Kindly Bent To Free Us

Gabriel Radanne Peter Thiemann

December 6, 2018

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val Tls_lwt.of_t : Tls_lwt.Unix.t -> in * out
(* Turn a file descr into input/output channels *)
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let fd : Tls_lwt.Unit.t = .....
let input, output = Tls_lwt.of_t fd
... (* read some things *)
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let%lwt c = Lwt_io.write output "thing" in (*Oups*)
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- Closures
- Monads
- Existential types
- ...

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What we really need is to enforce linearity.

Many places in OCaml where enforcing linearity is useful:

- IO (File handle, channels, network connections, . . .)
- Protocols (With session types! Mirage libraries)
- One-shot continuations (effects!)
- Transient data-structures
- C-style “struct parsing”
- . . .

Goals:

- Complete and principal type inference
- Impure strict context
- Works well with type abstraction
- Play balls with various other ongoing works (Effects, Resource polymorphism, . . .)

Non Goals:

- Support every linear code pattern under the sun
- Design associated compiler optimisations/GC integration (yet)

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The Affe language

Types and Behaviors

In Affe, the behavior of a variable is determined by its type:

```
type channel : A (* channel is Affine! *)


let with_file s f =
  let c = open_channel s
  let c = f c in
  close_channel c
val with_file : string -> (channel -> channel)


let () =
  let r = ref None in
  with_file "thing"
    (fun c -> r := Some c ; c) (* ✘ No! *)
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Inference at work

Infer unrestricted in case of duplication:

```
let f = fun c -> r := Some c ; c
val f : ('a : U) . 'a -> 'a
```

The kinds so far

So far, two kinds:

- **A** Affine types: can be used at most once
- **U** Unrestricted types

Additionally, we have:

$$\mathbf{U} \leq \mathbf{A}$$

Inference at work

What about closures?

```
let f = fun a -> fun b -> (a, b)
val f : 'a -> 'b -> 'a * 'b (* ? *)
```

Inference at work

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```
let f = fun a -> fun b -> (a, b)
val f : ('a : 'k) => 'a -> 'b -{'k}> 'a * 'b
```

Inference at work

```
let app f x = f x
val app :
  'k1 < 'k2 =>
  ('a -{'k1}> 'b) -> 'a -{'k2}> 'b
```

Closer look at type declarations

You can annotate the kinds on type declarations.

Vanilla OCaml references are fully unrestricted:

```
type ('a : U) ref : U = ...
```

We can also have constraints on kinds. The pair type operator:

```
type * : (k1 < k) & (k2 < k) => k1 -> k2 -> k
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More interesting example

Mixing with abstraction:

```
module AffineArray : sig
  type -'a w : A
  val create :
    ('a : U) . int -> 'a -> 'a w
  val set : 'a w -> int -{A}> 'a -{A}> 'a w

