The library, volume 2

The library, volume 2

The second volume of the report on raz. The first, `doc/raz.md`, defines the language; this one defines the modules that come with it, and refers to the first's sections by number, as "section 6.8". Only the core binds every implementation (appendix A of the first volume); the rest is the standard library.

Modules written in raz, in the compiler's `lib` directory:

Module	What
`Rt`	ending the program, `exit` and `atExit`; `stop`, which ends it with a message; `trace`, the calls under way; what the compiler's checks call when they fail
`Sys`	system calls: `open`, `openMode`, `openRead`, `create`, `read`, `write`, `seek`, `position`, `truncate`, `sync`, `syncAll`, `lock`, `close`, `dup`, `dupTo`, `dupAbove`, `keepOnExec`, `mmap`, `munmap`, `isTerminal`, `yield`, `exit`; files and directories, `rename`, `remove`, `removeDir`, `makeDir`, `chmod`, `access`, `umask`, `symlink`, `readLink`, `info`, `linkInfo`, `infoOf`, `openDir`, `nextEntry`, `entryKind`, `closeDir`; the terminal, `rawMode`, `restoreMode`, `getMode`, `setMode`, `termSize`, `ready`; the environment, `env`, `envAt`, `workDir`, `setWorkDir`; programs, `spawn` and `exec`, pipes and signals; the user, the machine, time used and limits; time, `clock`, `now`, `sleep`; `random`; sockets, among them datagrams served and files passed; and memory shared through a file. One file per target, and `Sys.raz` over the C library for the others
`Out`	writing text and numbers to standard output, buffered; safe to call from several threads
`C`	the parts of the C library the others use, and `printf`, `fflush`, `stdout`, `pthread_create`; a program that imports it uses C
`Lock`	a lock for short sections, for C's threads and `Thread`'s alike
`Thread`	threads, `spawn` and `join`, and `Mutex`, in any program; in one that uses C, made by C's `pthread_create`
`Mem`	`Allocator`, the interface of every allocator, and pages from the system
`Heap`	a general allocator, `Heap.heap`, safe to call from several threads; freeing a block twice, or one it never gave out, stops the program
`Arena`	an allocator that frees everything at once; `ADR(arena.base)` is its allocator
`Str`	operations on `[]U8` strings: comparing, hashing, finding, trimming and cutting, case, joining and replacing, UTF-8, numbers to and from text

Module	What
`Bytes`	searches of bytes, many at a time: `index`, `last`, `count` and `find` in a `[]U8`; one file per target where the target has instructions for it
`Buf`	a growable byte buffer
`Fmt`	formatted output: `Fmt.print("{} of {}\n", [Fmt.int(n), Fmt.real(x, 2)])`, or into a `Buf` with `Fmt.write`
`List`	a generic singly linked list, `List(T)`
`Map`	a generic hash map, `Map(K, V; hash, eq)`
`Vec`	a generic growable array, `Vec(T)`, indexed as a slice
`Sort`	sorting a slice in place, `Sort(T; less)`
`Math`	roots, powers, logarithms, rounding and trigonometry, and `pi`, for `F64`
`Files`	an argument as a string, and a whole file read or written
`Opt`	a command line read through one table, by `getopt`'s rules with long options; its help and its mistakes
`Width`	how many columns of a terminal a character, or a string, takes: 0, 1 or 2, as `wcwidth` says

Lengths, counts, file descriptors, process ids and statuses are `INT`s, and a character is an `I32`. What may pass an `INT` on a small target is an `I64`: a file's size and position, a time in nanoseconds, and a number read from text.

What follows is each module's interface, as `tools/Doc.raz` prints it from the module's file; `...` stands for fields that are the module's own. A module's `main`, where it has one, is its test, and is left out here.

```
module Rt;
const Full*: ERROR = "too many procedures to run at exit";
proc atExit*(p: proc): ERROR;   (* p run when the program ends by exit *)
proc exit*(status: INT);        (* the atExit procedures, the last first, then the end
*)
proc stop*(msg: []U8);          (* msg, and a line feed, on standard error, then exit
with status 2 *)
proc trace*;                    (* the calls under way, and their variables, on
standard error *)
```

`Rt` also holds what the compiler's checks call when they fail, and the handlers of the signals that stop a program (section 10). `exit` takes each procedure off the list before it runs it, so it runs once even if it fails or calls `exit` itself; in a program that uses C, it ends through C's `exit`, so that C flushes its buffers too.

```
module Mem;
type
    Allocator* = record
        alloc*: proc(a: ^Allocator; size, align: INT): ^U8;   (* nil if out of room *)
        free*:  proc(a: ^Allocator; p: ^U8);
    end;
const Page* = 4096;
proc pages*(size: INT): ^U8;         (* size bytes, in whole pages, zeroed; or nil *)
proc unmap*(p: ^U8; size: INT);      (* pages given back *)
proc alloc*(a: ^Allocator; size, align: INT): ^U8;   (* a^.alloc(a, size, align) *)
proc free*(a: ^Allocator; p: ^U8);   (* a^.free(a, p) *)

module Heap;
var heap*: ^Mem.Allocator;

module Arena;
type Arena* = record
    base*: Mem.Allocator;     (* first, so that ^Arena(a) finds the rest *)
    ...
end;
proc init*(ar: ^Arena; size: INT): BOOL;   (* an arena of size bytes; false if the
system has none *)
proc reset*(ar: ^Arena);                   (* every allocation forgotten; the memory
used again *)
proc done*(ar: ^Arena);                    (* its memory given back *)
```

`NEW(p, a)` calls `a^.alloc`. `Heap` is the general allocator. An arena hands out memory from one block: its `free` does nothing, and `reset` forgets everything.

```
module Lock;
type Lock* = record ... end;
proc take*(l: ^Lock);
proc give*(l: ^Lock);

module Thread;
const Failed*: ERROR = "can't start a thread";
type
    Thread* = record ... end;
    Mutex* = record ... end;     (* zero is free *)
proc spawn*(p: proc(arg: ^U8); arg: ^U8): (^Thread, ERROR);   (* p(arg) in a new
thread *)
proc join*(t: ^Thread);         (* waits for t to end, then frees its stack *)
proc lock*(m: ^Mutex);
proc unlock*(m: ^Mutex);
```

