How to Build an OS in Erlang:
A Whistle-stop Tour of HydrOS

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Outline

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2. Existing Systems and Architectures
3. Uncharted Territory: Ideas for Novel Erlang OS Architectures
4. Building An Erlang OS: Challenges
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Why Build an Erlang OS?

- Fault tolerance
- Scalability
- Native high-level execution environment with universal data exchange format (even including complex terms like functions).
- Machine independent programming environment – run the same OS and program code on x86, ARM, etc.

Erlang Unikernel Hosting Systems

ErlangOnXen

- Uses the Ling VM.
- Targets paravirtualised Xen deployments (among others).
- The most complete Erlang unikernel solution.
- 4mb deployable image sizes, with sub 250ms boot times.

Erlang Unikernel Hosting Systems (Cont.)

Erlang on RumpRun

- BEAM on small ‘rump’ kernel.
- Generates 6mb images.

Erlang on OSv

- Erjang on OSv, a small linux-compatible OS.
- Generates ‘fat’ unikernels.
- Greater Linux compatibility, at the cost of image deployment size.

ErlOS

- BEAM (on MiniOS) on Xen.
- Proof of concept. No longer supported.

Embedded Erlang Platforms

GRiSP

- Erlang on RTEMS (a small real-time OS).
- Built as a platform for creating wireless IoT applications.
- Targets ARM.

NERVES Project

- Elixir/Erlang on a thin Linux layer.
- Working to expose kernel functionality within the BEAM.

Erlang Embedded Initiative

- erlang-mini packages for embedded devices.
- Actor Library for Embedded (ALE).

HydrOS: A General-Purpose Erlang OS

- A general purpose operating system for server and desktop systems.
- Focuses on providing fault-tolerance and error recovery for typically catastrophic OS and hardware events.
- Written almost entirely in Erlang – from inter-node message passing and drivers, to GUI applications.

Open Areas in Erlang OS Design

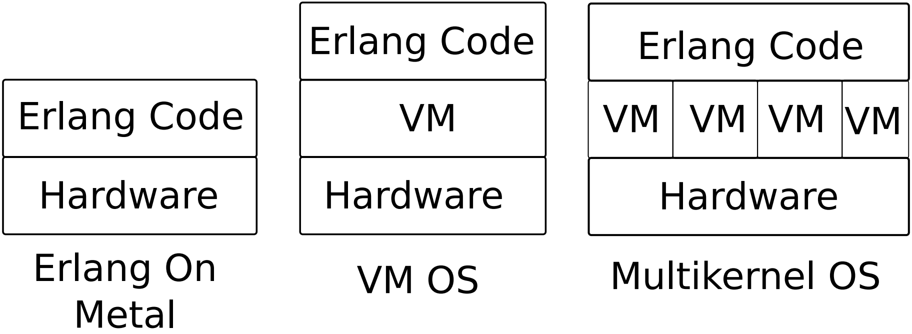
- Uninterpreted Erlang code on bare-metal via HiPE.
  - One unikernel per process?
  - Unikernels that build and launch other unikernels when processes are spawned?

- A tiny co-operative Erlang VM for many-core embedded devices (for example, the Paralella).
  - Support for platforms with hardware message passing?

Building An Erlang OS: Challenges

- How will your Erlang code run?
    - Will it be ‘native’, interpreted, or interpreted within another VM?
- Will it be BEAM compatible?
    - At what level? Instructions, AST, or BEAM code transpiler?

Erlang OS System Architectures



Erlang Code

Hardware

Erlang On Metal

Erlang Code

VM

Hardware

VM OS

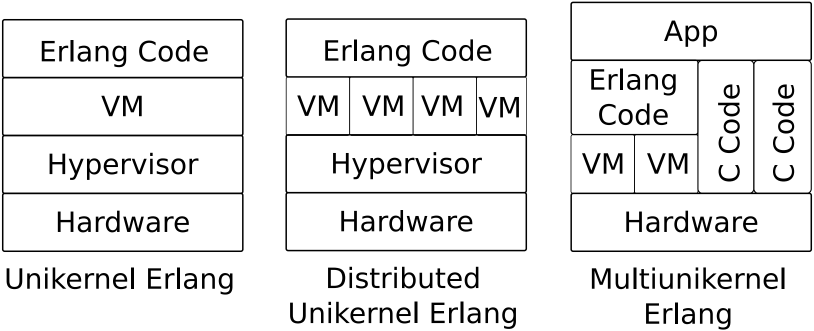
Erlang Code

VM VM VM VM

Hardware

Multikernel OS

Erlang OS System Architectures (Cont.)



