Does Blame Shifting Work?

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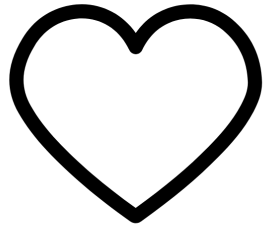
PLT @ Northwestern

Contracts and blame research

contracts  $\exists \vdash \Rightarrow \forall$

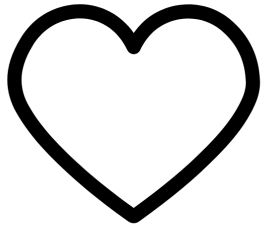
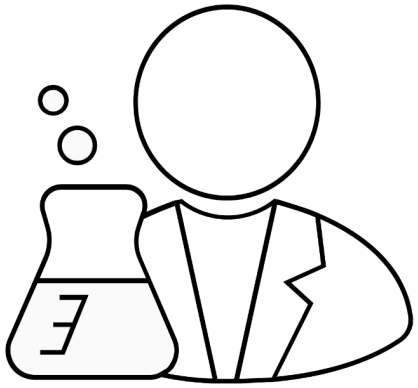
Blame is supposed to help debug

"Correct blame assignment **gets programmers started** with the **debugging process**"
[Dimoulas et al. POPL'11]

"After all, the **purpose of blame** assignment is to **assist programmers with debugging**"
[Strickland & Felleisen IFL'09]

Blame "narrow[s] down the **search for the error**"
[Dimoulas et al. OOPSLA'13]

Does blame actually work?

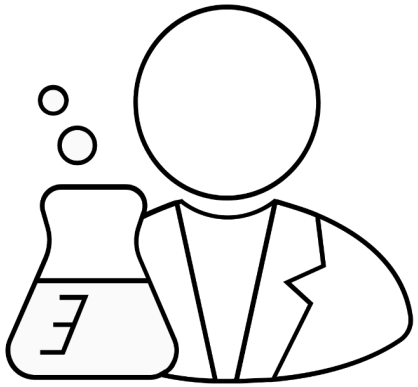
contracts   ?

The intuitive hypothesis

Blame has a systematic relationship

to the location of bugs in programs

Blame does work!



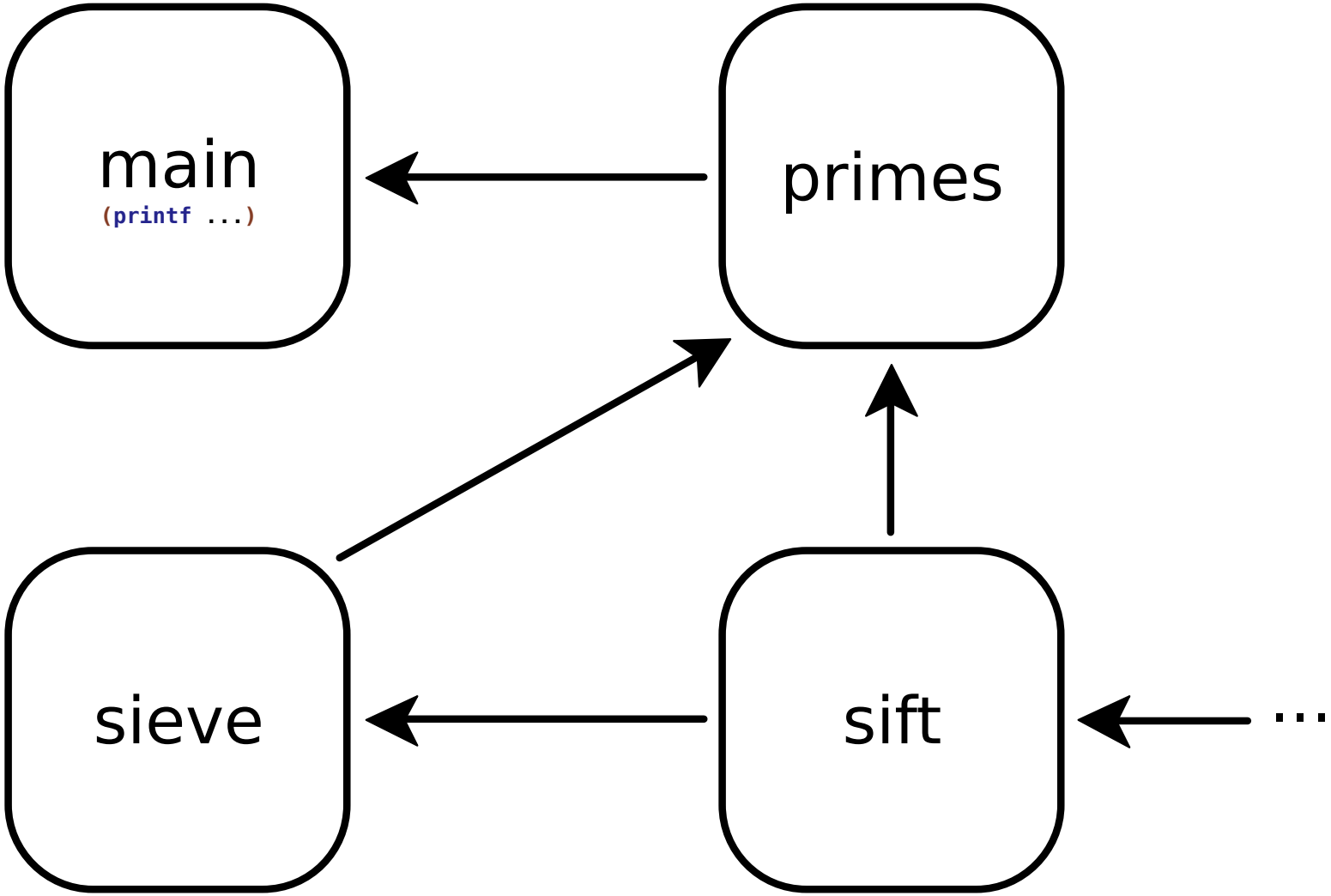
Let’s step back for a minute

Contracts

and

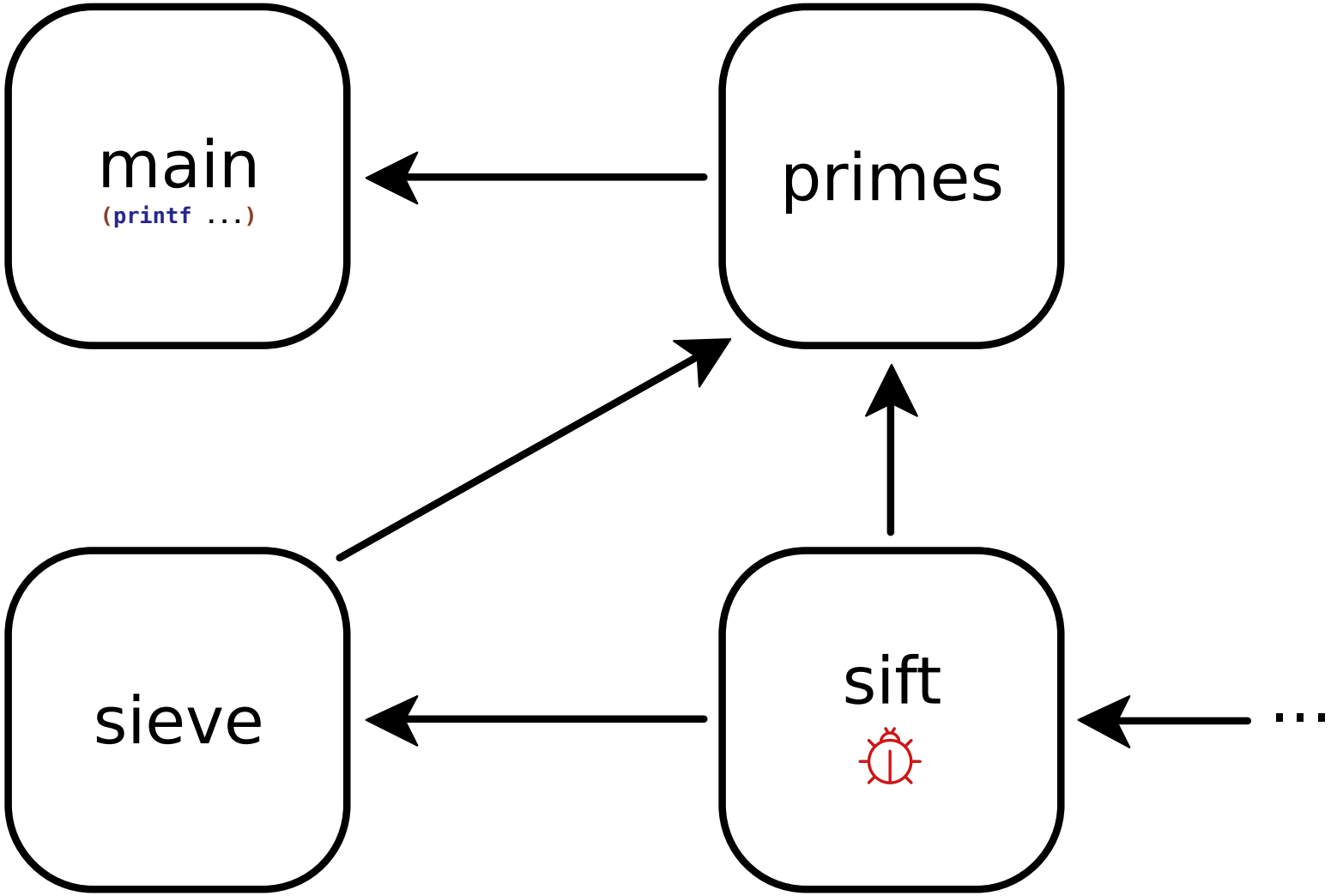
Blame

This is a program



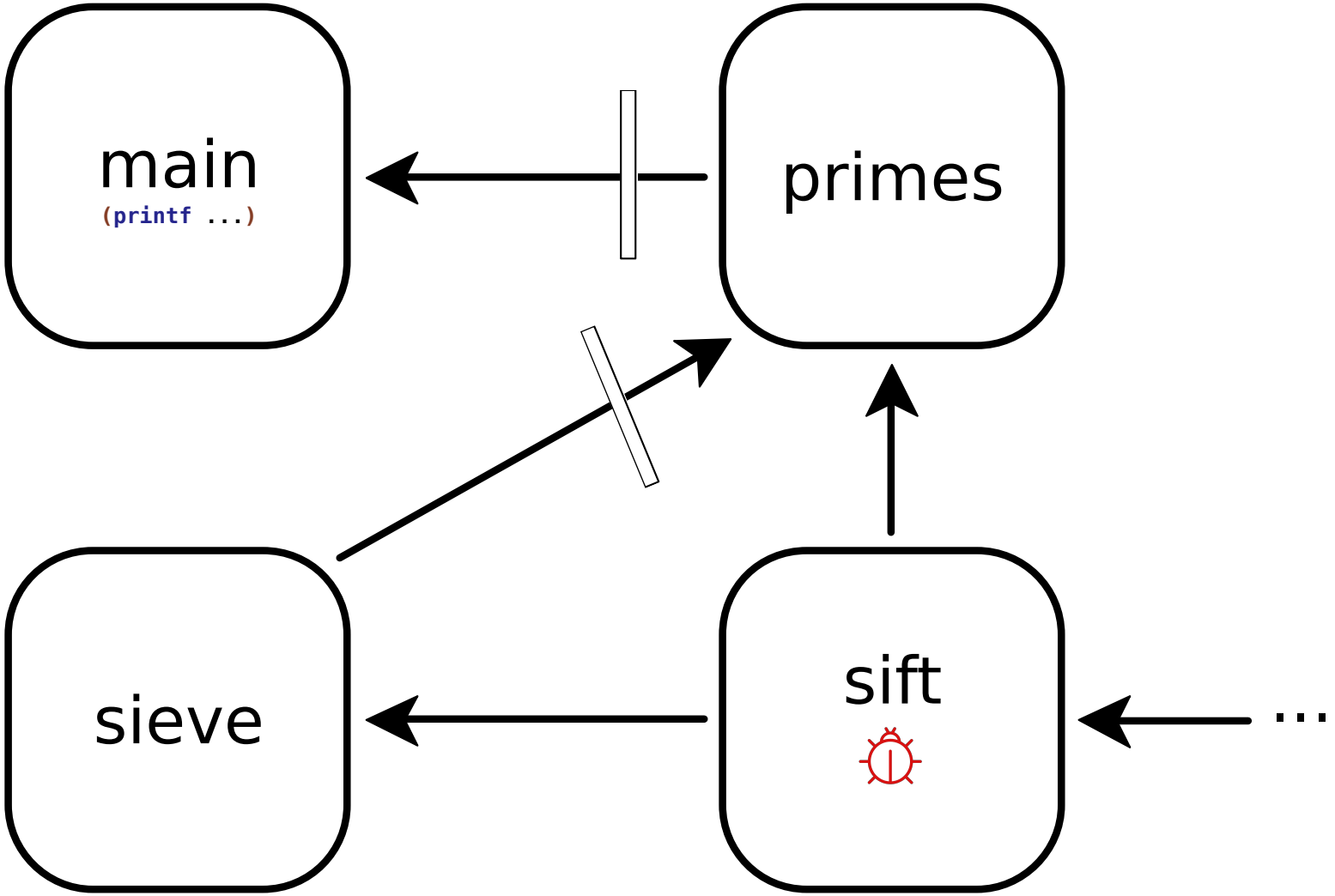
One component has a bug

2 3 4 5 ...



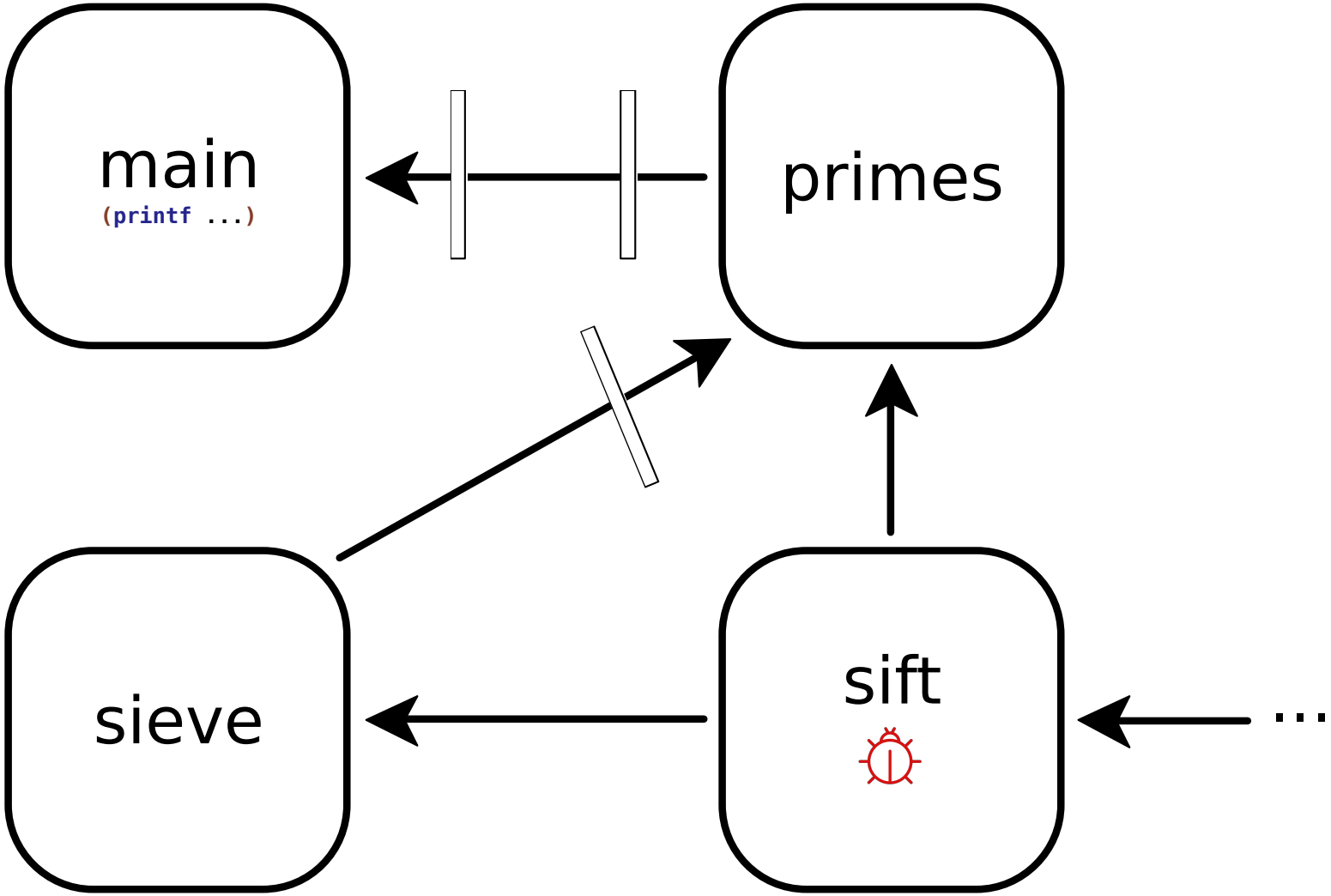
Contracts mediate component interaction

2 3 4 5 ...



Each component can impose contracts

2 3 4 5 ...



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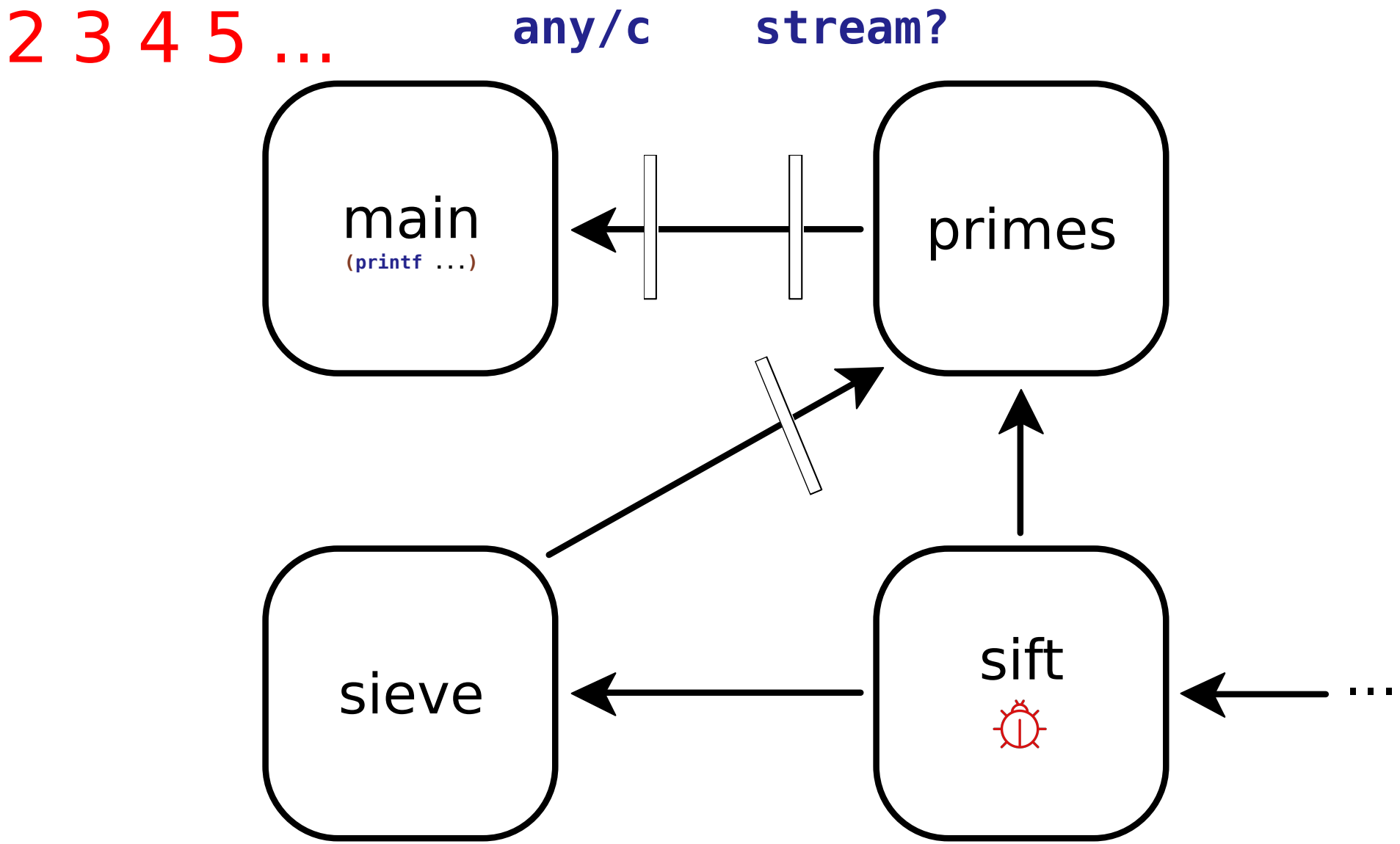
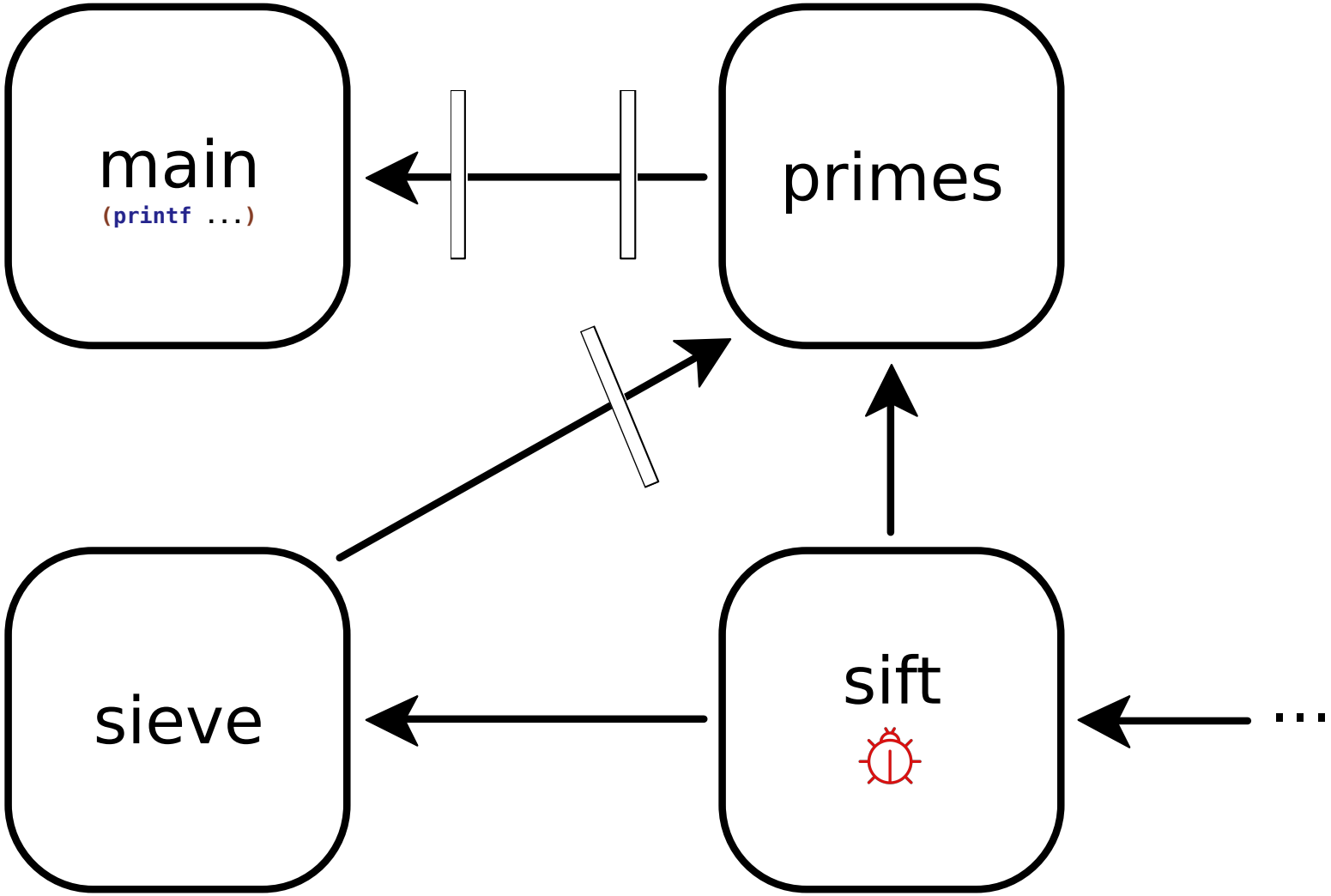


