Programmable Semantic Fragments

The Design and Implementation of **typy**

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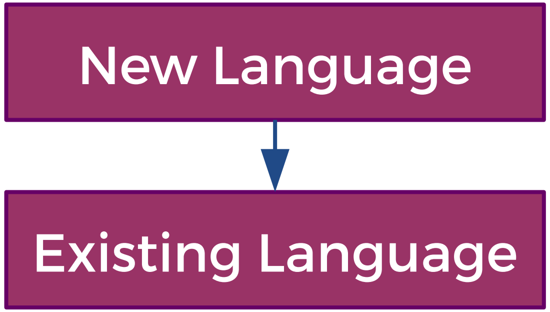
GPCE 2016

New Languages

New Language

Existing Language

New Languages



New Language

Existing Language

→ Safe & Natural Foreign Interface

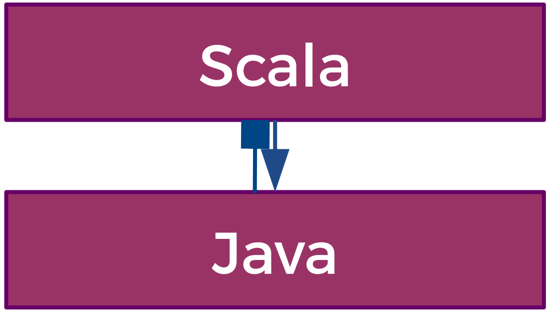
New Languages

Scala

Java

Safe & Natural Foreign Interface

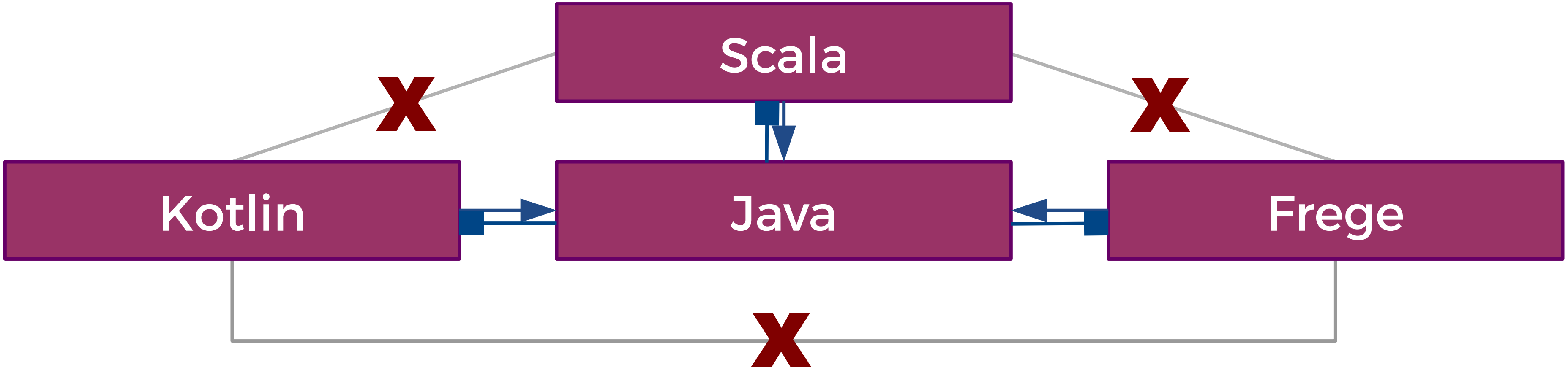
Problem: Backwards Compatibility



→ **Safe & Natural Foreign Interface**

—■ **Unsafe or Unnatural Foreign Interface**

