A Practical, Typed Variant Object Model

Or, How to Stand On Your Head and Enjoy the View

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Object Encodings

- Record-Based Encodings

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    - Foundation for traditional OO languages

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  - Actor-based languages (Erlang)

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  - Foundation for traditional OO languages
  - Easier to type
  - Common [Cardelli '84] [Cook '89] ...
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  - Actor-based languages (Erlang)
  - Harder to type

Record-Based Object Encoding

(Scala)

```
object a {
}
```

(OCaml)

```
let a = {
}
```

Record-Based Object Encoding

(Scala)

```
object a {
 val v = 5
}
```

(OCaml)

```
let a = {
  v = ref 5
}
```

- Object fields are record fields

Record-Based Object Encoding

(Scala)

```
object a {
 val v = 5
 def mth(x:Int)
   :Int = { x+v }
 def foo(x:Unit){}
}
```

(OCaml)

```
let a = {
   v = ref 5;
   mth = fun self ->
      fun x -> x+!self.v;
   foo = fun () -> ()
}
```

- Object fields are record fields
- Methods are fields with functions

Record-Based Object Encoding

(Scala)

```
object a {
 val v = 5
 def mth(x:Int)
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 def foo(x:Unit){}
};
a.mth(3)
```

(OCaml)

```
let a = {
  v = ref 5;
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} in
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- Invocation projects methods

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- Object fields are record fields
- Methods are fields with functions
- Invocation projects methods
  - We ignore self-hiding for now.

Duality

Variants $\Longleftrightarrow$ Records

Variant-Based Encoding

(Scala)

```
object a {
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```

(OCaml)

```
let a = fun msg ->
  match msg with
    ...
```

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- Fields by closure

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```ocaml
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- Fields by closure
- Methods are other message handlers

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(Scala)

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 val v = 5
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in a (`mth (a,3))
```

- Fields by closure
- Methods are other message handlers
- Invocation is just message passing

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object a {
 val v = 5
 def mth(x:Int)
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```
let v = ref 5 in
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  match msg with
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  | `foo () -> ()
in a (`mth (a,3))
```

- Fields by closure
- Methods are other message handlers
- Invocation is just message passing
- But this doesn't typecheck!

Typing Variant Destruction

```
match v with
  | `Odd y -> y mod 2 = 1
  | `Dbl x -> x + x
```

- Typechecking variant destruction is tricky

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$: \mathtt{int} \cup \mathtt{bool}$

- Typechecking variant destruction is tricky
- Most languages (e.g. Caml) fail on unification
- Union types

Typing Variant Destruction

```
match `Dbl 2 with
  | `Odd y -> y mod 2 = 1
  | `Dbl x -> x + x
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$: \texttt{int} \cup \texttt{bool}$

- Typechecking variant destruction is tricky
- Most languages (e.g. Caml) fail on unification
- Union types are insufficient!

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match `Dbl 2 with
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- Union types are insufficient!
- Record construction is heterogeneously typed

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match `Dbl 2 with
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- Typechecking variant destruction is tricky
- Most languages (e.g. Caml) fail on unification
- Union types are insufficient!
- Record construction is heterogeneously typed
- Variant destruction is not

Typing the Variant Encoding

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- A couple new expression forms
- Weakly dependent types
- Precise polymorphism
- A whole-program typechecking pass

Typing the Variant Encoding

Our objective: a purely type-inferred variant-based object encoding

This can work! We just need...

- A couple new expression forms
- Weakly dependent types
- Precise polymorphism
- A whole-program typechecking pass

...and then we reap the benefits!

How We Get It: TinyBang

&

Onions

(Extensible,
type-indexed records)

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χ ->

Scapes

(Functions with
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Variant-Based Object Encoding

TinyBang

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‘dbl x -> x + x
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- Methods are scapes

Variant-Based Object Encoding

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Variant-Based Object Encoding

TinyBang

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(`dbl x -> x + x) `dbl 3
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- Methods are scapes: functions with patterns
- Invoke methods by passing messages

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Variant-Based Object Encoding

TinyBang

```
(`dbl x -> x + x) `dbl 3
```

- Methods are scapes: functions with patterns
- Invoke methods by passing first-class messages (just labeled data)

Many Methods: Onioning Scapes

```
`dbl x -> x + x
```

Many Methods: Onioning Scapes

```
(`dbl x -> x + x) &
(`odd y -> y mod 2 == 1)
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- Scapes are combined by *onioning*

