

EFFECTS FOR LESS

Alexis King

ZuriHac 2020

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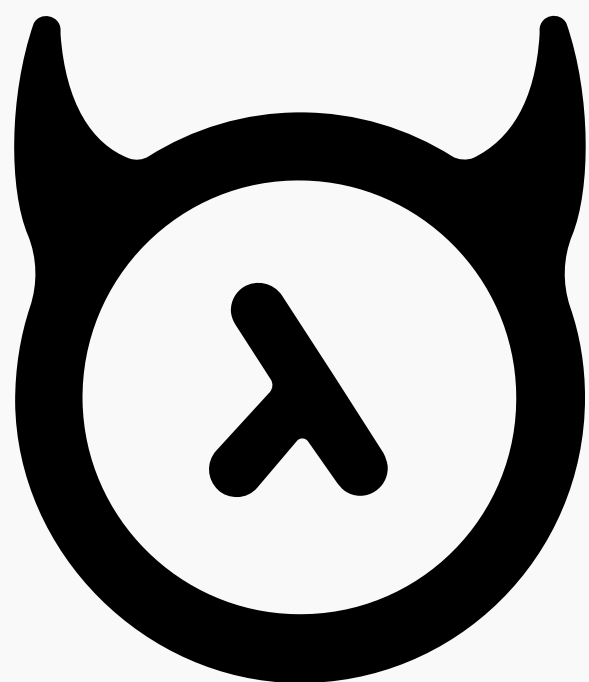
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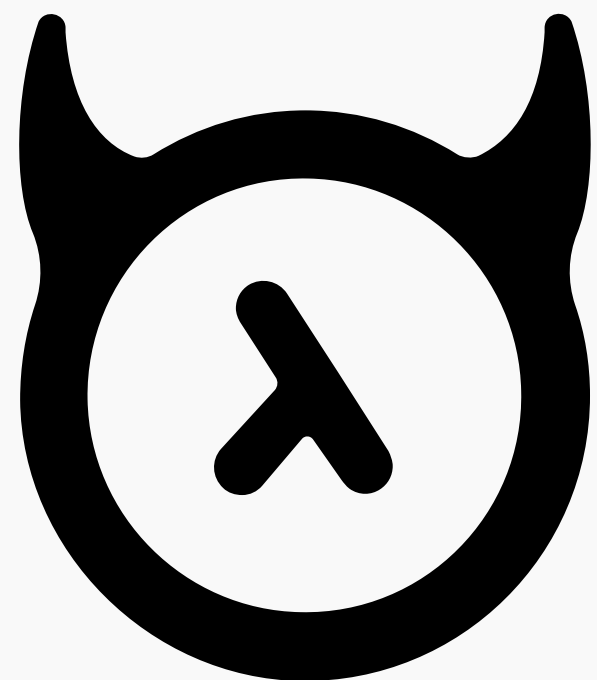
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- JUL 2019 ○ Back to writing Haskell.

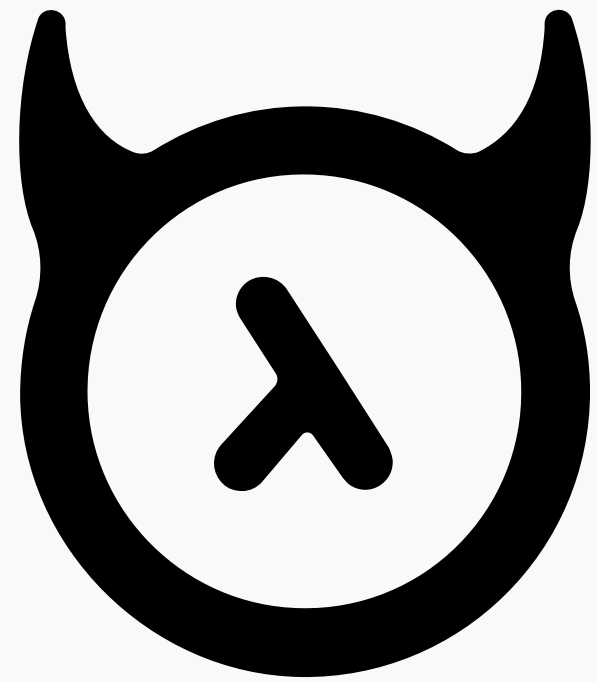


HASURA



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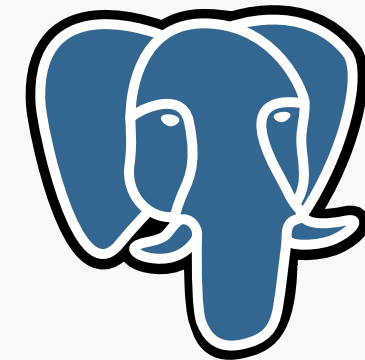
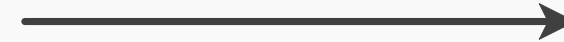
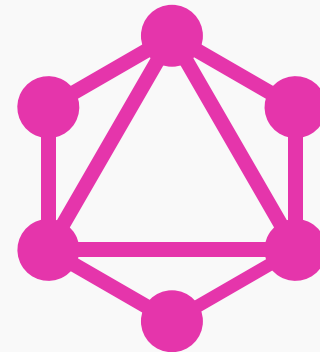
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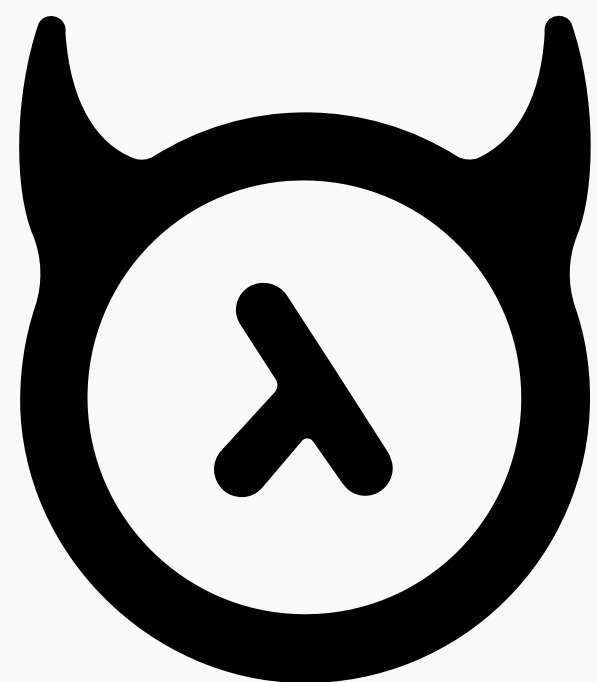


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Secretly: a GraphQL to SQL JIT compiler

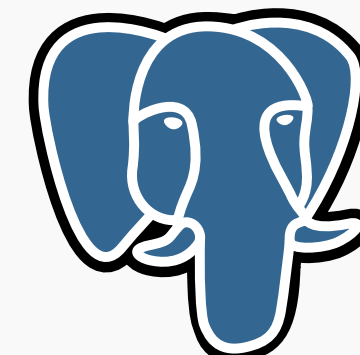
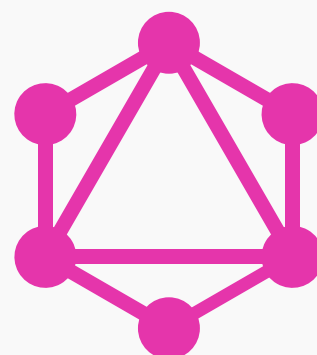


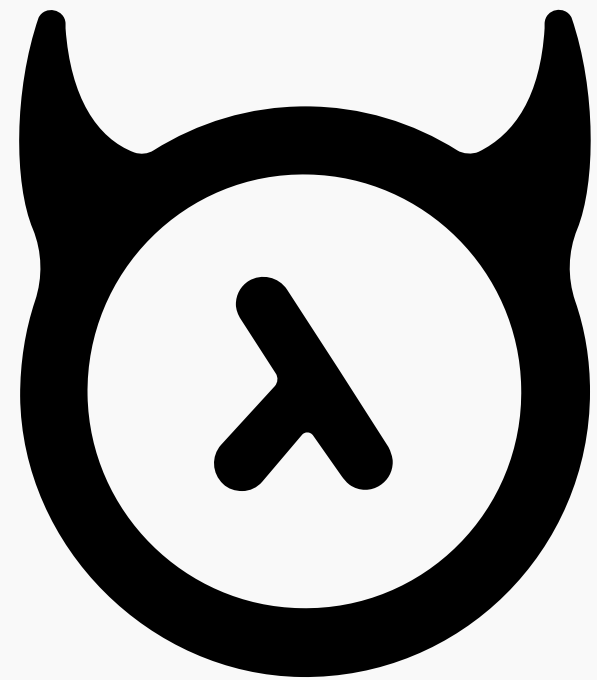


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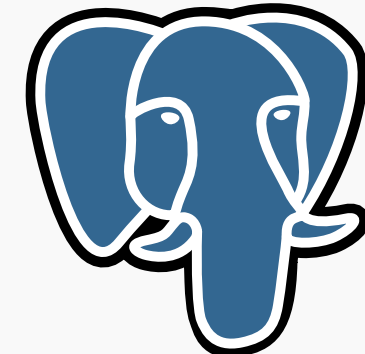
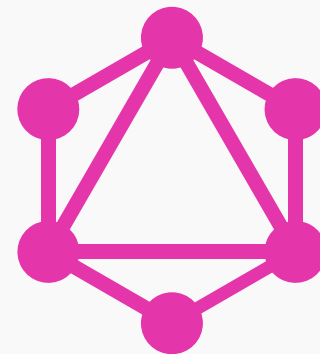




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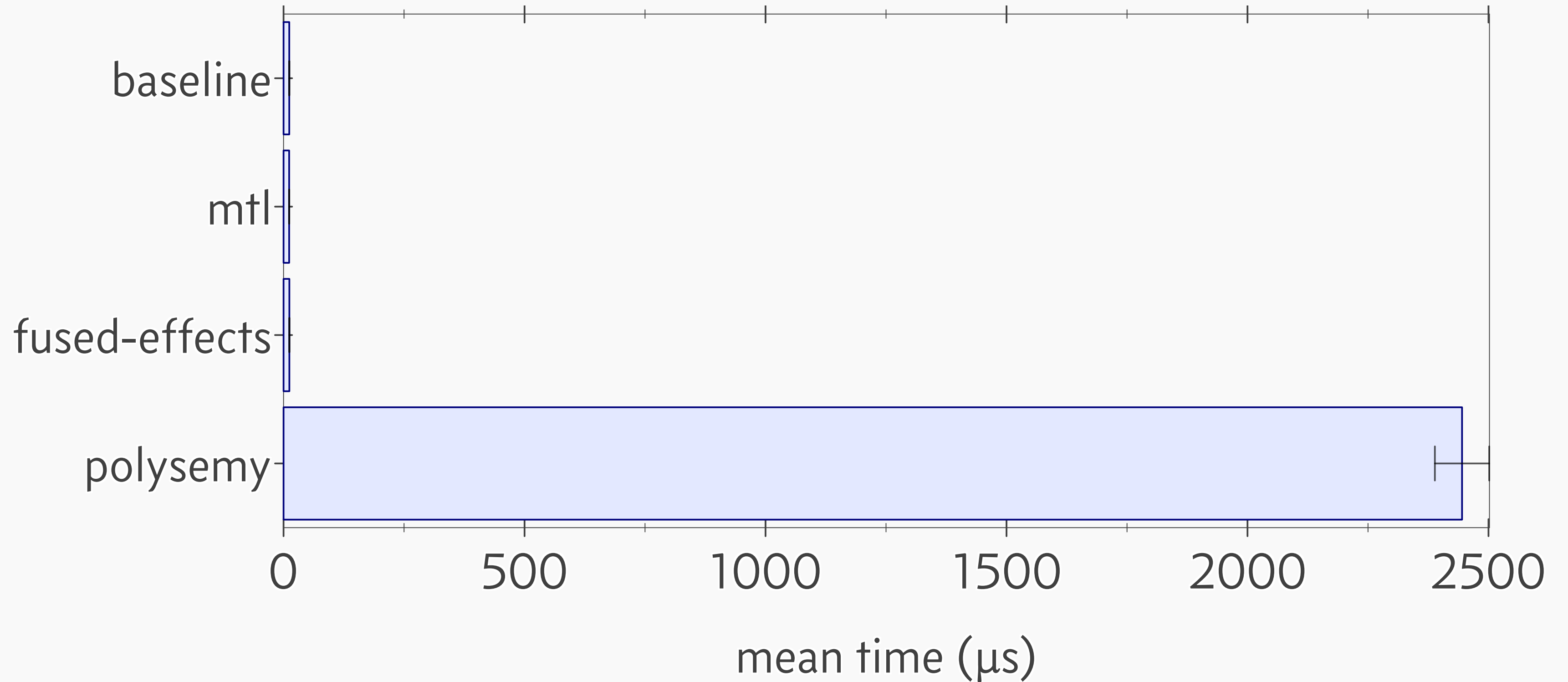
Performance is *really* important!

Can we afford to use an effect system?

BENCHMARKS

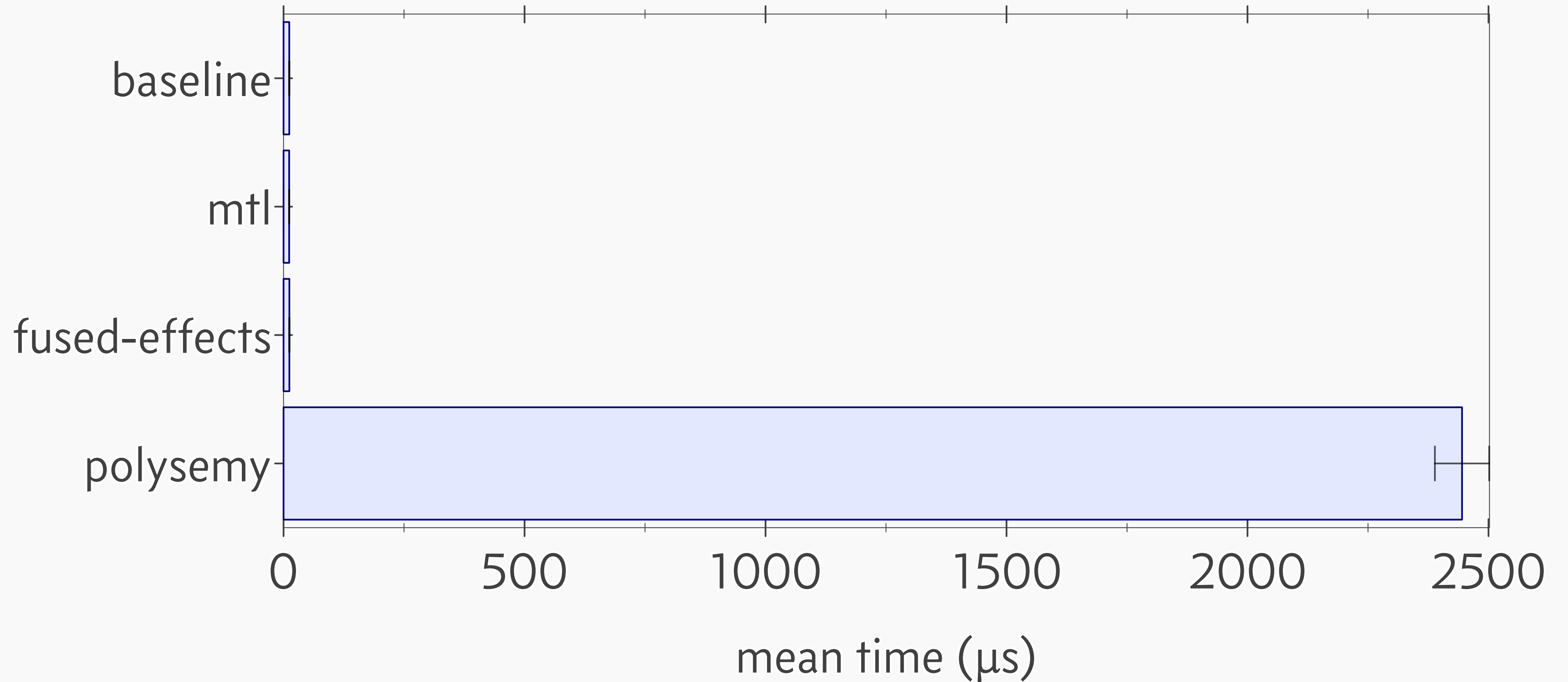
BENCHMARK: COUNTDOWN

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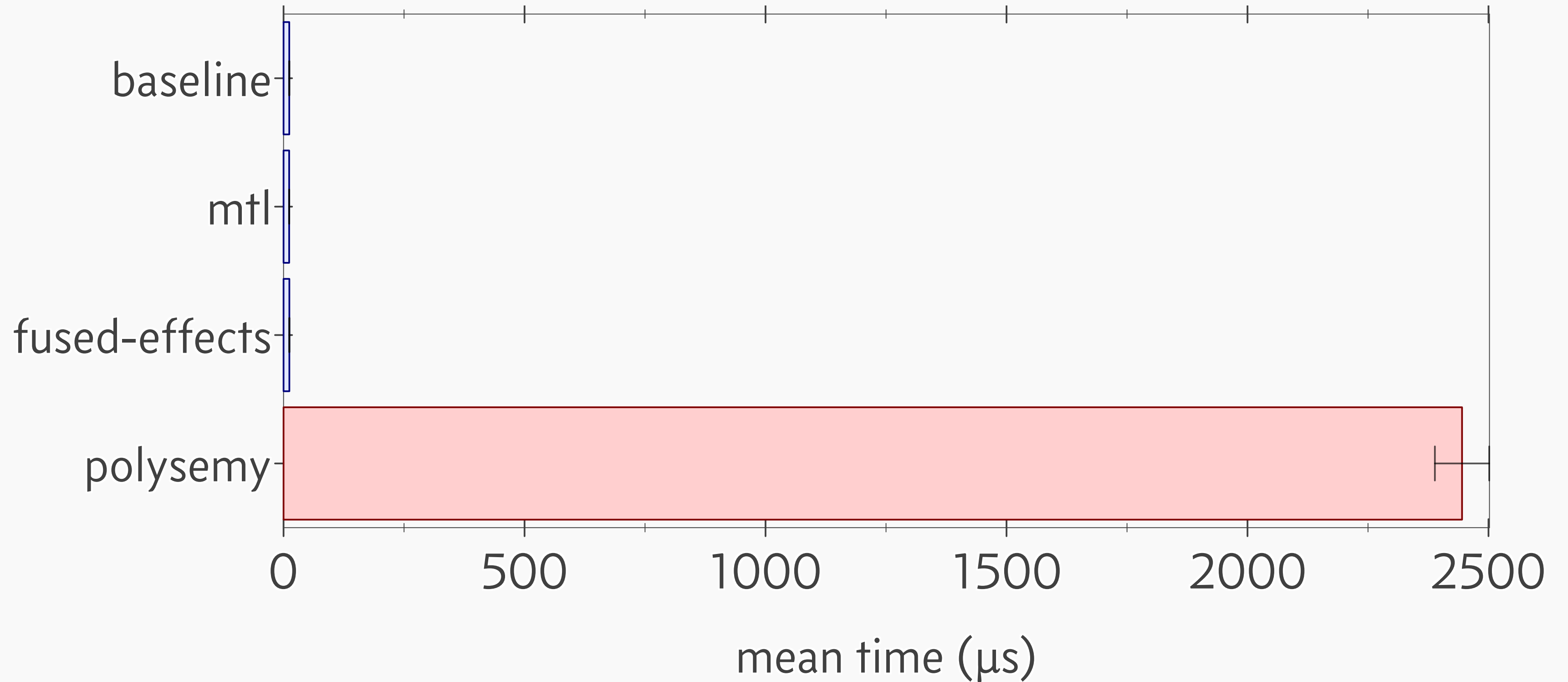
BENCHMARK: COUNTDOWN

