CAMLroot: revisiting the OCaml FFI

Frédéric Bour

Abstract

The OCaml language comes with a facility for interfacing with C code – the Foreign Function Interface or FFI. The primitives for working with the OCaml runtime – and, in particular, with the garbage collector (GC) – strive for a minimal overhead: they avoid unnecessary work and allow for calls to C code to be very cheap. But they are also hard to use properly. Satisfying the GC invariants leads to counter-intuitive C code and there are hardly any safety checks to warn the developer.

In this work, we explore two complementary approaches to mitigate these issues. First, simply adding an indirection to the API manipulating OCaml values let us write safer code amenable to optional runtime tests that assert proper use of the API. Second, a notion of region for tracking lifetimes of OCaml values on C side let us trade some performance for simpler code.

1 Introduction

Writing code bridging C libraries to OCaml code is a difficult task. While writing Cuite\(^1\), an OCaml library that interfaces the Qt tool-kit, we discovered a few idioms that help to keep this plumbing simple to reason about.

Qt is a C++ framework that enables writing portable user interfaces. User interfaces are challenging to write because they involve complex lifetimes and control flow: data is described as a dynamically changing graph of components, control can jump back-and-forth between user code and library code, different tasks can run concurrently, etc.

Interfacing with OCaml means exporting all these features while abiding by OCaml & Qt rules about memory management. By revisiting a few assumptions of the OCaml GC interface, we believe that the CAMLroot approach makes interface work more tractable and easier to debug.

1.1 Our approach: roots before values

In our opinion, the less natural part of OCaml interaction from C code is the manipulation of roots and the lifetime of OCaml values. The C programmer is accustomed to manual memory management: by explicitly creating and destroying pieces of memory or by tying the variable lifetime to the scope. While syntactically the management of OCaml memory seems to fall into these cases, it is actually much more subtle.

If the OCaml garbage collector triggers at the wrong time, (1) a value can get moved, (2) a piece of OCaml memory that is locally referenced but not registered as a root can get collected.

If (1) happens in the middle of a sequence point where the same value has been read, this results in an undefined behavior of the C language. In practice, the lifetime of the value gets disconnected from the lifetime of the variable that holds it. This behavior completely contradicts the intuition of the C developer who is not used to distinguishing a variable from its contents. Fortunately that can be addressed by a slight, almost mechanical, change to the C API of the garbage collector. By making most FFI functions take roots (in the form of pointer to values) rather than direct values as arguments, this class of error can be ruled-out.

\(^{1}\)https://github.com/let-def/cuite
And while the programmer could be blamed for not following the rules in (2), we propose
an alternative root management strategy that results in simpler C code and should prevent
that kind of mistake.
Furthermore, both approaches are amenable to dynamic checks that can detect even more
erroneous situations.

1.2 Contributions
We claim the following three contributions:

• a general design principle for OCaml FFI functions, working with value pointers rather
  than plain values, that prevents a class of FFI bugs and integrates well with existing FFI
code

• an alternative interface for managing local roots that trades some performance for ease
  of use and safety by batching roots them in regions

• camlroot\(^2\) a reusable and open-source library that implements both of those via the
  mlroot.h and mlregion.h files.

While these were developed in the context of Cuite, the Qt binding, this paper solely fo-
cuses on the management of OCaml memory from C code. However to illustrate its appli-
cability to realistic code, we describe how our proposed API behaves in complex situations –
involving callbacks, exceptions and multi-threaded code.

2 The original OCaml-C FFI

In this section we describe the existing solution for writing bindings to external library. The
OCaml FFI lets the developer manipulate OCaml values from another programming language.
A C library provided by the OCaml distribution exposes the primitive operations to achieve
that (Leroy et al.).

This library helps accomplishing two main tasks:

1. constructing and deconstructing OCaml values, interpreting them in a meaningful way
   from the C language (for instance by mapping back-and-forth between OCaml and C
   representations of integers, of strings, etc);

2. cooperating with the OCaml garbage collector, or GC, the runtime service that takes care
   of managing OCaml memory.

