (inline-build-flomap
        c new-w new-h
        (λ (k x y i)
          (define-values (old-x old-y) (g (+ (fx->fl x) x-offset)
                                          (+ (fx->fl y) y-offset)))
          (flomap-bilinear-ref fm k old-x old-y)))))]))
```

```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         racket/match racket/math
         "flonum.rkt"
         "flomap-struct.rkt"
         "flomap-stats.rkt")
(provide flomap-lift flomap-lift2 flomap-lift-helper flomap-lift-helper2
         fmneg fmabs fmsqr fmsin fmcos fmtan fmlog fmexp fmsqrt fmasin fmacos fmatan
         fmround fmfloor fmceiling fmtruncate fmzero
         fm+ fm- fm* fm/ fmmin fmmax
         flomap-normalize flomap-multiply-alpha flomap-divide-alpha)
; ============================================================================================
; Unary
(: flomap-lift-helper : (Float -> Float) -> (flomap -> flomap))
(define (flomap-lift-helper f)
  (λ: ([fm : flomap])
    (match-define (flomap vs c w h) fm)
    (flomap (inline-build-flvector (* c w h) (λ (i) (f (unsafe-flvector-ref vs i))))
            c w h)))
(: flomap-lift ((Flonum -> Real) -> (flomap -> flomap)))
(define (flomap-lift op)
  (flomap-lift-helper (λ (x) (real->double-flonum (op x)))))
(define fmneg (flomap-lift-helper -))
(define fmabs (flomap-lift-helper abs))
(define fmsqr (flomap-lift-helper sqr))
(define fmsin (flomap-lift-helper sin))
(define fmcos (flomap-lift-helper cos))
(define fmtan (flomap-lift-helper tan))
(define fmlog (flomap-lift-helper fllog))
(define fmexp (flomap-lift-helper exp))
(define fmsqrt (flomap-lift-helper flsqrt))
(define fmasin (flomap-lift-helper asin))
(define fmacos (flomap-lift-helper acos))
(define fmatan (flomap-lift-helper atan))
(define fmround (flomap-lift-helper round))
(define fmfloor (flomap-lift-helper floor))
(define fmceiling (flomap-lift-helper ceiling))
(define fmtruncate (flomap-lift-helper truncate))
(define fmzero (flomap-lift-helper (λ (x) (if (x . = . 0.0) 1.0 0.0))))
; ;; ============================================================================================
; Binary
(: flomap-lift-helper2 : Symbol (Float Float -> Float) -> ((U Real flomap) (U Real flomap) -> flomap))
(define (flomap-lift-helper2 name f)
  (let: ()
    (λ: ([fm1 : (U Real flomap)] [fm2 : (U Real flomap)])
      (cond
        [(and (real? fm1) (real? fm2))
         (error name "expected at least one flomap argument; given ~e and ~e" fm1 fm2)]
        [(real? fm1)  (let ([fm1  (real->double-flonum fm1)])
                        ((flomap-lift-helper (λ (v) (f fm1 v))) fm2))]
        [(real? fm2)  (let ([fm2  (real->double-flonum fm2)])
                        ((flomap-lift-helper (λ (v) (f v fm2))) fm1))]
        [else
         (match-define (flomap vs1 c1 w h) fm1)
         (match-define (flomap vs2 c2 w2 h2) fm2)
         (cond
           [(not (and (= w w2) (= h h2)))
            (error name "expected same-size flomaps; given sizes ~ex~e and ~ex~e" w h w2 h2)]
           [(= c1 c2)  (define n (* c1 w h))
                       (define res-vs (make-flvector n))
                       (flomap (inline-build-flvector n (λ (i) (f (unsafe-flvector-ref vs1 i)
                                                                  (unsafe-flvector-ref vs2 i))))
                               c1 w h)]
           [(= c1 1)  (inline-build-flomap
                       c2 w h
                       (λ (k x y i) (f (unsafe-flvector-ref vs1 (coords->index 1 w 0 x y))
                                       (unsafe-flvector-ref vs2 i))))]
           [(= c2 1)  (inline-build-flomap
                       c1 w h
                       (λ (k x y i) (f (unsafe-flvector-ref vs1 i)
                                       (unsafe-flvector-ref vs2 (coords->index 1 w 0 x y)))))]
           [else
            (error name (string-append "expected flomaps with the same number of components, "
                                       "or a flomap with 1 component and any same-size flomap; "
                                       "given flomaps with ~e and ~e components")
                   c1 c2)])])))))
(: flomap-lift2 (Symbol (Flonum Flonum -> Real) -> ((U Real flomap) (U Real flomap) -> flomap)))
(define (flomap-lift2 name f)
  (flomap-lift-helper2 name (λ (x y) (real->double-flonum (f x y)))))
(define fm+ (flomap-lift-helper2 'fm+ +))
(define fm- (flomap-lift-helper2 'fm- -))
(define fm* (flomap-lift-helper2 'fm* *))
(define fm/ (flomap-lift-helper2 'fm/ /))
(define fmmin (flomap-lift-helper2 'fmmin min))
(define fmmax (flomap-lift-helper2 'fmmax max))
(: flomap-normalize (flomap -> flomap))
(define (flomap-normalize fm)
  (define-values (v-min v-max) (flomap-extreme-values fm))
  (define v-size (- v-max v-min))
  (let* ([fm  (fm- fm v-min)]
         [fm  (if (v-size . = . 0.0) fm (fm/ fm v-size))])
    fm))
(define fmdiv/zero
  (flomap-lift-helper2 'fmdiv/zero (λ (x y) (if (y . = . 0.0) 0.0 (/ x y)))))
(: flomap-divide-alpha (flomap -> flomap))
(define (flomap-divide-alpha fm)
  (match-define (flomap _ c w h) fm)
  (cond [(c . <= . 1)  fm]
        [else
         (define alpha-fm (flomap-ref-component fm 0))
         (flomap-append-components alpha-fm (fmdiv/zero (flomap-drop-components fm 1) alpha-fm))]))
```

```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fx->fl fl->fx)
         racket/match racket/math
         "flonum.rkt"
         "flomap.rkt")
(provide deep-flomap deep-flomap? deep-flomap-argb deep-flomap-z
         deep-flomap-width deep-flomap-height deep-flomap-z-min deep-flomap-z-max
         deep-flomap-size deep-flomap-alpha deep-flomap-rgb
         flomap->deep-flomap
         ; Sizing
         deep-flomap-inset deep-flomap-trim deep-flomap-scale deep-flomap-resize
         ; Z-adjusting
         deep-flomap-scale-z deep-flomap-smooth-z deep-flomap-raise deep-flomap-tilt
         deep-flomap-emboss
         deep-flomap-bulge deep-flomap-bulge-round deep-flomap-bulge-round-rect
         deep-flomap-bulge-spheroid deep-flomap-bulge-horizontal deep-flomap-bulge-vertical
         deep-flomap-bulge-ripple
         ; Compositing
         deep-flomap-pin deep-flomap-pin*
         deep-flomap-lt-superimpose deep-flomap-lc-superimpose deep-flomap-lb-superimpose
         deep-flomap-ct-superimpose deep-flomap-cc-superimpose deep-flomap-cb-superimpose
         deep-flomap-rt-superimpose deep-flomap-rc-superimpose deep-flomap-rb-superimpose
         deep-flomap-vl-append deep-flomap-vc-append deep-flomap-vr-append
         deep-flomap-ht-append deep-flomap-hc-append deep-flomap-hb-append)
(struct: deep-flomap ([argb : flomap] [z : flomap])
  #:transparent
  #:guard
  (λ (argb-fm z-fm name)
    (match-define (flomap _ 4 w h) argb-fm)
    (match-define (flomap _ 1 zw zh) z-fm)
    (unless (and (= w zw) (= h zh))
      (error 'deep-flomap
             "expected flomaps of equal dimension; given dimensions ~ex~e and ~ex~e" w h zw zh))
    (values argb-fm z-fm)))
(: flomap->deep-flomap (flomap -> deep-flomap))
(define (flomap->deep-flomap argb-fm)
  (match-define (flomap _ 4 w h) argb-fm)
  (deep-flomap argb-fm (make-flomap 1 w h)))
(: deep-flomap-width (deep-flomap -> Nonnegative-Fixnum))
(define (deep-flomap-width dfm)
  (define w (flomap-width (deep-flomap-argb dfm)))
  (with-asserts ([w  nonnegative-fixnum?])
    w))
(: deep-flomap-height (deep-flomap -> Nonnegative-Fixnum))
(define (deep-flomap-height dfm)
  (define h (flomap-height (deep-flomap-argb dfm)))
  (with-asserts ([h  nonnegative-fixnum?])
    h))
(: deep-flomap-z-min (deep-flomap -> Flonum))
(define (deep-flomap-z-min dfm)
  (flomap-min-value (deep-flomap-z dfm)))
(: deep-flomap-z-max (deep-flomap -> Flonum))
(define (deep-flomap-z-max dfm)
  (flomap-max-value (deep-flomap-z dfm)))
(: deep-flomap-size (deep-flomap -> (values Nonnegative-Fixnum Nonnegative-Fixnum)))
(define (deep-flomap-size dfm)
  (values (deep-flomap-width dfm) (deep-flomap-height dfm)))
(: deep-flomap-alpha (deep-flomap -> flomap))
(define (deep-flomap-alpha dfm)
  (flomap-ref-component (deep-flomap-argb dfm) 0))
(: deep-flomap-rgb (deep-flomap -> flomap))
(define (deep-flomap-rgb dfm)
  (flomap-drop-components (deep-flomap-argb dfm) 1))
; ============================================================================================
; Z adjusters
(: deep-flomap-scale-z (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-scale-z dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (deep-flomap argb-fm (fm* z-fm z)))
(: deep-flomap-smooth-z (deep-flomap Real -> deep-flomap))
(define (deep-flomap-smooth-z dfm σ)
  (let ([σ  (exact->inexact σ)])
    (match-define (deep-flomap argb-fm z-fm) dfm)
    (define new-z-fm (flomap-blur z-fm σ))
    (deep-flomap argb-fm new-z-fm)))
; deep-flomap-raise and everything derived from it observe an invariant:
; when z is added, added z must be 0.0 everywhere alpha is 0.0
(: deep-flomap-raise (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-raise dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (define alpha-fm (deep-flomap-alpha dfm))
  (deep-flomap argb-fm (fm+ z-fm (fm* alpha-fm z))))
(: deep-flomap-emboss (deep-flomap Real (U Real flomap) -> deep-flomap))
(define (deep-flomap-emboss dfm xy-amt z-amt)
  (let ([σ       (/ xy-amt 3.0)])
    (define z-fm (flomap-normalize (deep-flomap-alpha dfm)))
    (define new-z-fm (fm* (flomap-blur z-fm σ) z-amt))
    (deep-flomap-raise dfm new-z-fm)))
(: deep-flomap-bulge-helper (deep-flomap (Flonum Flonum -> Flonum) -> deep-flomap))
(define (deep-flomap-bulge-helper dfm f)
  (let ()
    (define-values (w h) (deep-flomap-size dfm))
    (define half-x-size (- (* 0.5 (fx->fl w)) 0.5))
    (define half-y-size (- (* 0.5 (fx->fl h)) 0.5))
    (define z-fm
      (inline-build-flomap
       1 w h
       (λ (_ x y i)
         (f (- (/ (fx->fl x) half-x-size) 1.0)
            (- (/ (fx->fl y) half-y-size) 1.0)))))
    (deep-flomap-raise dfm z-fm)))
(: deep-flomap-bulge (deep-flomap (Flonum Flonum -> Real) -> deep-flomap))
(define (deep-flomap-bulge dfm f)
  (deep-flomap-bulge-helper dfm (λ (cx cy) (real->double-flonum (f cx cy)))))
```


It renders text, too!

```
#lang typed/racket/base
(require racket/match racket/math racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         "flonum.rkt"
         "flomap-struct.rkt")
(provide flomap-flip-horizontal flomap-flip-vertical flomap-transpose
         flomap-cw-rotate flomap-ccw-rotate
         (struct-out invertible-2d-function) Flomap-Transform
         transform-compose rotate-transform whirl-and-pinch-transform
         flomap-transform)
(: flomap-flip-horizontal (flomap -> flomap))
(define (flomap-flip-horizontal fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- w-1 x) y)))))
(define (flomap-flip-vertical fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k x (fx- h-1 y))))))
(define (flomap-transpose fm)
  (match-define (flomap vs c w h) fm)
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y x)))))
(define (flomap-cw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- h-1 y) x)))))
(define (flomap-ccw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y (fx- w-1 x))))))
(struct: invertible-2d-function ([f : (Flonum Flonum -> (values Flonum Flonum))]
                                 [g : (Flonum Flonum -> (values Flonum Flonum))]))
(define-type Flomap-Transform (Integer Integer -> invertible-2d-function))
(: transform-compose (Flomap-Transform Flomap-Transform -> Flomap-Transform))
(define ((transform-compose t1 t2) w h)
  (match-define (invertible-2d-function f1 g1) (t1 w h))
  (match-define (invertible-2d-function f2 g2) (t2 w h))
  (invertible-2d-function (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (f2 x y)])
                              (f1 x y)))
                          (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (g1 x y)])
                              (g2 x y)))))
(: flomap-transform (case-> (flomap Flomap-Transform -> flomap)
                            (flomap Flomap-Transform Real Real Real Real -> flomap
(define flomap-transform
  (case-lambda
    [(fm t)
     (match-define (flomap vs c w h) fm)
     (match-define (invertible-2d-function f g) (t w h))
     (define x-min +inf.0)
     (define x-max -inf.0)
     (define y-min +inf.0)
     (define y-max -inf.0)
     (let: y-loop : Void ([y : Integer  0])
       (when (y . fx< . h)
         (let: x-loop : Void ([x : Integer  0])
           (cond [(x . fx< . w)
                  (define-values (new-x new-y) (f (+ 0.5 (fx->fl x)) (+ 0.5 (fx->f
                  (when (new-x . < . x-min) (set! x-min new-x))
                  (when (new-x . > . x-max) (set! x-max new-x))
                  (when (new-y . < . y-min) (set! y-min new-y))
                  (when (new-y . > . y-max) (set! y-max new-y))
                  (x-loop (fx+ x 1))]
                 [else
                  (y-loop (fx+ y 1))])))))
     (flomap-transform fm t x-min x-max y-min y-max)]
    [(fm t x-min x-max y-min y-max)
     (let ([x-min  (real->double-flonum x-min)]
           [x-max  (real->double-flonum x-max)]
           [y-min  (real->double-flonum y-min)]
           [y-max  (real->double-flonum y-max)])
       (match-define (flomap vs c w h) fm)
       (match-define (invertible-2d-function f g) (t w h))
       (define int-x-min (fl->fx (floor x-min)))
       (define int-x-max (fl->fx (ceiling x-max)))
       (define int-y-min (fl->fx (floor y-min)))
       (define int-y-max (fl->fx (ceiling y-max)))
       (define new-w (- int-x-max int-x-min))
       (define new-h (- int-y-max int-y-min))
       (define x-offset (+ 0.5 (fx->fl int-x-min)))
       (define y-offset (+ 0.5 (fx->fl int-y-min)))
       (inline-build-flomap
        c new-w new-h
        (λ (k x y i)
          (define-values (old-x old-y) (g (+ (fx->fl x) x-offset)
                                          (+ (fx->fl y) y-offset)))
          (flomap-bilinear-ref fm k old-x old-y)))))]))
```