Contracts can have different strengths

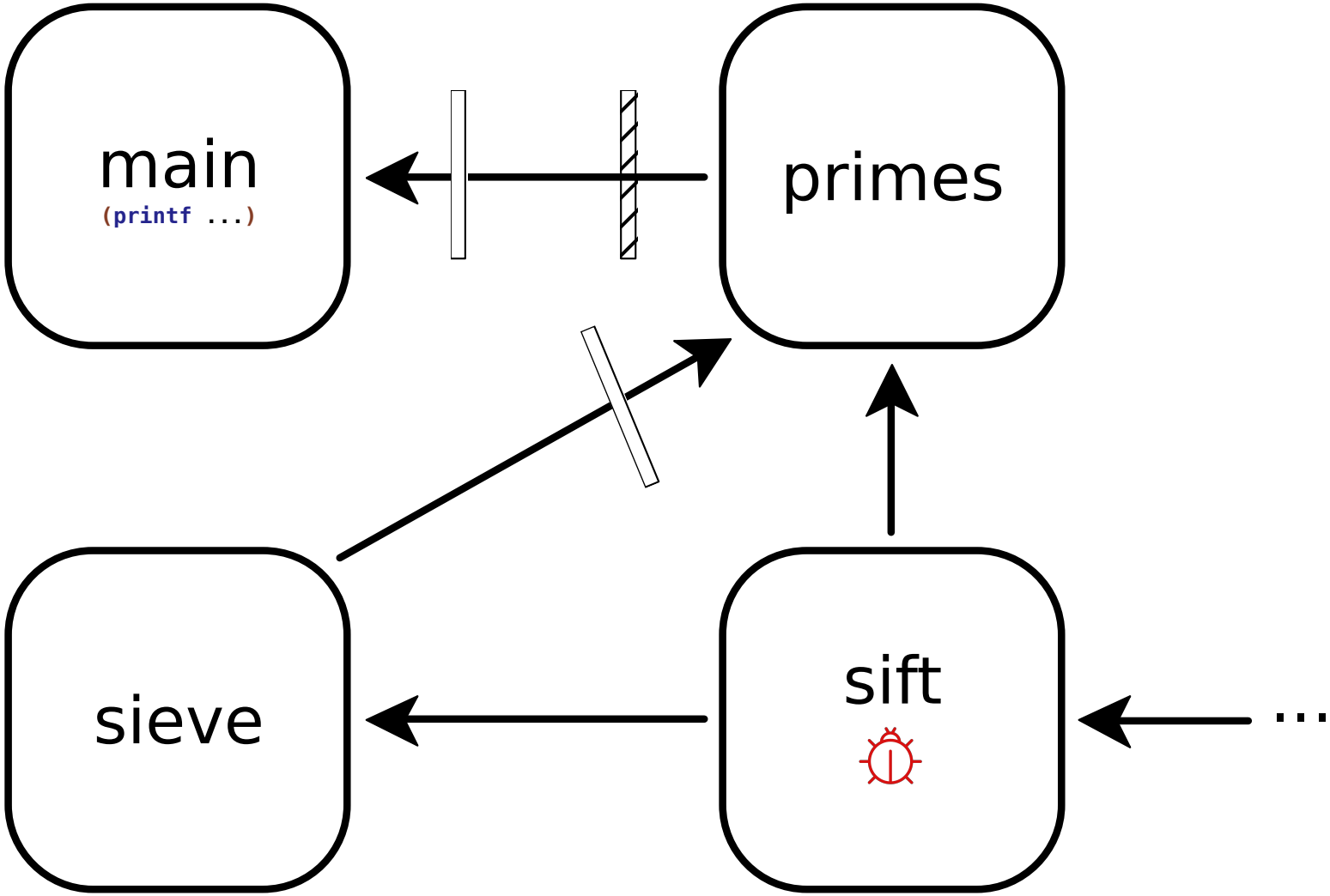
2 3 4 5 ...

stream?



Contracts can have different strengths

2 3 4 5 ... `(streamof positive-integer?)`



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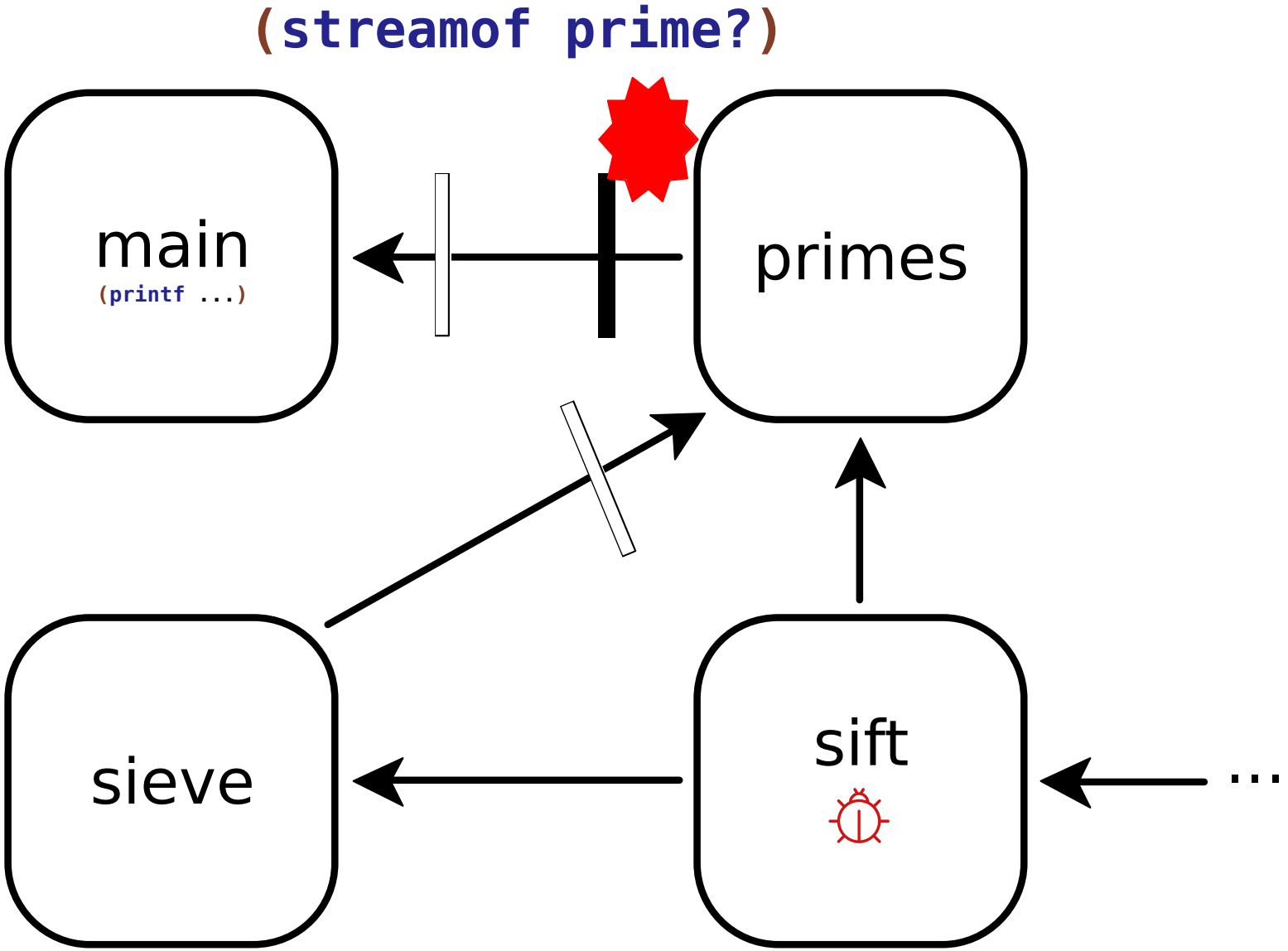

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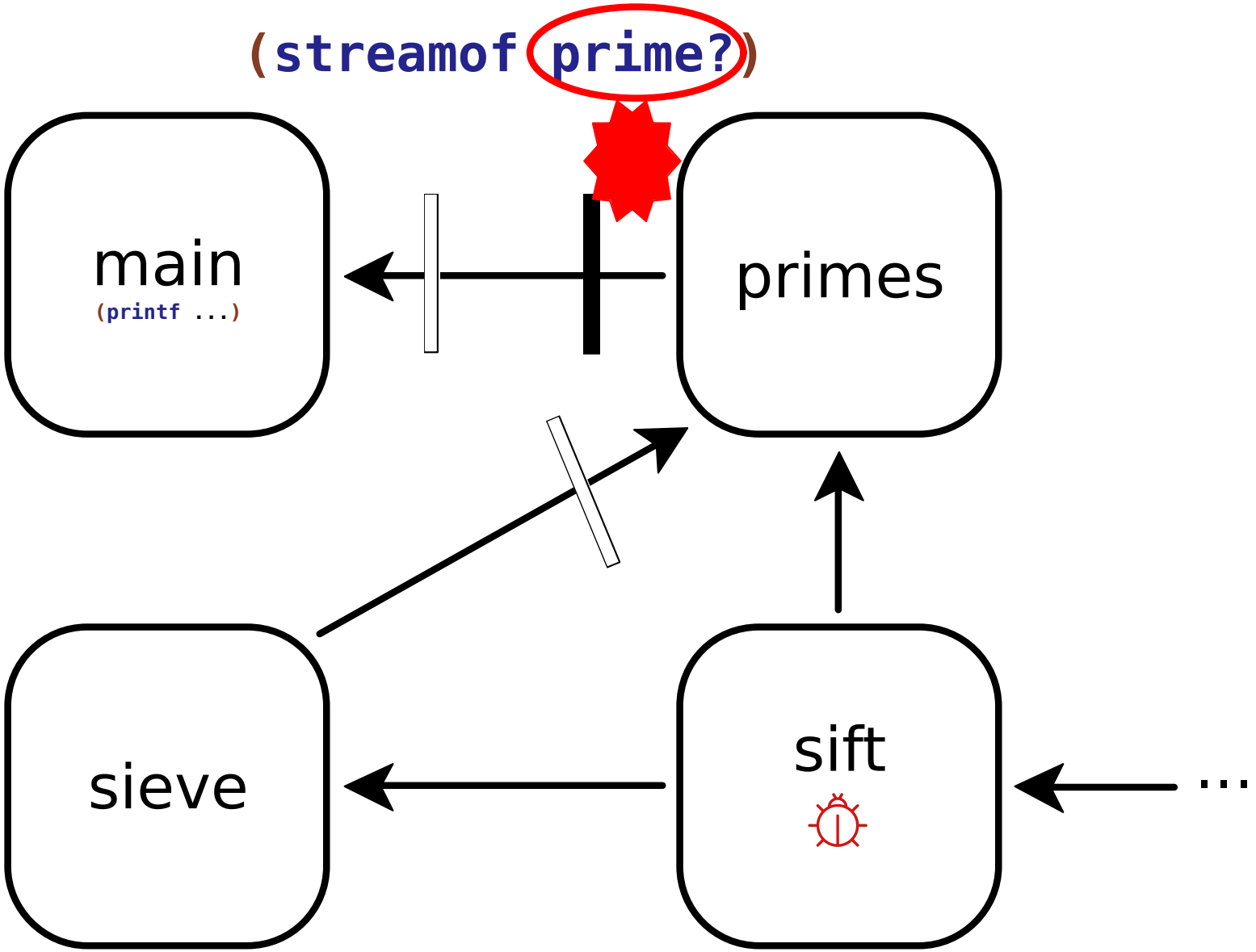
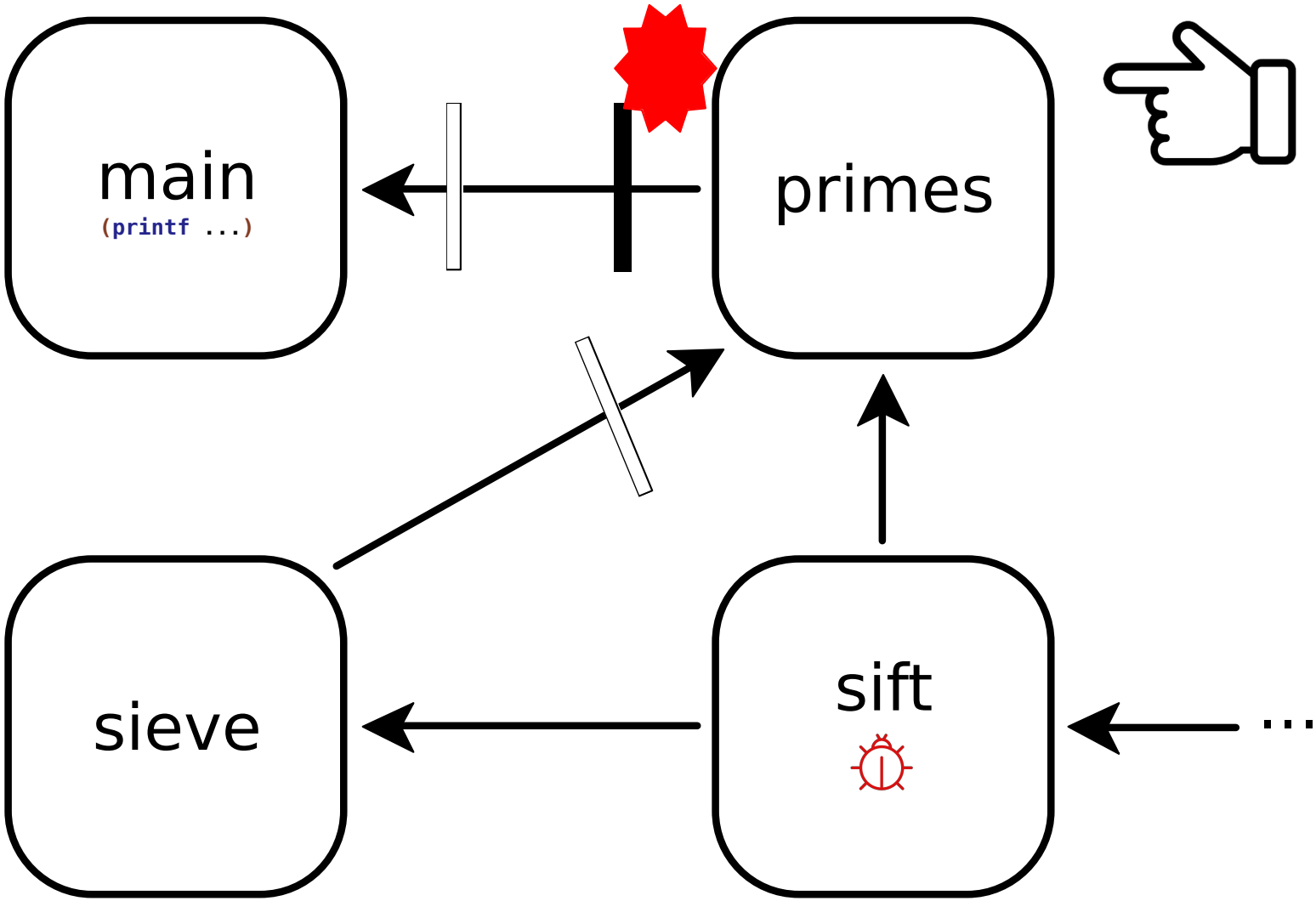


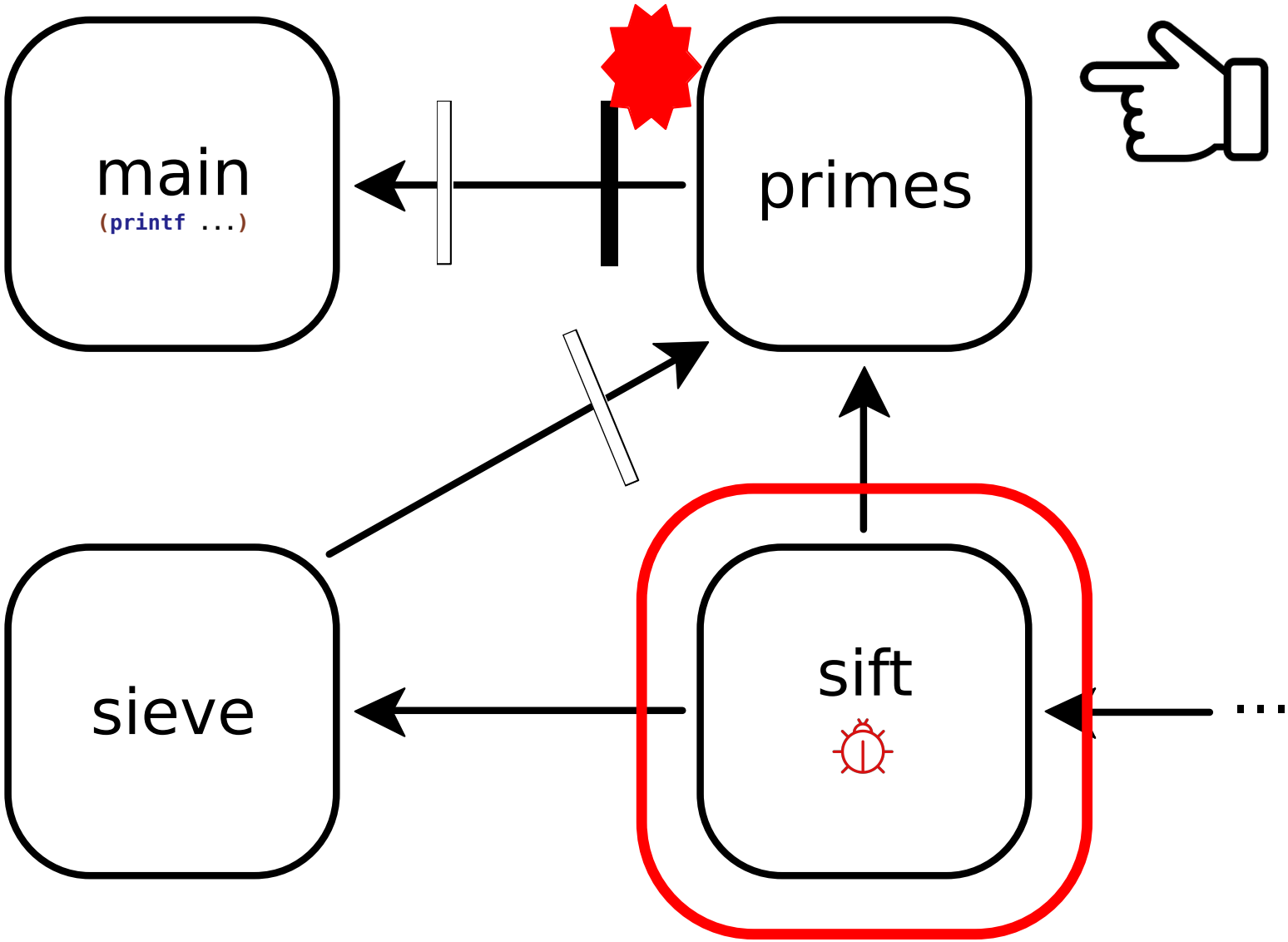
Violations blame a component

```
; primes: contract violation
;   promised: prime?
;   produced: 4
;   in: an element of
;       (streamof prime?)
;   contract from: primes.rkt
;   blaming: primes.rkt
;    (assuming the contract is correct)
```

