IGUANA[1]

A PROTECTION AND RESOURCE MANAGER FOR EMBEDDED SYSTEMS

Gernot Heiser, Ben Leslie
Embedded, Real-Time and Operating Systems Program
National ICT Australia

August 2004

[1]Name subject to change

OUTLINE

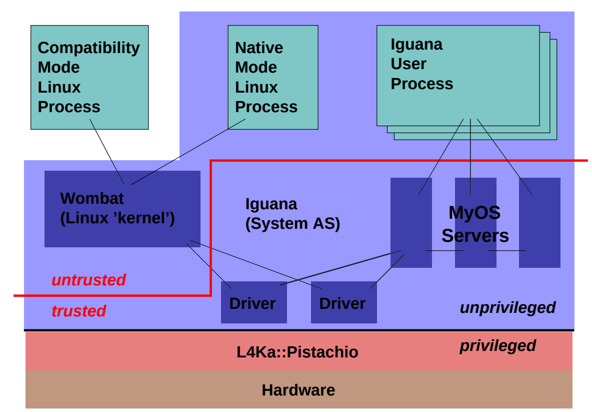
- Introduction
- Iguana concepts, abstractions and mechanisms
- Iguana API
- Kenge

WHAT IS IGUANA?

- Remember, L4 is a "strict" microkernel:
  - ➜ does not provide any services
  - ➜ does not provide policies (or only very few)
  - ➜ provides mechanisms
- L4 aspires to be generic kernel, suitable for all kinds of systems
- Almost any system requires a set of core services:
  - ➜ process management
  - ➜ memory management
  - ➜ security management

  ... based on some system-wide policies
- Iguana provides these (or at least more tools for providing them)
- Iguana is designed for use in embedded systems

SAMPLE IGUANA SYSTEM



What does Iguana Provide?

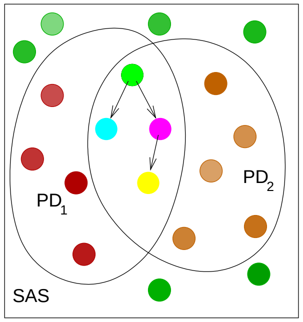
- Convenient way of using L4 primitives
  - ➜ OO-style method invocations instead of explicit IPC calls
  - ➜ IDL compiler for automatic generation of stubs
- Protection framework for access rights management
  - ➜ capability based, flexible
  - ➜ able to model most standard security models
- Virtual memory management
  - ➜ allocation, deallocation, sharing, ...
  - ➜ single-address-space view, supporting FASS on ARM
- Protection-domain (process) management
- Thread management

Outline

- Introduction
- Iguana concepts, abstractions and mechanisms
- Iguana API
- Kenge

Iguana : Basic Approach

- Basic idea: single address space (SAS)
  - eases sharing of data
    - ➜ minimises copying
    - ➜ no problems with pointers
- Per-process *protection domains*
  - enforce security policy
    - ➜ any access is subject to access control
  - do not interfere with sharing



- SAS layout supports fast-address-space switching on ARM
  - ➜ avoids AS overlaps for non-shared date without use of PID relocation
  - ➜ advantage: 1MB domain granularity instead of 32MB for PID relocation
    - ➜ less internal fragmentation

Iguana Concepts

- Memory section
  - ➜ unit of VM allocation and protection
  - ➜ can be an encapsulated object with methods and data
- Thread
  - ➜ execution abstraction, as in L4
- Server
  - ➜ thread associated with memory section
  - ➜ invoked through methods with well-defined interfaces
- Protection domain
  - ➜ defines access and resource rights of a thread
  - ➜ corresponds to a process in traditional OS

