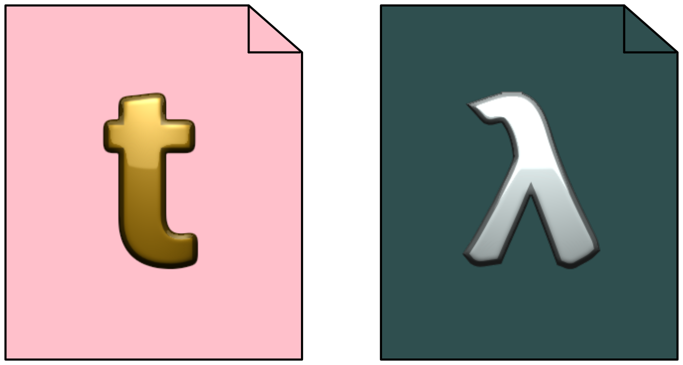
A Spectrum of Type Soundness and Performance

Ben Greenman & Matthias Felleisen
Northeastern University

Is type soundness all-or-nothing?

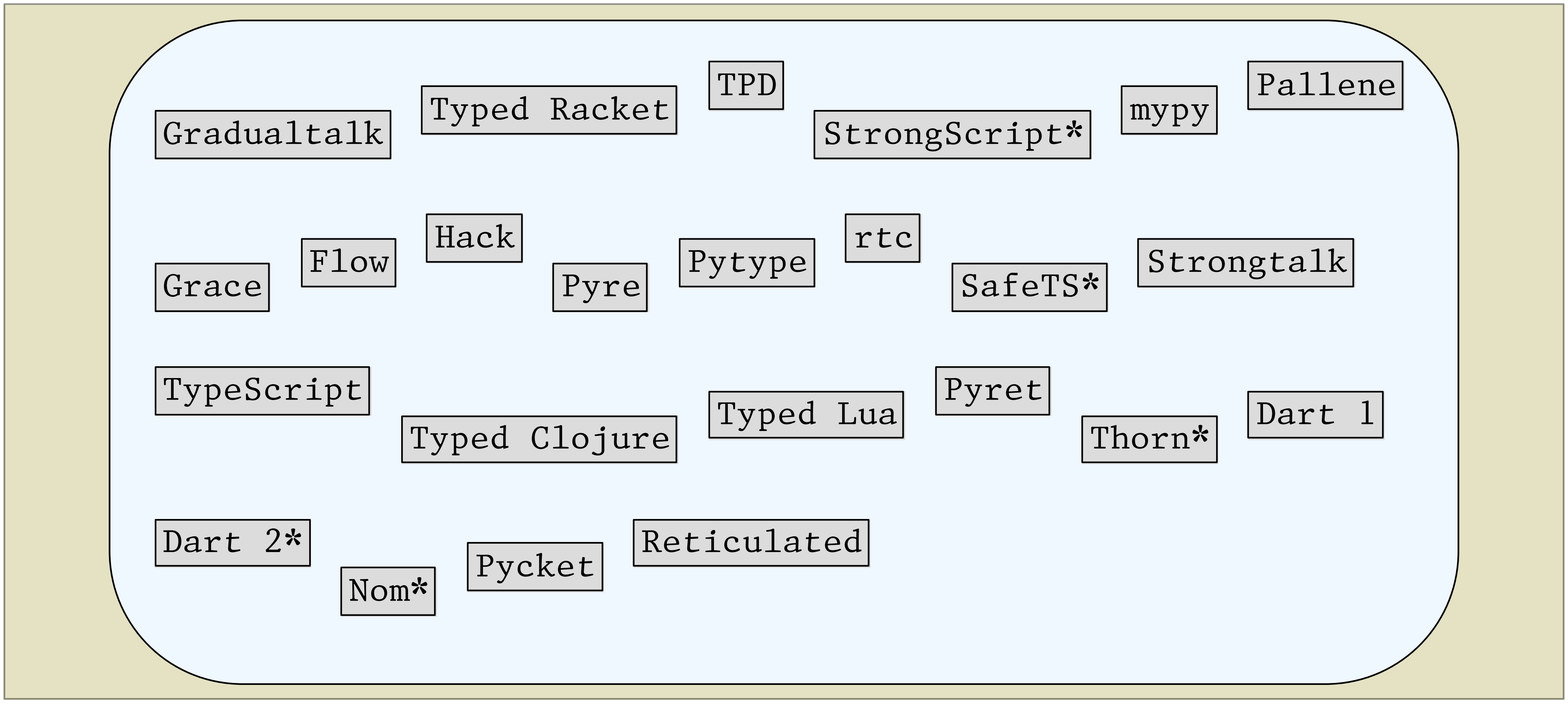
Can adding types slow down a program?

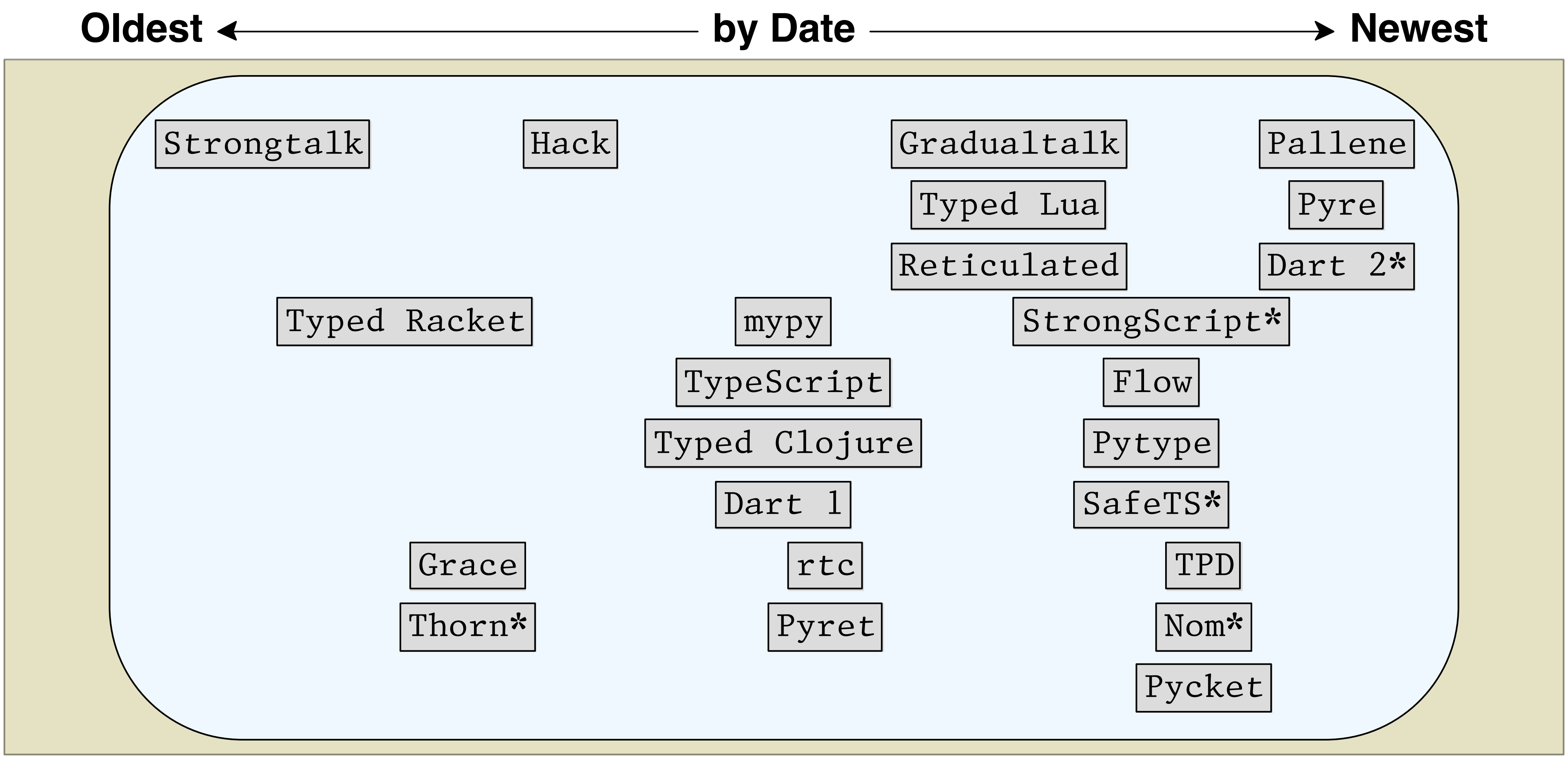
Migratory Typing

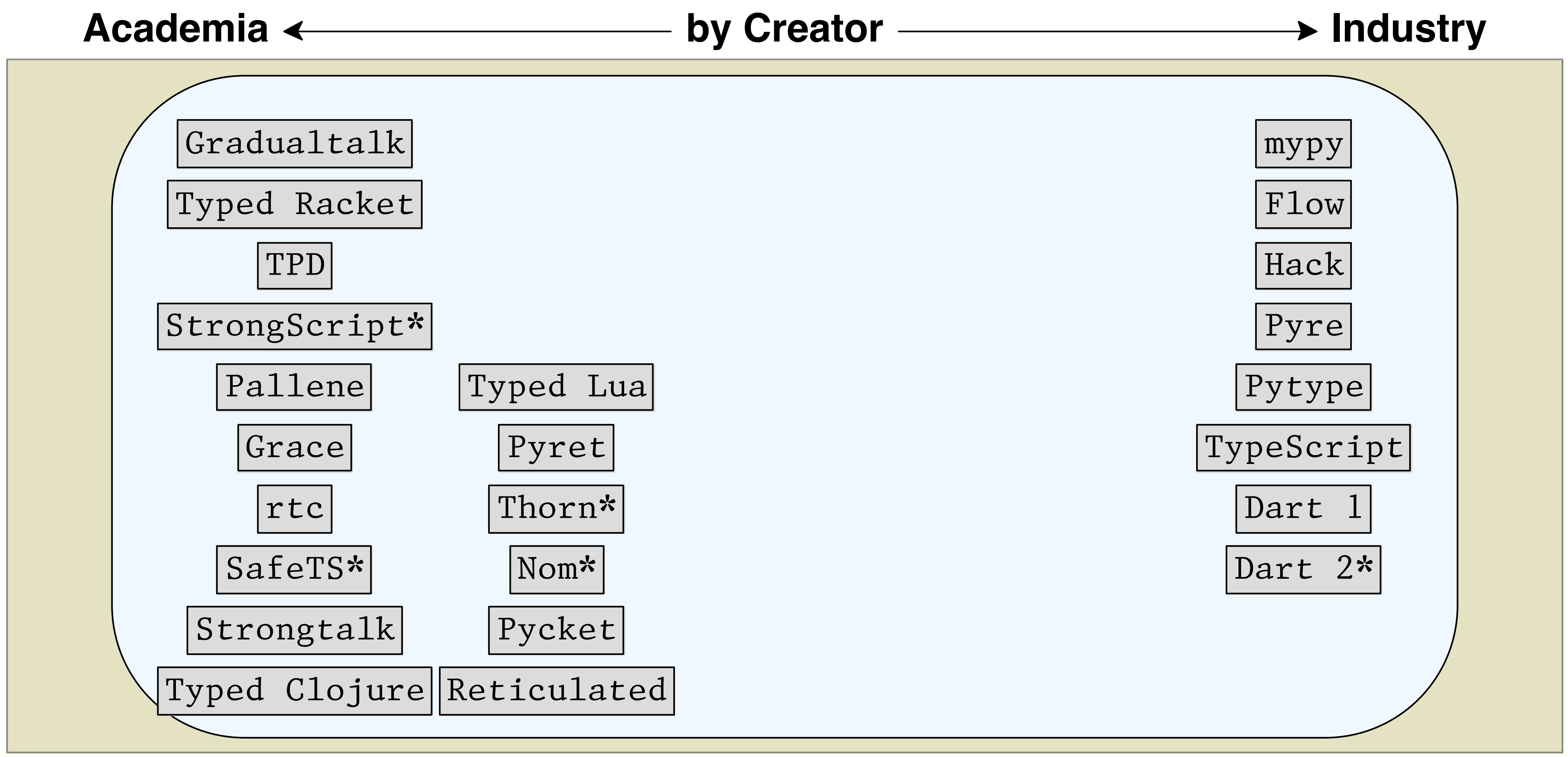

t
λ

Typed/Untyped Languages

Typed/Untyped Languages




Oldest
by Date
Newest
Strongtalk
Hack
Gradualtalk
Pallene
Typed Lua
Pyre
Reticulated
Dart 2*
Typed Racket
mypy
StrongScript*
TypeScript
Flow
Typed Clojure
Pytype
Dart 1
SafeTS*
Grace
rtc
TPD
Thorn*
Pyret
Nom*
Pycket


Academia
by Creator
Industry
Gradualtalk
Typed Racket
TPD
StrongScript*
Pallene
Grace
rtc
SafeTS*
Strongtalk
Typed Clojure
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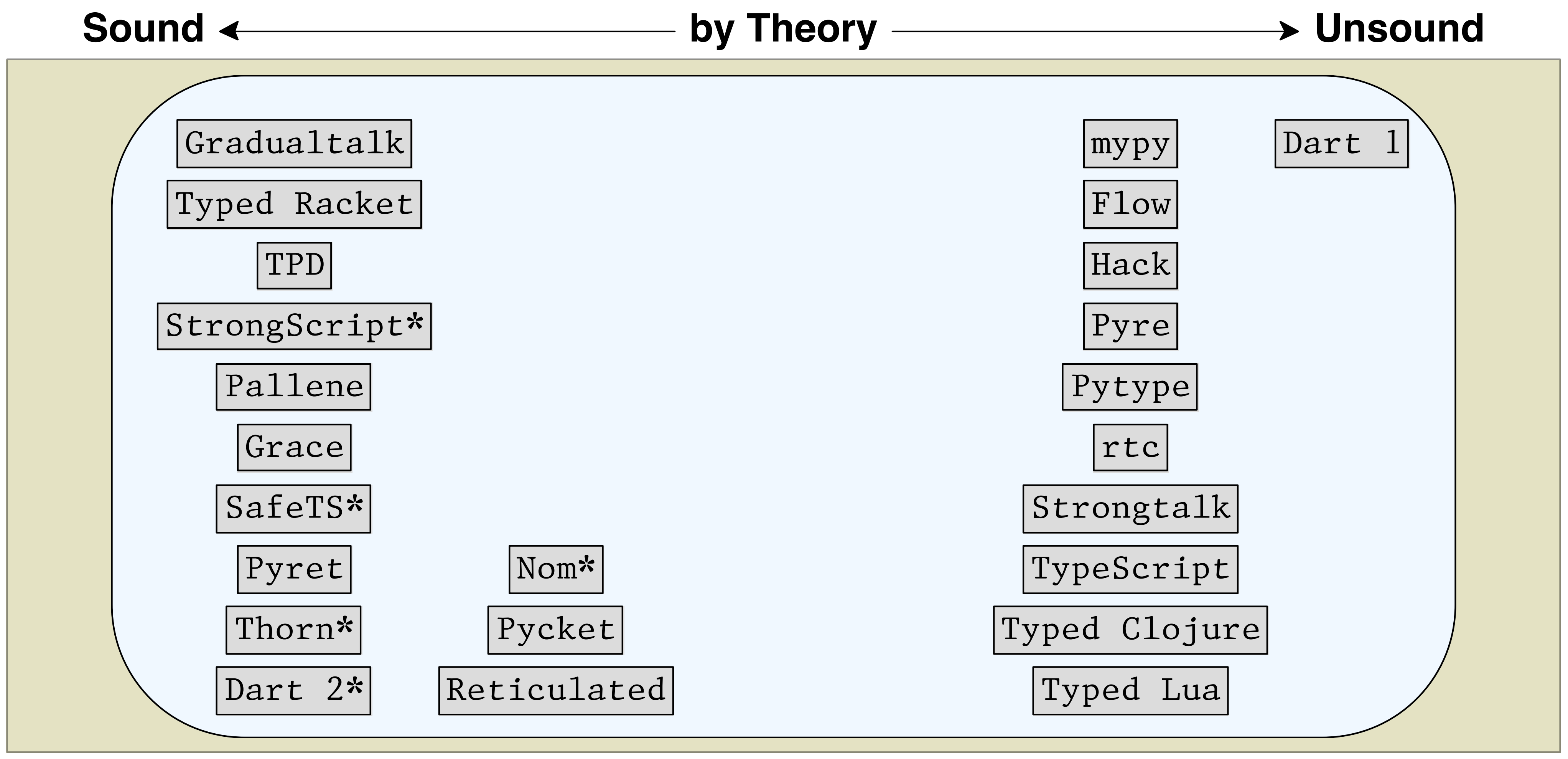
Pyret
Thorn*
Nom*
Pycket
Reticulated
mypy
Flow
Hack
Pyre
Pytype
TypeScript
Dart 1
Dart 2*


Sound
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Unsound
Gradualtalk
Typed Racket
TPD
StrongScript*
Pallene
Grace
SafeTS*
Pyret
Thorn*
Dart 2*
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Flow
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TypeScript
Typed Clojure
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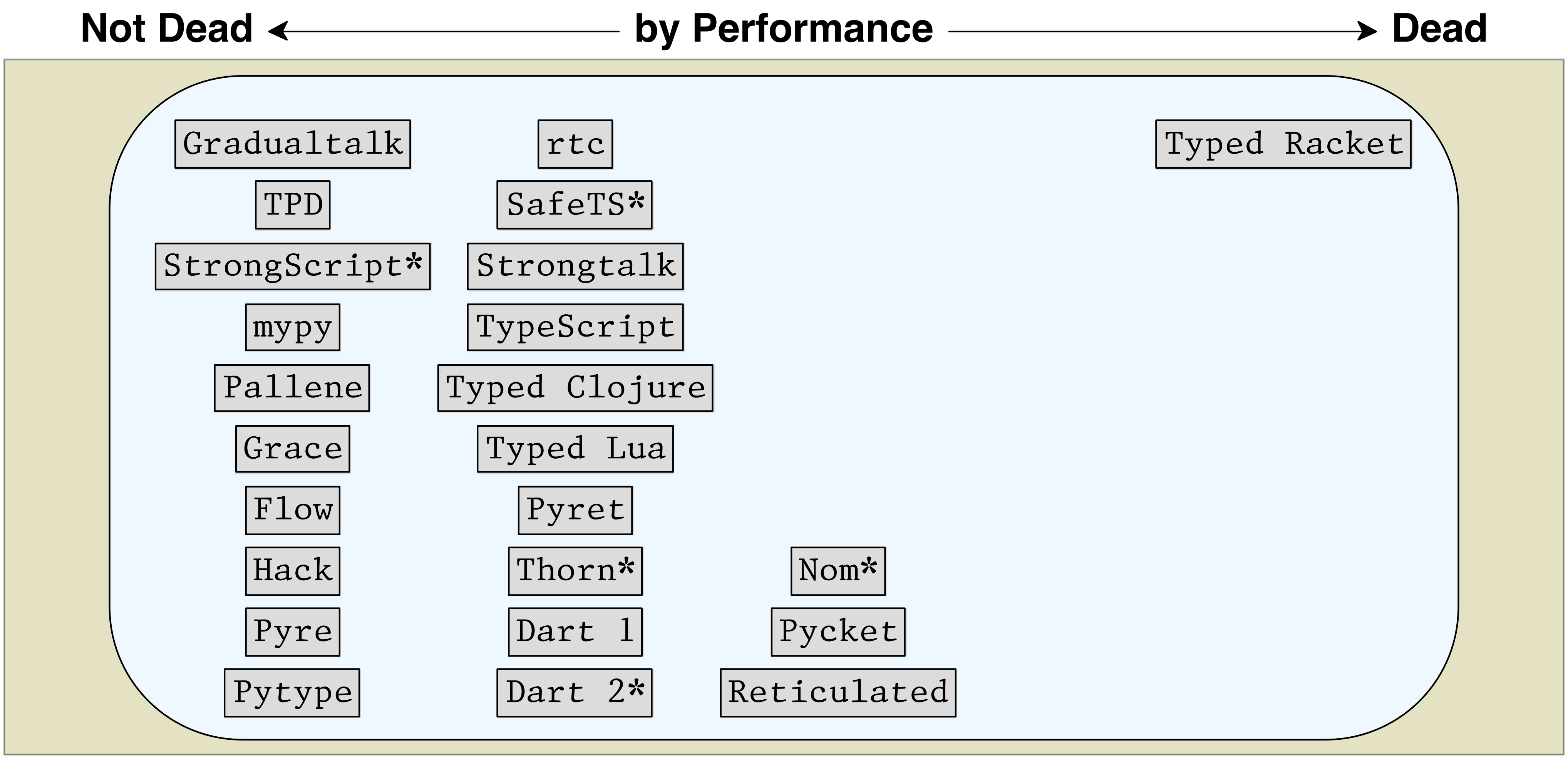
Dart 1