Problem: Lateral Compatibility

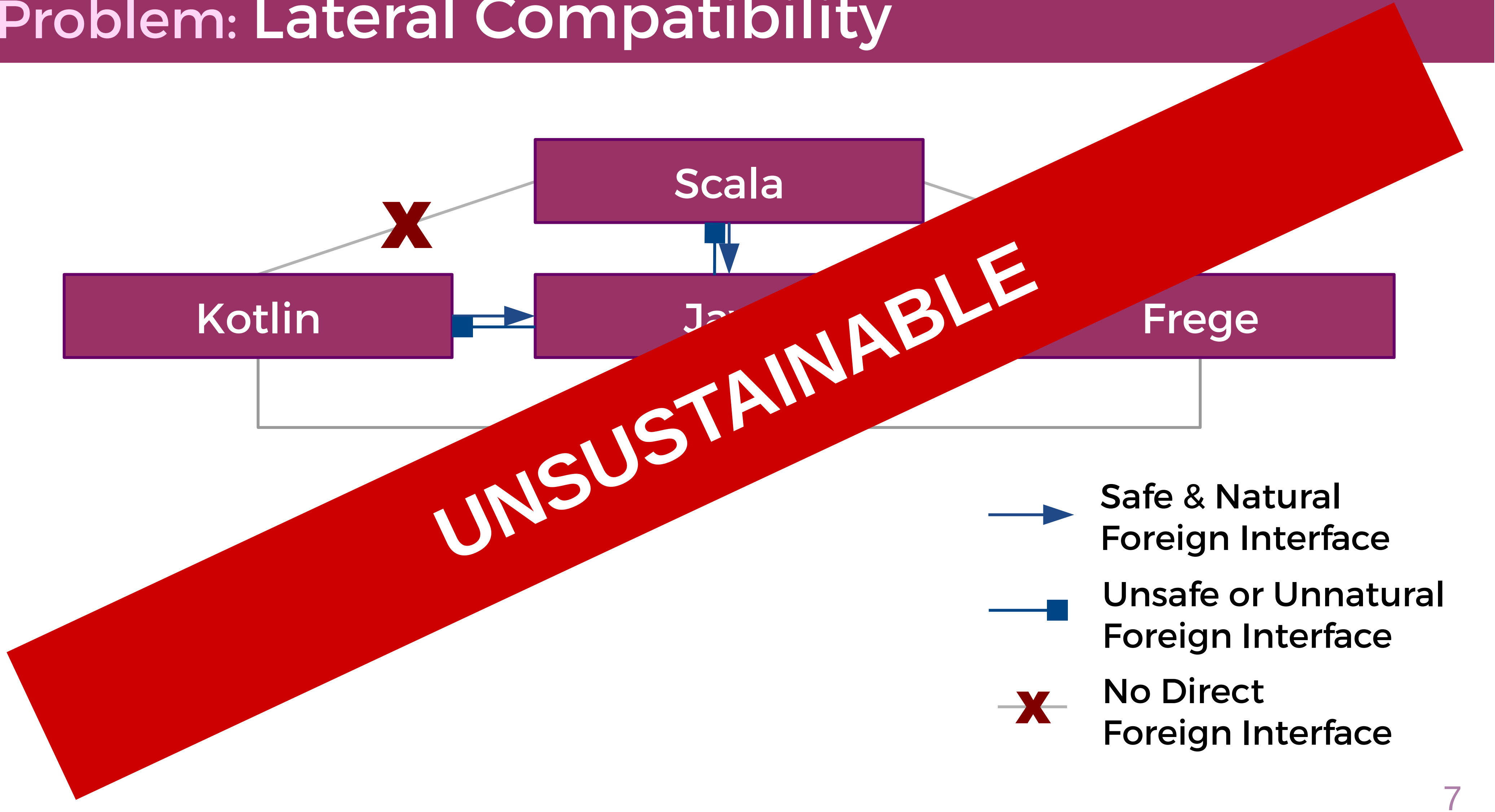



Unsafe or Unnatural Foreign Interface


Safe & Natural Foreign Interface


No Direct Foreign Interface

Problem: Lateral Compatibility



Safe & Natural Foreign Interface

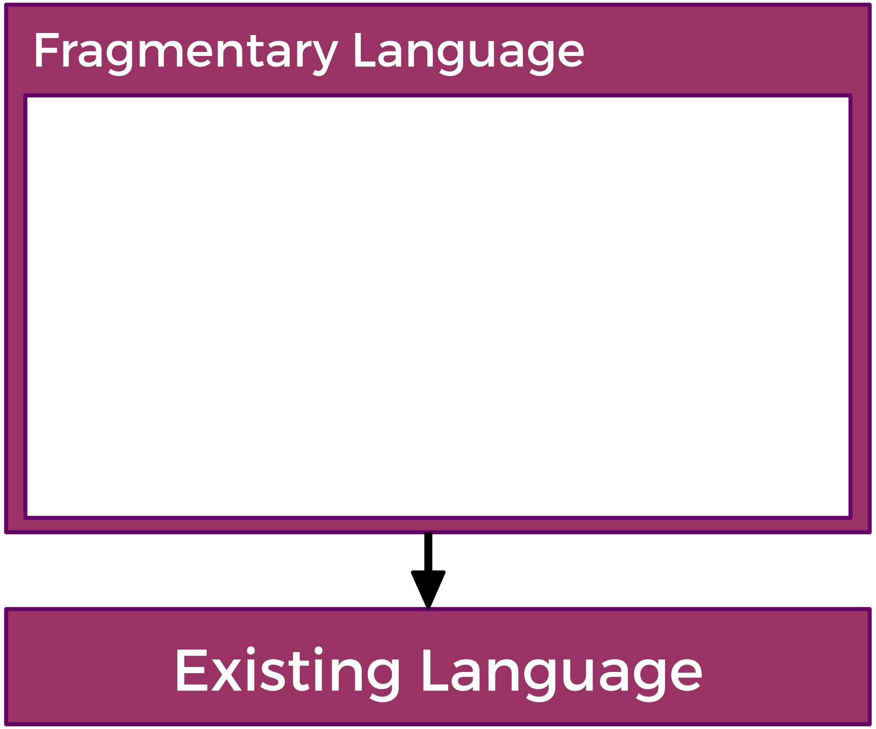
Unsafe or Unnatural Foreign Interface

No Direct Foreign Interface

Our Approach: A Fragmentary Semantics

Existing Language

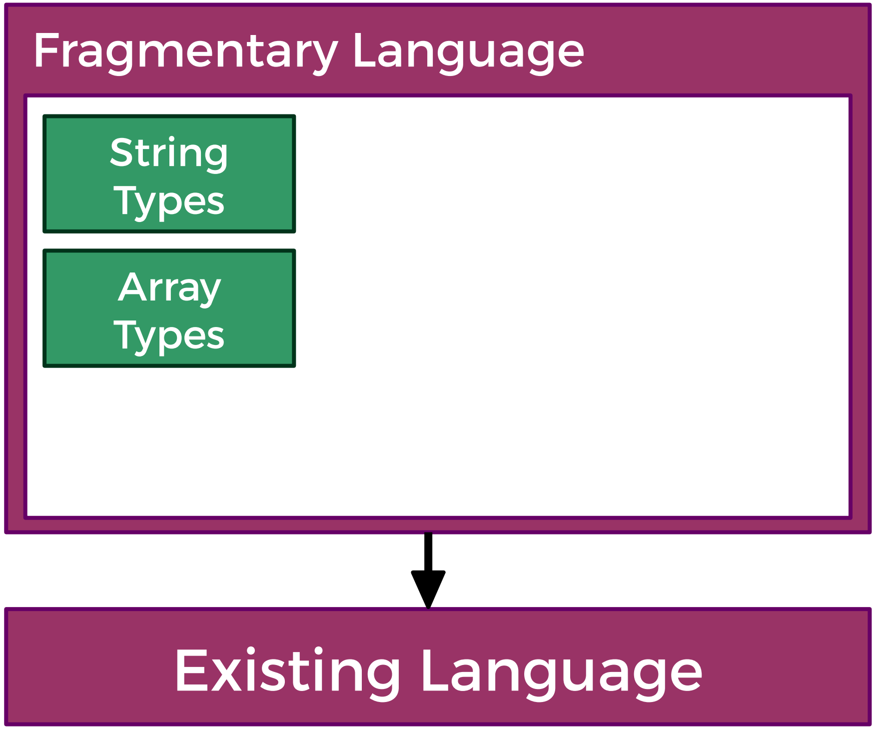
Our Approach: A Fragmentary Semantics



Fragmentary Language

Existing Language

Our Approach: A Fragmentary Semantics



Fragmentary Language

