

The Swish Concurrency Engine
Version 2.8.1

Bob Burger, editor

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Chapter 1

Introduction to Swish

1.1 Overview

The Swish Concurrency Engine is a framework used to write fault-tolerant programs with message-passing concurrency. It uses the Chez Scheme [6] programming language and embeds concepts from the Erlang [8] programming language. Swish also provides a web server following the HTTP protocol [14].

Swish uses message-passing concurrency and fault isolation to provide fault-tolerant software [1, 18]. The software is divided into lightweight processes that communicate via asynchronous message passing but are otherwise isolated from each other. Because processes share no mutable state, one process cannot corrupt the state of another process—a problem that plagues software using shared-state concurrency.

Exceptions are raised when the software detects an error and cannot continue normal processing. If an exception is not caught by the process that raised it, the process is terminated. An error logger records process crashes and other software errors.

There are two mechanisms for detecting process termination, *links* and *monitors*. Processes can be linked together so that when one exits abnormally, the others are killed. A process can monitor other processes and receive process-down messages that include the termination reason.

A single event dispatcher receives events from the various processes and sends them to all attached event handlers. Event handlers filter events based on their needs.

Swish is written in Chez Scheme for two main reasons. First, it provides efficient first-class continuations [4, 20] needed to implement lightweight processes with much less memory and CPU overhead than operating system threads. Second, Chez Scheme provides powerful syntactic abstraction capabilities [7] needed to make the code closely reflect the various aspects of the design. For example, the message-passing system uses syntactic abstraction to specify pattern matching succinctly.

I/O operations are performed asynchronously using C code (see Chapter 3), and they complete via Scheme callback functions. Asynchronous I/O is used so that Swish can run in a single thread without blocking for I/O. The results from asynchronous operations are invoked synchronously by the Scheme code, allowing it to control re-entrancy.

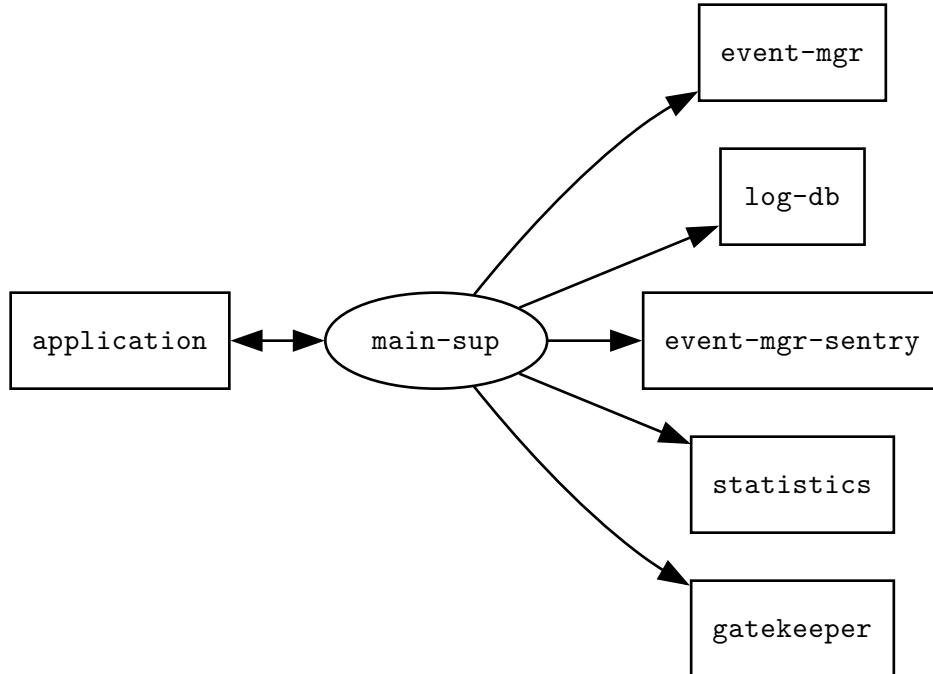


Figure 1.1: Supervision Tree

1.2 Supervision Tree

Calling `app:start` spawns a set of processes organized in a supervision tree. By default, Swish uses the supervision tree illustrated in Figure 1.1. The application (see Chapter 10) is a single gen-server that manages the lifetime of the program. It links the top-level supervisor and shuts down the program when requested or when the linked process dies. The top-level supervisor, `main-sup`, is configured one-for-all and no restarts so that a failure of any of its children crashes the program. The `event-mgr` worker is the event manager gen-server (see Chapter 7). The `log-db` worker is a database gen-server (see Chapter 12) that logs all events to the log database. The `event-mgr-sentry` worker is used during shutdown to make sure the event manager stops sending events to `log-db` before `log-db` shuts down. The `statistics` worker is a system statistics gen-server (see Chapter 13) that periodically posts a `<statistics>` event. The `gatekeeper` worker is the gen-server described in Chapter 8.

A web server can be added to the supervision tree by calling `http:add-file-server` or `http:add-server` (see Chapter 14) before calling `app:start`.

Chapter 2

Developing Software with Swish

2.1 Introduction

Swish can be used to build, test, and deploy programs ranging from small scripts to large stand-alone applications. This chapter describes some of the tools and mechanisms that Swish provides for these purposes.

2.2 Deployment Types

For interactive development, Swish provides a REPL that reads, evaluates, and prints the values of programs entered at the prompt. At the REPL, the `load` procedure can be used to evaluate the contents of a file containing source or object code. This is convenient when developing larger programs.

Swish provides several options for deploying programs. This section describes these options and their trade-offs.

2.2.1 Scripts

A simple deployment option is to place source code in a file that begins with a `#!` line specifying the absolute path to an executable that can evaluate the script. This could be the absolute path to the Swish executable. More often `/usr/bin/env` is used to locate the Swish executable via the program search path. For example, we might have:

```
$ cat hello
#!/usr/bin/env swish
(printf "Hello, World!\n")
$ chmod +x hello
$ ./hello
Hello, World!
```

In the preceding example, running `./hello` invokes the Swish executable with `./hello` as its sole

command-line argument. At boot time, Swish calls `swish-start` to process its command-line arguments. Since the first argument is not an option (`-h`, `--help`, etc.), `swish-start` runs the file named by that argument with the remaining arguments, if any, as its command-line arguments. For example, the following `Echo` script processes the arguments that are passed to the script.

```
$ cat Echo
#!/usr/bin/env swish
(printf "~{~:(~a~)}\n" (command-line-arguments))
$ chmod +x Echo
$ ./Echo some camel case identifiers are hard to read
SomeCamelCaseIdentifiersAreHardToRead
```

To provide arguments to the Swish executable before the script filename, add the `-S` option to `env` and add the desired arguments after `swish`. Here the `-q` option suppresses the startup message and sets the prompt to the empty string, and the `--` option tells Swish to start a REPL after loading the script.

```
$ cat howdy
#!/usr/bin/env -S swish -q --
(printf "Howdy, Folks!\n")
(printf "prompt: ~s\n" (waiter-prompt-string))
(printf "command-line: ~s\n" (command-line-arguments))
$ chmod +x howdy
$ ./howdy
Howdy, Folks!
prompt: ""
command-line: ("-q" "--" "./howdy")
(waiter-prompt-string "yes?")
yes? (+ 2 3)
5
yes? (exit)
```

Limitations

There are several constraints to consider when deploying Swish scripts.

- Naturally, Swish must be installed. To use `/usr/bin/env` as in the preceding examples, the `PATH` environment variable must contain the directory where the Swish executable is installed. This is preferable to hard-coding the absolute path to the Swish executable in your scripts.
- Chez Scheme must also be installed. In particular, the version of Chez Scheme that was used to build Swish must be installed. Swish must be able to locate the Chez Scheme boot files `petite.boot` and `scheme.boot`.

If Chez Scheme is installed in a non-standard location, it may be necessary to set the `SCHEME-HEAPDIRS` environment variable to help Swish locate the boot files. To see where Swish looks for boot files, run `swish --verbose`.

- The `#!` scripts shown in this section do not run under Windows. In MinGW/MSYS, these scripts may work unless Posix path conversion is disabled by setting the `MSYS_NO_PATHCONV` environment variable to 1. In Cygwin, these scripts may work if the directory containing the script is mounted as its Windows twin, e.g., `C:/Users` and `/Users`. For either of these options to work, Swish must be able to locate the appropriate Chez Scheme DLL via the standard search order. Scripts will fail if the current drive is not the drive containing the script.

2.2.2 Linked Programs

A linked program is simply a Scheme object file that begins with a `#!/usr/bin/env swish` line. Swish runs these programs the same way it runs scripts, except that `swish-start` skips the compilation step when it runs the file.

We can use `swish-build` to build a linked program `foo` from a source file `foo.ss`, as follows:

```
$ swish-build -o foo foo.ss
```

Limitations

All of the limitations in Section 2.2.1 apply. Since linked programs use `/usr/bin/env`, the Swish executable must be in a directory in the `PATH` on the target machine.

In addition, the Swish executable (and supporting code) that is used to run a linked program must be identical to the one that was used to build it.

2.2.3 Stand-alone Programs

A stand-alone program consists of an executable and a boot file that must be installed in the same directory. The name of the boot file is the same as the executable's name with any extension replaced by `.boot`. The executable is simply a copy of the Swish executable. The boot file includes the necessary Chez Scheme boot files along with the compiled application code.

We can use `swish-build` to build a linked program `foo` from a source file `foo.ss` by specifying a base boot file via the `-b` option:

```
$ swish-build -o foo foo.ss -b petite
```

Limitations

On Windows, the Swish DLLs `osi.dll`, `uv.dll`, and `sqlite3.dll` must be installed in the same directory as the program executable. These DLLs can be found in the directory containing the Swish executable. In addition, the program executable must be able to locate Microsoft's C Runtime Library `vcruntime140.dll` and the appropriate Chez Scheme DLL via the standard search order.

2.2.4 Services

On Linux and Windows, a Swish application can be started as a service that listens for system shutdown, suspend, and resume messages. To start a Swish application as a service, pass `/SERVICE` as the first command-line argument. On Windows, two additional command-line arguments are required: the service name and the path to the log file where stdout and stderr are redirected. See `swish_service` and `osi_is_service` for details.

2.3 Running Tests

Use the `mat` and `isolate-mat` forms described in Section 2.4.4 to define automated tests. Use the `swish-test` script to run tests and report the results. This script treats each file with a `.ms` extension as a suite of tests. See `swish-test --help all` for details.

2.4 Programming Interface

2.4.1 Configuration

(app:config [*obj*]) **procedure**
returns: a hashtable

When called with no arguments, the `app:config` procedure returns the configuration data cached in a private process parameter. If the cache is empty, `app:config` first populates the cache by reading data from the file identified by `app:config-filename`. If that file does not exist, the procedure returns an empty hashtable. Otherwise, `app:config` expects the file to contain a single JSON object.

The optional *obj* must be `#f` or a hashtable in the form returned by `json:make-object`. Calling `app:config` with `#f` clears the cache. Calling `app:config` with a hashtable installs the hashtable as the cached value.

(app:config-filename) **procedure**
returns: the name of the application's configuration file

The `app:config-filename` procedure returns the name of the application configuration file that `app:config` will read. The filename returned depends on the value of `app:path`.

If `app:path` is set to a value of the form `".../bin/app-name[.ext]"`, that ends with a `"bin"` directory, then the result is a `config` file in the corresponding `"lib"` directory `".../lib/app-name/config"`. If `app:path` is set to a value of the form `".../app-name[.ext]"`, then the result is a file with a `.config` extension in the same directory: `".../app-name.config"`.

If `app:path` is not set, the result is a `.config` file in the base directory identified by value of the `base-dir` parameter. This can be useful when loading program code at the REPL during interactive development.

(app:name [*name*]) **parameter**
value: a string or `#f`

The `app:name` parameter returns the short descriptive name of the application, if known. This value is used by the `app-exception-handler` to identify the program that is reporting an error. The value is also useful as an argument to `display-usage` and `display-help`.

When called with a string, `app:name` treats the value as a file-system path and stores only the last element of the path, dropping any file extension.

For stand-alone programs, `swish-start` sets this parameter to the path of the running executable. For scripts or linked programs, `swish-start` sets this parameter to the path of the script or program file.

(app:path [*path*]) **parameter**
value: an absolute path or #f

The `app:path` parameter returns the absolute path to the script or program, if known. This value is used by `app:config-filename` to determine the location of the application's configuration file. For scripts and linked programs, where the actual executable is Swish, this value is different from that returned by `osi_get_executable_path`.

When called with a string, `app:path` calls `get-real-path` to obtain an absolute path and stores the result.

(base-dir [*path*]) **parameter**
value: a file-system path

When called without arguments, `base-dir` returns the file-system path of the application's base directory. Otherwise, the base directory is set to *path*, which must specify the file-system path of a directory that exists and is writable by the application. Setting `base-dir` sets the values of `data-dir`, `log-file`, and `tmp-dir` so that they refer to locations within the base directory.

When the application starts, `base-dir` is set to the current directory.

(data-dir [*path*]) **parameter**
value: a file-system path

The `data-dir` parameter holds the file-system path of a directory in which the application can write persistent data. Applications should not assume that this directory exists, but should instead use `make-directory-path` when creating files under `data-dir`. Its initial value is the path to a "data" subdirectory of the directory specified by `base-dir`.

(log-file [*filename*]) **parameter**
value: a file name

The `log-file` parameter holds the name of the file containing the SQLite log database managed by the `log-db` gen-server, which creates the file and the requisite directory structure when started. Its initial value is the path to a "Log.db3" file in the directory specified by `data-dir`.

(tmp-dir [*path*]) **parameter**
value: a file-system path

The `tmp-dir` parameter holds the file-system path of a directory in which the application can write ephemeral data. Applications should not assume that this directory exists, but should instead use

`make-directory-path` when creating files under `tmp-dir`. Its initial value is the path to a "tmp" subdirectory of the directory specified by `base-dir`.

(include-line *filename* [*not-found*]) **syntax**
returns: see below

The `include-line` macro expects a string constant *filename* identifying a file either via absolute path or as a path relative to a directory in `source-directories`. If such a file can be found at expand time, `include-line` expands to a string containing the first line of that file or the end-of-file object if the file is empty. If the file cannot be found, `include-line` expands to (*not-found filename*), where *not-found* defaults to an expression that raises a syntax error indicating that the file could not be found.

(software-info) **procedure**
value: a JSON object

The `software-info` procedure returns a JSON object containing the values stored by `software-product-name`, `software-revision`, and `software-version`. Swish populates these parameters for the `swish` and `chezscheme` keys with values that are determined at compile time.

(software-product-name [*key*] [*value*]) **parameter**
value: a string or #f

The `software-product-name` procedure stores or retrieves the product name under the path (*key product-name*) in the `(software-info)` object. If *value* is omitted, this procedure returns the value, if any, associated with *key*, or else #f. If *key* and *value* are omitted, this procedure returns the value associated with the key (`string->symbol` (or (`app:name`) "swish")). If specified, *key* must be a symbol and *value* must be a string. If *key* and *value* are specified and a value has already been set for *key*, this procedure has no effect.

(software-revision [*key*] [*value*]) **parameter**
value: a string or #f

The `software-revision` procedure stores or retrieves the software revision under the path (*key revision*) in the `(software-info)` object. If *value* is omitted, this procedure returns the value, if any, associated with *key*, or else #f. If *key* and *value* are omitted, this procedure returns the value associated with the key (`string->symbol` (or (`app:name`) "swish")). If specified, *key* must be a symbol and *value* must be a string. If *key* and *value* are specified and a value has already been set for *key*, this procedure has no effect.

(software-version [*key*] [*value*]) **parameter**
value: a string or #f

The `software-version` procedure stores or retrieves the software version under the path (*key version*) in the `(software-info)` object. If *value* is omitted, this procedure returns the value, if any, associated with *key*, or else #f. If *key* and *value* are omitted, this procedure returns the value associated with the key (`string->symbol` (or (`app:name`) "swish")). If specified, *key* must be a symbol and *value* must be a string. If *key* and *value* are specified and a value has already been set for *key*, this procedure has no effect.

2.4.2 Program Life Cycle

(app-exception-handler *obj*) **procedure**

returns: unspecified

When a Swish application starts, it sets the default value of the `base-exception-handler` parameter to `app-exception-handler`. This procedure expects a single argument, typically a condition or an object passed to `throw` or `raise`, which it saves in the parameter `debug-condition`.

If `app:name` is set, then `app-exception-handler` writes a message to the console error port, prefixed with the application name, before calling `reset`. If *obj* is a condition, then the message is formed by stripping the “Warning:” or “Exception:” prefix from the output of `display-condition`. Otherwise, the message is generated by calling `exit-reason->english` on *obj*.

If `app:name` is not set, then `app-exception-handler` calls the default exception handler.

(app-sup-spec [*start-specs*]) **parameter**

value: a list of child specifications (see page 109)

The `app-sup-spec` parameter supplies the *start-specs* that define the tree of child processes that are started by `app:start` and supervised by the `main-sup` gen-server. The initial value of `app-sup-spec` is constructed by calling `make-swish-sup-spec` with `swish-event-logger` as the sole logger.

(app:shutdown [*exit-code*]) **syntax**

This is an alias for `application:shutdown`.

(app:start) **procedure**

returns: ok

The `app:start` procedure calls `application:start` with a *starter* thunk that calls `supervisor:start&link` with the value of the `app-sup-spec` parameter.

(make-swish-sup-spec *loggers*) **procedure**

returns: a list of child specifications (see page 109)

The `make-swish-sup-spec` procedure builds a list of child specifications representing the default supervision tree described in Section 1.2. The *loggers* argument is a list of `<event-logger>` tuples that will be passed to `log-db:setup` when the `log-db` gen-server is started.

(swish-start *arg ...*) **procedure**

returns: see below

When a stand-alone program starts, it initializes several parameters: `app:name`, `app:path`, `command-line`, and `command-line-arguments`. When a Swish script, linked program, or REPL is started, it performs this initialization by applying `swish-start` to the original command-line arguments.

The `swish-start` procedure expects zero or more strings as arguments and scans them left to right. It adds each string that begins with a single dash (-) or double dash (--) to a set of options to be

handled later. If it encounters the string "--", it sets the REPL option and saves the remaining arguments as files to be loaded. If it encounters a string that does not begin with a dash, it stops scanning the arguments and marks that string and those that follow as ordinary arguments.

If `swish-start` finds `--help` among the options, it displays a summary of Swish's command-line options and returns. If it finds `--version` among the options, it displays version information and returns. If the REPL option is set or it finds no ordinary arguments, then it suppresses the startup message and waiter prompt if `--quiet` is among the options, then loads any files that were specified, and then calls `new-cafe`. Otherwise, it treats the first ordinary argument as a script or linked program. In this case, it installs the ordinary arguments as the value of `command-line`, sets `app:name` and `app:path` to the first of them, sets `command-line-arguments` to the remaining ones, and clears `app:config` before loading the script or linked program. If an error occurs while loading the script or linked program, Swish exits with an exit code of 1. Otherwise, Swish exits normally.

When it starts a REPL, script, or linked program, `swish-start` attempts to import any libraries found in `library-list` whose library path begins with the symbol `swish`.

| <code>repl-level</code> | parameter |
|----------------------------------|-----------|
| value: nonnegative fixnum | |

The `repl-level` parameter returns the nesting depth of the `swish-start` REPL. The value of this parameter is initially zero; it is incremented when a process enters the `swish-start` REPL. It is not affected by `new-cafe`.

2.4.3 Foreign Interface

Scheme libraries that rely on shared objects must arrange to call `load-shared-object` before calling `foreign-procedure` or calling `make-ftype-pointer` on a function `ftype`. We must consider shared-object naming conventions and search paths on different platforms when calling `load-shared-object`. We can provide its filename argument through some combination of conditional compilation, hard-coded relative or absolute paths, and general computation.

The `provide-shared-object` and `require-shared-object` procedures in this section offer a simple way to: factor platform dependencies out of client code, load shared objects by absolute path to avoid search, specify shared object file names as paths relative to the application configuration file, and hook the operation that loads shared object code.

These procedures coordinate via the application configuration object stored in `app:config`, which is populated on demand by reading the file specified by `app:config-filename`. A Scheme library can call `require-shared-object` before its `foreign-procedure` definitions and rely on demand-loading of the configuration file to supply the absolute path to the shared object code when the library is invoked. This simplifies a process that can otherwise be complicated by the fact that Chez Scheme invokes a library lazily as soon as one of its exports may be referenced.

To see how these procedures are decoupled, consider the following Swish REPL transcript on a 64-bit Linux machine:

```
> (provide-shared-object 'libc "/lib64/libc.so.6")
> (foreign-entry? "fork")
#f
```



```

> (require-shared-object 'libc)
> (foreign-entry? "fork")
#t
> (let ([op (open-file-to-write (app:config-filename))])
      (on-exit (close-port op)
                (json:write op (app:config) 0)))
> (exit)

```

If we start a new Swish REPL, we can call `require-shared-object` without first calling `provide-shared-object` because we explicitly wrote the value of `app:config` to the location specified by `app:config-filename` before exiting the original REPL.

```

> (foreign-entry? "fork")
#f
> (require-shared-object "libc")
> (foreign-entry? "fork")
#t
> (display (utf8->string (read-file (app:config-filename))))
{
  "swish": {
    "shared-object": {
      "libc": {
        "a6le": {
          "file": "/lib64/libc.so.6"
        }
      }
    }
  }
}

```

(provide-shared-object *so-name filename*) **procedure**
returns: unspecified

The `provide-shared-object` procedure expects a symbol *so-name* as the generic name of a shared object and a string *filename* that is the name of the actual file containing the shared object code. This procedure records *filename* in `app:config` under a path that includes *so-name* and the host `machine-type`.

(require-shared-object *so-name [handler]*) **procedure**
returns: unspecified

The `require-shared-object` procedure loads a shared object via an absolute path to prevent `load-shared-object` from searching for the shared object file in a system-specific set of directories.

The *so-name* argument is a symbol that specifies the generic name of a shared object. The optional *handler* is a procedure that expects three arguments: *filename* is the absolute path to the shared object file, *key* is *so-name*, and *dict* is the hashtable retrieved from `app:config` via a path that includes *so-name* and the host `machine-type`. This hashtable contains a key `file` whose value is

the file name originally supplied by `provide-shared-object`. The handler might examine other keys within the hashtable before loading the shared object. The default handler simply calls `load-shared-object` on *filename*.

If the file name retrieved from `app:config` is a relative path, then `require-shared-object` determines the absolute path by treating the file name as a path relative to the parent directory containing the application configuration file name returned by `app:config-filename`.

```
(define-foreign name (arg-name arg-type) ...) syntax
```

expands to:

```
(begin
  (define name* (foreign-procedure (symbol->string 'name) (arg-type ...) ptr))
  (define (name arg-name ...)
    (match (name* arg-name ...)
      [(,who . ,err)
       (guard (symbol? who))
       (io-error 'name who err)])
    [,x x])))
```

The `define-foreign` macro defines two procedures: *name** is a raw foreign procedure that expects the specified argument types and returns a `ptr` value, while *name* is a wrapper that calls *name** and raises an `io-error` if it returns an error pair.

2.4.4 Testing

The `(swish mat)` library provides methods to define, iterate through, and run test cases, and to log the results. The `swish-test` script provides a convenient way to run tests and report the results. See `swish-test --help all` for details. To access the `(swish mat)` library directly, run `swish-test --repl` instead of `swish`, then import the library as usual.

Test cases are called *mats* and consist of a name, a set of tags, and a test procedure of no arguments. The set of mats is stored in reverse order in a single, global list. The list of tags allows the user to group tests or mark them. For example, tags can be used to note that a test was created for a particular change request.

```
(mat name (tag ...) e1 e2 ...) syntax
```

expands to: `(add-mat 'name '(tag ...) (lambda () e1 e2 ...))`

The `mat` macro creates a mat with the given *name*, *tags*, and test procedure *e1 e2 ...* using the `add-mat` procedure.

```
(isolate-mat name (tag ...) e1 e2 ...) syntax
```

```
(isolate-mat name (settings [key val] ...) e1 e2 ...)
```

expands to: `(mat name (tag ...) ($isolate-mat (lambda () e1 e2 ...)))`

Tests involving process operations, such as `spawn`, `send`, and `receive`, should use `isolate-mat` in place of `mat` to isolate the host system from the test code. The `isolate-mat` macro is provided by the `(swish testing)` library, which can be accessed via `swish-test`.

The `settings` form can be used within `isolate-mat` to override the following defaults:

| key | default | description |
|---------------------------------------|-----------------|---|
| <code>tags</code> | <code>()</code> | a list of <i>tag</i> ... |
| <code>timeout</code> | 60000 | deadline for test to complete, in milliseconds; computed as <code>(scale-timeout 'isolate-mat)</code> |
| <code>process-cleanup-deadline</code> | 500 | maximum time to wait for spawned processes to terminate, in milliseconds |
| <code>process-kill-delay</code> | 100 | delay in milliseconds before killing each spawned process that did not terminate by the <code>process-cleanup-deadline</code> |

(default-timeout *timeout* [*value*]) **procedure**

returns: see below

Given a symbol *timeout* and a *value*, which must be a nonnegative fixnum or the symbol `infinity`, `default-timeout` associates *timeout* with *value* and returns an unspecified value. If the optional *value* is omitted, `default-timeout` returns the value currently associated with *timeout*, or raises an exception if none. If *timeout* is a fixnum, `default-timeout` is the identity function. The following table lists predefined timeouts and their associated values.

| timeout | value | use |
|--------------------------|-----------------------|---|
| <code>infinity</code> | <code>infinity</code> | |
| <code>isolate-mat</code> | 60000 | default <code>timeout</code> for <code>isolate-mat</code> |
| <code>os-process</code> | 10000 | used internally by some Swish tests that call <code>spawn-os-process</code> |

(scale-timeout *timeout*) **procedure**

returns: see below

The `scale-timeout` procedure resolves *timeout* by calling `(default-timeout timeout)`. If the result is the symbol `infinity`, it is returned unmodified. If the result is a fixnum, `scale-timeout` returns the product of that number and the scale factor obtained by converting the value of the `TIMEOUT_SCALE_FACTOR` environment variable to a number via `string->number`. The scale factor defaults to 1 and must be nonnegative. The product is rounded to an exact number.

(mat:add-annotation! *expr*) **syntax**

returns: unspecified

The `mat:add-annotation!` macro extends the list of annotations recorded in the `meta-data` for the `mat` result of the current `mat`. Each annotation records the `erlang:now` timestamp, the source for the call site, if available, and the value of *expr*, which must evaluate to a valid JSON datum. This macro must be called only within the dynamic extent of a running `mat`. See `load-results` for more information.

(add-mat *name* *tags* *test*) **procedure**

returns: unspecified

The `add-mat` procedure adds a `mat` to the front of the global list. *name* is a symbol, *tags* is a list, and *test* is a procedure of no arguments.

If *name* is already used, an exception is raised.

(run-mat *name* *reporter*) **procedure**

returns: see below

The `run-mat` procedure runs the mat of the given *name* by executing its test procedure with an altered exception handler. If the test procedure completes without raising an exception, the mat result is `pass`. If the test procedure raises exception *e*, the mat result is `(fail . e)`.

After the mat completes, the `run-mat` procedure tail calls `(reporter name tags result statistics)`.

If no mat with the given *name* exists, an exception is raised.

(run-mats [*name*] ...) **syntax**

returns: unspecified

The `run-mats` macro runs each mat specified by symbols *name* When no names are supplied, all mats are executed. After each mat is executed, its result, name, and exception if it failed are displayed. When the mats are finished, a summary of the number run, passed, and failed is displayed.

(run-mats-to-file *filename*) **procedure**

returns: unspecified

The `run-mats-to-file` procedure executes all mats and writes the results into the file specified by the string *filename*. If the file exists, its contents are overwritten. The file format is a sequence of JSON objects readable with `load-results` and `summarize`.

(for-each-mat *procedure*) **procedure**

returns: unspecified

The `for-each-mat` procedure calls `(procedure name tags)` for each mat, in no particular order.

(load-results *filename*) **procedure**

returns: a JSON object

The `load-results` procedure reads the contents of the file specified by string *filename* and returns a JSON object with the following keys:

| | |
|--------------------------|------------------------|
| <code>meta-data</code> | a JSON object |
| <code>report-file</code> | <i>filename</i> |
| <code>results</code> | a list of JSON objects |

The `meta-data` object contains at least the following keys:

| | |
|---------------------------|---|
| <code>completed</code> | <code>#t</code> if test suite completed, <code>#f</code> otherwise |
| <code>hostname</code> | <code>(osi_get_hostname)</code> of the host system |
| <code>machine-type</code> | <code>(machine-type)</code> of the host system |
| <code>test-file</code> | name of the file containing the tests |
| <code>test-run</code> | uuid generated by <code>swish-test</code> for the set of tests run |
| <code>uname</code> | the result from <code>get-uname</code> as a JSON object containing <code>os-machine</code> , <code>os-release</code> , <code>os-system</code> , and <code>os-version</code> |

If the test suite completed, the `meta-data` object also contains the following keys:

`date` (format-rfc2822 (current-date)) at the start of the test suite
`software-info` (software-info) for the tested code
`timestamp` (erlang:now) at the start of the test suite

Each result is a JSON object with the following keys:

`message` error message from failing test, or empty string
`meta-data` a JSON object that contains:
 `annotations` an ordered list of JSON objects recording data from
 `mat:add-annotation!`,
 `start-time` (erlang:now) at the start of the test, and
 `end-time` (erlang:now) at the end of the test
`sstats` a JSON object representing the `sstats-difference` for the test
`stacks` if test failed with exception `e`, then
 (`map stack->json (exit-reason->stacks e)`)
`tags` a list of strings corresponding to the symbolic tags in the `mat` form
`test` a string corresponding to the symbolic `mat` name
`test-file` the name of the test file
`type` the type of result: "pass", "fail", "skip"

(summarize *files*)

procedure

returns: five values: the number of passing mats, the number of failing mats, the number of skipped mats, the number of completed suites, and the length of *files*.

The `summarize` procedure reads the contents of each file in *files*, a list of string filenames, and returns the number of passing mats, the number of failing mats, the number of skipped mats, the number of completed test suites, and the number of files specified. An error is raised if any entry is malformed.

Chapter 3

Operating System Interface

3.1 Introduction

This chapter describes the operating system interface. Swish is written in Chez Scheme and runs on Linux, macOS, and Windows. It provides asynchronous I/O via libuv [21] and database support via SQLite [22].

3.2 Theory of Operation

The operating system interface is written in C99 [5] as a shared library that links to the Chez Scheme, libuv, and SQLite libraries. Please refer to Chapter 4 of the *Chez Scheme Version 9 User's Guide* [6] for information on the foreign function interface. C++ is not used because C++ destructors may interact badly with `setjmp/longjmp`, used by Chez Scheme and Swish.

The single-threaded version of Chez Scheme is used because of its simplicity. All Scheme code runs in the main thread, and all C code must call Scheme functions from the main thread only. In order to keep this thread responsive, operations that block for more than a couple milliseconds are performed asynchronously.

Operations that take longer should be run in a worker thread. Results are communicated back to the main thread using a libuv async handle. Beware of running long operations in the libuv thread pool because there are only a few worker threads (four by default).

For each asynchronous function in the operating system interface, a Scheme callback procedure is passed as the last argument. This callback procedure is later returned to Scheme in a list that includes the results of the asynchronous function call. This approach is simpler and more efficient than calling the callback procedure directly from the C side.

Any time C code stores a pointer to a non-immediate Scheme object, the object must be locked. The operating system interface locks Scheme objects when it stores them in data structures managed in the C heap and unlocks them when the data structures are deallocated.

The operating system interface uses port objects for files, console input, pipes to other processes, and TCP/IP connections. A port object is created by the various open functions, which return a

port handle that is used for read, write, and close operations. Once a port is closed, its port object is freed.

Whenever Scheme receives a handle to an object allocated in the C heap, the handle is wrapped in a Scheme record and registered with a guardian. Each type of handle has an associated finalizer (see `add-finalizer`) that uses its guardian to free the objects from the C heap after each garbage collection (see the finalizer process in §4.3).

For interface functions that can fail, an error pair (*who* . *errno*) is returned, where *who* is a symbol representing the name of the particular function that failed and *errno* is either an error number or, in the case of certain SQLite functions, a pair whose car is the error number and cdr is the English error string.

Section 3.3 describes the programming interface from the C side. The Scheme library (`osi`) provides foreign procedures for each C function using the same name. For functions that may return an error pair, two Scheme procedures are defined: one that converts the error pair into an exception, and one with an asterisk suffix that returns the error pair. For example, if the `osi_read_port*` procedure returns error pair (*who* . *errno*), the `osi_read_port` procedure raises exception `#(osi-error osi_read_port who errno)`.

3.3 Programming Interface

Unless otherwise noted, all C strings are encoded in UTF-8.

3.3.1 C Interface

A single libuv I/O loop is used, `osi_loop`, which is unique to the operating system interface in order to avoid collisions with other libuv integrations.

```
void osi_init(void); function
```

The `osi_init` function disables libuv stdio inheritance, initializes `osi_loop`, initializes the timer used by `osi_get_callbacks`, and sets the list of callbacks to (). On Windows, it calls `timeBeginPeriod` to set the timer resolution to 1 ms. This function must be called exactly once from the main thread before any other `osi_*` functions are called.

```
void osi_add_callback_list(ptr callback, ptr args); function
```

The `osi_add_callback_list` function adds the callback list (*callback* . *args*) to the list of callbacks. This function must be called only on the main thread and only within the context of the event-loop's call to `osi_get_callbacks`, e.g., within a libuv callback such as `uv_async_cb`.

```
void osi_add_callback1(ptr callback, ptr arg); function
```

The `osi_add_callback1` function adds the callback list (*callback* *arg*) to the list of callbacks. This function must be called only on the main thread and only within the context of the event-loop's call to `osi_get_callbacks`, e.g., within a libuv callback such as `uv_async_cb`.

```
void osi_add_callback2(ptr callback, ptr arg1, ptr arg2); function
```

The `osi_add_callback2` function adds the callback list (*callback arg1 arg2*) to the list of callbacks. This function must be called only on the main thread and only within the context of the event-loop's call to `osi_get_callbacks`, e.g., within a libuv callback such as `uv_async_cb`.

```
void osi_add_callback3(ptr callback, ptr arg1, ptr arg2, ptr arg3); function
```

The `osi_add_callback3` function adds the callback list (*callback arg1 arg2 arg3*) to the list of callbacks. This function must be called only on the main thread and only within the context of the event-loop's call to `osi_get_callbacks`, e.g., within a libuv callback such as `uv_async_cb`.

```
ptr osi_make_error_pair(const char* who, int error); function
```

The `osi_make_error_pair` function returns the error pair (*who . error*). This function must be called on the main thread only.

```
int osi_send_request(handle_request_func handler, void* payload); function
```

The `osi_send_request` function blocks the calling thread until the main thread returns from calling *handler(payload)* within `osi_get_callbacks`. The *handler* function should execute quickly to avoid blocking the event loop. Typical handlers call `osi_add_callback_list` or one of its variants. `osi_send_request` returns zero if successful. Otherwise, it returns a libuv error code. Calling it from the main thread returns `UV_EPERM`.

```
char* osi_string_to_utf8(ptr s, size_t* utf8_len); function
```

The `osi_string_to_utf8` function returns the address of a freshly allocated nul-terminated string representing the Scheme string *s*. The length in bytes of this string excluding the terminating nul is written to **utf8_len*. It returns NULL if `malloc` fails. It is the caller's responsibility to call `free` when this memory is no longer needed.

```
int swish_run(int argc, const char* argv[], void (*custom_init)(void)); function
```

The `swish_run` function:

1. resolves the boot file based on *argv*[0] by replacing the extension, if any, with `.boot`,
2. initializes Scheme by calling `Sscheme_init`, `Sregister_boot_file`, and `Sbuild_heap`,
3. initializes the operating system interface by calling `osi_init`,
4. establishes a context for `osi_exit`,
5. starts the application by invoking the value of the `scheme-start` parameter, and

6. returns the status provided by `osi_exit`.

```
#if defined(__linux__) function
int swish_service(int argc, const char* argv[]);
#elif defined(_WIN32)
int swish_service(const wchar_t* service_name, const wchar_t* logfile,
                  int argc, const char* argv[]);
#endif
```

On Linux, the `swish_service` function:

1. resolves the boot file based on `argv[0]` by replacing the extension, if any, with `.boot`,
2. initializes Scheme by calling `Sscheme_init`, `Sregister_boot_file`, and `Sbuild_heap`,
3. initializes the operating system interface by calling `osi_init`,
4. adds a handler to listen for messages from `systemd-logind` on the D-Bus system bus,
5. establishes a context for `osi_exit`,
6. starts the application by invoking the value of the `scheme-start` parameter,
7. tears down the handler on exit, and
8. returns the status provided to `osi_exit`.

If the handler receives a `PrepareForShutdown` message with the argument `true`, it calls `$shutdown`. If it receives a `PrepareForSleep` message, it calls `$suspend` if the argument is `true` and `$resume` if the argument is `false`. See Figure 3.1 for information on these callbacks.

On Windows, the `swish_service` function:

1. redirects `stdout` and `stderr` to `logfile` and `stdin` from `NUL`,
2. connects to the Service Control Manager, establishing a new thread of execution to:
 - (a) resolve the boot file based on `argv[0]` by replacing the extension, if any, with `.boot`,
 - (b) initialize Scheme by calling `Sscheme_init`, `Sregister_boot_file`, and `Sbuild_heap`,
 - (c) initialize the operating system interface by calling `osi_init`,
 - (d) register a control handler with the Service Control Manager,
 - (e) establish a context for `osi_exit`, and
 - (f) start the application by invoking the value of the `scheme-start` parameter
3. sets the service status to the status provided by `osi_exit`.

