Gradual Soundness: Lessons from Static Python

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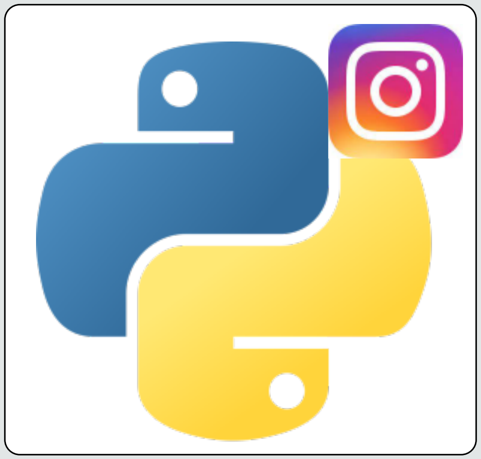
Aniket Panse Shriram Krishnamurthi

BROWN Meta

‹Programming› 2023

Static Python



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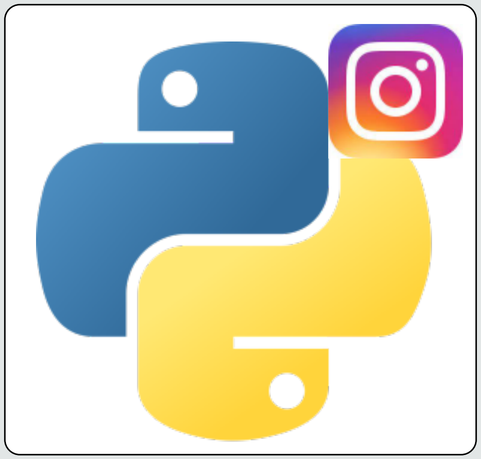
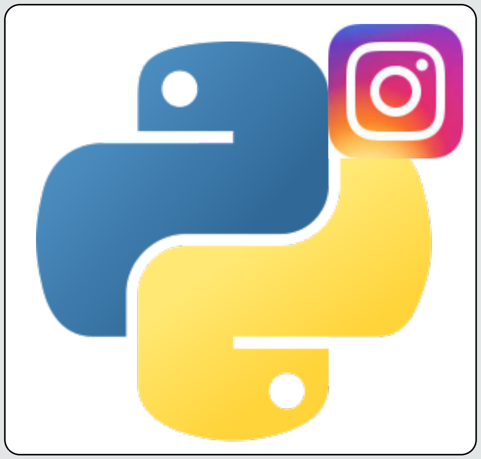


Enhanced Python, by Instagram

+2 years running **in production**

Static Python



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Gradually typed

... for some value of gradual

What is Gradual Typing?

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Idea: combine the best parts of typed and untyped code

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☹ so many parameters!

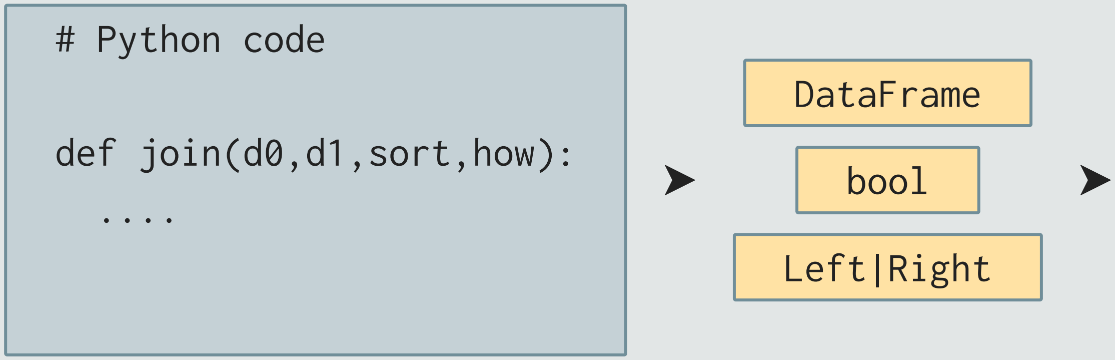
```
# Python code

def join(d0,d1,sort,how):
  ....
```

➤

What is Gradual Typing?

Idea: combine the best parts of typed and untyped code



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DataFrame

bool

Left|Right

What is Gradual Typing?

