XtratuM Hypervisor for LEON4

Volume 2: XtratuM User Manual

Miguel Masmano, Alfons Crespo, Javier Coronel

November, 2012
Reference: xm-4-usermanual-047d

This page is intentionally left blank.

Document control page

TITLE: XtratuM Hypervisor for LEON4: Volume 2: XtratuM User Manual

AUTHOR/S: Miguel Masmano, Alfons Crespo, Javier Coronel

LAST PAGE NUMBER: 134

VERSION OF SOURCE CODE: XtratuM 4 for LEON3 ()

REFERENCE ID: xm-4-usermanual-047d

SUMMARY: This guide describes the fundamental concepts and the features provided by the API of the XtratuM hypervisor.

REFERENCING THIS DOCUMENT:

```
@techreport {xm-4-usermanual-047d,
        title = {XtratuM Hypervisor for LEON4:  Volume 2:  XtratuM User Manual},
        author = { Miguel Masmano and Alfons Crespo and Javier Coronel},
        institution = {Universidad Politécnica de Valencia},
        number = {xm-4-usermanual-047d},
        year={November, 2012},
}
```

Changes:

Version	Date	Comments
0.1	November, 2011	[xm-4-usermanual-047] Initial document
0.2	March, 2012	[xm-4-usermanual-047b] IOMMU included. Fixed minor bugs
0.3	April, 2012	[xm-4-usermanual-047c] IOMMU updated to support paging translation
0.4	November, 2012	[xm-4-usermanual-047d] Final release. Code version 4.0 Typos corrected. New subsection about IPVI management. XML schema specification described in a separate annex.

This page is intentionally left blank.

Contents

This page is intentionally left blank.

Preface

The target readers for this document are software developers who need to use the services of XtratuM directly. The reader is expected to have an in-depth knowledge of the LEON3 (SPARC v8) architecture and experience in programming device drivers. It is also advisable to have some knowledge of the ARINC-653 and other related standards.

Typographical conventions

The following typographical conventions are used in this document:

- `typewriter`: used in assembler and C code examples, and to show the output of commands.
- *italic*: used to introduce new terms.
- **bold face**: used to emphasize or highlight a word or paragraph.

Code

Code examples are printed inside a box as shown in the following example:

```
static inline void XM_sparc_set_psr(xm_u32_t flags) {
   __asm__ __volatile__("mov "TO_STR(sparc_set_psr_nr)", %%o0\n\t" \
            "mov %0, %%o1\n\t" \
            __DO_XMAHC :: "r"(flags) : "o0", "o1");
}
```

Listing 1: Sample code

Caution sign

The caution sign stresses information that is critical to the integrity or continuity of the system.

Acknowledgements

The porting to LEON4 multicore has been achieved in the framework of the “ESA Project ESA ITT 6185 - System Impact of Distributed Multicore systems” leaded by Astrium EADS.

This page is intentionally left blank.

Chapter 1

Introduction

This document describes the XtratuM hypervisor, and how to write applications to be executed as XtratuM partitions.

A hypervisor is a layer of software that provides one or more virtual execution environments for partitions. Although virtualisation concepts have been employed since the 60's (IBM 360), the application of these concepts to the server, desktop, and recently the embedded and real-time computer segments, is relatively new. There have been some attempts, in the desktop and server markets, to standardise "how" a hypervisor should operate, but the research and the market is not mature enough. In fact, there is still not a common agreement on the terms used to refer to some of the new objects introduced. Check the glossary A for the exact meaning of the terms used in this document.

In the case of embedded systems and, in particular, in avionics, the ARINC-653 standard defines a partitioning system. Although the ARINC-653 standard was not designed to describe how a hypervisor has to operate, some parts of the APEX model of ARINC-653 are quite close to the functionality provided by a hypervisor.

During the porting of XtratuM to the LEON2 and LEON3 processors, we have also adapted the XtratuM API and internal operations to resemble ARINC-653 standard. It is not our intention to convert XtratuM in an ARINC-653 compliant system. ARINC-653 relies on the idea of a "*separation kernel*", which basically consists in extending and enforcing the isolation between processes or a group of processes. ARINC-653 defines both the API and operation of the partitions, but also how the threads or processes are managed inside each partition. It provides a complete APEX.

In a bare-metal hypervisor, and in particular in XtratuM, a partition is a *virtual computer* rather than a group of strongly isolated processes. When multi-threading (or tasking) support is needed in a partition, then an operating system or a run-time support library has to provide support to the application threads. In fact, it is possible to run a different operating system on each XtratuM partition.

It is important to point out that XtratuM is a bare-metal hypervisor with extended capabilities for highly critical systems. XtratuM provides a raw (close to the native hardware) virtual execution environment, rather than a full featured one. Therefore, **although XtratuM by itself can not be compatible with the ARINC-653 standard, the philosophy of the ARINC-653 has been employed when applicable**.

This document is organised as follows:

Chapter 2 describes the XtratuM architecture describing how the partitions are organised and scheduled; also, an overview of the XtratuM services is presented.

Chapter 3 outlines the development process on XtratuM: roles, elements, etc.

Chapter 4 describes the compilation process, which involves several steps to finally obtain a binary code which has to be loaded in the embedded system.

The goal of chapter 5 is to provide a view of the API provided by XtratuM to develop applications to be executed as partitions. The chapter puts more emphasis in the development of bare-applications than applications running on a real-time operating system.

Chapter 6 deals with the concrete structure and internal formats of the different components involved in the system development: system image, partition format, partition tables. The chapter ends with the description of the hypercall mechanism.

Chapter 7 and 8 detail the booting process and the configuration elements of the system, respectively. Finally, chapter 8 provides information of the preliminar tools developed to analyse system configuration schemas (XML format) and generate the appropriate internal structures to configure XtratuM for a specific payload.

1.1 History

The term XtratuM derives from the word "*stratum*". In geology and related fields it means:

> *Layer of rock or soil with internally consistent characteristics that distinguishes it from contiguous layers.*

In order to stress the tight relation with Linux and the open source the "S" was replaced by "X". XtratuM would be the first layer of software (the one closer to the hardware), which provides a rock-solid basis for the rest of the system.

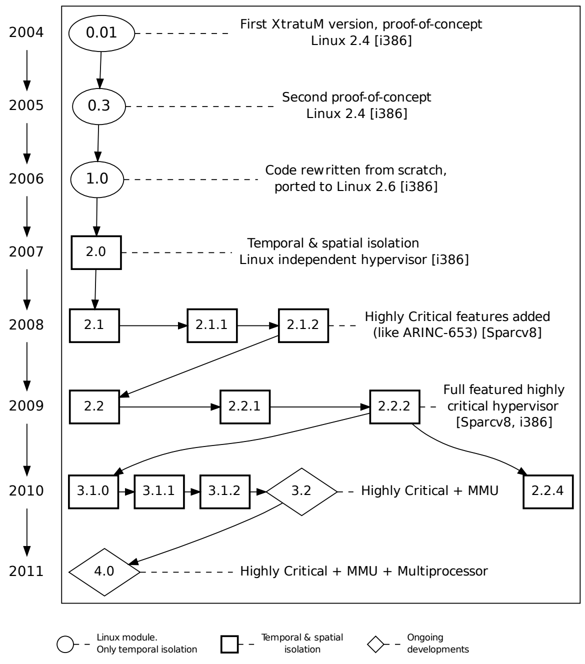

2004
2005
2006
2007
2008
2009
2010
2011
0.01
First XtratuM version, proof-of-concept Linux 2.4 [i386]
0.3
Second proof-of-concept Linux 2.4 [i386]
1.0
Code rewritten from scratch, ported to Linux 2.6 [i386]
2.0
Temporal & spatial isolation Linux independent hypervisor [i386]
2.1
2.1.1
2.1.2
Highly Critical features added (like ARINC-653) [Sparcv8]
2.2
2.2.1
2.2.2
Full featured highly critical hypervisor [Sparcv8, i386]
3.1.0
3.1.1
3.1.2
3.2
Highly Critical + MMU
2.2.4
4.0
Highly Critical + MMU + Multiprocessor
Linux module. Only temporal isolation
Temporal & spatial isolation
Ongoing developments

Figure 1.1: XtratuM evolution.

The first version of XtratuM (1.0) was initially developed to meet the requirements of a hard real-time system. The main goal of XtratuM 1.0 was to guarantee the temporal constrains for the real-time partitions. Other characteristics of this version are:

- The first partition shall be a modified version of Linux.
- Partition code has to be loaded dynamically.
- There is not a strong memory isolation between partitions.
- Linux is executed in processor supervisor mode.
- Linux is responsible of booting the computer.
- Fixed priority partition scheduling.

XtratuM 2.0 was a completely new redesign and implementation. This new version had nothing in common with the first one but the name. It was truly a hypervisor with both, spatial and temporal isolation. This version was developed for the x86 architecture but never released.

XtratuM 2.1 was the first porting to the LEON2 processor, and several safety critical features were added. Just to mention the most relevant features:

- Bare-metal hypervisor.
- Employs para-virtualisation techniques.
- A hypervisor designed for embedded systems: some devices can be directly managed by a designated partition.
- Strong temporal isolation: fixed cyclic scheduler.
- Strong spatial isolation: all partitions are executed in the user mode of the processor, and do not share memory.
- Resource allocation via a configuration table.
- Robust communication mechanisms (ARINC sampling and queuing ports).

Version 2.1 was a prototype to evaluate the capabilities of the LEON2 processor to support a hypervisor system.

XtratuM 2.2 was a more mature hypervisor on the LEON2 processor. This version has most of the final functionality.

XtratuM 3.1 introduces several changes. The main changes are:

- Audit events have been added as the XtratuM tracing subsistem.
- Virtual interrupt subsystem has been rewritten from scratch.
- Cache instruction burst fetch capability can be either enabled or disabled during the XtratuM building process.
- Cache snoop feature can be either enabled or disabled during the XtratuM building process.
- Several partitions can be built with the same virtual addresses.
- Hypercalls behaviour is more robust.

XtratuM 3.2 introduces several changes. The main changes are:

- Any exception caused by a partition when the processor is in supervisor mode causes a partition unrecoverable error.

- A cache flush is executed always in order to guarantee that a partition is unable to retrieve XM information. This operation is forced

XtratuM 3.5 is the developing version for XtratuM to LEON4 processor. It introduces important changes with respect to monocore versions. Changes impact on most of the features. A summary is

- XtratuM exports multiple virtual CPUS to the partitions
- Processor initialisation.
- Interrupt management
- Scheduling plan
- XML configuration file

When released it will be XtratuM 4.0.

Chapter 2

XtratuM Architecture

This chapter introduces the architecture of XtratuM.

The concept of partitioned software architectures was developed to address security and safety issues. The central design criteria involves isolating modules of the system into *partitions*. Temporal and spatial isolation are the key aspects in a partitioned system. Based on this approach, the Integrated Modular Avionics (IMA) is a solution allowed by the Aeronautic Industry to manage the increment of the functionalities of the software maintaining the level of efficiency.

XtratuM is a bare-metal hypervisor designed to achieve temporal and spatial partitioning for safety critical applications. Figure 2.1 shows the complete architecture.

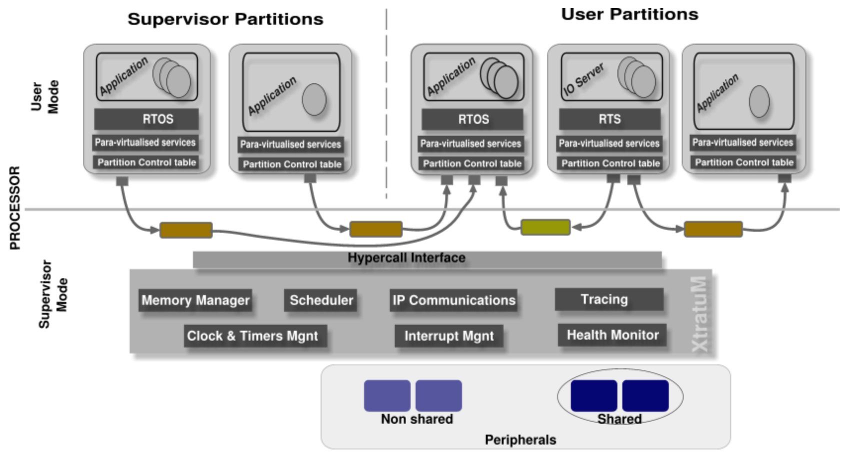


Figure 2.1: XtratuM architecture.

The main components of this architecture are:

- Hypervisor: XtratuM provides virtualisation services to partitions. It is executed in supervisor mode of the procesor and virtualises the CPU, memory, interrupts, and some specific peripherals. The internal XtratuM architecture includes the following components:
  - Memory management: XtratuM provides a memory model for the partitions enforcing the spatial isolation. It uses the hardware mechanisms to guarantee the isolation.
  - Scheduling: Partitions are scheduled by using a cyclic scheduling policy.
  - Interrupt management: Interrupts are handled by XtratuM and, depending on the interrupt nature, propagated to the partitions. XtratuM provides a interrupt model to the partitions

  that extends the concept of processor interrupts by adding 32 additional sources of interrupt (events).

  - Clock and timer management: XtratuM provides one global clock and one local clock to the partitions. Partitions can set one timer for each clock.
  - IP communication: Inter-partition communication is related to the communications between two partitions or between a partition and the hypervisor. XtratuM implements a message passing model which highly resembles the one defined in the ARINC-653. A communication channel is the logical path between one source and one or more destinations. Two basic transfer modes are provided: sampling and queuing. Partitions can access to channels through access points named ports. The hypervisor is responsible for encapsulating and transporting messages.
  - Health monitor: The health monitor is the part of XtratuM that detects and reacts to anomalous events or states. The purpose of the HM is to discover the errors at an early stage and try to solve or confine the faulting subsystem in order to avoid or reduce the possible consequences.
  - Tracing facilities: XtratuM provides a mechanism to store and retrieve the traces generated by partitions and XtratuM itself. Traces can be used for debugging, during the development phase of the application, but also to log relevant events or states during the production phase.

- API: Defines the para-virtualised services provided by XtratuM. The access to these services is provided through *hypercalls*.
- Partitions: A partition is an execution environment managed by the hypervisor which uses the virtualised services. Each partition consists of one or more concurrent processes (concurrency must be implemented by the operating system of each partition because it is not directly supported by XtratuM), that share access to processor resources based upon the requirements of the application. The partition code can be: an application compiled to be executed on a bare-machine; a real-time operating system (or runtime support) and its applications; or a general purpose operating system and its applications.

Partitions need to be *virtualised* to be executed on top of a hypervisor. Depending on the type of execution environment, the virtualisation implications in each case can be summarised as:

Bare application : The application has to be virtualised using the services provided by XtratuM. The application is designed to run directly on the hardware so the the provided and non-provided services of XtratuM must be taken into account.

Mono-core Operating system application : When the application runs on top of a (real-time) operating system, it uses the services provided by the operating system and does not need to be directly virtualised. However, the operating system has to deal with the virtualisation and be virtualised (ported on top of XtratuM).

Multi-core Operating system application : A guest OS can use multiple virtual CPU to support multicore applications

2.1 Multicore architecture

This section introduces the multicore approach for XtratuM. The following notation is used:

CPU : It identifies the real CPUs in the hardware.

virtual CPU : It represents the virtualisation of the CPU provided by XtratuM to the partitions.