A `Lock` is for short sections: a thread that finds it taken tries again, giving up the processor now and then. A `Mutex` sleeps. Each of `Thread`’s threads runs on a stack of its own, with a page below it that can’t be touched, so that running off the stack stops the program with a message, as in the main thread. In a program that uses C, `Thread` makes its threads with C’s `pthread_create`, so that C’s library knows of them; in one that doesn’t, with the system’s own calls. The program is the same either way.

```
module Out;
proc str*(s: []U8);
proc char*(c: U8);
proc ln*;                          (* a line feed *)
proc int*(n: I64);                 (* n in decimal *)
proc hex*(n: U64; digits: INT);  (* n in hexadecimal, digits digits at least *)
proc flush*;
```

Out and C's stdio. `Out` keeps a buffer of `Sys.outSize` bytes, 4 KB on Linux. It writes it out when it is full, at each line feed when standard output is a terminal, at `Out.flush`, and when the program ends by `Rt.exit`. A lock keeps what each call writes together when threads write at once. C's `stdio` keeps a buffer of its own for the same standard output. A program that writes with both flushes one before writing with the other, or the text comes out of order:

```
module Both;
import Out, C;      (* C: printf, fflush and C's FILE *stdout *)

proc main*;
begin
    Out.str("from raz\n");
    Out.flush;
    C.printf("from C\n");
    C.fflush(C.stdout);
    Out.str("from raz again\n");
end;

end Both.
```