Many Methods: Onioning Scapes

```
((`dbl x -> x + x) &
 (`odd y -> y mod 2 == 1))   (`dbl 2)
```

- Scapes are combined by *onioning*
- Application finds match

Many Methods: Onioning Scapes

```
((`dbl x -> x + x) &
 (`odd y -> y mod 2 == 1))  (`dbl 2)
```

```
object a {
  def dbl(x:Int):Int = { x + x }
  def pos(y:Int):Boolean = { y % 2 == 1 }
}
a.dbl(2)
```

Many Methods: Onioning Scapes

```
((`dbl x -> x + x) &
 (`odd y -> y mod 2 == 1))  (`dbl 2)
```

$$\Rightarrow \; 4$$

- Scapes are combined by *onioning*
- Application finds rightmost match (asymmetric)

Many Methods: Onioning Scapes

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(('dbl x -> x + x) &
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- Subsumes case expressions

Many Methods: Onioning Scapes

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$$\Rightarrow 4$$

- Scapes are combined by *onioning*
- Application finds rightmost match (asymmetric)
- Subsumes case expressions
- Generalizes First-Class Cases [Blume et. al. '06]

Typing the Onion

```
(`dbl x -> x + x) &
(`odd y -> y mod 2 == 1)
```

(`dbl int ∪ `odd int) -> (int ∪ bool)

- Simple union type loses alignment

Typing the Onion

```
(‘dbl x -> x + x) &
(‘odd y -> y mod 2 == 1)
```

```
(‘dbl int -> int) & (‘odd int -> bool)
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- Weakly dependent type

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- *Onion type* does not
- Weakly dependent type
- Relies heavily on polymorphism

Fields

- Pure variant model: get/set messages

Fields

```
('dbl x -> x + x) &
('odd y -> y mod 2 == 1) &
'Z 5
```

- ~~Pure variant model: get/set messages~~
- Hybrid model: variant methods, record fields

Fields

```
(`dbl x -> x + x) &
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`Z 5
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- Similar to type-indexed rows [Shields, Meijer '01]

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(`dbl x -> x + x) &
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- ~~Pure variant model: get/set messages~~
- Hybrid model: variant methods, record fields
- Similar to type-indexed rows [Shields, Meijer '01]
- Labels implicitly create cells

Fields

```
def o = (`dbl x -> x + x) &
        (`odd y -> y mod 2 == 1) &
        `Z 5
in o.Z
```

- ~~Pure variant model: get/set messages~~
- Hybrid model: variant methods, record fields
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- Labels implicitly create cells
- Field access by projection

Fields

```
def o = (`dbl x -> x + x) &
        (`odd y -> y mod 2 == 1) &
        `Z 5
in (`Z z -> z) o
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- Hybrid model: variant methods, record fields
- Similar to type-indexed rows [Shields, Meijer '01]
- Labels implicitly create cells
- Field access by projection/pattern match
- But what about self?

Naïve Self

```
def ticker =
  ‘x 0 &
  (‘inc _ ->
      self.x = self.x + 1 in self.x)
in ticker ‘inc ()
```

Naïve Self

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def ticker =
  `x 0 &
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       self.x = self.x + 1 in self.x)
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- Add `self to all parameters

Naïve Self

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  `x 0 &
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  - & is pattern conjunction

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def ticker =
  `x 0 &
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  - & is pattern conjunction
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def ticker =
  `x 0 &
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```

- Add `` `self `` to all parameters
  - & is pattern conjunction
- Add `` `self `` to all call sites
- Be happy?

Naïve Self: Type Problems

```
def obj =
  if something then
    (‘foo _ & ‘self s -> s ‘bar ()) &
    (‘bar _ -> 1)
  else
    (‘foo _ & ‘self s -> s ‘baz ()) &
    (‘baz _ -> 2)
in obj ‘foo ()
```

Naïve Self: Problems

$\alpha_{\textsc{Self}} =$

```
(`foo _ & `self α1 -> int) &
(`bar _ -> int)
    where α1 has `bar
```

$$\bigcup$$

