The *Mezzo* language

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INRIA

ML Workshop 2012

1. *Mezzo* pitch

2. A primer on permissions

3. A dynamic discipline of ownership

4. The current state of *Mezzo*

Plan

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What is *Mezzo*? (1)

Mezzo is a strict and impure functional programming language; *Mezzo* offers a fine-grained control of side-effects, aliasing and ownership.

What is *Mezzo*? (2)

Mezzo strikes a balance between ease-of-use and complexity by combining a static ownership discipline with runtime tests.

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My first permission!

Variables don't have types; there are permissions.

```
let y = ("foo", 3) in
```

This snippet generates a permission

```
y @ (string, int)
```

One can think of it as a token that grants access to **y** with type **(string, int)**.
Permissions do not exist at runtime.

Permissions and functions

```
val length: [a] (y: list a) -> int
```

- The argument has an (optional) name **y**.
- **length** requires a permission **y @ list a** and
- returns the very same permission: this is the default.
- The function also produces a value of type **int**.

Trading permissions

xswap swaps the two components of a mutable pair.

```
val xswap: [a, b] (consumes y: xpair a b)
  -> (| y @ xpair b a)
```

- we introduce **y** as the name of the argument;
- the argument is consumed, i.e. **y @ xpair a b** is not returned;
- however, a new permission **y @ xpair b a** is returned instead.

Permissions can change!

Permissions replace types. At one point, we may have:

```
y @ xpair a b
```

and later on, obtain:

```
y @ xpair b a
```

Therefore, the set of available permissions may change with time.

A sound example?

This is how a permission can be traded for another one.

```
let y = e1 in
(* y @ xpair a b *)
xswap y;
(* y @ xpair b a *)
e2
```

For the **xswap** example to be sound, “no one else” should “see” **y**. This implies **xswap** should have exclusive access to its argument (no aliases).

Different *modes* for types

	duplicable	*exclusive*
me	read-only	read-write
others	read-only	---

- `xpair` is exclusive: it is mutable (read-write), and uniquely-owned, while
- `int`, `string`, are duplicable: they are immutable (read-only), and shared.

Permissions enforce *access control*

This means:

- `y @ int` can be duplicated, while
- `y @ xpair int int` cannot.

What with separation logic?

If `τ` is an exclusive type,

- `y @ τ` guarantees we own a memory block with type `τ`;
- `y @ τ * z @ τ` is a conjunction that guarantees that `y` and `z` are distinct.

The latter is a must-not-alias constraint.

Internal representation

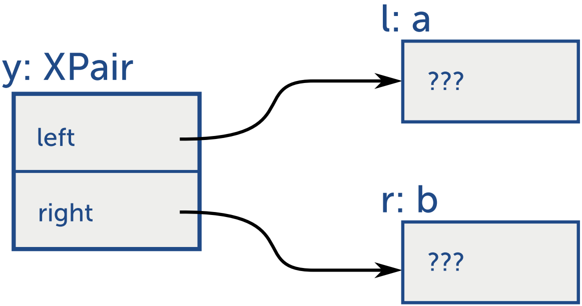
Internally, we manipulate a graph of permissions that makes aliasing explicit.

```
exclusive data xpair a b =
  XPair { left: a; right: b }
```

Let us see how the type checker represents this type.

A drawing

We can think of `y @ xpair a b` as the following drawing.



Expanding permissions

Permissions embody aliasing relationships

The type-checker first expands `y @ xpair a b` into

```
y @ XPair { left: a; right: b }
```

then, into

```
y @ XPair { left: =l; right: =r }
          * l @ a
          * r @ b
```

The singleton type

`=l` is a singleton type: `y @ =z` means `y` and `z` point to the same object: this is a must-alias constraint.

Some syntactic sugar

- We write `y = z` for `y @ =z`.
- We also write:

```
y @ XPair { left = l; right = r }
```

for

```
y @ XPair { left: =l; right: =r }
```

You said dynamic tests

`y @ list τ` with `τ` exclusive asserts all items in list `y` are distinct.