Not Dead
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Dead
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TPD
StrongScript*
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Pallene
Grace
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Pytype
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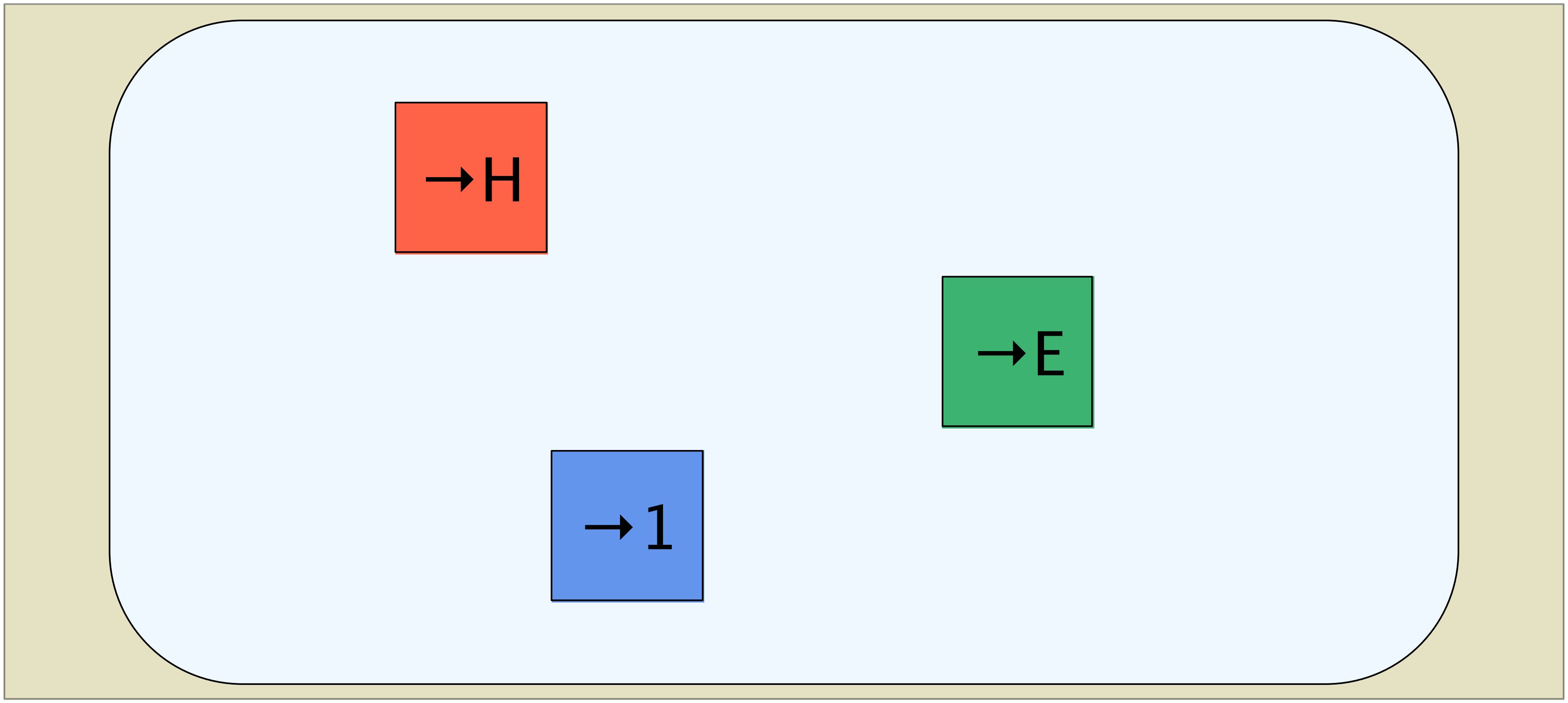
SafeTS*
Strongtalk
TypeScript
Typed Clojure
Typed Lua
Pyret
Thorn*
Dart 1
Dart 2*
Nom*
Pycket
Reticulated
Typed Racket

Chaos!

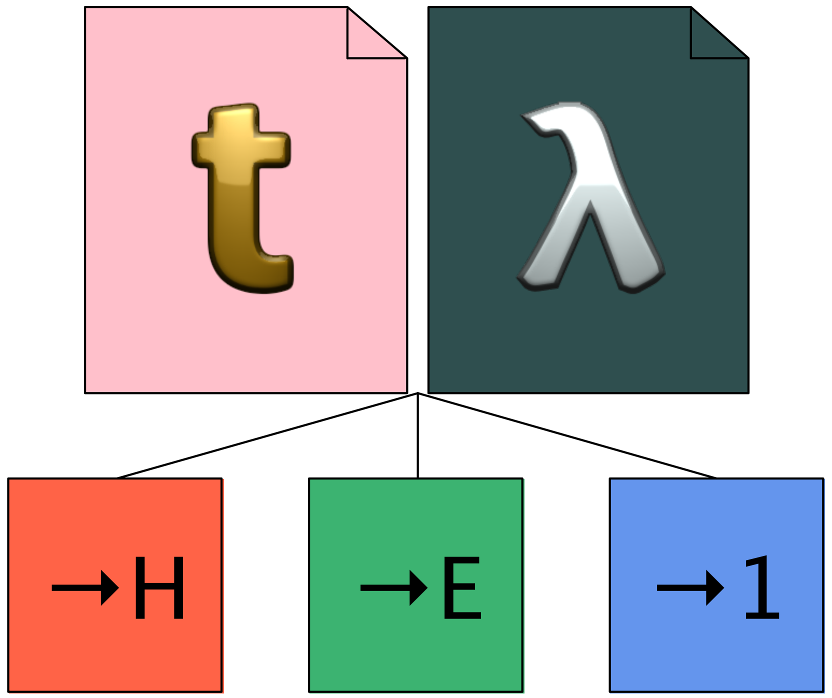
KafKa: Gradual Typing for Objects

Who	*Benjamin W Chung*, *Paley Li*, *Francesco Zappa Nardelli*, *Jan Vitek*
Track	ECOOP 2018 ECOOP Research Papers


→H
→E
→1

🟥 $\rightarrow_H$	higher-order semantics
🟩 $\rightarrow_E$	erasure semantics
🟦 $\rightarrow_1$	first-order semantics

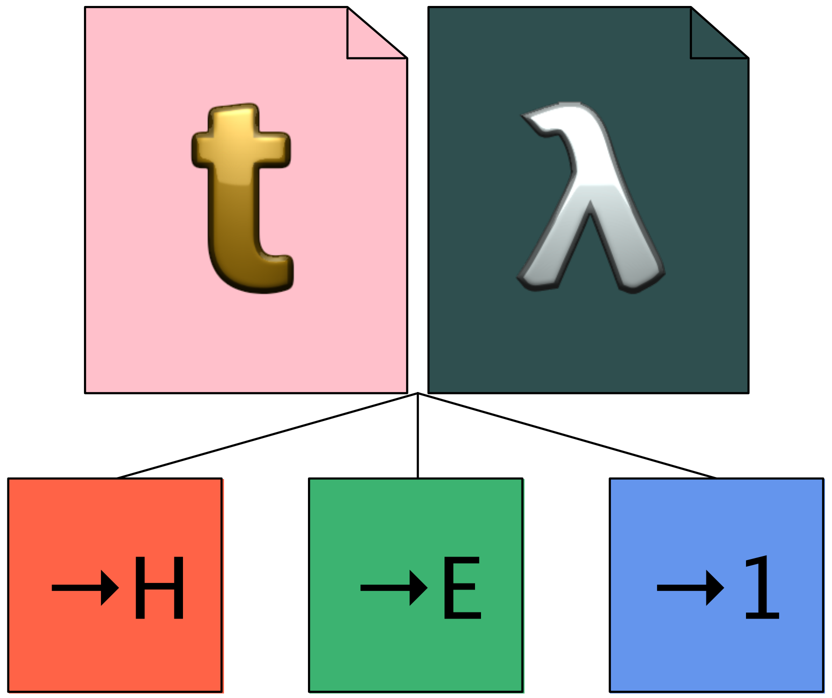
Contributions (1/2)



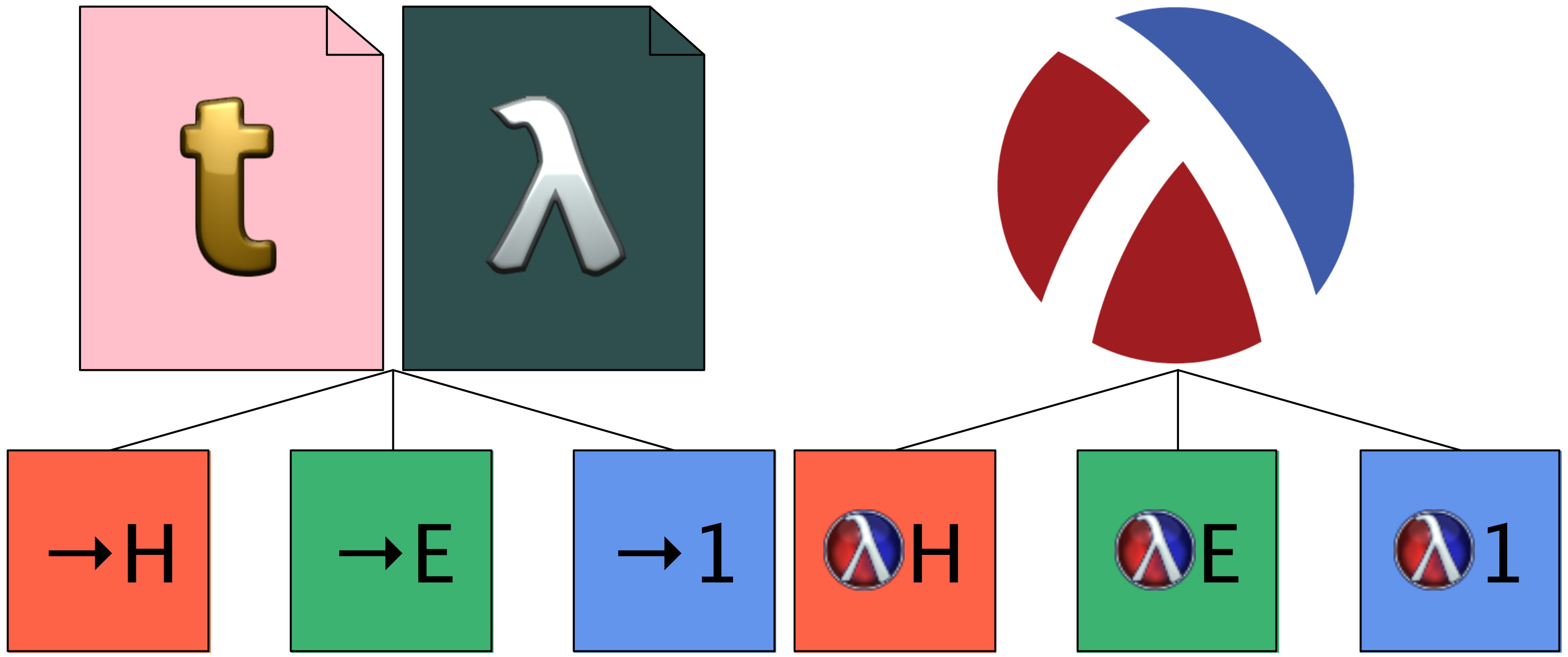
Model:

- one mixed-typed language
- one surface type system
- three semantics

Contributions (2/2)



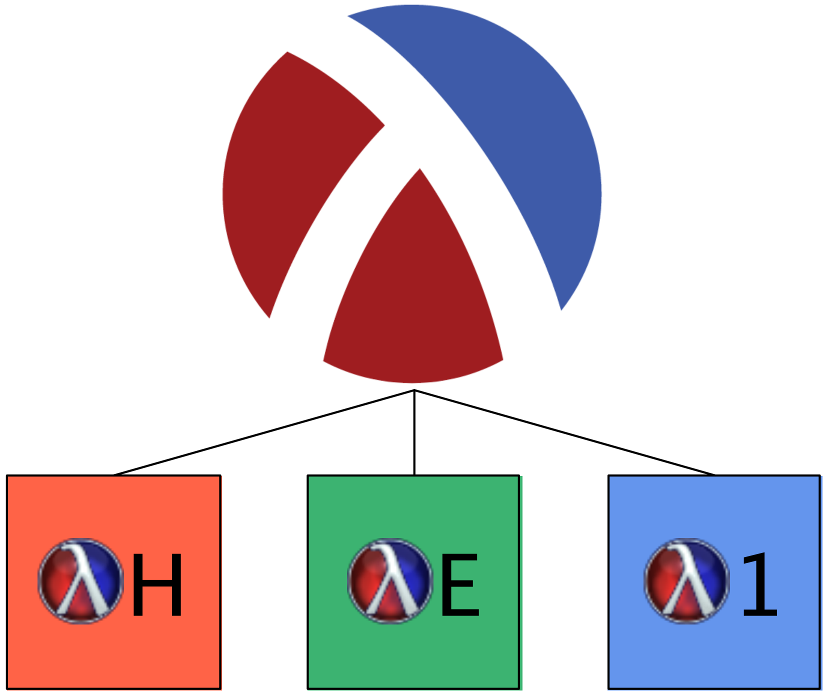
Contributions (2/2)



Contributions (2/2)

Implementation:

- Racket syntax/types
- three compilers
- the first controlled performance experiment



Model

t = Nat | Int | $t \times t$ | $t \to t$

Nat <: Int

t = Nat | Int | $t \times t$ | $t \to t$

Nat <: Int

v = n | i | $\langle$v,v$\rangle$ | λ(x)e | λ(x:t)e

n $\subset$ i

t = Nat | Int | $t \times t$ | $t \to t$

Nat <: Int

v = n | i | $\langle$v,v$\rangle$ | λ(x)e | λ(x:t)e

n $\subset$ i

e = ... | dyn t e | stat t e

```
t = Nat | Int | t×t | t → t
Nat <: Int

v = n | i | ⟨v,v⟩ | λ(x)e | λ(x:t)e

n ⊂ i

e = .... | dyn t e | stat t e
```

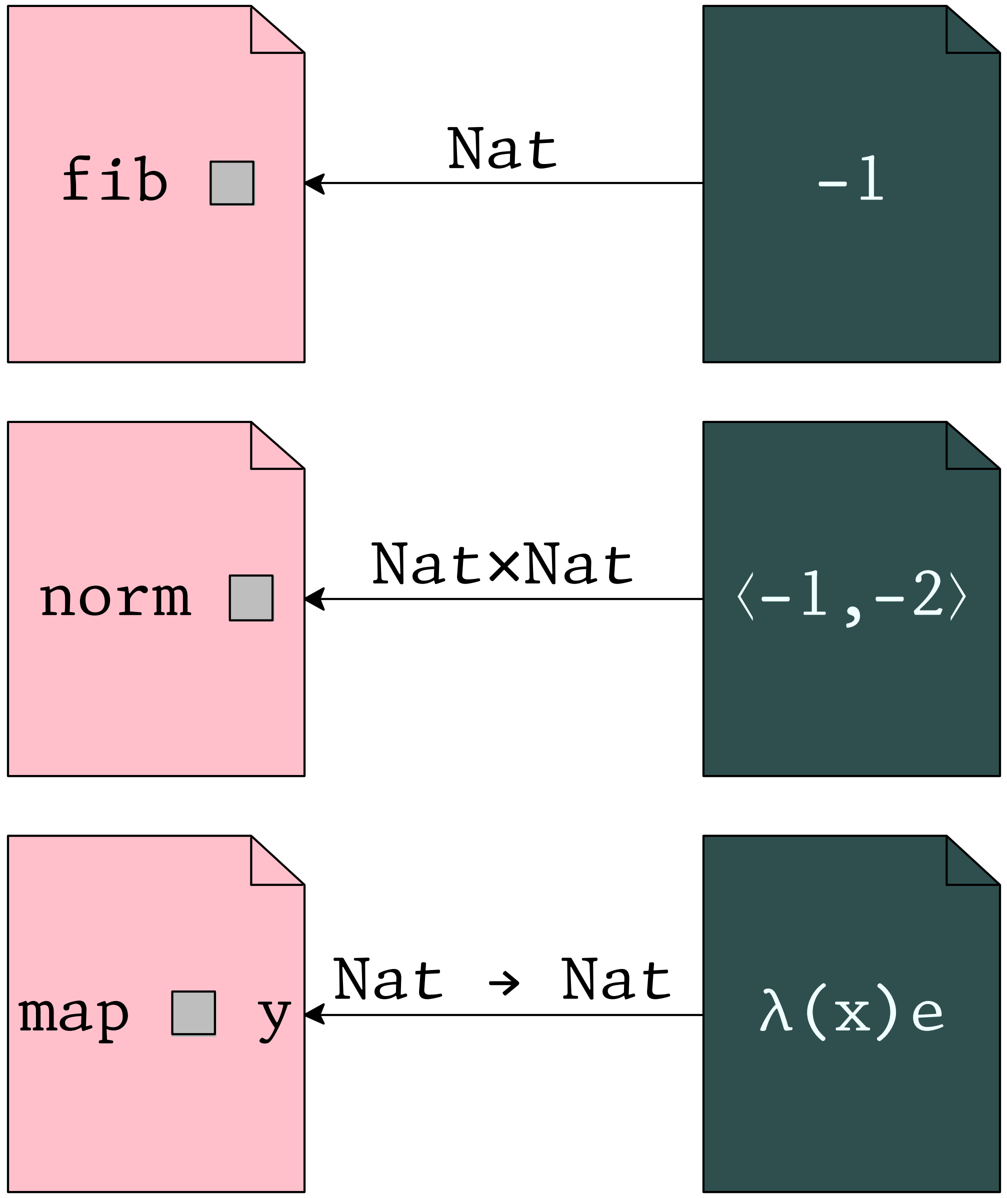
$$\frac{\vdash e}{\vdash \texttt{dyn}\ t\ e : t} \qquad \frac{\vdash e : t}{\vdash \texttt{stat}\ t\ e}$$