Once running as a service, the Service Control Manager may send control messages to the process via the control handler. For a stop message, the control handler calls the `$shutdown` top-level procedure. For a suspend power event or resume power event, the control handler calls `$suspend` or `$resume` respectively. See Figure 3.1 for information on these callbacks.

| symbol | default top-level value | with statistics gen-server (Chapter 13) |
|-------------------------|-----------------------------------|---|
| <code>\$shutdown</code> | <code>application:shutdown</code> | <code>application:shutdown</code> |
| <code>\$suspend</code> | <code>void</code> | <code>statistics:suspend</code> |
| <code>\$resume</code> | <code>void</code> | <code>statistics:resume</code> |

Figure 3.1: Service callbacks.

```
(osi_is_service) procedure
returns: a boolean
```

If Swish is running as a service, then `osi_is_service` returns true, otherwise false.

3.3.2 System Functions and Procedures

```
ptr osi_get_argv(void); function
```

The `osi_get_argv` function returns a Scheme vector of strings constructed from the most recent arguments passed to `osi_set_argv`.

```
size_t osi_get_bytes_used(void); function
```

The `osi_get_bytes_used` function returns the number of bytes used by the C run-time heap. On Linux, it calls the `mallinfo` function. On macOS, it calls the `mstats` function. On Windows, it calls the `_heapwalk` function.

```
(osi_get_free_memory) procedure
returns: an unsigned integer
```

The `osi_get_free_memory` procedure returns the number of bytes of free memory as reported by `uv_get_free_memory`.

```
(osi_get_total_memory) procedure
returns: an unsigned integer
```

The `osi_get_total_memory` procedure returns the number of bytes of total physical memory as reported by `uv_get_total_memory`.

```
ptr osi_get_callbacks(uint64_t timeout); function
```

The `osi_get_callbacks` function returns a list of callback lists in reverse order of time received. When the list is empty, it blocks up to `timeout` milliseconds before returning. Each callback list has

the form (*callback result ...*), where *callback* is the callback procedure passed to the asynchronous function that returned one or more *results*.

```
const char* osi_get_error_text(int err); function
```

The `osi_get_error_text` function returns the English string for the given error number.

```
ptr osi_get_hostname(void); function
```

The `osi_get_hostname` function returns the host name from `uv_os_gethostname`.

```
ptr osi_get_uname(void); function
```

The `osi_get_uname` function returns a `<uname>` tuple of the values retrieved by `uv_os_uname`.

```
<uname> tuple
```

system: operating system name as a string

release: operating system release as a string

version: operating system version as a string

machine: hardware architecture identifier as a string

```
uint64_t osi_get_hrttime(void); function
```

The `osi_get_hrttime` function returns the current high-resolution real time in nanoseconds from `uv_hrttime`. It is not related to the time of day and is not subject to clock drift.

```
uint64_t osi_get_time(void); function
```

The `osi_get_time` function returns the current clock time in milliseconds in UTC since the UNIX epoch January 1, 1970. On Windows, it calls the `GetSystemTimeAsFileTime` function in `kernel32.dll`. On all other systems, it calls the `clock_gettime` function with `CLOCK_REALTIME`.

```
int osi_is_quantum_over(void); function
```

The `osi_is_quantum_over` function returns 1 if the current time from `uv_hrttime` is greater than or equal to the threshold set by the most recent call to `osi_set_quantum` and 0 otherwise.

```
ptr osi_list_uv_handles(void); function
```

The `osi_list_uv_handles` function calls `uv_walk` and returns a list of pairs (*handle . type*), where *handle* is the address of the `uv_handle_t` and *type* is the `uv_handle_type`.

```
ptr osi_make_uuid(void); function
```

The `osi_make_uuid` function returns a new universally unique identifier (UUID) as a bytevector. On Windows, it calls the `UuidCreate` function in `rpcrt4.dll`. On all other systems, it calls the `uuid_generate` function.

```
(string->uuid s) procedure
```

returns: a UUID bytevector

The `string->uuid` procedure returns the bytevector `uuid` for string `s` such that `(uuid->string uuid)` is equivalent to `s`, ignoring case. If `s` is not a string with uppercase or lowercase hexadecimal digits and hyphens as shown in `uuid->string`, exception `#{bad-arg string->uuid s}` is raised.

```
(uuid->string uuid) procedure
```

returns: a string

The `uuid->string` procedure returns the uppercase hexadecimal string representation of `uuid`, `HH3HH2HH1HH0-HH5HH4-HH7HH6-HH8HH9-HH10HH11HH12HH13HH14HH15`, where `HHi` is the 2-character uppercase hexadecimal representation of the octet at index `i` of bytevector `uuid`. If `uuid` is not a bytevector of length 16, exception `#{bad-arg uuid->string uuid}` is raised.

```
void osi_set_argv(int argc, const char *argv[]); function
```

The `osi_set_argv` function stores the `argv` pointer to a C vector of `argc` strings for use in the `osi_get_argv` function. It does not copy the strings, so the caller must not deallocate the memory for the arguments.

```
void osi_set_quantum(uint64_t nanoseconds); function
```

The `osi_set_quantum` function sets the threshold for `osi_is_quantum_over` to be the current time from `uv_hrttime` plus the given number of `nanoseconds`.

3.3.3 Port Functions

The port functions in this section provide generic read, write, and close operations for port objects. The specific implementation depends on the type of port object.

Port handles point to structures whose first element is a pointer to a virtual function table whose type is `osi_port_vtable_t`. This table defines the specific `close`, `read`, and `write` procedures.

```
ptr osi_read_port(uptr port, ptr buffer, size_t start_index, uint32_t size, function  
int64_t offset, ptr callback);
```

The `osi_read_port` function issues a read on the given `port` of `size` bytes into the bytevector `buffer` at the zero-based `start_index`. For file ports, `offset` specifies the starting file position or `-1` for the current position; for all other port types, `offset` must be `-1`. The function returns `#t` when

the read operation is issued and an error pair otherwise. When the read operation finishes, it enqueues the callback list (*callback result*), where *result* is the nonnegative number of bytes read when successful and a negative error code otherwise.

```
ptr osi_write_port(uptr port, ptr buffer, size_t start_index, uint32_t size, function
                  int64_t offset, ptr callback);
```

The `osi_write_port` function issues a write on the given *port* of *size* bytes from the bytevector *buffer* at the zero-based *start_index*. For file ports, *offset* specifies the starting file position or -1 for the current position; for all other port types, *offset* must be -1 . The function returns `#t` when the write operation is issued and an error pair otherwise. When the write operation finishes, it enqueues the callback list (*callback result*), where *result* is the nonnegative number of bytes written when successful and a negative error code otherwise.

```
ptr osi_close_port(uptr port, ptr callback);
```

function

The `osi_close_port` function issues a close on the given *port*. It returns `#t` when the close operation is issued and an error pair otherwise. When the close operation finishes, it deallocates the port object and enqueues the callback list (*callback errno*), where *errno* is 0 when successful and a negative error code otherwise.

3.3.4 Process Functions

```
void osi_exit(int status);
```

function

The `osi_exit` function returns *status* to the context established by `swish_run` or `swish_service`, if any. Otherwise it calls the `_exit` function to terminate the current process with the given exit *status*. It does not return. The `exit` function is not used because on Unix systems it blocks if there is an outstanding read on `stdin`.

```
ptr osi_spawn(const char* path, ptr args, ptr callback);
```

function

The `osi_spawn` function uses the `uv_spawn` function to create a process with the list of string-valued *args* whose standard input, output and error are connected to pipes. It returns `#(to-stdin from-stdout from-stderr pid)` when the process has been successfully created and an error pair otherwise. *to-stdin* is a port handle for writing bytes to standard input, *from-stdout* is a port handle for reading bytes from standard output, *from-stderr* is a port handle for reading bytes from standard error, and *pid* is an integer identifying the process.

When the process exits, the callback list (*callback pid exit-status term-signal*) is enqueued, where *pid* is the integer process identifier, *exit-status* is the integer exit status, and *term-signal* is the integer termination signal or 0 if the process did not terminate because of a signal.

```
ptr osi_spawn_detached(const char* path, ptr args);
```

function

The `osi_spawn_detached` function uses the `uv_spawn` function to create a process with the list of string-valued *args* and the `UV_PROCESS_DETACHED` flag set. It returns an integer identifying the process when the process has been successfully created and an error pair otherwise.

```
int osi_get_pid(); function
```

The `osi_get_pid` function uses the `uv_os_getpid` function to return the current operating-system process ID.

```
ptr osi_kill(int pid, int signum); function
```

The `osi_kill` function uses the `uv_kill` function to send termination signal *signum* to the process identified by *pid*. It returns `#t` when successful and an error pair otherwise.

```
ptr osi_start_signal(int signum); function
```

The `osi_start_signal` function uses the `uv_signal_start` function to trap the signal *signum*. It returns a signal handle when successful and an error pair otherwise. Signals are delivered via the internal `@deliver-signal` procedure, which invokes the handler registered via `signal-handler`.

```
ptr osi_stop_signal(uptr signal_handle); function
```

The `osi_stop_signal` function stops trapping the signal and frees the signal handle returned by `osi_start_signal`.

3.3.5 File System Functions

```
ptr osi_open_fd(int fd, int close); function
```

The `osi_open_fd` function returns a port handle for the file descriptor *fd* when successful and an error pair otherwise. When the port is closed, the file descriptor *fd* is closed if and only if *close* is non-zero. It is an error to set *close* to a non-zero value on a standard I/O file descriptor ($0 \leq fd \leq 2$).

```
ptr osi_open_file(const char* path, int flags, int mode, ptr callback); function
```

The `osi_open_file` function issues an open using the `uv_fs_open` function and the given *path*, *flags*, and *mode*. It returns `#t` when the open operation is issued and an error pair otherwise. When the open operation finishes, it enqueues the callback list (*callback result*), where *result* is the nonnegative port handle when successful and a negative error code otherwise.

The following constants are defined for *flags*:

| | | | | | |
|--------------------------|------------------------|---------------------------|----------------------------|-------------------------|-----------------------|
| <code>O_APPEND</code> | <code>O_CREAT</code> | <code>O_DIRECT</code> | <code>O_DIRECTORY</code> | <code>O_DSYNC</code> | <code>O_EXCL</code> |
| <code>O_EXLOCK</code> | <code>O_NOATIME</code> | <code>O_NOCTTY</code> | <code>O_NOFOLLOW</code> | <code>O_NONBLOCK</code> | <code>O_RANDOM</code> |
| <code>O_RDONLY</code> | <code>O_RDWR</code> | <code>O_SEQUENTIAL</code> | <code>O_SHORT_LIVED</code> | <code>O_SYMLINK</code> | <code>O_SYNC</code> |
| <code>O_TEMPORARY</code> | <code>O_TRUNC</code> | <code>O_WRONLY</code> | | | |

The following constants are defined for *mode*:

S_IFMT S_IFIFO S_IFCHR S_IFDIR S_IFBLK S_IFREG S_IFLNK S_IFSOCK

`ptr osi_get_executable_path(void);` **function**

The `osi_get_executable_path` function uses the `uv_exepath` function to return the full path string of the executable file of the current process when successful and an error pair otherwise.

`ptr osi_get_file_size(uptr port, ptr callback);` **function**

The `osi_get_file_size` function uses the `uv_fs_fstat` function to issue a status operation on the file associated with the given file `port`. It returns `#t` when the status operation is issued and an error pair otherwise. When the status operation finishes, it enqueues the callback list (*callback result*), where *result* is the nonnegative file size when successful and a negative error code otherwise.

`ptr osi_get_real_path(const char* path, ptr callback);` **function**

The `osi_get_real_path` function uses the `uv_fs_realpath` function to issue a realpath operation on the given `path`. It returns `#t` when the realpath operation is issued and an error pair otherwise. When the realpath operation finishes, it enqueues the callback list (*callback result*), where *result* is the string path when successful and a negative error code otherwise.

`ptr osi_get_home_directory(void);` **function**

The `osi_get_home_directory` function uses the `uv_os_homedir` function to return the string path of the current user's home directory and an error pair otherwise.

`ptr osi_get_temp_directory(void);` **function**

The `osi_get_temp_directory` function uses the `uv_os_tmpdir` function to return the string path of the temporary directory and an error pair otherwise.

`ptr osi_chmod(const char* path, int mode, ptr callback);` **function**

The `osi_chmod` function issues a chmod operation using the `uv_fs_chmod` function and the given `path` and `mode`. It returns `#t` when the chmod operation is issued and an error pair otherwise. When the chmod operation finishes, it enqueues the callback list (*callback errno*), where *errno* is 0 when successful and a negative error code otherwise.

`ptr osi_make_directory(const char* path, int mode, ptr callback);` **function**

The `osi_make_directory` function issues a mkdir operation using the `uv_fs_mkdir` function with the given `path` and `mode`. It returns `#t` when the mkdir operation is issued and an error pair

otherwise. When the mkdir operation finishes, it enqueues the callback list (*callback errno*), where *errno* is 0 when successful and a negative error code otherwise.

```
ptr osi_list_directory(const char* path, ptr callback); function
```

The `osi_list_directory` function issues a `scandir` operation using the `uv_fs_scandir` function with the given *path*. It returns `#t` when the `scandir` operation is issued and an error pair otherwise. When the `scandir` operation finishes, it enqueues the callback list (*callback result*), where *result* is `((name . type) ...)` when successful and a negative error code otherwise.

name is the string name of the directory entry, and *type* is one of the following constants:

```
DIRENT_UNKNOWN  DIRENT_FILE  DIRENT_DIR    DIRENT_LINK  DIRENT_FIFO  
DIRENT_SOCKET   DIRENT_CHAR  DIRENT_BLOCK
```

```
ptr osi_remove_directory(const char* path, ptr callback); function
```

The `osi_remove_directory` function issues a `rmdir` operation using the `uv_fs_rmdir` function with the given *path*. It returns `#t` when the `rmdir` operation is issued and an error pair otherwise. When the `rmdir` operation finishes, it enqueues the callback list (*callback errno*), where *errno* is 0 when successful and a negative error code otherwise.

```
ptr osi_rename(const char* path, const char* new_path, ptr callback); function
```

The `osi_rename` function issues a `rename` operation using the `uv_fs_rename` function of *path* to *new_path*. It returns `#t` when the `rename` operation is issued and an error pair otherwise. When the `rename` operation finishes, it enqueues the callback list (*callback errno*), where *errno* is 0 when successful and a negative error code otherwise.

```
ptr osi_get_stat(const char* path, int follow, ptr callback); function
```

The `osi_get_stat` function issues a `status` operation on the given *path*. When *follow* is non-zero, it uses the `uv_fs_stat` function to follow a symbolic link; otherwise, it uses the `uv_fs_lstat` function. It returns `#t` when the `status` operation is issued and an error pair otherwise. When the `status` operation finishes, it enqueues the callback list (*callback result*), where *result* is a `<stat>` tuple when successful and a negative error code otherwise.

<stat> **tuple**

dev: device ID of the device containing the file
mode: mode of the file
nlink: number of hard links to the file
uid: user ID of the file
gid: group ID of the file
rdev: device ID if file is character or block special
ino: file serial number
size: For regular files, the file size in bytes. For symbolic links, the length in bytes of the path in the link.
blksize: optimal block size for I/O
blocks: number of blocks allocated for the file
flags: user-defined flags for the file
gen: file generation number
atime: time of last access
mtime: time of last data modification
ctime: time of last status change
birthtime: time of file creation

The time entries contain (*sec* . *nsec*), where *sec* is the number of seconds in UTC since the UNIX epoch January 1, 1970, and *nsec* is the number of nanoseconds after *sec*.

ptr osi_unlink(const char* path, ptr callback); **function**

The `osi_unlink` function issues an unlink operation using the `uv_fs_unlink` function with the given *path*. It returns `#t` when the unlink operation is issued and an error pair otherwise. When the unlink operation finishes, it enqueues the callback list (*callback errno*), where *errno* is 0 when successful and a negative error code otherwise.

ptr osi_watch_path(const char* path, ptr callback); **function**

The `osi_watch_path` function uses the `uv_fs_event_start` function to track changes to *path*. When *path* is a directory, its subdirectories are not tracked. Every time a change is detected, a callback list (*callback filename events*) is enqueued, where *events* is 1 for rename, 2 for change, and 3 for rename and change. If the watcher encounters an error, the callback list (*callback errno*) is enqueued.

The `osi_watch_path` function returns a path watcher handle when successful and an error pair otherwise.

void osi_close_path_watcher(uptr watcher); **function**

The `osi_close_path_watcher` function stops and closes the path *watcher* from `osi_watch_path`.

3.3.6 TCP/IP Functions

```
ptr osi_connect_tcp(const char* node, const char* service, ptr callback); function
```

The `osi_connect_tcp` function initiates a TCP/IP connection to host *node* on port *service*. It returns `#t` when the operation starts and an error pair otherwise. The *node* string may be a host name or numeric host address string, and the *service* string may be a service name or port number represented as a string. The `uv_getaddrinfo` function is used to retrieve a list of addresses. For the first address for which a connection succeeds using the `uv_tcp_connect` function, the completion list (*callback port*) is enqueued, where *port* is a handle to a port that reads from and writes to this connection. When the operation fails, the callback list (*callback error-pair*) is enqueued.

```
ptr osi_listen_tcp(const char* address, uint16_t port, ptr callback); function
```

The `osi_listen_tcp` function starts a TCP/IP listener on the given *port* of the IPv4 or IPv6 interface specified by *address* using the `uv_listen` function. It returns a TCP/IP listener handle when successful and an error pair otherwise.

Specify an IPv4 interface *address* using dot-decimal notation, e.g. 127.0.0.1. Use 0.0.0.0 to specify all IPv4 interfaces.

Specify an IPv6 interface *address* using colon-hexadecimal notation, e.g. ::1. Use :: to specify all IPv6 interfaces.

Specify *port* 0 to have the operating system choose an available port number, which can be queried using `osi_get_tcp_listener_port`.

When a connection is accepted, the callback list (*callback port*) is enqueued, where *port* is a handle to a port that reads from and writes to this connection. When a connection fails, the callback list (*callback error-pair*) is enqueued.

```
void osi_close_tcp_listener(uptr listener); function
```

The `osi_close_tcp_listener` function closes the given TCP/IP *listener* opened by `osi_listen_tcp`.

```
ptr osi_get_tcp_listener_port(uptr listener); function
```

The `osi_get_tcp_listener_port` function returns the port number of the given TCP/IP *listener* opened by `osi_listen_tcp` when successful and an error pair otherwise.

```
ptr osi_get_ip_address(uptr port); function
```

The `osi_get_ip_address` function uses the `uv_tcp_getpeername` function to return a string representation of the address of the peer of a TCP/IP *port* opened by `osi_connect_tcp` or `osi_listen_tcp` when successful and an error pair otherwise.

An IPv4 address is shown in dot-decimal notation followed by a colon and the port number, e.g. 127.0.0.1:80.

An IPv6 address is shown in bracketed colon-hexadecimal notation followed by a colon and the port number, e.g. `[::1]:80`.

```
ptr osi_tcp_nodelay(uptr port, int enable); function
```

The `osi_tcp_nodelay` function calls `uv_tcp_nodelay` to enable or disable `TCP_NODELAY` for the specified TCP/IP `port` based on the value of `enable`. It returns `#t` if successful and `#f` otherwise. Enabling `TCP_NODELAY` disables the Nagle algorithm.

3.3.7 SQLite Functions

For each open SQLite database, a single worker thread performs the operations so that the main thread is not blocked. SQLite is compiled in multi-thread mode. The documentation states: “In this mode, SQLite can be safely used by multiple threads provided that no single database connection is used simultaneously in two or more threads.” **Concern:** Two threads simultaneously access a SQLite database connection. **Mitigation:** The operating system interface maintains a busy bit for each database handle. Functions attempting to access a busy database return the error pair (`function-name . UV_EBUSY`).

SQLite has five data types, which are mapped as follows to Scheme data types:

| <i>SQLite</i> | <i>Scheme</i> |
|---------------|-----------------|
| NULL | <code>#f</code> |
| INTEGER | exact integer |
| REAL | flonum |
| TEXT | string |
| BLOB | bytevector |

SQLite extended result codes are enabled. Because the error codes overlap system error codes, the operating system interface maps them to system error codes by negating the sum of the result code and 6,000,000. The `osi_get_error_text` function supports these mapped error codes.

SQLite returns additional error information in English strings, so error pairs from SQLite are often of the form (`who . (errno . text)`), where `errno` is the mapped SQLite extended result code and `text` is the English error string.

```
ptr osi_open_database(const char* filename, int flags, ptr callback); function
```

The `osi_open_database` function starts a worker thread that uses the `sqlite3_open_v2` function to open the database specified by the `filename` string and `flags`. The `flags` specify, for example, whether the database should be opened in read-only mode or whether it should be created when the file does not exist. The function returns `#t` when the thread is created and an error pair otherwise.

When the open operation finishes, it enqueues the callback list (`callback result`), where `result` is the database handle when successful and an error pair otherwise.

```
ptr osi_close_database(uptr database, ptr callback); function
```

The `osi_close_database` function starts a close operation in the given *database* worker thread. It returns `#t` when the operation is started and an error pair otherwise.

After the worker thread finalizes all prepared statements, it uses the `sqlite3_close` function to close the *database*. When finished, it enqueues the callback list (*callback result*), where *result* is `#t` when successful and an error pair otherwise.

```
ptr osi_prepare_statement(uptr database, ptr sql, ptr callback); function
```

The `osi_prepare_statement` function starts a prepare operation on the given *database* worker thread. It returns `#t` when the operation is started and an error pair otherwise.

The worker thread uses the `sqlite3_prepare_v2` function to prepare the given *sql* statement. It enqueues the callback list (*callback result*), where *result* is the statement handle when successful and an error pair otherwise.

```
ptr osi_finalize_statement(uptr statement); function
```

The `osi_finalize_statement` function uses the `sqlite3_finalize` function to finalize the *statement*. It returns `#t` when successful and an error pair otherwise. The return code from `sqlite3_finalize` is not checked because the statement is finalized regardless of the return value.

```
ptr osi_bind_statement(uptr statement, int index, ptr datum); function
```

The `osi_bind_statement` function maps the Scheme *datum* to SQLite and binds it to the prepared *statement* at the zero-based SQL parameter *index*. It returns `#t` when successful and an error pair otherwise. The error pair (`osi_bind_statement . UV_EINVAL`) is returned when *datum* cannot be mapped to SQLite.

```
ptr osi_bind_statement_bindings(uptr statement, uptr mbindings); function
```

The `osi_bind_statement_bindings` binds the marshaled bindings *mbindings* to the prepared *statement*. It returns `#t` when successful and an error pair otherwise.

```
ptr osi_clear_statement_bindings(uptr statement); function
```

The `osi_clear_statement_bindings` function uses the `sqlite3_clear_bindings` function to clear the bindings for the *statement*. It returns `#t` when successful and an error pair otherwise.

```
ptr osi_get_last_insert_rowid(uptr database); function
```

The `osi_get_last_insert_rowid` function uses the `sqlite3_last_insert_rowid` function to return the last insert rowid of the *database* when successful and an error pair otherwise.

```
ptr osi_get_statement_columns(uptr statement); function
```

The `osi_get_statement_columns` function uses the `sqlite3_column_count` and `sqlite3_column_name` functions to return a vector of column name strings for the *statement* when successful and an error pair otherwise.

```
ptr osi_get_statement_expanded_sql(uptr statement); function
```

The `osi_get_statement_expanded_sql` function uses the `sqlite3_expanded_sql` function to return the expanded SQL string associated with the *statement* when successful and an error pair otherwise.

```
ptr osi_reset_statement(uptr statement); function
```

The `osi_reset_statement` function uses the `sqlite3_reset` function to reset the *statement*. It returns `#t` when successful and an error pair otherwise.

```
ptr osi_step_statement(uptr statement, ptr callback); function
```

The `osi_step_statement` function issues a step operation on the database worker thread associated with *statement*. It returns `#t` when the operation is started and an error pair otherwise.

The worker thread uses the `sqlite3_step` function to execute the *statement*. If it returns `SQLITE_DONE`, the callback list (*callback #f*) is enqueued. If it returns `SQLITE_ROW`, the callback list (*callback #(value ...)*) is enqueued with the vector of column values mapped from SQLite to Scheme. Otherwise, the callback list (*callback error-pair*) is enqueued.

```
ptr osi_interrupt_database(uptr database); function
```

The `osi_interrupt_database` function calls the `sqlite3_interrupt` function to interrupt the current operation of the *database*. It returns `#t` when the database is busy and `#f` otherwise.

```
ptr osi_get_sqlite_status(int operation, int resetp); function
```

The `osi_get_sqlite_status` function uses the `sqlite3_status64` function with the given *operation* and *reset* flag to return `#(current highwater)` when successful and an error pair otherwise.

```
ptr osi_marshall_bindings(ptr bindings); function
```

The `osi_marshall_bindings` function allocates an internal structure and copies each Scheme datum in *bindings*. The *bindings* argument may be a list or a vector. The result is a handle to the internal structure or NULL if *bindings* is empty. An error pair is returned when the internal structure cannot be allocated or the *bindings* cannot be mapped to SQLite data types.

```
ptr osi_get_bindings(uptr mbindings); function
```

The `osi_get_bindings` function allocates a vector containing a copy of each Scheme datum marshaled into *mbindings* by `osi_marshall_bindings`. It is an error to call `osi_get_bindings` on *mbindings* after calling `osi_unmarshal_bindings` on *mbindings*.

```
ptr osi_unmarshal_bindings(uptr mbindings); function
```

The `osi_unmarshal_bindings` function deallocates the internal structure allocated by `osi_marshall_bindings`.

```
ptr osi_bulk_execute(ptr statements, ptr mbindings, ptr callback); function
```

The `osi_bulk_execute` function executes all the queries defined by *statements* and *mbindings* on the database worker thread associated with the statements. The vector *statements* must contain statement handles created by `osi_prepare_statement`. All *statements* must be prepared on the same database. The vector *mbindings* must contain binding handles created by `osi_marshall_bindings`. It returns `#t` when the operation is started and an error pair otherwise.

When the bulk execute operation finishes, it enqueues the callback list (*callback result*), where *result* is `#t` when successful and an error pair otherwise.

3.3.8 Message-Digest Functions

```
ptr osi_open_SHA1(); function
```

The `osi_open_SHA1` function returns an error pair or a context for computing the SHA1 message digest.

```
ptr osi_hash_data(uptr ctxt, ptr bv, size_t start_index, uint32_t size); function
```

The `osi_hash_data` function computes the SHA1 message digest incrementally on the *size* bytes at the zero-based *start_index* of bytevector *bv* updating the context *ctxt*. It returns `#t` when successful and an error pair otherwise.

```
ptr osi_get_SHA1(uptr ctxt); function
```

The `osi_get_SHA1` function takes a *ctxt* that was created by `osi_open_SHA1` and updated by calling `osi_hash_data` on a set of buffers and returns as a bytevector the SHA1 message digest of the buffers. If unsuccessful, it returns an error pair.

```
ptr osi_close_SHA1(uptr ctxt); function
```

The `osi_close_SHA1` function frees a *ctxt* that was allocated by `osi_open_SHA1`.

Chapter 4

Erlang Embedding

4.1 Introduction

This chapter describes the design of the message-passing concurrency model. It provides a Scheme embedding of a significant subset of the Erlang programming language [1, 2].¹ Tuple and pattern matching macros provide succinct ways of composing and decomposing data structures.

The basic unit of sequential computation is the *process*. Each process has independent state and communicates with other processes by message passing. Because processes share no mutable state, one process cannot corrupt the state of another process—a problem that plagues software using shared-state concurrency. **Concern:** System procedures that mutate data can cause state corruption. **Mitigation:** The code is inspected for use of these procedures.

An uncaught exception in one process does not affect any other process. A process can be monitored for termination, and it can be linked to another process so that, when either process exits, the other one receives an exit signal. Processes are implemented with one-shot continuations [4], and the concurrent system is simulated by the single-threaded program using software timer interrupts. The operating system interface (see Chapter 3) provides asynchronous input/output (I/O) so that processes waiting for I/O do not stop other processes from executing.

For exceptions, we use Erlang’s approach of encoding the information in a machine-readable datum rather than a formatted string. Doing so makes it possible to write code that matches particular exceptions without having to parse strings, and the exception is human language independent.

The rest of this chapter is organized as follows. Section 4.2 introduces the main data structures, Section 4.3 describes how the concurrency model works, and Section 4.4 gives the programming interface.

4.2 Data Structures

q Queues are used in several key places: the inbox of messages for each process, the list of processes ready to run, and the list of sleeping processes. A *queue* is a doubly-linked list with a sentinel value,

¹Tuples, denoted by $\{e_1, \dots, e_n\}$ in Erlang, are implemented as vectors: $\#(e_1 \dots e_n)$. Similarly records, defined as syntactic sugar over tuples in Erlang, are implemented as syntactic sugar over vectors.

the queue's identity. Both the sentinel value and the elements of the queue are instances of `q`, a Scheme record type with mutable `prev` and `next` fields. This representation enables constant-time insertion and deletion operations.

`msg` When a *message* is sent to a process, its contents are wrapped in an instance of `msg`, a Scheme record type that extends `q` with an immutable `contents` field. This `msg` is inserted into the process's inbox and removed when the process receives it.

`pcb` A *process* is an instance of `pcb`, a Scheme record type that extends `q` with an immutable `id` field, the process's unique positive exact integer, an immutable `create-time` field, the process's create time from `erlang:now`, an immutable `parameters` field, the process's weak eq-hashtable mapping process parameters to values, and the following mutable fields:

- `name`: registered name or `#f`
- `cont`: one-shot continuation if live and not currently running or `#f` otherwise
- `sic`: system interrupt count
- `winders`: list of winders if live and not currently running or `()` otherwise
- `exception-state`: exception state if live and not currently running, exit reason if dead, or `#f` if currently running
- `inbox`: queue of `msg` if live or `#f` if dead
- `precedence`: wake time if sleeping or 0 if ready to run
- `flags`: fixnum with bit 0 set when sleeping, bit 1 set when the process traps exits, bit 2 set when the process is blocked for I/O, and bit 3 set when the process is pending a keyboard interrupt
- `links`: list of linked processes
- `monitors`: list of monitors
- `src`: source location `#(at char-offset filename)` when available if waiting in a `receive` macro, a string if blocked for I/O, or `#f`

`mon` A *monitor* is an instance of `mon`, a Scheme record type with two immutable fields, `origin` and `target`, each of which is a process.

`osi-port` An *osi-port* is an instance of `osi-port`, a Scheme record type with an immutable `name` field, an immutable `create-time` field, and a mutable `handle` field that wraps an operating system interface port. The `handle` field is set to `#f` when the `osi-port` is closed.

`path-watcher` A *path watcher* is an instance of `path-watcher`, a Scheme record type with an immutable `path` field, an immutable `create-time` field, and a mutable `handle` field. The `handle` field is set to `#f` when the path watcher is closed.

`listener` A *TCP listener* is an instance of `listener`, a Scheme record type with immutable `address`, `port-number`, and `create-time` fields and a mutable `handle` field. The `handle` field is set to `#f` when the listener is closed.

4.3 Theory of Operation

The system uses a *scheduler* to execute one process at a time. Each process holds its own system interrupt count (updated by `enable-interrupts` and `disable-interrupts`), list of winders (maintained by `dynamic-wind` and the system primitive `$current-winders`), and exception state (maintained by `current-exception-state`). The scheduler captures the one-shot continuation for a process with an empty list of winders so that, when it invokes the continuation of another process, it does not run any winders. **Concern:** Using a system procedure that relies on the global winders list may lead to incorrect behavior. **Mitigation:** System procedures that rely on the global winders list are called from only one process at a time using the *gatekeeper* described in Chapter 8. The *gatekeeper* hooks the `$cp0`, `$np-compile`, `pretty-print`, and `sc-expand` system primitives.

Spawning a new process is not as simple as capturing a one-shot continuation and creating a `pcb` record, because the continuation's stack link [20] would be the continuation of the caller, and its list of winders would be the caller's. Thus, the scheduler remembers the current list of winders and then sets it to the empty list before capturing a one-shot continuation. This return continuation is stored in a mutable variable so that it is not closed over by the new process. Next, a full continuation is captured to create the initial exception state that will terminate the new process when an uncaught exception is raised. So that this full continuation does not refer to the caller's continuation, the current stack link is set to the null continuation before capturing it. After capturing the full continuation, a one-shot continuation for the new process is captured and returned to the caller via the return continuation.

Each process runs until it waits in a `receive` macro or `wait-for-io` procedure, is preempted by the `timer-interrupt-handler`, or exits. The operating system interface (see Chapter 3) provides asynchronous I/O operations so that the scheduler can execute other processes while the system is performing I/O. The timer interrupt handler runs every 1000 procedure calls.² The scheduler uses `osi_set_tick` and `osi_is_tick_over` to determine when the time quantum for a process has elapsed.

When process p exits with reason r , a message matching `'(DOWN m p r)` is sent to each of its monitor m 's `origin` processes. A message matching `'(EXIT p r)` is sent to each linked process that traps exits. If r is not `normal`, each linked process that does not trap exits is killed with reason r .

A process can be registered with a global name, a symbol. This name can be used instead of the process record itself to send it messages. A global *registrar* maintains an eq-hashtable mapping names to processes. The reverse mapping is maintained in the `pcb` record through the `name` field.

There are two system processes: the *event-loop* and the *finalizer*.

The event-loop process calls `osi_get_callbacks` to retrieve callback lists from the operating system interface. It executes each callback with interrupts disabled. Event-loop callbacks are designed to execute quickly without failing or causing new completion packets to be enqueued. Typical callbacks

²1000 was chosen because Chez Scheme performs its internal interrupt checks every 1000 ticks.

register objects that wrap operating system interface handles with a guardian and send messages to a process. If the event-loop process exits with reason *r*, the system logs the event `#(event-loop-process-terminated r)` with `console-event-handler` and calls `osi_exit` with exit code 80.

The scheduler maintains the *run queue*, a queue of ready-to-run processes, and the *sleep queue*, a queue of sleeping processes. Both are ordered by increasing precedence and preserve the order of insertion for processes with the same precedence. For the run queue, each process has precedence 0 in order to implement round-robin scheduling. For the sleep queue, each process uses its wake time as the precedence.

When the run queue is empty, the event-loop process calls `osi_get_callbacks` with a non-zero timeout based on the first entry in the sleep queue to avoid busy waiting. When the event-loop process finishes processing all completion packets, it places itself at the end of the run queue.

Concern: Some process may starve another process. **Mitigation:** The run queue is managed with round-robin scheduling to prevent starvation. The event-loop process does not starve other processes because it drains the completion queue without causing new completion packets to be enqueued.

The finalizer process runs the finalizers registered via `add-finalizer`. These finalizers typically close operating system interface handles to objects that are no longer accessible. **Concern:** Ill-behaved finalizers may cause memory and handle leaks. **Mitigation:** Finalizers are designed to execute quickly without failing. Typical finalizers guard against errors when closing handles. If the finalizer process exits with reason *r*, the system logs the event `#(finalizer-process-terminated r)` with `console-event-handler` and calls `osi_exit` with exit code 80.

Once the finalizer process runs all the finalizers, it waits until another garbage collection has occurred before running again. The system hooks the `collect` procedure so that it sends a wake-up message to the finalizer process every time a garbage collection occurs. When the finalizer receives the wake-up message, it pumps all other wake-up messages from its inbox, since there may have been more than one garbage collection since it last ran.

Asynchronous I/O operations for COM ports, named pipes, external operating system processes, files, console input, and TCP connections are implemented with custom binary ports so that they have the same interface as the system I/O procedures. The system I/O procedures are not used because they perform synchronous I/O. The default custom port buffer size is set to 1024 with `custom-port-buffer-size`.³ When compiled with Chez Scheme versions 9.6.2 and later, Swish uses `file-buffer-size` as the buffer size for custom file ports. The custom binary port read and write procedures call `osi_read_port` and `osi_write_port` with callbacks that send a message to the calling process, which waits until it receives the message.

Concern: Using a port from more than one process at the same time may cause errors including buffer corruption. **Mitigation:** The code is inspected for concurrent use of ports. Port visibility is typically limited to a single process.

For two-way communication ports, we use two custom ports: one exclusively for input, and one exclusively for output. We do not use custom input/output ports for two reasons. First, textual input/output ports created with `transcoded-port` are not safe to use from two concurrent processes because one transcoding buffer is used for both reading and writing. Second, the input side of a

³1024 was chosen because prior versions of Chez Scheme use 1024 for the buffer size of buffered transcoded ports.

port is commonly used only by a reader process, and the output side of a port is commonly used only by a writer process. Keeping the input and output sides separate prevents concurrent use. The underlying handle is closed when the output port is closed.

Concern: Failing to close a handle from the operating system interface that is no longer used causes resource leaks. **Mitigation:** An *osi-port guardian* created by `make-foreign-handle-guardian` with type name `osi-ports` is used to identify and close inaccessible `osi-ports`. A *path-watcher guardian* created by `make-foreign-handle-guardian` with type name `path-watchers` is used to identify and close inaccessible path watchers. A *listener guardian* created by `make-foreign-handle-guardian` with type name `tcp-listeners` is used to identify and close inaccessible TCP listeners. In all cases, interrupts are disabled around code that wraps handles and registers objects with guardians in order to prevent the current process from being killed during this critical time.

4.4 Programming Interface

4.4.1 Process Creation

`(spawn thunk)` **procedure**
returns: a process

The `spawn` procedure creates and returns a new process that executes *thunk*, a procedure of no arguments. The new process starts with `name = #f`, `sic = 0` (interrupts enabled), `winders = ()`, an `exception-state` that terminates the process on an unhandled exception, an empty `inbox`, `precedence = 0`, `flags = 0` (the process is not sleeping and does not trap exits), `links = ()`, `monitors = ()`, and `src = #f`.

`(spawn&link thunk)` **procedure**
returns: a process

Like `spawn`, the `spawn&link` procedure creates and returns a new process that executes *thunk*. In addition, it links the new process to the calling process.

4.4.2 Process Registration

`(get-registered)` **procedure**
returns: a list of registered process names

The `get-registered` procedure returns a list of currently registered process names from the registrar.