- A mutable, doubly-linked list with arbitrary length,
- a list where an exclusive element is present twice,

... are both situations that cannot be represented statically.

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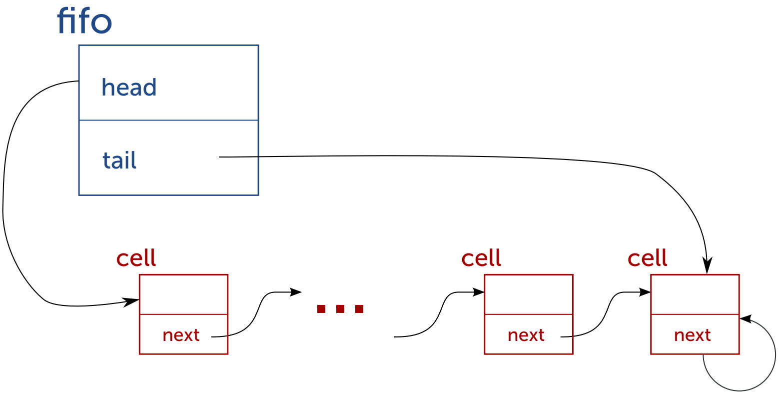
In a nutshell

We can represent immutable heaps with arbitrary shape, mutable heaps with a tree shape, but we cannot represent mutable heaps with arbitrary shape.

In order to alleviate this restriction, we use dynamic tests to ensure safety. This is achieved through the (new) adoption and abandon operations.

Our running example

A first-in, first-out queue, and its aliasing pattern.



Cells are mutable; the ownership pattern is no longer a tree.

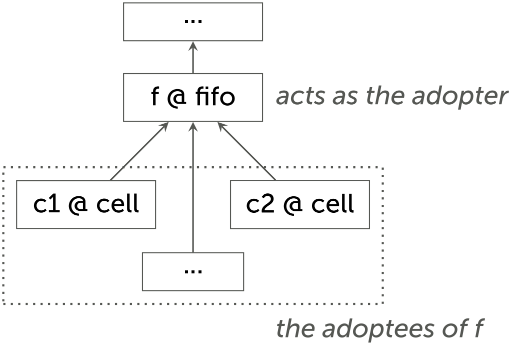
How does it work? Adoption

An object can be declared as adopting other objects.

```
exclusive data fifo a =
  | Empty ...
  | NonEmpty ...
adopts cell a
```

A permission for the adopter (the FIFO) grants permission for its adoptees (the cells).

An adoption hierarchy



How does it work? Adoption (cont'd)

```
(* x @ cell a * f @ fifo a *)
give x to f;
(* x @ dynamic * f @ fifo a *)
```

`x @ dynamic` means “**`x`** *may* currently be adopted by some other object”.

This is a duplicable permission.

How does it work? Abandon

We traded **x @ cell a** for **x @ dynamic**, which is duplicable but hides the true type of **x**.

```
(* x @ dynamic * f @ fifo a *)
take x from f;
(* x @ cell a * f @ fifo a *)
```

We regain the original permission, but we need to make sure no object can be abandoned twice: **abandon** involves a dynamic check.

How does it work? Implementation

- Each object contains a hidden field with the address of its adopter, or `null`
- The field is set when adopting and cleared when abandoning.
- We perform the check when abandoning an object: its hidden field and the address of (what the user claims is) the adopter must match.

An example!

We now explain how the `insert` operation is type-checked.