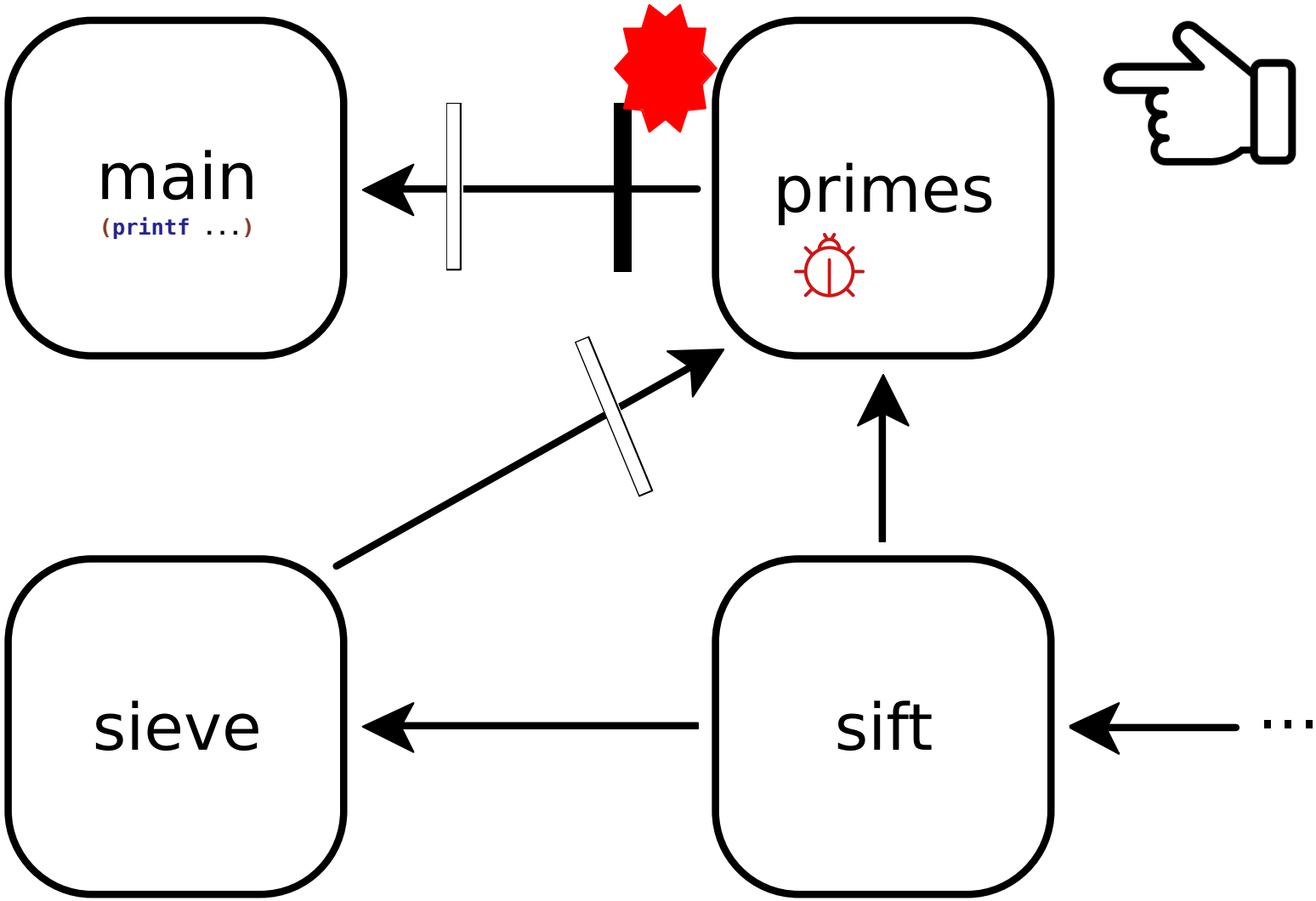
Violations blame a component



But blame may be far from the bug



Interpreting blame



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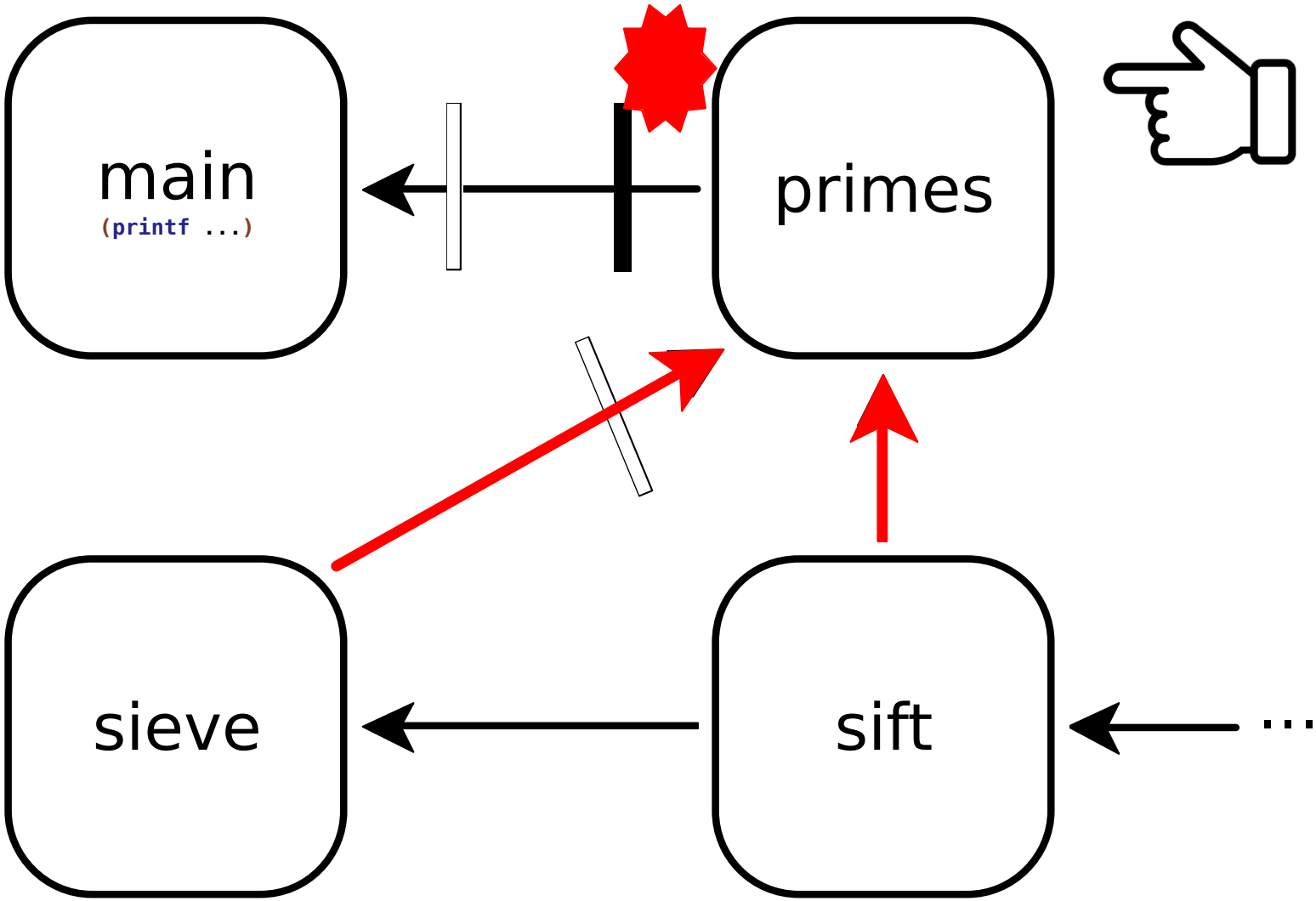

How does blame help?

“Correct blame assignment **gets programmers started** with the **debugging process**”
[Dimoulas et al. POPL'11]

“After all, the **purpose of blame** assignment is to **assist programmers with debugging**”
[Strickland & Felleisen IFL'09]

Blame “narrow[s] down the **search for the error**”
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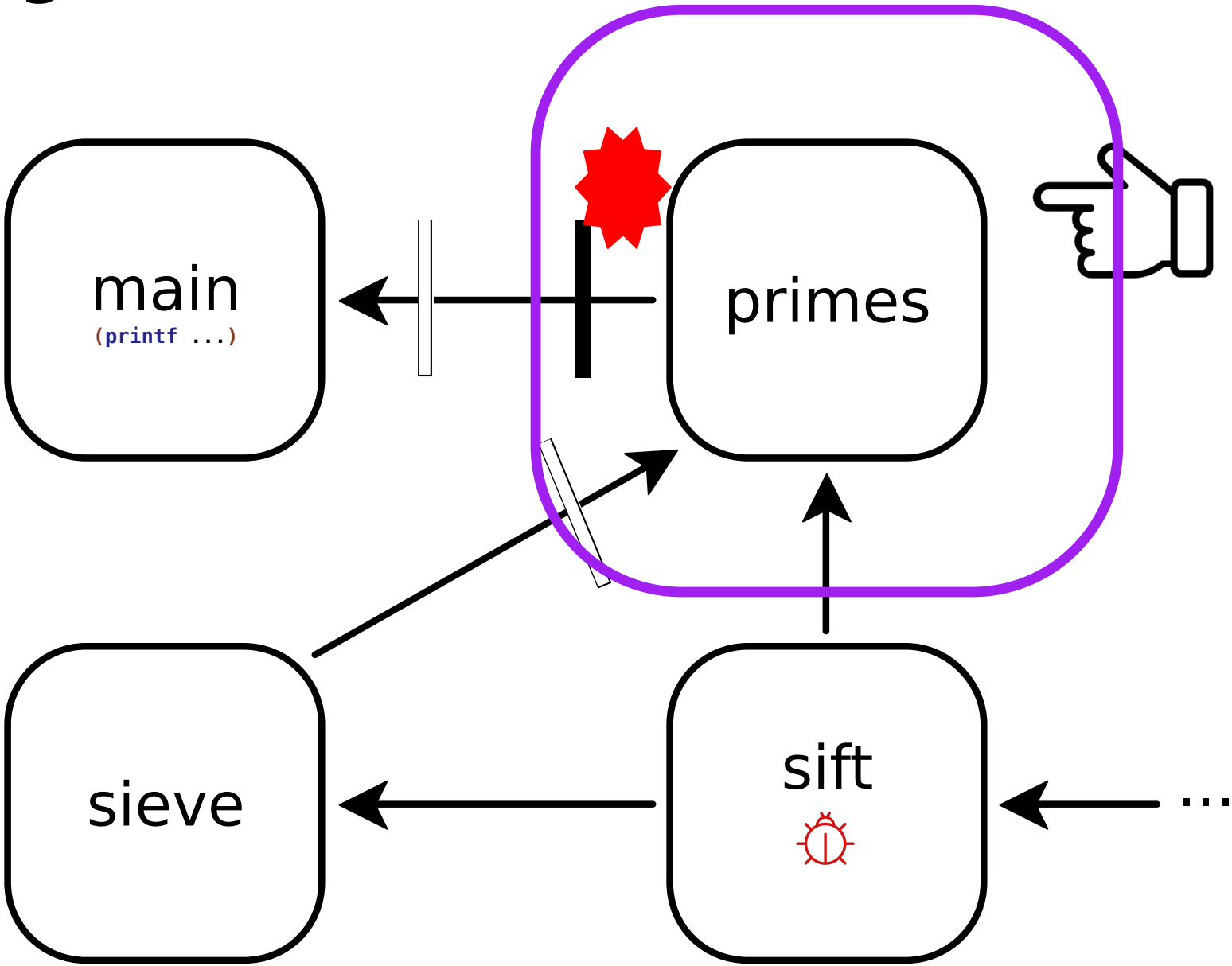
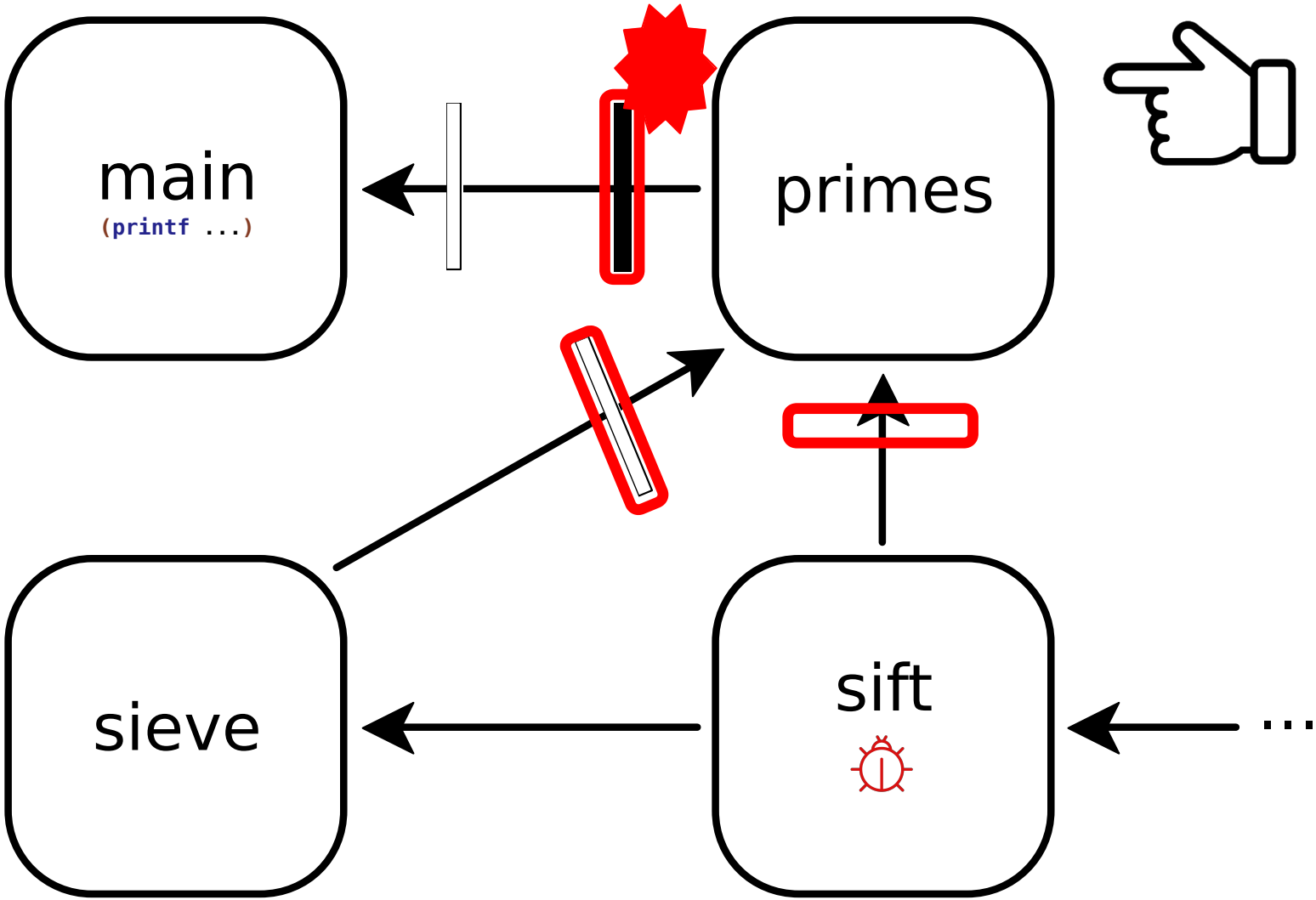
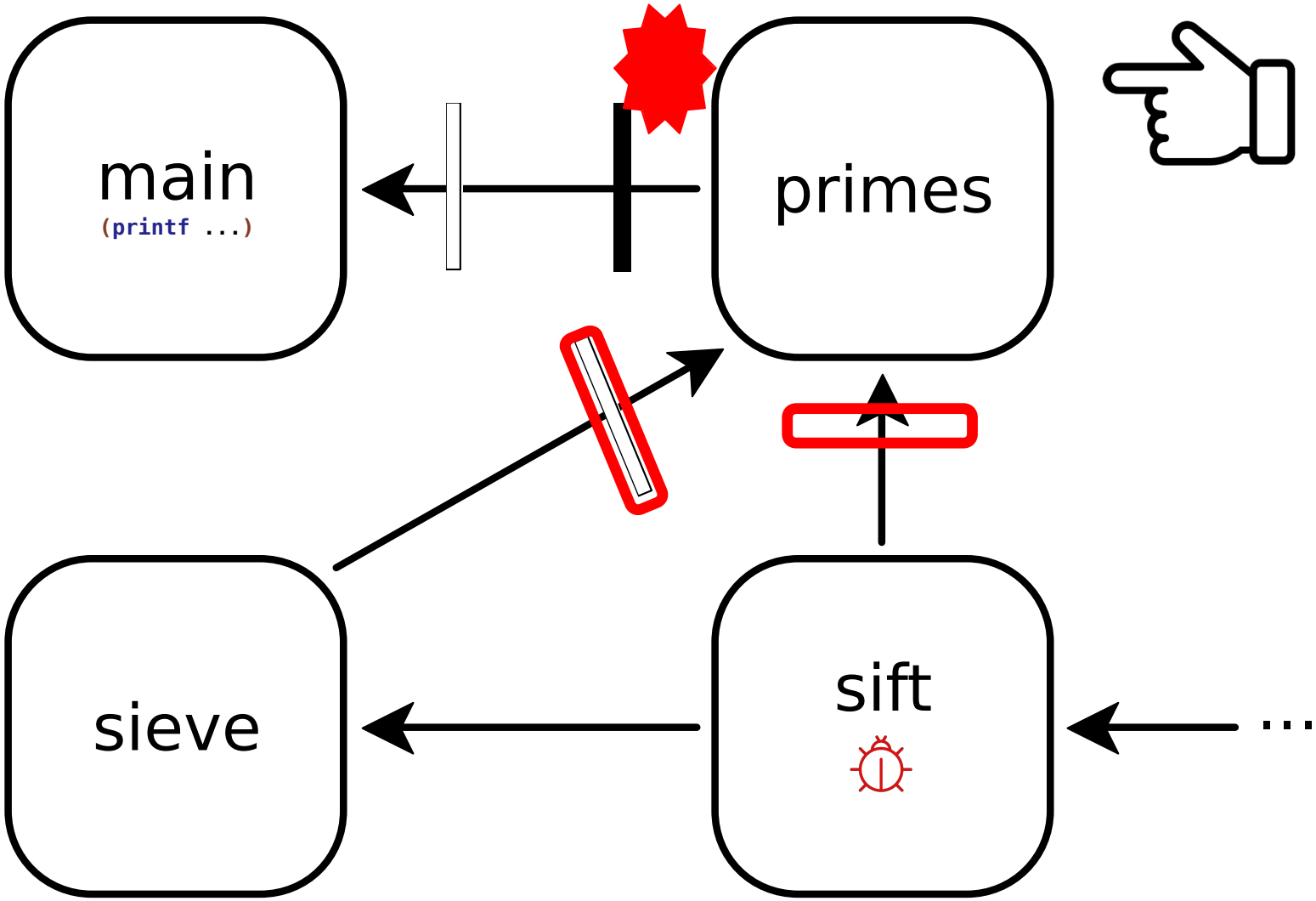
Using blame to focus our attention