Partition : It corresponds to the execution environment where the application are executed. The hypervisor offers a set of *virtual CPU*s that corresponds to the real CPUs are available in the platform.

The goal of the hypervisor is to provide *virtual CPU*s to partitions in the same way that a multicore OS see the CPUs if not virtualisation layer is present. From this point of view, the virtualisation layer will:

- Virtualise all the CPUs to the partitions offering them as *virtual CPU*s
- Initialise the execution of each CPU at the initialisation phase
- After the initialiation phase, start the execution of the plan 0.
- Initialise the *virtual CPU* identified as vcpu0 of each partition.

From the point of view of the partition:

- It can be mono or multicore.
- In monocore partitions, the vcpu0 is used.
  - It is started by the hypervisor.
  - The vcpu0 can be allocated by the integrator (XM_CF configuration file) in any of the real CPUs.
- In multicore partitions, only vcpu0 is initialised by the hypervisor.
  - The vcpu0 code has to initialise the rest of *virtual CPU*s required.
  - The *virtual CPU*s can be allocated by the integrator (XM_CF configuration file) in any of the real CPUs.

2.2 Architecture

Next figure 2.2 presents the approach in a monocore processor.

In the monocore architecture, XtratuM is in charge of the virtualisation of the CPU to the partitions. A partition uses the *virtual CPU* to execute the internal code of the partition. The CPU is initialised by the hypervisor and as soon as the system is initialised, the scheduling plan is started. The plan specifies the sequence of slots to be executed. Each slot identifies a temporal window and the partition to be executed.

Figure 2.3 presents the approach in a multicore processor.

In the multicore architecture, XtratuM virtualises the available CPUs offering to the partitions *virtual CPU*s. A partition can use one or more *virtual CPU*s to execute the internal code. Figure 2.4 shows an example of how partitions can use one or more *virtual CPU*s to implement mono or multicore partitions.

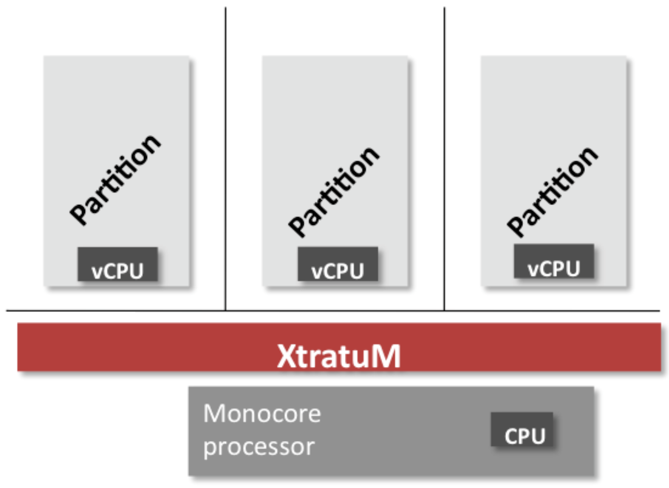


Figure 2.2: Monocore approach.

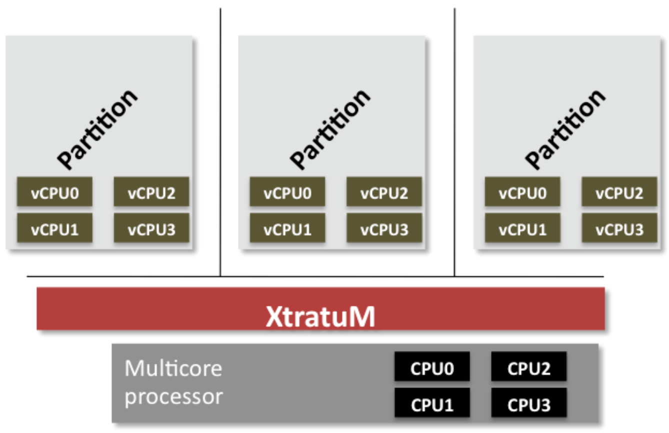


Figure 2.3: Multicore approach.

190 In this case, one of the partition is monocore and only will use one of the *virtual CPU* available (vCPU0). Others partitions are multicore and will use several *virtual CPUs*.

The system integrator is in charge of allocate the *virtual CPUs* to real CPUs in the configuration file. Figure 2.5 shows an example of this allocation.

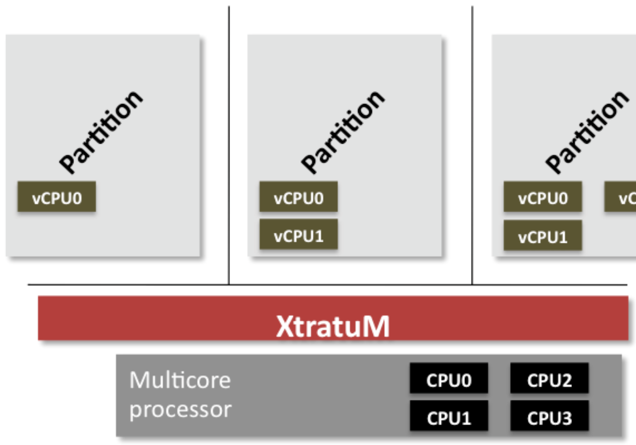


Figure 2.4: Example of mono and multi-core partitions.

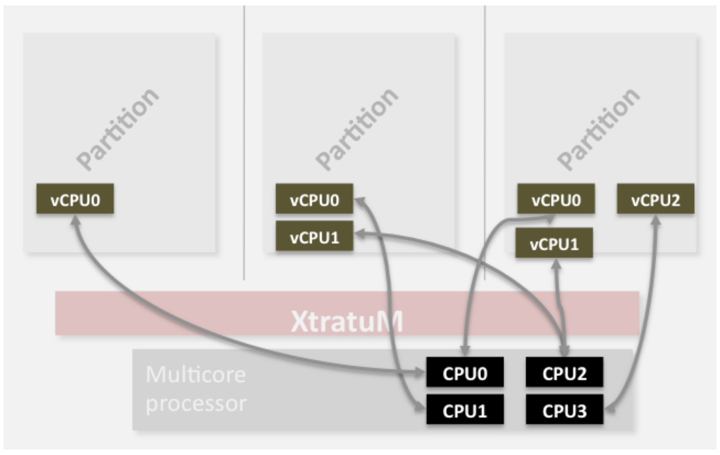


Figure 2.5: vCPU/CPU allocation scheme.

2.3 System states and services

2.3.1 System states

The system's states and its transitions are shown in figure 2.6.

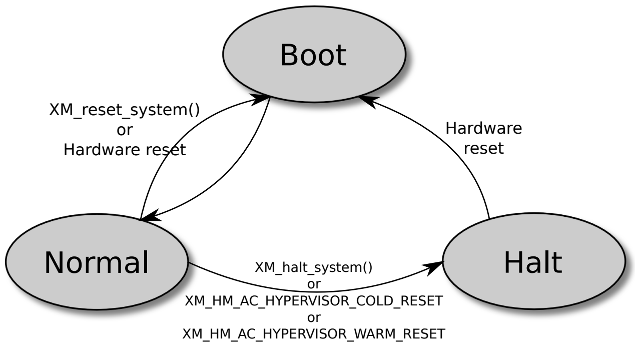


Figure 2.6: System's states and transitions.

At boot time, the resident software loads the image of XtratuM in main memory and transfers control to the entry point of XtratuM. The period of time between starting from the entry point, to the execution of the first partition is defined as **boot** state. In this state, the scheduler is not enabled and the partitions are not executed (see chapter 7).

At the end of the boot sequence, the hypervisor is ready to start executing partition code. The system changes to **normal** state and the scheduling plan is started. Changing from boot to normal state is performed automatically (the last action of the set up procedure).

The system can switch to **halt** state by the health monitoring system in response to a detected error or by a *system partition* invoking the service `XM_halt_system()`. In the halt state: the scheduler is disabled, the hardware interrupts are disabled, and the processor enters in an endless loop. The only way to exit from this state is via an external hardware reset.

It is possible to perform a warm or cold (hardware reset) system reset by using the hypercall (see `XM_reset_system()`). On a warm reset, the system increments the reset counter, and a reset value is passed to the new rebooted system. On a cold reset, no information about the state of the system is passed to the new rebooted system.

2.3.2 System states

Table 2.7 lists the system services.

Service	**Description**
`XM_get_system_status`	Get the system status
`XM_halt_system`	Halt the system
`XM_reset_system`	Reset the system

Figure 2.7: System services

2.4 Partition states and services

2.4.1 Partition states

Once XtratuM is in normal state, partitions are started. The partition's states and transitions are shown in figure 2.8.

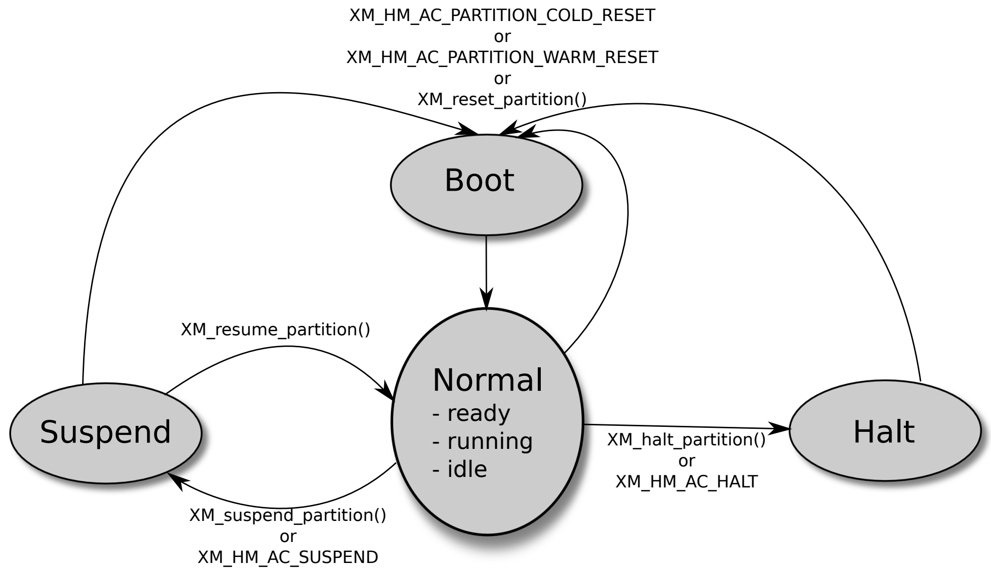


Figure 2.8: Partition states and transitions.

On start-up each partition is in boot state. It has to prepare the virtual machine to be able to run the applications[1]: it sets up a standard execution environment (that is, initialises a correct stack and sets up the virtual processor control registers), creates the communication ports, requests the hardware devices (I/O ports and interrupt lines), etc., that it will use. Once the partition has been initialised, it changes to normal mode.

The partition receives information from XtratuM about the previous executions, if any.

From the hypervisor point of view, there is no difference between the boot state and the normal state. In both states the partition is scheduled according to the fixed plan, and has the same capabilities. Although not mandatory, it is recommended that the partition emits a partition's state-change event when changing from boot to normal state.

The normal state is subdivided in three sub-states:

Ready The partition is ready to execute code, but it is not scheduled because it is not in its time slot.

Running The partition is being executed by the processor.

Idle If the partition does not want to use the processor during its allocated time slot, it can relinquish the processor, and wait for an interrupt or for the next time slot (see `XM_idle_self()`).

A partition can halt itself or be halted by a system partition. In the halt state, the partition is not selected by the scheduler and the time slot allocated to it is left idle (it is not allocated to other partitions).

[1]We will consider that the partition code is composed of an operating system and a set of applications.

All resources allocated to the partition are released. It is not possible to return to normal state.

In suspended state, a partition will not be scheduled and interrupts are not delivered. Interrupts raised while in suspended state are left pending. If the partition returns to normal state, then pending interrupts are delivered to the partition. The partition can return to ready state if requested by a system partition by calling `XM_resume_partition()` hypercall.

2.4.2 Partition services

Table 2.9 lists the partition services.

Service	**Description**
`XM_get_partition_status`	Get the status of the partition
`XM_halt_partition`	Halt the partition
`XM_reset_partition`	Reset the partition
`XM_resume_partition`	Resume the partition
`XM_shutdown_partition`	Shutdown the partition
`XM_suspend_partition`	Suspend the partition

Figure 2.9: Partition services

2.5 *Virtual CPU* states and operation

From the *CPU* point of view, XtratuM mimics the behaviour of a multicore system. When the system is booted, CPU0 is started and is the software (operating systems) the responsible of start the execution of the rest of CPUs.

XtratuM offers the same behaviour to partition for the *virtual CPU*. When booted each partition, they have *vCPU0* running and it is responsability of each partition to start the execution of others *virtual CPU*'s if required.

virtual CPU's are internal abstractions to each partition. *virtual CPU*'s only can be seen and handled by its partition. A partition can not access to any service related to *virtual CPU*'s of other partition.

virtual CPU's, as partitions, are controlled through a set of services that change its status. The *virtual CPU*'s states and transitions are shown in figure 2.10.

On start-up each *virtual CPU* is in boot state. It has to prepare the *virtual CPUs* to be able to run the applications: it sets up a standard execution environment (that is, initialises a correct stack and sets up each *virtual CPU* control registers), creates the communication ports, requests the hardware devices (I/O ports and interrupt lines), etc., that it will use. Once the *virtual CPU* has been initialised, it changes to normal mode.

From the hypervisor point of view, there is no difference between the boot state and the normal state. In both states the *virtual CPUs* are scheduled according to the fixed plan, and has the same capabilities.

The normal state is subdivided in three sub-states:

Ready The *virtual CPU* is ready to execute code, but it is not scheduled because it is not in its time slot.

Running The *virtual CPU* of the partition is being executed by the processor where the *virtual CPU* is allocated.

Idle If the *virtual CPU* does not want to use the processor during its allocated time slot, it can relinquish the processor, and wait for an interrupt or for the next time slot (see `XM_idle_self()`).

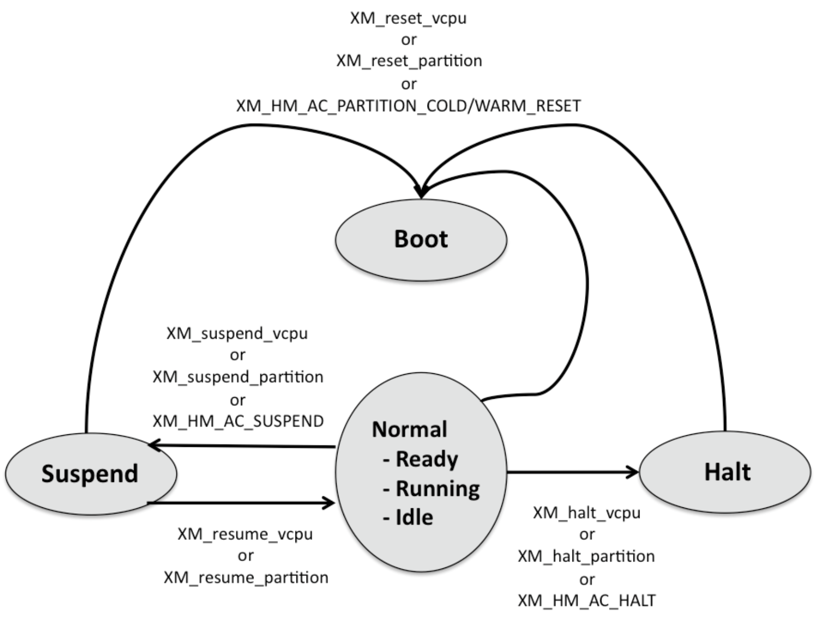


Figure 2.10: Virtual CPU states and transitions.