The interface for fifos

The FIFO implements the following interface.

```
type fifo :: TYPE -> TYPE
val create: [a] () -> fifo a
val insert: [a] (consumes a, fifo a) -> ()
val retrieve: [a] fifo a -> option a
```

The insert function

```
val insert: [a] (consumes a, fifo a) -> ()
let insert [a] (x, f) =
  let c = Cell { data = x; next = () } in
  c.next <- c;
  give c to f;
  match f with
  | Empty ->
      f <- NonEmpty;
      f.head <- c;
      f.tail <- c
  | NonEmpty { tail } ->
      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- ∅

Duplicable permissions

- ∅

```
val insert: [a] (consumes a, fifo a) -> ()
let insert [a] (x, f) =
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  end
```

Non-duplicable permissions

- `f @ fifo a`
- `x @ a`

Duplicable permissions

- ∅

```
val insert: [a] (consumes a, fifo a) -> ()
let insert [a] (x, f) =
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      f.tail <- c
  | NonEmpty { tail } ->
      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ fifo a`
- `x @ a`
- `c @ Cell { data = x; next: () }`

Duplicable permissions

- ∅

```
fifo a) -> ()
    let c = Cell { data = x; next = () } in
    c.next <- c;
    give c to f;
    match f with
    | Empty ->
        f <- NonEmpty;
        f.head <- c;
        f.tail <- c
    | NonEmpty { tail } ->
        take tail from f;
        tail.next <- c;
        give tail to f;
        f.tail <- c
    end
```

Non-duplicable permissions

- `f @ fifo a`
- `x @ a`
- `c @ Cell { data = x; next = c }`

Duplicable permissions

- ∅

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    end
```

Non-duplicable permissions

- `f @ fifo a`
- `c @ cell a`

Duplicable permissions

- ∅

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      give tail to f;
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  end
```

Non-duplicable permissions

- `f @ fifo a`

Duplicable permissions

- `c @ dynamic`

```
val insert: [a] (consumes a, fifo a) -> ()
let insert [a] (x, f) =
  let c = Cell { data = x; next = () } in
  c.next <- c;
  give c to f;
  match f with
  | Empty ->
      f <- NonEmpty;
      f.head <- c;
      f.tail <- c
  | NonEmpty { tail } ->
      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ Empty { head: (); tail: () }`

Duplicable permissions

- `c @ dynamic`

```
val insert: [a] (consumes a, fifo a) -> ()
let insert [a] (x, f) =
  let c = Cell { data = x; next = () } in
  c.next <- c;
  give c to f;
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      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ NonEmpty { head: (); tail: () }`

Duplicable permissions

- `c @ dynamic`

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val insert: [a] (consumes a, fifo a) -> ()
let insert [a] (x, f) =
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      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ NonEmpty { head = c; tail: () }`

Duplicable permissions

- `c @ dynamic`

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val insert: [a] (consumes a, fifo a) -> ()
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  let c = Cell { data = x; next = () } in
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  end
```

Non-duplicable permissions

- `f @ NonEmpty { head = c; tail = c }`

Duplicable permissions

- `c @ dynamic`

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val insert: [a] (consumes a, fifo a) -> ()
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  c.next <- c;
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      take tail from f;
      tail.next <- c;
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      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ fifo a`

Duplicable permissions

- `c @ dynamic`

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val insert: [a] (consumes a, fifo a) -> ()
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  let c = Cell { data = x; next = () } in
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      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = tail }`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
- `tail @ dynamic`

