KNOCK, KNOCK: UNIKERNELS CALLING!

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https://mirage.io/
http://decks.openmirage.org/cif16-loops/

Press <esc> to view the slide index, and the <arrow> keys to navigate.

ABOUT ME

- Ph.D. with Systems Research Group at Cambridge University Computer Lab
- Now faculty at the Cambridge University Computer Lab
- Previously with University of Nottingham, Microsoft Research, Sprint ATL, startups

ABOUT THIS DECK

Slides written in statically type-safe OCaml using Mirage on OSX

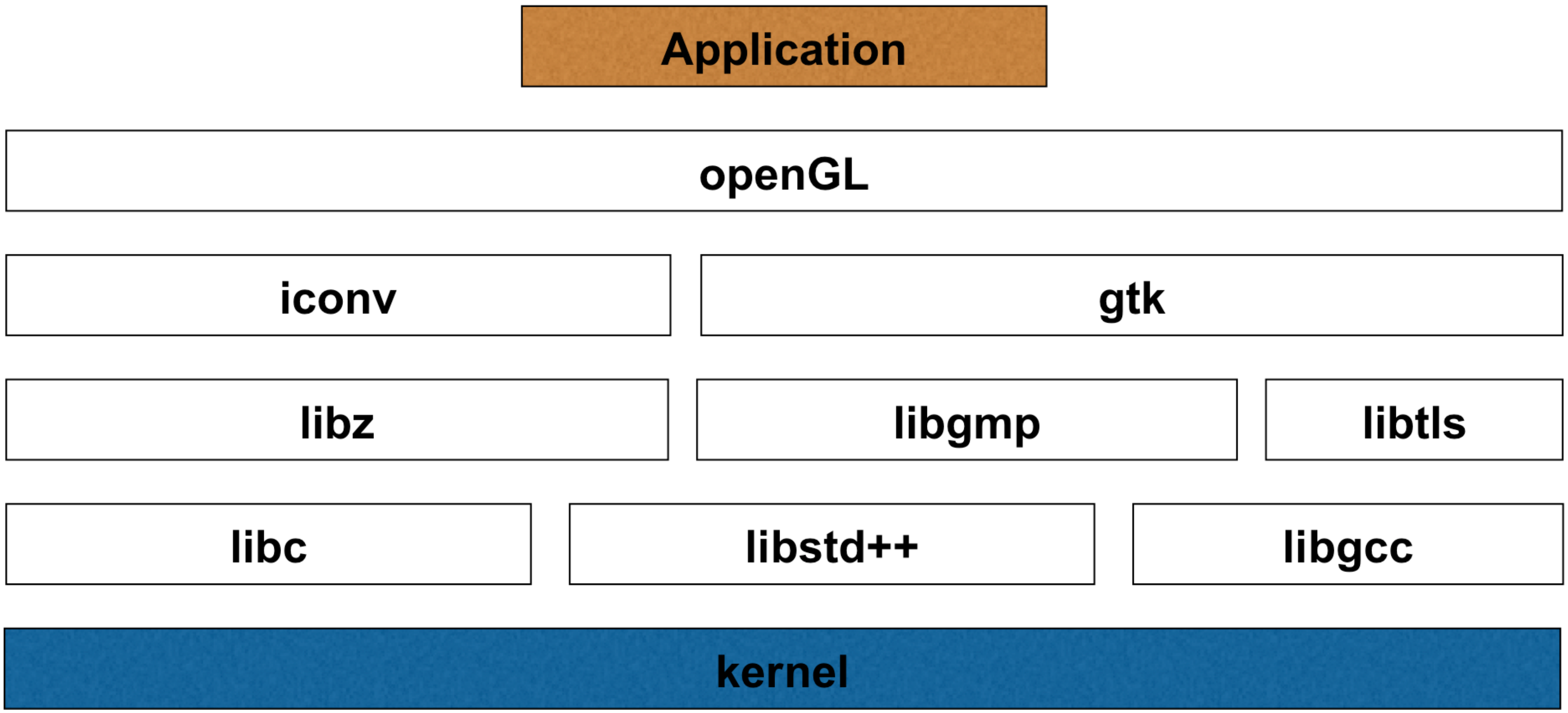
- They are hosted on my laptop as a content-specific webserver, connected to using a browser
- Their application logic is just a **couple of source files**, written independently of any OS dependencies
- **Without any source level changes** then can also be hosted in the cloud as an **x86 Xen unikernel** and on **ARM Cubieboard2**
- Binaries small enough to track the **entire deployment** in Git!