(lower is better)



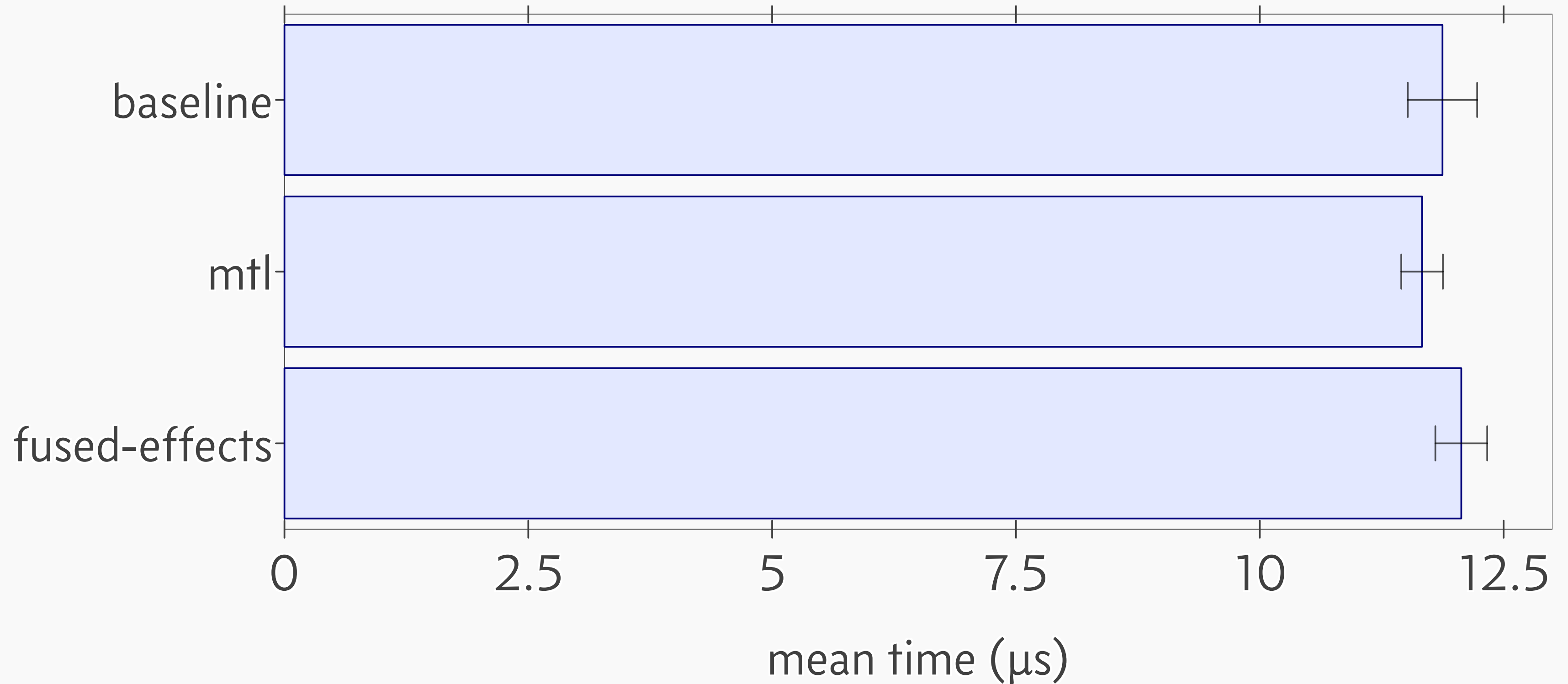
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Can we afford to use an effect system?

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Answer: yes.

Just don't pick polysemy.

It's never that simple!

QUESTIONS

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1. What *is* the countdown benchmark?
2. What is the “baseline” implementation?
3. Are these differences even meaningful?
4. Why does polysemy do *that* much worse?