```
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(require racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         racket/match racket/math
         "flonum.rkt"
         "flomap-struct.rkt"
         "flomap-stats.rkt")
(provide flomap-lift flomap-lift2 flomap-lift-helper flomap-lift-helper2
         fmneg fmabs fmsqr fmsin fmcos fmtan fmlog fmexp fmsqrt fmasin fmacos fmatan
         fmround fmfloor fmceiling fmtruncate fmzero
         fm+ fm- fm* fm/ fmmin fmmax
         flomap-normalize flomap-multiply-alpha flomap-divide-alpha)
; ============================================================================================
; Unary
(: flomap-lift-helper : (Float -> Float) -> (flomap -> flomap))
(define (flomap-lift-helper f)
  (λ: ([fm : flomap])
    (match-define (flomap vs c w h) fm)
    (flomap (inline-build-flvector (* c w h) (λ (i) (f (unsafe-flvector-ref vs i))))
            c w h)))
(: flomap-lift ((Flonum -> Real) -> (flomap -> flomap)))
(define (flomap-lift op)
  (flomap-lift-helper (λ (x) (real->double-flonum (op x)))))
(define fmneg (flomap-lift-helper -))
(define fmabs (flomap-lift-helper abs))
(define fmsqr (flomap-lift-helper sqr))
(define fmsin (flomap-lift-helper sin))
(define fmcos (flomap-lift-helper cos))
(define fmtan (flomap-lift-helper tan))
(define fmlog (flomap-lift-helper fllog))
(define fmexp (flomap-lift-helper exp))
(define fmsqrt (flomap-lift-helper flsqrt))
(define fmasin (flomap-lift-helper asin))
(define fmacos (flomap-lift-helper acos))
(define fmatan (flomap-lift-helper atan))
(define fmround (flomap-lift-helper round))
(define fmfloor (flomap-lift-helper floor))
(define fmceiling (flomap-lift-helper ceiling))
```

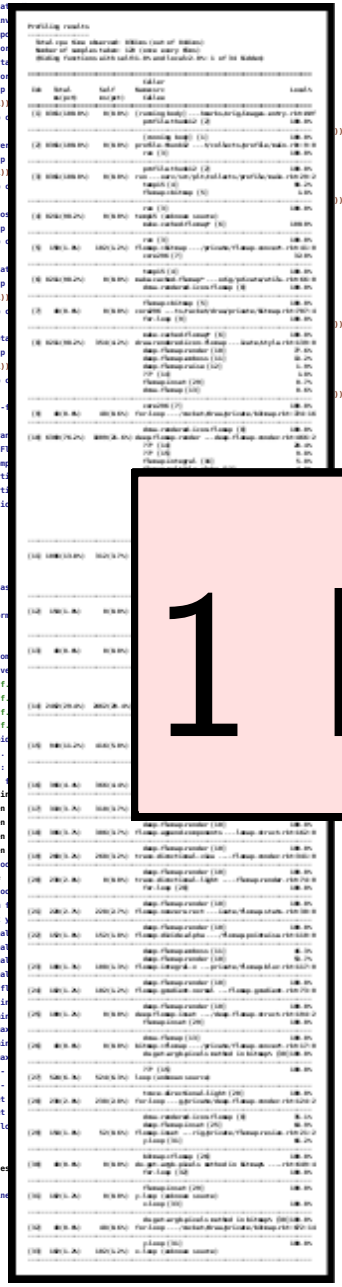
```
                                (unsafe-flvector-ref vs2 i))))]
      [(= c2 1)  (inline-build-flomap
                  c1 w h
                  (λ (k x y i) (f (unsafe-flvector-ref vs1 i)
                                  (unsafe-flvector-ref vs2 (coords->index 1 w 0 x y)))))]
      [else
       (error name (string-append "expected flomaps with the same number of components, "
                                  "or a flomap with 1 component and any same-size flomap; "
                                  "given flomaps with ~e and ~e components")
              c1 c2)])))))
(: flomap-lift2 (Symbol (Flonum Flonum -> Real) -> ((U Real flomap) (U Real flomap) -> flomap)))
(define (flomap-lift2 name f)
  (flomap-lift-helper2 name (λ (x y) (real->double-flonum (f x y)))))
(define fm+ (flomap-lift-helper2 'fm+ +))
(define fm- (flomap-lift-helper2 'fm- -))
(define fm* (flomap-lift-helper2 'fm* *))
(define fm/ (flomap-lift-helper2 'fm/ /))
(define fmmin (flomap-lift-helper2 'fmmin min))
(define fmmax (flomap-lift-helper2 'fmmax max))
(: flomap-normalize (flomap -> flomap))
(define (flomap-normalize fm)
  (define-values (v-min v-max) (flomap-extreme-values fm))
  (define v-size (- v-max v-min))
  (let* ([fm  (fm- fm v-min)]
         [fm  (if (v-size . = . 0.0) fm (fm/ fm v-size))])
    fm))
(define fmdiv/zero
  (flomap-lift-helper2 'fmdiv/zero (λ (x y) (if (y . = . 0.0) 0.0 (/ x y)))))
(: flomap-divide-alpha (flomap -> flomap))
(define (flomap-divide-alpha fm)
  (match-define (flomap _ c w h) fm)
  (cond [(c . <= . 1)  fm]
        [else
         (define alpha-fm (flomap-ref-component fm 0))
         (flomap-append-components alpha-fm (fmdiv/zero (flomap-drop-components fm 1) alpha-fm))]))
```

```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fx->fl fl->fx)
         racket/match racket/math
         "flonum.rkt"
         "flomap.rkt")
(provide deep-flomap deep-flomap? deep-flomap-argb deep-flomap-z
         deep-flomap-width deep-flomap-height deep-flomap-z-min deep-flomap-z-max
         deep-flomap-size deep-flomap-alpha deep-flomap-rgb
         flomap->deep-flomap
         ; Sizing
         deep-flomap-inset deep-flomap-trim deep-flomap-scale deep-flomap-resize
         ; Z-adjusting
         deep-flomap-scale-z deep-flomap-smooth-z deep-flomap-raise deep-flomap-tilt
         deep-flomap-emboss
         deep-flomap-bulge deep-flomap-bulge-round deep-flomap-bulge-round-rect
         deep-flomap-bulge-spheroid deep-flomap-bulge-horizontal deep-flomap-bulge-vertical
         deep-flomap-bulge-ripple
         ; Compositing
         deep-flomap-pin deep-flomap-pin*
         deep-flomap-lt-superimpose deep-flomap-lc-superimpose deep-flomap-lb-superimpose
         deep-flomap-ct-superimpose deep-flomap-cc-superimpose deep-flomap-cb-superimpose
         deep-flomap-rt-superimpose deep-flomap-rc-superimpose deep-flomap-rb-superimpose
         deep-flomap-vl-append deep-flomap-vc-append deep-flomap-vr-append
         deep-flomap-ht-append deep-flomap-hc-append deep-flomap-hb-append)
(struct: deep-flomap ([argb : flomap] [z : flomap])
  #:transparent
  #:guard
  (λ (argb-fm z-fm name)
    (match-define (flomap _ 4 w h) argb-fm)
    (match-define (flomap _ 1 zw zh) z-fm)
    (unless (and (= w zw) (= h zh))
      (error 'deep-flomap
             "expected flomaps of equal dimension; given dimensions ~ex~e and ~ex~e" w h zw zh))
    (values argb-fm z-fm)))
(: flomap->deep-flomap (flomap -> deep-flomap))
(define (flomap->deep-flomap argb-fm)
  (match-define (flomap _ 4 w h) argb-fm)
                -fm (make-flomap 1 w h)))
                h (deep-flomap -> Nonnegative-Fixnum))
                p-width dfm)
                -width (deep-flomap-argb dfm)))
                  nonnegative-fixnum?])

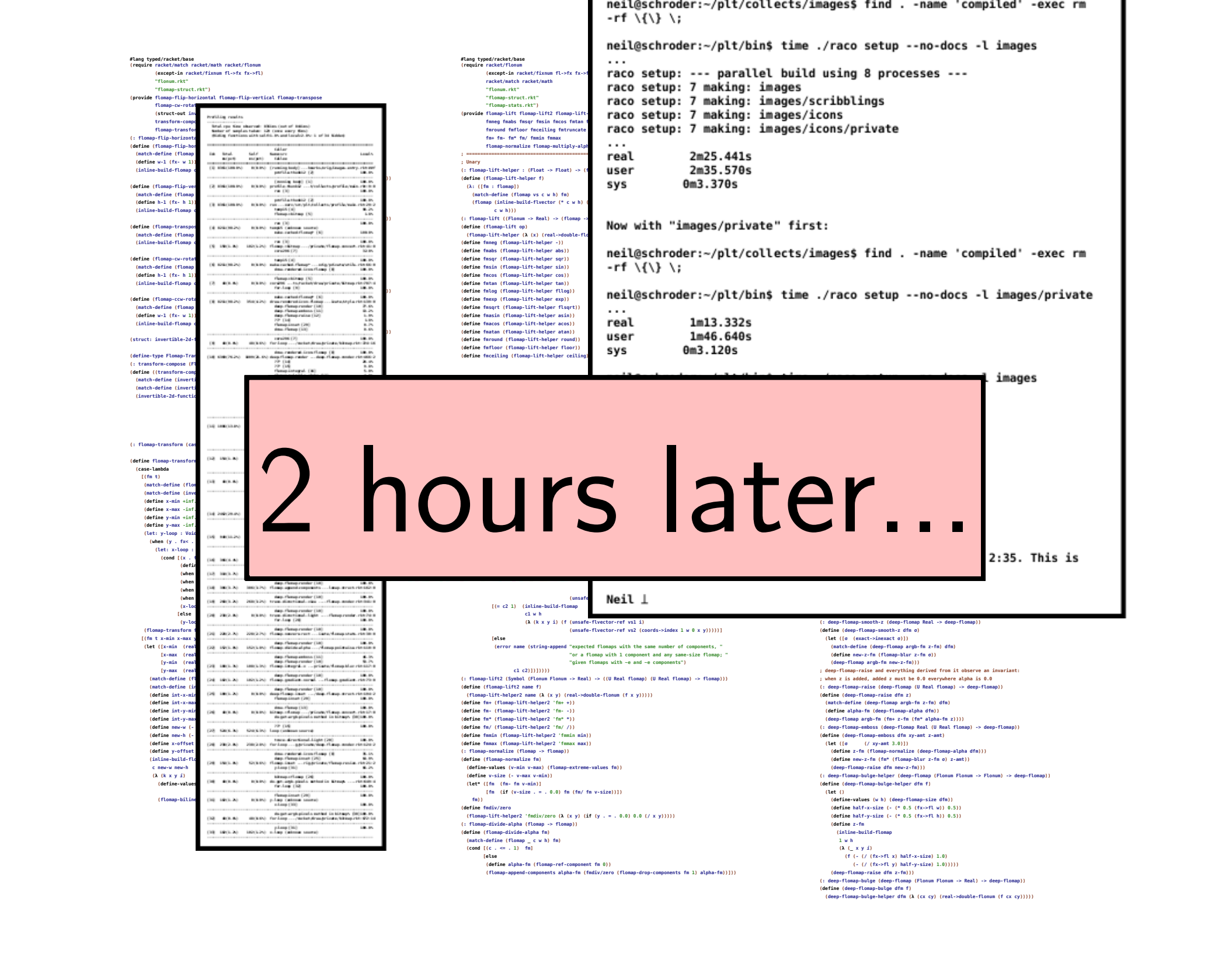
                ht (deep-flomap -> Nonnegative-Fixnum))
                p-height dfm)
                -height (deep-flomap-argb dfm)))
                  nonnegative-fixnum?])