Even though both tasks are much more difficult than when working from within OCaml
code (the typechecker will not help you in foreign code), it is at least possible to reason locally,
in a compositional way, about OCaml values – task (1). For instance, building nested tuples
just involves repeatedly building flat tuples. The same cannot be said about task (2). The GC
needs to know about all OCaml values that are manipulated from C code, and can look at
them at almost any moment. These restrictions are not natural while programming in C and
can lead to subtle bugs that are hard to discover.

Most of the time the GC will not do any work, preferring to wait for a batch of work
that is big enough to amortize its overhead. As such an improper use of the OCaml API can

\(^2\)https://github.com/let-def/camlroot
go unnoticed for a long time. But even once harm has been done, it might just lead to a corruption of the OCaml heap that will affect an unrelated piece of code and fails much later in the program. GC bugs combine two nasty properties: they cannot be studied in isolation and they trigger depending on a complex set of conditions that cannot be inferred by solely looking at the buggy code.

On the other hand, the OCaml FFI API enjoys a remarkably low overhead: the restrictions are difficult but lead to a cheap and portable interface with the OCaml runtime. This made OCaml applicable to domains where connecting to a foreign programming language is generally considered too expensive (Bourke et al., 2016).

We propose to explore a different trade-off in the design space of FFI API: providing a safer and more convenient API by giving up some of the performance. Many mainstream languages have adopted heavier FFIs by default (Lua, Java JNI, Go), optionally allowing to resort to a lower-level one for performance critical code (ctypes from LuaJit); thus, a relatively expensive FFI can still be relevant.

But before trying to build an alternative interface to the FFI, we will take a closer look at the restrictions imposed by the GC.

### 2.1 Value representation

In C code, all OCaml values are represented by the value type. It is a signed integer of the same size as a pointer of the host system (in practice, 32 or 64 bits). Values of this size are called “words”.

The least significant bit is reserved to help the GC traverse the OCaml heap:

- if it is set, the value is said to be immediate and the remaining bits are directly interpreted: as a 31-bit or 63-bit integer for the int OCaml type, or as a unique pattern of bits for constant variants and polymorphic variant constructors
- if it is not set, the value is interpreted as a pointer to a “block”; it is a piece of memory provided by the runtime that is guaranteed to be aligned to a word-boundary and as such to have its two or three lower bits set to 0

Blocks are preceded by a header that determines their “tag” and their size. The tag will determine how to interpret the contents of the block. For common OCaml values, such as algebraic data, records, tuples or arrays, blocks are made of other values.

### 2.2 Traversal and compaction

Under certain conditions, the OCaml GC might need to traverse the heap. The basic operation is to find which blocks are reachable from a value.

Depending on the tag, the OCaml GC will decide whether a block is made of other values (that, in turn, can be immediate or pointer to blocks) or just of an opaque chunk of memory that does not need to be scanned.

By repeating this operation, the GC can traverse the whole heap. The traversal starts from the roots, a distinguished set of values.

If necessary it might also decide to move some blocks. Moving blocks is more demanding than mere traversal: the GC not only needs to know all values referenced from C code, it also needs to be able to update them. The C compiler needs to be aware that all OCaml values have to be reloaded when such an operation can happen, as previous values might have been invalidated.
2.3 The memory management macros

A few C macros are provided by the OCaml runtime to implement foreign features. As a guiding example, here is a simple function that takes two values and makes a pair out of them:

```ocaml
(* The OCaml version *)
let mk_pair_ocaml x y = (x, y)

(* An external function, that we will implement in C *)
external mk_pair_c : 'a -> 'b -> 'a * 'b = "mk_pair_c_impl"
```

The string after the external declaration is the name of the C function that implements the functionality. The corresponding C code looks like this:

```c
CAMLprim
value mk_pair_c_impl (value a, value b) {
  CAMLparam2 (a, b);
  CAMLlocal1 (pair);
  pair = caml_alloc (2, 0);
  Store_field (pair, 0, a);
  Store_field (pair, 1, b);
  CAMLreturn (pair);
}
```

The first macro `CAMLprim` ensures that the symbol is visible from OCaml code.

