An extended type error slicer

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Programming languages

- Programming languages are languages designed to instruct computers to do computations.
- A language is usually defined by its 2 levels: syntactic and semantic.
- The static semantics of a language is given by types.
  For example, usually the expression 1 is of type int (integer).
  Typing rules are used to associate types to syntactic expressions.

Well-typed programs can be guaranteed not to "go wrong" *([SSW06, Mil78])*

The earlier type inference algorithms for SML

- (Most of) the implementations of SML use type inference algorithms based on the well known $\mathcal{W}$ **algorithm** (or its variants such as $\mathcal{M}$ or $\mathcal{U}$AE).
  (The type inference algorithm used by the SML/NJ compiler is based on the $\mathcal{W}$ algorithm.)
- All of these algorithms suffer a left-to-right bias.
- A consequence of this bias is that the type errors reported by these algorithms can sometimes be far away from the real error locations.

Algorithm $\mathcal{W}$

$\mathcal{W}(A, e) = (S, \tau)$ where A is a set of type assumptions, e is an expression, S is a substitution and τ is a type.

(If $\mathcal{W}(A, e) = (S, \tau)$ then (SA, τ) is a typing of e.)

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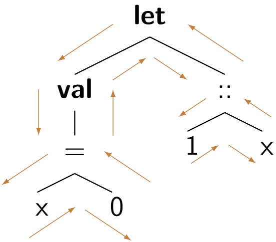
Example: let the expression f be **let val** x = 0 **in** 1 :: x **end**



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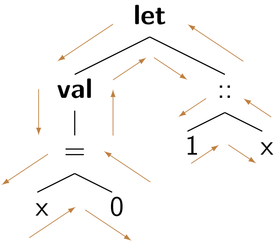

If we assume that the type of 0 is different from the type of a list then the expression f is not typable.

The $\mathcal{W}$ algorithm fails when trying to infer a type for 1 :: x.

Using Standard ML of New Jersey v110.52 we obtain the following error message:

```
Error: operator and operand don't agree [literal]
  operator domain: int * int list
  operand:         int * int
  in expression:
    1 :: x
```

Left-to-right bias

An example using the SML/NJ compiler

(1) We intended to write:

```
val g =
fn x =>
   fn y =>
      let
         val f = if x
                 then fn z => z + 1
                 else fn z => z
         in f y
      end
```

(2) We wrote:

```
val g =
fn x =>
   fn y =>
      let
         val f = if y
                 then fn z => z + 1
                 else fn z => z
         in f y
      end
```

(1) for example g true 2 evaluates to 3 and g false 2 evaluates to 2.

(2) Using Standard ML of New Jersey v110.52 we obtain the following error message:

```
Error: operator and operand don't agree [literal]
  operator domain: int
  operand:         bool
  in expression:
    f y
```

Left-to-right bias

An example using the SML/NJ compiler

Recall:

```
val g =
fn x =>
   fn y =>
      let
          val f = if y
                  then fn z => z + 1
                  else fn z => z
          in f y
      end
```

In our simple example the programmer's error is not far away from the reported error.

But it can happen that y is constrained to be of type bool because of some code located far away from the location proposed by SML/NJ (or in another file).

New type inference algorithms

How to overcome this left-to-right bias?

The earlier inference algorithms use a unification algorithm during their process.

In some new algorithms [SSW06, HW04], the two processes are split:

- First, the type inference algorithm **generates type constraints** for a given expression.
  Let us consider the following declaration d: **val** x = 1.
  One of the constraints generated for d is that the type of x has to be equal to the type of 1, but the type inferred for x is not actually int.
- Then, it applies a **unification algorithm** to the generated set of constraints.

The type error slicing project

- The type error slicer developed by Haack and Wells [HW04] is based on this new kind of algorithm (generation of type constraints then unification).
- It uses **intersection types** instead of for all types (it allows compositional analysis).
- As for similar projects [Wan86, HJSA02, SSW06], **justifications** are associated to the generated constraints to keep track of the type deductions.