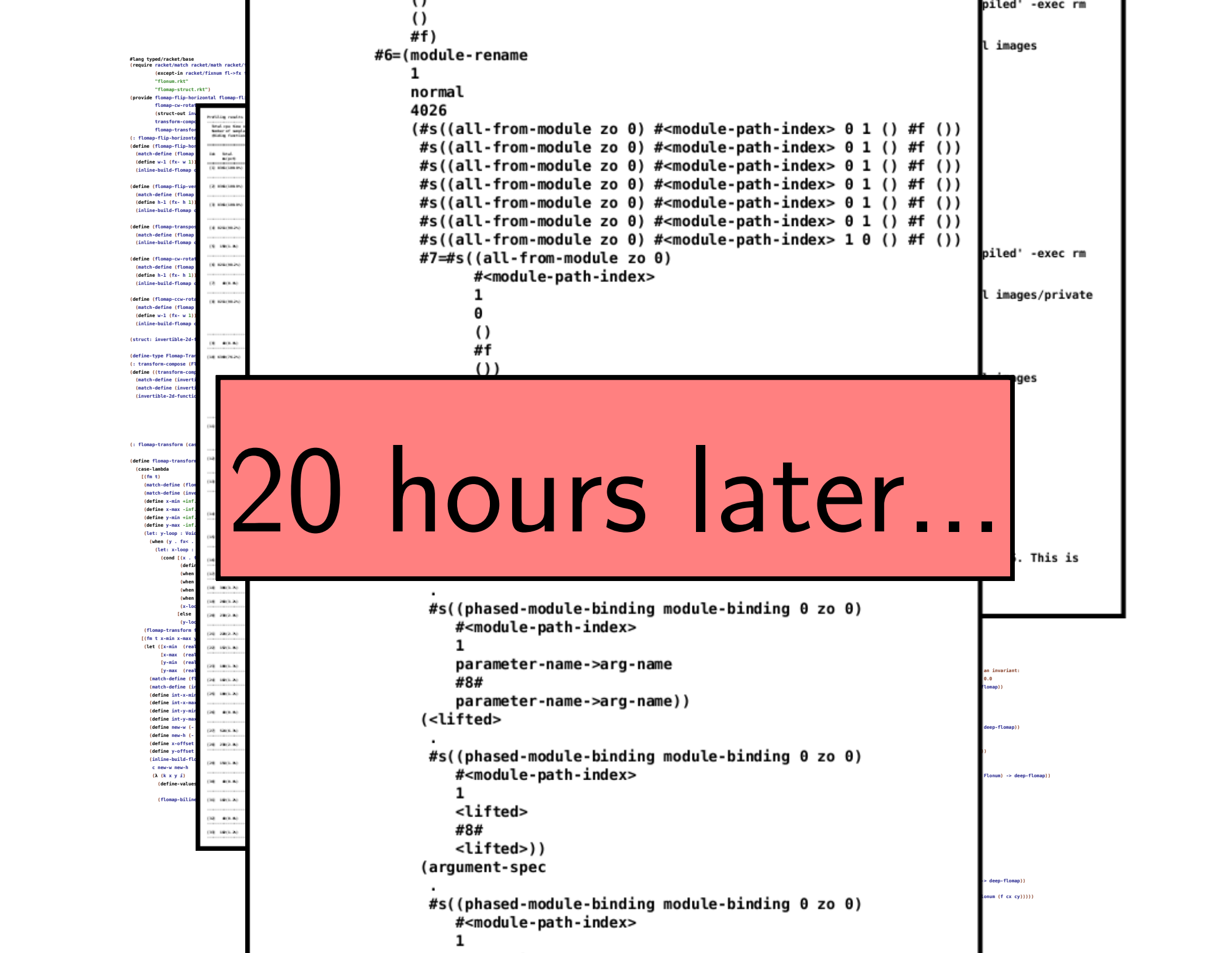
                n (deep-flomap -> Flonum))
                p-z-min dfm)
                 (deep-flomap-z dfm)))
                x (deep-flomap -> Flonum))
                p-z-max dfm)
                 (deep-flomap-z dfm)))
                 (deep-flomap -> (values Nonnegative-Fixnum Nonnegative-Fixnum)))
                p-size dfm)
                map-width dfm) (deep-flomap-height dfm)))
                a (deep-flomap -> flomap))
                p-alpha dfm)
                nent (deep-flomap-argb dfm) 0))
                (deep-flomap -> flomap))
                p-rgb dfm)
                onents (deep-flomap-argb dfm) 1))
                ================================================================================


                e-z (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-scale-z dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (deep-flomap argb-fm (fm* z-fm z)))
(: deep-flomap-smooth-z (deep-flomap Real -> deep-flomap))
(define (deep-flomap-smooth-z dfm σ)
  (let ([σ  (exact->inexact σ)])
    (match-define (deep-flomap argb-fm z-fm) dfm)
    (define new-z-fm (flomap-blur z-fm σ))
    (deep-flomap argb-fm new-z-fm)))
; deep-flomap-raise and everything derived from it observe an invariant:
; when z is added, added z must be 0.0 everywhere alpha is 0.0
(: deep-flomap-raise (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-raise dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (define alpha-fm (deep-flomap-alpha dfm))
  (deep-flomap argb-fm (fm+ z-fm (fm* alpha-fm z))))
(: deep-flomap-emboss (deep-flomap Real (U Real flomap) -> deep-flomap))
(define (deep-flomap-emboss dfm xy-amt z-amt)
  (let ([σ        (/ xy-amt 3.0)])
    (define z-fm (flomap-normalize (deep-flomap-alpha dfm)))
    (define new-z-fm (fm* (flomap-blur z-fm σ) z-amt))
    (deep-flomap-raise dfm new-z-fm)))
(: deep-flomap-bulge-helper (deep-flomap (Flonum Flonum -> Flonum) -> deep-flomap))
(define (deep-flomap-bulge-helper dfm f)
  (let ()
    (define-values (w h) (deep-flomap-size dfm))
    (define half-x-size (- (* 0.5 (fx->fl w)) 0.5))
    (define half-y-size (- (* 0.5 (fx->fl h)) 0.5))
    (define z-fm
      (inline-build-flomap
       1 w h
       (λ (_ x y i)
         (f (- (/ (fx->fl x) half-x-size) 1.0)
            (- (/ (fx->fl y) half-y-size) 1.0)))))
    (deep-flomap-raise dfm z-fm)))
(: deep-flomap-bulge (deep-flomap (Flonum Flonum -> Real) -> deep-flomap))
(define (deep-flomap-bulge dfm f)
  (deep-flomap-bulge-helper dfm (λ (cx cy) (real->double-flonum (f cx cy)))))
```



1 hour later...


neil@schroder:~/plt/collects/images$ find . -name 'compiled' -exec rm
-rf \{\} \;
neil@schroder:~/plt/bin$ time ./raco setup --no-docs -l images
...
raco setup: --- parallel build using 8 processes ---
raco setup: 7 making: images
raco setup: 7 making: images/scribblings
raco setup: 7 making: images/icons
raco setup: 7 making: images/icons/private
...
real 2m25.441s
user 2m35.570s
sys 0m3.370s
Now with "images/private" first:
neil@schroder:~/plt/collects/images$ find . -name 'compiled' -exec rm
-rf \{\} \;
neil@schroder:~/plt/bin$ time ./raco setup --no-docs -l images/private
...
real 1m13.332s
user 1m46.640s
sys 0m3.120s
2 hours later...
2:35. This is
Neil ⊥

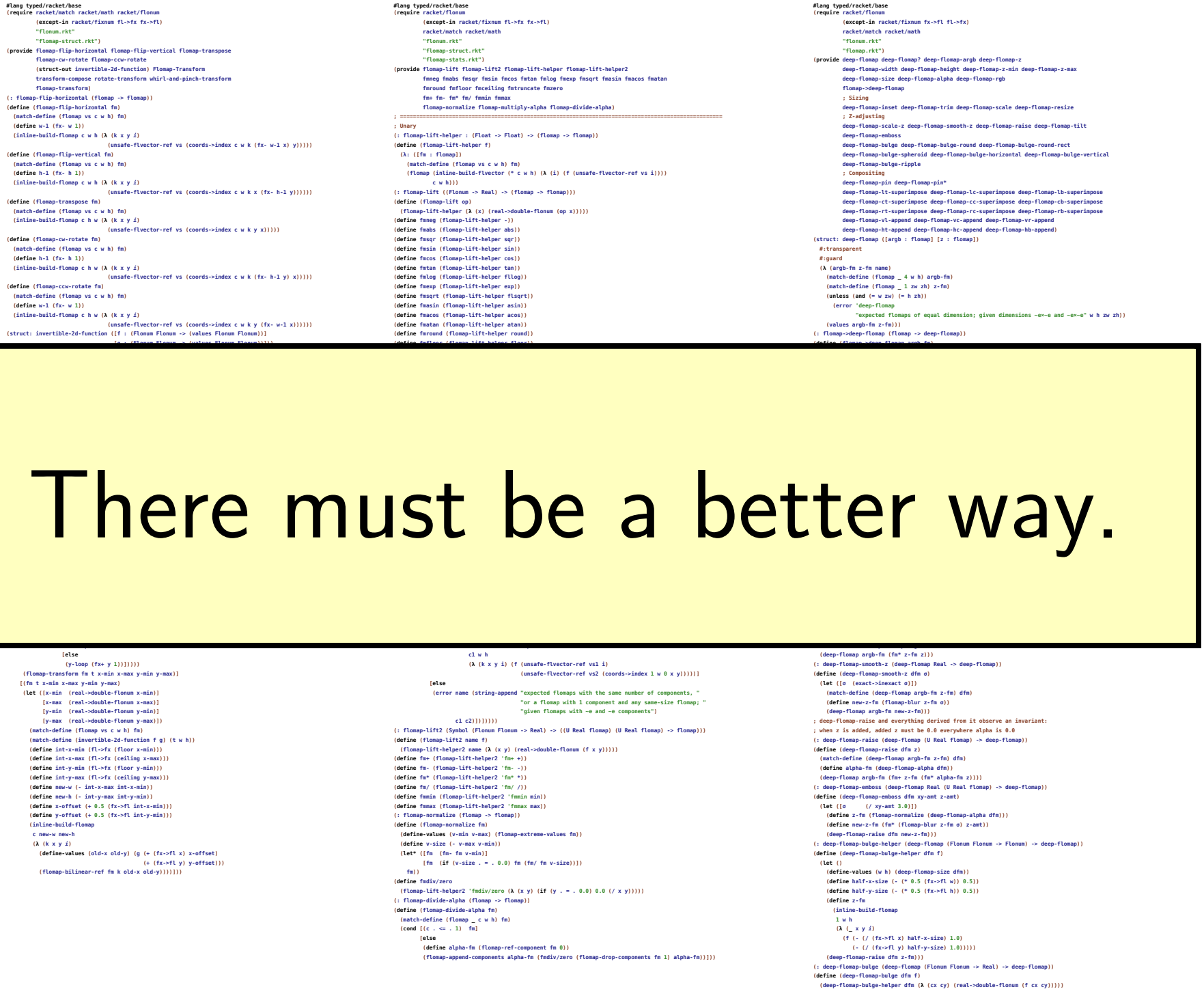

20 hours later...

```
#lang typed/racket/base
(require racket/match racket/math racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         "flonum.rkt"
         "flomap-struct.rkt")
(provide flomap-flip-horizontal flomap-flip-vertical flomap-transpose
         flomap-cw-rotate flomap-ccw-rotate
         (struct-out invertible-2d-function) Flomap-Transform
         transform-compose rotate-transform whirl-and-pinch-transform
         flomap-transform)
(: flomap-flip-horizontal (flomap -> flomap))
(define (flomap-flip-horizontal fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- w-1 x) y)))))
(define (flomap-flip-vertical fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k x (fx- h-1 y))))))
(define (flomap-transpose fm)
  (match-define (flomap vs c w h) fm)
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y x)))))
(define (flomap-cw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- h-1 y) x)))))
(define (flomap-ccw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y (fx- w-1 x))))))
(struct: invertible-2d-function ([f : (Flonum Flonum -> (values Flonum Flonum))]
                                 [g : (Flonum Flonum -> (values Flonum Flonum))]))
(define-type Flomap-Transform (Integer Integer -> invertible-2d-function))
(: transform-compose (Flomap-Transform Flomap-Transform -> Flomap-Transform))
(define ((transform-compose t1 t2) w h)
  (match-define (invertible-2d-function f1 g1) (t1 w h))
  (match-define (invertible-2d-function f2 g2) (t2 w h))
  (invertible-2d-function (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (f2 x y)])
                              (f1 x y)))
                          (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (g1 x y)])
                              (g2 x y)))))
(: flomap-transform (case-> (flomap Flomap-Transform -> flomap)
                            (flomap Flomap-Transform Real Real Real Real -> flomap)))
(define flomap-transform
  (case-lambda
    [(fm t)
     (match-define (flomap vs c w h) fm)
     (match-define (invertible-2d-function f g) (t w h))
     (define x-min +inf.0)
     (define x-max -inf.0)
     (define y-min +inf.0)
     (define y-max -inf.0)
     (let: y-loop : Void ([y : Integer  0])
       (when (y . fx< . h)
         (let: x-loop : Void ([x : Integer  0])
           (cond [(x . fx< . w)
                  (define-values (new-x new-y) (f (+ 0.5 (fx->fl x)) (+ 0.5 (fx->fl y))))
                  (when (new-x . < . x-min) (set! x-min new-x))
                  (when (new-x . > . x-max) (set! x-max new-x))
                  (when (new-y . < . y-min) (set! y-min new-y))
                  (when (new-y . > . y-max) (set! y-max new-y))
                  (x-loop (fx+ x 1))]
                 [else
                  (y-loop (fx+ y 1))]))))
     (flomap-transform fm t x-min x-max y-min y-max)]
    [(fm t x-min x-max y-min y-max)
     (let ([x-min  (real->double-flonum x-min)]
           [x-max  (real->double-flonum x-max)]
           [y-min  (real->double-flonum y-min)]
           [y-max  (real->double-flonum y-max)])
       (match-define (flomap vs c w h) fm)
       (match-define (invertible-2d-function f g) (t w h))
       (define int-x-min (fl->fx (floor x-min)))
       (define int-x-max (fl->fx (ceiling x-max)))
       (define int-y-min (fl->fx (floor y-min)))
       (define int-y-max (fl->fx (ceiling y-max)))
       (define new-w (- int-x-max int-x-min))
       (define new-h (- int-y-max int-y-min))
       (define x-offset (+ 0.5 (fx->fl int-x-min)))
       (define y-offset (+ 0.5 (fx->fl int-y-min)))
       (inline-build-flomap
        c new-w new-h
        (λ (k x y i)
          (define-values (old-x old-y) (g (+ (fx->fl x) x-offset)
                                          (+ (fx->fl y) y-offset)))
          (flomap-bilinear-ref fm k old-x old-y)))))]))
```