THE COUNTDOWN MICROBENCHMARK

```
countDown :: Int → (Int, Int)
countDown initial = runState program initial

program :: MonadState Int m ⇒ m Int
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Is countdown a bad benchmark?

IN DEFENSE OF MICROBENCHMARKS

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REAL-WORLD BENCHMARKS

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 - Costs are not considered in context.

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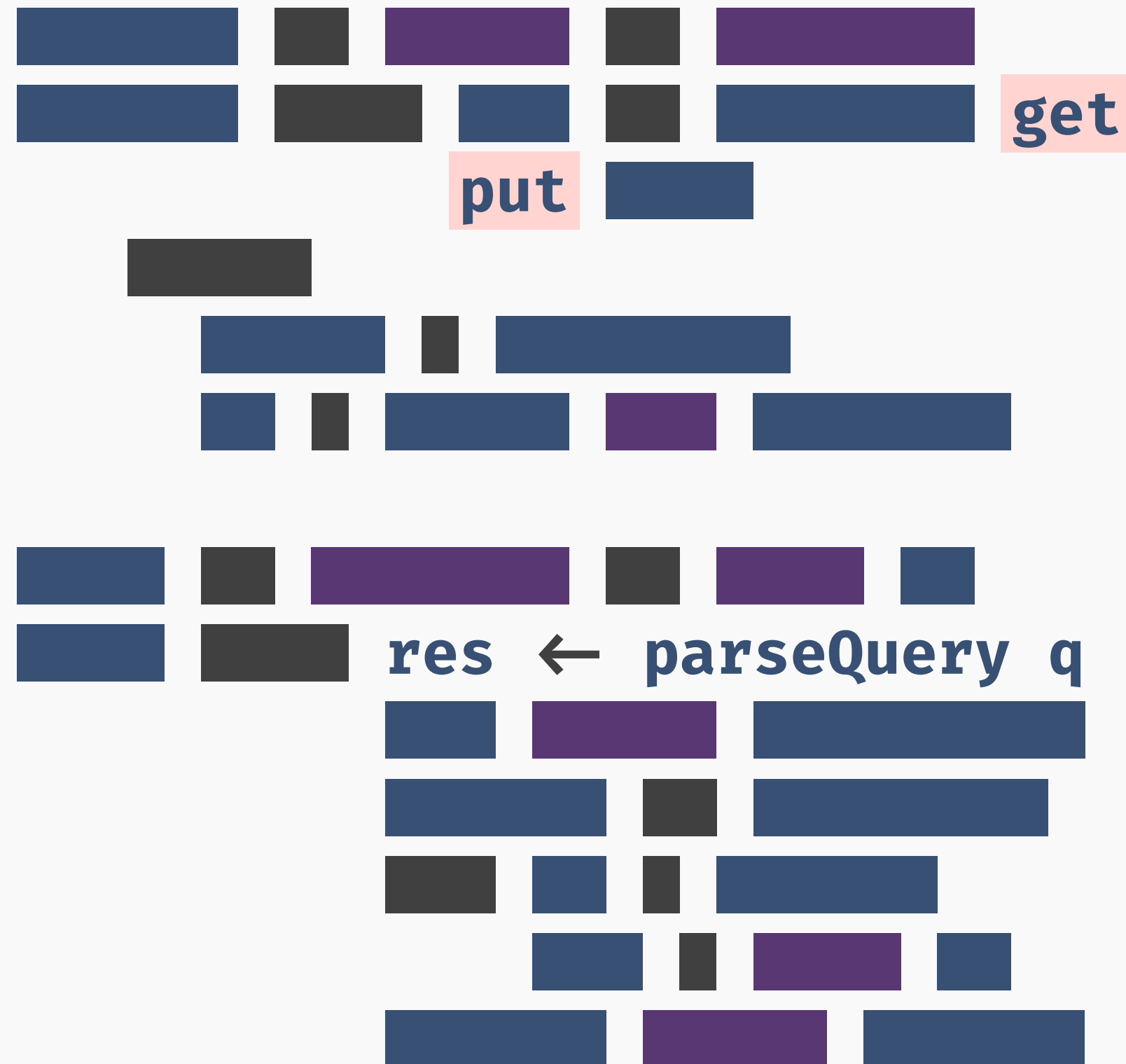
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What does countdown measure?

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call reallyExpensive
colorGraph mineBitcoin compileHaskell

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call reallyExpensive

colorGraph

mineBitcoin

compileHaskell

return to caller

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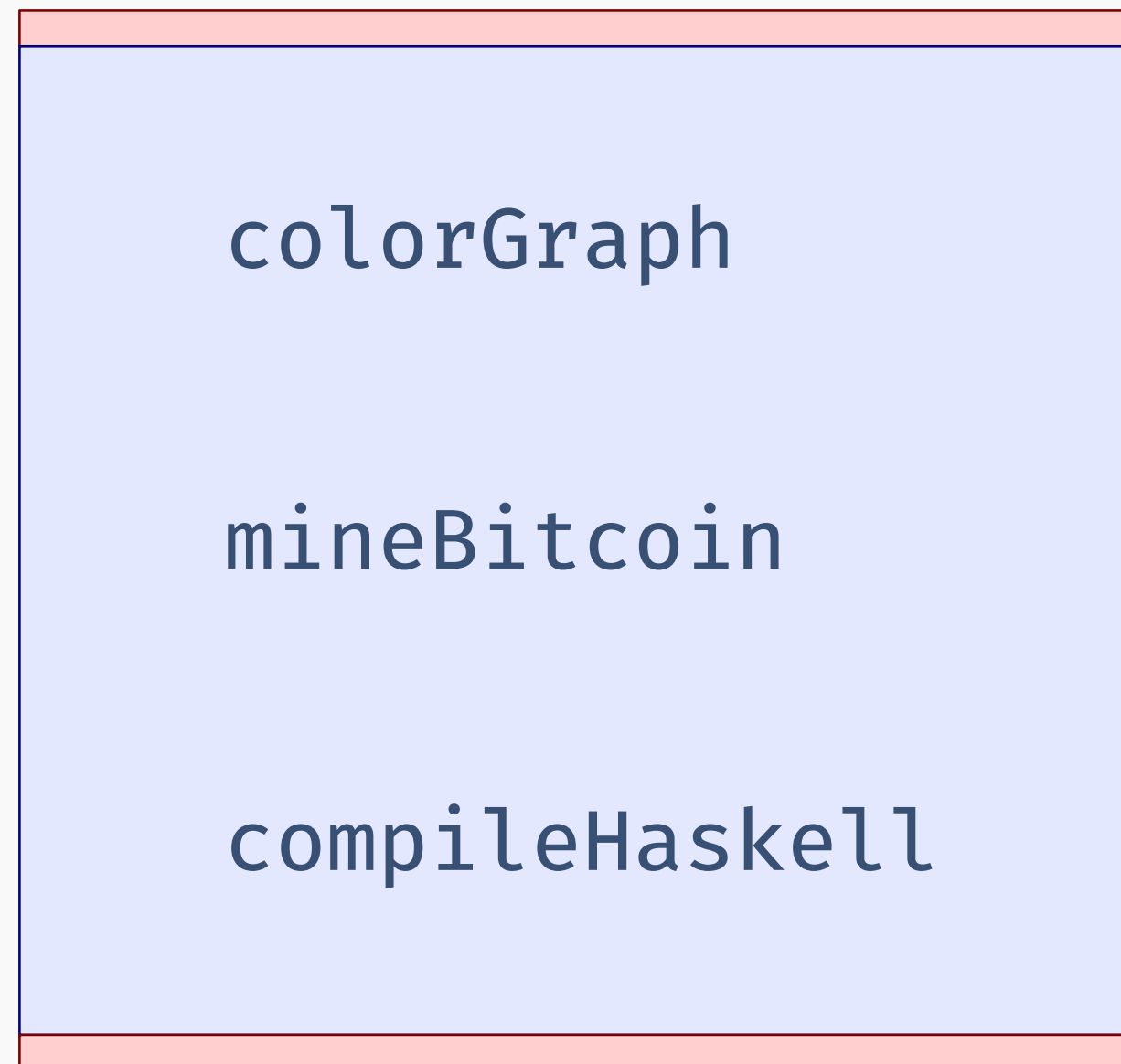
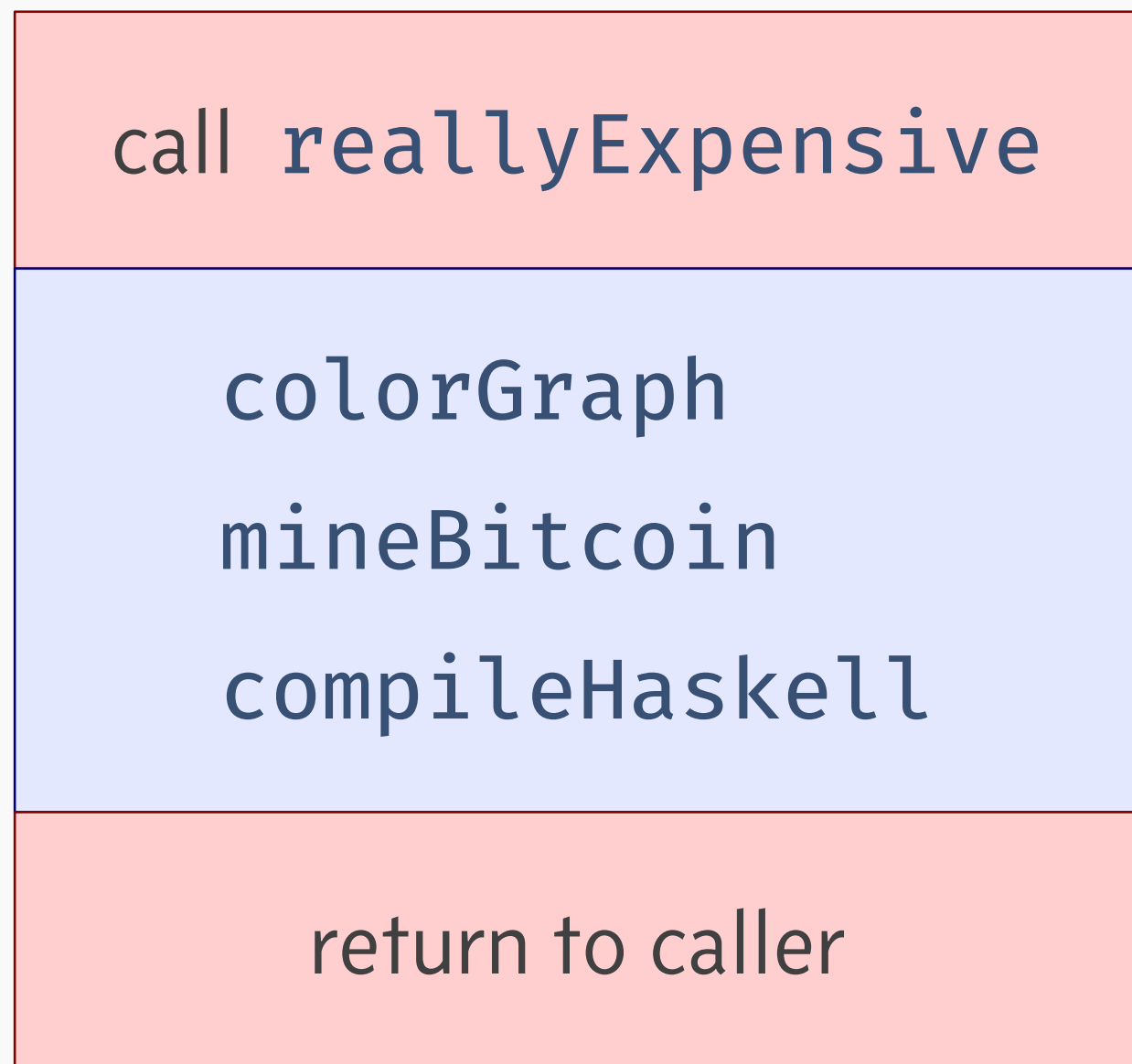
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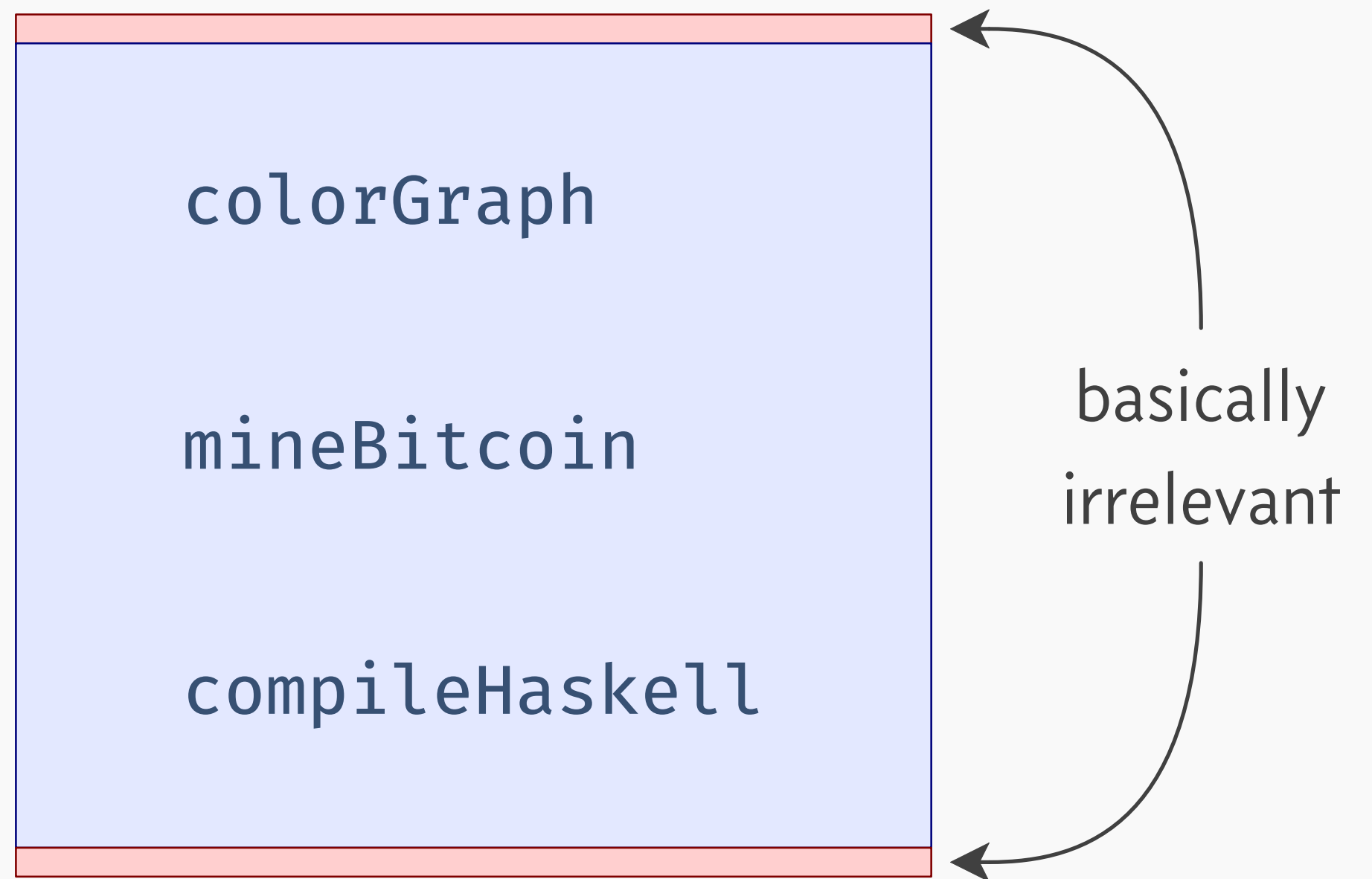
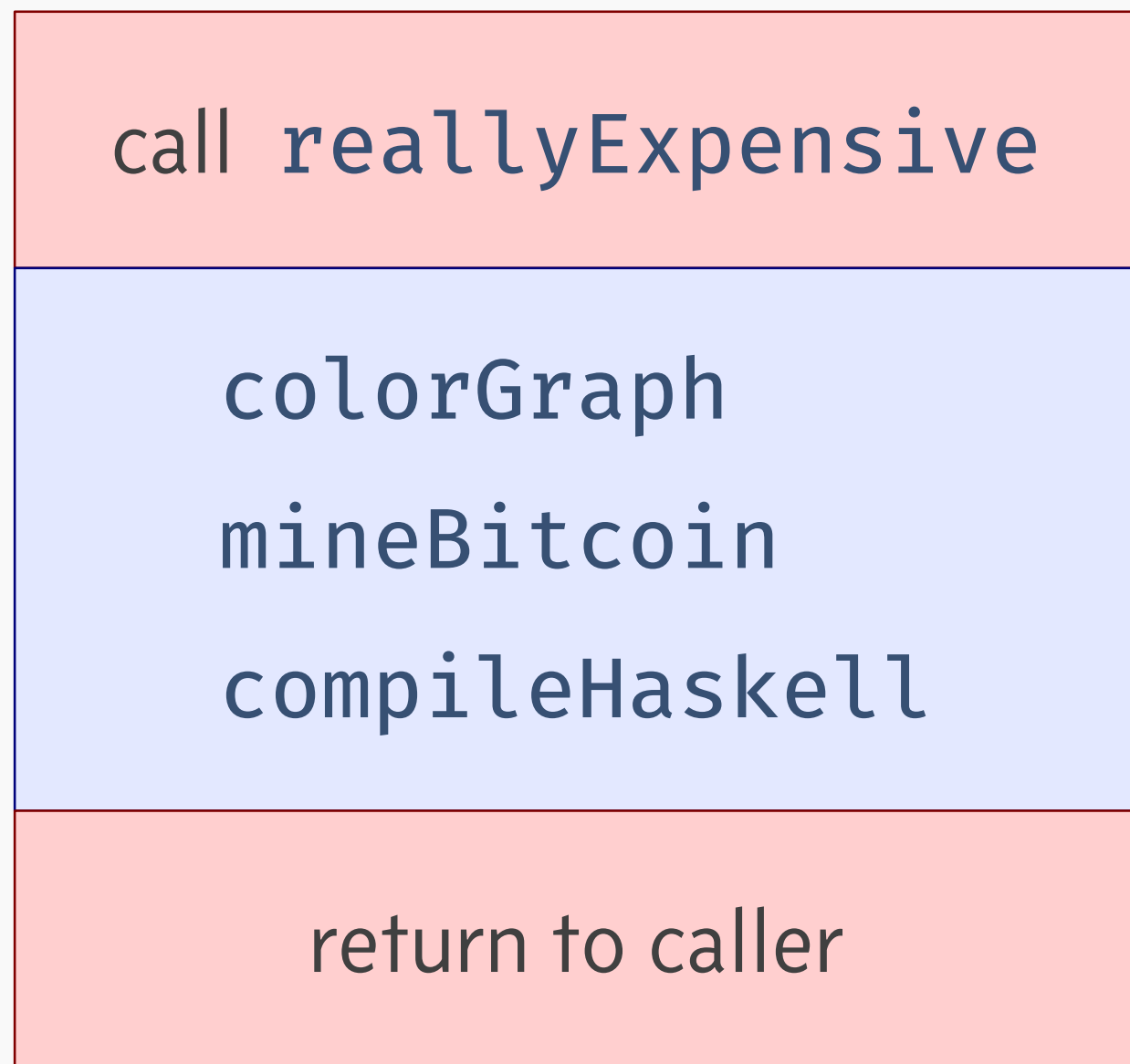
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call **get**

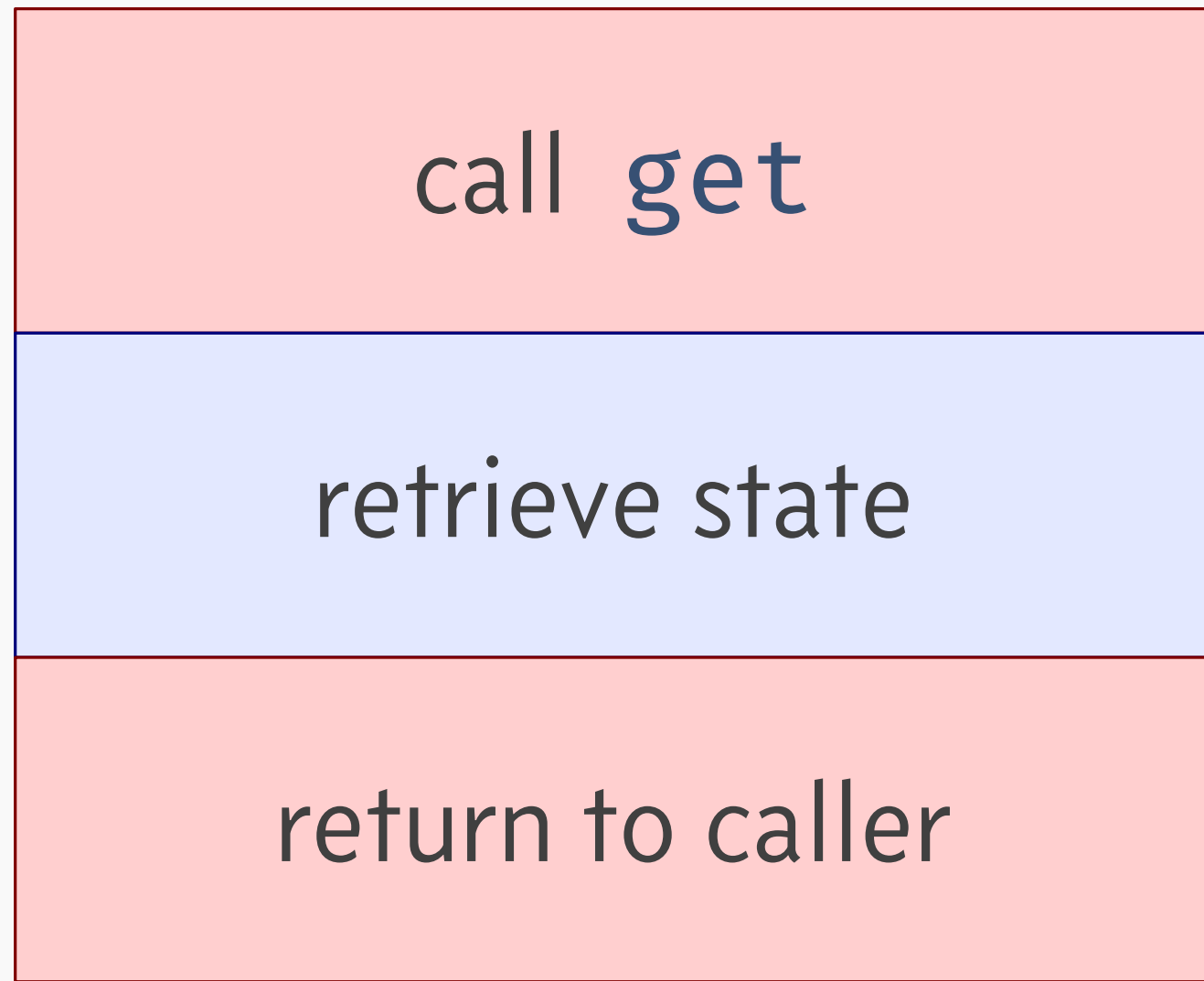
retrieve state

return to caller

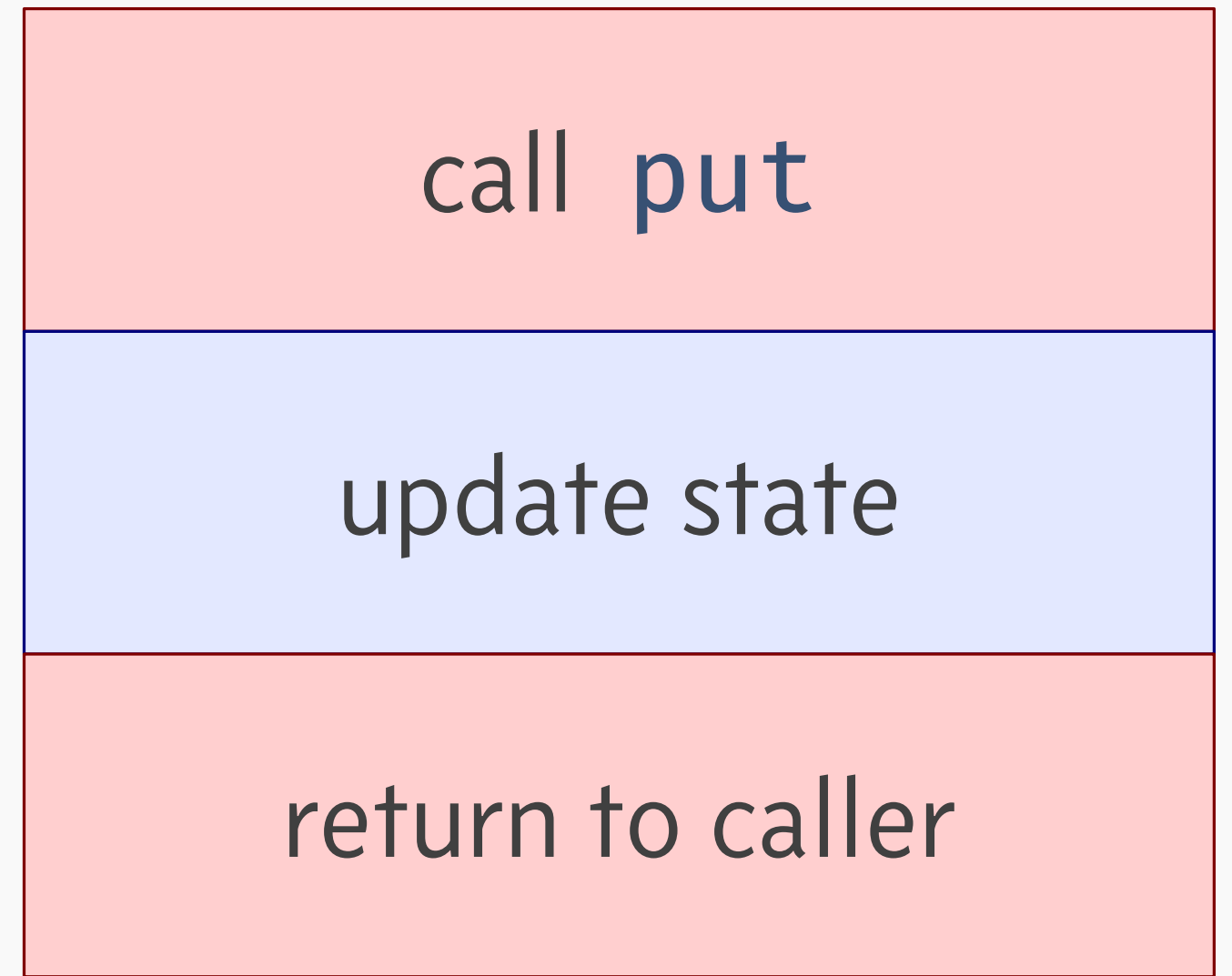
call **put**

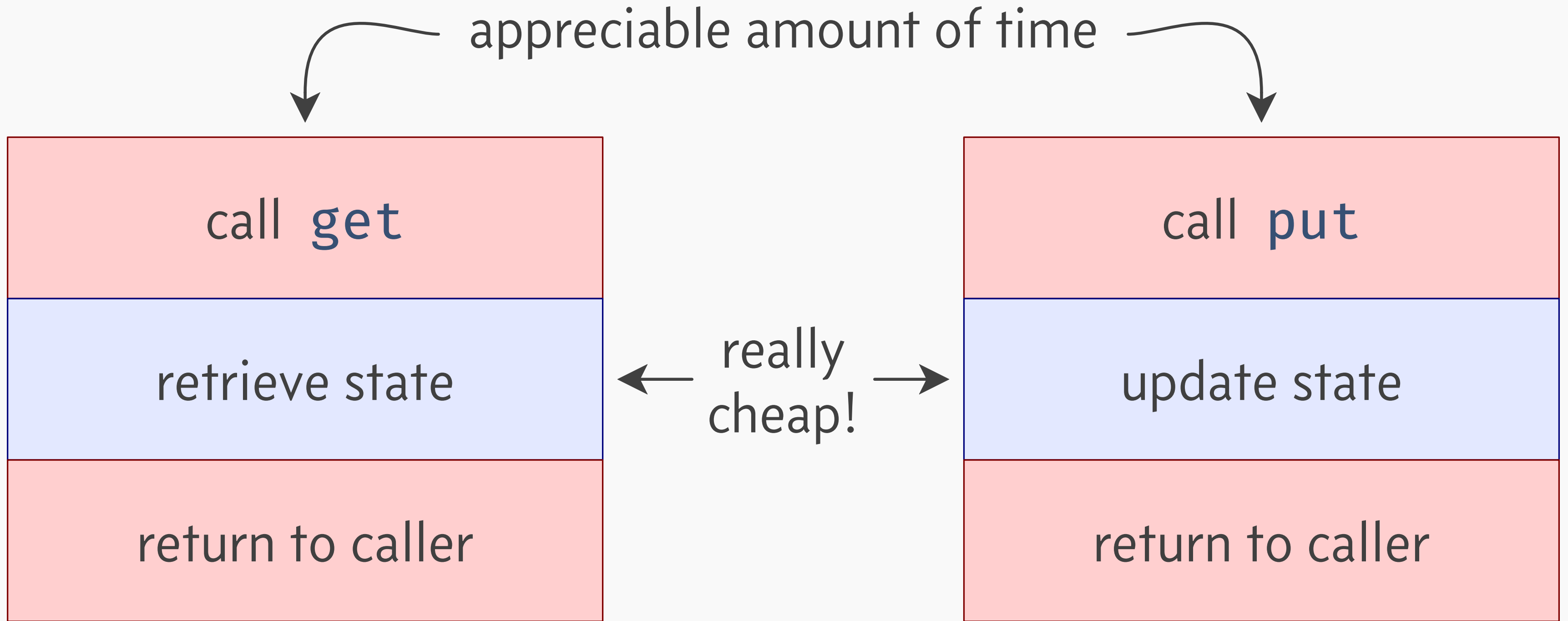
update state

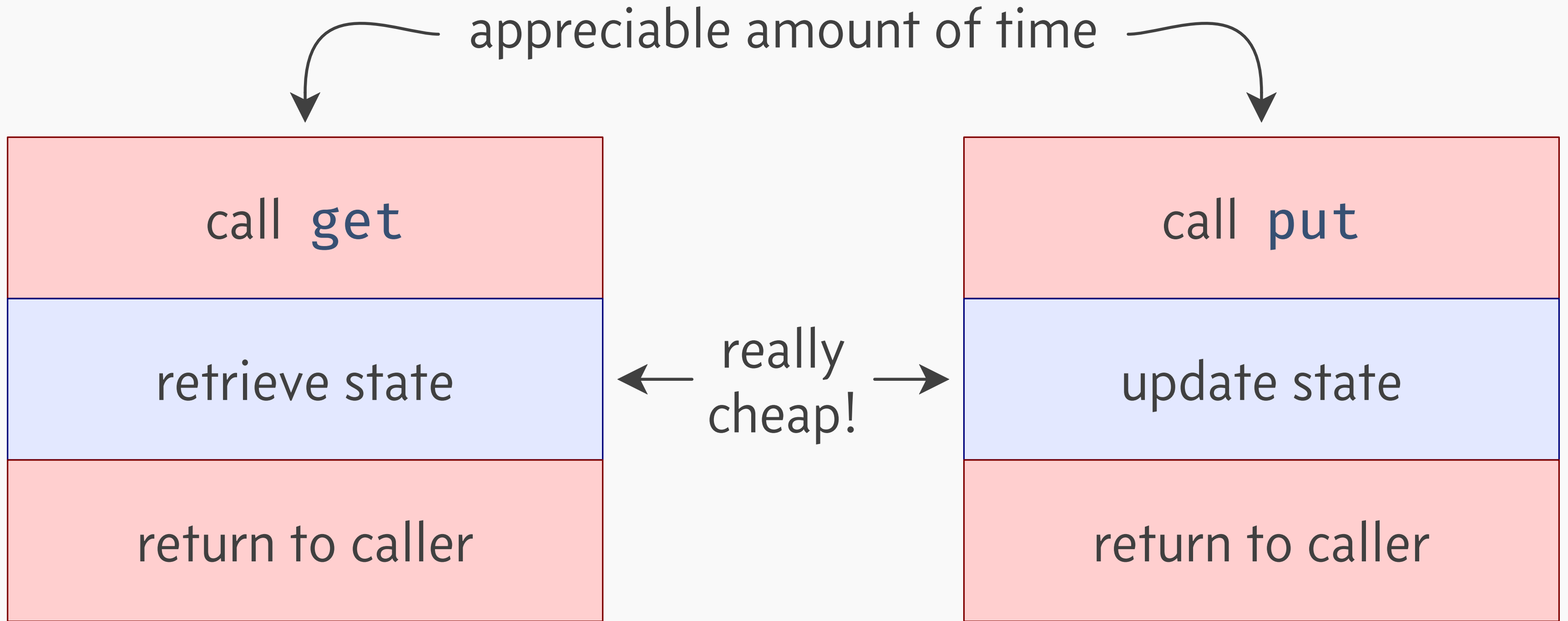
return to caller



← really cheap! →







Countdown benchmarks *effect dispatch*.

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do a ← f x  
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sequence
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when
unless
