Tracking which types are principally known in OCaml

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What is principality ?

```
> ocaml --help
Usage: ocaml <options> <files>
Options are:
    ...
    -principal  Check principality of type inference
    -no-principal  Do not check principality of type inference (default)
    ...
```

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A principal typing in S for a term M is a typing for M which somehow represents all other possible typings in S for M

J. B. Wells

An example of principal type

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let id = fun x → x
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- `unit → unit`

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- `'a → 'a`

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let f x (y : < m : 'a. 'a → 'a >) =
    ignore (
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`x = y`	⇒ `x : <m : 'a. 'a -> 'a>`	`x#m 3`	⇒ `x : <m : int -> 'b>`
`x#m 3`	⇒ principality warning	`x = y`	⇒ Fails

The type of `x` was not principal when typing `x#m 3`.

Principality warning with constructors

```
type 'a ta = C of 'a | A
type tb = C of int | B



let id x =
    let _ = C x in x
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type 'a ta = C of 'a | A
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(* val id :  int -> int *)
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type 'a ta = C of 'a | A
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let id x =
    let _ = [A; C x] in x
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Principality with labels

```
let foo (f : a:int → b:int → int) : int = ...

(* val bar : (a:int → b:int → int) → int *)
let bar f =
    foo f + f ~b:1 ~a:2
```

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let foo (f : a:int → b:int → int) : int = ...

(* val bar : (a:int → b:int → int) → int *)
let bar f =
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```

- Left to right ⇒ warning
- Right to left ⇒ error

Principality with first-class modules