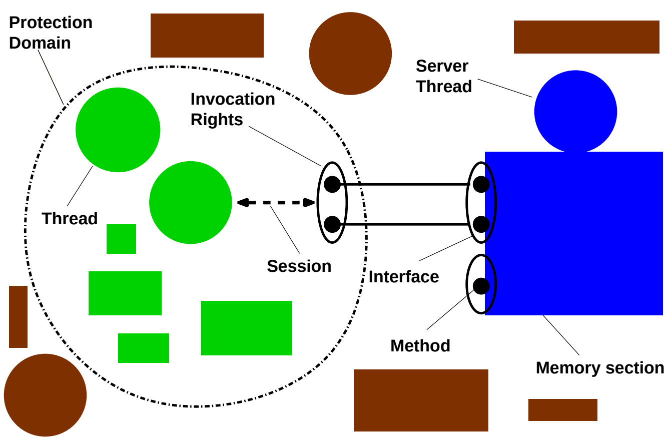
Iguana Concepts

- Session
  - ➜ client-server (or peer-to-peer) communication channel
  - ➜ amortises authentication cost over many invocations
- Capability
  - ➜ represents access rights
  - ➜ basis of protection
- Resource token
  - ➜ represents resource usage right
  - ➜ basis of resource management
- External Space
  - ➜ address space extern to Iguana's SAS
  - ➜ for legacy support and large processes

Iguana Philosophy

- Small and lightweight
  - ➜ geared towards embedded systems
  - ➜ allow optimal utilisation of hardware
- Strong yet unintrusive protection
  - ➜ hide protection machinery from most apps
  - ➜ able to emulate most standard protection models
- Support for resource management
  - ➜ in principle, although it isn't implemented yet!
- Legacy support
  - ➜ designed to run Linux server

Iguana Concepts



Outline

- Introduction
- Iguana concepts, abstractions and mechanisms
- Iguana API
  - ➜ Note: Under development, details still changing
- Kenge

Objects

- Six kinds of *objects*

1. memory sections
2. threads
3. protection domains (PDs)
4. sessions
5. resource tokens (restoks)
   - ➜ not yet implemented, not covered here
6. external spaces
   - ➜ not full Iguana objects
   - ➜ serve as proxies for non-Iguana objects

- Access controlled by *capabilities*

Objects: Commonalities

- Objects have a unique name — *object ID* (OID)
  - ➜ OIDs are addresses in Iguana's SAS
  - ➜ only for memory sections does this address correspond to actual memory
- Objects have *methods* that can be invoked
  - one method that exists for all objects: *destroy*
  - each kind of object has a set of pre-defined methods
- Objects are created by invoking constructor on a PD:
  - ➜ *kind*`_cap = `*pd*`->new_`*kind*`(`*args*`);`
- Methods are grouped into *interfaces*
  - interfaces also have unique IDs (IIDs) that are OID + interface number
  - interfaces have capabilities
    - ➜ grant rights to invoke an interface's methods
  - all pre-defined methods belong to separate interfaces
    - ➜ i.e., access is individually protected

Capabilities

- A capability is a token that confers some access right(s)
- Two kinds of capabilities in Iguana:
  - *master capability*
    - ➜ created when an object is created
    - ➜ confers rights on all methods of object
    - ➜ allows creation of further capabilities
  - *invocation capability*
    - ➜ created when an interface is created
    - ➜ confers right to invoke methods of a single interface
- Capabilities are only active if stored in PD's *capability lists*
  - ➜ details later

Memory Sections

- Memory sections represent virtual memory
  - allocation of a certain amount of virtual memory:

    mem_cap `=` *pd*`->new_mem(`*size*`);`
- Memory sections are the only objects that support user-defined methods
  - ➜ others have pre-defined (standard) methods only
- Used to provide encapsulated services:
  - service = memory (data) + server (thread) + methods

MEMORY SECTIONS...

- To create a service:
  - register a server thread on memory section

    base`->new_server(`*thread_id*`);`

    ➜ *base* is the base address (OID) of the memory section
  - register interfaces (user-defined methods)

    base `=` *iid*`->new_cap();`

    ➜ *iid* refers to number of new interface
- Registering interfaces supports user-defined methods
  - remember: each interface can have one or more methods

    ➜ interface number only interpreted by server

    ➜ similarly, the method number is an opcode delivered to the interface
  - IIDs and method numbers allocated by system implementor

    ➜ part of the service's interface protocol

MEMORY SECTIONS: PSEUDO METHODS

- Read (R), write (W), execute (X) are logically considered methods
  - subjects them to same protection mechanisms as other methods
  - no actual methods exist corresponding to those operations
- Further pseudo-method is *clist* (C)
  - needed for manipulating protection domains
  - more details later

THREADS

- Iguana threads are essentially L4 threads:
  - threads within same PD operated on by plain L4 syscalls

    ➜ correspond to local L4 threads (i.e., same L4 AS)

    ➜ `ExchangeRegisters`, `IPC`
  - direct IPC to non-local threads is not allowed

    ➜ use method invocations (corresponding to server thread)

