ON PERFORMANCE

(of gradual typing, esp. in Racket)

This Talk is NOT About

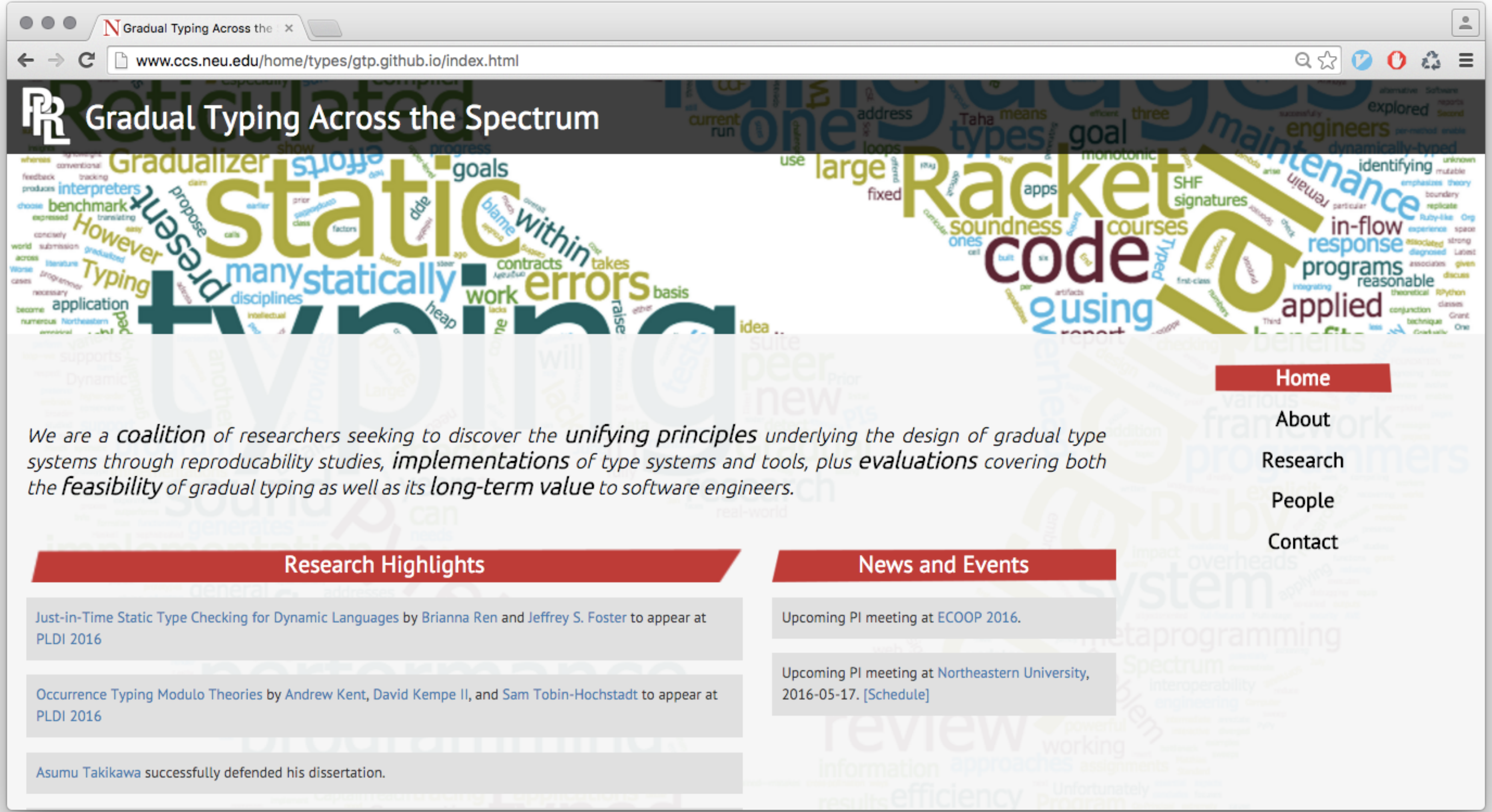
- Horrific performance overhead
- The death of gradual typing
- Impending doom

"[Typed Racket is] Very nice to work with!"

"The static typechecking is invaluable to me"

"Typed Racket has improved [my Racket prototype] considerably."

"What I find appealing about TR's **gradual typing** is the idea that, like the contract system, there's not One Right Way to use it. For instance, I've been using TR simply as a way of **creating better untyped code**, because the typechecker catches subtle reasoning errors."


Gradual Typing Across the
www.ccs.neu.edu/home/types/gtp.github.io/index.html
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People
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Gradual Typing Across the Spectrum

We are a coalition of researchers seeking to discover the unifying principles underlying the design of gradual type systems through reproducability studies, implementations of type systems and tools, plus evaluations covering both the feasibility of gradual typing as well as its long-term value to software engineers.

Research Highlights

Just-in-Time Static Type Checking for Dynamic Languages by Brianna Ren and Jeffrey S. Foster to appear at PLDI 2016

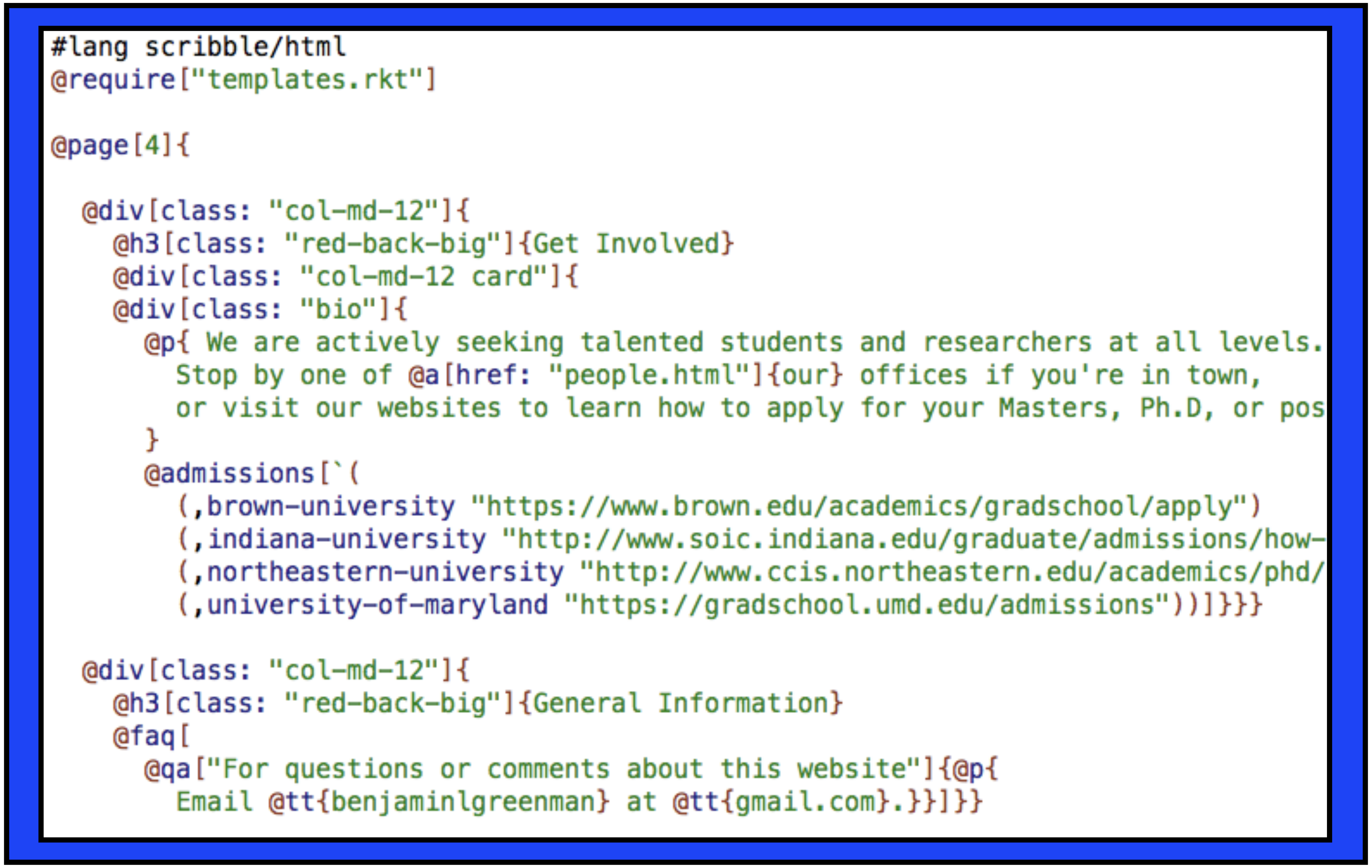
Occurrence Typing Modulo Theories by Andrew Kent, David Kempe II, and Sam Tobin-Hochstadt to appear at PLDI 2016

Asumu Takikawa successfully defended his dissertation.

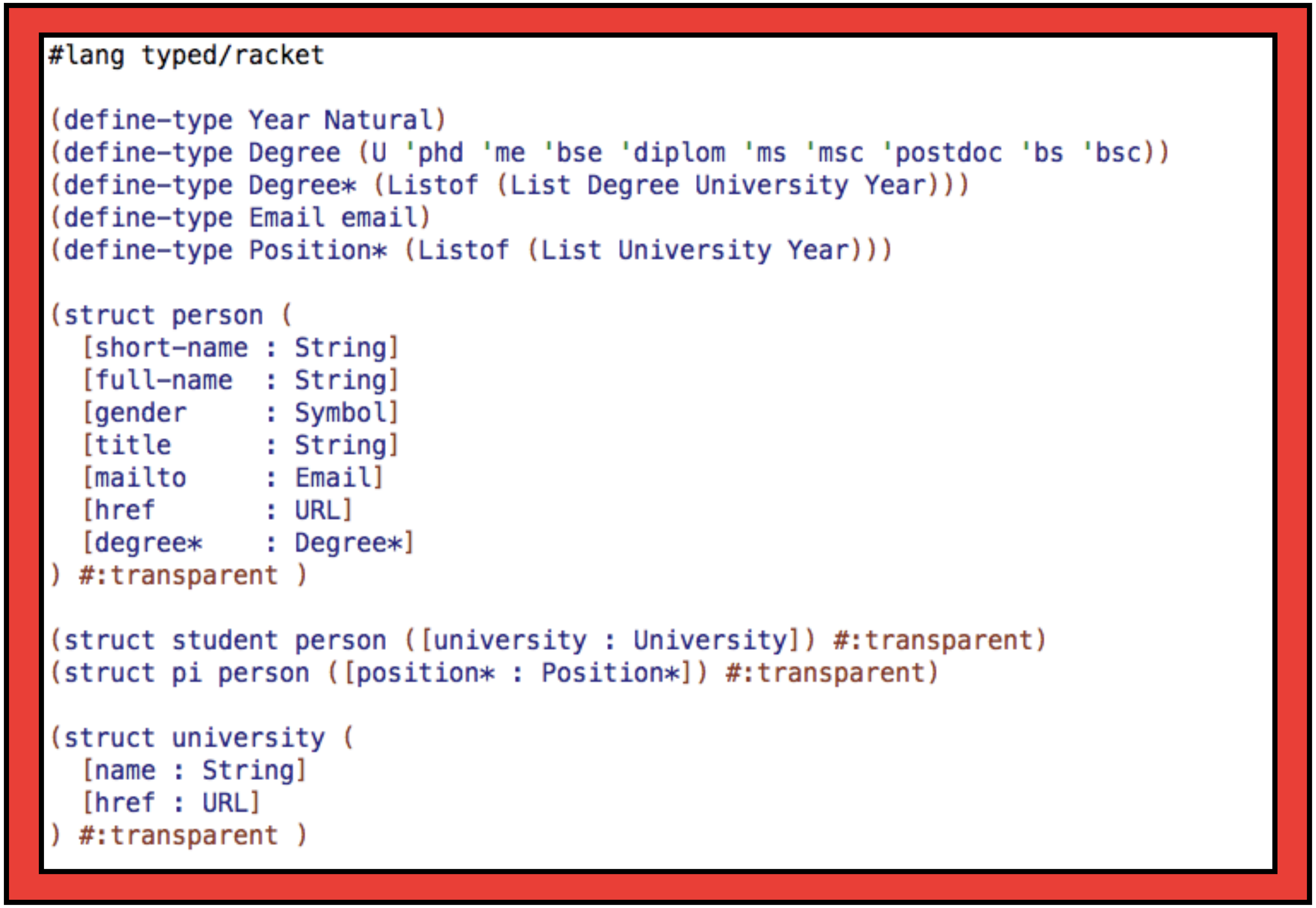
News and Events

Upcoming PI meeting at ECOOP 2016.

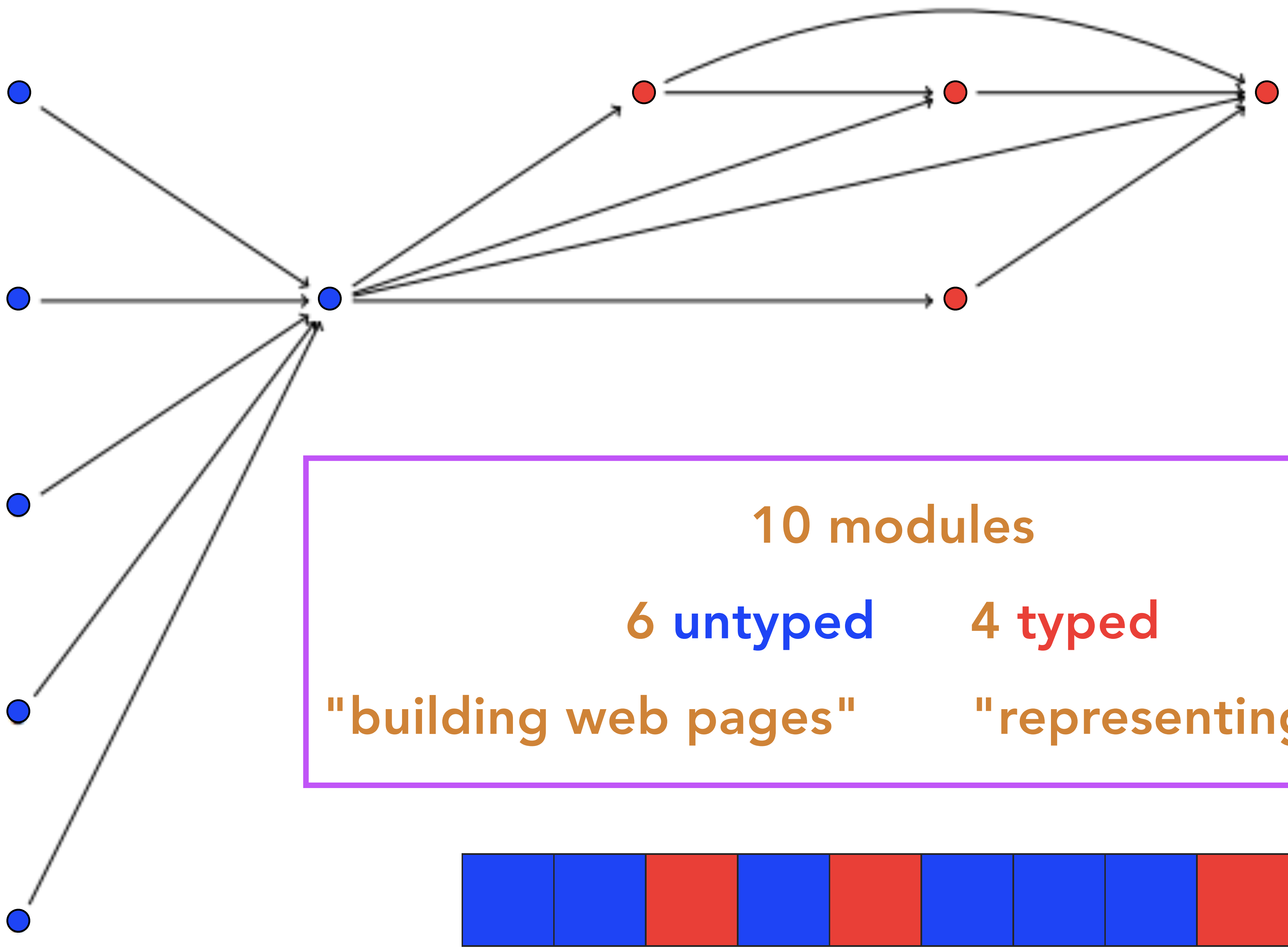
Upcoming PI meeting at Northeastern University, 2016-05-17. [Schedule]



```
#lang scribble/html
@require["templates.rkt"]

@page[4]{

  @div[class: "col-md-12"]{
    @h3[class: "red-back-big"]{Get Involved}
    @div[class: "col-md-12 card"]{
    @div[class: "bio"]{
      @p{ We are actively seeking talented students and researchers at all levels.
        Stop by one of @a[href: "people.html"]{our} offices if you're in town,
        or visit our websites to learn how to apply for your Masters, Ph.D, or pos
      }
      @admissions[`(
        (,brown-university "https://www.brown.edu/academics/gradschool/apply")
        (,indiana-university "http://www.soic.indiana.edu/graduate/admissions/how-
        (,northeastern-university "http://www.ccis.northeastern.edu/academics/phd/
        (,university-of-maryland "https://gradschool.umd.edu/admissions"))]}}}

  @div[class: "col-md-12"]{
    @h3[class: "red-back-big"]{General Information}
    @faq[
      @qa["For questions or comments about this website"]{@p{
        Email @tt{benjaminlgreenman} at @tt{gmail.com}.}}]}}
```



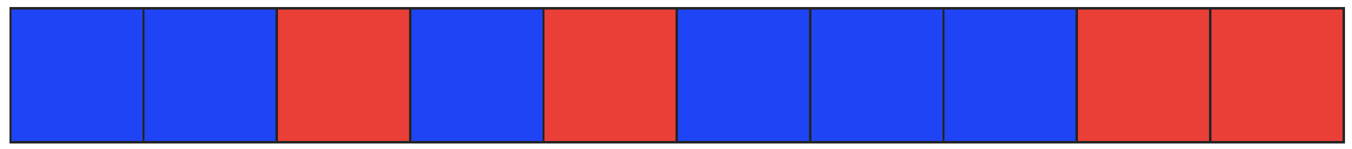
```
#lang typed/racket

(define-type Year Natural)
(define-type Degree (U 'phd 'me 'bse 'diplom 'ms 'msc 'postdoc 'bs 'bsc))
(define-type Degree* (Listof (List Degree University Year)))
(define-type Email email)
(define-type Position* (Listof (List University Year)))

(struct person (
  [short-name : String]
  [full-name  : String]
  [gender     : Symbol]
  [title      : String]
  [mailto     : Email]
  [href       : URL]
  [degree*    : Degree*]
) #:transparent )

(struct student person ([university : University]) #:transparent)
(struct pi person ([position* : Position*]) #:transparent)

(struct university (
  [name : String]
  [href : URL]
) #:transparent )
```



10 modules

6 untyped 4 typed

"building web pages" "representing data"



Typed Racket is:

Sound

All runtime type errors are **caught** at a **boundary** between typed and untyped code

Typed Racket is:

Sound and **Expressive**

All runtime type errors are **caught** at a **boundary** between typed and untyped code

Seamless integration with untyped code

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Sound and **Expressive**

All runtime type errors are **caught** at a **boundary** between typed and untyped code

"The static typechecking is invaluable to me"

Seamless integration with untyped code

"I've been using TR [for] creating better *untyped* code"

Performance?

