a partitioned pok operating system

POK Operating System

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Forewords

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- **The POK project**
  - **Design and implement safe and secure system**
  - **Complete development process with model-based engineering**
- **Now, focus on the underlying operating system**
  - **Main guidelines**
  - **Architecture, services**
  - **Go into code organization**

Outline

a partitioned pok operating system

- Introduction
- Overall architecture
- Kernel layer
- Partition Layer
- Conclusion

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Introduction

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- **Partitioning functionalities**
  - **Time isolation across partitions**
  - **Space isolation – segments and communication control**
- **Interoperability**
  - **Ada and C programming interfaces**
  - **ARINC653 compliance**
  - **POSIX compliance**
- **Embedded architectures support**
  - **X86/QEMU**
  - **PPC/QEMU**
  - **SPARC/Leon**

One OS, two layers

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- **Kernel layer**
  - **Critical functions**
  - **Few services, prone to verification/certification**
  - **Actually < 6000 SLOC**
- **libpok**
  - **Non-critical functions**
  - **All remaining services**
  - **Actually ~ 20000 SLOC**

Project guidelines

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- **Real-Time compliance**
  - **O(1) algorithms**
- **High-integrity compliance**
  - **Static allocation of kernel/partitions resources**
  - **Avoid dead code, useless functionalities**
- **Embedded systems compliance**
  - **Low complexity**
  - **Avoid memory overhead**

Development guidelines

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- Reduce critical code
  - Few services in kernel
  - Remaining services in libpok
- Each snapshot must work
  - Compilation of all examples on all architectures
  - Prevent functionalities breakage
- Enforce coding style
  - Use rules inspired by best-pratices
  - See MISRA-C for example
  - Look at `doc/CODING_GUIDELINES`

Naming guidelines

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- **Resources dimensioning**
  - **POK_CONFIG_NB_* macros**
  - **Ex: POK_CONFIG_NB_THREADS**
- **Service configuration, services inclusion**
  - **POK_NEEDS_FUNCTIONS**
  - **Ex : POK_NEEDS_TIME, POK_NEEDS_SCHED, …**
- **Headers**
  - **#ifndef __POK_SERVICE_NAME_H__**
  - **Ex : #ifndef __POK_SCHED_H__**

Naming guidelines – cont'd

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- **Types**
  - **pok_typename_t**
  - **See `include/types.h` for types definitions**
  - **Ex: `pok_partition_t`, type that contains partition attributes**
- **Functions**
  - **pok_servicename_functionname ()**
  - **Ex: `pok_partition_load`, function that loads a partition**