`(register name process)` **procedure**
returns: `#t`

The `register` procedure adds `name → process` to the registrar and sets `process.name = name`. When a registered process exits, its registration is removed. If *name* is not a symbol, exception `#{bad-arg register name}` is raised. If *process* is not a process, exception `#{bad-arg register process}` is raised. If *process* is dead, exception `#{process-dead process}` is raised. If *process* is

already registered to name *n*, exception `#(process-already-registered n)` is raised. If *name* is already registered to process *p*, exception `#(name-already-registered p)` is raised.

`(unregister name)` **procedure**
returns: `#t`

The `unregister` procedure removes *name* \rightarrow *process* from the registrar and sets *process.name* = `#f`. If *name* is not registered, exception `#(bad-arg unregister name)` is raised.

`(whereis name)` **procedure**
returns: a process | `#f`

The `whereis` procedure returns the process associated with *name* or `#f` if *name* is not registered. If *name* is not a symbol, exception `#(bad-arg whereis name)` is raised.

4.4.3 Process Termination, Links, and Monitors

`(catch e1 e2 ...)` **syntax**
expands to: `($trap (lambda () e1 e2 ...) ->EXIT)`

The `catch` macro evaluates expressions *e1 e2 ...* in a dynamic context that traps exceptions. If no exception is raised, the return value is the value of the last expression. If exception *reason* is raised, `#(EXIT reason)` is returned.

`(try e1 e2 ...)` **syntax**
expands to: `($trap (lambda () e1 e2 ...) ->fault-condition)`

The `try` macro evaluates expressions *e1 e2 ...* in a dynamic context that traps exceptions. If no exception is raised, the return value is the value of the last expression. If exception *reason* is raised, the return value is a fault condition matching the extended match pattern `'(catch reason [e])`.

`'(catch r [e])` **match-extension**
matches: exceptions trapped by `try` or `catch`

The extended match pattern `'(catch r [e])` matches exceptions trapped by `try`. For compatibility with older code, this pattern also matches exceptions trapped by `catch`. The *r* pattern is matched against the exit reason in the trapped exception. The optional *e* pattern is typically a *,variable* pattern that binds *variable* for use as an argument to `throw` or `raise`. If the trapped exception is a fault condition generated by `throw`, `make-fault`, or `make-fault/no-cc`, then *e* is matched against the fault condition, which may contain additional debugging context. Otherwise, *e* is matched against the exit reason.

`(throw r [inner])` **procedure**
returns: does not return

The `throw` procedure raises a fault condition containing reason *r*, an optional inner exception *inner*, and the current continuation, which may provide useful debugging context. The exception raised may be trapped by `try` and matched using the extended match pattern `'(catch r [e])`.

`(make-fault r [inner])` **procedure**

returns: a fault condition

The `make-fault` procedure returns a fault condition containing reason *r*, an optional inner exception *inner*, and the current continuation, which may provide useful debugging context. The return value matches the extended match pattern `(catch r [e])`.

`(make-fault/no-cc r [inner])` **procedure**

returns: a fault condition

The `make-fault/no-cc` procedure returns a fault condition containing reason *r*, and an optional inner exception *inner*, but omits the current continuation. The return value matches the extended match pattern `(catch r [e])`.

`(demonitor monitor)` **procedure**

returns: #t

The `demonitor` procedure removes a *monitor* created by the calling process (*self*) from *self.monitors* and *monitor.target.monitors* if present. If *monitor* is not a monitor with `origin = self`, exception `#{bad-arg demonitor monitor}` is raised.

`(demonitor&flush monitor)` **procedure**

returns: #t

The `demonitor&flush` procedure provides a convenient way to demonitor and flush any remaining DOWN message from the calling process's `inbox`. It performs the following operations:

```
(demonitor monitor)
(receive (until 0 #t)
  [ `(DOWN ,@monitor ,_ ,_) #t])
```

`(kill process reason)` **procedure**

returns: #t

The `kill` procedure is used to terminate a process.

1. If *process* is not a process, exception `#{bad-arg kill process}` is raised.
2. If *process* has already exited, nothing happens.
3. If *reason* is `kill`, *process* is terminated with reason `killed`, even if it traps exits.
4. If *process* traps exits, a message matching `(EXIT self reason)` is sent to *process*, where *self* is the calling process.
5. If *process* does not trap exits and *reason* is `normal`, nothing happens.
6. Otherwise, *process* is terminated with *reason*.

(link process) **procedure**

returns: #t

The `link` procedure creates a bi-directional link between the calling process (*self*) and *process*. No more than one link can exist between two processes, but it is not an error to call `link` more than once on the same two processes.

1. If *process* is not a process, exception `#(bad-arg link process)` is raised.
2. If *process* is *self*, nothing happens.
3. If *process* has not exited, then if the two processes are already linked, nothing happens; otherwise, *self* is added to *process.links*, and *process* is added to *self.links*.
4. Otherwise, *process* has exited with reason $r = \text{process.exception-state}$.
 - (a) If *self* traps exits, a message matching `(EXIT process r)` is sent to *self*.
 - (b) If *self* does not trap exits and *reason* is `normal`, nothing happens.
 - (c) Otherwise, *self* is terminated with reason *r*.

(monitor process) **procedure**

returns: a monitor

The `monitor` procedure creates and returns a new monitor *m* with `origin` = the calling process (*self*) and `target` = *process*. Unlike `link`, `monitor` can create more than one connection between the same processes. It adds *m* to *self.monitors* and *process.monitors*. When *process* exits or has already exited with reason *r*, a message matching `(DOWN m process r)` is sent to *self*. If *process* is not a process, exception `#(bad-arg monitor process)` is raised.

(monitor? x) **procedure**

returns: a boolean

The `monitor?` procedure determines whether or not the datum *x* is a monitor.

(unlink process) **procedure**

returns: #t

The `unlink` procedure removes the bi-directional link if present between the calling process (*self*) and *process* by removing *self* from *process.links* and *process* from *self.links*. If *process* is not a process, exception `#(bad-arg unlink process)` is raised.

'(EXIT p r [e]) **match-extension**

matches: exit messages generated by `kill` or `link`

The extended match pattern `'(EXIT p r [e])` matches exit messages generated by `kill` or `link`. The pattern *p* is matched against the *process* in the message. If the *reason* in the message is an exception trapped by `try` or `catch`, or a fault condition generated by `make-fault` or `make-fault/no-cc`, then the patterns *r* and *e* are matched against *reason* as if by the extended match pattern `'(catch r [e])`. Otherwise, both *r* and *e* are matched against *reason* directly.

| pattern | matches |
|--|---|
| <i>symbol</i> | itself |
| <i>number</i> | itself |
| <i>boolean</i> | itself |
| <i>character</i> | itself |
| <i>string</i> | itself |
| <i>bytevector</i> | itself |
| () | itself |
| (<i>p</i> ₁ . <i>p</i> ₂) | a pair whose car matches <i>p</i> ₁ and cdr matches <i>p</i> ₂ |
| #(<i>p</i> ₁ ... <i>p</i> _{<i>n</i>}) | a vector of <i>n</i> elements whose elements match <i>p</i> ₁ ... <i>p</i> _{<i>n</i>} |
| #!eof | a datum satisfying eof-object? |
| ,_ | any datum |
| , <i>variable</i> | any datum and binds a fresh <i>variable</i> to it |
| ,@ <i>variable</i> | any datum <code>equal?</code> to the bound <i>variable</i> |
| ,(<i>variable</i> <= <i>pattern</i>) | any datum that matches <i>pattern</i> and binds a fresh <i>variable</i> to it |
| ‘(<i>type</i> {, <i>field</i> ,@ <i>field</i> [<i>field</i> <i>pattern</i>]} ...) | an instance of the tuple or native record <i>type</i> , each <i>field</i> of which is bound to fresh variable <i>field</i> or matches the corresponding <i>pattern</i> ; ,@ <i>field</i> is treated as [<i>field</i> ,@ <i>field</i>]; <i>type</i> must be known at expand time |
| ‘(<i>ext spec</i> ...) | as specified by <code>define-match-extension</code> for <i>ext</i> |

Figure 4.1: Pattern Grammar

```
‘(DOWN m p r [e]) match-extension
matches: down messages generated by monitor
```

The extended match pattern ‘(DOWN *m p r* [*e*]) matches down messages generated by `monitor`. The pattern *m* is matched against the *monitor* in the message. The pattern *p* is matched against the monitored *process* in the message. If the *reason* in the message is an exception trapped by `try` or `catch`, or a fault condition generated by `make-fault` or `make-fault/no-cc`, then the patterns *r* and *e* are matched against *reason* as if by the extended match pattern ‘(catch *r* [*e*]). Otherwise, both *r* and *e* are matched against *reason* directly.

4.4.4 Messages and Pattern Matching

The pattern matching syntax of Figure 4.1 provides a concise and expressive way to match data structures and bind variables to parts. The `receive`, `match`, `match-define`, and `match-let*` macros use this pattern language. The implementation makes a structurally recursive pass over the pattern to check for duplicate pattern variables as it emits code that matches the input against the pattern left to right.

```
(match exp syntax
  (<pattern> [(guard g)] b1 b2 ...)
  ...)
```

returns: the value of the last expression *b1 b2* ... for the matched pattern

The `match` macro evaluates *exp* once and tests its value *v* against each pattern and optional guard.

Each guard expression g is evaluated in the scope of its associated pattern variables. When g returns `#f`, v fails to match that clause. For the first pattern and guard that matches v , the expressions $b1$ $b2$... are evaluated in the scope of its pattern variables. If v fails to match all patterns, exception `#{bad-match v src}` is raised, where src is the source location of the `match` clause if available.

See Figure 4.1 for the pattern grammar.

```
(match-define <pattern> exp) syntax
expands to: see below
```

The `match-define` macro evaluates exp and matches the resulting input against the pattern. Pattern-variable bindings are established via `define` and inhabit the same scope in which the `match-define` form appears. The `match-define` macro does not support guard expressions. If the pattern fails to match, exception `#{bad-match v src}` is raised, where v is the datum that failed to match the pattern at source location src if available.

See Figure 4.1 for the pattern grammar.

```
(match-let* ([<pattern> [(guard g)] exp]
            ...)
  b1 b2 ...) syntax
```

returns: the value of the last expression $b1$ $b2$...

The `match-let*` macro evaluates each exp in the order specified and matches its value against its pattern and guard. The pattern variables of each clause extend the scope of its guard expression g and all subsequent pattern clauses and body expressions $b1$ $b2$... The `match-let*` macro returns the value of the last body expression. If any pattern fails to match or any g returns `#f`, exception `#{bad-match v src}` is raised, where v is the datum that failed to match the pattern or guard at source location src if available.

See Figure 4.1 for the pattern grammar.

```
(receive
  [(after timeout t1 t2 ...) | (until time t1 t2 ...)]
  (<pattern> [(guard g)] b1 b2 ...)
  ...) syntax
```

returns: the value of the last evaluated expression

The `receive` macro examines each message m in the calling process's `inbox` by testing it against each pattern and optional guard. Each guard expression g is evaluated in the scope of its associated pattern variables. When g returns `#f`, m fails to match that clause. For the first pattern and guard that matches m , m is removed from `inbox`, and the expressions $b1$ $b2$... are evaluated in the scope of its pattern variables. If m fails to match all patterns, the examination continues with the next message in `inbox`. When all messages have been examined, the calling process waits with its `src` field set to the source location of the `receive` macro if available. The process awakens when a new message or the time specified by the optional `after` or `until` clause arrives. If a new message arrives before the timeout, the examination process continues as before. Otherwise, the timeout expressions $t1$ $t2$... are evaluated.

The optional `after` clause specifies a *timeout* in milliseconds from the time at which control enters the `receive` macro. Similarly, the optional `until` clause specifies a clock *time* in milliseconds as

measured by `erlang:now`. In addition, `timeout` and `time` can be `infinity` to indicate no timeout. If `t = timeout` or `time` is not a non-negative exact integer or `infinity`, exception `#{timeout-value t src}` is returned, where `src` is the source location of the `receive` macro if available.

See Figure 4.1 for the pattern grammar.

(define-match-extension *ext handle-object* [*handle-field*]) **syntax**
expands to: see below

The `define-match-extension` macro attaches a property to the identifier `ext`, via `define-property`, so that the expander calls `handle-object` to translate ‘(*ext spec ...*)’ patterns when generating code for `match`, `match-define`, `match-let*`, or `receive`. The `handle-object` procedure takes two arguments: `v`, an identifier that will be bound in the generated code to the value to be matched, and `pattern`, a syntax object for an expression of the form ‘(*ext spec ...*)’. The `handle-object` procedure can return `#f` to report an invalid `pattern`. Otherwise, `handle-object` should translate the given `pattern` to a list of one or more instructions in the following simple language:

| | |
|--|---|
| <code>(bind <i>v e</i>)</code> | binds <code>v</code> to the value of <code>e</code> via <code>let</code> or <code>define</code> |
| <code>(guard <i>g</i>)</code> | rejects the match if <code>g</code> evaluates to <code>#f</code> |
| <code>(sub-match <i>e pattern</i>)</code> | matches the value of <code>e</code> against <code>pattern</code> |
| <code>(handle-fields <i>input field-spec ...</i>)</code> | invokes <code>handle-field</code> to translate each <code>field-spec</code> |

The generated code evaluates the instructions in the order they are returned. For example, a `guard` expression may refer to a binding established by a `bind` earlier in the list of instructions. The `sub-match` and `handle-fields` instructions are processed at expand time and may appear only as the final instruction in the list returned by `handle-object`.

The `(handle-fields input field-spec ...)` instruction parses each `field-spec` from left to right and calls `handle-field` with five arguments: the `input` from the instruction, the `field` identified, the `var` that should be bound to the value of `field`, a list of `options` appearing in the `field-spec`, and the original pattern `context`. The following table shows how each `field-spec` is parsed into arguments for `handle-field`:

| <i>field-spec</i> | <i>field</i> | <i>var</i> | <i>options</i> | notes |
|--|---------------------------|----------------------------|----------------------------------|---|
| <code>,<i>field</i></code> | <code><i>field</i></code> | <code><i>field</i></code> | <code>()</code> | <code>field</code> must be an identifier |
| <code>,@<i>field</i></code> | <code><i>field</i></code> | <code><i>unique</i></code> | <code>()</code> | <code>field</code> must be an identifier |
| <code>[<i>field pattern option ...</i>]</code> | <code><i>field</i></code> | <code><i>unique</i></code> | <code>(<i>option ...</i>)</code> | <code>unique</code> is matched against <code>pattern</code> |

The `handle-field` procedure can return `#f` to report an invalid `field`. Otherwise, `handle-field` should return a list of `bind` or `guard` instructions that bind `var` and perform any checks needed to confirm a match. The resulting instructions are evaluated in the order they are returned.

Where temporaries are introduced in the generated output, the `handle-object` and `handle-field` procedures should use `with-temporaries` to avoid unintended variable capture.

(send *destination message*) **procedure**
returns: unspecified

The `send` procedure sends `message` to a process or registered name, `destination`. If `destination` is not a process or registered name, exception `#{bad-arg send destination}` is raised. If `destination` has exited, nothing else happens. Otherwise, `message` is added to the end of `destination.inbox`. If `destination` is sleeping, it is awakened. If `destination` is not blocked for I/O and not on the run

queue, it is placed on the run queue with precedence 0.

4.4.5 Process Properties

(pps [*op*]) **procedure**
returns: unspecified

The `pps` procedure prints information about all processes to textual output port *op*, which defaults to the current output port. If *op* is not an output port, exception `#{bad-arg pps op}` is raised.

(process? *x*) **procedure**
returns: a boolean

The `process?` procedure determines whether or not the datum *x* is a process.

(process-id [*process*]) **procedure**
returns: the process id

The `process-id` procedure returns *process.id*, where *process* defaults to `self`. If *process* is not a process, exception `#{bad-arg process-id process}` is raised.

(global-process-id *process*) **procedure**
returns: a string; see below

The `global-process-id` procedure returns a string of the form `"session-id:process-id"`. The *process-id* is the `process-id` of *process*. If the `log-db` gen-server has been started, then *session-id* is an integer session identifier that is unique in that database instance. Otherwise, *session-id* is omitted. If *process* is not a process, exception `#{bad-arg global-process-id process}` is raised.

(process-name [*process*]) **procedure**
returns: the process name or `#f`

The `process-name` procedure returns *process.name*, where *process* defaults to `self`. If *process* is not a process, exception `#{bad-arg process-name process}` is raised.

(process-parent) **procedure**
returns: the parent process or `#f`

The `process-parent` procedure returns the process which spawned the current process or `#f` if the parent process has been garbage collected.

process-trap-exit **parameter**
value: boolean or a procedure

The `process-trap-exit` parameter specifies whether or not the calling process traps exit signals as messages. Processes do not trap exit signals by default; therefore, processes start with this parameter set to `#f`. To trap exit signals as messages, a process sets this parameter to `#t` or a procedure. A gen-server can set the parameter to `#t` and handle exit messages via its `handle-info` callback; see Section 6.5 for details. Other processes can handle these messages via `receive`.

A process may set the `process-trap-exit` parameter to a *handler* procedure that accepts one argument, *msg*. When the scheduler resumes that process, it checks whether `kill` or `link` has delivered an exit signal as a message. If so, it retrieves the first exit message, invokes *handler* on that message, and repeats this until it has consumed the available exit messages.⁴ A *handler* procedure may be useful, for example, to perform some cleanup in case an exit signal arrives while a process is blocked awaiting a reply in `gen-server:call`.

(raise-on-exit *msg*) **procedure**

returns: see below

The `raise-on-exit` procedure expects an exit message *msg* matching `(EXIT pid reason)`. If *reason* is `normal`, `raise-on-exit` returns an unspecified value. Otherwise, it raises an exception involving *reason*.

self **syntax**

returns: the current process

The `self` macro uses `identifier-syntax` to expand into code that retrieves the global `self` variable's top-level value. The global variable cannot be used directly because library bindings are immutable.

(with-interrupts-disabled-for-io *body*₁ *body*₂ ...) **syntax**

expands to: see below

The `with-interrupts-disabled-for-io` macro is like `with-interrupts-disabled` except that, just before returning, it checks for trapped exit messages. The system handles trapped exit messages at this time only if `process-trap-exit` is set to a procedure. This macro is intended for use in code that calls `wait-for-io` and `complete-io` with interrupts disabled.

4.4.6 Miscellaneous

(add-finalizer *finalizer*) **procedure**

returns: unspecified

The `add-finalizer` procedure adds *finalizer* to the global list of finalizers. *finalizer* is a procedure of no arguments that runs in the finalizer process after garbage collections. If *finalizer* is not a procedure, exception `#(bad-arg add-finalizer finalizer)` is raised.

**(make-foreign-handle-guardian *type-name* *get-handle* *set-handle!*
get-create-time *close-handle* *print*)** **procedure**

returns: a procedure that expects *r* and *handle*

The `make-foreign-handle-guardian` procedure assists in managing handles returned by foreign procedures. A common pattern is to wrap each foreign handle in a record, register the record with a guardian, and add a finalizer that closes the handles of records the guardian identifies as inaccessible. The `make-foreign-handle-guardian` procedure supports this pattern by creating a

⁴An exit message delivered via `send` will not trigger *handler* on its own, but *handler* may consume that message if the scheduler invokes *handler*.

guardian and installing a suitable finalizer via `add-finalizer`. It also adds *type-name* to the set of foreign types recognized by `count-foreign-handles`, `foreign-handle-count`, `foreign-handle-print`, and `print-foreign-handles` to help monitor foreign handles that are still open.

The *type-name* must be a symbol; the remaining arguments must be procedures. It is an error if *type-name* has already been registered. The *get-handle* and *get-create-time* procedures should expect a single argument *r*; *get-create-time* must return an integer. The *set-handle!* procedure should expect *r* and *handle* and store *handle* in *r*, where it can be retrieved by *get-handle*.

The *close-handle* procedure runs in the finalizer process. It should take *r* and disable interrupts before checking whether (*get-handle* *r*) is already `#f`, since the guardian may return inaccessible objects that are already closed. If not, it should close the foreign handle and call the foreign-handle guardian with *r* and `#f` to clear the association of *r* with *handle*.

The *print* procedure should expect a textual output port *op*, *r*, and *handle* and print diagnostic information about the *handle* to *op* followed by a newline. See the output of `print-foreign-handles` for examples.

The `make-foreign-handle-guardian` procedure returns a procedure that expects two arguments: *r* and a *handle* that is either an integer or `#f`. Other code should not call *set-handle!* but should instead call the resulting procedure with interrupts disabled. If *handle* is `#f`, this procedure calls (*set-handle!* *r* `#f`) and removes *r* from the weak eq-hashtable consulted by `foreign-handle-count`, etc. If *handle* is not `#f`, then the procedure checks whether (*get-handle* *r*) is `#f`. If so, it calls (*set-handle!* *r* *handle*). Otherwise, it registers *r* with the guardian. In either case, it adds *r* to the weak eq-hashtable consulted by `foreign-handle-count`, etc. To ensure that *r* is registered with the guardian just once, *r* should already contain *handle* the first time the procedure is called with *r* and a *handle* that is not `#f`.

`(count-foreign-handles obj report-count)` **procedure**
returns: *obj*

The `count-foreign-handles` procedure takes an arbitrary *obj* and a procedure *report-count* that takes *obj*, a symbol *type* identifying a source of foreign handles, and *count*, the number of open handles of that type. The `count-foreign-handles` procedure calls *report-count* once for each foreign-handle type registered with `make-foreign-handle-guardian`, in an unspecified order.

`(foreign-handle-count type-name)` **procedure**
returns: a procedure

The `foreign-handle-count` procedure takes a symbol *type-name* that must already have been registered with `make-foreign-handle-guardian` and returns a procedure of no arguments that returns the number of open foreign handles of that type.

`(foreign-handle-print type-name)` **procedure**
returns: a procedure

The `foreign-handle-print` procedure takes a symbol *type-name* that must already have been registered with `make-foreign-handle-guardian` and returns a procedure that prints information about open handles of that type. The procedure returned uses the *print* and *get-create-time* procedures registered with `make-foreign-handle-guardian`. The procedure takes an optional textual

output port *op*, which defaults to the current output port, and calls *print* for each open handle of the designated type in increasing order of the creation time from *get-create-time* and then by increasing handle.

(print-foreign-handles [op]) **procedure**

returns: unspecified

The `print-foreign-handles` procedure prints information about open foreign handles to textual output port *op*, which defaults to the current output port. The `print-foreign-handles` procedure calls the procedure returned by `(foreign-handle-print type-name)` for each foreign-handle type registered with `make-foreign-handle-guardian`.

(arg-check who [arg pred ...] ...) **syntax**

expands to:

```
(let ([who who])
  (let ([arg arg])
    (unless (and (pred arg) ...)
      (profile-me-as arg-check)
      (bad-arg who arg)))
    ...
  (void))
```

The `arg-check` macro raises a `bad-arg` exception if any *arg* fails any *pred* specified for that *arg*. Within coverage reports, profile counts on the `arg-check` keyword indicate the number of `bad-arg` cases encountered.

(procedure/arity? mask [obj]) **procedure**

returns: see below

If both arguments are supplied, `procedure/arity?` returns true if *obj* is a procedure that supports all of the argument counts specified by *mask*. If only the *mask* is supplied, then `procedure/arity?` returns a procedure `(lambda (p) (procedure/arity? mask p))` suitable for use with `andmap` or `arg-check`, for example. In either case *mask* must be an exact integer bitmask of the form returned by `procedure-arity-mask`.

(bad-arg who arg) **procedure**

returns: never

The `bad-arg` procedure raises exception `#(bad-arg who arg)`.

(complete-io process) **procedure**

returns: unspecified

The `complete-io` procedure is used in callback functions to unblock a *process* from a call to `wait-for-io`. If *process* is not a process, exception `#(bad-arg complete-io process)` is raised.

(console-event-handler event) **procedure**

returns: unspecified

The `console-event-handler` procedure prints an *event* to the console error port. It is used when the event manager is not available. It disables interrupts so that it can be called from multiple processes safely. The output is designed to be machine readable. The output looks like this:

```
Date: Fri Aug 06 11:54:59 2010
Timestamp: 1281110099144
Event: event
```

The date is the local time from the `date-and-time` procedure, the timestamp is the clock time from `erlang:now`, and *event* is printed as with `write`.

```
(dbg) procedure
(dbg id)
returns: see below
```

The `dbg` procedure is used to debug processes that exit with a continuation condition.

(`dbg`) prints to the current output port the process id and exception message for each process that exited with a continuation condition.

(`dbg id`) enters the interactive debugger using the exception state of process *id*. If process *id* does not exist or did not exit with a continuation condition, the following message is printed: “Nothing to debug.”

```
(ps-fold-left id<? base f) procedure
returns: see below
```

The `ps-fold-left` procedure folds over the process table ordered by *id*<? on `process-id` and calls *f* with the accumulator value (initially *base*) and the process for each entry in the table.

```
(with-process-details p f) procedure
returns: see below
```

The `with-process-details` procedure takes a process *p* and returns the value obtained by calling the procedure *f* with four values: the process id, the process name, the value of `erlang:now` when the process was created, and a representation of the process state that may be passed to `print-process-state`.

```
(print-process-state state op) procedure
returns: unspecified
```

The `print-process-state` procedure takes a *state* from `with-process-details` and prints a description of the process state to the textual output port *op* in the format used by `pps`.

```
(dump-stack [op]) procedure
(dump-stack k op max-depth)
returns: unspecified
```

The `dump-stack` procedure calls `walk-stack` to print information about the stack to textual output port *op*, which defaults to the current output port.

k is a continuation, and *max-depth* is either the symbol `default` or a positive fixnum. See `walk-stack` for details on the *max-depth* argument.

`(dump-stack op)` calls `(call/cc (lambda (k) (dump-stack k op 'default)))`.

(limit-stack *e0 e1 ...*) **syntax**

expands to: `($limit-stack (lambda () e0 e1 ...) source)`

The `limit-stack` macro adds a stack frame that may be recognized by `limit-stack?`. By default, `walk-stack` avoids descending below such frames. The `limit-stack` macro evaluates expressions *e0 e1 ...* from left to right and returns the values of the last expression.

(limit-stack? *x*) **procedure**

returns: see below

The `limit-stack?` procedure returns true if *x* is a continuation whose top frame is a `limit-stack` frame. Otherwise it returns `#f`.

(walk-stack *k base handle-frame combine [who max-depth truncated]*) **procedure**

returns: see below

The `walk-stack` procedure walks the stack of continuation *k* by calling the *handle-frame* and *combine* procedures for each stack frame until it reaches the base of the stack or a `limit-stack` frame, or depth reaches the optional *max-depth*, or the *next* argument to *combine* is not called.

The *handle-frame* procedure is called with four arguments:

description a string describing the stack frame, e.g., `"#<continuation in g>"`
source a source object identifying the return point or `#f`
proc-source a source object identifying the procedure containing the return point or `#f`
vars a list associating live free variables by name (or index) with their values

If *max-depth* is omitted or is the symbol `default`, then `walk-stack` uses the value of `walk-stack-max-depth` as *max-depth* and stops if recognizes a `limit-stack` frame. If *max-depth* is specified explicitly, then `walk-stack` does not stop at `limit-stack` frames. If `walk-stack` reaches a depth of *max-depth*, it calls the optional *truncated* procedure with *base* and *depth*. Otherwise, `walk-stack` calls the *combine* procedure with four arguments:

frame the value returned by *handle-frame* for the current frame
base the accumulator
depth the zero-based depth of the current frame
next a procedure that takes *base* and continues with the next frame

If `walk-stack` receives an invalid argument *val*, it calls `(bad-arg who val)` with the symbol `walk-stack` as the default value for the optional *who* argument. The default *truncated* procedure simply returns the value of *base* passed in.

walk-stack-max-depth **parameter**

returns: a nonnegative fixnum

The `walk-stack-max-depth` parameter specifies the default maximum depth to which `walk-stack` descends when the optional *max-depth* argument is omitted or is the symbol `default`.

(exit-reason->stacks *x*) **procedure**

returns: a list of continuations

The `exit-reason->stacks` procedure takes a Swish condition *x*, as created by `throw` or trapped by `try`, and returns a list of continuations recorded in *x*. The continuations are listed innermost to outermost.

(erlang:now) **procedure**

returns: the current clock time in milliseconds

The `erlang:now` procedure calls `osi_get_time` to return the number of milliseconds in UTC since the UNIX epoch January 1, 1970.

(make-process-parameter *initial* [*filter*]) **procedure**

returns: a process-parameter procedure

The `make-process-parameter` procedure creates a parameter procedure *p* that provides per-process, mutable storage via the `parameters` weak eq-hashtable of each process. Calling *p* with no arguments returns the current value of the parameter for the calling process, and calling *p* with one argument sets the value of the parameter for the calling process. The *filter*, if present, is a procedure of one argument that is applied to the *initial* and all subsequent values. If *filter* is not a procedure, exception `#(bad-arg make-process-parameter filter)` is raised.

The following system parameters are not process safe and have been redefined to use `make-process-parameter`: `command-line`, `command-line-arguments`, `custom-port-buffer-size`, `exit-handler`, `keyboard-interrupt-handler`, `pretty-initial-indent`, `pretty-line-length`, `pretty-maximum-lines`, `pretty-one-line-limit`, `pretty-standard-indent`, `print-brackets`, `print-char-name`, `print-gensym`, `print-graph`, `print-length`, `print-level`, `print-precision`, `print-radix`, `print-record`, `print-unicode`, `print-vector-length`, `reset-handler`, and `waiter-prompt-and-read`, `waiter-prompt-string`.

inherited-parameters **parameter**

value: a list of process-parameter procedures

The `inherited-parameters` parameter contains a list of procedures representing process parameters whose values are propagated into spawned processes. Before creating a process, `spawn` and `spawn&link` record the current values of the `inherited-parameters` and install these values in the new process just before it calls the thunk. For efficiency, `spawn` and `spawn&link` do not re-apply a parameter's *filter* when installing these values in the new process. These values are already filtered, since the filter, if any, is called when a parameter is set.

(make-inherited-parameter *initial* [*filter*]) **procedure**

returns: a process-parameter procedure

The `make-inherited-parameter` procedure calls `make-process-parameter` to create a per-process parameter procedure *p* and adds *p* to the `inherited-parameters` list before returning *p*.

(keyboard-interrupt *process*) **procedure**

returns: unspecified

The `keyboard-interrupt` procedure causes *process* to call `((keyboard-interrupt-handler))` as soon as possible.

`(on-exit finally b1 b2 ...)` **syntax**

expands to:

```
(dynamic-wind
  void
  (lambda () b1 b2 ...)
  (lambda () finally))
```

The `on-exit` macro executes the body expressions *b1 b2 ...* in a dynamic context that executes the *finally* expression whenever control leaves the body.

`(profile-me)` **procedure**

returns: unspecified

The `profile-me` procedure does nothing but provide a place-holder for the system profiler to count the call site. When profiling is turned off, `(profile-me)` expands to `(void)`, and the system optimizer eliminates it.

`(profile-me-as form)` **syntax**

returns: unspecified

The `profile-me-as` macro does nothing but provide a place-holder for the system profiler to count the call site. If source information is present on *form*, the profile count for this call site is attributed to that *form*. When profiling is turned off or when source information is not present on *form*, `profile-me-as` expands to `(void)`, and the system optimizer eliminates it.

`(wait-for-io name)` **procedure**

returns: unspecified

The `wait-for-io` procedure blocks the current process for I/O. The *name* string indicates the target of the I/O operation. To unblock the process, call `complete-io` from a callback function.

`windows?` **syntax**

expands to: a boolean

The `windows?` macro expands to `#t` if the host is running Microsoft Windows and `#f` if not.

4.4.7 Tuples

For users of the concurrency model, a *tuple* is a container of named, immutable fields implemented as a vector whose first element is the tuple name and remaining elements are the fields. Each tuple definition is a macro that provides all tuple operations using field names only, not field indices. The macro makes it easy to copy a tuple without having to specify the fields that don't change. We decided not to use the Scheme record facility because it does not provide name-based constructors, copy operators, or convenient serialization.

(define-tuple *name field ...*) **syntax**

expands to: a macro definition of *name* described below

The `define-tuple` macro defines a macro for creating, copying, identifying, and accessing tuple type *name*. *name* and *field ...* must be identifiers. No two field names can be the same. The following field names are reserved: `make`, `copy`, `copy*`, and `is?`.

(*name make [field value] ...*) **syntax**

returns: a new instance of tuple type *name* with *field = value ...*

The `make` form creates a new instance of the tuple type *name*. *field* bindings may appear in any order. All fields from the tuple definition must be specified.

(*name field instance*) **syntax**

returns: *instance.field*

The field accessor form retrieves the value of the specified *field* of *instance*. If *r = instance* is not a tuple of type *name*, exception `#(bad-tuple name r src)` is raised, where *src* is the source location of the field accessor form if available.

(*name field*) **syntax**

returns: a procedure that, given *instance*, returns *instance.field*

The `(name field)` form expands to `(lambda (instance) (name field instance))`.

(*name open instance [prefix] (field ...)*) **syntax**

expands to: definitions for *field ...* or *prefixfield ...* described below

The `open` form defines identifier syntax for each specified *field* so that a reference to *field* expands to `(name field r)` where *r* is the value of *instance*. If *r* is not a tuple of type *name*, exception `#(bad-tuple name r src)` is raised, where *src* is the source location of the `open` form if available. The `open` form is equivalent to the following, except that it checks the tuple type only once:

```
(begin
  (define instance instance)
  (define-syntax field (identifier-syntax (name field instance)))
  ...)
```

The `open` form introduces definitions only for fields listed explicitly in `(field ...)`. If the optional *prefix* identifier is supplied, `open` produces a definition for *prefixfield* rather than *field* for each *field* specified.

(*name copy instance [field value] ...*) **syntax**

returns: a new instance of tuple type *name* with *field = value ...* and remaining fields copied from *instance*

The `copy` form creates a copy of *instance* except that each specified *field* is set to the associated *value*. If *r = instance* is not a tuple of type *name*, exception `#(bad-tuple name r src)` is raised, where *src* is the source location of the `copy` form if available. *field* bindings may appear in any order.

(name copy* instance [field value] ...) **syntax**
returns: a new instance of tuple type *name* with *field* = *value* ... and remaining fields copied from *instance*

The `copy*` form is like `copy` except that, within the *value* expressions, each specified *field* is bound to an identifier macro that returns the value of *instance.field*. If *r* = *instance* is not a tuple of type *name*, exception `#{bad-tuple name r src}` is raised, where *src* is the source location of the `copy*` form if available. The `copy*` form is equivalent to the following, except that it checks the tuple type only once:

```
(let ([instance instance])
  (name open instance (field ...))
  (name copy instance [field value] ...))
```

(name is? x) **syntax**
returns: a boolean

The `is?` form determines whether or not the datum *x* is an instance of tuple type *name*.

(name is?) **syntax**
expands to: a predicate that returns true if and only if its argument is an instance of tuple type *name*

The `(name is?)` form expands to `(lambda (x) (name is? x))`.

4.4.8 I/O

(binary->utf8 bp) **procedure**
returns: a transcoded textual port wrapping *bp*

The `binary->utf8` procedure takes a binary port *bp* and returns a textual port wrapping *bp* using `transcoded-port` and `(make-utf8-transcoder)`. The original port *bp* is marked closed so that it cannot be used except through the associated textual port.

(close-osi-port port) **procedure**
returns: unspecified

The `close-osi-port` procedure closes `osi-port` *port* using `osi_close_port`. If *port* has already been closed, `close-osi-port` does nothing.

(close-path-watcher watcher) **procedure**
returns: unspecified

The `close-path-watcher` procedure uses `osi_close_path_watcher` to close the given path *watcher*. If *watcher* is not a path watcher, exception `#{bad-arg close-path-watcher watcher}` is raised. If *watcher* has already been closed, `close-path-watcher` does nothing.

(close-tcp-listener listener) **procedure**
returns: unspecified

The `close-tcp-listener` procedure closes a TCP *listener* using `osi_close_tcp_listener`. If *listener* is not a TCP listener, exception `#{bad-arg close-tcp-listener listener}` is raised. If *listener* has already been closed, `close-tcp-listener` does nothing.

(connect-tcp *hostname port-spec*) **procedure**

returns: two values: a binary input port and a binary output port

The `connect-tcp` procedure calls `osi_connect_tcp` and blocks while the TCP connection to *hostname* on *port-spec* is established or fails to be established. The *port-spec* may be a port number or a string service name such as “http”. The procedure returns a custom binary input port that reads from the new connection and a custom binary output port that writes to the new connection. These ports support `port-position` but not `set-port-position!`, and the underlying `osi-ports` are registered with the `osi-port` guardian.

If `osi_connect_tcp` fails with error pair (*who* . *errno*), exception `#{io-error "[hostname]:port-spec" who errno}` is raised. If *hostname* is not a string, exception `#{bad-arg connect-tcp hostname}` is raised. If *port-spec* is not a fixnum between 0 and 65535 inclusive or a string, exception `#{bad-arg connect-tcp port-spec}` is raised.

(directory? *path*) **procedure**

returns: a boolean

The `directory?` procedure calls `(get-stat path)` to determine whether or not *path* is a directory.

(filter-files *path* [*keep-dir?* *keep-file?*]) **procedure**

returns: a list of filenames

The `filter-files` procedure calls `fold-files` to accumulate a list of filenames. *keep-dir?* is a procedure which should accept a full directory name and return true to descend into that directory. *keep-file?* is a procedure which should accept a full path to a file and return true to keep the filename in the final result list.

When *keep-dir?* and *keep-file?* are not specified, all directories under *path* are traversed, and all filenames are returned.

(fold-files *path* *init* *keep-dir?* *f*) **procedure**

returns: see below

The `fold-files` procedure folds over directories and files starting at *path* and calls *f* with the full path to each file and an accumulator (initially *init*).

