High-level error messages for modules through diffing

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```
module String_map = Map.Make(String)(String)
```

```
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Error: This module is not a functor; it has type
       sig
         type key = String.t
         type 'a t = 'a Map.Make(String).t
         val empty : 'a t
         val is_empty : 'a t -> bool
         val mem : key -> 'a t -> bool
         val add : key -> 'a -> 'a t -> 'a t
         val update : key -> ('a option -> 'a option) -> 'a t -> 'a t
         val singleton : key -> 'a -> 'a t
        ...(elided for the slide)
       end
```

```
module String_map = Map.Make(String)(String)

Error: The functor application is ill-typed.
       These arguments:
         String String
       do not match these parameters:
         functor (Ord : Map.OrderedType)  -> ...
  1. Module String matches the expected module type Map.OrderedType
  2. The following extra argument is provided
         String : ...(elided)
```

Modules: theory vs practice

Theory: Most complex part of the language

Practice: Shallow hierarchy of submodules, a handful of functors with few arguments

A typical example

A common example of functors (such as Ocamlgraph)

```
module Graph(Vertex:VERTEX)(Edge:EDGE) = struct ... end
```

Common errors

- Unnecessary argument

```
module G = Graph(Label)(Vertex)(Edge)
```

- Forgotten argument:

```
module G = Graph(Edge)
```

- Wrong argument:

```
module G = Graph(Label)(Edge)
```

All those errors are frequent during refactorings.

Classical error messages consider only the last alternative:

```
module G = Graph(Label)(Vertex)(Edge)

Error: Signature mismatch:
       Modules do not match:
         sig type t = string end
       is not included in
         VERTEX
       The value `label' is required but not provided
       The value `create' is required but not provided
       The type `label' is required but not provided
       The value `equal' is required but not provided
       The value `hash' is required but not provided
       The value `compare' is required but not provided
```

A little bit of perspective

For errors, we need to keep the *multi-application* context

Consider the arguments as two lists:

```
Graph(Label)(Vertex)(Edge)
```

```
module Graph(Vertex:VERTEX)(Edge:EDGE) = ...
```

use diffing between lists or strings: addition, deletion, or change.

Unnecessary argument

```
module G=Graph(Label)(Vertex)(Edge)

Error: The functor application is ill-typed.
       These arguments:
         Label Vertex Edge
       do not match these parameters:
         functor  (Vertex : VERTEX) (Edge : EDGE) -> ...
  1. The following extra argument is provided
      Label : sig type t = string end
  2. Module Vertex matches the expected module type VERTEX
  3. Module Edge matches the expected module type EDGE
```

Missing argument

```
module G=Graph(Edge)

Error: The functor application is ill-typed.
       These arguments:
          Edge
       do not match these parameters:
         functor (Vertex : VERTEX) (Edge : EDGE) -> ...
  1. An argument appears to be missing with module type VERTEX
  2. Module Edge matches the expected module type EDGE
```

Wrong argument

```
module G=Graph(Label)(Edge)

Error: The functor application is ill-typed.
       These arguments:
         Label Edge
       do not match these parameters:
         functor (Vertex : VERTEX) (Edge : EDGE) -> ...
  1. Modules do not match:
       Label : sig type t = string end
     is not included in
       VERTEX
     ...(elided for the slide)
  2. Module Edge matches the expected module type EDGE
```

How does this work?

String diffing

Error classes seen this far: Addition, Deletion, Change

Those are classical errors in string diffing

String diffing is everywhere: spellchecking, fuzzy search, control version, DNA sequence matching, ...

String diffing – details

Typical operations:

- Addition: A B C D
- Deletion: A B ~~C~~ D
- Change: A B ~~F~~ C D
- Swap: A B C D (C ⟷ D)

Well-studied topic:

- many distances: Levenstein, LCS, Hamming, ...
- many algorithms: Wagner-Fischer, Myers diff, Hirschberg's algorithm, ...

String diffing – details

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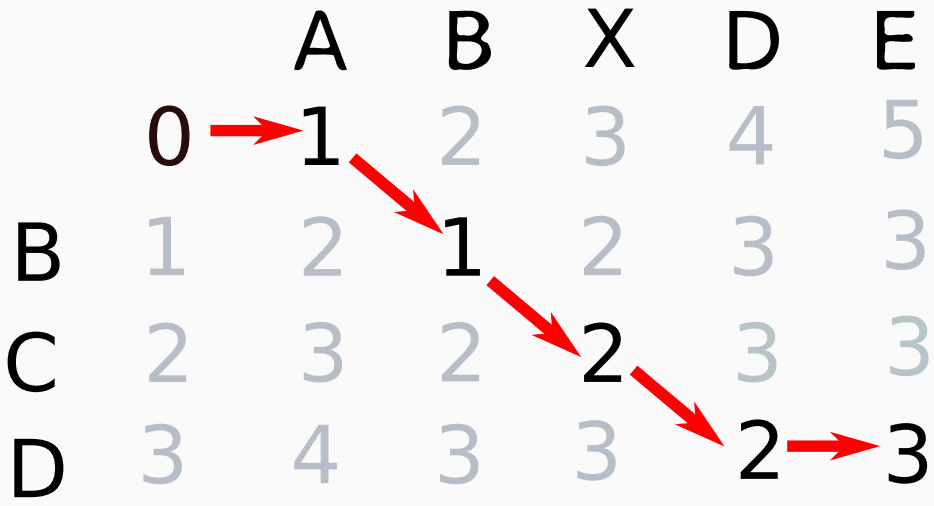
Wagner-Fischer illustrated



Our choice

Dynamically-sized variant of the Wagner-Fischer algorithm for computing distance with addition-deletion-change

- Argument comparison: OCaml typechecker comparison used as a black box
- Complexity: $O(\max(|\mathrm{arguments}|, |\mathrm{parameters}|)^2)$
- implemented as a patch on the OCaml compiler:
  `https://github.com/ocaml/ocaml/pull/9331`

Unreasonably complicated error