TRADITIONAL OPERATING SYSTEMS

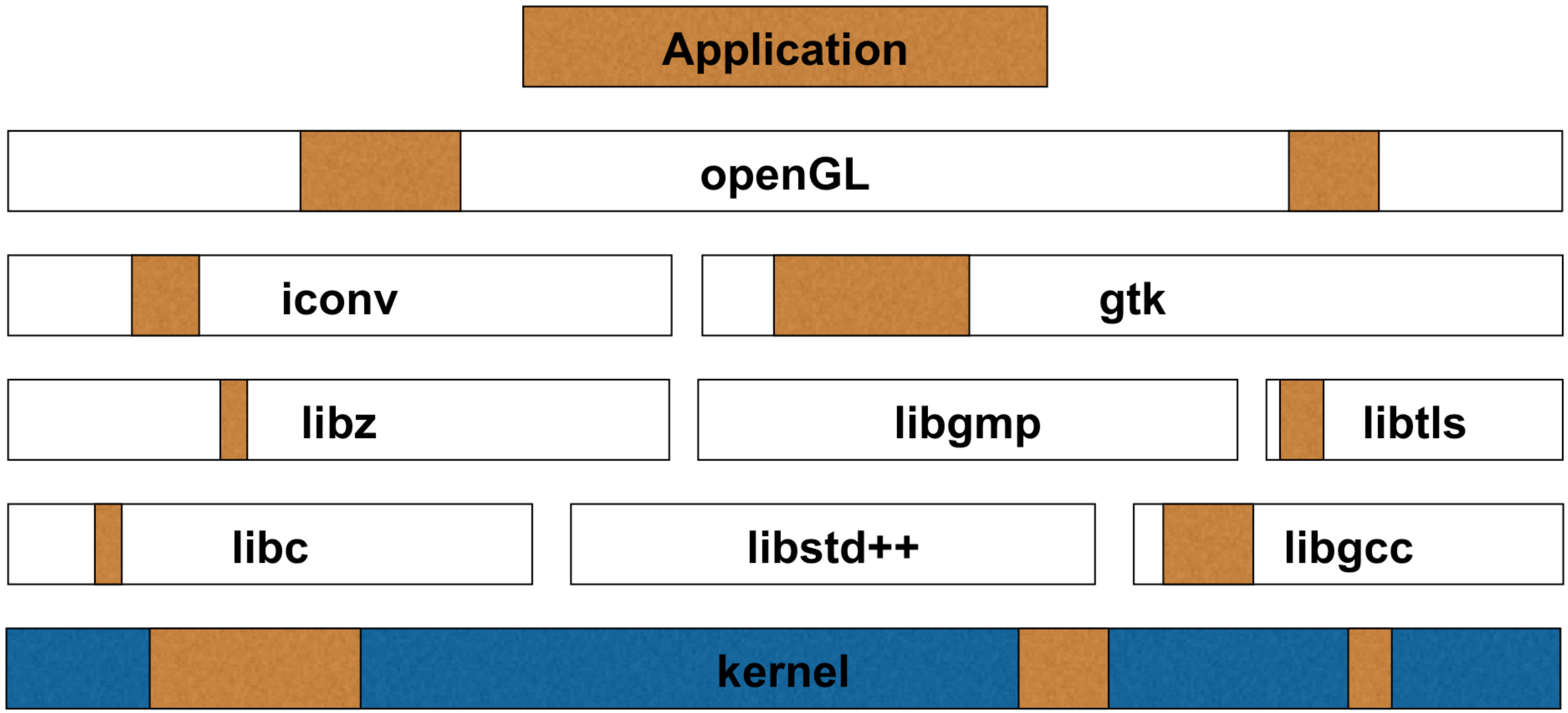
A lot of code!