```
(`foo _ & `self α2 -> int) &
(`baz _ -> int)
    where α2 has `baz
```

Naïve Self: Problems

$$\alpha_{\textsc{Self}} \quad <: \quad \begin{array}{l} (\texttt{`foo \_ \& `self } \alpha_1 \texttt{ -> int) \&} \\ (\texttt{`bar \_ -> int}) \\ \qquad \texttt{where } \alpha_1 \texttt{ has `bar} \end{array}$$

$$\alpha_{\textsc{Self}} \quad <: \quad \begin{array}{l} (\texttt{`foo \_ \& `self } \alpha_2 \texttt{ -> int) \&} \\ (\texttt{`baz \_ -> int}) \\ \qquad \texttt{where } \alpha_2 \texttt{ has `baz} \end{array}$$

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  - Sealing is meta-theoretic
- TinyBang
  - Sealing is encodable (no meta-theory)
  - Sealed objects can be **extended** and **resealed**

Sealing in TinyBang

```
def rec seal = obj ->
  obj &
  (msg -> obj (`self (seal obj) & msg)) in
def point =
  `x 2 & `y 4 &
  (`l1 _ & `self self -> self.x + self.y) in
def sealedPoint = seal point in
sealedPoint `l1 ()
...
```

Resealing Objects

```
...
def obj = seal (
  ‘x 0 &
  (‘inc _ & ‘self self ->
     self.x = self.x + 1 in self.x)) in
obj ‘inc (); obj ‘inc ();
def extobj = seal (
  obj &
  (‘dbl _ & ‘self self ->
     self.x = self.x + self.x in self.x)) in
extobj ‘dbl (); extobj ‘inc ()
```

$$x = 0$$

Resealing Objects

```
...
def obj = seal (
  `x 0 &
  (`inc _ & `self self ->
    self.x = self.x + 1 in self.x)) in
obj `inc (); obj `inc ();
def extobj = seal (
  obj &
  (`dbl _ & `self self ->
    self.x = self.x + self.x in self.x)) in
extobj `dbl (); extobj `inc ()
```

$$x = 1$$

Resealing Objects

```
...
def obj = seal (
  `x 0 &
  (`inc _ & `self self ->
     self.x = self.x + 1 in self.x)) in
obj `inc (); obj `inc ();
def extobj = seal (
  obj &
  (`dbl _ & `self self ->
     self.x = self.x + self.x in self.x)) in
extobj `dbl (); extobj `inc ()
```

$$x = 2$$

Resealing Objects

```
...
def obj = seal (
  `x 0 &
  (`inc _ & `self self ->
    self.x = self.x + 1 in self.x)) in
obj `inc (); obj `inc ();
def extobj = seal (
  obj &
  (`dbl _ & `self self ->
    self.x = self.x + self.x in self.x)) in
extobj `dbl (); extobj `inc ()
```

$$x = 4$$

Resealing Objects

```
...
def obj = seal (
  ‘x 0 &
  (‘inc _ & ‘self self ->
     self.x = self.x + 1 in self.x)) in
obj ‘inc (); obj ‘inc ();
def extobj = seal (
  obj &
  (‘dbl _ & ‘self self ->
     self.x = self.x + self.x in self.x)) in
extobj ‘dbl (); extobj ‘inc ()
```

$$x = 5$$

Resealing Objects

```
...
def obj = seal (...) in
obj 'inc (); obj 'inc ();
def extobj = seal (...) in
extobj 'dbl (); extobj 'inc ()
```

Resealing Objects

```
...
def obj = seal (...) in
obj `inc (); obj `inc ();
def extobj = seal (...) in
extobj `dbl (); extobj `inc ()
```

`inc ()

Resealing Objects

```
...
def obj = seal (...) in
obj `inc (); obj `inc ();
def extobj = seal (...) in
extobj `dbl (); extobj `inc ()
```

```
`self extobj & `inc ()
```

Resealing Objects

```
...
def obj = seal (...) in
obj ‘inc (); obj ‘inc ();
def extobj = seal (...) in
extobj ‘dbl (); extobj ‘inc ()
```

```
‘self obj & ‘self extobj & ‘inc ()
```

Resealing Objects

```
...
def obj = seal (...) in
obj ‘inc (); obj ‘inc ();
def extobj = seal (...) in
extobj ‘dbl (); extobj ‘inc ()
```

```
‘self obj & ‘self extobj & ‘inc ()
```

Other Features

```
def point = seal (‘x 0 & ‘y 0 &
  (‘l1 _ & ‘self self ->
     self.x + self.y)) in
def mixin = (‘nearZero _ & ‘self self ->
                        (self ‘l1 ()) <= 4) in
def mixedPoint = seal (point & mixin) in
mixedPoint ‘nearZero ()
```

- Mixins

Other Features