A *virtual CPU* can halt itself or be halted by another vCPU of the same partition. When halted, the *virtual CPU* is not selected by the scheduler and the time slot allocated to it is left idle (it is not allocated to other partitions). All resources allocated to the *virtual CPU* are released. It is not possible to return to normal state. 265

In suspended state, the *virtual CPU* is not be scheduled and interrupts are not delivered. Interrupts raised while in suspended state are left pending. The *virtual CPU* can return to ready state if requested by another vCPU of the the partition by calling `XM_resume_vcpu()` hypercall.

The state of the *virtual CPU*'s of a partition depends on the partition state. When a partition management service is invoked to a target partition, the following effects are produced: 270

Partition reset All *virtual CPU*'s of the partition are halted. The partition restarts with the vCPU0.

Partition suspend All *virtual CPU*'s of the partition in normal state are suspended.

Partition resume All *virtual CPU*'s of the partition, as they were when the partition was suspended, are restored. 275

Partition halt All *virtual CPU*'s of the partition are halted.

2.5.1 *virtual CPU* services

Table 2.1 lists the *virtual CPU* services.

2.6 System partitions

XtratuM defines two types of partitions: *normal* and *system*. System partitions are allowed to manage and monitor the state of the system and other partitions. Some hypercalls only can be invoked from 280

Service	Description
XM_get_vcpuid	Get the vCPU identifier
XM_halt_vcpu	Halt the vCPU
XM_reset_vcpu	Reset the vCPU
XM_resume_vcpu	Resume the vCPU
XM_suspend_vcpu	Suspend the vCPU

Table 2.1: *CPU* services

a system partition or, more properly, these hypercall only can succeed when are invoked from system partition. Normal partitions requesting these services get a permission error as response.

It is important to point out that system partition rights are related to the capability to manage the system, and not to the capability to access directly to the native hardware or to break the isolation: a system partition is scheduled as a normal partition; and it can only use the resources allocated to it in the configuration file.

Table 2.2 shows the list of hypercalls reserved for system partitions. A hypercall labeled as "partial" indicates that a normal partition can invoke it if a system reserved service is not requested. For instance, a normal partition can invoke the service `XM_halt_partition` if the target partition is itself. To use this service with another partition, the invoking partition has to be defined as system partition.

Hypercall	System
XM_get_gid_by_name	Partial
XM_get_partition_status	Partial
XM_get_system_status	Yes
XM_halt_partition	Partial
XM_halt_system	Yes
XM_hm_open	Yes
XM_hm_read	Yes
XM_hm_seek	Yes
XM_hm_status	Yes
XM_memory_copy	Partial
XM_reset_partition	Partial
XM_reset_system	Yes
XM_resume_partition	Yes
XM_shutdown_partition	Partial
XM_suspend_partition	Partial
XM_switch_sched_plan	Yes
XM_trace_open	Yes
XM_trace_read	Yes
XM_trace_seek	Yes
XM_trace_status	Yes

Table 2.2: List of system reserved hypercalls.

A partition has system capabilities if the `/System_Description/Partition_Table/Partition/@flags` attribute contains the flag "`system`" in the XML configuration file. Several partitions can be defined as system partition.

2.7 Names and identifiers

Each partition is globally identified by a unique identifier *id*. Partition identifiers are assigned by the integrator in the XM_CF file. XtratuM uses this identifier to refer to partitions. System partitions use partition identifiers to refer to the target partition. The "C" macro XM_PARTITION_SELF can be used by a partition to refer to itself.

These *ids* are used internally as indexes to the corresponding data structures[2]. The fist "id" of each object group shall start in zero and the next id's shall be consecutive. It is mandatory to follow this order in the XM_CF file.

The attribute *name* of a partition is a human readable string. This string shall contain only the following set of characters: upper and lower case letters, numbers and the underscore symbol. It is advisable not to use the same name on different partitions. A system partition can get the name of another partition by consulting the status object of the target partition.

In order to avoid name collisions, all the hypercalls of XtratuM contain the prefix "XM". Therefore, the prefix "XM", both in upper and lower case, is reserved.

2.7.1 *Virtual CPU* identifiers

Each *virtual CPU* in each partition is locally identified by a unique identifier *vcpuId*. Each *virtual CPU* can identify itself by the symbol XM_VCPU_SELF.

These *vcpuIds* are used internally as indexes to the corresponding data structures.

2.8 Partition scheduling

XtratuM schedules partitions in a fixed, cyclic basis (ARINC-653 scheduling policy). This policy ensures that one partition cannot use the processor for longer than scheduled to the detriment of the other partitions. The set of *time slots* allocated to each partition is defined in the XM_CF configuration file during the design phase. Each partition is scheduled for a time slot defined as a start time and a duration. Within a time slot, XtratuM allocates the processor to the partition.

If there are several concurrent activities in the partition, the partition shall implement its own scheduling algorithm. This two-level scheduling scheme is known as *hierarchical scheduling*. XtratuM is not aware of the scheduling policy used internally on each partition.

In general, a cyclic plan consists of a major time frame (MAF) which is periodically repeated. The MAF is typically defined as the least common multiple of the periods of the partitions (or the periods of the threads of each partition, if any).

For instance, consider the partition set of figure 2.3a, its hyper-period is 200 time units (milliseconds) and has a CPU utilisation of the 90%. The execution chronogram is depicted in figure 2.11. One of the possible cyclic scheduling plans can be described, in terms of start time and duration, as it is shown in the table 2.3b.

This plan has to be specified in the configuration file. An XML file describing this schedule is shown below.

```
<Processor id="0" frequency="50Mhz">
  <CyclicPlanTable>
    <Plan id="0" majorFrame="200ms">
       <Slot id="0" start="0ms" duration="20ms" partitionId="0 />
       <Slot id="1" start="20ms" duration="10ms" partitionId=1/>
```

[2]For efficiency and simplicity reasons.

	Name	Period	WCET	Util. %
Partition 1	System Mngmt	100	20	20
Partition 2	Flight Control	100	10	10
Partition 3	Flight Mngmt	100	30	30
Partition 4	IO Processing	100	20	20
Partition 5	IHVM	200	20	10

(a) Partition set.

	Start	Dur.	Start	Dur.	Start	Dur.	Start	Dur.
Partition 0	0	20	100	20				
Partition 1	20	10	120	10				
Partition 2	40	30	140	30				
Partition 3	30	10	70	10	130	10	170	10
Partition 4	180	20						

(b) Detailed execution plan.

Table 2.3: Partition definition.

```
        <Slot id="2" start="30ms" duration="10ms" partitionId="3 />
        <Slot id="3" start="40ms" duration="30ms" partitionId=2 />
        <Slot id="4" start="70ms" duration="10ms" partitionId="3 />

        <Slot id="5" start="100ms" duration="20ms" partitionId="0 />
        <Slot id="6" start="120ms" duration="10ms" partitionId=1/>
        <Slot id="7" start="130ms" duration="10ms" partitionId="3 />
        <Slot id="8" start="140ms" duration="30ms" partitionId=2 />
        <Slot id="9" start="170ms" duration="10ms" partitionId=3 />
        <Slot id="10" start="180ms" duration="20ms" partitionId=4/>
     </Plan>
   </CyclicPlanTable>
 </Processor>
 </Processor>
```

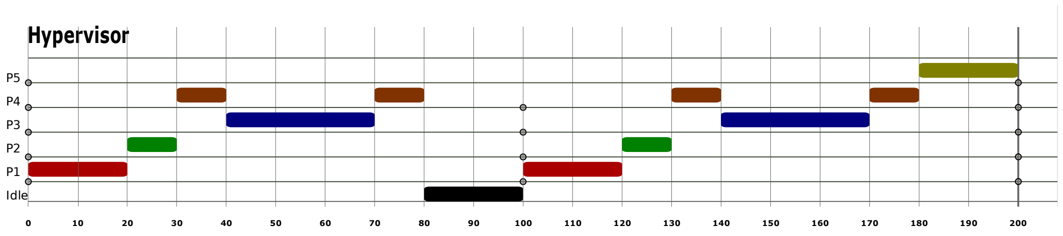


Figure 2.11: Scheduling example.

One important aspect in the design of the XtratuM hypervisor scheduler is the consideration of the overhead caused by the partition's context switch. In the document "*XtratuM Scheduling analysis*" it is provided a deep analysis of the scheduling aspects related to the partition context switch and its implications.

2.8.1 Multiple scheduling plans

In some cases, a single scheduling plan may be too restrictive. For example:

- Depending on the guest operating system, the initialisation can require a certain amount of time and can vary significantly. If there is a single plan, the initialisation of each partition can require a different number of slots due to the fact that the slot duration has been designed considering the operational mode. This implies that a partition can be executing operational work whereas others are still initialising its data.

- The system can require to execute some maintenance operations. These operation can require allocating other resources different from the ones required during the operational mode.

In order to deal with these issues, XtratuM provides multiple scheduling plans that allows to reallocate the timing resources (the processor) in a controlled way. In the scheduling theory this process is known as mode changes. Figure 2.12 shows how the modes have been considered in the XtratuM scheduling.

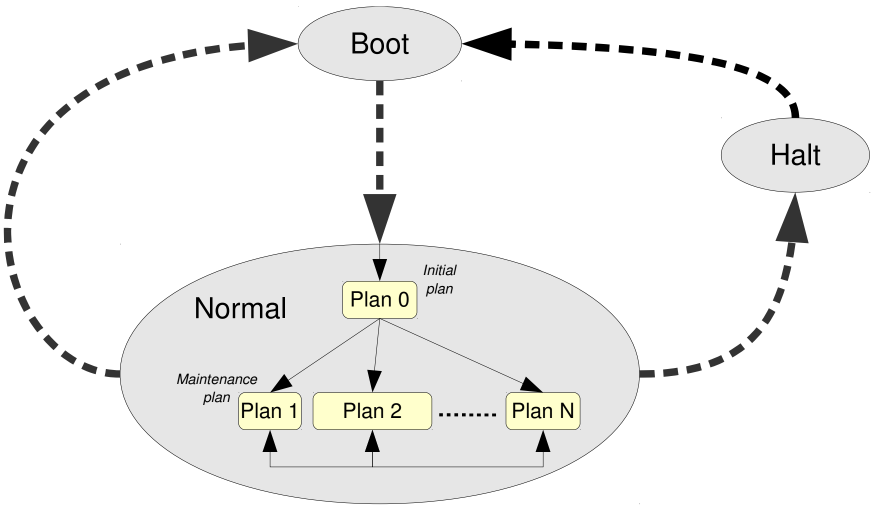


Figure 2.12: Scheduling modes.

The scheduler (and so, the plans) is only active while the system is in *normal* mode. Plans are defined in the XM_CF file and identified by a identifier. Some plans are reserved or have a special meaning:

Plan 0: *Initial plan*. The system selects this plan after a system reset. The system will be in plan 0 until a plan change is requested.

It is not legal to switch back to this plan. That is, this plan is only executed as a consequence of a system reset (software or hardware).

Plan 1: *Maintenance plan*. This plan can be activated in two ways:

- As a result of the health monitoring action XM_HM_AC_SWITCH_TO_MAINTENANCE. The plan switch is done immediately.
- Requested from a system partition. The plan switch occurs at the end the current plan.

It is advisable to allocate the first slot of this plan to a system partition, in order to start the maintenance activity as soon as possible after the plan switch. Once the maintenance activities have been completed, it is responsibility of a system partition to switch to another plan (if needed).

A system partition can also request a switch to this.

Plan x (x>1): Any plan greater than 1 is user defined. A system partition can switch to any of these defined plan at any time.

2.8.2 Switching scheduling plans

When a plan switch is requested by a system partition (through a hypercall), the plan switch is not immediate; all the slots of the current plan will be completed, and the new plan will be started at the end of the current one.

The plan switch that occurs as a consequence of the `XM_HM_AC_SWITCH_TO_MAINTENANCE` action is synchronous. The current slot is terminated, and the Plan 1 is started immediately.

2.9 XtratuM Multicore Scheduling

In this section, the scheduling policies implemented and how they are specified in the configuration file are described,

2.9.1 Scheduling units

The scheduling unit is a *virtual CPU* of a partition. By default, if the *virtual CPU* is not specified, it is assumed that it refers to the vCPU0 (vcpuId = 0). In general, we refer to this unit as a pair represented as $< partition, vcpu >$.

2.9.2 Scheduling policies

XtratuM provides different policies that can be attached to any of the CPU. Two basic policies are defined:

Cyclic scheduling : Pairs $< partition, vcpu >$ are scheduled in a fixed, cyclic basis (ARINC-653 scheduling policy). This policy ensures that one partition cannot use the processor for longer than scheduled to the detriment of the other partitions. The set of *time slots* allocated to each $< partition, vcpu >$ is defined in the `XM_CF` configuration file. Each $< partition, vcpu >$ is scheduled for a time slot defined as a start time and a duration. Within a time slot, XtratuM allocate the system resources to the partition and *virtual CPU* specified.

Priority scheduling : Under this scheduling policy, pairs $< partition, vcpu >$ are scheduled based on the partition priority. The partition priority is specified in the configuration file. Priority 0 corresponds to the highest priority. All pairs $< partition, vcpu >$ in normal state (ready) allocated in the configuration file to a processor attached to this policy are executed taking into account its priority.

2.9.3 Cyclic scheduling

In general, a cyclic plan consists of a major time frame (MAF) which is periodically repeated. The MAF is typically defined as the least common multiple of the periods of the partitions (or the periods of the threads of each partition, if any).

This plan has to be specified in the configuration file. An XML file describing this schedule is shown below.

```
<Processor id="0" frequency="50Mhz">
  <CyclicPlanTable>
    <Plan id="0" majorFrame="800ms">
      <Slot id="0" start="0ms" duration="200ms" partitionId="0 vCpuId="0"/>
```

```
        <Slot id="1" start="200ms" duration="200ms" partitionId=2 vCpuId="0"/>
        <Slot id="2" start="400ms" duration="200ms" partitionId="0 vCpuId="1"/>
        <Slot id="3" start="600ms" duration="200ms" partitionId=1 vCpuId="0"/>
      </Plan>
    </CyclicPlanTable>
  </Processor>
  <Processor id="1" frequency="50Mhz">
    <CyclicPlanTable>
      <Plan id="0" majorFrame="800ms">
        <Slot id="0" start="0ms" duration=300ms" partitionId= 3  vCpuId="0"/>
        <Slot id="1" start=300ms" duration="200ms" partitionId= 0  vCpuId= 2 "/>
        <Slot id="1" start=500ms" duration="200ms" partitionId= 2  vCpuId= 1 "/>
      </Plan>
    </CyclicPlanTable>
  </Processor>
```

This plan produces a scheduling as detailed in the next figure 2.13.