- Linux: over 25 million lines of code
- Debian 5.0: 65 million lines of code
- OSX 10.4: 85 million lines of code

TRADITIONAL APPLICATIONS

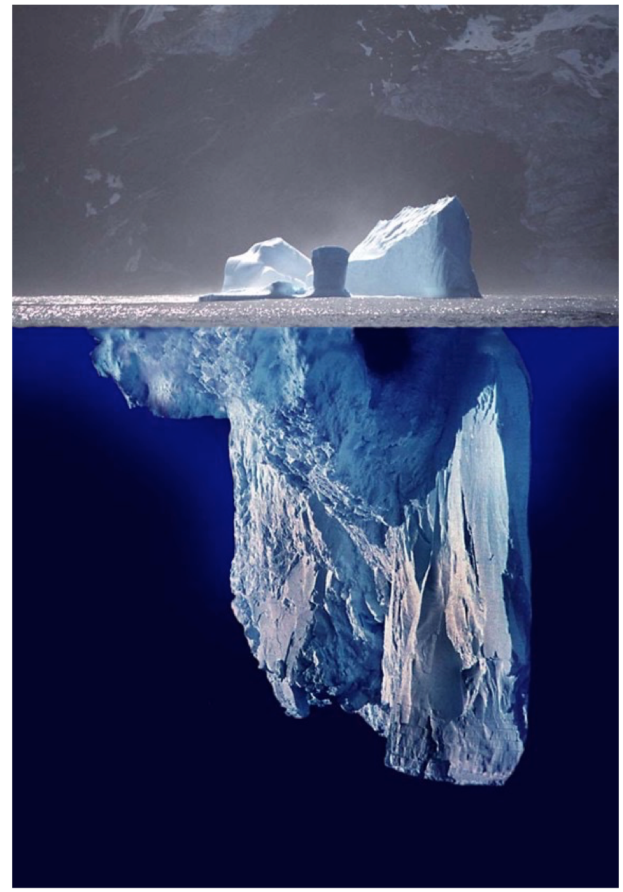


TRADITIONAL APPLICATIONS



TRADITION

- Current applications effectively rely on a software stack of 100M+ lines of code software stack
- Most of that stack is written in C, a long time ago
- As a result, it's hard to re-use it in different – **and new** – contexts
- It's great that we can engineer software to make all this work – but **can we do better**?



UNIKERNELS!

Concepts derived from library OS technology from the 1990s

- Link application code together with platform libraries at build time
- Contain only the platform code specifically required by the application
- Single process, single address space
- Run anywhere simply by switching out lowest layer libraries during build

MIRAGEOS UNIKERNELS!

A unikernel platform built in OCaml

- Strongly statically type-safe language dating back to the 1970s
- Very efficient runtime
- Builds over the Xen Mini-OS, targeting Xen's stable device driver interface
- Support for other backends in place and in development, including POSIX, KVM, bare-metal, your web browser...

BENEFITS

✓ *Reduced attack surface*

- **Static linking of only required libraries**: removes unnecessary services – no Shellshock!
- **Modern, high-level languages**: static and runtime analysis, dead-code elimination

BENEFITS

✓ *Reduced attack surface* ✓ *Increased speed*

- **Reduced boot time**: can boot inside a TCP connection setup or packet RTT
- **Fewer scheduling layers**: lower latency, more predictable performance

BENEFITS

✓*Reduced attack surface* ✓*Increased speed*

✓*Efficient resource use*

- **Reduced memory footprint**: a typical stateless MirageOS app is ~10MB of RAM
- **Small on-disk footprint**: whole-program optimisation can create a MirageOS DNS server that comes in at ~200kB

BENEFITS

✓*Reduced attack surface* ✓*Increased speed*

✓*Efficient resource use* ✓*Immutable Infrastructure*

- **Statically link data into your application**: if desired, reduces dependency on external components
- **Store outputs in Git**: manage via `git`, introducing new models for update, upgrade, triage
- **Can be sealed**: once built, can even enable hardware memory-protection so running image is **really** immutable

MIRAGEOS WORKFLOW

As easy as 1—2—3!