```
def point = ... in
def mixin = ((‘nearZero _ & ‘self self ->
                (self ‘l1 ()) <= 4)) in
def mixedPoint = seal (point & mixin) in
mixedPoint ‘nearZero ()
```

- Mixins
- Higher-order object extension

Other Features

```
def obj = seal (
  `x 0 & (`inc _ & `self self ->
    self.x = self.x + 1 in self.x)) in
def obj2 = seal (
  (obj &. `x) & `y 0 &
  (`inc _ & `self self ->
    self.y = self.y + self.x in self.y)) in
...
```

- Mixins
- Higher-order object extension
- Data sharing

Other Features

```
def obj = seal (
  ‘x 0 &
  (‘inc n:int & ‘self self ->
    self.x = self.x + n in self.x) &
  (‘inc n:unit & ‘self self ->
    self ‘inc 1)  in
obj (‘inc ()); obj (‘inc 4)
```

- Mixins
- Higher-order object extension
- Data sharing
- Overloading

Other Features

etc.

- Mixins
- Higher-order object extension
- Data sharing
- Overloading
- Classes, inheritance, etc.

Type Inference

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- Assign each subexpression a type variable

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- Derive initial constraint set over expression

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- Subtype constraint system
- Assign each subexpression a type variable
- Derive initial constraint set over expression
- Perform knowledge closure on constraints
- Check resulting closure for consistency
- **Soundness** is proven over inference system

Constraint Types

$$\textbf{int} \cup \textbf{unit}$$

Constraint Types

$$\textbf{int} \cup \textbf{unit}$$

$$\Updownarrow$$

$$\alpha \backslash \{\textbf{int} <: \alpha, \textbf{unit} <: \alpha\}$$

Constraint Closure

5 + 3

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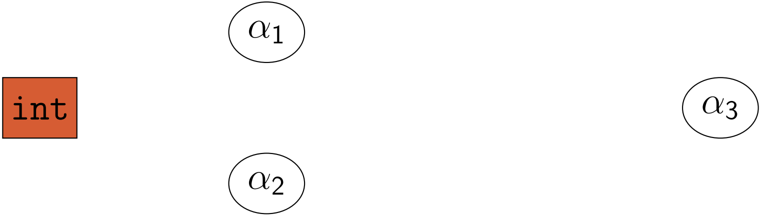
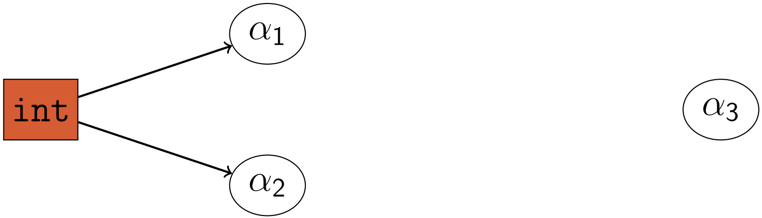
Constraint Closure

`5 + 3`



Constraint Closure

`5 + 3`



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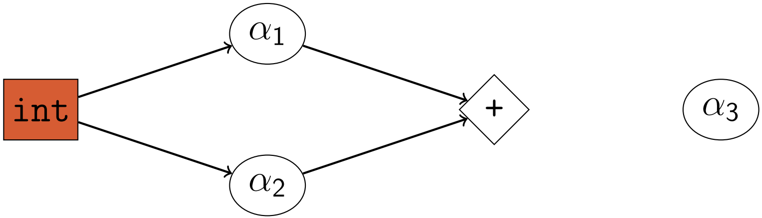

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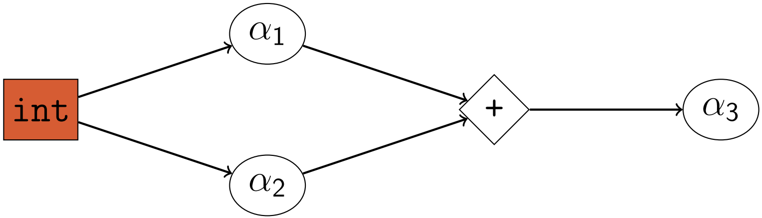

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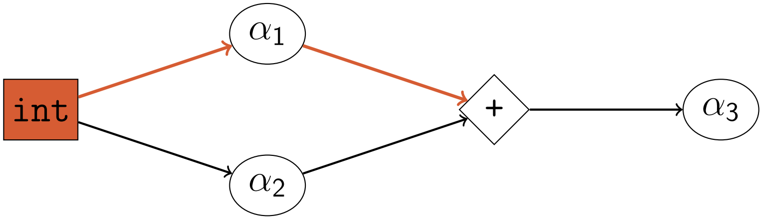

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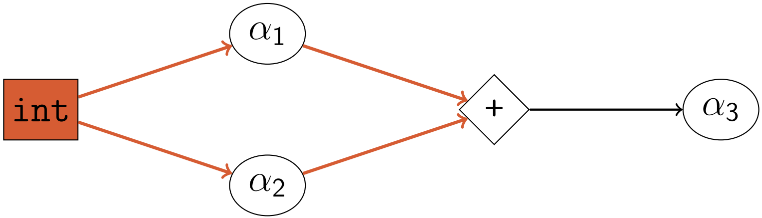

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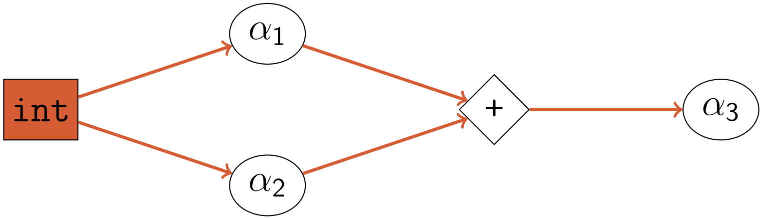