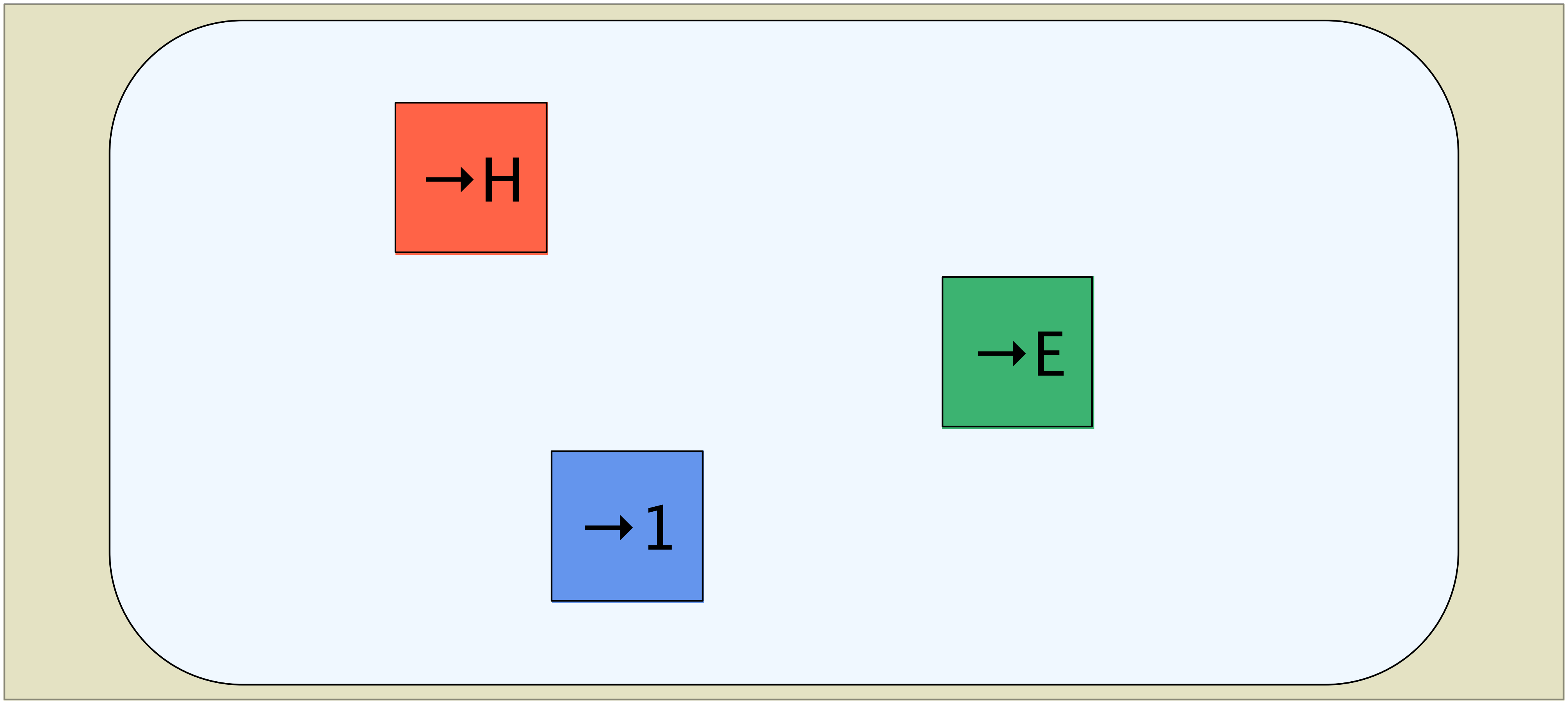
$$\Gamma = \begin{cases} \texttt{fib : Nat → Nat} \\ \texttt{norm : Nat×Nat → Nat} \\ \texttt{map : (Nat → Nat) → Nat×Nat → Nat×Nat} \end{cases}$$

$\Gamma \vdash$ `fib (dyn Nat -1) : Nat`

$\Gamma \vdash$ `norm (dyn Nat×Nat ⟨-1,-2⟩) : Nat`

$\Gamma \vdash$ `map (dyn (Nat → Nat) (λ(x)e)) y : Nat×Nat`


fib ◻
Nat
-1
norm ◻
Nat×Nat
⟨-1,-2⟩
map ◻ y
Nat → Nat
λ(x)e


→H
→E
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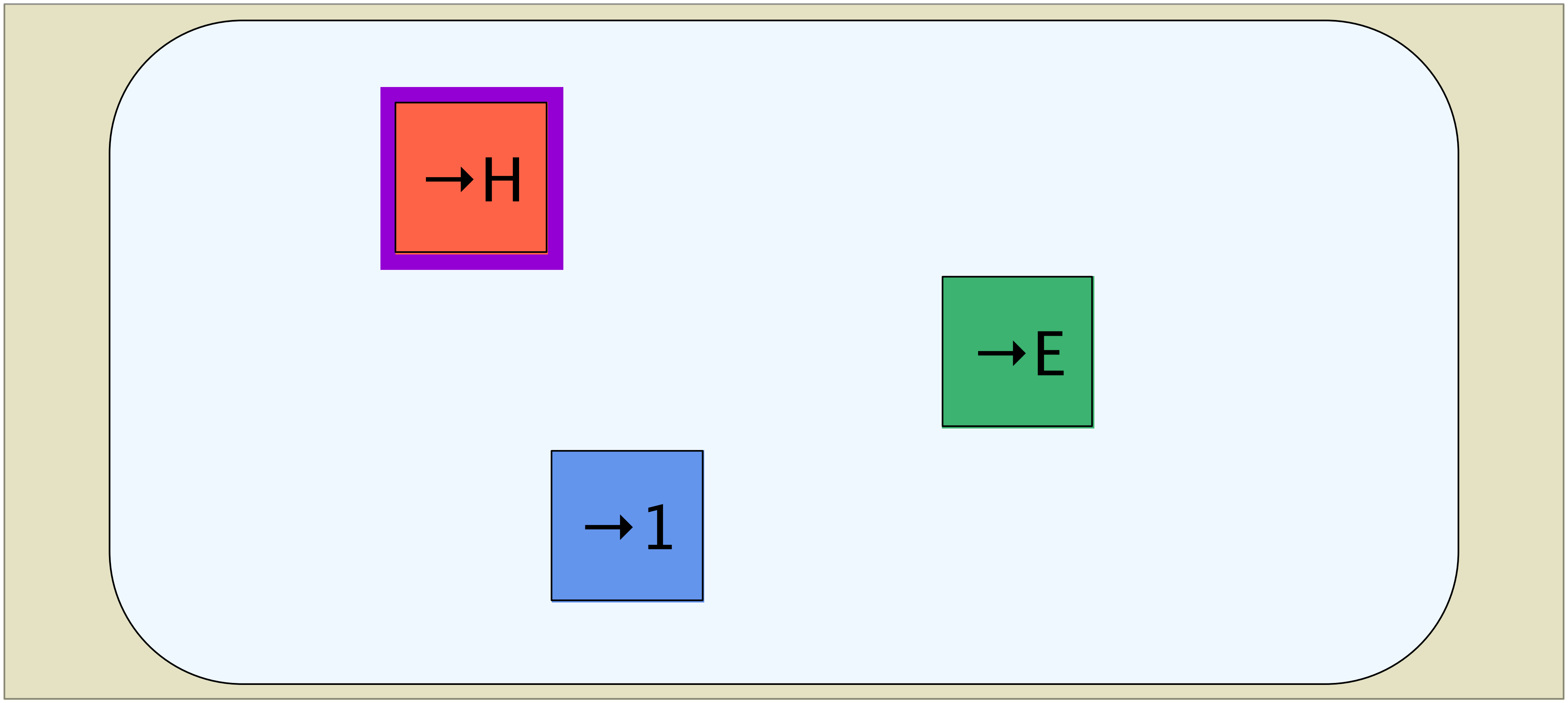
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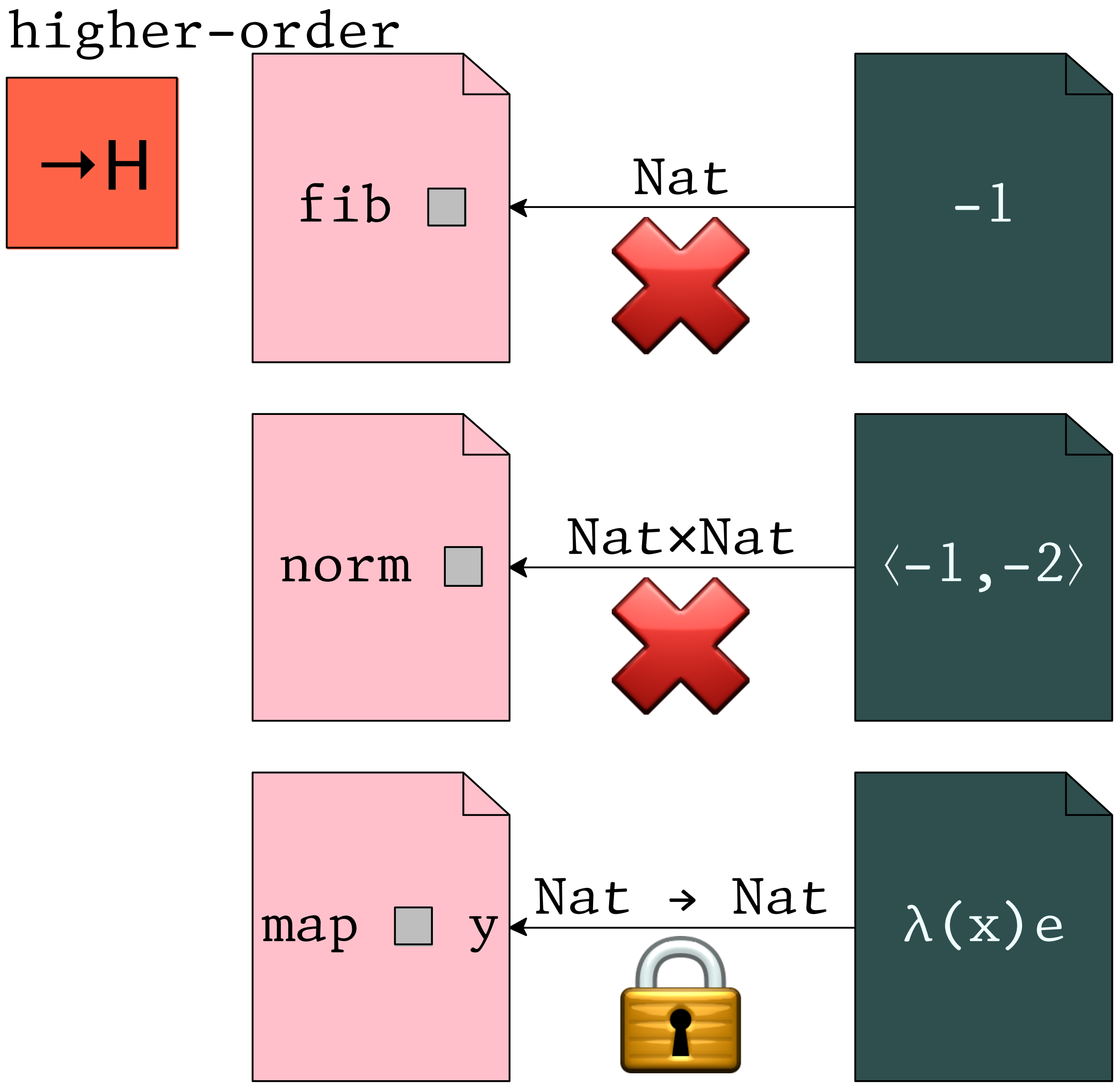
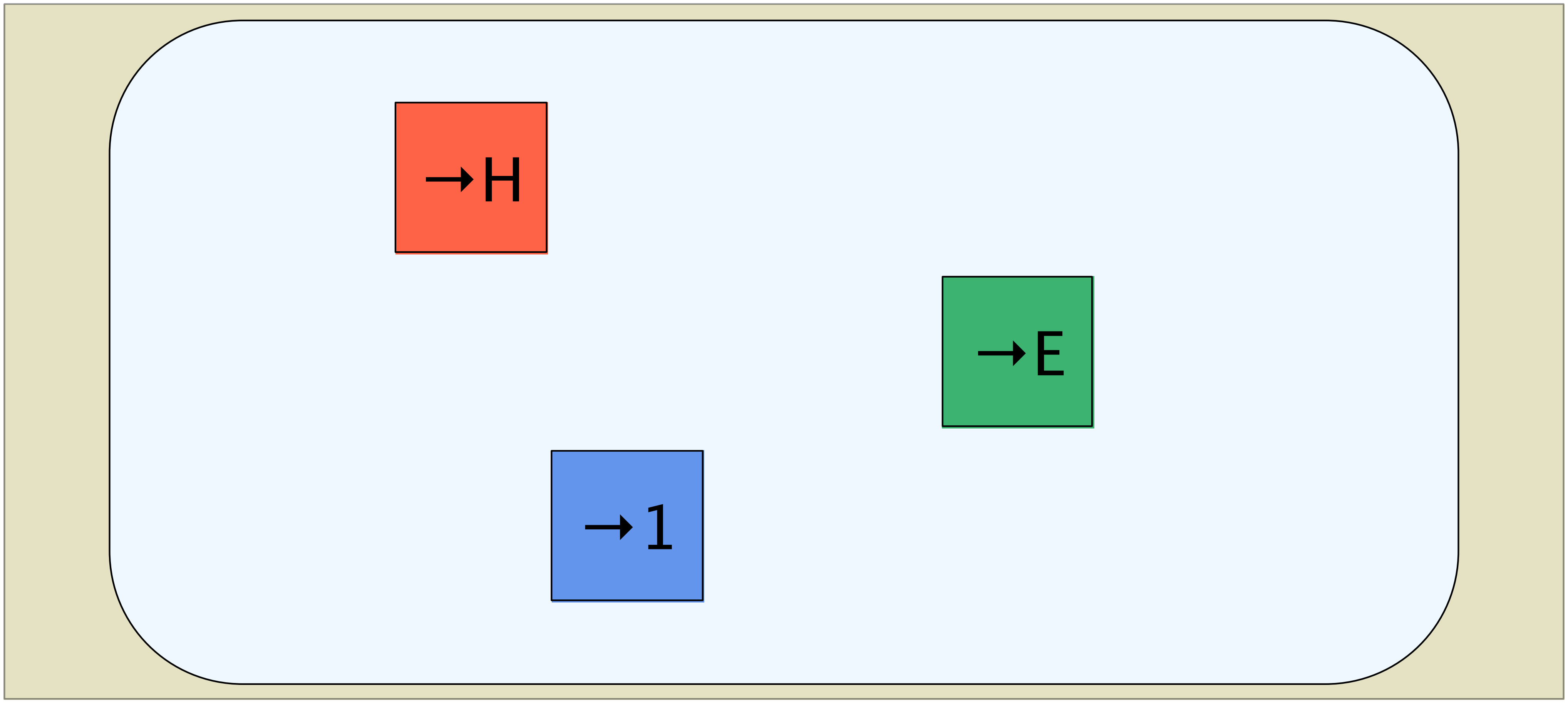
→E
→1