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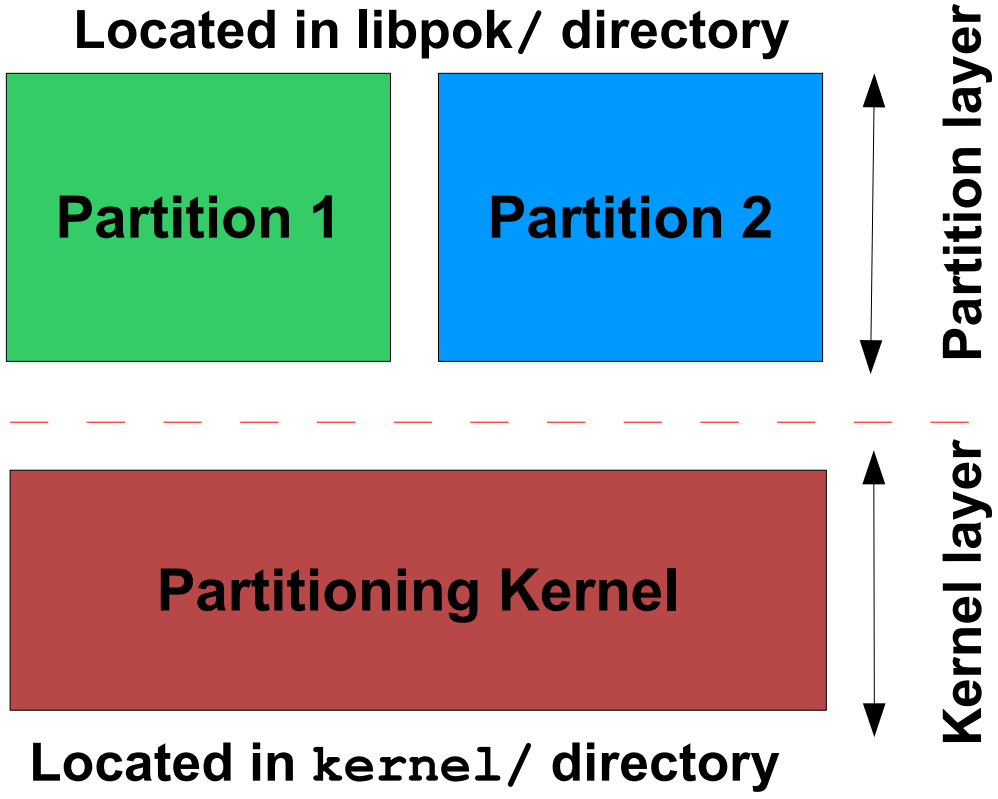
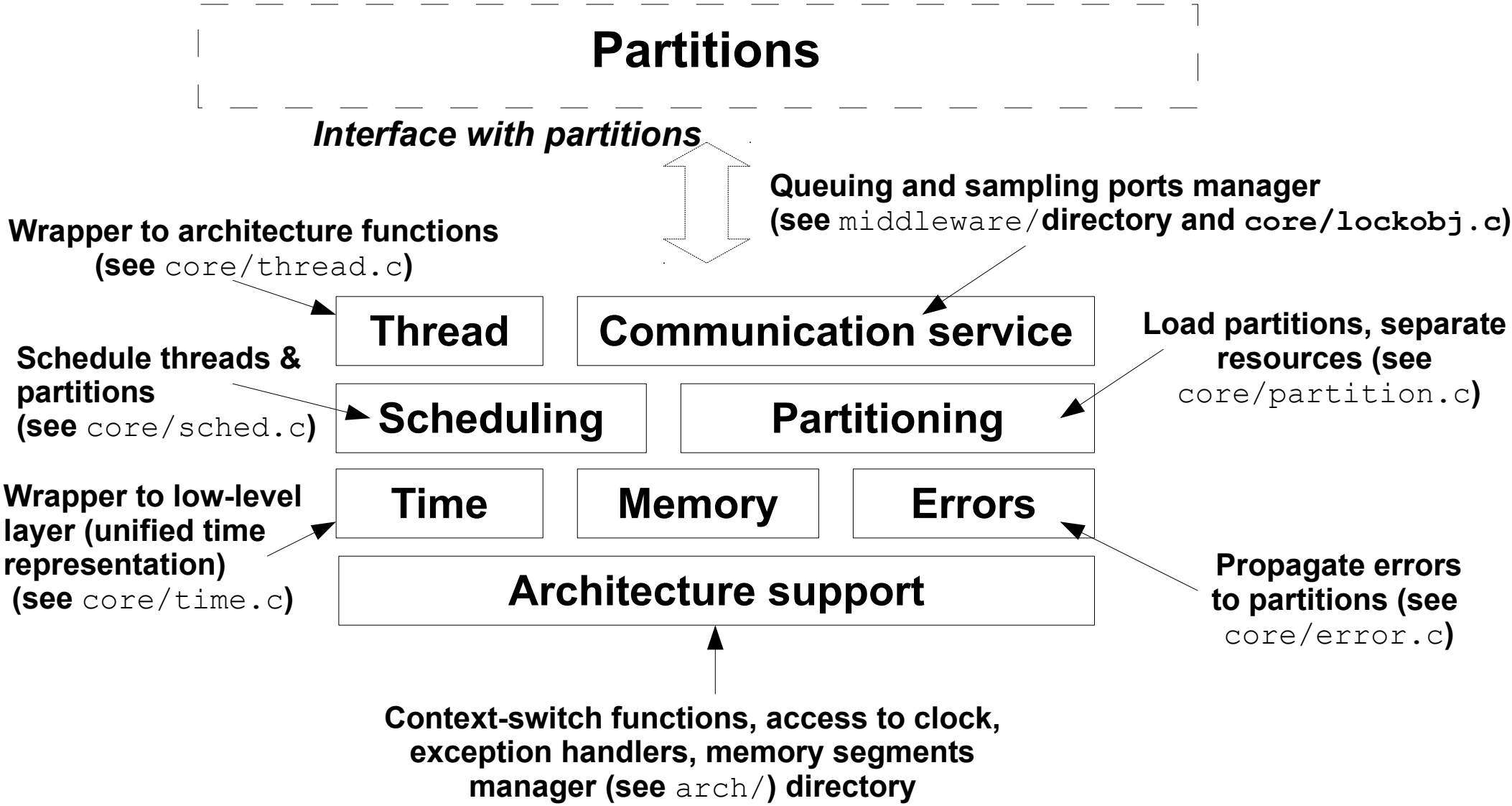
Main architecture