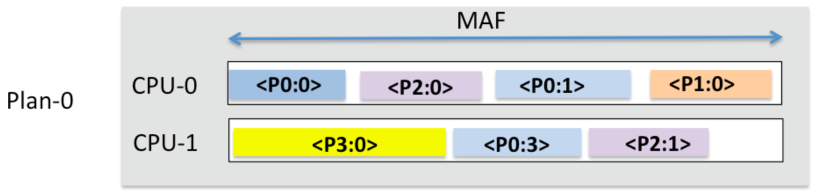


Figure 2.13: Cyclic plan example.

In this scheduling plan, the configuration file defines:

- partition P0 allocates its vCPU0 and vCPU1 in CPU0 and VCPU2 in CPU1.
- partition P1 allocates its vCPU0 in CPU0
- partition P2 allocates its vCPU0 in CPU0 and vCPU1 in CPU1
- partition P3 allocates its vCPU0 in CPU1

2.9.4 Fixed priority scheduling

The priority based policy selects between the ready VCPUs allocated to the core, the VCPU with a highest priority. This scheduling policy is preemptive allowing to switch to a higher priority VCPU at any time.

The definition of the CPUs under the priority based scheduling policy and they allocation of pairs $< partition, vcpu >$ to it has to be specified in the configuration file. A XML file describing this schedule is shown below.

```
<Processor id="2" frequency="50Mhz">
  <FixedPriority>
    <Partition id="0" vCpuId=3" priority="10"/>
    <Partition id="1" vCpuId="1" priority="5"/>
  </FixedPriority>
</Processor>
```

In this example, the CPU2 is defined to be scheduled under the priority based scheduling policy. Pairs $< P0, vCPU3 >$ and $< P1, vCPU1 >$ are allocated to this processor and, as consequence, to this policy. to this policy independently of the plan.

Note that if the scheduling policy of a CPU is defined as fixed priority, this CPU is not affected by the the cyclic plans of other CPUs.

In the multicore approach, the following aspects have to be taken into account:

- Only cyclic plans are associated to the multiple plans.
- If a processor is defined under a priority based policy, the policy applies independently of the plan.
- Plans involving several processors have to define the same Major Frame (MAF).

An example of the scheduling definition is listed below.

```
<ProcessorTable>
        <Processor id="0" frequency="50Mhz">
                <CyclicPlanTable>
                        <Plan id="0" majorFrame="1s">
                                <Slot id="0" start="0ms" duration="500ms" partitionId
                                    ="0" vCpuId="0"/>
                                <Slot id="1" start="500ms" duration="500ms"
                                    partitionId="1" vCpuId="0"/>
                        </Plan>
                        <Plan id="1" majorFrame="600ms">
                                <Slot id="0" start="0ms" duration="410ms" partitionId
                                    ="0" vCpuId="0"/>
                                <Slot id="1" start="450ms" duration="150ms"
                                    partitionId="1" vCpuId="0"/>
                        </Plan>
                </CyclicPlanTable>
        </Processor>
        <Processor id="1" frequency="50Mhz">
                <CyclicPlanTable>
                        <Plan id="0" majorFrame="1s">
                                <Slot id="0" start="0ms" duration="500ms" partitionId
                                    ="2" vCpuId="0"/>
                                <Slot id="0" start="500ms" duration="500ms"
                                    partitionId="3" vCpuId="0"/>
                        </Plan>
                        <Plan id="1" majorFrame="600ms">
                                <Slot id="0" start="0ms" duration="400ms" partitionId
                                    ="2" vCpuId="0"/>
                                <Slot id="1" start="400ms" duration="200ms"
                                    partitionId="3" vCpuId="0"/>
                        </Plan>
                </CyclicPlanTable>
        </Processor>
        <Processor id="2" frequency="50Mhz">
                <CyclicPlanTable>
                        <Plan id="1" majorFrame="600ms">
                                <Slot id="0" start="0ms" duration="200ms" partitionId
                                    ="0" vCpuId="1"/>
                                <Slot id="1" start="200ms" duration="360ms"
                                    partitionId="2" vCpuId="1"/>
                        </Plan>
                </CyclicPlanTable>
        </Processor>

        <Processor id="3" frequency="50Mhz">
                <FixedPriority>
```

```
                  <Partition id="0" vCpuId=2" priority="10"/>
                  <Partition id="1" vCpuId="1" priority="5"/>
            </FixedPriority>
      </Processor>
</ProcessorTable>
```

2.10 Memory management

Partitions and XtratuM core can be allocated at defined memory areas specified in the XM_CF.

A partition define several memory areas. Each memory area can define some attributes or rights to permit to other partitions to access to their defined areas or allow the cache management. The following attributes area allowed:

unmapped Allocated to the partition, but not mapped by XtratuM in the page table.

mappedAt It allows to allocate this area to a virtual address.

shared It is allowed to map this area in other partitions.

read-only The area is write-protected to the partition.

uncacheable Memory cache is disabled.

The implementation of the whole set of features will depend on the available hardware. For systems with a MMU (*Memory Management Unit*), most (or all of them) will be available, though in systems with MPU (*Memory Protection Unit*) or WPR (*Write Protection Registers*) most of the may not be. See section 5.16 for more details.

2.11 IO-MMU support

LEON4 processor implements an io-mmu in order to enable logic partitioning of io resources: any partition access to IO resources is translated through the mmu, allowing an effective spatial isolation. Nevertheless, since DMA accesses were not translated, its use permitted to break spatial isolation: a partition could program a DMA transference overwriting or retrieving the content of area belonging to another partition or the hypervisor.

The io-mmu is a mmu interposed between master AHB devices and slaves ones, enabling an effective real spatial isolation. XtratuM allows to the system integrator to make use of the io-mmu through the xml configuration file. More concretely, the element `/SystemDescription/Hypervisor/IoMmu` permits to define a table in order to link one or a set of AHB master buses to a partition. A maximum of 6 of such links are allowed (restriction imposed by the LEON4 implementation). Additionally, the system integrator must define the bus to use for accesses by the AHB master (`@busRouting`) which can be either `processor` or `memory` and the vendor and device PNP Id of the master.

Eventually, in order to avoid huge io-memory tables, XtratuM implements:

- The lowest possible ITR (area protected size). Taken into account that the upper part shall start in 0xffffffff (restriction imposed by LEON4).
- The largest page size which better fits with the partition's area sizes.
- A new possible flag **iommu** has been added to `PhysicalMemoryAreas/Area/@flags` in order to indicate that only the areas with this new flags shall be mapped in the io-mmu.

Following is an example of use of the io-mmu with two partitions:

```
<?xml version="1.0"?>
<SystemDescription xmlns="http://www.xtratum.org/xm-3.x" version="1.0.0"
    name="Example_iommu">
  <HwDescription>
    <ProcessorTable>
      <Processor id="0" frequency="50Mhz">
        <Sched>
          <CyclicPlan>
            <Plan id="0" majorFrame="500ms">
              <Slot id="0" start="0ms" duration="250ms" partitionId="0"/>
              <Slot id="1" start="250ms" duration="250ms" partitionId="1"/>
            </Plan>
          </CyclicPlan>
        </Sched>
      </Processor>
    </ProcessorTable>
    <Devices>
      <Uart id="0" baudRate="115200" name="Uart"/>
    </Devices>
    <MemoryLayout>
      <Region type="stram" start="0x0" size="32MB"/>
      <Region type="rom" start="0x80000000" size="32MB" />
    </MemoryLayout>
  </HwDescription>
  <XMHypervisor console="Uart">
    <PhysicalMemoryAreas>
      <Area start="0x40000000" size="512KB" flags="uncacheable"/>
    </PhysicalMemoryAreas>
```

```
      <IoMmu>
        <AhbMst id="0" partitionId="1" busRouting="processor" vendorId="0x1
            " deviceId="0x20" />
        <AhbMst id="1" partitionId="0" busRouting="memory" vendorId="0x1"
            deviceId="0x20" />
        <AhbMst id="2" partitionId="0" busRouting="memory" vendorId="0x1"
            deviceId="0x20" />
      </IoMmu>
  </XMHypervisor>
  <PartitionTable>
    <Partition id="0" name="Partition1" flags="" console="Uart">
      <PhysicalMemoryAreas>
        <Area start="0x300000" size="512KB"/>
        <Area start="0x80000000" size="4KB" flags="iommu"/>
      </PhysicalMemoryAreas>
      <TemporalRequirements duration="500ms" period="500ms"/>
    </Partition>
    <Partition id="1" name="Partition2" flags="system" console="Uart">
      <PhysicalMemoryAreas>
        <Area start="0x500000" size="512KB" flags="uncacheable"/>
        <Area start="0x80001000" mappedAt="0xff000000" size="512KB" flags="
            uncacheable iommu"/>
      </PhysicalMemoryAreas>
    </Partition>
  </PartitionTable>
</SystemDescription>
```

Listing 2.1: XML example

In the example, two master buses (AHB1 and AHB2) use an io-mmu table having access to the area [0x80000000 - 0x80000fff] (area defined by the partition 0) and the bus AHB0 which has been allocated to the partition 1, uses a table which translates any access to the area [0xff000000 - 0xff070000] to [0x80001000 - 0x8008ffff]. In this example, the ITR is 7, the page size is 4KB and there will be two tables of 2 MBytes each one.

2.12 Inter-partition communications (IPC)

Inter-partition communications are communications between two partitions. XtratuM implements a message passing model which highly resembles the one defined in the ARINC-653 standard. A message is a variable[3] block of data. A message is sent from a source partition to one or more destination partitions. The data of a message is transparent to the message passing system.

A communication channel is the logical path between one source and one or more destinations. Partitions can access to channels through access points named ports. The hypervisor is responsible for encapsulating and transporting messages that have to arrive to the destination(s) unchanged.

At the partition level, messages are atomic entities i.e., either the whole message is received or nothing is received. Partition developers are responsible for agreeing on the format (data types, endianess, padding, etc.).

Channels, ports, maximum message sizes and maximum number of messages (queuing ports) are entirely defined in the configuration files (see section 8).

XtratuM provides two basic transfer modes: *sampling* and *queuing*.

Sampling port: It provides support for broadcast, multicast and unicast messages. No queuing is supported in this mode. A message remains in the source port until it is transmitted through the channel or it is overwritten by a new occurrence of the message, whatever occurs first. Each new instance of a message overwrites the current message when it reaches a destination port, and remains there until it is overwritten. This allows the destination partitions to access the latest message.

A partition's write operation on a specified port is supported by `XM_write_sampling_message()` hypercall. This hypercall copies the message into an internal XtratuM buffer. Partitions can read the message by using `XM_read_sampling_message()` which returns the last message written in the buffer. XtratuM copies the message to the partition space.

Any operation on a sampling port is non-blocking: a source partition can always write into the buffer and the destination partition/s can read the last written message.

The channel has an optional configuration attribute named `@refreshPeriod`. This attribute defines the maximum time that the data written in the channel is considered "valid". Messages older than the valid period are marked as invalid. When a message is read, a bit is set accordingly to the valid state of the message.

Queuing port: It provides support for buffered unicast communication between partitions. Each port has associated a queue where messages are buffered until they are delivered to the destination partition. Messages are delivered in FIFO order.

Sending and receiving messages are performed by two hypercalls: `XM_send_queuing_message()` and `XM_receive_queuing_message()`, respectively. XtratuM implements a classical producer-consumer circular buffer without blocking. The sending operation writes the message from partition space into the circular buffer and the receive one performs a copy from the XtratuM circular buffer into the destination memory.

If the requested operation cannot be completed because the buffer is full (when trying to send a message) or empty (when attempting to receive a message), then **the operation returns immediately with the corresponding error**. The partition's code is responsible for retrying the operation later.

Queuing ports can specify a policy `FIFO` or `PRIORITY` for the source or destination. XtratuM does not handle this attribute but provides the attribute to the partitions in order to be handled by the guest operating system to wake blocked threads in write or read operations on the port under any of these disciplines.

[3] XtratuM defines the maximum length of a message.

In order to optimise partition's resources and reduce the performance loss caused by polling the state of the port, XtratuM triggers an extended interrupt when a new message is written/sent to a port. Since there is only one single interrupt line to notify for incoming messages, on the reception of the interrupt, the partition code has to determine which port or ports are ready to perform the operation. XtratuM maintains a bitmap in the Partition Control Table to inform about the state of each port. A "1" in the corresponding entry indicates that the requested operation can be performed.

When a new message is available in the channel, XtratuM triggers an extended interrupt to the destination(s).

2.12.1 Multicore implications

When the plan allocates partitions in several CPU's, partitions involved in a communication can be running or not at the same time. If they do not overlap in time, the reader will receive the interrupt at the begining of its slot. If they overlap, as soon as the writer partition sends the message, XtratuM will deliver the interrupt the reader partition that will be able to receive the message.

In order to implement the notification of the message, a set of interrupts have been added. List below shos these interrupts.

```
* Inter-Partition Virtual Interrupts */
#define XM_MAX_IPVI CONFIG_XM_MAX_IPVI
#define XM_VT_EXT_IPVI0 (24+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI1 (25+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI2 (26+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI3 (27+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI4 (28+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI5 (29+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI6 (30+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI7 (31+XM_VT_EXT_FIRST)
```

XtratuM implements a homogeneous policy for access, on a per-partition basis, to the resources. It implies that the internal subjects (VCPUs or threads) in a partition have the same requirements for access to the resources specified in the configuration file.

Is responsability of the guest OS to define another policy. For instance, a guest OS could define a **Least Provilege Abstraction** which assumes that the internal subjects (VCPU or threads) in a partition have heterogeneous requirements for access to the resources. In this case, the guest OS could restrict the defined operations to some internal subjects.

2.13 Health monitor (HM)

The health monitor is the part of XtratuM that detects and reacts to anomalous events or states. The purpose of the HM is to discover the errors at an early stage and try to solve or confine the faulting subsystem in order to avoid a failure or reduce the possible consequences.

It is important to clearly understand the difference between 1) an incorrect operation (instruction, function, application, peripheral, etc.) which is handled by the normal control flow of the software, and 2) an incorrect behaviour which affects the normal flow of control in a way not considered by the developer or which can not be handled in the current scope.

An example of the first kind of errors is: the `malloc()` function returns a null pointer because there is not memory enough to attend the request. This error is typically handled by the program by checking the return value. As for the second kind, an attempt to execute an undefined instruction (processor instruction)may not be properly handled by a program that attempted to execute it.

The XtratuM health monitoring system will manage those faults that cannot, or should not, be managed at the *scope* where the fault occurs.

The XtratuM HM system is composed of four logical blocks:

HM event detection:
to detect abnormal states, using logical probes in the XtratuM code.

HM actions:
a set of predefined actions to recover a fault or confine an error.

HM configuration:
to bind the occurence of each HM event with the appropriate HM action.

HM notification:
to report the occurrence of the HM events.

Since HM events are, by definition, the result of a unexpected behaviour of the system, it may be difficult to clearly determine which is the original cause of the fault, and so, what is the best way to handle the problem. XtratuM provides a set of "coarse grain" actions (see section 2.13.2) that can be used at the first stage, right when the fault is detected. Although XtratuM implements a default action for each HM event, the integrator can map an HM action to each HM event using the XML configuration file.

Once the defined HM action is carried out by XtratuM, a HM notification message is stored in the HM log stream (if the HM event is marked to generate a log). A system partition can then read those log messages and perform a more advanced error handling. As an example of what can be implemented:

1. Configure the HM action to stop the faulting partition, and log the event.
2. The system partition can resume an alternate one, a redundant dormant partition, which can be implemented by another developer team to achieve diversity.