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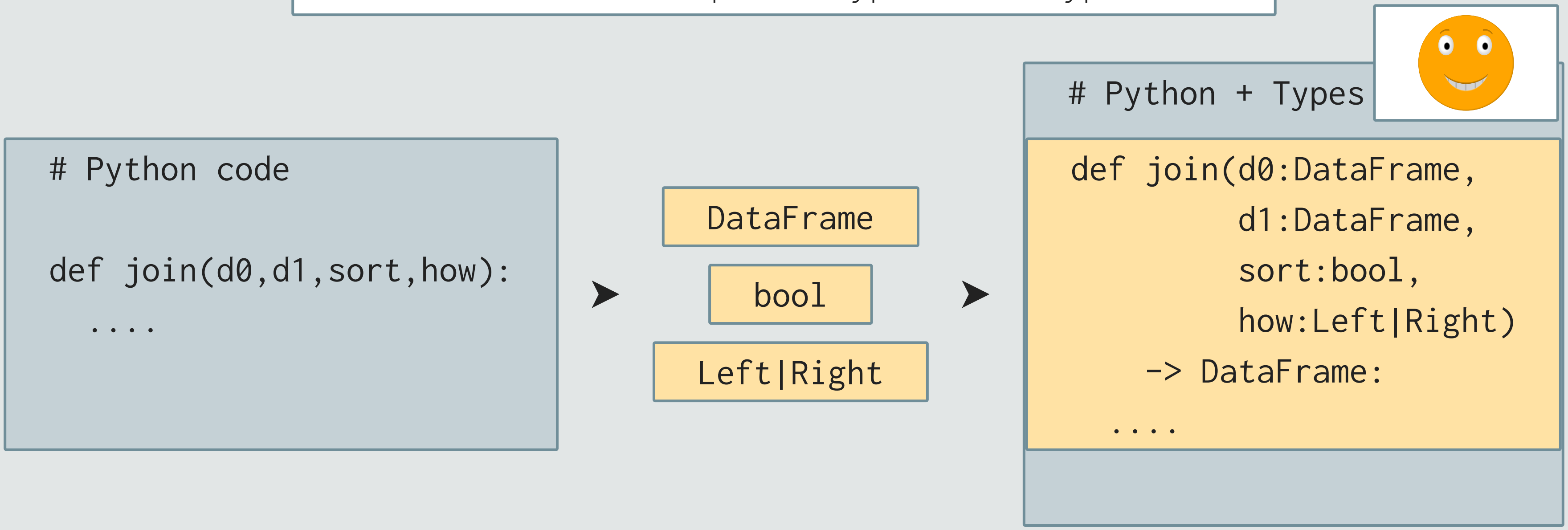

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# Python code

def join(d0,d1,sort,how):
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# Python + Types

def join(d0:DataFrame,
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.
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Great!

But, **what happens** when

typed code and untyped code

interact?

Are types sound?

What is Gradual Typing?

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A1.

A2.

A3.

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A1. Optional static checks, nothing at run-time

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How to debug? `join(42, "hola", ...)`

A2. Static types + contracts

Performance? `join(huge0, huge1, ...)`

A3. Progressive static types + tags

Today!

A3. Progressive static types + tags

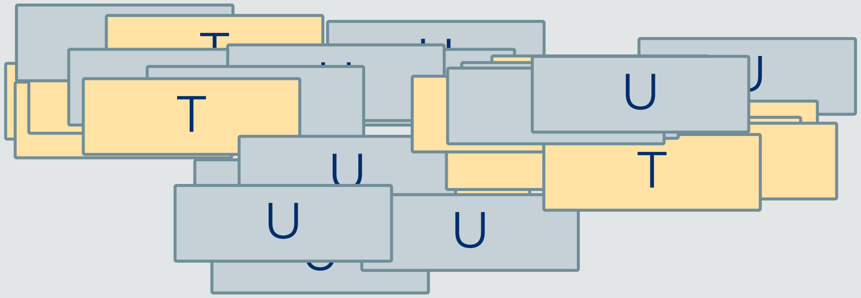
Experience @ Instagram Web Server

A3. Progressive static types + tags

Experience @ Instagram Web Server

+500 modules with **sound types**

+30k T — U interactions



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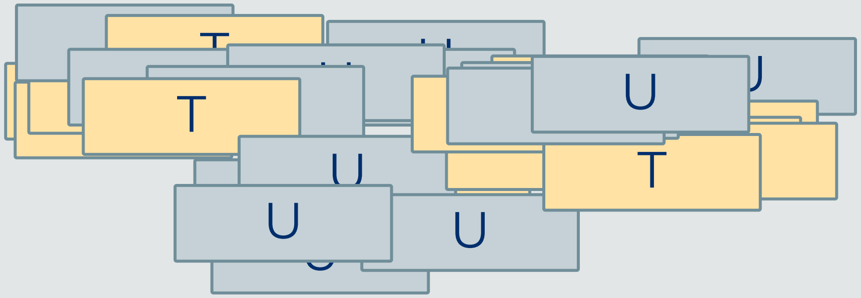

3.9% increase in CPU efficiency

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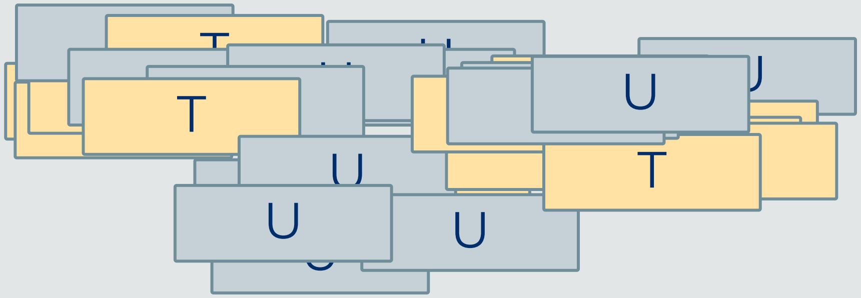

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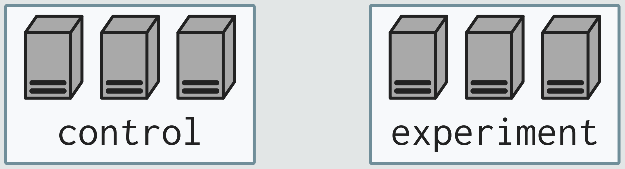