For each directory, `fold-files` calls *keep-dir?* with the full directory name. When *keep-dir?* returns true `fold-files` will descend into that directory.

Errors while enumerating the file system are ignored.

(force-close-output-port *op*) **procedure**

returns: unspecified

The `force-close-output-port` procedure is used to close an output port, even if it has unflushed output that would otherwise cause it to fail to close. If *op* is not already closed, `force-close-`

`output-port` tries to close it with (`close-output-port` *op*). If it fails, the output buffer is cleared with (`clear-output-port` *op*), and (`close-output-port` *op*) is called again.

(get-bytevector-exactly-n *ip* *n*) **procedure**
returns: a bytevector of length *n*

The `get-bytevector-exactly-n` procedure takes a binary input port *ip* and an exact nonnegative integer *n* and returns a bytevector of the next *n* bytes from *ip*. If *ip* reaches end-of-file before it obtains *n* bytes, `get-bytevector-exactly-n` throws an `unexpected-eof` exception.

(get-datum/annotations-all *ip* *sfd* *bfp*) **procedure**
returns: a list of annotated objects

The `get-datum/annotations-all` procedure takes a textual input port *ip*, a source-file descriptor *sfd*, and an exact nonnegative integer *bfp* representing the character position of the next character to be read from *ip*. The procedure returns a list of the annotated objects, in order, obtained by repeatedly calling `get-datum/annotations` with the advancing *bfp*, until *ip* reaches the end of file.

(get-file-size *port*) **procedure**
returns: the number of bytes in the file associated with `osi-port` *port*

The `get-file-size` procedure calls `osi_get_file_size` to return the number of bytes in the file associated with `osi-port` *port*.

If `osi_get_file_size` fails with error pair (*who* . *errno*), exception `#(io-error filename who errno)` is raised.

(get-real-path *path*) **procedure**
returns: the canonicalized absolute pathname of *path*

The `get-real-path` procedure calls `osi_get_real_path` and returns the canonicalized absolute pathname of *path*.

(get-source-offset *ip*) **procedure**
returns: an exact nonnegative integer

The `get-source-offset` procedure takes a binary input port *ip* that supports `port-position`, skips over the `#!interpreter-directive` line, if any, and returns the resulting `port-position`.

(get-stat *path* [*follow?*]) **procedure**
returns: a `<stat>` tuple

The `get-stat` procedure calls `osi_get_stat` and returns the `<stat>` tuple for *path*, following a symbolic link unless *follow?* is `#f`. If `osi_get_stat` fails with error pair (*who* . *errno*), exception `#(io-error path who errno)` is raised.

(get-uname) **procedure**
returns: a `<uname>` tuple

The `get-uname` procedure returns a `<uname>` tuple of information about the operating system.

(hook-console-input) **procedure**
returns: unspecified

The `hook-console-input` procedure replaces the system console input port, which uses synchronous I/O, with a custom textual input port that uses asynchronous I/O. It builds a custom binary input port with `osi_get_stdin`, wraps it with `binary->utf8`, and sets the result as the `console-input-port`, `current-input-port`, and the system internal `$console-input-port`. It does nothing after it has been called once.

(io-error *name who errno*) **procedure**
returns: never

The `io-error` procedure raises exception `#{io-error name who errno}`. The string *name* identifies the port. The symbol *who* specifies the procedure that raised an error, and the number *errno* specifies the error code. The `read-osi-port` procedure raises this exception with *who*=`osi_read-port`, and the `write-osi-port` procedure raises it with *who*=`osi_write_port`.

(list-directory *path*) **procedure**
returns: `((name . type) ...)`

The `list-directory` procedure calls `osi_list_directory` and returns `((name . type) ...)`, the list of directory entries of *path*. It does not include “.” and “..”. *name* is the string name of the directory entry, and *type* is one of the following constants:

DIRENT_UNKNOWN DIRENT_FILE DIRENT_DIR DIRENT_LINK DIRENT_FIFO
DIRENT_SOCKET DIRENT_CHAR DIRENT_BLOCK

If `osi_list_directory` fails with error pair `(who . errno)`, exception `#{io-error path who errno}` is raised.

(listen-tcp *address port-number process*) **procedure**
returns: a TCP listener

The `listen-tcp` procedure calls `osi_listen_tcp` to create a TCP listener on the given *address* and *port-number* and returns a TCP listener that is registered with the listener guardian.

For each accepted connection, the message `#{accept-tcp listener ip op}` is sent to *process*, where *ip* is the custom binary input port and *op* is the custom binary output port. Both ports support `port-position` but not `set-port-position!`.

For each failed connection, the message `#{accept-tcp-failed listener who errno}` is sent to *process*, where *who* and *errno* specify the error.

The *address* is a dotted quad IPv4 address or an IPv6 address. Use “:.” to listen on all IPv4 and IPv6 interfaces. Use “0.0.0.0” to listen on all IPv4 interfaces. Otherwise, it listens on the given *address* only. If *address* is not a string, exception `#{bad-arg listen-tcp address}` is raised.

If *port-number* is zero, the operating system will choose an available port number, which can be queried with `listener-port-number`. If *port-number* is not a fixnum between 0 and 65535 inclusive, exception `#{bad-arg listen-tcp port-number}` is raised.

If `osi_listen_tcp` fails with error pair `(who . errno)`, exception `#{listen-tcp-failed address port-number who errno}` is raised.

(listener-address *listener*) **procedure**

returns: the address field of *listener*

The `listener-address` procedure returns the `address` of the given TCP *listener*.

(listener-create-time *listener*) **procedure**

returns: a clock time in milliseconds

The `listener-create-time` procedure returns the clock time from `erlang:now` when the given TCP *listener* was created.

(listener-port-number *listener*) **procedure**

returns: the port-number field of *listener*

The `listener-port-number` procedure returns the `port-number` of the given TCP *listener*.

(listener? *x*) **procedure**

returns: a boolean

The `listener?` procedure determines whether or not the datum *x* is a TCP listener.

(make-directory *path* [*mode*]) **procedure**

returns: unspecified

The `make-directory` procedure calls `osi_make_directory` to make directory *path* with *mode*, which defaults to `#o777`.

If `osi_make_directory` fails with error pair (*who* . *errno*), exception `#{io-error path who errno}` is raised.

(make-directory-path *path* [*mode*]) **procedure**

returns: *path*

The `make-directory-path` procedure creates directories as needed for the file *path* using *mode*, which defaults to `#o777`. It returns *path*.

(make-osi-input-port *p*) **procedure**

returns: a binary input port

The `make-osi-input-port` procedure returns a custom binary input port that reads from *osi-port* *p* and supports `port-position` but not `set-port-position!`. Closing the input port closes the underlying *osi-port* *p*.

(make-osi-output-port *p*) **procedure**

returns: a binary output port

The `make-osi-output-port` procedure returns a custom binary output port that writes to *osi-port* *p* and supports `port-position` but not `set-port-position!`. Closing the output port closes the underlying *osi-port* *p*.

(make-utf8-transcoder) **procedure**

returns: a UTF-8 transcoder

The `make-utf8-transcoder` procedure creates a UTF-8 transcoder with end-of-line style `none` and error-handling mode `replace`.

(open-fd-port *name fd close?*) **procedure**

returns: an `osi-port`

The `open-fd-port` procedure creates an `osi-port` with the given *name* by calling `osi_open_fd` with *fd* and *close?*. The `osi-port` is registered with the `osi-port` guardian. When the `osi-port` is closed, the underlying file descriptor *fd* is closed if and only if *close?* is not `#f`. When $0 \leq fd \leq 2$, *close?* must be `#f` for the standard I/O file descriptor.

(open-file *name flags mode type*) **procedure**

returns: a custom file port

The `open-file` procedure creates a custom file port by calling `(open-file-port name flags mode)`. The custom port supports both getting and setting the file position, except when *type*=`append`. The particular type of custom port returned is determined by *type*:

- `binary-input`: a binary input port
- `binary-output`: a binary output port
- `binary-append`: a binary output port. Each write appends to the file by specifying position `-1`.
- `input`: a textual input port wrapping a binary input port with `binary->utf8`
- `output`: a textual output port wrapping a binary output port with `binary->utf8`
- `append`: a textual output port wrapping a binary output port with `binary->utf8`. Each write appends to the file by specifying position `-1`.

If *type* is any other value, exception `#(bad-arg open-file type)` is raised.

(open-file-port *name flags mode*) **procedure**

returns: an `osi-port`

The `open-file-port` procedure creates an `osi-port` by calling `osi_open_file` with *name*, *flags*, and *mode*. The `osi-port` is registered with the `osi-port` guardian.

The following constants are defined for *flags*:

| | | | | | |
|--------------------------|------------------------|---------------------------|----------------------------|-------------------------|-----------------------|
| <code>O_APPEND</code> | <code>O_CREAT</code> | <code>O_DIRECT</code> | <code>O_DIRECTORY</code> | <code>O_DSYNC</code> | <code>O_EXCL</code> |
| <code>O_EXLOCK</code> | <code>O_NOATIME</code> | <code>O_NOCTTY</code> | <code>O_NOFOLLOW</code> | <code>O_NONBLOCK</code> | <code>O_RANDOM</code> |
| <code>O_RDONLY</code> | <code>O_RDWR</code> | <code>O_SEQUENTIAL</code> | <code>O_SHORT_LIVED</code> | <code>O_SYMLINK</code> | <code>O_SYNC</code> |
| <code>O_TEMPORARY</code> | <code>O_TRUNC</code> | <code>O_WRONLY</code> | | | |

The following constants are defined for *mode*:

| | | | | | | | |
|---------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|
| <code>S_IFMT</code> | <code>S_IFIFO</code> | <code>S_IFCHR</code> | <code>S_IFDIR</code> | <code>S_IFBLK</code> | <code>S_IFREG</code> | <code>S_IFLNK</code> | <code>S_IFSOCK</code> |
|---------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|

If `osi_open_file` fails with error pair (*who* . *errno*), exception `#(io-error name who errno)` is raised.

(open-binary-file-to-append *name*) **procedure**
returns: a binary file port

The `open-binary-file-to-append` procedure calls
(`open-file name (+ O_WRONLY O_CREAT O_APPEND) #o666 'binary-append`).

(open-binary-file-to-read *name*) **procedure**
returns: a binary file port

The `open-binary-file-to-read` procedure calls (`open-file name O_RDONLY 0 'binary-input`).

(open-binary-file-to-replace *name*) **procedure**
returns: a binary file port

The `open-binary-file-to-replace` procedure calls
(`open-file name (+ O_WRONLY O_CREAT O_TRUNC) #o666 'binary-output`).

(open-binary-file-to-write *name*) **procedure**
returns: a binary file port

The `open-binary-file-to-write` procedure calls
(`open-file name (+ O_WRONLY O_CREAT O_EXCL) #o666 'binary-output`).

(open-file-to-append *name*) **procedure**
returns: a textual file port

The `open-file-to-append` procedure calls
(`open-file name (+ O_WRONLY O_CREAT O_APPEND) #o666 'append`).

(open-file-to-read *name*) **procedure**
returns: a textual file port

The `open-file-to-read` procedure calls (`open-file name O_RDONLY 0 'input`).

(open-file-to-replace *name*) **procedure**
returns: a textual file port

The `open-file-to-replace` procedure calls
(`open-file name (+ O_WRONLY O_CREAT O_TRUNC) #o666 'output`).

(open-file-to-write *name*) **procedure**
returns: a textual file port

The `open-file-to-write` procedure calls
(`open-file name (+ O_WRONLY O_CREAT O_EXCL) #o666 'output`).

(open-utf8-bytevector *bv*) **procedure**

returns: a transcoded textual input port wrapping *bv*

The `open-utf8-bytevector` procedure calls `(binary->utf8 (open-bytevector-input-port bv))`.

(osi-port-closed? *p*) **procedure**

returns: a boolean

The `osi-port-closed?` procedure determines whether or not the osi-port *p* is closed.

(osi-port-count) **procedure**

returns: the number of open osi-ports

The `osi-port-count` procedure returns the number of open osi-ports.

(osi-port-create-time *p*) **procedure**

returns: a clock time in milliseconds

The `osi-port-create-time` procedure returns the clock time from `erlang:now` when the osi-port *p* was created.

(osi-port-name *p*) **procedure**

returns: a string

The `osi-port-name` procedure returns the name of osi-port *p*.

(osi-port? *x*) **procedure**

returns: a boolean

The `osi-port?` procedure determines whether or not the datum *x* is an osi-port.

(path-combine *path*₁ *path*₂ ...) **procedure**

returns: the string combining the paths

The `path-combine` procedure appends one or more paths, inserting the directory-separator character between each pair of paths as needed, while ignoring empty paths.

(path-watcher-count) **procedure**

returns: the number of open path watchers

The `path-watcher-count` procedure returns the number of open path watchers.

(path-watcher-create-time *watcher*) **procedure**

returns: a clock time in milliseconds

The `path-watcher-create-time` procedure returns the clock time from `erlang:now` when the given path *watcher* was created.

(path-watcher-path *watcher*) **procedure**

returns: the `path` field of *watcher*

The `path-watcher-path` procedure returns the `path` of the given path *watcher*.

(path-watcher? *x*) **procedure**
returns: a boolean

The `path-watcher?` procedure determines whether or not the datum *x* is a path watcher.

(port->notify-port *p notify!*) **procedure**
returns: a port

The `port->notify-port` procedure takes a custom binary port *p* and a *notify!* procedure of one argument. It marks port *p* as closed and returns a new custom port whose `r!` or `w!` procedure calls *notify!* with the number of bytes returned. This procedure is currently restricted to ports returned by `connect-tcp` and ports obtained from an `#(accept-tcp listener ip op)` tuple.

(print-osi-ports [*op*]) **procedure**
returns: unspecified

The `print-osi-ports` procedure prints information about all open `osi-ports` to textual output port *op*, which defaults to the current output port.

(print-path-watchers [*op*]) **procedure**
returns: unspecified

The `print-path-watchers` procedure prints information about all open path watchers to textual output port *op*, which defaults to the current output port.

(print-signal-handlers [*op*]) **procedure**
returns: unspecified

The `print-signal-handlers` procedure prints information about all active signal handlers to textual output port *op*, which defaults to the current output port.

(print-tcp-listeners [*op*]) **procedure**
returns: unspecified

The `print-tcp-listeners` procedure prints information about all open TCP listeners to textual output port *op*, which defaults to the current output port.

(read-bytevector *name contents*) **procedure**
returns: a list of annotations

The `read-bytevector` procedure takes a filename *name* and *contents* bytevector and returns a list of annotations read using `get-datum/annotations` from the *contents* bytevector transcoded with `(make-utf8-transcoder)`.

(read-file *name*) **procedure**
returns: a bytevector with the contents of *name*

The `read-file` procedure calls (`open-file-port name 0_RDONLY 0`) to open the file *name* and returns the contents as a bytevector.

(read-osi-port *port bv start n fp*) **procedure**
returns: the number of bytes read

The `read-osi-port` procedure calls `osi_read_port` with the handle from the given osi-port *port*, bytevector buffer *bv*, starting 0-based buffer index *start*, maximum number of bytes to read *n*, and starting 0-based file position *fp*. To specify the current position, use *fp*=-1. The calling process blocks for the I/O to complete. If the read fails with error pair (*who . errno*), exception `#(io-error name who errno)` is raised, where *name* is the name of *port*. Otherwise, the number of bytes read is returned. Error code `UV_EOF` (end of file) is not considered an error, and 0 is returned.

(regular-file? *path*) **procedure**
returns: a boolean

The `regular-file?` procedure calls (`get-stat path`) to determine whether or not *path* is a regular file.

(remove-directory *path*) **procedure**
returns: unspecified

The `remove-directory` procedure calls `osi_remove_directory` to remove directory *path*.

If `osi_remove_directory` fails with error pair (*who . errno*), exception `#(io-error path who errno)` is raised.

(remove-file *path*) **procedure**
returns: unspecified

The `remove-file` procedure calls `osi_unlink` to remove file *path*.

If `osi_unlink` fails with error pair (*who . errno*), exception `#(io-error path who errno)` is raised.

(rename-path *path new-path*) **procedure**
returns: unspecified

The `rename-path` procedure calls `osi_rename` to rename *path* to *new-path*.

If `osi_rename` fails with error pair (*who . errno*), exception `#(io-error path who errno)` is raised.

(set-file-mode *path mode*) **procedure**
returns: unspecified

The `set-file-mode` procedure calls `osi_chmod` to set the file mode of *path* to *mode*.

If `osi_chmod` fails with error pair (*who . errno*), exception `#(io-error path who errno)` is raised.

(signal-handler *signum* [*callback*]) **procedure**

returns: see below

The `signal-handler` procedure manages an internal table of global handlers for low-level signals. The `signum` argument must be a positive fixnum. If no `callback` is supplied, `signal-handler` returns the callback, if any, registered to handle that signal, or else `#f`. If the optional `callback` argument is supplied, it must be `#f` or a procedure of one argument that is called with the signal number when that signal is delivered. Since the `callback` procedure is called on the event loop, it must obey the restrictions on event-loop callbacks (see page 41). Do not call `app:shutdown` from `callback`, because it is not process-safe when no application is running. Instead, `(spawn app:shutdown)`. At startup, Swish installs handlers that call `app:shutdown` safely when certain signals are delivered. The set of signals trapped at startup depends on the platform.

This procedure is like Chez Scheme's `register-signal-handler`, except that `signal-handler` is integrated into the Swish event loop. In particular, the callback supplied to `signal-handler` can wake a sleeping process via `send`. When a signal `signum` is delivered to the Swish operating-system process, e.g., via `osi_kill`, `osi_get_callbacks` returns a list of callbacks that includes `(@deliver-signal signum)`. If `callback` has been established to handle `signum`, then `@deliver-signal` calls `callback` with `signum`.

The `(swish io)` library exports constants for the available signal numbers, which vary among platforms. For platform-specific notes on signal handling, see [21]. Some signals cannot be handled even though a handler may be established. Handling some signals may result in undefined behavior.

(signal-handler-count) **procedure**

returns: the number of open signal handlers

The `signal-handler-count` procedure returns the number of open signal handlers.

(spawn-os-process *path args process*) **procedure**

returns: four values: a binary output port `to-stdin`, a binary input port `from-stdout`, a binary input port `from-stderr`, and an integer process identifier `os-pid`

The `spawn-os-process` procedure calls `osi_spawn` to spawn an operating system process with the string `path` and list of string-valued `args`. It returns a custom binary output port `to-stdin` that writes to the standard input of the process, custom binary input ports `from-stdout` and `from-stderr` that read from the standard output and standard error of the process, respectively, and a process identifier `os-pid`. These ports support `port-position` but not `set-port-position!`, and the underlying `osi-ports` are registered with the `osi-port` guardian.

When the spawned process terminates, `#(process-terminated os-pid exit-status term-signal)` is sent to `process`.

If `osi_spawn` returns error pair `(who . errno)`, exception `#(io-error path who errno)` is raised.

(spawn-os-process-detached *path args*) **procedure**

returns: an integer operating-system process identifier

The `spawn-os-process-detached` procedure calls `osi_spawn_detached` to spawn an operating system process with the string `path` and list of string-valued `args`. It returns an integer operating-system process identifier.

If `osi_spawn_detached` returns error pair (*who* . *errno*), exception `#(io-error path who errno)` is raised.

(stat-directory? *x*) **procedure**
returns: a boolean

The `stat-directory?` procedure determines whether or not the datum *x* is a `<stat>` tuple for a directory.

(stat-regular-file? *x*) **procedure**
returns: a boolean

The `stat-regular-file?` procedure determines whether or not the datum *x* is a `<stat>` tuple for a regular file.

(tcp-listener-count) **procedure**
returns: the number of open TCP listeners

The `tcp-listener-count` procedure returns the number of open TCP listeners.

(tcp-nodelay *port enabled?*) **procedure**
returns: a boolean

The `tcp-nodelay` procedure calls `osi_tcp_nodelay` to enable or disable the Nagle algorithm on the specified TCP/IP *port*. It returns true if successful or false otherwise.

(watch-path *path process*) **procedure**
returns: a path watcher

The `watch-path` procedure calls `osi_watch_path` to track changes to *path* and returns a path watcher that is registered with the path-watcher guardian.

Every time a change is detected, `#(path-changed path filename events)` is sent to *process*, where *filename* is a string or `#f` and *events* is 1 for rename, 2 for change, and 3 for rename and change. If the watcher encounters an error, `#(path-watcher-failed path errno)` is sent to *process*.

If `osi_watch_path` returns error pair (*who* . *errno*), exception `#(io-error path who errno)` is raised.

(with-sfd-source-offset *name handler*) **procedure**
returns: see below

The `with-sfd-source-offset` procedure takes a filename *name* and returns the result of calling the procedure *handler* with three arguments: *ip*, a textual port transcoded with `(make-utf8-transcoder)`, *sfd*, a source-file descriptor that refers to *name*, and *source-offset*, the value returned by `get-source-offset`. Before returning, `with-sfd-source-offset` closes the textual port.

(write-osi-port *port bv start n fp*) **procedure**
returns: the number of bytes written

The `write-osi-port` procedure calls `osi_write_port` with the handle from the given `osi-port` `port`, bytevector buffer `bv`, starting 0-based buffer index `start`, maximum number of bytes to write `n`, and starting 0-based file position `fp`. To specify the current position, use `fp=-1`. The calling process blocks for the I/O to complete. If the write fails with error pair (`who . errno`), exception `#{io-error name who errno}` is raised, where `name` is the name of `port`. Otherwise, the number of bytes written is returned.

4.4.9 Queues

A queue is represented as a pair of lists, (`in . out`). The `out` list contains the first elements of the queue, and the `in` list contains the last elements of the queue in reverse. This representation allows for $O(1)$ amortized insertion and removal times. The implementation is based on the Erlang queue module [11].

`(queue:add x q)` **procedure**

returns: a queue that adds `x` to the rear of `q`

`(queue:add-front x q)` **procedure**

returns: a queue that adds `x` to the front of `q`

`(queue:drop q)` **procedure**

returns: a queue without the first element of `q`

`queue:empty` **syntax**

returns: the empty queue

`(queue:empty? q)` **procedure**

returns: `#t` if `q` is `queue:empty`, `#f` otherwise

`(queue:get q)` **procedure**

returns: the first element of `q`

4.4.10 Hash Tables

The implementation of functional hash tables is based on the Erlang dict module [9, 16].

`(ht:delete ht key)` **procedure**

returns: a hash table formed by dropping any association of `key` from `ht`

`(ht:fold ht f init)` **procedure**

returns: see below

The `ht:fold` procedure accumulates a value by applying `f` to each key/value association in `ht` and the accumulator, which is initially `init`. It can be defined recursively as follows, where `n` is the size of `ht`, and the result of `ht:fold` is F_n :

$$F_0 = \text{init}$$

$$F_i = (f \text{ key}_i \text{ val}_i F_{i-1}) \text{ for } 1 \leq i \leq n$$

(ht:is? *x*) **procedure**
returns: #t if *x* is a hash table, #f otherwise

(ht:keys *ht*) **procedure**
returns: a list of the keys of *ht*

(ht:make *hash-key equal-key? valid-key?*) **procedure**
returns: an empty hash table

The `ht:make` procedure returns an empty hash table.

The `hash-key` procedure takes a key and returns an exact integer. It must return the same integer for equivalent keys.

The `equal-key?` procedure takes two keys and returns a true value if they are equivalent and #f otherwise.

The `valid-key?` procedure takes a datum and returns a true value if it a valid key and #f otherwise.

(ht:ref *ht key default*) **procedure**
returns: the value associated with *key* in *ht*, *default* if none

(ht:set *ht key val*) **procedure**
returns: a hash table formed by associating *key* with *val* in *ht*

(ht:size *ht*) **procedure**
returns: the number of entries in *ht*

4.4.11 Error Strings

current-exit-reason->english **parameter**
value: a procedure of one argument that returns an English string

The `current-exit-reason->english` parameter specifies the conversion procedure used by `exit-reason->english`. It defaults to `swish-exit-reason->english`.

(exit-reason->english *x*) **procedure**
returns: a string in U.S. English

The `exit-reason->english` procedure converts an exit reason into an English string using the procedure stored in parameter `current-exit-reason->english`.

(swish-exit-reason->english *x*) **procedure**
returns: a string in U.S. English

The `swish-exit-reason->english` procedure converts an exit reason from Swish into an English string.

4.4.12 String Utilities

The string utilities below are found in the (swish `string-utils`) library.

`(ct:join sep s ...)` **syntax**

expands to: a string or a call to `string-append`

The `ct:join` macro uses `ct:string-append` to join adjacent string literals into a literal string or a call to `string-append` where adjacent string literals are combined. The `sep`, which must be a literal string or character, is inserted between adjacent elements of `s ...`.

`(ct:string-append s ...)` **syntax**

expands to: a string or a call to `string-append`

The `ct:string-append` macro appends adjacent string literals at compile time and expands into the resulting literal string or a call to `string-append` where adjacent string literals are combined.

`(ends-with? s p)` **procedure**

returns: a boolean

The `ends-with?` procedure determines whether or not the string `s` ends with string `p` using case-sensitive comparisons.

`(ends-with-ci? s p)` **procedure**

returns: a boolean

The `ends-with-ci?` procedure determines whether or not the string `s` ends with string `p` using case-insensitive comparisons.

`(format-rfc2822 d)` **procedure**

returns: a string like “Thu, 28 Jul 2016 17:20:11 -0400”

The `format-rfc2822` procedure returns a string representation of the date object `d` in the form specified in Section 3.3 of RFC 2822 [23].

`(join ls separator [last-separator])` **procedure**

returns: a string

The `join` procedure returns the string formed by displaying each of the elements of list `ls` separated by displaying `separator`. When `last-separator` is specified, it is used as the last separator.

`(natural-string<? s1 s2)` **procedure**

`(natural-string-ci<? s1 s2)`

returns: a boolean

These procedures compare strings `s1` and `s2` in a way that is more natural to humans than the corresponding `string<?` and `string-ci<?` predicates. The natural comparison predicates:

1. ignore leading and trailing whitespace,

2. treat runs of multiple whitespace characters as a single space,
3. compare integers numerically, treating - as a dash if it follows an alphanumeric character or else as negation, and
4. fall back to character comparison otherwise, with the `-ci<?` variant being case-insensitive.

`(oxford-comma [prefix] elt-fmt conj [suffix])` **procedure**
returns: a string

The `oxford-comma` procedure constructs a format string for use with `errorf`, `format`, `printf`, etc., to join the elements of a list with commas and/or `conj`, as appropriate. The `elt-fmt` argument is the format string for individual items of the list. The `conj` argument is a string used to separate the final two elements of the list. The `prefix` and `suffix` arguments must be supplied together or omitted. If omitted, `prefix` defaults to "`~{`" and `suffix` defaults to "`~}`".

`(split str separator)` **procedure**
returns: a list of strings

The `split` procedure divides the `str` string by the `separator` character into a list of strings, none of which contain `separator`.

`(split-n str separator n)` **procedure**
returns: a list of no more than `n` strings

The `split-n` procedure divides the `str` string by the `separator` character into a list of at most `n` strings. The last string may contain `separator`.

`(starts-with? s p)` **procedure**
returns: a boolean

The `starts-with?` procedure determines whether or not the string `s` starts with string `p` using case-sensitive comparisons.

`(starts-with-ci? s p)` **procedure**
returns: a boolean

The `starts-with-ci?` procedure determines whether or not the string `s` starts with string `p` using case-insensitive comparisons.

`(trim-whitespace s)` **procedure**
returns: a string

The `trim-whitespace` procedure returns a string in which any leading or trailing whitespace in `s` has been removed. Internal whitespace is not affected.

`(wrap-text op width initial-indent subsequent-indent text)` **procedure**
returns: unspecified

The `wrap-text` procedure writes the given *text* to the textual output port *op* after collapsing spaces that separate words. The first line is indented by *initial-indent* spaces. Subsequent lines are indented by *subsequent-indent* spaces. If possible, `wrap-text` breaks lines that would exceed *width*. Newlines and tabs are preserved, but tabs are treated as if they were the width of a single character.

The *text* argument may be a string or a list of strings. If *text* is a list, it is treated as if it were the string obtained via `(join text #\space)`.

(symbol-append . *ls*) **procedure**
returns: a symbol

The `symbol-append` procedure returns the symbol formed by appending the symbols passed as arguments.

4.4.13 Message Digests

(make-digest-provider *name open hash! get-hash close*) **procedure**
returns: a digest provider record

The `make-digest-provider` procedure takes a symbol *name* and a set of procedures and returns a new digest provider that can be used as the value of `current-digest-provider` or as an argument to `open-digest`.

The *open* procedure takes a string *alg* and an *hmac-key* that is either `#f` or a bytevector to use for HMAC keyed hashing. If the digest provider does not support the specified message-digest algorithm *alg* or the *hmac-key*, it should return an error pair or one of the symbols `algorithm` or `hmac-key` to indicate which argument is invalid. Otherwise it should return a message-digest context that can be passed to *hash!*, *get-hash*, and *close*.

The *hash!* procedure has the same interface as `osi_hash_data` and performs the analogous function for the message-digest context initialized by *open*. It computes the message digest incrementally on the set of bytes specified and updates the message-digest context.

The *get-hash* procedure has the same interface as `osi_get_SHA1` and performs the analogous function for the message-digest context initialized by *open* and updated by *hash!*.

The *close* procedure frees a message-digest context initialized by *open*.

current-digest-provider **parameter**
returns: a digest provider record

The `current-digest-provider` parameter specifies the digest provider used by `bytevector->hex-string` and by `open-digest` when the digest provider is not explicit.

default-digest-provider **binding**
returns: the default digest provider record

The default value of `current-digest-provider` is bound to `default-digest-provider`. The default digest provider supports only the SHA1 message-digest algorithm; it does not support HMAC keyed hashing.

(digest-provider-name *dp*) **procedure**

returns: the name of the digest provider

The `digest-provider-name` procedure returns the symbol that was supplied to `make-digest-provider` when *dp* was created.

(open-digest *alg* [*hmac-key* [*dp*]]) **procedure**

returns: a message digest

The `open-digest` procedure takes a string or symbol *alg* naming a message-digest function supported by the digest provider *dp*, which defaults to the value of `current-digest-provider`. If *alg* is a symbol, it is converted to an upper-case string before proceeding. The optional *hmac-key* may be `#f` to disable HMAC keyed hashing; otherwise it must be a bytevector or a string. If *hmac-key* is a string, it is converted to a bytevector using `string->utf8`.

The `open-digest` procedure disables interrupts while it calls the `open` procedure that was registered with `make-digest-provider`, passing it the algorithm name as a string and the *hmac-key* as either `#f` or a bytevector. If successful, it wraps the message-digest context returned by `open` in a message-digest record *md*, registers *md* with a foreign-handle guardian using the type name `digests`, and returns *md*.

(hash! *md* *bv* [*start-index* [*size*]]) **procedure**

returns: unspecified

The `hash!` procedure disables interrupts while it calls the `hash!` procedure of the message-digest provider used in the `open-digest` call that returned *md*. The `hash!` procedure computes the message digest incrementally on the set of *size* bytes in the bytevector *bv* starting at the zero-based *start-index*. If omitted, *start-index* defaults to zero and *size* defaults to the size of *bv*. The `hash!` procedure updates the message-digest context within *md*.

(get-hash *md*) **procedure**

returns: a bytevector

The `get-hash` procedure disables interrupts while it calls the `get-hash` procedure of the message-digest provider used in the `open-digest` call that returned *md*. It returns a bytevector containing the message digest accumulated in *md* by zero or more calls to `hash!`.

(close-digest *md*) **procedure**

returns: unspecified

The `close-digest` procedure disables interrupts, unregisters *md* with the foreign-handle guardian, calls the `close` procedure of the message-digest provider used in the `open-digest` call that returned *md*, then enables interrupts.

(hash->hex-string *bv*) **procedure**

returns: a string of lower-case hexadecimal digits

The `hash->hex-string` procedure takes a bytevector *bv* and returns the unsigned bytes in *bv* as a string of lower-case hexadecimal digits.

(hex-string->hash *s*) **procedure**

returns: a bytevector

The `hex-string->hash` procedure takes a string *s* containing an even number of hexadecimal digits and returns a bytevector half that size containing the unsigned bytes specified by adjacent pairs of hexadecimal digits.

(bytevector->hex-string *bv alg [block-size]*) **procedure**

returns: a string of lower-case hexadecimal digits

The `bytevector->hex-string` procedure takes a bytevector *bv* and a string or symbol *alg* naming a message-digest function supported by the `current-digest-provider` and returns the message digest of *bv* using *alg* as a string of lower-case hexadecimal digits. To keep the event loop responsive, `bytevector->hex-string` computes the message digest of *bv* incrementally in chunks of *block-size*, which defaults to 16384. When the size of *bv* is not more than *block-size*, this is functionally equivalent to the following:

```
(let ([md (open-digest alg)])
  (on-exit (close-digest md)
    (hash! md bv)
    (hash->hex-string (get-hash md))))
```

(print-digests [*op*]) **procedure**

returns: unspecified

The `print-digests` procedure prints information about all open message-digest contexts to textual output port *op*, which defaults to the current output port. This is the procedure returned by `(foreign-handle-print 'digests)`.

(digest-count) **procedure**

returns: the number of open message-digest contexts

The `digest-count` procedure returns the number of open message-digest contexts. This is the procedure returned by `(foreign-handle-count 'digests)`.

4.4.14 Data-Encoding Utilities

(base64-decode-bytevector *bv*) **procedure**

(base64url-decode-bytevector *bv*)

returns: a bytevector

The `base64-decode-bytevector` and `base64url-decode-bytevector` procedures return a new bytevector containing the data decoded from bytevector *bv*. The data in *bv* must be in the form described in Section 4 or 5, respectively, of IETF RFC 4648 [24]. In keeping with Sections 3.1 and 3.3 of [24], line feeds and non-alphabetic characters are not permitted in *bv* and should be removed before calling these procedures.

(base64-encode-bytevector *bv*) **procedure**

(base64url-encode-bytevector *bv*)

returns: a bytevector

The `base64-encode-bytevector` and `base64url-encode-bytevector` procedures return a new bytevector containing the binary data from bytevector *bv* encoded as printable US-ASCII characters as described in Sections 4 and 5, respectively, of IETF RFC 4648 [24]. Both procedures encode data using an alphabet including A-Z, a-z, and 0-9. For `base64-encode-bytevector`, the alphabet also includes + and /. For `base64url-encode-bytevector` it includes - and _. In keeping with Section 3.1 of [24], these procedures do not introduce line breaks in the output.

4.4.15 Macro Utilities

`(pretty-syntax-violation msg form [subform [who]])` **procedure**

returns: never

The `pretty-syntax-violation` procedure raises a syntax violation. It differs from the native `syntax-violation` in that it formats *form* and *subform* using `pretty-format` abbreviations, and it does not attempt to infer a *who* condition when *who* is not provided, as this can produce confusing results in error messages involving match patterns. To provide more readable exception messages, it constructs the formatted message condition by calling `pretty-print` before raising the exception, and it prevents `display-condition` from formatting the `&syntax` condition within the compound condition it constructs.

`(with-temporaries (id ...) e0 e1 ...)` **syntax**

expands to:

```
(with-syntax ([ (id ...) (generate-temporaries '(id ...)) ])
  e0 e1 ...)
```

The `with-temporaries` macro binds each macro-language pattern variable *id* to a fresh generated identifier within the body (`begin e0 e1 ...`).

`(define-syntactic-monad m id ...)` **syntax**

expands to: see below

The `define-syntactic-monad` macro defines a macro *m* for defining and calling procedures that take implicit *id ...* arguments in addition to any explicit arguments that may be provided. Such macros make it easier to write state machines in a functional style by allowing the programmer to specify only the values that change at a call.

A call to *m* takes the form (*m* *e*₀ ([*id*_{*i*} *e*_{*i*}] ...) *x* ...) or (*m* *kwd* *form* ...) where *kwd* is `case-lambda`, `define`, `lambda`, `let`, `trace-case-lambda`, `trace-define`, `trace-lambda`, or `trace-let`. The first form constructs a call to *e*₀ and is described below along with the `let` case. The other cases may be understood in terms of the following template expansions or their natural extension to tracing variants:

$$(m \text{ lambda } fmls \text{ body } \dots) \rightarrow (\text{lambda } (id \dots . fmls) \text{ body } \dots)$$

$$(m \text{ define } (proc . fmls) \text{ body } \dots) \rightarrow (\text{define } proc (m \text{ lambda } fmls \text{ body } \dots))$$

$$(m \text{ case-lambda } [fmls \text{ body } \dots] \dots) \rightarrow (\text{case-lambda } [(id \dots . fmls) \text{ body } \dots] \dots)$$

The call form (*m* *e*₀ ([*id*_{*i*} *e*_{*i*}] ...) *x* ...) constructs a call to *e*₀ where the arguments are the *id ...* with any *id*_{*i*} replaced by *e*_{*i*} all followed by the *x ...* expressions. Any *id* that does not

have an explicit $[id_i e_i]$ binding in the call form must have a binding in scope. For calls within the body of an $(m \text{ case-lambda } \dots)$, $(m \text{ define } \dots)$, $(m \text{ lambda } \dots)$, or $(m \text{ let } \dots)$ form such bindings are already in scope. As a convenience, the call syntax $(m f)$ is equivalent to $(m f ())$ which specifies an empty list of implicit-binding updates.

The $(m \text{ let } \dots)$ form constructs a named **let** using syntax inspired by the call form described above. That is, $(m \text{ let } name ([id_i e_i] \dots) ([x_j e_j] \dots) body \dots)$ constructs a named **let** *name* that binds *id* ... *x* ... with the initial value of each *id* coming from the value of the corresponding *e_i* or else the binding already in scope and the initial value of each *x_j* supplied by the corresponding *e_j*. Within *body* ..., a call of the form $(m \text{ name } (id_i \dots) e_j \dots)$ can supply required values for each of the *x_j* along with new values for *id* ... if needed.