- Intra-partition comm.
- ARINC653 & POSIX layers
- Libc & libm support
- Ada layer
- Device drivers
- Ciphers algorithms
- Time & space partitioning
- I/O interface
- Scheduling

Kernel architecture



We love globvars ...

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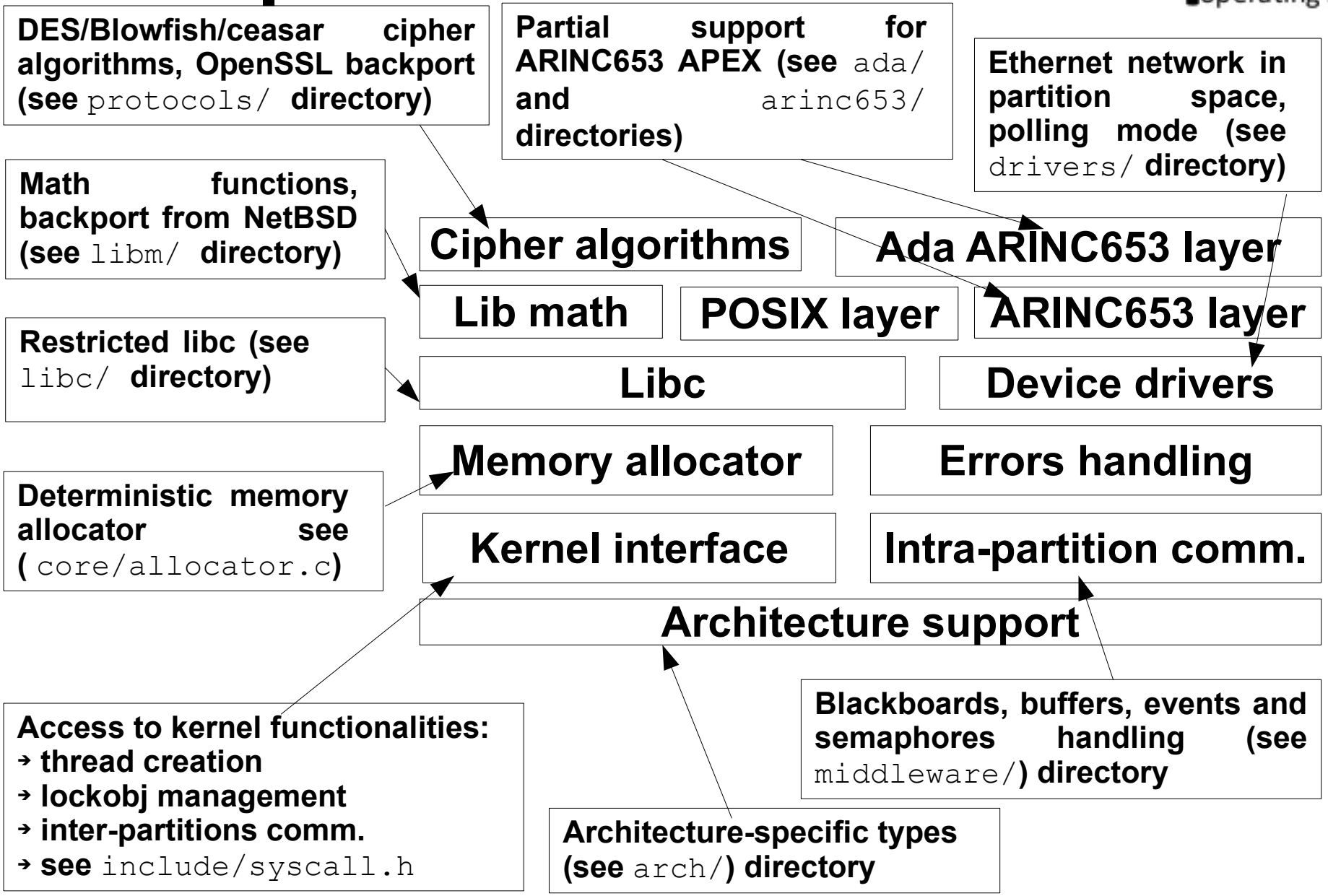
- **Globvars = hell !**
  - **Don't use them, it introduces too many bugs !**
- **… but useful when programming a kernel**
  - **pok_thread_t threads[POK_CONFIG_NB_THREADS]**
  - **pok_partition_t pok_partitions[POK_CONFIG_NB_PARTITIONS]**
  - **pok_port_t pok_ports[POK_CONFIG_NB_PORTS]**
  - **Used very carefully inside the kernel !**