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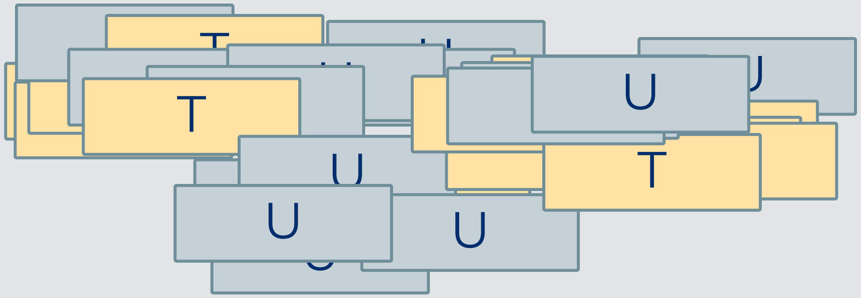

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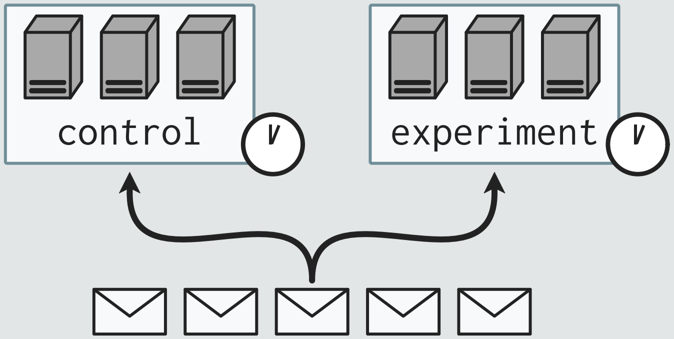

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How is Static Python so Fast?

Step 0. Better Compiler & Runtime

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cinder

https://github.com/facebookincubator/cinder

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Cinder Runtime

V Tables

Method-based JIT

...

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Cinder Runtime

V Tables

Method-based JIT

...

Type-Aware Bytecode

`CALL_FUNCTION`	Python default
`INVOKE_METHOD`	V Table lookup
`INVOKE_FUNCTION`	direct call

Step 1. Fast Soundness Checks

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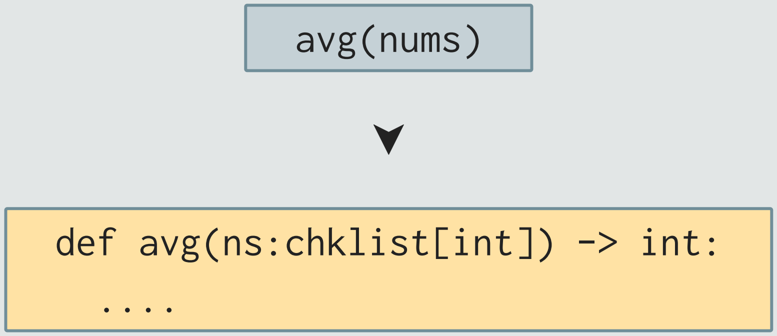

```
avg(nums)
```

```
def avg(ns:chklist[int]) -> int:
  ....
```

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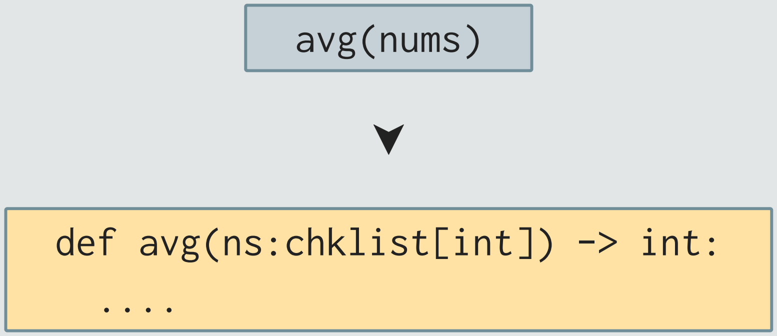

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Q. How to enforce soundness?

A. **Tag check**

Is `nums` an instance of `chklist[int]` ?

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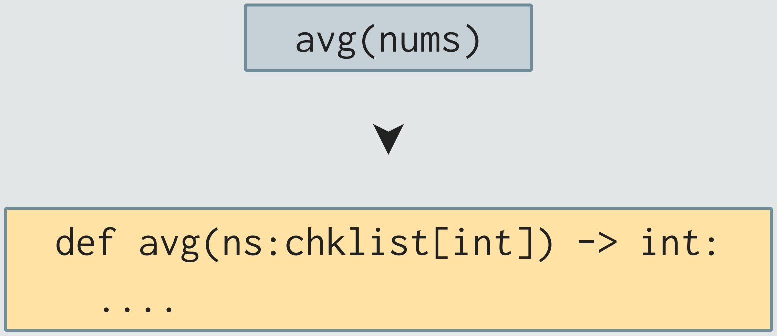

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Q. How to enforce soundness?

A. **Tag check**

Is `nums` an instance of `chklist[int]` ?