Chapter 5

Regular Expressions

5.1 Introduction

The regular expressions library (`swish pregexp`) is a derivative of `pregexp`: Portable Regular Expressions for Scheme and Common Lisp [25]. It provides regular expressions modeled on Perl's [15, 27] and includes such powerful directives as numeric and non-greedy quantifiers, capturing and non-capturing clustering, POSIX character classes, selective case- and space-insensitivity, back-references, alternation, backtrack pruning, positive and negative look-ahead and look-behind, in addition to the more basic directives familiar to all regexp users.

A *regexp* is a string that describes a pattern. A regexp matcher tries to *match* this pattern against (a portion of) another string, which we will call the *text string*. The text string is treated as raw text and not as a pattern.

Most of the characters in a regexp pattern are meant to match occurrences of themselves in the text string. Thus, the pattern "abc" matches a string that contains the characters a, b, c in succession.

In the regexp pattern, some characters act as *metacharacters*, and some character sequences act as *metasequences*. That is, they specify something other than their literal selves. For example, in the pattern "a.c", the characters a and c do stand for themselves but the *metacharacter* '.' can match *any* character (other than newline). Therefore, the pattern "a.c" matches an a, followed by *any* character, followed by a c.

If we needed to match the character '.' itself, we *escape* it, i.e., precede it with a backslash (\). The character sequence \. is thus a *metasequence*, since it doesn't match itself but rather just '.'. So, to match a followed by a literal '.' followed by c, we use the regexp pattern "a\\.c".¹ Another example of a metasequence is \t, which is a readable way to represent the tab character.

We will call the string representation of a regexp the *U-regexp*, where *U* can be taken to mean *Unix-style* or *universal*, because this notation for regexps is universally familiar. Our implementation uses an intermediate tree-like representation called the *S-regexp*, where *S* can stand for *Scheme*, *symbolic*, or *s-expression*. S-regexps are more verbose and less readable than U-regexps, but they are much easier for Scheme's recursive procedures to navigate.

¹The double backslash is an artifact of Scheme strings, not the regexp pattern itself. When we want a literal backslash inside a Scheme string, we must escape it so that it shows up in the string at all. Scheme strings use backslash as the escape character, so we end up with two backslashes.

5.2 Programming Interface

(pregexp *regexp*) **procedure**
returns: an S-regexp

The `pregexp` procedure takes a U-regexp string *regexp* and returns an S-regexp.

(re *regexp*) **syntax**
expands to: (pregexp *regexp*)

If *regexp* is a literal string, the `re` macro expands to the result of evaluating (pregexp *regexp*) at expand time. Otherwise it expands into a run-time call to `pregexp`.

(pregexp-match-positions *pat str* [*start* [*end*]]) **procedure**
returns: ((*s . e*) ...) or #f

The `pregexp-match-positions` procedure takes a regexp pattern *pat* and a text string *str* and returns a *match* if the regexp matches (some part of) the text string between the inclusive *start* index (defaults to 0) and the exclusive *end* index (defaults to the length of *str*).

The regexp may be either a U- or an S-regexp. `pregexp-match-positions` will internally compile a U-regexp to an S-regexp before proceeding with the matching. If you find yourself calling `pregexp-match-positions` repeatedly with the same U-regexp, it may be advisable to explicitly convert the latter into an S-regexp once beforehand, using `pregexp`, to save needless recompilation.

`pregexp-match-positions` returns a list of *index pairs* if the regexp matches the string and #f if it does not match. Index pair (*s . e*) gives the inclusive starting index *s* and exclusive ending index *e* of the matching substring with respect to *str*. The first index pair indicates the entire match, and subsequent pairs indicate submatches. Some of the submatches may be #f.

(pregexp-match *pat str* [*start* [*end*]]) **procedure**
returns: list of matching substrings or #f

The `pregexp-match` procedure is called like `pregexp-match-positions`, but instead of returning index pairs, it returns the matching substrings. The first substring is the entire match, and subsequent substrings are submatches, some of which may be #f.

(pregexp-split *pat str*) **procedure**
returns: list of substrings from *str*

The `pregexp-split` procedure takes two arguments, a regexp pattern *pat* and a text string *str*, and returns a list of substrings of the text string, where the pattern identifies the delimiter separating the substrings. The returned substrings do not include the delimiter.

If the pattern can match an empty string, then the list of all the single-character substrings is returned.

To identify one or more spaces as the delimiter, take care to use the regexp " +", not " *".

(pregexp-replace *pat str ins*) **procedure**
returns: a string

The `pregexp-replace` procedure replaces the matched portion of the text string by another string. The first argument is the pattern *pat*, the second the text string *str*, and the third is the string to be inserted *ins*, which may contain back-references (see §5.3.4).

If the pattern doesn't occur in the text string, the returned string is identical (eq?) to *str*.

```
(pregexp-replace* pat str ins) procedure  
returns: a string
```

The `pregexp-replace*` procedure replaces *all* matches of regexp *pat* in the text string *str* by the insert string *ins*, which may contain back-references (see §5.3.4).

As with `pregexp-replace`, if the pattern doesn't occur in the text string, the returned string is identical (eq?) to *str*.

```
(pregexp-quote str) procedure  
returns: a U-regexp
```

The `pregexp-quote` procedure takes an arbitrary string *str* and returns a U-regexp string that precisely represents it. In particular, characters in the input string that could serve as regexp metacharacters are escaped with a backslash, so that they safely match only themselves.

`pregexp-quote` is useful when building a composite regexp from a mix of regexp strings and verbatim strings.

5.3 The Regexp Pattern Language

5.3.1 Basic Assertions

The *assertions* `^` and `$` identify the beginning and the end of the text string respectively. They ensure that their adjoining regexps match at the beginning or end of the text string. Examples:

```
(pregexp-match-positions "^contact" "first contact") ⇒ #f
```

The regexp fails to match because `contact` does not occur at the beginning of the text string.

```
(pregexp-match-positions "laugh$" "laugh laugh laugh laugh") ⇒ ((18 . 23)).
```

The regexp matches the *last* laugh.

The metasequence `\b` asserts that a *word boundary* exists.

```
(pregexp-match-positions "yack\b" "yackety yack") ⇒ ((8 . 12))
```

The `yack` in `yackety` doesn't end at a word boundary so it isn't matched. The second `yack` does and is.

The metasequence `\B` has the opposite effect to `\b`. It asserts that a word boundary does not exist.

```
(pregexp-match-positions "an\B" "an analysis") ⇒ ((3 . 5))
```

The `an` that doesn't end in a word boundary is matched.

5.3.2 Characters and Character Classes

Typically a character in the regexp matches the same character in the text string. Sometimes it is necessary or convenient to use a regexp metasequence to refer to a single character. Thus, metasequences `\n`, `\r`, `\t`, and `\.` match the newline, return, tab, and period characters respectively.

The *metacharacter* period (`.`) matches *any* character other than newline.

```
(pregexp-match "p.t" "pet") => ("pet")
```

It also matches `pat`, `pit`, `pot`, `put`, and `p8t` but not `peat` or `pffft`.

A *character class* matches any one character from a set of characters. A typical format for this is the *bracketed character class* `[...]`, which matches any one character from the non-empty sequence of characters enclosed within the brackets.² Thus `"p[aeiou]t"` matches `pat`, `pet`, `pit`, `pot`, `put` and nothing else.

Inside the brackets, a hyphen (`-`) between two characters specifies the ASCII range between the characters. For example, `"ta[b-dgn-p]"` matches `tab`, `tac`, `tad`, *and* `tag`, *and* `tan`, `tao`, `tap`.

An initial caret (`^`) after the left bracket inverts the set specified by the rest of the contents, i.e., it specifies the set of characters *other than* those identified in the brackets. For example, `"do[^g]"` matches all three-character sequences starting with `do` except `dog`.

Note that the metacharacter `^` inside brackets means something quite different from what it means outside. Most other metacharacters (`.`, `*`, `+`, `?`, etc.) cease to be metacharacters when inside brackets, although you may still escape them for peace of mind. `-` is a metacharacter only when it's inside brackets, and neither the first nor the last character.

Bracketed character classes cannot contain other bracketed character classes (although they contain certain other types of character classes—see below). Thus a left bracket (`[`) inside a bracketed character class doesn't have to be a metacharacter; it can stand for itself. For example, `"[a[b]"` matches `a`, `[`, and `b`.

Furthermore, since empty bracketed character classes are disallowed, a right bracket (`]`) immediately occurring after the opening left bracket also doesn't need to be a metacharacter. For example, `"[]ab]"` matches `]`, `a`, and `b`.

Some Frequently Used Character Classes

Some standard character classes can be conveniently represented as metasequences instead of as explicit bracketed expressions. `\d` matches a digit using `char-numeric?`; `\s` matches a whitespace character using `char-whitespace?`; and `\w` matches a character that could be part of a word.³

The upper-case versions of these metasequences stand for the inversions of the corresponding character classes. Thus `\D` matches a non-digit, `\S` a non-whitespace character, and `\W` a non-word character.

Remember to include a double backslash when putting these metasequences in a Scheme string:

²Requiring a bracketed character class to be non-empty is not a limitation, since an empty character class can be more easily represented by an empty string.

³Following regexp custom, we identify word characters as alphabetic, numeric, or underscore (`_`).

```
(pregexp-match "\\d\\d" "0 dear, 1 have 2 read catch 22 before 9") ⇒ ("22")
```

These character classes can be used inside a bracketed expression. For example, "[a-z\\d]" matches a lower-case letter or a digit.

POSIX Character Classes

A *POSIX character class* is a special metasequence of the form "[...:]" that can be used only inside a bracketed expression. The POSIX classes supported are:

| | |
|------------|---|
| [:alnum:] | letters and digits |
| [:alpha:] | letters |
| [:algor:] | the letters c, h, a and d |
| [:ascii:] | 7-bit ASCII characters |
| [:blank:] | widthful whitespace, i.e., space and tab |
| [:cntrl:] | control characters, viz, those with code < 32 |
| [:digit:] | digits, same as \\d |
| [:graph:] | characters that use ink |
| [:lower:] | lower-case letters |
| [:print:] | ink-users plus widthful whitespace |
| [:space:] | whitespace, same as \\s |
| [:upper:] | upper-case letters |
| [:word:] | letters, digits, and underscore, same as \\w |
| [:xdigit:] | hex digits |

For example, the regexp "[[:alpha:]_]" matches a letter or underscore.

```
(pregexp-match "[[:alpha:]_]" "-x-") ⇒ ("x")
```

```
(pregexp-match "[[:alpha:]_]" "-_-" ) ⇒ ("_")
```

```
(pregexp-match "[[:alpha:]_]" "-:-") ⇒ #f
```

The POSIX class notation is valid *only* inside a bracketed expression. For instance, [:alpha:], when not inside a bracketed expression, will *not* be read as the letter class. Rather it is (from previous principles) the character class containing the characters :, a, l, p, and h.

```
(pregexp-match "[:alpha:]" "-a-") ⇒ ("a")
```

```
(pregexp-match "[:alpha:]" "-_-" ) ⇒ #f
```

By placing a caret (^) immediately after [:, you get the inversion of that POSIX character class. Thus, [:^alpha:] is the class containing all characters except the letters.

5.3.3 Quantifiers

The *quantifiers* *, +, and ? match respectively: zero or more, one or more, and zero or one instances of the preceding subpattern.

```
(pregexp-match-positions "c[ad]*r" "cadaddaddr") ⇒ ((0 . 11))
```

```
(pregexp-match-positions "c[ad]*r" "cr") ⇒ ((0 . 2))
(pregexp-match-positions "c[ad]+r" "cadaddaddr") ⇒ ((0 . 11))
(pregexp-match-positions "c[ad]+r" "cr") ⇒ #f
(pregexp-match-positions "c[ad]?r" "cadaddaddr") ⇒ #f
(pregexp-match-positions "c[ad]?r" "cr") ⇒ ((0 . 2))
(pregexp-match-positions "c[ad]?r" "car") ⇒ ((0 . 3))
```

Numeric Quantifiers

You can use braces to specify much finer-tuned quantification than is possible with `*`, `+`, and `?`.

The quantifier `{m}` matches exactly m instances of the preceding subpattern. m must be a non-negative integer.

The quantifier `{m,n}` matches at least m and at most n instances. m and n are nonnegative integers with $m \leq n$. You may omit either or both numbers, in which case m defaults to 0 and n to infinity.

It is evident that `+` and `?` are abbreviations for `{1,}` and `{0,1}` respectively. `*` abbreviates `{,}`, which is the same as `{0,}`.

```
(pregexp-match "[aeiou]{3}" "vacuous") ⇒ ("uou")
(pregexp-match "[aeiou]{3}" "evolve") ⇒ #f
(pregexp-match "[aeiou]{2,3}" "evolve") ⇒ #f
(pregexp-match "[aeiou]{2,3}" "zeugma") ⇒ ("eu")
```

Non-greedy Quantifiers

The quantifiers described above are *greedy*, i.e., they match the maximal number of instances that would still lead to an overall match for the full pattern.

```
(pregexp-match "<.*>" "<tag1> <tag2> <tag3>") ⇒ ("<tag1> <tag2> <tag3>")
```

To make these quantifiers *non-greedy*, append a `?` to them. Non-greedy quantifiers match the minimal number of instances needed to ensure an overall match.

```
(pregexp-match "<.*?>" "<tag1> <tag2> <tag3>") ⇒ ("<tag1>")
```

The non-greedy quantifiers are respectively: `*?`, `+?`, `??`, `{m}?`, and `{m,n}?`. Note the two uses of the metacharacter `?`.

5.3.4 Clusters

Clustering, i.e., enclosure within parentheses `(...)`, identifies the enclosed subpattern as a single entity. It causes the matcher to *capture* the *submatch*, or the portion of the string matching the subpattern, in addition to the overall match.

```
(pregexp-match "([a-z]+) ([0-9]+), ([0-9]+)" "jan 1, 1970")
⇒ ("jan 1, 1970" "jan" "1" "1970")
```

Clustering also causes a following quantifier to treat the entire enclosed subpattern as an entity.

```
(pregexp-match "(poo )*" "poo poo platter") ⇒ ("poo poo " "poo ")
```

The number of submatches returned is always equal to the number of subpatterns specified in the regexp, even if a particular subpattern happens to match more than one substring or no substring at all.

```
(pregexp-match "([a-z ]+;)*" "lather; rinse; repeat;")
⇒ ("lather; rinse; repeat;" " repeat;")
```

Here the *-quantified subpattern matches three times, but it is the last submatch that is returned.

It is also possible for a quantified subpattern to fail to match, even if the overall pattern matches. In such cases, the failing submatch is represented by #f.

```
(define date-re
  ;; match 'month year' or 'month day, year'.
  ;; subpattern matches day, if present
  (pregexp "([a-z]+) +([0-9]+,)? *([0-9]+)"))
```

```
(pregexp-match date-re "jan 1, 1970") ⇒ ("jan 1, 1970" "jan" "1," "1970")
```

```
(pregexp-match date-re "jan 1970") ⇒ ("jan 1970" "jan" #f "1970")
```

Back-references

Submatches can be used in the insert string argument of the procedures `pregexp-replace` and `pregexp-replace*`. The insert string can use `\n` as a *back-reference* to refer back to the n^{th} submatch, i.e., the substring that matched the n^{th} subpattern. `\0` refers to the entire match, and it can also be specified as `&`.

```
(pregexp-replace "_(.+?)" "the _nina_, the _pinta_, and the _santa maria_" "*\\1*")
⇒ "the *nina*, the _pinta_, and the _santa maria_"
```

```
(pregexp-replace* "_(.+?)" "the _nina_, the _pinta_, and the _santa maria_" "*\\1*")
⇒ "the *nina*, the *pinta*, and the *santa maria*"
```

```
(pregexp-replace "(\\S+) (\\S+) (\\S+)" "eat to live" "\\3 \\2 \\1")
⇒ "live to eat"
```

Use `\\` in the insert string to specify a literal backslash. Also, `\\$` stands for an empty string, and is useful for separating a back-reference `\n` from an immediately following number.

Back-references can also be used within the regexp pattern to refer back to an already matched subpattern in the pattern. `\n` stands for an exact repeat of the n^{th} submatch.⁴

⁴`\0`, which is useful in an insert string, makes no sense within the regexp pattern, because the entire regexp has not matched yet that you could refer back to it.

```
(pregexp-match "([a-z]+) and \\1" "billions and billions")
⇒ ("billions and billions" "billions")
```

Note that the back-reference is not simply a repeat of the previous subpattern. Rather it is a repeat of *the particular substring already matched by the subpattern*.

In the above example, the back-reference can only match `billions`. It will not match `millions`, even though the subpattern it harks back to—`([a-z]+)`—would have had no problem doing so:

```
(pregexp-match "([a-z]+) and \\1" "billions and millions") ⇒ #f
```

The following corrects doubled words:

```
(pregexp-replace* "(\\S+) \\1" "now is the the time for all good men to to come to
the aid of of the party" "\\1")
⇒ "now is the time for all good men to come to the aid of the party"
```

The following marks all immediately repeating patterns in a number string:

```
(pregexp-replace* "(\\d+)\\1" "123340983242432420980980234" "\\1,\\1")
⇒ "123,34098324,243242098,0980234"
```

Non-capturing Clusters

It is often required to specify a cluster (typically for quantification) but without triggering the capture of submatch information. Such clusters are called *non-capturing*. In such cases, use `(?:` instead of `(` as the cluster opener. In the following example, the non-capturing cluster eliminates the directory portion of a given pathname, and the capturing cluster identifies the basename.

```
(pregexp-match "^(?:[a-z]*/)*([a-z]+)$" "/usr/local/bin/scheme")
⇒ ("/usr/local/bin/scheme" "scheme")
```

Cloisters

The location between the `?` and the `:` of a non-capturing cluster is called a *cloister*.⁵ You can put *modifiers* there that will cause the enclustered subpattern to be treated specially. The modifier `i` causes the subpattern to match *case-insensitively*:

```
(pregexp-match "(?i:hearth)" "HeartH") ⇒ ("HeartH")
```

The modifier `x` causes the subpattern to match *space-insensitively*, i.e., spaces and comments within the subpattern are ignored. Comments are introduced as usual with a semicolon (`;`) and extend till the end of the line. If you need to include a literal space or semicolon in a space-insensitized subpattern, escape it with a backslash.

```
(pregexp-match "(?x: a lot)" "alot") ⇒ ("alot")
```

```
(pregexp-match "(?x: a \\ lot)" "a lot")
⇒ ("a lot")
```

```
(pregexp-match "(?x:
```

⁵A useful, if terminally cute, coinage from the abbots of Perl [27].

```

a \\ man \\; \\ ; ignore
a \\ plan \\; \\ ; me
a \\ canal ; completely
)"
"a man; a plan; a canal")
⇒ ("a man; a plan; a canal")

```

You can put more than one modifier in the cloister.

```

(pregexp-match "(?ix:
  a \\ man \\; \\ ; ignore
  a \\ plan \\; \\ ; me
  a \\ canal ; completely
)")
"A Man; a Plan; a Canal")
⇒ ("A Man; a Plan; a Canal")

```

A minus sign before a modifier inverts its meaning. Thus, you can use `-i` and `-x` in a *subcluster* to overturn the insensitivities caused by an enclosing cluster.

```

(pregexp-match "(?i:the (?-i:TeX)book)" "The TeXbook") ⇒ ("The TeXbook")

```

This regexp will allow any casing for `the` and `book` but insists that `TeX` not be differently cased.

5.3.5 Alternation

You can specify a list of *alternate* subpatterns by separating them by `|`. The `|` separates subpatterns in the nearest enclosing cluster (or in the entire pattern string if there are no enclosing parentheses).

```

(pregexp-match "f(ee|i|o|um)" "a small, final fee") ⇒ ("fi" "i")

```

```

(pregexp-replace* "([yi])s(e[sdr]?|ing|ation)"
  "it is energising to analyse an organisation pulsing with noisy organisms"
  "\\1z\\2")
⇒ "it is energizing to analyze an organization pulsing with noisy organisms"

```

Note again that if you wish to use clustering merely to specify a list of alternate subpatterns but do not want the submatch, use `(?:` instead of `(`.

```

(pregexp-match "f(?:ee|i|o|um)" "fun for all") ⇒ ("fo")

```

An important thing to note about alternation is that the leftmost matching alternate is picked regardless of its length. Thus, if one of the alternates is a prefix of a later alternate, the latter may not have a chance to match.

```

(pregexp-match "call|call/cc" "call/cc") ⇒ ("call")

```

To allow the longer alternate to have a shot at matching, place it before the shorter one:

```

(pregexp-match "call/cc|call" "call/cc") ⇒ ("call/cc")

```


In any case, an overall match for the entire regexp is always preferred to an overall non-match. In the following, the longer alternate still wins, because its preferred shorter prefix fails to yield an overall match.

```
(pregexp-match "(?:call|call/cc) constrained" "call/cc constrained")
⇒ ("call/cc constrained")
```

5.3.6 Backtracking

We've already seen that greedy quantifiers match the maximal number of times, but the overriding priority is that the overall match succeed. Consider

```
(pregexp-match "a*a" "aaaa")
```

The regexp consists of two subregexps, `a*` followed by `a`. The subregexp `a*` cannot be allowed to match all four `a`'s in the text string `"aaaa"`, even though `*` is a greedy quantifier. It may match only the first three, leaving the last one for the second subregexp. This ensures that the full regexp matches successfully.

The regexp matcher accomplishes this via a process called *backtracking*. The matcher tentatively allows the greedy quantifier to match all four `a`'s, but then when it becomes clear that the overall match is in jeopardy, it *backtracks* to a less greedy match of *three* `a`'s. If even this fails, as in the call

```
(pregexp-match "a*aa" "aaaa")
```

the matcher backtracks even further. Overall failure is conceded only when all possible backtracking has been tried with no success.

Backtracking is not restricted to greedy quantifiers. Nongreedy quantifiers match as few instances as possible, and progressively backtrack to more and more instances in order to attain an overall match. There is backtracking in alternation, too, as the more rightward alternates are tried when locally successful leftward ones fail to yield an overall match.

Disabling Backtracking

Sometimes it is efficient to disable backtracking. For example, we may wish to *commit* to a choice, or we know that trying alternatives is fruitless. A non-backtracking regexp is enclosed in `(?>...)`.

```
(pregexp-match "(?>a+)." "aaaa") ⇒ #f
```

In this call, the subregexp `?>a+` greedily matches all four `a`'s, and is denied the opportunity to backtrack. So the overall match is denied. The effect of the regexp is therefore to match one or more `a`'s followed by something that is definitely non-`a`.

5.3.7 Looking Ahead and Behind

You can have assertions in your pattern that look *ahead* or *behind* to ensure that a subpattern does or does not occur. These look-around assertions are specified by putting the subpattern checked for in a cluster whose leading characters are `?=` for positive look-ahead, `?!` for negative look-ahead,

?<= for positive look-behind, and ?<! for negative look-behind. Note that the subpattern in the assertion does not generate a match in the final result. It merely allows or disallows the rest of the match.

Look-ahead

Positive look-ahead (?=) peeks ahead to ensure that its subpattern *could* match.

```
(pregexp-match-positions "grey(=?hound)" "i left my grey socks at the greyhound")  
⇒ ((28 . 32))
```

The regexp "grey(=?hound)" matches **grey**, but *only* if it is followed by **hound**. Thus, the first **grey** in the text string is not matched.

Negative look-ahead (?!) peeks ahead to ensure that its subpattern could not possibly match.

```
(pregexp-match-positions "grey(!hound)" "the gray greyhound ate the grey socks")  
⇒ ((27 . 31))
```

The regexp "grey(!hound)" matches **grey**, but only if it is *not* followed by **hound**. Thus the **grey** just before **socks** is matched.

Look-behind

Positive look-behind (?<=) checks that its subpattern *could* match immediately to the left of the current position in the text string.

```
(pregexp-match-positions "(?<=grey)hound" "the hound is not a greyhound")  
⇒ ((23 . 28))
```

The regexp "(?<=grey)hound" matches **hound**, but only if it is preceded by **grey**.

Negative look-behind (?<!) checks that its subpattern could not possibly match immediately to the left.

```
(pregexp-match-positions "(?<!grey)hound" "the greyhound is not a hound")  
⇒ ((23 . 28))
```

The regexp "(?<!grey)hound" matches **hound**, but only if it is *not* preceded by **grey**.

Look-aheads and look-behinds can be convenient when they are not confusing.

Chapter 6

Generic Server

The generic server provides an “empty” server, that is, a framework from which instances of servers can be built.

—Joe Armstrong [1]

6.1 Introduction

In a concurrent system, many processes need to access a shared resource or sequentially manipulate the state of the system. This is generally modeled using a client/server design pattern. To help developers build robust servers, a generic server (`gen-server`) implementation inspired by Erlang’s Open Telecom Platform is provided.

The principles of the generic server can be found in Joe Armstrong’s thesis [1] or *Programming Erlang—Software for a Concurrent World* [2]. Documentation for Erlang’s `gen_server` is available online [10]. Source code for the Erlang Open Telecom Platform can be found online [8]. The source code for `gen_server` is part of `stdlib` and can be found in `/lib/stdlib/src/gen_server.erl`.

6.2 Theory of Operation

A `gen-server` provides a consistent mechanism for programmers to create a process which manages state, timeout conditions, and failure conditions using functional programming techniques. A programmer uses `gen-server:start&link` and implements the callback API to instantiate particular behavior.

A generic server starts a new process, registers it as a named process, and invokes the `init` callback procedure while blocking the calling process.

Clients can then send messages to a server using the synchronous `gen-server:call`, the asynchronous `gen-server:cast`, or the raw `send` procedure. The `gen-server` framework will automatically process messages and dispatch them to `handle-call`, `handle-cast`, and `handle-info` respectively.

The `gen-server` framework code automatically interprets a `stop` return value from the callback API or an `EXIT` message from the process which created it as a termination request and calls

terminate. If the termination reason satisfies the `informative-exit-reason?` predicate, generic servers use `event-mgr:notify` to report the termination.

Erlang's `gen_server` supports timeouts during `gen_server:start` and `gen_server:start&link`. In order to simplify the startup code, we have not implemented this feature. Timeouts while running the `init` callback may cause resources to be stranded until the garbage collector can clean them up. Timeouts during initialization should be considered carefully.

6.3 Programming Interface

```
(gen-server:start&link name arg ...) syntax  
returns: #(ok pid) | #(error reason) | ignore
```

name: a symbol for a registered server or `#f` for an anonymous server
arg: any Scheme datum

`gen-server:start&link` spawns the server process, links to the calling process, registers the server process as *name*, and calls `(init arg ...)` within that process. To ensure a synchronized startup procedure, `gen-server:start&link` does not return until `init` has returned.

This macro uses the current scope to capture the callback functions `init`, `handle-call`, `handle-cast`, `handle-info`, and `terminate`.

Attempting to register a name that already exists results in `#(error #(name-already-registered pid))`, where *pid* is the existing process.

The return value of `gen-server:start&link` is propagated from the `init` callback.

An `init` which returns `#(ok state [timeout])` will yield `#(ok pid)` where *pid* is the newly created process.

An `init` which returns `#(stop reason)` or exits with *reason* will terminate the process and yield `#(error reason)`.

An `init` which returns `ignore` will terminate the process and yield `ignore`. This value is useful to inform a supervisor that the `init` procedure has determined that this server is not necessary for the system to operate.

An `init` which returns *other* values will terminate the process and yield `#(error #(bad-return-value other))`.

```
(gen-server:start name arg ...) syntax  
returns: #(ok pid) | #(error error) | ignore
```

`gen-server:start` behaves the same as `gen-server:start&link` except that it does not link to the calling process.

```
(gen-server:enter-loop state [timeout]) syntax  
returns: does not return
```

`gen-server:enter-loop` transforms the calling process into a generic server. The *state* and *timeout* are equivalent to those returned by `init`.

On entry, the macro calls `(process-name)` to determine the registered name of the process, if any, and `(process-parent)` to determine the spawning process, if available, for logging and process-
ing termination. As a result, the name recorded in `<gen-server-terminating>` will not reflect
subsequent changes in process registration.

This macro uses the current scope to capture the callback functions `handle-call`, `handle-cast`,
`handle-info`, and `terminate`.

While `gen-server:enter-loop` does not return normally, it does raise an exception upon termi-
nation. This allows any exception handlers or winders on the stack to run.

(gen-server:call *server request* [*timeout*]) **procedure**

returns: *reply*

server: process or registered name

request: any Scheme datum

timeout: non-negative exact integer in milliseconds or `infinity`, defaults to 5000

`gen-server:call` sends a synchronous *request* to *server* and waits for a *reply*. The server processes
the request using `handle-call`.

Failure to receive a reply causes the calling process to exit with reason `#(timeout #(gen-server
call (server request)))` if no timeout is specified, or `#(timeout #(gen-server call (server
request timeout)))` if a timeout is specified. If the caller catches the failure and continues running,
the caller must be prepared for a possible late reply from the server.

When the reply is a fault condition, the fault is thrown in the calling process.

`gen-server:call` exits if the server terminates while the client is waiting for a reply. When that
happens, the client exits for the same reason as the server.

(gen-server:cast *server request*) **procedure**

returns: `ok`

server: process or registered name

request: any Scheme datum

`gen-server:cast` sends an asynchronous *request* to a *server* and returns `ok` immediately. When
using `gen-server:cast` a client does not expect failures in the server to cause failures in the client;
therefore, this procedure ignores all failures. The server will process the request using `handle-cast`.

(gen-server:reply *client reply*) **procedure**

returns: `ok`

client: a *from* argument provided to the `handle-call` callback

reply: any Scheme datum

A server can use `gen-server:reply` to send a *reply* to a *client* that called `gen-server:call` and
is blocked awaiting a reply.

In some situations, a server cannot reply immediately to a client. In such cases, `handle-call` may
store the *from* argument and return `no-reply`. Later, the server can call `gen-server:reply` using
that *from* value as *client*. The *reply* is the return value of the `gen-server:call` in this case.

`(gen-server:debug server server-options client-options)` **procedure**

returns: ok

server: process or registered name
server-options: ([message] [state] [reply]) | #f
client-options: ([message] [reply]) | #f

`gen-server:debug` sets the debugging mode of *server*. The *server-options* argument specifies the logging of calls in the server. When *server-options* is `#f`, server logging is turned off. Otherwise, server logging is turned on, and *server-options* is a list of symbols specifying the level of detail. In logging mode, the *server* sends a `<gen-server-debug>` event for each call to `handle-call`, `handle-cast`, and `handle-info`. The *message* field is populated when `message` is in *server-options*, the *state* field is populated when `state` is in *server-options*, and the *reply* field is populated when `reply` is in *server-options*.

Similarly, the *client-options* argument specifies the logging of client calls to *server* with `gen-server:call`. When *client-options* is `#f`, client logging is turned off. Otherwise, client logging is turned on, and *client-options* is a list of symbols specifying the level of detail. In logging mode, `gen-server:call` sends a `<gen-server-debug>` event. The *message* field is populated when `message` is in *client-options*, and the *reply* field is populated when `reply` is in *client-options*.

`(define-state-tuple name field ...)` **syntax**

This form defines a tuple type using `(define-tuple name field ...)` and defines a new syntactic form `$state`. `$state` provides a succinct syntax for the `state` variable.

`$state` transforms `($state op arg ...)` to `(name op state arg ...)` where `state` is a variable in the same scope as `$state`.

Given this definition:

```
(define-state-tuple <my-state> x y z)
```

The following code is equivalent:

```
(<my-state> copy state [x 2]) ($state copy [x 2])  
(<my-state> x state)         ($state x)  
(<my-state> y state)         ($state y)  
(<my-state> z state)         ($state z)
```

There is no equivalent for constructing a state tuple because constructing a tuple does not require the `state` variable. The `<my-state> make ...` syntax must be used.

6.4 Published Events

All generic servers send the event manager the following event:

<gen-server-terminating> **event**

timestamp: the time the event occurred
name: the name of the server
pid: the server process
last-message: the last message received by the server
state: the last state passed into `terminate`
reason: the reason for termination
details: `#f` or a fault-condition containing the reason for termination

This event is fired after a successful call to `terminate` if the reason for termination satisfies the `informative-exit-reason?` predicate. If the `terminate` procedure exits with a new *reason*, the event contains the new *reason*.

<gen-server-debug> **event**

timestamp: the time the operation started
duration: the duration of the operation in milliseconds
type: 1 for `handle-call`, 2 for `handle-cast`, 3 for `handle-info`, 4 for `terminate`, 5 for a successful `gen-server:call`, and 6 for a failed `gen-server:call`
client: the client process or `#f`
server: the server process
message: the message sent to the server or `#f`
state: the state of the server when it received the message or `#f`
reply: the server's reply or `#f`

6.5 Callback Interface

A programmer implements the callback interface to define a particular server's behavior. All callback functions are called from within the server process.

The callback functions for `gen-server` processes are supposed to be *well-behaved functions*, i.e., functions that work correctly. The generation of an exception in a well-behaved function is interpreted as a failure [1].

When a callback function exits with a reason, `terminate` is called and the server exits.

When a callback function returns an unexpected *value*, `terminate` is called with the reason `#(bad-return-value value)`, and the server exits.

A callback may specify a *timeout* as a relative time in milliseconds up to one day, an absolute time in milliseconds (e.g., from `erlang:now`), or `infinity`. The default *timeout* is `infinity`. If the time period expires before another message is received, then a `timeout` message will be processed by `handle-info`.

Messages sent using `send`, including those matching `'(EXIT pid reason)` and `'(DOWN monitor pid reason)`, are processed by `handle-info`.

The generic server framework will automatically interpret an `EXIT` message from the process which spawned it as a reason for termination. `terminate` will be called directly. `handle-info` will not be called. The server must use `(process-trap-exit #t)` to receive `EXIT` messages.

(init arg ...) **procedure**

returns: `#(ok state [timeout]) | #(stop reason) | ignore`

arg ...: the *arg ...* provided to `gen-server:start&link` or `gen-server:start`
state: any Scheme datum
timeout: relative time in milliseconds up to one day, absolute time in milliseconds
(e.g., from `erlang:now`), or `infinity` (default)
reason: any Scheme datum

`(init arg ...)` is called from a new server process started by a call to `gen-server:start&link` or `gen-server:start`. Calls to those procedures block until `init` returns.

A successful `init` returns `#(ok state [timeout])`. The *state* is then maintained functionally by the generic server framework.

`init` may specify that server initialization failed by returning `#(stop reason)`. The server will then fail to start using this *reason*. `terminate` will not be called as the server has not properly started.

`init` may return `ignore`. The server will then exit with reason `normal`, and `gen-server:start&link` will return `ignore`. This is used to inform a supervisor that the server is not necessary for the system to operate. `terminate` will not be called.

(handle-call request from state) **procedure**

returns: `#(reply reply state [timeout]) | #(no-reply state [timeout]) | #(stop reason [reply] state)`

request: the *request* provided to `gen-server:call`
from: `#(client-process tag)`
state: server state
reply: any Scheme datum
timeout: relative time in milliseconds up to one day, absolute time in milliseconds
(e.g., from `erlang:now`), or `infinity` (default)
reason: any Scheme datum

`handle-call` is responsible for processing a client *request* generated by `gen-server:call`.

`handle-call` may return `#(reply reply state [timeout])` to indicate that *reply* is to be returned from `gen-server:call` to the caller. The server state will become *state*.

`handle-call` may return `#(no-reply state [timeout])` to continue operation and to indicate that the caller of `gen-server:call` will continue to wait for a reply. The server state will become *state*. The server will need to use `gen-server:reply` and *from* to reply to the client.

`handle-call` may return `#(stop reason [reply] state)` to set a new *state*, then terminate the server with the given *reason*. If the optional *reply* is specified, it will be the return value of `gen-server:call`; otherwise, `gen-server:call` will exit with *reason*.

reply is any Scheme datum.

state is any Scheme datum.

reason is any Scheme datum.

(handle-cast request state) **procedure**

returns: `#(no-reply state [timeout])` | `#(stop reason state)`

request: the *request* provided to `gen-server:cast`

state: server state

timeout: relative time in milliseconds up to one day, absolute time in milliseconds

(e.g., from `erlang:now`), or `infinity` (default)

reason: any Scheme datum

`handle-cast` is responsible for processing a client *request* generated by `gen-server:cast`.

`handle-cast` may return `#(no-reply state [timeout])` to continue operation. The server state will become *state*.

`handle-cast` may return `#(stop reason state)` to terminate the server with the given *reason*. The server state will become *state*.

(handle-info msg state) **procedure**

returns: `#(no-reply state [timeout])` | `#(stop reason state)`

msg: `timeout` or a Scheme datum sent via `send`

state: server state

timeout: relative time in milliseconds up to one day, absolute time in milliseconds

(e.g., from `erlang:now`), or `infinity` (default)

reason: any Scheme datum

`handle-info` is responsible for processing timeouts and miscellaneous messages sent to the server via `send`.

`handle-info` may return `#(no-reply state [timeout])` to continue operation. The server state will become *state*.

`handle-info` may return `#(stop reason state)` to terminate the server with the given *reason*. The server state will become *state*.

(terminate reason state) **procedure**

returns: ignored

reason: shutdown reason

state: server state

`terminate` is called when the server is about to terminate. It is responsible for cleaning up any resources that the server allocated. When it returns, the server exits for the given *reason*.

reason can be any reason specified by a stop return value `#(stop ...)`. When a supervision tree is terminating, *reason* will be `shutdown`.

The return value of `terminate` is ignored. If the termination reason satisfies the `informative-exit-reason?` predicate, the generic server framework uses `event-mgr:notify` to report the termination. The server then terminates for that reason.

If `terminate` exits with *reason*, then that reason is logged, and the server terminates with *reason*.

Chapter 7

Event Manager

7.1 Introduction

The event manager (`event-mgr`) is a gen-server that provides a single dispatcher for events within the system. It buffers events and dispatches them to the log handler and a collection of other event handlers. If the log handler fails, the event manager logs events directly to the console error port.