  A label is associated to (almost) each term:

  The label ^{l} is associated to the expression 1: 1^l.

  At this point a constraint labelled by ^{l} is generated specifying that the type of 1 is equal to the integer type.
- A type error is identified to a (minimal) set of justifications.

The type error slicing project

- The slicer developed by Haack and Wells goes further by computing a **minimal slice** from a minimal set of justifications.
- These minimal slices are designed so that they present all and only the information needed by the programmer to repair its errors.
- Their slicer handles a small extension of the terms typable by HM.

Haack and Wells's slicer meet the criteria listed in [YWTM00]: **correct**, **precise**, **succinct**, **non-mechanical** (for example, no artificial type variable), **source-based** (this is almost true, the slices actually contain some extra parentheses and dots), **unbiased**, **comprehensive** (every location needed by the programmer to solve his error is reported).

3 main steps:

- Generations of the type constraints for to a given term.
- Enumeration of the minimal unsatisfiable sets of constraints. The enumerator makes an extensive use of a unification algorithm.
- Computation of a slice from each minimal set of justifications (extracted from a minimal unsatisfiable set of constraints).

Type error slicing
Example

Recall:

```
val g =
fn x =>
   fn y =>
      let
          val f = if y
                  then fn z => z + 1
                  else fn z => z
          in f y
      end
```

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```

Haack and Wells's slicer computes two slices (two minimal type errors):

```
(..    y => (.. val f = if y then fn z => (z + (..)) else (..) .. f y ..) ..)
```

```
(..    y =>
        (.. val f = if y then fn (..) => ((..) + (..)) else fn z => z
         .. f y ..) ..)
```

Type error slicing
Example

Recall:

```
val g =
fn x =>
   fn y =>
      let
         val f = if y
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      end
```

We can solve the errors by replacing y by x.

We can also solve the errors by replacing z + 1 by not z.

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```

An extended slicer

- We consider new programming features such as data types. Example:

```
datatype Nat = Z | S of Nat
and LC = VAR of Nat | ABS of LC | APP of (LC * LC)
```

- In **val** x = D true, D can be a **value variable** or a **value constructor**.
- We don't want to make assumptions over the status of the identifiers and we want our slicer to be compositional.

An extended slicer
Example

Recall:

```
val g =
fn x =>
   fn y =>
      let
          val f = if y
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                  else fn z => z
          in f y
      end
```

Here is one of the slice computed by Haack and Wells's slicer:

```
(..   y => (.. val f = if y then fn z => (z + (..)) else (..) .. f y ..) ..)
```

This slice wouldn't be a slice if y was a value constructor.

In our extended slicer we specify some **constraints** for the slice to exist: y, f and z have to be value variables and not value constructors.

For example if we have a declaration such as **datatype** t = y, we wouldn't obtain the slice presented above.

```
let
    datatype t = y
    val g = fn x =>
               fn y =>
                  let
                      val f = if y
                              then fn z => z + 1
                              else fn z => z
                  in f y
                  end
in ()
end
```

Using Standard ML of New Jersey v110.52 we obtain the following error message:

```
Error: test expression in if
       is not of type bool [tycon mismatch]
  test expression: ?.t
  in expression:
    if y then (fn z => z + 1) else (fn z => z)
```

Programmer's error might be in the datatype declaration.
One of the slice we obtain is:

```
(..
datatype (..) = (..y..)
..
val f = if (..) then fn (..(..) => (..) + (..)..) else fn (..z => z..)..f y
..)
```

An extended slicer
Example

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Future work

Remark: As for Haack and Wells we also highlight the slices into the original piece of code.

- Finish the technical parts of our slicer (finish the implementation, test the implementation, improve the syntax of the slices, improve the highlighting).
- Prove the different properties (termination, correctness, minimisation, . . .) of the different modules of our slicer.
- Extend the framework to a bigger language.

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