  type +'a r : U
  val freeze : 'a w -> 'a r
  val get : int -> 'a r -> 'a
end
```

The calculus

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Expressions

$$
\begin{aligned}
e ::= {} & c \mid x \mid (e\ e') \mid \lambda x.e \\
& \mid \texttt{let}\ x = e\ \texttt{in}\ e' \\
& \mid (K\ e) \mid \texttt{elim}_K\ e
\end{aligned}
$$

Type Expressions

$$
\begin{aligned}
\tau ::= {} & \alpha \mid \tau \xrightarrow{\mathsf{k}} \tau \mid (\tau^*)\ \mathrm{t} \\
k ::= {} & \kappa \mid \ell \in \mathcal{L}
\end{aligned}
$$

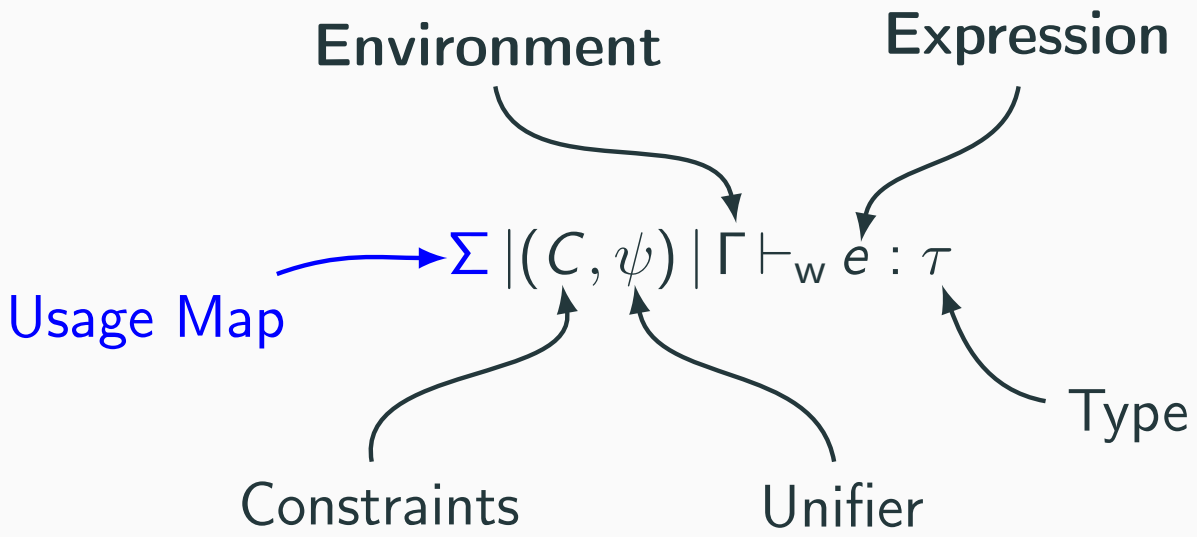
Constraints are only acceptable in schemes:

$$\sigma ::= \forall \kappa^* \forall (\alpha : k)^* . (C \Rightarrow \tau)$$
$$\theta ::= \forall \kappa^* . (C \Rightarrow k_i^* \to k)$$

The constraint language in schemes is limited to list of inequalities:

$$C ::= (k \leq k')^*$$

Typing


Environment
Expression
$\Sigma \mid (C, \psi) \mid \Gamma \vdash_w e : \tau$
Usage Map
Type
Constraints
Unifier

Variables can be kind-polymorphic and all their instances might not have the same kinds.

$\Longrightarrow$ We must track the kinds of all use-sites for each variable.

Use maps (Σ) associates variables to multisets of kinds and are equipped with three operations:

$$\Sigma \cap \Sigma' \qquad \Sigma \cup \Sigma' \qquad \Sigma \leq k$$

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When typechecking (e1, e2):