Libpok architecture



Services separation

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- No globvars
  - Too many potential interactions
- Easily add/remove services
  - Rely on POK_NEEDS_* macros
- Services configuration
  - POK_CONFIG_* macros

Error Handling

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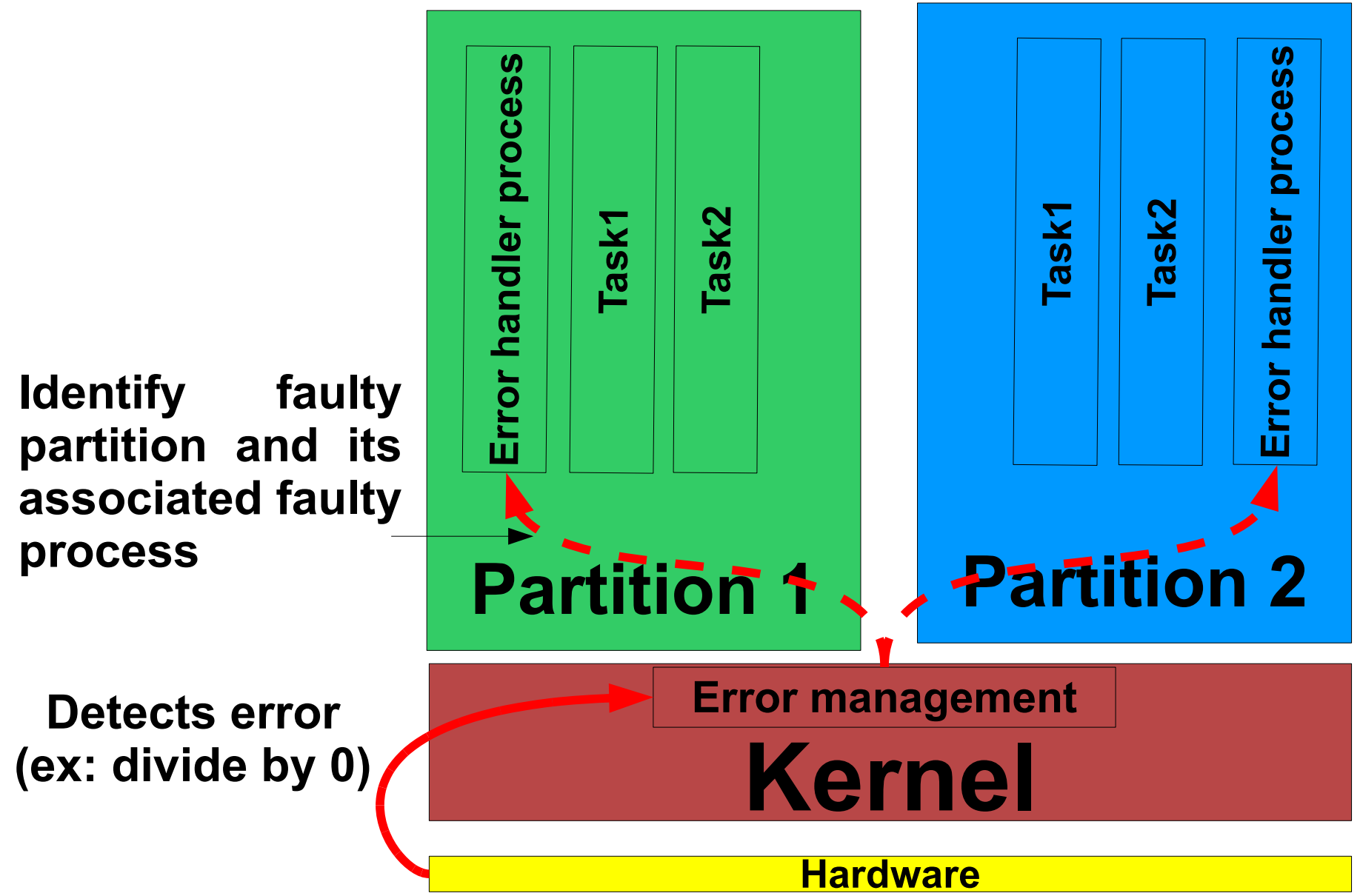
- **Kernel level**
  - **Kernel layer function**
  - **Discriminant: raised error**
- **Partition level**
  - **Kernel layer function**
  - **Discriminants: raised error, faulty partition**
- **Process level**
  - **Dedicated thread in each partition**
  - **Discriminants: raised error, faulty partition**
  - **Kernel receives exception and activates the thread**