1. Write your OCaml application using the Mirage module types
   - Express its configuration as OCaml code too!

```
$ mirage configure app/config.ml --unix # target standard Unix binary
```

MIRAGEOS WORKFLOW

As easy as 1—2—3!

1. Write your OCaml application using the Mirage module types
   - Express its configuration as OCaml code too!
2. Compile it and debug under Unix using the `mirage` tool

```
$ cd app
$ make depend # install library dependencies
$ make build  # build the unikernel
```

MIRAGEOS WORKFLOW

As easy as 1—2—3!

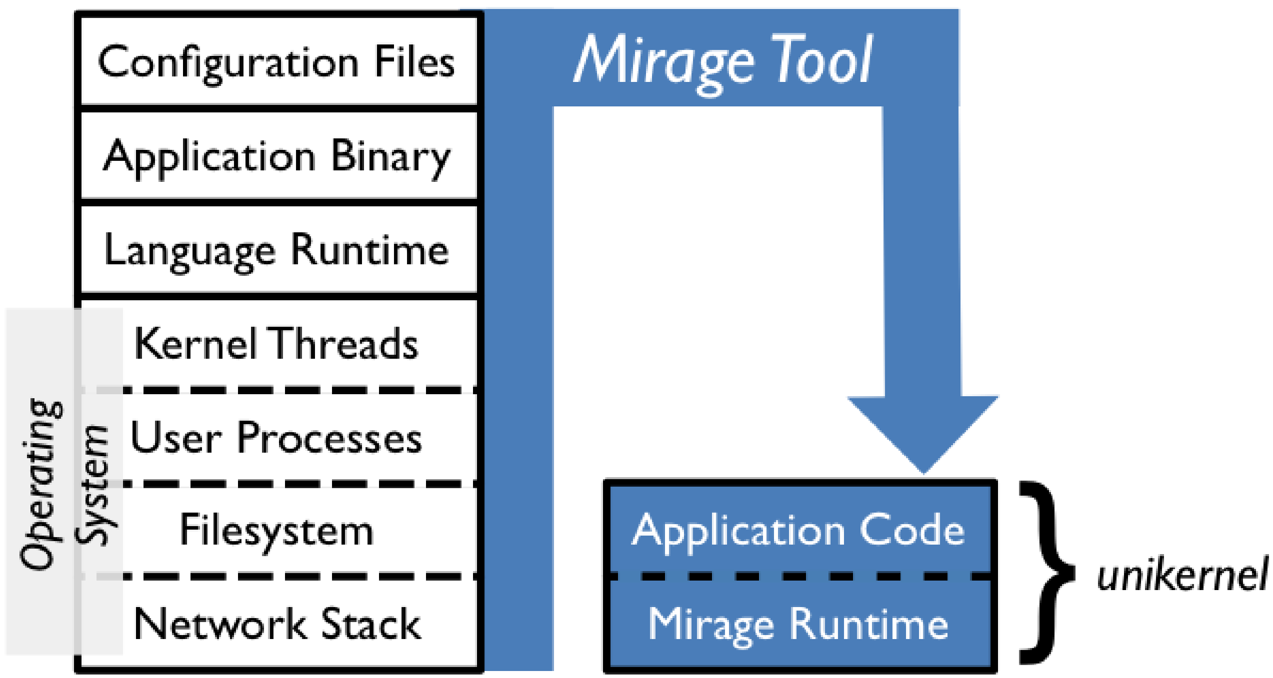
1. Write your OCaml application using the Mirage module types
   - Express its configuration as OCaml code too!
2. Compile it and debug under Unix using the `mirage` tool
3. Once debugged, simply retarget it to Xen, and rebuild!

```
$ mirage configure app/config.ml --xen # retarget to Xen
$ cd app && make depend && make build  # rebuild
```