replicateM

RECAP

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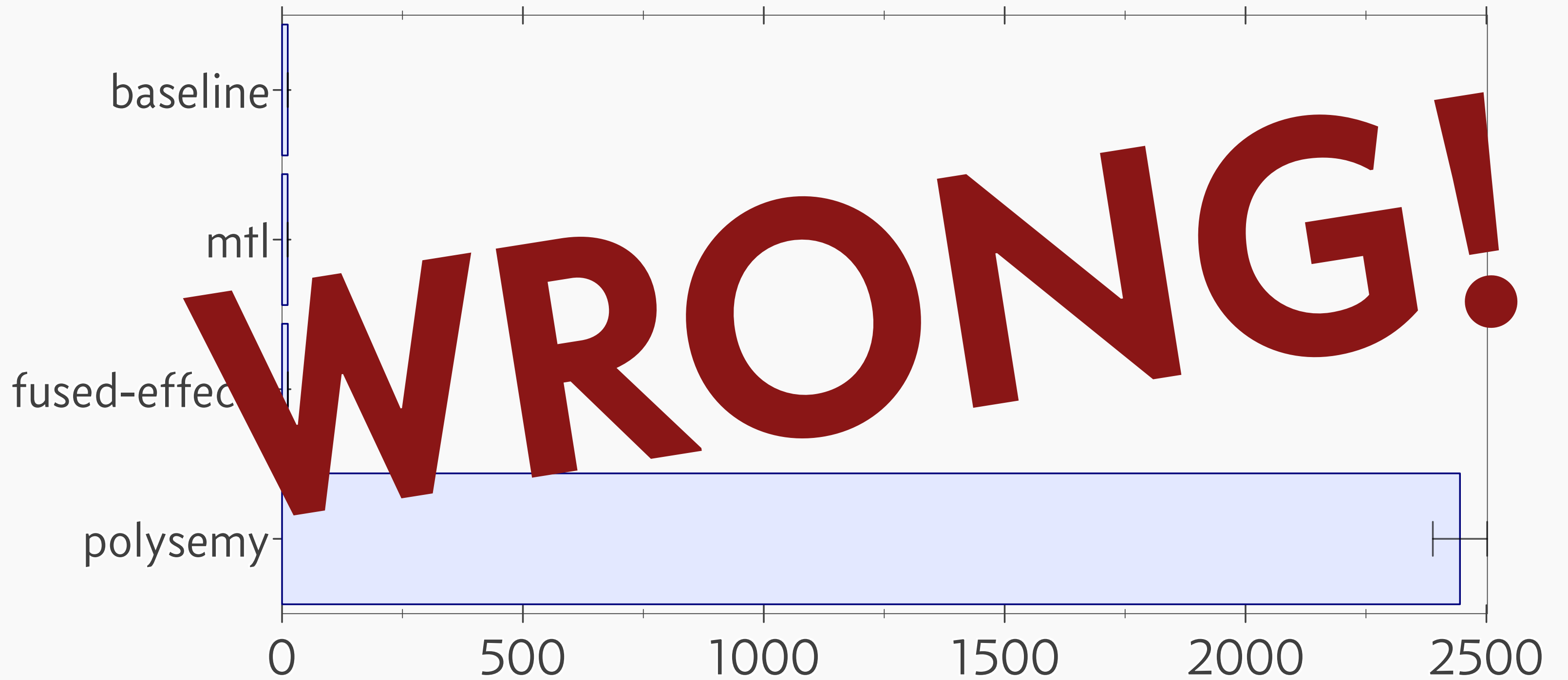
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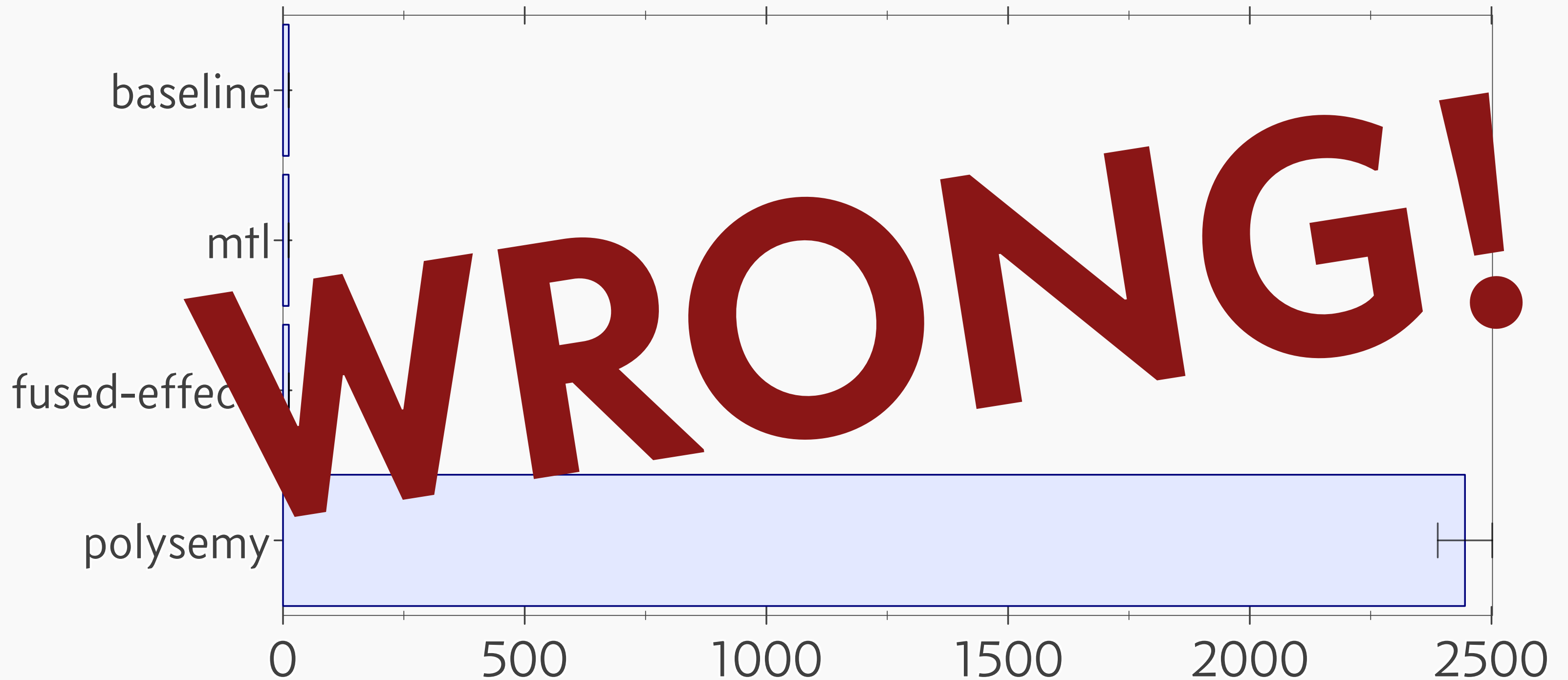
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RECAP

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 - ...the cost of effect dispatch.
 - ...the cost of $\gg=$.

Why am I belaboring this point?





...or at least highly misleading.

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module CountDown where

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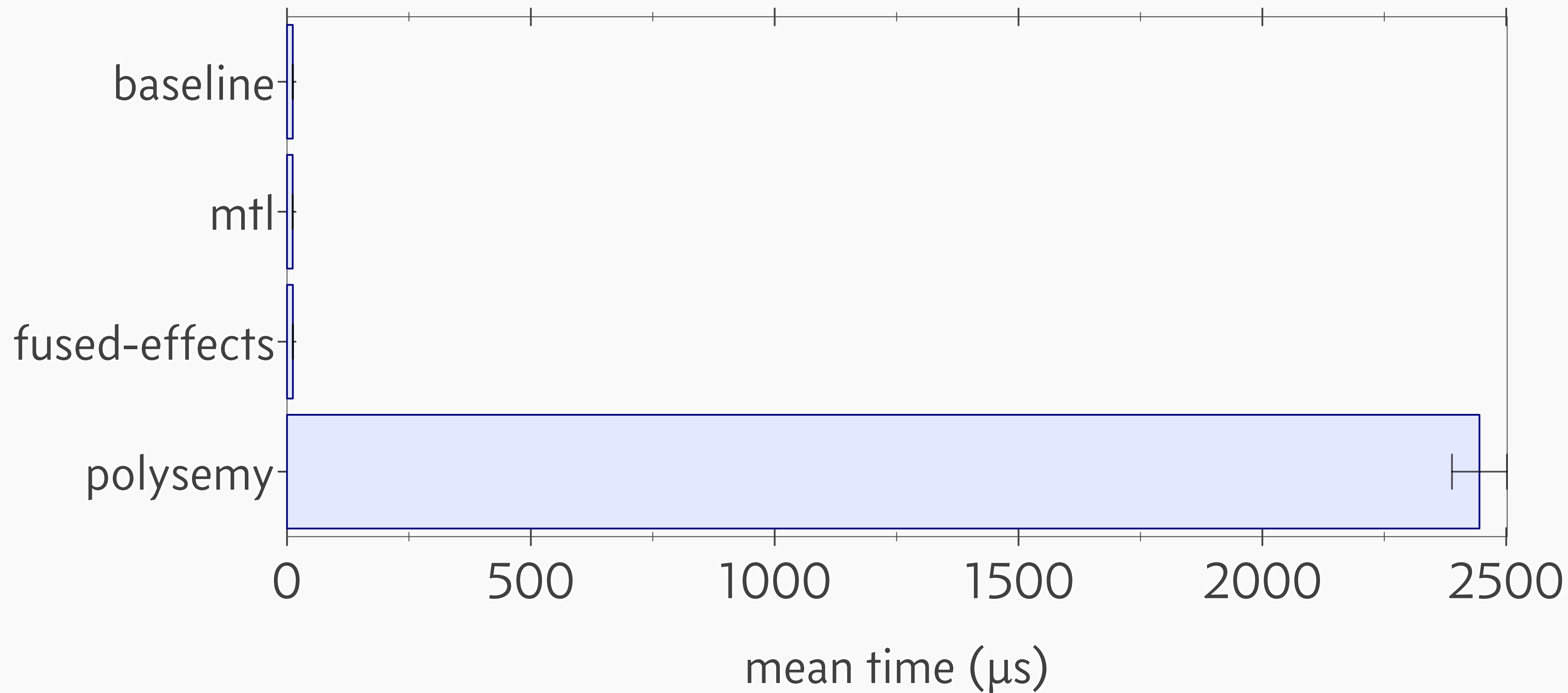
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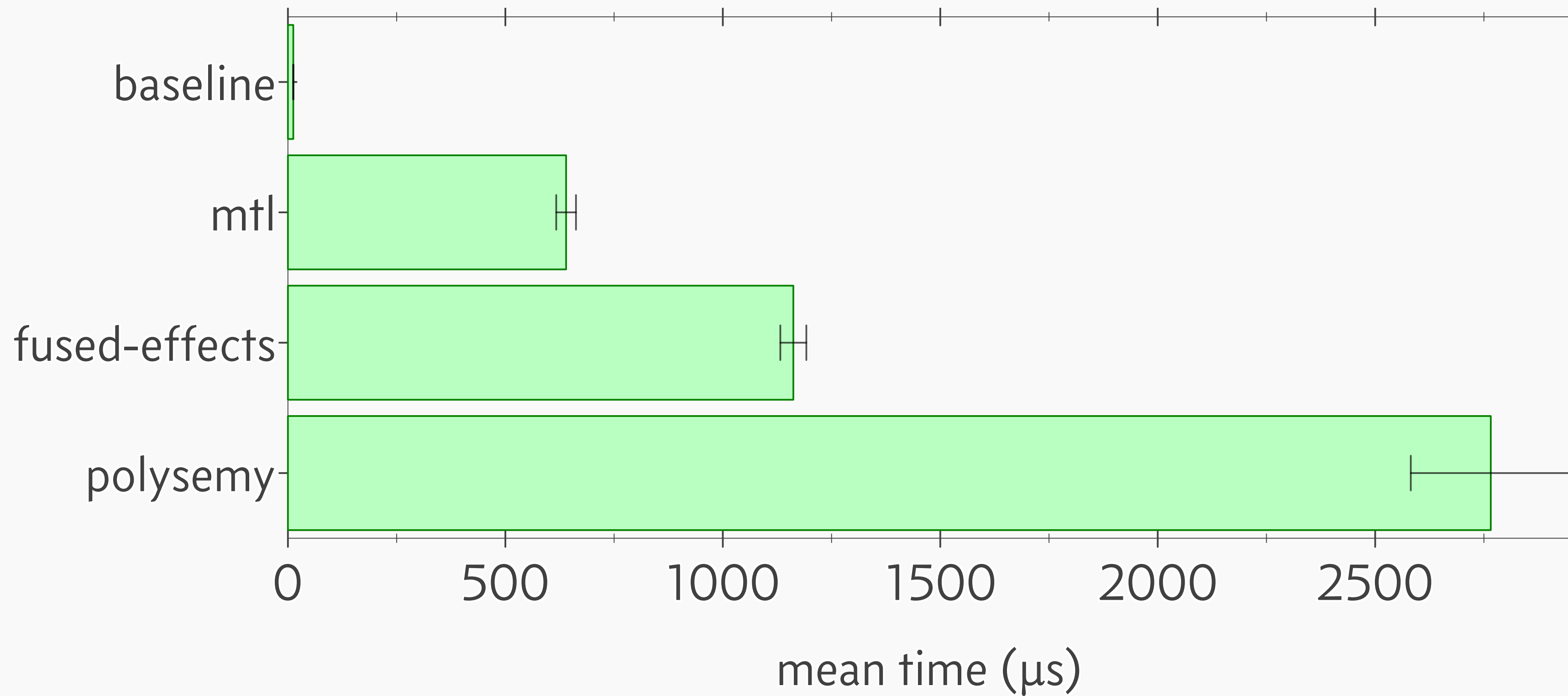
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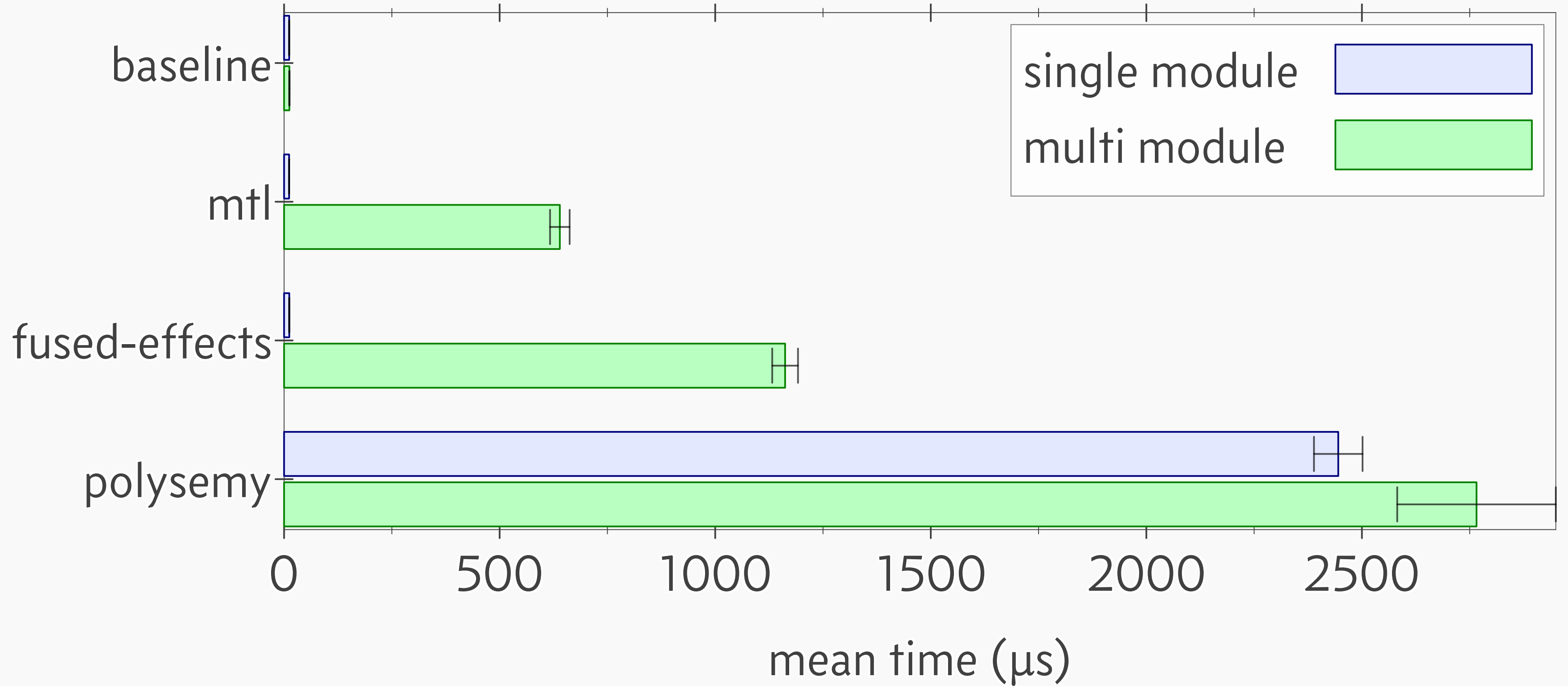
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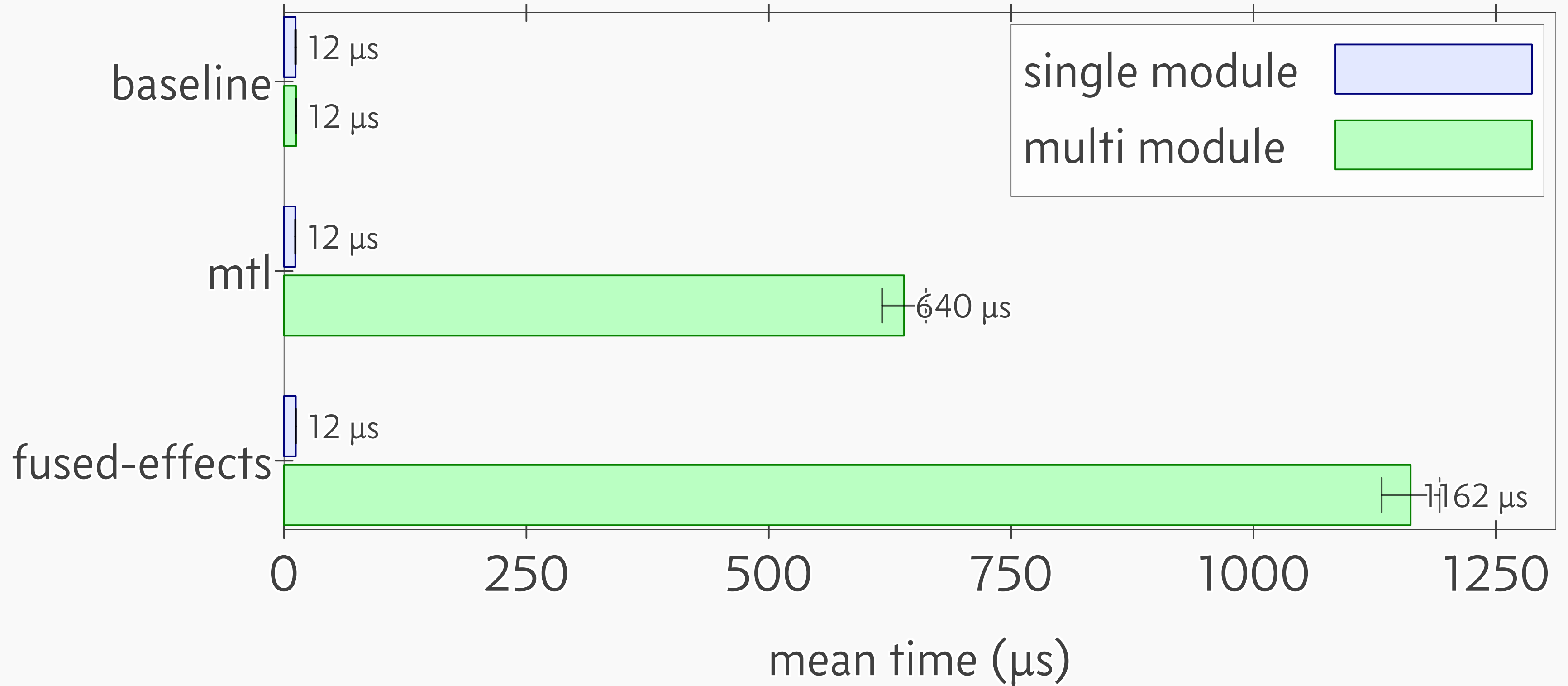
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```

Surely this shouldn't change anything?

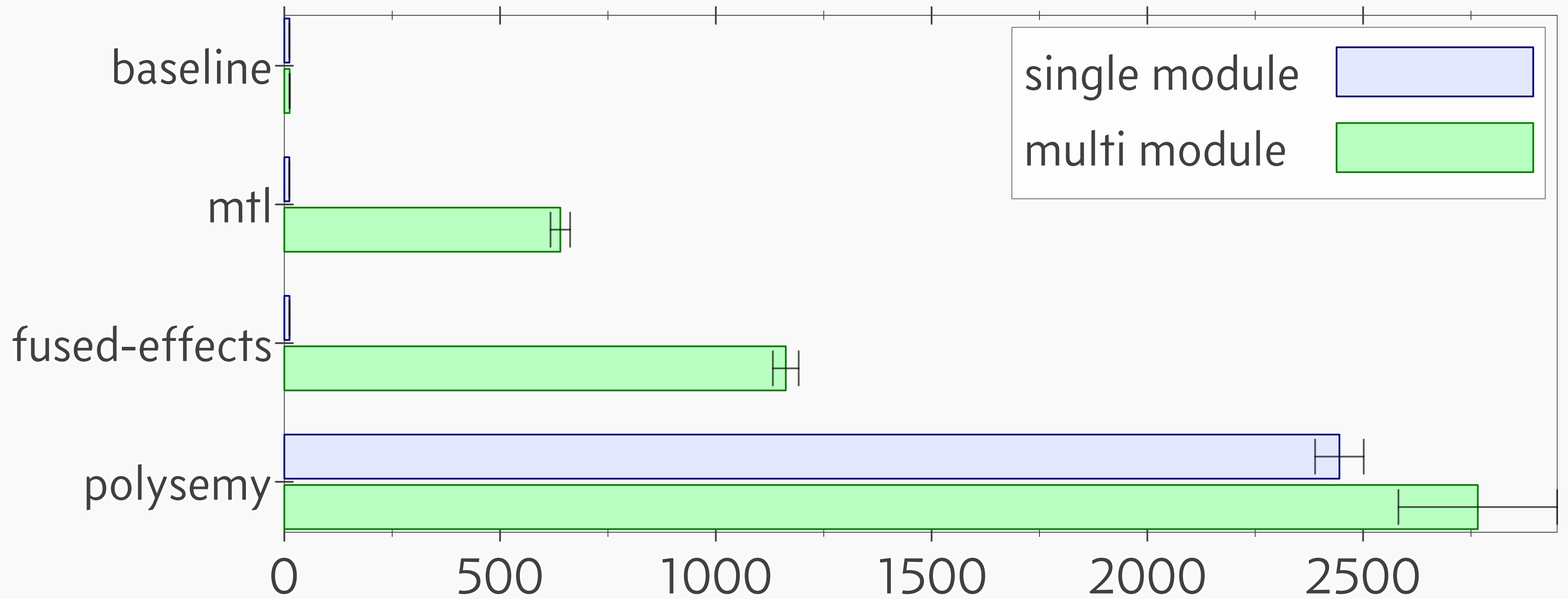


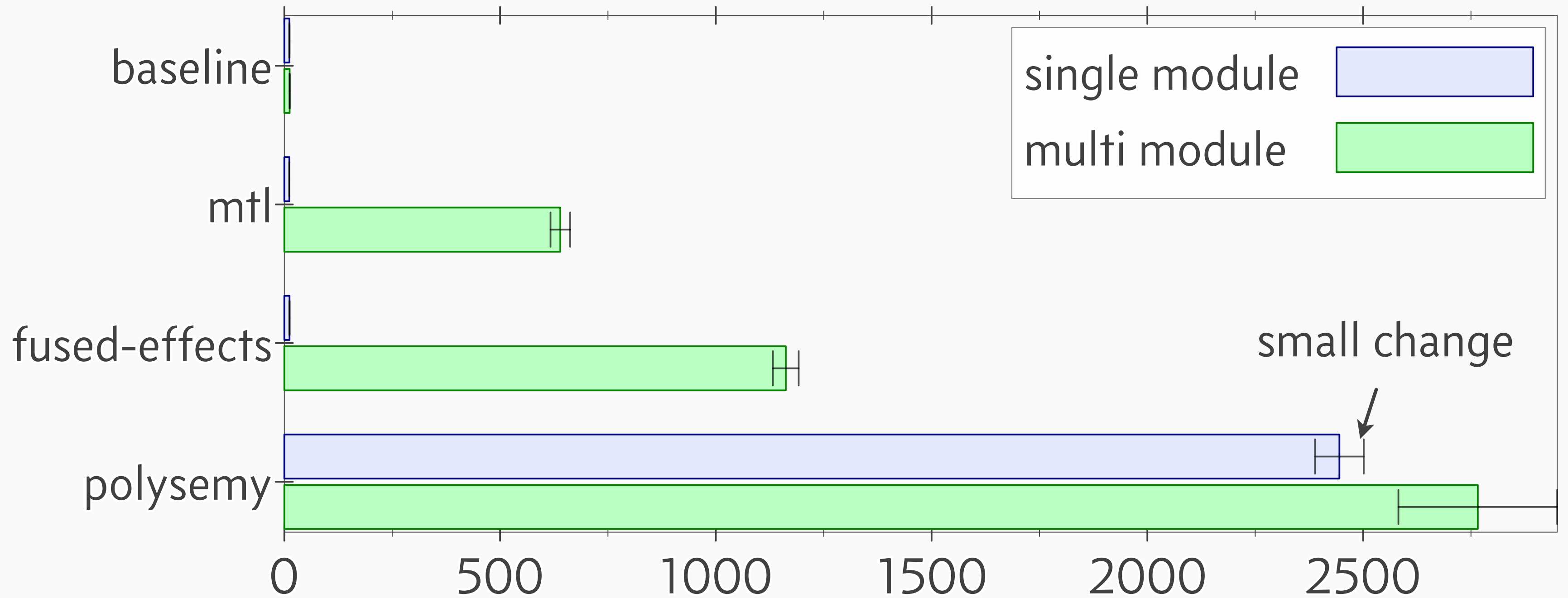


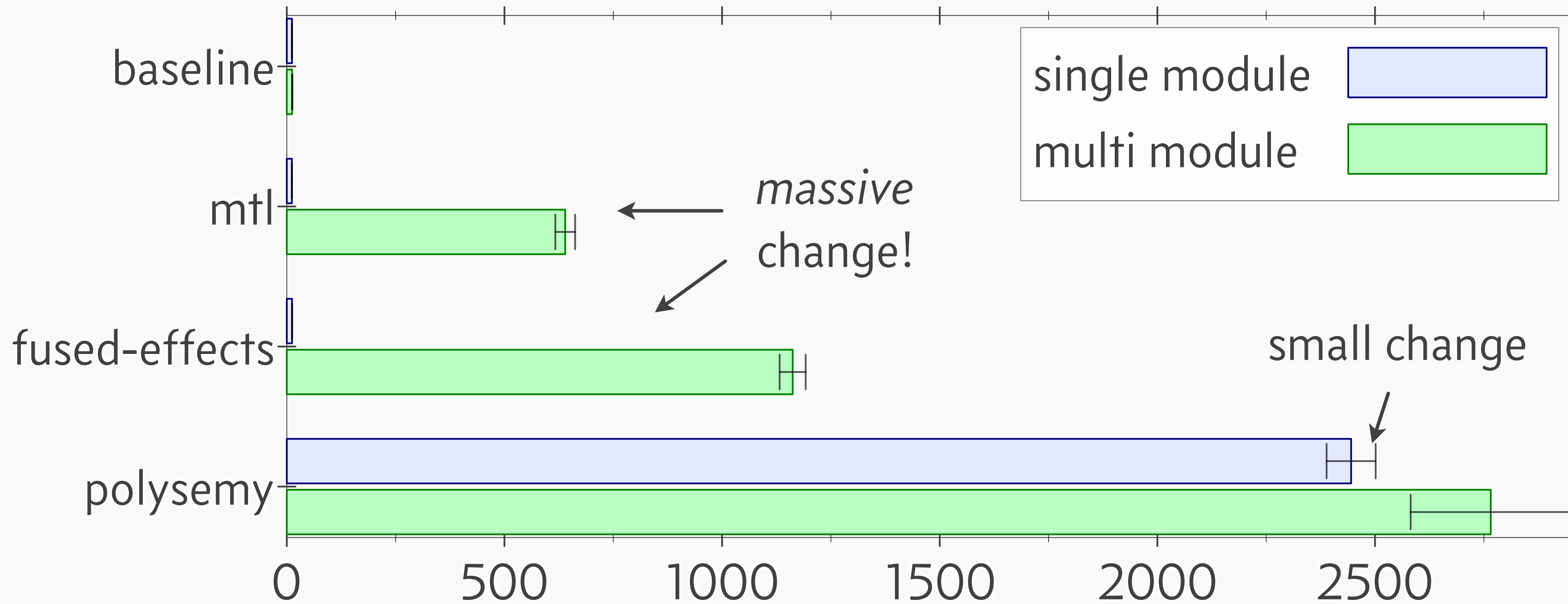


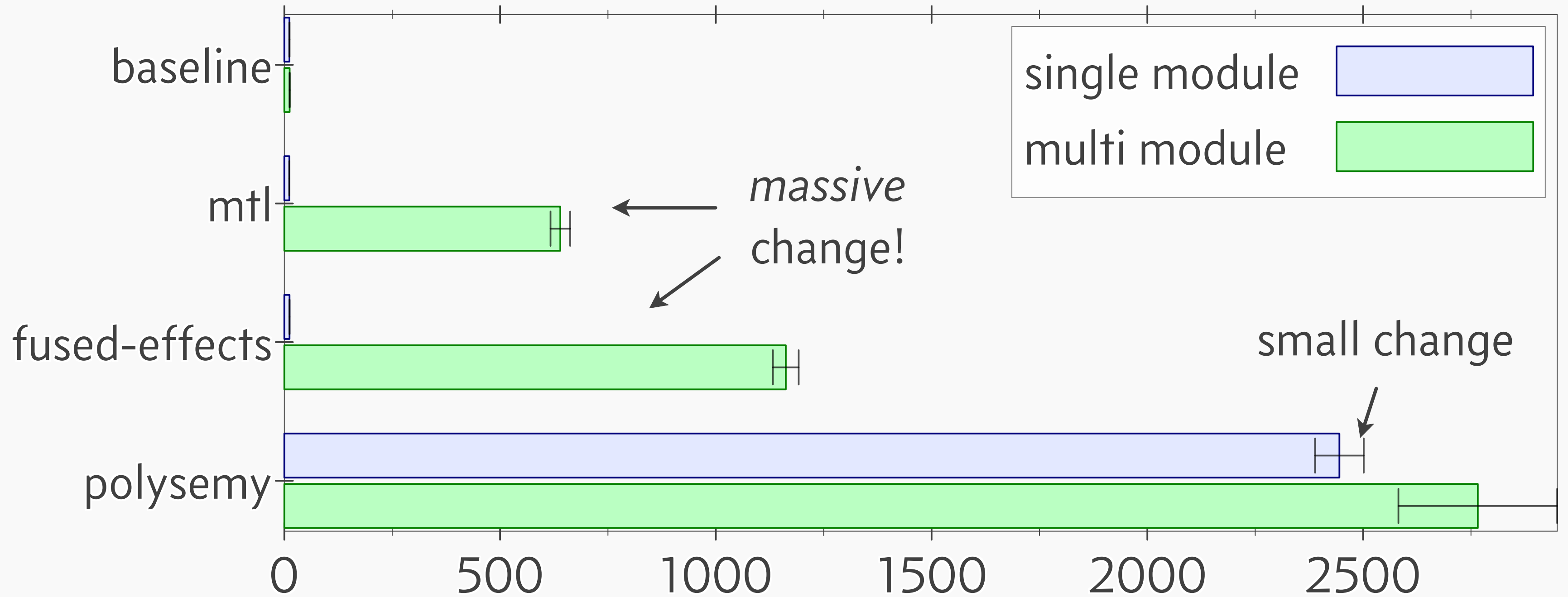


What happened?









mtl and fused-effects are victims of the optimizer.

KEY TAKEAWAYS

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1. mtl and fused-effects *are* faster than polysemy...

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1. mtl and fused-effects *are* faster than polysemy...
2. ...but are more reliant on compiler optimizations for best-case perf.
3. Tiny program changes can have huge perf diffs!

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Examples: `freer-simple`, `polysemy`