"About twice as slow on common queries"

"From 1 ms to 12 seconds ... I feel like I got a bit burned here"

"The end product appears to be a 50% performance hybrid due to boundary contracts"

"So far Typed Quad is running about 10x slower than regular

...it seems that whatever I'm gaining [from the TR optimizer]

is more than offset by other factors.

"FWIW, as a practitioner, there are **costs** associated with using TR, therefore it has to provide **equivalent performance improvements** to be worthwhile at all.

"'equally good' runtime perf = net loss overall = I can't justify using it."

Research Questions

How to leverage **case studies** to **systematically improve** performance?

How to **evaluate** the performance of a gradual type **system**?

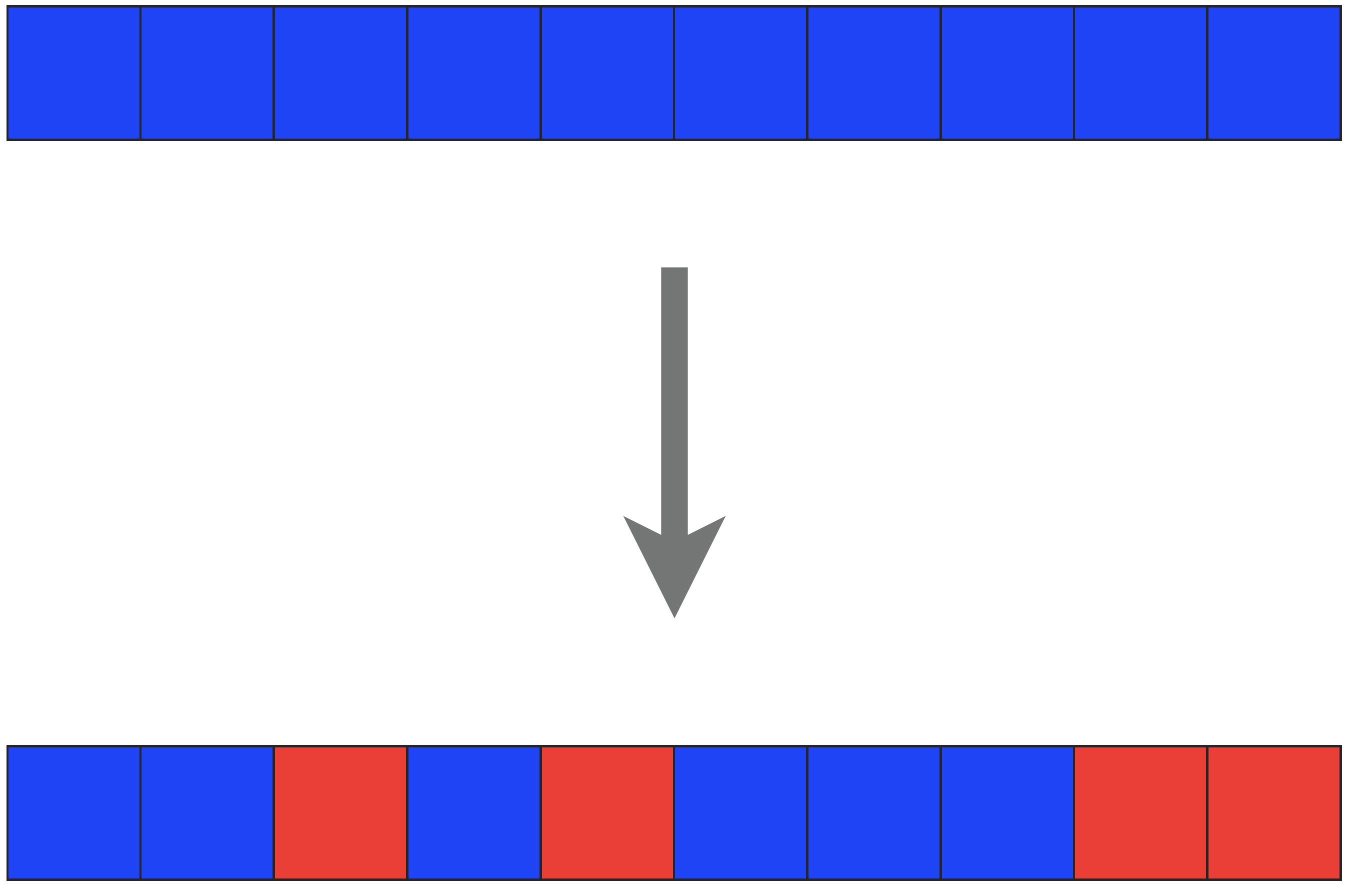
5 Lessons $\rightarrow$ **2 Design Criteria** $\rightarrow$ **1 Design**

"About twice as slow on common queries"

"From 1ms to 12 seconds ...

"... a 50% performance hybrid ..."

"... about 10x slower than regular ..."



Lesson 1: the problem is **overhead** introduced by gradual typing

● "About twice as slow on common queries"

🟥 "From 1ms to 12 seconds … "

◆ "… a 50% performance hybrid …"

🟥 "… about 10x slower than regular …"

Lesson 2: users have **diverse** performance requirements

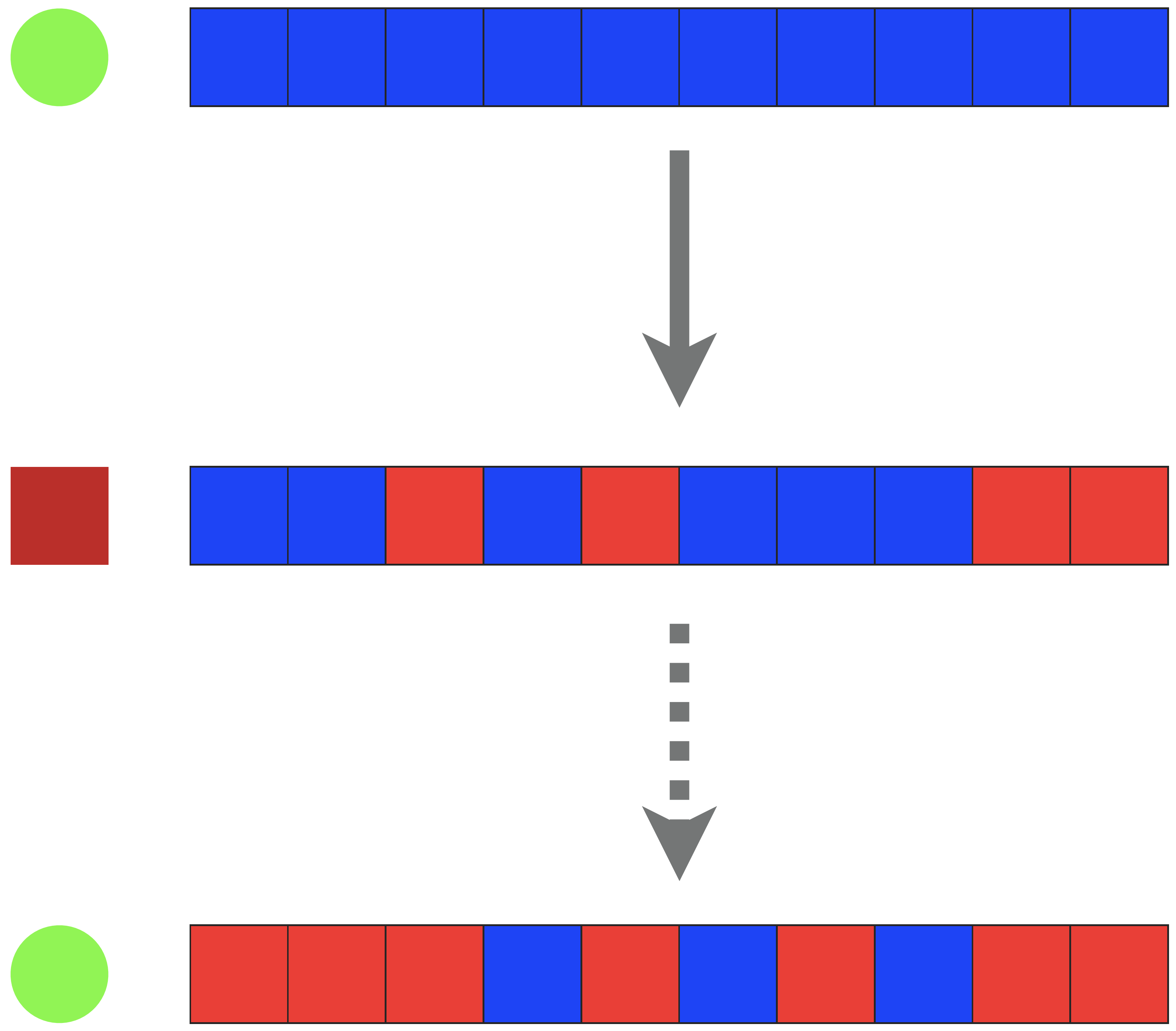
3x is **NOT** "Deliverable"

10x is **NOT** "Usable"

Lesson 2: users have **diverse** performance requirements

- ● "About twice as slow on common queries"
- 🟥 "From 1ms to 12 seconds ... "
- [✓ ◆] "... a 50% performance hybrid ..."
- 🟥 "... about 10x slower than regular ..."

Lesson 3: developers **may** tolerate slowdown between releases



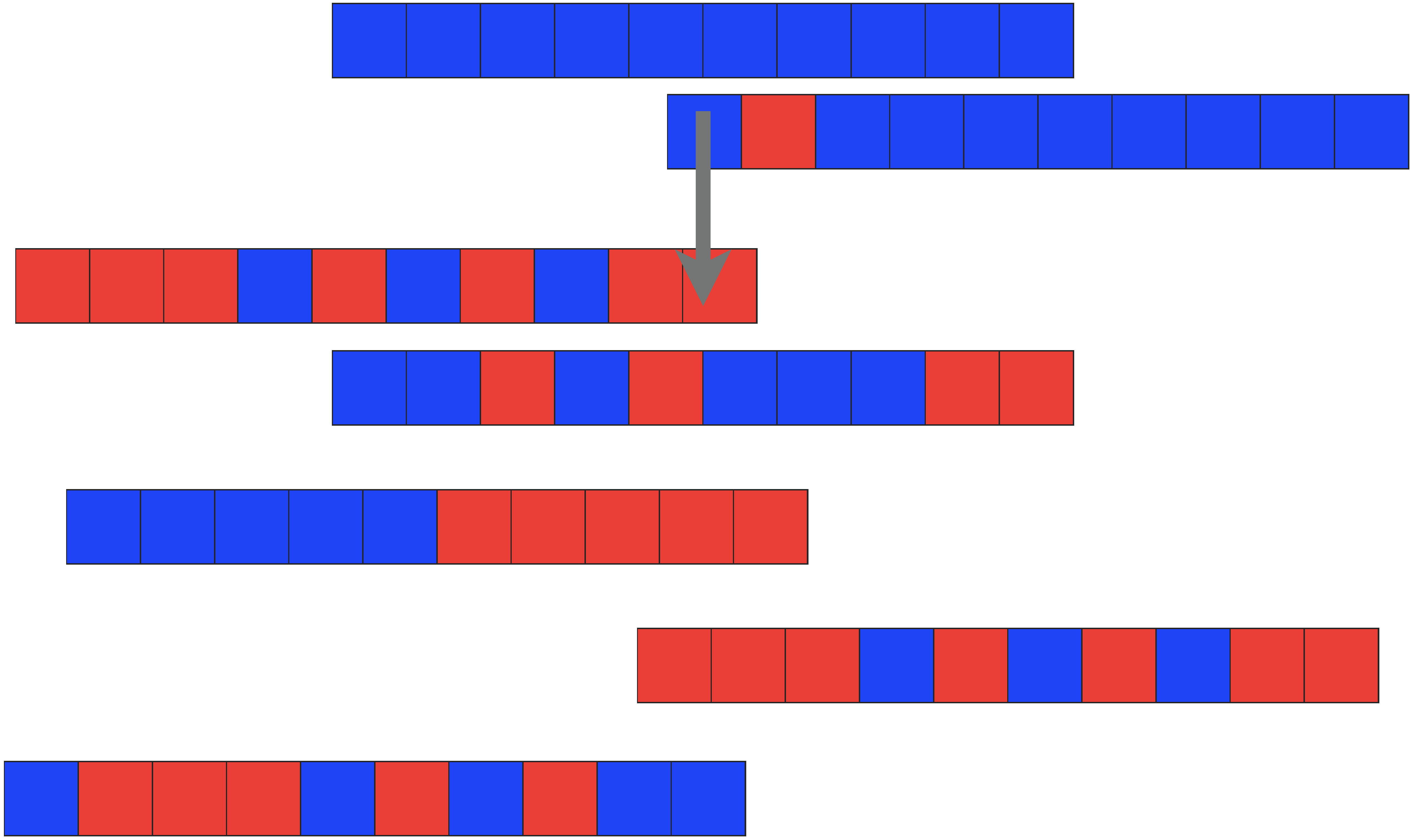
Lesson 1: problem = overhead

Lesson 2: diverse user requirements

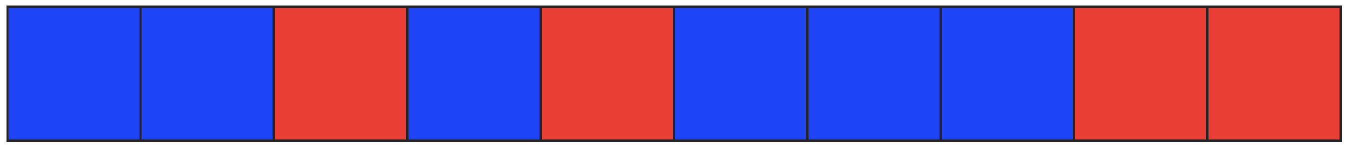
Lesson 3: development vs. production

Criteria 1: evaluation must show a range of overhead values

Lesson 4: we don't know **why** programmers add types

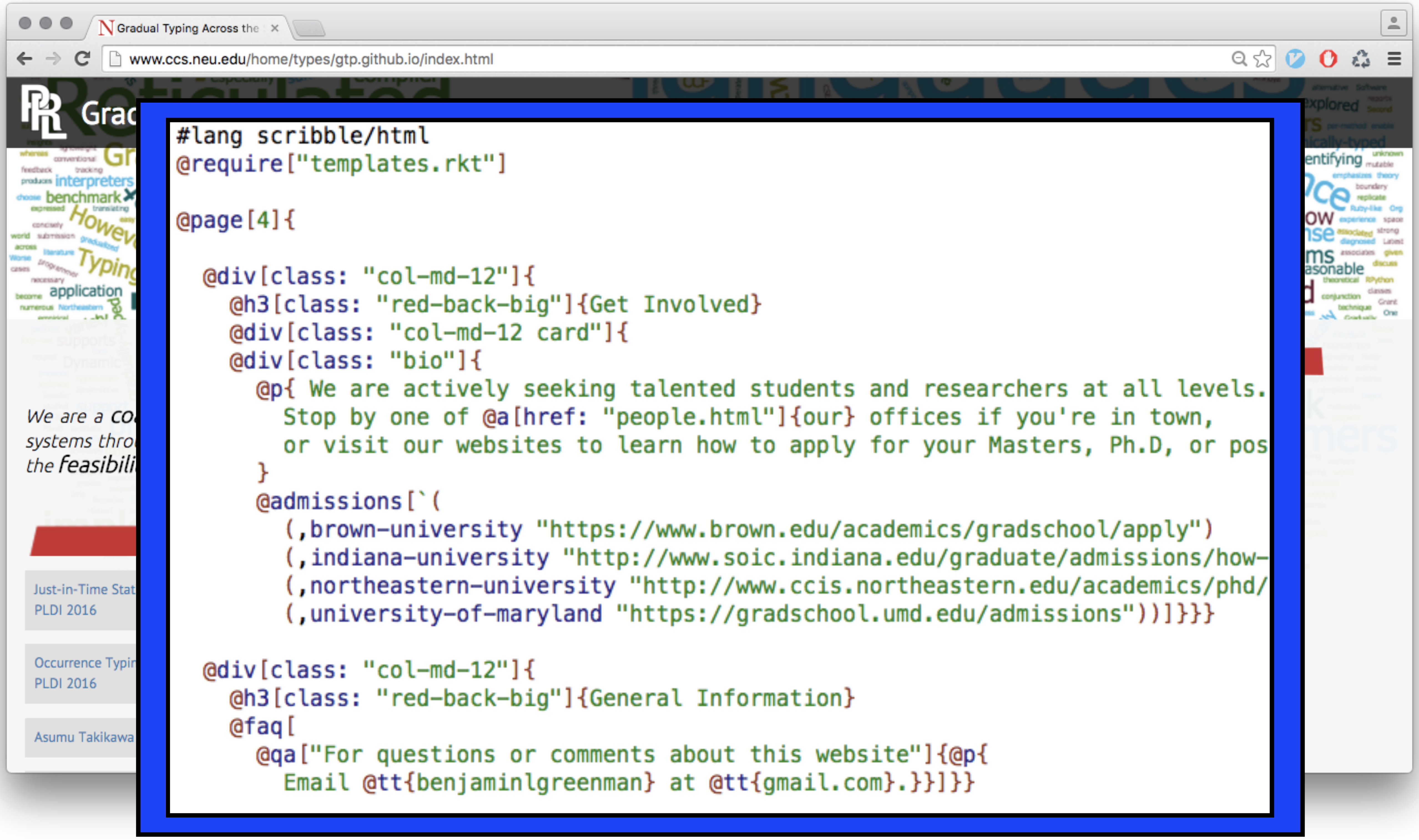


- High security?
- Stable API?
- Tightly coupled?
- Easy to annotate?