```
(* val foo : ((module S) → 'a) → 'a * 'a *)
let foo bar =
    (bar (module M1 : S),
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Types have levels

```
type int = O | S of int

type bool = True | False

let foo x =
    let bar (y : _ → _) z = (z, [x; y]) in
    bar x
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Types have levels

int^1

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Introducing int

Types have levels

int^1 $\quad$ $bool^2$

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Introducing `bool`

Types have levels

int^1 $bool^2$

$?^3$

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type int = 0 | S of int

type bool = True | False

let foo x =
    let bar (y : _ → _) z = (z, [x; y]) in
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Introducing x

Types have levels

int^1 $bool^2$ $?^4$ $?^4$

$?^3$

$\_ \rightarrow^4 \_$

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let foo x =
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$?^5$

Introducing y and z

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int^1 $\quad$ $bool^2$ $\quad$ $?^4$ $\quad$ $?^4$

$?^3$ $\quad$ $\_ \rightarrow^4 \_$

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Typing [x; y]

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$?^3 = \_ \rightarrow^4 \_$

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$?^3$ $\_ \to^3 \_$

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$\_ \text{ list}^5$

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`[x; y]`

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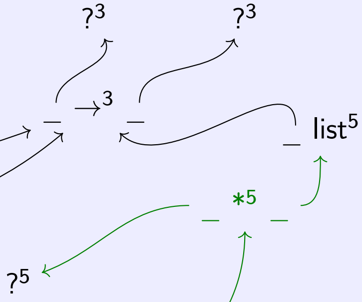

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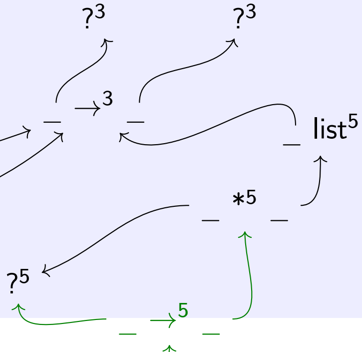


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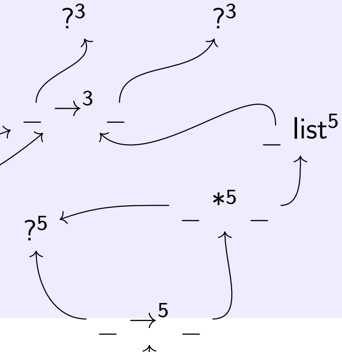


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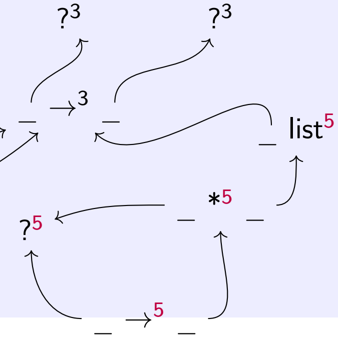


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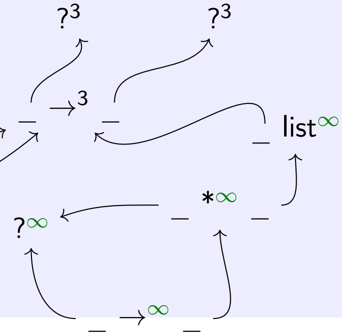


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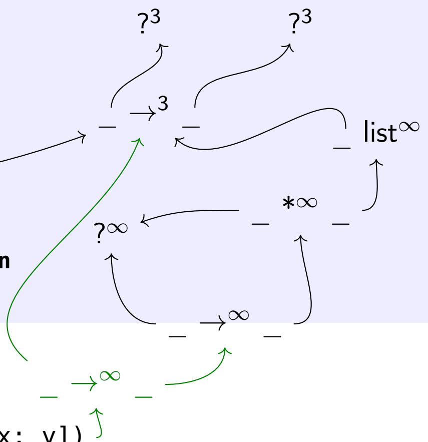


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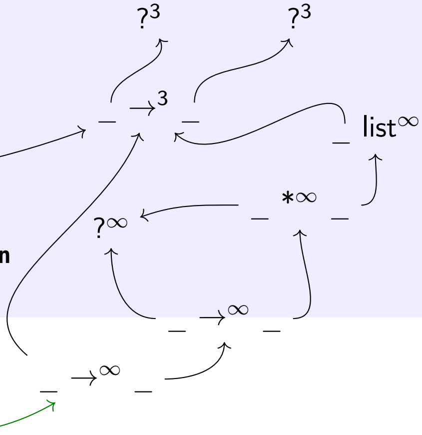

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$\_ \rightarrow {}'a \rightarrow {}'a * \_$ list

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Important notice :

- Allows easy error detection/reporting :

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- Also works with GADTs !

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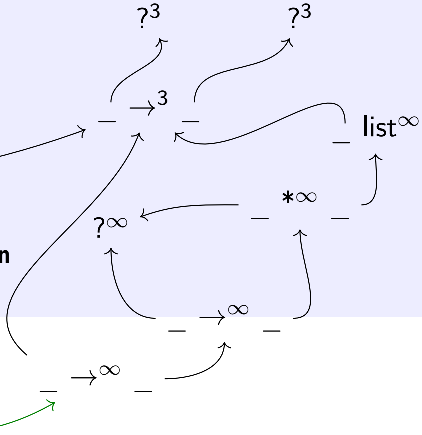

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$\_ \rightarrow 'a \rightarrow 'a * \_\ \mathsf{list}$

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`x#m 3`	$\Rightarrow$ principality warning	`x = y`	$\Rightarrow$ Fails

The type of `x` was not principal when typing `x#m 3`, because the level of `.` is not ∞.

What about y ?

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let f (y : <m : 'a. 'a → 'a>) =
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Does this code raise a warning ?

What about y ?

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let f (y : <m : 'a. 'a → 'a>) =
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Does this code raise a warning ?

No, because

$$\texttt{y : <m : 'a.}^{\infty}\ \texttt{'a ->}^{\infty}\ \texttt{'a>}^{\infty}$$

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Unification Ex : `f x` Levels are propagated.	

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Code infered from type can be :

- Labelled arguments
- Constructor/record disambiguation
- First-class modules
- Modular implicits (?)

1. Principality, definition and use in OCaml
2. Annotating types with levels
3. How to use levels for principality
4. What about modular implicits ?

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implicit module PInt = struct ... end
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let () =
    print 3;
    print [1; 2; 3];
    print "Hello world\n"
```

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Current principality tracing in OCaml cannot handle such a feature.