Since the differences between *fault*[4] and *error*[5] are so subtle and subjective, we will use both terms to refer to the original reason of an incorrect state.

The XtratuM health monitoring subsystem defines four different execution scopes, depending on which part of the system has been initially affected:

1. Process scope: Partition process or thread.
2. Partition scope: Partition operating system or run-time support.
3. Hypervisor scope: XtratuM code.
4. Board scope: Resident software (BIOS, BOOT ROM or firmware).

The scope[6] where an HM event should be managed has to be greater than the scope where it is "believed" it can be produced.

There is not a clear and unique scope for each HM event. Therefore the same HM event may be handled at different scopes. For example, fetching an illegal instruction is considered hypervisor scope if it happens when while XtratuM is executing; and partition level if the event is raised while a partition is running.

XtratuM tries to determine the most likely scope target, and to deliver the HM to the corresponding upper scope.

[4]Fault: What is believed to be the original reason that caused an error.
[5]Error: The manifestation of a fault.
[6]The term **level** is used in the ARINC-653 standard to refer to this idea

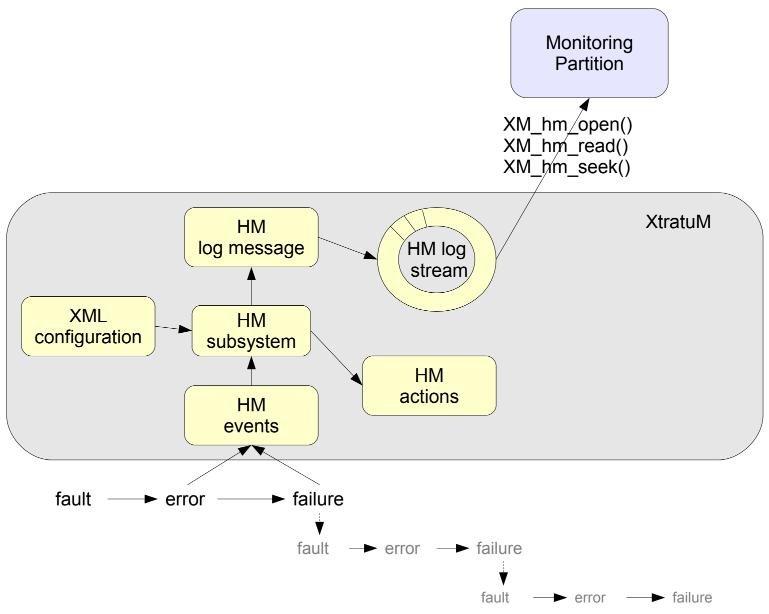


Figure 2.14: Health monitoring overview.

2.13.1 HM Events

740 There are three sources of HM events:

- Events caused by abnormal hardware behaviour. Most of the processor exceptions are managed as health monitoring events.
- Events detected and triggered by partition code. These events are usually related to checks or assertions on the code of the partitions. **Health monitoring events raised by partitions are a special type of tracing message** (see sections 2.16). Highly critical tracing messages are 745 considered as HM events.
- Events triggered by XtratuM. Caused by a violation of a sanity check performed by XtratuM on its internal state or the state of a partition.

When a HM event is detected, the relevant information (error scope, offending partition identifier, 750 memory address, faulting device, etc.) is gathered and used to select the apropiate HM action.

The next table shows the event detected by XtratuM:

Action	Description
XM_HM_EV_INTERNAL_ERROR	Internal XtratuM error.
XM_HM_EV_UNEXPECTED_TRAP	
XM_HM_EV_PARTITION_UNRECOVERABLE	
XM_HM_EV_PARTITION_ERROR	
XM_HM_EV_PARTITION_INTEGRITY	XtratuM detected a mismatch between the partition's digest stored in the container and the one calculated from the partition's section inside the container.
XM_HM_EV_MEM_PROTECTION	Either XtratuM or a partition triggered a memory protection error.
XM_HM_EV_OVERRUN	
XM_HM_EV_SCHED_ERROR	
XM_HM_EV_WATCHDOG_TIMER	The processor received a watchdog timer signal.
XM_HM_EV_INCOMPATIBLE_INTERFACE	
XM_HM_EV_ARM_UNDEF_INSTR	The processor detected an unknown instruction.
XM_HM_EV_ARM_PREFETCH_ABORT	An instruction prefetching error was encountered according to the conditions described in the ARM architecture manual.
XM_HM_EV_ARM_DATA_ABORT	A data access abort has been detected according to the conditions described in the ARM architecture manual.

2.13.2 HM Actions

Once an HM event is raised, XtratuM has to react quickly to the event. The set of configurable HM actions is listed in the next table:

Action	Description
XM_HM_AC_IGNORE	No action is performed.
XM_HM_AC_SHUTDOWN	The shutdown extended interrupt is sent to the failing partition.
XM_HM_AC_COLD_RESET	The failing partition/processor is cold reset.
XM_HM_AC_WARM_RESET	The failing partition/processor is warm reset.
XM_HM_AC_PARTITION_COLD_RESET	The failing partition is cold reset.
XM_HM_AC_PARTITION_WARM_RESET	The failing partition is warm reset. 755
XM_HM_AC_HYPERVISOR_COLD_RESET	The hypervisor is cold reset.
XM_HM_AC_HYPERVISOR_WARM_RESET	The hypervisor is warm reset.
XM_HM_AC_SUSPEND	The failing partition is suspended.
XM_HM_AC_HALT	The failing partition/processor is halted.
XM_HM_AC_PROPAGATE	No action is performed by XtratuM. The event is redirected to the partition as a virtual trap.
XM_HM_AC_SWITCH_TO_MAINTENANCE	The current scheduling plan is switched to the maintenance one.

2.13.3 HM Configuration

There are two tables to bind the HM events with the desired handling actions:

XtratuM HM table: which defines the actions for those events that must be managed at system or hypervisor scope.

Partition HM table: which defines the actions for those events that must be managed at hypervisor or partition scope. 760

Note that the same HM event can be binded with different recovery actions in each partition HM table and in the XtratuM HM table.

The HM system can be configured to send a HM message after the execution of the HM action. It is possible to select whether a HM event is logged or not. See the chapter 8.

2.13.4 HM notification

The log events generated by the HM system (those events that are configured to generate a log) are stored in the device configured in the XM_CF configuration file.

In the case that the logs are stored in a log stream, then they can be retrieved by system partitions by using the XM_hm_X services.

Health monitoring log messages are fixed length messages defined as follows:

```
struct xmHmLog {
#define XM_HMLOG_SIGNATURE 0xfecf
    xm_u16_t signature;
    xm_u16_t checksum;
    xm_u32_t opCode;
#define HMLOG_OPCODE_EVENT_MASK (0x1fff<<HMLOG_OPCODE_EVENT_BIT)
#define HMLOG_OPCODE_EVENT_BIT 19
// Bits 18 and 17 free
#define HMLOG_OPCODE_SYS_MASK (0x1<<HMLOG_OPCODE_SYS_BIT)
#define HMLOG_OPCODE_SYS_BIT 16
#define HMLOG_OPCODE_VALID_CPUCTXT_MASK (0x1<<
    HMLOG_OPCODE_VALID_CPUCTXT_BIT)
#define HMLOG_OPCODE_VALID_CPUCTXT_BIT 15
#define HMLOG_OPCODE_MODID_MASK (0x7f<<HMLOG_OPCODE_MODID_BIT)
#define HMLOG_OPCODE_MODID_BIT 8
#define HMLOG_OPCODE_PARTID_MASK (0xff<<HMLOG_OPCODE_PARTID_BIT)
#define HMLOG_OPCODE_PARTID_BIT 0
    xm_u32_t seq;
    xmTime_t timestamp;
    union {
#define XM_HMLOG_PAYLOAD_LENGTH 4
        struct hmCpuCtxt cpuCtxt;
        xmWord_t payload[XM_HMLOG_PAYLOAD_LENGTH];
    };
} __PACKED;
```

Listing 2.2: HM log definition

where

signature: A magic number to identify the content of the structure as HM log.

checksum: A MD5 digestion of the data structure allowing to verify the integrity of its content.

opCode: The bits of this field codifies

Bits 31..19 (eventId): Identifies the event that caused this log.

Bits 16 (sys): Set if the HM event was generated by the hypervisor, otherwise clear.

Bits 15..8 (validCpuCtxt): Set if the field cpuCtxt (see below) holds a valid processor context.

Bits 7..0 (`partitionId`): The `Id` attribute of the partition that caused the event.

`seq`: Number of sequence enabling to sort the event respect other events. It is codified as unsigned integer, incremented each time a new HM event is logged.

`timeStamp`: A time stamp of when the event was detected.

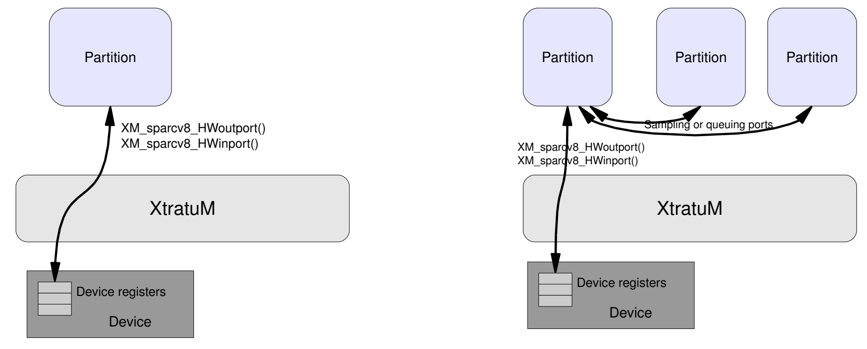
Either `cpuCtxt` or `payload`: When `validCpuCtxt` bit is set (`opCode`), then this field holds the processor context when the HM event was generated, otherwise, this field may hold information of the generated event. For instance, an application can manually generate a HM event specifying this information.

2.13.5 Multicore implications

Health monitor management has not visibility on the VCPUs internal to the partitions. From this point of view, a trap generated by a VCPU will:

- will raise a HM event
- XtratuM will handle the event as execute the action defined in the configuration file which is common to all the internal VCPUs.
- In the case of a propagation action, XtratuM identifies the VCPU that generated the trap and delivers to the causing VCPU the associated virtual interrupt
- In the case of a partition action (halt, reset, etc.), the action is aplied independently of the causing VCPU.

2.14 Access to devices



(a) Partition using exclusively a device. (b) I/O Server partition.

A partition, using exclusively a device (peripheral), can access the device through the device driver implemented in the partition (figure 2.15a). The partition is in charge of handling properly the device. The configuration file has to specify the I/O ports and the interrupt lines that will be used by each partition.

Two partitions cannot use the same interrupt line. XtratuM provides a fine grain access control to I/O ports, so that, several partitions can use (read and write) different bits of the the same I/O port. Also, it is possible to define a range of valid values that can be written in an I/O port (see section 5.10).

When a device is used by several partitions, an user implemented I/O server partition (figure 2.15b) may be in charge of the device management. An I/O server partition is a specific partition which accesses and controls the devices attached to it, and exports a set of services via the inter-partition communication mechanisms provided by XtratuM (sampling or queuing ports), enabling the rest of partitions to make use of the managed peripherals. The policy access (priority, FIFO, etc.) is implemented by the I/O server partition.

Note that the I/O server partition is not part of XtratuM. It should, if any, be implemented by the user of XtratuM. XtratuM does not force any specific policy to implement I/O server partitions but a set of services to implement it.

2.15 Traps, interrupts and exceptions

2.15.1 Traps

A **trap** is the mechanism provided by the LEON3 processor to implement the asynchronous transfer of control. When a trap occurs, the processor switches to supervisor mode and unconditionally jumps into a predefined handler.

SPARC v8 defines 256 different trap handlers. The table which contains these handlers is called *trap table*. The address of the trap table is stored in a special processor register (called `$tbr`). Both, the `$tbr` and the contents of the trap table are exclusively managed by XtratuM. All native traps jump into XtratuM routines.

The trap mechanism is used for several purposes:

Hardware interrupts Used by peripherals to request the attention of the processor.

Software traps Raised by a processor instruction; commonly used to implement the system call mechanism in the operating systems.

Processor exceptions Raised by the processor to inform about a condition that prevents the execution of an instruction. There are basically two kinds of exceptions: those caused by the normal operation of the processor (such as register window under/overflow), and those caused by an abnormal situation (such as a memory error).

XtratuM defines 32 new interrupts called *extended interrupts*. These new interrupts are used to inform the partition about XtratuM specific events. In the case of SPARC v8, these interrupts are vectored starting at trap handler 224.

The trap handler raised by a trap can be changed by invoking the `XM_route_irq()` hypercall.

Partitions are not allowed to directly access (read or write) the `$tbr` register. XtratuM implements a *virtual trap table* instead.

2.15.2 Interrupts

Although in a fully virtualised environment, a partition should not need to manage hardware interrupts; XtratuM only virtualises those hardware peripherals that may endanger the isolation, but leaves to the partitions to directly manage non-critical devices.

In order to properly manage peripherals, a partition needs to:

1. have access to the peripheral control and data registers.
2. be informed about triggered interrupts.
3. be able to block (mask and unmask) the associated interrupt line.

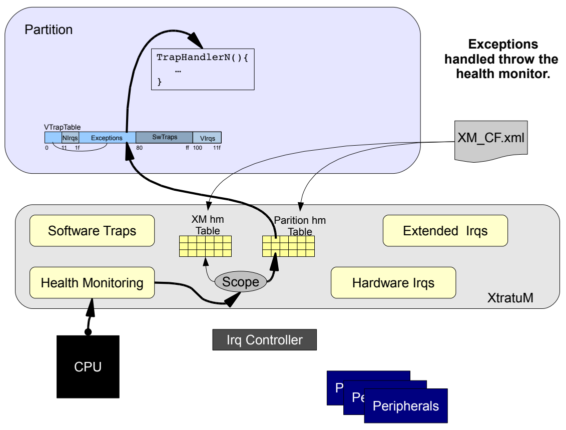


Figure 2.15: Exceptions handled by the health monitoring subsystem.

A hardware interrupt can only be allocated to one partition (in the XM_CF configuration file). The partition can then mask and unmask the hardware line in the native interrupt controller by using the XM_mask_irq() and XM_unmask_irq() functions.

XtratuM extends the concept of processor traps by adding 32 additional interrupts. This new range is used to inform the partition about events detected or generated by XtratuM. 870

Figure 2.16 shows the sequence from the occurrence of an interrupt to the partition's trap handler.

