The FFI Reference Manual

a Foreign Function Interface (version 1.0)
for MIT/GNU Scheme version 9.0.1
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1 Introduction

This FFI provides Scheme syntax for calling C functions and accessing C data. The functions and data structures are declared in a case sensitive `.cdecl` file, which is used by a shim generator to produce callout and callback trampoline functions. The trampolines are compiled and linked to the C toolkit, producing a shared object that Scheme can dynamically load.

Synopsis

Examples of the new syntax:

```
(C-include "prhello")

(malloc (C-sizeof "GdkEvent"))
 ⇒ #[alien 42 0x081afc60]

(C->= #@42 "GdkEvent any type" 14)

(C-> #@42 "GdkEvent any type")
 ⇒ 14

(C-enum "GdkEventType" 14)
 ⇒ |GDK_MAP|

(C-enum "GDK_MAP")
 ⇒ 14

(C-sizeof "GdkColor")
 ⇒ 12

(C-offset "GdkColor blue")
 ⇒ 8

(C-array-loc #@43 "GdkColor" (C-enum "GTK_STATE_NORMAL"))
 ⇒ #[alien 44 0x081afc60] ; New alien.

(C-array-loc! #@43 "GdkColor" (C-enum "GTK_STATE_PRELIGHT"))
 ⇒ #[alien 43 0x081afc78] ; Modified alien.

(C-call "gtk_window_new" retval args ...)
 ⇒ #!unspecific

(C-callback "delete_event")
 ⇒ #[alien-function 44 Scm_delete_event]

(C-callback (lambda (window event) ...))
 ⇒ 13                        ; A fixnum registration ID.
```

Summary

A Scheme-like declaration of a toolkit's C functions, constants, and data types is given in a case sensitive `.cdecl` file. The C declarations look like this:

```
(extern (* GtkWidget)
        gtk_window_new
        (type GtkWindowType))

(typedef GtkWindowType
         (enum
          (GTK_WINDOW_TOPLEVEL)
          (GTK_WINDOW_POPUP)))
```

The `c-generate` procedure reads these declarations and writes three files: *library*`-types.bin` (a fasdump of the parsed declarations), *library*`-const.c` (a C program that prints C constants and struct offsets), and *library*`-shim.c` (trampoline functions adapting Scheme procedure application to C function call). The `-const.c` program generates a `-const.scm` file, which can be expanded into a `-const.bin` file.

```
(load-option 'FFI)
(c-generate "prhello" "#include <gtk/gtk.h>")
```

The `-types.bin` and `-const.bin` files together provide the information needed to expand `C-...` syntax, and are only needed at syntax time. The compiled `-shim.so` file is used at run time, dynamically loaded into the Scheme machine. See Chapter 6 [Compiling and Linking], page 10, which describes these files in more detail, and shows how they might be built and installed.

```
(C-include "prhello")
```

The `C-include` syntax loads the `-types.bin` and `-const.bin` files *at syntax time*. It should appear at the top level of any file containing `C-...` syntax, or be expanded in the syntax environment of such code.

The `C-call` syntax arranges to invoke a callout trampoline. Arguments to the trampoline can be integers, floats, strings (or bytevectors) or aliens (non-heap pointers, to C data structures, see Chapter 3 [Alien Data], page 7). If a string argument might contain non-ASCII characters (code points U+0080 and larger), it should be converted to a bytevector e.g. by `string->utf8`, else an error could be signaled.

```
(let ((alien (make-alien '|GtkWidget|)))
  (C-call "gtk_window_new" alien type)
  (if (alien-null? alien) (error "could not open new window"))
  alien)
```

The `C-callback` syntax is used when registering a Scheme callback trampoline. The two forms of the syntax provide two arguments for the registration function: the callback trampoline's address, and a "user data" argument. When the toolkit calls the trampoline, it must provide the fixnum-sized user data as an argument.

```
(C-call "g_signal_connect" window "delete_event"
        (C-callback "delete_event")     ; e.g. &Scm_delete_event
        (C-callback                     ; e.g. 314
          (lambda (window event)
            (C-call "gtk_widget_destroy" window)
            0)))
```

The first use of `C-callback` (above) expands into a callback trampoline address — an alien function. The second use evaluates to a fixnum, which is associated with the given Scheme procedure.