higher-order
→H
fib □
Nat
-1
norm □
Nat×Nat
⟨-1,-2⟩
map □ y
Nat → Nat
λ(x)e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→E
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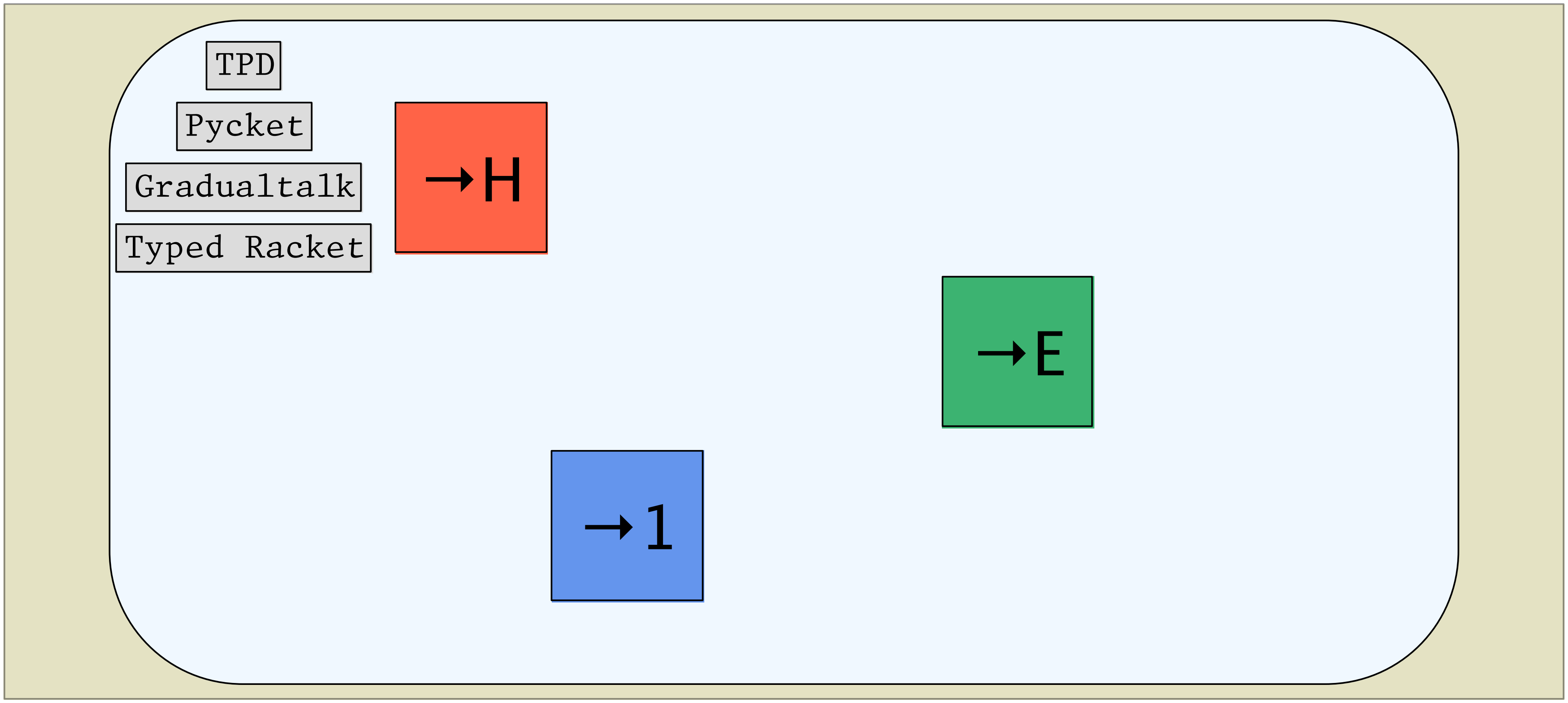
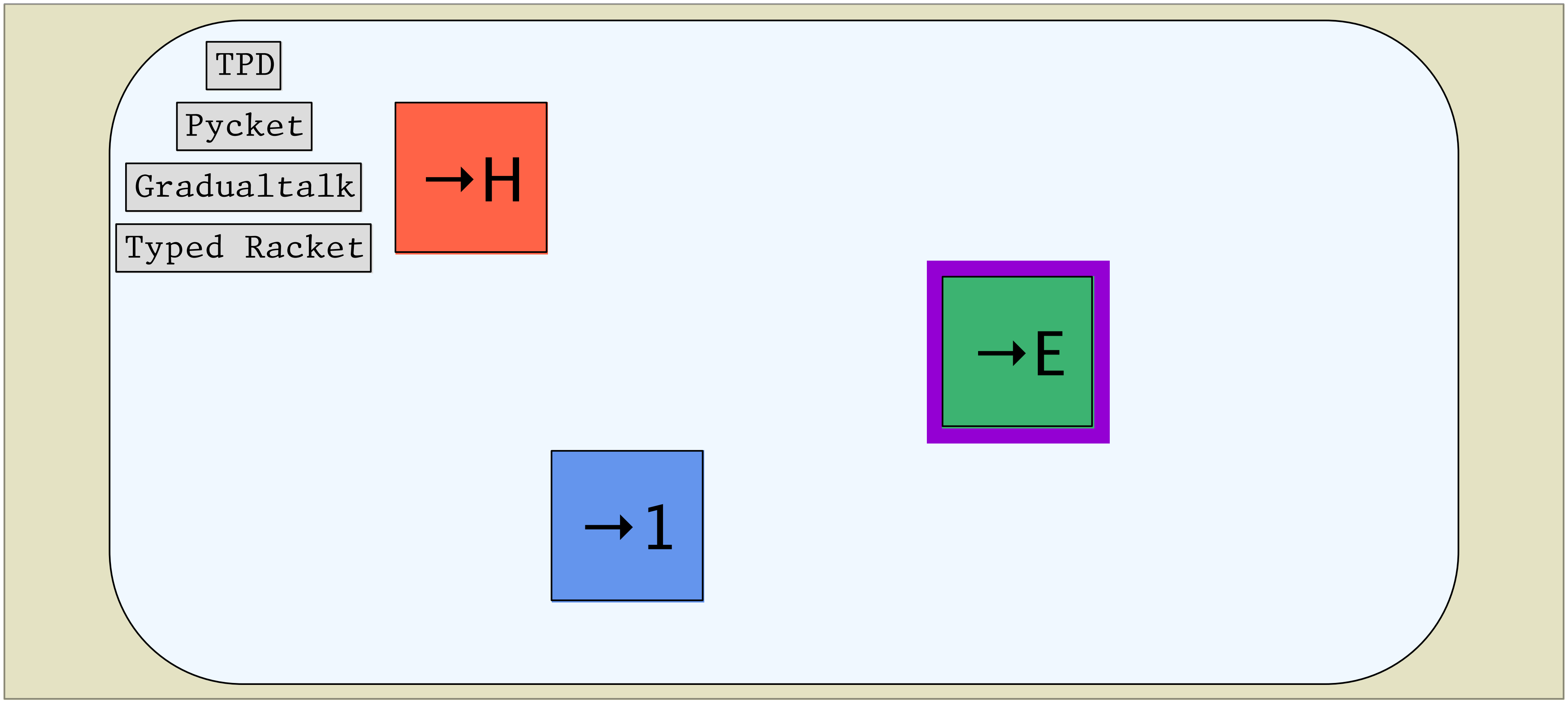

TPD
Pycket
Gradualtalk
Typed Racket
→H
→E
→1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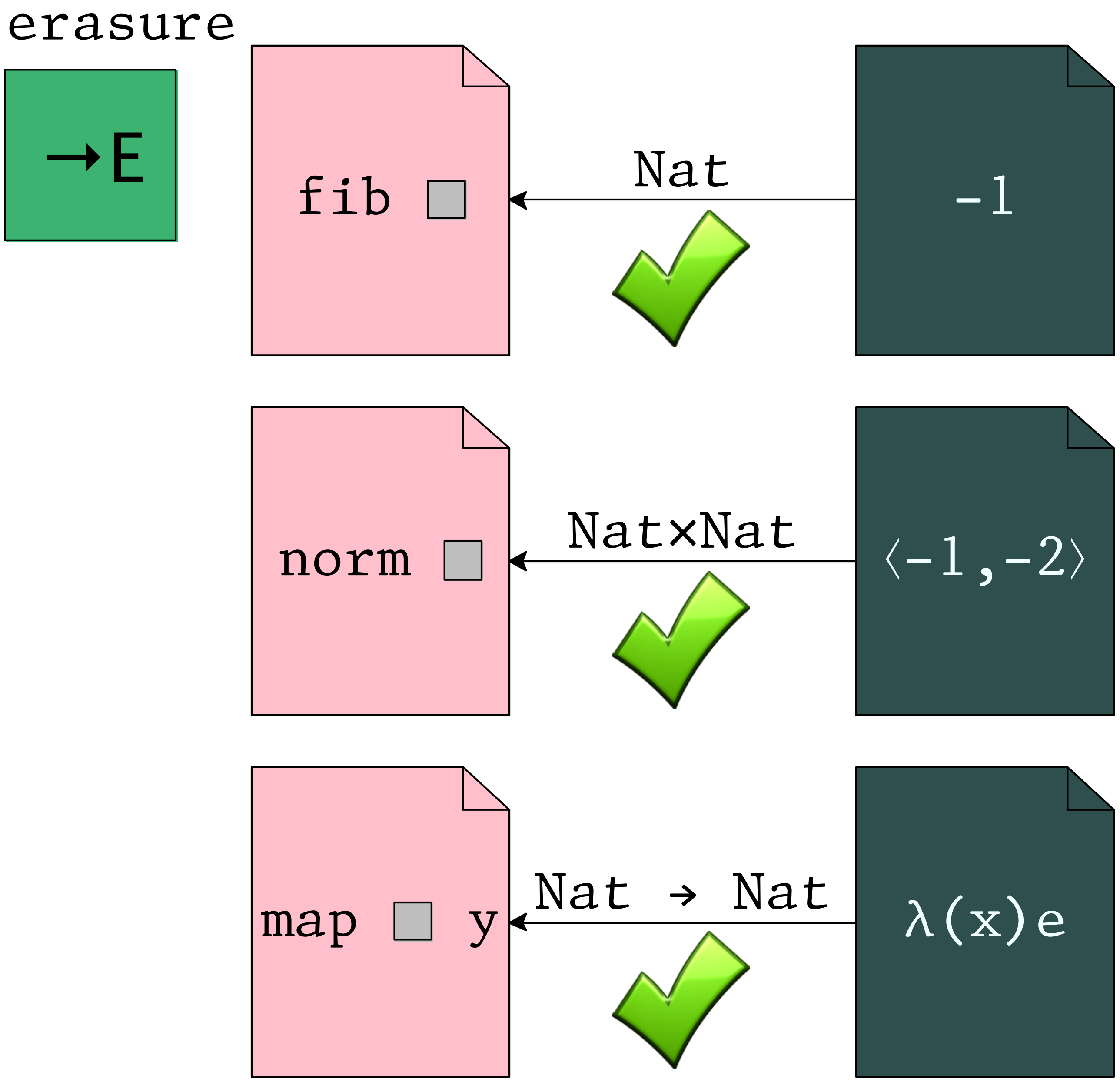
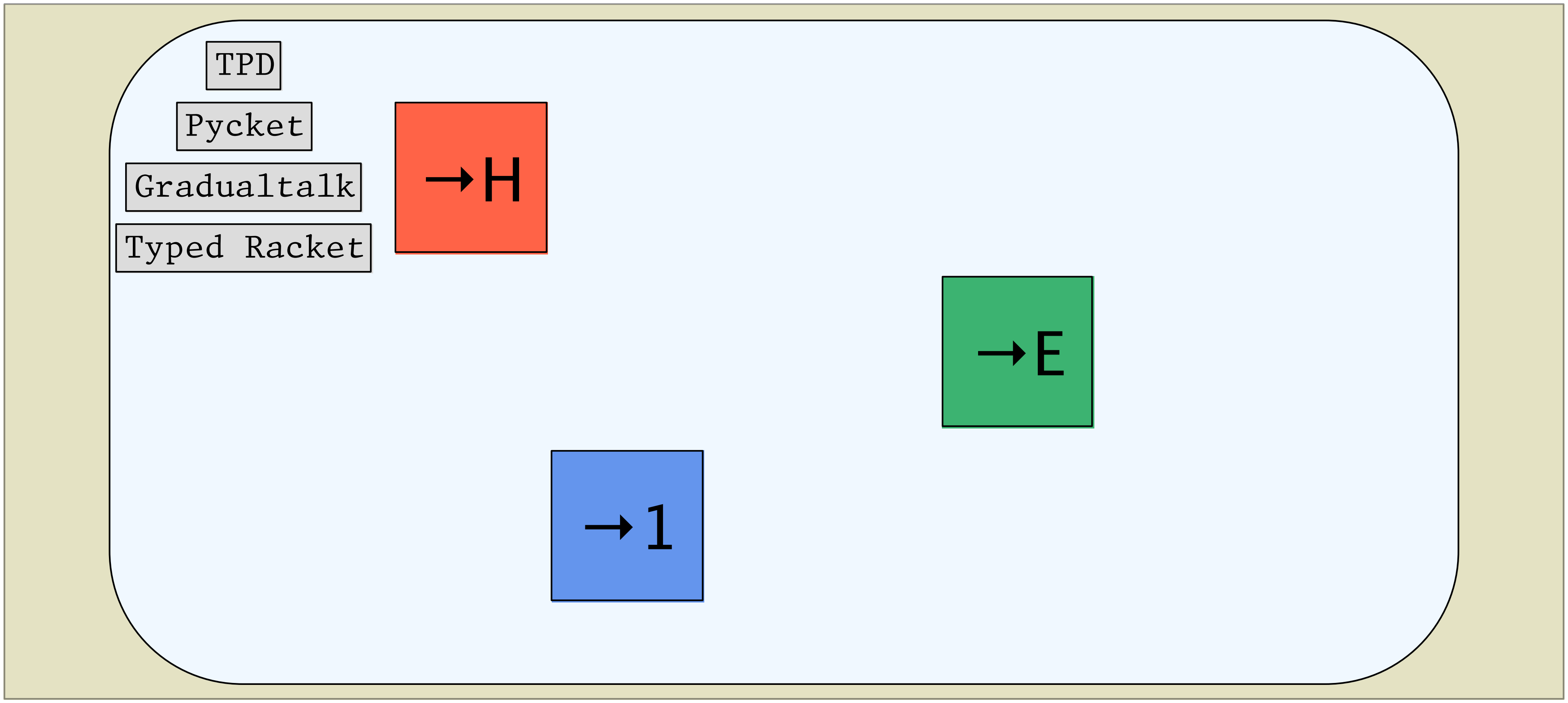

erasure
→E
fib □
Nat
-1
norm □
Nat×Nat
⟨-1,-2⟩
map □ y
Nat → Nat
λ(x)e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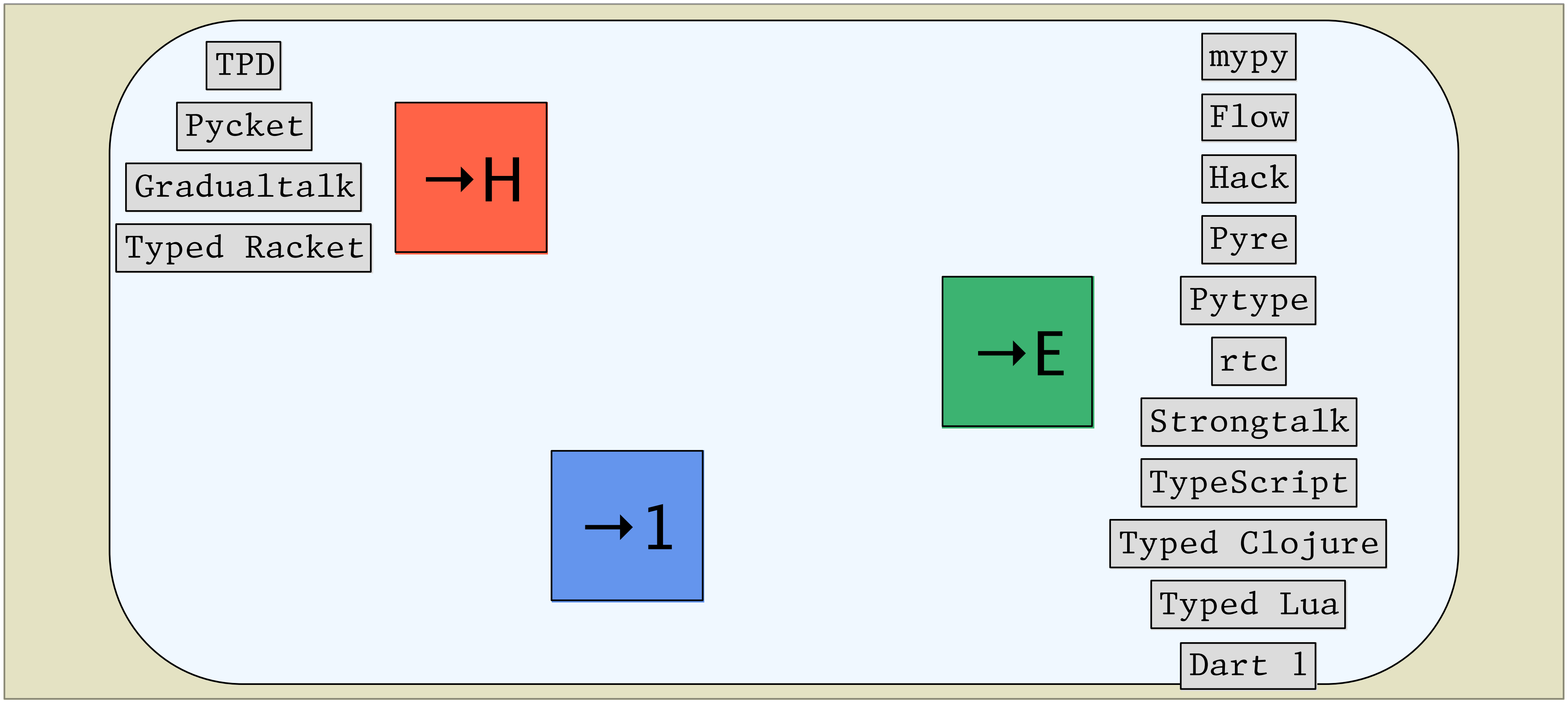
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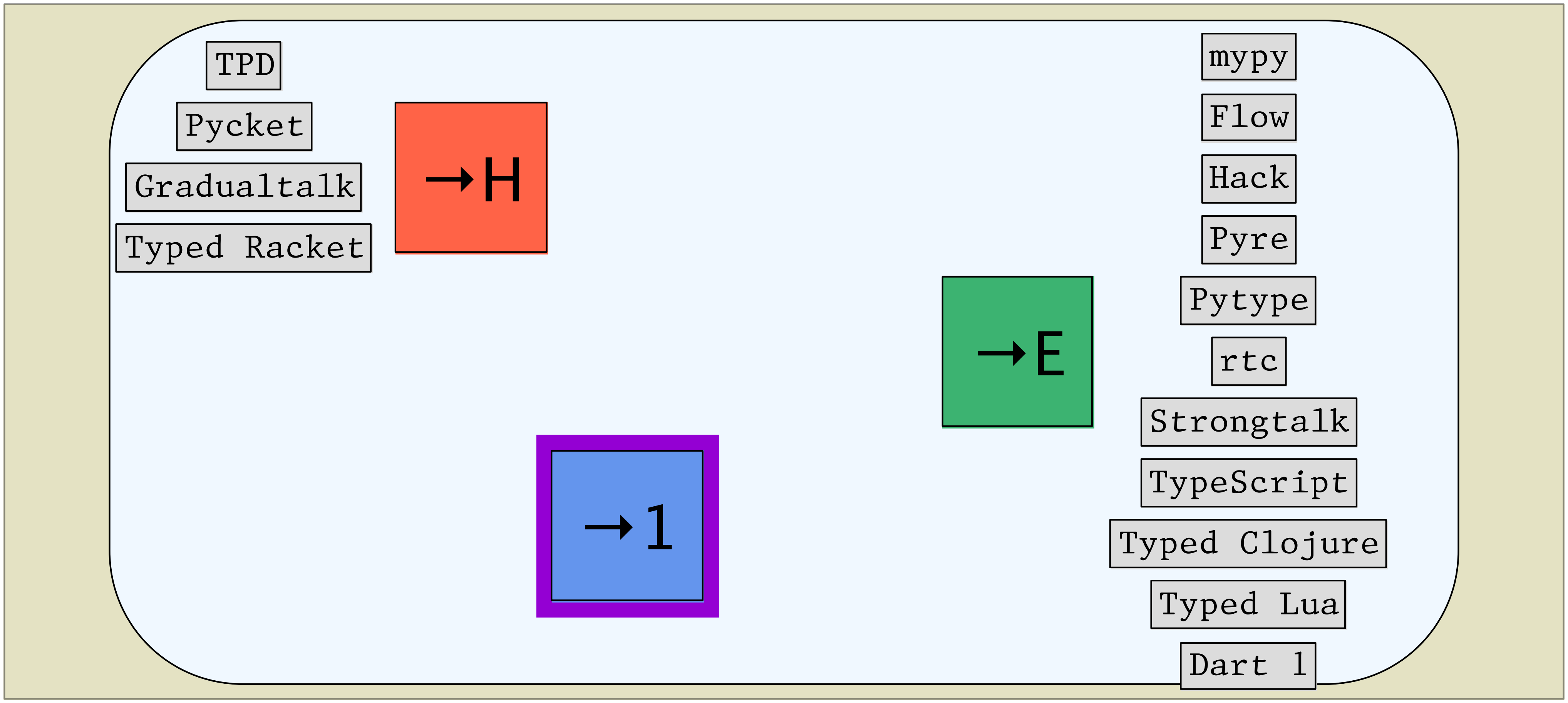
Typed Clojure
Typed Lua
Dart 1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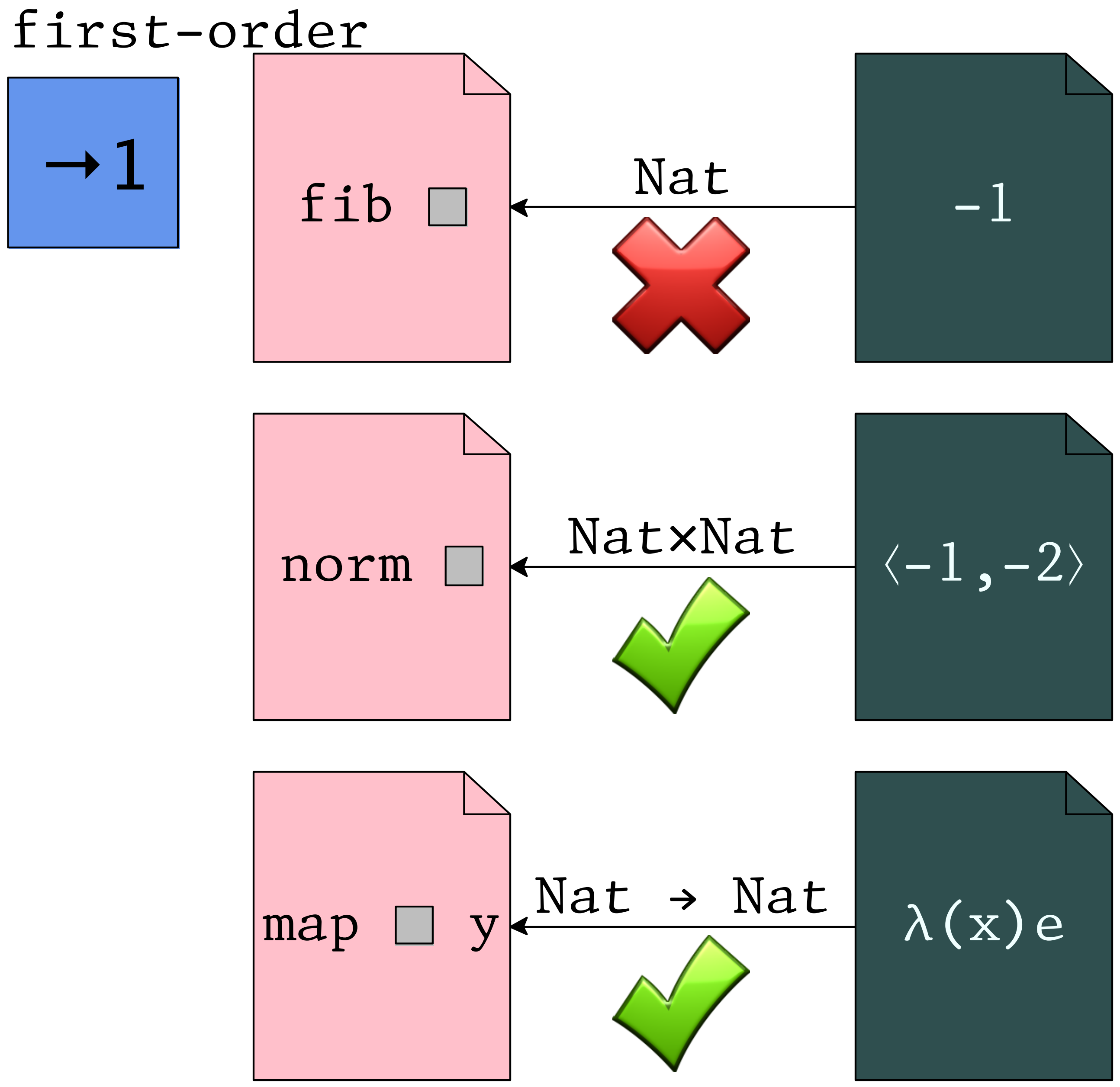
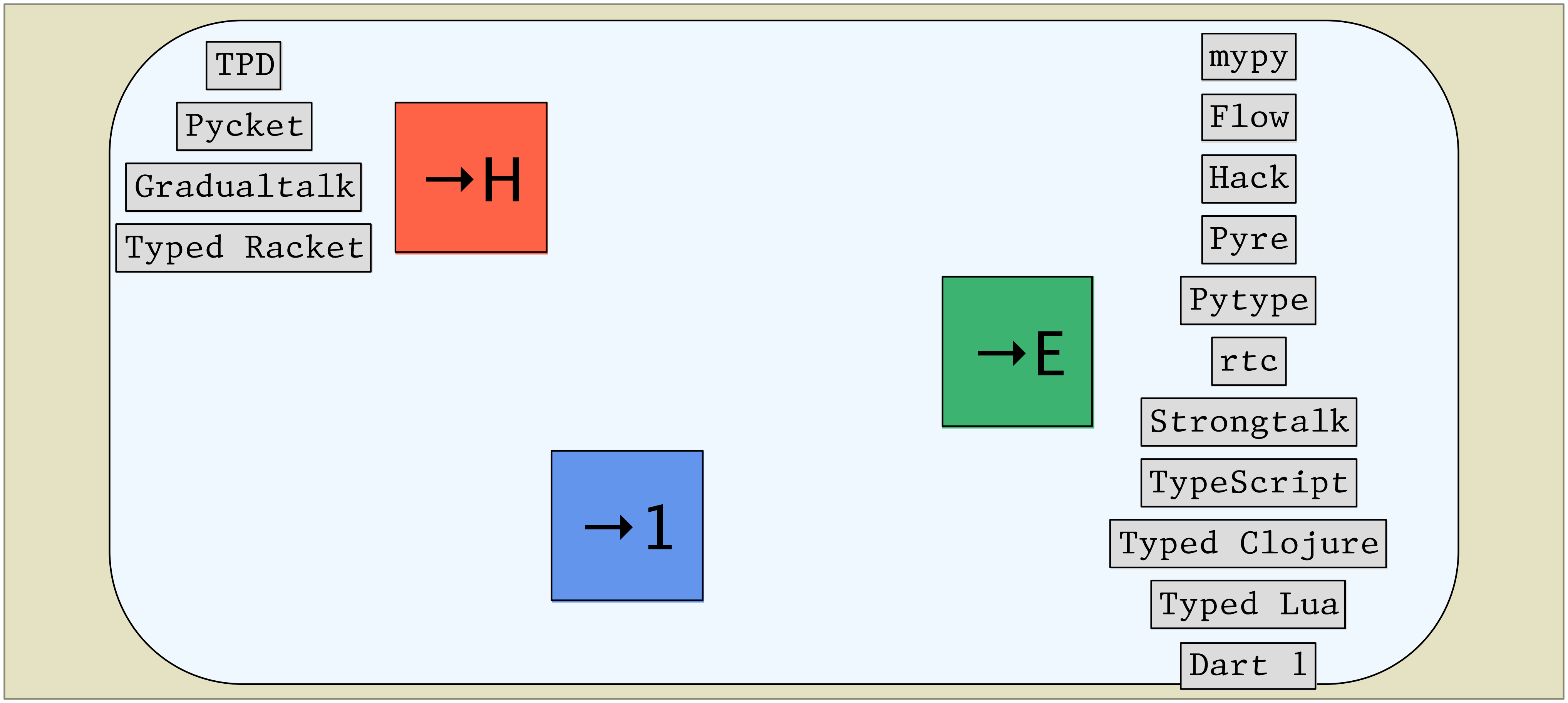
Typed Lua
Dart 1
→1