```
program = get  $\gg$  \n  $\rightarrow$   
    if n  $\leq$  0  
        then return n  
    else put (n - 1)  $\gg$  program
```



```

program = get  $\gg$  \n  $\rightarrow$ 
    if n  $\leq$  0
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    else put (n - 1) >> program

```



```

program :: Eff (State Int) Int
program = Get `Then` \n  $\rightarrow$ 
    if n  $\leq$  0
    then Return n
    else Put (n - 1) `Then` \_  $\rightarrow$  program

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```

data Eff f a where

Return :: a → Eff f a

Then :: f a → (a → Eff f b) → Eff f b

data Eff f a where

Return :: a → Eff f a

Then :: f a → (a → Eff f b) → Eff f b

data State s a where

Get :: State s s

Put :: s → State s ()

data Eff f a where

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Then :: f a → (a → Eff f b) → Eff f b

data State s a where

Get :: State s s

Put :: s → State s ()

runState :: s → Eff (State s) a → (s, a)

runState s (Return x) = (s, x)

runState s (Get `Then` k) = runState s (k s)

runState _ (Put s `Then` k) = runState s (k ())

PROS

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→ Beautifully simple.

PROS

- Beautifully simple.
- Extremely flexible.

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CONS

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- Reifies the entire program as a tree.

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CONS

- Reifies the entire program as a tree.
- Obscures structure to the optimizer.

```
program :: Eff (State Int) Int
program = Get `Then` \n →
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```



```
newtype State s a = State { runState :: s → (s, a) }
```

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```
instance Monad (State s) where
```

```
    return x = State $ \s → (s, x)
```

```
    m >>= f = State $ \s → case runState m s of  
        (s', a) → runState (f a) s'
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```
get :: State s s
```

```
get = State $ \s → (s, s)
```

```
put :: s → State s ()
```

```
put s = State $ \_ → (s, ())
```

```
program :: State Int Int
program = get >=> \n →
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program :: State Int Int
program = get >=> \n →
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```
program :: State Int Int
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  (s2, n) → if n ≤ 0
    then runState (return n) s2
    else case runState (put (n - 1)) s2 of
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```

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              else program (s1 - 1)
```

```
program :: Int → (Int, Int)
program n = if n ≤ 0
              then (n, n)
              else program (n - 1)
```

program $:: \text{Int} \rightarrow (\text{Int}, \text{Int})$
program $s1 = \text{if } s1 \leq 0$
 then $(s1, s1)$
 else program $(s1 - 1)$

program $:: \text{Int} \rightarrow (\text{Int}, \text{Int})$
program $n = \text{if } n \leq 0$
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 else program $(n - 1)$

This is great! But it's not an effect system.

```
program :: State Int Int
program = get >=> \n →
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```


This is great! But it's not an effect system.

```
program :: State Int Int
program = get >>= \n →
    if n ≤ 0
    then return n
    else put (n - 1) >> program
```

← coupled to implementation

Can we get the flexibility of free monads
with the performance of monad transformers?

Similar to the list fusion problem.

Similar to the list fusion problem.