```
module A = Seq module A' = Complex
module B = Option module B' = Bigarray
module C = Result module C' = Bool
module D = Char module D' = Uchar
module E = Sys module E' = List
module F = Bytes module F' = Map.Make
module G = String module G' = Unit
module H = Marshal module H' = Obj
```

Unreasonably complicated error

```
module Little_functor =
    (A: module type of A) (B: module type of B)
    (C: module type of C) (D: module type of D)
    (E: module type of E) (F: module type of F)
    (G: module type of G) (H: module type of H)
    = struct end
```

Unreasonably complicated error

```
module E = Little_functor(A)(A)(B)(C')(E)(F')(G)(H)(H')
```

```
These arguments:
  A A B C'  E F' G H H'
do not match these parameters:
  functor (A : ...)  (B : ...) (C : ...(C)) (D : ...(D)) (E : ...)
  (F : ...(F)) (G : ...) (H : ...)  -> ...
1. Module A matches the expected module type
2. The following extra argument is provided: ...(elided)
3. Module B matches the expected module type
4. Modules do not match: C' : ...(elided)
5. An argument appears to be missing ...(elided)
6. Module E matches the expected module type
7. Modules do not match: F' ...(elided)
8. Module G matches the expected module type
9. Module H matches the expected module type
10. The following extra argument is provided H' : ...(elided)
```

Dependent functors?

```
module type f =
  functor
    (B:sig type x type y type u=x type v=y end)
    (Y:sig type yu = Y of B.u end)
    (Z:sig type zv = Z of B.v end)
   -> sig end
module F: f =
  functor
    (X:sig type x type y end)
    (Z:sig type zv = Z of X.y end)
   -> struct end
```

Dependent functors?

```
Error: Signature mismatch:
       Modules do not match:
         functor (X : ...(X))  (Z : ...(Z)) -> ...
       is not included in
         functor (B : ...(B)) (Y : ...(Y)) (Z : ...(Z)) -> ...
```

1. Module types ...(X) and ...(B) match
2. An argument appears to be missing with module type
   ...(Y) = sig type yu = Y of B.u end
3. Module types ...(Z) and ...(Z) match

Dynamically-sized?

Functors are complicated, they can be variadic in OCaml:

```
module F(X:sig
  module type t
  module M:t
end) = X.M
module Ft = struct
  module M = F
  module type t = module type of F
end
```

```
F(Ft)(Ft)(Ft)(Ft)...
```

Our modified Wagner-Fischer algorithm handles those cases (and yet always terminates).

What about swaps?

Hard to present well in text output.

We may consider a subcase where all arguments are here:

```
Graph(Edge)(Vertex)
```

Hypothetical error message:

```
The functor Arguments appears to be in the wrong order.
Did you mean Graph(Vertex)(Edge)?
```

Does this scale?

A question of performances?

- Quadratic module comparisons
- Errors are for human. Human are slow.
- Which effect matters?

A not that small functor

- A 26 argument functor, with all stdlib modules involved

```
These arguments:
  A A B C'  E F' G H H' I J  L M N' O O' P  R S T' U' V W W X Y Z Z
do not match these parameters:
  functor (A : ...)  (B : ...) (C : ...(C)) (D : ...(D)) (E : ...)
  (F : ...(F)) (G : ...) (H : ...)  (I : ...) (J : ...) (K : ...(K))
  (L : ...) (M : ...) (N : ...(N)) (O : ...)  (P : ...) (Q : ...(Q))
  (R : ...) (S : ...) (T : ...(T)) (U : ...(U)) (V : ...) (W : ...)
  (X : ...) (Y : ...) (Z : ...)  -> ...
```

- 100 ms with ocamlopt

```
module M = F
    (Ft)(Ft)(List)(Ft)(Ft)(Ft)(List)(Ft)(Ft)(List)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Arg)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Float)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Gc)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Map)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Seq)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Queue)(Ft)(Ft)(Ft)(Ft)(Ft)
    (Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)(Ft)
```

300 ms later

These arguments:

Ft Ft **List** Ft Ft Ft **List** Ft Ft **List** Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft **Arg** Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Float Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft **Gc** Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft **Map** Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft **Seq** Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft **Queue** Ft Ft Ft Ft Ft Ft

Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Bigarray Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft Ft

Bounty

If you have existing code (before the 27 August 2020), with functors with more than ten arguments, we are offering a bounty of one drink.[1]

[1] Mirage-generated code does not count

Conclusion and future works

Take-away

- Diffing for functor application and inclusion
- non-optimized implementation of the Wagner-Fischer

Future works

- Signature difference
  - ground work is already implemented
  - The user interface needs to be written.
- Moving to other structural types (in OCaml: objects, polymorphic variants)
- Tying everything together (tree diffing)

The End