Sys gives every target the same procedures, so that a program that needs only these runs wherever raz does: through system calls on Linux, through the C library elsewhere. A result that can fail is a number, minus an errno, as on Linux; 0 is success.

```
module Sys;
const
    stdin* = 0; stdout* = 1; stderr* = 2;
    outSize* = 4096;    (* the bytes Out keeps; each target has its own *)
    (* signals, by their numbers on Linux; each target has its own *)
    sigHup* = 1; sigInt* = 2; sigQuit* = 3; sigKill* = 9; sigPipe* = 13;
    sigTerm* = 15; sigChld* = 17; sigCont* = 18; sigStop* = 19;
    sigTstp* = 20; sigTtin* = 21; sigTtou* = 22; sigWinch* = 28;
    sigUsr1* = 10; sigUsr2* = 12; sigAlrm* = 14;
    (* the limits limit and setLimit take, by their numbers on Linux; each target has
its own *)
    limitCpu* = 0; limitFileSize* = 1; limitData* = 2; limitStack* = 3;
    limitCore* = 4; limitProcs* = 6; limitFiles* = 7; limitMemory* = 9;

type
    Access* = (reading, writing, creating, exclusive, truncating, appending,
executing);
    Accesses* = set of Access;
    Info* = record
        size*: I64;      (* in bytes *)
        mtime*: I64;     (* when its contents last changed, in nanoseconds since 1970
*)
        mode*: INT;      (* its permission bits, as chmod takes them: 1EDH is rwxr-xr-
x *)
        dir*: BOOL;      (* a directory *)
        file*: BOOL;     (* a regular file: not a directory, device, pipe or socket *)
        symlink*: BOOL;  (* the path itself is a symbolic link *)
        ino*: U64;       (* its inode, which a rename keeps and a new file doesn't *)
        dev*: U64;       (* the file system it is on; with ino, it names the file *)
    end;
    Kind* = (unknown, isFile, isDir, isLink, isOther);   (* what a directory says a
name in it is *)
    Dir* = record ... end;   (* an open directory; its fields are the target's *)
    Program* = record
        path*: []U8;
        args*: [][]U8;      (* the first is its name *)
        env*: [][]U8;       (* NAME=value, each added to this program's environment *)
        onlyEnv*: BOOL;     (* env is its whole environment *)
        dir*: []U8;         (* its working directory; "" for this program's *)
        fds*: [3]INT;       (* its standard input, output and error; 0 for this
program's own *)
        group*: INT;        (* the process group it joins: 0 for this program's, -1 a
new one it leads *)
        foreground*: BOOL;  (* its group takes the terminal on standard input *)
        tty*: INT;          (* a pseudo-terminal's fd, to start a session on; 0 for
none *)
        more*: []INT;       (* fds above 2 passed on to it, at the same numbers *)
    end;
    Status* = (running, exited, killed, stopped);
    Mode* = record ... end;   (* a terminal's modes; its fields are the target's *)
    Peer* = record ... end;   (* whom a datagram came from *)

proc write*(fd: INT; s: []U8): INT;     (* the bytes written *)
proc read*(fd: INT; buf: []U8): INT;    (* the bytes read; 0 at the end *)
proc open*(path: []U8; how: Accesses): INT;   (* its fd *)
```

```
proc openMode*(path: []U8; how: Accesses; mode: INT): INT;   (* open, a file it makes
given mode *)
proc openRead*(path: []U8): INT;         (* open(path, {reading}) *)
proc create*(path: []U8): INT;           (* open(path, {writing, creating,
truncating}) *)
proc seek*(fd: INT; pos: I64; fromEnd: BOOL): I64;  (* the new position *)
proc position*(fd: INT): I64;            (* where the next read or write is *)
proc truncate*(fd: INT; size: I64): INT; (* the file made size bytes long *)
proc sync*(fd: INT): INT;                (* what was written to it, on the disk *)
proc syncAll*(fd: INT): INT;             (* all that was written to its file system,
on the disk *)
proc lock*(fd: INT; wait: BOOL): INT;    (* the file's lock, held until fd is closed
*)
proc close*(fd: INT);
proc dup*(fd: INT): INT;                 (* a new fd for the same file, the lowest
free *)
proc dupTo*(fd, into: INT): INT;         (* into made the same file as fd, closing
what it was *)
proc dupAbove*(fd, least: INT): INT;     (* a new fd for the same file, the lowest
free from least on, closed on exec *)
proc keepOnExec*(fd: INT; yes: BOOL): INT;   (* fd left open, or not, in the program
exec runs *)
proc isTerminal*(fd: INT): BOOL;
proc mmap*(size: INT): ^U8;              (* size bytes of zeroed memory, in whole
pages; or nil *)
proc munmap*(p: ^U8; size: INT);
proc yield*;                             (* the processor given to another thread *)
proc exit*(status: INT);                 (* the program ended at once, without Rt's
atExit *)

proc rename*(old, new: []U8): INT;       (* replaces what new names *)
proc remove*(path: []U8): INT;           (* a file, not a directory *)
proc removeDir*(path: []U8): INT;        (* an empty directory *)
proc makeDir*(path: []U8): INT;          (* readable by all, writable by its owner *)
proc chmod*(path: []U8; mode: INT): INT;
proc access*(path: []U8; how: Accesses): INT;   (* 0 if this user may read, write or
execute it *)
proc umask*(mask: INT): INT;             (* the bits taken from every file made; the
mask it was *)
proc symlink*(target, path: []U8): INT;  (* path made a link to target *)
proc readLink*(path: []U8): ([]U8, INT); (* what the link names, good until the next
call *)
proc info*(path: []U8): (Info, INT);     (* following a symbolic link *)
proc linkInfo*(path: []U8): (Info, INT); (* the link itself *)
proc infoOf*(fd: INT): (Info, INT);      (* the open file's *)
proc space*(path: []U8): (I64, I64, INT);   (* the bytes free and in all on path's
file system *)

proc openDir*(d: ^Dir; path: []U8): INT;
proc nextEntry*(d: ^Dir): ([]U8, BOOL);  (* a name, good until the next call; false at
the end *)
proc entryKind*(d: ^Dir): Kind;          (* what the name nextEntry gave last is *)
proc closeDir*(d: ^Dir);

proc rawMode*(fd: INT): BOOL;      (* the terminal on fd: no echo, no lines, no
signals *)
```

```
proc restoreMode*(fd: INT);        (* as rawMode found it *)
proc getMode*(fd: INT): (Mode, INT);     (* the terminal's modes, to set again *)
proc setMode*(fd: INT; m: Mode): INT;    (* once what was written to it is sent *)
proc termSize*(fd: INT): (INT, INT);   (* columns and rows; 80 and 24 if unknown *)
proc ready*(fd, ms: INT): BOOL;          (* something to read within ms, or ever if ms
< 0 *)
proc readyOf*(fds: []INT; ms: INT): INT;   (* the first of fds with something to read
within ms, or -1 *)
proc readyFor*(reads, writes: []INT; ms: INT): INT;   (* readyOf, and the first of
writes with room to write *)
proc setBlocking*(fd: INT; yes: BOOL): INT;   (* if not yes, a read or write that
would wait is -11 at once *)

proc env*(name: []U8): []U8;       (* the environment variable's value; "" if unset *)
proc envAt*(i: INT): ([]U8, BOOL); (* the environment's ith NAME=value, from 0; false
past the last *)
proc workDir*: ([]U8, INT);        (* the working directory, good until the next call
*)
proc setWorkDir*(path: []U8): INT;

proc pipe*: (INT, INT);            (* the fd to read and the fd to write; or minus an
errno and -1 *)
proc openPty*: INT;                (* a pseudo-terminal: the fd of its controlling
side *)
proc setTermSize*(fd, cols, rows: INT): INT;   (* the size its programs are told of *)
proc spawn*(p: Program): INT;      (* a program started: its process id *)
proc exec*(p: Program): INT;       (* p run in this program's place; returns only if
it can't *)
proc fork*: INT;                   (* this program copied: 0 in the copy, its process
id in this one *)
proc wait*(pid: INT; block: BOOL): (INT, Status, INT);   (* which program, how, and
its code *)
proc kill*(pid, signal: INT): INT;
proc pid*: INT;                    (* this program's process id *)
proc group*: INT;                  (* the process group this program is in *)
proc setGroup*(pid, group: INT): INT;    (* pid 0 is this program; group 0 a new one
pid leads *)
proc foreground*(fd, group: INT): INT;   (* the terminal on fd gives its keys to group
*)
proc foregroundOf*(fd: INT): INT;  (* the group the terminal on fd gives its keys to
*)
proc uid*: INT;                    (* the user this program runs as *)
proc euid*: INT;                   (* the user whose rights it has: 0 is root *)
proc hostName*: ([]U8, INT);       (* this machine's name, good until the next call *)
proc cpuTime*(children: BOOL): (I64, I64);   (* ns used in the program and in the
system; or by its children *)
proc limit*(which: INT): (I64, I64, INT);    (* the soft limit and the hard; -1 for
none *)
proc setLimit*(which: INT; soft, hard: I64): INT;

proc catch*(sigs: []INT): INT;     (* sigs caught: an fd to wait on *)
proc caught*(fd: INT): INT;        (* the next signal caught, or 0 if none is waiting
*)
proc ignore*(sig: INT; yes: BOOL): INT;  (* sig ignored; or, if not yes, back to what
it does at first *)
proc handle*(sig: INT): INT;       (* sig noted, for came; a system call it comes
```

```
during is -4 *)
proc came*(sig: INT): BOOL;        (* whether sig came since the last time it was
asked *)

proc clock*: I64;                  (* nanoseconds, on a clock that only goes forward
*)
proc now*: I64;                    (* nanoseconds since 1970-01-01, UTC *)
proc sleep*(ms: INT);
proc random*(b: []U8);             (* b filled with random bytes *)

proc connect*(path: []U8): INT;    (* a stream socket, connected to the Unix socket at
path: its fd *)
proc connectTcp*(addr: []U8; port: INT): INT;   (* addr an IPv4 or IPv6 address, as
numbers *)
proc connectUdp*(addr: []U8; port: INT): INT;
proc listen*(path: []U8): INT;     (* a Unix socket made at path, taking connections
*)
proc listenTcp*(addr: []U8; port: INT): INT;
proc accept*(fd: INT): INT;        (* the next connection, waiting for one *)
proc send*(fd: INT; s: []U8): INT; (* write, to a socket: -32 (EPIPE), not a signal,
if it is closed *)
proc connectTcpWithin*(addr: []U8; port, ms: INT): INT;   (* connectTcp, or -110
(ETIMEDOUT) after ms *)
proc listenUdp*(addr: []U8; port: INT): INT;   (* a socket of datagrams on port at
addr *)
proc receive*(fd: INT; buf: []U8): (INT, Peer);   (* the next datagram, in buf, and
who sent it *)
proc reply*(fd: INT; peer: Peer; s: []U8): INT;   (* s, as one datagram, to peer *)
proc localPort*(fd: INT): INT;     (* the port the socket fd is bound to *)
proc sendFds*(fd: INT; s: []U8; fds: []INT): INT;   (* send, and with it fds, to a
Unix socket *)
proc receiveFds*(fd: INT; buf: []U8; fds: []INT): (INT, INT);   (* read, and the fds
that came with it *)

proc memFile*(size: INT): INT;     (* a file of size zero bytes, in memory, with no
name: its fd *)
proc mapFile*(fd, size: INT): ^U8; (* the first size bytes of fd, shared; munmap gives
them back; or nil *)
```

`info` follows a symbolic link: `size`, `dir` and `file` are those of what it names, and `symlink` says the path was a link, so that a program walking a tree can choose not to follow one back up it. A link to nothing is `-ENOENT`, as a missing file is. `file` lets a walk open only what holds data: opening a pipe would wait for a program to write to it.