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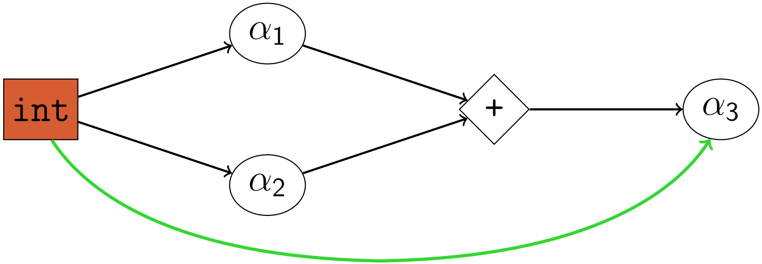

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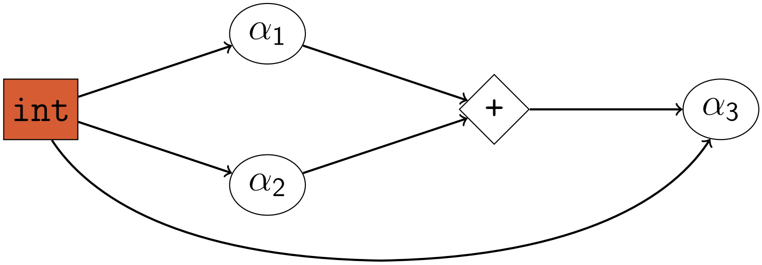

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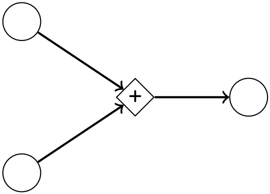

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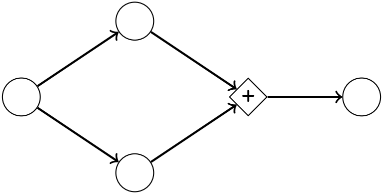

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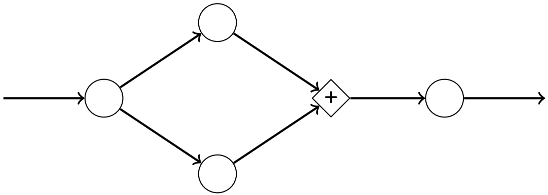

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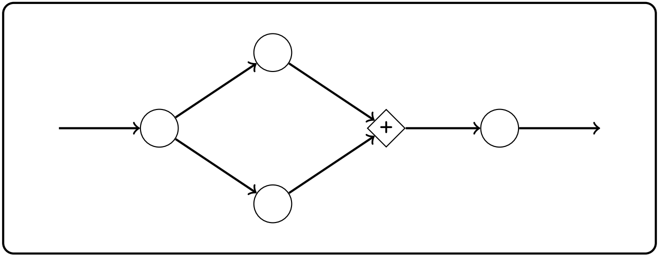

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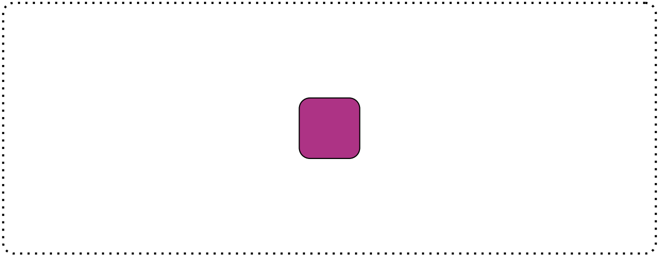

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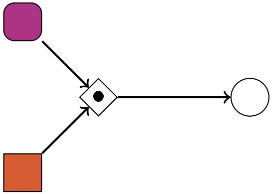

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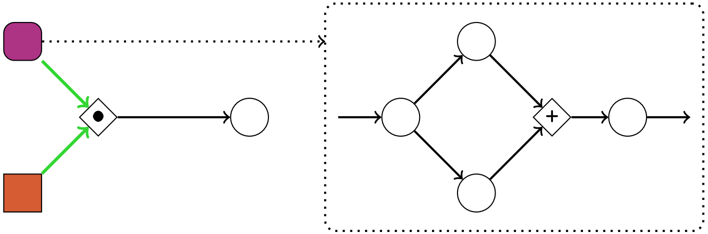

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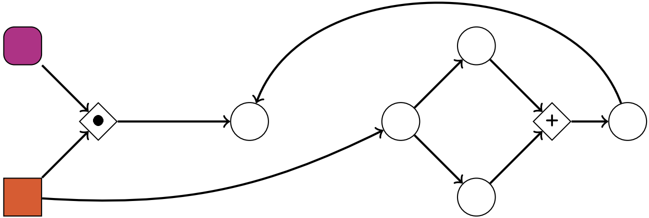

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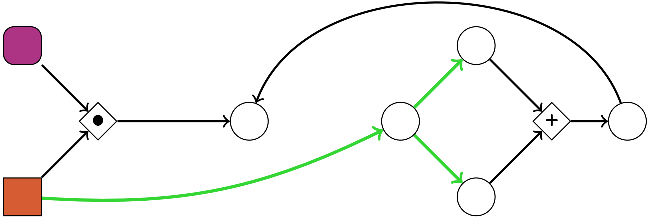

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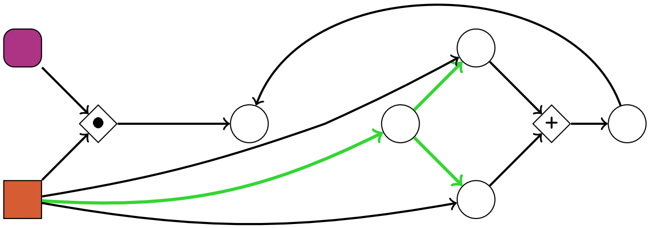