String Types

Array Types

Existing Language

🟩 Semantic Fragments

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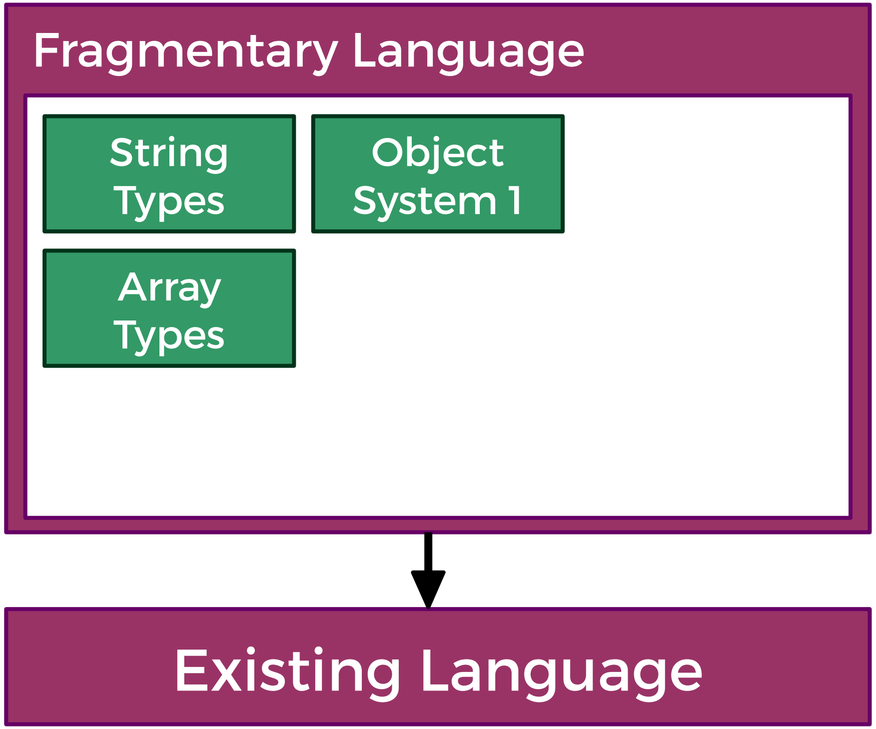
Fragmentary Language

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Object System 1

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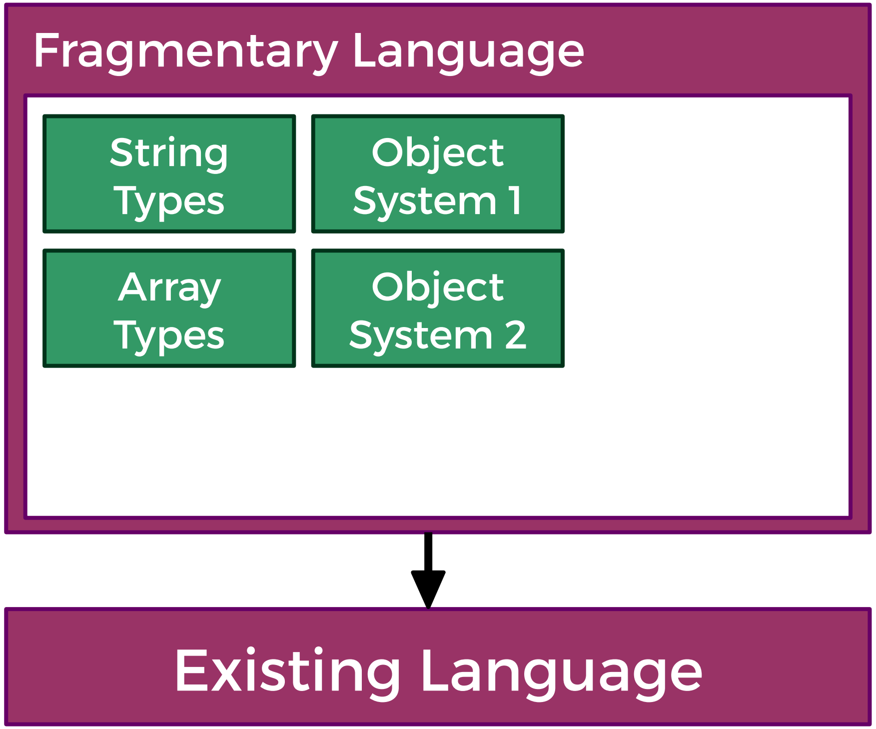

Fragmentary Language

String Types

Object System 1

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Object System 2

Existing Language

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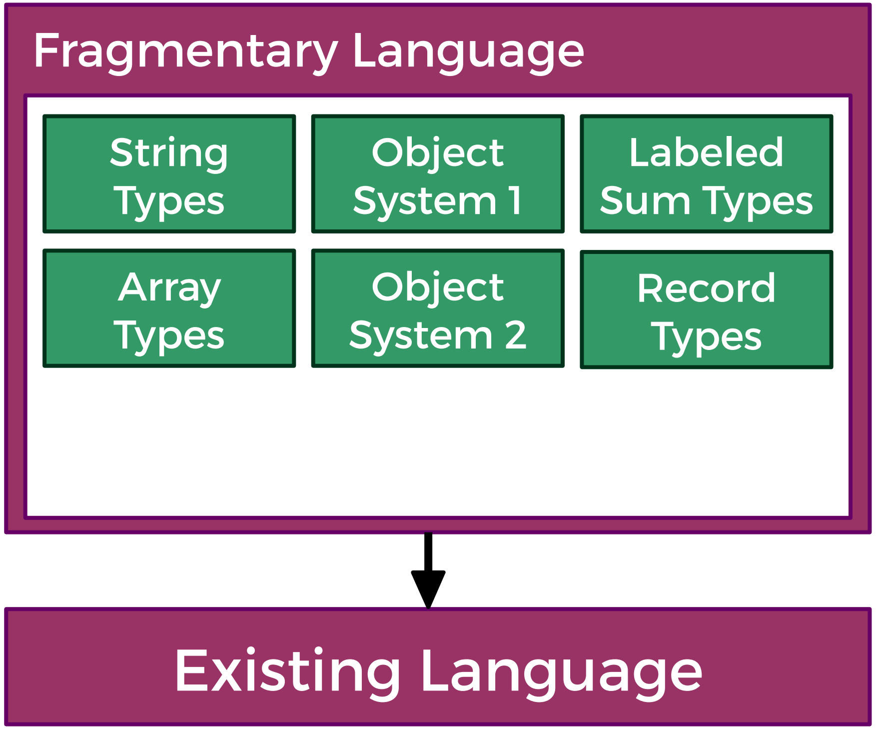