```
foldr (+) 0 [1..5]
```

Similar to the list fusion problem.

foldr (+) 0 [1..5]

↑
producer

producer

Similar to the list fusion problem.

`foldr (+) 0 [1..5]`

↑
consumer

↑
producer

Similar to the list fusion problem.

`foldr (+) 0 [1..5]`



`foldr (+) 0 (1:2:3:4:5:[])`

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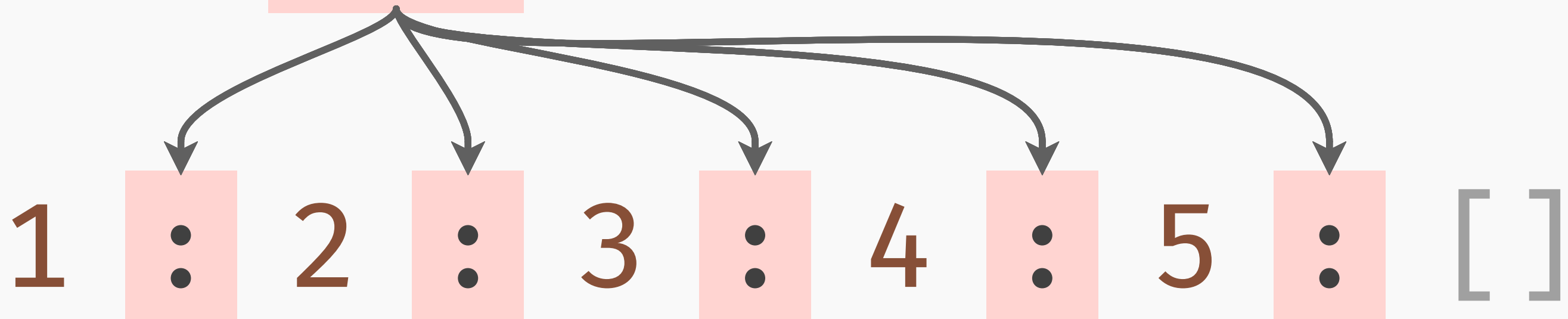
`1 : 2 : 3 : 4 : 5 : []`

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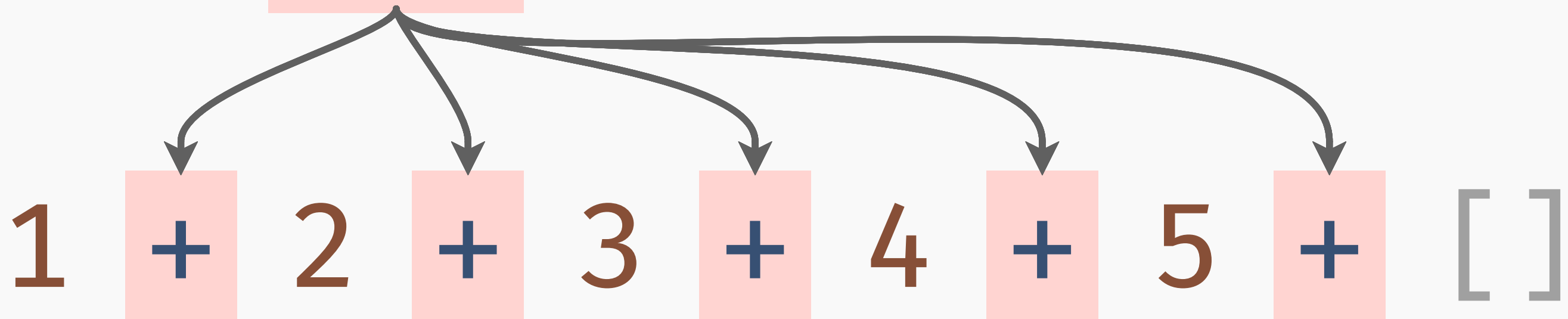


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`foldr (+) 0 (1:2:3:4:5:[])`

$1 + 2 + 3 + 4 + 5 + 0$

Similar to the list fusion problem.

`foldr (+) 0 [1..5]`



`foldr (+) 0 (1:2:3:4:5:[])`

$1 + 2 + 3 + 4 + 5 + 0$

```

program :: Eff (State Int) Int
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```

```

runState :: s → Eff (State s) a → (s, a)
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producer 

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producer 

 consumer

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runState :: s → Eff (State s) a → (s, a)
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```

Can we get GHC to do this?

Can we get GHC to do this?

Might `mtl` do better?

```
program :: MonadState Int m => m Int
```

```
program = get >=> \n ->
```

```
    if n ≤ 0
```

```
        then return n
```

```
        else put (n - 1) >> program
```



```
program :: MonadState Int m => m Int
```

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program = get >= \n ->  
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```

How is this compiled?

`program :: MonadState Int m => m Int`

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```

How is this compiled?

How are typeclasses compiled?

Non-Solution 1: Type Dispatch

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```
show x = case typeOf x of
  Bool    → show_Bool x
  Char    → show_Char x
  String  → show_String x
  ...
```

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Immediate problem: requires
whole-program compilation.

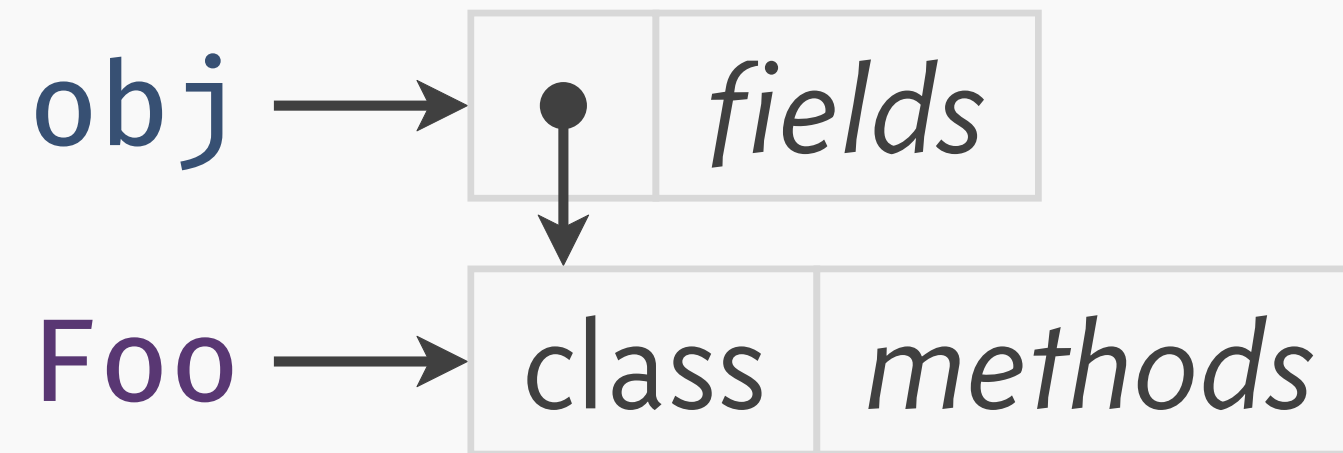
Deeper problem: full type erasure.

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Java: `if (obj instanceof Foo) { ... }`

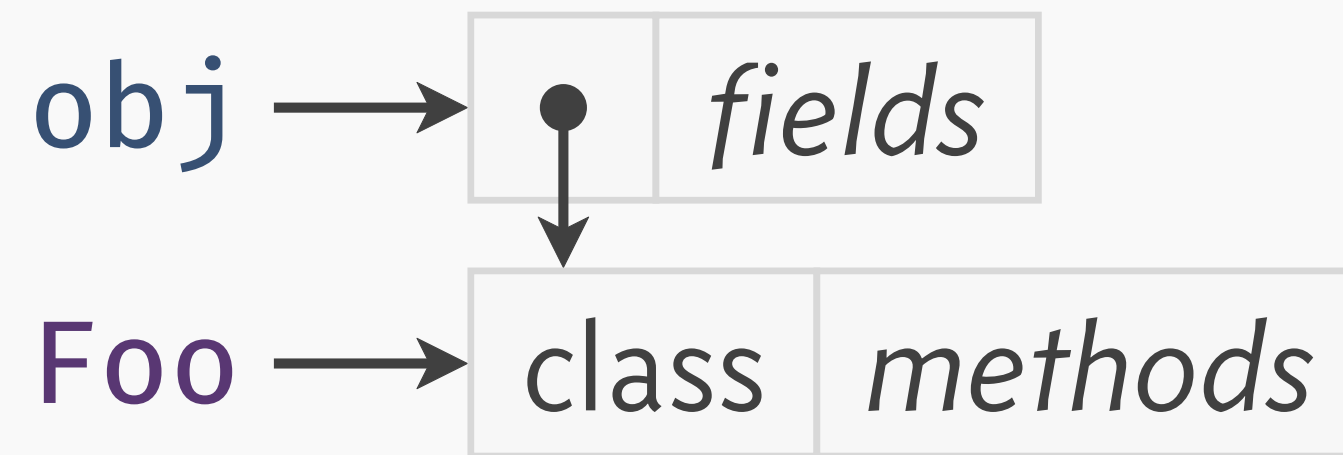
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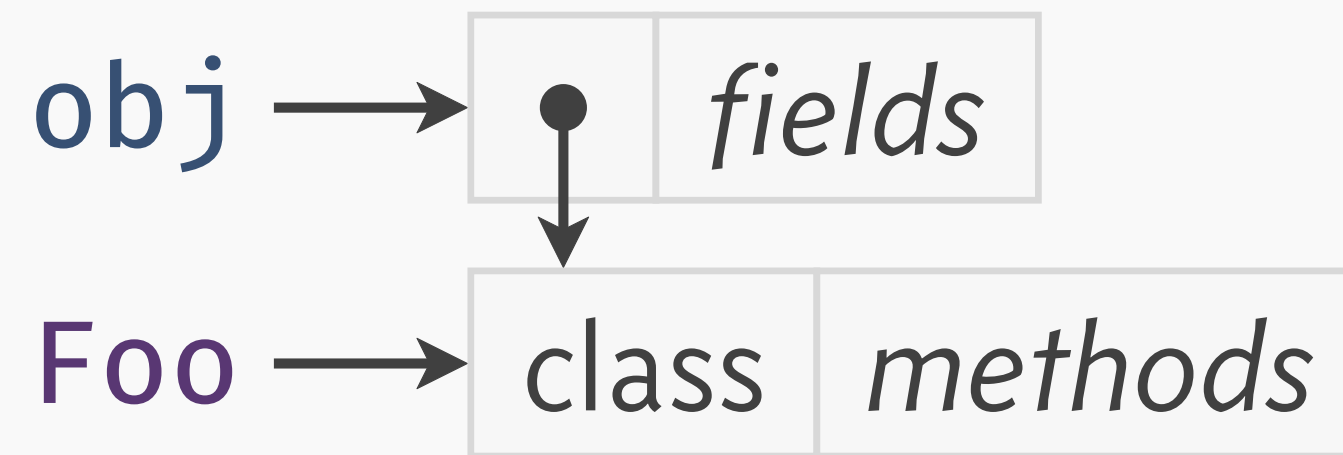
Java: `if (obj instanceof Foo) { ... }`



Haskell: `data Foo = MkFoo Int String`

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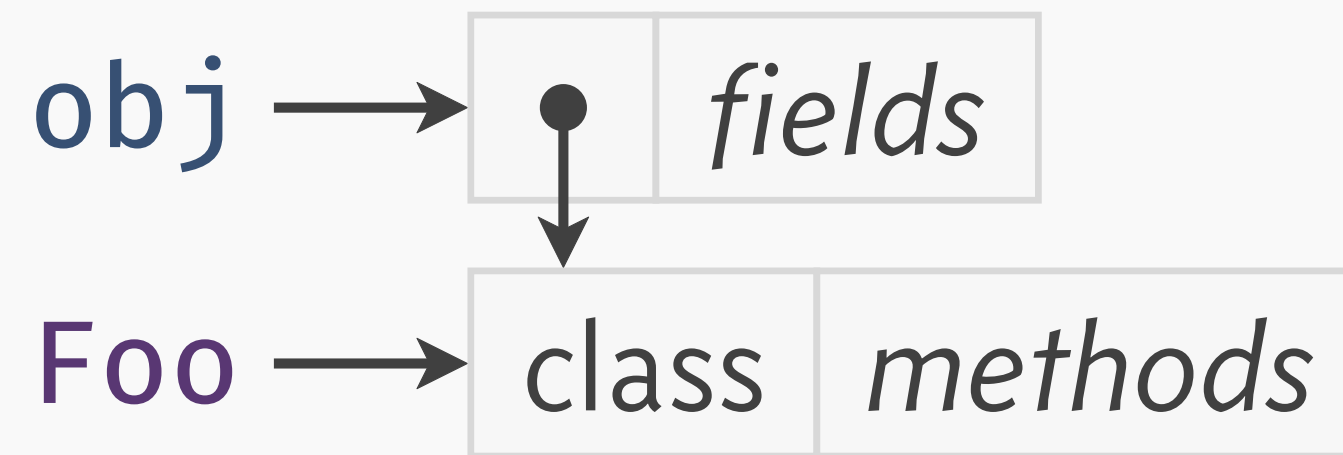
Java: `if (obj instanceof Foo) { ... }`



Haskell: `data Foo = MkFoo Int String`
`let val = MkFoo 42 "hello"`

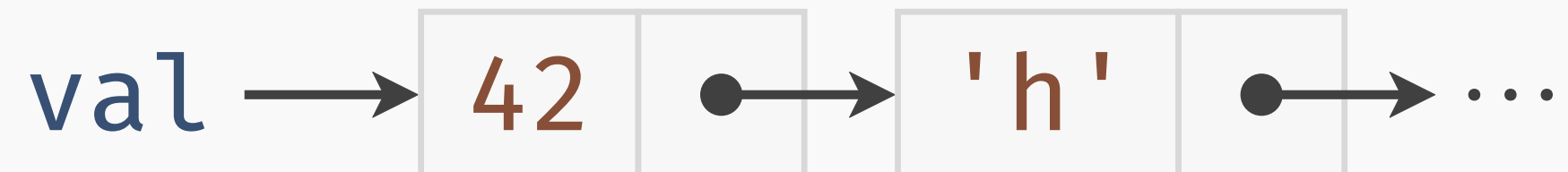
Deeper problem: full type erasure.

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Non-Solution 2: *Monomorphization*

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`exclaim :: Show a \Rightarrow a \rightarrow String`
`exclaim x = show x ++ "!"`

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`exclaim x = show x ++ "!"`

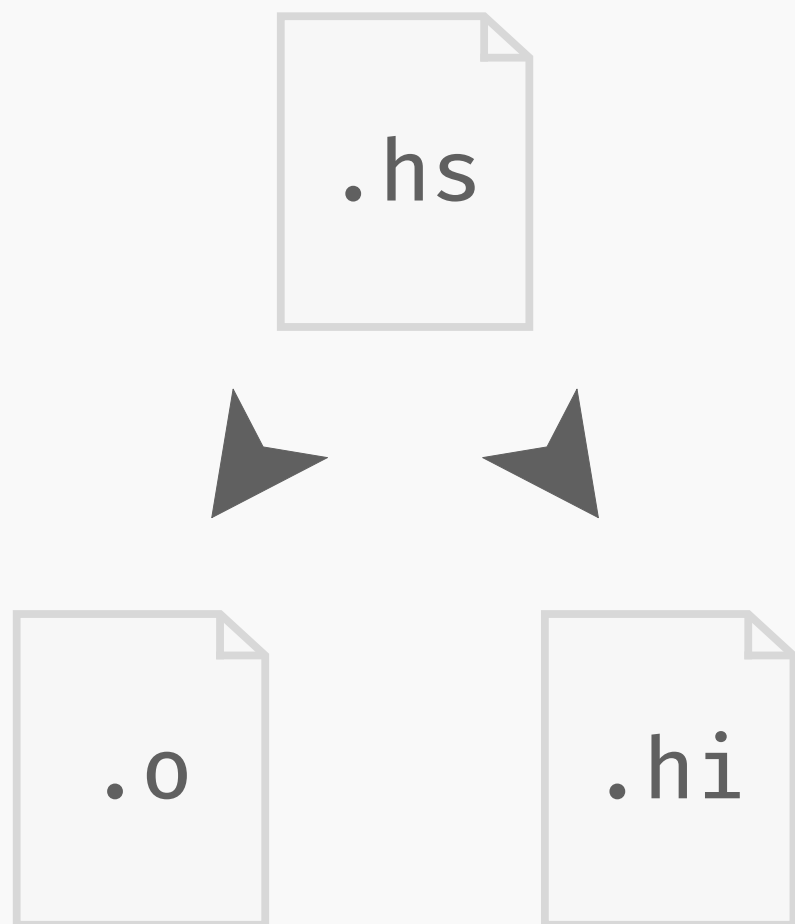
1. Generate *no code* for `exclaim`.

Non-Solution 2: Monomorphization

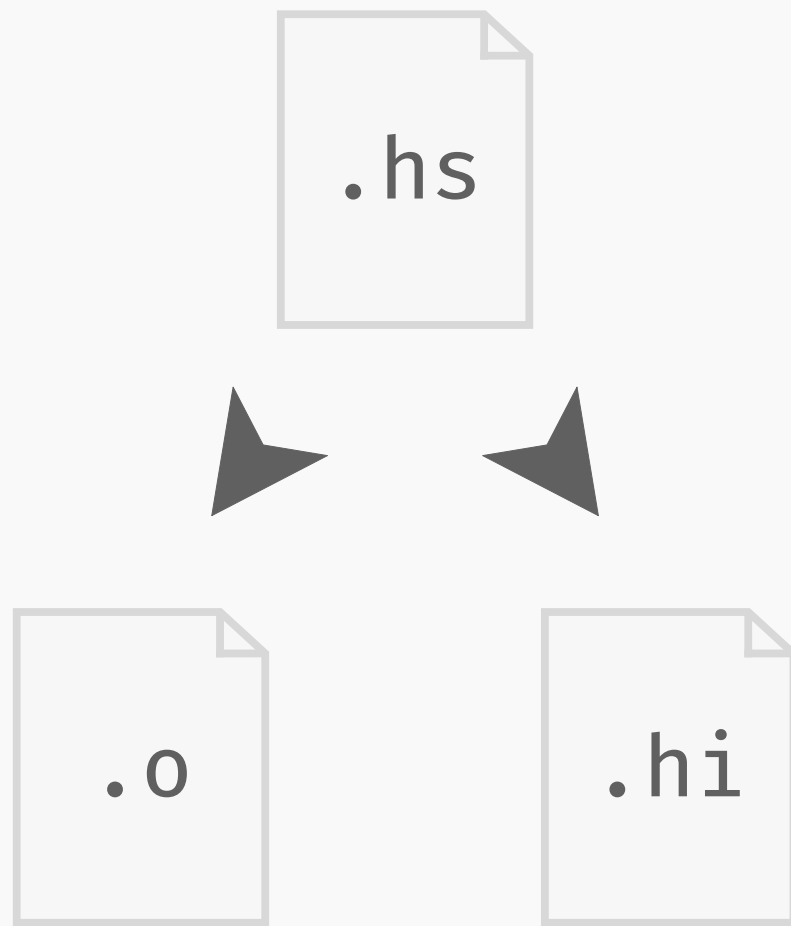
```
exclaim :: Show a => a -> String  
exclaim x = show x ++ "!"
```