Gradual typing promises to support **ANY** use-case

Lesson 5: fully-typed is **not** the goal



Gradual Typing Across the

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        Stop by one of @a[href: "people.html"]{our} offices if you're in town,
        or visit our websites to learn how to apply for your Masters, Ph.D, or pos
      }
      @admissions[`(
        (,brown-university "https://www.brown.edu/academics/gradschool/apply")
        (,indiana-university "http://www.soic.indiana.edu/graduate/admissions/how-
        (,northeastern-university "http://www.ccis.northeastern.edu/academics/phd/
        (,university-of-maryland "https://gradschool.umd.edu/admissions"))]}}}

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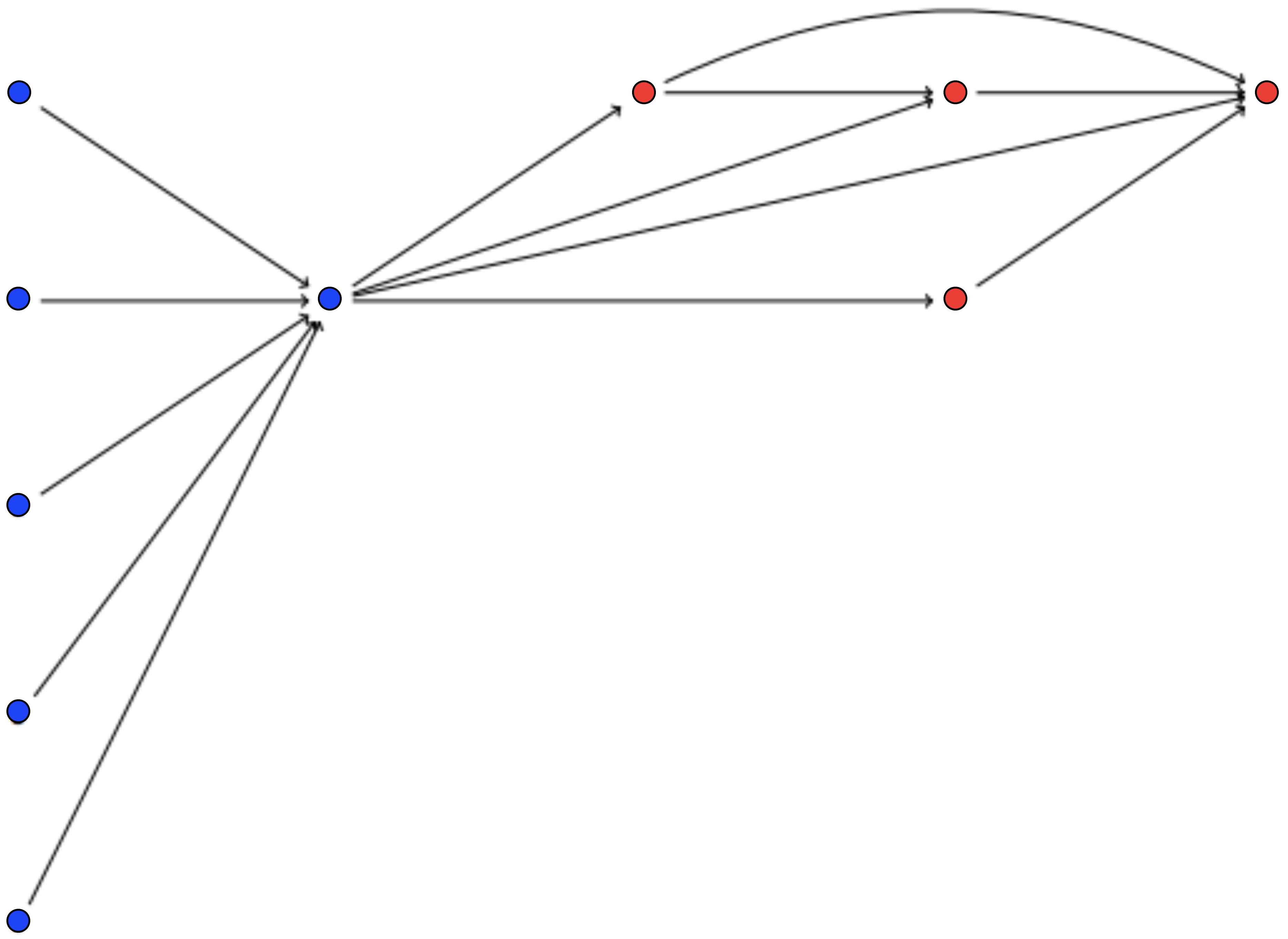
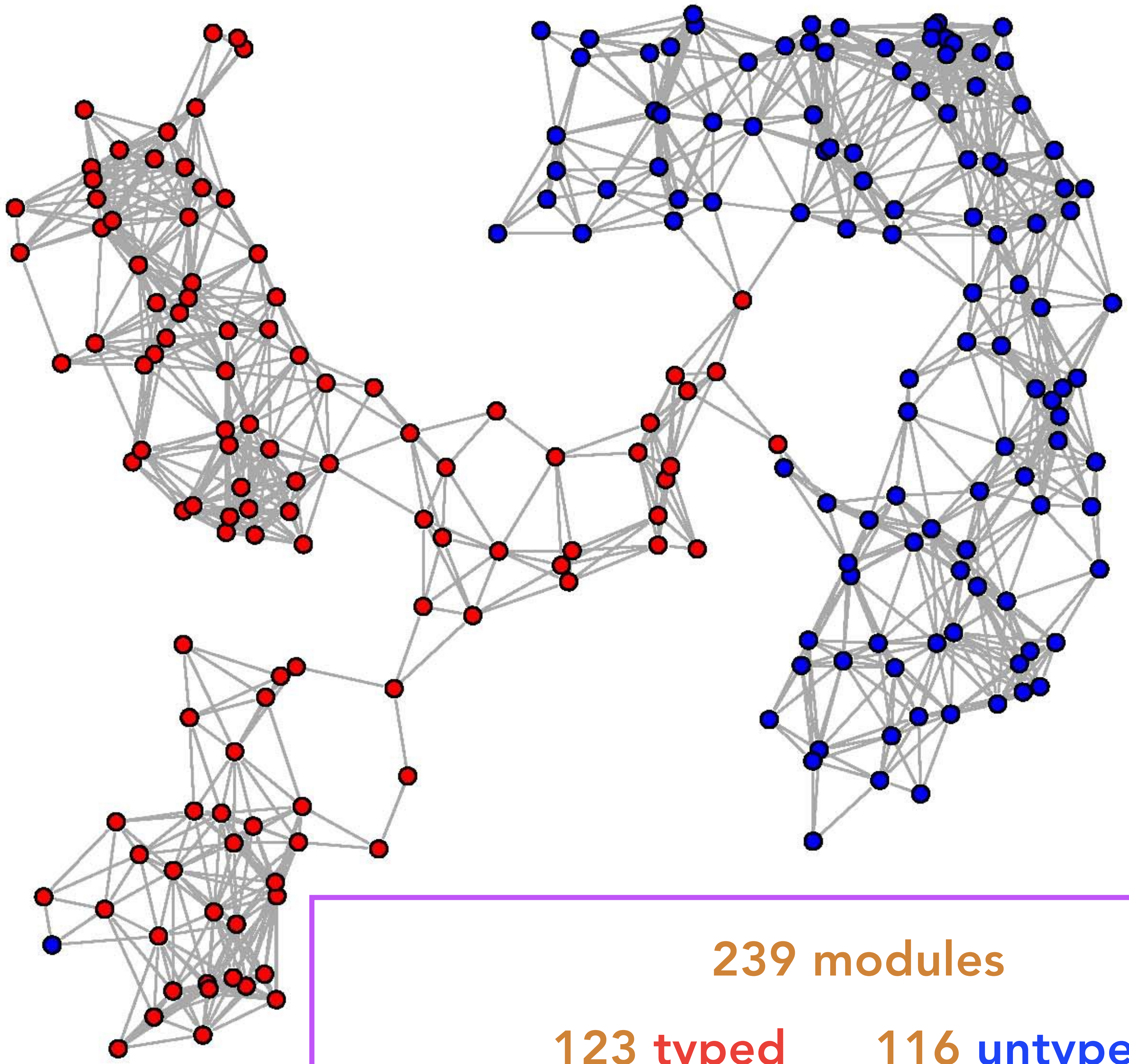
Just-in-Time Stat
PLDI 2016

Occurrence Typin
PLDI 2016

Asumu Takikawa

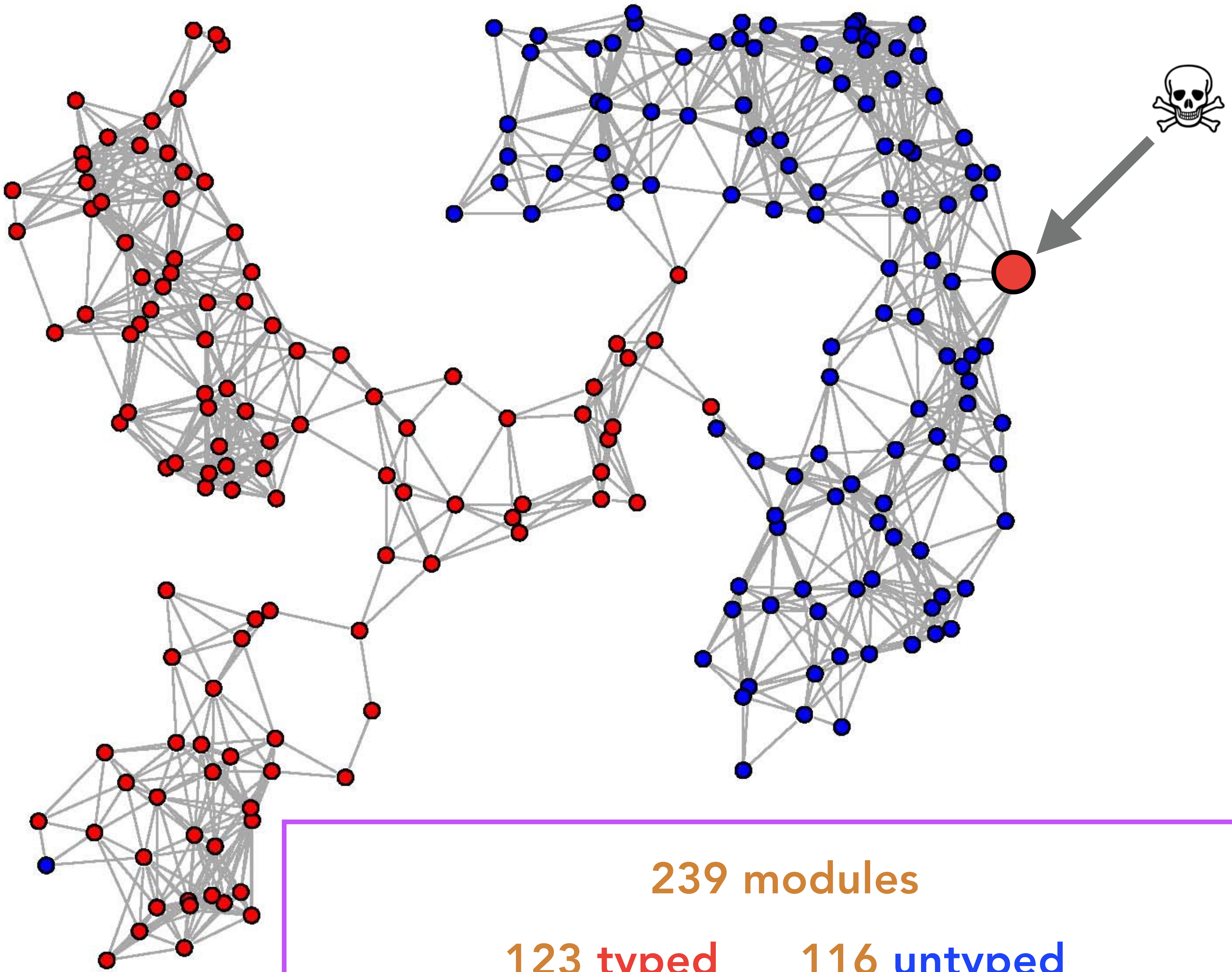




239 modules

123 typed 116 untyped

"new code" "legacy code"



239 modules

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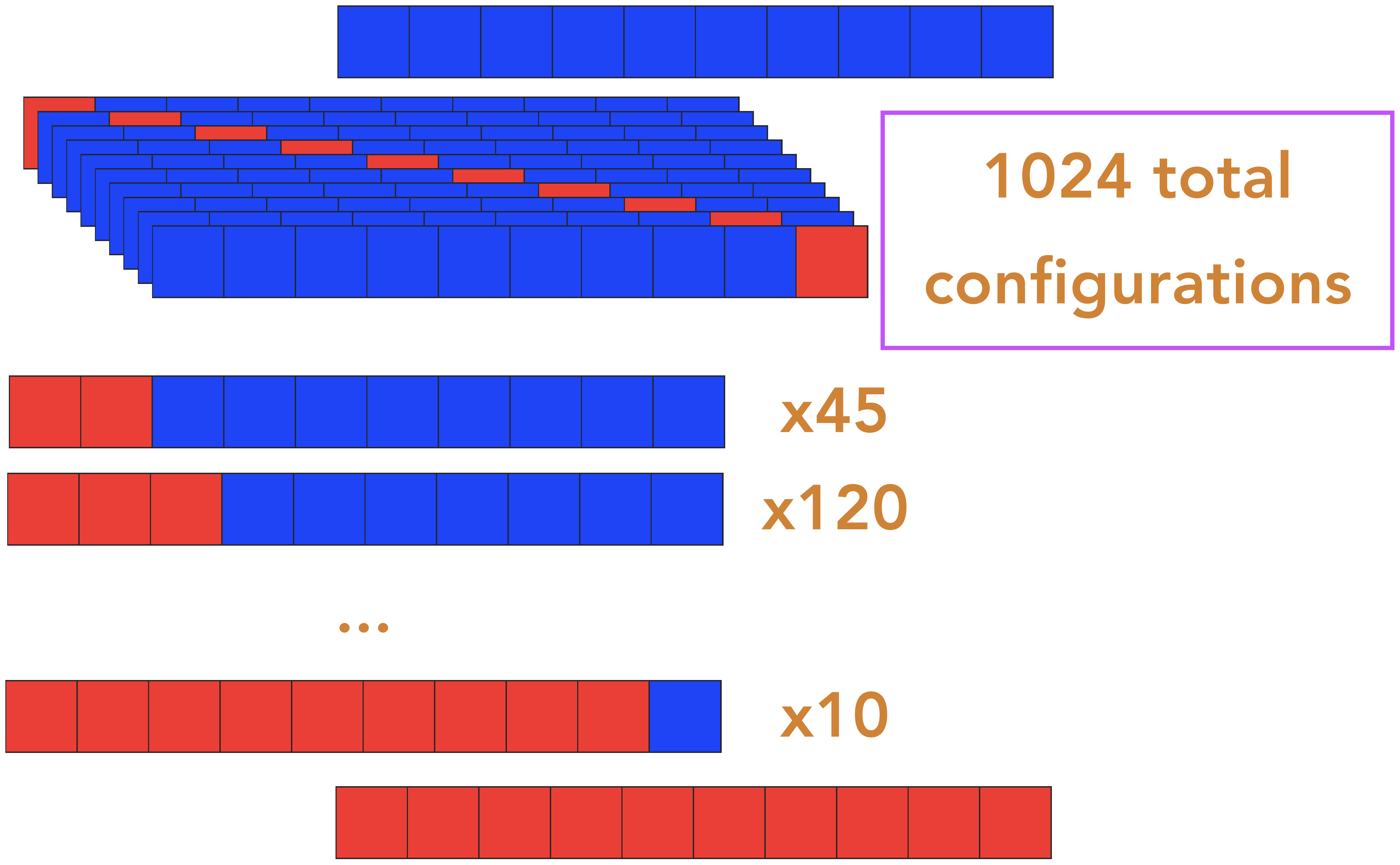
"new code" "legacy code"

