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Programming with permissions: the *Mezzo* language

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Mezzo is a functional programming language with effects, in the tradition of ML. *Mezzo* aims to provide a successor to OCaml with a finer control of aliasing and effects. We offer stronger static guarantees on the mutable store: the language can express non-aliasing and separation properties. This fine-grained control of ownership and effects allows *Mezzo* to type-check programs previously deemed unsafe by the OCaml type-checker.

Idioms such as delayed initialization or strong (type-changing) updates are possible: *Mezzo* understands the in-place `swap` function, which swaps the two components of a pair. Similarly, a tail-recursive, destination-passing style version of `map` can be type-checked.

Mezzo is a language for users: our system tracks effects more accurately than global effect systems, but we use dynamic checks (section 3.1) to keep the system simple. This introduction is hardly self-contained, and the curious reader may wish to refer to [1] for a full introduction to the language.

1 Permissions

The key concept in *Mezzo* is the notion of permission. Permissions describe how objects are laid out in memory: they describe the shape of the heap. Permissions also enable programmers to control the ownership of objects, which turns out to be paramount in a concurrent setting.

A permission is written $x @ t$, meaning “ x may be viewed with type t ”. A permission grants access to an object: $x @ \text{ref int}$ asserts that “we” have the right to access x , and that it is a valid integer reference to boot. Permissions have no existence at runtime.

A permission may also assert what “others” (other threads, other parts of the program) are allowed to do, depending on the *mode* of the permission. *Duplicable* permissions describe read-only blocks in the heap; such permissions can be freely copied and passed to others – effectively sharing access to the block. *Exclusive* permissions describe read-write blocks in the heap; they cannot be copied, that is, the block has a unique owner.

	duplicable	exclusive
we	read-only	read-write
others	read-only	—

Figure 1: Access control

At any point in the program, a set (conjunction) of permissions is available; the set may include several permissions that refer to the same object.

1.1 Permission conjunction

The conjunction of two permissions p and q is written $p * q$. Our conjunction extends the separating conjunction of separation logic:

- on *exclusive* portions of the heap, $*$ behaves as the usual separating statement: $x @ t * x' @ t'$ asserts that x and x' cannot point to the same memory location – this is a *must-not-alias* constraint;
- on non-exclusive portions of the heap, the various permissions just need to be consistent with each other: $x @ \text{int} * x @ \text{int}$ is such a consistent conjunction.

1.2 Manipulating permissions

Here is a datatype definition for duplicable pairs:

```
data pair a b = Pair { left: a; right: b }
```

`let x = Pair {left = 7; right = 3}` creates such a pair, yielding a new duplicable permission $x @ \text{pair int int}$. *Mezzo* automatically *unfolds* this permission and introduces fresh names for the components, thus yielding the following conjunction:

```
x @ Pair { left: =1; right: =r } *  
1 @ int * r @ int
```

The `left` field of x has the singleton type `=1`: this means $x.\text{left}$ and `1` refer to the same object – this is a *must-alias* constraint. From now on, we will omit the colon and write `Pair { left = 1; right = r }`.

Should the programmer write `let y = x.left`, a new permission will be added, namely $y @ =1$, which we write $y = 1$. Thus, a conjunction of permissions can include a set of equations.

1.3 Example: swapping a pair in place

Objects of type `pair` are duplicable, hence immutable. Uniquely-owned, mutable pairs are defined as follows:

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

The code from figure 2 demonstrates how to swap the two components of such a pair (comments indicate the set of available permissions after the line has been executed).

Notice the change in the permission of x between lines 2 and 3: it accounts for the new aliasing relationship, since the `left` field now points to `r` instead of `1`. Line 4 works in a similar fashion.

If we wish, we can trade the final conjunction for a weaker, more concise permission, namely $x @ \text{xpair b a}$. This code snippet changes the type of x : we call this a *strong update*. We'll see in the following section how to turn this code snippet into a function.

```

1 let x = XPair {left = ...; right = ...} in (* x @ XPair {left = l; right = r} * l @ a * r @ b *)
2 let t = x.left in (* x @ XPair {left = l; right = r} * l @ a * r @ b * t = l *)
3 x.left <- x.right; (* x @ XPair {left = r; right = r} * l @ a * r @ b * t = l *)
4 x.right <- t (* x @ XPair {left = r; right = t} * l @ a * r @ b * t = l *)

```

Figure 2: A fragment of code that performs a swap

2 Effects in function types

2.1 Some base types

Tuple types are written (t_1, \dots, t_n) . If z is the tuple expression (x, y) , then we have $z @ (=x, =y)$. Furthermore, if $x @ t * y @ u$ is also available, then we can recombine these three permissions to obtain $z @ (t, u)$.