7.2 Theory of Operation

The event manager is a singleton process through which all events in the system are routed. Any component may notify the event manager that something has occurred by using `event-mgr:notify`. This model is illustrated in Figure 7.1.

The event manager is a registered process named `event-mgr`.

The event manager is created as part of the application's supervision hierarchy. It buffers incoming events during startup until `event-mgr:flush-buffer` is called. The buffered events are then sent to the current event handlers and the log handler. This provides the ability to log the startup details of processes, including the event manager itself.

The event handlers should not perform blocking operations, because they block the entire event manager.

If the log handler or its associated process fails, the event manager logs events to the console error port. If another event handler fails with some reason, the associated process is killed with the same reason. When the process associated with a handler terminates, the event manager removes it from the list.

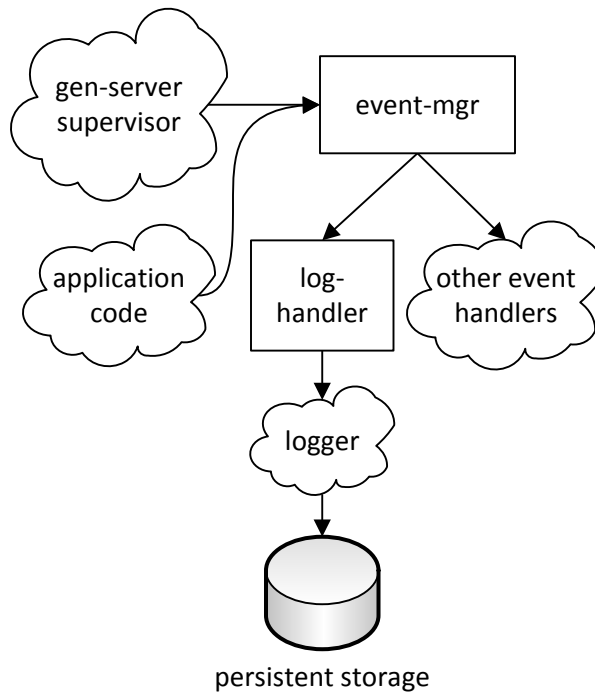


Figure 7.1: Event flow

state

<event-mgr-state> **tuple**

event-buffer: list of events to be processed (most recent first), or #f when buffering is disabled

log-handler: <handler> tuple or #f

handlers: list of <handler> tuples

<handler> **tuple**

proc: procedure of one argument, the event

owner: process that owns the handler

init The **init** procedure initializes the state of the gen-server. Event buffering is enabled.

The gen-server traps exits so that it can detect failure of event handler owner processes, as well as the EXIT message from the parent process.

terminate The **terminate** procedure flushes any pending events to the console error port using **do-notify**.

handle-call The **handle-call** procedure processes the following messages:

- `#(add-handler proc owner)`: Link to the *owner* process, add a handler to the state and return `ok`.

An invalid argument results in the following error reasons:

- `#(invalid-procedure proc)`
- `#(invalid-owner owner)`

- `flush-buffer`: Process the events in the buffer using `do-notify`, turn off buffering, and return `ok`.
- `#(set-log-handler proc owner endure?)`: Link to the *owner* process, set the log handler of the state, and return `ok`.

An invalid argument results in the following error reasons:

- `log-handler-already-set`
- `#(invalid-procedure proc)`
- `#(invalid-owner owner)`

`handle-cast` The `handle-cast` procedure does not process any messages.

`handle-info` The `handle-info` procedure handles messages matching the following patterns:

- `#(notify event)`: Process *event* using `do-notify`.
event is any Scheme datum.
- `'(EXIT pid _)`: Removes the log or other event handler associated with *pid*.

Internally, the `(do-notify event state)` procedure handles the processing of each *event* with respect to the current *state*. It evaluates the *state* in the following way:

- If the state is not buffering:
 1. Call each handler's *proc* with *event*. If it exits for some reason, kill the handler's *owner* with the same reason.
 2. If there is a log handler, call its *proc* with *event*. If it exits for some reason, unlink its *owner*, kill it with the same reason, log *event* to the console error port using `console-event-handler`, and remove the log handler from the state.
- Otherwise, buffer the event.

7.3 Programming Interface

`(event-mgr:start&link)` **procedure**
returns: `#(ok pid) | #(error reason)`

The `event-mgr:start&link` procedure creates a new `event-mgr` gen-server using `gen-server:start&link`.

The event manager is registered as `event-mgr`.

(event-mgr:add-handler *proc* [*owner*]) **procedure**
returns: ok | #(error *reason*)

The `event-mgr:add-handler` procedure calls `(gen-server:call event-mgr #(add-handler proc owner))`.

proc is a procedure of one argument, the event. Failure in *proc* results in the event manager killing the *owner* process with the same failure reason. The handler is removed when the event manager receives an EXIT message from *owner*.

owner is a process. The default is the calling process.

(event-mgr:flush-buffer) **procedure**
returns: ok

The `event-mgr:flush-buffer` procedure calls `(gen-server:call event-mgr flush-buffer)`.

(event-mgr:notify *event*) **procedure**
returns: ok

The `event-mgr:notify` procedure sends message `#(notify event)` to registered process `event-mgr` if it exists. If `event-mgr` does not exist, it prints *event* using `console-event-handler`.

event is any Scheme datum.

(event-mgr:set-log-handler *proc* *owner* [*endure?*]) **procedure**
returns: ok | #(error *reason*)

The `event-mgr:set-log-handler` procedure calls `(gen-server:call event-mgr #(set-log-handler proc owner endure?))`.

proc and *endure?* are procedures of one argument, the event. If *proc* fails and *endure?* returns false, the event is logged to the console and the event manager kills the *owner* process with the same failure reason. This is the default behavior since the default *endure?* procedure always returns false. However, if *proc* fails and *endure?* returns true, the event is logged to the console followed by the fault in *proc*, and the fault is tolerated. The log handler is removed when *proc* fails and *endure?* returns true or when the event manager receives an EXIT message from *owner*.

owner is a process.

(informative-exit-reason? *x*) **procedure**
returns: boolean

The `informative-exit-reason?` procedure returns `#t` if *x* is a fault condition containing a continuation or containing a reason other than `normal` or `shutdown`. Otherwise it returns `#f` if *x* is not `normal` or `shutdown`.

(normalize-exit-reason *r* [*e*]) **procedure**
returns: *reason* and *details*

The `normalize-exit-reason` procedure takes *r* and *e* from matching `'(catch ,r [,e])`, `'(EXIT p ,r [,e])`, or `'(DOWN m p ,r [,e])` and returns two values, *reason* and *details*, suitable for use in

<child-end>, <gen-server-terminating>, and <supervisor-error> events. If *r* is a condition, then *reason* is the symbol `exception` and *details* is either *e* if it satisfies `informative-exit-reason?` or *r*. Otherwise *reason* is *r* and *details* is *e* if it satisfies `informative-exit-reason?` or a fault condition for *r* if *r* satisfies the `informative-exit-reason?` predicate. If the optional *e* is omitted, then *r* is matched against the extended match pattern `(catch ,r ,e)`. If this pattern matches, then `normalize-exit-reason` is called with the values obtained for *r* and *e*. Otherwise, *r* is used for both *r* and *e*.

Chapter 8

Gatekeeper

8.1 Introduction

The gatekeeper is a single gen-server named `gatekeeper` that manages shared resources using mutexes. Before a process uses a shared resource, it asks the gatekeeper to enter the corresponding mutex. When the process no longer needs the resource or terminates, it tells the gatekeeper to leave the mutex. A process may enter the same mutex multiple times, and it needs to leave the mutex the same number of times. The gatekeeper breaks deadlocks by raising an exception in one of the processes waiting for a mutex involved in a cyclic dependency chain.

The gatekeeper hooks system primitives `$cp0`, `$np-compile`, `pretty-print`, and `sc-expand` because they are not safe to be called from two processes at the same time (see the discussion of the global winders list in Section 4.3). The `$cp0` procedure uses resource `$cp0`, the `$np-compile` procedure uses resource `$np-compile`, and so forth.

8.2 Theory of Operation

state The gatekeeper state is a list of `<mutex>` tuples, each of which has the following fields:

- *resource*: resource compared for equality using `eq?`
- *process*: process that owns *resource*
- *monitor*: monitor of *process*
- *count*: number of times *process* has entered this mutex
- *waiters*: ordered list of *from* arguments from `handle-call` for processes that are waiting to enter this mutex

init The gatekeeper `init` procedure hooks the system primitives listed in the introduction so that they use `with-gatekeeper-mutex` with a timeout of one minute, and it sets the `current-expand` parameter to the hooked `sc-expand` procedure. The process traps exits so that `terminate` can unhook the system primitives when the process is shut down. It returns an empty list of `<mutex>` tuples.

terminate The gatekeeper **terminate** procedure unhooks the system primitives listed in the introduction and sets the **current-expand** parameter to the unhooked **sc-expand** procedure.

handle-call The gatekeeper **handle-call** procedure handles the following messages:

- **#(enter resource)**: Find $mutex \in state$ where $mutex.resource = resource$.
If no such $mutex$ exists, no-reply with **(enter-mutex resource from '() state)**.
If $mutex.process = from.process$, increment $mutex.count$, and reply **ok** with the updated state.
If **(deadlock? from.process mutex state)**, reply **#(deadlock resource)** with $state$.
Otherwise, add $from$ to the end of $mutex.waiters$, and no-reply with the updated state.
- **#(leave resource)**: Find $mutex \in state$ where $mutex.resource = resource$ and $mutex.process = from.process$.
If no such $mutex$ exists, reply **#(unowned-resource resource)** with $state$.
If $mutex.count > 1$, decrement $mutex.count$, and reply **ok** with the updated state.
Otherwise, reply **ok** with **(leave-mutex mutex state)**.

handle-cast The gatekeeper **handle-cast** procedure raises an exception on all messages.

handle-info The gatekeeper **handle-info** procedure handles messages matching the following pattern:

- **'(DOWN monitor _ _)**: Find $mutex \in state$ where $mutex.monitor = monitor$. No-reply with **(leave-mutex mutex state)**.

(enter-mutex resource from waiters state) **procedure**
returns: updated state

The **enter-mutex** procedure calls **(gen-server:reply from 'ok)** to reply to the caller waiting to enter the mutex. It adds a **<mutex>** tuple with $resource = resource$, $process = from.process$, $monitor = (monitor process)$, $count = 1$, and $waiters = waiters$ to $state$.

(leave-mutex mutex state) **procedure**
returns: updated state

The **leave-mutex** procedure calls **(demonitor&flush mutex.monitor)**. If $mutex.waiters = ()$, it returns **(remq mutex state)**. Otherwise, it returns **(enter-mutex mutex.resource (car mutex.waiters) (cdr mutex.waiters) (remq mutex state))**.

(deadlock? process mutex state) **procedure**
returns: a boolean

The **deadlock?** procedure returns **#t** if $process$ would deadlock waiting for $mutex$. Let $owner = mutex.process$. If $owner = process$, return **#t**. Otherwise, find the mutex $waiting \in state$ where **#(owner _) \in waiting.waiters**. If no such $waiting$ exists, return **#f**. Otherwise, return **(deadlock? process waiting state)**.

8.3 Programming Interface

```
(gatekeeper:start&link) procedure  
returns: #(ok pid) | #(error reason)
```

The `gatekeeper:start&link` procedure calls `(gen-server:start&link 'gatekeeper)`.

```
(gatekeeper:enter resource timeout) procedure  
returns: ok
```

The `gatekeeper:enter` procedure calls `(gen-server:call 'gatekeeper #(enter resource) timeout)` to enter the mutex for *resource*. If it returns $e \neq \text{ok}$, it raises exception e .

```
(gatekeeper:leave resource) procedure  
returns: ok
```

The `gatekeeper:leave` procedure calls `(gen-server:call 'gatekeeper #(leave resource))` to leave the mutex for *resource*. If it returns $e \neq \text{ok}$, it raises exception e .

```
(with-gatekeeper-mutex resource timeout body1 body2 ...) syntax  
expands to: ($with-gatekeeper-mutex 'resource timeout (lambda () body1 body2 ...))
```

The `with-gatekeeper-mutex` form executes the body expressions in a dynamic context where the calling process owns *resource*, which must be an identifier. The *timeout* expression specifies how long the caller is willing to wait to enter the mutex for *resource* as defined by `gen-server:call`. The internal `$with-gatekeeper-mutex` procedure is defined as follows:

```
(define ($with-gatekeeper-mutex resource timeout body)  
  (dynamic-wind  
    (lambda () (gatekeeper:enter resource timeout))  
    body  
    (lambda () (gatekeeper:leave resource))))
```

Chapter 9

Supervisor

9.1 Introduction

In a fault tolerant system, faults must first be observed and then acted upon. A `supervisor` monitors child processes for failure and can be composed into a hierarchy to monitor for faults within other supervisors.

The principles of supervisors and supervision hierarchies can be found in Joe Armstrong's thesis [1] or *Programming Erlang—Software for a Concurrent World* [2]. Documentation for Erlang's `supervisor` is available online [12]. Source code for the Erlang Open Telecom Platform can be found online [8]. The source code for `supervisor` is part of `stdlib` and can be found in `/lib/stdlib/src/-supervisor.erl`.

Patterns for Fault Tolerant Software [17] is a good reference for understanding the mindset of creating fault tolerant systems.

9.2 Theory of Operation

A *supervisor* is a gen-server which is responsible for starting, stopping, and monitoring its child processes. A supervisor observes its children, and when a failure occurs, restarts child processes.

A *watcher* is a supervisor which is configured to only observe the children. A watcher interface is provided for convenience.

A supervisor can be configured to restart individual children when those children fail, or to restart all children when any child fails. This is called the restart *strategy*. A strategy of `one-for-one` indicates that when a child process terminates, it should be restarted; only that child process is affected. A strategy of `one-for-all` indicates that when a child process terminates and should be restarted, all other child process are terminated and then restarted.

A supervisor maintains a list of times of when a restart occurs. When a child fails and is to be restarted, a timestamp is added to the *restarts* list. A maximum restart frequency is represented as an *intensity* and a *period* of time. If more than *intensity* restarts occur in a *period* of time, the supervisor terminates all child processes and then itself. This prevents the possibility of an infinite

cycle of child process termination and restarts.

A supervisor is started with a list of child specifications. These specifications are used to start child processes from within the supervisor process during initialization.

Child specifications can be added to a supervisor at run time. These dynamic children will not be automatically restarted if the supervisor itself terminates and is restarted.

state (define-state-tuple <supervisor-state> strategy intensity period children restarts)

- **strategy** defines how the supervisor processes a child termination: **one-for-one** or **one-for-all**.
- **intensity** is the maximum restart intensity for all children within the period.
- **period** is the maximum restart period in milliseconds.
- **children** is a list of <child> tuples with the most recently started child first.
- **restarts** is an ordered list of times when restarts have occurred.

<child> **tuple**

(define-tuple <child> pid name thunk restart-type shutdown type)

pid stores the child process or #f. The remaining fields are copied from the child specification described below.

init The **init** procedure validates the startup arguments and starts the initial child processes. Invalid startup arguments cause the supervisor to fail to start. If any child fails to start, all started children are terminated and the supervisor fails to start.

This process traps exits so that it can detect child exits, as well as the **EXIT** message from the parent process.

An invalid argument results in a specific error reason that includes the invalid input.

- **invalid-strategy** *strategy*
- **invalid-intensity** *intensity*
- **invalid-period** *period*

An invalid child specification during initialization will result in **(error #(start-specs reason))** where *reason* is one of the reasons listed in the programming interface below.

terminate The **terminate** procedure shuts each child process down in order (most recently added first).

handle-call The **handle-call** procedure processes the following messages:

- **#(start-child *child-spec*)**: Validates the *child-spec*, starts the child, adds it to the state, and replies with **#(ok *pid*)** where *pid* is the new child process.
If a child specification of the same name already exists, **#(error already-present)** is returned. If the child process was already started **#(error #(already-started *pid*))** is returned.
A successfully started child is linked to the supervisor, an event is fired to the event manager to log the start, and **#(ok *pid*)** is returned. If the *pid* already occurs in the children list, then **start-child** returns **#(error #(duplicate-process *pid*))**.
If the child process start function returns **ignore**, the child specification is added to the supervisor, and the function returns **#(ok #f)**.
If the child process start function returns **#(error *reason*)**, then **start-child** returns **#(error *reason*)**.
If the child process start function exits with *reason*, **#(error *reason*)** is returned.
If the child process start function returns *other* values **#(error #(bad-return-value *other*))** is returned.
- **#(restart-child *name*)**: Finds a child by *name*, verifies that it is not currently running, then starts that child.
If the child process is already running, **#(error running)** is returned. If the child specification does not exist, **#(error not-found)** is returned.
A successfully started child is linked to the supervisor, an event is fired to the event manager to log the start, and **#(ok *pid*)** is returned. If the *pid* already occurs in the children list, then **restart-child** returns **#(error #(duplicate-process *pid*))**.
If the child process start function returns **ignore**, the child specification is added to the supervisor and the function returns **#(ok #f)**.
If the child process start function returns **#(error *reason*)**, then **restart-child** returns **#(error *reason*)**.
If the child process start function exits with *reason*, **#(error *reason*)** is returned.
If the child process start function returns *other* values **#(error #(bad-return-value *other*))** is returned.
- **#(delete-child *name*)**: Finds a child by *name*, verifies that it is not currently running, then removes the child specification from the state and returns **ok**.
If the child process is running, **#(error running)** is returned. If the child specification does not exist, **#(error not-found)** is returned.
- **#(terminate-child *name*)**: Finds a child by *name* and terminates it if it is running. The child *pid* is updated to **#f** and returns **ok**.
If the child specification does not exist, **#(error not-found)** is returned.
- **get-children**: Returns the state's children field.

handle-cast The **handle-cast** procedure does not process any messages.

`handle-info` The `handle-info` procedure processes messages matching the following patterns:

- ‘(EXIT *pid* *reason*): Find *pid* in the children list and apply the restart strategy. An unknown *pid* is ignored.

When the child specification *restart-type* is `permanent` or `transient` the current timestamp is prepended to the *restarts* list. The list is then pruned based on the *period*. If the resulting list length \leq *intensity*, the supervisor continues. Otherwise, the supervisor terminates with reason `shutdown`.

Internally, the `(shutdown pid x)` function kills child processes and returns the exit reason. This function is used by `terminate`, `terminate-child`, and during a failed `init`. The following steps are necessary to defend against a “naughty” child which unlinks from the supervisor.

- Monitor *pid* to protect against a child process which may have called `unlink`.
- Unlink *pid* to stop receiving EXIT messages from *pid*.
- An EXIT message may already exist for *pid*. If it does, then wait for the DOWN message, and return the exit reason.
- If $x = \text{brutal-kill}$, kill *pid* with reason `kill` and wait for the DOWN message to determine the exit reason.
- Otherwise, x is a *timeout*. kill *pid* with reason `shutdown` and wait for the DOWN message to determine the exit reason. If a *timeout* occurs, kill *pid* with reason `kill`, and wait for the DOWN message to determine the exit reason.

9.3 Design Decisions

Our initial implementation did not automatically link to child processes, but this led to unexpected behavior when child processes neglected to link to the supervisor. Therefore, this implementation links to all child processes.

9.4 Programming Interface

`supervisor:start&link` and `supervisor:start-child` use a child specification. A child specification is defined as:

child-spec \rightarrow `#(name thunk restart-type shutdown type)`

name is a symbol unique to the children within the supervisor.

thunk is a procedure that should spawn a process and link to the supervisor process, then return `#(ok pid)` or `#(error reason)` or `ignore`. Typically, the *thunk* will call `gen-server:start&link` which provides the appropriate behavior and return value.

restart-type is a symbol with the following meaning:

- A `permanent` child process is always restarted.
- A `temporary` child process is never restarted.

- A `transient` child process is only restarted if it terminates with an exit reason other than `normal` or `shutdown`.
- A `watch-only` child process is never restarted, and its child specification is removed from the supervisor when it terminates.

`shutdown` defines how a child process should be terminated.

- `brutal-kill` indicates that the child process will be terminated using `(kill pid kill)`.
- A fixnum > 0 represents a timeout. The supervisor will use `(kill pid shutdown)` and wait for an exit signal. If no exit signal is received within the timeout, the child process will be terminated using `(kill pid kill)`. `infinity` can be used if and only if the `type` of the process is `supervisor`.

The `type` is useful for validating the `shutdown` parameter, but is otherwise unused. It may be useful in conjunction with `supervisor:get-children` to generate a tree of the running supervision hierarchy.

```
type → supervisor
      | worker
```

Invalid child specifications will result in specific error reasons which include the invalid input.

- `#(invalid-name name)`
- `#(invalid-thunk thunk)`
- `#(invalid-restart-type restart-type)`
- `#(invalid-type type)`
- `#(invalid-shutdown shutdown)`
- `#(invalid-child-spec spec)`

```
(supervisor:start&link name strategy intensity period start-specs) procedure
returns: #(ok pid) | #(error reason)
```

The `supervisor:start&link` procedure creates a new `supervisor` gen-server using `gen-server:start&link`.

`name` is the registered name of the process. For an anonymous server, `#f` may be specified.

```
strategy → one-for-one
           | one-for-all
```

```
intensity → a fixnum  $\geq 0$ 
```

```
period → a fixnum  $> 0$ 
```

```
start-specs → (child-spec ...)
```

```
(supervisor:validate-start-specs specs) procedure
returns: #f | reason
```

The `supervisor:validate-start-specs` procedure takes a list of child specifications and checks them in order. If it encounters an invalid child specification, `supervisor:validate-start-specs` returns a reason suitable as input to `exit-reason->english`. Otherwise it returns `#f`.

(supervisor:start-child *supervisor* *child-spec*) **procedure**
returns: `#(ok pid) | #(error reason)`

This procedure dynamically adds the given *child-spec* to the *supervisor* which starts a child process.

The `supervisor:start-child` procedure calls `(gen-server:call supervisor #(start-child child-spec) infinity)`.

(supervisor:restart-child *supervisor* *name*) **procedure**
returns: `#(ok pid) | #(error reason)`

This procedure restarts a child process identified by *name*. The child specification must exist, and the child process must not be running.

The `supervisor:restart-child` procedure calls `(gen-server:call supervisor #(restart-child name) infinity)`.

(supervisor:delete-child *supervisor* *name*) **procedure**
returns: `ok | #(error reason)`

This procedure deletes the child specification identified by *name*. The child process must not be running.

The `supervisor:delete-child` procedure calls `(gen-server:call supervisor #(delete-child name) infinity)`.

(supervisor:terminate-child *supervisor* *name*) **procedure**
returns: `ok | #(error reason)`

This procedure terminates the child process identified by *name*. The child specification must exist, but the child process does not need be running. Terminating a child does not cause a restart.

The `supervisor:terminate-child` procedure calls `(gen-server:call supervisor #(terminate-child name) infinity)`.

(supervisor:get-children *supervisor*) **procedure**
returns: a list of `<child>` tuples

This procedure returns the *supervisor* internal representation of child specifications.

The `supervisor:get-children` procedure calls `(gen-server:call supervisor get-children infinity)`.

9.5 Published Events

A supervisor can notify the event manager of the same events as a gen-server, as well as the following events.

```
event → <supervisor-error>
      | <child-start>
      | <child-end>
```

<supervisor-error> **event**

timestamp: the time the event occurred
supervisor: the supervisor's process id
error-context: the context in which the event occurred
reason: the reason for the error
details: **#f** or a fault-condition containing the reason for the error
child-pid: the child's process id
child-name: the child's name

This event is fired when the supervisor fails to start its children, fails to restart its children, or when it has exceeded the maximum restart frequency.

<child-start> **event**

timestamp: the time the event occurred
supervisor: the supervisor's process id
pid: the child's process id
name: the child's name
restart-type: the child's restart-type
shutdown: the child's shutdown
type: the child's type

This event is fired after the child start procedure has returned a valid value.

<child-end> **event**

timestamp: the time the event occurred
pid: the child's process id
killed: 1 indicates the supervisor terminated the child, 0 otherwise
reason: the reason the child has terminated
details: **#f** or a fault-condition the reason the child has terminated

This event is fired after the supervisor terminates a child process, and after the supervisor detects a failure in a child.

9.6 Watcher Interface

(*watcher:start&link name*) **procedure**
returns: **#(ok *pid*) | #(error *reason*)**

The `watcher:start&link` procedure creates a supervisor with a strategy of `one-for-one`, an intensity of 0, a period of 1, and no children.

name is the registered name of the process. For an anonymous server, **#f** may be specified.

`(watcher:start-child watcher name shutdown thunk)` **procedure**
returns: `#(ok pid) | #(error reason)`

The `watcher:start-child` procedure calls `(supervisor:start-child watcher #(name thunk watch-only shutdown worker))`.

`(watcher:shutdown-children watcher)` **procedure**
returns: unspecified

The `watcher:shutdown-children` procedure terminates and deletes each `watch-only` child in *watcher*.

Chapter 10

Application

10.1 Introduction

The application is a single gen-server named `application` that manages the lifetime of the program. It links to a process, typically the root supervisor, and shuts down the program when requested by `application:shutdown` or when the linked process dies.

10.2 Theory of Operation

state The application state is the process returned by the *starter* of `application:start`. It is typically the root supervisor. We refer to this variable as *process*. It may also be `#f` after `handle-info` receives the exit message for the process.

init The application `init` procedure takes a *starter* procedure. It calls (*starter*) and checks the return value *r*. If *r* = `#(ok process)`, it links to *process*, traps exits so that it receives exit messages from *process* and `application:shutdown`, and returns `#(ok process)`. If *r* = `#(error reason)`, it returns `#(stop reason)`.

terminate The application `terminate` procedure shuts down *process*. When *process* is not `#f`, it kills *process* with reason `shutdown` and waits indefinitely for it to terminate. It flushes the console output and error ports, ignoring any exceptions, and then calls (`osi_exit exit-code`), where *exit-code* is initially 2 but set to the value passed to `application:shutdown`. In this way, the exit code can be used to determine if the application shut down normally.

handle-call The application `handle-call` procedure raises an exception on all messages.

handle-cast The application `handle-cast` procedure raises an exception on all messages.

handle-info The application `handle-info` procedure handles messages matching the pattern:

- ‘(EXIT *p reason*): If *p = process*, return #(stop *reason #f*). Otherwise, return #(stop *reason process*).

10.3 Programming Interface

(application:start *starter*) **procedure**
returns: ok

The `application:start` procedure calls `(gen-server:start 'application starter)`. If it returns `#{ok _}`, `application:start` returns ok. If it returns `#{error reason}`, `application:start` calls `(console-event-handler #(application-start-failed reason))` and `(exit 1)`.

(application:shutdown [*exit-code*]) **procedure**
returns: unspecified

The `application:shutdown` procedure kills the `application` process with reason `shutdown`. The `exit-code` defaults to 0, indicating normal shutdown. The procedure does not wait for the `application` process to terminate so that it can be called from a process managed by the supervision hierarchy without causing a deadlock on shutdown. If the `application` process does not exist, `application:shutdown` flushes the console output and error ports, ignoring any exceptions, and then calls `(osi_exit exit-code)`.

Chapter 11

Database Interface

11.1 Introduction

The database (`db`) interface is a gen-server which provides a basic transaction framework to retrieve and store data in a SQLite database. It provides functions to use transactions (directly and lazily). The low-level SQLite interface can be found in the operating system interface design (see Chapter 3). Other SQLite resources are available online [26] or in The Definitive Guide to SQLite [22].

11.2 Theory of Operation

The `db` gen-server serializes internal requests to the database. For storage and retrieval of data, each transaction is processed in turn by a separate monitored *worker* process. The gen-server does not block waiting for this process to finish so that it can maintain linear performance by keeping its inbox short. The return value of the transaction is returned to the caller or an error is generated without tearing down the gen-server.

To facilitate logging, the `db` gen-server can execute SQL statements asynchronously. It enqueues SQL statements submitted via `db:log` and executes them by opening a transaction lazily when an explicit transaction is enqueued, when a *worker* process exits normally, or when the `db` message queue is empty and `commit-delay` has elapsed since enqueueing a `db:log` request in an empty queue. To maintain responsiveness, each lazy transaction commits at most `commit-limit db:log` requests. See `db:options` on page 120 for details. By default, each database is created with write-ahead logging enabled to prevent write operations from blocking on queries made from another connection.

SQLite has three types of transactions: deferred, immediate, and exclusive. This interface uses only immediate transactions to simplify the handling of the `SQLITE_BUSY` error. Using immediate transactions means that `SQLITE_BUSY` will only occur during `BEGIN IMMEDIATE`, `BEGIN TRANSACTION`, `COMMIT`, and `ROLLBACK`¹ statements. For each of these statements, when a `SQLITE_BUSY` occurs, the code waits for a brief time, then retries the statement. The wait times in milliseconds follow

¹Our testing showed that `ROLLBACK` returns `SQLITE_BUSY` only when a `COMMIT` for the same transaction returned `SQLITE_BUSY`. This framework never causes that situation to occur, but it guards against it anyway.

the pattern (2 3 6 11 16 21 26 26 26 51 51 . #0=(101 . #0#)), and up to 500 retries are attempted before exiting with #(db-retry-failed *sql count*). When the retry count is positive, it is logged to the event manager along with the total duration with a <transaction-retry> event.

<transaction-retry> **event**

timestamp: timestamp from erlang:now
database: database filename
duration: duration in milliseconds
count: retry count
sql: query

The db gen-server uses the operating system interface to interact with SQLite. To prevent memory leaks, each raw database and statement handle is wrapped in a Scheme record and registered with a guardian via make-foreign-handle-guardian.

state (define-state-tuple <db-state> filename db cache queue worker)

- **filename** is the database specified when the server was started.
- **db** is the database record.
- **cache** is a hash table mapping SQL strings to SQLite prepared statements.
- **queue** is a queue of log and transaction requests.
- **worker** is the pid of the active worker or #f.

dictionary parameters

- **current-database** stores a Scheme record:

```
(define-record-type database
  (fields
    (immutable filename)
    (immutable create-time)
    (mutable handle)))
```

The **handle** is set to #f when the database is closed.

- **statement-cache** stores a Scheme record:

```
(define-record-type cache
  (fields
    (immutable ht)
    (immutable expire-timeout)
    (mutable waketime)
    (mutable lazy-objects)))
```

The `expire-timeout` is the duration in milliseconds that entries live in the cache. This is configurable using the `cache-timeout` option.

The `waketime` is the next time the cache will attempt to remove dead entries.

The hash table, `ht`, maps SQL strings to a Scheme record:

```
(define-record-type entry
  (fields
    (immutable stmt)
    (mutable timestamp)))
```

When a SQL string is not found in the cache, `osi_prepare_statement` is used with the `current-database` to make a SQLite statement. The raw statement handle is stored in a Scheme record:

```
(define-record-type statement
  (fields
    (immutable database)
    (immutable sql)
    (immutable create-time)
    (mutable handle)))
```

The statement is finalized using `osi_finalize_statement` when it is removed from the cache. `osi_close_database` will finalize any remaining statements associated with the database.

When a SQL string is found in the cache, the entry's `timestamp` is updated. Entries older than 5 minutes will be removed from the cache.

Accessing the cache may exit with reason `reason #(db-error prepare error sql)`, where `error` is a SQLite error pair.

The `lazy-objects` list contains `statement` and marshaled `bindings` records created by `lazy-execute`. These records are finalized when a transaction completes.

init The `init` procedure takes a filename, mode symbol, and an initialization procedure and attempts to open that database and invoke the initialization procedure. The handle returned from `osi_open_database` is wrapped in a `database` record that is registered with a foreign-handle guardian using the type name `databases`. The foreign-handle guardian hooks the garbage collector so that dead databases are closed even if the `db` gen-server fails to close them for any reason.

The gen-server traps exits so that it can close the database in its `terminate` procedure.

terminate The `terminate` flushes the queue and closes the database.

handle-call The `handle-call` procedure processes the following messages:

- `#(transaction f)`: Add this transaction along with the `from` argument to `handle-call` to the queue. Process the queue.
- `filename`: Return the database filename.
- `stop`: Flush the queue and stop with reason `normal`, returning `stopped` to the caller.

`handle-cast` The `handle-cast` procedure processes the following message:

- `#(<log> sql mbindings)`: Add this tuple to the queue. Process the queue.

`handle-info` The `handle-info` procedure processes messages matching the following patterns:

- `timeout`: If the request queue is empty, remove old entries from the statement cache. Process the queue.
- `'(DOWN _ worker-pid reason e)`: The worker finished the previous request. If successful, process the queue. Otherwise, flush the queue and stop with the fault `e`.
- `'(DOWN _ _ _)`: Ignore the unexpected `DOWN` message. Process the queue.
- `'(EXIT pid _ e)`: If the `pid` is the worker, ignore the message. Do not update the state. A follow-up `DOWN` message will process the queue. Otherwise, flush the queue, and stop with the fault `e`.

11.3 Design Decisions

There is a one-to-one relationship between a SQLite database handle and the `db` gen-server. For clarity, the database handle and a SQLite statement cache are implemented in terms of Erlang process dictionary parameters.

An alternate approach for logging was already explored where a transaction was not lazily opened. Such an approach means that when a third party tool tries to access the database, it will hang until the transaction is complete.

A commit threshold of 10,000 was chosen because it was large enough to minimize the cost of a transaction but small enough to execute simple queries in less than one second.

Version 2.1.0 adds the concept of marshaled bindings. Bindings are copied into the C heap. The resulting handle is wrapped in a Scheme record and registered with a guardian via `make-foreign-handle-guardian`. The database worker process uses marshaled bindings to invoke `sqlite:bulk-execute` when processing log messages.

11.4 Programming Interface

```
(db:start&link name filename mode [db-init]) procedure  
(db:start&link name filename mode [db-options])  
returns: #(ok pid) | #(error error)
```

The `db:start&link` procedure creates a new `db` gen-server using `gen-server:start&link`.

`name` is the registered name of the process. For an anonymous server, `#f` may be specified.

`filename` is the path to a SQLite database.

`mode` is one of the following symbols used to pass SQLite flags to `osi_open_database`:

- `read-only` uses the SQLite flag `SQLITE_OPEN_READONLY`.

- `open` uses the SQLite flag `SQLITE_OPEN_READWRITE`.
- `create` combines the SQLite flags (`logor SQLITE_OPEN_READWRITE SQLITE_OPEN_CREATE`).

The SQLite constants can be found in `sqlite3.h` or online [26].

`db-init` is a procedure that takes one argument, a database record instance. The return value is ignored. When the `mode` is `create` and `filename` is not a special SQLite filename, the default procedure sets `journal_mode` to “wal”; otherwise, no additional initialization occurs.

`db-options` can be defined using (`db:options [option value] ...`). The following options may be used:

| option | default | description |
|----------------------------|-----------|--|
| <code>init</code> | see right | a procedure, (<code>lambda (filename mode db) ...</code>), called when initializing the gen-server, where <code>db</code> is a database record instance; the default <code>init</code> procedure is equivalent to the default <code>db-init</code> procedure described above |
| <code>cache-timeout</code> | 5 minutes | a nonnegative fixnum; the number of milliseconds before unreferences statements expire from the statement cache |
| <code>commit-delay</code> | 0 | a nonnegative fixnum; the number of milliseconds to wait before opening a lazy transaction |
| <code>commit-limit</code> | 10,000 | a positive fixnum; the maximum number of <code>db:log</code> entries to include when opening a lazy transaction |

The `db:start&link` procedure may return an *error* of `#{db-error open error filename}`, where *error* is a SQLite error pair.

```
(db:start name filename mode [db-init]) procedure
(db:start name filename mode [db-options])
returns: #{ok pid} | #{error error}
```

`db:start` behaves the same as `db:start&link` except that it does not link to the calling process.

```
(db:stop who) procedure
returns: stopped
```

The `db:stop` procedure calls (`gen-server:call who stop infinity`).

```
(with-db [db filename flags] body1 body2 ...) syntax
expands to:
```

```
(let ([db (sqlite:open filename flags)])
  (on-exit (sqlite:close db)
    body1 body2 ...))
```

The `with-db` macro opens the database in `filename`, executes the statements in the body, and closes the database before exiting. This is a suitable alternative to starting a `gen-server` when you need to query a database using a separate SQLite connection, and you do not need to cache prepared SQL statements.

`(db:expire-cache who)` **procedure**
returns: unspecified

The `db:expire-cache` procedure enqueues a request to remove entries from the statement cache regardless of their expiration time. `BEGIN IMMEDIATE` and `COMMIT` remain in the cache because they are used frequently.

`(db:filename who)` **procedure**
returns: the database filename

The `db:filename` procedure calls `(gen-server:call who filename)`.

`(db:log who sql . bindings)` **procedure**
returns: ok

The `db:log` procedure calls `(gen-server:cast who #(<log> sql mbindings))`, where *sql* is a SQL string, *bindings* is a list of values to be bound in the query, and *mbindings* is the result of `(sqlite:marshal-bindings bindings)`. Because `db:log` does not wait for a reply from the server, any error in processing the request will crash the server.

`(db:transaction who f)` **procedure**
returns: `#(ok result) | #(error error)`

The `db:transaction` procedure calls `(gen-server:call who #(transaction f) infinity)`.

f is a thunk which returns a single value, *result*. `execute`, `lazy-execute`, and `columns` can be used inside the procedure *f*.

result is the successful return value of *f*. Typically, this is a list of rows as returned by a `SELECT` query.

error is the failure reason of *f*.

`(transaction db body ...)` **syntax**
expands to:

```
(match (db:transaction db (lambda () body ...))  
  [#(ok ,result) result]  
  [#(error ,reason) (throw reason)])
```

The `transaction` macro runs the body in a transaction and returns the result when successful and exits when unsuccessful.

`(execute sql . bindings)` **procedure**
returns: a list of rows where each row is a vector of data in column order as specified in the *sql* statement

`execute` should only be used from within a thunk *f* provided to `db:transaction`.

sql is mapped to a SQLite statement using the `statement-cache`. The *bindings* are then applied using `osi_bind_statement`. The statement is then executed using `osi_step_statement`. The

results are accumulated as a list, and the statement is reset using `osi_reset_statement` to prevent the statement from locking parts of the database.