Lesson 4: cannot predict use-cases

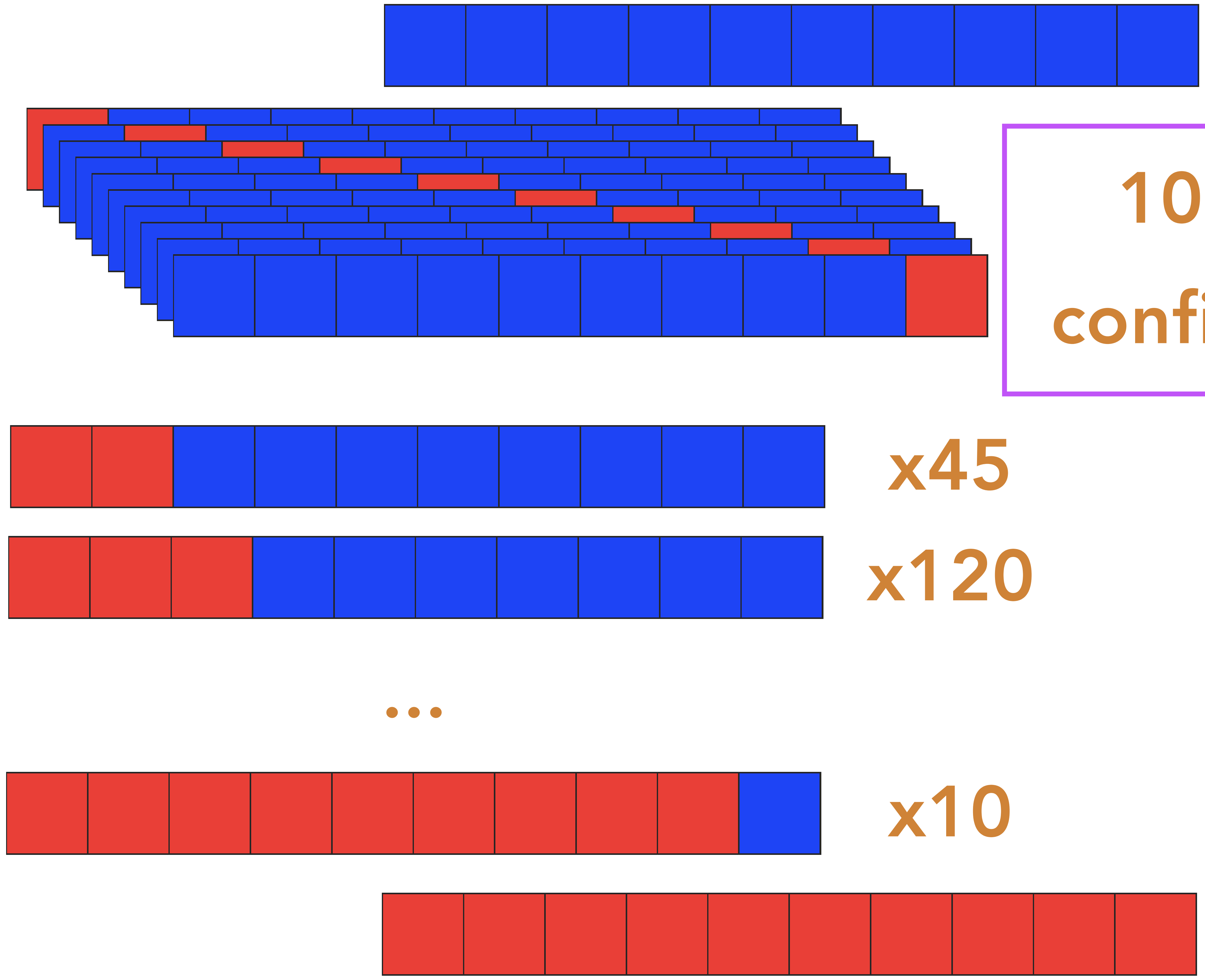
Lesson 5: fully-typed is **not** the goal

Criteria 2: evaluation must consider **all possible ways** of gradually using types in a program

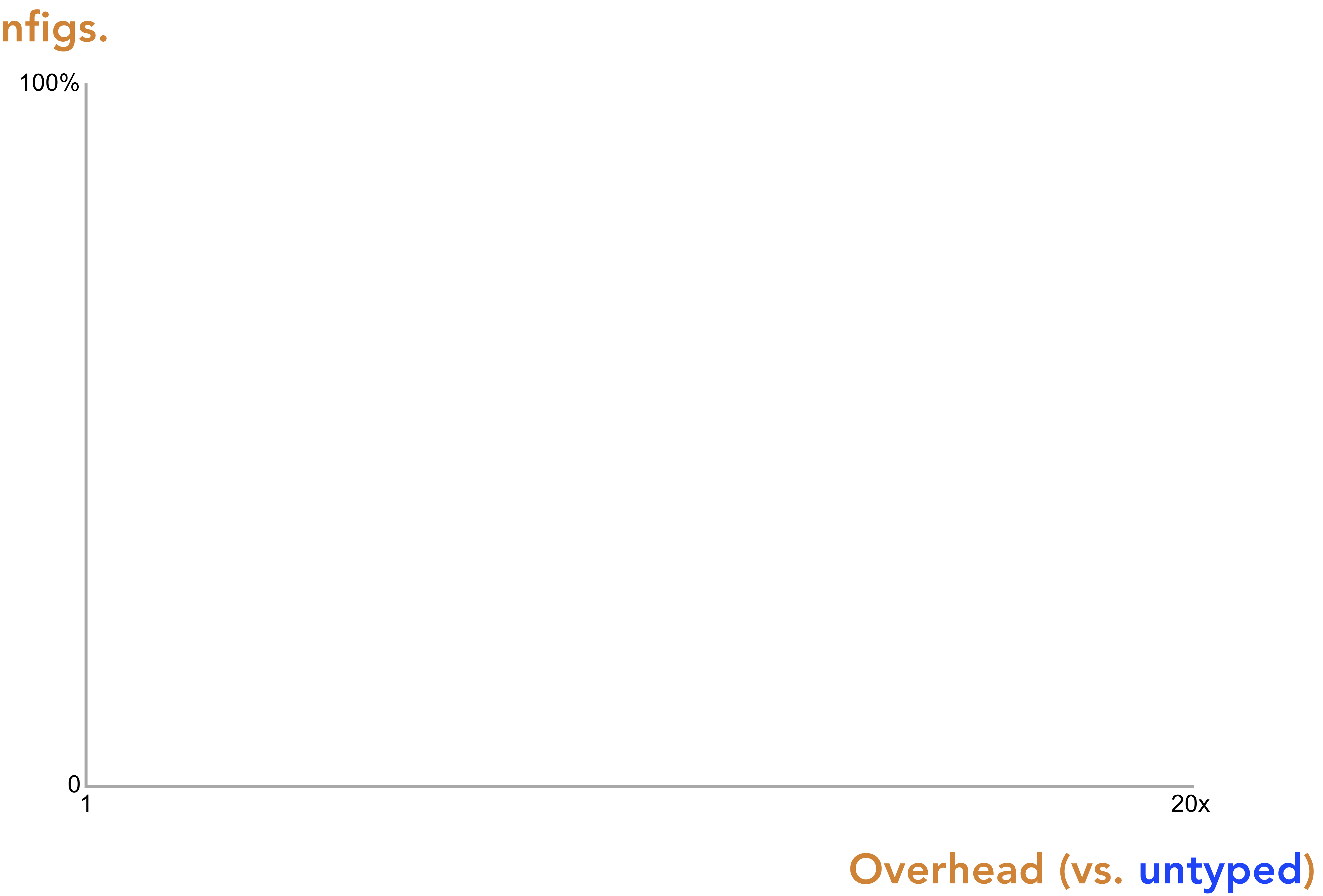

1024 total configurations
x45
x120
...
x10

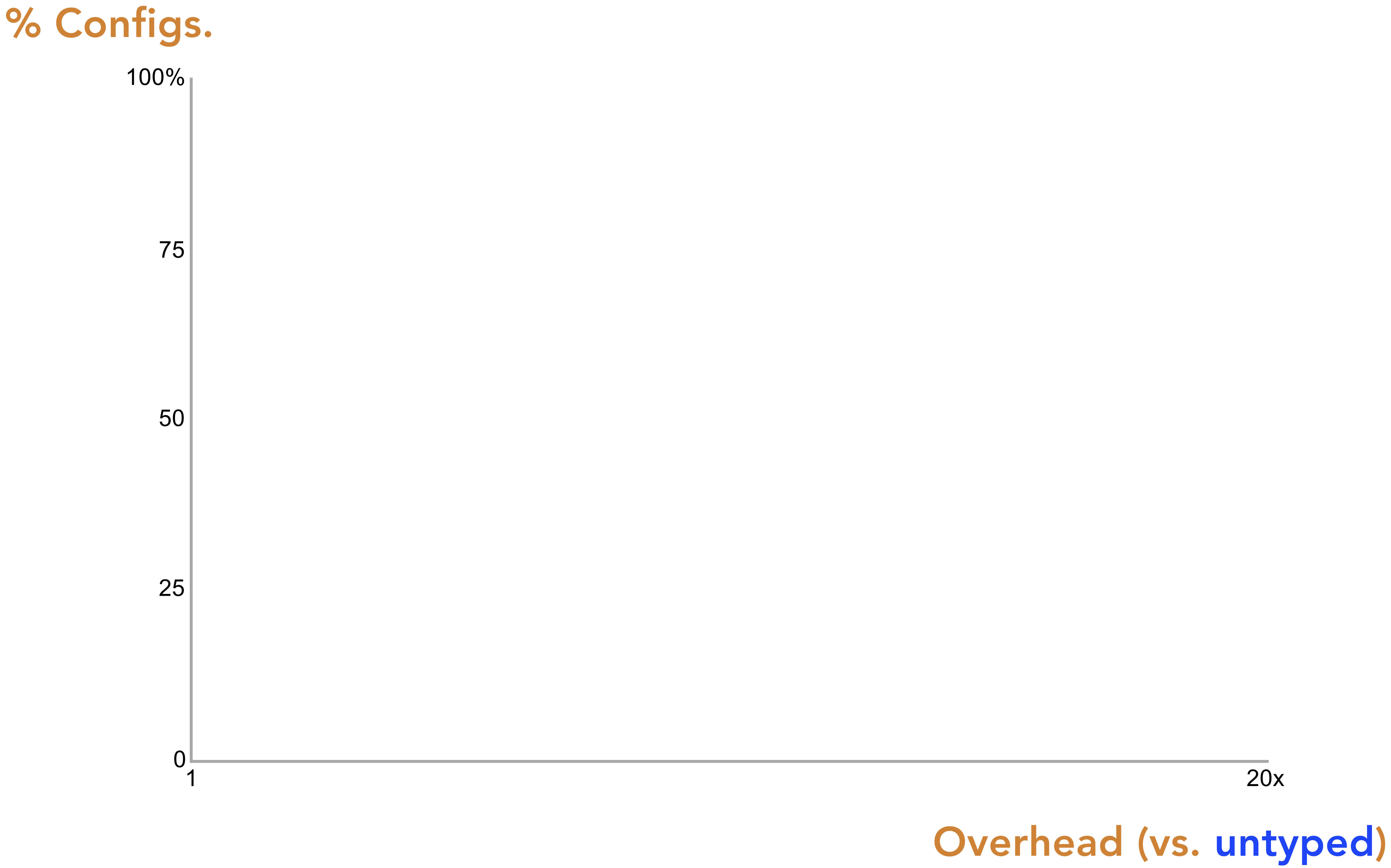
Criteria 1: show a range of overhead values

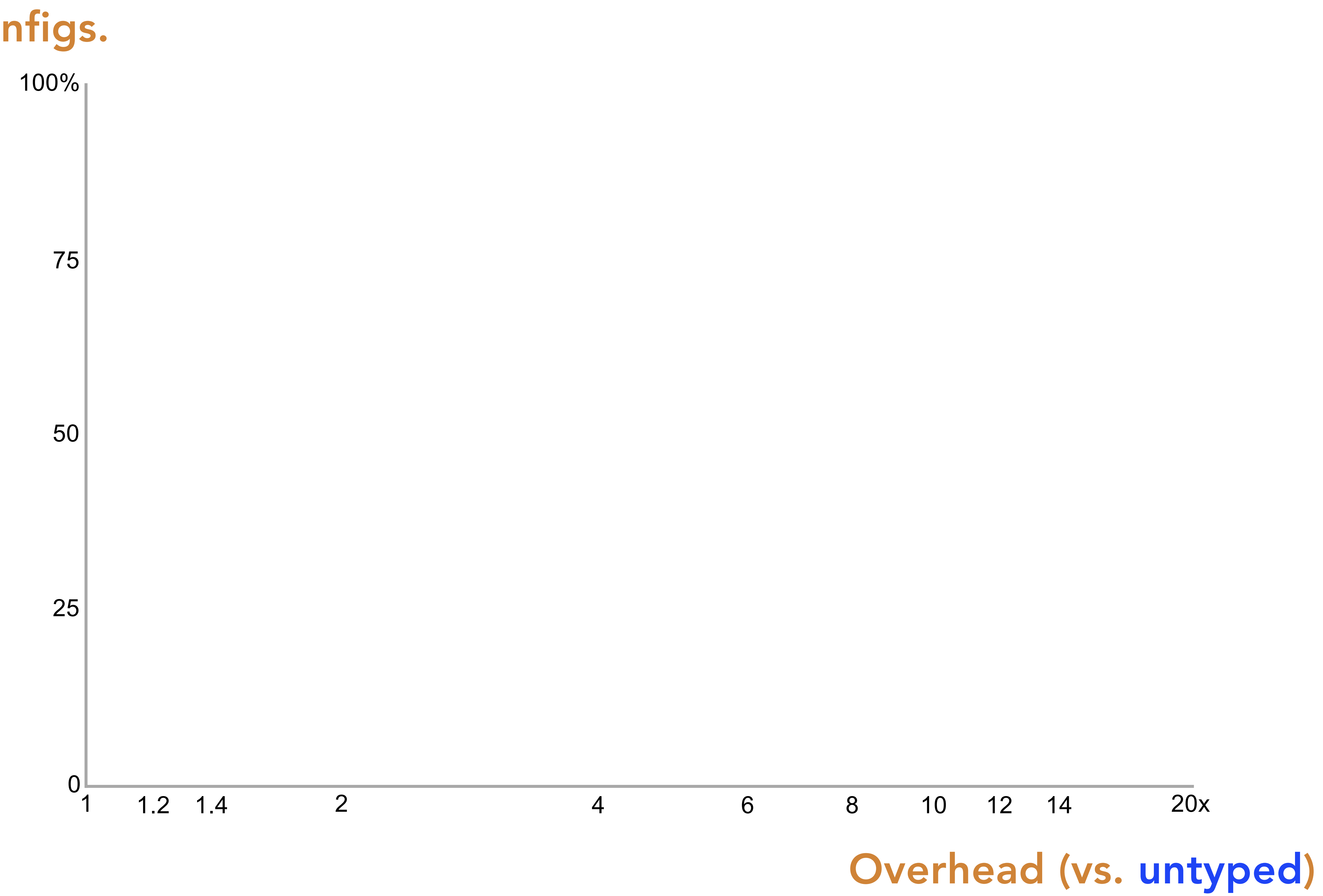
Criteria 2: consider **all possible ways** of using types in a program



1024 total configurations


% Configs.
100%
0
1
20x
Overhead (vs. untyped)


% Configs.
100%
75
50
25
0
1
20x
Overhead (vs. untyped)


% Configs.
100%
75
50
25
0
1
1.2
1.4
2
4
6
8
10
12
14
20x
Overhead (vs. untyped)