Process level error handling



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Sources organization

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- `arch/`
  - Architecture/BSP-dependent files
  - Ex : `arch/x86/x86-qemu`
- `core/`
  - Mainly wrappers to architecture-dependent services
  - Maintain isolation across partitions
  - Partitions loading
- `middleware/`
  - Inter-partitions communication

Resources organization

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- **Statically defined**
  - **All resources are statically defined**
  - **Massive use of arrays**
- **No memory allocation in kernel layer**
  - **Analysis purpose**
  - **Ease further certification/verification**

pok_partition_t

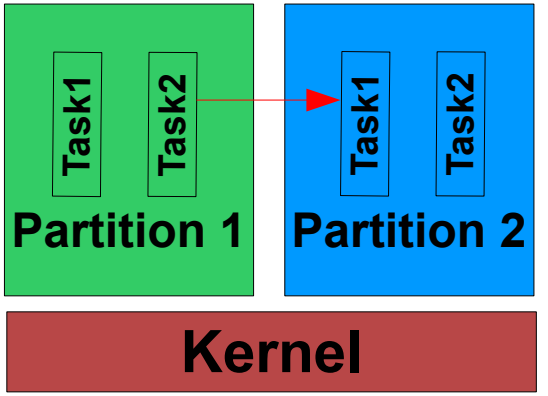
```
typedef struct
{
   uint32_t                base_addr;
   uint32_t                base_vaddr;
   uint32_t                size;
   const char              *name;
   uint32_t                nthreads;
   uint8_t                 priority;
   uint32_t                period;

   pok_sched_t             sched;

   uint32_t (*sched_func)(uint32_t low, uint32_t high);

   uint64_t                activation;
   uint32_t                current_thread;
   uint32_t                thread_index_low;
   uint32_t                thread_index_high;
   uint32_t                thread_index;

#if defined(POK_NEEDS_LOCKOBJECTS) ||
defined(POK_NEEDS_ERROR_HANDLING)
   uint8_t                 lockobj_index_low;
   uint8_t                 lockobj_index_high;
   uint8_t                 nlockobjs;
#endif
/* … */
} pok_partition_t;
```