- ✓ Fast! No traversal, no wrapper
- 🟥 Rejects built-in Python lists

Step 2. Progressive Types

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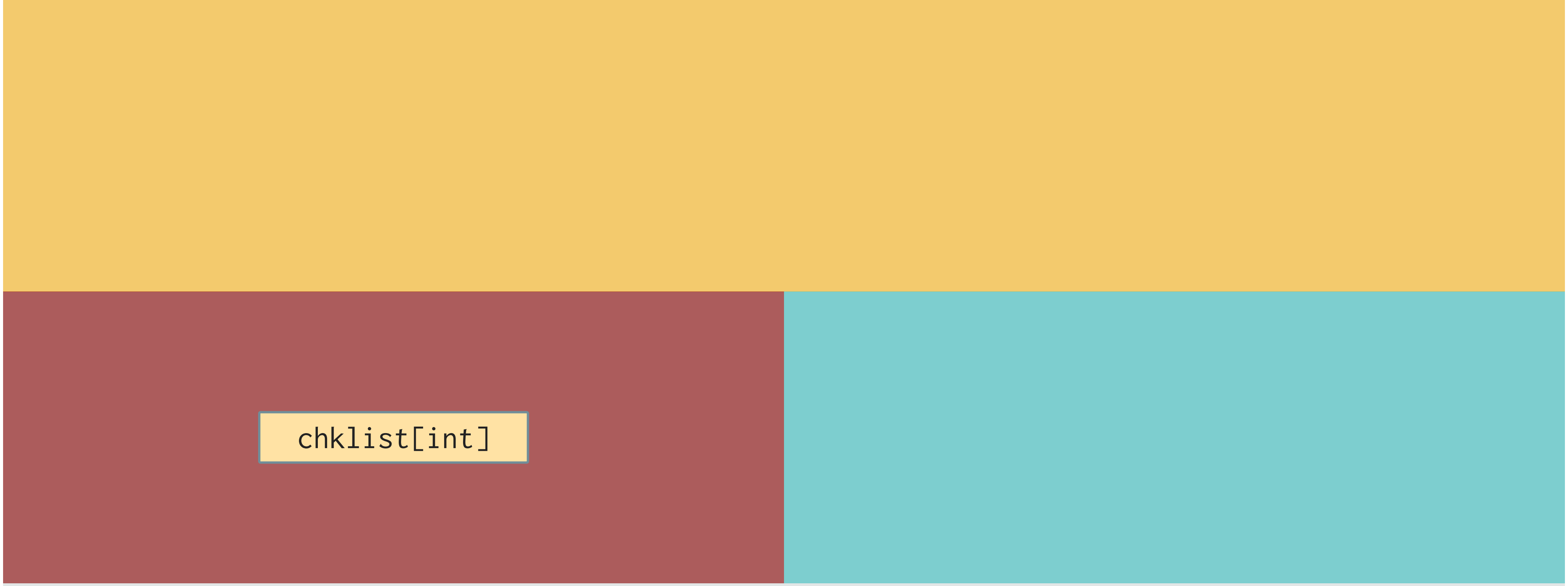
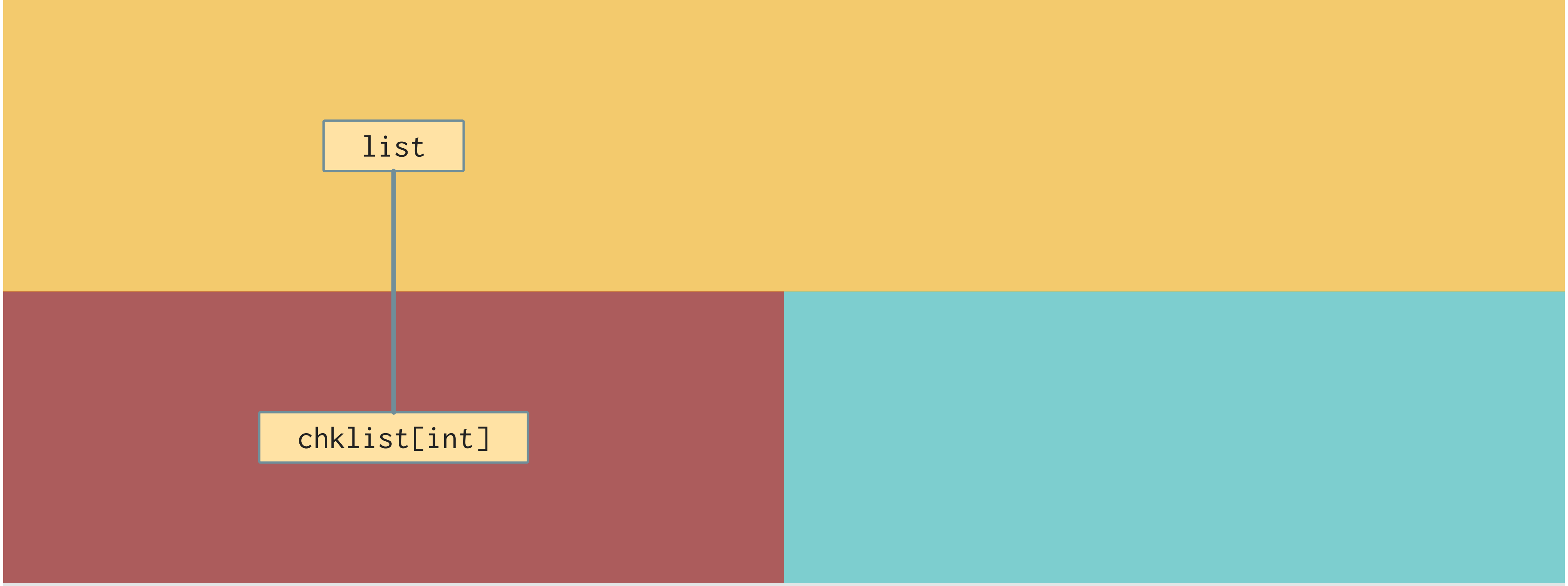