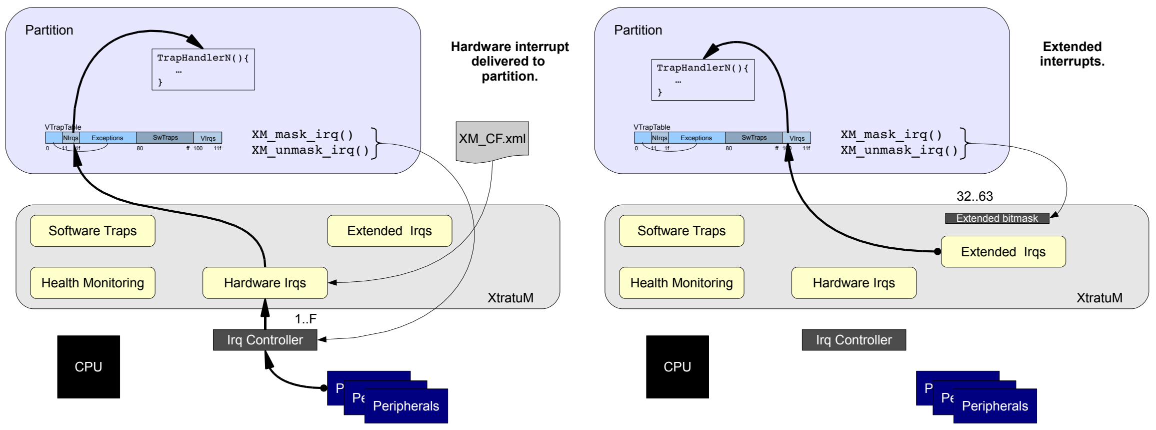


Figure 2.16: Hardware and extended interrupts delivery.

Partitions shall manage this new set of events in the same way standard traps are. These new interrupts are vectored in the trap table. These trap handlers are invoked by XtratuM on the occurrence of an event alike a standard LEON3 trap.

2.15.3 Interpartition virtual interrupt management 875

Additionally to the interrupts propagated by XtratuM to the partitions, XtratuM provides the mechanisms to send an interrupt from a partition to other or others. This are the inter-partition virtual interrupts (IPVI). A IPVI is an interrupt, or more properly an event, generated by a partition to inform to other or others partitions about some relevant state.

Next table shows the list of IPVIs available to be used by the partitions. 880

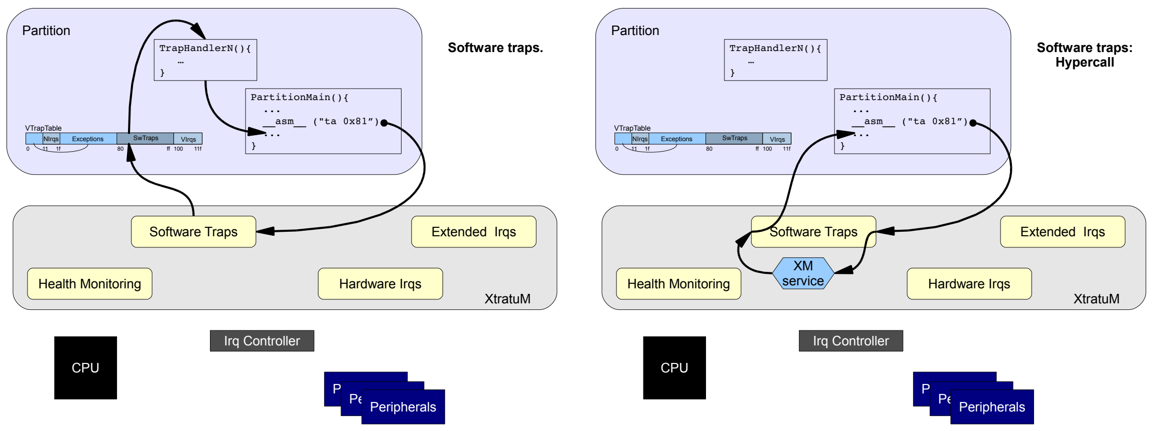


Figure 2.17: Software traps.

```
......
/* Inter-Partition Virtual Interrupts */
#define XM_MAX_IPVI             CONFIG_XM_MAX_IPVI
#define XM_VT_EXT_IPVI0         (24+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI1         (25+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI2         (26+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI3         (27+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI4         (28+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI5         (29+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI6         (30+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI7         (31+XM_VT_EXT_FIRST)
```

Listing 2.3: sources/core/include/guest.h

IPVIs are raised by partitions without the explicit knowledge of the partition or partitions that will receive them. The connection or channel that defines the IPVI route is specified in the configuration file (XM_CF). Next example shows the specification of the IPVI route.

```
  <Channels>
      <Ipvi id="0" sourceId="0" destinationId="1 2" />
      <Ipvi id="1" sourceId="0" destinationId="2" />
  </Channels>
```

Listing 2.4: IPVI route specification

It defines that `XM_VT_EXT_IPVI0()` (Ipvi identifier 0) can be generated by partition with identifier 0 and it will be received by partitions with identifier 1 and 2. Additionally, the same partition 0 can raise `XM_VT_EXT_IPVI1()` (Ipvi with identifier 1) that can be received by partition 2.

2.15.4 Multicore implications

Interrupts are allocated to the partitions in the configuration file. In multicore operating system, it is responsible of attach the interrupts to the CPUs. In the same way, the guest OS is responsible of the assignement of the interrupts allocated to it, to the appropriated VCPU.

The following interrupt symbols for LEON4 has been added.

```
#define GPTIMER_U0_T1_NR 1
#define GPTIMER_U0_T2_NR 2
#define GPTIMER_U0_T3_NR 3
#define GPTIMER_U0_T4_NR 4
#define GPTIMER_U0_T5_NR 5
#define GPTIMER_U1_NR 6
#define GPTIMER_U2_NR 7
#define GPTIMER_U3_NR 8
#define GPTIMER_U4_NR 9
#define IRQ_AMP_NR 10
#define GRPCIDMA_NR 11
#define GRGPIO0_NR 16
#define GRGPIO1_NR 17
#define GRGPIO2_NR 18
#define GRGPIO3_NR 19
#define SPWROUTER0_NR 20
#define SPWROUTER1_NR 21
#define SPWROUTER2_NR 22
#define SPWROUTER3_NR 23
#define GRETH_GBIT0_NR 24
#define GRETH_GBIT1_NR 25
#define AHBSTAT_NR 27
#define MEMSCRUBL2CACHE_NR 28
#define APBUART0_NR 29
#define APBUART1_NR 30
#define GRIOMMU_NR 31
```

2.16 Traces

XtratuM provides a mechanism to store and retrieve the traces generated by partitions and XtratuM itself. Traces can be used for debugging, during the development phase of the application, but also to log relevant events during the production phase.

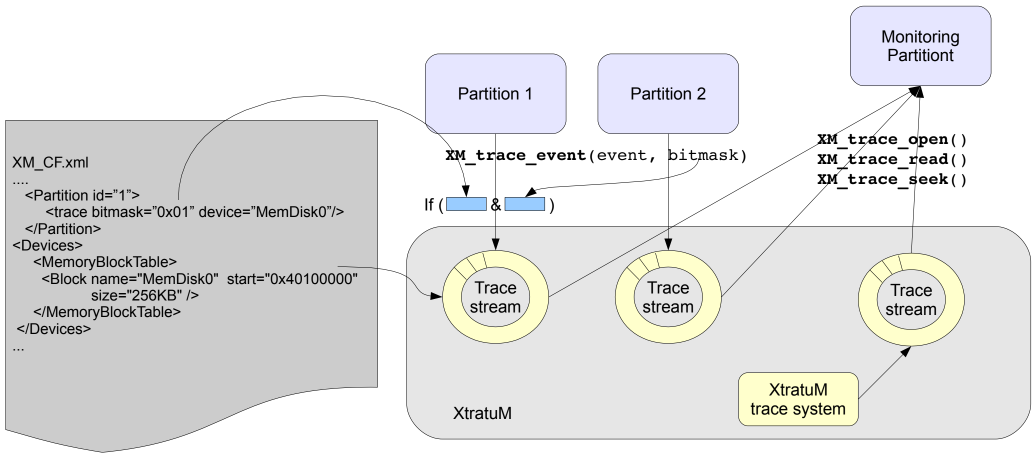
In order to enforce resource isolation, each partition (as well as XtratuM) has a dedicated trace log stream to store its own trace messages, which is specified in the `@device` attribute of the `Trace` element. `Trace` is an optional element of `XMHypervisor` and `Partition` elements.

The hypercall to write a trace message has a parameter (bitmask) used to select the traces messages are stored in the log stream. The integrator can select which trace messages are actually stored in the log stream with the `Trace/@bitmask` attribute. If both, the corresponding bit set in the value configured in the `Partition/Trace/@bitmask` and the value of the `bitmask` parameter of the `XM_trace_event()` hypercall are set, then the event is stored, otherwise, it is discarded.

Figure 2.18 sketches the configuration of the traces. In the example, the traces generated by partition 1 will be stored in the device `MemDisk0`, which is defined in the `Devices` section as a memory block device. Only those traces whose least significant bit is set in the bitmask parameter will be recorded.

2.16.1 Multicore implications

No implications.



```
XM_CF.xml
....
  <Partition id="1">
      <trace bitmask="0x01" device="MemDisk0"/>
  </Partition>
<Devices>
    <MemoryBlockTable>
      <Block name="MemDisk0"  start="0x40100000"
               size="256KB" />
    </MemoryBlockTable>
 </Devices>
...
```

Figure 2.18: Tracing overview.

2.17 Clocks and timers

There are two clocks per partition:

XM_HW_CLOCK: Associated with the native hardware clock. The resolution is 1μsec.

XM_EXEC_CLOCK: Associated with the execution of the partition. This clock only advances while the partition is being executed. It can be used by the partition to detect overruns. This clock relies on the XM_HW_CLOCK and its resolution is also 1μsec.

Only one timer can be armed for each clock.

In the multicore approach, XtratuM provides:

- one global hardware clock (XM_HW_CLOCK) global for all *virtual CPU*
- one local execution clock (XM_EXEC_CLOCK) for each *virtual CPU*

Each *virtual CPU* can control its execution time using the local execution clock.

Associated to each each clock, the partition can arm one timer. In the multicore approach, the partition (any of the *virtual CPU*) can arm one time based on the global hardware clock. Each *virtual CPU* can arm a one timer based on the local execution clock.

It is responsability of the guestOS or partition runtime of handling more than one timers based on the same clock using the appropriated data structures.

2.18 Status

Relevant internal information regarding the current state of the XtratuM and the partitions, as well as accounting information is maintained in an internal data structure that can be read by system partitions.

This optional feature shall be enabled in the XtratuM source configuration, and then recompile the XtratuM code. **By default it is disabled**. The hypercall is always present; but if not enabled, then XtratuM does not gather statistical information and then some status information fields are undefined. It is enabled in the XtratuM `menuconfig`: `Objects` → `XM partition status accounting`.

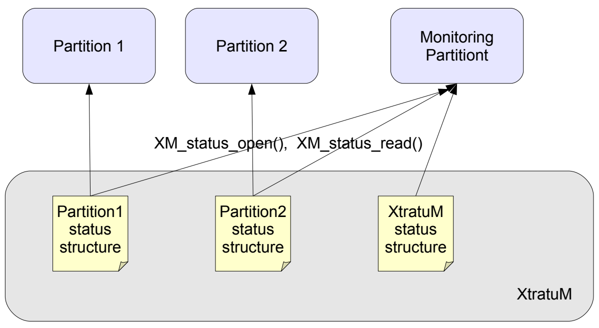

Partition 1
Partition 2
Monitoring Partitiont
XM_status_open(), XM_status_read()
Partition1 status structure
Partition2 status structure
XtratuM status structure
XtratuM

Figure 2.19: Status overview.

2.19 Summary

Next is a brief summary of the ideas and concepts that shall be kept in mind to understand the internal operation of XtratuM and how to use the hypercalls:

- A partition behaves basically as the native computer. Only those services that have been explicitly para-virtualised should be managed in a different way.
- Partition's code may not be self-modifying. The partition is responsible to appropriately flush cache in order to guarantee the coherency.
- Partition's code is always executed with native interrupts enabled. This behaviour is enforced by XtratuM.
- Partition's code is not allowed to disable native interrupts, only their own virtual interrupts.
- XtratuM code is non-preemptive. It should be considered as a single critical section.
- Partitions are scheduled by using a predefined scheduling cyclic plan.
- Inter-partition communication is done through messages.
- There are two kinds of virtual communication devices: sampling ports and queuing ports.
- All hypercall services are non-blocking.
- Regarding the capabilities of the partitions, XtratuM defines two kinds of partitions: system and standard.
- Only system partitions are allowed to control the state of the system and other partitions, and to query about them.
- XtratuM is configured off-line and no dynamic objects can be added at run-time.
- The XtratuM configuration file (`XM_CF`) describes the resources that are allowed to be used by each partition.
- XtratuM provides a fine grain error detection and a coarse grain fault management.
- It is possible to implement advanced fault analysis techniques in system partitions.
- An I/O Server partition can handle a set of devices used by several partitions.
- XtratuM implements a highly configurable health monitoring and handling system.
- The logs reported by the health monitoring system can be retrieved and analysed by a system partition online.

- XtratuM provides a tracing service that can be used to both debug partitions and online monitoring.
- The same tracing mechanism is used to handle partition and XtratuM traces.

Chapter 3

Developing Process Overview

XtratuM is a layer of software that extends the capabilities of the native hardware. There are important differences between a classical system and a hypervisor based one. This chapter provides an overview of the XtratuM developing environment.

The simplest scenario is composed of two actors: the *integrator* and the *partition developer* or partition supplier. There shall be only one integrator team and one or more partition developer teams (in what follows, we will use “integrator” and “partition developer” for short).

The tasks to be done by the **integrator** are:

1. Configure the XtratuM source code (jointly with the resident software). Customise it for the target board (processor model, etc.) and a miscellaneous set of code options and limits (debugging, identifiers length, etc.). See section 8.1 for a detailed description.
2. Build XtratuM: hypervisor binary, user libraries and tools.
3. Distribute the resulting binaries to the partition developers. All partition developers shall use the same binary version of XtratuM.
4. Allocate the available system resources to the partitions, according to the resources required to execute each partition:
    - memory areas where each partition will be executed or can use,
    - design the scheduling plan,
    - communication ports between partitions,
    - the virtual devices and physical peripherals allocated to each partition,
    - configure the health monitoring,
    - etc.

   By creating the `XM_CF` configuration file[1]. See section 8.3 for a detailed description.
5. Gather the partition images and customisation files from partition developers.
6. Pack all the files (resident software, XtratuM binary, partitions, and configuration files) into the final system image.

The **partition developer** activity:

[1]Although it is not mandatory to name “`XM_CF`” the configuration file, we will use this name in what follows for simplicity.

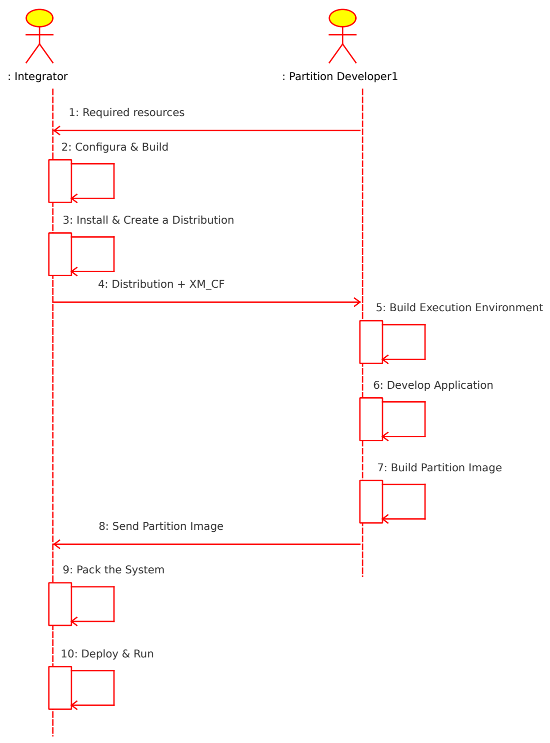


Figure 3.1: Integrator and partition developer interactions.