This procedure may exit with reason `#{db-error prepare error sql}`, where *error* is a SQLite error pair.

(lazy-execute *sql* . *bindings*) **procedure**
returns: a thunk

`lazy-execute` should only be used from within a thunk *f* provided to `db:transaction`.

A new SQLite statement is created from *sql* using `osi_prepare_statement` so that the statement won't interfere with any other queries. The statement is added to the `lazy-objects` list of the `statement-cache` and is finalized when the transaction completes. The *bindings* are marshaled via `sqlite:marshal-bindings`. The resulting bindings record instance is added to the `lazy-objects` list and applied using `osi_bind_statement_bindings`. A thunk is returned which, when called, executes the statement using `osi_step_statement`. The thunk returns one row of data or `#f`.

This procedure may exit with reason `#{db-error prepare error sql}`, where *error* is a SQLite error pair.

(execute-sql *db sql* . *bindings*) **procedure**
returns: a list of rows where each row is a vector of data in column order as specified in the *sql* statement

`execute-sql` should only be used for statements that do not need to be inside a transaction, such as a one-time query.

sql is prepared into a SQLite statement for use with *db*, executed via `sqlite:execute` with the specified *bindings*, and finalized.

This procedure may exit with reason `#{db-error prepare error sql}`, where *error* is a SQLite error pair.

(columns *sql*) **procedure**
returns: a vector of column names in order as specified in the *sql* statement

`columns` should only be used from within a thunk *f* provided to `db:transaction`.

sql is mapped to a SQLite statement using the `statement-cache`. The statement columns are then retrieved using `osi_get_statement_columns`.

(parse-sql *x* [*symbol->sql*]) **procedure**
returns: two values: a query string and a list of syntax objects for the arguments

The `parse-sql` procedure is used by macro transformers to take syntax object *x* and produce a query string and associated arguments according to the patterns below. When one of these patterns is matched, the *symbol->sql* procedure is applied to the remaining symbols of the input before they are spliced into the query string, as if by `(format "~a" (symbol->sql sym))`. By default, *symbol->sql* is the identity function.

- `(insert table ([column e1 e2 ...] ...))`

The `insert` form generates a SQL insert statement. The *table* and *column* patterns are SQL identifiers. Any *e* expression that is `(unquote exp)` is converted to `?` in the query, and *exp* is added to the list of arguments. All other expressions are spliced into the query string.

- `(update table ([column e1 e2 ...] ...) where ...)`

The `update` form generates a SQL update statement. The *table* and *column* patterns are SQL identifiers. Any *e* or *where* expression that is `(unquote exp)` is converted to `?` in the query, and *exp* is added to the list of arguments. All other expressions are spliced into the query string.

- `(delete table where ...)`

The `delete` form generates a SQL delete statement. The *table* pattern is a SQL identifier. Any *where* expression that is `(unquote exp)` is converted to `?` in the query, and *exp* is added to the list of arguments. All other expressions are spliced into the query string.

`(database? x)` **procedure**

returns: a boolean

The `database?` procedure determines whether or not the datum *x* is a database record instance.

`(database-create-time db)` **procedure**

returns: a clock time in milliseconds

The `database-create-time` procedure returns the clock time from `erlang:now` when database record instance *db* was created.

`(database-filename db)` **procedure**

returns: a string

The `database-filename` procedure returns the filename of database record instance *db*.

`(database-count)` **procedure**

returns: the number of open databases

The `database-count` procedure returns the number of open databases. This is the procedure returned by `(foreign-handle-count 'databases)`.

`(print-databases [op])` **procedure**

returns: unspecified

The `print-databases` procedure prints information about all open databases to textual output port *op*, which defaults to the current output port. This is the procedure returned by `(foreign-handle-print 'databases)`.

`(statement? x)` **procedure**

returns: a boolean

The `statement?` procedure determines whether or not the datum *x* is a statement record instance.

(statement-create-time *stmt*) **procedure**

returns: a clock time in milliseconds

The `statement-create-time` procedure returns the clock time from `erlang:now` when statement record instance *stmt* was created.

(statement-database *stmt*) **procedure**

returns: a string

The `statement-database` procedure returns the database record instance of the statement record instance *stmt*.

(statement-sql *stmt*) **procedure**

returns: a string

The `statement-sql` procedure returns the SQL string of the statement record instance *stmt*.

(statement-count) **procedure**

returns: the number of unfinalized statements

The `statement-count` procedure returns the number of unfinalized statements. This is the procedure returned by `(foreign-handle-count 'statements)`.

(print-statements [*op*]) **procedure**

returns: unspecified

The `print-statements` procedure prints information about all unfinalized statements to textual output port *op*, which defaults to the current output port. This is the procedure returned by `(foreign-handle-print 'statements)`.

(bindings? *x*) **procedure**

returns: a boolean

The `bindings?` procedure determines whether or not the datum *x* is a marshaled bindings record instance.

(bindings-count) **procedure**

returns: the number of live marshaled bindings records

The `bindings-count` procedure returns the number of live marshaled bindings records. This is the procedure returned by `(foreign-handle-count 'bindings)`.

(print-bindings [*op*]) **procedure**

returns: unspecified

The `print-bindings` procedure prints information about all live marshaled bindings records to textual output port *op*, which defaults to the current output port. This is the procedure returned by `(foreign-handle-print 'bindings)`.

(sqlite:bind *stmt bindings*) **procedure**

returns: unspecified

The `sqlite:bind` procedure binds the variables in statement record instance *stmt* with the list of *bindings*. It resets the statement before binding the variables.

(sqlite:bulk-execute *stmts mbindings*) **procedure**
returns: unspecified

The `sqlite:bulk-execute` procedure extracts the handles of the vectors *stmts* and *mbindings* and calls `osi_bulk_execute`. *stmts* is a vector of statement record instances, and *mbindings* is a vector of corresponding marshaled bindings obtained via `sqlite:marshal-bindings`.

(sqlite:clear-bindings *stmt*) **procedure**
returns: unspecified

The `sqlite:clear-bindings` procedure clears the variable bindings in statement record instance *stmt*.

(sqlite:close *db*) **procedure**
returns: unspecified

The `sqlite:close` procedure closes the database associated with database record instance *db*.

(sqlite:columns *stmt*) **procedure**
returns: a vector of column names

The `sqlite:columns` procedure returns a vector of column names for the statement record instance *stmt*.

(sqlite:execute *stmt bindings*) **procedure**
returns: a list of rows where each row is a vector of data in column order

The `sqlite:execute` procedure binds any variables in statement record instance *stmt* and then calls `(sqlite:step stmt)` repeatedly to build the resulting list of rows. If *bindings* is a marshaled bindings record instance, then `sqlite:execute` calls `osi_bind_statement_bindings` to bind variables in the statement. Otherwise it calls `sqlite:marshal-bindings` before binding the variables and calls `sqlite:unmarshal-bindings` before returning. As a result, `sqlite:execute` accepts as *bindings* a list, a vector, or a marshaled bindings record instance. When the procedure exits, it resets the statement and clears the bindings.

(sqlite:expanded-sql *stmt*) **procedure**
returns: a string

The `sqlite:expanded-sql` procedure returns the SQL string expanded with the binding values for the statement record instance *stmt*.

(sqlite:finalize *stmt*) **procedure**
returns: unspecified

The `sqlite:finalize` procedure finalizes the statement record instance *stmt*.

(sqlite:get-bindings *bindings*) **procedure**

returns: a vector or #f

The `sqlite:get-bindings` procedure returns a vector of the values marshaled in the *bindings* record instance via `sqlite:marshal-bindings`, or #f if the record has been unmarshaled by `sqlite:unmarshal-bindings`.

(sqlite:interrupt *db*) **procedure**

returns: a boolean

The `sqlite:interrupt` procedure interrupts any pending operations on the database associated with database record instance *db*. It returns #t when the database is busy and #f otherwise.

(sqlite:last-insert-rowid *db*) **procedure**

returns: unspecified

The `sqlite:last-insert-rowid` procedure returns the rowid of the most recent successful insert into a rowid table or virtual table on the database associated with database record instance *db*. It returns 0 if no such insert has occurred.

(sqlite:marshal-bindings *bindings*) **procedure**

returns: a marshaled bindings record instance or #f

The `sqlite:marshal-bindings` procedure returns a marshaled bindings record instance for the provided list or vector of *bindings*. The `sqlite:marshal-bindings` procedure registers the marshaled bindings record with a foreign-handle guardian using the type name `bindings`.

(sqlite:open *filename flags*) **procedure**

returns: a database record instance

The `sqlite:open` procedure opens the SQLite database in file *filename* with *flags* specified by `sqlite3_open_v2` [26]. The constants `SQLITE_OPEN_CREATE`, `SQLITE_OPEN_READONLY`, and `SQLITE_OPEN_READWRITE` are exported from the (`swish db`) library. The `sqlite:open` procedure registers the database record with a foreign-handle guardian using the type name `databases`.

(sqlite:prepare *db sql*) **procedure**

returns: a statement record instance

The `sqlite:prepare` procedure returns a statement record instance for the *sql* statement in the database record instance *db*. The `sqlite:prepare` procedure registers the statement record with a foreign-handle guardian using the type name `statements`.

(sqlite:sql *stmt*) **procedure**

returns: a string

The `sqlite:sql` procedure returns the unexpanded SQL string for the statement record instance *stmt*.

(sqlite:step *stmt*) **procedure**

returns: a vector of data in column order or #f

The `sqlite:step` procedure steps the statement record instance *stmt* and returns the next row vector in column order or `#f` if there are no more rows.

`(sqlite:unmarshal-bindings mbindings)` **procedure**
returns: unspecified

The `sqlite:unmarshal-bindings` procedure deallocates the memory associated with the marshaled bindings record instance *mbindings*.

Chapter 12

Log Database

12.1 Introduction

The log database is a single gen-server named `log-db` that uses the database interface (see Chapter 11) to log system events (see Chapter 7).

12.2 Theory of Operation

12.2.1 Initialization

The `log-db` gen-server handles startup and setup through two separate procedures. Startup uses the `db:start&link` procedure to connect to the the SQLite log database specified by the (`log-file`) parameter. It creates the file if it does not exist, but otherwise startup does not modify the database.

Setup makes sure the schema of the log database has been created and is up-to-date. A unique symbol identifying the schema version is stored in a table named `version`. This allows the software to upgrade between known schema versions and to exit with an error when it encounters an unsupported database version. These schema updates happen within a database transaction so that if there is an error, the changes are rolled back.

Setup calls `event-mgr:set-log-handler` after updating the schema. This registers the `log-db` to log system events. It also calls `event-mgr:flush-buffer`. This causes the event manager to stop buffering startup events and the `log-db` to log the events that were buffered.

Setup sends a `<system-attributes>` event so that `log-db` receives and logs it. Finally, setup calls `db:expire-cache` to release the schema definition queries.

Once the `log-db` gen-server has been setup, it continues to receive events from the system event manager. It converts events that it recognizes into insertions to the log database. Events that it does not recognize are ignored.

The tables are pruned using insert triggers to hold 90 days of information. To keep the insert operations fast, the timestamp columns are indexed, and the pruning deletes no more than 10 rows

per insert. See `make-swish-event-logger`.

12.2.2 Extensions

An application typically produces events beyond those that are part of Swish and may wish to log them in the same log database file where the Swish events are logged. The `log-db` design allows for this type of extension.

The `log-db:setup` procedure takes a list of `<event-logger>` tuples or `log-db:event-logger` objects. Each logger represents an extension to the log database schema and contains two procedures, `setup` and `log`. The `log-db:setup` procedure calls the `setup` procedure of logger to make sure that its portion of the schema has been created and is up-to-date. Then, when `log-db` receives an event, it calls the `log` procedure of each logger. If the event is recognized by that portion of the schema, the `log` procedure inserts or updates data in the log database. Otherwise, the procedure ignores that event.

Additionally, the version table does not store a single schema version. Instead, it stores schema versions associated with names. The `setup` procedure of an `<event-logger>` uses an unique name for its portion of the schema and the `log-db:version` procedure to retrieve and set its version.

The schema and logging for Swish events is implemented as an `<event-logger>` defined by `swish-event-logger` and using the schema version name `swish`. An application that wishes to use this logging must provide `swish-event-logger` in the list to `log-db:setup`. If the application wishes to log Swish events in a different structure, it can omit the `swish-event-logger` and provide its own logger with its own schema. However, doing so makes the application more brittle with respect to changes in the Swish implementation.

12.3 Programming Interface

| | |
|--|--------------|
| <code><event-logger></code> | tuple |
| <i>setup</i> : procedure of no arguments that makes sure this portion of the schema is created and up-to-date | |
| <i>log</i> : procedure of one argument, an event, that logs the event if it recognizes it and otherwise ignores it | |

| | |
|--|------------------|
| <code>(log-db:start&link [db-options])</code> | procedure |
| returns: <code> #(ok pid) #(error error)</code> | |

The `log-db:start&link` procedure creates a new `db` gen-server named `log-db` using `db:start&link`. It uses the value of the `(log-file)` parameter as the path to the SQLite database and specifies `create` mode. The optional `db-options` must be an object created by `db:options`.

| | |
|---|------------------|
| <code>(log-db:setup loggers)</code> | procedure |
| returns: <code> ignore #(error error)</code> | |

The argument `loggers` is a list of `<event-logger>` tuples or objects constructed by `log-db:event-logger`. The `log-db:setup` makes sure the `log-db` is setup to run by doing the following in order.

1. Initialize or upgrade the database schema from within a `db:transaction` call. It does this by calling the `setup` procedure of each logger.
2. Register a procedure with `event-mgr:set-log-handler` to have the `log-db` gen-server log events it recognizes. When this procedure receives an event, it calls the `log` procedure of each logger.
3. Call `event-mgr:flush-buffer` to stop buffering system events and apply the log handler to the events already buffered.
4. Send a `<system-attributes>` event.

If everything succeeds, the procedure returns `ignore`. If either the `db:transaction` or `event-mgr:set-log-handler` indicate an error, the procedure returns that error.

A logger may be configured via `(log-db:event-logger [option value] ...)`, which supports the following options:

| option | default | description |
|------------------------------|----------------------------------|--|
| <code>setup</code> | <i>required</i> | a procedure of no arguments that makes sure this portion of the schema is created and up-to-date |
| <code>log</code> | <i>required</i> | a procedure of one argument, an event, that logs the event if it recognizes it and otherwise ignores it |
| <code>tolerate-fault?</code> | <code>(lambda (event) #f)</code> | a procedure of one argument, an event, that returns true if <code>event-mgr</code> should tolerate the fault in <code>log</code> for that event or false if <code>event-mgr</code> should kill <code>log-db</code> |

`(log-db:version name [version])` procedure

name: symbol identifying the schema

version: string specifying the version of the schema

When called with one argument, `log-db:version` retrieves the version associated with *name* from the database and returns it as a string. It returns `#f` if no version associated with *name* is stored in the database.

When called with two arguments, it stores *version* as the version associated with *name* in the database.

`(log-db:get-instance-id)` procedure

returns: a string

`log-db:setup` associates a globally unique identifier with the database file. The `log-db:get-instance-id` function caches and returns that identifier.

`(make-swish-event-logger [prune-max-days prune-limit])` property

The `make-swish-event-logger` procedure returns an `<event-logger>` tuple that defines the schema for Swish events. It uses the name `swish` to store its schema version. The optional *prune-*

max-days and *prune-limit* arguments are passed to `create-prune-on-insert-trigger` when initializing the Swish event log tables. The default *prune-max-days* is 90. The default *prune-limit* is 10.

swish-event-logger

property

The `swish-event-logger` is an `<event-logger>` tuple created by calling `(make-swish-event-logger)`.

```
(create-table name
  (field type . inline)
  ...)
```

syntax

expands to: `(execute "create table if not exists ...")`

The `create-table` syntax describes the schema of a single table and expands into a call to `execute` to create the table if no table with that name already exists. The name of the table, *name*, and of each field, *field*, are converted from Scheme to SQL identifiers by replacing hyphen characters with underscores and eliminating any non-alphanumeric and non-underscore characters. The SQL definition of each field is produced by joining the converted field name, the *type* and any additional *inline* arguments into a space separated string.

```
(define-simple-events create handle
  (name clause ...)
  ...)
```

syntax

expands to: A definition of the *create* and *handle* procedures

The `define-simple-events` syntax is used to log tuple types by inserting a row into a table with the same name and the same fields. Each *name* is a tuple type. Each *clause* is a valid `create-table` clause for one of the fields in that tuple type.

It defines *create* as a procedure of 0 arguments that consists of a `(create-table name clause ...)` for each tuple in the `define-simple-events`. This means that the name of the tuple type and each field are converted to SQL names by the `create-table` syntax.

It defines *handle* as a procedure of 1 argument, an event. If the event is one of the tuple types in the `define-simple-events`, it calls `db:log` with an insert statement applying `coerce` to each value. If the event is unrecognized, it returns `#f`.

```
(coerce x)
```

procedure

returns: a Scheme object

The argument *x* is a Scheme object mapped to a SQLite value.

| <i>type</i> | transformation |
|-------------------------------|---|
| <i>string</i> | <i>string</i> |
| <i>bytevector</i> | <i>bytevector</i> |
| <i>number</i> | <i>number, if it fits in 64 bits</i> |
| <i>symbol</i> | <i>symbol->string</i> |
| <i>date</i> | <i>format-rfc2822</i> |
| <i>JSON object</i> | <i>json:object->string</i> |
| <i>process</i> | <i>global-process-id</i> |
| <i>condition</i> | a string representing a JSON object with the following fields: <i>message</i> containing (<i>exit-reason->english x</i>) and <i>stacks</i> containing (<i>map stack->json (exit-reason->stacks x)</i>) |
| <i>continuation-condition</i> | a string containing <i>#(error reason stack)</i> where the <i>stack</i> is obtained from <i>dump-stack</i> |

`coerce` passes `#f` through unmodified which SQLite interprets as NULL. Other values are converted to string using `write`.

(create-prune-on-insert-trigger *table column max-days limit*) **procedure**
returns: unspecified

The `create-prune-on-insert-trigger` procedure should be called only within a thunk *f* provided to `db:transaction`. It creates a temporary trigger that prunes, after an insert, up to *limit* rows of the specified *table* where the `erlang:now` timestamp in *column* is older than *max-days*. *max-days* must be a nonnegative fixnum, and *limit* must be a positive fixnum. To keep insert operations fast, *column* should be indexed.

(stack->json *k* [*max-depth*]) **procedure**
returns: a JSON object

The `stack->json` procedure renders the stack of continuation *k* as a JSON object by calling `walk-stack`. The return value may contain the following keys:

| | |
|------------------------|--|
| <code>type</code> | <code>"stack"</code> |
| <code>depth</code> | the depth of the stack |
| <code>truncated</code> | if present, the <i>max-depth</i> at which the stack dump was truncated |
| <code>frames</code> | if present, a list of JSON objects representing stack frames |

A stack frame may contain the following keys:

| | |
|-------------------------------|---|
| <code>type</code> | <code>"stack-frame"</code> |
| <code>depth</code> | the depth of this frame |
| <code>source</code> | if present, a source object for the return point |
| <code>procedure-source</code> | if present, a source object for the procedure containing the return point |
| <code>free</code> | if present, a list of JSON objects representing free variables |

A source object *x* with source file descriptor *sfd* is represented by a JSON object containing the following keys:

| | |
|-----------------------|--|
| <code>bfp</code> | <code>(source-object-bfp x)</code> |
| <code>efp</code> | <code>(source-object-efp x)</code> |
| <code>path</code> | <code>(source-file-descriptor-path sfd)</code> |
| <code>checksum</code> | <code>(source-file-descriptor-checksum sfd)</code> |

A free variable with value *val* is represented by a JSON object containing the following keys:

name a string containing the variable name or its index
value the result of `(format "~s" val)`

`(json-stack->string [op] x)` **procedure**

returns: see below

The two argument form of `json-stack->string` prints the stack represented by JSON object *x* to the textual output port *op*. The single argument form of `json-stack->string` prints the stack represented by JSON object *x* to a string output port and returns the resulting string. In either case, the printed form resembles that generated by `dump-stack` except that source locations are given as file offsets rather than line and character numbers.

12.4 Published Events

`<system-attributes>` **event**

timestamp: timestamp from `erlang:now`
date: date from `current-date`
software-info: JSON object from `software-info`
machine-type: `(symbol->string (machine-type))`
computer-name: computer name from `osi_get_hostname`
os-pid: the operating-system process ID for the Swish process
os-system: `(<uname> system (get-uname))`
os-release: `(<uname> release (get-uname))`
os-version: `(<uname> version (get-uname))`
os-machine: `(<uname> machine (get-uname))`
os-total-memory: `(osi_get_total_memory)`

The `<system-attributes>` event is sent exactly once, when `log-db:setup` is called.

Chapter 13

System Statistics

13.1 Introduction

The system uses a single gen-server named `statistics` to periodically query statistics about the system, such as memory usage.

13.2 Theory of Operation

When the `statistics` gen-server starts, it posts a `<statistics>` event with `reason = startup`. Every five minutes thereafter, it posts a `<statistics>` event with `reason = update`. If the computer sleeps or hibernates, the gen-server posts a `<statistics>` event with `reason = suspend`. When the computer awakens, the gen-server posts a `<statistics>` event with `reason = resume`. When the gen-server terminates, it posts a `<statistics>` event with `reason = shutdown`.

The `<statistics>` event is handled by the `log-db` gen-server (see Chapter 12), which adds the data to the `statistics` table in the log database.

13.3 Programming Interface

```
(statistics:start&link) procedure  
returns: #(ok pid) | #(error error)
```

The `statistics:start&link` procedure creates a new gen-server named `statistics` using `gen-server:start&link`. It then posts a `<statistics>` event with `reason = startup`.

```
(statistics:resume) procedure
```

The `statistics:resume` procedure casts a message to the `statistics` gen-server that causes it to publish a `<statistics>` event with `reason = resume`. This procedure is called from the operating system interface via the top-level-value `$resume`.

(statistics:suspend)

procedure

The `statistics:suspend` procedure casts a message to the `statistics` gen-server that causes it to publish a `<statistics>` event with `reason = suspend`. This procedure is called from the operating system interface via the top-level-value `$suspend`.

13.4 Published Events

`<statistics>`

event

timestamp: timestamp from `erlang:now`
date: date from `current-date`
reason: `startup`, `update`, `suspend`, `resume`, or `shutdown`
bytes-allocated: Scheme heap size from `bytes-allocated`
current-memory-bytes: Scheme heap size including overhead, from `current-memory-bytes`
maximum-memory-bytes: maximum Scheme heap size including overhead, since startup or since the last `<statistics>` event, from `maximum-memory-bytes`
osi-bytes-used: C heap size from `osi_get_bytes_used`
sqlite-memory: SQLite memory used from `osi_get_sqlite_status`
sqlite-memory-highwater: SQLite memory highwater since last event from `osi_get_sqlite_status`
foreign-handles: JSON object with types and counts reported by `count-foreign-handles`
cpu: CPU time in seconds since last event
real: elapsed time in seconds since last event
bytes: Scheme heap bytes allocated since last event
gc-count: number of garbage collections since last event
gc-cpu: CPU time in seconds of garbage collections since last event
gc-real: elapsed time in seconds of garbage collections since last event
gc-bytes: Scheme heap bytes reclaimed since last event
os-free-memory: current free memory from `osi_get_free_memory`

Each time a `<statistics>` event is emitted, the maximum memory bytes value is reset via `reset-maximum-memory-bytes!`.

The JSON object in the `foreign-handles` field contains at least the following entries:

| | |
|----------------------------|--|
| <code>bindings</code> | number of live marshaled SQLite bindings |
| <code>databases</code> | number of open SQLite databases |
| <code>osi-ports</code> | number of open osi-ports |
| <code>path-watchers</code> | number of open path watchers |
| <code>statements</code> | number of unfinalized SQLite statements |
| <code>tcp-listeners</code> | number of open TCP/IP listeners |

This event is sent every five minutes while the `statistics` gen-server is running.

Chapter 14

HTTP Interface

14.1 Introduction

The HTTP interface provides a basic implementation of the Hypertext Transfer Protocol [14] and the WebSocket Protocol [13]. The programming interface includes procedures for the HyperText Markup Language (HTML) version 5 [19] and JavaScript Object Notation (JSON) [3].

14.2 Theory of Operation

The HTTP interface provides `http:add-file-server` to listen for connections on a TCP port and serve files from a directory and `http:add-server` to serve content via a user-defined procedure. These procedures configure the `app-sup-spec` to include one or more web servers in the supervision hierarchy that is started by `app:start`.

Both `http:add-file-server` and `http:add-server` are implemented in terms of `http:configure-server`, which defines a supervisor that manages the *listener* gen-server, *dispatcher* processes, *cache* gen-servers, and *evaluator* processes. Internally, the listener starts a cache manager process to support evaluating and serving files. The dispatcher starts a connection process to manage protocol details. This structure is illustrated in Figure 14.1.

The HTTP supervisor provided via `http:configure-server` is configured one-for-one with up to 10 restarts within 10 seconds.

The *listener* gen-server awaits TCP connections using `listen-tcp` and accepts them using `accept-tcp`. For each TCP connection, the listener uses its supervisor to spawn and link a *dispatcher* process that reads each request, calls the *URL handler* configured for that listener, and repeats until the connection closes. The listener closes the associated output port when the dispatcher exits.

Each *dispatcher* process spawns a *connection* gen-server. The connection is responsible for reading and parsing requests in a timely manner. A connection server reads from its input port until a CR LF occurs. Well-formed input is converted to a `<request>` tuple. The HTTP request header is then read and associated with the request. If the connection takes more than `request-timeout` milliseconds to parse a request, the dispatcher fires an exception, and the TCP connection is closed.

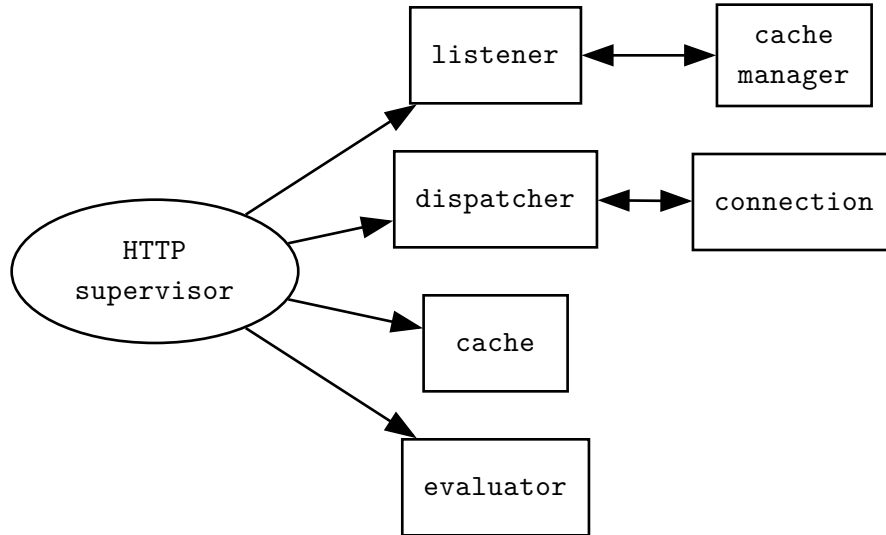


Figure 14.1: HTTP supervision tree

The dispatcher logs the specific request, validates that the requested path does not include “.”, and invokes the URL handler provided by the listener.

For forms, the URL handler is responsible for checking the request method and reading form content with `http:call-with-form`. Any unread content as determined by `Content-Length` is ignored.

After a request is processed, the current process and connection can be reused. Unless the `Connection` header specifies `close`, the system reads another request from the input port after skipping any unread content from the current request.

14.2.1 URL handler and Media Type handler

Using `http:add-server` or `http:configure-server` configures a web server to serve content via a URL handler that may be compiled into the Swish application.

A *URL handler* is a procedure that should return `#t` when it processes a request, and `#f` otherwise.

To allow future extension without change to application code, the HTTP interface provides `http:url-handler` to define a handler which exposes the following implicit variables:

- conn*: a connection process
- request*: a `<request>` tuple
- header*: a JSON object
- params*: a JSON object

`http:call-url-handler` can be used to invoke a handler, and `http:compose-url-handlers` chains a sequence of handlers together.

A *media type handler* is a procedure that takes a file extension as input and returns a media type or `#f`. The default media type handler always returns `#f`.

14.2.2 Default file handling

Using `http:add-file-server` or `http:configure-file-server` configures a web server to serve files from a directory. These procedures generate a URL handler by calling `http:make-default-file-url-handler`. This handler asks the *cache manager* gen-server for a cache responsible for the given directory.

The *cache manager* gen-server maintains the mapping of the top-level web directory to a *cache* gen-server. If a cache does not exist for the given path, a new *cache* gen-server is created.

A *cache* gen-server stores URL handlers and provides a mapping from file extension to media type. It creates a directory watcher using `watch-directory` to invalidate the cache when anything in the directory tree changes. It terminates after 5 minutes of inactivity.

The optional `media-type-handler` is configured via `http:make-default-media-type-handler` to match the extension of *filename* case insensitively against an extension in the `mime-types` file of the configured directory. Each line of `mime-types` has the form ("*extension*" . "*Content-Type*").

14.2.3 Dynamic Pages

A *dynamic page* is any file that is transformed before its content is sent to the browser. For example, by setting the option `file-transform` to `http:enable-dynamic-pages`, a path that ends in “.ss” containing a sequence of definitions followed by a sequence of expressions is wrapped in a URL handler and evaluated by the `eval` system procedure. The page explicitly sends a response via `http:respond` or `http:respond-file`.

In general, a cache gen-server resolves a URL to a file path and checks its internal state. If a URL handler is unavailable, the gen-server calls the optional `file-transform` procedure passing the absolute file path.

The `file-transform` procedure returns `#f` or a procedure. When it returns `#f`, the URL is considered static and is sent directly over the connection using `http:respond-file`.

When it returns a procedure, the cache starts an *evaluator* process. The evaluator process calls the procedure with the cache’s root directory and the absolute file path. The evaluator procedure returns `#f` or a URL handler. The cache stores the URL handler.

14.2.4 WebSocket Protocol

The WebSocket Protocol enables bidirectional communication and is well supported by web browsers and software platforms. The protocol utilizes message fragmentation and control frame messages. The (`swish websocket`) library represents a WebSocket connection as a gen-server referred to as a *websocket*.

The *websocket* gen-server manages message fragmentation, ping and pong control messages, and sends messages to a separate process. The following messages are sent:

- `#(ws:init ws)`: Indicates that the HTTP protocol upgrade to websocket is complete for process *ws* and messages can be exchanged.

- `#(ws:message ws message)`: Indicates that a *message* bytevector or string was received by process *ws*.
- `#(ws:closed ws code reason)`: Indicates that the websocket and underlying output port is closed. The cause is indicated by the numeric status *code*. Status codes 1000 and 1001 are used to indicate normal exit reasons. The *reason* string may be useful for logging and debugging but is not necessarily presentable to a user.

As a server, a URL handler can call `ws:upgrade` in tail position to switch to the WebSocket Protocol.

A client establishes a connection to a server using `ws:connect` to connect and request usage of the WebSocket Protocol.

14.3 Security

The HTTP interface is written in Scheme, and therefore buffer overrun exploits cannot be used against the system.

User input should be carefully checked before calling `eval` or invoking a database query.

A URL which directs the system away from a cache's root path using `..` could allow access to system files. Therefore, the dispatcher explicitly rejects relative paths.

The HTTP interface limits incoming data to protect against large memory allocation that may crash the application.

The HTTP interface allows individual form URL handlers to specify incoming data and file upload limits to protect against large memory allocation and running out of disk space.

14.4 Programming Interface

<request> **tuple**

host: a string
method: a symbol
path: a decoded string
original-path: same as *path*
header: a decoded JSON object
params: a decoded JSON object

The *original-path* is used internally when redirecting the browser to a new location. If user code copies the `<request>` tuple, it should not modify *original-path*.

(http:configure-server name port url-handler [options]) **procedure**
returns: a list of child specifications (see page 109)

name: a symbol for the listener gen-server or **#f** for an anonymous server
port: a fixnum $0 \leq port \leq 65535$
url-handler: a procedure
options: see below

The `http:configure-server` procedure returns a list of supervisor child specifications that define an HTTP server.

The specification defines a supervisor configured as one-for-one with up to 10 restarts every 10 seconds. The supervisor starts a listener gen-server. This supervisor is used to create dispatcher, cache, and evaluator processes.

The listener is a gen-server registered as *name*. It accepts connections on the given TCP *port* and processes them with *url-handler*.

The *options* can be defined using (`http:options (option value) ...`). The following options may be used:

| option | default | description |
|-------------------------------------|---------------------------------|--|
| <code>request-limit</code> | 8,192 | a positive fixnum; the maximum length in bytes of the first line of an HTTP request |
| <code>request-timeout</code> | 30,000 | a positive fixnum; the maximum number of milliseconds to wait to receive an HTTP request after initial connection |
| <code>response-timeout</code> | 60,000 | a positive fixnum; the maximum number of milliseconds to allow the server to send a response |
| <code>header-limit</code> | 1,048,576 | a positive fixnum; the maximum length in bytes of the HTTP request headers |
| <code>media-type-handler</code> | <code>(lambda (ext) #f)</code> | a procedure; given a file extension returns the media type of the file or #f |
| <code>file-search-extensions</code> | <code>'(".html")</code> | a list of strings; a cache process uses the list to disambiguate URL paths to file system paths. |
| <code>file-transform</code> | <code>(lambda (path) #f)</code> | a procedure; a cache process calls this procedure with a file path and expects an evaluator procedure or #f (see §14.2.3) |
| <code>validate-path</code> | <code>http:valid-path?</code> | a predicate; the server raises an exception if the <code><request></code> <i>path</i> does not satisfy this predicate. |

`(http:add-server arg ...)` **syntax**

The `http:add-server` macro expands to code that appends the result of (`http:configure-server arg ...`) to the `app-sup-spec` parameter.

`(http:configure-file-server name port dir [options])` **procedure**
returns: a list of child specifications (see page 109)

The `http:configure-file-server` procedure defines an HTTP server that provides content from the file-system rooted at *dir*.

The `http:configure-file-server` procedure calls `http:configure-server` with (`http:make-default-file-url-handler dir`) as the URL handler. If the `media-type-handler` option is not

specified, it defaults to one constructed via (`http:make-default-media-type-handler dir`).

`(http:add-file-server arg ...)` **syntax**

The `http:add-file-server` macro expands to code that appends the result of (`http:configure-file-server arg ...`) to the `app-sup-spec` parameter.

`(http:make-default-file-url-handler dir)` **procedure**

returns: a URL handler

The `http:make-default-file-url-handler` defines a URL handler that retrieves the cache responsible for the directory *dir*. It then looks up a URL handler from the cache for the given request. If found, it calls the handler and flushes the output port. Otherwise, it returns `#f`.

`(http:make-default-media-type-handler dir)` **procedure**

returns: a media type handler

The `http:make-default-media-type-handler` defines a media type handler that retrieves the cache responsible for the directory *dir*. It then requests the media type for the given file extension. If found, the type is returned. Otherwise, it returns `#f`.

`(http:url-handler body1 body2 ...)` **syntax**

The `http:url-handler` macro defines a URL handler procedure described in Section 14.2.1.

`(http:call-url-handler handler)` **syntax**

The `http:call-url-handler` macro invokes a URL handler, implicitly capturing variables in scope as described in Section 14.2.1.

`(http:compose-url-handlers handlers)` **procedure**

returns: a URL handler

The `http:compose-url-handlers` procedure defines a URL handler that takes a list of *handlers* and invokes each handler, in order, until one returns `#t`. Otherwise, it returns `#f`.

If a URL handler returns `#f` but sends output to the output-port, exception `http-side-effecting-handler` is raised.

`(http:get-port-number listener)` **procedure**

returns: the listener gen-server TCP port number

The `http:get-port-number` procedure calls (`gen-server:call listener 'get-port-number`). If the listener's port was configured to be zero, the operating system will choose an available port number. `http:get-port-number` uses `listener-port-number` to retrieve the actual port number that the server is listening on.

(http:find-header *name header*) **procedure**
returns: a string | #f

The `http:find-header` procedure returns the value associated with *name* in JSON object *header* if present and #f otherwise. If *name* is a symbol, the lookup uses `eq?`. If *name* is a string, it is first mapped to a lower-case symbol before performing the lookup. Otherwise, the exception `#(bad-arg http:find-header name)` is raised.

(http:get-header *name header*) **procedure**
returns: a string

The `http:get-header` procedure returns the value associated with *name* in JSON object *header* if present and raises exception `#(http-invalid-header name)` otherwise. If *name* is a symbol, the lookup uses `eq?`. If *name* is a string, it is first mapped to a lower-case symbol before performing the lookup. Otherwise, the exception `#(bad-arg http:get-header name)` is raised.

(http:get-content-length *header*) **procedure**
returns: an unsigned integer | #f

The `http:get-content-length` procedure returns the unsigned integer value associated with `content-length` in JSON object *header* if present and #f otherwise. It raises exception `#(http-invalid-content-length value)` if the *value* string does not represent an unsigned integer.

(http:find-param *name params*) **procedure**
returns: a string | #f

The `http:find-param` procedure returns the value associated with *name* in JSON object *params* if present and #f otherwise. If *name* is a symbol, the lookup uses `eq?`. If *name* is a string, it is converted to a symbol before performing the lookup. Otherwise, the exception `#(bad-arg http:find-param name)` is raised.

(http:get-param *name params*) **procedure**
returns: a string

The `http:get-param` procedure returns the value associated with *name* in JSON object *params* if present and raises exception `#(http-invalid-param name)` otherwise. If *name* is a symbol, the lookup uses `eq?`. If *name* is a string, it is converted to a symbol before performing the lookup. Otherwise, the exception `#(bad-arg http:get-param name)` is raised.