`nextEntry` gives every name in the directory except `.` and `..`, in no particular order. `entryKind` says what the name it gave last is, a file, a directory, a symbolic link (whatever it names) or something else, as the directory itself records it, so that a program walking a tree needn't ask `linkInfo` of every name, a system call each; where the file system doesn't record it, it is `unknown`, and `linkInfo` must be asked. `rawMode` turns off what the terminal does with keys before the program reads them (echo, line editing, signals, flow control), and NL to CR NL on output. A program that turns it on restores it before it ends: `Rt.atExit` is the place.

Files. `open` gives a file for what `how` asks: `reading`, `writing` or both; `creating` it if it is missing, readable by all and writable by its owner; with `exclusive`, failing with -17 (EEXIST) if it is there, as a program does that

makes a lock or a file of its own; `truncating` it to nothing; `appending`, each write going to its end, however other programs write it too. `openMode` is `open` that gives a file it makes the bits `mode`, less those the umask takes away: 1EDH (755) for a program, 124H (444) for a file never to be written; `open` gives 1A4H (644). `seek` moves to `pos` from the start of the file, or from its end if `fromEnd`, where a negative `pos` reads back from the end; `position` says where the file is, without moving. `truncate` makes the file `size` bytes long, cutting it or adding zeros, and leaves the position where it was. `sync` returns once what was written to the file is on the disk, as a program needs before it says a file is saved; `syncAll` returns once everything written to the file system that holds the file is on the disk, at once rather than a file at a time, and may flush other file systems too. `lock` takes the file's lock, which one open file holds at a time: another that asks for it waits if `wait`, and otherwise fails with -11 (EAGAIN). The lock goes when the file is closed or the program ends, however it ends, so it never goes stale as a file made with `exclusive` does. `infoOf` is `info` of an open file: its size is what it holds now, however it was written; `linkInfo` is `info` of a symbolic link itself, not what it names, so that `symlink` is true, `dir` and `file` false, and `size` the length of what it names, which need not be there. `Info.mtime` is what a program checks to see whether a file changed under it, and `Info.ino` whether it is still the same file, not one renamed over it; 0 on a target whose files have none. `Info.dev` is the file system the file is on: two files are one only if both `dev` and `ino` agree, which is how a program following links finds that one has led it back into a directory it is already in. `Info.mode` holds the nine bits of `rwxrwxrwx`, and `chmod` sets them, 1EDH (755) for a program, 1A4H (644) for data.

Programs. `openPty` makes a pseudo-terminal, a terminal that a program, a terminal emulator, plays the screen and the keyboard of: what it writes to the fd is typed, and what the programs on the terminal write it reads.

`spawn` starts the program at `p.path`, with `p.args` as its arguments, the first being its name. A `p.path` without a `/` is looked for as a shell looks for a command, and as C's `execvp` does: in each directory of this program's `PATH` in turn, an empty one being the working directory, or of `/bin:/usr/bin` if `PATH` is unset or empty; the first that runs is the program. Its environment is this program's with each `NAME=value` of `p.env` added or put in place of the old value, or, if `p.onlyEnv`, `p.env` alone. It starts in `p.dir`. Its standard input, output and error are `p.fds`; a 0 gives it this program's own, so `{path: "ls", args: ["ls"]}` runs `ls` as a shell runs it, with every other field zero. It gets no other open file but those of `p.more`, each at its own number, as a shell passes `3<file` on, every signal does what it does at first, and none is blocked. If `p.tty` is a pseudo-terminal's fd, the program starts a session on that terminal: it is its controlling terminal, and its standard input, output and error, and `p.fds` and `p.group` are not used.

`p.group` puts the program in a process group, the programs that a shell's job is made of: -1 makes it the first of a new group, whose number is its process id, and the other programs of the job join that number. The terminal gives its keys, and the signals of Ctrl-C and Ctrl-Z, to one group, the one in its foreground: `p.foreground` puts the program's group there before it starts, and `foreground` puts any group there, as a shell does to take the terminal back. `setGroup` moves a program to a group, as the shell does for each program it starts, for whichever of the two runs first; a shell runs in a group of its own, `setGroup(0, 0)`.

`exec` runs the program `p` describes in this program's place, as a shell's `exec cmd` does, found and started as `spawn` would start it, `p.tty`, `p.group`, `p.foreground`, `p.fds` and `p.dir` included, except that it keeps this program's other open files: each stays open in the program unless `keepOnExec(fd, false)` was said of it, as it is of `pipe`'s, and those of `p.more` are kept. It returns only if the program can't run: -2 (ENOENT) or -13 (EACCES) if there is none to run, with nothing done; or, if the program is found but won't start, minus the errno, with what `p` asks of the terminal, the group, the files and the directory done, and this program's signals as they were.

A shell moves its own files with `dup` and `dupTo`, for `2>&1` and `exec >log` and around a builtin: `dupTo(fd, into)` makes `into` the same open file as `fd`, closing what `into` was, and `dup` gives a new fd for it, the lowest free, as a shell saves a file to give it back. `dupAbove(fd, 10)` gives one at 10 or above, closed on exec, out of the way of the fds a script names (`3>log`), as a shell keeps its own. `fork` copies this program, which goes on from there in both: it is 0 in the copy and the copy's process id in this one, as a shell runs a builtin or a procedure as a stage of a pipe. Only the thread that calls it is copied, so a program with threads mustn't; and what `Out` keeps is copied too, to be written twice, so `Out.flush` comes first. `group` is the process group this program is in: a shell starting on a terminal waits until it is `foregroundOf(0)` before it takes it. `access` says whether this user, by its real ids, may read, write or execute a file, as `test -r`, `-w` and `-x` ask, which `Info.mode` alone can't say; an empty `how` asks only whether it is there. `open` refuses `executing`, with -22 (EINVAL). `umask` sets the bits taken away from the mode of every file this program, and those it starts, make, and says what they were. `envAt` gives the environment one variable at a time, from 0, for a shell to list it and to pass it on whole with `onlyEnv`. `getMode` reads a terminal's modes, and `setMode` sets them again once what was written is sent, so that a shell keeps them for each job: a program stopped by Ctrl-Z with its terminal raw gets it back raw, and the shell its own between. `cpuTime` says how long the processor ran this program, in its own code and in the system for it, or, if `children`, the programs it started and has waited for, as `time` and `times` say. `limit` gives a limit, `limitFiles` say, soft and hard, and `setLimit` sets them, as `ulimit` does: a program may raise its soft limit up to the hard one, and lower either. `uid` is the user this program runs as, `euid` the one whose rights it has, 0 for root, as a prompt shows `#`; `hostName` is the machine's name.