first-order
→1
fib □
Nat
-1
norm □
Nat×Nat
⟨-1,-2⟩
map □ y
Nat → Nat
λ(x)e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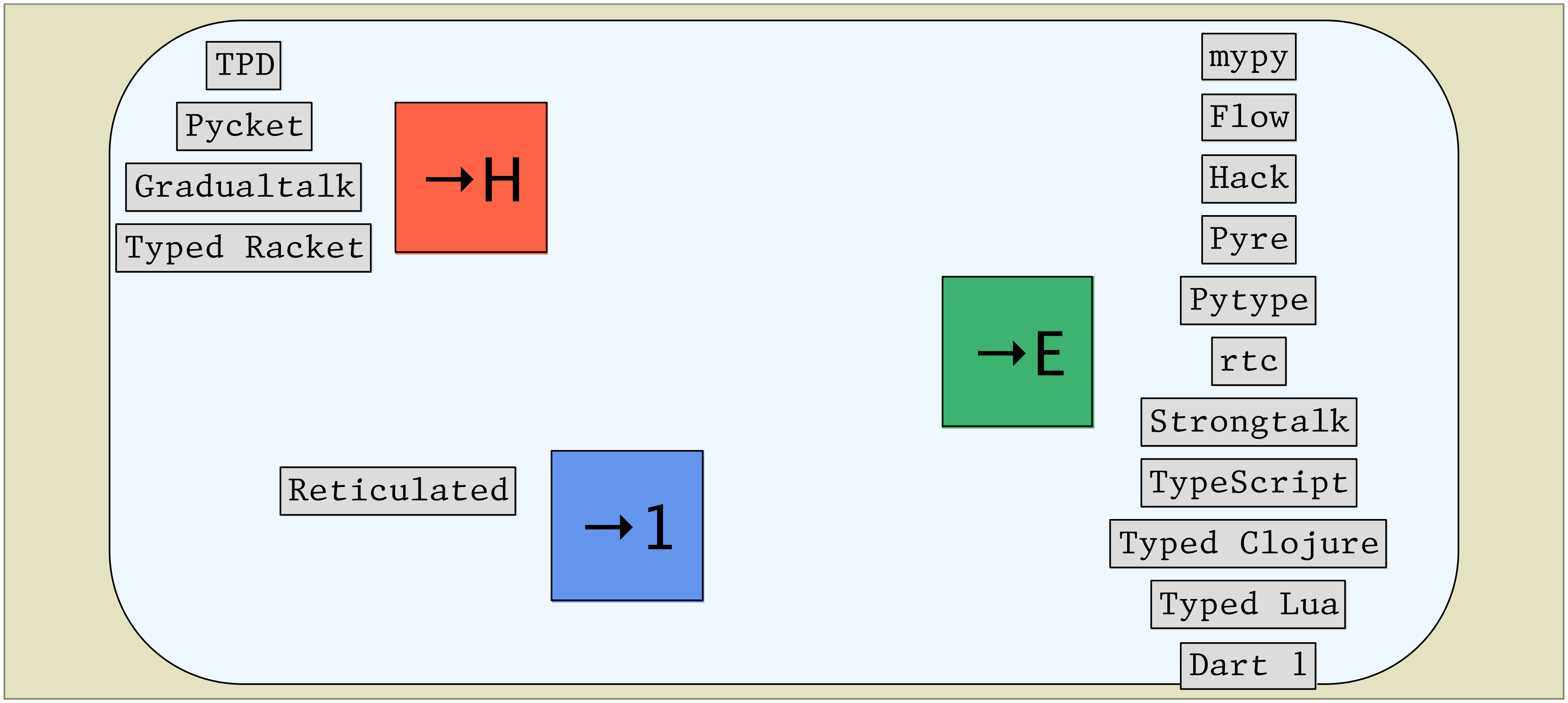
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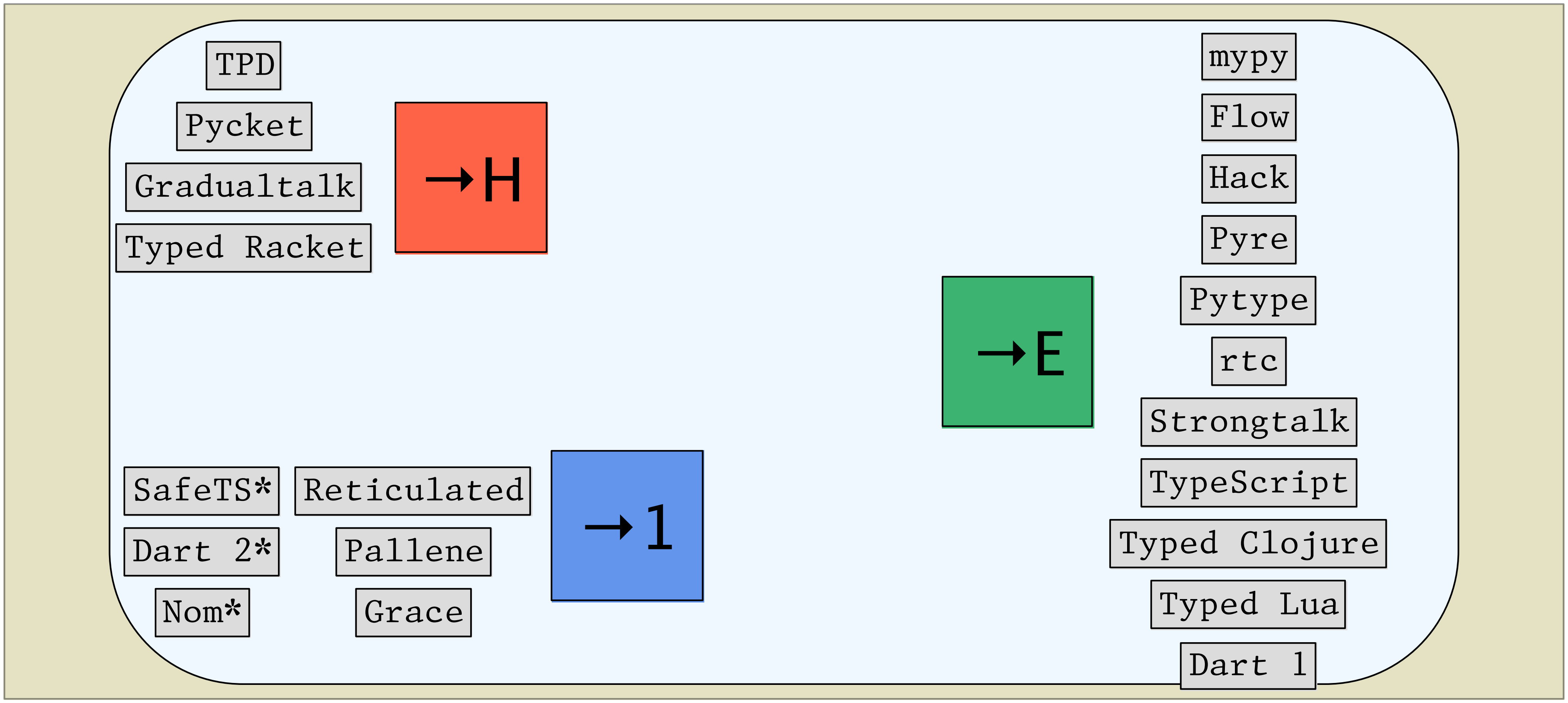
TypeScript
Typed Clojure
Typed Lua
Dart 1
Reticulated
→1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Nom*
Grace
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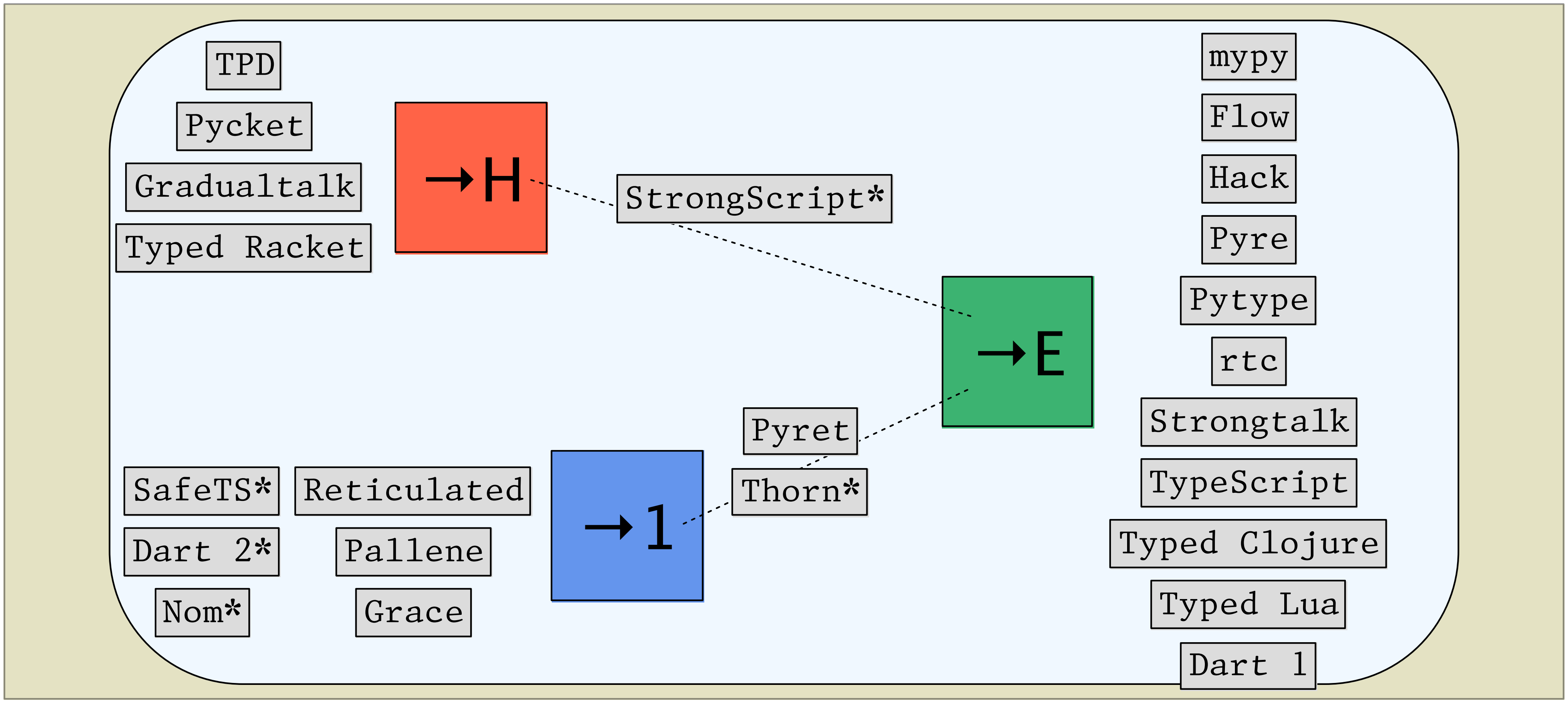
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→E
Pyret
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SafeTS*
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Nom*
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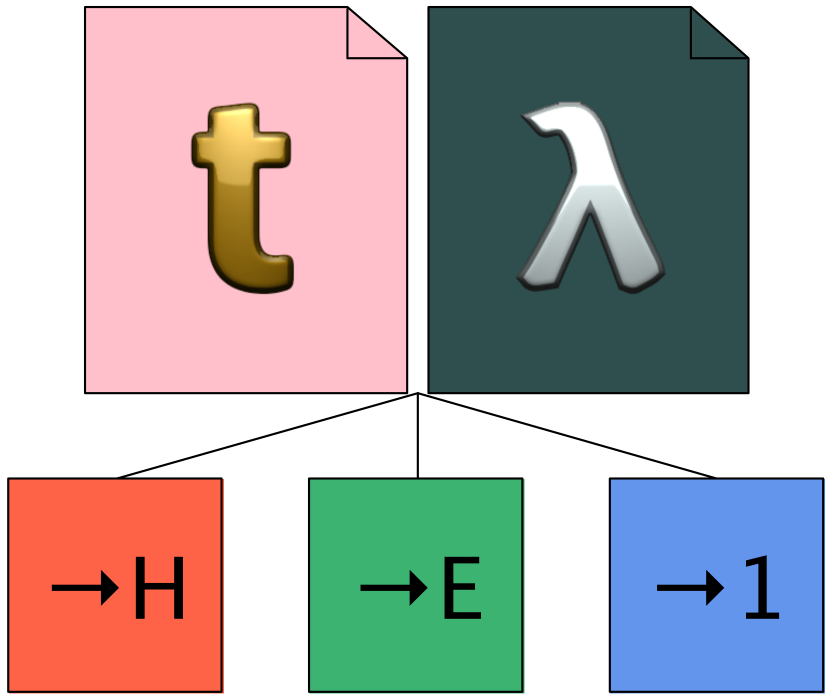
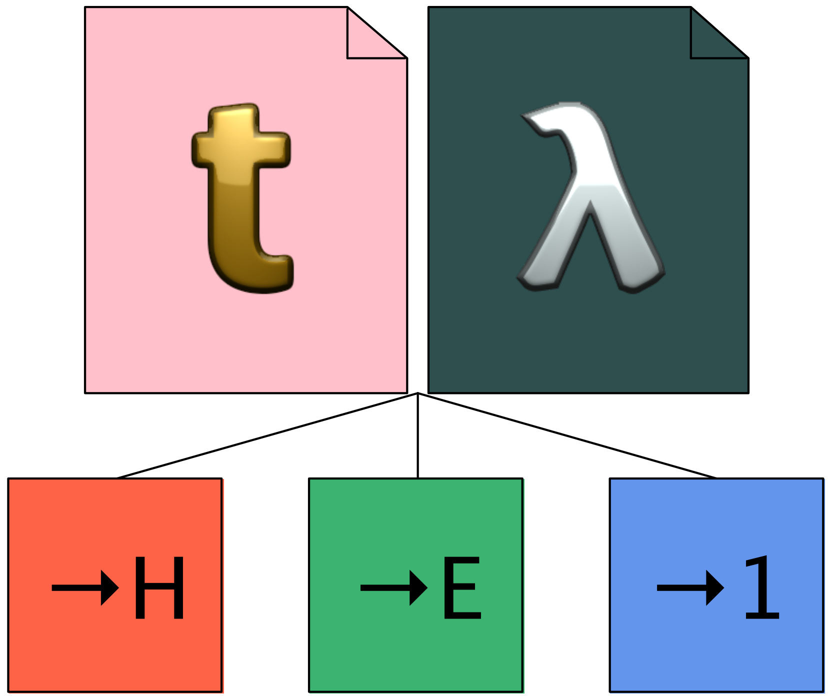
Pallene
Grace

Is type soundness all-or-nothing?