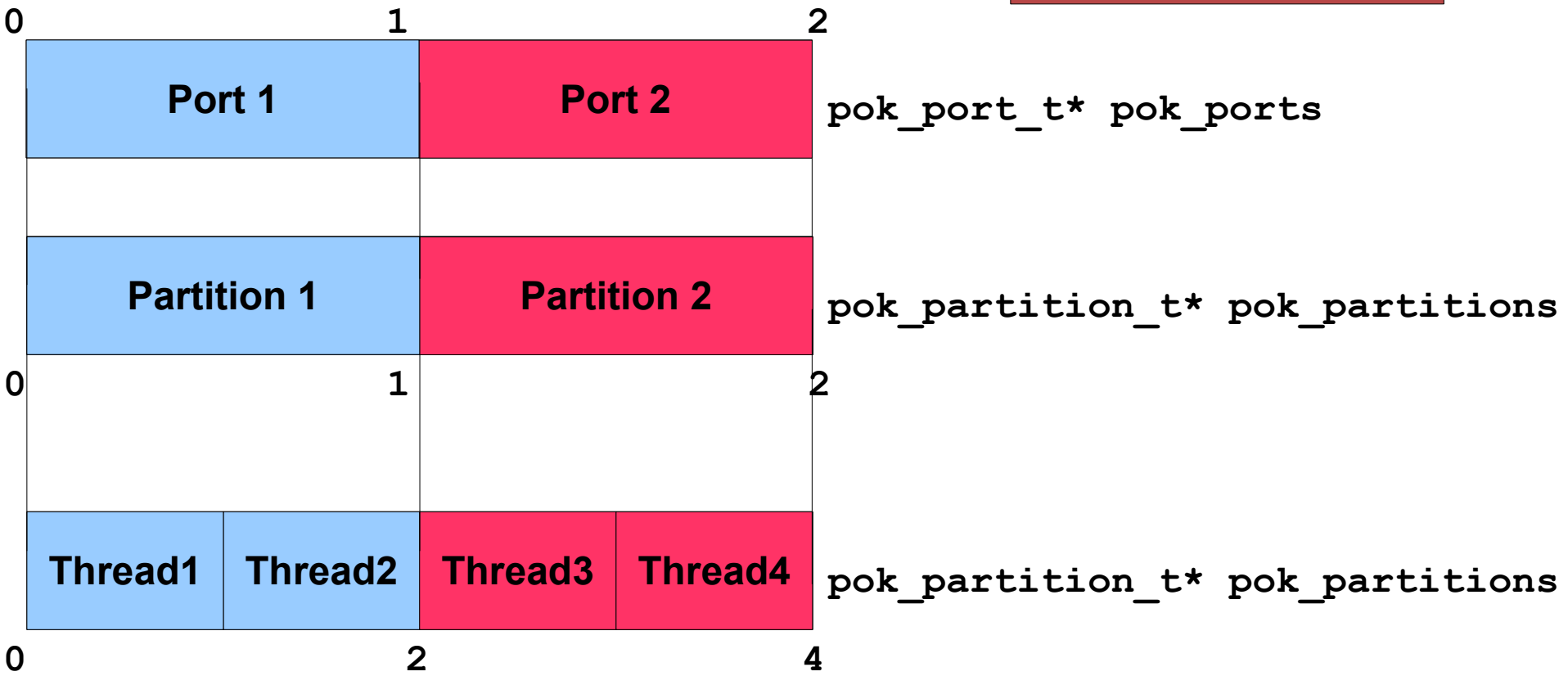
Indicates where the threads of a partition reside.

Bound partition accesses in the lockobjects array.

Critical functions must absolutly CHECK these bound to enforce resources isolation.