*Magic happens via the **OCaml module system***

MIRAGEOS TECHNOLOGY

Capture system dependencies in code and compile them away



MIRAGEOS TECHNOLOGY

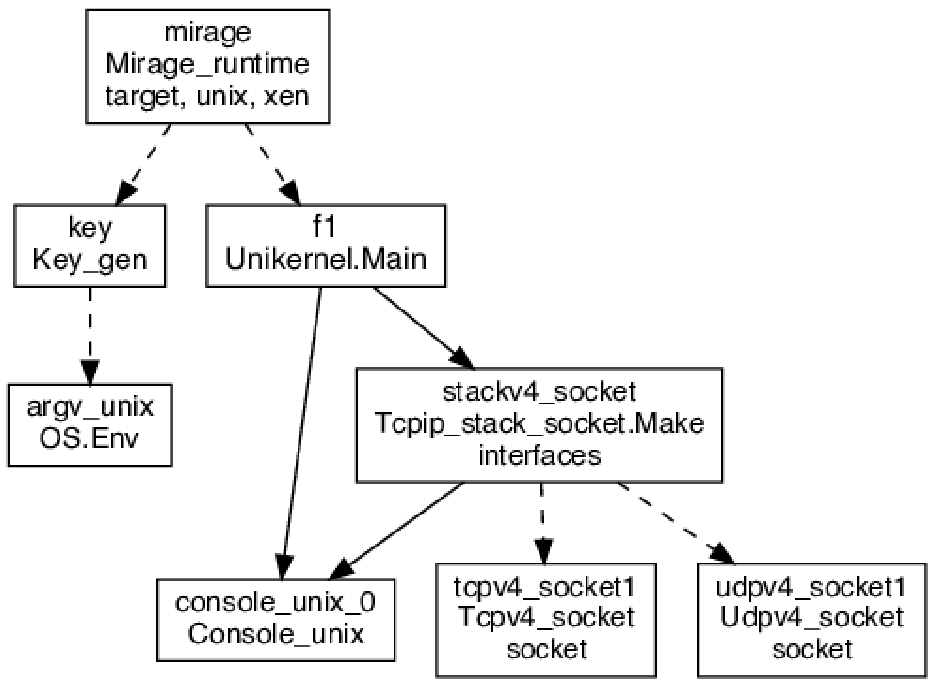
A Mirage component usually contains

- Code parameterised by functors with very limited (Mirage-only) dependencies, and particularly **no OS dependencies**
- A collection of libraries where the functors are (fully or partially) applied, suitable for interactive use

Functors in the OCaml module system clearly separate OS component dependencies, breaking the monolithic OS down into components