1. Generate *no code* for `exclaim`.
2. Record `exclaim`'s definition in the interface file.



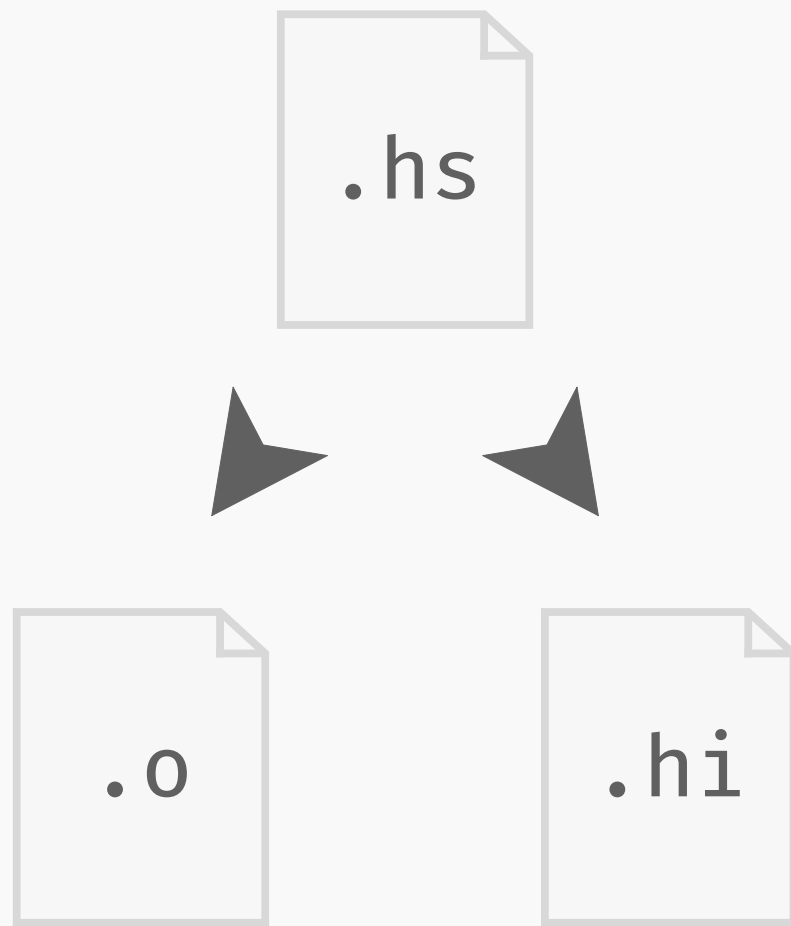


`.hi` — “Haskell interface”



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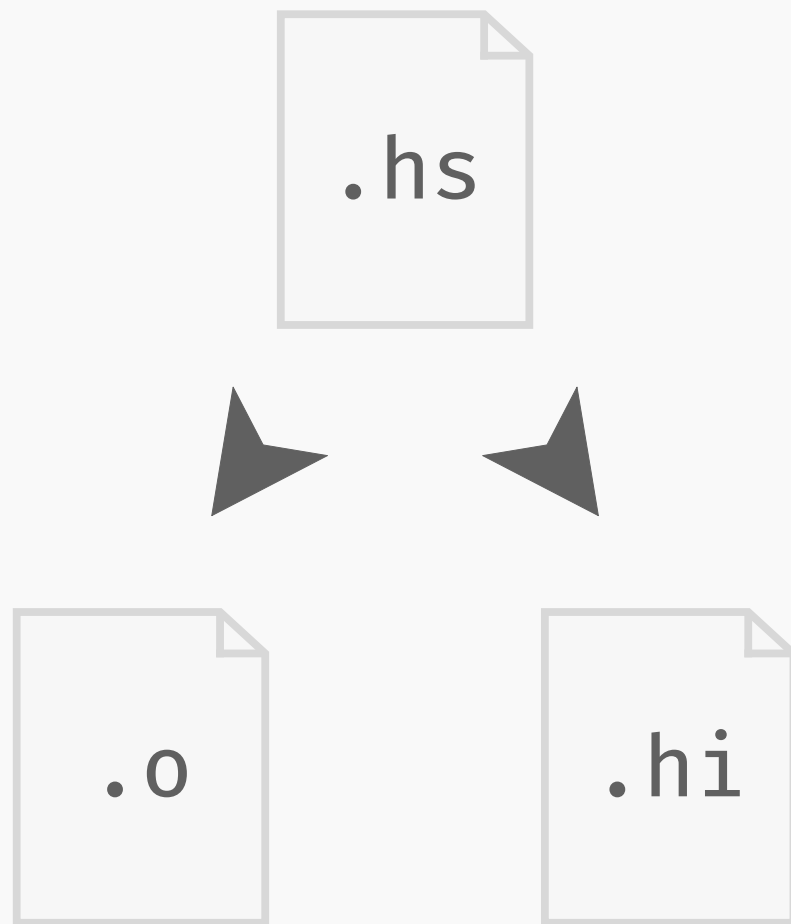
→ type/class/instance declarations

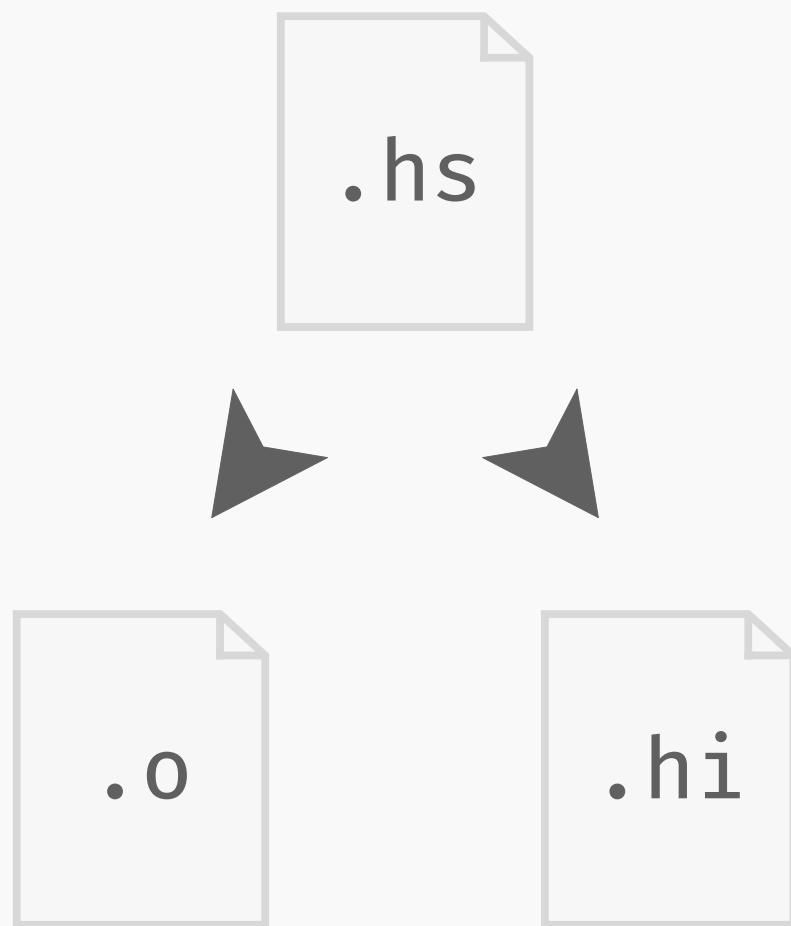


`.hi` — “Haskell interface”

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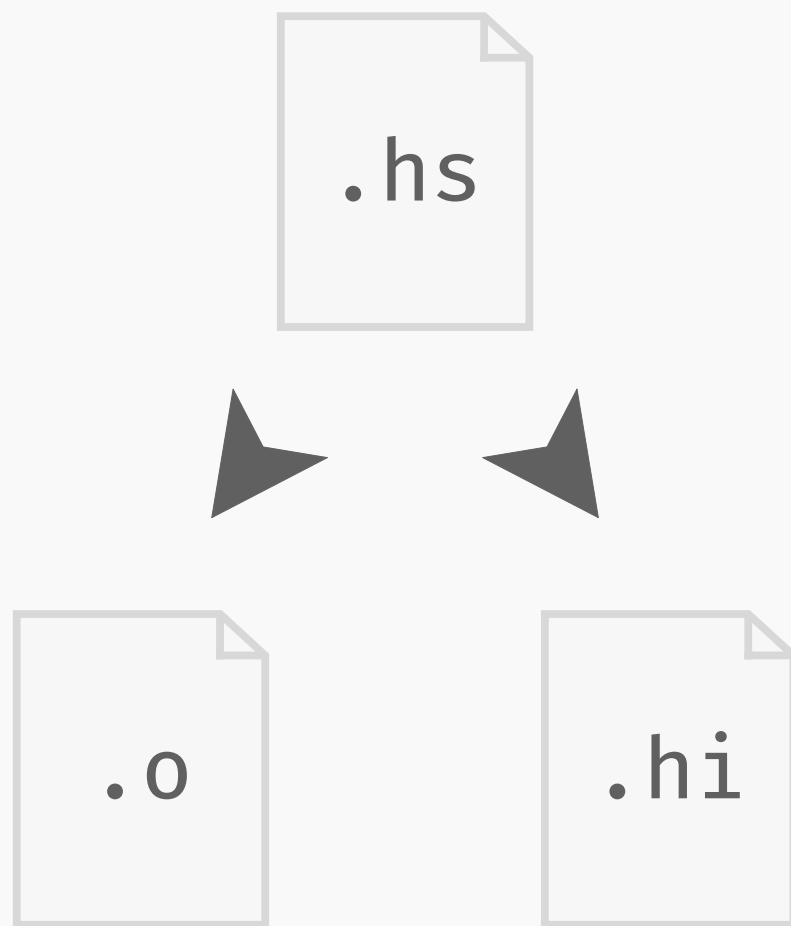
→ types of exported bindings





`.hi` — “Haskell interface”

- type/class/instance declarations
- types of exported bindings
- source code of small bindings



`.hi` — “Haskell interface”

- type/class/instance declarations
- types of exported bindings
- source code of small bindings
- for monomorphization: source code of *all* overloaded bindings

exclaim True

exclaim True

exclaim :: Show a \Rightarrow a \rightarrow String
exclaim x = show x ++ "!"

exclaim True

exclaim :: Show a \Rightarrow a \rightarrow String
exclaim x = show x ++ "!"

exclaim_Bool :: Bool \rightarrow String
exclaim_Bool x = show_Bool x ++ "!"

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exclaim True \triangleright exclaim_Bool True

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exclaim True \triangleright exclaim_Bool True

Overloading has no runtime cost!

...but it can create a lot of bloat.

...but it can create a lot of bloat.

exclaim True exclaim 42 exclaim "hello"

...but it can create a lot of bloat.

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exclaim_Bool :: Bool → String

exclaim_Bool x = show_Bool x ++ "!"

exclaim_Int :: Int → String

exclaim_Int x = show_Int x ++ "!"

exclaim_String :: String → String

exclaim_String x = show_String x ++ "!"

`reallyBig` :: (Foo a, Bar b, Baz c) \Rightarrow ...
`reallyBig` = < *really big RHS* >

reallyBig :: (Foo a, Bar b, Baz c) => ...
 reallyBig = <really big RHS>



reallyBig @Bool @Bool @Bool
 reallyBig @Bool @Int @Bool
 reallyBig @Bool @String @Bool
 reallyBig @Int @Bool @Bool
 reallyBig @Int @Int @Bool
 reallyBig @Int @String @Bool
 reallyBig @String @Bool @Bool
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Monomorphization

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- Can be good for runtime performance.
- Can be very bad for code size & compile times.
- C++/Rust programmers have to worry about this!
- Haskell programmers generally do not.

`exclaim :: Show a \Rightarrow a \rightarrow String`

`exclaim x = show x ++ "!"`

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`exclaim True` ➤ `exclaim show_Bool True`

`exclaim 42`

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`exclaim True` ➤ `exclaim show_Bool True`

`exclaim 42` ➤ `exclaim show_Int 42`


```
class Show a where  
  show      :: a → String  
  showsPrec :: Int → a → ShowS  
  showList  :: [a] → ShowS
```

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```
data Show a = ShowDict
```

```
  { show      :: a → String
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```
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data Show a = ShowDict

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exclaim :: Show a → a → String

exclaim dict x = show dict x ++ "!"

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- Does it have a runtime cost?

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program :: MonadState Int m => m Int
program = get >= \n ->
    if n <= 0
    then return n
    else put (n - 1) >> program
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Nope: we can't inline anything.

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```
fst ("hello", "world")
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`fst` ("hello", "world")

$\text{fst} :: (a, b) \rightarrow a$
 $\text{fst } (x, _) = x$

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`"hello"`

Higher-order functions make *unknown* calls.

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Unknown calls are *hard stops* for the optimizer.

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This is the cost of AOT compilation!

Typeclass overloading creates unknown calls.

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Overloading is **not** free!

Unknown calls are not a death sentence.

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```
sumIndicies :: Eq a => a -> [a] -> [Int]
sumIndicies v xs = zip [1..] xs
                  & filter ((== v) . snd)
                  & map fst
                  & sum
```

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```

List fusion can still happen!

Unknown calls to \gg are a problem.

Unknown calls to $\gg=$ are a problem.

```
foo :: k → Map k Int → Either String Int
foo key vals = do
  nums ← case Map.lookup key vals of
    Nothing → Left "not found"
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  Right $ sum nums
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Unknown calls to $\gg=$ are a problem.

```
foo :: MonadError String m => k -> Map k Int -> m Int
foo key vals = do
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    Nothing   -> throwError "not found"
    Just val  -> return  [1..val]
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$\gg=$ is *glue*.

Conclusion: not surprising at all that mtl has a cost!

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But why is it *sometimes* fast?

SPECIALIZATION

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program :: MonadState Int m => m Int
program = do n <- get
           if n ≤ 0
             then return n
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```

program :: State Int Int
program = get >=> \n →
           if n ≤ 0
             then return n
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```



```
program :: MonadState Int m => m Int
program = do n ← get
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```

```

program :: MonadState Int m  $\Rightarrow$  m Int
program = do n  $\leftarrow$  get
           if n  $\leq$  0
           then return n
           else put (n - 1) >> program

```



```

program :: MonadState Int m  $\rightarrow$  m Int
program stateDict@(MonadStateDict monadDict _ _) =
  (  $\gg$  ) monadDict
    ( get stateDict
    (\n  $\rightarrow$  if n  $\leq$  0
            then return monadDict n
            else (  $\gg$  ) monadDict
                  ( put stateDict (n - 1) )
                  ( program stateDict )
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```

Why bother explaining all of this?

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Because we're not done.

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1. It would be annoying.
2. It requires *whole-program* specialization!
 - Probably recompiles everything in `Main.hs`.
 - Compilation may not terminate.
 - This cost is incurred for *each* specialization.
 - Can be defeated by existential quantification.

Let's take a step back.

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Why is specialization necessary here?

Proposition 1: effect systems are
fundamentally about dynamic dispatch.


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program = get  $\gg$  \n  $\rightarrow$   
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Proposition 1: effect systems are
fundamentally about dynamic dispatch.

program = `get`  interpretation not yet decided!

if `n` \leq `0`

then return `n`

else `put (n - 1)` \gg program

Proposition 2: effect dispatch can be made perfectly affordable. The real problem is \gg .

```
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1. $\gg=$ gets called a *lot*.
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3. Unknown calls to $\gg=$ balloon closure allocation.

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`f x y = foo x >=> \z -> bar (+ y z)`

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`f x y = case foo x of
 Left e -> Left e
 Right z -> bar (+ y z)`

$f\ x\ y = \text{foo}\ x \gg= \backslash z \rightarrow \text{bar}\ (+\ y\ z)$



$f\ x\ y = \text{case}\ \text{foo}\ x\ \text{of}$
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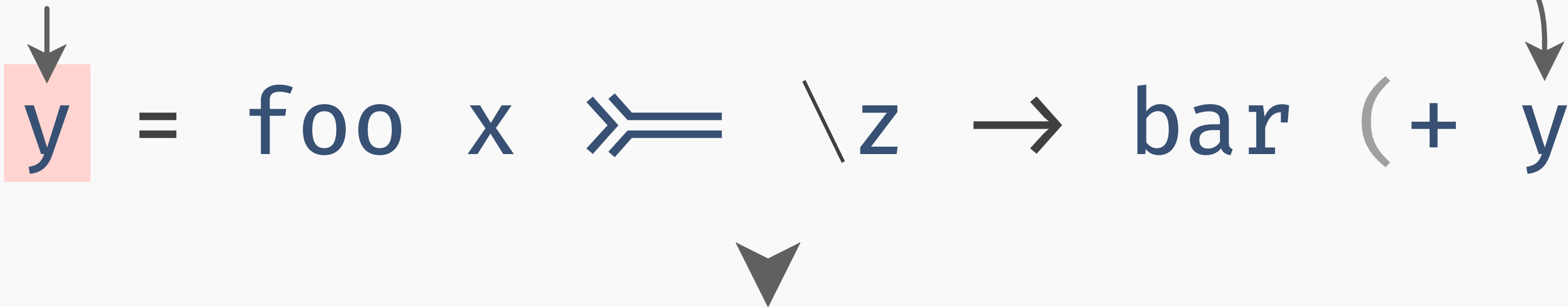
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captured in closure

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$f\ x\ y = \text{foo}\ x \gg \lambda z \rightarrow \text{bar}\ (+\ y\ z)$

stored on stack

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 $\text{Left}\ e \rightarrow \text{Left}\ e$
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 $\text{Left}\ e \rightarrow \text{Left}\ e$
 $\text{Right}\ z \rightarrow \text{bar}\ (+\ y\ z)$

used in a case RHS

If \gg is an unknown call, the caller must allocate a closure for the continuation.