Fragmentary Language

String Types

Object System 1

Labeled Sum Types

Array Types

Object System 2

Record Types

Existing Language

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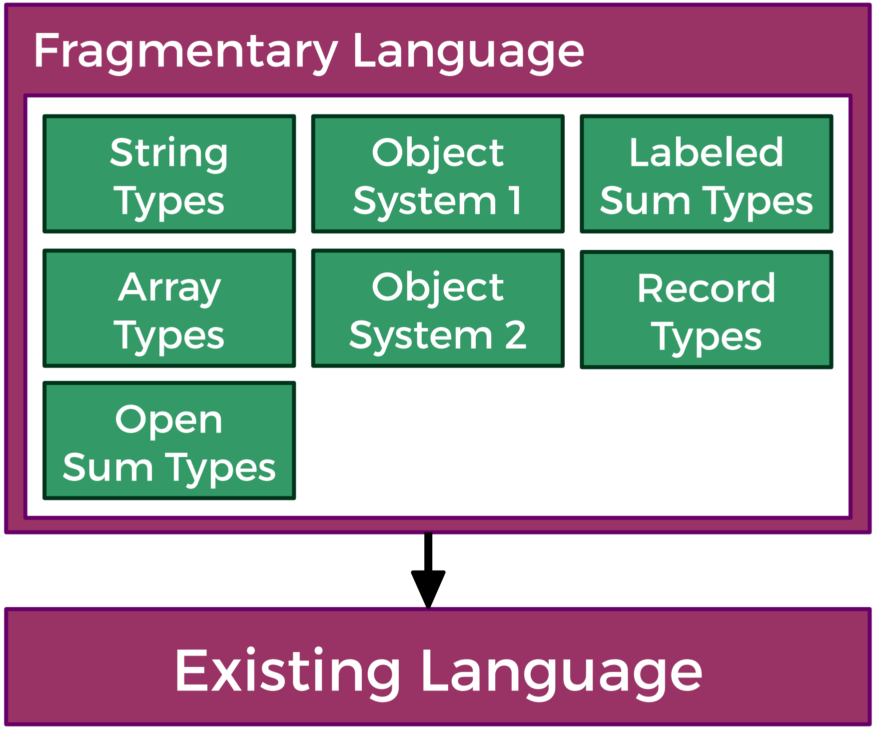

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Open Sum Types

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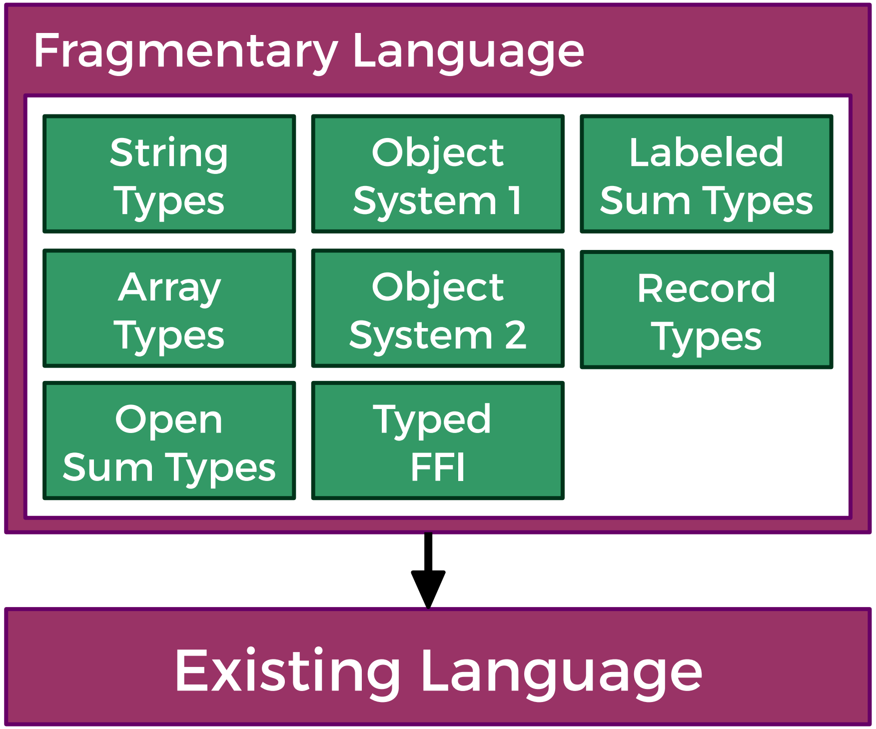

Fragmentary Language

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Open Sum Types

Typed FFI

Existing Language

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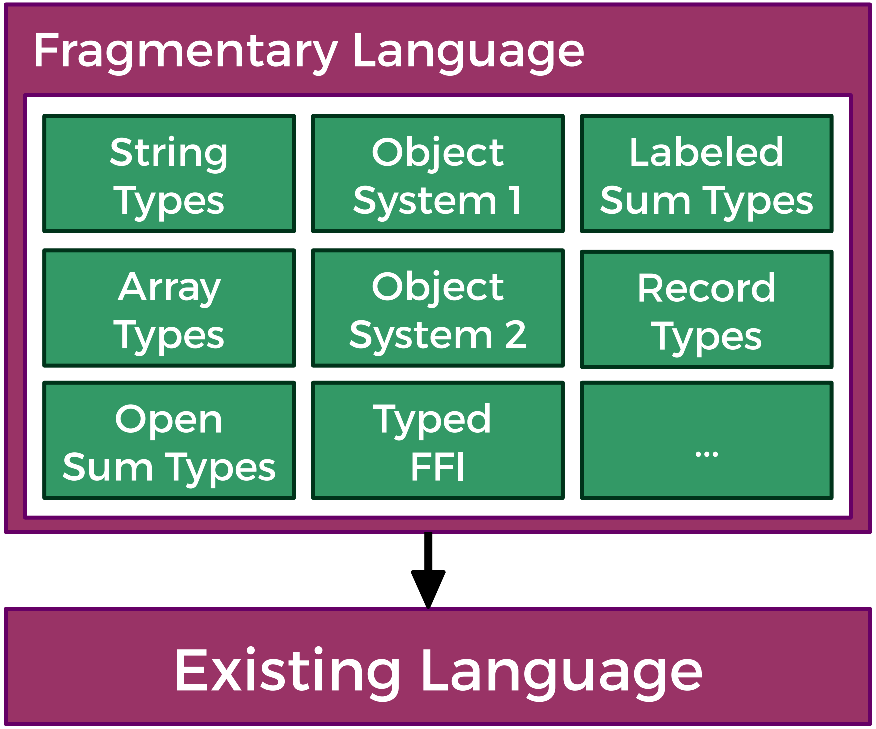

