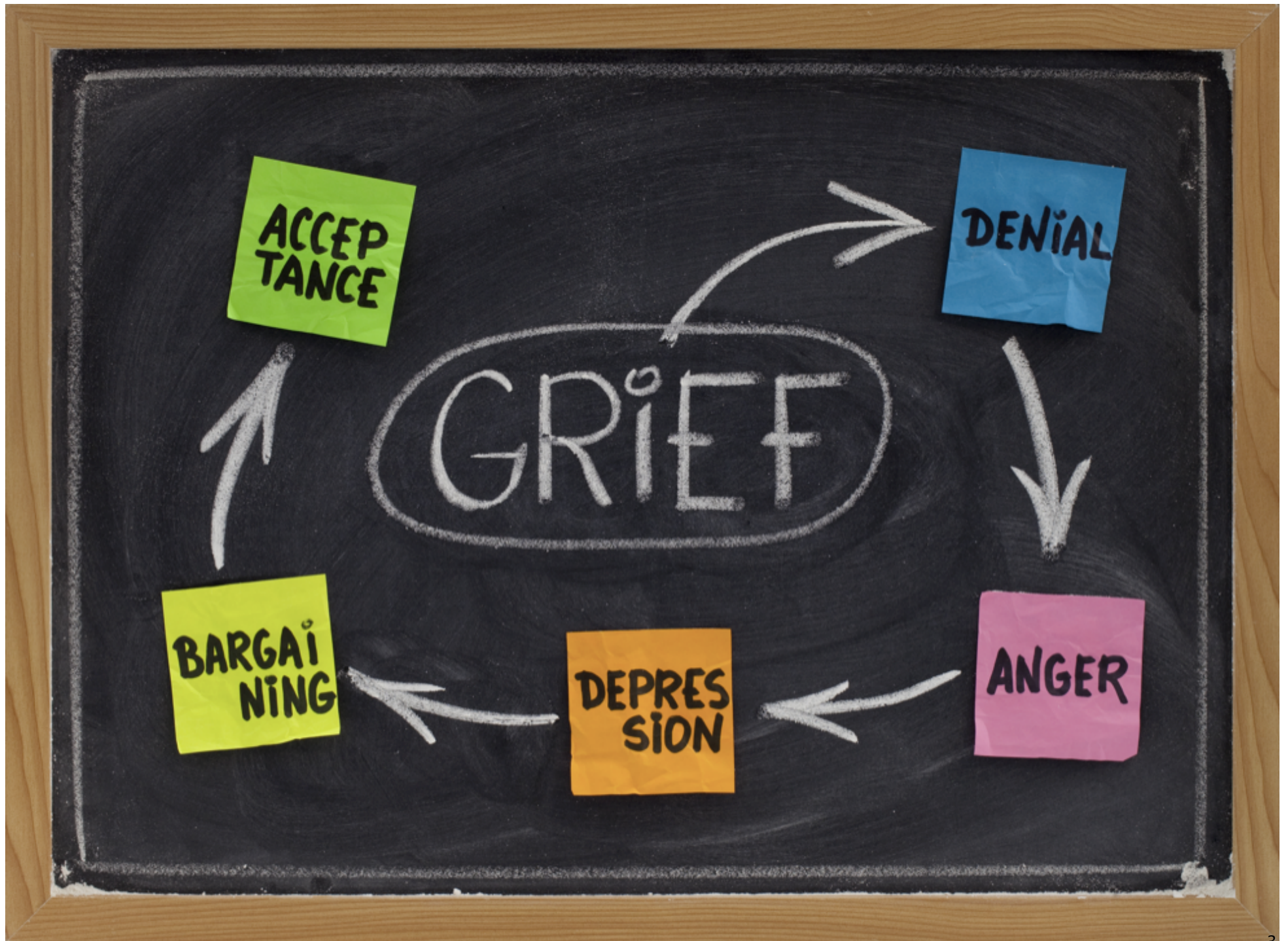


# MEASURING RETICULATED PYTHON

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# Reticulated Python

- Gradual typing for Python [DLS 2014]
- Static type checking
- Dynamic type enforcement
- Formal model is type is sound [POPL 2017]

# Example Program

```
def f(n):  
    return n*(n+1) // 2  
  
def get_numbers(count):  
    nums = []  
    for i in range(1, 1+count):  
        nums.append(f(i))  
    return nums  
  
get_numbers(4)  
# [1, 3, 6, 10]
```