Types have levels

int^1 $bool^2$

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type bool = True | False

let foo x =
    let bar (y : _ → _) z = (z, [x; y]) in
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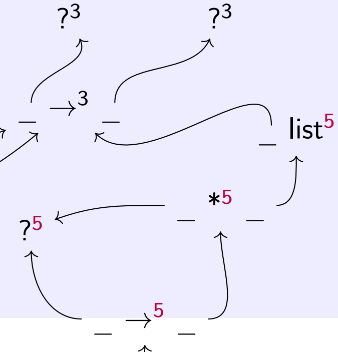


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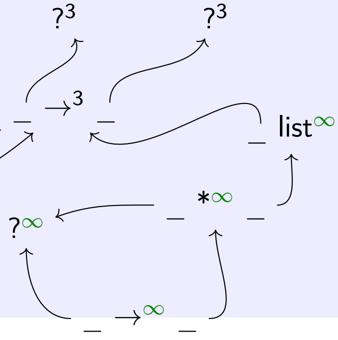


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What if we didn't want types to become principal

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implicit module M = struct
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    let d = ...
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(* val f : a:int → b:int → int *)
let f = default ()
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(* val f : a:int → b:int → int *)
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(* val _ : int *)
let _ = f ~b:2 ~a:1
```

A fix ?

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    let _ f ~a:1 ~b:2 in f
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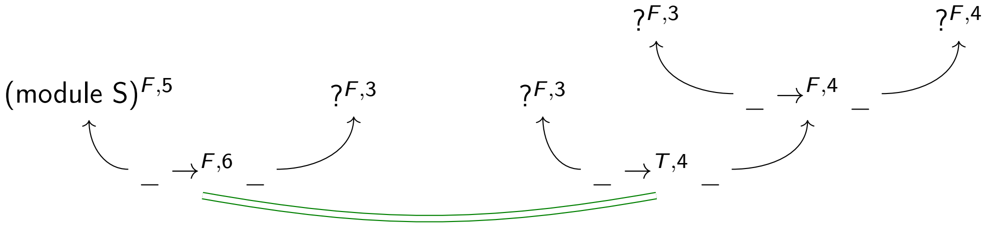
```
let fail f = id f ~b:1 ~a:1
```