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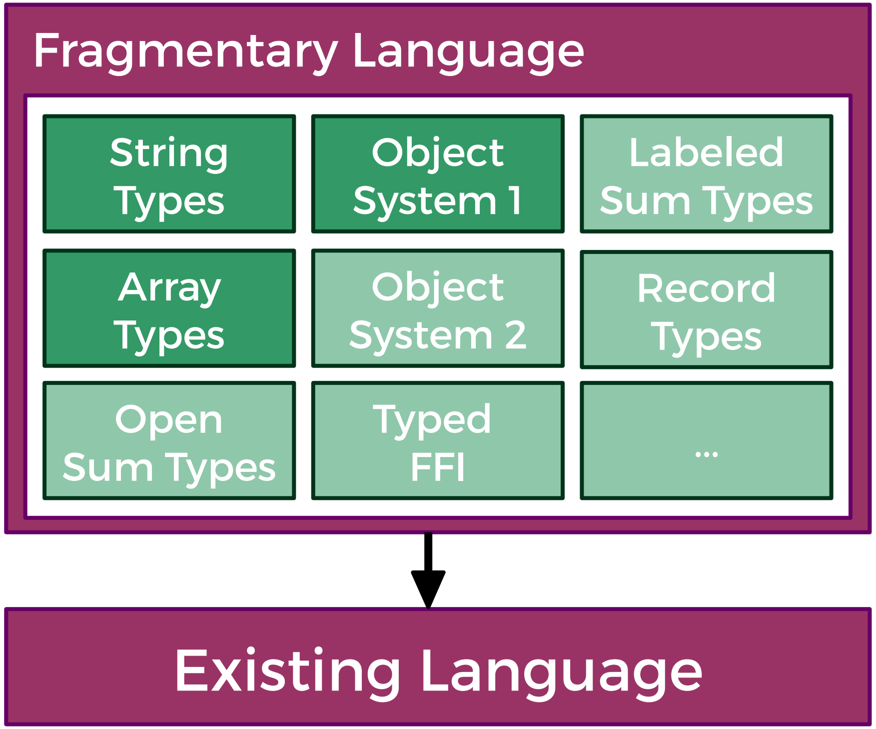

🟩 Semantic Fragments

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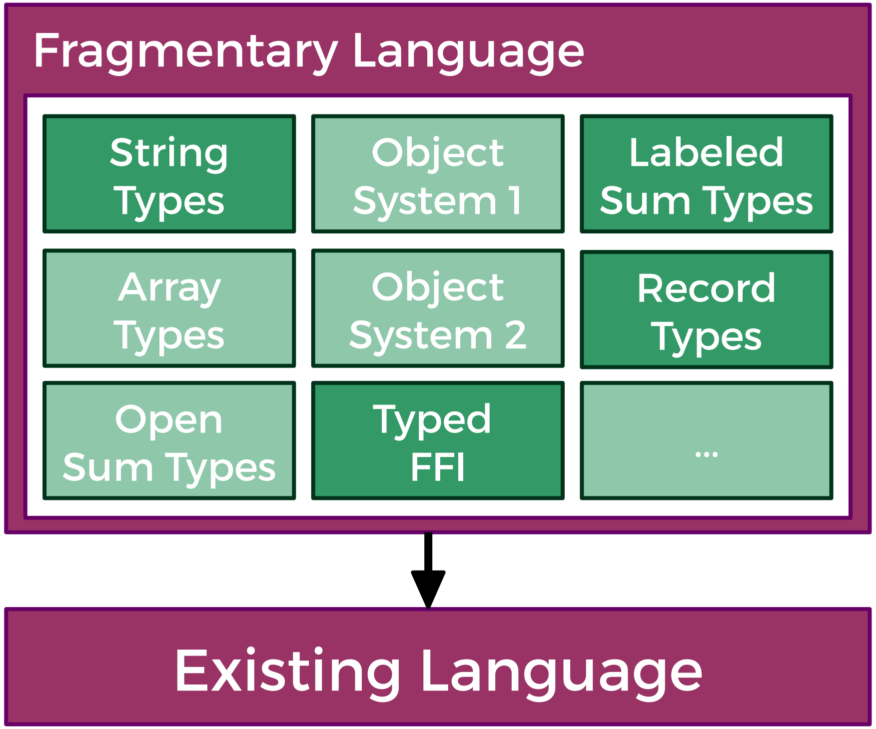

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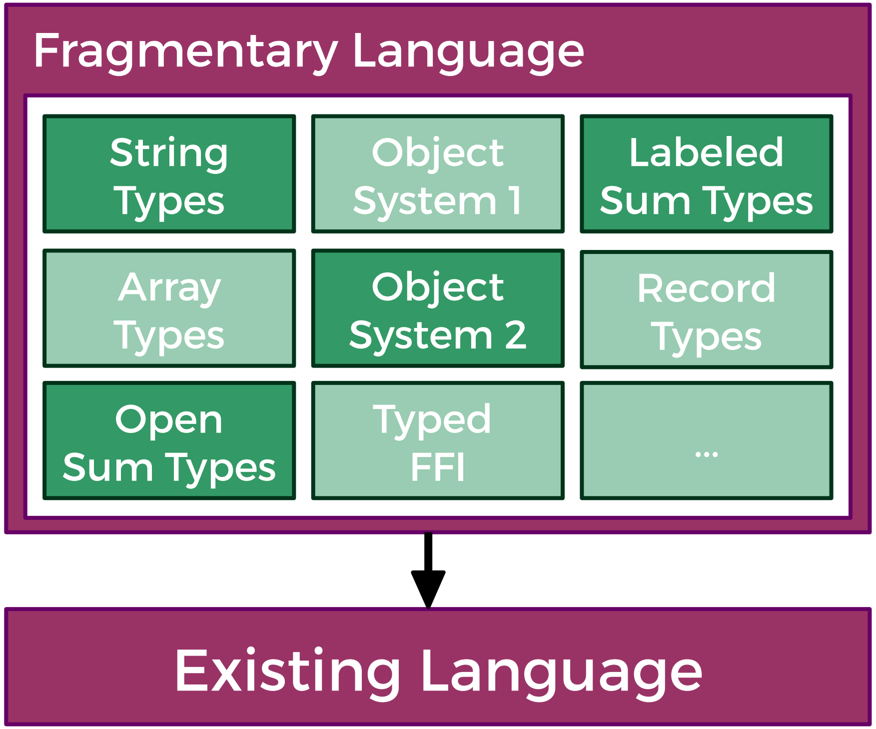