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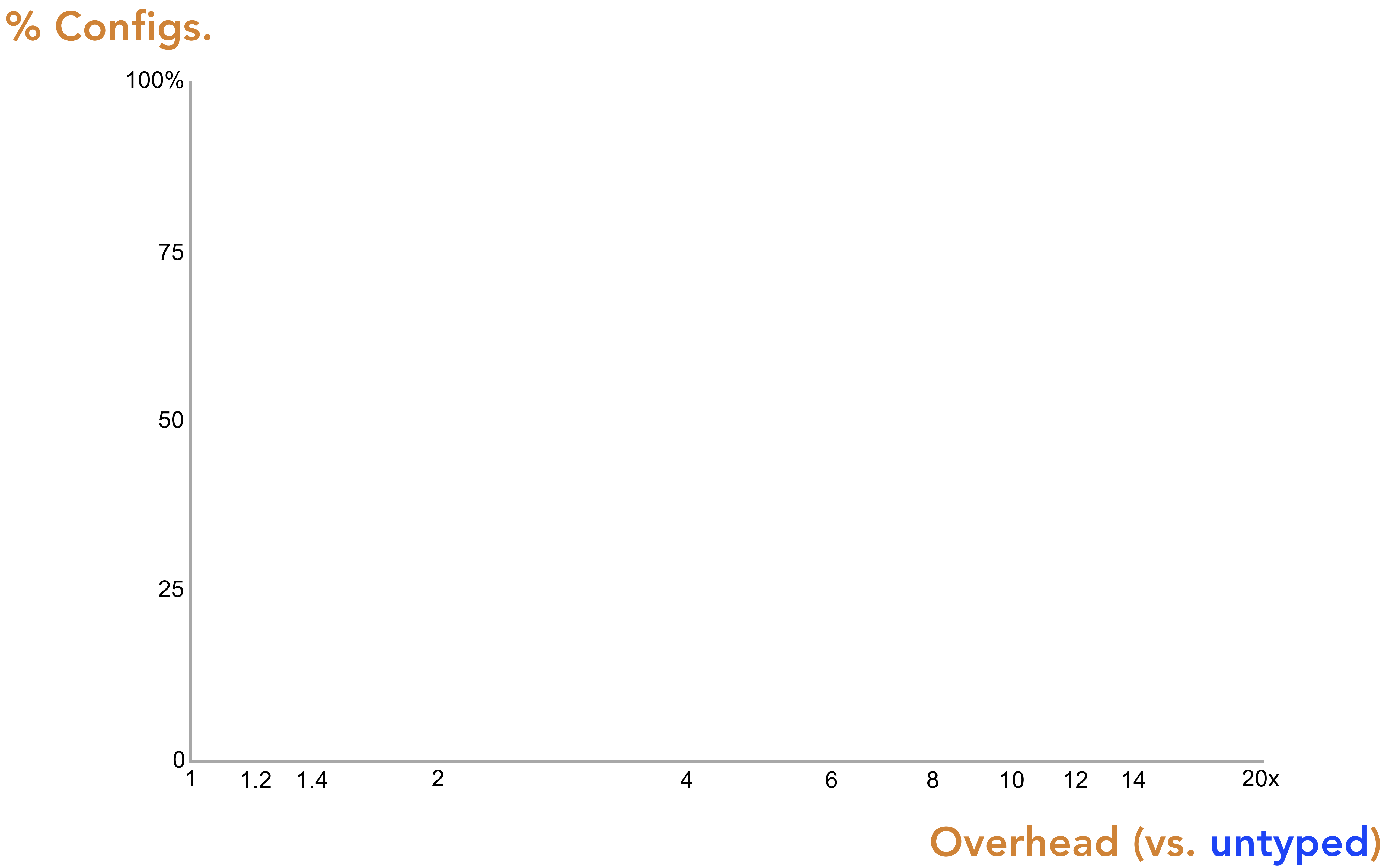
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10
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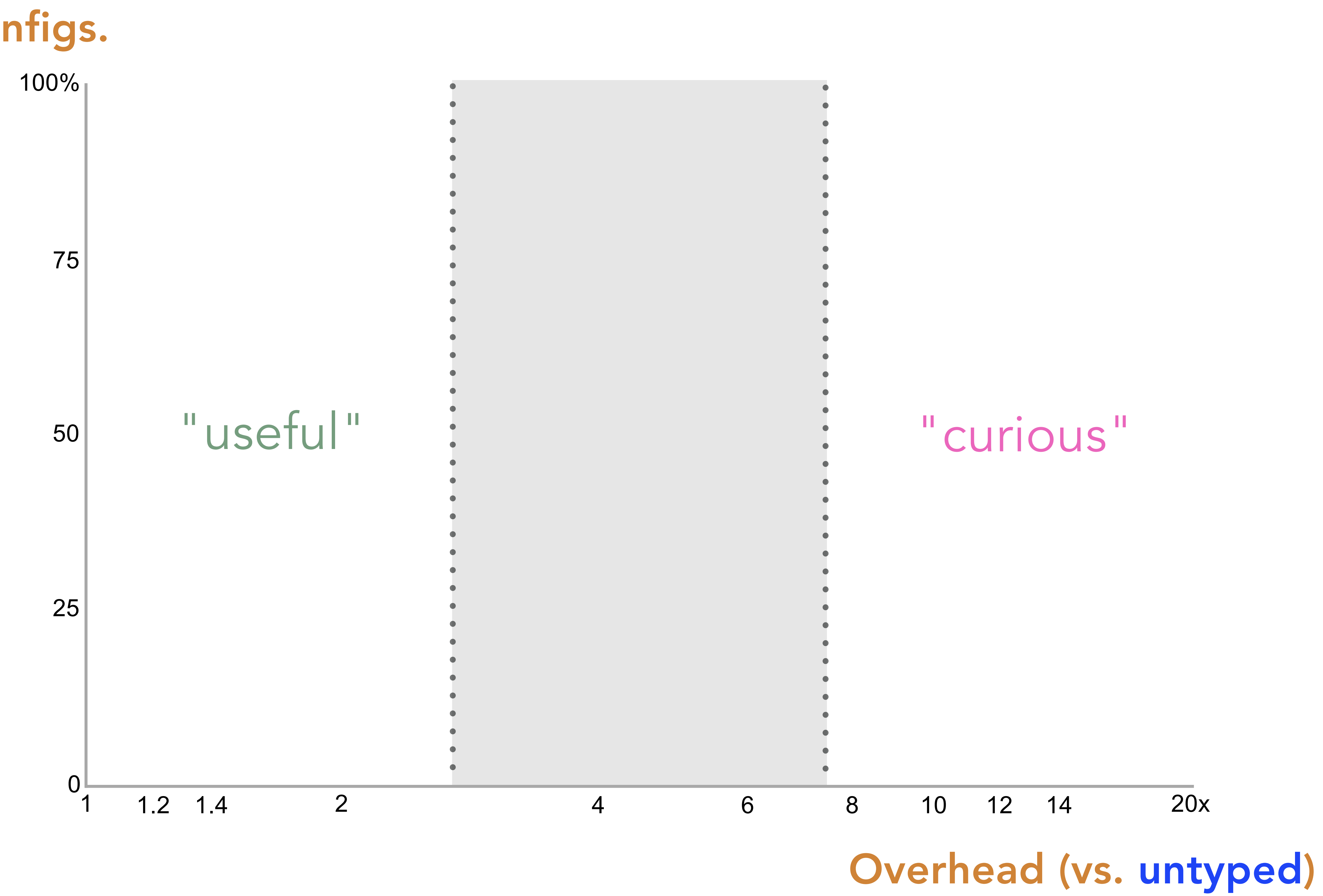
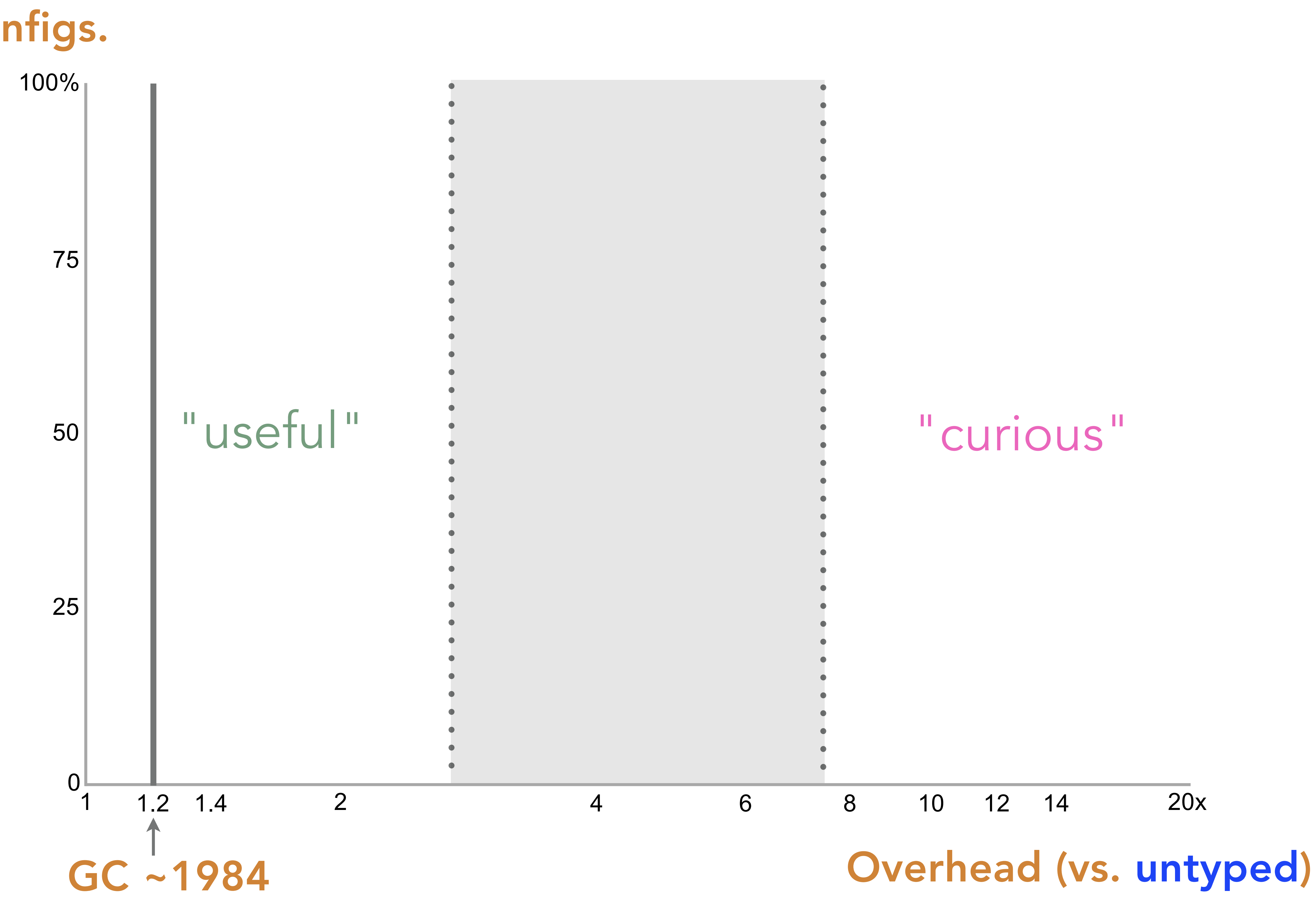

% Configs.
100%
75
50
25
0
"useful"
"curious"
1
1.2
1.4
2
4
6
8
10
12
14
20x
Overhead (vs. untyped)


% Configs.
100%
75
50
25
0
1
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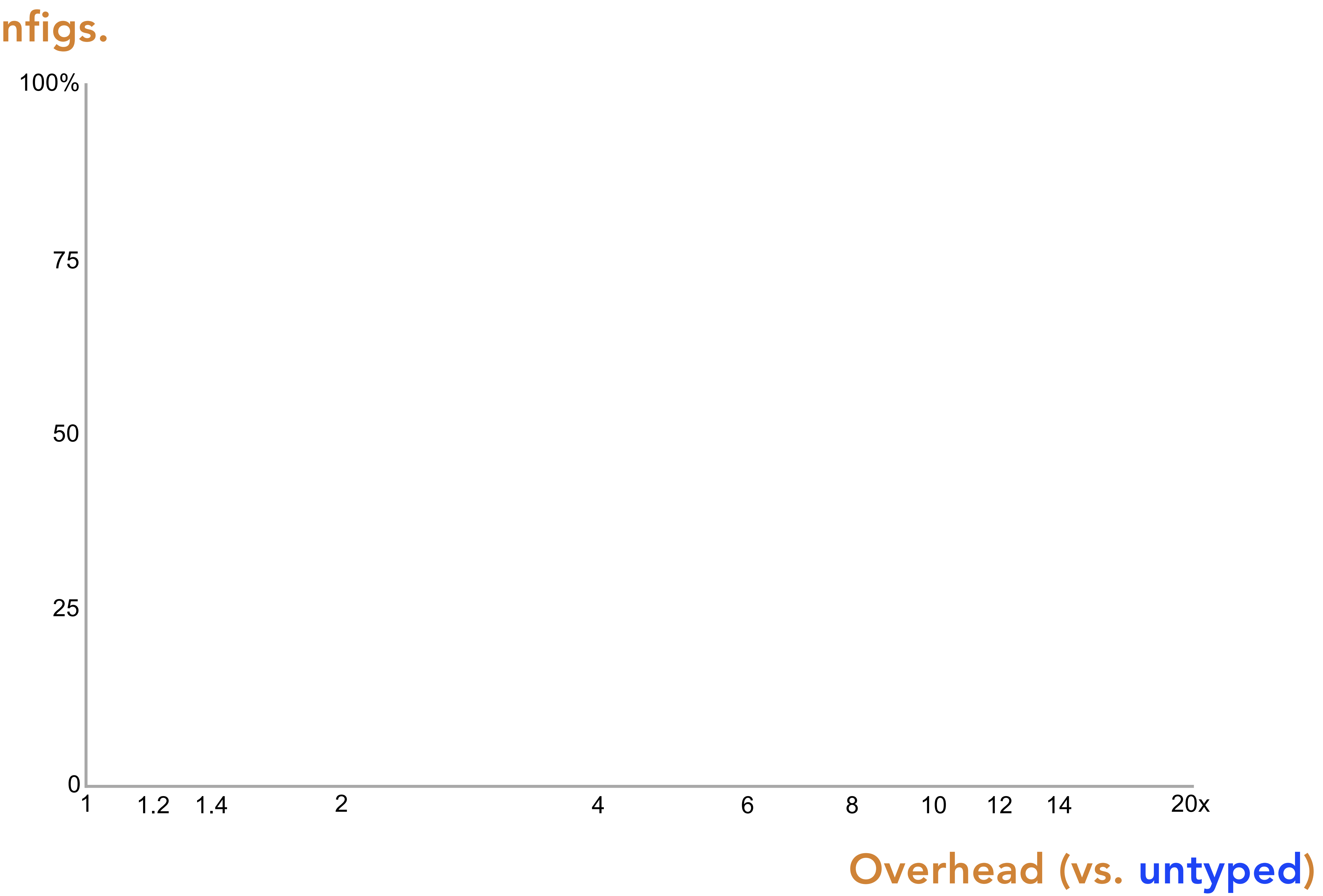
8
10
12
14
20x
"useful"
"curious"
GC ~1984
Overhead (vs. untyped)


% Configs.
100%
75
50
25
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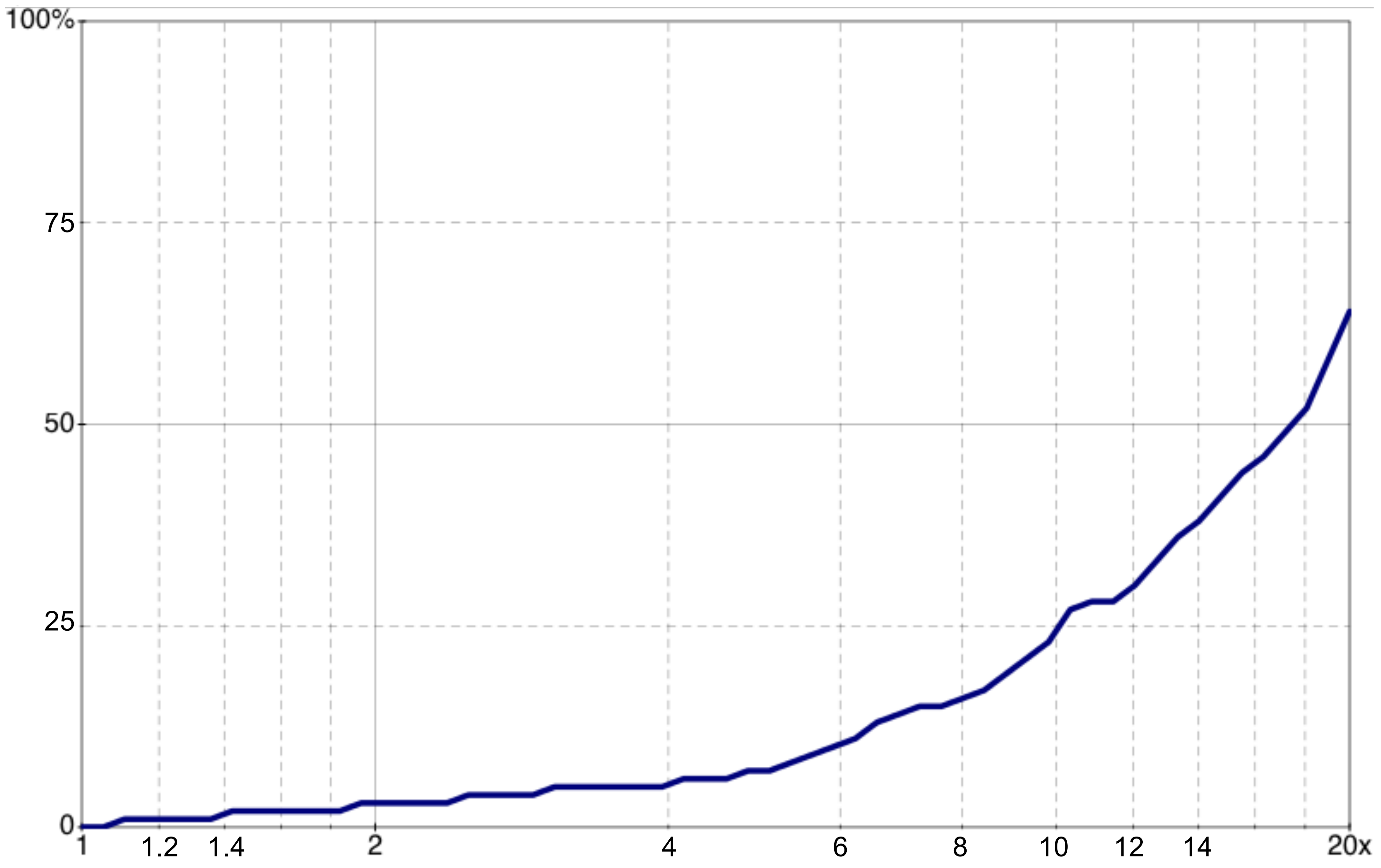
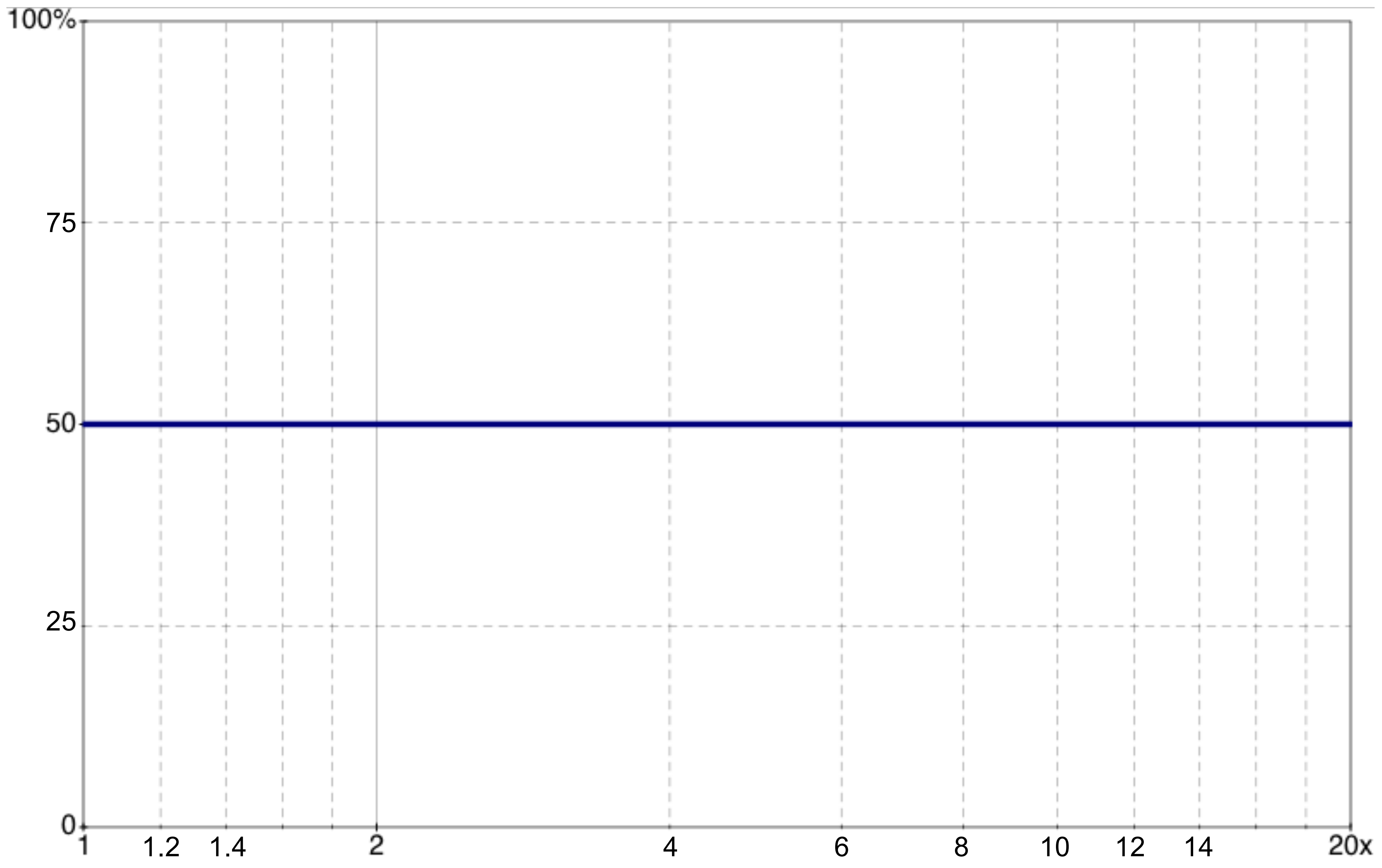
20x
Overhead (vs. untyped)