- $\Sigma_1 \,|(C_1, \psi_1)\,|\, \Gamma \vdash_{\mathsf{w}} e_1 : \tau_1$
- $\Sigma_2 \,|(C_2, \psi_2)\,|\, \Gamma \vdash_{\mathsf{w}} e_2 : \tau_2$
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Constraints

A slightly more general context: $\mathcal{C}_{\mathcal{L}}$ is the constraint system:

$$C ::= (\tau_1 \leq \tau_2) \mid (k_1 \leq k_2) \mid C_1 \wedge C_2 \mid \exists \alpha . C$$

where $k ::= \kappa \mid \ell \in \mathcal{L}$ and $(\mathcal{L}, \leq_{\mathcal{L}})$ is a complete lattice.

Respect, among other things:

$$\frac{\ell \leq_{\mathcal{L}} \ell'}{\vdash_{\mathsf{e}} (\ell \leq \ell')} \qquad \vdash_{\mathsf{e}} (k \leq \ell^{\top}) \qquad \vdash_{\mathsf{e}} (\ell^{\bot} \leq k)$$

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Example : $\lambda f.\lambda x.((f\ x), x)$

Raw constraints:

$$(\alpha_f : \kappa_f)(\alpha_x : \kappa_x)\ldots$$

$$(\alpha_f \leq \gamma \xrightarrow{\kappa_1} \beta) \wedge (\gamma \leq \alpha_x) \wedge (\beta * \alpha_x \leq \alpha_r) \wedge (\kappa_x \leq \mathbf{U})$$

We unify the types and discover new constraints:

$$\alpha_r = (\gamma \xrightarrow{\kappa_3} \beta) \xrightarrow{\kappa_2} \gamma \xrightarrow{\kappa_1} \beta * \gamma$$

$$(\kappa_x \leq \mathbf{U}) \wedge (\kappa_\gamma \leq \kappa_x) \wedge (\kappa_x \leq \kappa_r) \wedge (\kappa_\beta \leq \kappa_r) \wedge (\kappa_3 \leq \kappa_f) \wedge (\kappa_f \leq \kappa_1)$$