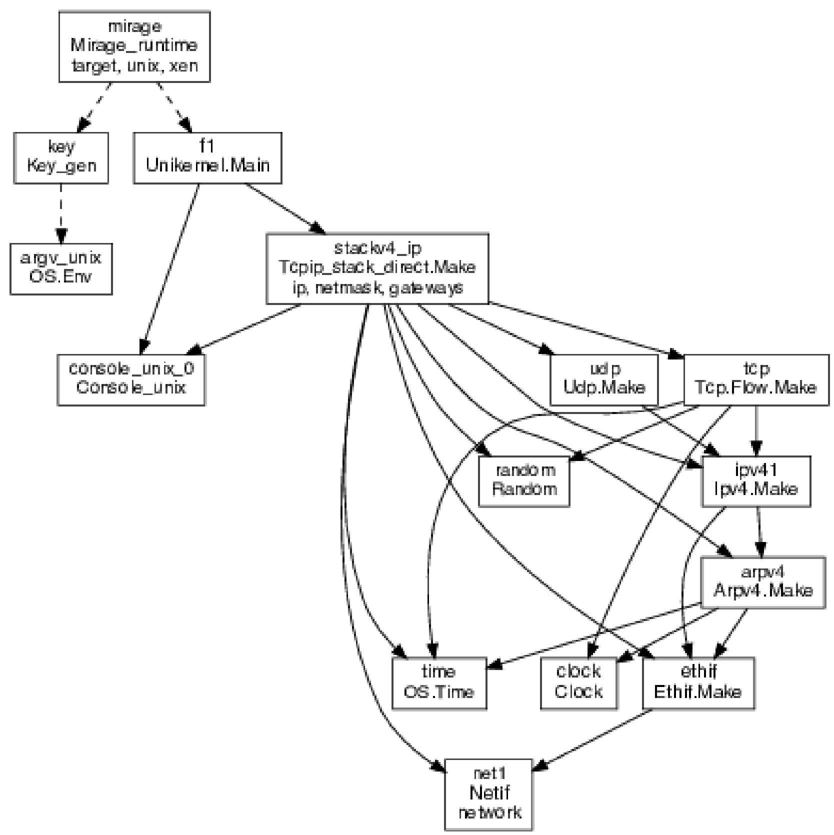
MIRAGEOS TECHNOLOGY

Unix/Sockets



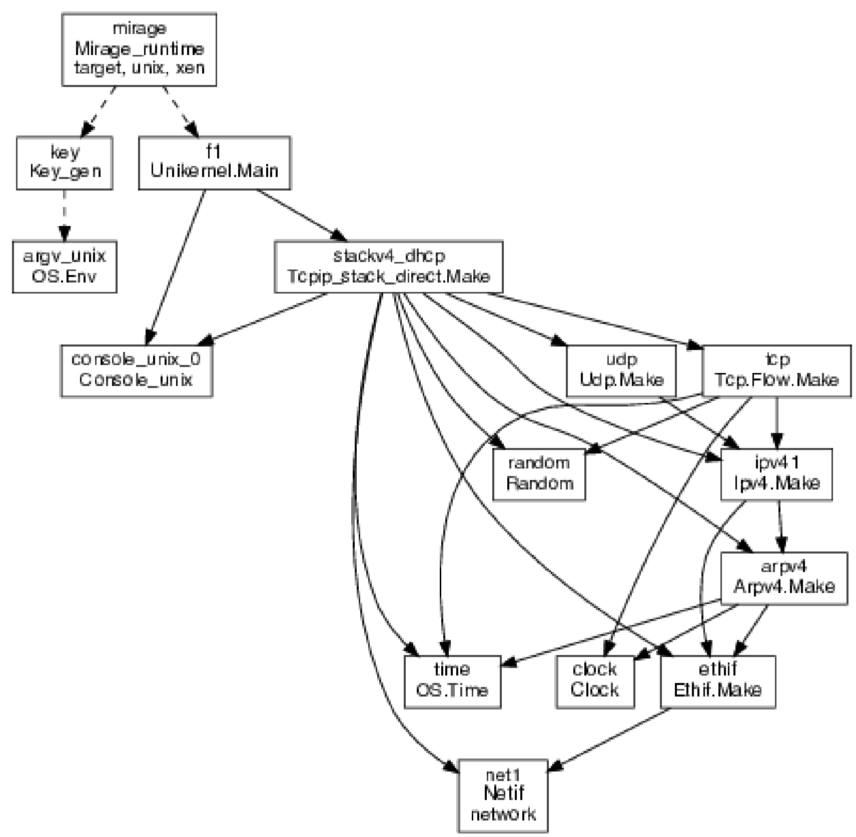
MIRAGEOS TECHNOLOGY

Direct/Static



MIRAGEOS TECHNOLOGY

Direct/DHCP



DEMO: KNOCK KNOCK!