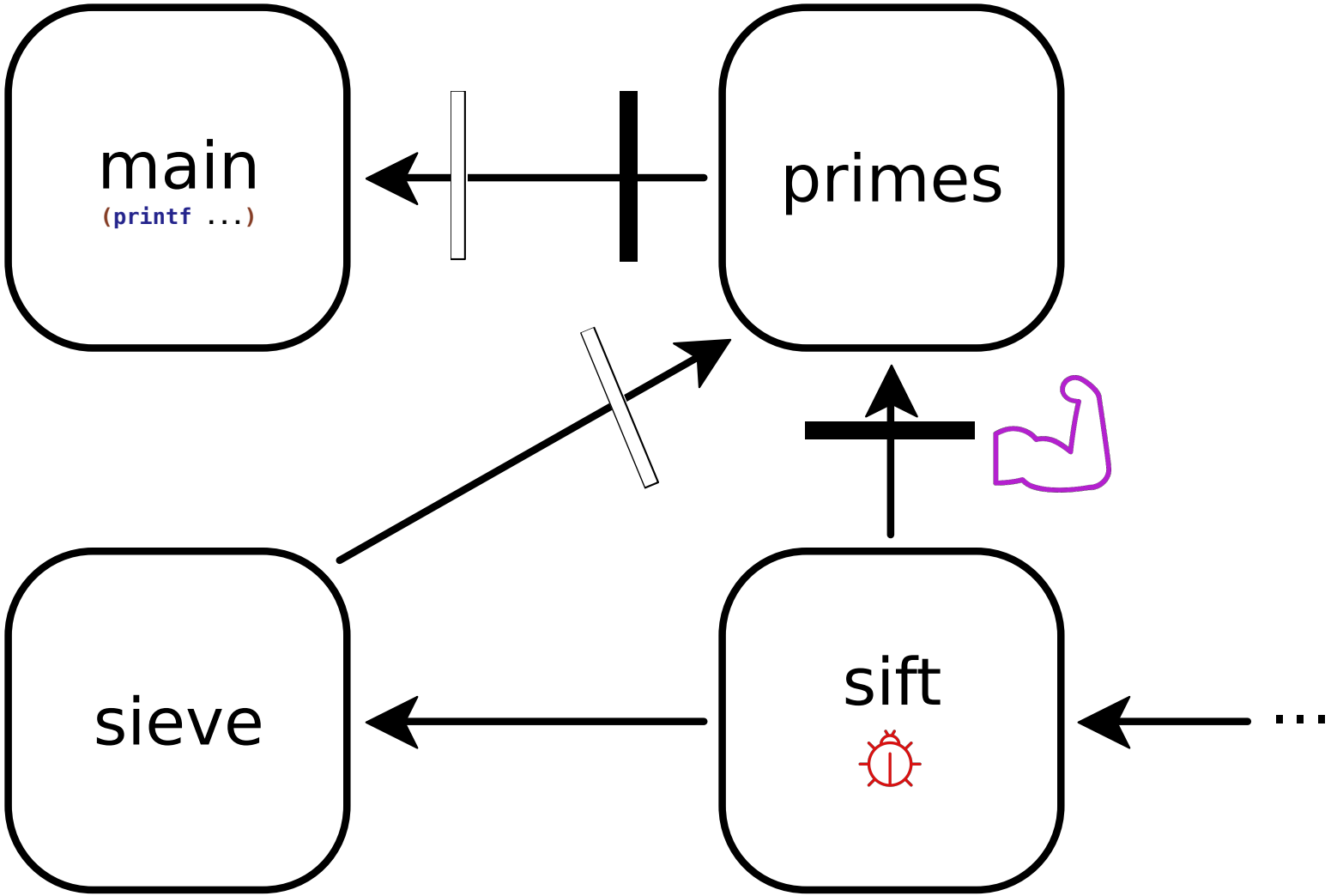
Contracts around a component



Contracts around a component



Trying to shift blame



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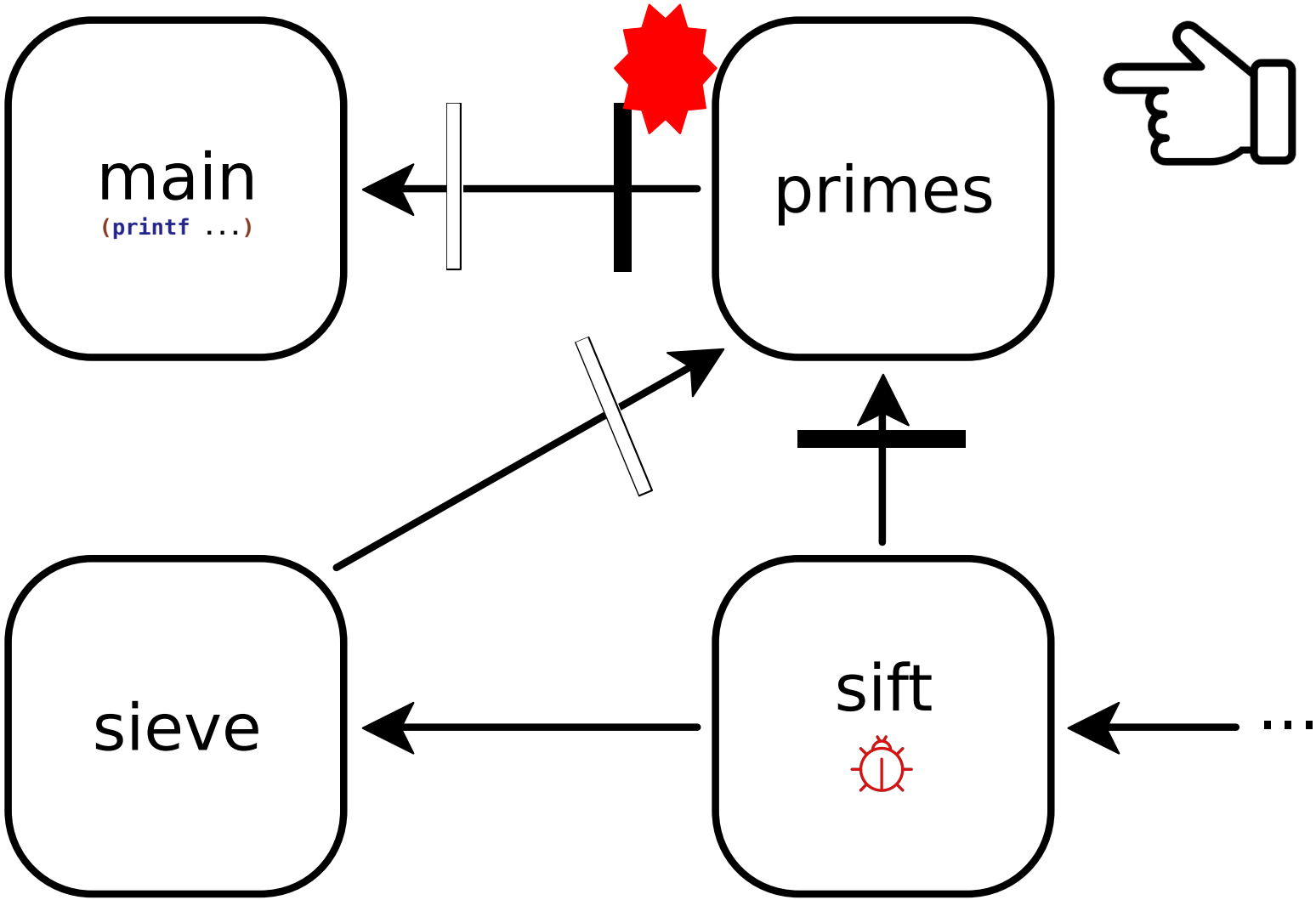

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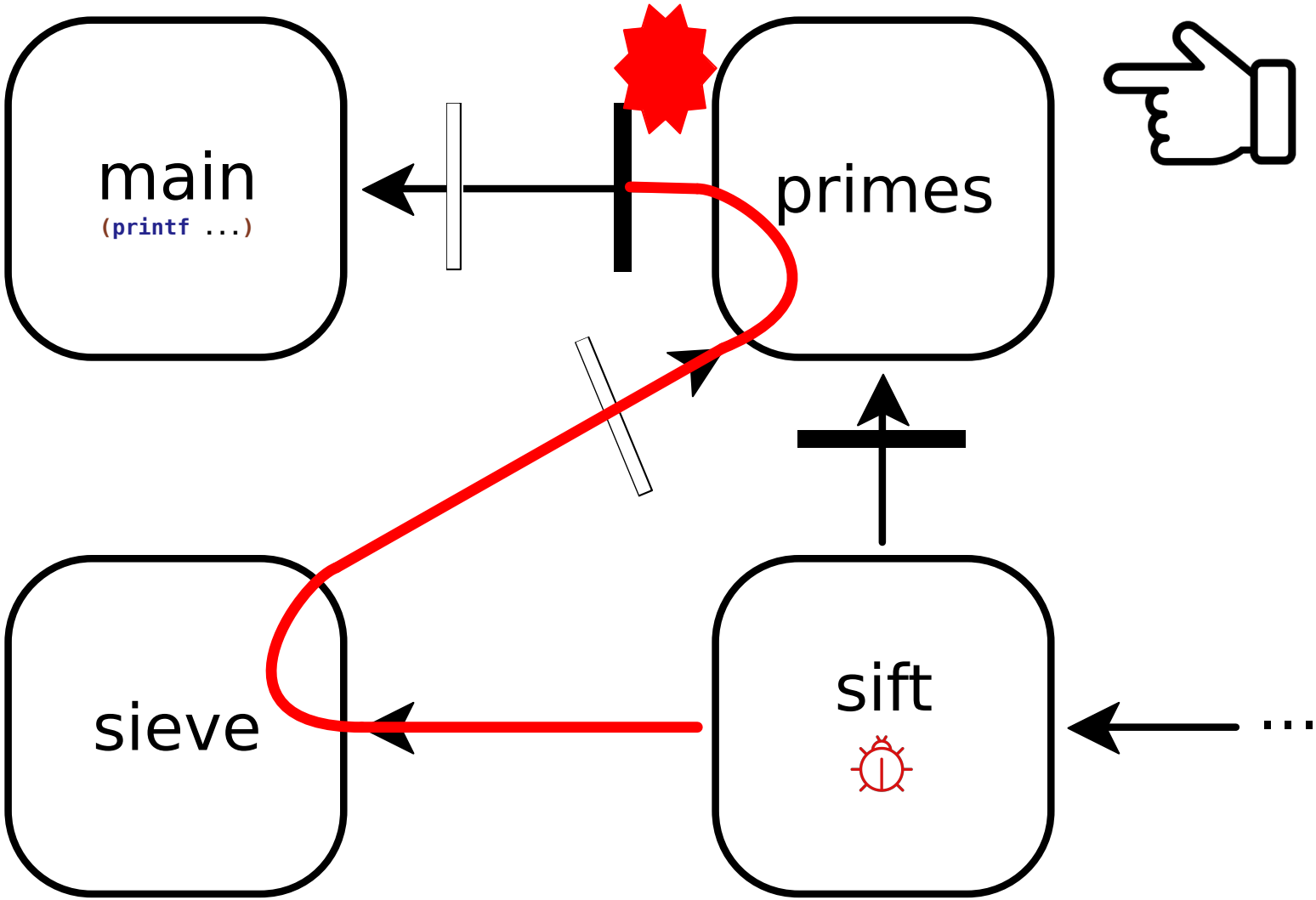

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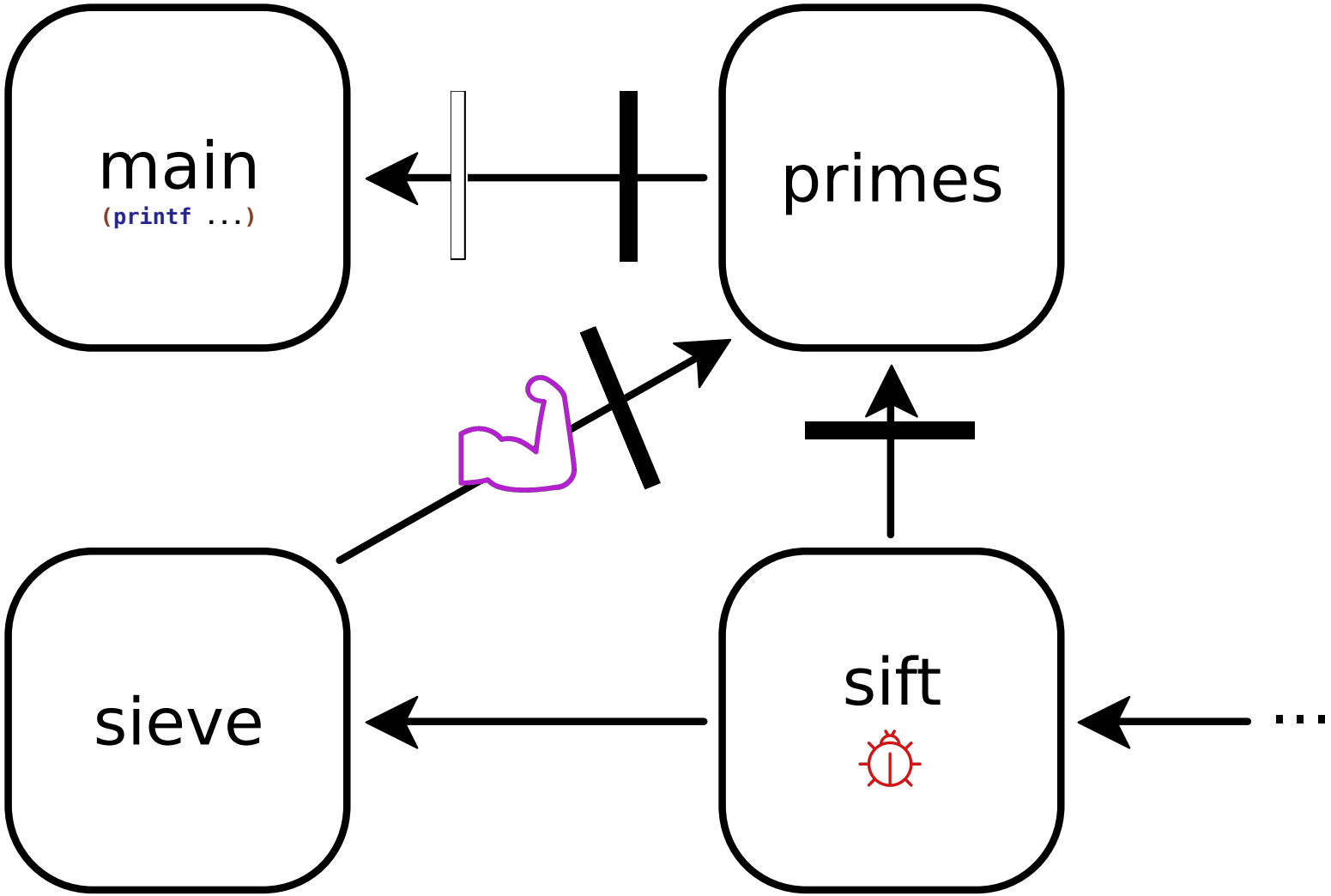

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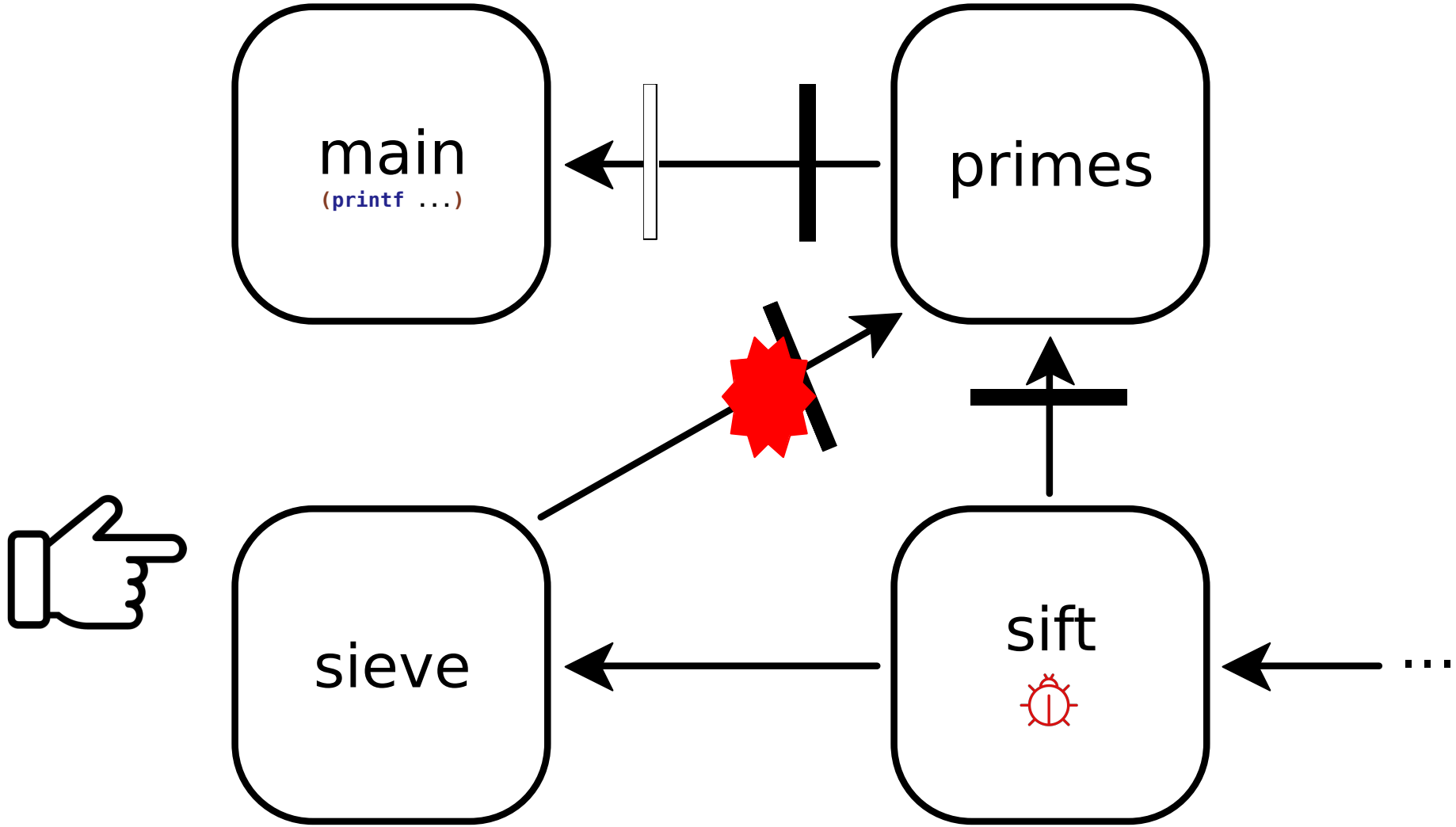

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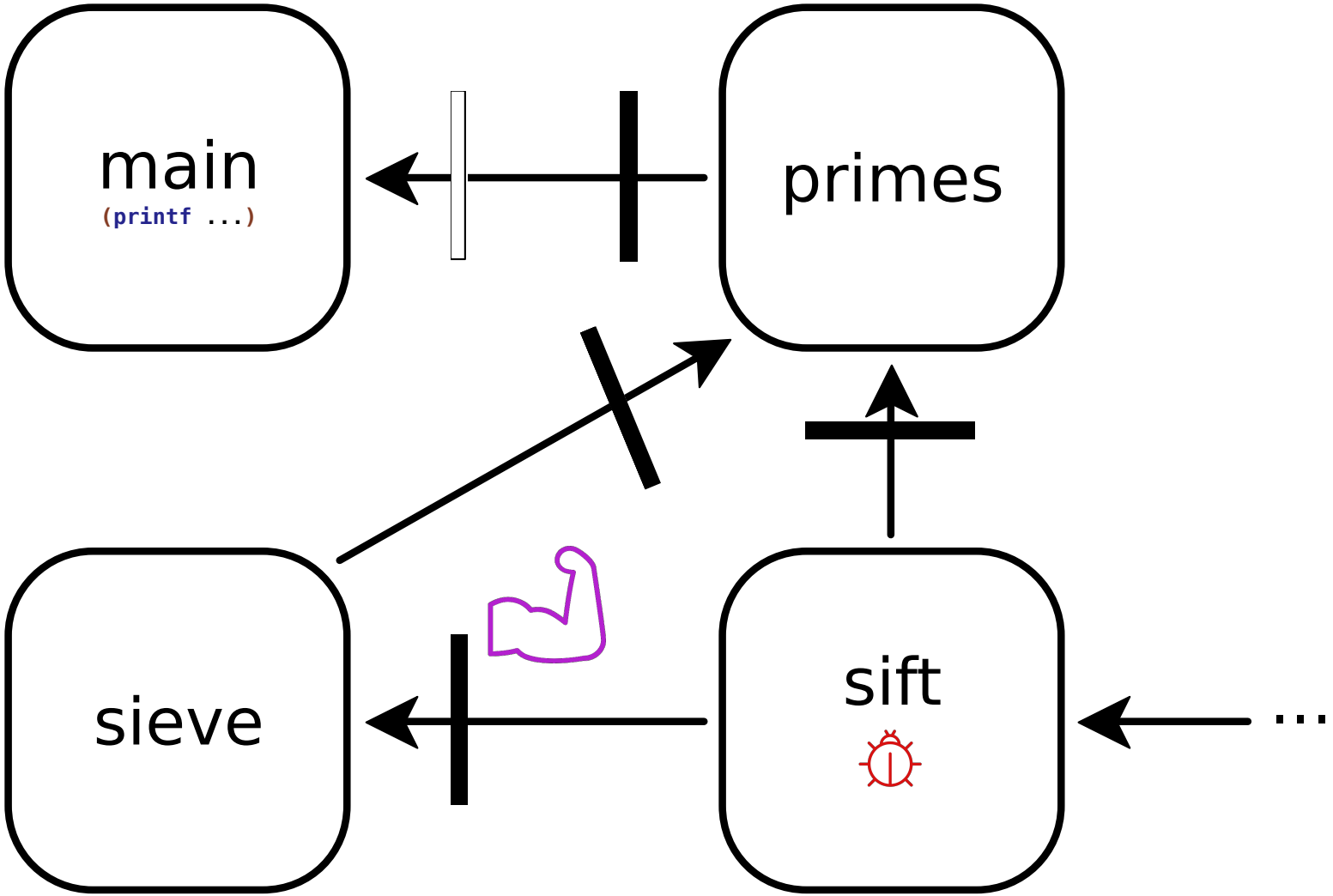