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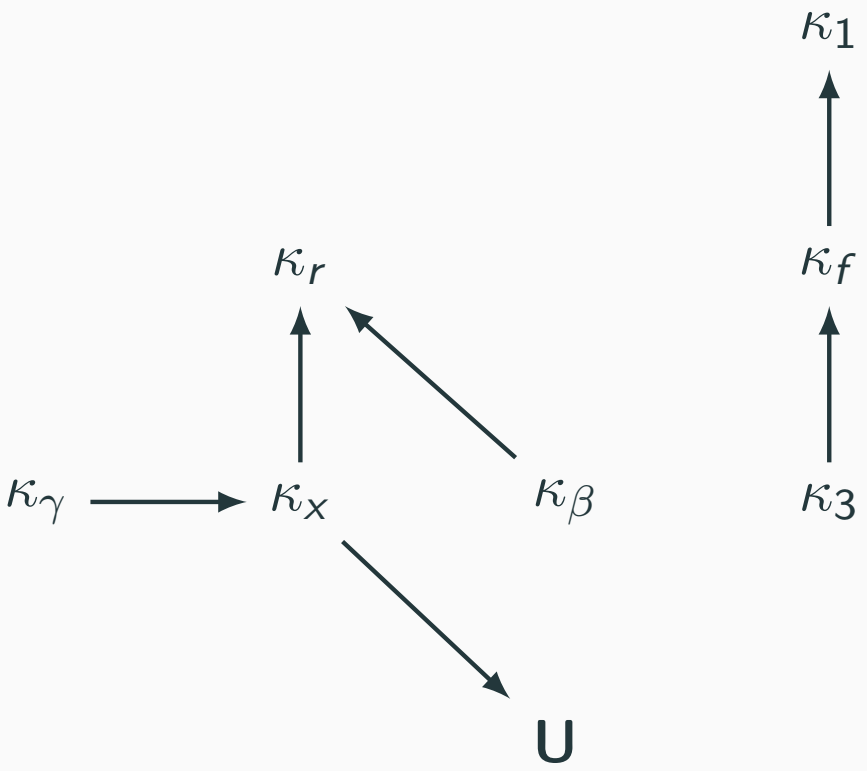

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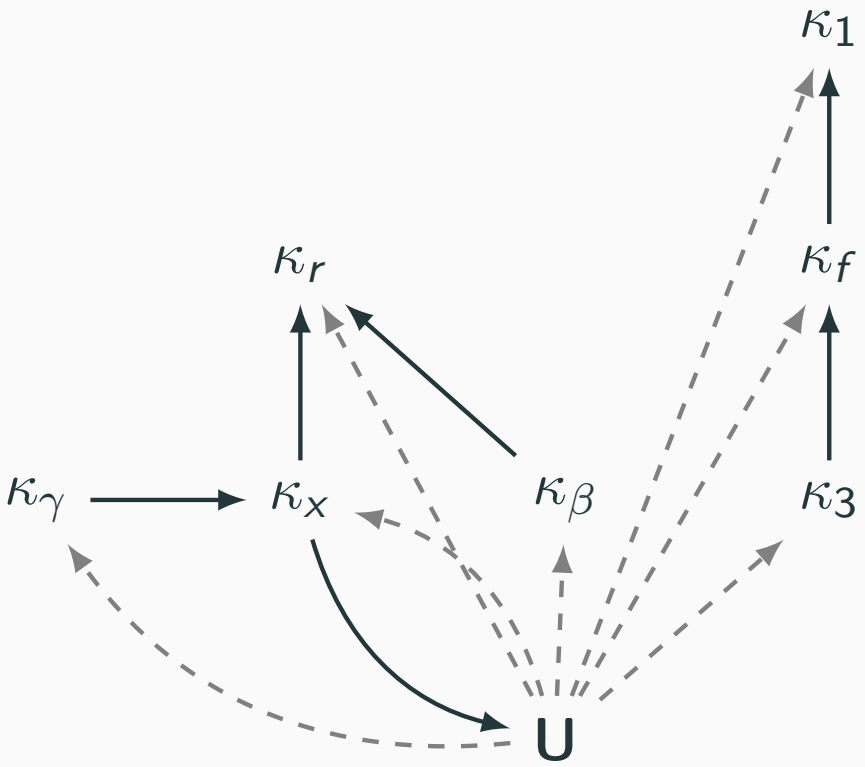

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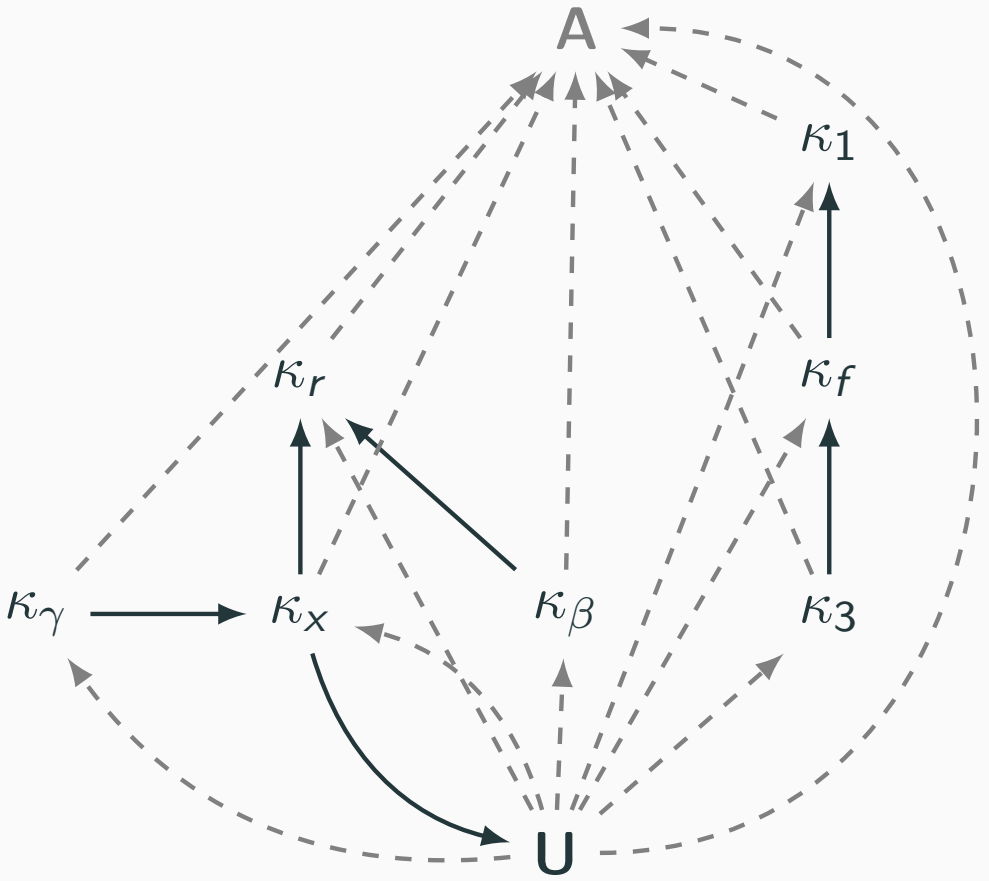

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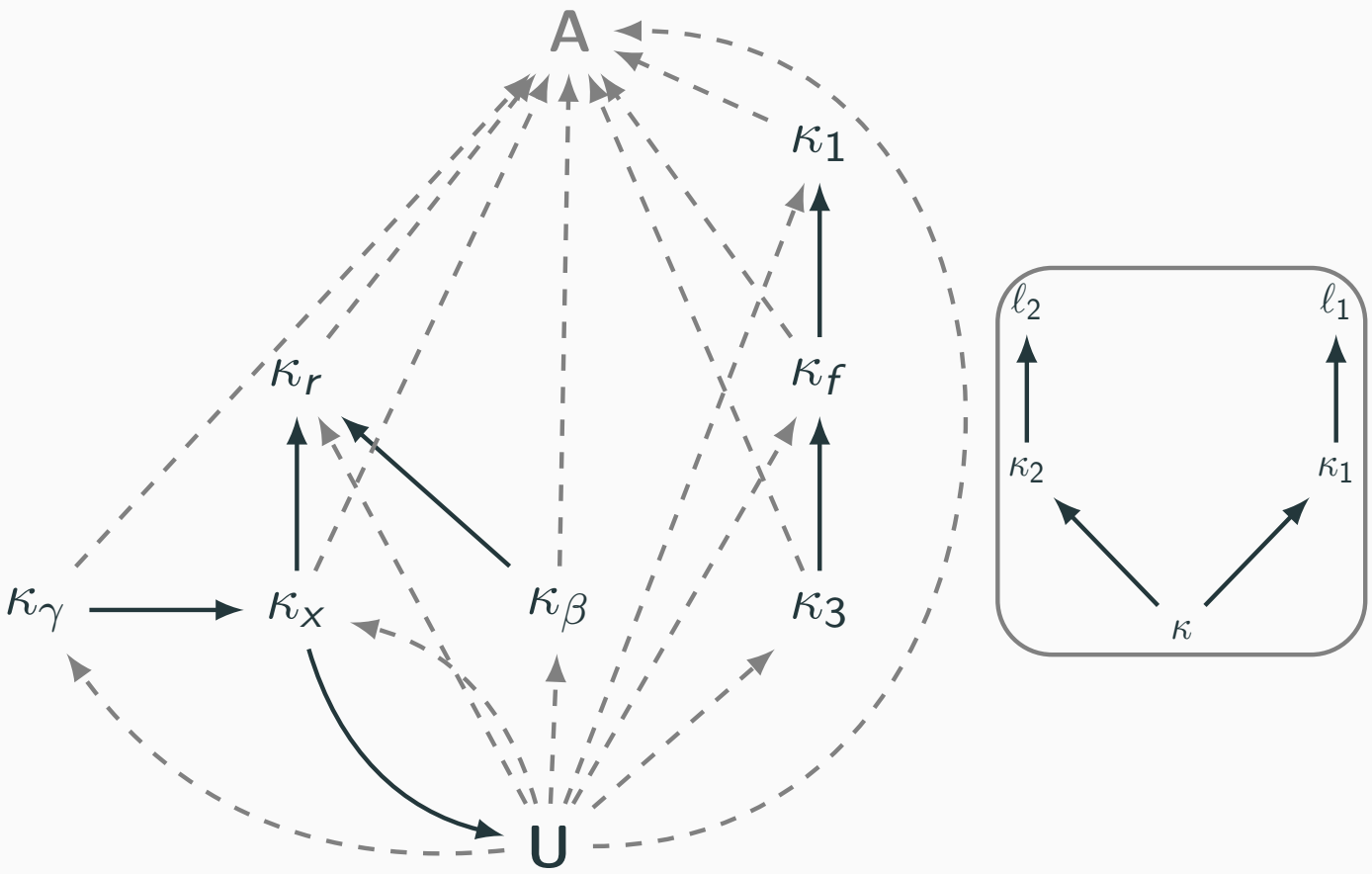

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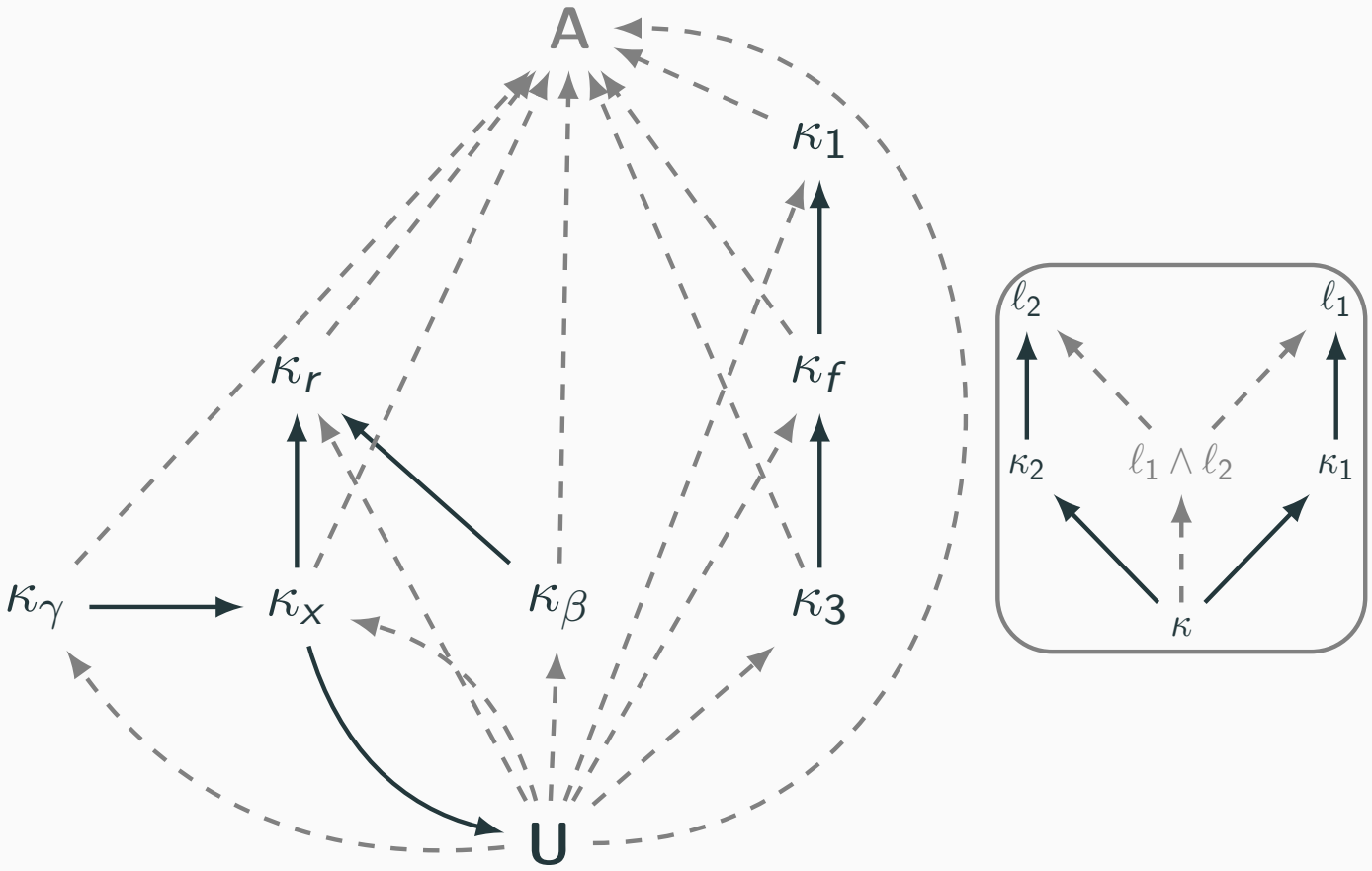

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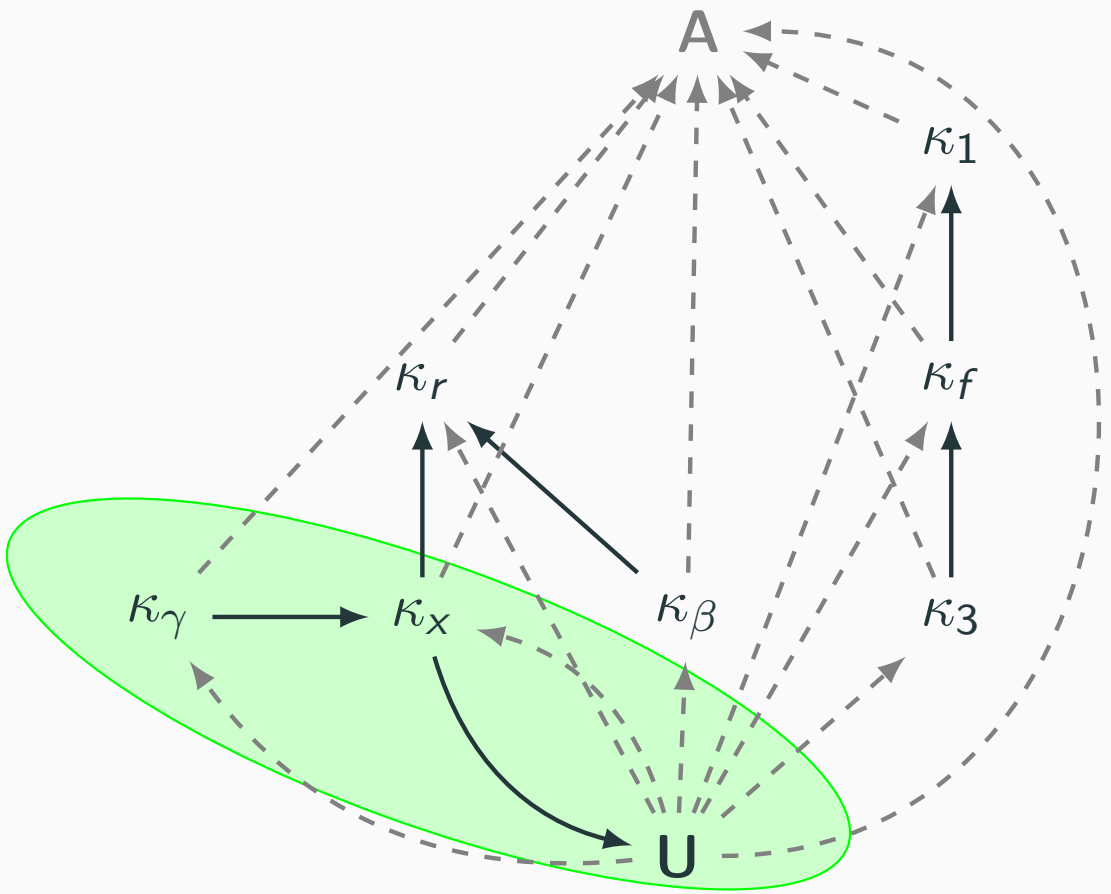

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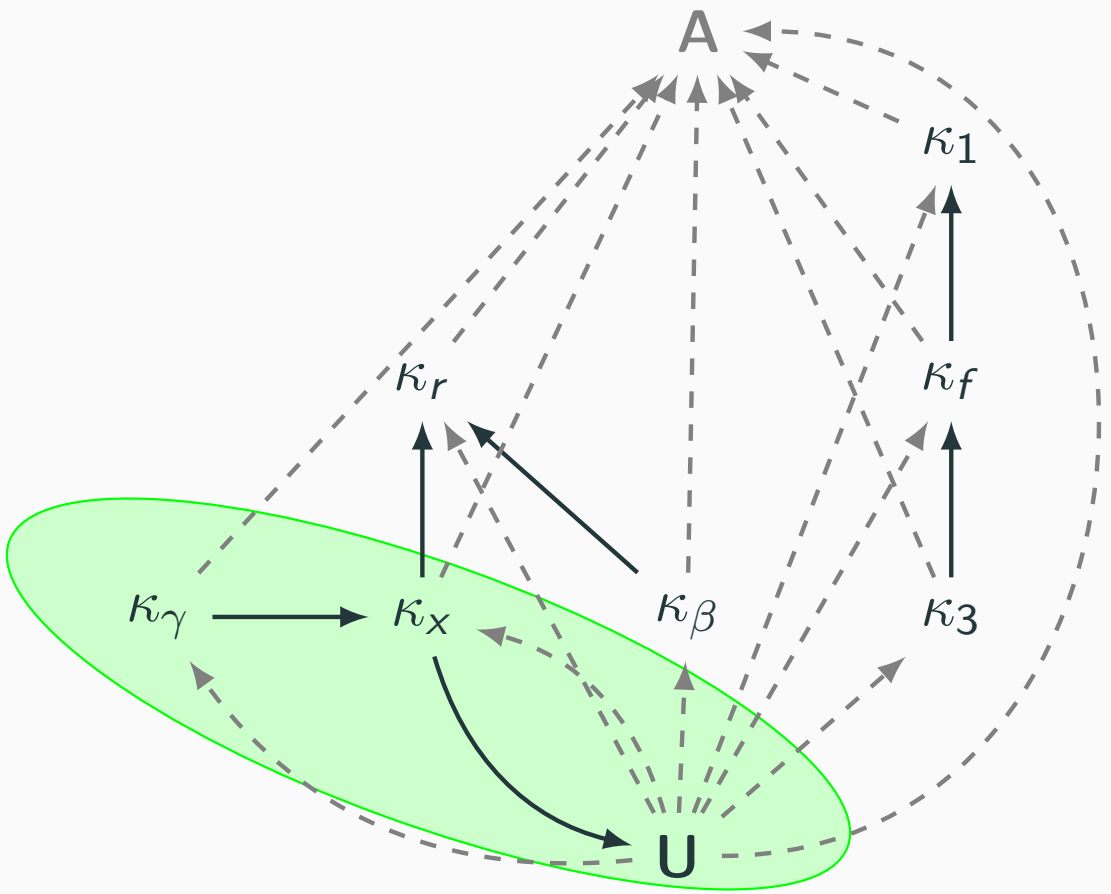

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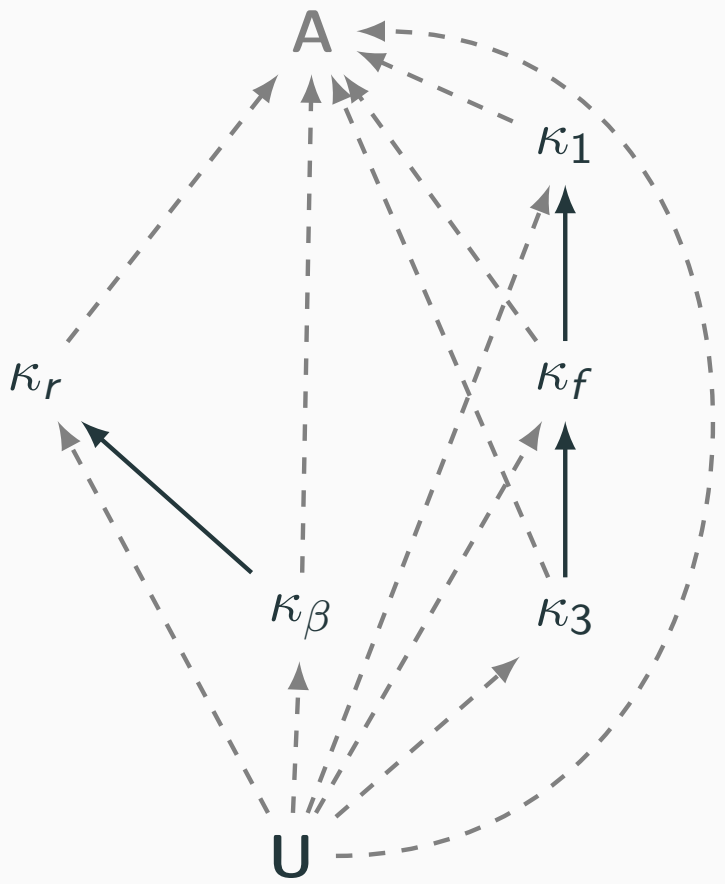

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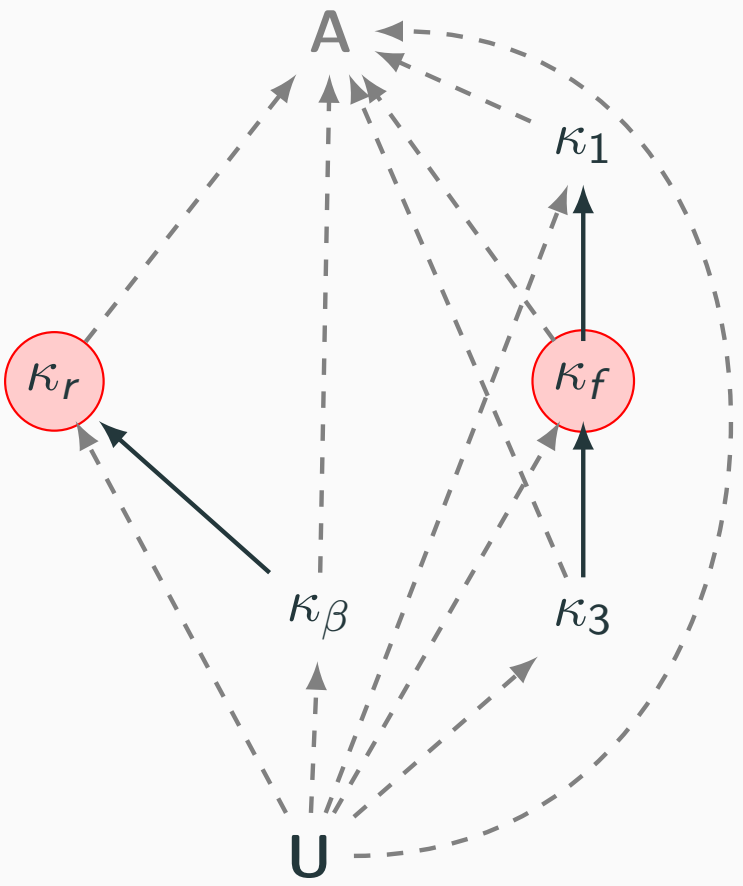

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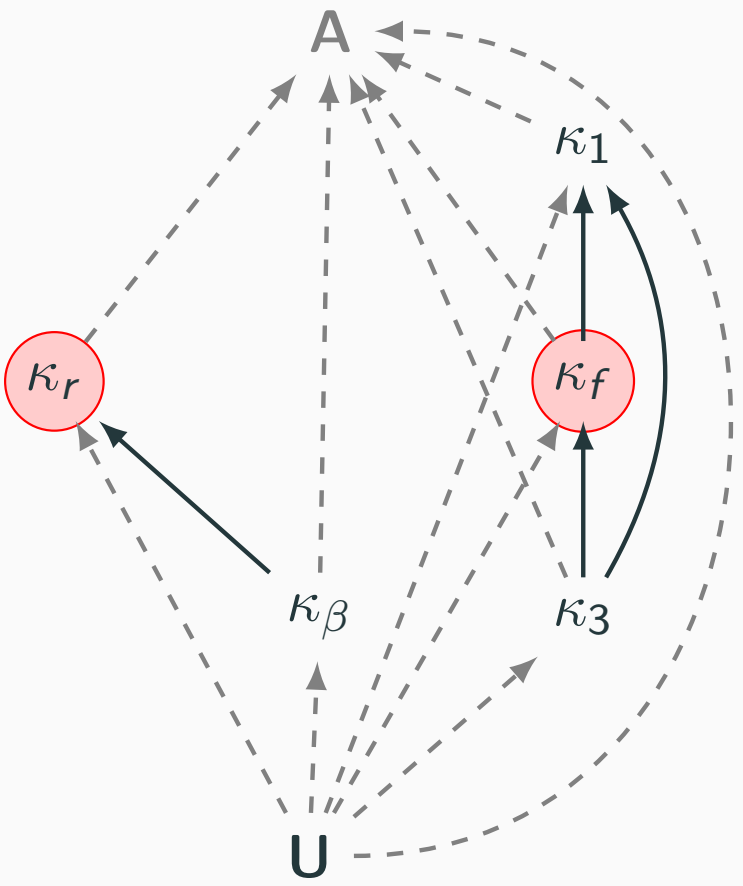

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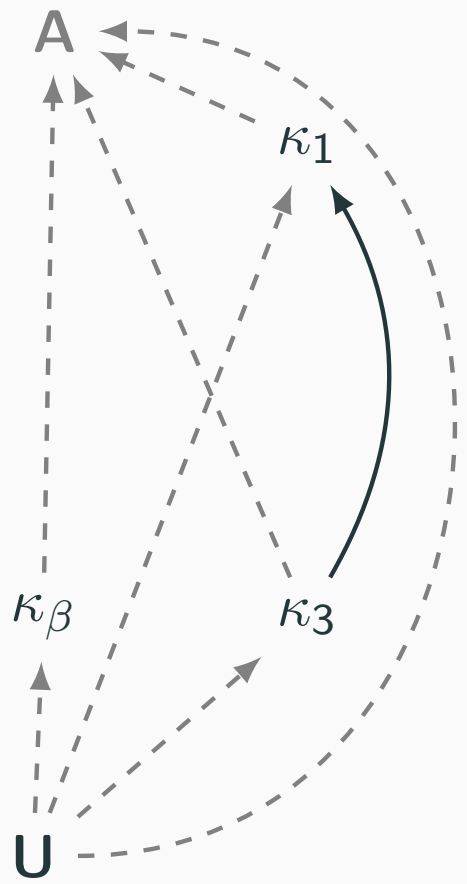

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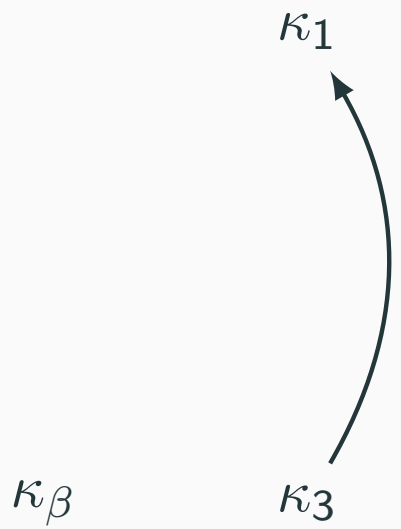

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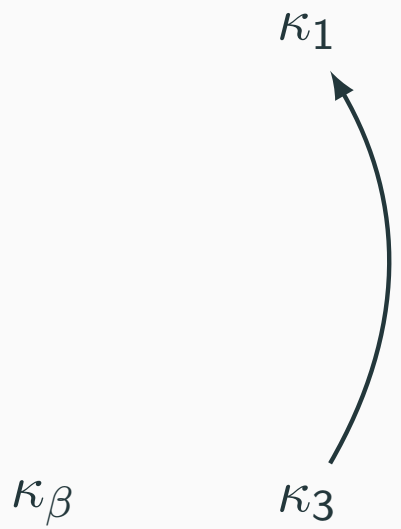

Normalization is complete and principal.

$$\lambda f.\lambda x.((f\ x), x) :$$

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$\Longrightarrow$ Unfinished, need to investigate principality