# Example Program, Fully-Typed

```
def f(n: Int) -> Int:
    return n * (n + 1) // 2

def get_numbers(count: Int) -> List(Int):
    nums = []
    for i in range(1, 1 + count):
        nums.append(f(i))
    return nums

get_numbers(4)
# [1, 3, 6, 10]
```

# Example Program, Partially Typed

```
def f(n: Int) :  
    return n*(n+1) // 2  
  
def get_numbers(count) -> List(Int) :  
    nums = []  
    for i in range(1, 1+count) :  
        nums.append(f(i))  
    return nums  
  
get_numbers(4)  
# [1, 3, 6, 10]  
  
f("not a number")  
# Static type error  
  
get_numbers("not a number")  
# Dynamic type error
```

# Reticulated Python

- Gradual typing for Python [DLS 2014]
- Static type checking
- Dynamic type enforcement
- Formal model is type is sound [POPL 2017]

# **STAGE I: GRIEF**



# Something Weird

```
def f(n: Int) :  
    return n*(n+1) // 2  
  
def get_numbers(count) -> List(Int) :  
    nums = []  
    for i in range(1, 1+count) :  
        nums.append(f)    # typo!  
    return nums  
  
get_numbers(4)  
  
# [<fun>, <fun>, <fun>, <fun>]  
  
def apply_first(funs) :  
    return funs[0](10)  
apply_first(get_numbers(4))  
# 55
```

## Another Something Weird

```
@fields({"dollars": Int
        , "cents": Int})
class Cash:
    dollars = 0
    cents = 0

    def add_dollars(self, dollars):
        self.dollars += dollars

def get_cash() -> Cash:
    c = Cash()
    c.add_dollars(3.14159)
    return c

get_cash()
# Cash(3.14159, 0)
```

# **STAGE II: DENIAL**

# Type Soundness

If  $e$  has type  $T$ , then either:

- $e$  reduces to a value  $v$  with type  $T$
- $e$  raises an error due to a partial primitive
- $e$  diverges

# Reticulated Type Soundness

If  $e$  has type  $T$ , then either:

- $e$  reduces to a value  $v$  with type  $\llbracket T \rrbracket$ 
  - e.g.  $\llbracket \text{Int} \rightarrow \text{Int} \rrbracket = \rightarrow$
- $e$  raises a blame error
- $e$  diverges

# Big Types in Little Runtime

## Open-World Soundness and Collaborative Blame for Gradual Type Systems

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### Abstract

Gradual typing combines static and dynamic typing in the same language, offering programmers the error detection and strong guarantees of static types and the rapid prototyping and flexible programming idioms of dynamic types. Many gradually typed languages are implemented by translation into an untyped target language (e.g., Typed Clojure, TypeScript, Gradualtalk, and Reticulated Python). For such languages, it is desirable to sup-

typed code interacts: the consistency relation plays the role that type equality usually does in the type system. Types are consistent if they are equal up to the presence of  $\star$ .

Most existing gradually typed languages operate by translating a surface language program into an underlying target language, which is then executed. For many gradually-typed systems such as Typed Racket and TypeScript, the target language is a dynamically typed programming language, and gradually-typed programs are expected to seamlessly interact with legacy code in the dynamic

**Corollary 5.5.1** (Type soundness). *If  $\emptyset \vdash e_s \rightsquigarrow e : T$  then  $\emptyset; \emptyset \vdash e : [T]$  and either:*

- $\langle e, \emptyset, \emptyset \rangle \longrightarrow^* \langle v, \sigma, \mathcal{B} \rangle$  and  $\emptyset; \Sigma \vdash v : [T]$  and  $\Sigma \vdash \sigma$ , or
- $\langle e, \emptyset, \emptyset \rangle \longrightarrow^* \text{BLAME}(\mathcal{L})$ , or
- for all  $\varsigma$  such that  $\langle e, \emptyset, \emptyset \rangle \longrightarrow^* \varsigma$ , have that  $\varsigma = \langle e', \sigma, \mathcal{B} \rangle$  and exists  $\varsigma'$  such that  $\langle e', \sigma, \mathcal{B} \rangle \longrightarrow \varsigma'$ .

$$\boxed{[T] = S}$$

$$\begin{array}{l} [\star] = \star \\ [T_1 \rightarrow T_2] \Rightarrow \end{array} \quad \begin{array}{l} [\text{int}] = \text{int} \\ [\text{ref } T] = \text{ref} \end{array}$$

$$\boxed{T \triangleright T}$$

$$\begin{array}{l} \text{ref } T \triangleright \text{ref } T \\ T_1 \rightarrow T_2 \triangleright T_1 \rightarrow T_2 \end{array} \quad \begin{array}{l} \star \triangleright \text{ref } \star \\ \star \triangleright \star \rightarrow \star \end{array}$$

$$\boxed{T \sim T}$$

$$\text{int} \sim \text{int} \quad \star \sim T \quad T \sim \star$$

$$\frac{T_1 \sim T_2}{\text{ref } T_1 \sim \text{ref } T_2} \quad \frac{T_1 \sim T_3 \quad T_2 \sim T_4}{T_1 \rightarrow T_2 \sim T_3 \rightarrow T_4}$$