```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         racket/match racket/math
         "flonum.rkt"
         "flomap-struct.rkt"
         "flomap-stats.rkt")
(provide flomap-lift flomap-lift2 flomap-lift-helper flomap-lift-helper2
         fmneg fmabs fmsqr fmsin fmcos fmtan fmlog fmexp fmsqrt fmasin fmacos fmatan
         fmround fmfloor fmceiling fmtruncate fmzero
         fm+ fm- fm* fm/ fmmin fmmax
         flomap-normalize flomap-multiply-alpha flomap-divide-alpha)
; ============================================================================================
; Unary
(: flomap-lift-helper : (Flonum -> Flonum) -> (flomap -> flomap))
(define (flomap-lift-helper f)
  (λ: ([fm : flomap])
    (match-define (flomap vs c w h) fm)
    (flomap (inline-build-flvector (* c w h) (λ (i) (f (unsafe-flvector-ref vs i))))
            c w h)))
(: flomap-lift ((Flonum -> Real) -> (flomap -> flomap)))
(define (flomap-lift op)
  (flomap-lift-helper (λ (x) (real->double-flonum (op x)))))
(define fmneg (flomap-lift-helper -))
(define fmabs (flomap-lift-helper abs))
(define fmsqr (flomap-lift-helper sqr))
(define fmsin (flomap-lift-helper sin))
(define fmcos (flomap-lift-helper cos))
(define fmtan (flomap-lift-helper tan))
(define fmlog (flomap-lift-helper fllog))
(define fmexp (flomap-lift-helper exp))
(define fmsqrt (flomap-lift-helper flsqrt))
(define fmasin (flomap-lift-helper asin))
(define fmacos (flomap-lift-helper acos))
(define fmatan (flomap-lift-helper atan))
(define fmround (flomap-lift-helper round))
(define fmfloor (flomap-lift-helper floor))
(define fmceiling (flomap-lift-helper ceiling))
(define fmtruncate (flomap-lift-helper truncate))
(define fmzero (flomap-lift-helper (λ (x) (if (x . = . 0.0) 1.0 0.0))))
; ;; ============================================================================================
; Binary
(: flomap-lift-helper2 : Symbol (Float Float -> Float) -> ((U Real flomap) (U Real flomap) -> flomap))
(define (flomap-lift-helper2 name f)
  (let: ()
    (λ: ([fm1 : (U Real flomap)] [fm2 : (U Real flomap)])
      (cond
        [(and (real? fm1) (real? fm2))
         (error name "expected at least one flomap argument; given ~e and ~e" fm1 fm2)]
        [(real? fm1)  (let ([fm1  (real->double-flonum fm1)])
                        ((flomap-lift-helper (λ (v) (f fm1 v))) fm2))]
        [(real? fm2)  (let ([fm2  (real->double-flonum fm2)])
                        ((flomap-lift-helper (λ (v) (f v fm2))) fm1))]
        [else
         (match-define (flomap vs1 c1 w h) fm1)
         (match-define (flomap vs2 c2 w2 h2) fm2)
         (cond
           [(not (and (= w w2) (= h h2)))
            (error name "expected same-size flomaps; given sizes ~ex~e and ~ex~e" w h w2 h2)]
           [(= c1 c2)  (define n (* c1 w h))
                       (define res-vs (make-flvector n))
                       (flomap (inline-build-flvector n (λ (i) (f (unsafe-flvector-ref vs1 i)
                                                                  (unsafe-flvector-ref vs2 i))))
                               c1 w h)]
           [(= c1 1)  (inline-build-flomap
                       c2 w h
                       (λ (k x y i) (f (unsafe-flvector-ref vs1 (coords->index 1 w 0 x y))
                                       (unsafe-flvector-ref vs2 i))))]
           [(= c2 1)  (inline-build-flomap
                       c1 w h
                       (λ (k x y i) (f (unsafe-flvector-ref vs1 i)
                                       (unsafe-flvector-ref vs2 (coords->index 1 w 0 x y)))))]
           [else
            (error name (string-append "expected flomaps with the same number of components, "
                                       "or a flomap with 1 component and any same-size flomap; "
                                       "given flomaps with ~e and ~e components")
                   c1 c2)])])))))
(: flomap-lift2 (Symbol (Flonum Flonum -> Real) -> ((U Real flomap) (U Real flomap) -> flomap)))
(define (flomap-lift2 name f)
  (flomap-lift-helper2 name (λ (x y) (real->double-flonum (f x y)))))
(define fm+ (flomap-lift-helper2 'fm+ +))
(define fm- (flomap-lift-helper2 'fm- -))
(define fm* (flomap-lift-helper2 'fm* *))
(define fm/ (flomap-lift-helper2 'fm/ /))
(define fmmin (flomap-lift-helper2 'fmmin min))
(define fmmax (flomap-lift-helper2 'fmmax max))
(: flomap-normalize (flomap -> flomap))
(define (flomap-normalize fm)
  (define-values (v-min v-max) (flomap-extreme-values fm))
  (define v-size (- v-max v-min))
  (let* ([fm  (fm- fm v-min)]
         [fm  (if (v-size . = . 0.0) fm (fm/ fm v-size))])
    fm))
(define fmdiv/zero
  (flomap-lift-helper2 'fmdiv/zero (λ (x y) (if (y . = . 0.0) 0.0 (/ x y)))))
(: flomap-divide-alpha (flomap -> flomap))
(define (flomap-divide-alpha fm)
  (match-define (flomap _ c w h) fm)
  (cond [(c . <= . 1)  fm]
        [else
         (define alpha-fm (flomap-ref-component fm 0))
         (flomap-append-components alpha-fm (fmdiv/zero (flomap-drop-components fm 1) alpha-fm))]))
```