    ➜ presently not enforced by Iguana

    ➜ requires enhancements to L4 (forthcoming API) to do efficiently

    ➜ will provide attribute to ensure enforcement (at a cost)
- Certain operations require privileges
  - e.g. thread creation and deletion done by privileged L4 `ThreadControl()` call
- Done by Iguana on invocation of appropriate methods

THREAD OPERATIONS

- Thread creation:

  thread_cap `=` *pd*`->new_thread(&`*l4_tid*`);`
  - returns two kinds of thread IDs
    - ∗ Iguana thread ID (*tid*), part of the *thread_cap*

      ➜ used for protection and other Iguana-specific purposes
    - ∗ L4 thread ID (*l4_tid*)

      ➜ used for L4 syscalls
- New thread created *inactive*
  - can be activated by:

    ➜ L4 syscall `ExchangeRegisters()` (local threads only)

    ➜ Iguana method `tid->start(ip,sp)`

Thread Operations...

- Obtain L4 thread ID
  - ➜ `l4tid = tid->l4_tid();`
- Obtain own thread ID
  - ➜ `tid = myself();`
- Obtain protection domain of thread
  - ➜ `pd = tid->domain();`
- Obtain and modify scheduling parameters
  - ➜ `tid->schedule_info(&info);`

Sessions

- Sessions reduce authentication overheads of repeated calls
- Prior to invoking methods on a service, must establish session

```
session = pd->new_session(server);
```

  - establishes session between target PD and server
  - `server` is a PD ID
    - ➜ **Note:** This is likely to change
  - Iguana informs the server by invoking its notification method

```
server->session_created(pd);
```

  - Iguana notifies remaining partners if the session is destroyed

```
pd_or_server->session_destroyed(session);
```


Iguana Capabilities

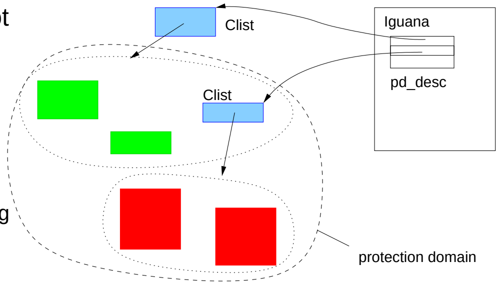
- Iguana capabilities are user-level objects
  - ➜ *password capabilities*, consisting of OID and password

object ID	password

  - ➜ Length of password is configurable (normally $\geq$ 64 bits)
- Iguana has a list of all valid capabilities
  - ➜ when validating an operation, matches user's capability against list
- Capabilities are never explicitly presented to Iguana, instead
  - ➜ client stores caps in PD's *capability list* (Clist) data structures
  - ➜ client presents object ID to system on method invocation
  - ➜ system traverses client's Clists for matching capabilities
- Most applications don't need to know about capabilities
  - ➜ protection system is unintrusive
  - ➜ can emulate wide range of protection models

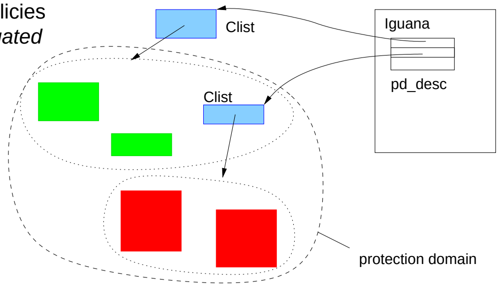
Protection Domains

- Protection domain is defined as a set of capabilities
  - Iguana PDs represented by a two-level data structure
    - ➜ PD associated with an array of Clists
    - ➜ Clist is an array of capabilities
    - ➜ Clist is (part of) a memory section
      - ➜ subject to memory protection like any memory section
  - PD may or may not contain its Clists
    - ➜ may or may not be able to modify itself
    - ➜ can freeze access rights of a domain
    - ➜ also control over adding and removing Clists



Protection Domains

- Two-level scheme for capability storage provides flexibility
  - can give users full control over their access rights
    - ➜ purely discretionary access control, no system policies
  - can force all Clists to be kept by a single server (or set)
    - ➜ allows server to implement almost arbitrary security policies
    - ➜ essentially a *segregated* capability scheme
  - hybrid schemes are possible