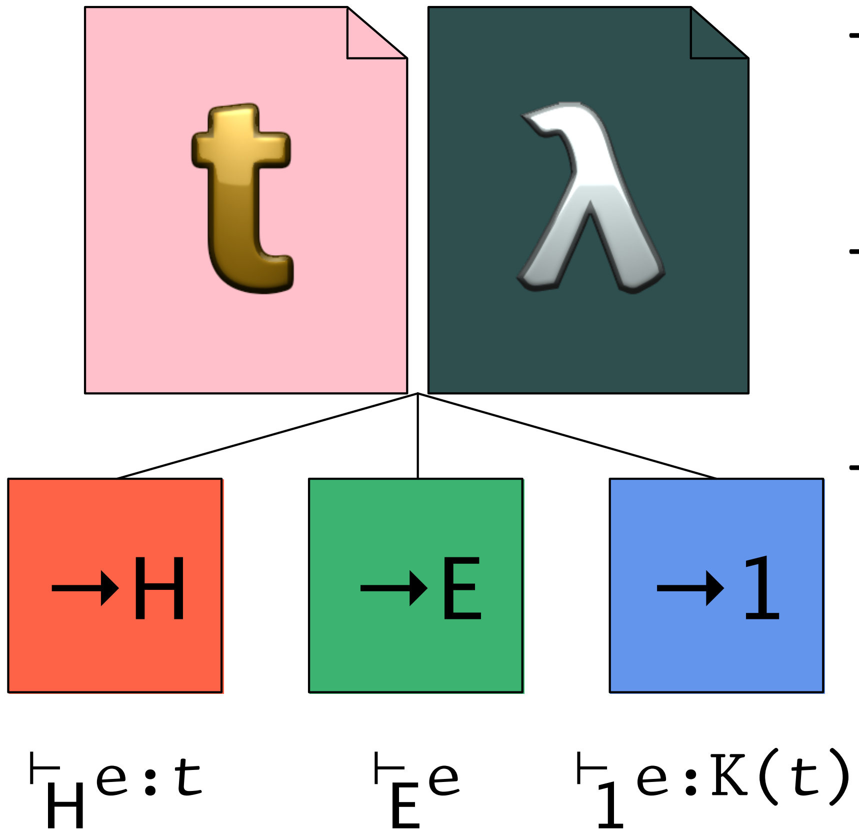


Same type soundness?



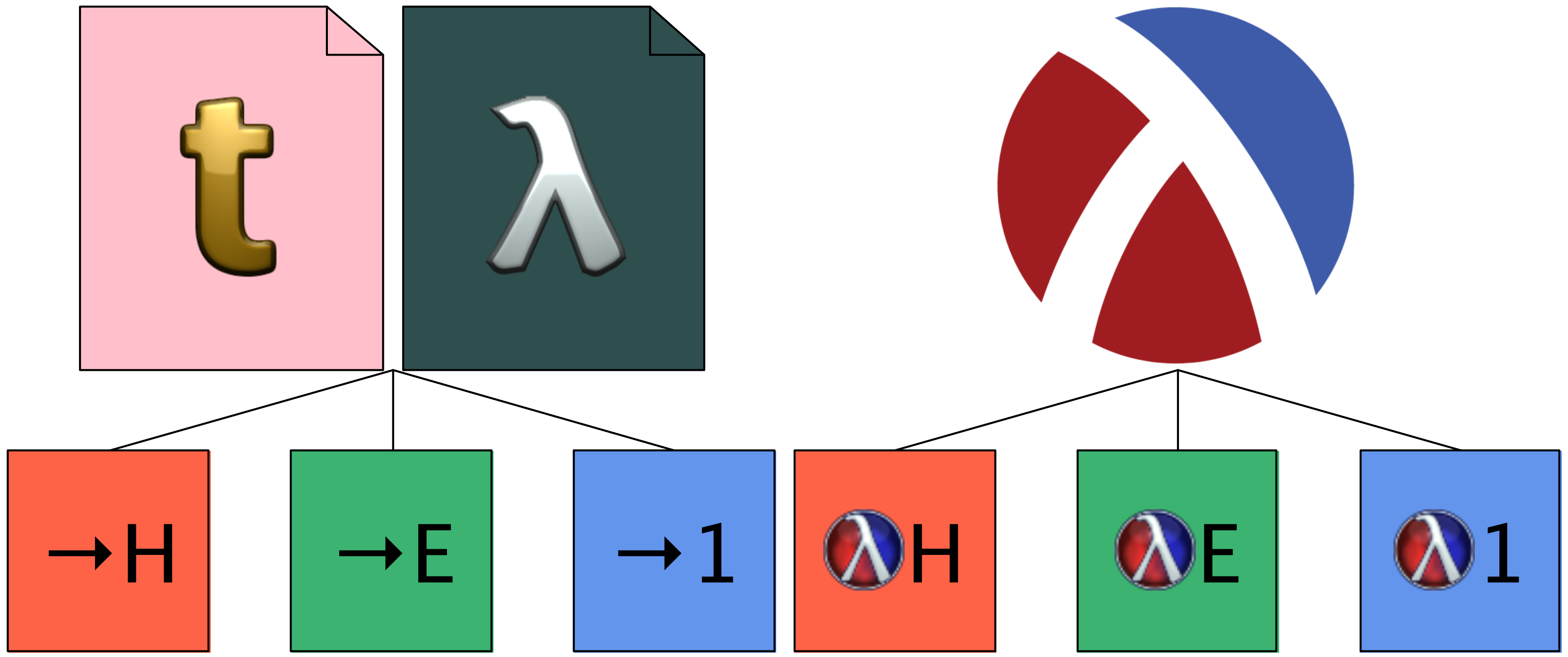
Same type soundness?

No!

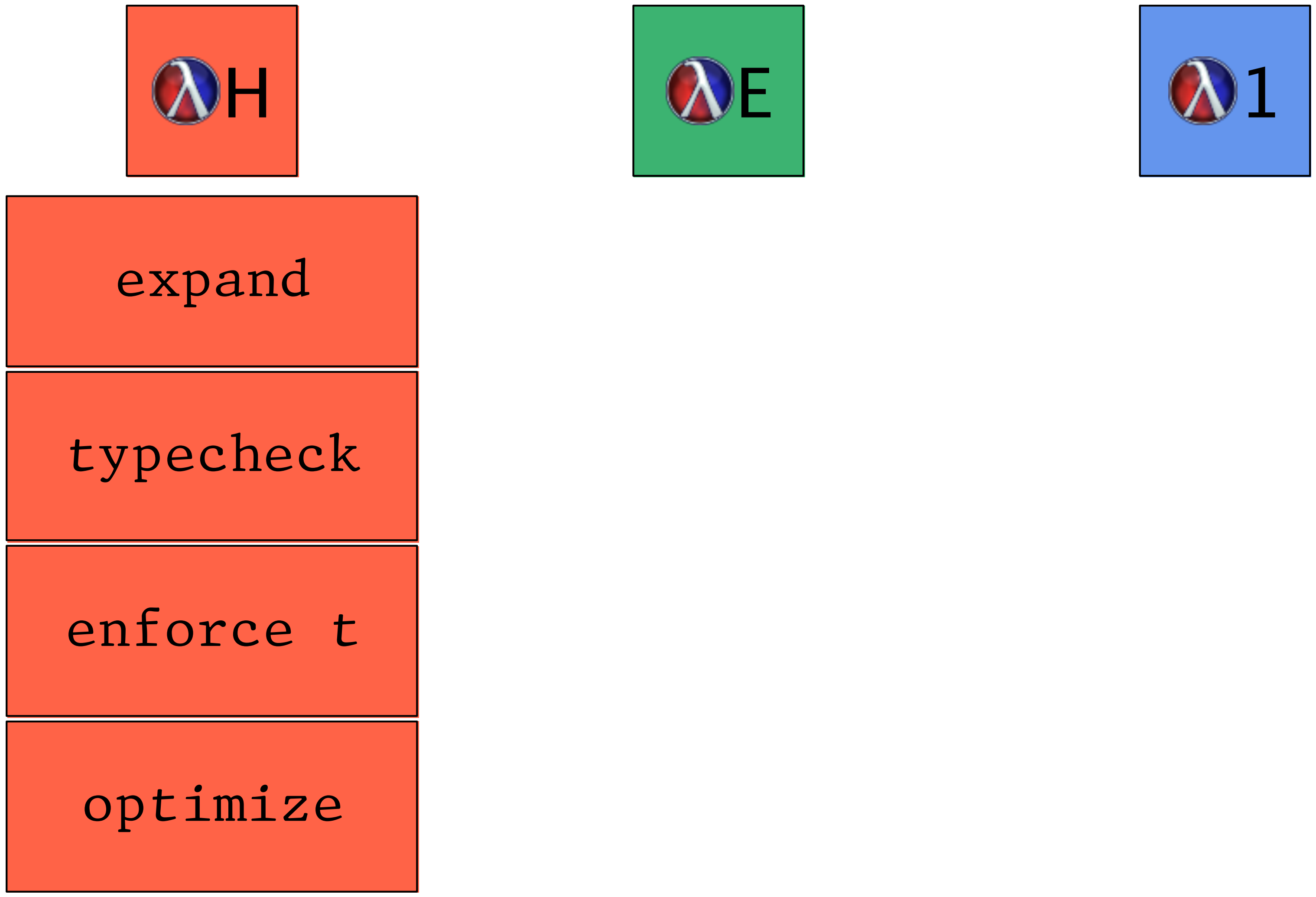


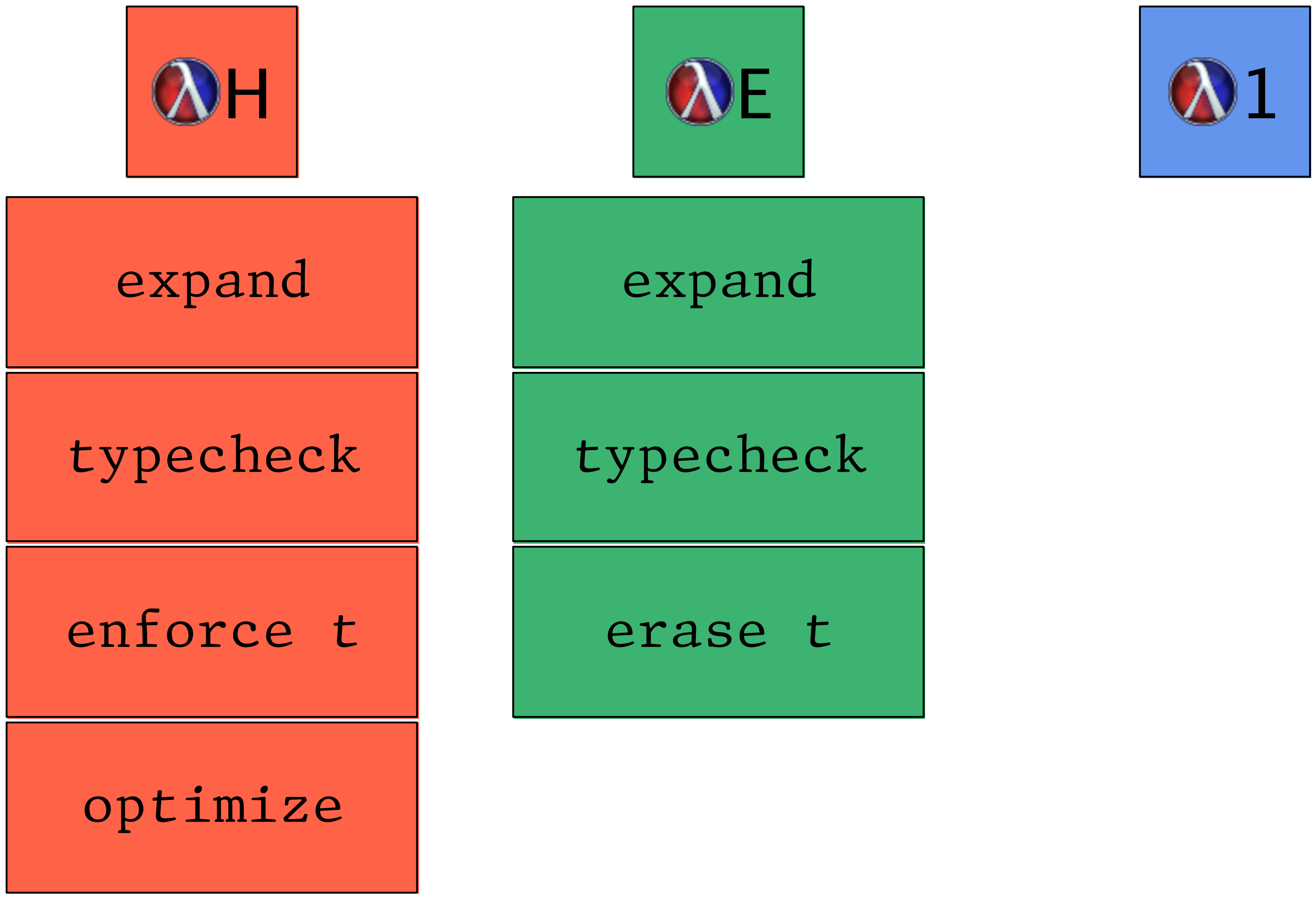
- $\vdash_H e : t$ sound for $\to H$
- $\vdash_E e$ sound for $\to E$
- $\vdash_1 e : K(t)$ sound for $\to 1$