```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fx->fl fl->fx)
         racket/match racket/math
         "flonum.rkt"
         "flomap.rkt")
(provide deep-flomap deep-flomap? deep-flomap-argb deep-flomap-z
         deep-flomap-width deep-flomap-height deep-flomap-z-min deep-flomap-z-max
         deep-flomap-size deep-flomap-alpha deep-flomap-rgb
         flomap->deep-flomap
         ; Sizing
         deep-flomap-inset deep-flomap-trim deep-flomap-scale deep-flomap-resize
         ; Z-adjusting
         deep-flomap-scale-z deep-flomap-smooth-z deep-flomap-raise deep-flomap-tilt
         deep-flomap-emboss
         deep-flomap-bulge deep-flomap-bulge-round deep-flomap-bulge-round-rect
         deep-flomap-bulge-spheroid deep-flomap-bulge-horizontal deep-flomap-bulge-vertical
         deep-flomap-bulge-ripple
         ; Compositing
         deep-flomap-pin deep-flomap-pin*
         deep-flomap-lt-superimpose deep-flomap-lc-superimpose deep-flomap-lb-superimpose
         deep-flomap-ct-superimpose deep-flomap-cc-superimpose deep-flomap-cb-superimpose
         deep-flomap-rt-superimpose deep-flomap-rc-superimpose deep-flomap-rb-superimpose
         deep-flomap-vl-append deep-flomap-vc-append deep-flomap-vr-append
         deep-flomap-ht-append deep-flomap-hc-append deep-flomap-hb-append)
(struct: deep-flomap ([argb : flomap] [z : flomap])
  #:transparent
  #:guard
  (λ (argb-fm z-fm name)
    (match-define (flomap _ 4 w h) argb-fm)
    (match-define (flomap _ 1 zw zh) z-fm)
    (unless (and (= w zw) (= h zh))
      (error 'deep-flomap
             "expected flomaps of equal dimension; given dimensions ~ex~e and ~ex~e" w h zw zh))
    (values argb-fm z-fm)))
(: flomap->deep-flomap (flomap -> deep-flomap))
(define (flomap->deep-flomap argb-fm)
  (match-define (flomap _ 4 w h) argb-fm)
  (deep-flomap argb-fm (make-flomap 1 w h)))
(: deep-flomap-width (deep-flomap -> Nonnegative-Fixnum))
(define (deep-flomap-width dfm)
  (define w (flomap-width (deep-flomap-argb dfm)))
  (with-asserts ([w  nonnegative-fixnum?])
    w))
(: deep-flomap-height (deep-flomap -> Nonnegative-Fixnum))
(define (deep-flomap-height dfm)
  (define h (flomap-height (deep-flomap-argb dfm)))
  (with-asserts ([h  nonnegative-fixnum?])
    h))
(: deep-flomap-z-min (deep-flomap -> Flonum))
(define (deep-flomap-z-min dfm)
  (flomap-min-value (deep-flomap-z dfm)))
(: deep-flomap-z-max (deep-flomap -> Flonum))
(define (deep-flomap-z-max dfm)
  (flomap-max-value (deep-flomap-z dfm)))
(: deep-flomap-size (deep-flomap -> (values Nonnegative-Fixnum Nonnegative-Fixnum)))
(define (deep-flomap-size dfm)
  (values (deep-flomap-width dfm) (deep-flomap-height dfm)))
(: deep-flomap-alpha (deep-flomap -> flomap))
(define (deep-flomap-alpha dfm)
  (flomap-ref-component (deep-flomap-argb dfm) 0))
(: deep-flomap-rgb (deep-flomap -> flomap))
(define (deep-flomap-rgb dfm)
  (flomap-drop-components (deep-flomap-argb dfm) 1))
; ============================================================================================
; Z adjusters
(: deep-flomap-scale-z (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-scale-z dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (deep-flomap argb-fm (fm* z-fm z)))
(: deep-flomap-smooth-z (deep-flomap Real -> deep-flomap))
(define (deep-flomap-smooth-z dfm σ)
  (let ([σ  (exact->inexact σ)])
    (match-define (deep-flomap argb-fm z-fm) dfm)
    (define new-z-fm (flomap-blur z-fm σ))
    (deep-flomap argb-fm new-z-fm)))
; deep-flomap-raise and everything derived from it observe an invariant:
; when z is added, added z must be 0.0 everywhere alpha is 0.0
(: deep-flomap-raise (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-raise dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (define alpha-fm (deep-flomap-alpha dfm))
  (deep-flomap argb-fm (fm+ z-fm (fm* alpha-fm z))))
(: deep-flomap-emboss (deep-flomap Real (U Real flomap) -> deep-flomap))
(define (deep-flomap-emboss dfm xy-amt z-amt)
  (let ([σ       (/ xy-amt 3.0)])
    (define z-fm (flomap-normalize (deep-flomap-alpha dfm)))
    (define new-z-fm (fm* (flomap-blur z-fm σ) z-amt))
    (deep-flomap-raise dfm new-z-fm)))
(: deep-flomap-bulge-helper : deep-flomap (Flonum Flonum -> Flonum) -> deep-flomap)
(define (deep-flomap-bulge-helper dfm f)
  (let ()
    (define-values (w h) (deep-flomap-size dfm))
    (define half-x-size (- (* 0.5 (fx->fl w)) 0.5))
    (define half-y-size (- (* 0.5 (fx->fl h)) 0.5))
    (define z-fm
      (inline-build-flomap
       1 w h
       (λ (_ x y i)
         (f (- (/ (fx->fl x) half-x-size) 1.0)
            (- (/ (fx->fl y) half-y-size) 1.0)))))
    (deep-flomap-raise dfm z-fm)))
(: deep-flomap-bulge (deep-flomap (Flonum Flonum -> Real) -> deep-flomap))
(define (deep-flomap-bulge dfm f)
  (deep-flomap-bulge-helper dfm (λ (cx cy) (real->double-flonum (f cx cy)))))
```


define-syntax-rule
(define (flomap-lift-helper f) ...)



There must be a better way.

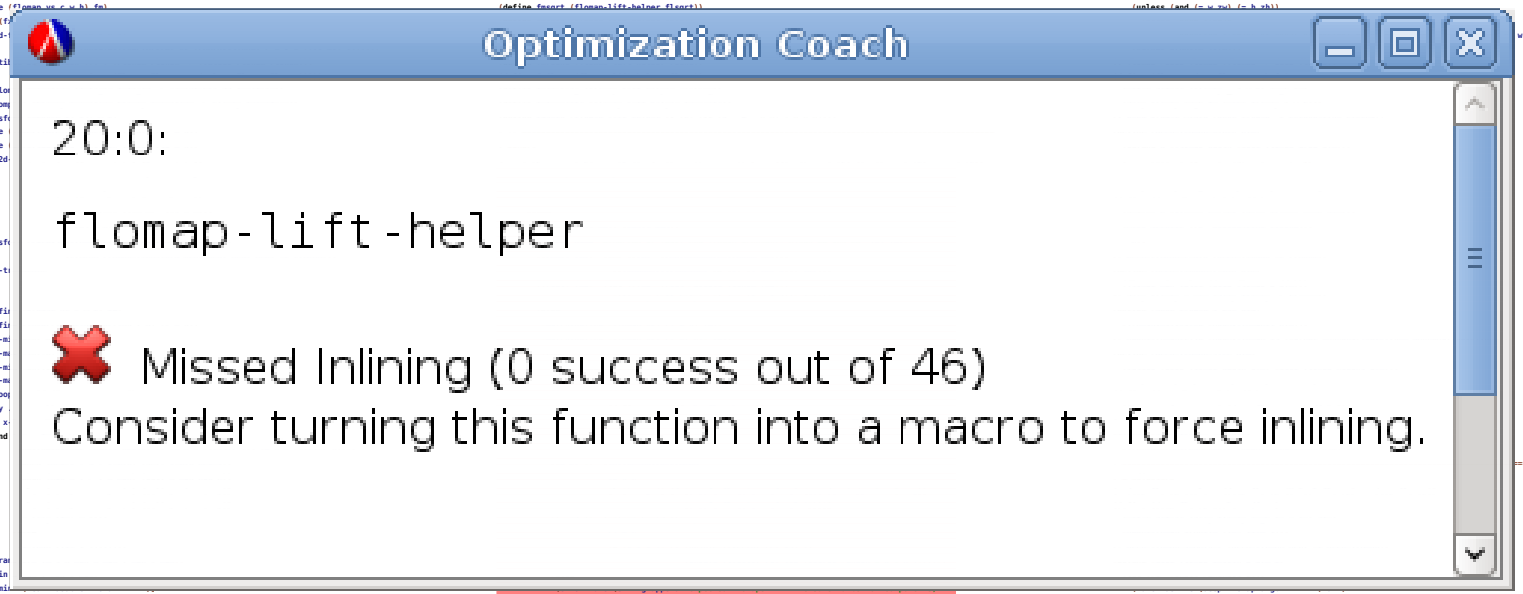
Optimization Coach

Seconds later

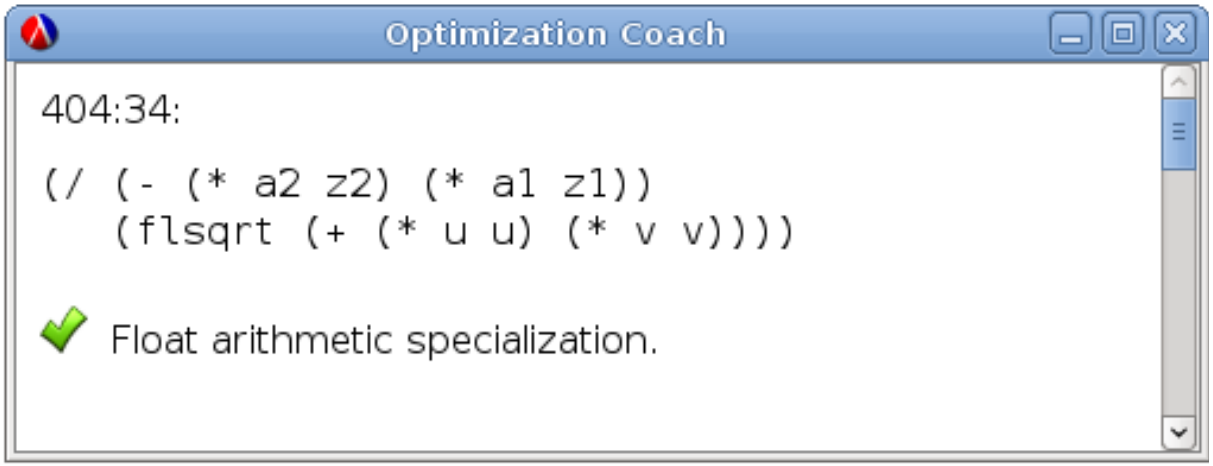
```
#lang typed/racket/base
(require racket/match racket/math racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         "flonum.rkt"
         "flomap-struct.rkt")
(provide flomap-flip-horizontal flomap-flip-vertical flomap-transpose
         flomap-cw-rotate flomap-ccw-rotate
         (struct-out invertible-2d-function) Flomap-Transform
         transform-compose rotate-transform whirl-and-pinch-transform
         flomap-transform)
(: flomap-flip-horizontal (flomap -> flomap))
(define (flomap-flip-horizontal fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- w-1 x) y)))))
(define (flomap-flip-vertical fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c w h (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k x (fx- h-1 y))))))
(define (flomap-transpose fm)
  (match-define (flomap vs c w h) fm)
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y x)))))
(define (flomap-cw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define h-1 (fx- h 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k (fx- h-1 y) x)))))
(define (flomap-ccw-rotate fm)
  (match-define (flomap vs c w h) fm)
  (define w-1 (fx- w 1))
  (inline-build-flomap c h w (λ (k x y i)
                               (unsafe-flvector-ref vs (coords->index c w k y (fx- w-1 x))))))
(struct: invertible-2d-function ([f : (Flonum Flonum -> (values Flonum Flonum))]
                                 [g : (Flonum Flonum -> (values Flonum Flonum))]))
(define-type Flomap-Transform (Integer Integer -> invertible-2d-function))
(: transform-compose (Flomap-Transform Flomap-Transform -> Flomap-Transform))
(define ((transform-compose t1 t2) w h)
  (match-define (invertible-2d-function f1 g1) (t1 w h))
  (match-define (invertible-2d-function f2 g2) (t2 w h))
  (invertible-2d-function (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (f2 x y)])
                              (f1 x y)))
                          (λ: ([x : Flonum] [y : Flonum])
                            (let-values ([(x y)  (g1 x y)])
                              (g2 x y)))))
(: flomap-transform (case-> (flomap Flomap-Transform -> flomap)
                            (flomap Flomap-Transform Real Real Real Real -> flomap)))
(define flomap-transform
  (case-lambda
    [(fm t)
     (match-define (flomap vs c w h) fm)
     (match-define (invertible-2d-function f g) (t w h))
     (define x-min +inf.0)
     (define x-max -inf.0)
     (define y-min +inf.0)
     (define y-max -inf.0)
     (let: y-loop : Void ([y : Integer  0])
       (when (y . fx< . h)
         (let: x-loop : Void ([x : Integer  0])
           (cond [(x . fx< . w)
                  (define-values (new-x new-y) (f (+ 0.5 (fx->fl x)) (+ 0.5 (fx->fl y))))
                  (when (new-x . < . x-min) (set! x-min new-x))
                  (when (new-x . > . x-max) (set! x-max new-x))
                  (when (new-y . < . y-min) (set! y-min new-y))
                  (when (new-y . > . y-max) (set! y-max new-y))
                  (x-loop (fx+ x 1))]
                 [else
                  (y-loop (fx+ y 1))])))))
     (flomap-transform fm t x-min x-max y-min y-max)]
    [(fm t x-min x-max y-min y-max)
     (let ([x-min  (real->double-flonum x-min)]
           [x-max  (real->double-flonum x-max)]
           [y-min  (real->double-flonum y-min)]
           [y-max  (real->double-flonum y-max)])
       (match-define (flomap vs c w h) fm)
       (match-define (invertible-2d-function f g) (t w h))
       (define int-x-min (fl->fx (floor x-min)))
       (define int-x-max (fl->fx (ceiling x-max)))
       (define int-y-min (fl->fx (floor y-min)))
       (define int-y-max (fl->fx (ceiling y-max)))
       (define new-w (- int-x-max int-x-min))
       (define new-h (- int-y-max int-y-min))
       (define x-offset (+ 0.5 (fx->fl int-x-min)))
       (define y-offset (+ 0.5 (fx->fl int-y-min)))
       (inline-build-flomap
        c new-w new-h
        (λ (k x y i)
          (define-values (old-x old-y) (g (+ (fx->fl x) x-offset)
                                          (+ (fx->fl y) y-offset)))
          (flomap-bilinear-ref fm k old-x old-y)))))]))
```

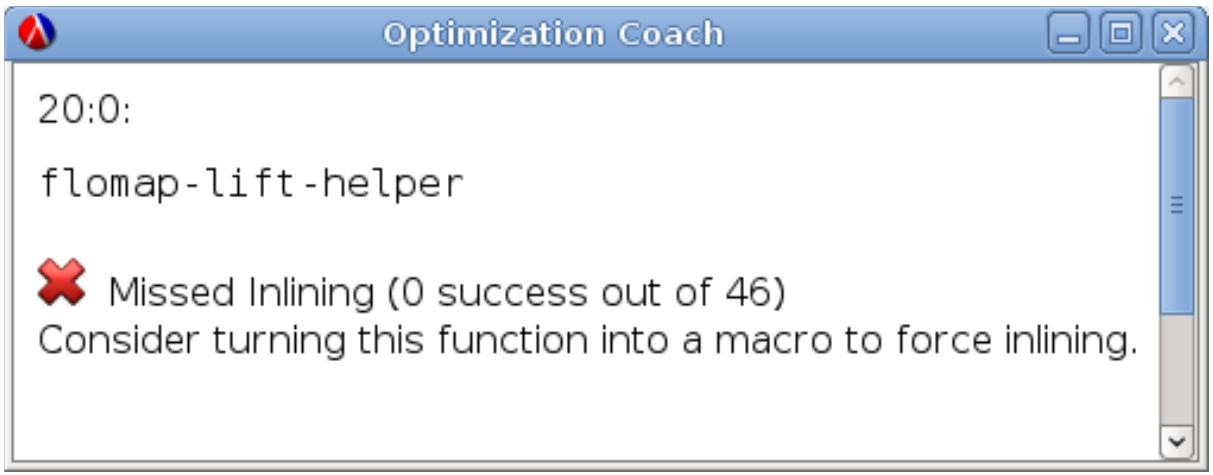
```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fl->fx fx->fl)
         racket/match racket/math
         "flonum.rkt"
         "flomap-struct.rkt"
         "flomap-stats.rkt")
(provide flomap-lift flomap-lift2 flomap-lift-helper flomap-lift-helper2
         fmneg fmabs fmsqr fmsin fmcos fmtan fmlog fmexp fmsqrt fmasin fmacos fmatan
         fmround fmfloor fmceiling fmtruncate fmzero
         fm+ fm- fm* fm/ fmmin fmmax
         flomap-normalize flomap-multiply-alpha flomap-divide-alpha)
; ============================================================================================
; Unary
(: flomap-lift-helper : (Float -> Float) -> (flomap -> flomap))
(define (flomap-lift-helper f)
  (λ: ([fm : flomap])
    (match-define (flomap vs c w h) fm)
    (flomap (inline-build-flvector (* c w h) (λ (i) (f (unsafe-flvector-ref vs i))))
            c w h)))
(: flomap-lift ((Flonum -> Real) -> (flomap -> flomap)))
(define (flomap-lift op)
  (flomap-lift-helper (λ (x) (real->double-flonum (op x)))))
(define fmneg (flomap-lift-helper -))
(define fmabs (flomap-lift-helper abs))
(define fmsqr (flomap-lift-helper sqr))
(define fmsin (flomap-lift-helper sin))
(define fmcos (flomap-lift-helper cos))
(define fmtan (flomap-lift-helper tan))
(define fmlog (flomap-lift-helper fllog))
(define fmexp (flomap-lift-helper exp))
(define fmsqrt (flomap-lift-helper flsqrt))
(define fmasin (flomap-lift-helper asin))
(define fmacos (flomap-lift-helper acos))
(define fmatan (flomap-lift-helper atan))
(define fmround (flomap-lift-helper round))
(define fmfloor (flomap-lift-helper floor))
(define fmceiling (flomap-lift-helper ceiling))
(define fmtruncate (flomap-lift-helper truncate))
(define fmzero (flomap-lift-helper (λ (x) (if (x . = . 0.0) 1.0 0.0))))
; ;; ============================================================================================
; Binary
(: flomap-lift-helper2 : Symbol (Float Float -> Float) -> ((U Real flomap) (U Real flomap) -> flomap))
(define (flomap-lift-helper2 name f)
  (let: ()
    (λ: ([fm1 : (U Real flomap)] [fm2 : (U Real flomap)])
      (cond
        [(and (real? fm1) (real? fm2))
         (error name "expected at least one flomap argument; given ~e and ~e" fm1 fm2)]
        [(real? fm1)  (let ([fm1  (real->double-flonum fm1)])
                        ((flomap-lift-helper (λ (v) (f fm1 v))) fm2))]
        [(real? fm2)  (let ([fm2  (real->double-flonum fm2)])
                        ((flomap-lift-helper (λ (v) (f v fm2))) fm1))]
        [else
         (match-define (flomap vs1 c1 w h) fm1)
         (match-define (flomap vs2 c2 w2 h2) fm2)
         (cond
           [(not (and (= w w2) (= h h2)))
            (error name "expected same-size flomaps; given sizes ~ex~e and ~ex~e" w h w2 h2)]
           [(= c1 c2)  (define n (* c1 w h))
                       (define res-vs (make-flvector n))
                       (flomap (inline-build-flvector n (λ (i) (f (unsafe-flvector-ref vs1 i)
                                                                  (unsafe-flvector-ref vs2 i))))
                               c1 w h)]
           [(= c1 1)  (inline-build-flomap
                       c2 w h
                       (λ (k x y i) (f (unsafe-flvector-ref vs1 (coords->index 1 w 0 x y))
                                       (unsafe-flvector-ref vs2 i))))]
           [(= c2 1)  (inline-build-flomap
                       c1 w h
                       (λ (k x y i) (f (unsafe-flvector-ref vs1 i)
                                       (unsafe-flvector-ref vs2 (coords->index 1 w 0 x y)))))]
           [else
            (error name (string-append "expected flomaps with the same number of components, "
                                       "or a flomap with 1 component and any same-size flomap; "
                                       "given flomaps with ~e and ~e components")
                   c1 c2)])])))))
(: flomap-lift2 (Symbol (Flonum Flonum -> Real) -> ((U Real flomap) (U Real flomap) -> flomap)))
(define (flomap-lift2 name f)
  (flomap-lift-helper2 name (λ (x y) (real->double-flonum (f x y)))))
(define fm+ (flomap-lift-helper2 'fm+ +))
(define fm- (flomap-lift-helper2 'fm- -))
(define fm* (flomap-lift-helper2 'fm* *))
(define fm/ (flomap-lift-helper2 'fm/ /))
(define fmmin (flomap-lift-helper2 'fmmin min))
(define fmmax (flomap-lift-helper2 'fmmax max))
(: flomap-normalize (flomap -> flomap))
(define (flomap-normalize fm)
  (define-values (v-min v-max) (flomap-extreme-values fm))
  (define v-size (- v-max v-min))
  (let* ([fm  (fm- fm v-min)]
         [fm  (if (v-size . = . 0.0) fm (fm/ fm v-size))])
    fm))
(define fmdiv/zero
  (flomap-lift-helper2 'fmdiv/zero (λ (x y) (if (y . = . 0.0) 0.0 (/ x y)))))
(: flomap-divide-alpha (flomap -> flomap))
(define (flomap-divide-alpha fm)
  (match-define (flomap _ c w h) fm)
  (cond [(c . <= . 1)  fm]
        [else
         (define alpha-fm (flomap-ref-component fm 0))
         (flomap-append-components alpha-fm (fmdiv/zero (flomap-drop-components fm 1) alpha-fm))]))
```