**CAMLparam** The `CAMLparam2(a,b)` call expands to two other macros:

- `CAMLparam0()` saves the previous set of local roots
- `CAMLxparam2(a,b)` setups a new block of roots with the addresses of `a` and `b`.

The local roots are in a linked list of pointer to OCaml values, implemented by the struct `caml__roots_block` type, and stored in the `caml_local_roots` global variable.

The job of the memory management macros is to make it as easy as possible to register all local variables of type `value` in this linked list and to remove them when returning from the function.

There should be only one `CAMLparam0()` in a function, but there can be as many calls to `CAMLxparam` as needed. The variants from `CAML(x)param1` to `CAML(x)param5` are available as well as `CAML(x)paramN(array, array_size)` for registering array of values.

**CAMLlocal** The next macro call of interest is `CAMLlocal1(pair)`.

It expands to `value pair = Val_unit; CAMLxparam1(pair)`:

- it declares and initializes a local variable named `pair`,
- it adds its address to the set of local roots.

The next lines, the calls to `caml_alloc` and `Store_field`, are not directly related to the management of roots. They deal with the construction of OCaml values – assuming that all variables have been registered properly.
// Allocating values
value caml_alloc(int size, int tag);
value caml_copy_string(const char *string);
value caml_alloc_string(int length);
...

// Deconstructing and mutating values (actually implemented by macros)
long Long_val(value v);
value Val_long(long x);
value Field(value v, int offset);
void Store_field(value v, int offset, value x);
...

Figure 1: Some OCaml FFI functions for manipulating values

CAMLreturn This last macro restores the previous set of local roots. It sets the variable

caml_local_roots

to the state that was saved by CAMLparam0().

Thus, the code above can be desugared to the equivalent:

```
CAMLprim
value mk_pair_c_impl(value a, value b)
{
    // CAMLparam2(a, b);
    CAMLparam0();     // 1) save the state of local roots
    CAMLxparam2(a, b); // 2a) add &a and &b to local roots

    // CAMLlocal1(pair);
    value pair = Val_unit;
    CAMLxparam1(pair); // 2b) add &pair to local roots

    ...

    // CAMLreturn(pair);
    CAMLdrop;         // 3) restore the state of local roots
                        // (forgetting &a, &b and &pair)
    return(pair);
}
```

The three fundamental operations of root managements are saving local roots, registering
new ones, and restoring the saved ones when leaving a scope.

The OCaml FFI provides macros to automate most of this work but has no way to enforce
their proper use. mlroot.h API can detect large classes of possible misuses while mlregion.h
introduces an alternative approach to the management of roots.
2.3.1 Carefully dealing with intermediate results

Here is an example that shows how easy it is to misuse this API, taken from (Dolan, 2018, caml-oxide). Let's imagine one wants to make a triplet as two nested pairs:

```ocaml
let triplet x y z = (x,(y,z))
```

Armed with `mk_pair_c_impl` and the rules above, one might be tempted to write:

```caml
CAMLprim value c_triplet(value x, value y, value z)
{
    CAMLparam3(x,y,z);
    CAMLlocal1(triplet);

    triplet = mk_pair_c_impl (x, mk_pair_c_impl (y, z));

    CAMLreturn(triplet);
}
```

But a bug lies in this implementation: the C compiler might have already loaded the value of `x` (for instance, by copying it on the stack) before the nested call to `mk_pair_c_impl(y, z)`. If this call triggers a compaction and `x` gets moved, the old, and wrong, value of `x` will be passed to the outer call.