Resources organization





Kernel startup (core/boot.c)

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```
void pok_boot ()
{
   pok_arch_init();
   pok_bsp_init();

#if defined (POK_NEEDS_TIME) || defined (POK_NEEDS_SCHED) || defined (POK_NEEDS_THREADS)
   pok_time_init();
#endif

#ifdef POK_NEEDS_PARTITIONS
   pok_partition_init ();
#endif

#ifdef POK_NEEDS_THREADS
   pok_thread_init ();
#endif

#if defined (POK_NEEDS_SCHED) || defined (POK_NEEDS_THREADS)
   pok_sched_init ();
#endif

#if (defined POK_NEEDS_LOCKOBJ) || defined (POK_NEEDS_PORTS_QUEUEING) || defined (POK_NEEDS_PORTS_SAMPLING
   pok_lockobj_init ();
#endif
#if defined (POK_NEEDS_PORTS_QUEUEING) || defined (POK_NEEDS_PORTS_SAMPLING)
   pok_port_init ();
   pok_queue_init ();
#endif

#if defined (POK_NEEDS_DEBUG) || defined (POK_NEEDS_CONSOLE)
  pok_cons_write ("POK kernel initialized\n", 23);
#endif

  pok_arch_preempt_enable();
}
```

Activate services according to system requirements (POK_NEEDS*)

Initialize kernel services

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  - Mainly wrappers to architecture-dependent services
  - Maintain isolation across partitions
  - Partitions loading
- `middleware/`
  - Inter-partitions communication

Important functions

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- `pok_sched()`
  - Called every tick
  - Reschedule the system, enforce time isolation
  - Flush partitions ports when major time frame is reached
- `pok_core_syscall ()`
  - Interface with partitions
  - Highly critical
  - Check space isolation of arguments

Important functions – cont'd

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- `pok_port_flushall ()`
  - Called at each major time frame
  - Flush partitions ports

- `pok_error_declare ()`
  - Wakeup the error process in the partition
  - Complete necessary information to handle the error (error type, faulty thread)

Important functions – cont'd

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- `pok_partition_error ()`
  - Raised an error at the partition level
  - Error handler differentiates each partition
- `pok_kernel_error ()`
  - Raise an error at kernel level

Important variables

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- `pok_threadt_t* threads`
  - Contain informations about all threads of all partitions
  - Include IDLE and KERNEL threads
  - Access to current thread: `POK_CURRENT_THREAD`
- `pok_partition_t* pok_partitions`
  - Array of all partitions
  - Statically defined
  - Used everywhere in the sources
  - Access to the current partition: `POK_CURRENT_PARTITION`

Important variables – cont'd

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- `pok_port_t *pok_ports`
  - Information about ALL ports of ALL partitions
  - Used in the middleware layer (sampling & queuing ports)
- `pok_queue_t pok_queue`
  - Big array
  - Contain data of ALL ports of the current node
  - Statically bound

Important variables – cont'd

- `uint64_t current_time`
  - **Amount of elapsed ticks**
  - **Clock granularity in POK : 1ms**

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Architecture-dependent layer

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- Syscall handling ...
  - Marshall syscall args
- … but mainly types interfacing
  - Do not handle many low-level functions
  - Use unprivileged rights (ring 3 on x86)
- Other functions on x86
  - PCI management
  - Input/Output ports

Kernel interfacing

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- **Access to kernel functionalities**
  - **Threads**
  - **Mutexes**
  - **Partition management**
  - **Inter-partitions ports**
  - **Time**
  - **...**
- **Use software interrupts (aka syscalls)**
  - **Syscalls functions for many potential arguments**
  - **See. `include/core/syscall.h`**

Intra-partition comm.

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- **Four communications functionalities**
  - **Blackboard**
  - **Buffer**
  - **Semaphore**
  - **Event**
- **Resources statically allocated**
  - **cf. POK_CONFIG_NB_BLACKBOARDS, POK_CONFIG,NB_BUFFERS, …**
  - **Same mechanisms as inter-partitions functionalities in kernel**
- **Rely on kernel interfacing functions**
  - **Require mutex handling**

Errors handling

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- **Error process handler creation**
  - **cf. `pok_error_handler_create ()`**
  - **Create a task, entrypoint=`pok_error_handler_worker`**
- **Error handler internals**
  - **Declare as ready (`pok_error_handler_set_ready ()`)**
  - **Catch an error (`pok_error_get ()`)**
  - **Handle error (written by the developer)**
- **Execution of error process**
  - **Executed as soon as an error is raised**

Errors handling – con't

- **Raise application error**
  - **cf.** `pok_raise_application_error ()`
  - **Report errors to the error handler process**
-

Error worker example