```
#lang typed/racket/base
(require racket/flonum
         (except-in racket/fixnum fx->fl fl->fx)
         racket/match racket/math
         "flonum.rkt"
         "flomap.rkt")
(provide deep-flomap deep-flomap? deep-flomap-argb deep-flomap-z
         deep-flomap-width deep-flomap-height deep-flomap-z-min deep-flomap-z-max
         deep-flomap-size deep-flomap-alpha deep-flomap-rgb
         flomap->deep-flomap
         ; Sizing
         deep-flomap-inset deep-flomap-trim deep-flomap-scale deep-flomap-resize
         ; Z-adjusting
         deep-flomap-scale-z deep-flomap-smooth-z deep-flomap-raise deep-flomap-tilt
         deep-flomap-emboss
         deep-flomap-bulge deep-flomap-bulge-round deep-flomap-bulge-round-rect
         deep-flomap-bulge-spheroid deep-flomap-bulge-horizontal deep-flomap-bulge-vertical
         deep-flomap-bulge-ripple
         ; Compositing
         deep-flomap-pin deep-flomap-pin*
         deep-flomap-lt-superimpose deep-flomap-lc-superimpose deep-flomap-lb-superimpose
         deep-flomap-ct-superimpose deep-flomap-cc-superimpose deep-flomap-cb-superimpose
         deep-flomap-rt-superimpose deep-flomap-rc-superimpose deep-flomap-rb-superimpose
         deep-flomap-vl-append deep-flomap-vc-append deep-flomap-vr-append
         deep-flomap-ht-append deep-flomap-hc-append deep-flomap-hb-append)
(struct: deep-flomap ([argb : flomap] [z : flomap])
  #:transparent
  #:guard
  (λ (argb-fm z-fm name)
    (match-define (flomap _ 4 w h) argb-fm)
    (match-define (flomap _ 1 zw zh) z-fm)
    (unless (and (= w zw) (= h zh))
      (error 'deep-flomap
             "expected flomaps of equal dimension; given dimensions ~ex~e and ~ex~e" w h zw zh))
    (values argb-fm z-fm)))
(: flomap->deep-flomap (flomap -> deep-flomap))
(define (flomap->deep-flomap argb-fm)
  (match-define (flomap _ 4 w h) argb-fm)
  (deep-flomap argb-fm (make-flomap 1 w h)))
(: deep-flomap-width (deep-flomap -> Nonnegative-Fixnum))
(define (deep-flomap-width dfm)
  (define w (flomap-width (deep-flomap-argb dfm)))
  (with-asserts ([w  nonnegative-fixnum?])
    w))
(: deep-flomap-height (deep-flomap -> Nonnegative-Fixnum))
(define (deep-flomap-height dfm)
  (define h (flomap-height (deep-flomap-argb dfm)))
  (with-asserts ([h  nonnegative-fixnum?])
    h))
(: deep-flomap-z-min (deep-flomap -> Flonum))
(define (deep-flomap-z-min dfm)
  (flomap-min-value (deep-flomap-z dfm)))
(: deep-flomap-z-max (deep-flomap -> Flonum))
(define (deep-flomap-z-max dfm)
  (flomap-max-value (deep-flomap-z dfm)))
(: deep-flomap-size (deep-flomap -> (values Nonnegative-Fixnum Nonnegative-Fixnum)))
(define (deep-flomap-size dfm)
  (values (deep-flomap-width dfm) (deep-flomap-height dfm)))
(: deep-flomap-alpha (deep-flomap -> flomap))
(define (deep-flomap-alpha dfm)
  (flomap-ref-component (deep-flomap-argb dfm) 0))
(: deep-flomap-rgb (deep-flomap -> flomap))
(define (deep-flomap-rgb dfm)
  (flomap-drop-components (deep-flomap-argb dfm) 1))
; ============================================================================================
; Z adjusters
(: deep-flomap-scale-z (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-scale-z dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (deep-flomap argb-fm (fm* z-fm z)))
(: deep-flomap-smooth-z (deep-flomap Real -> deep-flomap))
(define (deep-flomap-smooth-z dfm σ)
  (let ([σ  (exact->inexact σ)])
    (match-define (deep-flomap argb-fm z-fm) dfm)
    (define new-z-fm (flomap-blur z-fm σ))
    (deep-flomap argb-fm new-z-fm)))
; deep-flomap-raise and everything derived from it observe an invariant:
; when z is added, added z must be 0.0 everywhere alpha is 0.0
(: deep-flomap-raise (deep-flomap (U Real flomap) -> deep-flomap))
(define (deep-flomap-raise dfm z)
  (match-define (deep-flomap argb-fm z-fm) dfm)
  (define alpha-fm (deep-flomap-alpha dfm))
  (deep-flomap argb-fm (fm+ z-fm (fm* alpha-fm z))))
(: deep-flomap-emboss (deep-flomap Real (U Real flomap) -> deep-flomap))
(define (deep-flomap-emboss dfm xy-amt z-amt)
  (let ([σ        (/ xy-amt 3.0)])
    (define z-fm (flomap-normalize (deep-flomap-alpha dfm)))
    (define new-z-fm (fm* (flomap-blur z-fm σ) z-amt))
    (deep-flomap-raise dfm new-z-fm)))
(: deep-flomap-bulge-helper (deep-flomap (Flonum Flonum -> Flonum) -> deep-flomap))
(define (deep-flomap-bulge-helper dfm f)
  (let ()
    (define-values (w h) (deep-flomap-size dfm))
    (define half-x-size (- (* 0.5 (fx->fl w)) 0.5))
    (define half-y-size (- (* 0.5 (fx->fl h)) 0.5))
    (define z-fm
      (inline-build-flomap
       1 w h
       (λ (_ x y i)
         (f (- (/ (fx->fl x) half-x-size) 1.0)
            (- (/ (fx->fl y) half-y-size) 1.0)))))
    (deep-flomap-raise dfm z-fm)))
(: deep-flomap-bulge (deep-flomap (Flonum Flonum -> Real) -> deep-flomap))
(define (deep-flomap-bulge dfm f)
  (deep-flomap-bulge-helper dfm (λ (cx cy) (real->double-flonum (f cx cy)))))
```

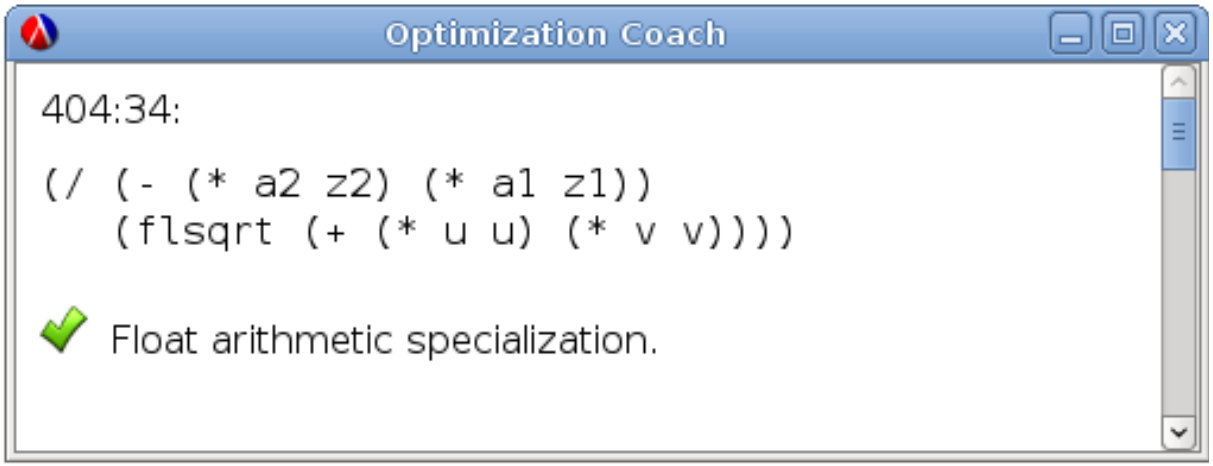

Optimization Coach
20:0:
flomap-lift-helper
Missed Inlining (0 success out of 46)
Consider turning this function into a macro to force inlining.

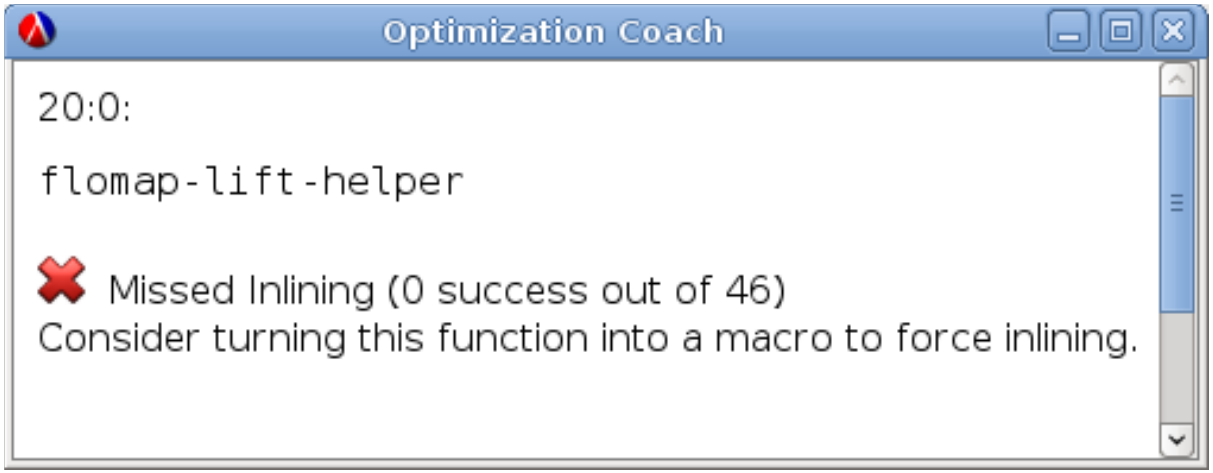
Dialog between compilers and programmers





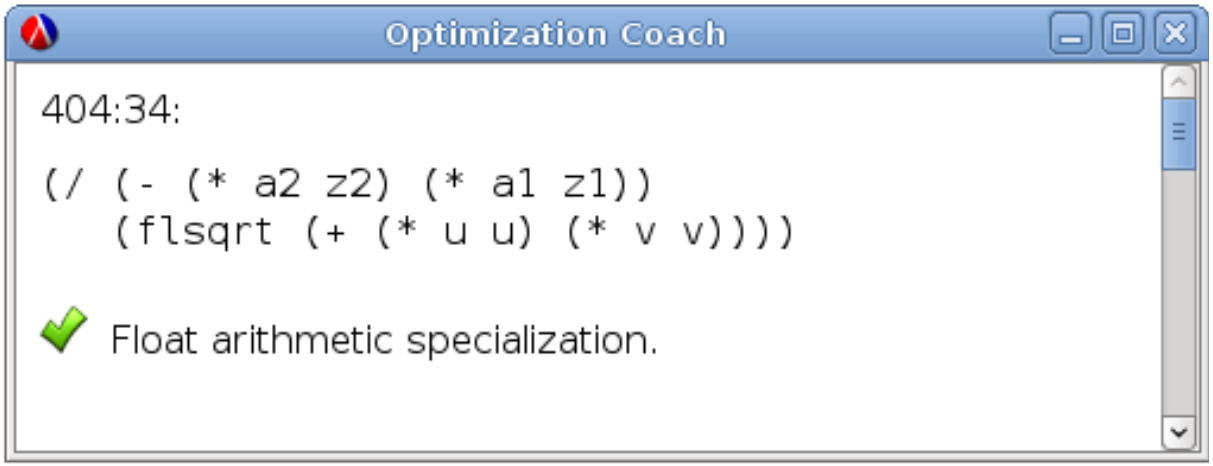
Dialog between compilers and programmers

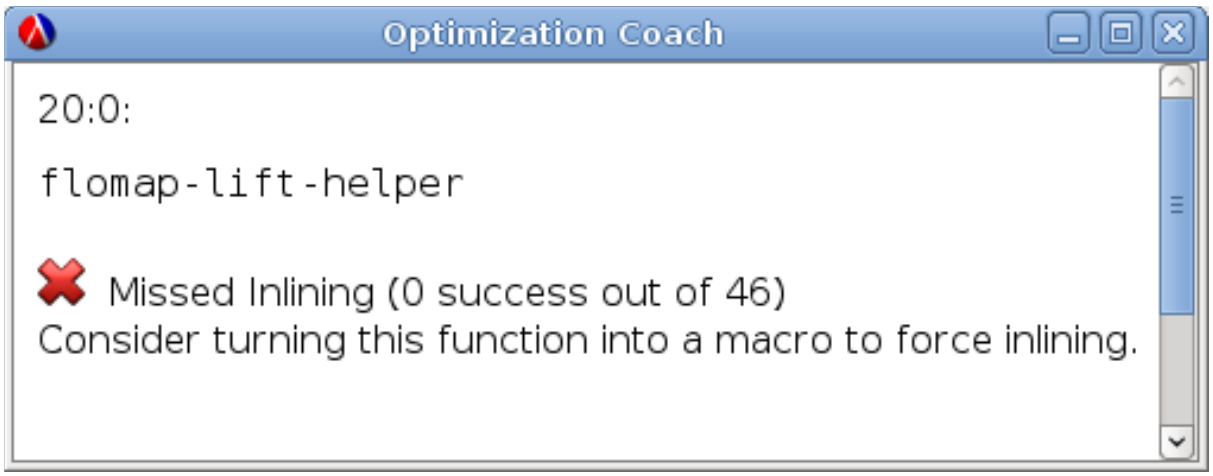




Successes

Dialog between compilers and programmers





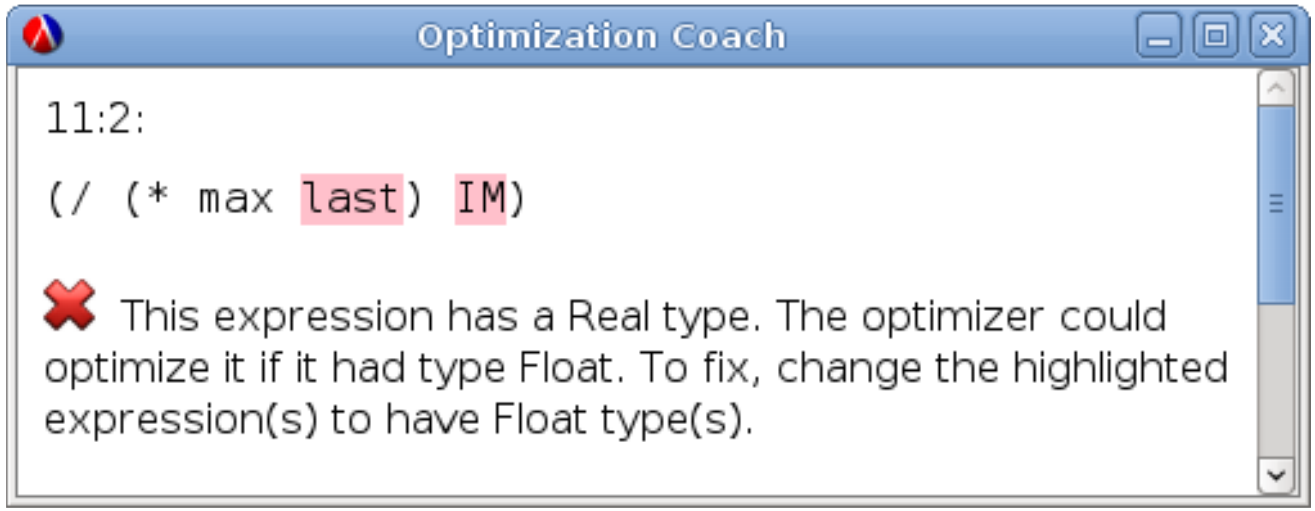
Successes

Near misses

+

Recommendations

Programmers can do more than compilers

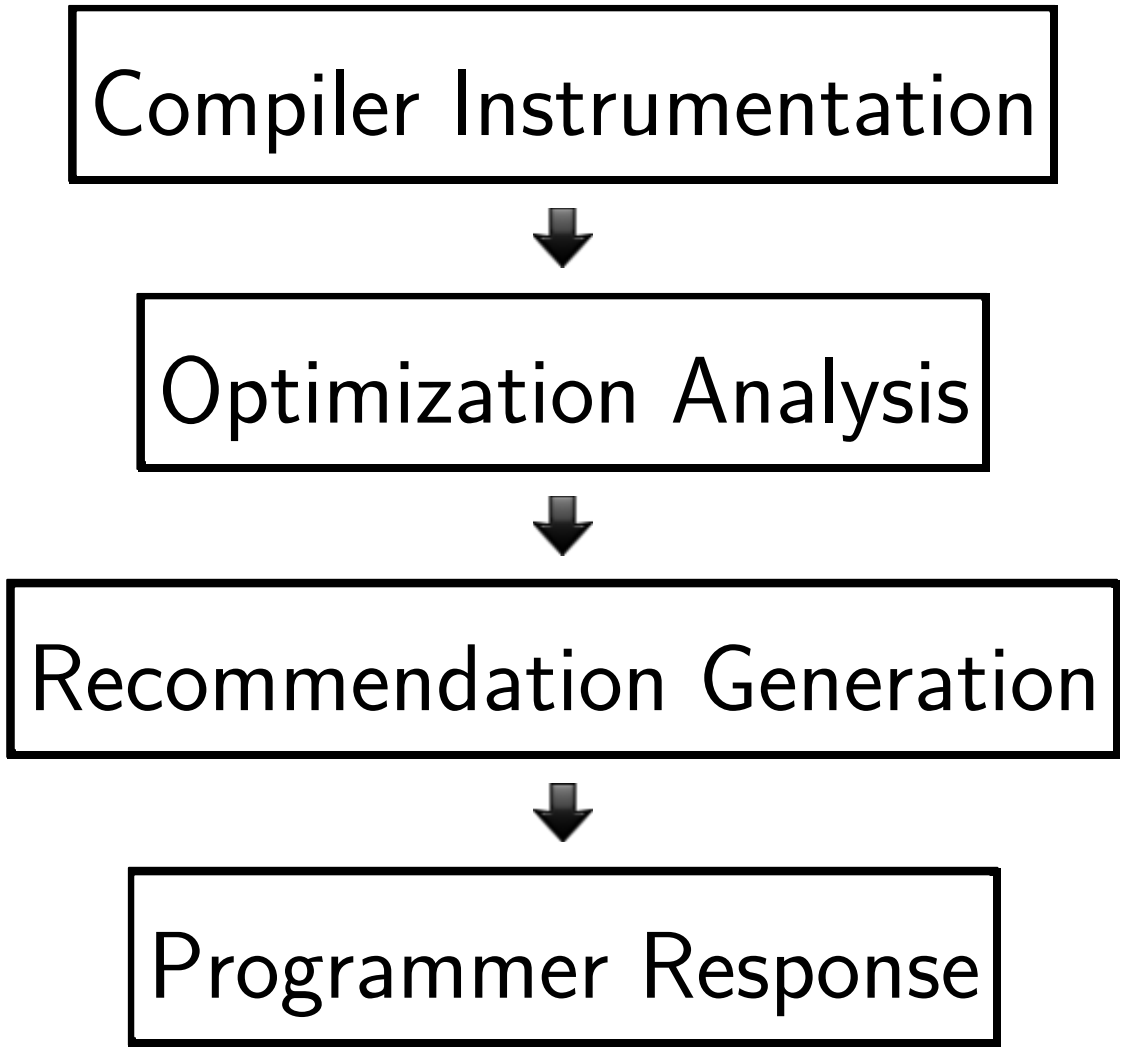


Recommendations can change semantics!