The correct version uses an intermediate variable for the temporary value:

```caml
CAMLprim value c_triplet(value x, value y, value z)
{
    CAMLparam3(x,y,z);
    CAMLlocal2(intermediate, triplet);

    intermediate = mk_pair_c_impl(y, z);
    triplet = mk_pair_c_impl(x, intermediate);

    CAMLreturn(triplet);
}
```

To avoid bugs, calls to functions manipulating the OCaml memory should be linearized and temporary results should be stored in local roots.

3 mlroot: solving problems with one level of indirection

The first change we propose is to replace the type of arguments of type `value` to the type `value*`, representing roots rather than direct values. Similarly, return values of type `value` are replaced by an extra argument of type `value*`, which will be used to store result.

This rewriting is only necessary for functions that allocates, but for the sake of uniformity we offer alternatives in this style for most GC functions. Figure 2 show what this style of API looks like. This minor change brings many benefits.
No risk of unexpected copy. A tricky source of bug that we highlighted in the previous section was that OCaml values get unexpectedly copied while being manipulated. With the added indirection only the pointer gets copied. If the GC kicks in and rewrites the roots, the pointer will not be affected anyway.

Looking at the operations involved in terms of lifetime, reading a value from a root makes it ephemeral: the value is valid only until the next OCaml allocation – or simply undefined if an allocation can happen in the same sequence-point.

When directly working with \texttt{value}, this operation is implicit. Working with \texttt{value*}, the operation becomes explicit and forces the developer to think about its effects – they choose when to dereference the pointer. In practice this is almost never needed outside of implementation of \texttt{mlroot}, relieving the user of the API from this burden.

```
// Allocating values
void mlroot_alloc(value *root, size_t size, int tag);
void mlroot_copy_string(value *root, const char *string);
void mlroot_alloc_string(value *root, size_t size);
...

// Deconstructing and mutating values
long mlroot_long_val(value *x);
value mlroot_val_long(long x);
value mlroot_get_field(value *root, int n);
void mlroot_set_field(value *root, int n, value *v);
void mlroot_set_field_long(value *root, int n, long v);
...
```

Figure 2: Excerpt of the mlroot API

Return values become explicit. Now that all functions that interact with the garbage collector take pointers, most offending code patterns become impossible to write:

- functions returning void simply cannot be nested,
- nesting a call to a function returning \texttt{value} where a \texttt{value*} is expected would require taking the address of a temporary (such as \&get_field(x, 0)), which is rejected by the C compiler.

Here is what the triplet would look like with this approach:

```
static void mk_pair(value *result, value *a, value *b)
{
  mlroot_assert(result != a && result != b);
  mlroot_alloc(result, 2, 0);
  mlroot_set_field(result, 0, a);
  mlroot_set_field(result, 1, b);
}
```
value caml_triplet(value x, value y, value z) {
    CAMLparam3(x, y, z);
    CAMLlocal2(pair, result);
    mk_pair(&pair, &y, &z);
    mk_pair(&result, &x, &pair);
    CAMLreturn(result);
}

No need to repeat roots. Callees no longer have the responsibility of registering roots for their arguments.

With the existing OCaml API, any function receiving an argument of type value has to register a corresponding root. There are as many roots for the same value as sub-routines calls that received it as argument. With the indirect approach only places that have their address taken need to be registered as root. Since this operation is explicit, we believe the risk of mistake is reduced.

Dereferencing should also be done with care, but this will generally be done by a primitive function of the GC interface and not by the user code anymore.

Dealing with immediate values. A reader familiar with OCaml binding code might be worried that working with immediate values (an integer directly stored in a value) becomes more complicated with our approach than with the normal API.

Immediate values enjoy a lot of nice properties in the OCaml FFI. Since they do not interact with the memory graph of OCaml – they don’t reference blocks, they cannot be moved – the rules for dealing with them are relaxed: they don’t have to be put in roots, they can be created without triggering a garbage collection, etc.