Package types allow one to bundle permissions along with a type: we write $(t|p)$ to store permission p along with a value of type t . The left-hand-side exists at runtime; the right-hand side does not.

2.2 Some accurate function types

Let us now consider the simple case of `swap1`, a function that takes a pair and returns a new pair with its components swapped. The function does not perform an in-place update: it returns a fresh pair.

```

val swap1: pair a b -> pair b a
let swap1 (Pair { left = l; right = r }) =
  Pair { right = l; left = r }

```

Functions must be annotated with their signature in *Mezzo*. This signature may read like ML, but it conveys requirements about the permissions *consumed* and *returned* by the function. This naïve version of the swap function fails to type-check; let us now see why.

In order to call `swap1 x`, the permission $x @ \text{pair } a \ b$ must be available to the caller, to be consumed by `swap1`. Moreover, we understand this permission to be *returned to the caller*. Therefore, `swap1 x` will return to the caller both the original permission on x and a new value with type `pair b a`.

However, after calling `swap1`, the components of the pair will be pointed to by both the old pair and the fresh one. Therefore, for the body of `swap1` to type-check, its signature must demand that a and b be duplicable types.

```

val swap: duplicable (a, b) =>
  pair a b -> pair b a

```

The body of the function will now type-check. Interestingly enough, the following signature is also valid:

```

val swap2: (consumes x: pair a b) -> pair b a

```

Here, the argument x is *consumed* by the function; that is, the permission referring to it is not returned to the caller. This type is more general: we leave it up to the caller to (implicitly) save a copy of the permission on x , by duplicating the permission before calling `swap2`, if possible.

Finally, if we want to write an in-place version of `swap` that operates on exclusive pairs, we need to express the fact that the function *modifies* the type of its argument.

```

val xswap: (consumes x: xpair a b)
-> ( | x @ xpair b a)

```

Here, `xswap` operates in place; therefore, it returns a tuple with no value components, i.e. the unit type. The permission on the argument is *not* returned; instead, a different permission for x is returned to the caller, reflecting the fact that the type of x has now changed.

3 Beyond simple permissions

3.1 An adoption mechanism for sharing

Basic permissions only allow for ownership trees; for mutable data structures with sharing, *Mezzo* uses a mechanism called *adoption*. It allows one to alias mutable objects, but uses runtime checks to ensure only one person at a time may “view” the mutable object. These dynamic checks may fail: we believe this is the price to pay to keep the system reasonably simple and expressive.

3.2 Concurrency

Permissions embody access control: only one thread at a time may own an exclusive permission, i.e. access a mutable location in the heap. Moreover, the adoption feature is thread-safe: several threads may try to acquire an object through the *abandon* operation, but runtime-checks make sure only one thread obtains an exclusive permission in the end. Finally, we provide a library for locks, exposed as duplicable objects that protect a permission. Therefore, programs written in *Mezzo* are data-race free.

The interaction of *Mezzo* and concurrency is still being worked on; we do not have sophisticated mechanisms such as fractional permissions yet, but this is an area of the design of *Mezzo* that is likely to evolve.

4 The current status of Mezzo

We are presently working on a prototype type-checker; the prototype can already type-check simple programs. Challenges include providing useful error messages, and elaborating heuristics for expressions with no principal type. In parallel, we are working on a formal proof of correctness for *Mezzo*, using the Coq proof assistant. We proved subject reduction for a core subset of *Mezzo*; we are looking forward to extend this proof to the whole language.

References

- [1] François Pottier and Jonathan Protzenko. Programming with permissions: an introduction to *Mezzo* (long version). <http://gallium.inria.fr/~fpottier/publis/mezzo-tutorial-long.pdf>, September 2012.