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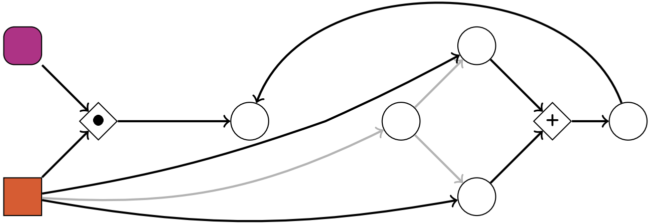

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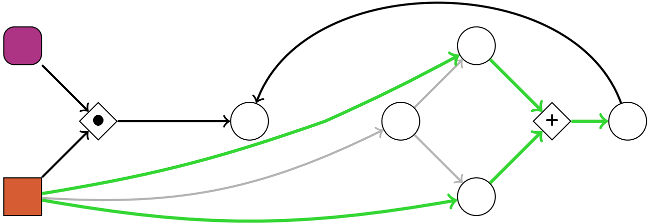

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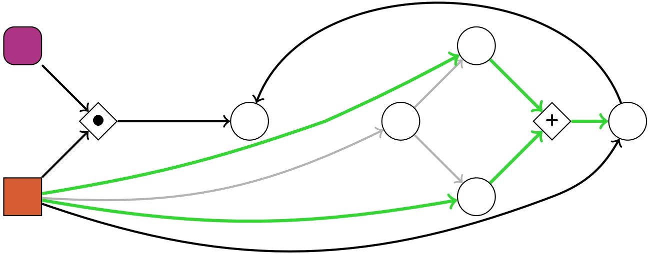

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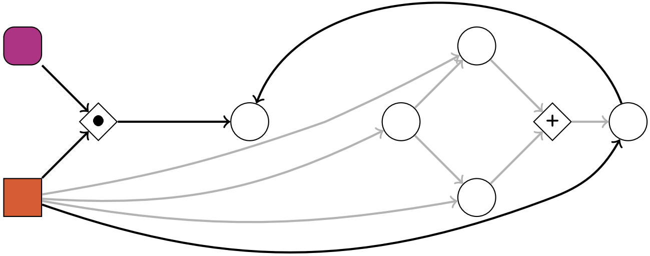

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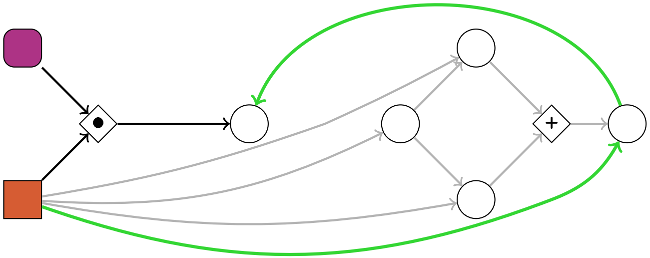

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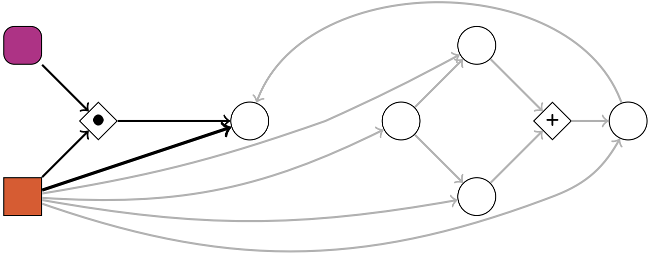
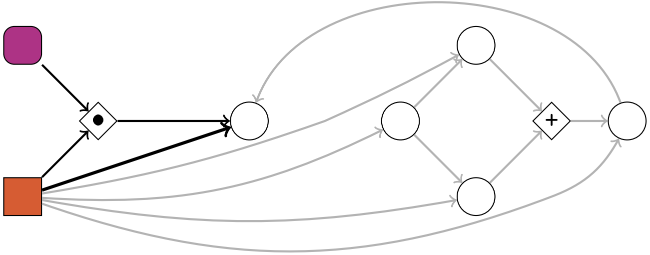


Application

`(x -> x + x) 5 :  int`



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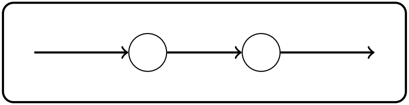

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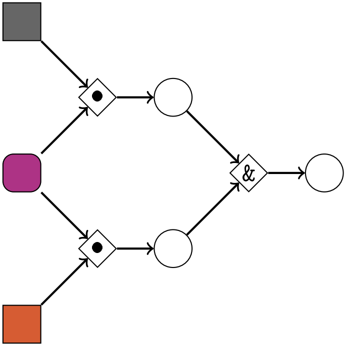

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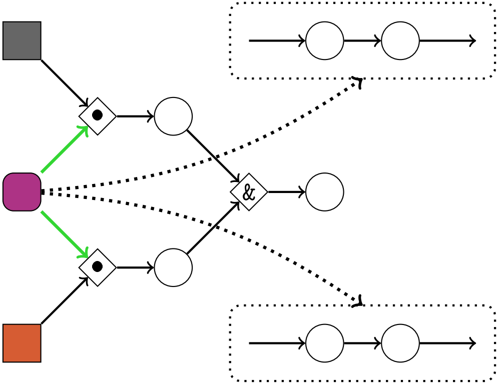

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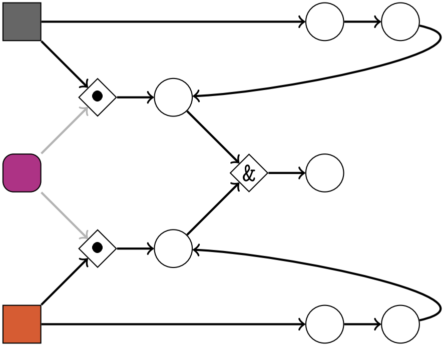

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Questions?