---

**Figure 3.** Translation from  $\lambda_{\rightarrow}^{\star}$  to  $\lambda_{\ell}^{\Downarrow}$ .



# **STAGE III: ANGER, BARGAINING, DEPRESSION**

# What are Reticulated Types Good For?

- Protect invariants? No
- Reliable documentation? No
- Enable optimizations? No

Any untyped code

=>

No compositional reasoning!

# **STAGE IV: ACCEPTANCE**

# Interoperability & Performance

# Interoperability

```
def get_numbers(count) -> List(Int):  
    ....  
    return proxy(nums, List(Int))
```

- The proxy must be compatible with existing code

```
nums.append(...)
```

```
len(nums)
```

```
nums is nums
```

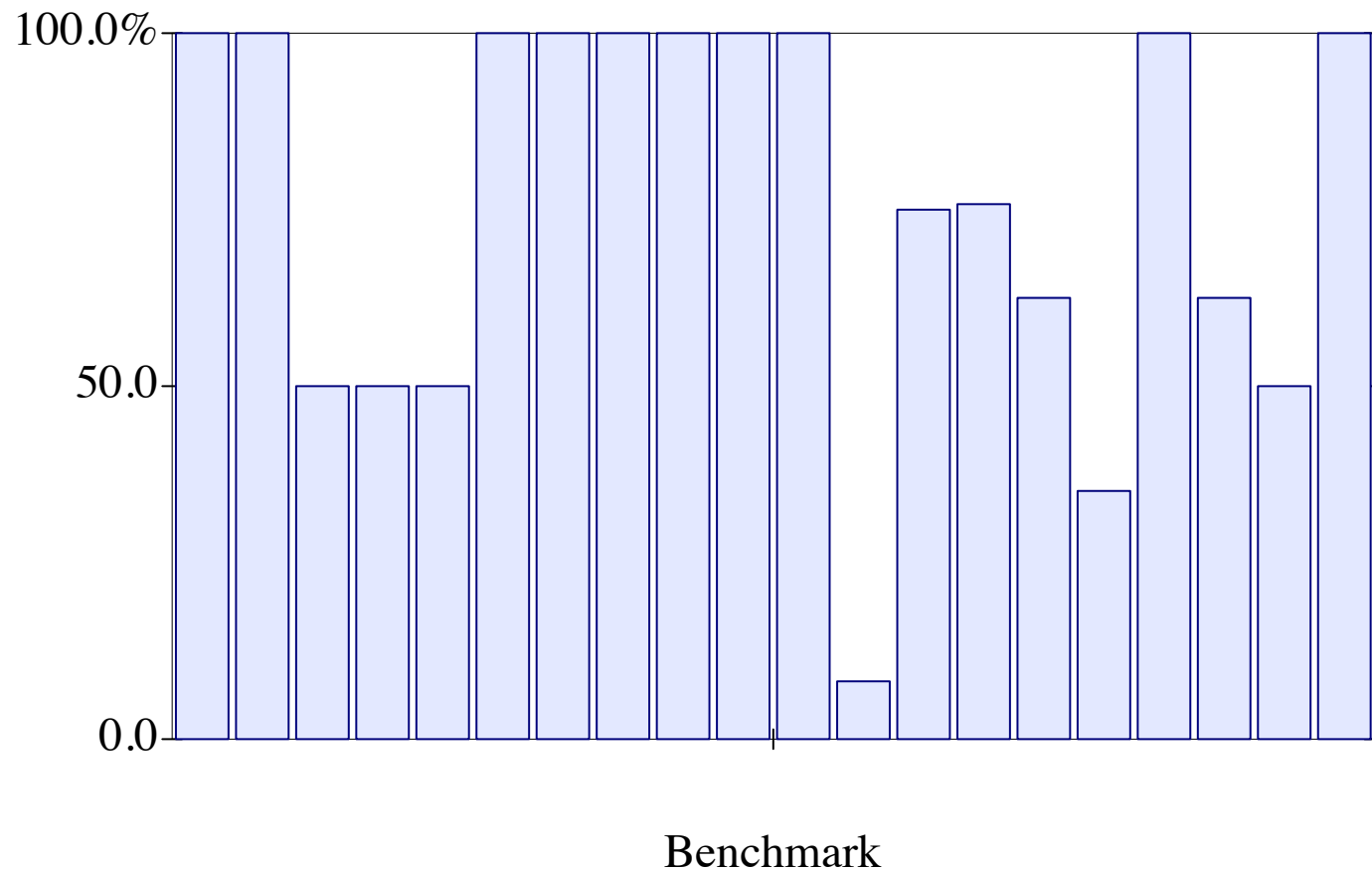
# Performance

```
def get_numbers(count) -> List(Int) :  
    . . .  
    return proxy(nums, List(Int))
```