We argue these properties should not be exploited. That some values can be represented without interacting with the GC is an implementation detail. Being prepared for the “worst case” allow to present an uniform interface.

Still, the library provides the mlroot_val_long and mlroot_set_field_long short-hands for cases that are known to be safe.

3.1 Safety of this indirect API

Moving everything to pointers opened a new opportunity for incorrect uses: aliasing. In the triplet case it would mean using the result variable both as input and output in the same call:

CAMLprim
value caml_triplet(value x, value y, value z) {
    CAMLparam3(x, y, z);
    CAMLlocal1(result);
    mk_pair(&result, &y, &z);
    mk_pair(&result, &x, &result); // result is aliased!
    CAMLreturn(result);
}
While problematic indeed, this case is actually less worrying. The code that dereferences roots can be instrumented to deal with that:

• by properly handling aliasing, for instance by ensuring that all arguments are read before any are written,

• by checking for this case and failing or emitting a warning, as illustrated by the assertions in the implementation of `mk_pair` primitive.

**A debugging workflow.** Actually thanks to the indirection we can go further than that. The observation is that any well-formed argument of type `value*` should point to a root.

Native OCaml FFI is `value`-centric: functions directly take and produce values. Our rewriting make it `root`-centric: functions receive roots and manipulate values through them.

While the connection between a root and its value is lost with native OCaml FFI, we can access it at any time with the indirect API. Plugging into GC infrastructure we can introspect the roots and provide a debug variant of the FFI where all roots received by FFI functions are checked for proper registration.

**Where to add the indirection?** Having made explicit the distinction between values (of type `value`) and roots (of type `value*`) in the API, one could wonder why our API makes use of roots in places where values would be fine: the arguments to `mlroot_get_field`, `mlroot_long_val`, etc.

We are not totally decided on this issue and might revisit this design in the future. However the ability to dynamically check for correct use and the more explicit, safer-looking nature of the resulting code makes us favor the root arguments.

Beside the slight increase in verbosity, we did not find any drawback to this approach.

### 4 mlregion: dynamic allocation of roots

To further simplify the API described above we propose to make allocation of roots simpler.

The `CAMLparam` and `CAMLlocal` macros declare OCaml roots with a static lifetime, known at compile-time. This is nice for performance but puts more burden on the developer.

The semantics of these macros is hard to understand and some use cases are not easily covered. As we already saw, returning values is tricky, but storing temporary values in code controlled by an external framework is even more problematic.

**The need for side-channels allocation.** For the sake of the example, let’s imagine that we need to sort some C structures containing OCaml values. To achieve this the `qsort_r` from the C standard library seems appropriate. It takes an array of user-defined structures and a custom comparison operator in the form of a function pointer.

```c
struct item {
    my_c_type x;
    value v;
};

static int
c_comparator(const void *item1, const void *item2, void *comparator)
```
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```c
{  
  value v1 = ((const struct item *)item1)->v;
  value v2 = ((const struct item *)item2)->v;
  value ml_comparator = *(value*)comparator;
  return Val_int(caml_callback2(ml_comparator,v1,v2));
}

void sort_ocaml_items(struct item *items, size_t count, value *comparator)
{
  qsort_r(items, count, sizeof(struct item), c_comparator, comparator);
}
```

caml_callback2 is a primitive function of native OCaml FFI that allows to invoke an OCaml closure from C code\(^3\).

Because of this callback, the garbage collector can get called in the middle of the sorting. Even if we registered roots for all the values in this array, the implementation of qsort_r might have made copies that will not be updated by the GC. More generally, rewriting the array in the middle of the sort can lead to unexpected behaviors.

Since we know all the OCaml values that will be reached prior to calling qsort_r, a solution is to work with pointer to values. One first allocates an array of roots and pass pointers to this array.

However there exist situations where the set of roots cannot be pre-determined. Regions appeared as a solution to this problem, and proved to be convenient in the simpler cases too.

### 4.1 Region-based management

To let the developer dynamically manage the set of roots, we propose a simple API that over-approximates the lifetime of local roots:

```c
typedef struct ... region_t;
void mlregion_enter(region_t *region);
void mlregion_leave(region_t *region);
value *mlregion_new_root(void);
#define CAMLRregion(...) ...
#define CAMLRregion_return (p) ...
```

In this approach, we distinguish between external and helper functions:

- external functions are the ones that can be directly called from OCaml,
- helper functions implement useful routines for binding foreign code.

The external functions are responsible for setting up the region while helper functions assume that a region has already been setup. Mimicking CAMLparam... macros, we provide some sugar for registering parameters while setting up the region:

```c
value *pair_helper(value *a, value *b)
{
```

\(^3\)For the sake of simplicity we do not deal with the case where the callback raises an exception
value *v = mlregion_new_root();
mlroot_alloc(v, 2, 0);
mlroot_set_field(v, 0, a);
mlroot_set_field(v, 0, b);
return v;
}

CAMLprim
value mk_pair(value a, value b)
{
    CAMLregion(&a, &b);
    CAMLregion_return(pair_helper(&a, &b));
}

CAMLprim
value mk_triplet(value x, value y, value z)
{
    CAMLregion(&x, &y, &z);
    CAMLregion_return(pair_helper(&x, pair_helper(&y, &z)));
}

Setting up a region introduces a new set of local roots that can grow dynamically as new roots are requested. Leaving a region releases all the roots at once.

**Dynamic scoping of regions.** A point that might surprise users of this API is that the current region is not explicitly passed to functions, instead it is accessed by some external means. This choice of design was made to simplify integration with Qt code: sometimes OCaml code might get called from some method deep in the object hierarchy, which interface is imposed by the framework. As there was no easy way to thread a region handle to that point, dynamic scoping came naturally as a solution. We might revisit this decision.

### 4.2 Sub-regions

Assuming that all roots have the same life-time as the external entrypoint works well if a fixed amount of work has to be done. However, for long-running function (for instance, an event loop driven by C-code), the over-approximation of lifetimes can be problematic. For these cases, we allow the introduction of sub-regions, valid in a local scope.

These sub-regions follow a stack discipline: they can be nested and are released in the reverse order of their allocation.

```c
void mlregion_subenter(region_t *region);
void mlregion_subleave(region_t *region);
```

For instance, the following code avoids leaking roots while transforming all the elements of an array:

```c
void process_item(value *acc, value *item);
void fold_array(value *acc, value *array)
{
```

```c
```
Like for normal regions, macros can be used to automate some of the boilerplate.

### 4.3 Releasing the lock in a region

So far we demonstrated the use of region to allocate and manage OCaml memory. The concept can also be applied to the converse: preventing allocation and manipulation of OCaml memory in a given scope.

Although a multi-core runtime is being developed (Dolan et al., 2014), the vanilla OCaml runtime can only execute on a single thread of execution. When multiple threads are in use, a lock is used by the OCaml runtime to ensure that only one of them executes OCaml code at any given time.

The C FFI provides an API for releasing the OCaml runtime in a given scope of code.

```c
// Existing API
void caml_release_runtime_system(void);
void caml_acquire_runtime_system(void);
```

These APIs can be wrapped in corresponding `mlregion_{acquire,release}_runtime_system` functions that does additional bookkeeping to ensure proper use of regions while the runtime is released:

- new roots cannot be allocated,
- dereferencing a value is forbidden, most helper functions won’t work,
- setting up normal regions is forbidden, but a special kind of region allows reacquiring the runtime.

All these restrictions can be tested at a moderate cost. While no checks are done at compile-time, misuse of the API can be reliably detected during execution.