The code behind the demo

- Single MirageOS unikernel
- Listens on `80/TCP` as a web proxy
  - Default: returns a basic `hello` page
- Also has knocking control channel on `32000/TCP`
  - Single request `RESET` to reset knocking state
- Finally, listens on `[32001,32256]/TCP` for knocks

Once correct knock sequence received, proxy configured to forward HTTP requests to indicated site instead of returning static page.

UNIKERNEL CONFIGURATION

config.ml

```
open Mirage

(* Declare where the unikernel code is *)
let main = foreign
    "Unikernel.Main"                (* the name of the functor *)
    (console @-> stackv4 @-> job) (* the functor signature *)

let packages =  ["mirage-http"] (* additional OPAM packages needed *)
let libraries = ["mirage-http"] (* additional ocamlfind libraries needed *)

(* Register the application *)
let () =
  let stack = generic_stackv4 default_console tap0 in
  register "knocking" ~packages ~libraries [ main $ default_console $ stack ]
```

PROXY STATE

unikernel.ml

```
module State: sig
  type t
  (** The type for proxy knocking state. *)

  val create: control_port:int -> t
  (** Create a new proxy state. [control_port] is the control port number. *)

  val ports: t -> int list
  (** [ports t] is the sequence of port knocking stored in the state. *)

  val add: t -> int -> unit
  (** [add t port] add [port] to the current observed sequence of ports. *)

  val reset: t -> unit
  (** [reset t] resets the proxy state. *)

  val control_port: t -> int
  (** [control_port t] retrieves the control port number. *)
end
```

DECODING KNOCKS

unikernel.ml

```
module Hostname (C: CONSOLE): sig

  val decode: C.t -> State.t -> string option
  (** [decode c st] resolves port knocks stored in proxy [!State] [st] into
      hostname. [c] is a console for log output. *)

end = struct

  let log c fmt = ... (* console logging; private to module *)

  (* the ports table, private to module *)
  let table = [
    [1]    , "unikernel.org";
    [1; 2], "mirage.io";
  ]

  let decode c t = ... (* lookup knock sequence in [table] *)

end
```

UNIKERNEL: HELPERS

unikernel.ml

```
module Main (C: CONSOLE) (S: STACKV4) = struct

  module Proxy = Proxy(C)(S)
  module Hostname = Hostname(C)

  type request = Reset | Unknown of string
  let string_of_request buf =
    match String.trim (Cstruct.to_string buf) with
    | "reset" -> Reset
    | req     -> Unknown req

  let log c fmt = ...           (* console logger *)
  let ok_or_error dbg c = ...   (* chaining invocations with error handling *)
  let not_found c con = ...     (* port knock not recognised *)
  let reply_one c s t con = match Hostname.decode c t with
    | Some host -> proxy c s con host | None -> not_found c con

  let proxy c s con host = ...
  (* actually proxy incoming request: creates an HTTP server listening thread
     that receives incoming HTTP requests and proxies it to the target host *)
```

UNIKERNEL: HANDLING A KNOCK

unikernel.ml

```
let update c t port flow =
   match port - State.control_port t with
   | 0 ->
     S.TCPV4.read flow >>= fun question ->
     ok_or_error "update" c question >>= fun buf ->
     begin match string_of_request buf with
       | Reset ->
         log c "Port 0: RESET!" >>= fun () ->
         State.reset t;
         S.TCPV4.close flow
       | Unknown req ->
         log c "Port 0: Unknown request (%s)" req >>= fun () ->
         S.TCPV4.close flow
     end
   | port ->
     log c "Port %d: KNOCK KNOCK!" port >>= fun () ->
     State.add t port;
     S.TCPV4.close flow
```

UNIKERNEL: ENTRY POINT

unikernel.ml

```
let start c s =
  log c "Port Knocking Proxy Unikernel booted!\n"

  >>= fun () ->
  let control_port = 32000 in
  let t = State.create ~control_port in

  (* register a knock handler for all the ports we are interested in *)
  for i = 0 to 256 do
    let port = control_port + i in
    S.listen_tcpv4 s ~port (update c t port)
  done;

  (* start the web proxy on 80/TCP *)
  S.listen_tcpv4 s ~port:80 (reply_one c s t);
  S.listen s
```