`wait` waits for the program `pid` to change, for any of this program's if `pid` is -1, or for any of the group `g` if `pid` is `-g`, as a shell waits for a job's programs, and says which one, and how: `exited`, with its exit status; `killed`, with the number of the signal that ended it; or `stopped`, by Ctrl-Z or a signal, with the signal's number. Without `block` it doesn't wait, and is 0 and `running` if no program changed. A program that has nothing to wait for is -10 (ECHILD). `kill` sends a program a signal, `sigTerm` to end it; to a group, if `pid` is minus its number.

Signals. `catch` takes the signals `sigs` away from what they would do, ending the program most of them, and gives an fd that is ready to read when one comes, so that a program waits for signals with `ready` and `readyOf` as it waits for keys or a server. `caught` gives each signal that came, in turn. A later `catch` adds to the signals caught and gives the same fd. Catching `sigKill` or `sigStop`, or the signals `Rt` reports, SIGSEGV and SIGFPE, is -22 (EINVAL). `ignore` makes a signal do nothing, as a shell ignores `sigTtou` so that it can take its terminal back, and `ignore(sig, false)` gives it back what it does at first. A program that `spawn` starts begins with neither.

`handle` is for a program that must see a signal while it waits in a system call, as a shell waiting for its foreground program, or for a key, sees Ctrl-C: the signal is noted, and the call it comes during, `wait`, `read`, `ready` and the rest, fails with -4 (EINTR) rather than going on; `sleep` sleeps its time all the same. `came(sig)` says whether it came since the last time it was asked. Nothing else runs when the signal comes, so the program does what it does after it, in its own time; `Out` and `Files` try again after -4. `ignore(sig, false)` gives the signal back what it does at first, and the signals `catch` refuses, `handle` refuses too.

Time. `clock` is for measuring how long something takes: it never goes back, and says nothing of the date. `now` is the date and time, which a person or the network may set back. `sleep` waits `ms` milliseconds.

Sockets. `connect` is for talking to a server on the same machine, an X server at `/tmp/.X11-unix/X0` say; `connectTcp` for one across the network, given its address as numbers, `"127.0.0.1"` or `"::1"`: turning a name into an address is a library's work over these. `connectUdp` gives a socket of datagrams, each `send` one message

to that address and each `read` one message from it, as a program asks a name server. What a socket receives comes by `read`, what it sends goes by `send`, and `close` ends it. `send` is `write` for a socket, except when the other end has closed it: `write` would stop the program with the signal SIGPIPE, where `send` returns -32 (EPIPE), so that a program learns its server has gone and can end as it wants. `listen` and `listenTcp` are the other side: a server's socket, on `path`, which must not be there yet, or on `port` at `addr`, `"0.0.0.0"` or `"::"` for every address the machine has; `accept` gives each connection that comes, as a socket of its own. A server started on port 0 gets a port the system chooses, which `localPort` says, as a test does that must not take a port in use. `connectTcp` waits as long as the system does, minutes for a host that never answers; `connectTcpWithin` gives up after `ms` milliseconds, with -110 (ETIMEDOUT).

`listenUdp` is the server's side of `connectUdp`: a socket of datagrams from anyone, as a name server has. `receive` gives the next datagram, at most `LEN(buf)` bytes of it, the rest lost, and a `Peer` that `reply` sends an answer to.

Passing files and sharing memory. A program can give another an open file over a Unix socket: `sendFds` sends `s`, at least one byte, and with it `fds`, at most 16, each a file the other program then has open too; `receiveFds` reads into `buf` as `read` does, puts the fds that came with it in `fds`, as many as there is room for, closing the rest, and says how many bytes and how many fds. Each is closed in a program exec starts. `memFile` makes a file that lives in memory, of `size` zeroed bytes, and `mapFile` maps it, or any file, so that what one program writes there another sees at once: so a program hands an X server or a Wayland compositor its pixels, by `sendFds` of a `memFile` both map, rather than by copying them down a socket.

`readyOf` waits on several file descriptors at once, as a program does that listens to a server and a terminal both; a descriptor at its end, or failed, counts as ready, since a read of it won't wait. It looks at the first 64 of `fds`, and `connect` and `listen` take a path of at most 107 bytes, as `struct sockaddr_un` holds; a longer one is -36 (ENAMETOOLONG).

A program that both reads from a descriptor and writes much to it, as a terminal writes what is pasted to its program while it reads what the program writes back, must not wait on either: the program may be waiting for its own writes to be read. `setBlocking(fd, false)` has a read or a write on `fd` that would wait return -11 (EAGAIN) at once, a write having written what there was room for; `readyFor` waits, as `readyOf` does, for something to read on any of `reads` or for room to write on any of `writes`. A descriptor in both is given once, when it is ready for either; the 64 it looks at are `reads`, then `writes`.