`chklist[int]`

Step 2. Progressive Types



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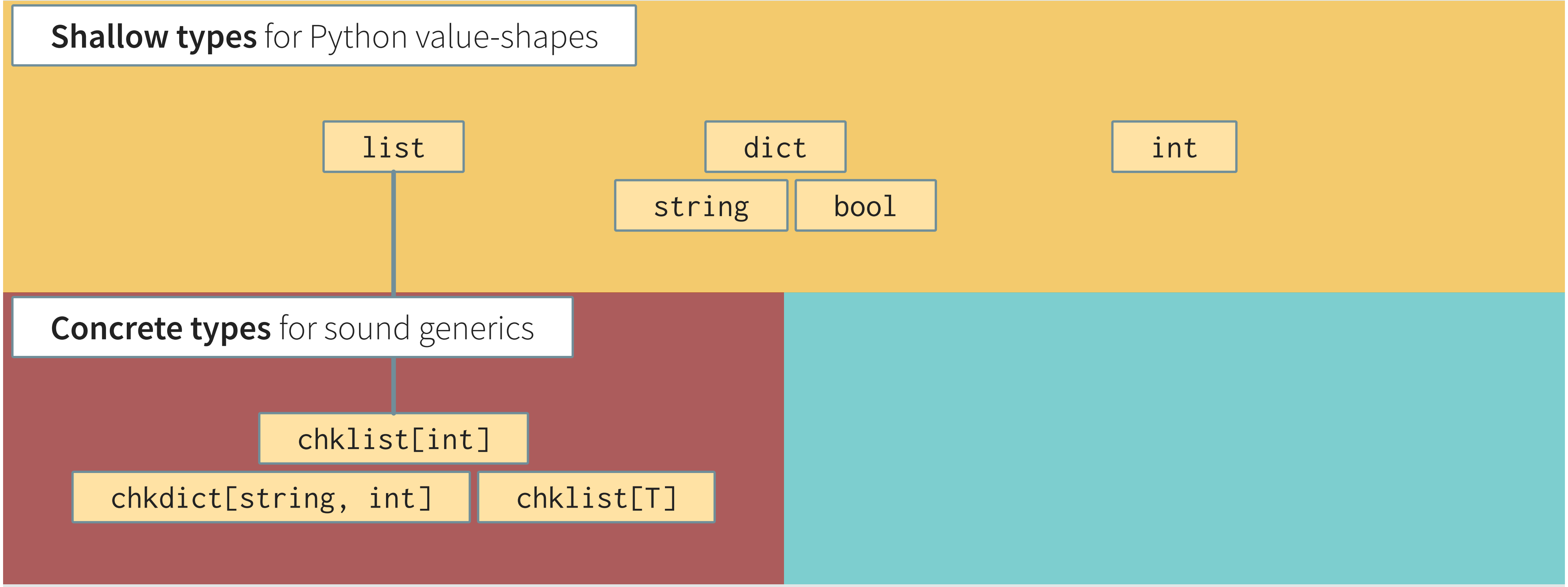


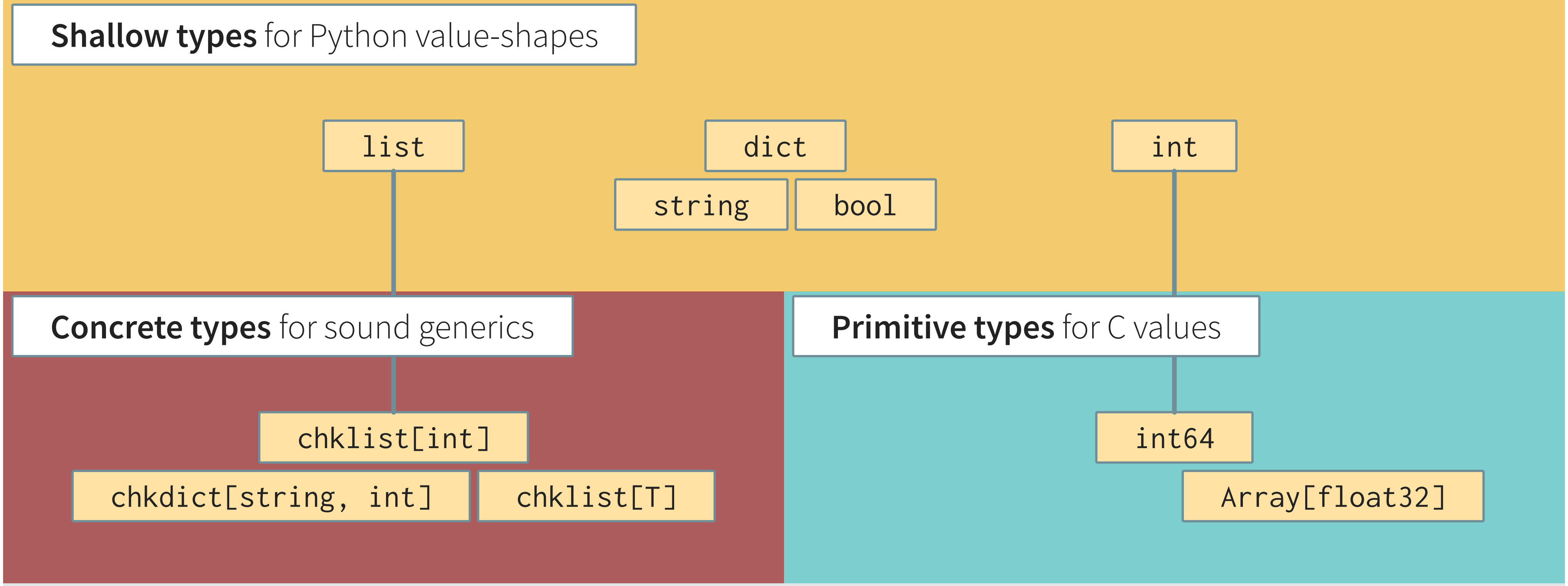
Shallow types for Python value-shapes

`list` `dict` `int` `string` `bool`

Concrete types for sound generics

`chklist[int]` `chkdict[string, int]` `chklist[T]`

Step 2. Progressive Types



Shallow types for Python value-shapes

list

dict

string

bool

int

Concrete types for sound generics

chklist[int]

chkdict[string, int]

chklist[T]