```
val insert: [a] (consumes a, f
let insert [a] (x, f) =
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      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = tail }`
- `tail @ cell a`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`

```
fifo a) -> ()
let insert [a] (x, f) =
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  c.next <- c;
  give c to f;
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     f <- NonEmpty;
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     take tail from f;
     tail.next <- c;
     give tail to f;
     f.tail <- c
  end
```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = tail }`
- `tail @ Cell { data = data; next = next }`
- `data @ a`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
- `next @ dynamic`

```
f.
ext = () } in
```

```
match f with
| Empty ->
    f <- NonEmpty;
    f.head <- c;
    f.tail <- c
| NonEmpty { tail } ->
    take tail from f;
    tail.next <- c;
    give tail to f;
    f.tail <- c
end
```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = tail }`
- `tail @ Cell { data = data; next = c }`
- `data @ a`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
- `next @ dynamic`

```
f.
...ext = () } in
  give c to f;
  match f with
  | Empty ->
      f <- NonEmpty;
      f.head <- c;
      f.tail <- c
  | NonEmpty { tail } ->
      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = tail }`
- `tail @ cell a`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
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```
let insert [a] (x, f) =
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```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = tail }`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
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- `tail @ dynamic`

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```

Non-duplicable permissions

- `f @ NonEmpty { head = head; tail = c }`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
- `next @ dynamic`
- `tail @ dynamic`

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val insert: [a] (consumes a, f
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  | Empty ->
      f <- NonEmpty;
      f.head <- c;
      f.tail <- c
  | NonEmpty { tail } ->
      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

Non-duplicable permissions

- `f @ fifo a`

Duplicable permissions

- `c @ dynamic`
- `head @ dynamic`
- `next @ dynamic`
- `tail @ dynamic`

```
val insert: [a] (consumes a, f
let insert [a] (x, f) =
  let c = Cell { data = x; next
  c.next <- c;
  give c to f;
  match f with
  | Empty ->
      f <- NonEmpty;
      f.head <- c;
      f.tail <- c
  | NonEmpty { tail } ->
      take tail from f;
      tail.next <- c;
      give tail to f;
      f.tail <- c
  end
```

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Future work

Concurrency in the style of concurrent separation logic.

Inference e.g. polymorphic function calls.

Proof soundness and type preservation.

The prototype

- We have a prototype that successfully type-checks most of the examples found in our tutorial paper (see websites).
- We plan on writing an interpreter.
- We started working on better ways to report error messages.

Demo time

Thank you

fifo and cell definitions

```
exclusive data cell a =
  | Cell { data: a; next: dynamic }

exclusive data bag a =
  | Empty { head, tail: () }
  | NonEmpty { head, tail: dynamic; }
adopts cell a
```

length implementation

```
val rec length [a] (x: list a): int =
  match x with
  | Nil ->
      0
  | Cons { tail = tail } ->
      1 + length tail
  end

val zero = length Nil
```

(this is a real example from the prototype's testsuite)

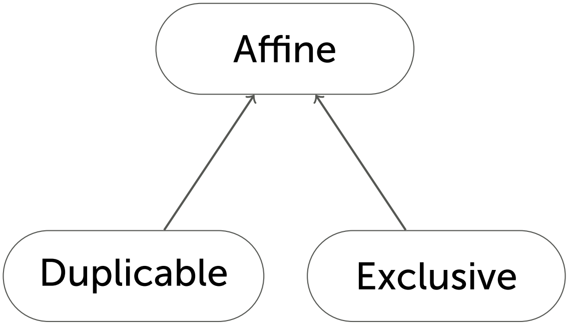
xswap implementation

```
exclusive data xpair a b =
  XPair { left: a; right: b }

val xswap [a, b] (consumes x: xpair a b):
    (| x @ xpair b a) =
  let t = x.left in
  x.left <- x.right;
  x.right <- t
```

(this is a real example from the prototype's testsuite)

The mode system (1)



The mode system (2)

Some types are truly affine, e.g.

```
list (xpair int int)
```

Some other types are abstract, and must be conservatively treated as affine, such as `a` in the body of

```
length: [a] list a -> int.
```

An interface for locks

```
type lock :: PERM -> TYPE
fact [p :: PERM] duplicable (lock p)
val create: [p :: PERM] () -> lock p
val acquire: [p :: PERM] lock p -> (| p)
val release: [p :: PERM]
  (lock p | consumes p) -> ()
```

The concept of permission plays very nice with locks.

A bonus feature

```
data outcome (p :: PERM) =
  | Success { p }
  | Failure { }

val try_acquire: [p :: PERM]
  lock p -> outcome p
```

We embed permissions inside a data type definition. When matching on **Success**, permission **p** is added to the environment.