Strings, buffers and collections.

```
module Str;
proc cmp*(a, b: []U8): INT;           (* -1, 0 or 1 as a sorts before, with or after
b, byte by byte *)
proc eq*(a, b: []U8): BOOL;
proc eqFold*(a, b: []U8): BOOL;       (* eq, an ASCII letter's capital and small the
same *)
proc copy*(a: ^Mem.Allocator; s: []U8): ([]U8, BOOL);   (* s's bytes in memory from a;
false if a has none *)
proc free*(a: ^Mem.Allocator; s: []U8);                 (* what copy gave from a,
given back; "" is none *)
proc hash*(s: []U8): U64;             (* FNV-1a, 64 bits *)
proc find*(s, sub: []U8): INT;        (* where sub first starts in s, or -1 *)
proc findLast*(s, sub: []U8): INT;    (* where sub last starts in s, or -1 *)
proc hasPrefix*(s, p: []U8): BOOL;
proc hasSuffix*(s, x: []U8): BOOL;
proc trim*(s: []U8): []U8;            (* s without the spaces at either end *)
proc trimLeft*(s: []U8): []U8;        (* s without the spaces at its start *)
proc trimRight*(s: []U8): []U8;       (* s without the spaces at its end *)
proc cut*(s, sep: []U8): ([]U8, []U8, BOOL);   (* what comes before the first sep, and
after it *)
proc field*(s: []U8): ([]U8, []U8);   (* the first run of bytes in s that aren't
spaces, and what follows it *)
proc lower*(s: []U8);                 (* s's ASCII capitals made small, in place *)
proc upper*(s: []U8);                 (* s's ASCII small letters made capitals, in
place *)
proc join*(b: ^Buf.Buf; parts: [][]U8; sep: []U8);   (* the parts added to b, sep
between each two *)
proc replace*(b: ^Buf.Buf; s, old, new: []U8);       (* s added to b, with new for
each old in it *)
proc encode*(c: I32): ([4]U8, INT);   (* c in UTF-8: its bytes, and how many *)
proc decode*(s: []U8): (I32, INT);    (* the character s starts with, and its length
in bytes *)
proc decodeLast*(s: []U8): (I32, INT);   (* the character s ends with, and its length
in bytes *)
proc next*(s: []U8; i: INT): (I32, INT);  (* the character at i, and where the next
starts; -1 at the end *)
proc valid*(s: []U8): BOOL;           (* s is UTF-8, every character rightly spelled
*)
proc chars*(s: []U8): INT;            (* the characters in s, as decode reads them *)
proc toInt*(s: []U8): (I64, BOOL);    (* s, in decimal; false if it isn't a number an
I64 holds *)
proc toHex*(s: []U8): (U64, BOOL);    (* s, in hexadecimal; false if it isn't a number
a U64 holds *)
proc fromInt*(n: I64): ([20]U8, INT); (* n in decimal: its bytes, and how many *)
proc le*(s: []U8): U64;               (* s, at most 8 bytes, the first the lowest *)
proc be*(s: []U8): U64;               (* s, at most 8 bytes, the first the highest *)
proc putLE*(s: []U8; v: U64);         (* v into s, the lowest byte first *)
proc putBE*(s: []U8; v: U64);         (* v into s, the highest byte first *)

module Buf;
type Buf* = record len*: INT; ... end;
proc init*(b: ^Buf; a: ^Mem.Allocator);
proc room*(b: ^Buf; n: INT): BOOL;    (* room for n more bytes; false if the allocator
has none *)
proc add*(b: ^Buf; c: U8);
```

```
proc str*(b: ^Buf; s: []U8);
proc spare*(b: ^Buf; n: INT): []U8;   (* room for n more bytes, and those bytes, to
fill *)
proc bytes*(b: ^Buf): []U8;           (* what it holds, until it next grows *)
proc reset*(b: ^Buf);                 (* emptied, its memory kept *)
proc done*(b: ^Buf);                  (* its memory given back *)

module Fmt;
type Arg* = variant
    int(i: I64);
    uint(u: U64);
    hex(h: U64);
    str(s: []U8);
    char(c: U8);
    bool(b: BOOL);
    real(r: F64; places: INT);
end;
proc print*(f: []U8; args: []Arg);              (* to standard output *)
proc write*(b: ^Buf.Buf; f: []U8; args: []Arg); (* added to b *)

module List(T);
type
    Node* = record next*: ^Node; val*: T; end;
    List* = record head*: ^Node; len*: INT; ... end;
proc init*(l: ^List; a: ^Mem.Allocator);
proc push*(l: ^List; v: T): BOOL;     (* v at the front; false if the allocator has no
room *)
proc pop*(l: ^List): (T, BOOL);       (* the front value, taken off; false if the list
is empty *)
proc reverse*(l: ^List);
proc clear*(l: ^List);

module Map(K, V; hash: proc(k: K): U64; eq: proc(a, b: K): BOOL);
type Map* = record len*: INT; ... end;
proc init*(m: ^Map; a: ^Mem.Allocator);
proc put*(m: ^Map; k: K; v: V): BOOL;         (* k now maps to v; false if there was
no room *)
proc remove*(m: ^Map; k: K): BOOL;            (* false if k wasn't there *)
proc get*(m: ^Map; k: K): (V, BOOL);          (* what k maps to, and whether it maps
to anything *)
proc next*(m: ^Map; i: INT): (INT, K, V);     (* the entry after i *)
proc done*(m: ^Map);                          (* its memory given back, leaving it
empty *)

module Vec(T);
type Vec* = record len*: INT; ... end;
proc init*(v: ^Vec; a: ^Mem.Allocator);
proc room*(v: ^Vec; n: INT): BOOL;    (* room for n more; false if the allocator has
none *)
proc push*(v: ^Vec; x: T);            (* x added at the end *)
proc add*(v: ^Vec): ^T;               (* a new element at the end, zero, to fill in
place *)
proc resize*(v: ^Vec; n: INT);        (* n elements: cut short, or the new ones zero
*)
proc all*(v: ^Vec): []T;              (* the elements, until it next grows *)
proc reset*(v: ^Vec);                 (* emptied, its memory kept *)
```

```
proc done*(v: ^Vec);                  (* its memory given back *)

module Sort(T; less: proc(a, b: T): BOOL);
proc sort*(s: []T);

module Math;
const pi* = 3.141592653589793;
proc sqrt*(x: F64): F64;
proc pow*(x, y: F64): F64;            (* x to the power y *)
proc floor*(x: F64): F64;
proc ceil*(x: F64): F64;
proc round*(x: F64): F64;             (* to the nearest whole number; a half away from
0 *)
proc exp*(x: F64): F64;
proc ln*(x: F64): F64;
proc log2*(x: F64): F64;
proc log10*(x: F64): F64;
proc sin*(x: F64): F64;
proc cos*(x: F64): F64;
proc tan*(x: F64): F64;
proc asin*(x: F64): F64;              (* from -pi/2 to pi/2 *)
proc acos*(x: F64): F64;              (* from 0 to pi *)
proc atan*(x: F64): F64;              (* from -pi/2 to pi/2 *)
proc atan2*(y, x: F64): F64;          (* the angle of (x, y) from the x axis, from -pi
to pi *)
proc bits*(x: F64): U64;              (* the bits of x, as IEEE 754 lays them out *)
proc fromBits*(u: U64): F64;          (* the F64 whose bits are u *)
proc mul*(a, b: U64): (U64, U64);     (* a times b: the low 64 bits of the product,
and the high *)
proc toReal*(s: []U8): (F64, BOOL);   (* s as a real, the F64 nearest it; false if it
isn't one *)
```