Fragmentary Language

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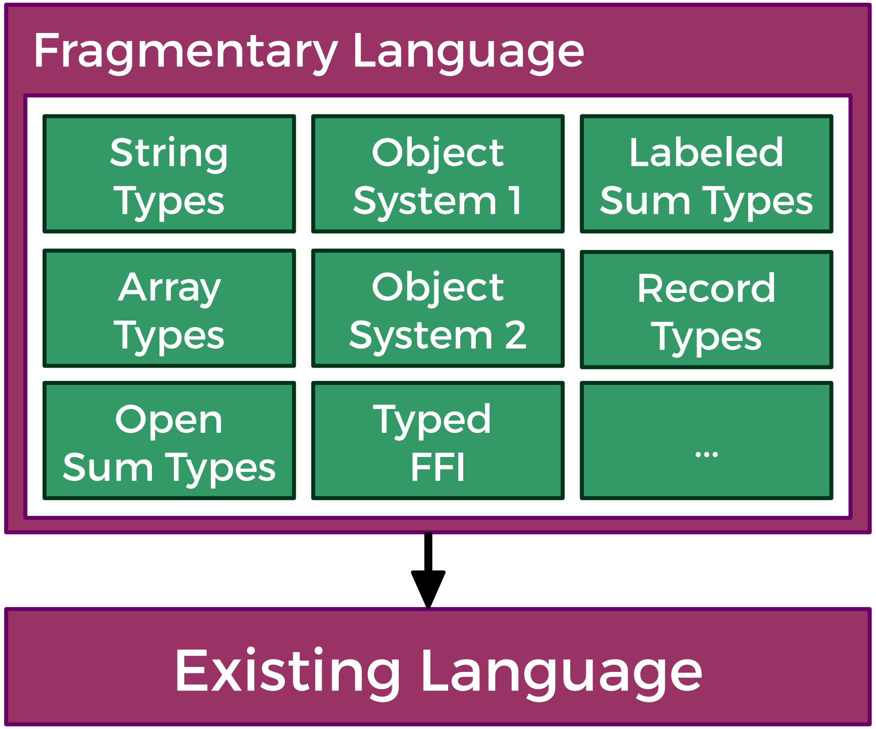
Existing Language

🟩 Semantic Fragments

Problem: Composition



🟩 Semantic Fragments

Problem: Composition

```
test_acct = {
  name: “Harry Q. Bovik”,
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}
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Is this

- a **record**?
- an **object**?
- a **dynamic dictionary**?
- an **ordered dictionary**?
- a **JSON value**?

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}
```

Is this

- a **record**?
- an **object**?
- a **dynamic dictionary**?
- an **ordered dictionary**?
- a **JSON value**?
- a **set**?

Solution: Type-Directed Disambiguation

```
test_acct : Account = {
  name: “Harry Q. Bovik”,
  account_num: “00-12345678”,
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}
```

Is this

- a **record**?
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- a **dynamic dictionary**?
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Solution: Type-Directed Disambiguation

```
type Account = record[
  name : string,
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]

test_acct : Account = {
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Is this

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This is a **record**.

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]

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  name: “Harry Q. Bovik”,
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}
```

This is a **dynamic dictionary**.

(Similar to Omar et al., ECOOP 2014)

```
type Account = record[
  name : string,
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]

test_acct : Account = {
  name: “Harry Q. Bovik”,
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  memo: { }
}
```

What is a **record**?

Solution: Fragment Delegation

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type Account = record[
  name : string,
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  memo : dyn
]

test_acct : Account = {
  name: “Harry Q. Bovik”,
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  memo: { }
}
```

```
fragment record:
  def init_idx(idx_ast):
    # … type formation logic …
    return idx


  def ana_Dict(ctx, e, idx):
    # … type analysis …

  def trans_Dict(ctx, e, idx):
    # … translation …
```

Solution: Fragment Delegation

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```

Every type is of the form `fragment[idx]`.
(If `[idx]` is omitted, assumed `[()]`)

Solution: Fragment Delegation

```
type Account = record[
  name : string,
  account_num : string,
  memo : dyn
]

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```

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    # … translation …
```

The language applies `fragment.init_idx` to validate the type index.

Solution: Fragment Delegation

```
type Account = record[
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    # … translation …
```

The language applies `fragment.ana_Dict` to perform type analysis of dictionary literal forms.

Solution: Fragment Delegation

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type Account = record[
  name : string,
  account_num : string,
  memo : dyn
]

test_acct : Account = {
  name: “Harry Q. Bovik”,
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```

```
fragment record:
  def init_idx(idx_ast):
    # … type formation logic …
    return idx


  def ana_Dict(ctx, e, idx):
    # … type analysis …

  def trans_Dict(ctx, e, idx):
    # … translation …
```

The language then applies `fragment.trans_Dict` to compute the translation of the dictionary literal.

Solution: Fragment Delegation

```
type Account = record[
  name : string,
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test_acct : Account = {
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}

test_acct.name
```

```
fragment record:
  def init_idx(idx_ast):
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```

For targeted forms, the language first recursively synthesizes a type for the target...

Solution: Fragment Delegation

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```

For targeted forms, the language first recursively synthesizes a type for the target…
and delegates to the fragment defining that type.