```
              ^^
Error: This function is applied to arguments
       in an order different from other calls.
       This is only allowed when the real type is known.
```

Unification with a boolean



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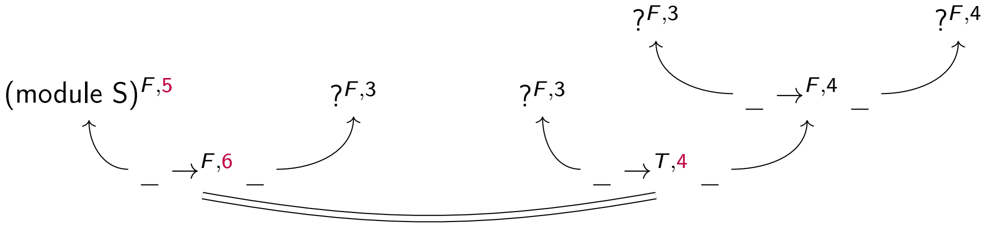

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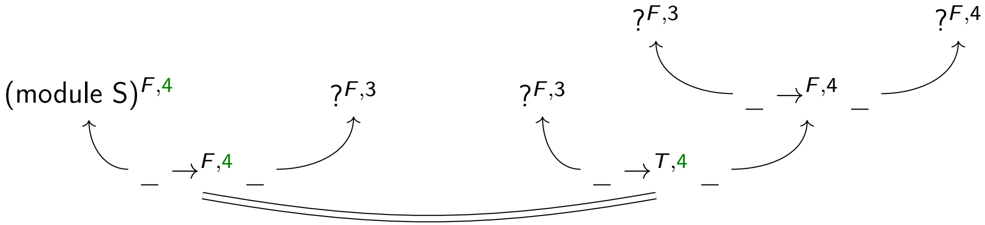

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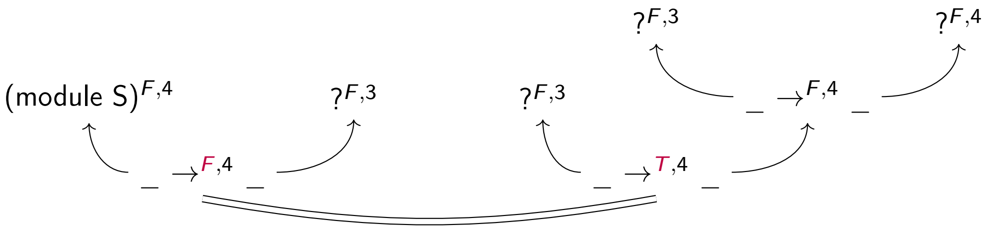

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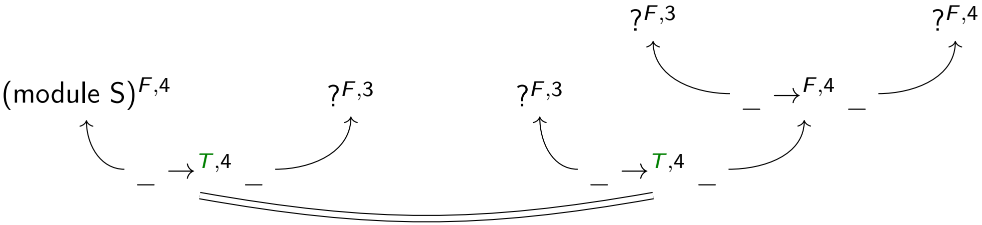

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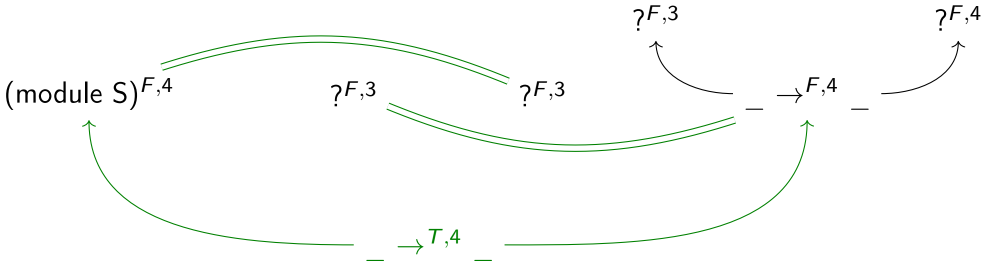

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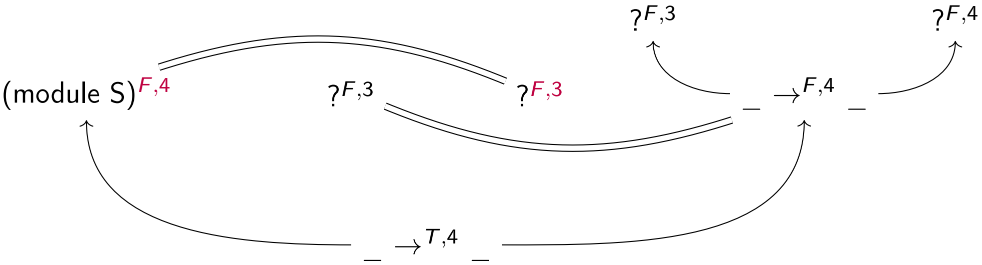