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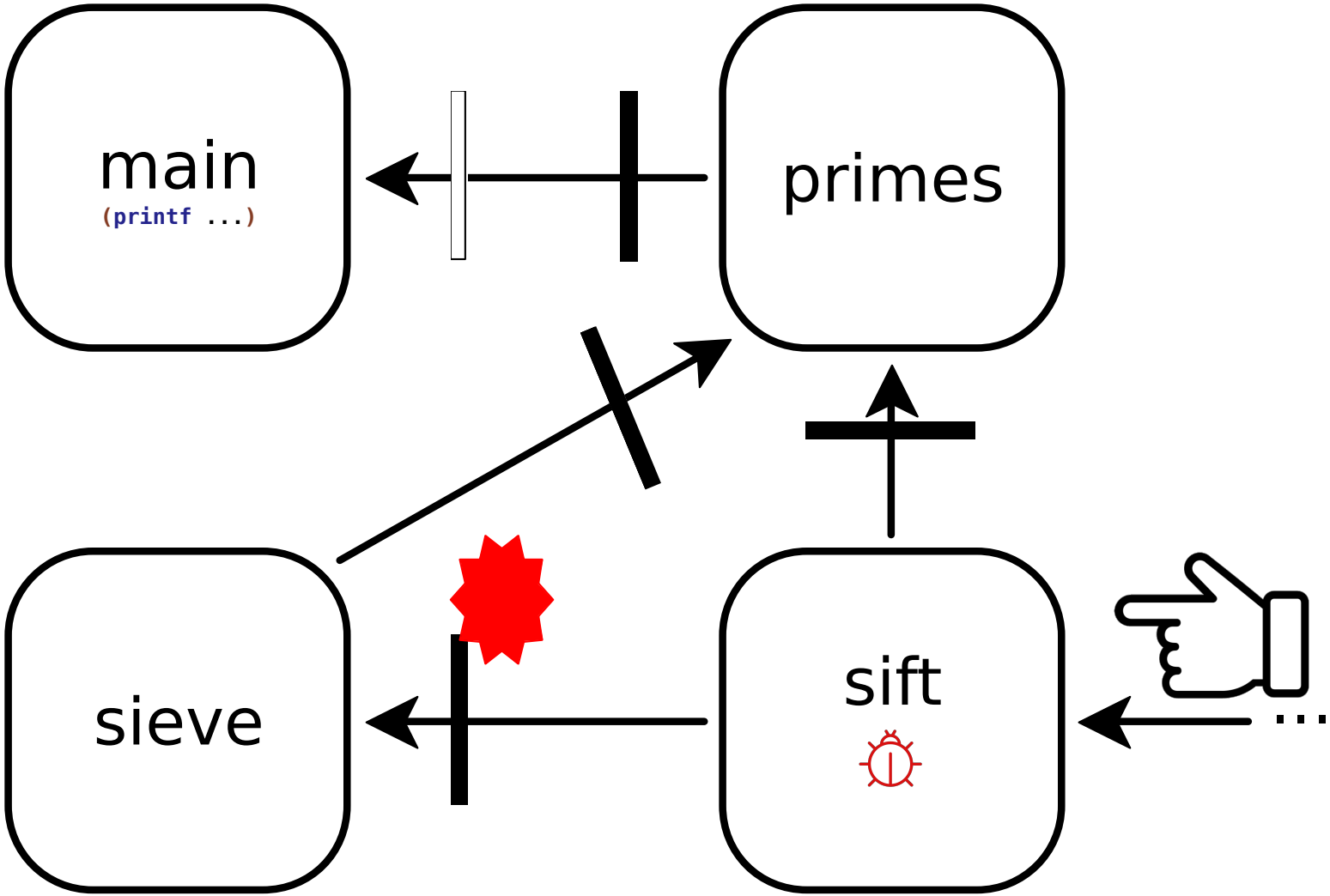
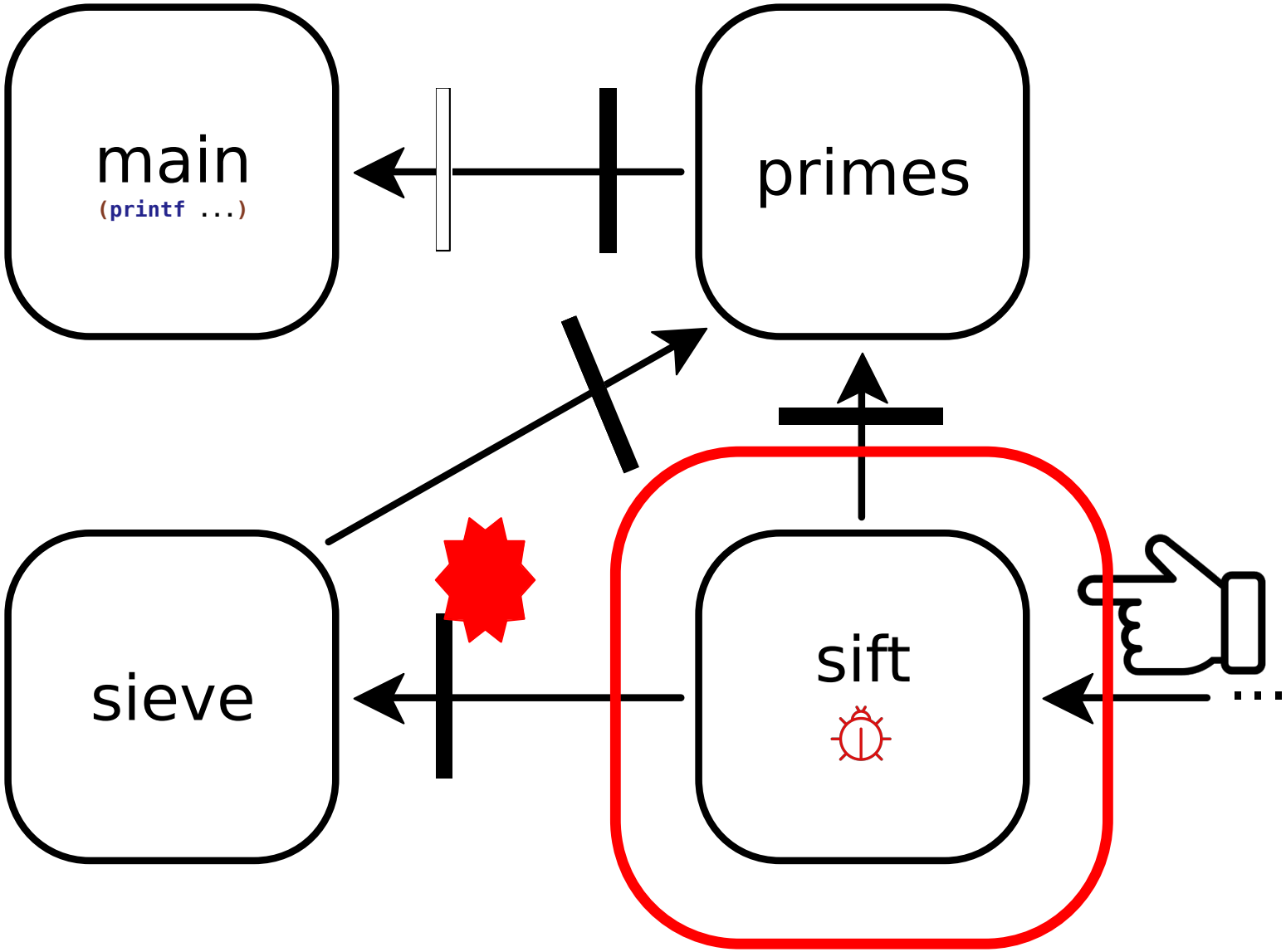


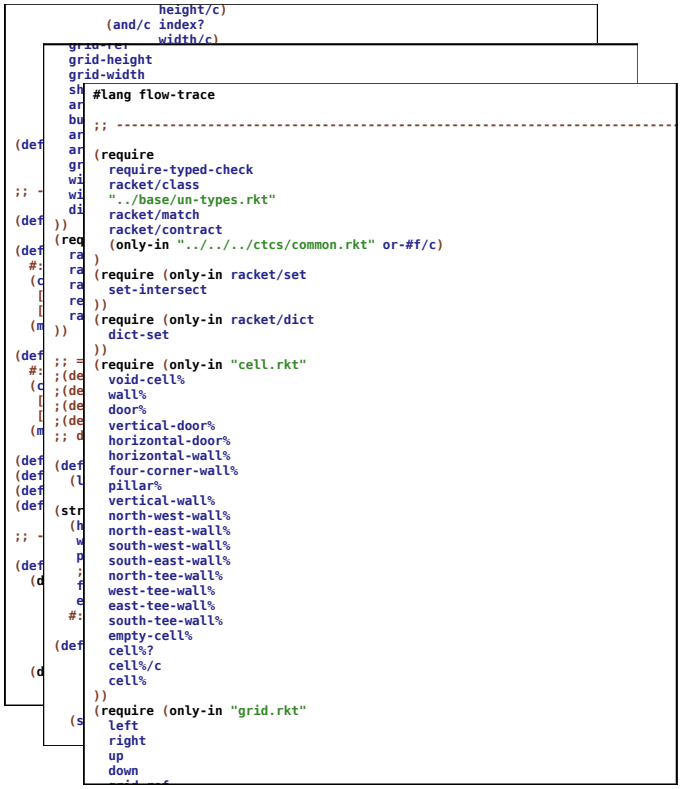
Blame shifting should lead us to the bug



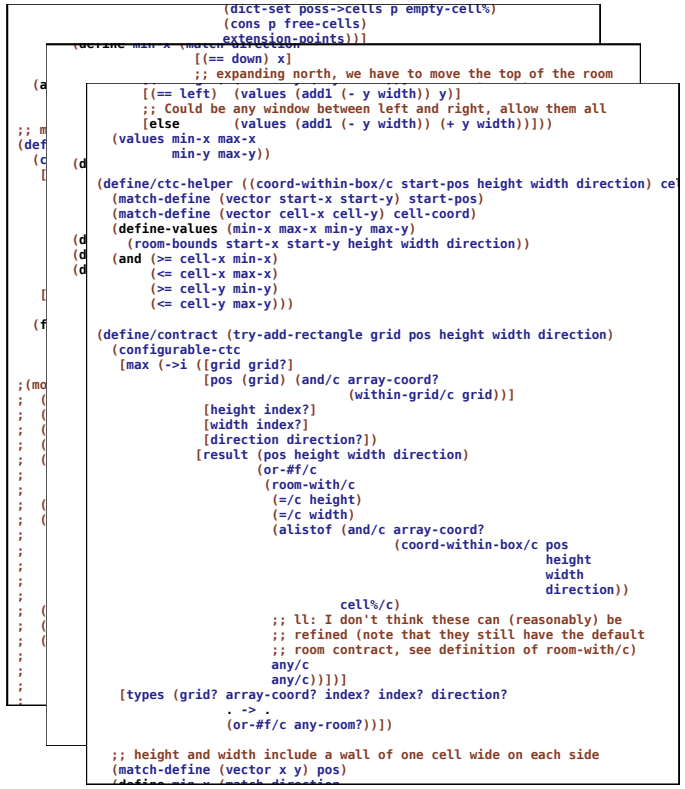
The hypothesis, a little more precisely

Blame can be systematically translated into the location of the bug via blame shifting

Empirically evaluating blame shifting

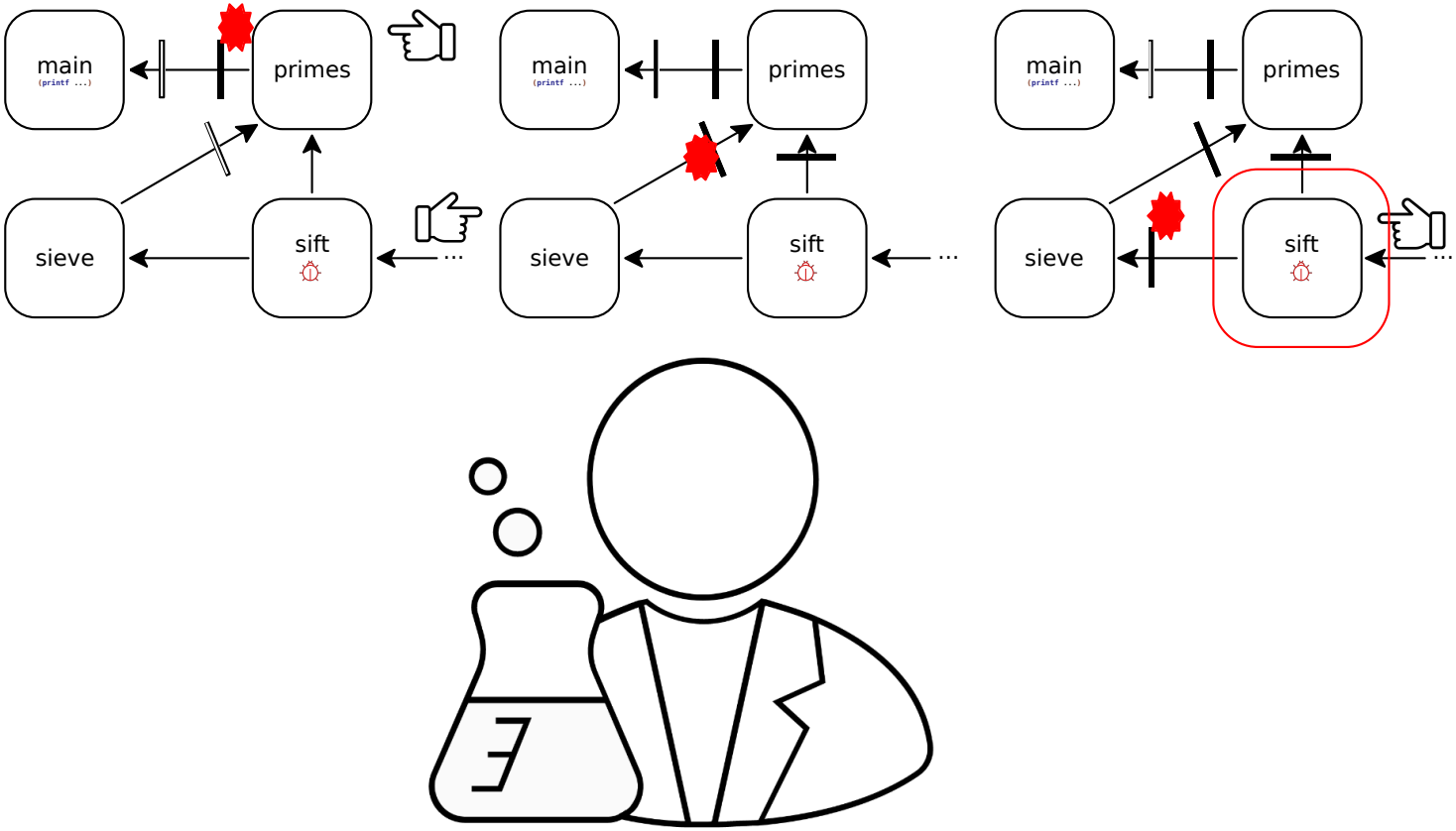


```
#lang flow-trace

;; ------------------------------------------------------------------------

(require
  require-typed-check
  racket/class
  "../base/un-types.rkt"
  racket/match
  racket/contract
  (only-in "../../../ctcs/common.rkt" or-#f/c)
)
(require (only-in racket/set
  set-intersect
))
(require (only-in racket/dict
  dict-set
))
(require (only-in "cell.rkt"
  void-cell%
  wall%
  door%
  vertical-door%
  horizontal-door%
  horizontal-wall%
  four-corner-wall%
  pillar%
  vertical-wall%
  north-west-wall%
  north-east-wall%
  south-west-wall%
  south-east-wall%
  north-tee-wall%
  west-tee-wall%
  east-tee-wall%
  south-tee-wall%
  empty-cell%
  cell%?
  cell%/c
  cell%
))
(require (only-in "grid.rkt"
  left
  right
  up
  down
```

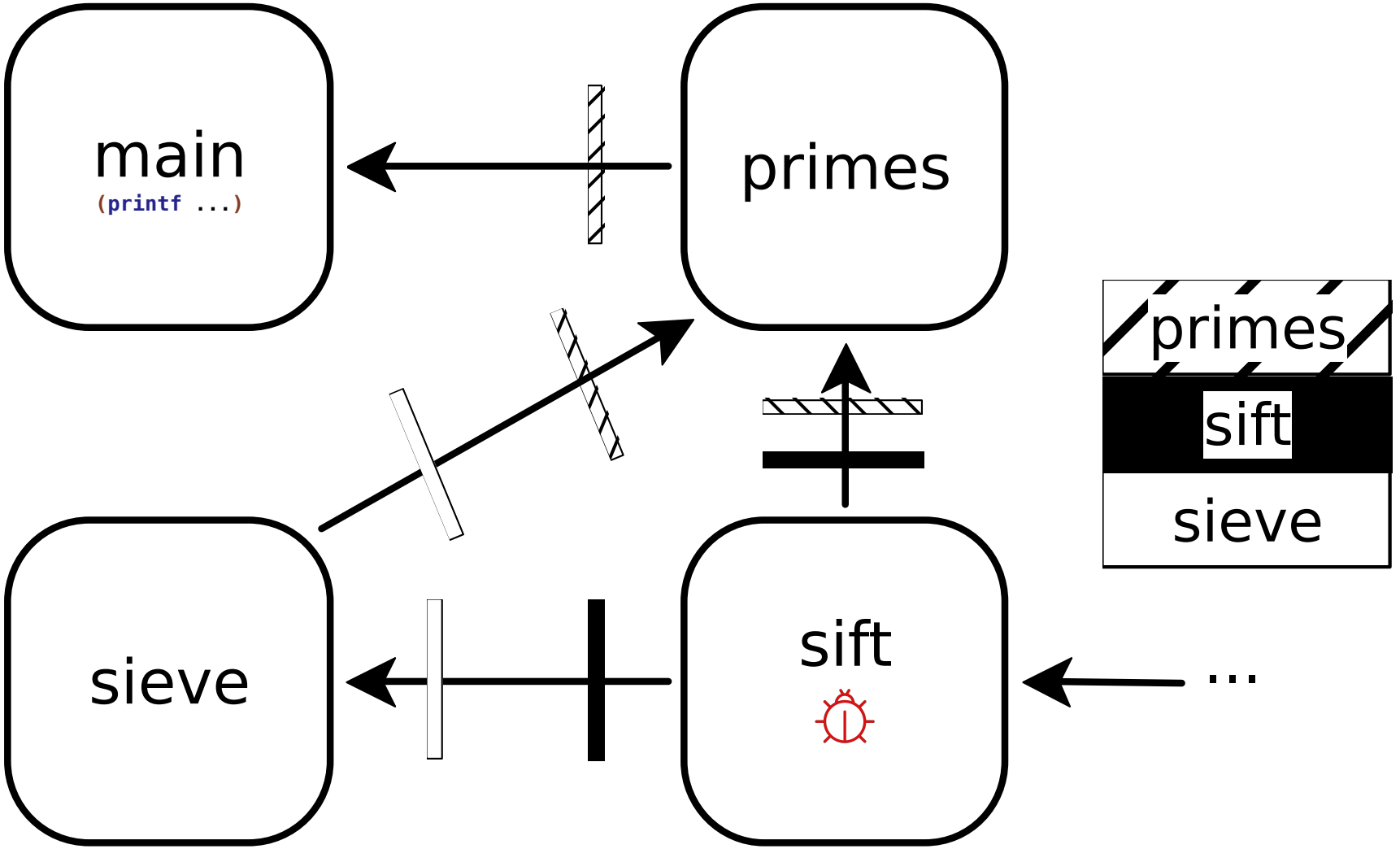


```
      [(== left)  (values (add1 (- y width)) y)]
      ;; Could be any window between left and right, allow them all
      [else       (values (add1 (- y width)) (+ y width))]))
  (values min-x max-x
          min-y max-y))

(define/ctc-helper ((coord-within-box/c start-pos height width direction) ce
  (match-define (vector start-x start-y) start-pos)
  (match-define (vector cell-x cell-y) cell-coord)
  (define-values (min-x max-x min-y max-y)
    (room-bounds start-x start-y height width direction))
  (and (>= cell-x min-x)
       (<= cell-x max-x)
       (>= cell-y min-y)
       (<= cell-y max-y)))

(define/contract (try-add-rectangle grid pos height width direction)
  (configurable-ctc
   [max (->i ([grid grid?]
              [pos (grid) (and/c array-coord?
                                 (within-grid/c grid))]
              [height index?]
              [width index?]
              [direction direction?])
             [result (pos height width direction)
                     (or-#f/c
                      (room-with/c
                       (=/c height)
                       (=/c width)
                       (alistof (and/c array-coord?
                                       (coord-within-box/c pos
                                                           height
                                                           width
                                                           direction))
                                cell%/c)
                       ;; ll: I don't think these can (reasonably) be
                       ;; refined (note that they still have the default
                       ;; room contract, see definition of room-with/c)
                       any/c
                       any/c))])]
   [types (grid? array-coord? index? index? direction?
           . -> .
           (or-#f/c any-room?))])

  ;; height and width include a wall of one cell wide on each side
  (match-define (vector x y) pos)
```