% Configs.



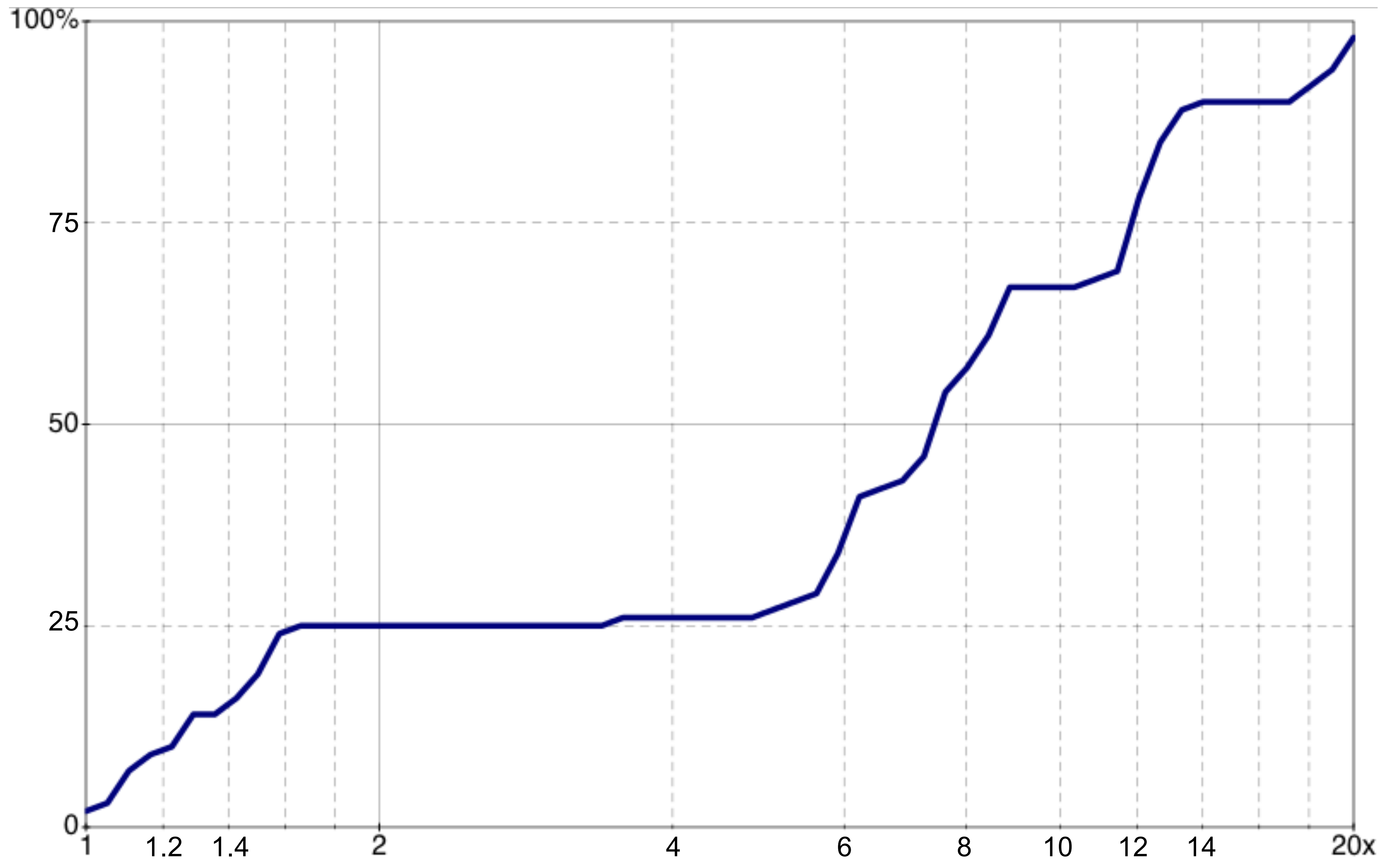
Overhead (vs. untyped)

% Configs.



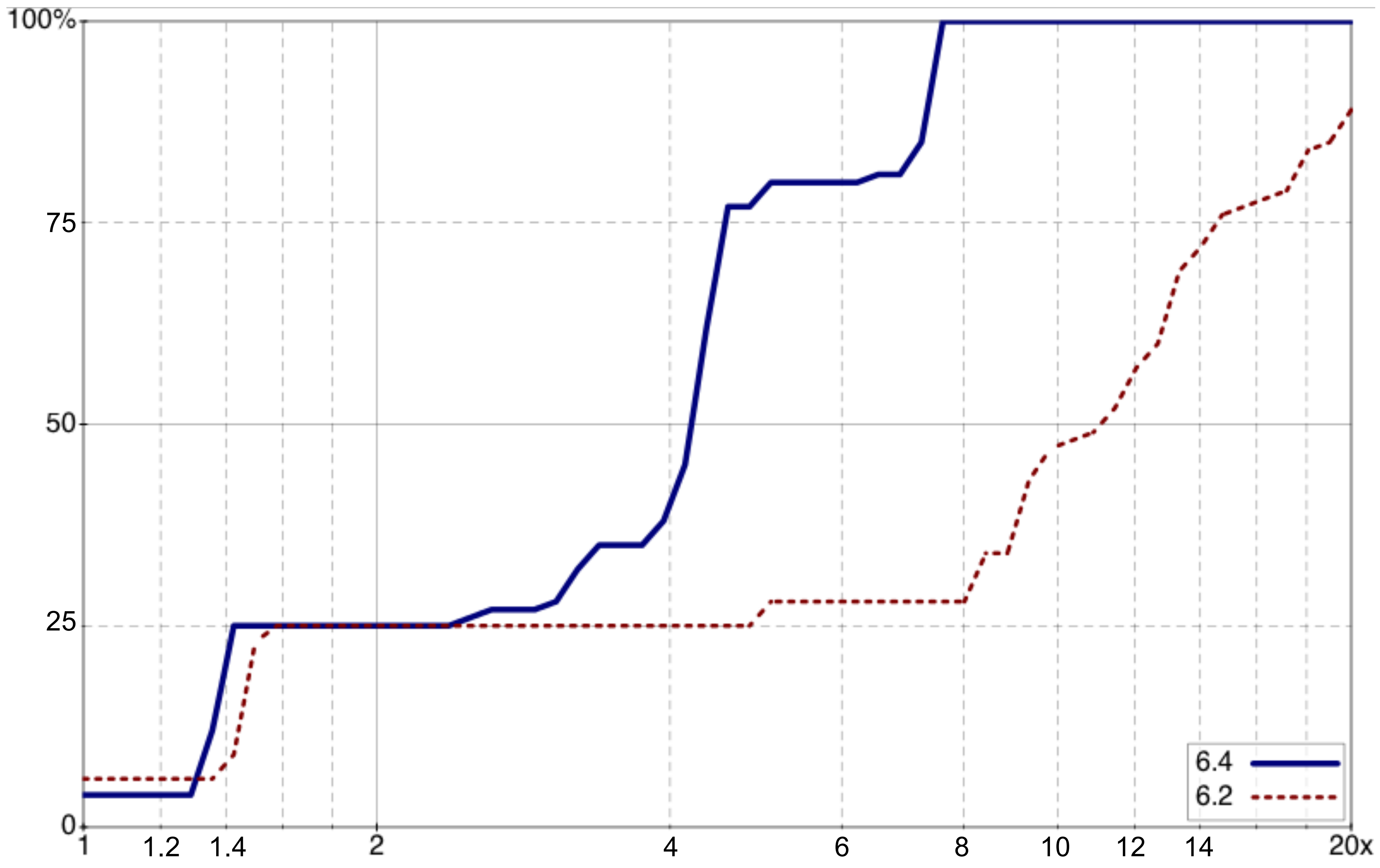
Overhead (vs. untyped)

% Configs.

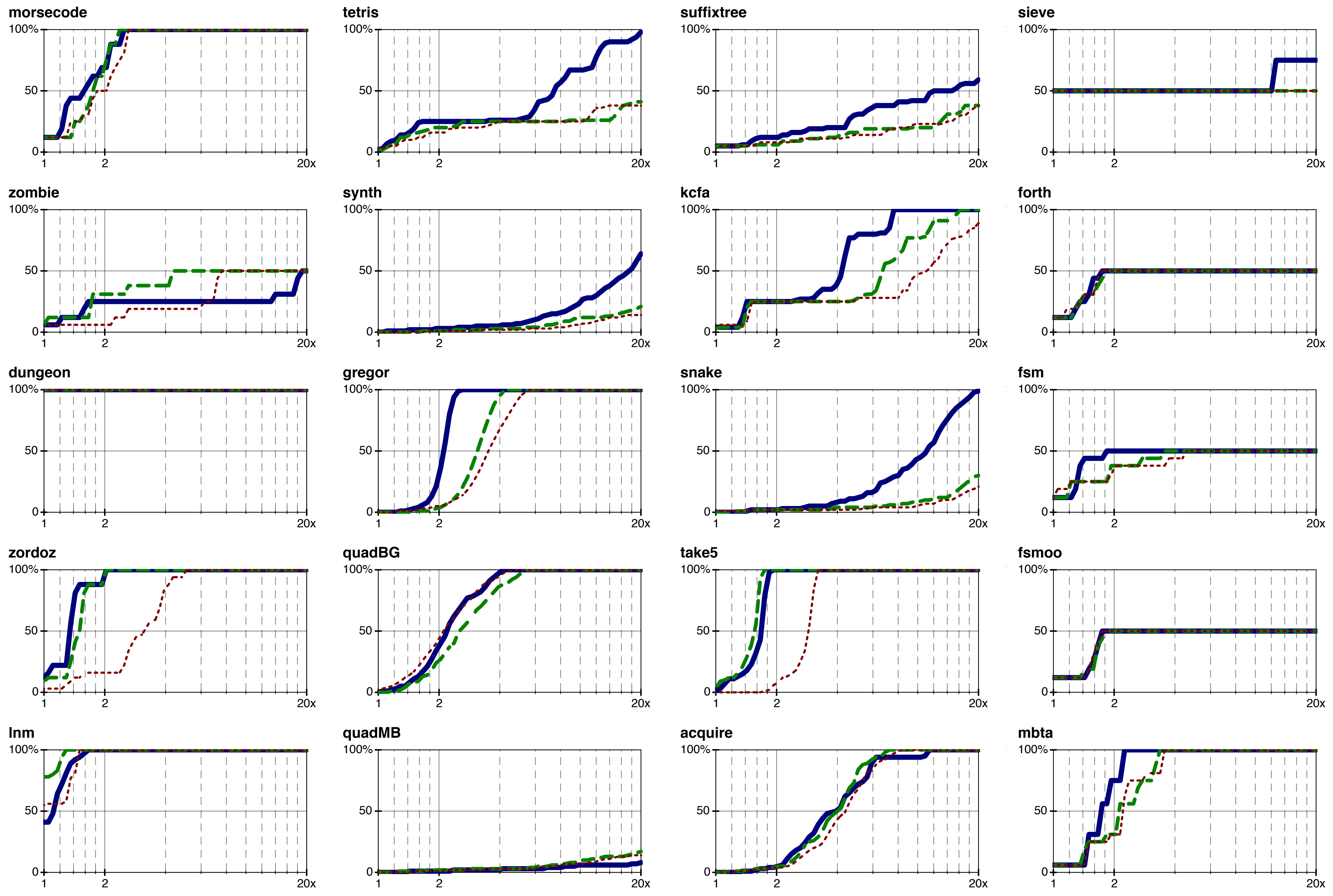


Overhead (vs. untyped)

% Configs.