Language Responsibility Division

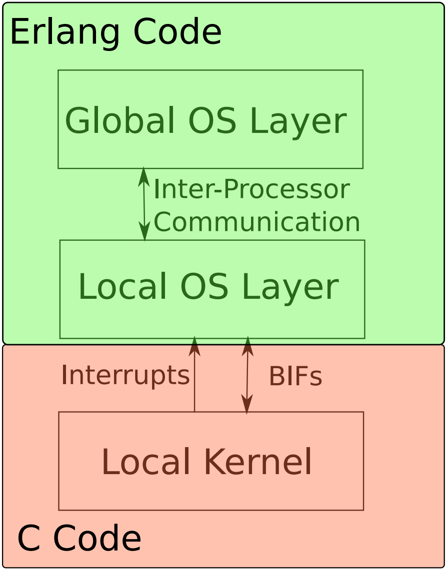
How much of the work of the OS will be performed in Erlang? How much will be performed by native code?

- Will drivers be written in Erlang?
- What about performance critical GUI app code?
- Will you expose an Erlang interface to malloc and free, allowing raw buffers?

HydrOS uses a system of layers:

- Local kernel layer
- Local OS layer
- Global OS layer

Language Responsibility Division in HydrOS



Erlang Code

Global OS Layer

Inter-Processor Communication

Local OS Layer

Interrupts

BIFs

Local Kernel

C Code

Foreign Function Interfaces

How will your operating system incorporate native (C, assembly) code, if at all?

- How will you load and execute libraries?
- If you are using them, how will your native-code drivers interact with the VM scheduling system? Could they be purely event (interrupt) driven?

Reaching a Secure Steady-State

How will your OS boot?

- Will you use an existing bootloader like GRUB/LILO/SYSLINUX?
- Will you implement EFI boot?

Once the OS has loaded, how will you ensure its security?

- Secure the perimeter, not the interior?
- HydrOS style capabilities?

General Lessons Learnt

- There is a fault-tolerance–performance spectrum on which your OS must be placed.
  - Native-code is fast, but failures are harder to recover from.
  - This trade-off is particularly important for drivers and interrupt handlers.
- You may not need SMP support – design your systems appropriately.
  - *'This simplifies the implementation greatly and speeds things up. The philosophy is that you need more VMs to achieve true multi-core parallelism. Hypervisor is the only 'hardware' scheduler, Erlang processes are green threads.'*
    - Maxim Kharchenko, ErlangOnXen.

Delving Into HydrOS

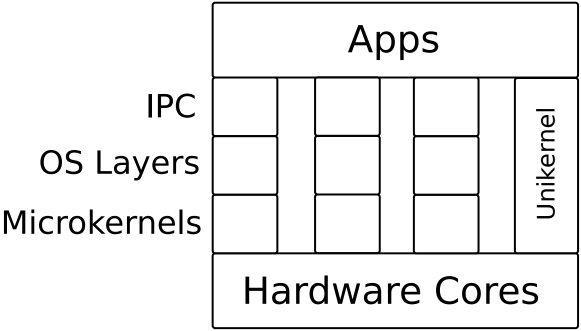
Erlang OS design, by example.

- Architecture
- Implementation
- Demonstration

Multikernel Architecture

HydrOS is built with a multikernel architecture.

- Split the machine into multiple independent cores.
- Each core gets a VM.
- ‘Single System Image’ layer unifies environment at Erlang level.



Fault-Tolerance Through Isolation

- Failures (even at the hardware level) in one core will not affect other cores.
- OS subsystems and drivers are also isolated from one another.
    - Restartable on demand.
- Potential for de-centralisation in the future.