- Allocation cost
- Traverse, recursively proxy
- Interpose on future operations

# Measuring Typed Racket

- 20 programs
- Measured all gradually-typed configurations
- How many 20-deliverable?



# Measuring Typed Racket

## Worst-Case Overhead

acquire	5	quadBG	4
dungeon	10	quadMB	139
forth	27	sieve	43
fsm	1527	snake	32
fsmoo	233	suffixtree	29
gregor	2	synth	47
kcfa	5	take5	1
lnm	1	tetris	34
mbta	1	zombie	292
morsecode	1	zordoz	1

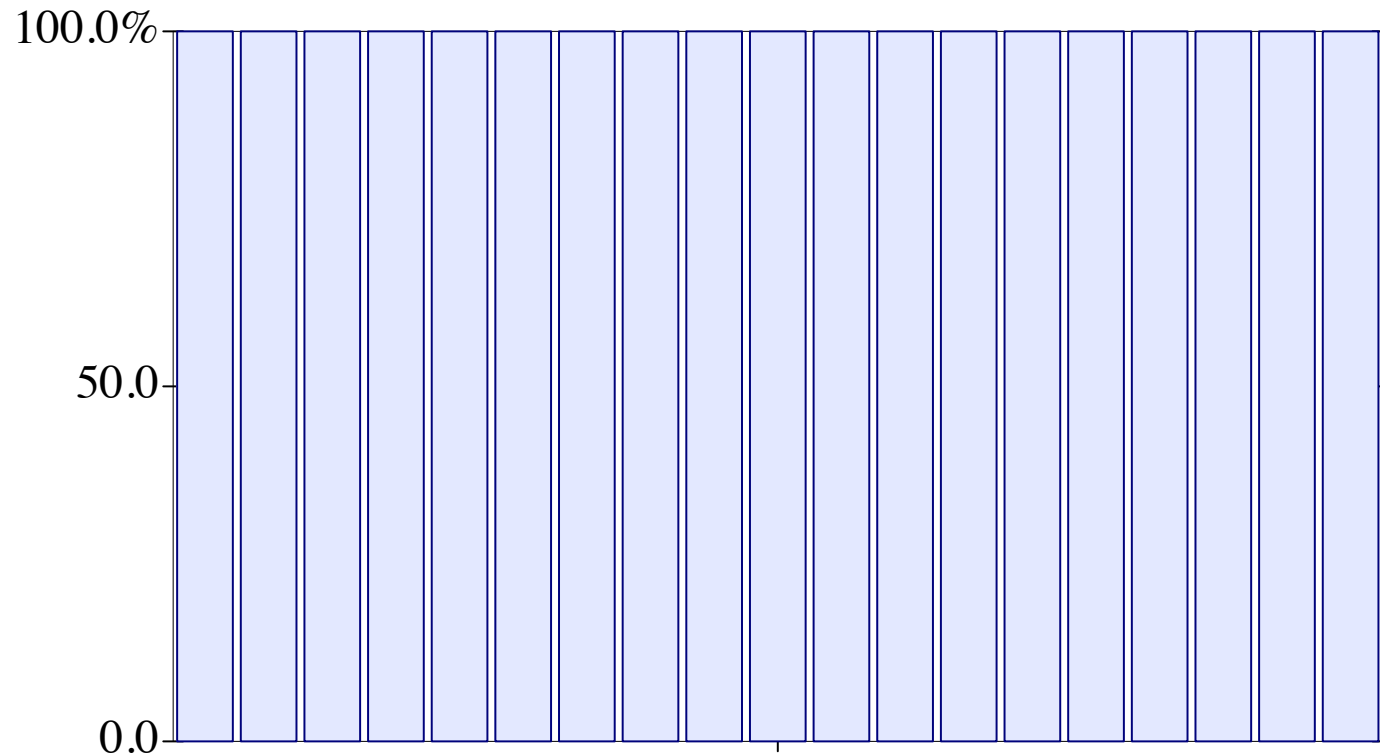


# Measuring Typed Racket

Frequently an order-of-magnitude slowdown

# Measuring Reticulated

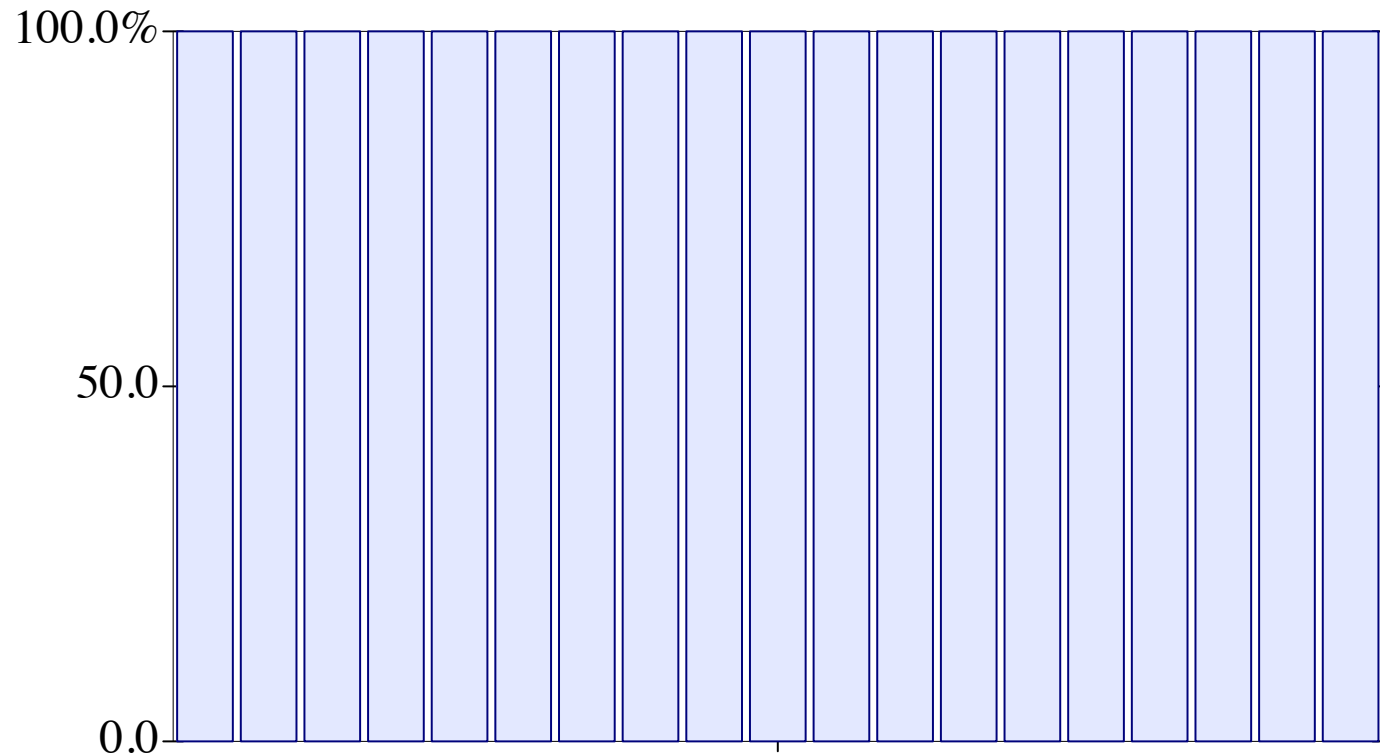
- 19 **different** programs
- Measured all *function-level* configurations
- How many 20-deliverable?



Benchmark

# Measuring Reticulated

- 19 **different** programs
- Measured all *function-level* configurations
- How many 10-deliverable?



Benchmark

# Measuring Reticulated

## Worst-Case Overhead

futen	1	meteor	2
http2	3	nbody	1
slowSHA	2	nqueens	1
call_method	7	pidigits	1
call_method_slots	8	pystone	2
call_simple	3	spectralnorm	8
chaos	3	Espionage	5
fannkuch	1	PythonFlow	7
float	3	take5	1
go	7		

# Measuring Reticulated

Never an order-of-magnitude slowdown

# **STAGE V: MOVING ON**

# Moving On

- Q1. Is Reticulated's soundness practical?
- Q2. Can Typed Racket soundness be performant?
- Q3. Is Typed Racket soundness portable?
- Q4. Is there a useful, "efficient" Soundness 3.0?