Primitive types for C values

int64

Array[float32]

Step 3. Limited Dyn Type

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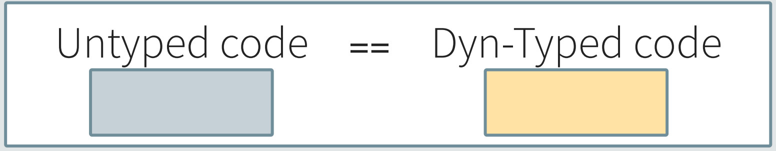
GT Theory



Untyped code == Dyn-Typed code

Step 3. Limited Dyn Type

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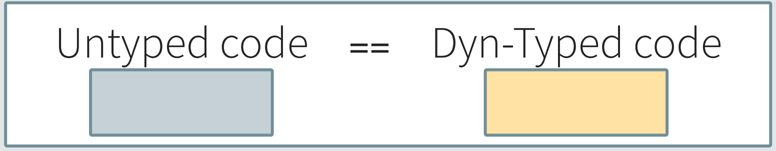

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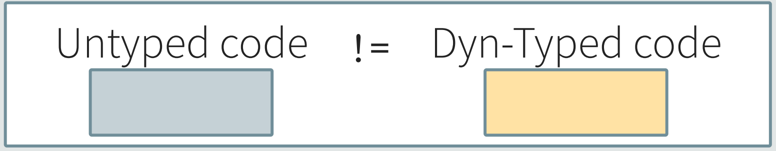
Static Python



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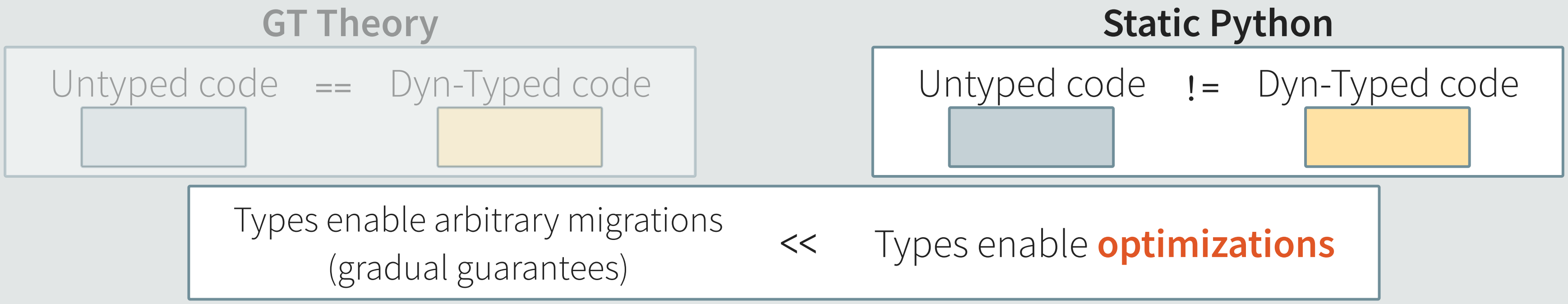

GT Theory

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Types enable arbitrary migrations (gradual guarantees) << Types enable **optimizations**

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Shallow ~ dispatch

Concrete ~ fast checks

Primitive ~ unboxing

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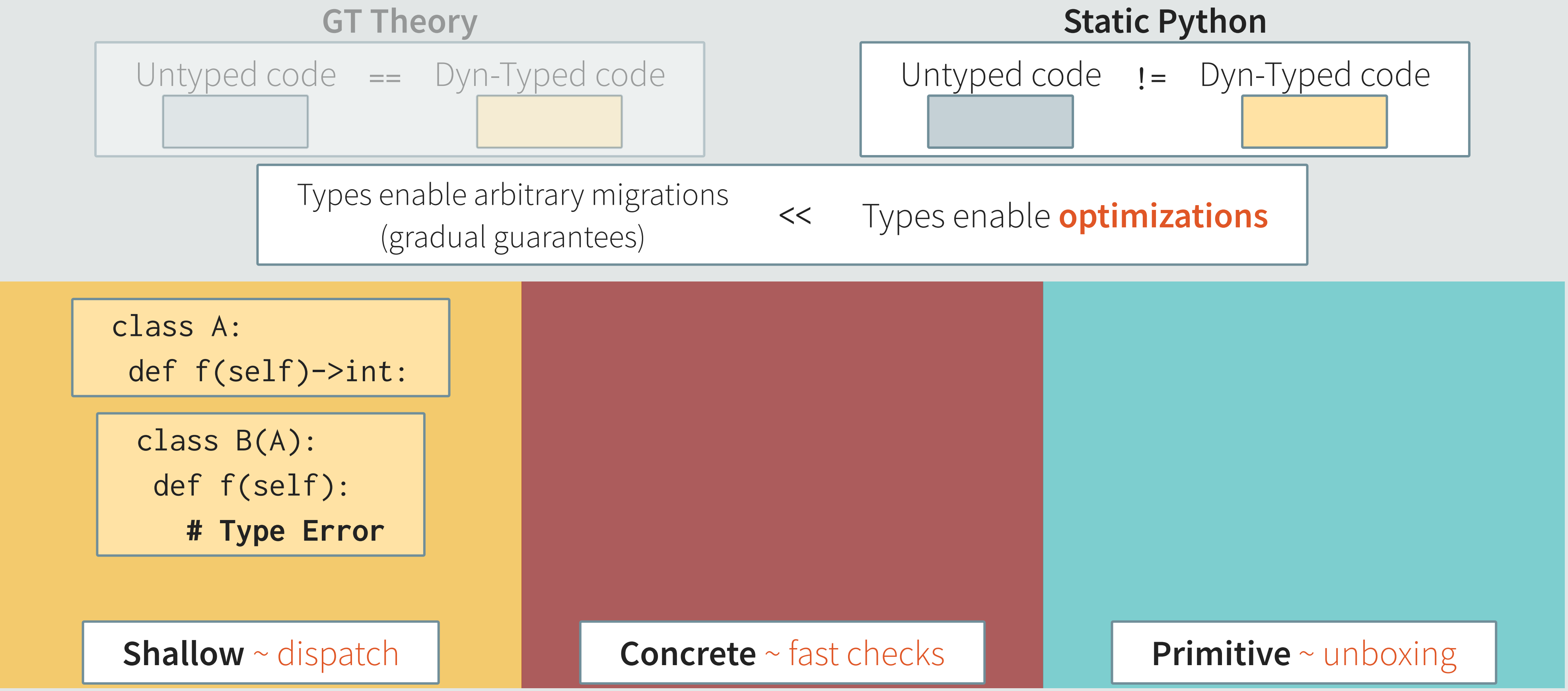