Solution: Fragment Delegation

```
type Account = record[
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test_acct.name
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fragment record:
  def init_idx(idx_ast):
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  def ana_Dict(ctx, e, idx):
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  def trans_Dict(ctx, e, idx):
    # … translation …

  def syn_Attribute(ctx, e, idx):
    # … type synthesis …

  def trans_Attribute(ctx, e, idx):
    # … translation …
```

Solution: Fragment Delegation

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type Account = record[
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```

Summary: Fragment Delegation Protocol

Form	Delegates To
Type forms	Explicitly named fragment
Introductory forms (dicts, sets, lists, tuples, lambdas, ...)	Fragment defining type provided for analysis.
Targeted forms (attributes, subscript, call, guarded, ...)	Fragment defining type that target synthesizes.
Binary operations	Precedent fragment (see paper).
Definition forms	Fragment provided as decorator (see paper).
Patterns	Fragment defining type of scrutinee (see paper).

Key idea: both concrete and abstract syntax are fixed. Each form is assigned static and dynamic meaning by a fragment according to this delegation protocol.

Implementation: typy

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Implementation: typy

```
from typy import component
from typy.std import (record, string, dyn)

@component
def Listing1():
  type Account = record[
    name : string,
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  ]

  test_acct : Account = {
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Implementation: typy

```
class record(typy.Fragment):
  def init_idx(idx_ast):
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    # … translation …
```

Implementation: typy

```
class record(typy.Fragment):
  @classmethod
  def init_idx(cls, idx_ast):
    # … type formation logic (see paper) …
    return idx

  @classmethod
  def ana_Dict(cls, ctx, e, idx):
    # … type analysis (see paper) …

  @classmethod
  def trans_Dict(cls, ctx, e, idx):
    # … translation (see paper) …
```

Advanced Example: OpenCL FFI

```
add5 = pyopencl.Program(cl_ctx, ‘
  __kernel void add5(__global double* x) {
    size_t gid = get_global_id(0);
    x[gid] = x[gid] + 5;
  }’).build()
```

Advanced Example: OpenCL FFI

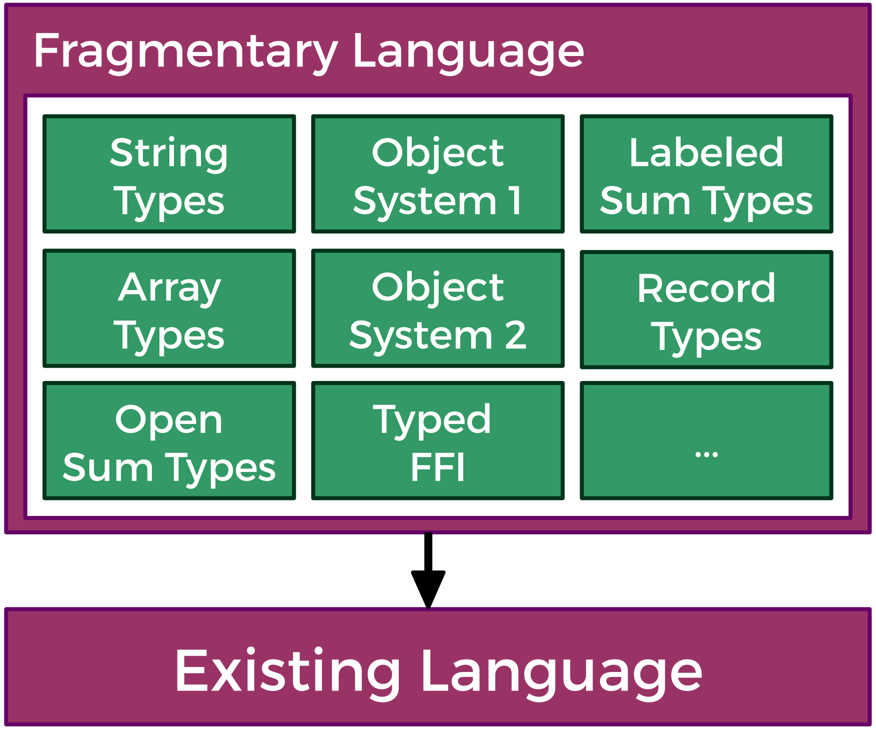
```
from typy import component
from typy.numpy import array, f64
from typy.cl import buffer, to_device, kernel

@component
def Example():
  x [: array[f64]] = [1, 2, 3, 4]
  d_x = to_device(x)

  @kernel
  def add5(x : buffer[f64]):
    gid = get_global_id(0)
    x[gid] = x[gid] + 5