A `Buf`, a `List`, a `Map` and a `Vec` take their memory from the allocator `init` gives them. `Buf.add`, `str` and `spare` stop the program, as a failed check does, if the allocator has no room; `room` asks first. A program reads into a `Buf` through `spare`, then adds what it read to `len`: `s := Buf.spare(b, 4096); n := Sys.read(fd, s); if n > 0 then INC(b^.len, n); end;`. A `Vec` is `Buf` for any `T`: one block, which doubles when it is full, so `push` costs the same on average however long it grows. `all` gives the elements as a slice, indexed and checked as any is, and `v.len` is their number; the slice, and what `add` gives, are good until the array next grows. `push`, `add` and `resize` stop the program, as `Buf.add` does, if the allocator has no room; `room` asks first: `import Lines := Vec([]U8);`. `Fmt`'s format takes the next argument at each `{}`; `{{` and `}}` stand for `{` and `}`. A `Map` hashes and compares its keys with the procedures it is given: `import Count := Map([]U8, INT, Str.hash, Str.eq);`.

`Str` reads and writes UTF-8. `encode` writes a character, of at most 10FFFFH, in one to four bytes; a number that isn't one becomes FFFDH, the character that stands for a wrong one. `decode` reads the first character of `s`, and gives FFFDH and 1 for a byte that doesn't start one rightly, and 0 and 0 for an empty `s`: a continuation, a byte followed by too few continuations, a surrogate, a character beyond 10FFFFH or one spelled in more bytes than it needs. `decodeLast` reads the last character in the same way, to walk a string backwards. `valid` says that `decode` finds no such byte in `s`, and `chars` counts the characters, each such byte one. `next` walks a string a character at a time, as `decode` reads them: from 0, it gives the character at `i` and where the one after it starts, and 0 and -1 when `i` is at the end, or past it:

```
c, i := Str.next(s, 0);
while i >= 0 do
    ...                                 (* c is a character of s *)
    c, i := Str.next(s, i);
end;
```

A string is bytes, and `Str` takes no more of Unicode than UTF-8: `lower`, `upper` and `eqFold` change and match ASCII letters alone, and nothing says how wide a character is on a terminal, nor which spellings of a text are the same.

A space, to `trim`, `trimLeft`, `trimRight` and `field`, is a blank, a tab, a line feed, a carriage return, a vertical tab or a form feed. `cut` gives what comes before the first `sep` in `s`, what comes after it, and `true`; or `s`, an empty string and `false` if `s` has no `sep`. `field` passes the spaces at the start of `s` and gives the bytes up to the next space or the end, and the rest of `s` from there; two empty strings if `s` holds only spaces. They take a string apart without memory of their own, each part a slice of `s`:

```
line, rest, more := Str.cut(text, "\n");     (* the first line, and the others *)
key, val, ok := Str.cut(line, "=");
w, rest := Str.field(line);                 (* the words of a line *)
while LEN(w) > 0 do
    Out.str(w); Out.ln;
    w, rest := Str.field(rest);
end;
```

`lower` and `upper` write `s`'s bytes, so they take a variable's, not a string literal's (section 5.10). `join` and `replace` add to a `Buf` as `Buf.str` does; an empty `old` adds `s` as it is.

`toInt` reads a decimal number, with a `-` or `+` before it if any, and nothing else. `toHex` reads hexadecimal digits, capitals or not, and nothing else: no sign, `0x` or `H`. `fromInt` writes a number as `Out.int` does, with a `-` if it is negative, its bytes the first of the 20 it gives.

`le` and `be` read an unsigned number of up to 8 bytes in a fixed order, little-endian or big-endian, whatever the machine's own, and `putLE` and `putBE` write one; more than 8 bytes stops the program. They are how a file format or a network protocol is read and written:

```
len := U32(Str.le(header[4..8]));
Str.putBE(packet[0..2], U64(port));
```

`Math.toReal` reads a real as a constant is written (section 2), with a `-` or `+` before it if any, its point and the digits after it, or its exponent, left out if it has none, and `e` taken as `E`: `2`, `-0.5` and `1.5e-3` are reals to it. It gives the `F64` nearest the number, and `false` for anything else, or a number too big for an `F64`.

`Map.next` walks a map: from 0, it gives the next entry and the number to pass for the one after it, and -1 when there are no more. A walk sees each entry once if the map doesn't change during it:

```
i, k, v := Names.next(ADR(names), 0);
while i >= 0 do
    Fmt.print("{} is {}\n", [Fmt.str(k), Fmt.int(v)]);
    i, k, v := Names.next(ADR(names), i);
end;
```

`Sort.sort` puts `s` in the order `less` gives, in place, without memory of its own, in time `n log n` at most; two elements equal by `less` may change places. `Math`'s procedures are as C's `math.h` has them, to within the last bit or so. `Fmt.real(x, places)` writes `x` with `places` digits after the point, at most 9, rounded to the nearest; from 1e15 on, with an exponent, as `1.50e17`; and `nan`, `inf` and `-inf` as themselves.