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```
class A:
 def f(self)->int:
```

```
class B(A):
 def f(self):
   # Type Error
```

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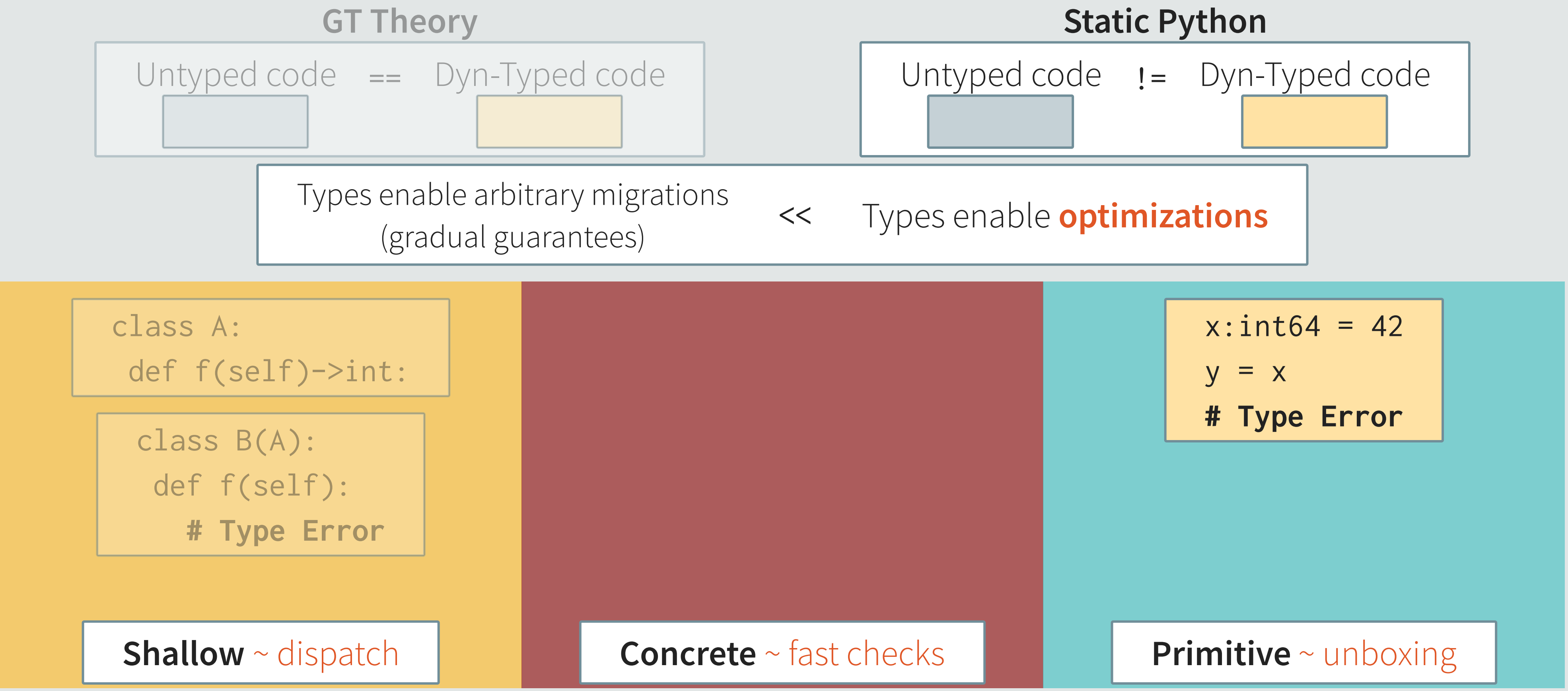

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class A:
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```
x:int64 = 42
y = x
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class A:
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Shallow ~ dispatch