Constraints

The only requirement is that $\ell^{\perp} = \mathbf{U}$.

- **A** doesn't appear in the typing rules.
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- The lattice doesn't have to be finite.
- The constraint language can be expanded further.

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Conclusion

I presented a somewhat minimalistic approach to add linear types to an existing ML language (like OCaml).

- Based on kinds and constraints
- Works with type abstraction and modules
- Support type inference
- Doesn't break the whole ecosystem

The system is still small. We must look at concrete code pattern used in OCaml and decide how to support them.

Area of future work:

- Explore various interactions with modules
- Borrowing
- Better control-flow interactions

Close(Talk)

Really??

Do you really think adding kinds, subkinding and qualified types to OCaml *is a good idea?*

Yes, I do!

- Qualified types are coming for modular implicits anyway.
- Having proper kinds would fix many weirdness (rows, . . .) and enable nice extensions (units of measures).
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Going further

Current area of work

1. Richer type system
2. Modules
3. Borrowing
4. Prototype cool APIs with it

Constraints in a similar style have been applied to:

- (Relaxed) value restriction
- GADTs
- Rows
- Type elaboration
- ...

Modules

Several distinct problematic:

- Type abstraction
- Linear/affine values in modules
- Functors
- Separate compilation

Modules

Several distinct problematic:

- Type abstraction ✔
  Can declare unrestricted types and expose them as Affine.
- Linear/affine values in modules
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Modules

Several distinct problematic:

- Type abstraction
- Linear/affine values in modules

  Behave like tuples: take the LUB of the kinds of the exposed values.

  What about values that are not exposed? They don't matter!
- Functors
- Separate compilation

Modules

Several distinct problematic:

- Type abstraction
- Linear/affine values in modules
- Functors

  What happens if a functor takes a module containing affine values?

  $\Longrightarrow$ We need kind annotation on the functor arrow... ☹
- Separate compilation

Modules

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  What about linear/affine constants?

  $\Longrightarrow$ Should probably be forbidden...

Modules

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- Linear/affine values in modules
- Functors
- Separate compilation

  What about linear/affine constants?

  $\Longrightarrow$ Should probably be forbidden...

  But what about `stdout` ?

Borrowing

Borrowing seem essential to express many patterns found in OCaml.

Read-only borrows, in `CCHashTrie`:

```
val add_mut : id -> key -> 'a -> 'a t -> 'a t
(* add_mut ~id k v m behaves like add k v m, except
   it will mutate in place whenever possible. *)
```

Mutable borrows, in `lacaml`:

```
val Lacaml.D.sycon :
  ... -> ?iwork:Common.int32_vec -> mat -> float
(* iwork is an optional preallocated work buffer *)
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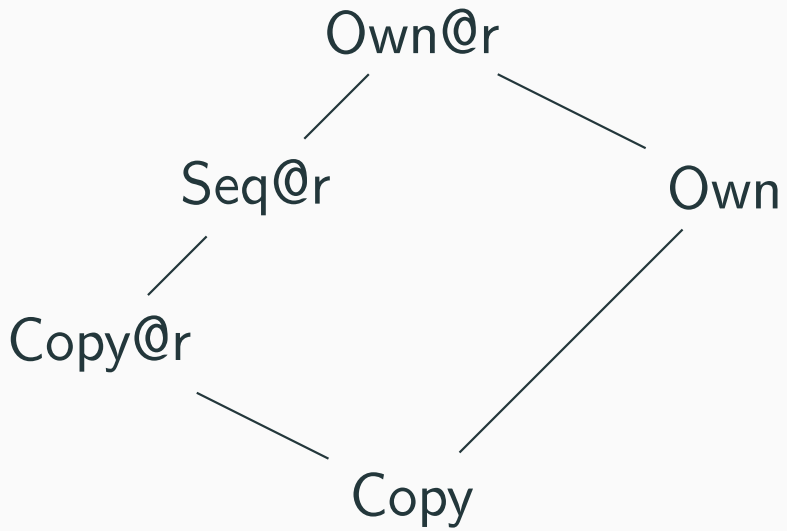
Borrowing