(http:read-header *ip limit*) **procedure**
returns: a JSON object

The `http:read-header` procedure reads from the binary input port *ip* until it reads a blank line. It creates a JSON object where the key is a symbol formed from the down-cased characters before the first colon and the value is a string formed from the characters that remain after skipping white space. Duplicate message-header fields result in a single entry where the value is a comma-separated list.

Reading beyond *limit* raises exception `http-input-limit-exceeded`.

Failure to find a colon on any given line raises exception `http-invalid-header`.

(http:read-status *ip limit*) **procedure**

returns: number | #f

The `http:read-status` procedure reads the HTTP response status line from the binary input port *ip* and returns the status code as a number if well formed and #f otherwise. Reading beyond *limit* raises exception `http-input-limit-exceeded`.

(http:write-status *op status*) **procedure**

returns: unspecified

The `http:write-status` procedure writes the HTTP response status line to the binary output port *op*.

Unless *status* is a fixnum and $100 \leq status \leq 599$, the exception `#(bad-arg http:write-status status)` is raised.

According to HTTP [14] the status line includes a human-readable reason phrase. The grammar shows that it can in fact be zero characters long; therefore, the reason phrase is not included in this implementation.

(http:write-header *op header-alist*) **procedure**

returns: unspecified

The `http:write-header` procedure writes the HTTP *header-alist* and trailing CR LF to the binary output port *op*.

header-alist is an association list whose keys and values are strings. If any of its keys are not strings, exception `#(bad-arg http:write-header header-alist)` is raised.

(http:respond *conn status header-alist [content [timeout]]*) **procedure**

returns: #t

The `http:respond` procedure writes the HTTP *status* and *header-alist* to the connection *conn* using `http:write-status` and `http:write-header`, adding `Content-Length` to *header-alist* in situations described below. When `Cache-Control` is not present in *header-alist*, it is added with value `no-cache`. When *content* is a bytevector, it is written. Then the output port is flushed.

The default value of *content* is #f, which specifies that the `Content-Length` header is not added. When *status* is 100–199, 204, or 304, the `Content-Length` header is not added, and if *content* is a bytevector, it must be empty. Otherwise, the `Content-Length` header is added with the length of *content*.

The default value of *timeout* is `(response-timeout)`.

(http:respond-file *conn status header-alist filename [timeout]*) **procedure**

returns: #t

The `http:respond-file` procedure writes the HTTP *status* and *header-alist* to the connection *conn* using `http:write-status` and `http:write-header`, adding `Content-Length` to *header-alist*. The `Cache-Control` header is added, if it is not already present, with value `max-age=3600`. The `Content-Type` header is added, if it is not already present, by calling the `media-type-handler`.

The content of the file is streamed to the output port so that the file does not need to be loaded into memory. The output port is flushed.

The default value of *timeout* is `(response-timeout)`.

`(http:call-with-form conn header content-limit file-limit files f [timeout])` **procedure**
returns: see below

The `http:call-with-form` procedure checks JSON object *header* for a `content-type` of `multipart/form-data` or `application/x-www-form-urlencoded`. It parses form name/value pairs into a JSON object. After parsing the form data, the function *f* is called with the JSON object. After *f* returns, all uploaded files are deleted, and the return value is passed to the caller.

Because `http:call-with-form` is used inside a URL handler after the `<http-request>` event has been fired, the specific form data is not logged. Applications should consider the sensitivity of submitted data before logging.

When files are sent and the form variable name appears in the *files* list, the file is stored in `(tmp-dir)`, and the JSON value is a JSON object with `type="file"` and `filename=filename`.

For example, a form sending the variables `name`, `rank`, and `image` might look like:

```
{
  "name": "Steve R",
  "rank": "Captain",
  "image":
  {
    "type": "file",
    "filename": filename
  }
}
```

Name/value pairs count against *content-limit* while file data counts against *file-limit*. An exception is raised when either limit is exceeded.

The default value of *timeout* is `(request-timeout)`.

`(http:call-with-ports conn f [timeout])` **procedure**
returns: see below

The `http:call-with-ports` procedure ignores any current connection state and calls *f* in the connection process with the connection's input and output ports. Running *f* in the connection process allows the caller to timeout when input is unavailable. The return value of *f* is returned to the caller.

The default value of *timeout* is 5000 milliseconds.

`(http:switch-protocol proc)` **procedure**
returns: see below

When used in a URL handler, `http:switch-protocol` returns a special value to control the dispatcher loop. The dispatcher detaches from the connection process and calls *proc* with the input and output ports.

(http:percent-encode *s*) **procedure**
returns: an encoded string

The `http:percent-encode` procedure writes the characters A-Z, a-z, 0-9, hyphen, underscore, period, and ~. Other characters are converted to a % prefix and two digit hexadecimal representation.

(http:enable-dynamic-pages *path*) **procedure**
returns: a procedure | #f

If the file extension of *path* is “.ss”, the `http:enable-dynamic-pages` procedure returns the `http:eval-dynamic-page` procedure. Otherwise, it returns #f.

(http:eval-dynamic-page *root-dir abs-path*) **procedure**
returns: a URL handler

The `http:eval-dynamic-page` procedure wraps a `http:url-handler` around the contents of a file, extends the syntax with the constructs described in Section 14.4.1, and calls the `eval` system procedure.

(http:valid-path? *path*) **procedure**
returns: boolean

The `http:valid-path?` procedure checks that the *path* from a `<request>` is a string that begins with / and contains no “..” path elements when decomposed as a filesystem path. On Windows this procedure treats both / and \ as path separators since some filesystem operations accept both.

14.4.1 Dynamic Page Constructs

A dynamic page exposes the same implicit variables as a URL handler described in Section 14.2.1 as well as the following additional syntax.

(find-param *key*) **syntax**

Implementation: The `find-param` macro expands to `(http:find-param key params)`.

(get-param *key*) **syntax**

Implementation: The `get-param` macro expands to `(http:get-param key params)`.

(http:include "*filename*") **syntax**

The `http:include` construct includes the definitions from *filename*, a path relative to the root path of the cache if *filename* begins with a forward slash, else relative to the directory of the current file.

Implementation: The `http:include` macro calls `read-file` and `read-bytevector` to retrieve a list of expressions that are spliced in at the same scope as the use of `http:include`. The splicing is done with `let-syntax` so that any nested `http:include` expressions are processed relative to the directory of *filename*.

14.4.2 WebSocket Protocol

(ws:upgrade *conn request process [options]*) **procedure**

returns: see below

The `ws:upgrade` procedure checks the header of the *request* tuple and upgrades the calling process to a gen-server that speaks the WebSocket protocol. The connection *conn* is used during the opening handshake to report errors. As it runs, the gen-server sends the messages defined in Section 14.2.4 to the given *process*. It raises an exception upon termination (see `gen-server:enter-loop`).

The *options* are defined with `(ws:options (option value) ...)`. The following options may be used:

| option | default | description |
|-----------------------------------|------------|--|
| <code>fragmentation-size</code> | 1,048,576 | a positive fixnum or <code>#f</code> to disable; the maximum length in bytes of a single message payload |
| <code>maximum-message-size</code> | 16,777,216 | a positive fixnum; the maximum length in bytes of the total payload for a single message that can be read from input |
| <code>ping-frequency</code> | 30,000 | a positive fixnum; the maximum number of milliseconds since last receiving a message before issuing a ping request |
| <code>pong-timeout</code> | 5,000 | a positive fixnum; the maximum number of milliseconds to wait for a reply to a ping before failing |

(ws:connect *hostname port request process [options]*) **procedure**

returns: a websocket gen-server process

The `ws:connect` procedure initiates a TCP connection to *hostname* on the given *port* number and issues an upgrade for the *request* uniform resource identifier string. It then spawns and returns a gen-server process that sends the messages defined in Section 14.2.4 to the given *process*.

The *options* are the same as defined for `ws:upgrade`.

(ws:send *server message*) **procedure**

(ws:send! *server message*)

returns: ok

The `ws:send` procedure uses `gen-server:cast` to transmit the bytevector or string *message* to the websocket process or registered name *server*. The `ws:send!` procedure is like `ws:send` except that it does not copy bytevector messages, but may instead destructively update them to apply a mask for transmission.

(ws:close *server*) **procedure**

returns: ok

The `ws:close` procedure uses `gen-server:cast` to close the websocket process or registered name *server*.

14.4.3 HyperText Markup Language

`(html:encode s)` **procedure**
`(html:encode op s)`
returns: see below

The `html:encode` procedure converts special character entities in string *s*.

| input | output |
|-------|--------|
| " | " |
| & | & |
| < | < |
| > | > |

The single argument form of `html:encode` returns an encoded string.

The two argument form of `html:encode` sends the encoded string to the textual output port *op*.

`(html->string x)` **procedure**
`(html->string op x)`
returns: see below

The `html->string` procedure transforms an object into HTML. The transformation, *H*, is described below:

| <i>x</i> | <i>H(x)</i> |
|---|---|
| () | nothing |
| <code>#!void</code> | nothing |
| <i>string</i> | <i>E(string)</i> |
| <i>number</i> | <i>number</i> |
| <code>(begin pattern ...)</code> | <i>H(pattern)</i> ... |
| <code>(cdata string ...)</code> | <code>[!CDATA[<i>string</i>...]]</code> |
| <code>(html5 [(@ attr ...)] pattern ...)</code> | <code><!DOCTYPE html><html A(attr) ...><i>H(pattern)</i>...</html></code> |
| <code>(raw string ...)</code> | <i>string</i> ... |
| <code>(script [(@ attr ...)] string ...)</code> | <code><script A(attr) ...><i>string</i>...</script></code> |
| <code>(style [(@ attr ...)] string ...)</code> | <code><style A(attr) ...><i>string</i>...</style></code> |
| <code>(tag [(@ attr ...)] pattern ...)</code> | <code><tag A(attr) ...><i>H(pattern)</i>...</tag></code> |
| <code>(void-tag [(@ attr ...)])</code> | <code><void-tag A(attr) ...></code> |

E denotes the `html:encode` function.

For the `html5` tag, if there is no *attr* with `lang` as its key, then *H* acts as if the *attr* (`lang "en"`) were specified.

A *void-tag* is one of `area`, `base`, `br`, `col`, `embed`, `hr`, `img`, `input`, `keygen`, `link`, `menuitem`, `meta`, `param`, `source`, `track`, or `wbr`. A *tag* is any other symbol.

The attribute transformation, *A*, is described below, where *key* is a symbol:

| <i>attr</i> | <i>A(attr)</i> |
|---------------------|------------------------------|
| <code>#!void</code> | nothing |
| <i>(key)</i> | <i>key</i> |
| <i>(key string)</i> | <code>key="E(string)"</code> |
| <i>(key number)</i> | <code>key="number"</code> |

The single argument form of `html->string` returns an encoded HTML string.

The two argument form of `html->string` sends the encoded HTML string to the textual output port *op*.

Input that does not match the specification causes a `#(bad-arg html->string x)` exception to be raised.

`(html->bytevector x)` **procedure**
returns: a bytevector

The `html->bytevector` procedure calls `html->string` on *x* using a bytevector output port transcoded using `(make-utf8-transcoder)` and returns the resulting bytevector.

14.4.4 JavaScript Object Notation

This implementation translates JavaScript types into the following Scheme types:

| JavaScript | Scheme |
|--------------------|-------------------------------------|
| <code>true</code> | <code>#t</code> |
| <code>false</code> | <code>#f</code> |
| <code>null</code> | <code>#\nul</code> |
| <i>string</i> | <i>string</i> |
| <i>number</i> | <i>number</i> |
| <i>array</i> | <i>list</i> |
| <i>object</i> | hashtable mapping symbols to values |

This implementation does not range check values to ensure that a JavaScript implementation can interpret the data.

`(json:extend-object ht [key value] ...)` **syntax**

The `json:extend-object` construct adds the *key / value* pairs to the hashtable *ht* using `hashtable-set!`. Each *key* is a literal identifier or an unquoted expression, *e* that evaluates to a symbol. The resulting expression returns *ht*.

`(json:make-object [key value] ...)` **syntax**

The `json:make-object` construct expands into a call to `json:extend-object` with a new hashtable.

`(json:object? x)` **procedure**
returns: a boolean

The `json:object?` procedure determines whether or not the datum *x* is an object created by `json:make-object`.

`(json:cells ht)` **procedure**
returns: a vector

The `json:cells` procedure returns a vector containing the cells of the underlying hashtable.

(json:size *ht*) **procedure**
returns: an integer

The `json:size` procedure returns the number of cells in the underlying hashtable.

(json:delete! *ht path*) **procedure**
returns: unspecified

The `json:delete!` procedure expects *path* to be a symbol or a non-empty list of symbols. If *path* is a symbol, then `json:delete!` is equivalent to `hashtable-delete!`. Otherwise, `json:delete!` follows *path* as it descends into the nested hashtable *ht*, treating each element as a key into the hashtable reached by traversing the preceding elements. When `json:delete!` reaches the final key in *path*, it calls `hashtable-delete!` to remove the association for that key in the hashtable reached at that point. If any key along the way does not map to a hashtable, `json:delete!` has no effect.

(json:ref *ht path default*) **procedure**
returns: the value found by traversing *path* in *ht*, *default* if none

The `json:ref` procedure expects *path* to be a symbol or a non-empty list of symbols. If *path* is a symbol, then `json:ref` is equivalent to `hashtable-ref`. Otherwise, `json:ref` follows *path* as it descends into the nested hashtable *ht*, treating each element as a key into the hashtable reached by traversing the preceding elements. When `json:ref` reaches the final key in *path*, it calls `hashtable-ref` to retrieve the value of that key in the hashtable reached at that point. If any key along the way does not map to a hashtable, or if the final hashtable does not contain the final key, `json:ref` returns *default*.

(json:set! *ht path value*) **procedure**
returns: unspecified

The `json:set!` procedure expects *path* to be a symbol or a non-empty list of symbols. If *path* is a symbol, then `json:set!` is equivalent to `hashtable-set!`. Otherwise, `json:set!` follows *path* as it descends into the nested hashtable *ht*, treating each element as a key into the hashtable reached by traversing the preceding elements. When `json:set!` reaches the final key in *path*, it calls `hashtable-set!` to set that key in the hashtable reached at that point. If any key along the way does not map to a hashtable, `json:set!` installs an empty hashtable at that key before proceeding. If *path* is malformed at some point, `json:set!` may still mutate hashtables along the valid portion of the path before reporting an error.

(json:update! *ht path procedure default*) **procedure**
returns: unspecified

The `json:update!` procedure expects *path* to be a symbol or a non-empty list of symbols. If *path* is a symbol, then `json:update!` is equivalent to `hashtable-update!`. Otherwise, `json:update!` follows *path* as it descends into the nested hashtable *ht*, treating each element as a key into the hashtable reached by traversing the preceding elements. When `json:update!` reaches the final key in *path*, it calls `hashtable-update!` to update that key in the hashtable reached at that point. If any key along the way does not map to a hashtable, `json:update!` installs an empty hashtable at that key before proceeding. If *path* is malformed at some point, `json:update!` may still mutate hashtables along the valid portion of the path before reporting an error.

`(json:read ip [custom-inflate])` **procedure**

returns: a Scheme object or the eof object

The `json:read` procedure reads characters from the textual input port `ip` and returns an appropriate Scheme object. When `json:read` encounters a JSON object, it builds the corresponding hashtable and calls `custom-inflate` to perform application-specific conversion. By default, `custom-inflate` is the identity function.

The following exceptions may be raised:

- `invalid-surrogate-pair`
- `unexpected-eof`
- `#(unexpected-input data input-position)`

`(json:write op x [indent] [custom-write])` **procedure**

returns: unspecified

The `json:write` procedure writes the object `x` to the textual output port `op` in JSON format. By default, `json:write` sorts the keys of JSON objects using `string<?`, after converting the symbolic keys to strings. This sort order provides stable output. The `json:key<?` parameter may be used to alter or disable key sorting. Scheme fixnums, bignums, and finite flonums may be used as numbers.

When `indent` is a non-negative fixnum, the output is more readable by a human. List items and key/value pairs are indented on individual lines by the specified number of spaces. When `indent` is 0, a newline is added to the end of the output. The default indent of `#f` produces compact output.

The optional `custom-write` procedure may intervene to handle lists and hashtables differently or to handle objects that have no direct JSON counterpart. If `custom-write` does not handle a given object, it should return `false` to let `json:write` proceed normally. The `custom-write` procedure is called with four arguments: the textual output port `op`, the Scheme object `x`, the current `indent` level, and a writer procedure `wr` that should be used to write the values of arbitrary Scheme objects. The `wr` procedure is equivalent to `(lambda (op x indent) (json:write op x indent custom-write))`.

The default value of `custom-write` is the value stored in the `json:custom-write` process-parameter.

If an object cannot be formatted, `#(invalid-datum x)` is raised.

`(json:write-object op indent wr [key value] ...)` **syntax**

returns: `#t`

Given a textual output port `op`, an `indent` level, and a writer procedure `wr`, the `json:write-object` construct writes a JSON object with the given `key / value` pairs to `op`. By default, `json:write-object` sorts the keys using `string<?` on the string values of the symbols. To alter or disable key sorting, see the `json:key<?` parameter.

Each `key` must be a distinct symbol. The `wr` procedure takes `op`, an object `x`, and an `indent` level just like the `wr` procedure that is passed to `json:write`'s `custom-write` procedure.

The following are equivalent, provided the keys are symbols and `json:key<?` has its default value.

```
(begin (json:write op (json:make-object [key value] ...) indent) #t)
(json:write-object op indent json:write [key value] ...)
```

The latter trades code size and compile time for run-time efficiency. At compile time, `json:write-object` sorts the keys and preformats the strings that will separate values.

```
(json:pretty x [op]) procedure
returns: unspecified
```

The `json:pretty` procedure formats an object `x` to the optional textual output port `op` in a human-readable form. The object is indented and keys are sorted using `natural-string-ci<?`. The default value of `op` is `(current-output-port)`.

Calling `(json:pretty x)` is roughly equivalent to the following:

```
(parameterize ([json:key<? natural-string-ci<?])
  (json:write (current-output-port) x 0))
```

```
json:custom-write parameter
returns: a procedure or #f
```

The `json:custom-write` process-parameter determines the default `custom-write` argument for `json:write` and the other JSON output procedures.

```
json:key<? parameter
returns: a boolean or a predicate for comparing two strings
```

The `json:key<?` parameter determines whether and how `json:pretty`, `json:write`, and `json:write-object` sort keys when writing JSON objects. If set to `#f`, keys are not sorted and the output order is arbitrary. Otherwise, the output is sorted by obtaining a string for each key via `symbol->string` and comparing those strings using the predicate specified by `json:key<?`. If `json:key<?` is set to `#t`, which is the default, then `json:pretty` sorts with `natural-string-ci<?` while `json:write` and `json:write-object` sort with `string<?`. To affect the output of `json:write-object`, `json:key<?` must be set to the desired value at expand time.

```
(json:object->bytevector x [indent] [custom-write]) procedure
returns: a bytevector
```

The `json:object->bytevector` procedure calls `json:write` on `x` with the optional `indent` and `custom-write`, if any, using a bytevector output port transcoded using `(make-utf8-transcoder)` and returns the resulting bytevector.

```
(json:bytevector->object x [custom-inflate]) procedure
returns: a Scheme object
```

The `json:bytevector->object` procedure creates a bytevector input port on `x`, calls `json:read` with the optional `custom-inflate`, if any, and returns the resulting Scheme object after making sure the rest of the bytevector is only whitespace.

```
(json:object->string x [indent] [custom-write]) procedure
returns: a JSON formatted string
```

The `json:object->string` procedure creates a string output port, calls `json:write` on `x` with the optional `indent` and `custom-write`, if any, and returns the resulting string.

`(json:string->object x [custom-inflate])` **procedure**
returns: a Scheme object

The `json:string->object` procedure creates a string input port on `x`, calls `json:read` with the optional `custom-inflate`, if any, and returns the resulting Scheme object after making sure the rest of the string is only whitespace.

`(json:write-structural-char x indent op)` **procedure**
returns: the new indent level

The `json:write-structural-char` procedure writes the character `x` at an appropriate `indent` level to the textual output port `op`. The character should be one of the following JSON structural characters: `[] { } : ,`

This procedure is intended for use within custom writers passed in to `json:write` and, for performance, it does not check its input arguments.

14.5 Published Events

`<http-request>` **event**

timestamp: timestamp from `erlang:now`
pid: handler process
host: the IP address of the client
method: `<request>` method
path: `<request>` path
header: a JSON object
params: a JSON object

Chapter 15

Command Line Interface

15.1 Introduction

The command-line interface (`cli`) provides parsing of command-line arguments as well as consistent usage of common options and display of help.

15.2 Theory of Operation

Many programs parse command-line arguments and perform actions based on them. The `cli` library helps to make programs that process arguments and display help simple and consistent. Command-line arguments are parsed left to right in a single pass. Command-line interface specifications, or `cli-specs`, are used for parsing and error checking a command line, displaying one-line usage, and displaying a full help summary.

Arguments may be preceded by a single dash (`-`), a double dash (`--`), or no dash at all. A single dash precedes short, single character arguments. The API does not allow numbers as they could be mistaken as a negative numerical value supplied to another argument. A double dash precedes longer, more descriptive arguments, `--repl` for example. Positional arguments are not preceded by any dashes. As arguments with dashes are consumed, the remaining arguments are matched against the positional specifications in order.

Argument specifications include a type such as: `bool`, `count`, `string`, and `list`. A set of `bool` and `count` arguments can be specified together (`-abc` is equivalent to `-a -b -c`). Arguments of type `list` collect values in left to right order.

The API does not directly support sub-commands and alternate usage help text. These can be implemented using the primitives provided. The implementations of `swish-build` and `swish-test` provide examples of advanced command-line handling.

In the following REPL transcript, we define `example-cli` using `cli-specs`. We then set the `command-line-arguments` parameter as they would be for an application. Calling `parse-command-line-arguments` returns a procedure, `opt`, which we can use to access the parsed command-line values. Finally, we use `display-help` to display the automatically generated help.

```

> (define example-cli
  (cli-specs
   default-help
   [verbose -v count "indicates verbosity level"]
   [output -o (string "<output>") "print output to an <output> file"]
   [repl --repl bool "start a repl"]
   [files (list "<file>" ...) "a list of input files"]))
> (command-line-arguments '("-vvv" "-o" "file.out" "file.in"))
> (define opt (parse-command-line-arguments example-cli))
> (opt 'verbose)
3
> (opt 'output)
"file.out"
> (opt 'files)
("file.in")
> (display-help "sample" example-cli)
Usage: sample [-hv] [-o <output>] [--repl] <file> ...

-h, --help      display this help and exit
-v              indicates verbosity level
-o <output>     print output to an <output> file
--repl         start a repl
<file> ...     a list of input files

```

Putting the parts together into `sample.ss`, we have a working example albeit incomplete.

```

#!/usr/bin/env swish

(define example-cli
  (cli-specs
   default-help
   [verbose -v count "indicates verbosity level"]
   [output -o (string "<output>") "print output to an <output> file"]
   [repl --repl bool "start a repl"]
   [files (list "<file>" ...) "a list of input files"]))

(let ([opt (parse-command-line-arguments example-cli)])
  (when (opt 'help)
    (display-help "sample" example-cli)
    (exit 0))
  (let ([verbosity (or (opt 'verbose) 0)])
    (when (> verbosity 0)
      (printf "showing verbosity level: ~a~n" verbosity)))
  (when (opt 'repl)
    (new-cafe)))

```

15.3 Programming Interface

```
(cli-specs syntax
  [default-help]
  (name [short] [long] type help
    [(conflicts conflicts)]
    [(requires requires)]
    [(usage [visibility] [how])])
  ...)
```

expands to:

a list of `<arg-spec>` tuples

The `cli-specs` macro simplifies the creation of the `<arg-spec>` tuples. The `<arg-spec>` name field uniquely identifies a specification, and is used to retrieve parsed argument values and check constraints.

name: a symbol to identify the argument

short: a symbol of the form `-x`, where *x* is a single character, see below

long: a symbol of the form `--x`, where *x* is a string

type: see Figure 15.1

help: a string or list of strings that describes the argument

conflicts: a list of `<arg-spec>` names

requires: a list of `<arg-spec>` names

To specify `-i` or `-I` for *short*, use `|-i|` and `|-I|` respectively to prevent Chez Scheme from reading them as the complex number `0 - 1i`.

| Type | Result |
|---------------------------|---|
| <code>bool</code> | <code>#t</code> |
| <code>count</code> | a positive integer |
| <code>(string x)</code> | a string |
| <code>(list x)</code> | a list of one item |
| <code>(list x ...)</code> | a list of one or more items up to the next argument |
| <code>(list . x)</code> | a list of the rest of the arguments |

For each type where *x* is specified, *x* is a string that is used in the help display.

Figure 15.1: Command-line argument types

The `list` types can support multiple *x* arguments, for instance `(list "i1" "i2")` would specify a list of two arguments.

```
visibility → show
           | hide
           | fit
```

When printing the help usage line, a *visibility* of `show` means the argument must be displayed. `hide` forces the argument to be hidden. `fit` displays the argument if it fits on the line.

```

how → short
    | long
    | opt
    | req

```

The *how* expands into input of the `format-spec` procedure according to Figure 15.2.

| | |
|--------------------|---|
| Keyword | Expands into: |
| <code>short</code> | <code>(opt (and short args))</code> |
| <code>long</code> | <code>(opt (and long args))</code> |
| <code>opt</code> | <code>(opt (and (or short long) args))</code> |
| <code>req</code> | <code>(req (and (or short long) args))</code> |

Figure 15.2: `cli-specs` *how* field

For options with *short* or *long* specified, `fit` and `opt` are the defaults. For other options, `show` and `req` are the defaults.

conflicts is a list of specification names that prevent this argument from processing correctly. When multiple command-line arguments are specified that are in conflict, an exception is raised.

requires is a list of other specification names that are necessary for this argument to be processed correctly. Unless all the required command-line arguments are specified, an exception is raised.

The `conflicts`, `requires`, and `usage` clauses may be specified in any order.

```

(display-help exe-name specs [args] [op]) procedure
returns: unspecified

```

The `display-help` procedure is equivalent to calling `display-usage` with a prefix of "Usage:" followed by `display-options`.

```

(display-options specs [args] [op]) procedure
returns: unspecified

```

For each specification in *specs*, the `display-options` procedure renders two columns of output to *op*, which defaults to the current output port. The first column renders the short and long form of the argument with its additional inputs. The second column renders the `<arg-spec>` `help` field and will automatically wrap if the `help-wrap-width` is exceeded.

If an *args* hash table is specified, the specified value appended to the second column. This is useful for displaying default or current values.

```

(display-usage prefix exe-name specs [width] [op]) procedure
returns: unspecified

```

The `display-usage` procedure displays the first line of help output to *op*, which defaults to the current output port. It starts with *prefix* and *exe-name* then attempts to fit *specs* onto the line using `format-spec`. When the line will exceed *width* characters, some arguments may collapse to `[options]`.

A *width* of `#f` defaults the line width to `help-wrap-width`.

(format-spec spec [how]) **procedure**

returns: a string

The `format-spec` procedure is responsible rendering `spec` as a string as specified by `how`. `format-spec` can display dashes in front of arguments, ellipses on list types, and brackets around optional arguments. A `how` of `#f` defaults to the `<arg-spec>` usage field.

| <i>how</i> | Return value: | | | | | | | | | | | | | | |
|----------------------------|---|-------------|---------------|-------------------|-----------------|--------------------|-----------------|-------------------------|-----|-----------------------|-----|---------------------------|---------|-------------------------|---------|
| <code>short</code> | "-x" if <i>spec short</i> is x, else <code>#f</code> | | | | | | | | | | | | | | |
| <code>long</code> | "--x" if <i>spec long</i> is x, else <code>#f</code> | | | | | | | | | | | | | | |
| <code>args</code> | The <i>spec type</i> is evaluated as follows: <table><thead><tr><th><i>type</i></th><th>Return value:</th></tr></thead><tbody><tr><td><code>bool</code></td><td><code>#f</code></td></tr><tr><td><code>count</code></td><td><code>#f</code></td></tr><tr><td><code>(string x)</code></td><td>"x"</td></tr><tr><td><code>(list x)</code></td><td>"x"</td></tr><tr><td><code>(list x ...)</code></td><td>"x ..."</td></tr><tr><td><code>(list . x)</code></td><td>"x ..."</td></tr></tbody></table> | <i>type</i> | Return value: | <code>bool</code> | <code>#f</code> | <code>count</code> | <code>#f</code> | <code>(string x)</code> | "x" | <code>(list x)</code> | "x" | <code>(list x ...)</code> | "x ..." | <code>(list . x)</code> | "x ..." |
| <i>type</i> | Return value: | | | | | | | | | | | | | | |
| <code>bool</code> | <code>#f</code> | | | | | | | | | | | | | | |
| <code>count</code> | <code>#f</code> | | | | | | | | | | | | | | |
| <code>(string x)</code> | "x" | | | | | | | | | | | | | | |
| <code>(list x)</code> | "x" | | | | | | | | | | | | | | |
| <code>(list x ...)</code> | "x ..." | | | | | | | | | | | | | | |
| <code>(list . x)</code> | "x ..." | | | | | | | | | | | | | | |
| <code>(or how ...)</code> | Recur and use the first non- <code>#f</code> | | | | | | | | | | | | | | |
| <code>(and how ...)</code> | Recur and concatenate all non- <code>#f</code> values | | | | | | | | | | | | | | |
| <code>(opt how)</code> | Recur and surround the result with square brackets [] if non- <code>#f</code> | | | | | | | | | | | | | | |
| <code>(req how)</code> | Recur and use the result | | | | | | | | | | | | | | |

help-wrap-width **parameter**

value: a positive fixnum

The `help-wrap-width` parameter specifies the default width for `display-usage` and `display-options`.

(parse-command-line-arguments specs [ls] [fail]) **procedure**

returns: a procedure

The `parse-command-line-arguments` procedure processes the elements of `ls` from left to right in a single pass. As it scans each `x` in `ls`, the parser must find a suitable `s` within `specs`. If a suitable `s` cannot be found, the parser reports an error by calling `fail`. Based on the type of `s`, the parser may consume additional elements following `x`. The type of `s` determines what data the parser records for that argument. When `s` is satisfied, the parser continues scanning the remaining elements of `ls`.

The parser returns a procedure `p` that accepts zero or one argument. When called with no arguments, `p` returns a hash table that maps the name of each `s` found while processing `ls` to the data recorded for that argument. When called with the name of an element `s` in `specs`, `p` returns the data, if any, recorded for that name in the hash table or else `#f`. If a particular `s` was not found while processing `ls`, the internal hash table has no entry for the name of `s` and `p` returns `#f` when given that name. If called with a name that is not in `specs`, `p` raises an exception.

The following table summarizes the parser's behavior.

| <code><arg-spec></code> | type | extra arguments consumed / recorded | return value of (<i>p name</i>) |
|--|------|---|-----------------------------------|
| <code>bool</code> | | none | #t |
| <code>count</code> | | none | an exact positive integer |
| <code>(string x)</code> | | one | a string |
| <code>(list x₀ ... x_n ...)</code> | | <i>n</i> or more, up to the next option | a list of strings |
| <code>(list x₀ ... x_n . rest)</code> | | at least <i>n</i> and all remaining | a list of strings |

By default *ls* is the value of `(command-line-arguments)` and *fail* is a procedure that applies `errorf` to its arguments. Providing a *fail* procedure allows a developer to accumulate parsing errors without necessarily generating exceptions.

`<arg-spec>` **tuple**

- name*: a symbol to use as the key of the output hash table
- type*: see Figure 15.1
- short*: **#f** | a character
- long*: **#f** | a string
- help*: a string or list of strings describing argument
- conflicts*: a list of `<arg-spec>` names
- requires*: a list of `<arg-spec>` names
- usage*: a list containing one *visibility* symbol and a `format-spec how` expression

Chapter 16

Parallel

16.1 Introduction

The parallel interface provides an API for spawning multiple worker processes and collecting results in a fault-tolerant system. Because Swish is single-threaded using lightweight processes, not all programs benefit from multiplexing using this mechanism. Programs that are I/O bound or spawn external OS processes benefit the most.

16.2 Theory of Operation

The (`swish parallel`) library implements a kernel capable of spawning multiple processes, managing their lifetimes, and collecting results. The processes involved are the caller, the kernel, and the workers. The caller is the user code intending to multiplex the work. The kernel spawns and manages the worker processes. Each worker process is responsible for one unit of user-code work. These processes are shown in Figure 16.1.

The desired behavior here is a uni-directional link, which is not native to Swish. To accomplish this, the caller starts the kernel using `spawn&link`, and the kernel enables `process-trap-exit`. An exit signal generated by a worker propagates to other workers, but does not signal the caller. An exit signal from the caller will propagate to the workers, and the kernel will complete normally.

The kernel is configured using `parallel:options`. The kernel starts up to `start-limit` worker processes using `spawn&link` in some `order`¹. As each worker completes, a new one starts. When all the workers complete, the kernel returns an API-specific value.

The kernel also supports a `timeout` for the entire parallel operation. When the timeout expires, all remaining workers are killed with the reason `timeout`, and an exception is thrown in the caller process.

Because the caller is not killed by the kernel, it acts as an observer of the kernel's behavior. As such, when an `event-mgr` process exists, the caller publishes `<child-start>` and `<child-end>` events described in Section 9.5. Because the potential number of workers may be high, the worker

¹Because workers are independent processes, start order does not guarantee execution order. Control of start order provides a mechanism to help detect and test for assumptions and errors in user code.

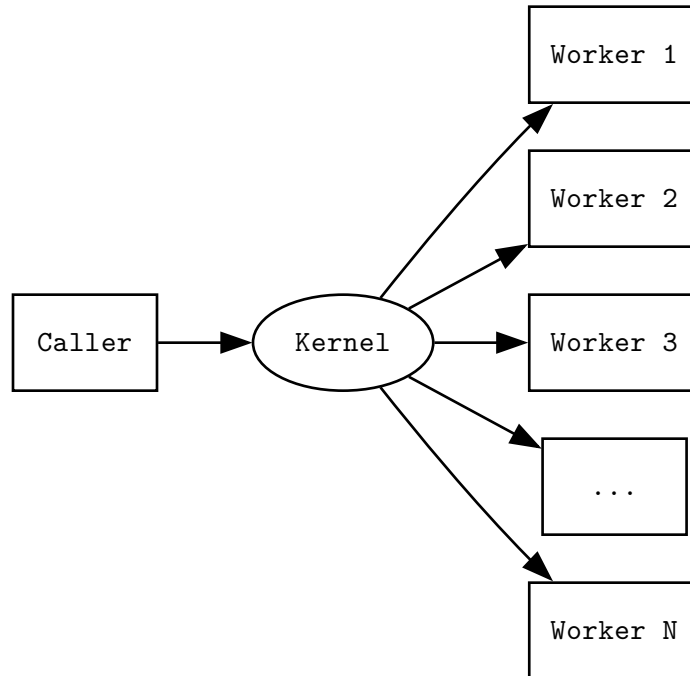


Figure 16.1: Parallel kernel

processes are not logged.

16.3 Programming Interface

Kernel options can be defined using `(parallel:options [option value] ...)`. The following options may be used:

| option | default | description |
|--------------------------|-------------------------------------|--|
| <code>start-limit</code> | <code>(most-positive-fixnum)</code> | a positive fixnum; the number of workers allowed to start and run concurrently |
| <code>order</code> | <code>random</code> | a symbol, one of <code>random</code> , <code>left</code> , or <code>right</code> |
| <code>timeout</code> | <code>infinity</code> | <code>infinity</code> or a nonnegative fixnum; the number of milliseconds the workers are allowed to execute before failing the entire operation |

```

(parallel () e ...)
(parallel ([option value] ...) e ...)
(parallel ,options e ...)

```

syntax

The `parallel` construct invokes each expression `e, ...` concurrently and returns a list of the resulting values. Expressions may run concurrently unless `start-limit` is 1.

The `(parallel ([option value] ...) e ...)` form constructs a copy of the default options, overriding each specified `option` with the specified `value`.

The `(parallel ,options e ...)` form allows you to specify an expression for the `parallel:options` object described in Section 16.3.

```
(parallel! () e ...) syntax  
(parallel! ([option value] ...) e ...)  
(parallel! ,options e ...)
```

The `parallel!` construct behaves as `parallel` but returns an unspecified value.

```
(parallel:execute [options] thunks) procedure  
returns: a list of results
```

The `parallel:execute` procedure takes a list of *thunks* (procedures of no arguments), each of which returns a single value. `parallel:execute` invokes the thunks concurrently and returns a list of the resulting values. Each *procedure* may run concurrently unless `start-limit` is 1.

The optional *options* argument is defined using `parallel:options` described in Section 16.3.

```
(parallel:execute! [options] thunks) procedure  
returns: unspecified
```

The `parallel:execute!` procedure behaves as `parallel:execute` but returns an unspecified value.

```
(parallel:for-each [options] procedure list1 list2 ...) procedure  
returns: unspecified
```

The `parallel:for-each` procedure works like the `parallel:map` procedure except that it does not accumulate and return a list of values. Each application of *procedure* may run concurrently unless `start-limit` is 1.

The optional *options* argument is defined using `parallel:options` described in Section 16.3.

```
(parallel:map [options] procedure list1 list2 ...) procedure  
returns: a list of results
```

The `parallel:map` procedure works like Chez Scheme's `map` procedure. Each application of *procedure* may run concurrently unless `start-limit` is 1.

The optional *options* argument is defined using `parallel:options` described in Section 16.3.

```
(parallel:vector-map [options] procedure vector1 vector2 ...) procedure  
returns: a vector of results
```

The `parallel:vector-map` procedure works like Chez Scheme's `vector-map` procedure. Each application of *procedure* may run concurrently unless `start-limit` is 1.

The optional *options* argument is defined using `parallel:options` described in Section 16.3.

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