Built-In Functions

HydrOS uses a library of BIFs to interact directly with the hardware.

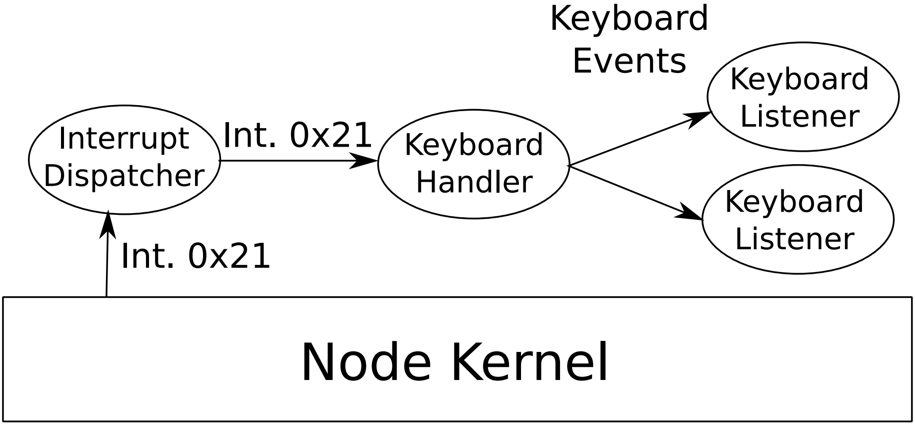
- Provides interfaces to CPU functionality.
    - Enabling and disabling interrupts, for example.
- (Roughly) 24 functions, most with very short definitions.

Erlang Drivers

HydrOS currently uses Erlang-only drivers.

- Sets of communicating processes that provide message-passing interfaces for hardware interaction.
- Can (should?) be spread across multiple nodes in a machine.
- IOAPICs used to route interrupts to the correct core.
- De-asserts interrupts after message is generated.
  - May be a problem for level-triggered interrupts.

Example HydrOS Driver



Keyboard Events

Interrupt Dispatcher

Int. 0x21

Keyboard Handler

Keyboard Listener

Keyboard Listener

Int. 0x21

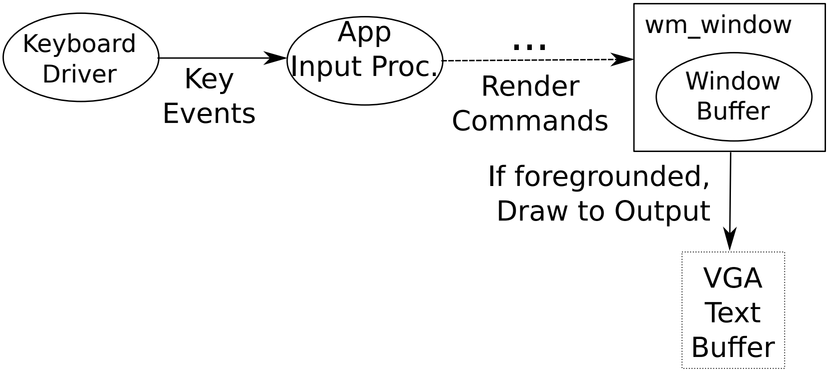
Node Kernel

HydrOS Window Management

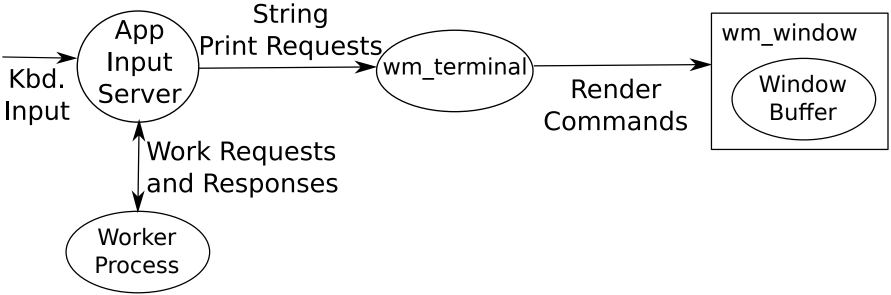
HydrOS provides a framework for building and organising graphical terminal applications.