```
(/ 1 3)       ➡ 1/3
(/ 1.0 3.0)   ➡ 0.3333333333333333
```

How does it work?

Overview


Compiler Instrumentation
Optimization Analysis
Recommendation Generation
Programmer Response

A day in the life of a near miss

```
#lang typed/racket/base

(define IM   139968)
(define IA     3877)
(define IC    29573)

(define last 42)
(define min  35.3)
(define max  156.8)
(define (gen-random)
  (set! last (modulo (+ (* last IA) IC) IM))
  (+ (/ (* (- max min) last) IM) min))
```

A day in the life of a near miss

```
#lang typed/racket/base

(define IM
(define IA
(define IC

(define last 42)
(define min  35.3)
(define max  156.8)
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  (set! last (modulo (+ (* last IA) IC) IM))
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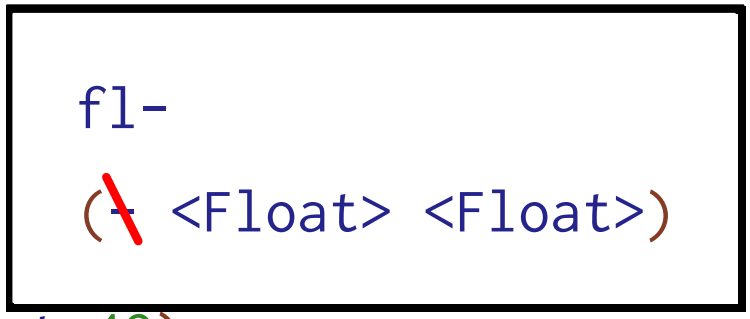
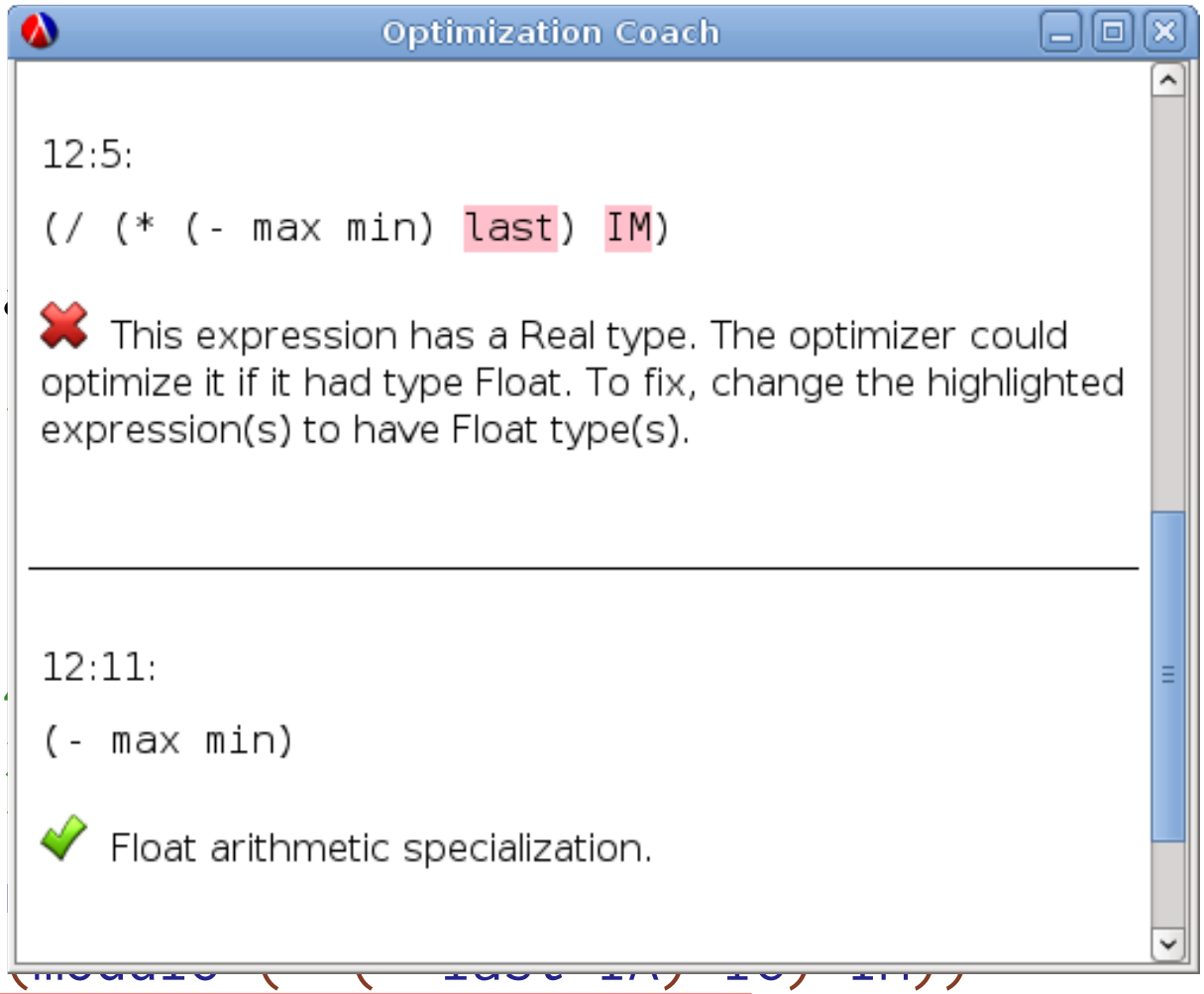


A day in the life of a near miss

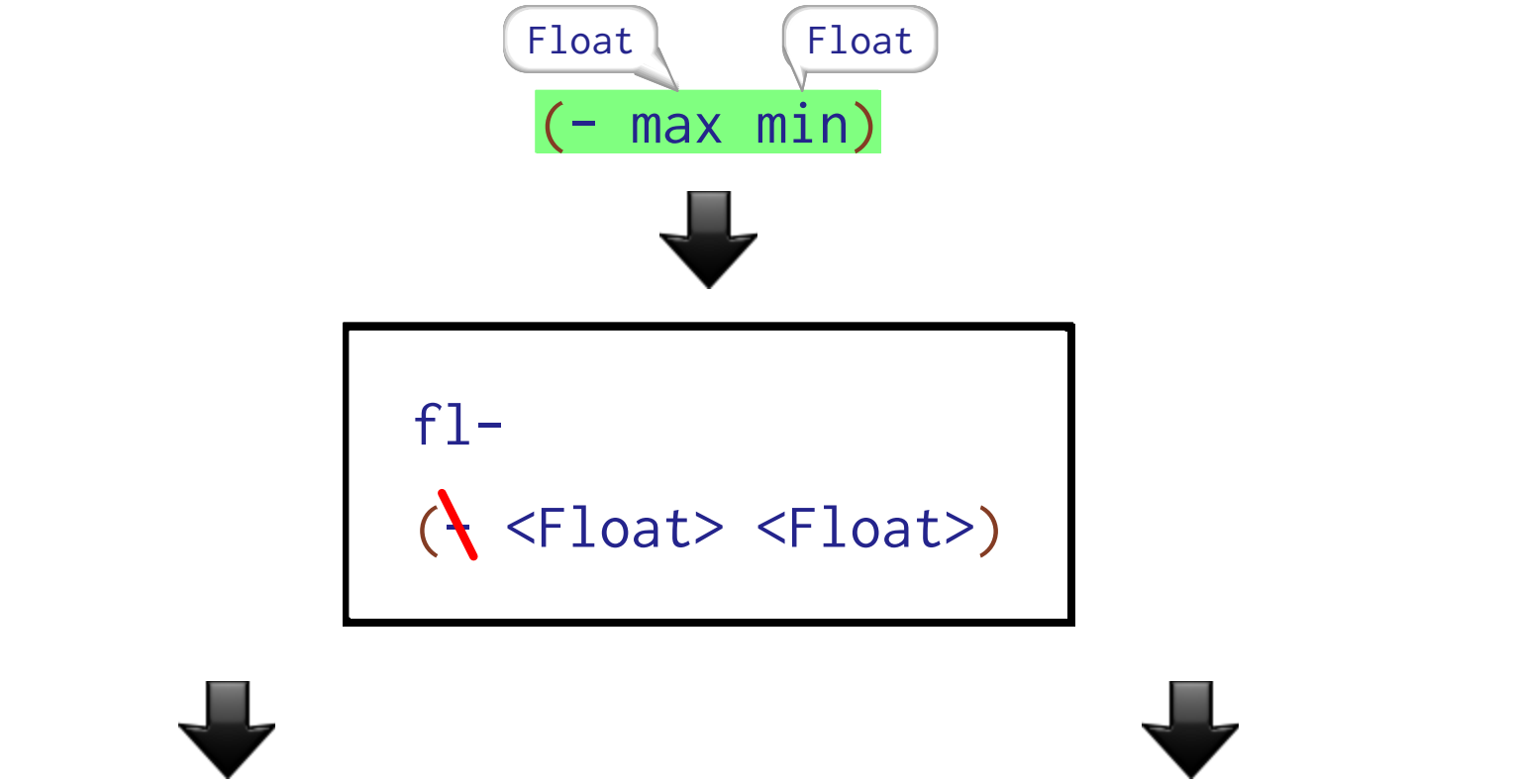
```
#lang typed/r

(define IM
(define IA
(define IC

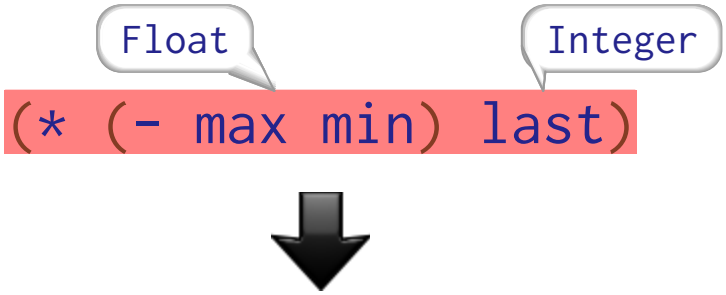
(define last
(define min
(define max
(define (gen-
  (set! last
  (+ (/ (* (- max min) last) IM) min))
```



Compiler Instrumentation



Compiler Instrumentation



(* <Number> <Number>) ; no change

(* (- max min) last)

```
TR opt failure: prng-example.rkt 12:8
  (* (- max min) last)
  Float Integer
  generic multiplication
```

Optimization Analysis

Optimization proximity

Incomprehensible failure pruning

Irrelevant failure pruning

Harmless failure pruning

Irritant analysis

Causality merging

Locality merging

Optimization Analysis

Optimization proximity

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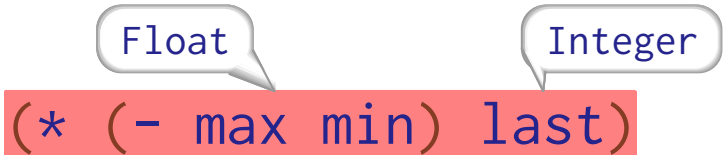
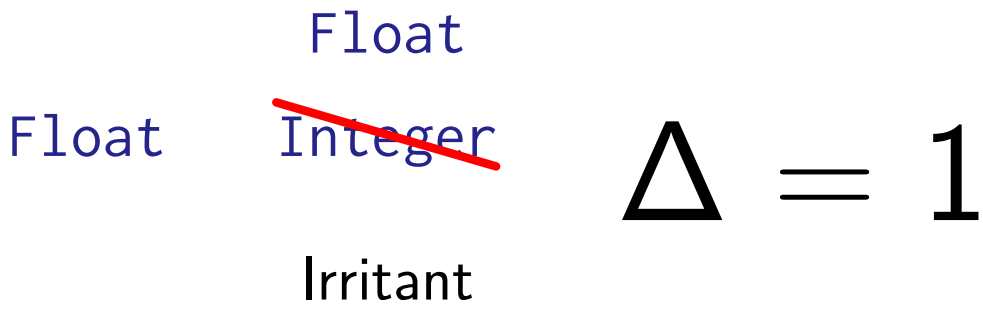