```c
// Wrappers for releasing the runtime
void mlregion_release_runtime_system(void);
void mlregion_acquire_runtime_system(void);
```

```c
// Wrappers for locally reacquiring the runtime
void mlregion_reacquire_runtime_system(void);
void mlregion_rerelease_runtime_system(void);
```
4.4 Calling OCaml from region-managed code

The last feature that needs some special care from the region API is the ability to call OCaml closures from C code. When switching back to OCaml code, the runtime marks a region as disabled: the roots it contains are still reachable, but no new roots can be added to the region. This helps detecting and handling a few unfortunate cases:

- When re-entering C code from OCaml deeper in the call stack, an entrypoint that forgot to setup a region could allocate from the outer region by mistake.

- If we are unlucky, the OCaml thread scheduler could preempt the current thread and the re-entry would happen from another thread, damaging the internal datastructures of the regions library. By wrapping calls with custom code, we can rely on the OCaml runtime lock to also protect region sections.

- The OCaml closure could raise an exception. The native FFI deals with this situation by simply dropping roots from the local roots linked list: since the nodes allocated by `CAMLparam/local` macros are stored on the stack, when an exception is raised the local root and stack pointers are simply reset to their value before entering the C code. A workaround for regions is discussed below.

Handling exceptions. The OCaml native FFI provides two means for calling OCaml closures:

- the `CAMLcallback()` variants, that do not intercept exceptions. The C code will be aborted by directly jumping to the OCaml code that called an external function.

- the `CAMLcallback_exn()` variants, that tag the return value to distinguish exceptional case.

The return value of `CAMLcallback_exn()` should be tested for the exceptional case with `Is_exception_result` before resuming normal execution. Because our region management code needs to execute cleanup code when leaving a scope, we forbid the former case. The user-code has to handle the exceptional case without resorting to non-local control flow.

While it would have been possible to provide support for non-local jumps, it did not make much sense in the Qt case: the binding is implemented in C++, which allow arbitrary code to be executed when leaving a scope. C++ exceptions are expressive enough to handle all our requirements (non-local control flow, proper interaction with the regions and with OCaml GC), but the bindings themselves did not need that feature.

5 Future work

`mlroot` and `mlregion` emerged during the design of the Cuite library and are extracted from its core code. As the project is still in its infancy, it is evolving rapidly and the libraries have been properly tested only for the use cases stressed by Cuite. We still have to cover the rest of the FFI API.

Similarly, the support for runtime checks was only used for a few ad-hoc cases. Devising and implementing a robust suite of dynamic checks that are useful beyond Cuite is on our roadmap. Thanks to the transparent integration with the original FFI, this would help to debug existing bindings.
As Cuite is developed in C++, we have already developed a C++ layer on top of the C API to make it more idiomatic and remove some of the boilerplate – using references instead of pointers for dealing roots, using RAII-idiom (Stroustrup, 1994) to ensure well-bracketed nesting of regions, etc. Extracting and generalizing this part would extend the usefulness of our library to other C++ bindings.

Finally, the only part of the OCaml runtime that we rely on and that is not already in the public interface is the representation of local roots. This part has already been stable for years. We are quite confident that it will be possible to get guarantees that this API will not break in future releases of OCaml.

6 Related Work

The safety and simplicity of foreign function interfaces for OCaml has been approached from many angles.

O-Sa ffi (Furr and Foster, 2005) is a static analysis that works on the official OCaml FFI. It goes beyond checking the registration of roots and also checks that the value representation on C and OCaml sides is compatible.

Ctypes (Yallop et al., 2018) proposes an alternative way to bind libraries. Rather than writing C code, a specification of the library is described in OCaml code. From this specification bridging code will be generated. The code can be instrumented to check for different safety properties.

Caml-oxide (Dolan, 2018) is a proof of concept implementation of an OCaml FFI for Rust. In particular, it demonstrates that the restriction applying to GC roots can be tracked by Rust type system.

References

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