1. Define the resources required by its application, and send it to the integrator.
2. Prepare the development environment. Install the binary distribution created by the integrator.
3. Develop the partition application, according to the system resources agreed by the integrator.
4. Deliver to the integrator the resulting partition image and the required customisation files (if any).

There should be an agreement between the integrator and the partition developers on the resources allocated to each partition. The binaries, jointly with the XM_CF configuration file defines the partitioned system. **All partition developers shall use exactly the same XtratuM binaries and configuration files during the development.** Any change on the configuration shall be agreed with the integrator.

Since the development of the partitions may be carried out in parallel (or due to intellectual property restrictions), the binary image of some partitions may not be available to a partition developer team. In this case, it is advisable to use dummy partitions to replace those non-available, rather than changing the configuration file.

3.1 Development at a glance

① The first step is to buid the hypervisor binaries. The integrator shall configure and compile the XtratuM sources to produce:

`xm_core.xef`: The hypervisor image which implements the support for partition execution.

`libxm.a`: A helper library which provides a "C" interface to the para-virtualised services via the hypercall mechanism.

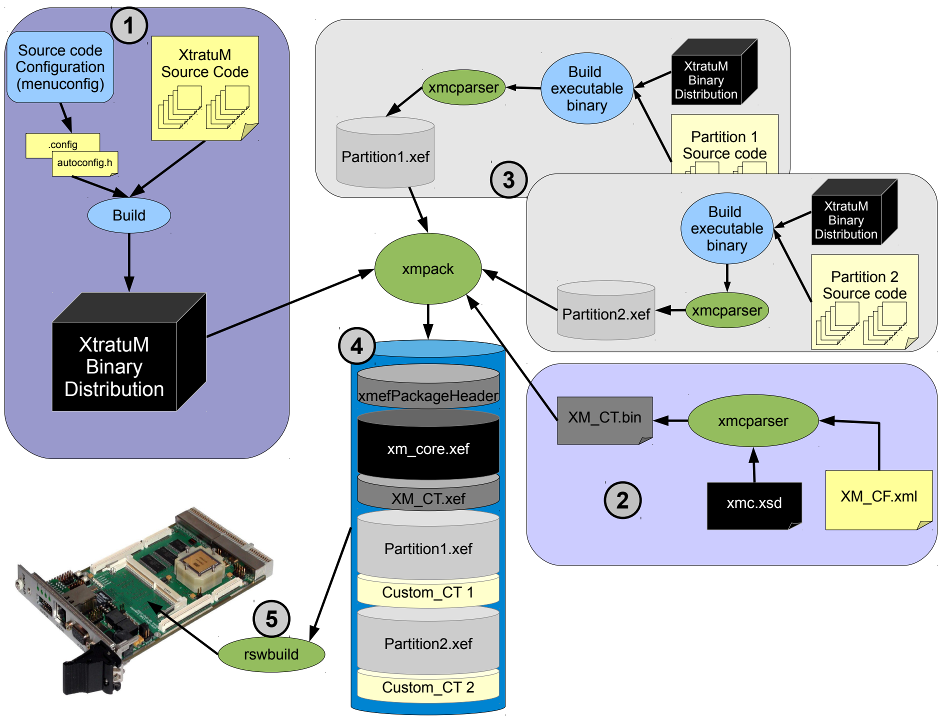


Figure 3.2: The big picture of building a XtratuM system.

xmc.xsd: The XML schema specification to be used in the XM_CF configuration file. 1050

tools: A set of tools to manage the partition images and the XM_CF file.

The result of the build process can be prepared to be delivered to the partition developers as a binary distribution.

② The next step is to define the hypervisor system and resources allocated to each partition. This is done by creating the configuration file XM_CF file. 1055

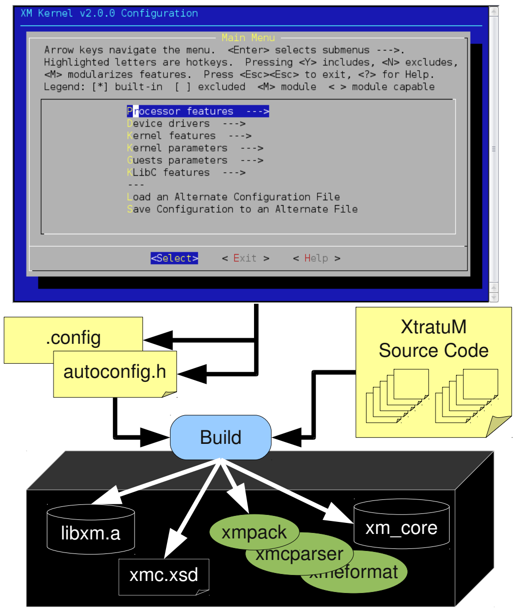
③ Using the binaries resulted from the compilation of XtratuM and the system configuration file, partition developers can implement and test its own partition code by their own.

④ The tool xmpack is used to build the complete system (hypervisor plus partitions code). The result is a single file called *container*. Partition developers shall replace the image of non-available partitions by a dummy partition. Up to a maximum of CONFIG_MAX_NO_CUSTOMFILES customisation 1060 files can be attached to each partition.

⑤ The container shall be loaded in the target system using the corresponding resident software (or boot loader). For convenience, a resident software is provided.

3.2 Building XtratuM

In the first stage, **XtratuM shall be tailored to the hardware available on the board, and the expected workload**. This configuration parameters will be used in the compilation of the XtratuM code 1065



```
XM Kernel v2.0.0 Configuration
                              Main Menu
  Arrow keys navigate the menu.  <Enter> selects submenus --->.
  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help.
  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

              Processor features  --->
              Device drivers  --->
              Kernel features  --->
              Kernel parameters  --->
              Guests parameters  --->
              KLibC features  --->
              ---
              Load an Alternate Configuration File
              Save Configuration to an Alternate File

                  <Select>    < Exit >    < Help >
```

Figure 3.3: Menuconfig process.

to produce a compact and efficient XtratuM executable image. Parameters like the processor model or the memory layout of the board are configured here (see section 8.1).

The configuration interface is the same as the one known as "*menuconfig*" used in the Linux kernel, see figure 3.3. It is a ncurses-based graphic interface to edit the configuration options. The selected choices are stored in two files: a "C" include file named "`core/include/autoconf.h`"; and a Makefile include file named "`core/.config`". Both files contain the same information but with different syntax to be used "C" programs and in Makefiles respectively.

Although it is possible to edit these configuration files, with a plain text editor, it is advisable not to do so; since both files shall be synchronized.

Once configured, the next step is to build XtratuM binaries, which is done calling the command `make`.

Ideally, configuring and compiling XtratuM should be done at the initial phases of the design and should not be changed later.

The build process leaves the objects and executables files in the source directory. Although it is possible to use these files directly to develop partitions it is advisable to install the binaries in a separate read-only directory to avoid accidental modifications of the code. It is also possible to build a TGZ[2] package with all the files to develop with XtratuM, which can be delivered to the partition developers. See chapter 4.

3.3 System configuration

The integrator, jointly with the partition developers, has to define the resources allocated to each partition, by creating the **XM_CF** file. It is an XML file which shall be a valid XML against the XMLSchema defined in section 8.3. Figure 3.4 shows a graphical view of the configuration schema.

The main information contained in the XM_CF file is:

[2]TGZ: Tar Gzipped archive.

Memory: The amount of physical memory available in the board and the memory allocated to each partition.

Processor: How the virtual processors are allocated to each partition: the scheduling plan.

Peripherals: Those peripherals not managed by XtratuM can be used by one partition. The I/O port ranges and the interrupt line if any.

Health monitoring: How the detected errors are managed by the partition and XtratuM: direct action, delivered to the offending partition, create a log entry, reset, etc.

Inter-partition communication: The ports that each partition can use and the channels that link the source and destination ports.

Tracing: Where to store trace messages and what messages shall be traced.

Since XM_CF defines the resources allocated to each partition, this file represents a **contract between the integrator and the partition developers**. A partner (the integrator or any of the partition developers) should not change the contents of the configuration file on its own. All the partners should be aware of the changes and should agree in the new configuration in order to avoid problems later during the integration phase.

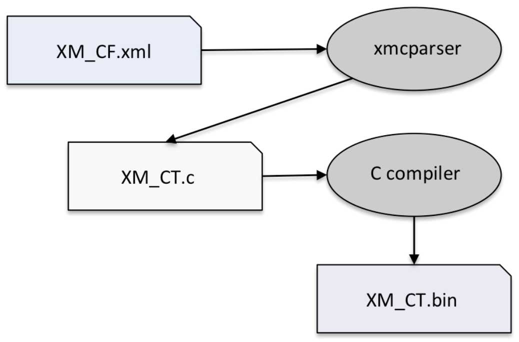


Figure 3.4: Graphical representation of an XML configuration file.

In order to reduce the complexity of the XtratuM hypervisor, the XM_CF is parsed and translated into a binary format which can be directly used by XtratuM. The XML data is translated into a set of initialised data structures ready to be used by XtratuM. Otherwise, XtratuM would need to contain a XML parser to read the XM_CF information. See section 9.1.1.

The resulting configuration binary is passed to XtratuM as a "customisation" file.

3.4 Compiling partition code

Partition developers should use the XtratuM user library (named `libxm.a` which has been generated during the compilation of the XtratuM source code) to access the para-virtualised services. The resulting binary image of the partition shall be self-contained, that is, it shall not contain linking information. The ABI of the partition binary is described in section 6.

In order to be able to run the partition application, each partition developer requires the following files:

`libxm.a`: Para-virtualised services. The include files are distributed jointly with the library, and they should be provided by the integrator.

XM_CF.xml: The system configuration file. This file describes the whole system. The same file should be used by all the partners.

xm_core.bin: The hypervisor executable. This file is also produced by the integrator, and delivered to the other partners.

xmpack: The tool that packs together, into a single system image container, all the *components*.

xmeformat: For converting an ELF file into an XEF one.

xmcparser: The tool to translate the configuration file (`XM_CF.xml`) into a "C" file which should be compiled to produce the configuration table (`XM_CT`).

Partition developer should use an execution environment as close as possible to the final system: the same processor board and the same hypervisor framework. To achieve this goal, they should use the same configuration file as the one used by the integrator. But the code of other partitions may be replaced by dummy partitions. This dummy partition code could execute, for instance, just a busy loop to waste time.

3.5 Passing parameters to the partitions: customisation files

User data can be passed to each partition at boot time. This information is passed to the partition via the *customisation* files.

It is possible to attach up to a maximum of `CONFIG_MAX_NO_CUSTOMFILES` customisation files per partition. The content of each customisation file is copied into the partition memory space at boot time (before the partition boots). The buffer where each customisation file is loaded is specified in the partition header by the partition developer. See section 6.

This is the mechanism used by XtratuM to get the compiled XML system configuration.

3.6 Building the final system image

The partition binary is not an ELF file. It is a custom format file (called *XEF*) which contains the machine code and the initialized data. See section 6.

The *container* is **a single file** which contains all the code, data and configuration information that is loaded in the target board. In the context of the container, a *component* refers to the set of files that are part of an execution unit (which can be a partition or the hypervisor itself). `xmpack` is a program that reads all the executable images (XEF files) and the configuration/customisation files and produces the container.

The container is not a bootable code. That is, it is like a "tar" file which contains a set of files. In order to be able to start the partitioned system, a boot loader shall load the content of the container into the corresponding partition addresses. The utility `rswbuild` creates an bootable ELF file with the resident software and the container to be executed on the target hardware.

Chapter 4

XtratuM Configuration and Build

4.1 Developing environment

XtratuM has been compiled and tested with the following package versions:

Package	Version	Linux package name		Purpose
host gcc	4.2.3 / 4.4.3	gcc-4.2	req	Build host utilities
make	3.81-3build1	make	req	Core
libncurses	5.7+20100313-5	libncurses5-dev	req	Configure source code
binutils	2.18.1build1 / 2.20.1	binutils	req	Core
sparc-toolchain	linux-3.4.4		req	Core
libxml2	2.6.27 / 2.7.6	libxml2-dev	req	Configuration parser
tsim	2.0.10 / 2.0.15		opt	Simulated run
grmon	1.1.31		opt	Deploy and run
perl	5.8.8-12 / 5.10.1		opt	Testing
makeself	2.1.5	makeself	opt	Build self extracting distribution

Packages marked as “req” are required to compile XtratuM. Those packages marked as “opt” are needed to compile or use it in some cases.

4.2 Compile XtratuM Hypervisor

It is not required to be supervisor (root) to compile and run XtratuM. 1150

The first step is to prepare the system to compile XtratuM hypervisor.

1. Check that the GNU LIBC Linux GCC 3.4.4 toolchain for SPARC LEON is installed in the system. It can be downloaded from: `http://www.gaisler.com` `sparc-linux-3.4.4-x.x.x.tar.bz2`

2. Make a deep clean to be sure that there is not previous configurations:

```
$ make distclean
```

3. In the root directory of XtratuM, copy the file `xmconfig.sparc` into `xmconfig`, and edit it to meet your system paths. The variable `XTRATUM_PATH` shall contain the root directory of XtratuM. Also, 1155
if the `sparc-linux` toolchain directory is not in the `PATH` then the variable `TARGET_CCPREFIX` shall

contain the path to the actual location of the corresponding tools. The prefix of the SPARC v8 tool chain binaries, shall be "`sparc-linux-`"; otherwise, edit also the appropiate variables.

In the seldom case that the host toolchain is not in the `PATH`, then it shall be specified in the `HOST_CCPREFIX` variable.

```
$ cp xmconfig.sparc xmconfig
$ vi xmconfig .....
```

4. Configure the XtratuM sources. The ncurses5 library is required to compile the configuration tool. In a Debian system with internet connection, the required library can be installed with the following command: `sudo apt-get install libncurses5-dev`.

   The configuration utility is executed (compiled and executed) with the next command:

   ```
   $ make menuconfig
   ```

   Note: The menuconfig target configures the XtratuM source code, the resident software and the XAL environment. Therefore, two different configuration menus are presented,

   (a) The XtratuM itself.
   (b) The Resident Software, which is charge of loading the system from ROM -¿ RAM.
   (c) The XAL, a basic partition execution environment.

4.2.1 XtratuM configuration

With respect to the processor, the following options have to be selected in the menuconfig.

- CPU (LEON2 — LEON3 — LEON4)
- Board type
- Memory protection Scheme
- Enable SMP to enable/disable the use of multicore. The number of CPUs have to be defined.
- Enable VMM update hypercalls
- Enable cache
- Enable cache snoop
- Enable instruction burst fetch
- Flush cache after context switch

4.2.2 Resident software configuration

It permits to specify the configuration parameters of the resident software as:

- Stack size (KB)
- Stand-alone version
- Load container at a fixed address
- RSW memory layout: Container physical location address, Read-only section addresses and Read/write section addresses.
- Enable RSW output
- Autodetect CPU frequency

4.2.3 Xtratum Abstraction Layer (XAL) configuration

XAL is a minimal layer to give support to bare-C applications. The XAL configuration only specifies the stack size to be used by the bare-C partition.

4.2.4 Compiling XtratuM 1190

For running XtratuM in the simulator, select the appropriate processor model from the menuconfig menus.