- Composable window interfaces.
- Necessarily multi-process apps.
- Apps can be distributed across different Erlang VMs, but present as if they are part of a single operating system.
- Currently uses raw memory buffers.

A Generic HydrOS WM App



HydrOS Console App



Getting in the MUK: HydrOS Multiunikernels

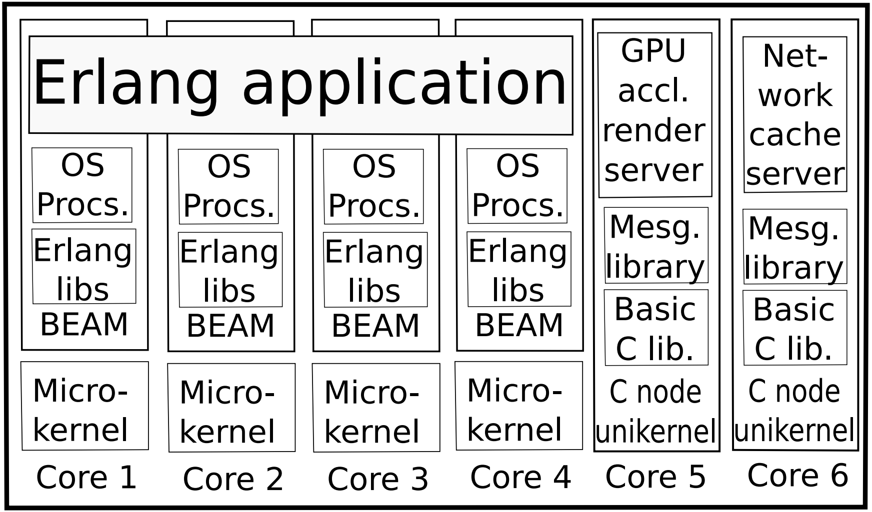
The HydrOS approach to native code hosting.

- Dedicate a single core in the system to acheiving your task.
- Run a unikernel program on this core directly, without intervention by any other part of the system.
- Provide a library for communication with Erlang nodes.

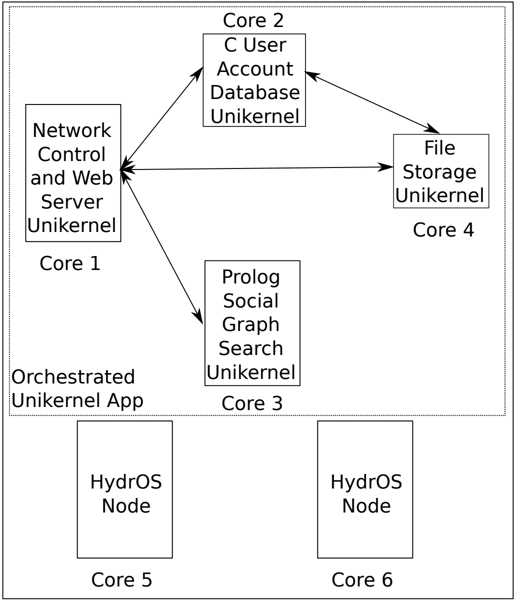
HydrOS MUKs can be created by simply placing a C file in a directory in the source tree.

The MUK generation system also accommodates more complex build environments.

HydrOS MUKs


Erlang application
OS Procs.
Erlang libs
BEAM
Micro-kernel
Core 1
OS Procs.
Erlang libs
BEAM
Micro-kernel
Core 2
OS Procs.
Erlang libs
BEAM
Micro-kernel
Core 3
OS Procs.
Erlang libs
BEAM
Micro-kernel
Core 4
GPU accl. render server
Mesg. library
Basic C lib.
C node unikernel
Core 5
Net-work cache server
Mesg. library
Basic C lib.
C node unikernel
Core 6