The `C->` and `C->=` syntaxes peek and poke values into alien data structures. They take an alien and a constant string specifying the alien data type and the member to be accessed (if any).

```
(C-> alien "GdkRectangle y")
↦
(#[primitive c-peek-int] alien 4)

(C->= alien "GdkRectangle width" 0)
↦
(#[primitive c-poke-int] alien 8 0)
(C-> alien "GdkEvent any type")
↦
(#[primitive c-peek-int] alien 0)
(C-> alien "gfloat")
↦
(#[primitive c-peek-float] alien 0)
```

A three argument form of the syntax provides an alien to receive a peeked pointer. This avoids consing a new alien.

```
(C-> alien "GtkWidget style" alien)
```

The above syntax is understood to say "The data at this `alien` address is a GtkWidget. Load its `style` member into `alien` (clobbering `alien`'s old address)."

The `C-enum`, `C-sizeof` and `C-offset` syntaxes all transform into integer constants. The last two transform into a padded byte size and a byte offset respectively.

```
(C-enum "GTK_WINDOW_POPUP")
↦
1

(C-sizeof "GdkColor")
↦
12

(C-offset "GdkColor blue")
↦
8
```

The two element form of the `C-enum` syntax can be used to find the name of a constant given its runtime value. It expects the name of an enum type in a constant string. If the runtime (second) argument is not one of the constants declared by that type, the returned value is `#f`.

```
(C-enum "GdkEventType" (C-> #@42 "GdkEvent any type"))
 ⇒ |GDK_MAP|
```

The `c-array-loc` and `c-array-loc!` syntaxes compute the locations of C array elements. They can be used to advance a scan pointer or locate an element by its index. The examples in the synopsis might expand as shown here.

```
(C-array-loc #@43 "GdkColor" (C-enum "GTK_STATE_NORMAL"))
↦
(alien-byte-increment #@43 (* (C-sizeof "GdkColor")
                              (C-enum "GTK_STATE_NORMAL")))
↦
(alien-byte-increment #@43 (* 12 0))
 ⇒ #@44
```

```
(C-array-loc! #@43 "GdkColor" (C-enum "GTK_STATE_PRELIGHT"))
↦
(alien-byte-increment! #@43 (* (C-sizeof "GdkColor")
                               (C-enum "GTK_STATE_PRELIGHT")))
↦
(alien-byte-increment! #@43 (* 12 2))
 ⇒ #@43
```

A simple scan of characters in the wide string `alien` might look like this.

```
(let ((len (C-> alien "toolkit_string_type int_member"))
      (scan (C-> alien "toolkit_string_type array_member")))
  (let loop ((n 0))
    (if (< n len)
        (let ((wchar (C-> scan "wchar")))
          (process wchar)
          (C-array-loc! scan "wchar" 1)
          (loop (1+ n))))))
```

That is a quick look at the facilities. The next section describes the C declaration language, and the following sections examine the FFI's syntax and runtime facilities in detail. Final sections provide an example program and show how its dynamically loaded shim is built.

2 C Declarations

A shim between Scheme and a C toolkit is specified by a case sensitive `.cdecl` file containing Scheme-like declarations of all relevant toolkit types, constants, and functions. Callback functions to be passed to the toolkit are also specified here.

Each top-level form in the C declaration file must look like one of these:

```
(include "filename")
(typedef Name any)
(struct Name (Member type) ...)
(union Name (Member type) ...)
(enum Name (Member) ...)
(extern function-type Name (param1 arg-type) ...)
(callback callback-type Name (param1 callback-arg-type) ...)
```

The `include` expression includes another `.cdecl` file in the current `.cdecl` file. The string argument is interpreted relative to the current file's directory.

any can be a *type* or the word `void`.

arg-type can be any *type* *except* anonymous structs and unions.

function-type can be any *arg-type* or `void`.

callback-arg-type can be any *type* *except* struct and union types.

callback-type can be any *callback-arg-type* or `void`.

type can look like any of these:

```
Name
basics
(* any)
(enum Name)
(enum Name (Member) ...)
(struct Name)
(struct Name (Member type) ...)
(union Name)
(union Name (Member type) ...)
```

Name should be defined via a `typedef` form somewhere in the (included) file(s). It does not have to be defined before it is referenced. It does not have to be defined *at all* if it is only the target of a pointer type.

basics can be any of the words: `char`, `uchar`, `short`, `ushort`, `int`, `uint`, `long`, `ulong`, `float`, or `double` (all lowercase).