THE PLUMBING

`main.ml`: autogenerated code to build the functors

Unix with kernel socket networking stack

```
module Tcpip_stack_socket1 = Tcpip_stack_socket.Make(Console_unix)
```

Unix with direct networking stack

```
module Ethif1 = Ethif.Make(Netif)
module Arpv41 = Arpv4.Make(Ethif1)(Clock)(OS.Time)
module Ipv41 = Ipv4.Make(Ethif1)(Arpv41)
module Udp1 = Udp.Make(Ipv41)
module Tcp1 = Tcp.Flow.Make(Ipv41)(OS.Time)(Clock)(Random)
module Tcpip_stack_direct1 = Tcpip_stack_direct.Make(Console_unix)(OS.Time)
    (Random)(Netif)(Ethif1)(Arpv41)(Ipv41)(Udp1)(Tcp1)
```

Xen

```
...
module Tcpip_stack_direct1 = Tcpip_stack_direct.Make(Console_xen)(OS.Time)
    (Random)(Netif)(Ethif1)(Arpv41)(Ipv41)(Udp1)(Tcp1)
```

THE PLUMBING

`main.ml`: plumb together to create the TCP/IP network stack

```
let stackv4_socket1 = lazy (
  let __console_unix_01 = Lazy.force console_unix_01 in
  let __udpv4_socket11 = Lazy.force udpv4_socket11 in
  let __tcpv4_socket11 = Lazy.force tcpv4_socket11 in
  __console_unix_01 >>= function
  | `Error _e -> fail (Failure "console_unix_01")
  | `Ok _console_unix_01 ->
    __udpv4_socket11 >>= function
    | `Error _e -> fail (Failure "udpv4_socket11")
    | `Ok _udpv4_socket11 ->
      __tcpv4_socket11 >>= function
      | `Error _e -> fail (Failure "tcpv4_socket11")
      | `Ok _tcpv4_socket11 ->
        let config = { V1_LWT.name = "stackv4_socket"; console = _console_unix_01 ;
                       interface = (Key_gen.interfaces ()) ; mode = () } in
        Tcpip_stack_socket1.connect config _udpv4_socket11 _tcpv4_socket11
)
```

THE PLUMBING

`main.ml`: plumb together the console and the stack

```
let f11 = lazy (
  let __console_unix_01 = Lazy.force console_unix_01 in
  let __stackv4_socket1 = Lazy.force stackv4_socket1 in
  __console_unix_01 >>= function
  | `Error _e -> fail (Failure "console_unix_01")
  | `Ok _console_unix_01 ->
    __stackv4_socket1 >>= function
    | `Error _e -> fail (Failure "stackv4_socket1")
    | `Ok _stackv4_socket1 ->
      Unikernel1.start _console_unix_01 _stackv4_socket1
      >>= fun t -> Lwt.return (`Ok t)
)
```

THE PLUMBING

`main.ml`: plumb together the stack and the platform type

```
let mirage1 = lazy (
  let __key1 = Lazy.force key1 in
  let __f11 = Lazy.force f11 in
  __key1 >>= function
  | `Error _e -> fail (Failure "key1")
  | `Ok _key1 ->
    __f11 >>= function
    | `Error _e -> fail (Failure "f11")
    | `Ok _f11 ->
      Lwt.return_unit
)
```

THE PLUMBING

`main.ml`: finally, run the unikernel passing it the plumbed devices

```
let run =
  OS.Main.run

let () =
  let t =
    Lazy.force key1 >>= function
    | `Error _e -> exit 1
    | `Ok _ -> Lazy.force mirage1
  in run t
```

HTTPS://MIRAGE.IO/

Thanks for listening! Questions?

Give it a try: http://github.com/mor1/loops-mirage/

Particular thanks to Thomas Gazagnaire for the demo unikernel!

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