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When $\gg=$ is passed via dictionary, the program is *reified as a tree of lambdas!*

```

program :: Eff (State Int) Int
program = Get `Then` \n →
    if n ≤ 0
    then Return n
    else Put (n - 1) `Then` \_ → program

```

```

program :: MonadState Int m ⇒ m Int
program = get >= \n →
    if n ≤ 0
    then return n
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Without specialization, these *aren't that different!*

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How do we escape?

ESCAPE PLAN

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Requirements ② and ③ are especially hard.

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What's left?

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Big idea: equip a monad with a pair of super powerful control operators, **prompt** and **control**.

DELIMITED CONTINUATIONS

There is a deep, well-known connection between delimited continuations and algebraic effects.

(Well outside the scope of this talk!)

Big idea: equip a monad with a pair of super powerful control operators, **prompt** and **control**.

All effect handlers can be defined in terms of these operators.

» does not need to know anything about effect behavior.

New problem: the only way to implement delimited continuations in Haskell is CPS.

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$$m \gg= f = \backslash k \rightarrow m (\backslash x \rightarrow f x k)$$

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In CPS, continuation is passed via closure:

$$m \gg= f = \backslash k \rightarrow m (\backslash x \rightarrow f x k)$$

All calls to non-inlined monadic functions must allocate.
(This isn't much better than free monads.)

Cost is okay for continuation-happy code, but effects that don't need them (very common!) still must pay for them.

But this is frustrating!

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There are well-known, efficient implementation techniques for delimited continuations!

I give up.

I give up. Let's just patch GHC.

 [ghc-proposals](#) / [ghc-proposals](#)

 Watch ▾

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 Code

 Issues 15

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 Insights

Delimited continuation primops #313

 Open

lexi-lambda wants to merge 4 commits into [ghc-proposals:master](#) from [lexi-lambda:delimited-continuation-](#)

 Conversation 39

 Commits 4

 Checks 0

 Files changed 2



lexi-lambda commented on Feb 22 • edited ▾



This is a proposal for adding primops for capturing slices of the RTS stack to improve the performance of algebraic effect systems, which require delimited continuations.

Rendered

 75

 17

 10

 10

EFF

🚧 a work in progress effect system for Haskell 🚧

Edit

Manage topics

26 commits

5 branches

0 packages

0 releases

1 environment

3 contributors

ISC

Branch: master

New pull request

Create new file

Upload files

Find file

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lexi-lambda	Rename `shift` to `control`	Latest commit 17cc75d on Mar 3
eff	Rename `shift` to `control`	3 months ago
.gitignore	initial commit	8 months ago
.travis.yml	Update to support continuation primop changes	4 months ago
LICENSE	initial commit	8 months ago
README.md	Rename `swizzle` to `lift`, remove old version of `lift`	3 months ago
cabal.project	Completely rewrite implementation to use delimited continuations	4 months ago
cabal.project.travis	Completely rewrite implementation to use delimited continuations	4 months ago

README.md

eff

— screaming fast extensible effects for less

build passing

docs 0.0.0.0

🚧

This library is currently under construction.

🚧

eff

 is a work-in-progress implementation of an *extensible effect system* for Haskell, a general-purpose solution for tracking effects at the type level and handling them in flexible ways. Compared to other effect systems currently available,

eff

 differentiates itself in the following respects:

EFF: KEY FEATURES

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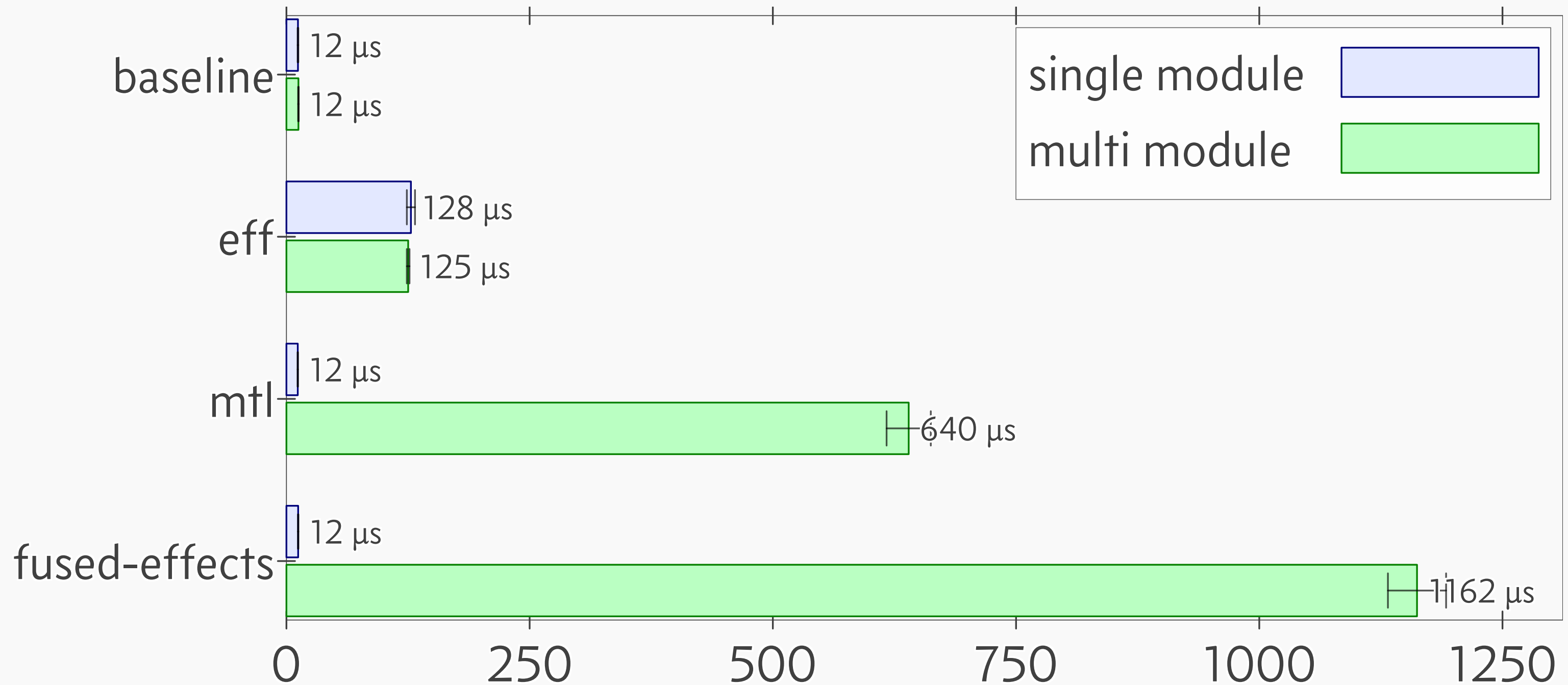
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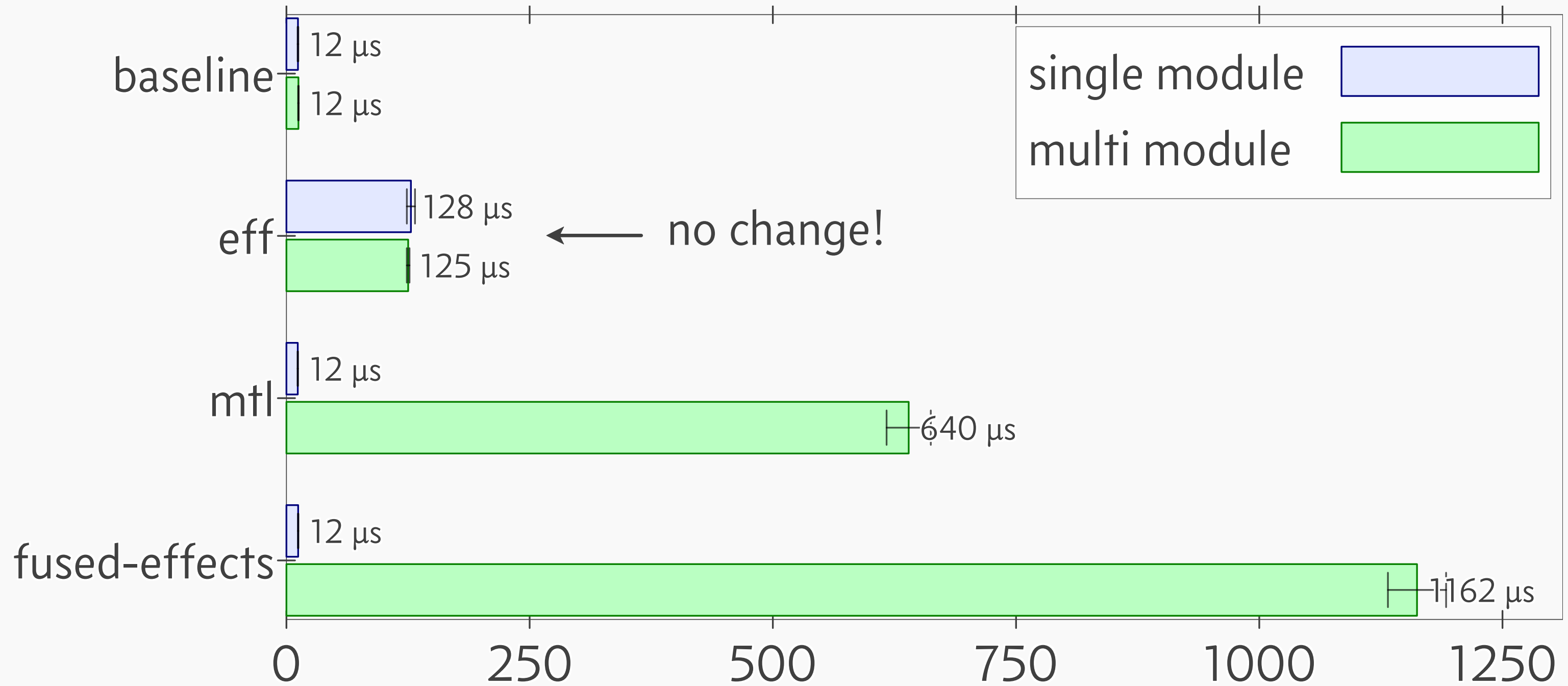
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 - Reader context holds current handlers.
 - Wraps the unsafe primops in a safe API.
- Effect dispatch takes constant time (not amortized).
- Faster for most use cases than unspecialized `mtl`.

EFF: THE NUMBERS

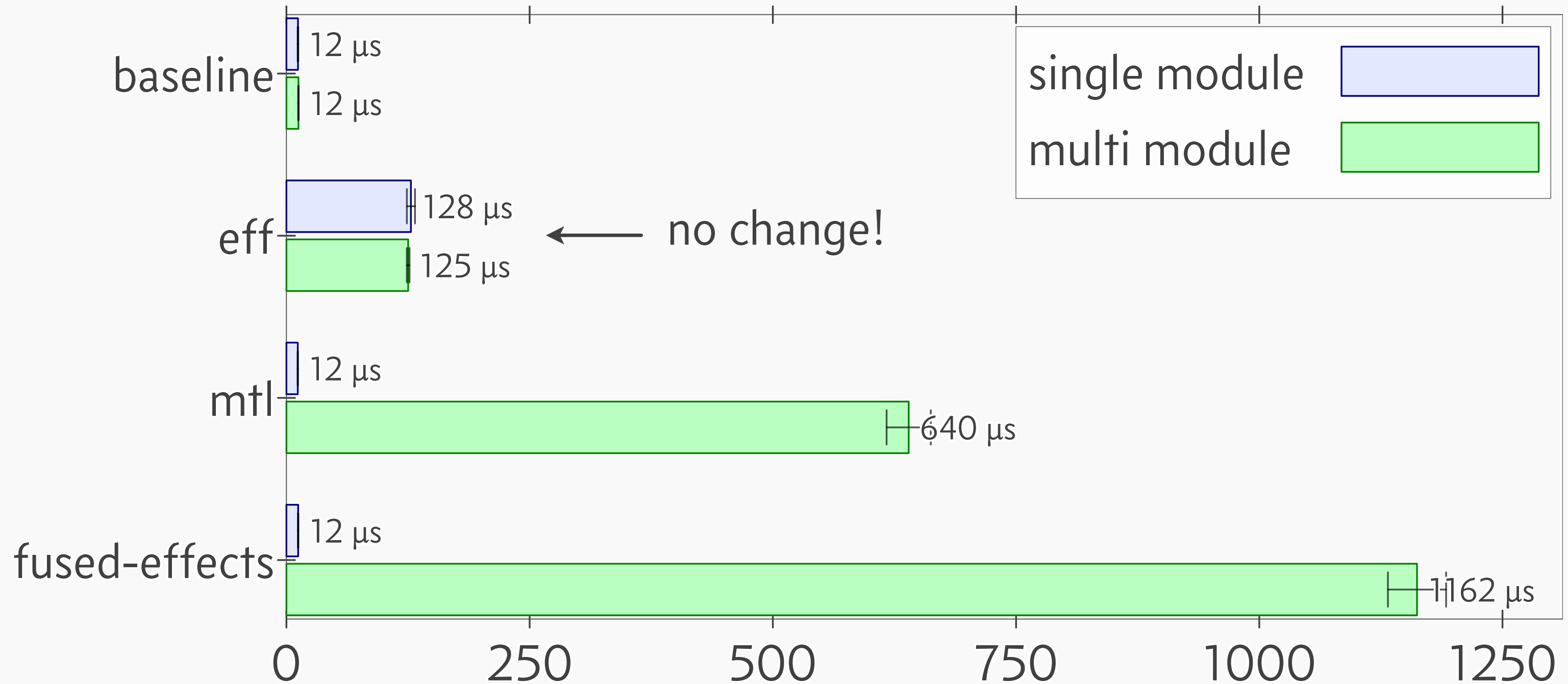
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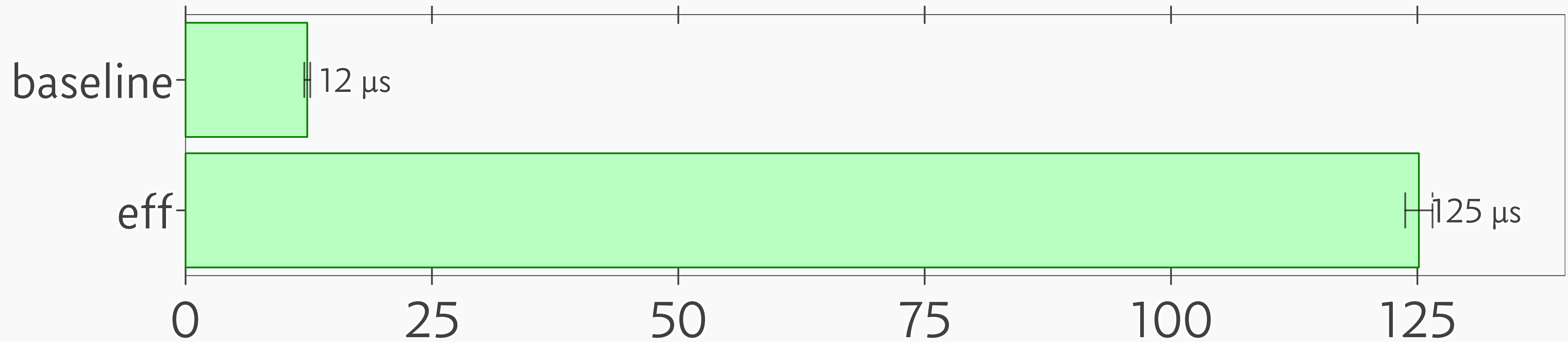


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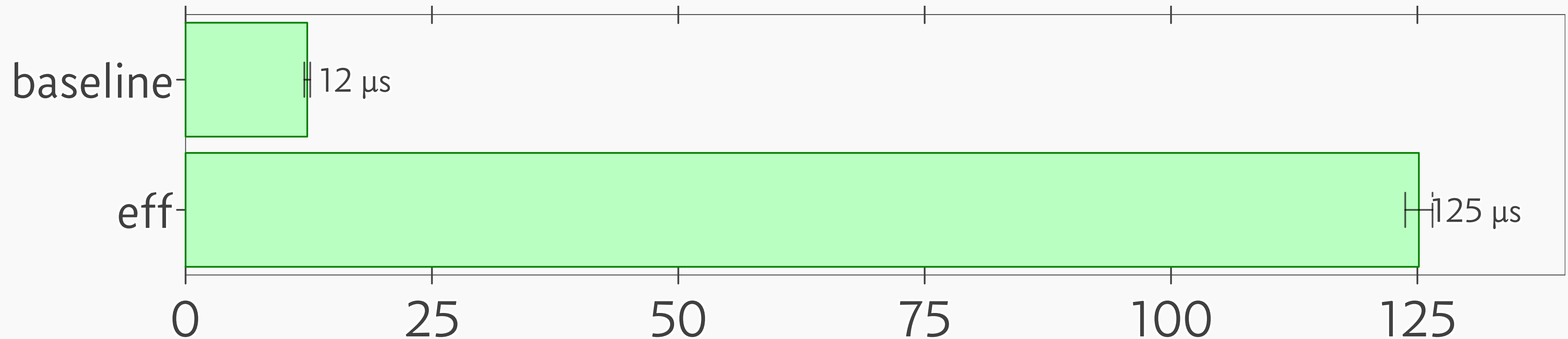


`eff`'s performance does *not* depend on compiler optimizations!

EFF: THE NUMBERS



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Should we be worried?

COUNTDOWN: THE REST OF THE STORY

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program :: Int → (Int, Int)
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Why so much faster?


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8 instructions!

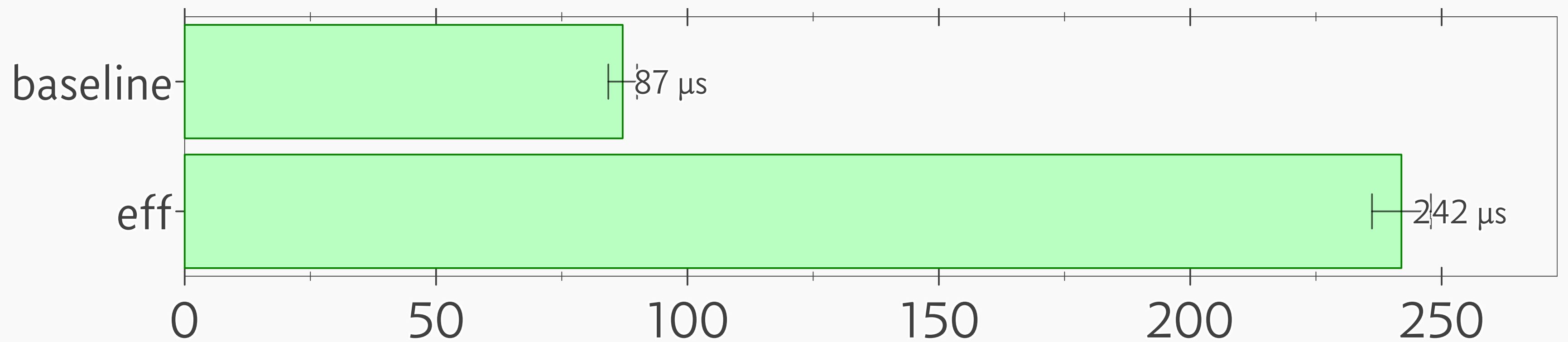
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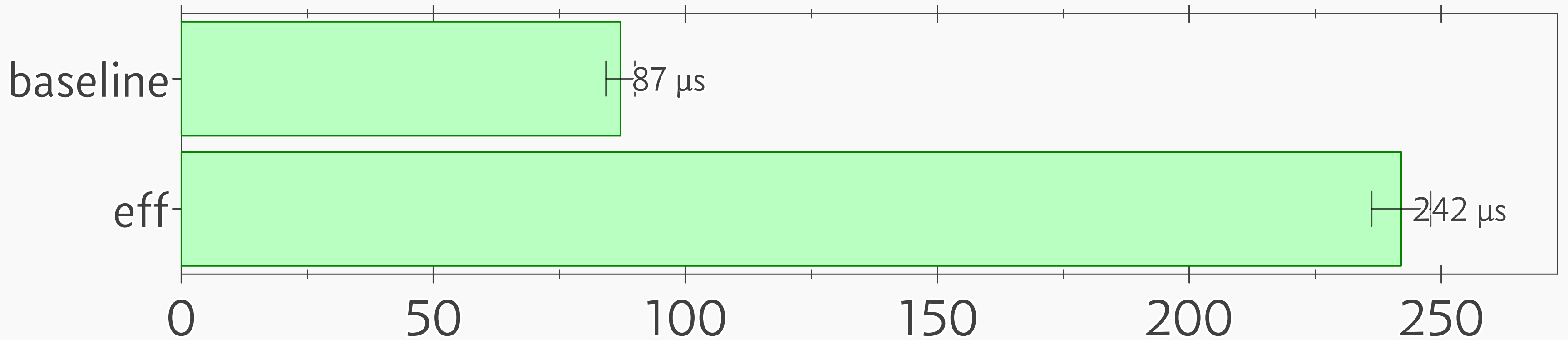


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COUNTDOWN: NO UNBOXING



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Not quite so bad, after all!

Phew.

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`eff`: <https://github.com/hasura/eff>

benchmarks: <https://github.com/ocharles/effect-zoo>

proposal: <https://github.com/ghc-proposals/ghc-proposals/pull/313>

Hasura: <https://hasura.io>

me: <https://lexi-lambda.github.io>