  add5(d_x, global_size=d_x.length)
```

The Idea



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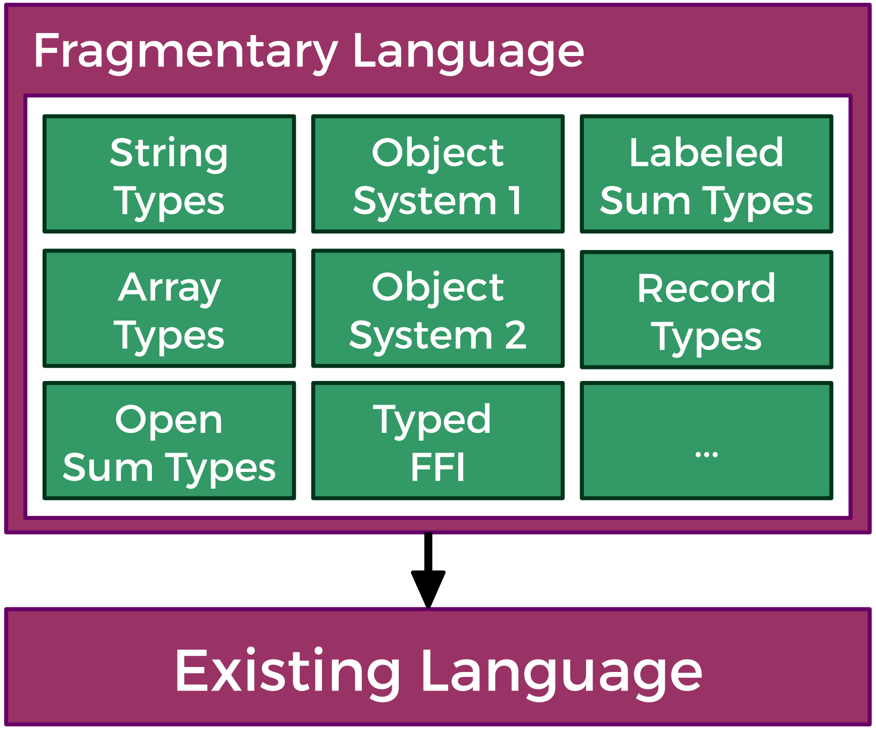

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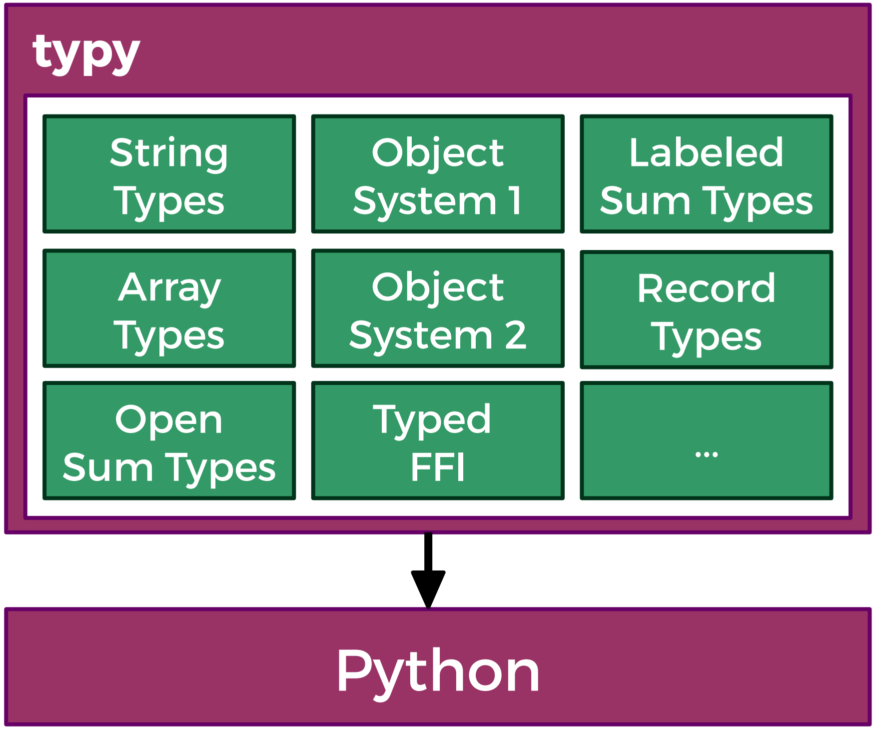

typy

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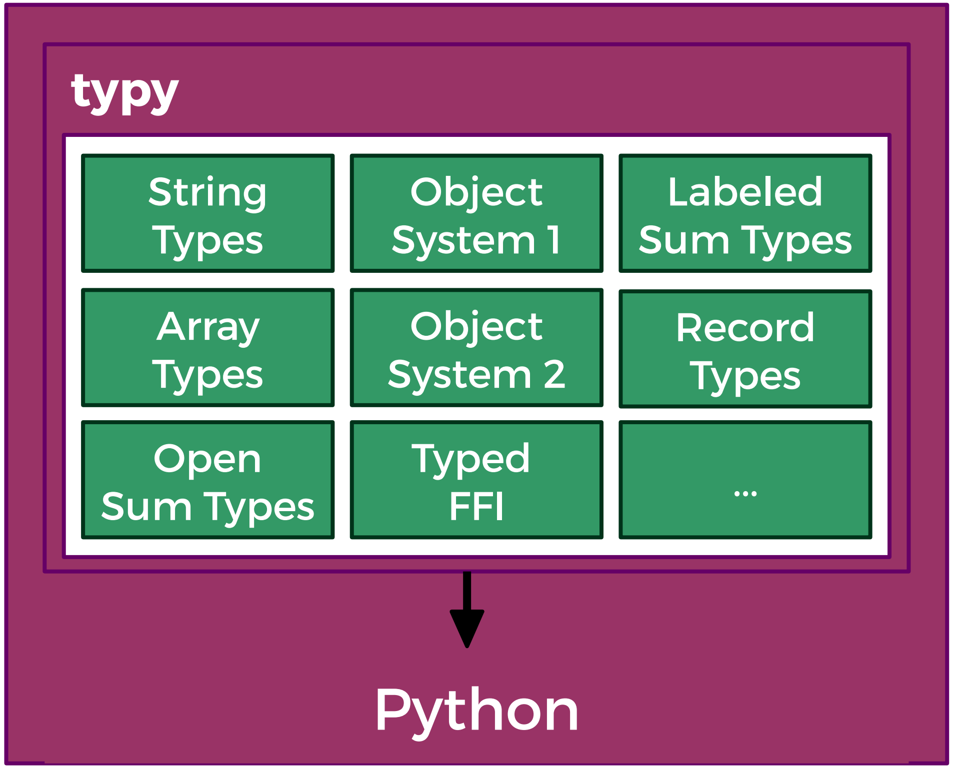
Python

The Implementation



Related Work

- **Extensible compilers and language workbenches**
  - No expression problem because syntax is fixed (+ some free tool support)
  - Determinism
  - Stability

- ***Metatheory a la carte*** *[Delaware et al]*
  - **typy** fragments *implement* the statics and dynamics
  - Future: extract typy from a specification in a proof assistant

- **Refinement types / pluggable type systems** (e.g. mypy)
  - These operate over a fixed dynamic semantics
  - **typy** fragments control both the static and dynamic semantics
  - Could layer on a fragmentary refinement system

- **Macro systems** (e.g. Racket, Scala)
  - **typy** fragments manipulate terms but also types
  - Delegation protocol is type-directed, not based on explicit invocation

Limitations & Future Work

- **Type theoretic foundations**
  - Started working on this, more interesting modular reasoning principles…

- **Typed internal language**
  - Use techniques from TIL compiler for ML

- **Hygiene**
  - Need a more disciplined binding structure in IL

- **More implementation work!**

http://github.com/cyrus-/typy

Conclusion

- Semantic fragments support **semantic extensions over a fixed concrete and abstract syntax**.

- Simple!

- You should consider organizing your next statically typed language (or, at least, its compiler) in this way.

- **typy** is a practical implementation of this concept that uses Python:
  - Python's syntax, unchanged
  - Python as the target language
  - Embedded into Python