Empirically evaluating blame shifting



Configuring the program with contracts



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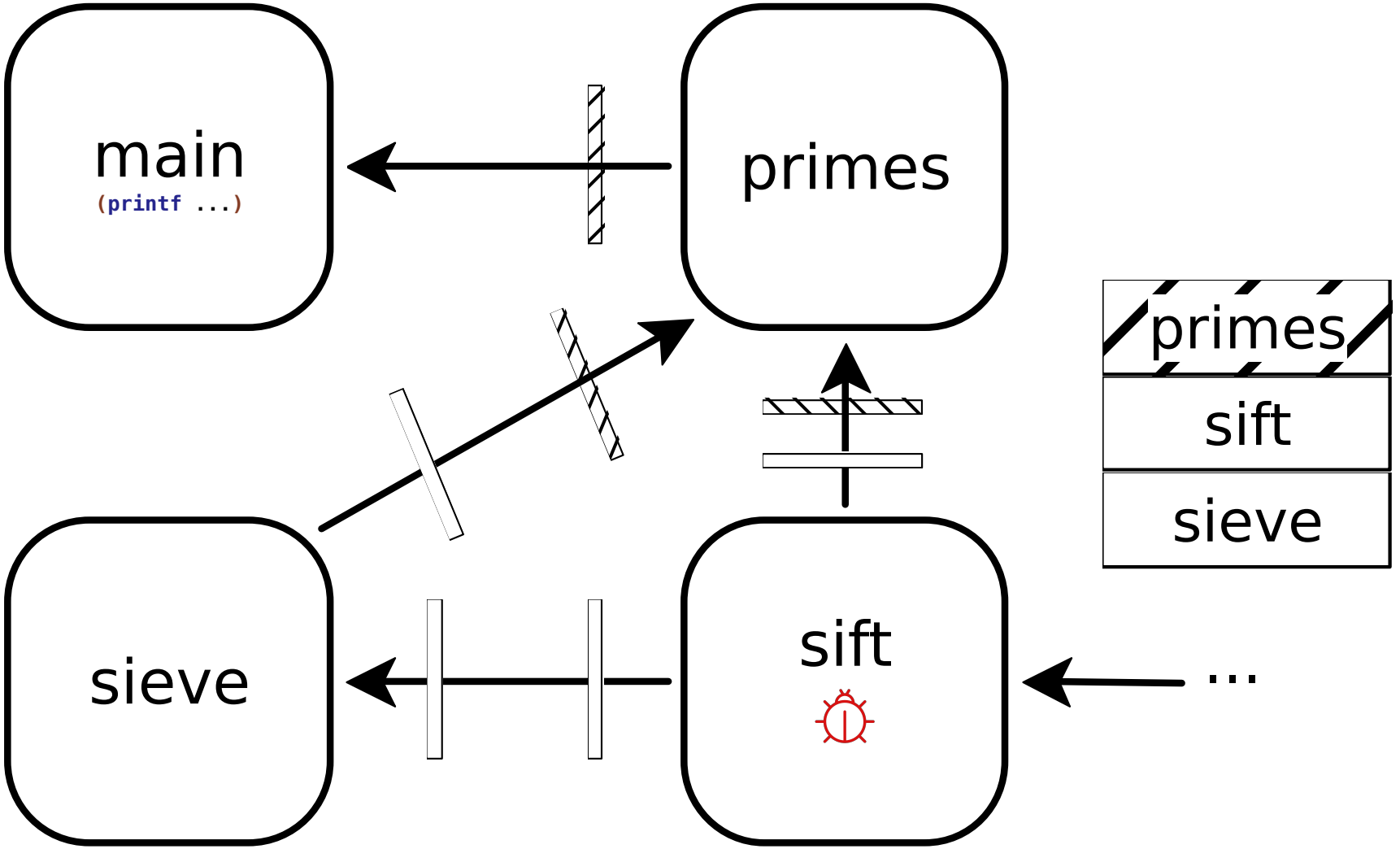
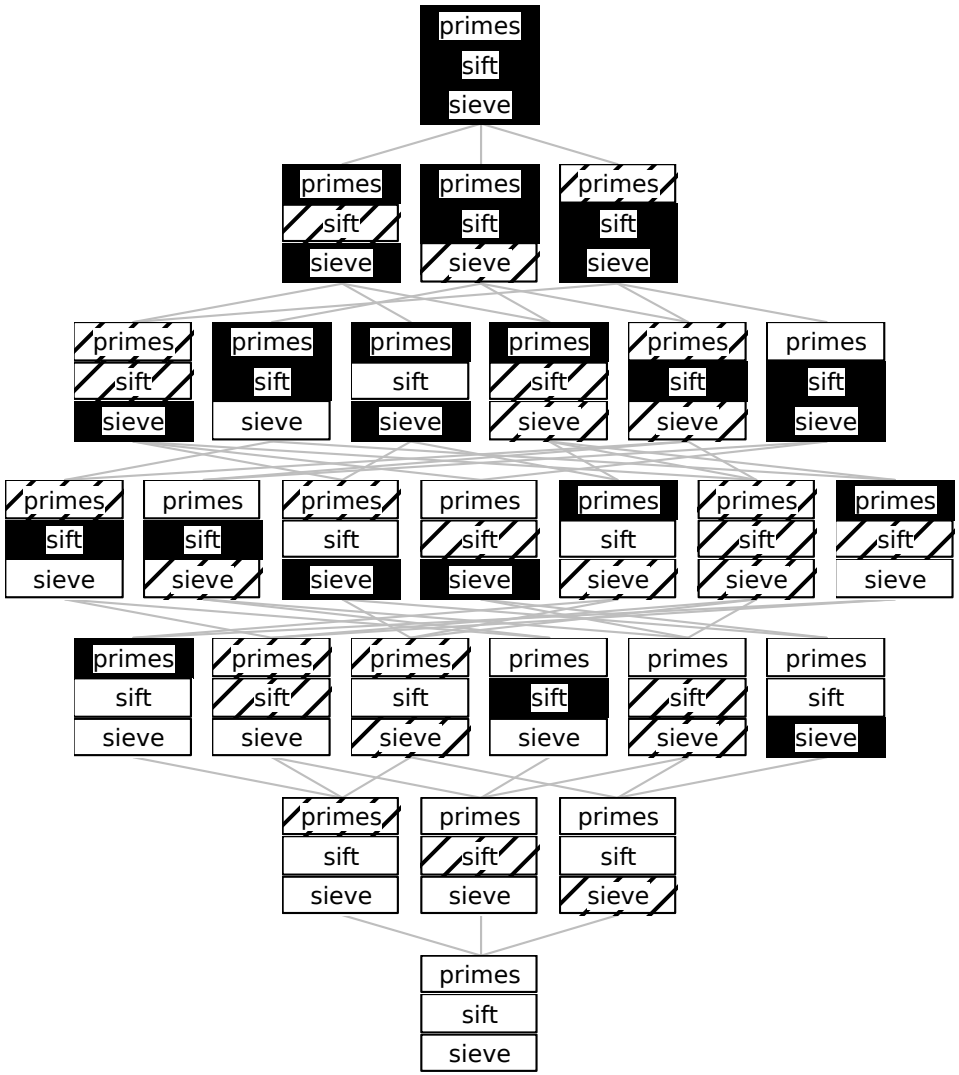
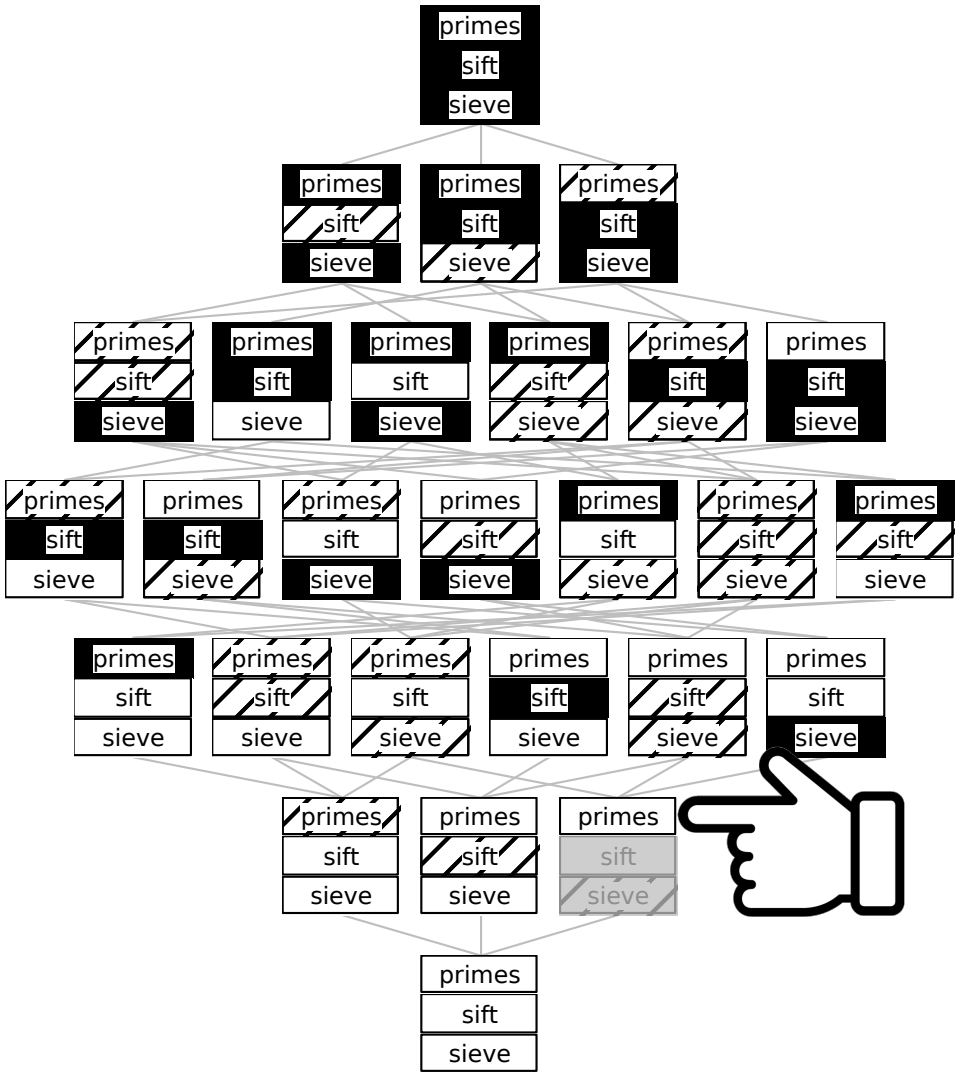


Configurations form a lattice



Blame shifting forms a blame trail



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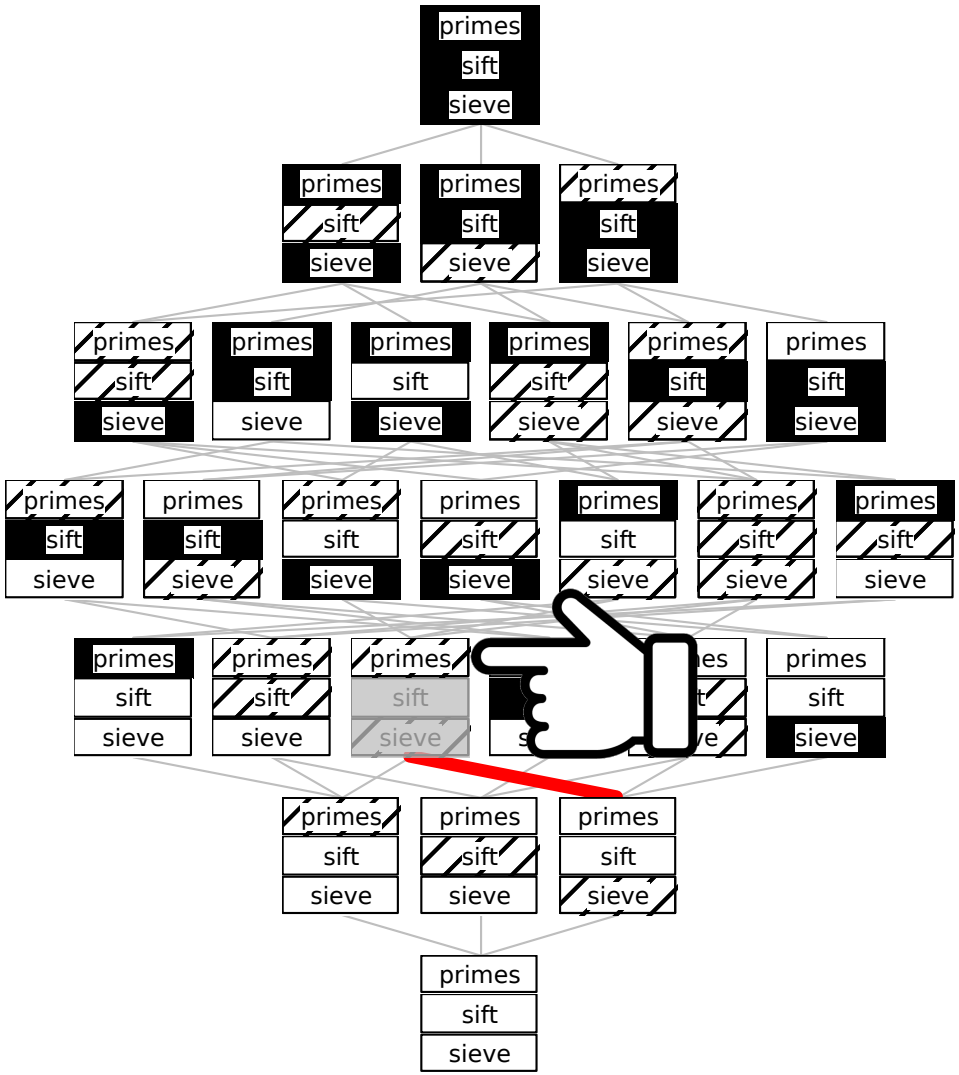

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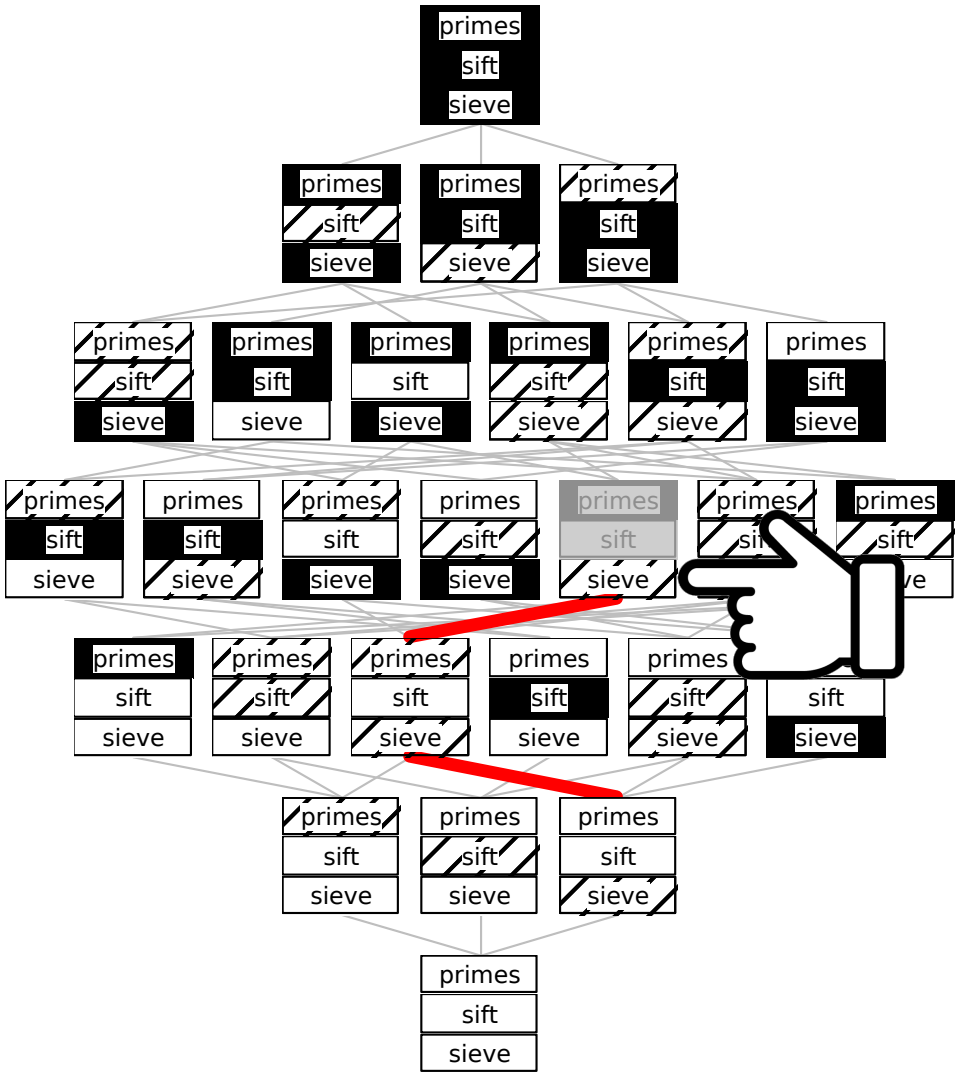

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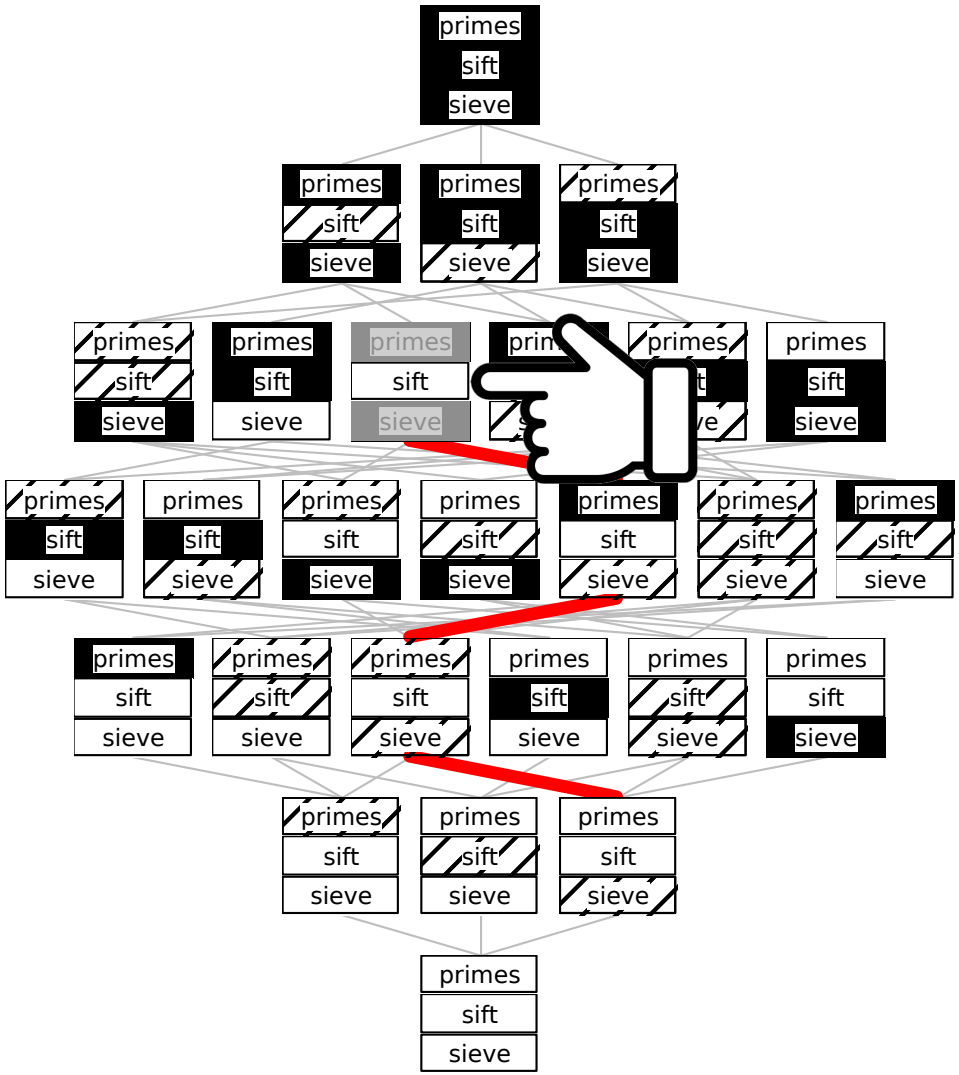

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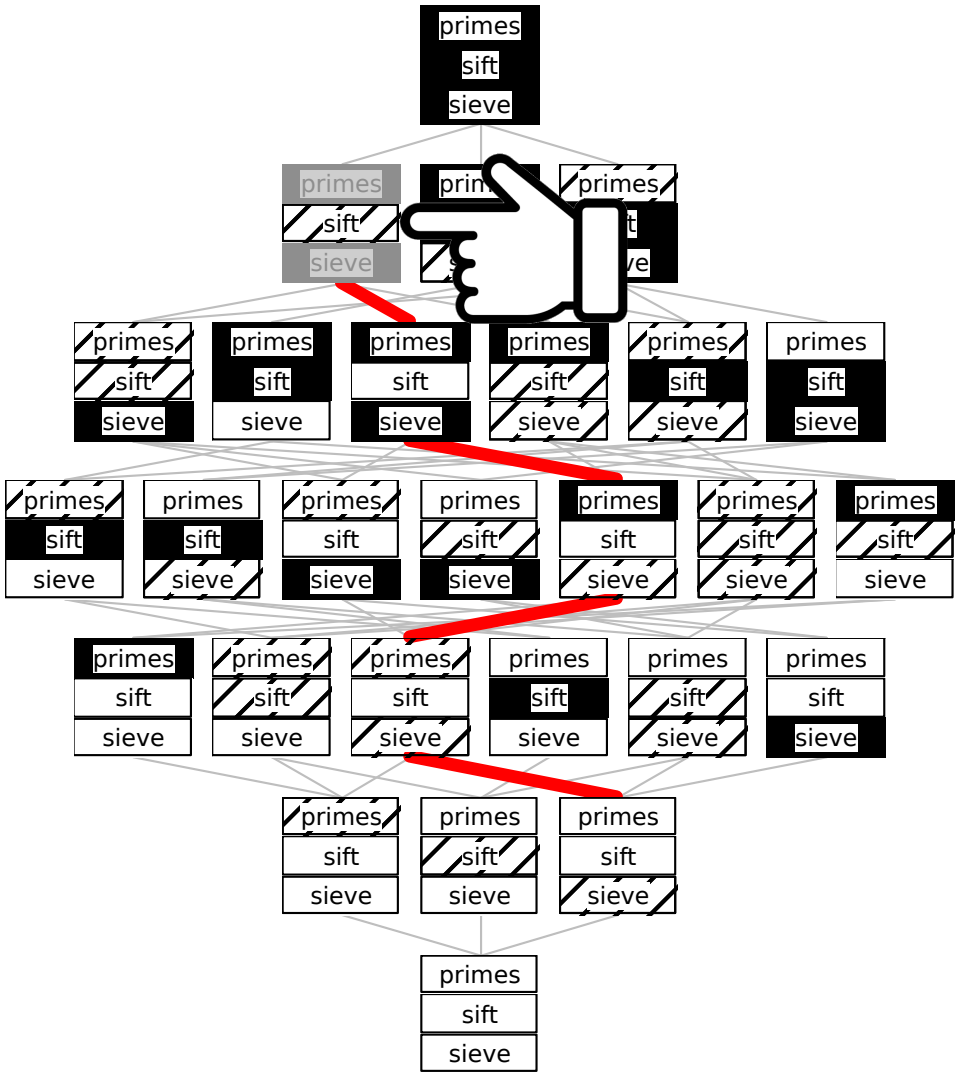

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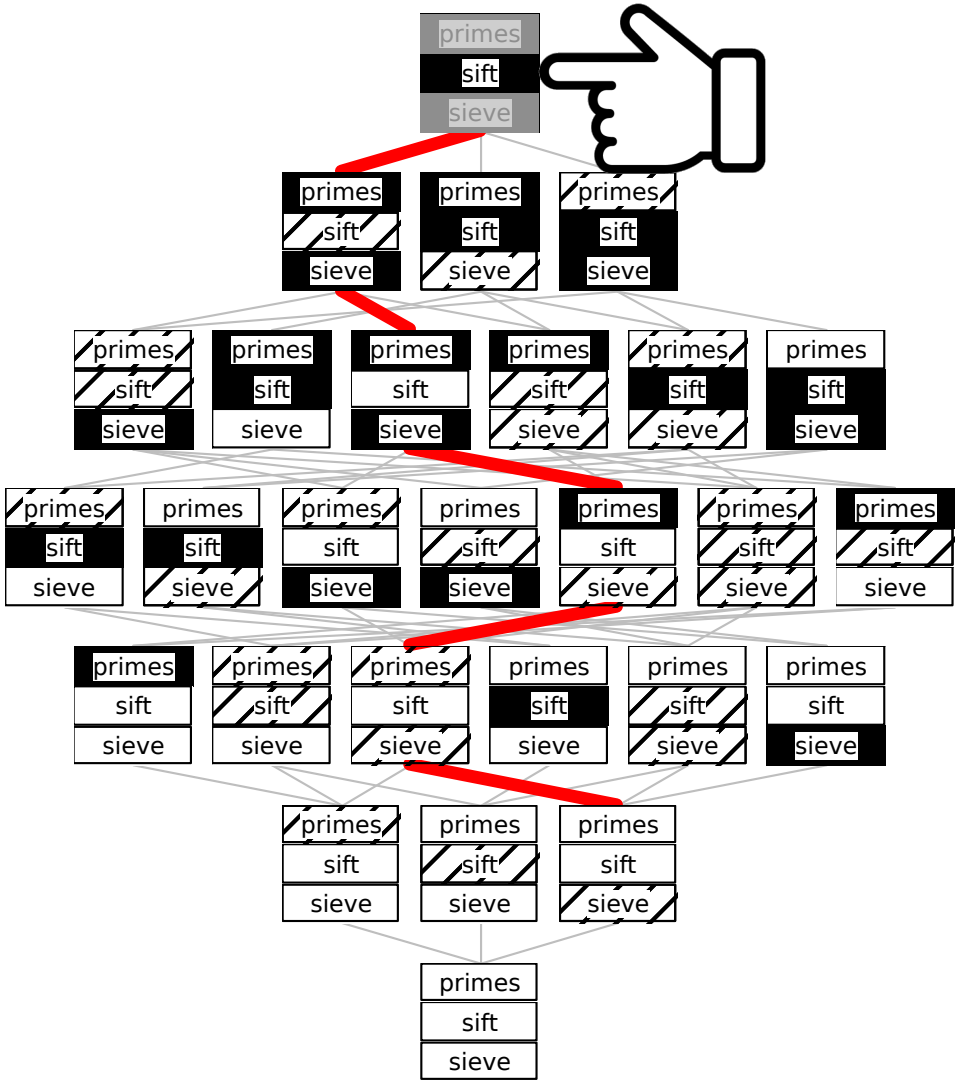
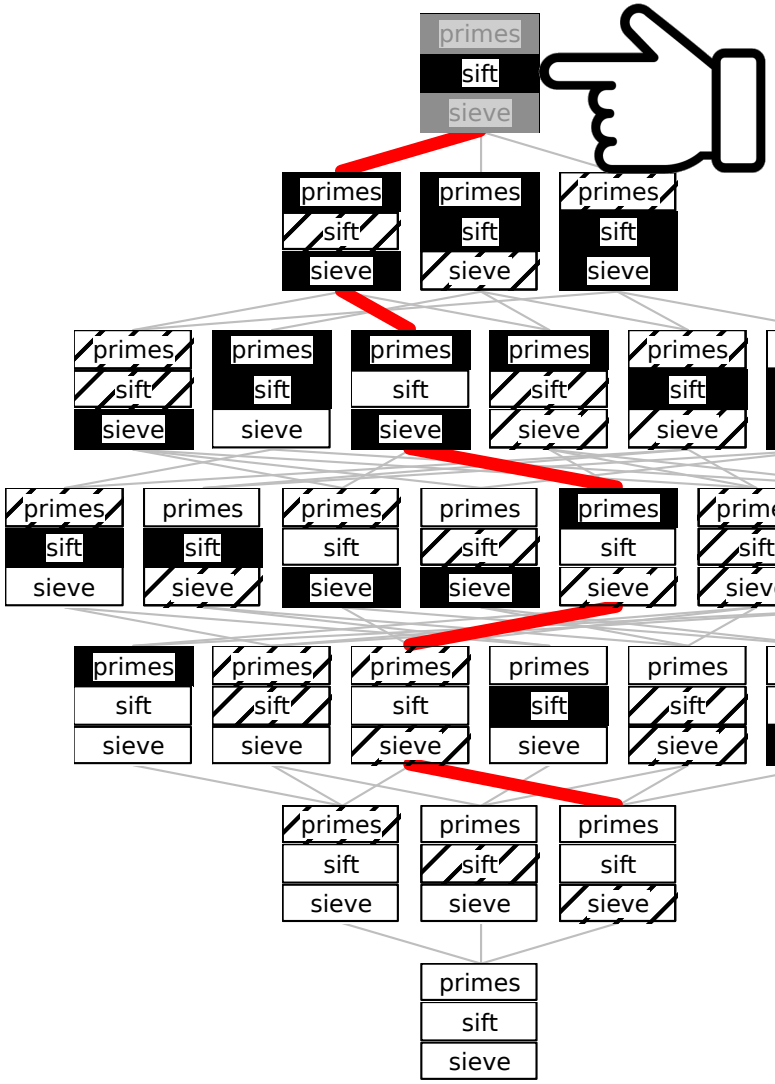


What we want to know



sift contains bug?