Overhead (vs. untyped)


morsecode
tetris
suffixtree
sieve
zombie
synth
kcfa
forth
dungeon
gregor
snake
fsm
zordoz
quadBG
take5
fsmoo
lnm
quadMB
acquire
mbta
100%
50
0
1
2
20x

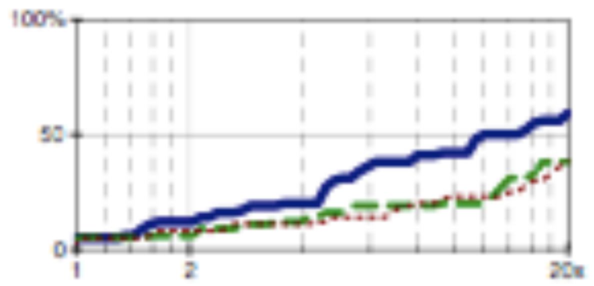
Lessons:

- problem = overhead
- diverse user requirements
- development vs. production
- cannot predict use-cases
- fully-typed is **not** the goal

Criteria:

- show range of overheads
- consider all possible ways of using types

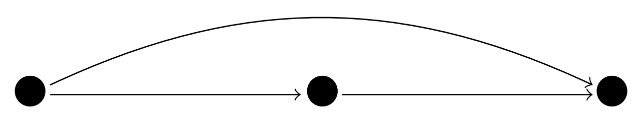
Implementation:



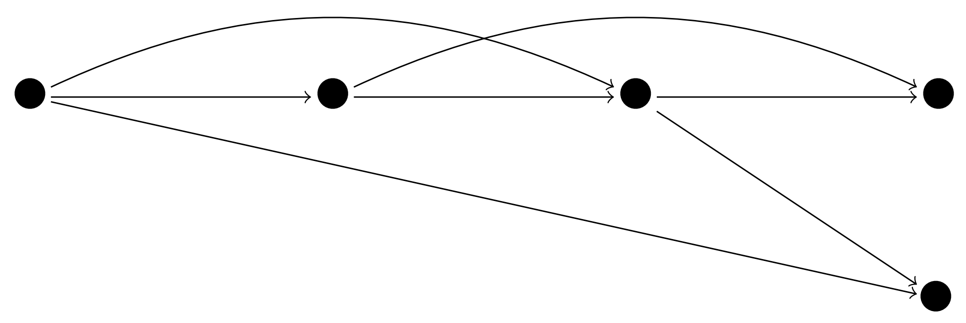
with Zeina Migeed

- Apply methodology to Reticulated
- Identify bottlenecks (and bugs)
- Compare cast insertion strategies

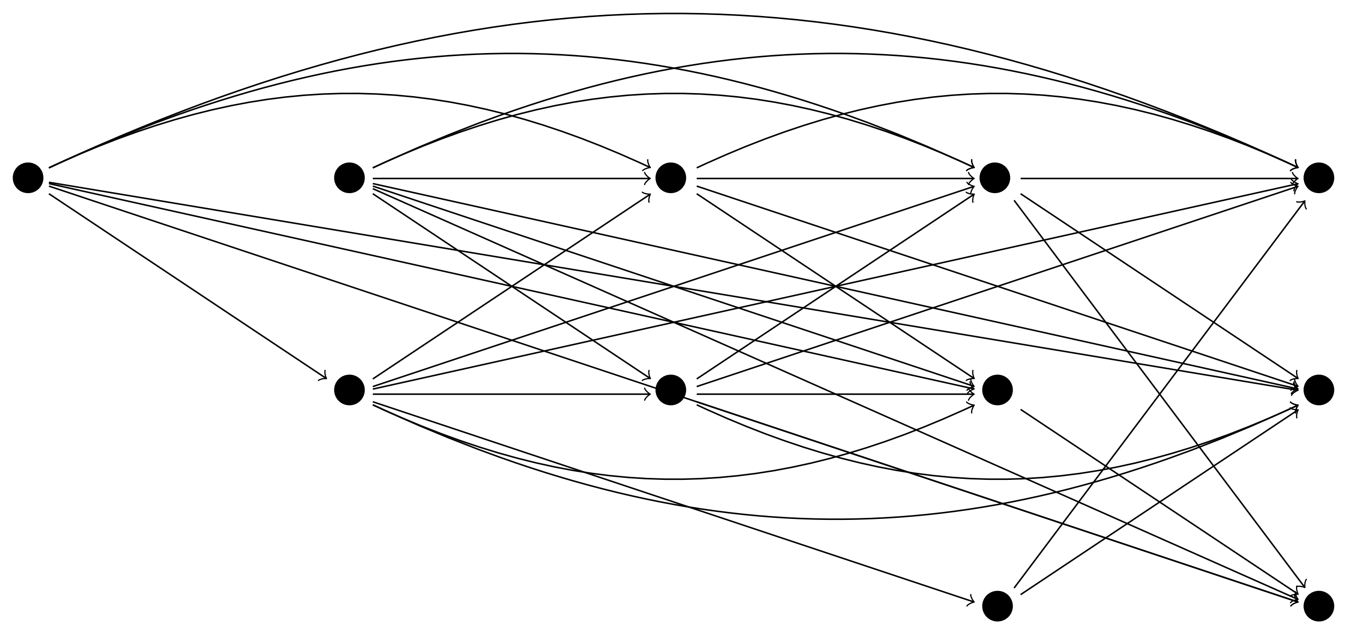
Take5



FSM



Evolution



	Modules	Classes	Fields	Functions	Args
Take5	3	2	10	14	30
FSM	5	2	6	17	30
Evolution	11	10	39	+50	++50

$2^{11} = 2{,}048$ $2^{17} = 131{,}072$ $2^{39} = 549{,}755{,}813{,}888$

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Take5	3	2	10	14	30
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Evolution	11	10	39	+50	++50

$2^{11} = 2{,}048$ $2^{17} = 131{,}072$ $2^{39} = 549{,}755{,}813{,}888$

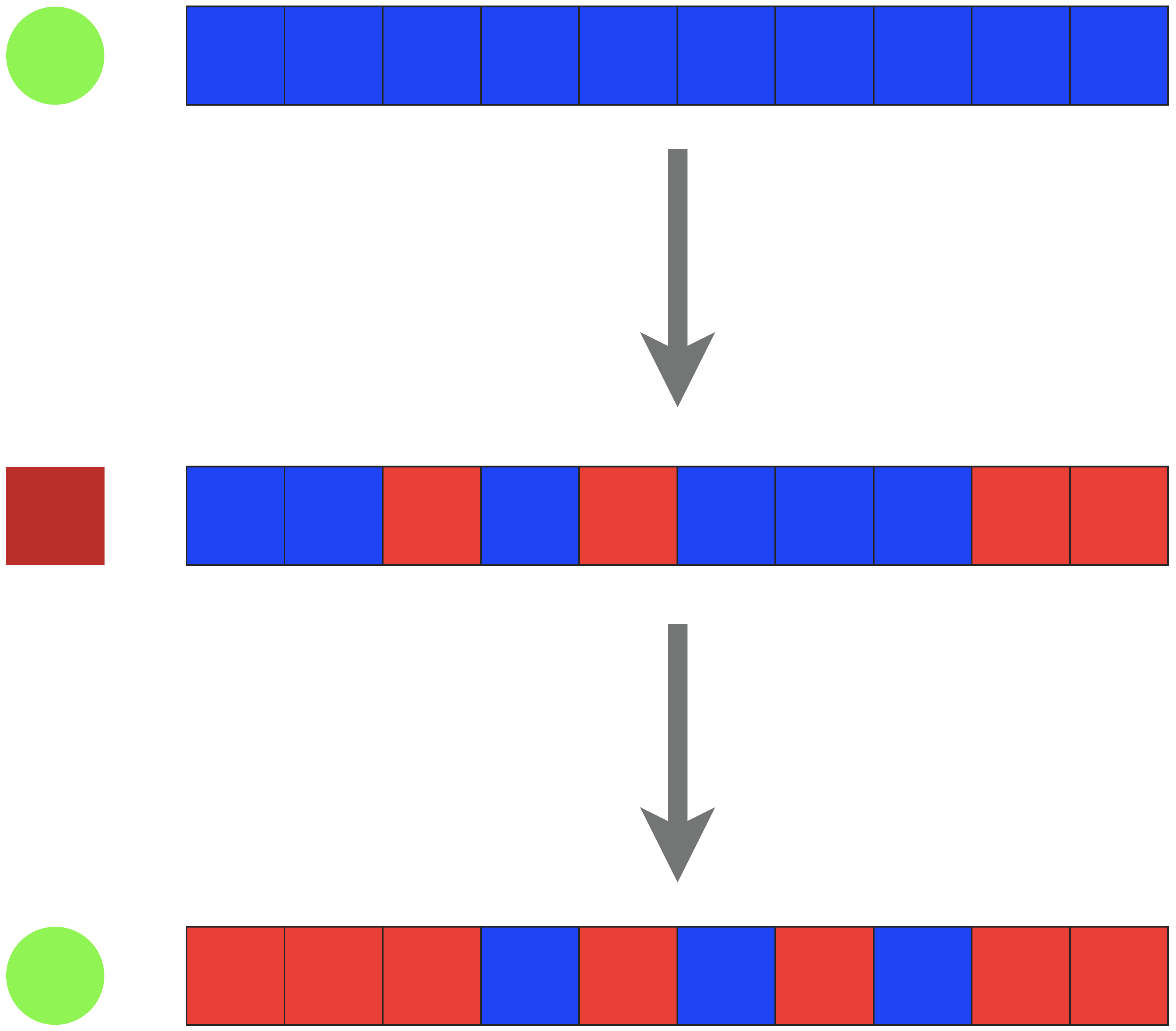
```
from retic import List,Tuple,Void,String,Int

class Player:

    def __init__(self, name:Int, cards:List(Tuple(Int,Int)))->Void:
        self.name = name
        self.cards = cards

    def discard(self)->Int:
        ....

    def choose_correct_stack(self, stacks:List(List(Tuple(Int,Int))))->Int:
        ....

    def get_index_of_closest_stack(self, cards:List(Tuple(Int,Int)), card:Tuple(Int,Int))->Int:
        ....
```

Can we predict performance for **exponentially many** configurations given a **linear number** of measurements?

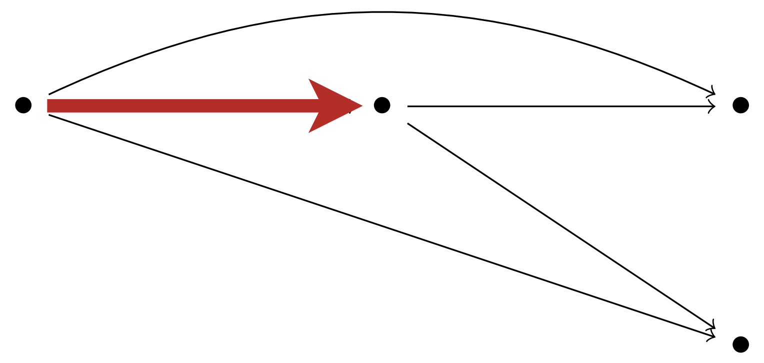
"The End"

Weaknesses

- No absolute runtimes
- No map from configs. to overheads
- Does not express migration paths



FSM

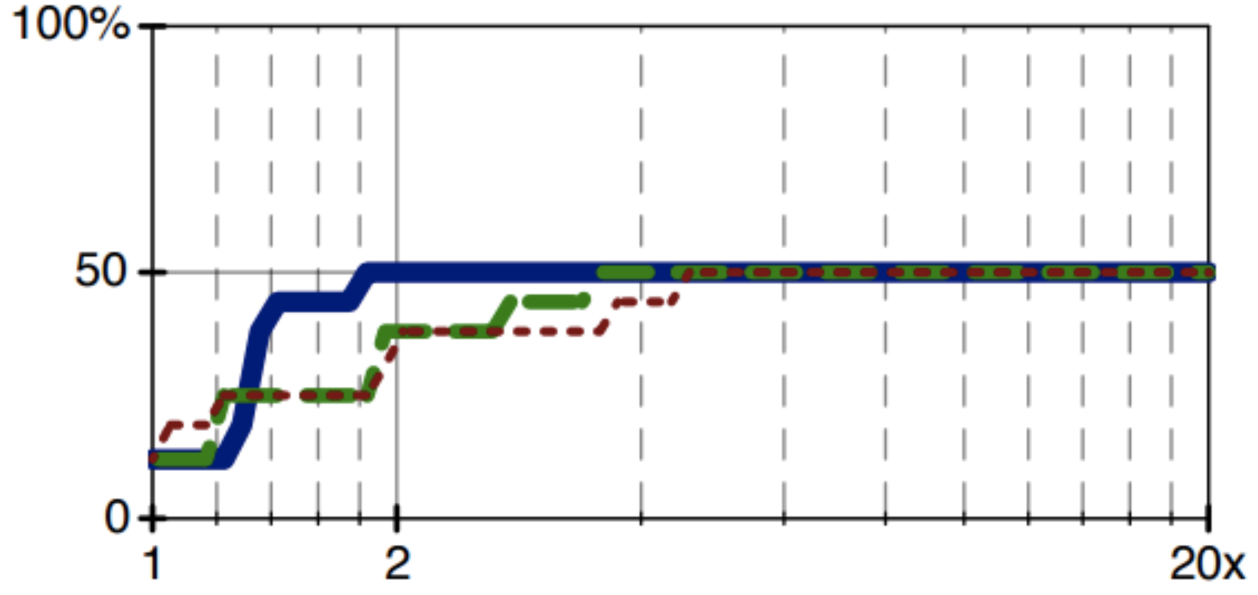


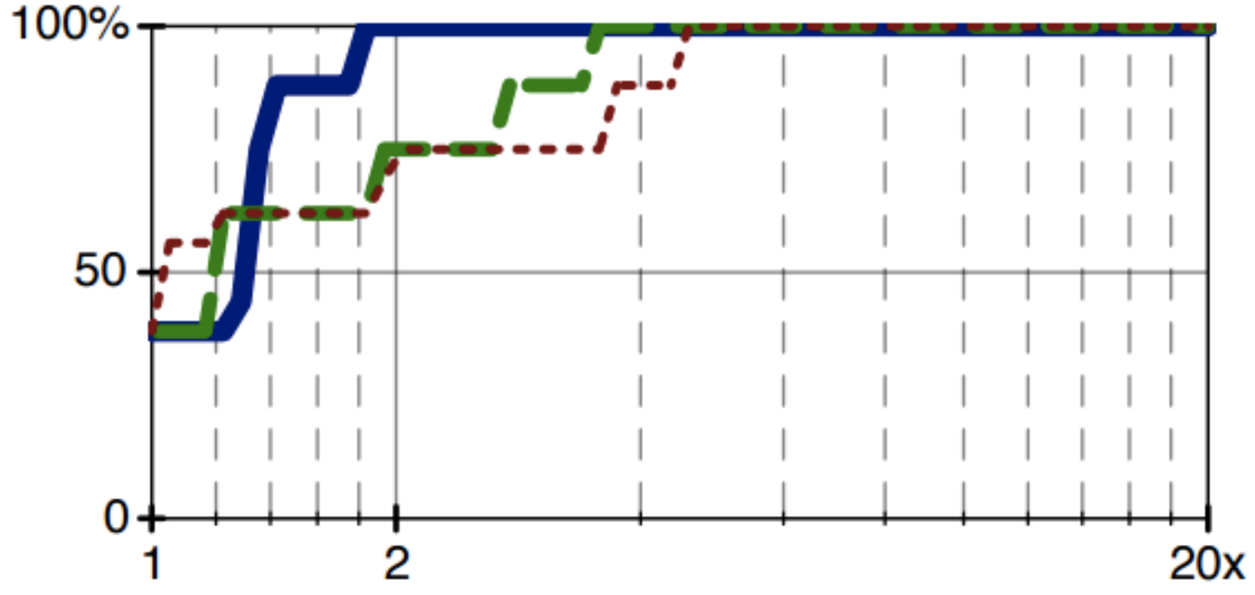
```
(require "population.rkt")

(define (evolve pop count)
  (if (zero? count)
    null
    (evolve (step pop) (- count 1))))

(evolve (create 100) 5)
```

```
(define-type Population
  (Class ....))

(provide
  (step (Population -> Population))
  (create (Natural -> Population)))
```