Orchestrated MUK Apps

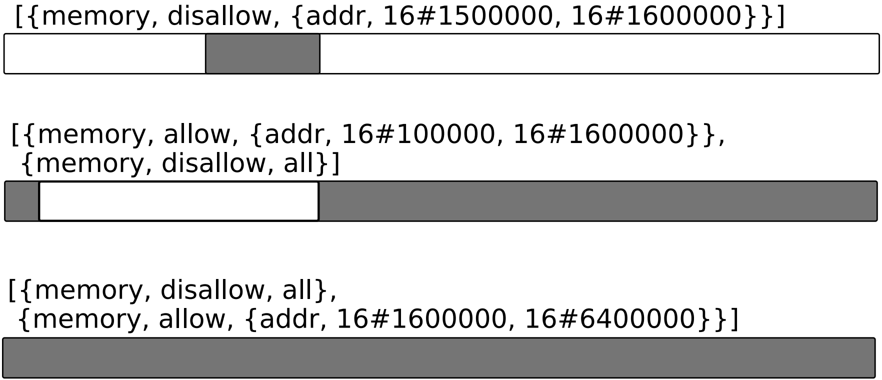


Securing BEAMs: HydrOS Capabilities

Create a tree of decreasingly capable processes.

Processes have the same or fewer capabilities than their parents.

Capability Mechanics

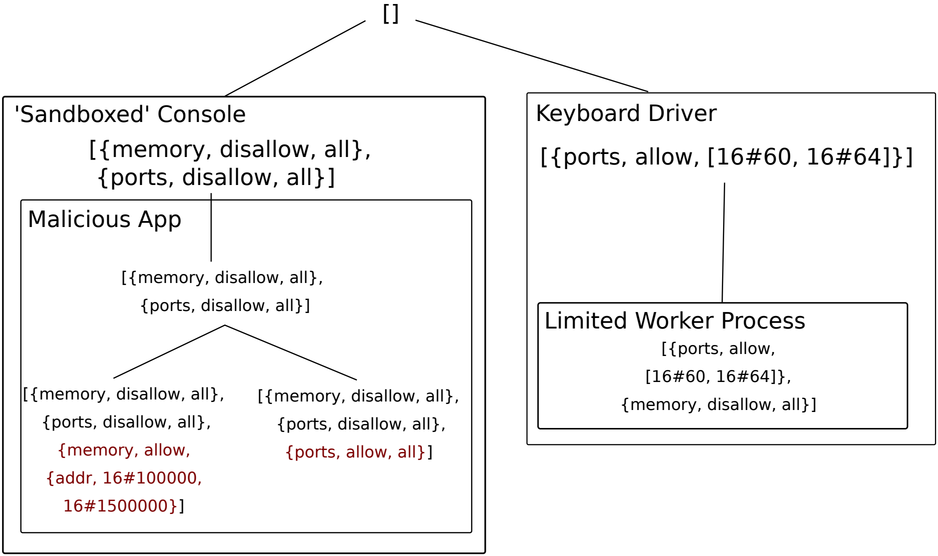


```
[{memory, disallow, {addr, 16#1500000, 16#1600000}}]
```

```
[{memory, allow, {addr, 16#100000, 16#1600000}},
 {memory, disallow, all}]
```

```
[{memory, disallow, all},
 {memory, allow, {addr, 16#1600000, 16#6400000}}]
```

Trees of Decreasingly Capable Processes



[]

'Sandboxed' Console

[{memory, disallow, all},
{ports, disallow, all}]

Malicious App

[{memory, disallow, all},
{ports, disallow, all}]

[{memory, disallow, all},
{ports, disallow, all},
{memory, allow,
{addr, 16#100000,
16#1500000}]

[{memory, disallow, all},
{ports, disallow, all},
{ports, allow, all}]

Keyboard Driver

[{ports, allow, [16#60, 16#64]}]

Limited Worker Process

[{ports, allow,
[16#60, 16#64]},
{memory, disallow, all}]

Demo!

- Basic terminal usage.
- Window and system management.
- Killing and restarting a live HydrOS node.

Acknowledgements

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- Anton Thomasson

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Try it out!

Prebuilt images, sources, and build instructions are available at http://hydros-project.org.

I can be contacted at secw2 [at] kent [dot] ac [dot] uk.