While the informal grammar above allows anonymous structs to be member types, they are useless outside a named type declaration. The peek and poke (`C->` and `C->=`) syntaxes require a type name (e.g. `"GdkEventAny"` or `"struct _GdkEventAny"`) before any member names.

```
(C-include "prhello")
```

The `C-include` syntax takes a library name and loads the corresponding `-types` and `-const` files at syntax time. This makes the C types and constants available to the other `C-...` syntax expanders. The form binds `c-includes` in the syntax environment *unless* it is already defined there. Thus a `(C-include "library")` form can be placed at the top of every file with `C-...` syntax, *or* loaded into the syntax-time environment of those files.

3 Alien Data

A C data structure is represented by an alien containing the data structure's memory address. "Peek" primitives are available to read pointers and the basic C types (e.g. ints, floats) at small (fixnum) offsets from an alien's address. They return to Scheme an alien address, integer or flonum as appropriate. "Poke" primitives do the reverse, storing pointers, integers or floats at fixnum offsets from alien addresses. Other procedures on aliens are `alien?`, `alien-null?`, `alien-null!`, `copy-alien`, `alien=?`, `alien-byte-increment`, and `c-peek-cstring`. Refer to `ffi.pkg` in The Source for a complete list.

The `C->` and `C->=` syntaxes apply the peek and poke primitives to constant offsets. They expect their first argument subform to be a constant string — space-separated words naming a C type and any member to be accessed. A member within a struct or union member is specified by appending its name. For example `"struct _GdkEvent any window"` would specify a peek at the `window` member of the `any` member of the `struct _GdkEvent` data at some alien address. Note that the final member's type must be a basic C type, pointer type, or enum type. Otherwise, an error is signaled at syntax time.

```
(C-> alien "struct _GdkEvent any window" window-alien)
↦
(#[primitive c-peek-pointer] alien 0 window-alien)
 ⇒ #[alien 44 (* GdkWindow) 0x081afc60]
```

Note that in the example above, the final member has a pointer type. In this case an extra alien argument can be provided to receive the peeked pointer. Otherwise a new alien is created and returned.

Malloc

The `malloc` procedure returns an alien that will automatically free the malloced memory when it is garbage collected. It can also be explicitly freed with the `free` procedure. The alien address can be incremented to scan the malloced memory, then freed (without returning it to the original, malloced address). A band restore marks all malloced aliens as though they have been freed.

```
(free (malloc '|GdkRectangle|))
```

4 Alien Functions

The `C-call` syntax produces code that applies `call-alien` to an alien function structure — a cache for the callout trampoline's entry address.

```
(C-call "gtk_button_new" (make-alien '(* |GtkWidget|)))
↦
(call-alien '#[alien-function gtk_button_new] (make-alien ...))
```

The alien function contains all the information needed to load the callout trampoline on demand (i.e. its name and library). Once the alien function has cached the entry address, `call-alien` can invoke the trampoline (via `#[primitive c-call]`). The trampoline gets its arguments off the Scheme stack, converts them to C values, calls the C function, conses a result, and returns it to Scheme.

A function returning a pointer type is treated specially. Its trampoline expects an extra (first) argument. If the argument is `#f`, the return value is ignored. If the argument is an alien, the function's return value clobbers the alien's address. This makes it easy to grab pointers to toolkit resources without dropping them, and to avoid unnecessary consing of aliens.

A function returning a struct or union type is treated similarly. Its trampoline expects an extra (first) argument. If the argument is `#f`, the return value is ignored. If the argument is an alien, the returned struct or union is copied to that address.

Struct and union type parameters of a function are treated similarly. The function's trampoline expects an alien argument for each such parameter and copies the struct or union from the argument address into a local variable. Callbacks currently cannot receive struct or union type arguments, though they *can* receive pointer type arguments (consing an alien for each).

The `alien-function` structures are fasdumpable. The caching mechanism invalidates the cache when a band is restored, or a fasdumped object is fasloaded. The alien function will lookup the trampoline entry point again on demand.

5 Callbacks

A callback declaration must include a parameter named "ID". The ID argument will be used to find the Scheme callback procedure. It must be the same "user data" value provided to the toolkit when the callback was registered. For example, a callback trampoline named `Scm_delete_event` might be declared like this:

```
(callback gint
          delete_event
          (window (* GtkWidget))
          (event (* GdkEventAny))
          (ID gpointer))
```

The callback might be registered with the toolkit like this:

```
(C-call "g_signal_connect" window "delete_event"
        (C-callback "delete_event")     ; e.g. &Scm_delete_event
        (C-callback                     ; e.g. 314
          (lambda (window event)
            (C-call "gtk_widget_destroy" window)
            0)))
```

The toolkit's registration function, `g_signal_connect`, would be declared like this:

```
(extern void
        g_signal_connect
        (object (* GtkObject))
        (name (* gchar))
        (CALLBACK GtkSignalFunc)
        (ID gpointer))
```

This function should have parameters named `CALLBACK` and `ID`. The callout trampoline will convert the callback argument from a Scheme alien function to an entry address. The `ID` argument will be converted to a C integer and then cast to its declared type (in this example, `gpointer`).