The hypothesis, precisely

Every blame trail ends on a configuration that blames the buggy component

Applying the experiment to Racket

- 7 programs
  [Takikawa et al. POPL'16, Greenman et al. JFP'19]
- contracts at 3 strength levels
  (none, types, full)
- 228 viable mutants
  e.g. `(+ 4 2)` ⟶ `(- 4 2)`
- lattice size from 59k to 14 octillion (10^{27})
- 43k blame trails across all programs

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Blame works

blame shifting works

43466

Blame works (mostly)

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43466

blame doesn't settle on bug

276 ⟶ need protocol contracts

Blame works (mostly)

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43466

blame doesn't settle on bug

276 ⟶ need protocol contracts

blame doesn't always move closer to bug

3

Blame works (mostly)

blame shifting works

43466

blame doesn't settle on bug

276 ⟶ need protocol contracts

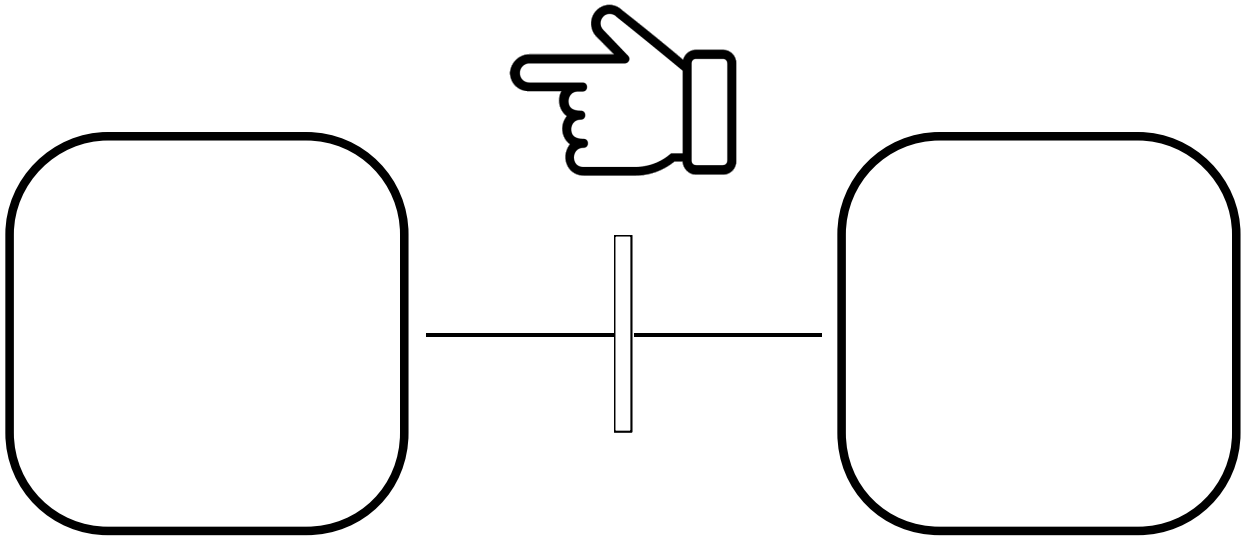
blame doesn't always move closer to bug

3 ⟶ need to tame violations during contract checking

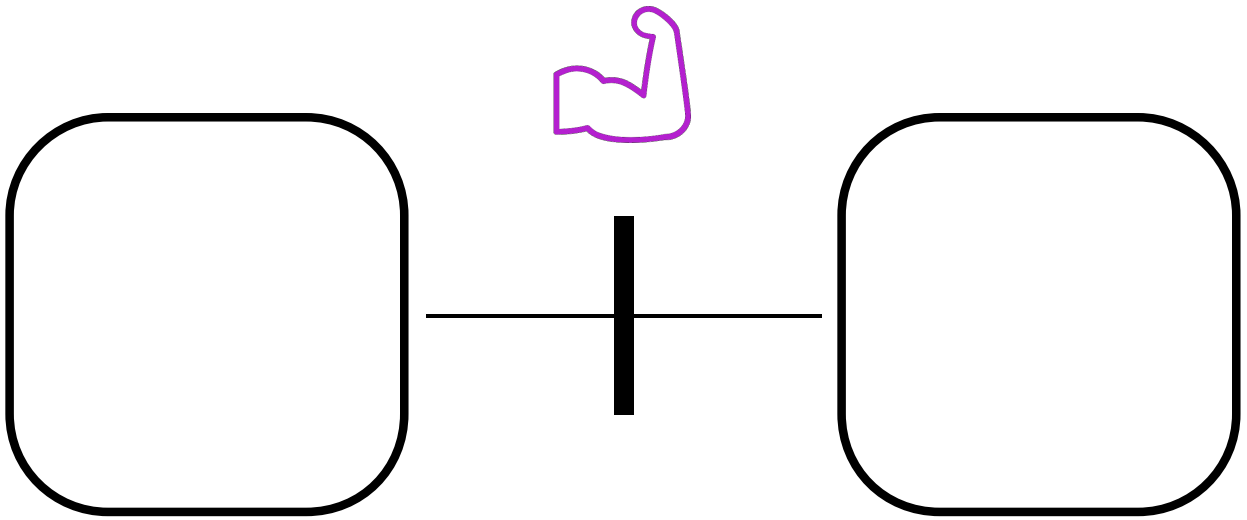
state in contracts

state in contracts ⟶ blame shifts

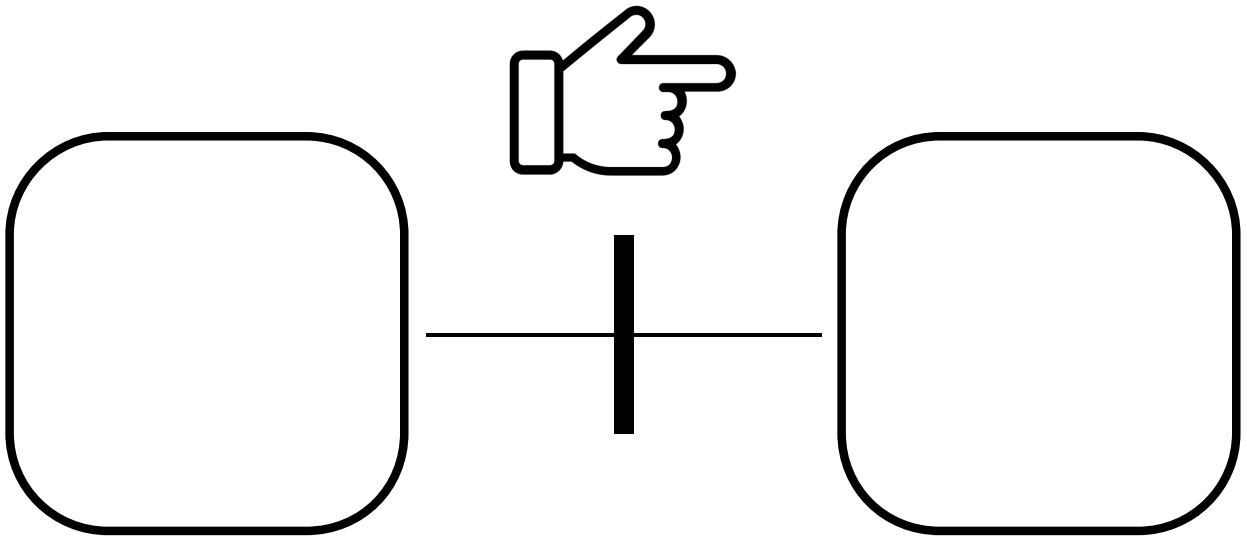
Unexpected blame shifting?



Unexpected blame shifting?



Unexpected blame shifting?



Adding an innocuous contract

```
#lang racket

(require require-typed-check
         racket/set
         "structs.rkt"
         "benv.rkt"
         "denotable.rkt"
         "time.rkt"
         (only-in racket/string string-join)
         "ai.rkt")

(define (summarize states)
  (for/fold ([store empty-store])
    ([state (in-set states)])
    (store-join (State-store state) store)))

(define (f v)



  (for/fold ([mono-store empty-mono-store])
    ([(b vs) (in-hash store)])
    (hash-update mono-store
                 (Binding-var b)
                 (update-lam vs)
                 default-lam)))

(define (analyze exp)
  (define init-state (State exp empty-benv empty-store time-zero))
  (define states (explore (set)
                          (list init-state)))
  mono-store)



(for ([x (in-set a-set)])
  (displayln x))
```

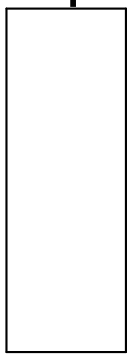
output

```
1
2
3
4
```

Adding an innocuous contract

```
#lang racket

(require require-typed-check
         racket/set
         "structs.rkt"
         "benv.rkt"
         "denotable.rkt"
         "time.rkt"
         (only-in racket/string string-join)
         "ai.rkt")

(define (summarize states)
  (for/fold ([store empty-store])
    ([state (in-set states)])
    (store-join (State-store state) store)))

(define/contract (f v)
  (-> (λ (x) (set-member? ok-vs x))
      number?)
  (for/fold ([mono-store empty-mono-store])
    ([(b vs) (in-hash store)])
    (hash-update mono-store
                 (Binding-var b)
                 (update-lam vs)
                 default-lam)))

(define (analyze exp)
  (define init-state (State exp empty-benv empty-store time-zero))
  (define states (explore (set)
                          (list init-state)))
  mono-store)



(for ([x (in-set a-set)])
  (displayln x))
```

output



Adding an innocuous contract

```
#lang racket

(require require-typed-check
         racket/set
         "structs.rkt"
         "benv.rkt"
         "denotable.rkt"
         "time.rkt"
         (only-in racket/string string-join)
         "ai.rkt")

(define (summarize states)
  (for/fold ([store empty-store])
    ([state (in-set states)])
    (store-join (State-store state) store)))

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  (-> (λ (x) (set-member? ok-vs x))
      number?)
  (for/fold ([mono-store empty-mono-store])
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    (hash-update mono-store
                 (Binding-var b)
                 (update-lam vs)
                 default-lam)))

(define (analyze exp)
  (define init-state (State exp empty-benv empty-store time-zero))
  (define states (explore (set)
                          (list init-state)))
  mono-store)



(for ([x (in-set a-set)])
  (displayln x))
```