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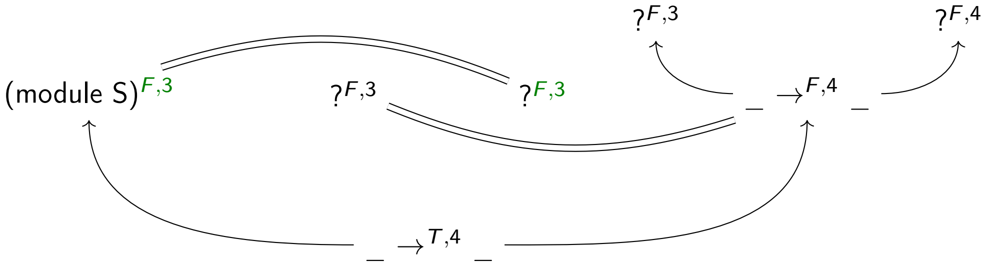

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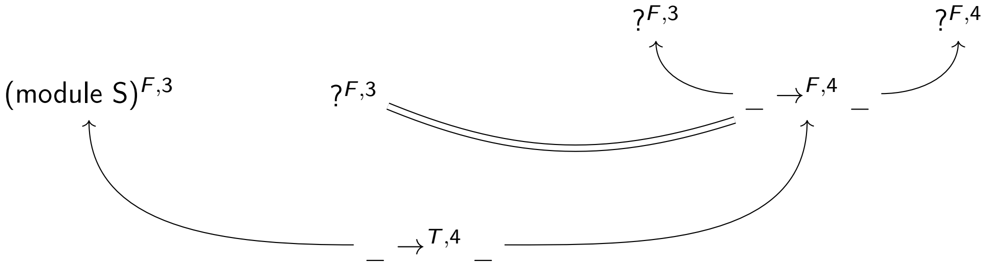

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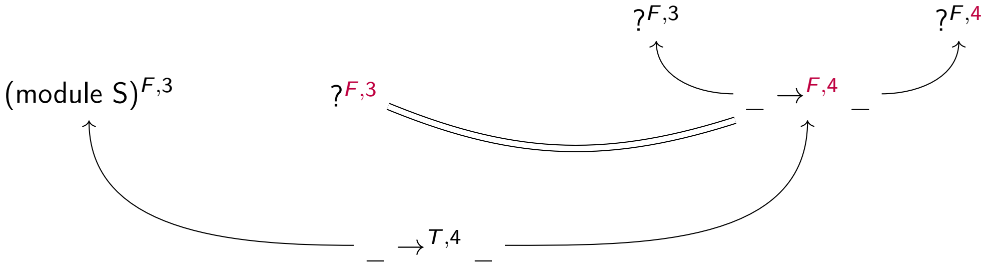

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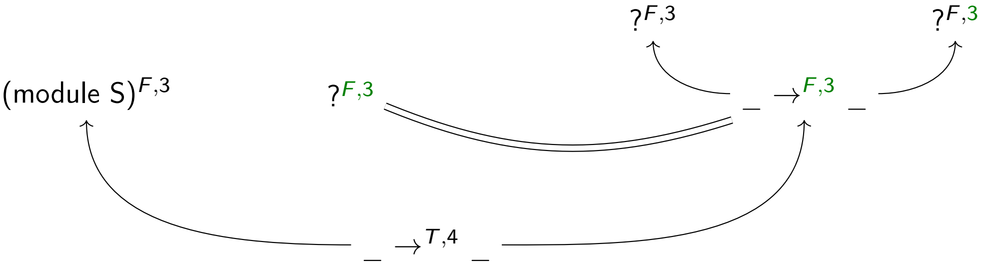

Unification with a boolean

$$
\begin{tikzcd}
& & & ?^{F,3} & & ?^{F,3} \\
(\text{module S})^{F,3} & & & & \_ \to^{F,3} \_ \arrow[ul, bend left] \arrow[ur, bend right] & \\
& & \_ \to^{T,4} \_ \arrow[ull, bend left] \arrow[urr, bend right] & & &
\end{tikzcd}
$$

Questions ?

Do you have any questions ?