Note that the registered callback procedures are effectively pinned. They cannot be garbage collected. They are "on call" to handle callbacks from the toolkit until they are explicitly de-registered. A band restore automatically de-registers all callbacks.

Callback procedures are executed with thread preemption suspended. Thus Scheme will not switch to another thread, especially not one preempted in an earlier callback. Such a thread could finish its callback and return from the later callback, not to its original caller.

Scheme will not preempt a callback, but if the callback calls `suspend-thread` it will switch to a running thread. If the callback does IO (and blocks), suspends, yields, sleeps, or grabs (waits for) a mutex, the runtime system will switch to another thread, possibly a thread that blocked for IO during an earlier callback but is now recently unblocked and determined to finish and return to the wrong caller. Thus callback procedures should be written as if they were interrupt handlers. They should be short and simple because they must not wait.

The `outf-error` procedure is provided for debugging purposes. It writes one or more argument strings (and `write`s any non-strings) to the Unix "stderr" channel, atomically, via a machine primitive, bypassing the runtime's IO buffering and thread switching. Thus trace messages from multiple threads will appear on stderr intact, uninterrupted.

6 Compiling and Linking

The `c-generate` procedure takes a library name and an optional preamble. It reads the *`library`*`.cdecl` file and writes two `.c` files. The preamble is included at the top of both. It typically contains `#include` C pre-processor directives required by the C library, but could include additional shim code. Here is a short script that generates a shim for the example "Hello, World!" program.

```
(load-option 'FFI)
(c-generate "prhello" "#include <gtk/gtk.h>")
```

This script will produce three files:

`prhello-shim.c`
: This file contains the trampoline functions — one for each declared C extern or callback. It includes the `mit-scheme.h` header file, found in the `AUXDIR` directory — e.g. `/usr/local/lib/mit-scheme-i386/`.

`prhello-const.c`
: This file contains a C program that creates `prhello-const.scm`. It is compiled and linked as normal for programs using the toolkit, and does not depend on the Scheme machine. It does not actually call any toolkit functions. It just collects information from the compiler about the declared C types and constants.

`prhello-types.bin`
: This file is a fasdumped `c-includes` structure containing all of the types, constants and functions declared in the `.cdecl` file.

The following Makefile rules describe the process of building and installing a shim for the example "Hello, World!" program.

```
AUXDIR=/usr/local/lib/mit-scheme-i386

install: build
        install -m 644 prhello-types.bin $(AUXDIR)
        install -m 644 prhello-const.bin $(AUXDIR)
        install -m 644 prhello-shim.so $(AUXDIR)

uninstall:
        rm $(AUXDIR)/prhello-*

clean:
        rm prhello-const* prhello-types* prhello-shim*

build: prhello-shim.so prhello-types.bin prhello-const.bin

prhello-shim.so: prhello-shim.o
        $(CC) -shared -fPIC -o $@ $^ `pkg-config --libs gtk+-3.0`

prhello-shim.o: prhello-shim.c
        $(CC) -I$(AUXDIR) -Wall -fPIC `pkg-config --cflags gtk+-3.0` -o $@ -c $<
```

```
prhello-shim.c prhello-const.c prhello-types.bin: prhello.cdecl
        echo '(generate-shim "prhello" "#include <gtk/gtk.h>")' \
        | mit-scheme --batch-mode

prhello-const.bin: prhello-const.scm
        echo '(sf "prhello-const")' | mit-scheme --batch-mode

prhello-const.scm: prhello-const
        ./prhello-const

prhello-const: prhello-const.o
        $(CC) $(CFLAGS) -o $@ $^ $(LDFLAGS) `pkg-config --libs gtk+-3.0`

prhello-const.o: prhello-const.c
        $(CC) `pkg-config --cflags gtk+-3.0` $(CFLAGS) -o $@ -c $<
```

The FFI also supports libraries created by GNU automake (libtool). The source distribution includes several simple plugins. Each uses a portable Makefile.am to build and install its shared object.