output

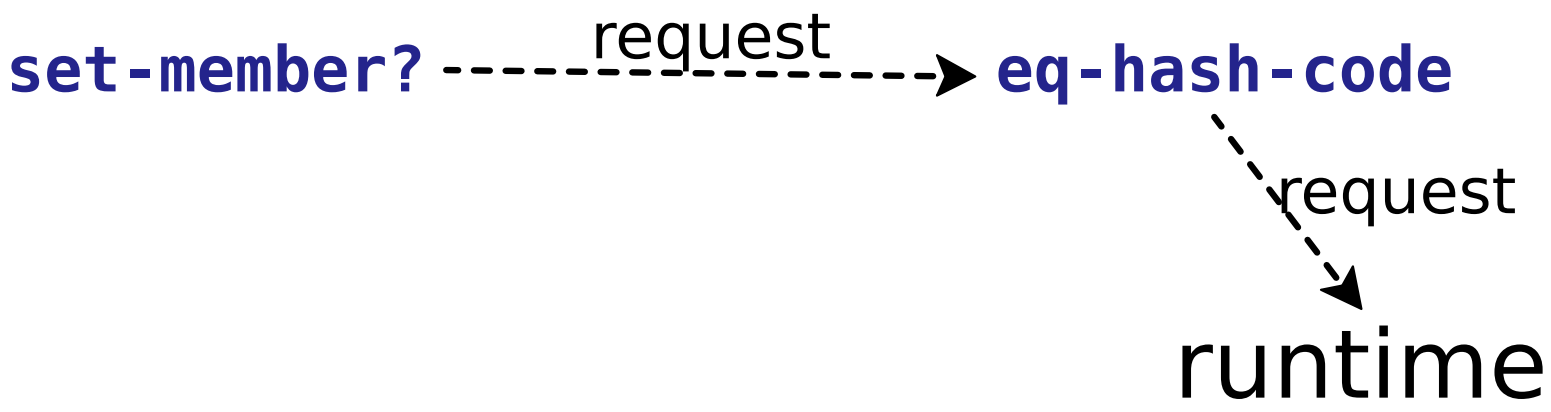
```
2
4
3
1
```

The runtime is working against you

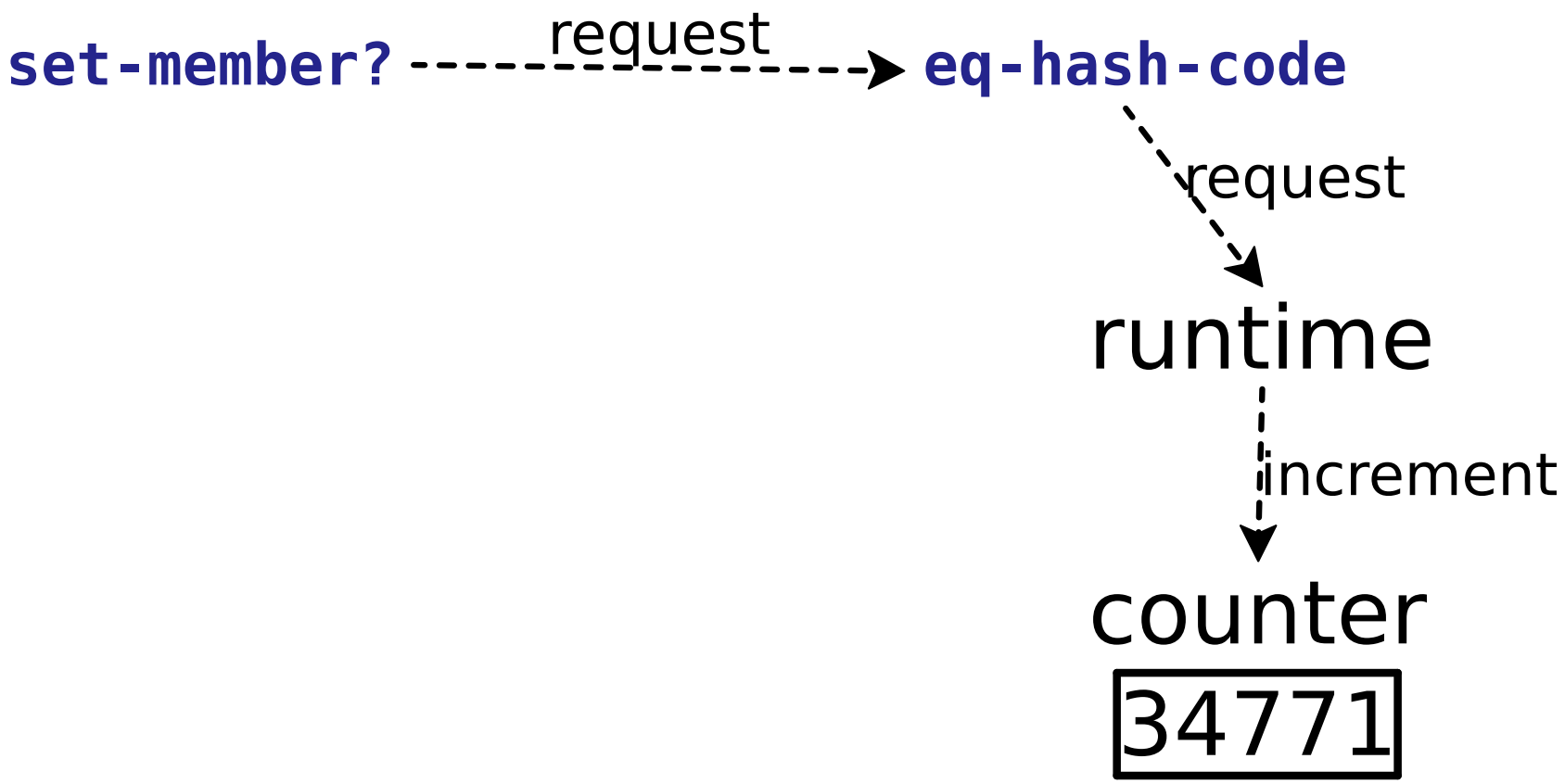
```
set-member?
```

The runtime is working against you

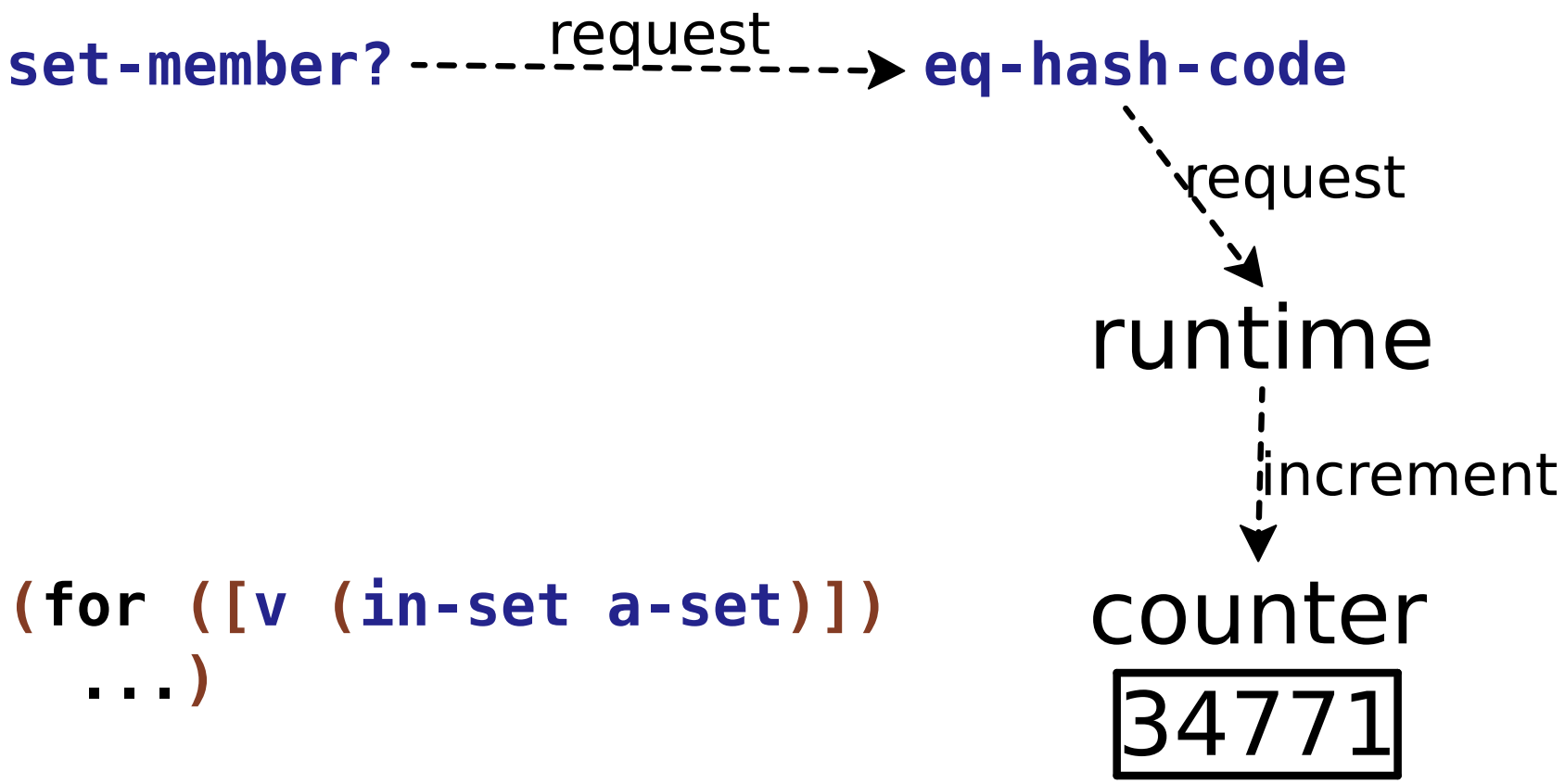
The runtime is working against you



The runtime is working against you

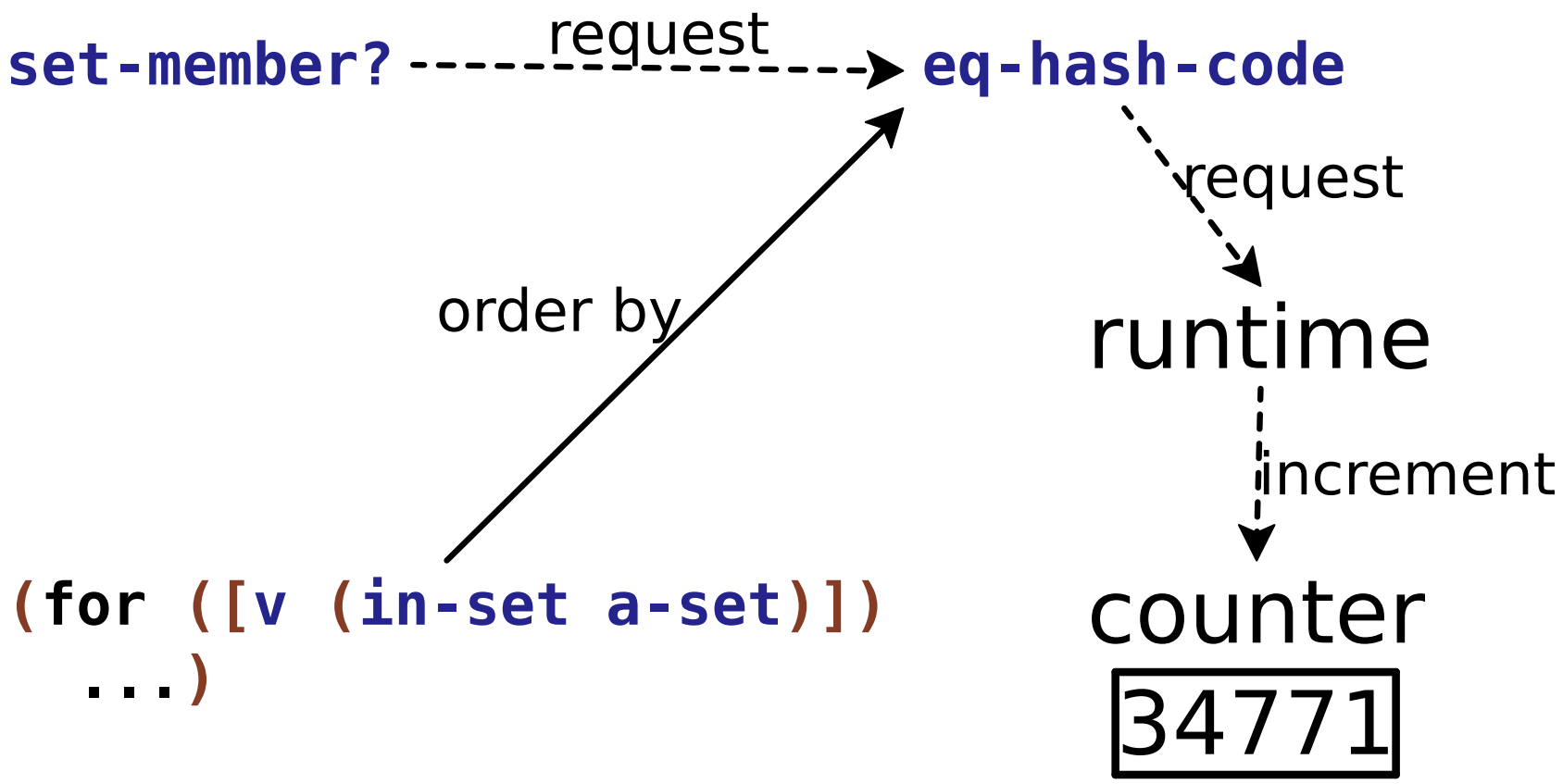


The runtime is working against you

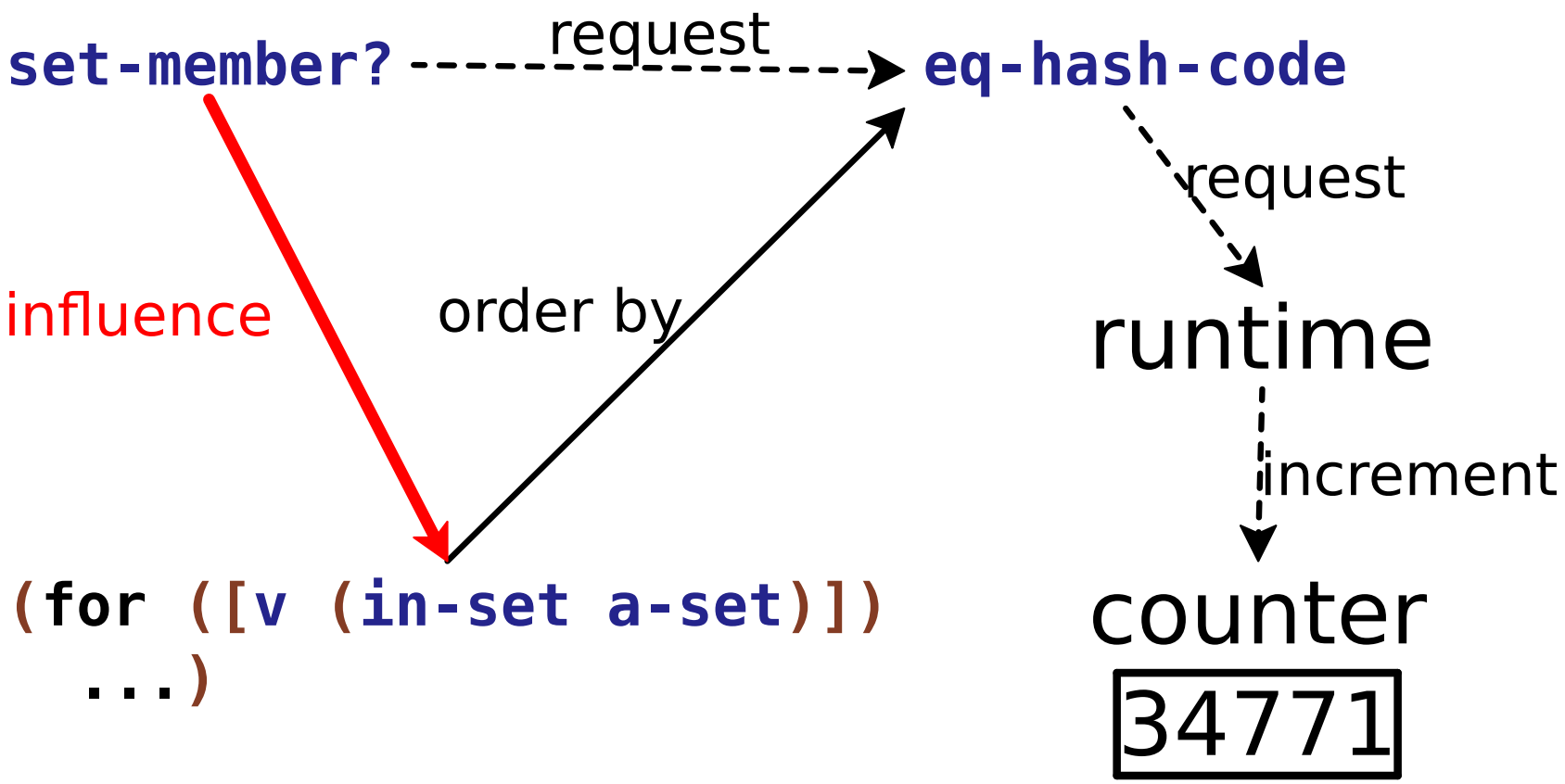



```
(for ([v (in-set a-set)])
  ...)
```

The runtime is working against you



The runtime is working against you



This can affect blame

```
#lang racket

(require require-typed-check
         racket/set
         "structs.rkt"
         "benv.rkt"
         "denotable.rkt"
         "time.rkt"
         (only-in racket/string string-join)
         "ai.rkt")

(define (summarize states)
  (for/fold ([store empty-store])
    ([state (in-set states)])
    (store-join (State-store state) store)))

(define/contract (f v)
  (-> (λ (x) (set-member? ok-vs x))
      number?)
  (for/fold ([mono-store empty-mono-store])
    ([(b vs) (in-hash store)])
    (hash-update mono-store
                 (Binding-var b)
                 (update-lam vs)
                 default-lam)))

(define (analyze exp)
  (define init-state (State exp empty-benv empty-store time-zero))
  (define states (explore (set)
                          (list init-state)))
  mono-store)



(for ([x (in-set a-set)])
  (displayln x))
```

This can affect blame

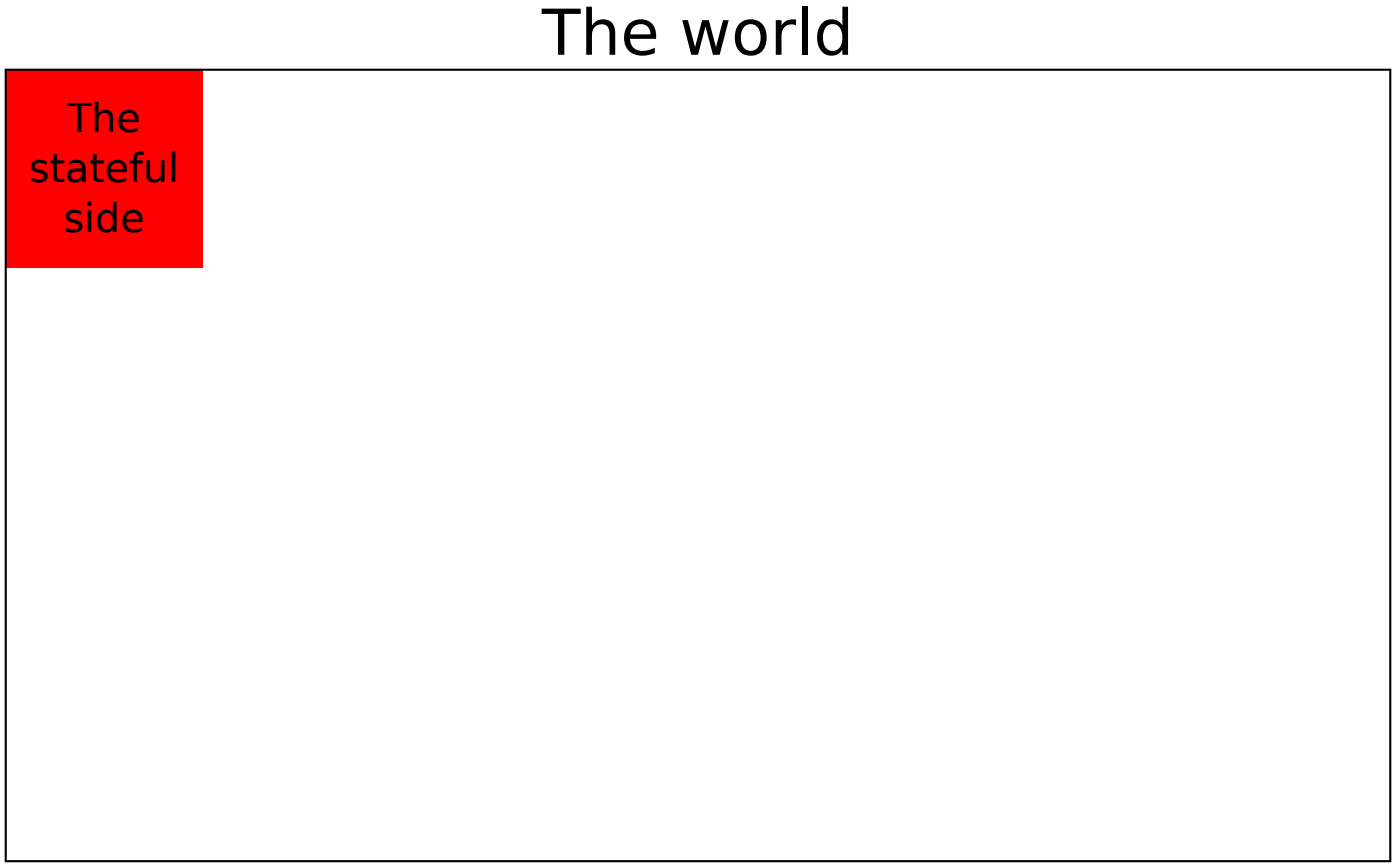
```
#lang racket

(require require-typed-check
         racket/set
         "structs.rkt"
         "benv.rkt"
         "denotable.rkt"
         "time.rkt"
         (only-in racket/string string-join)
         "ai.rkt")

(define (summarize states)
  (for/fold ([store empty-store])
    ([state (in-set states)])
    (store-join (State-store state) store)))

(define/contract (f v)
  (-> (λ (x) (set-member? ok-vs x))
      number?)
  (for/fold ([mono-store empty-mono-store])
    ([(b vs) (in-hash store)])
    (hash-update mono-store
                 (Binding-var b)
                 (update-lam vs)
                 default-lam)))

(define (analyze exp)
  (define init-state (State exp empty-benv empty-store time-zero))
  (define states (explore (set)
                          (list init-state)))
  mono-store)



(for ([a-function (in-set a-set)])
  (a-function))
```

This can affect blame

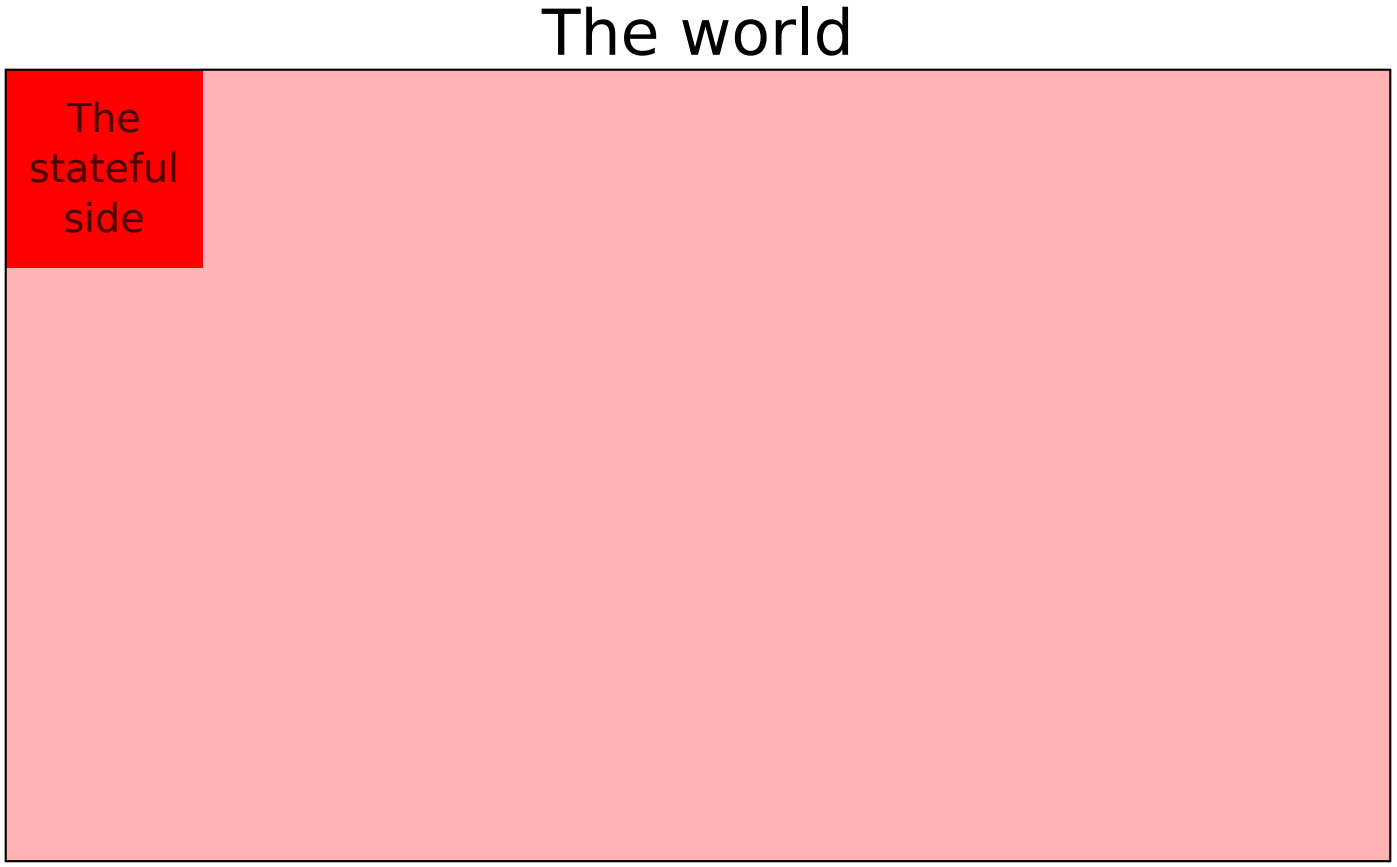
KCFA

```
#lang racket

(require require-typed-check
         racket/set
         "structs.rkt"
         "benv.rkt"
         "denotable.rkt"
         "time.rkt"
         (only-in racket/string string-join)
         "ai.rkt")

(define (summarize states)
  (for/fold ([store empty-store])
    ([state (in-set states)])
    (store-join (State-store state) store)))

(define/contract (f v)
  (-> (λ (x) (set-member? ok-vs x))
      number?)
  (for/fold ([mono-store empty-mono-store])
    ([(b vs) (in-hash store)])
    (hash-update mono-store
                 (Binding-var b)
                 (update-lam vs)
                 default-lam)))

(define (analyze exp)
  (define init-state (State exp empty-benv empty-store time-zero))
  (define states (explore (set)
                          (list init-state)))
  mono-store)



(for ([a-function (in-set a-set)])
  (a-function))
```

We knew state is a problem



But state is pervasive



Closing the loop

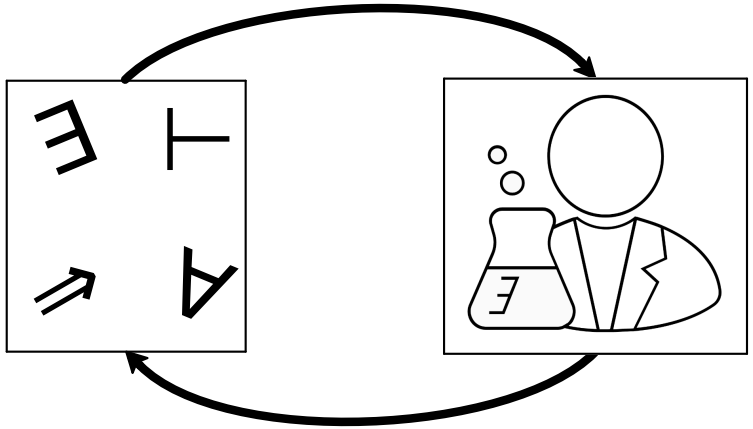
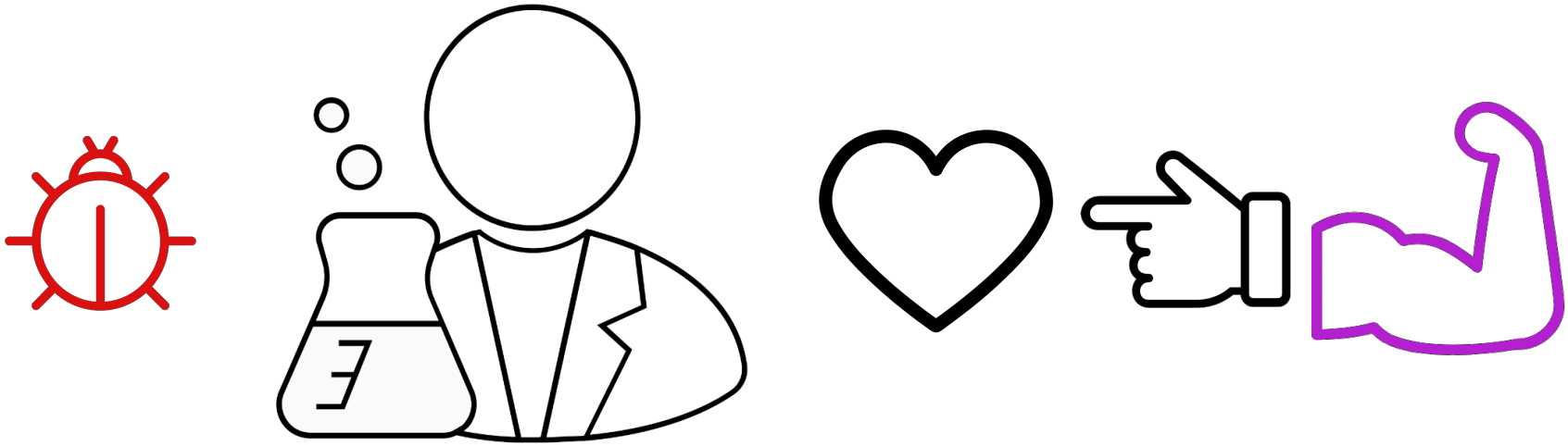


Image credits



The Noun Project: alvianwijaya, ID; parkjisun; BomSymbols, TH; Vectors Point, PK; Vectors Market