Implementation


→H
→E
→1
H
E
1

H
E
1


H
E
1
expand
typecheck
enforce t
optimize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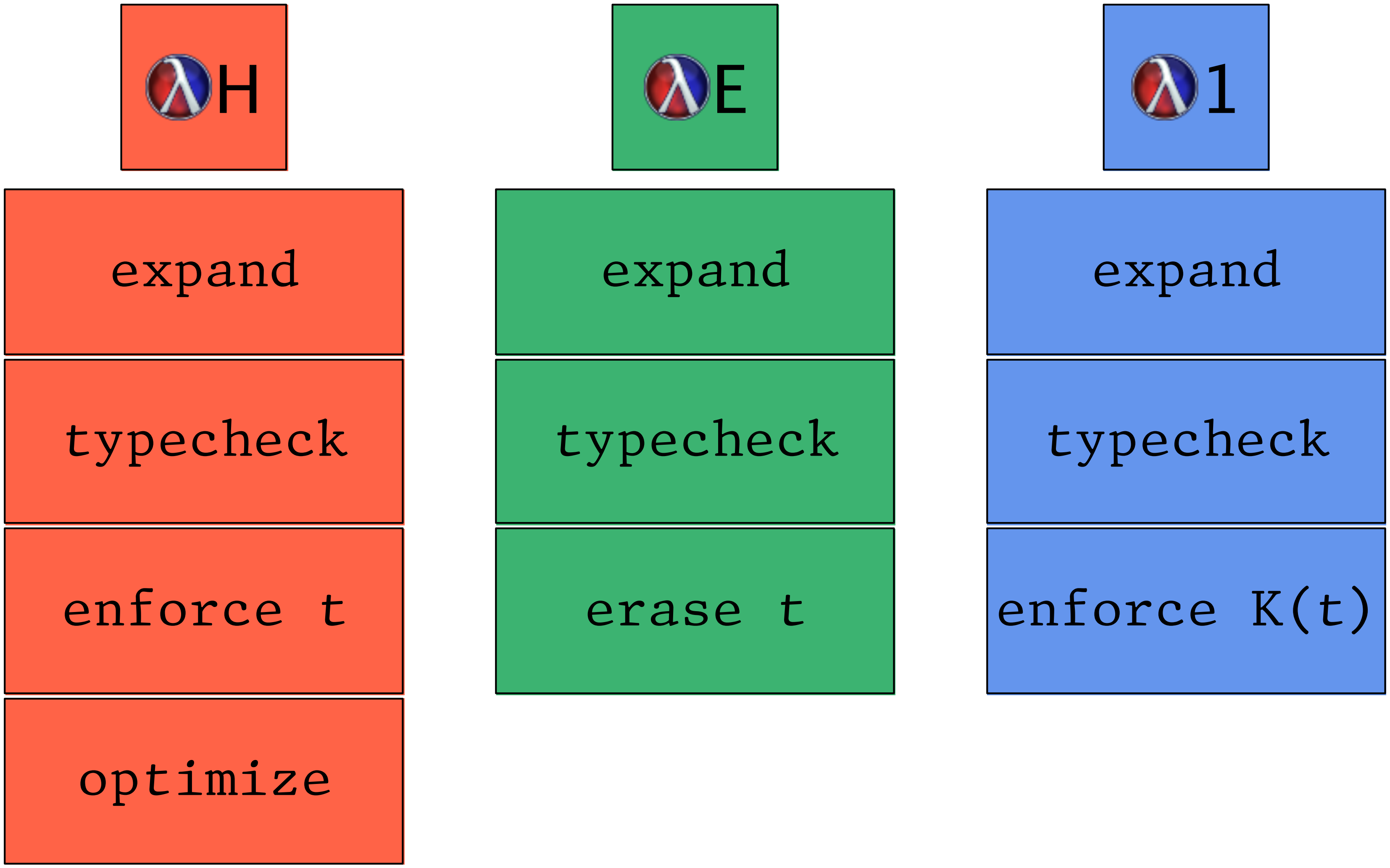
expand
typecheck
enforce t
optimize
E
expand
typecheck
erase t
1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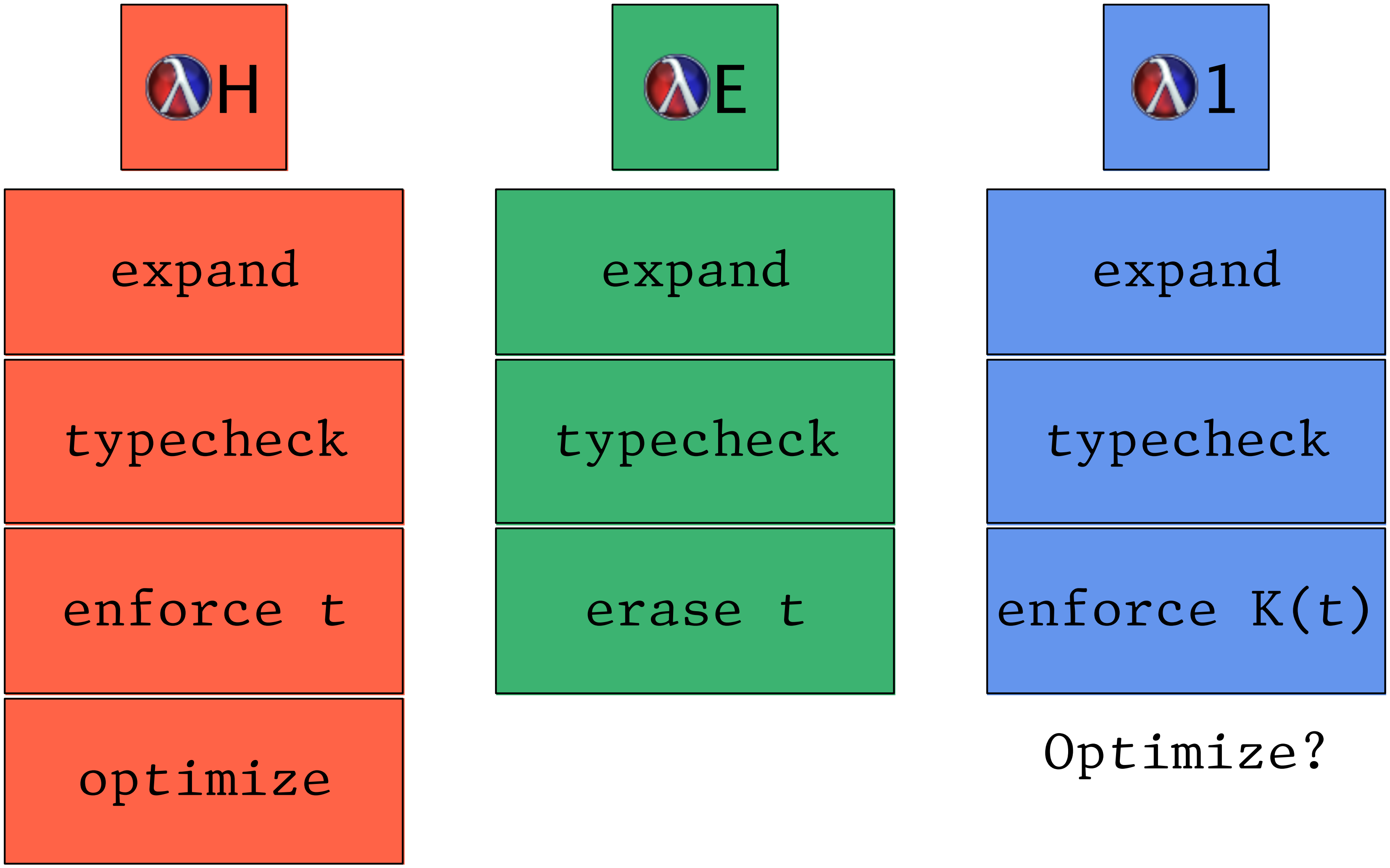
typecheck
enforce t
optimize
E
expand
typecheck
erase t
1
expand
typecheck
enforce K(t)


H
expand
typecheck
enforce t
optimize
E
expand
typecheck
erase t
1
expand
typecheck
enforce K(t)
Optimize?

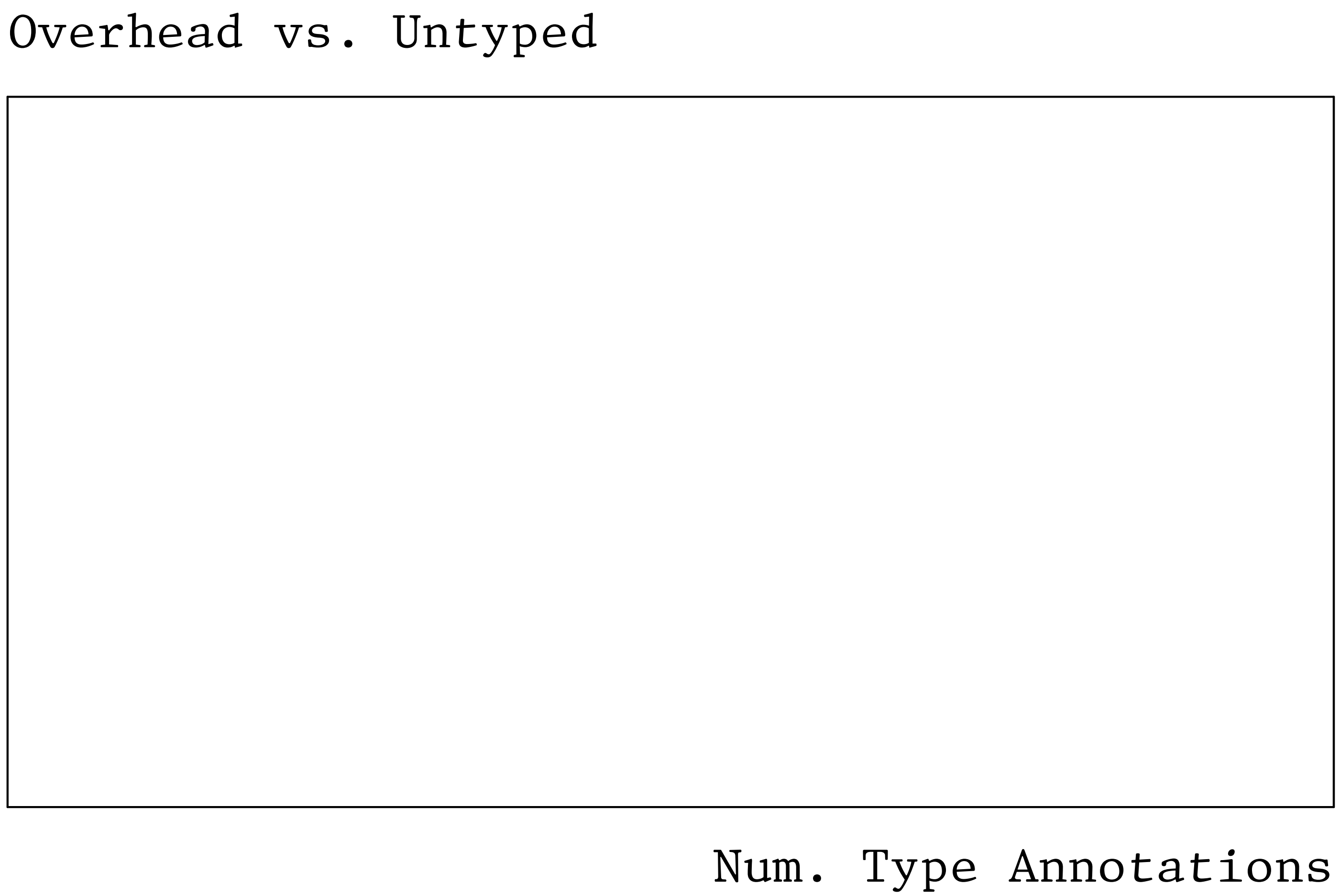
Experiment

- 10 benchmark programs
- 2 to 10 modules each
- 4 to 1024 configurations each
- compare overhead to untyped

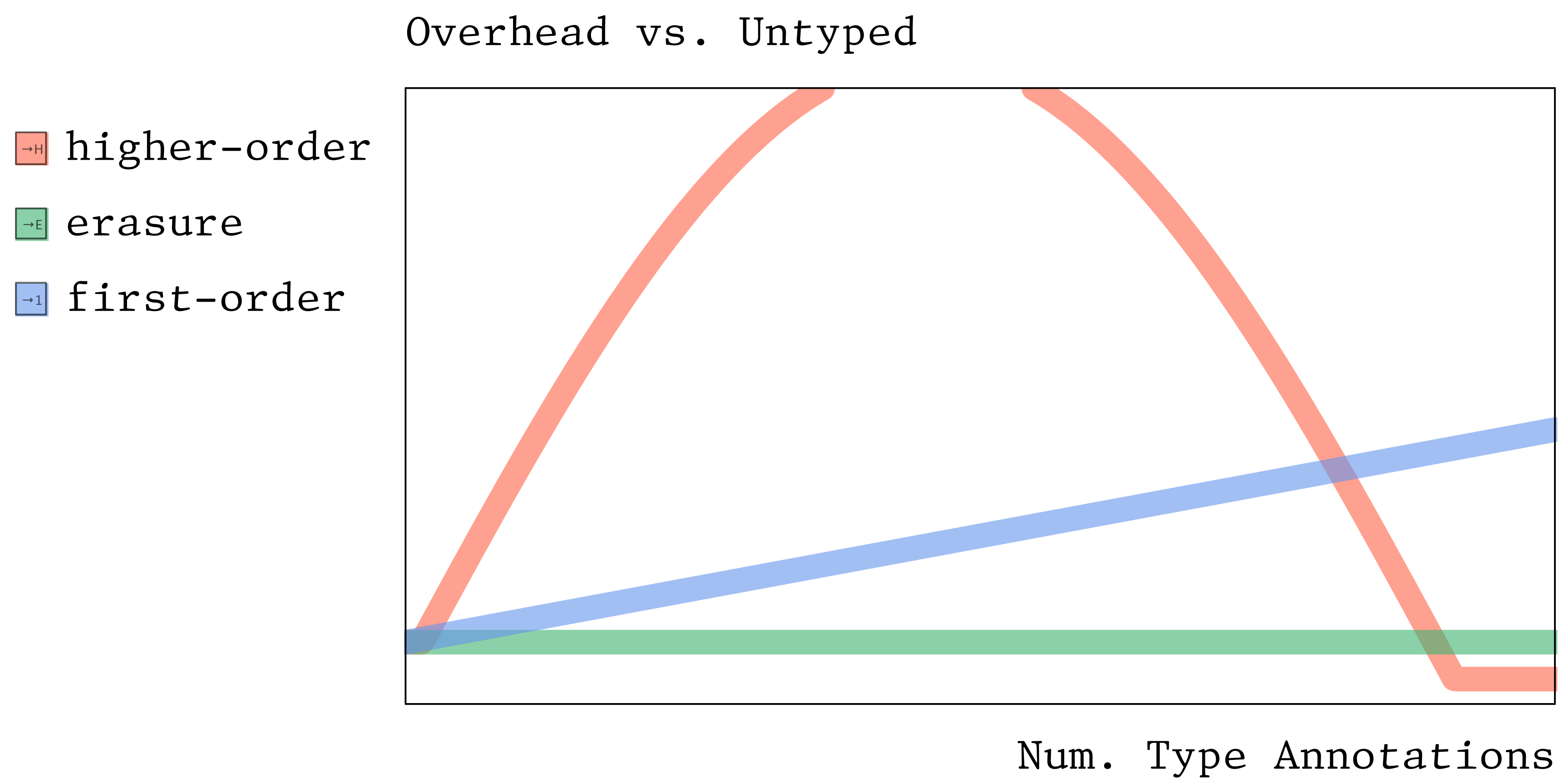
docs.racket-lang.org/gtp-benchmarks

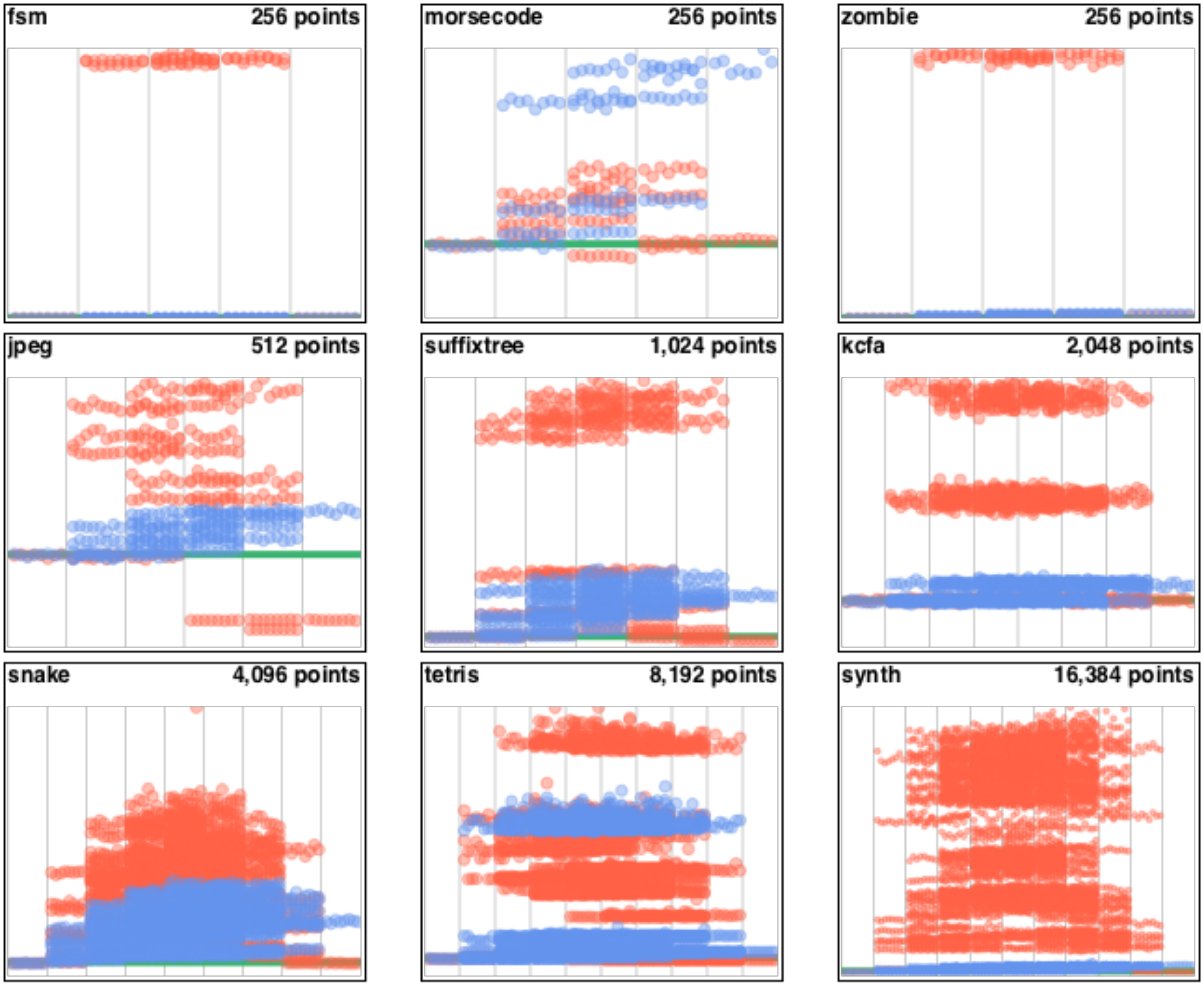
Results

Typical program



Typical program

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256 points
morsecode
256 points
zombie
256 points
jpeg
512 points
suffixtree
1,024 points
kcfa
2,048 points
snake
4,096 points
tetris
8,192 points
synth
16,384 points

Implications

Theory Implications

$$\boxed{\to H} \supset \boxed{\to 1} \supset \boxed{\to E}$$

$\to H$ `progress + preserves types`

$\to E$ `progress`

$\to 1$ `progress + preserves type constructors`

Theory Implications

$$\boxed{\rightarrow\mathrm{H}} \supset \boxed{\rightarrow 1} \supset \boxed{\rightarrow\mathrm{E}}$$

$\rightarrow$H progress + preserves types

$\rightarrow$E progress

$\rightarrow$1 progress + preserves type constructors

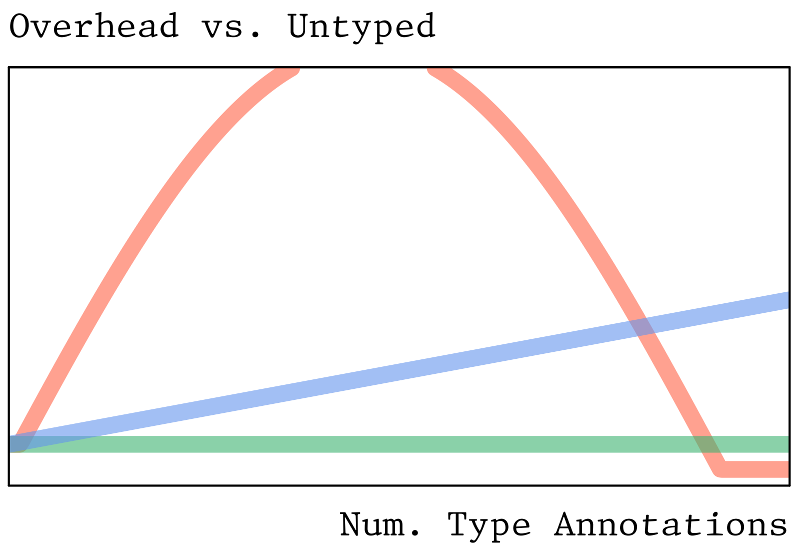
- $\rightarrow$H refines $\rightarrow$1
- $\rightarrow$1 refines $\rightarrow$E