7 Hello World

This chapter includes the C declarations and Scheme code required to implement Havoc Pennington's Hello World example from GGAD (`http://developer.gnome.org/doc/GGAD/`). For an extra, Schemely treat, its `delete_event` callback is a Scheme procedure closed over a binding of `counter` that is used to implement some impertinent behavior.

```
#| -*-Scheme-*-

This is Havoc Pennington's Hello World example from GGAD, in the raw
FFI.  Note that no arrangements have been made to de-register the
callbacks. |#

(declare (usual-integrations))

(C-include "prhello")

(define (hello)
  (C-call "gtk_init" 0 null-alien)
  (let ((window (let ((alien (make-alien '|GtkWidget|)))
                  (C-call "gtk_window_new" alien
                          (C-enum "GTK_WINDOW_TOPLEVEL"))
                  (if (alien-null? alien) (error "Could not create window."))
                  alien))
        (button (let ((alien (make-alien '|GtkWidget|)))
                  (C-call "gtk_button_new" alien)
                  (if (alien-null? alien) (error "Could not create button."))
                  alien))
        (label (let ((alien (make-alien '|GtkWidget|)))
                 (C-call "gtk_label_new" alien "Hello, World!")
                 (if (alien-null? alien) (error "Could not create label."))
                 alien)))
    (C-call "gtk_container_add" button label)
    (C-call "gtk_container_add" window button)
    (C-call "gtk_window_set_title" window "Hello")
    (C-call "gtk_container_set_border_width" button 10)
    (let ((counter 0))
      (C-call "g_signal_connect" window "delete_event"
              (C-callback "delete_event")       ;trampoline
              (C-callback                       ;callback ID
               (lambda (w e)
                 (outf-error ";Delete me "(- 2 counter)" times.\n")
                 (set! counter (1+ counter))
                 ;; Three or more is the charm.
                 (if (> counter 2)
                     (begin
                       (C-call "gtk_main_quit")
                       0)
```

```
                    1))))
      (C-call "g_signal_connect" button "clicked"
              (C-callback "clicked")    ;trampoline
              (C-callback                       ;callback ID
               (lambda (w)
                 (let ((gstring (make-alien '(* |gchar|))))
                   (C-call "gtk_label_get_text" gstring label)
                   (let ((text (c-peek-cstring gstring)))
                     (C-call "gtk_label_set_text" label
                             (list->string (reverse! (string->list text))))))
                 unspecific))))
    (C-call "gtk_widget_show_all" window)
    (C-call "gtk_main")
    window))
```

Here are the C declarations.

```
#| -*-Scheme-*-

C declarations for prhello.scm. |#

(typedef gint int)
(typedef guint uint)
(typedef gchar char)
(typedef gboolean gint)
(typedef gpointer (* mumble))

(extern void
        gtk_init
        (argc (* int))
        (argv (* (* (* char)))))

(extern (* GtkWidget)
        gtk_window_new
        (type GtkWindowType))

(typedef GtkWindowType
         (enum
          (GTK_WINDOW_TOPLEVEL)
          (GTK_WINDOW_POPUP)))

(extern (* GtkWidget)
        gtk_button_new)

(extern (* GtkWidget)
        gtk_label_new
        (str (* (const char))))
```

```
(extern void
        gtk_container_add
        (container (* GtkContainer))
        (widget    (* GtkWidget)))

(extern void
        gtk_window_set_title
        (window (* GtkWindow))
        (title  (* (const gchar))))

(extern void
        gtk_container_set_border_width
        (container (* GtkContainer))
        (border_width guint))

(extern void
        gtk_widget_show_all
        (widget (* GtkWidget)))

(extern void
        g_signal_connect
        (instance gpointer)
        (name (* gchar))
        (CALLBACK GCallback)
        (ID gpointer))

(typedef GCallback (* mumble))

(callback gboolean
          delete_event
          (window (* GtkWidget))
          (event (* GdkEventAny))
          (ID gpointer))

(callback void
          clicked
          (widget (* GtkWidget))
          (ID gpointer))

(extern void
        gtk_widget_destroy
        (widget (* GtkWidget)))

(extern (* (const gchar))
        gtk_label_get_text
        (label (* GtkLabel)))
```

```
(extern void
        gtk_label_set_text
        (label (* GtkLabel))
        (str (* (const char))))

(extern void gtk_main)
(extern void gtk_main_quit)
```

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