Design and Evaluation of Gradual Typing for Python

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Gradual typing

```
def abs(n: int)->int:
  if n < 0:
    return -n
  else:
    return n

def dist(x, y):
  return abs(x - y)
```

Gradual typing

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def abs(n: int)->int:
  if n < 0:
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def dist(x:Dyn, y:Dyn)->Dyn:
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Gradual typing

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def abs(n: int)->int:
  if n < 0:
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  else:
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def dist(x:Dyn, y:Dyn)->Dyn:
  return abs(cast(x - y, Dyn, int))
```

Gradual typing for Python

Challenges

- Static type system
- Semantics of runtime checks
- Evolution of code from dynamic to static

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Need to experiment!

Reticulated Python

Reticulated Python

- Gradual typing for Python
- Typechecker and source-to-source translator
- Python libraries that implement runtime semantics
- Testbed for different dialects
    - Common static semantics
    - Different dynamic semantics

Case studies

- CherryPy: web application framework
  - Heavy use of objects
  - Some APIs annotated, most of the code left as-is
  - 40k LoC
- Statistics library
  - Functions, lists, math, and `eval`
  - Annotated functions wherever possible
  - 1250 LoC
- SlowSHA
  - Objects and math
  - Annotated functions and objects
  - 350 LoC
- Unmodified Python Standard Library
  - 150k LoC

Bugs in target programs

```
class Node:
  def appendChild(self, node):
    ...
class Entity(Node): # subclass of Node
  def appendChild(self, newChild):
    ...
```

Python allows keyword arguments to be used anywhere:

`n.appendChild(node=Node())`

If `n` is an `Entity`, call will fail

Problem: object casts

Designing semantics for casts

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    assert isinstance(v, int)
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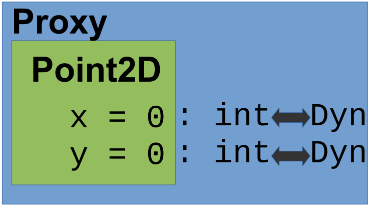
- Functions, other complex values harder
  - Traditional approach: function wrappers and object proxies



Proxy

Point2D

`x = 0` : int↔Dyn

`y = 0` : int↔Dyn

Identity preservation is important

```
class _localbase(object):
  def __new__(cls, *args, **kw):
    if args or kw and\
        (cls.__init__ is object.__init__):
      raise TypeError("Initialization arguments are
          not supported")
```

- Under standard semantics, `cls.__init__` may be a proxy. . .

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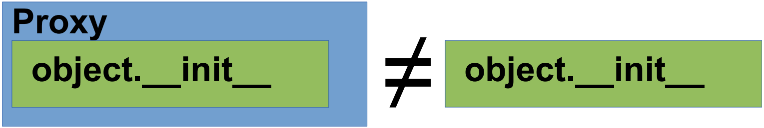
    - And a proxy is *not* pointer-identical (`is` operator) to its underlying object



Proxy

object.__init__ ≠ **object.__init__**

- Python Standard Library relies on object identity. CherryPy unable to run

Designing casts for mutable objects

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- Alternative approaches — *transient* and *monotonic* semantics
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class Point2D:
  x = 0
  y = 0

def bad_update(pt):
  pt.x = '42'
def update_x(pt:Object({'x': int,'y': int}))->int:
  bad_update(pt)
  return pt.x
update_x(Point2D())
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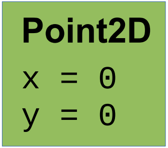

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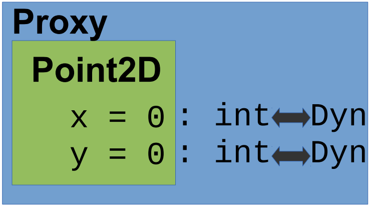

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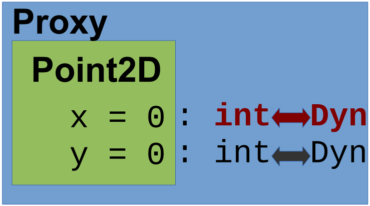

Proxy

Point2D

x = 0 : **int⟷Dyn**

y = 0 : int⟷Dyn

The *guarded* system

- Pros: well-understood, straightforward
- Cons: breaks object identity

	CherryPy	`stats.py`	SlowSHA
Guarded	✗	✓	✓
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Monotonic			

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Point2D

x = '42'
y = 0

The *transient* system

- Casts only return the casted value itself (or an error), don't prevent future modification
- Checks ensure that later mutations will be detected (if they become relevant)
- Pros: Preserves object identity, simple to implement, *works*
- Cons: Many checks inserted, slightly more permissive, weaker invariants

	CherryPy	`stats.py`	SlowSHA
Guarded	✗	✓	✓
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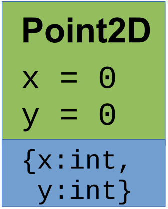

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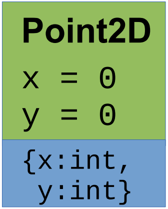

Point2D

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y = 0

{x:int,
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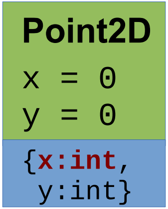

Point2D

x = 0

y = 0

{x:int,
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The *transient* system

- RTTI becomes monotonically less dynamic as objects flow through casts
- Pros: No casts on reads from statically-typed code, preserves object identity
- Cons: RTTI is permanent and casts cause action-at-a-distance
- Under construction

	CherryPy	`stats.py`	SlowSHA
Guarded	✗	✓	✓
Transient	✓	✓	✓
Monotonic			✓

Conclusions

- Reticulated Python is a framework for experimenting with gradual typing in Python
- Performed case studies on real Python code
- Found bugs
- Implemented and tested semantics designs
    - Found that object identity problems from proxies are a major practical issue
    - Showed that transient is a reasonable alternative
- Lots more: static type system, type inference, implementation of the runtime semantics, load-time typechecking

Check it out: `github.com/mvitousek/reticulated`

Thanks!