Protection Domains

- Presently, access control is disabled
  - ➜ implementation incomplete
  - ➜ will be completed in the near future (code is mostly there)
- Present L4 mechanisms are defi cient
  - L4 provides *redirectors* for information flow control
    - ➜ presently not implemented
    - ➜ to be done later this year
  - Redirectors are theoretically suffi cient, practically ineffi cient
    - ➜ would require all inter-PD communication to go via Iguana server
    - ➜ doubling of number of IPC operations
  - L4 API revision in progress for resolving these issues
    - ➜ Iguana ready to take advantage of this
    - ➜ until then will have a security/performance tradeoff

External Spaces

- External spaces are “raw” L4 address spaces
  - ➜ not part of Iguana SAS
- Provided to deal with restrictions of Iguana model
  - ➜ 32-bit address space may not be large enough to share between all protection domains
  - ➜ legacy support (e.g. strict `fork()` semantics) may require separate address spaces
- External spaces come at a cost
  - unable to make full use of fast address-space switching on ARM
  - not well integrated with Iguana world
    - ➜ no fine-grained access control provided by Iguana capabilities
    - ➜ not allowed to communicate with any PD other than creator
      - ➜ not even with Iguana — cannot invoke methods
      - ➜ this **will** be enforced as soon as L4 redirectors are implemented

External Spaces — Operations

- Creation requires explicit specifi cation of KIP and UTCB address

```
es = pd->new_es (kip, utcb_area);
```

- Thread creation also requires arguments similar to L4

```
l4tid = es->new_thread(pager,scheduler,starter,utcb);
```

Hardware Access

- Device drivers need to access raw hardware features
- Iguana provides a (static) `hardware` object for this
  - physical memory access:

    ```
    hardware->back_mem(adr, p_adr, caching);
    ```
    ➜ maps the memory section (`adr`) to the specified physical address with specified caching attributes
  - interrupt association:

    ```
    hardware->register_interrupt(tid,irq);
    ```
    ➜ registers the specified thread as the handler of the specified interrupt

Resource Tokens

- Iguana's resource management mechanism
- Note: presently this only exists conceptually
  - ➜ details of the model still need to be worked out
  - ➜ however, model is based on our experience with a similar model in Mungi
- Basic idea: all resources have a price that must be paid by the user
- Model provides great flexibility for defi ning charging details

Outline

- Introduction
- Iguana concepts, abstractions and mechanisms
- Iguana API
- Kenge

Kenge

- Kenge is a set of support libraries for building operating systems
  - mostly OS independent
    - ➜ ... but geared towards L4
  - implemented in C
- Kenge is **not:**
  - an L4 server (or servers)
  - an OS personality
  - a part of Iguana
    - ➜ although Iguana's implementation uses Kenge

Kenge Components

libc a C library

- ➜ C99 compliant
- ➜ mostly OS independent, but can be specialised for particular OS
  - ➜ I/O, memory allocation, CRT, ...

libdriver device driver library

- ➜ provides an API against which drivers can be developed
- ➜ host OS must provide wrappers implementing the required functionality
- ➜ provides a set of drivers (presently SA1100 UART only)
- ➜ more on drivers later...

elf library for parsing ELF files

l4e convenience functions around L4

- ➜ parsing bootinfo
- ➜ parsing memory descriptors

Kenge Components

l4 L4 system call library

- ➜ from L4Ka::Pistachio distribution
- ➜ more appropriate place for distribution

Generic data structures:

bit_fl: free list based on a bit array

range_fl: free list baed on linked list of ranges

circular_buffer:

hash:

ll: linked list

Device Driver Framework

- Generic library to write device drivers to
- Write once, run everywhere
  - drivers portable across processor architectures
    - ➜ e.g., IDE disk, NICs
  - drivers portable across operating systems
    - ➜ Iguana user-level
    - ➜ Linux user-level and in-kernel

Device Driver Framework

- Handles driver's interaction with environment transparently
  - ➜ interrupt model: interrupt invokes function in driver
- Handles allocation of device-specific memory
  - ➜ provision of PCI-consistent memory
  - ➜ pinning
  - ➜ virtual ⟶ physical address translation

DEVICE DRIVER FRAMEWORK

- Interaction of driver with environment
  - driver to export a certain API
  - dependent on device class:
    - ➜ stream device
    - ➜ network device
    - ➜ block device
    - ➜ frame buffer