```
void pok_error_handler_worker ()
{
  pok_error_status_t error_status;
  while (1)
  {
    pok_thread_stop_self ();
    pok_error_get (&(error_status));
    switch (error_status.failed_thread)
    {
      case 1:
      {
          case POK_ERROR_KIND_APPLICATION_ERROR:
          {
            pok_thread_restart (1);

            break;
          }
          case POK_ERROR_KIND_NUMERIC_ERROR:
          {
            pok_partition_set_mode (POK_PARTITION_MODE_INIT_WARM);

            break;
          }
        }
        break;
      }
    }
  }
}
```

Get error informations (fault type, faulty thread)

Error code

Restart the partition

libc

- **Memory allocation (`stdlib.h`)**
  - **Rely on the deterministic memory allocation**
- **String handling (`string.h`)**
  - **`memcmp()`, `strcpy()`, ...**
- **Basic input/output (`stdio.h`)**
  - **Basic `printf()`**
- **Partial implementation**
  - **Some functions are missing (see `include/libc/`)**
  - **Easily extendable with code reuse from NetBSD**

Device drivers

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- Requires access to low-level concerns
  - Reservation of low-level access at initialization time
  - No reservation allowed at runtime
-
- Polling mode
-
- Experiment with one device
  - Realtek 8029, network device of QEMU
  - See `drivers/` directory

Device drivers – cont'd

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- Constrained to partition restrictions
  - Time & space isolation
  - Communication with other partitions using inter-partitions mechanisms
- Analyze end to end latency
  - Time isolation increases response time
  - See impact of the major frame
- Incoming work on this topic
  - Preliminary work with implementation of HFPPS scheduling algorithm (cf. Burns and Nolte work)

ARINC653 layer

- Implementation of ARINC653 APEX
  - Definition of APEX in include/arinc653
- Wrapper to POK legacy API
  - Use kernel interface
  - Use on intra-partition communication
- Complete implementation
  - Almost all functions are implemented
  - Need to synchronize with newer version of the APEX

Lib math

- **Access to mathematical functions**
  - **Required by some application code (Simulink, Lustre)**
- **Complete implementation**
  - **Successful usage with Lustre and OpenSSL algorithms**
- **Port of NetBSD libm**
  - **No licence conflicts**

Cipher algorithms

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- Cipher data before sending
  - Prevent data sniffing over ethernet networks
- Implementation of symmetric algorithms
  - Data Encryption Standard (DES)
  - Blowfish
  - Ceasar
- Configuration with dedicated macros
  - `POK_NEEDS_PROTOCOLS`
  - `POK_BLOWFISH_KEY`, `POK_DES_KEY`, ...
- Port of OpenSSL algorithms

Ada ARINC653 layer

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- Compliant with standardize ARINC653 APEX
- Wrapper to the C version
  - Keep consistency between types
  - Massive use of `with Interfaces.C`
- Disable Ada runtime
  - Lose benefits of Ada runtime (Task, Protected objects …)
  - Lightweight implementation
  - `pragma No_Run_Time`

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Conclusion

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- **First *libre* partitioned operating system !**
  - **Really *libre* (not a GPL-like software !)**
- **Remaining technical challenges**
  - **Integrate device drivers with respect to T&S isolation**
  - **Improve system analysis**
- **Improve POK !**
  - **Better standard support**
  - **Feel free to join the POK community**

Thanks to ...

- François Goudal
  - Initial project (Gunther)
- Julian Pidancet
  - First version of space isolation
- Laurent Lec
  - Device drivers & Ada/ARINC653 layer
- Fabien Chouteau
  - SPARC/LEON port & Ada/ARINC653 layer
- Tristan Gingol
  - PowerPC/QEMU port

Questions ?