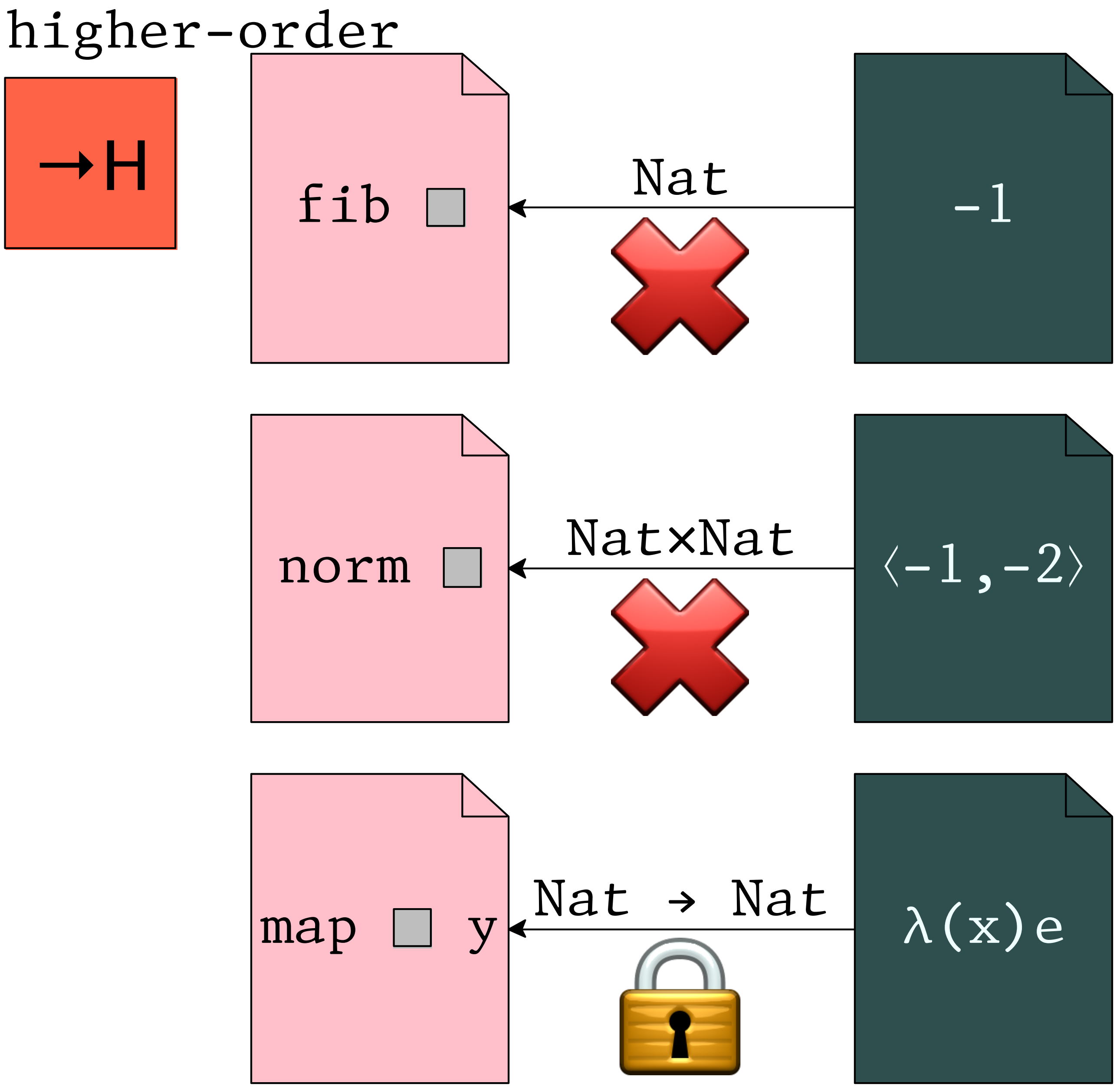
Performance Implications

→H add types to 'packages'

→E add types anywhere

→1 add types sparingly




higher-order
→H
fib □
Nat
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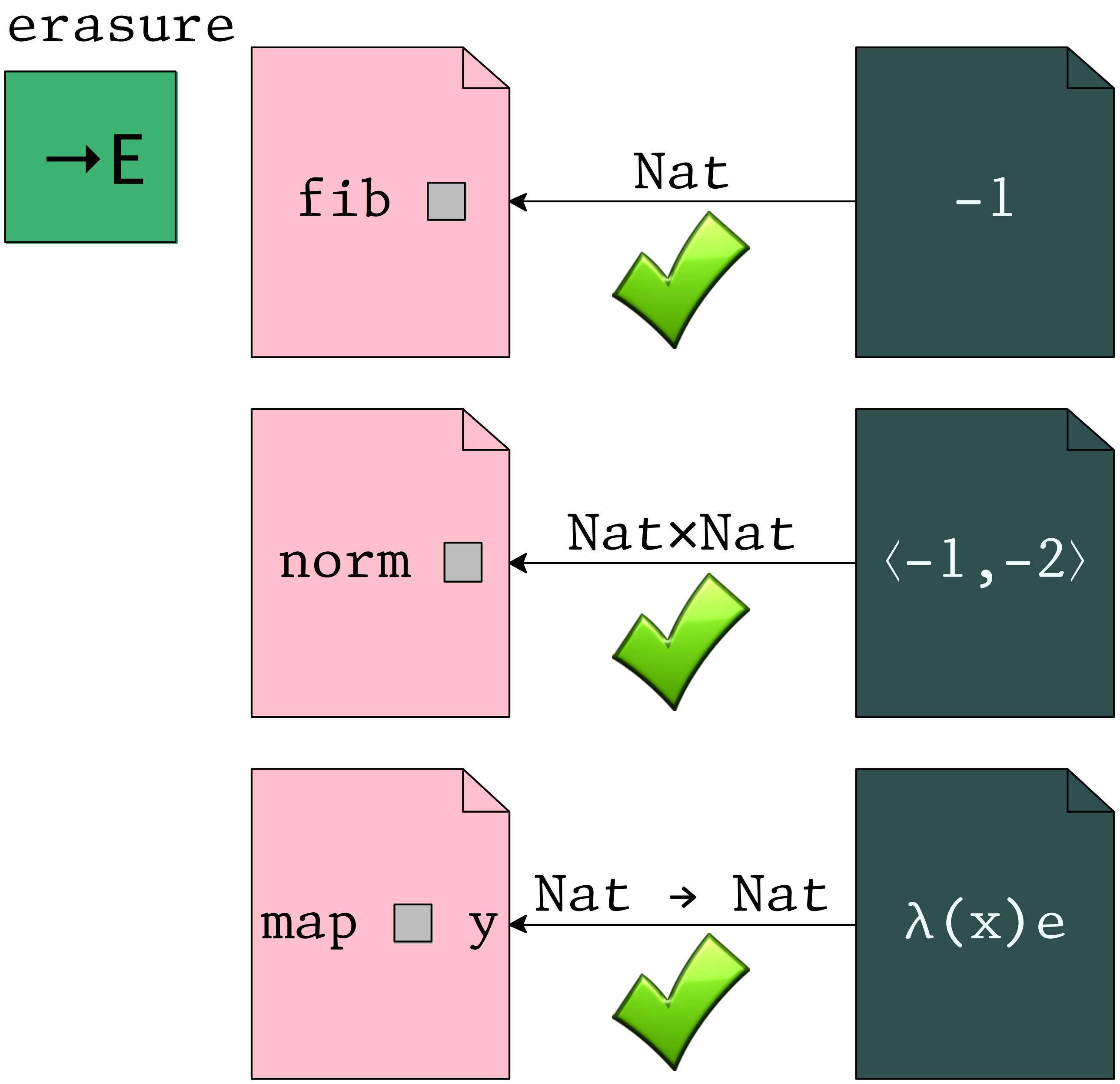
norm □
Nat×Nat
⟨-1,-2⟩
map □ y
Nat → Nat
λ(x)e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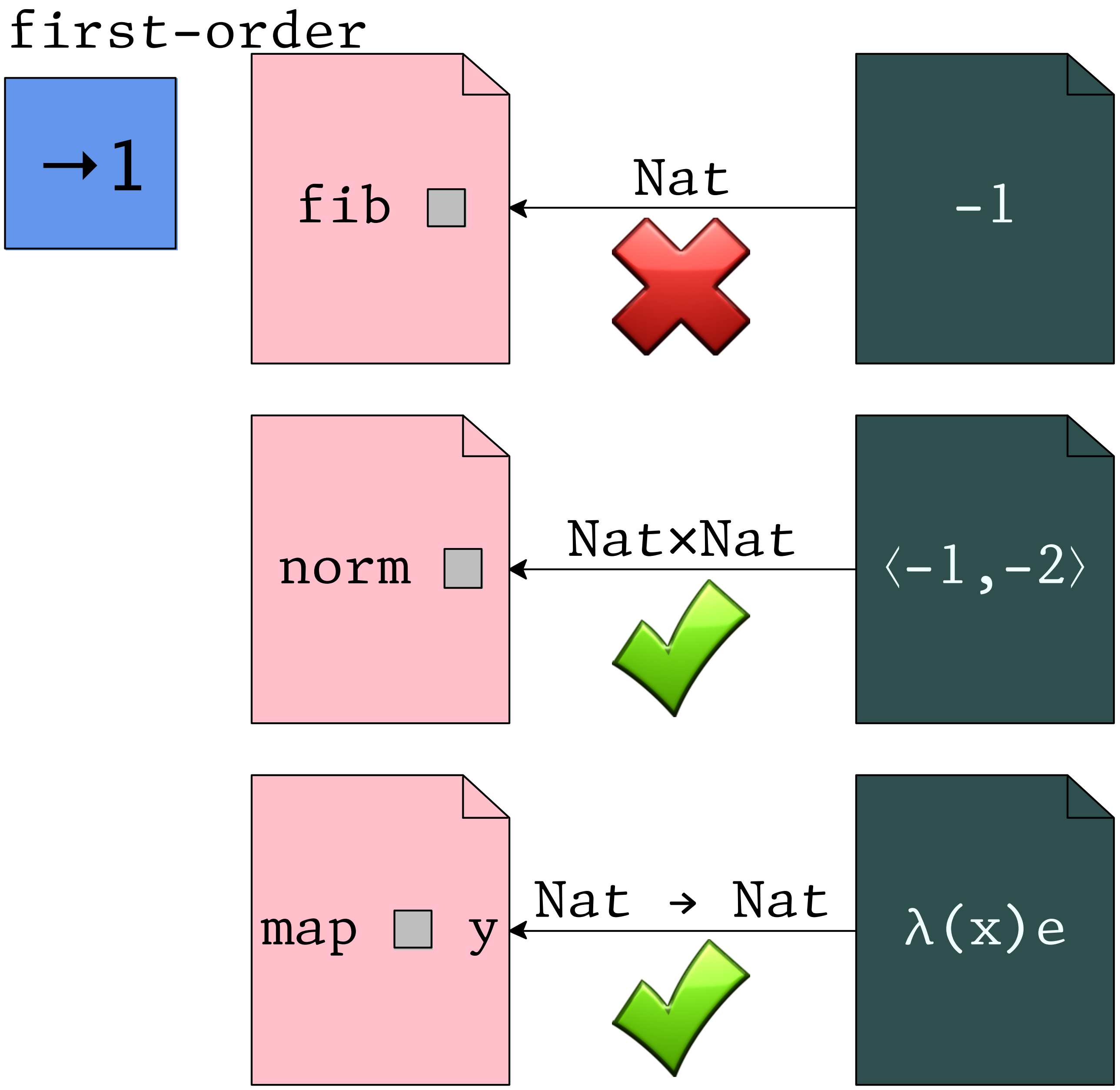
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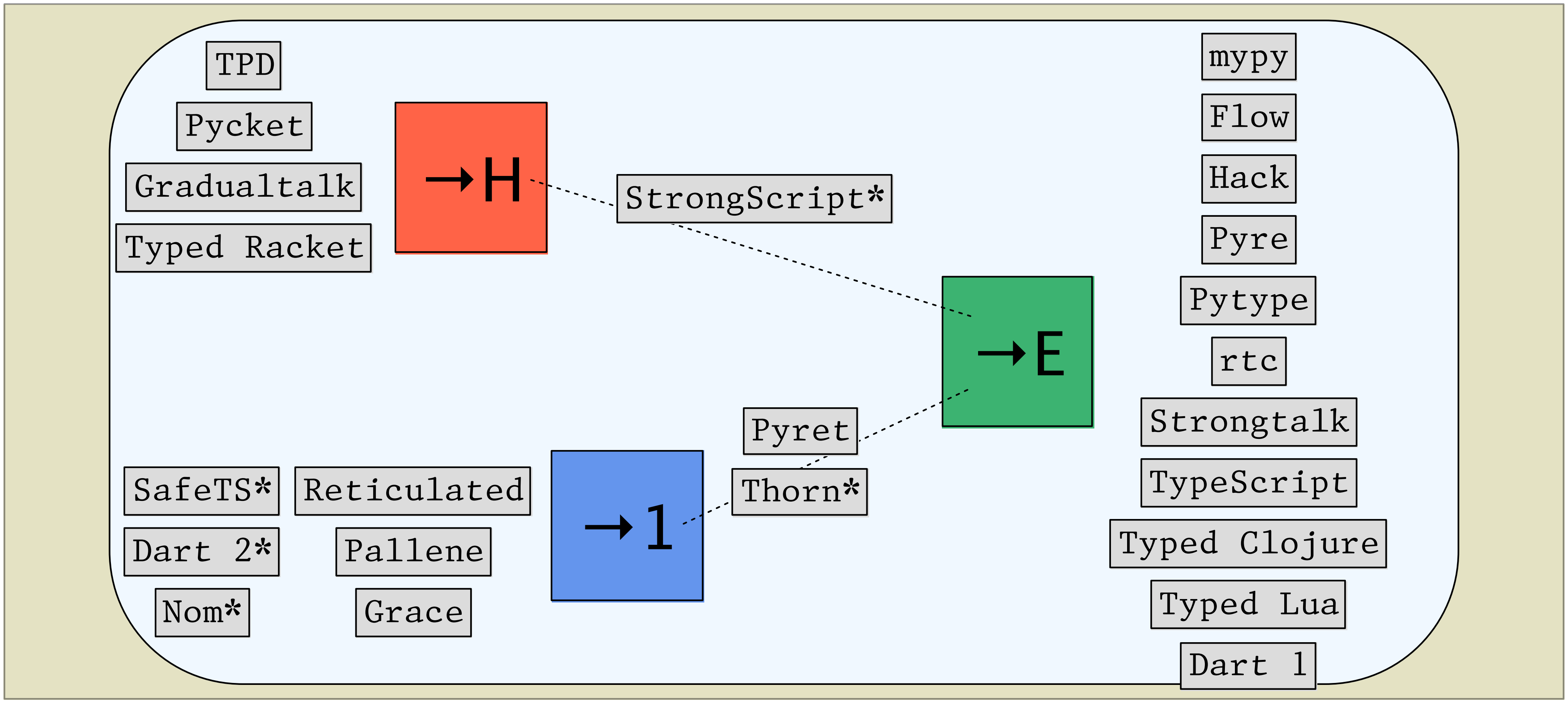
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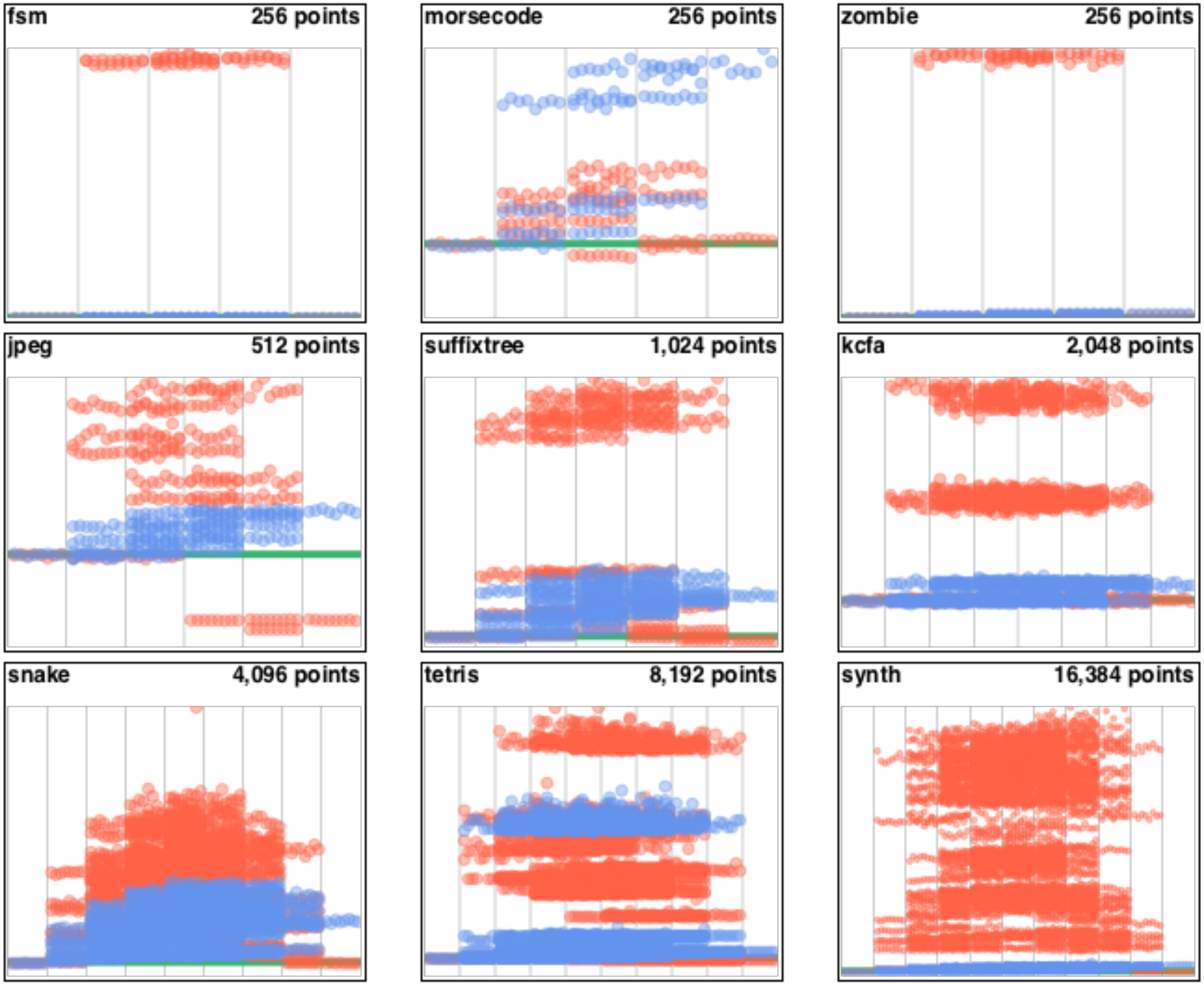
fsm
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Is type soundness all-or-nothing?

Can adding types slow down a program?

Is type soundness all-or-nothing?

What invariants should the language guarantee?

Can adding types slow down a program?

Yes, through interaction with untyped code (or data)