Unfolding ML datatype declarations without loops

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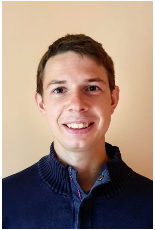

This talk

An OCaml feature we wanted: constructor unboxing.

A general (language-agnostic) problem we solved:
unfolding of (recursive) type declarations, in a terminating way.

Constructor unboxing

Single-constructor unboxing: in OCaml since November 2016

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type id = Id of int [@@unboxed]
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Extension proposed by Jeremy Yallop in March 2020:

OCaml RFC #14: constructor unboxing

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type id = Id of int [@@unboxed]
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```
type bignum =
| Small of int [@unboxed]
| Big of Gmp.t
```

(`int` and `(Big of Gmp.t)`: disjoint representations)

Head, head shape

We define the *head* of an OCaml value, in $\{\texttt{Imm}, \texttt{Block}\} \times \mathbb{Z}$, by:

- the head of an immediate is the immediate itself
  `head(42) = (Imm, 42)`
- the head of a block is its tag
  `head("foo") = (Block, Obj.string_tag) = (Block, 252)`

We define the *head shape* of a type as set of heads of its values:

$$\texttt{head}(\tau) = \{\texttt{head}(v) \mid v : \tau\}$$

Unboxing specification

```
type bignum =                                  match num with
| Small of int              (* Block 0 *)      | Small n -> ...
| Big of Gmp.t              (* Block 1 *)      | Big gmp -> ...
```

Unboxing constructors is valid if the head shapes remain disjoint.

```
type bignum =                                  match num with
| Small of int [@unboxed] (* Imm ℤ *)          | Small n -> ...
| Big of Gmp.t            (* Block 0 *)        | Big gmp -> ...
```

Constructors: runtime-checkable disjointness.
(Note: This morality is language-independent.)

Problem (1/3)

How to compute the head shape of a type?

(In presence of recursive type declarations)

Problem (2/3)

```
type 'a tree = Node of ('a * 'a tree) seq [@unboxed]
and 'a seq = Nil | Next of (unit -> 'a * 'a seq) [@unboxed]
type foo = Foo of int tree [@unboxed] | ...

  shape(int tree)
= shape((int * int tree) seq)
= shape(Nil) + shape(unit -> (int * int tree) * ... seq)
= Imm 0 + function_shape
```

Problem (2/3)

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Expanding a type definition is a β-reduction.
Call-by-name normal form... with arbitrary recursion.

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```

Expanding a type definition is a β-reduction.
Call-by-name normal form... with arbitrary recursion.

```
type t = U of u [@unboxed] | Bar
and u = T of t [@unboxed]
```

How to prevent nontermination?

Problem (3/3)

How to compute the (CBN-)normal form of a type modulo unboxing?

(In presence of recursive type declarations.)

This is useful for many static analyses of types:
head shape, immediacy, etc.

Attempt 1: rule out cycles statically

“Statically”: without expanding definitions.

(As done for type synonym/aliases.)

Problem: too restrictive

```
type 'a seq = ...

type 'a tree = Node of ('a * 'a tree) seq [@unboxed]
```

Attempt 2: prevent repetition of whole types

Keep track of type inputs, abort if they come again during expansion.

Problem: may loop in presence of non-regular type parameters.

```
type 'a bad = Loop of ('a * 'a) bad [@unboxed]
```

```
   int bad
→ (int * int) bad
→ ((int * int) * (int * int)) bad
→ ...
```

Attempt 3: prevent repetition of head constructors

Keep track of constructors that have already been expanded.
Abort if an expanded constructor comes again in head position.

Problem: too restrictive

```
type 'a id = Id of 'a [@unboxed]

type foo = Foo of int id id [@unboxed]
```

	`foo`	`[]`
$\rightarrow$	`int id id`	`[foo]`
$\rightarrow$	`int id`	`[foo, id]`
$\not\rightarrow$		

Solution: annotate (sub)expressions with expansion context

```
type 'a id = Id of 'a [@unboxed]
type 'a delay = Delay of 'a id [@unboxed]

type foo = Foo of int delay delay [@unboxed]

   foo[]
→ int[foo] delay[foo] delay[foo]
→ int[foo] delay[foo] id[foo,delay]
→ int[foo] delay[foo]
→ int[foo] id[foo,delay]
→ int[foo]
```

Track when subexpressions *appeared* in the type,
not how they came to head position.

Solution: annotate (sub)expressions with expansion context

```
type 'a id = Id of 'a [@unboxed]
type 'a delay = Delay of 'a id [@unboxed]

type foo = Foo of int delay delay [@unboxed]
```

```
  foo[]
→ int[foo] delay[foo] delay[foo]
→ int[foo] delay[foo] id[foo,delay]
→ int[foo] delay[foo]
→ int[foo] id[foo,delay]
→ int[foo]
```

Track when subexpressions *appeared* in the type,
not how they came to head position.

(Stephen Dolan remarks: similar to cpp termination control.)

Termination proof

Suprisingly tricky!
https://github.com/ocaml/ocaml/pull/10479#issuecomment-876644067
With help from Stephen Dolan and Irène Waldspurger.

Completeness ?

Our criterion: "Recursive calls" in type definitions
must be guarded by a *boxed* constructor.

(Complete for the pure *first-order* calculus.)

Summary

Unboxed constructors: an optimization requiring type analysis.

Normalizing types in presence of cyclic references.

Thanks! Questions?