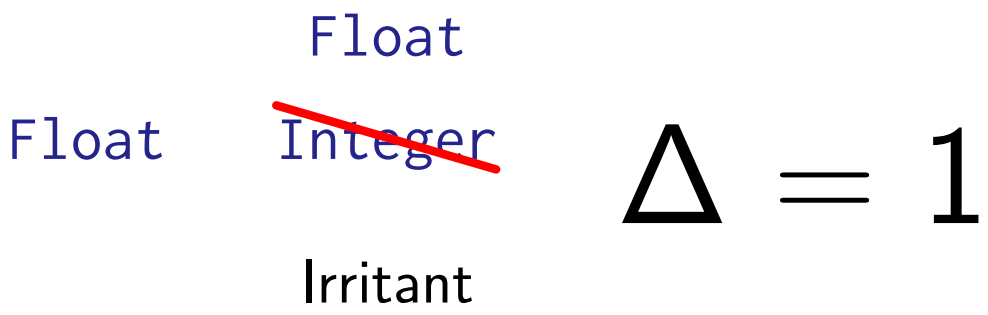


$$\Delta = 1$$

Optimization Analysis

Optimization proximity

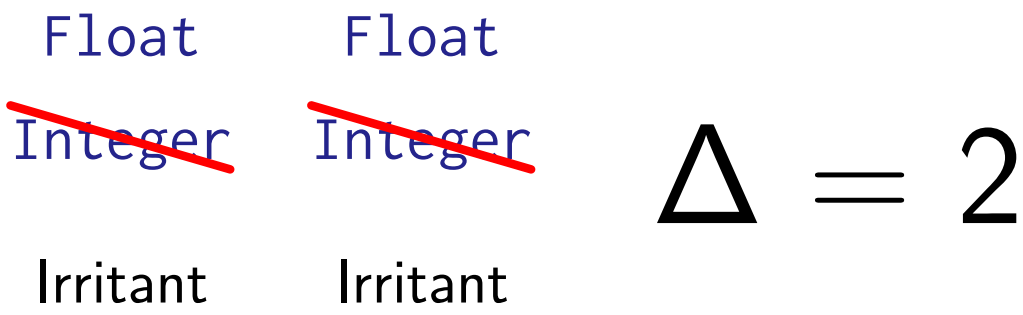
Near miss, report



$$\Delta = 1$$

Optimization Analysis

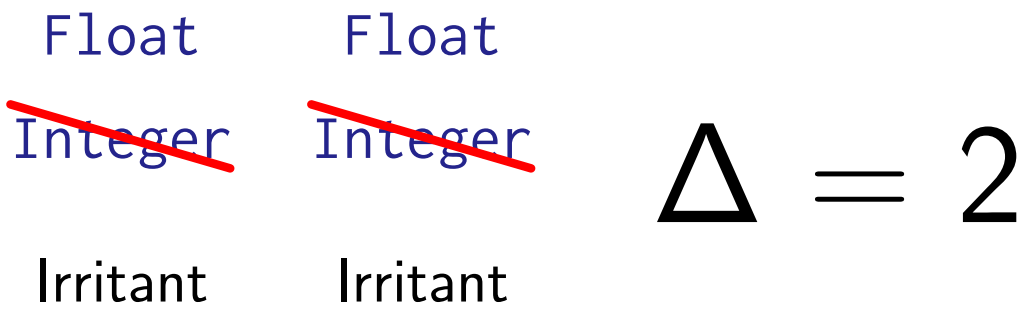
Optimization proximity



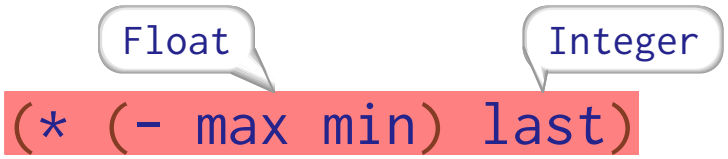
Optimization Analysis

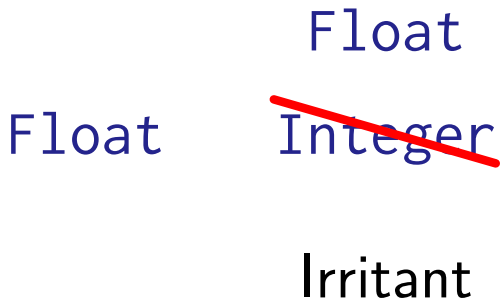
Optimization proximity

Too far, don't report



Recommendation Generation





12:5:

```
(/ (* (- max min) last) IM)
```

This expression has a Real type. The optimizer could optimize it if it had type Float. To fix, change the highlighted expression(s) to have Float type(s).

Programmer Response

```
                    (->fl last)  (->fl IM)
(+ (/ (* (- max min) last) IM) min)
```

12:5:

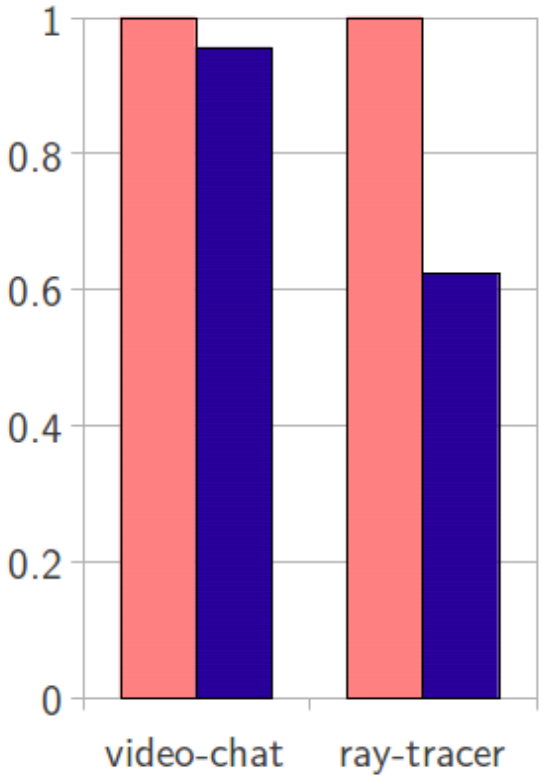
```
(/ (* (- max min) last) IM)
```

This expression has a Real type. The optimizer could optimize it if it had type Float. To fix, change the highlighted expression(s) to have Float type(s).

How well does it work?

Baseline: Non-optimized

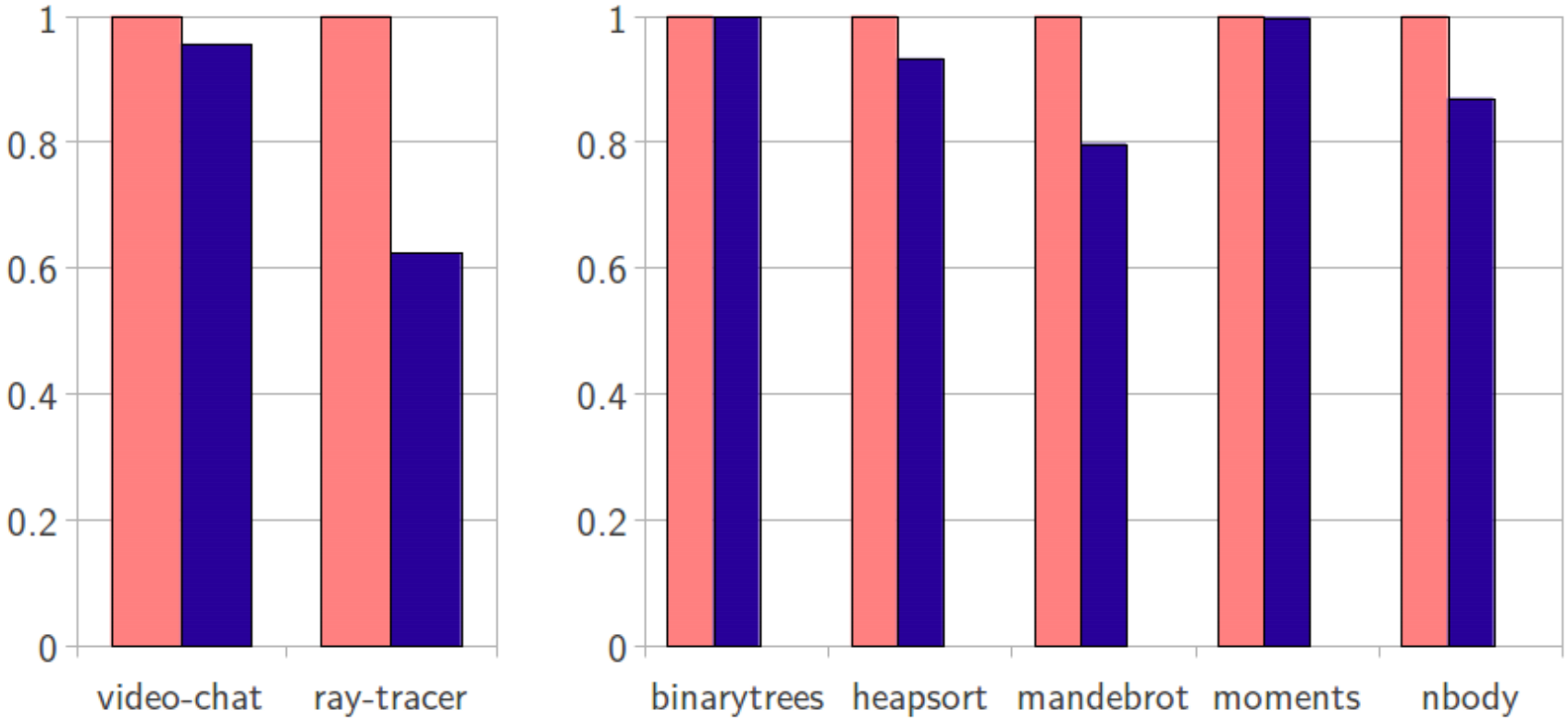
Coached: Followed recommendations (Minutes of work)



Lower is better

Baseline: Non-optimized

Coached: Followed recommendations (Minutes of work)

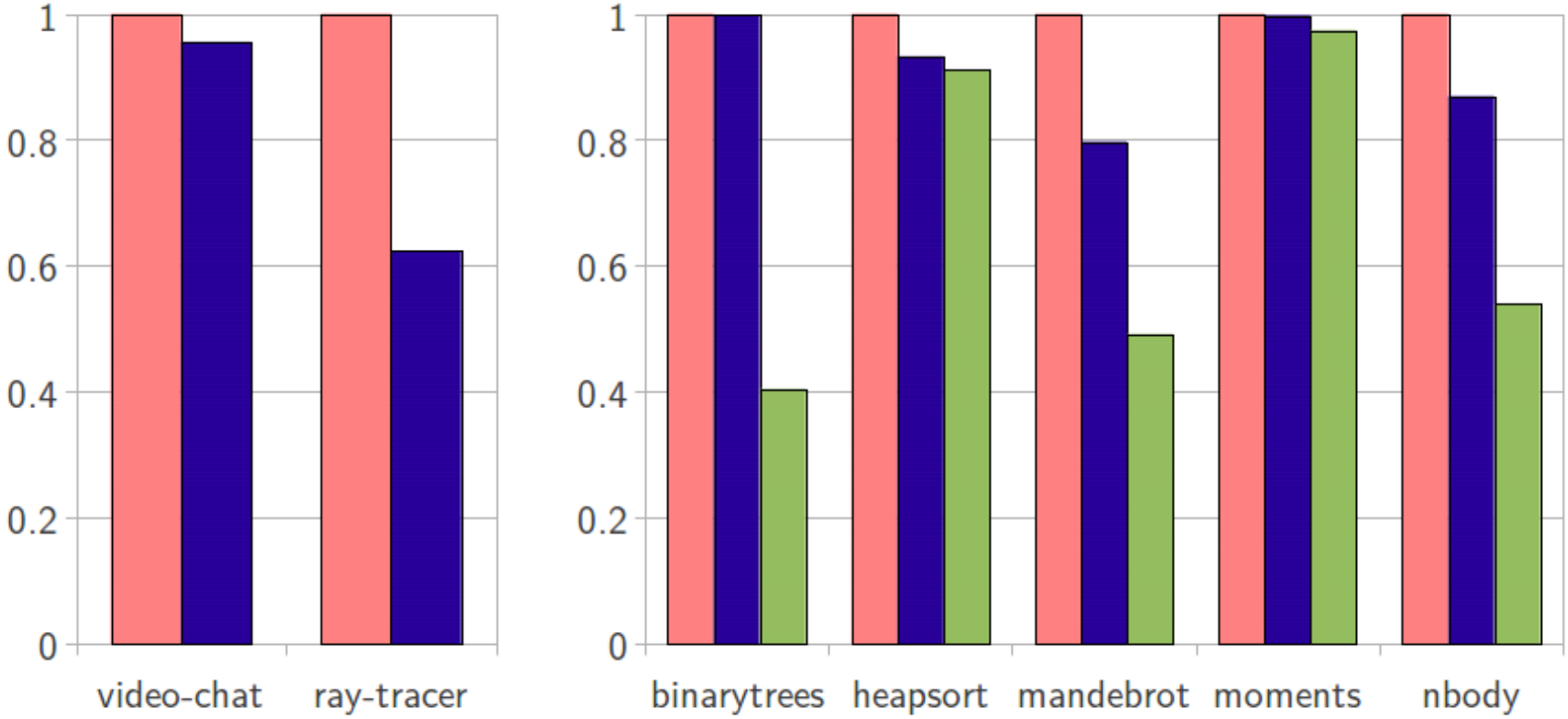


Lower is better

Baseline: Non-optimized

Coached: Followed recommendations (Minutes of work)

Gold standard: Hand-optimized by experts (Days of work)



Lower is better

The take-away

Key idea: The compiler *talks back*

General optimization analysis techniques

\+ *Optimization-specific* heuristics

Targeted recommendations

The take-away

Key idea: The compiler *talks back*

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Targeted recommendations

`racket-lang.org`