Files and Opt are what most programs need of their command line.

```
module Files;
proc arg*(i: INT): []U8;                      (* argument i; 0 is the program's name *)
proc read*(path: []U8; b: ^Buf.Buf): BOOL;    (* the whole file added to b *)
proc load*(path: []U8; b: ^Buf.Buf): INT;     (* as read: 0, or minus the errno that
stopped it *)
proc write*(path, data: []U8): BOOL;          (* the file made to hold data *)

module Opt;
type
    Row* = variant
        usage(scope, line: []U8);           (* a synopsis line, without "usage: " *)
        sub(scope, name, help: []U8);       (* a subcommand *)
        option(scope: []U8; letter: U8; long, value, help: []U8);
    end;
    Parser* = record
        letter*: U8;    (* the option just read *)
        value*: []U8;   (* its value; "" for a flag *)
        long*: BOOL;    (* it was written by its long name *)
        ...
    end;
proc init*(p: ^Parser; name: []U8; table: []Row);  (* the arguments from 1 on, by
table *)
proc next*(p: ^Parser): BOOL;                     (* the next option; false when they
end *)
proc operand*(p: ^Parser): ([]U8, BOOL);          (* the next operand; false when
there are no more *)
proc at*(p: ^Parser): INT;                        (* the argument operand would give
next *)
proc scope*(p: ^Parser; name: []U8);              (* subcommand name's options, from
the word after it *)
proc number*(p: ^Parser; lo, hi: I64): I64;       (* the value just read, a number
from lo to hi *)
proc fail*(p: ^Parser; text: []U8);               (* the program's own mistake *)
```

`Opt` reads a command line by the rules of the C library's `getopt`, with GNU's long options, so that a program's options behave as every other Unix program's. The program describes itself once, in a table of `Row`s: its synopsis lines, its subcommands and its options. The help and the messages for mistakes are made from the table, so they can't drift from it; the program's test of `p.letter` is the only other place an option appears. The parser is a record the program owns, and the table a slice it keeps as long as the parser: a literal written in the call to `init` lives as long as the procedure that makes it.

A row's `scope` is `""` for the program itself, or a subcommand's name: `"start"`, or `"remote.add"` for a subcommand of `remote`. An option has a `letter`, a `long` name, or both. One with a long name only has a key of its own below `'!'` for a letter, so that the program can tell it from the others. With a `value`, the name the help and the messages give it, the option takes a value; with `""` it is a flag.

```
const wait = 1;     (* the key of --wait, which has no letter *)
...
Opt.init(ADR(p), "keep", [
    Opt.usage("", "keep [-v] [--wait secs] start ..."),
    Opt.sub("", "start", "start a job"),
    Opt.option("", 'v', "verbose", "", "say more"),
    Opt.option("", wait, "wait", "secs", "give the job secs to start"),
    Opt.usage("start", "keep start [-b label] name command [argument ...]"),
    Opt.option("start", 'b', "bar", "label", "show the job in the bar as label")]);
while Opt.next(ADR(p)) do
    if p.letter = 'v' then verbose := true;
    elsif p.letter = wait then secs := Opt.number(ADR(p), 1, 600);
    end;
end;
w, ok := Opt.operand(ADR(p));
if not ok or (w # "start") then Opt.fail(ADR(p), "no command; see keep -h"); end;
Opt.scope(ADR(p), "start");
while Opt.next(ADR(p)) do
    if p.letter = 'b' then bar := p.value; end;
end;
job, ok := Opt.operand(ADR(p));
```

The rules are `getopt`'s:

- Flags may share a dash: `-lw` is `-l -w`. A letter's value is the rest of its word, `-bdev`, or the whole next word, `-b dev`, even one that starts with a dash or is empty; in a group, the first letter that takes a value takes the rest, `-qn12`.
- A long option is written in full, with its value after a `=` or in the next word: `--bar=dev`, `--bar dev`. An abbreviation is unknown, not guessed, so that adding an option never breaks a script. A value given to a flag, `--follow=x`, is a mistake.
- `--` ends the options, and isn't an operand; `-` alone is one. The options end at the first operand, so in `keep start site python -m http.server` the `-m` is python's.
- Each scope has its own options. An option given twice is read twice.

`number` reads the value as `Str.toInt` does. `operand` reads what options are left first, and the program doesn't see them. So does `at`, which says where the operands are: the arguments from `operand`'s next on are `Files.arg(i)` for `i` from `at(p)` to `ARGC() - 1`, so that an interpreter hands a script its arguments as they are:

```
script, ok := Opt.operand(ADR(p));       (* tery file arg ... *)
first := Opt.at(ADR(p));                 (* file's own arguments, from here on *)
```

`-h` or `--help` among a scope's options prints its help on standard output and ends the program with status 0. `init` and `scope` answer it, looking through the scope's options before `next` gives one, so that the program has done nothing yet: `keep -v -h -x` prints the help, and the program never sees `-v`, nor the mistake. The help is the scope's synopsis lines, a blank line, and its subcommands, its options and the help itself, each with its line of help:

```
usage: keep start [-b label] name command [argument ...]

  -b, --bar label   show the job in the bar as label
  -h, --help        print this and exit
```

A scope with several synopsis lines has the others indented under the first; one with none, `usage:` and its words, as `usage: keep start`.

A mistake on the command line is a sentence on standard error, the program's name first, then the scope's synopsis lines, as the help begins, and status 2:

```
keep: unknown option -x
usage: keep start [-b label] name command [argument ...]
```

The sentences are `unknown option -x` (or `--name`, up to its `=`), `-b needs a label`, `--follow takes no value` and `--wait wants a number from 1 to 600, not '0'`. `fail` writes the program's own mistakes the same way, but alone, so that the sentence can say where the help is: `keep: no command; see keep -h`.

A mistake in the table is the program's, not its user's. `init` checks the table before it reads a word, and ends the program with status 1: `keep: option table, row 3: the option is in the scope already`. The others are an option with neither a letter nor a long name, a long name with `=` in it, a letter `-`, and `-h` or `--help` in the table, since they are `Opt`'s.

Width says how many columns of a terminal text takes, for a program with a screen that wraps its lines and cuts them at the window's edge.

```
module Width;
proc width*(c: I32): INT;      (* the columns the character c takes: 0, 1 or 2 *)
proc columns*(s: []U8): INT;   (* the columns the UTF-8 text s takes *)
```

A combining mark, a format character, a control and Hangul's medial and final jamo take 0 columns; an ideograph, a kana, most emoji and the rest that Unicode calls East Asian Wide or Fullwidth take 2; every other character takes 1, the ambiguous ones among them, as most terminals draw them. These are the C library's `wcwidth`'s answers, but for a control, which is -1 there. `Width` knows characters, not clusters: an emoji joined to another by a zero width joiner, or a flag, counts as its parts. Its tables, about 4 KB, come from Unicode's data, made again by `tools/Widths.raz` for a new version of Unicode; a program that imports `Width` and calls neither procedure carries none of them.