fsm

16 configurations





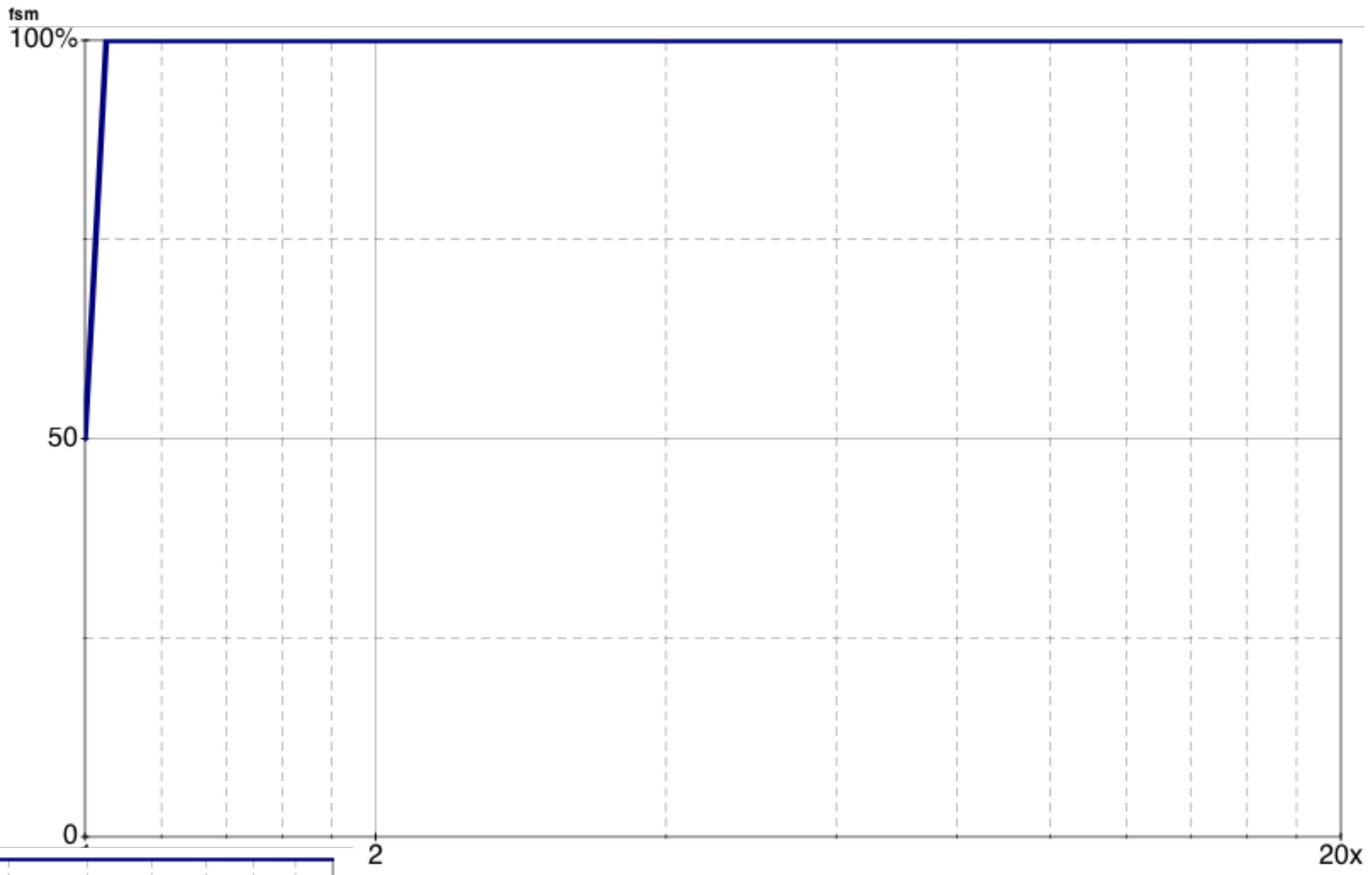
Weaknesses 2

- Many ways of typing a program
- Many ways of modularizing a program

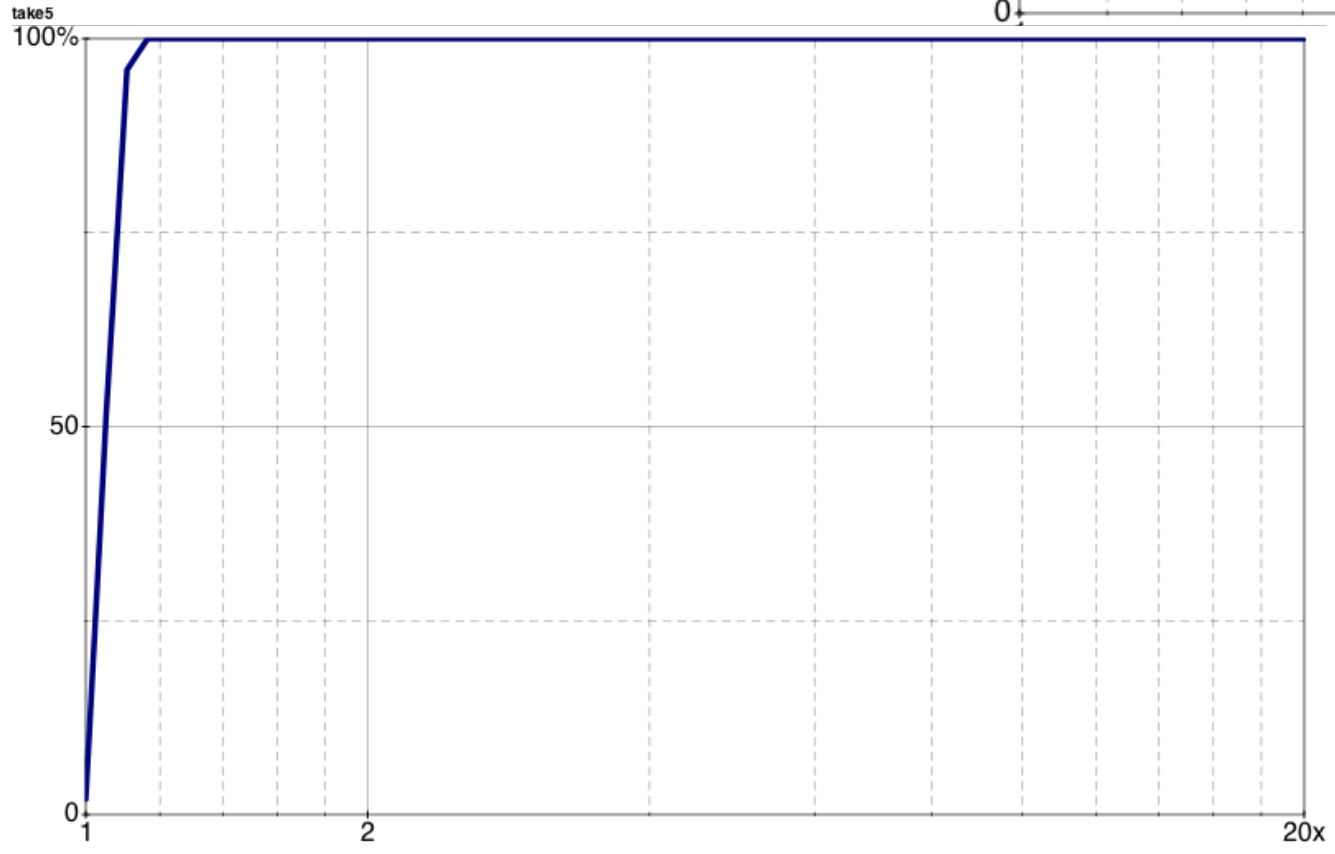
Data from Reticulated

FSM

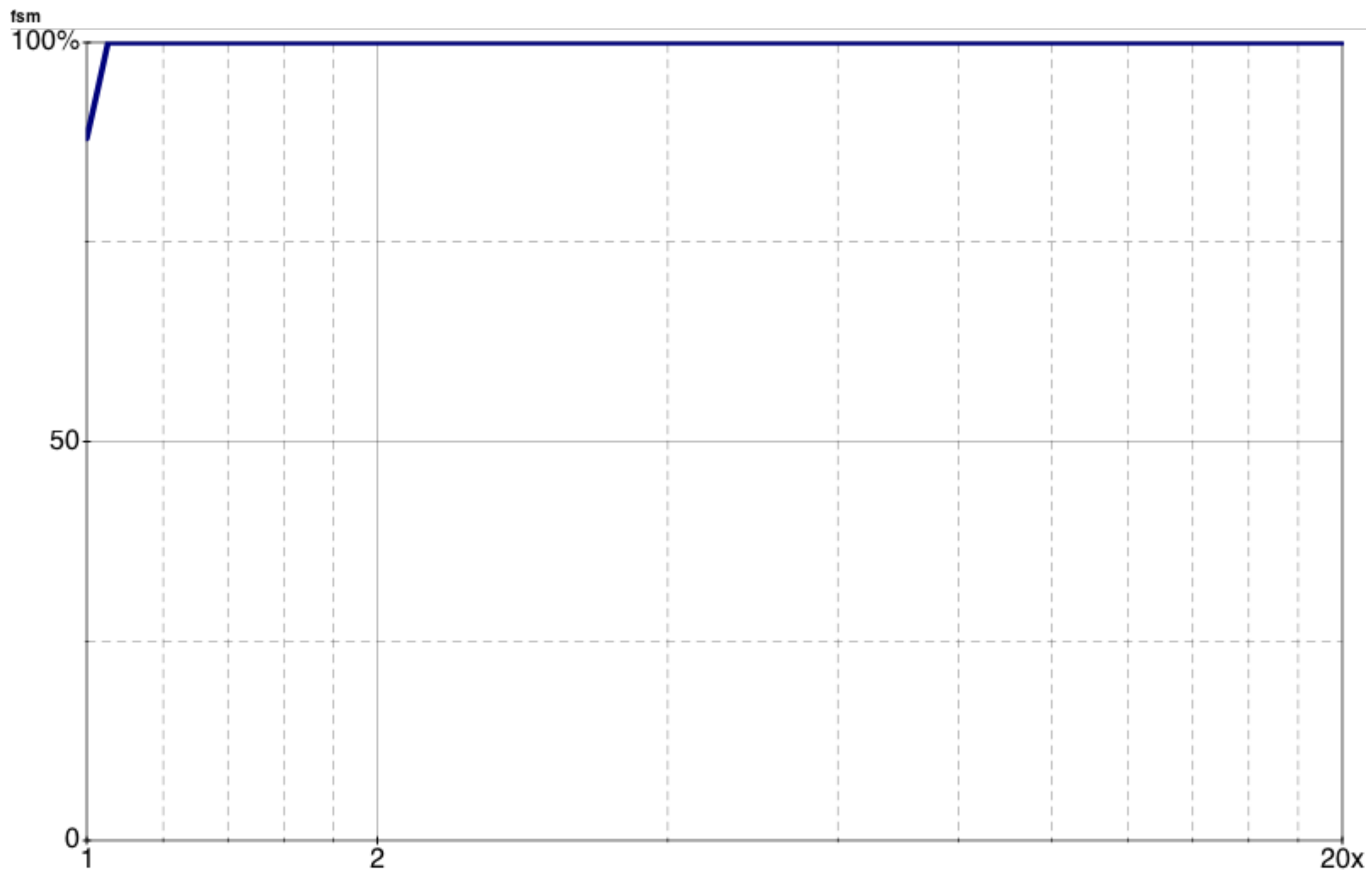
transient



Take5

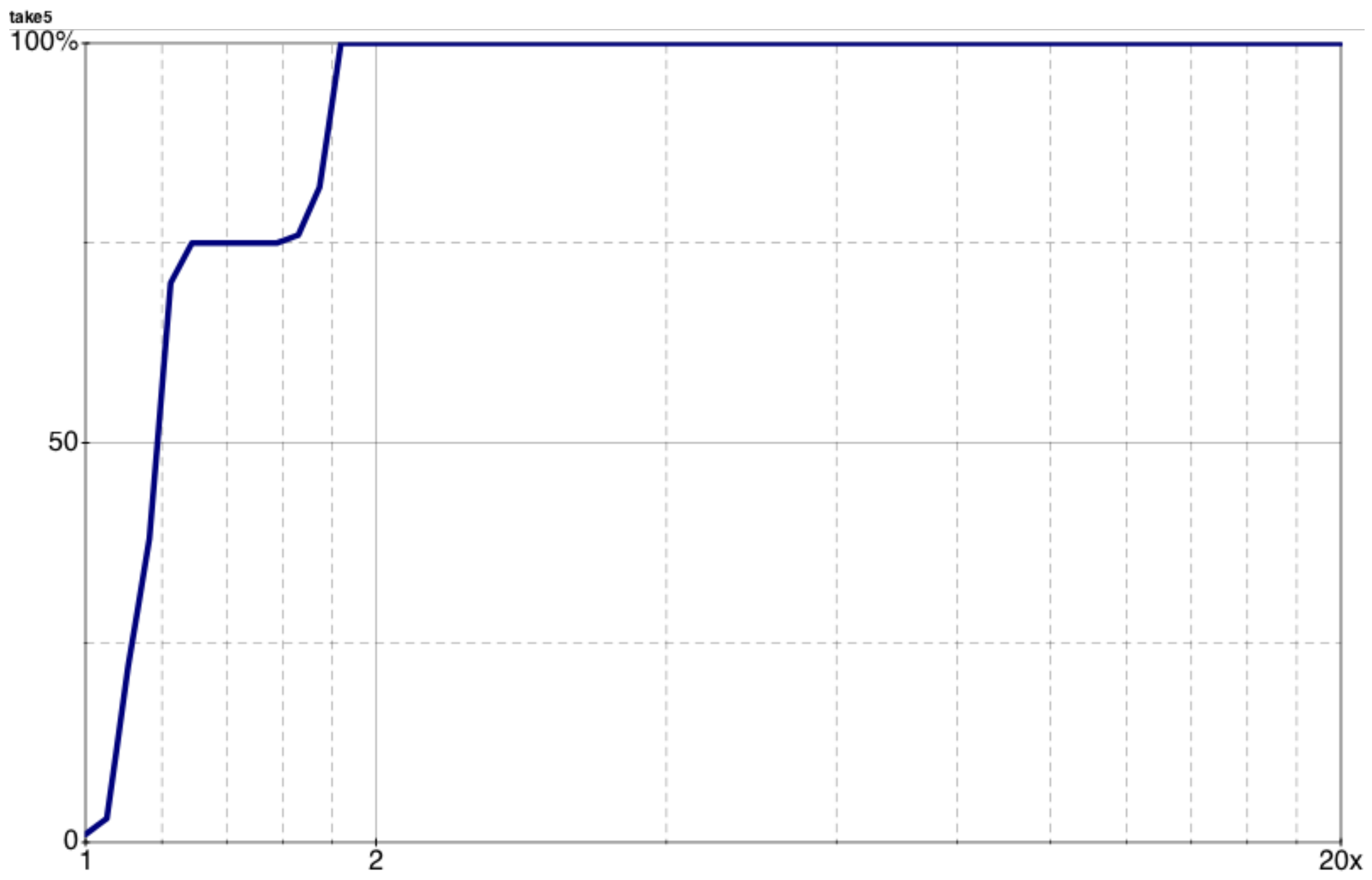


FSM



guarded

Take5



low overheads!

Finally, it is absurd to make elaborate security checks on debugging runs, when no trust is put in the results, and then remove them in production runs, when an erroneous result could be expensive or disastrous.

What would we think of a sailing enthusiast who wears his lifejacket when training on dry land, but takes it off as soon as he goes to sea?

- C.A.R. Hoare

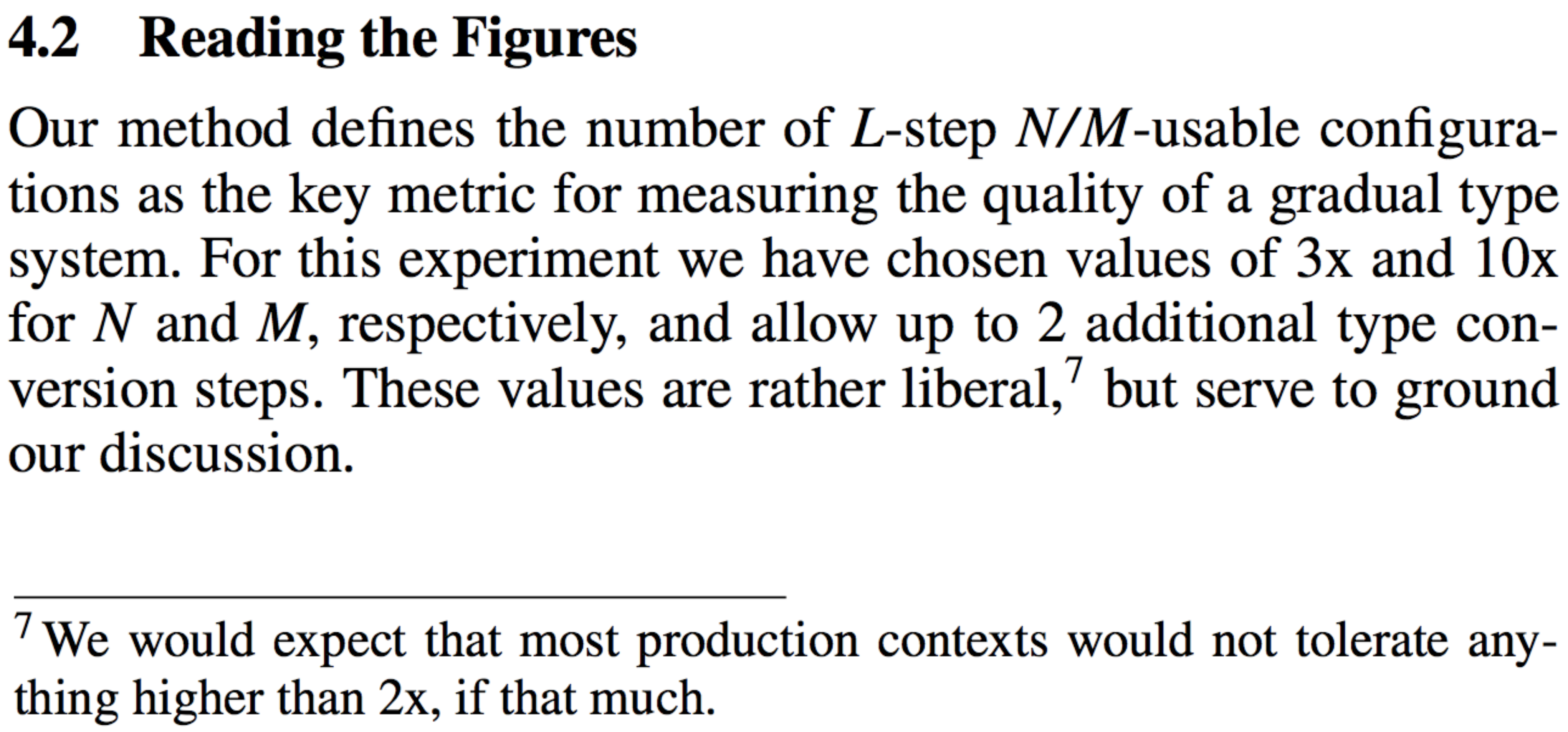
On the other hand, that sailor isn't so foolish if life vests are extremely expensive and if he is such an excellent swimmer that the chance of needing one is quite small compared with the other risks he is taking.

- Donald Knuth

3x is **NOT** "Deliverable"

10x is **NOT** "Usable"

Takikawa et. al 2016



4.2 Reading the Figures

Our method defines the number of L-step N/M-usable configurations as the key metric for measuring the quality of a gradual type system. For this experiment we have chosen values of 3x and 10x for N and M, respectively, and allow up to 2 additional type conversion steps. These values are rather liberal,[7] but serve to ground our discussion.

[7] We would expect that most production contexts would not tolerate anything higher than 2x, if that much.

Misc. Quotes from Typed Racket users

But user time is limited too. In my case, I'm trying to decide whether TR is a cost-effective upgrade for my Racket program

The end-product appears to be a 50%-performance hybrid due to boundary contracts, but ameliorated runtime-wise by utilizing the typed/racket/no-check language after it's all working in type checked mode. JGC *needs to be at least 10x faster. This was the original impetus for trying TR — improving performance by avoiding contracts + getting type-optimized operations. But it seems that whatever I'm gaining is more than offset by other factors.*

MB

Unfortunately, the prototype worked so well that I'm using it now for real JGC

I use typed racket in production too, and I also heavily use Scribble on the same source codebase. WG

For me as a programmer, ***Typed Racket is a different language*** *from Racket, because a valid program in one language is not a valid program in the other. Whether or not Typed Racket's hash ends up calling plain Racket's hash is an implementation detail I don't care about, except perhaps when dealing with interfacing modules in the two languages.*

From this point of view, Typed Racket is to a large degree an ***undocumented*** *language. Much of the documentation simply points to the one of plain Racket, which doesn't fully apply. Moreover, there is no simple set of rules that would let me deduce Typed Racket's API (which includes types) from plain Racket's API.*

KH

https://groups.google.com/forum/#!searchin/racket-users/typed$20racket/racket-users/-RI1p1Z1ZRE/u2e6ECZ1_LcJ *the recurring tasks that sends me looking for documentation is instantiating polymorphic functions into appropriate type-specific forms using `(inst proc args ...)`.*