```
def avg(ns:chklist[dyn]):
  ....
```

```
avg(chklist[int](1,2))
# Runtime Error
```

Concrete ~ fast checks

```
x:int64 = 42
y = x
# Type Error
```

Primitive ~ unboxing

Step 4. Limited Scope

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Focus on high-payoff **optimizations**
rather than feature-completeness

`eval` `first-class class`
`multiple inheritance` ==> defer to Python

`Callable[T0, T1]` `Setof[T]`
`Union[T0, T1, T2]` ==> defer to Pyre

PYRE

How is Static Python so Fast?

0. Better Compiler & Runtime
1. Fast Soundness Checks
2. Progressive Types
3. Limited Dyn Type
4. Limited Overall Scope

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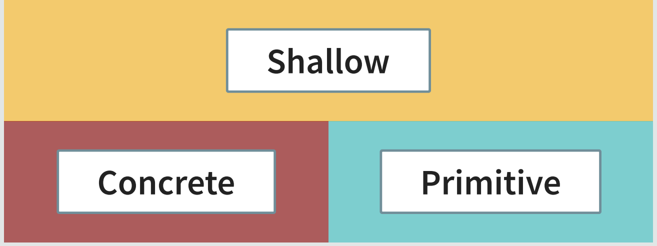


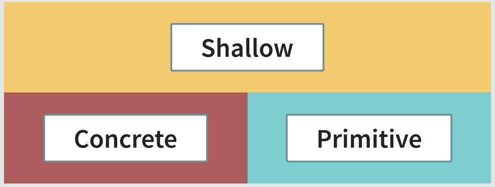
Shallow

Concrete **Primitive**

Types gradually enable optimizations

Gradual Soundness

More Experience



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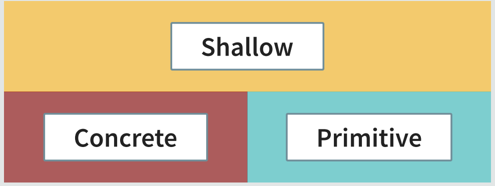

Instagram, March 2023:

959 typed modules

10 with **Concrete** (fast reads)

16 with **Primitives** (unboxed math)

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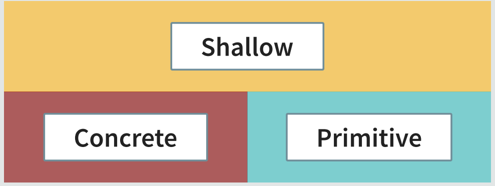

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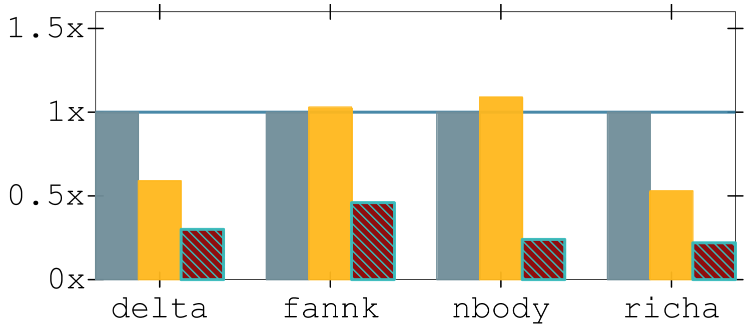
Microbenchmarks

1x = Python, **lower** is faster



Takeaways

Takeaways

τ λ

GT Researchers

Guarantees vs. Performance?

Takeaways

τ λ

GT Researchers

Guarantees vs. Performance?

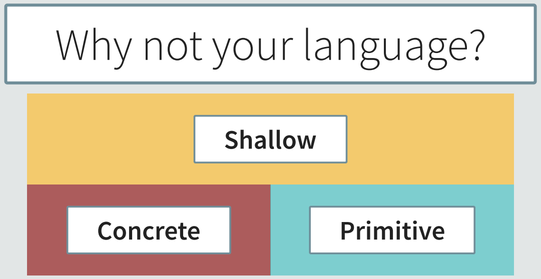
Qs for Concrete:

* migrating `list` to `chklist[T]` etc.

* fast tags for `Union[T0, T1, T2]`

Takeaways

Practitioners



Why not your language?

Takeaways

Language Designers

Redex model found:

5 critical soundness bugs

16 correctness issues

Takeaways

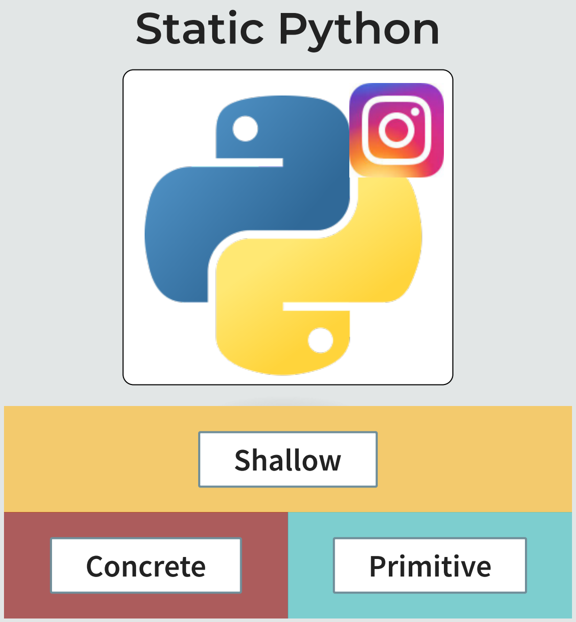
The End

τ λ

New research directions

Who's next?

Model found:
5 soundness + **16** other issues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