"Resource Polymorphism" has the following lattice:



It would requires:

- More syntactic annotations
- Regions

Which kind of linearity?

- Ownership approaches
- Capabilities and typestates
- Substructural type systems
- ...

Which kind of linearity?

- Ownership approaches
  Suitable to imperative languages (Rust, . . .).
- Capabilities and typestates
- Substructural type systems
- . . .

Which kind of linearity?

- Ownership approaches
- Capabilities and typestates
  Often use in Object-Oriented contexts (Wyvern, Plaid, Hopkins Objects Group, . . .).
- Substructural type systems
- . . .

Which kind of linearity?

- Ownership approaches
- Capabilities and typestates
- Substructural type systems
  Many variations, mostly in functional languages:
  - Inspired directly from linear logic (Linear Haskell, Walker, . . .)
  - Uniqueness (Clean)
  - Kinds (Alms, Clean, F°)
  - Constraints (Quill)
- . . .

Which kind of linearity?

- Ownership approaches
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- . . .

  Mix of everything: Mezzo

Which kind of linearity?

- Ownership approaches
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The HM(X) framework

HM(X) (Odersky et al., 1999) is a framework to build an HM type system (with inference) based on a given constraint system.

We provide two additions:

- A small extension of HM(X) that tracks kinds and linearity
- An appropriate constraint system

References

Martin Odersky, Martin Sulzmann, and Martin Wehr. 1999. Type Inference with Constrained Types. *TAPOS* 5, 1 (1999), 35–55.