5. Compile XtratuM sources:

```
$ make
> Configuring and building the "XtratuM hypervisor"
> Building XM Core
  - kernel/sparcv8
  - kernel/mmu
  - kernel
  - klibc
  - klibc/sparcv8
  - objects
  - drivers
> Linking XM Core
   text    data     bss     dec     hex filename
 114545   11548  103800  229893   38205 xm_core
0e05cac54e969a5a34130c22def008fb xm_core.xef
> Done

> Configuring and building the "User utilities"
> Building XM user
  - libxm
  - tools
  - tools/xmpack
  - tools/xmcparser
  - tools/xmbuildinfo
  - tools/rswbuild
  - tools/xef
  - xal
  - bootloaders/rsw
  - examples
> Done
```

4.3 Generating binary a distribution

The generated files from the compilation process are in source code directories. In order to distribute the compiled binary version of XtratuM to the partition developers, a distribution package shall be generated. There are two distribution formats: 1195

Tar file: It is a compressed tar file with all the XtratuM files and an installation script.

```
$  make distro-tar
```

Self-extracting installer: It is a single executable file which contains the distribution and the installation script.

```
$ make distro-run
```

The final installation is exactly the same regarding the distribution format used.

```
$ make distro-run
.......

> Installing XM in "/tmp/xtratum-X.X.X/xtratum-X.X.X/xm"
   - Generating XM sha1sums
   - Installing XAL
   - Generating XAL sha1sums
   - Installing XM examples
   - Generating XM examples sha1sums
   - Setting read-only (og-w) permission.
   - Deleting empty files/directories.
> Done

> Generating XM distribution "xtratum-X.X.X.tar.bz2"
> Done

> Generating self extracting binary distribution "xtratum-X.X.X.run"
> Done
```

The files `xtratum-x.x.x.tar.bz2` or `xtratum-x.x.x.run` contain all the files requires to work (develop and run) with the partitioned system. This tar file contains two root directories: **`xal`** and **`xm`**, and an installation script.

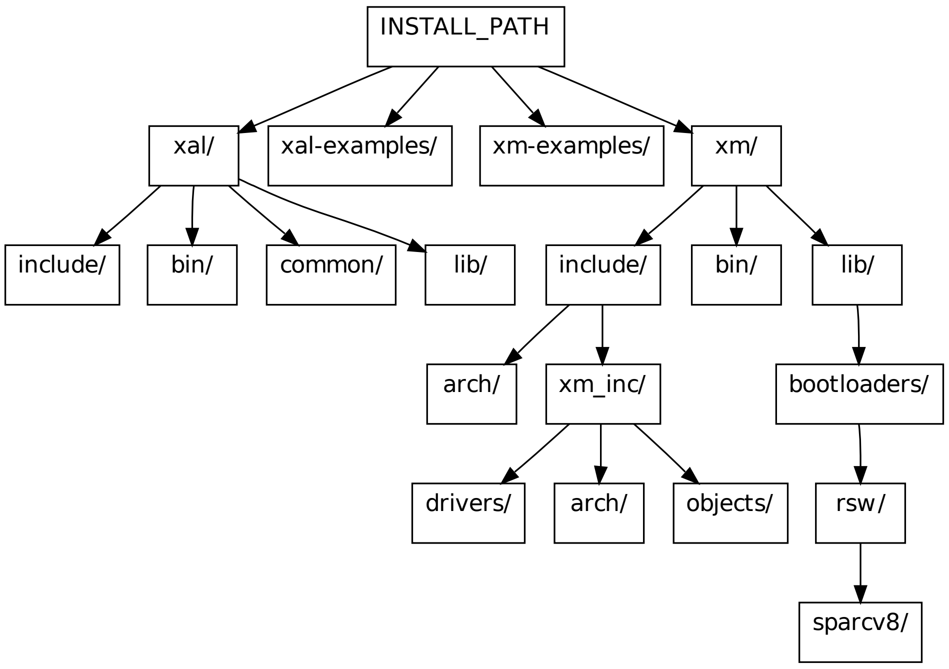


Figure 4.1: Content of the XtratuM distribution.

The directory xm contains the XtratuM kernel and the associated developer utilities. Xal stands for *XtratuM Abstraction Layer*, and contains the partition code to setup a basic "C" execution environment. Xal is provided for convenience, and it is not mandatory to use it. Xal is only useful for those partitions with no operating system.

Although XtratuM core and related libraries are compiled for the LEON3 processor, some of the host configuration and deploying tools (`xmcparser`, `xmpack` and `xmeformat`) are host executables. If the computer where XtratuM was compiled on and the computer where it is being installed are different processor architectures (32bit and 64bit), the tools may not run properly.

4.4 Installing a binary distribution

Decompress the `xtratum-x.x.x.tar.bz2` file in a temporal directory, and execute the install script. Alternatively, if the distributed file is `xtratum-x.x.x.run` then just execute it.

The install script requires only two parameters:

1. The installation path.
2. The path to the proper cross-compile toolchain.

Note that it is assumed that the host toolchain binaries can be located in the PATH variable. It is necessary to provide again the path to the LEON3 toolchain because it may be located in a different place than in the system where XtratuM was build. In any case, it shall be the same version, than the one used to compile XtratuM.

```
$ ./xtratum-X.X.X.run
Verifying archive integrity... All good.
Uncompressing XtratuM binary distribution X.X.X:......

Starting installation.
Installation log in: /tmp/xtratum-installer.log

1. Select the directory where XtratuM will be installed. The installation
  directory shall not exist.

2. Select the target compiler toolchain binary directory (arch sparc).

3. Confirm the installation settings.

Important: you need write permision in the path of the installation directory.

Continue with the installation [Y/n]? Y

Press [Enter] for the default value or enter a new one.
Press [TAB] to complete directory names.

1.- Installation directory [/opt]: /home/xmuser/xmenv
2.- Path to the sparc toolchain [/opt/cross-compiler/bin/]: /opt/cross-compiler/bin

Confirm the Installation settings:
Selected installation path : /home/xmuser/xmenv
Selected toolchain path : /opt/cross-compiler/bin

3.- Perform the installation using the above settings [Y/n]? Y

Installation completed.
```

Listing 4.1: Output of the self-executable distribution file.

4.5 Compile the Hello World! partition

1. Change to the `INSTALL_PATH/xm-examples/hello_world` directory.
2. Compile the partition:

```
$ make
.....
Created by "xmuser" on "xmhost" at "Wed Feb 3 13:21:02 CET 2011"
XM path: " /home/xmuser/xm2env/xm"

XtratuM Core:
   Version: "3.1.2"
   Arch:    "sparcv8"
   File:    "/home/xmuser/xm2env/xm/lib/xm_core.xef"
   Sha1:    "962b930e8278df873599e6b8bc4fcb939eb92a19"
   Changed: "2010-02-03 13:19:51.000000000 +0100"

XtratuM Library:
   Version: "3.1.2"
   File:    "/home/xmuser/xm2env/xm/lib/libxm.a"
   Sha1:    "46f64cf2510646833a320e1e4a8ce20e4cd4e0a9"
   Changed: "2010-02-03 13:19:51.000000000 +0100"

XtratuM Tools:
   File:    "/home/xmuser/xm2env/xm/bin/xmcparser"
   Sha1:    "8fa5dea03739cbb3436d24d5bc0e33b20906c47a"
```

   Note that the compilation is quite verbose: the compilation commands, messages, detailed information about the tools libraries used, etc. are printed.

   1220 The result from the compilation is a file called "`resident_sw`".

3. To run this file just load it in the tsim or grmon and run (go) it:

```
$ tsim-leon3 -mmu
...
serial port A on stdin/stdout
allocated 4096 K RAM memory, in 1 bank(s)
allocated 16 M SDRAM memory, in 1 bank
allocated 2048 K ROM memory
icache: 1 * 4 kbytes, 16 bytes/line (4 kbytes total)
dcache: 1 * 4 kbytes, 16 bytes/line (4 kbytes total)
tsim> load resident_sw
section: .text, addr: 0x40200000, size 14340 bytes
section: .rodata, addr: 0x40203808, size 790 bytes
section: .container, addr: 0x40203b20, size 48888 bytes
section: .got, addr: 0x4020fa18, size 8 bytes
section: .eh_frame, addr: 0x4020fa20, size 64 bytes
read 38 symbols
tsim> go
resuming at 0x40200d24
XM Hypervisor (3.1 r2)
Detected 50.0MHz processor.
>> HWClocks [LEON clock (1000Khz)]
[CPU:0] >> HwTimer [LEON timer (1000Khz)]
```

```
[CPU:0] [sched] using cyclic scheduler
2 Partition(s) created
P0 ("Partition1":0) flags: [ SYSTEM BOOT (0x40080000) ]:
    [0x40080000 - 0x400fffff]
P1 ("Partition2":1) flags: [ SYSTEM BOOT (0x40100000) ]:
    [0x40100000 - 0x4017ffff]
Jumping to partition at 0x40082000
Jumping to partition at 0x40102000
I am Partition2
Hello World!
I am [CPU:0] [HYPERCALL] (0x1) Halted
Partition1
Hello World!
[CPU:0] [HYPERCALL] (0x0) Halted
```

4.6 XtratuM directory tree

Next list shows the installed tree directory for XtratuM and XAL.

```
/home/xmuser/xmEnvs/xm4/
         xal
                bin
                common
                include
                       arch
                lib
         xm
                bin
                include
                       arch
                       xm_inc
                           arch
                           objects
                lib
                    bootloaders
                       rsw
                           sparcv8
```

Listing 4.2: Installation tree.

This page is intentionally left blank.

Chapter 5

Partition Programming

This chapter explains how to build a XtratuM partition: partition developer tutorial.

5.1 Partition definition

A partition is an execution environment managed by the hypervisor which uses the virtualised services.

Each partition consists of one or more concurrent processes (implemented by the operating system of each partition), sharing access to processor resources based upon the requirements of the application. The partition code can be:

- An application compiled to be executed on a bare-machine (bare-application).
- A real-time operating system and its applications.
- A general purpose operating system and its applications.

Partitions need to be *virtualised* to be executed on top of XtratuM. For instance, the partitions cannot manage directly the hardware interrupts (enable/disable interrupts) which have to be replaced by hypercalls[1] to ask for the hypervisor to enable/disable the interrupts.

Depending on the type of execution environment, the virtualisation implies:

Bare application The application has to be virtualised using the services provided by XtratuM. The application is designed to run directly on the hardware and it has to be aware about it.

Operating system application When the application runs on top of a (real-time) operating system, it uses the services provided by the operating system and does not need to be virtualised. But the operating system has to deal with the virtualisation. The operating system has to be virtualised (ported on top of XtratuM).

5.2 Implementation requirements

Below is a checklist of what the partition developer and the integrator should take into accout when using XtratuM. It is advisable to revisit this list to avoid incorrect assumptions.

[1]para-virtualised operations provided by the hypervisor

Development host: If the computer where XtratuM was compiled on and the computer where it is being installed are different processor architectures (32bit and 64bit), the tools may not run properly.

Check that the executable files in `xm/bin` are compatible with the host architecture.

Para-virtualised services: Partition's code shall use the para-virtualised services. The use of native services is considered an error and the corresponding exception will be raised.

PCT: The Partition Control Table is located within the partition, mapped in read-only mode. Its content shall be modified by using the appropriate hypercalls. In a multicore platform, there are as PCT as *virtual CPUs*. Each *virtual CPU* see only its own PCT.

Store ordering: XtratuM has been implemented considering that the LEON2 processor is operating in TSO (Total Store Ordering) mode. This is the standard SPARC v8 working mode. If changed to PSO (Partial Store Ordering) mode then random errors will happen.

Memory allocation:

- Care shall be taken to avoid overlapping the memory allocated to each partition.
- If MMU in not used, then the partition code shall be linked to work on the allocated memory areas. If the memory allocated in the `XM_CF` file is changed, then the linker script of the affected partition shall be updated accordingly.

Reserved names: The prefix "xm", both in upper and lower case, is reserved for XtratuM identifiers.

Stack management: XtratuM manages automatically the register window of the partitions. The partition code is responsible of initialising the stack pointer to a valid memory area, and reserve enough space to accommodate all the data that will be stored in the stack. Otherwise, a stack overflow may occur.

Data Alignment: By default, all data structures passed to or shared with XtratuM shall by aligned to 8 bytes.

Units definition and abbreviations:

"KB" (KByte or Kbyte) is equal to 1024 (2^{10}) bytes.

"Kb" (Kbit) is equal to 1024 (2^{10}) bits.

"MB" (MByte or Mbyte) is equal to 1048576 ($1024 \cdot 1024 = 2^{20}$) bytes.

"Mb" (Mbit) is equal to 1048576 ($1024 \cdot 1024 = 2^{20}$) bits.

"KHz" (Kilo Hertz) is equal to 1000 Hertzs.

"MHz" (Mega Hertz) is equal to 1000.000 Hertzs.

XtratuM memory footprint: XtratuM does not use dynamic memory allocation. Therefore, all internal data structures are declared statically. The size of these data structures are defined during the source code configuration process.

The following configuration parameters are the ones that have an impact on the memory needed by XtratuM:

Maximum identifier length: Defines the space reserved to store the names of the partitions, ports, scheduling slots and channels.

Kernel stack size: For each partition, XtratuM reserves a kernel stack. Do not reduce the value of this parameter unless you know the implications.

Partition memory areas (if the WPR is used and MMU disabled): Due to the hardware device (WPR) used to force memory protection, the area of memory allocated to the partitions shall fulfil the next conditions:

- The size shall be greater than or equal to 32KB.
- The size shall be a power of two.
- The start address shall be a multiple of the size.

Configuration of the resident software (RSW): The information contained in the XM_CF regarding the RSW is not used to configure the RSW itself. That information is used: 1290

- by XtratuM to perform a system cold reset,
- and by the xmcparser to check for memory overlaps.

Partition declaration order: The partition elements, in the XM_CF file, shall be ordered by "id" and the id's shall be consecutive starting at zero.

5.3 XAL development environment

XAL is a minimal developing environment to create bare "C" applications. It is provided jointly with the 1295 XtratuM core. Currently it is only the minimal libraries and scripts to compile and link a "C" application. More features will added in the future (mathematic lib, etc.).

In the previous versions of XtratuM, XAL was included as part of the examples of XtratuM. It has been moved outside the tree of XtratuM to create an independent developer environment.

When XtratuM is installed, the XAL environment is also installed. It is included in the target directory 1300 of the installation path.

```
target_directory
    |-- xal               # XAL components
    |-- xal-examples      # examples of XAL use
    |-- xm
    `-- xm-examples
```

Listing 5.1: Installation tree.

The XAL subtree contains the following elements:

```
  xal
   |-- bin              # utilities
   |   |-- xpath
   |   `-- xpathstart
   |-- common          # compilation rules
   |   |-- config.mk
   |   |-- config.mk.dist
   |   `-- rules.mk
   |-- include          # headers
   |   |-- arch
   |   |   `-- irqs.h
   |   |-- assert.h
   |   |-- autoconf.h
   |   |-- config.h
   |   |-- ctype.h
   |   |-- irqs.h
   |   |-- limits.h
   |   |-- stdarg.h
   |   |-- stddef.h
   |   |-- stdio.h
   |   |-- stdlib.h
   |   |-- string.h
```

```
    |   `-- xal.h
    |-- lib              # libraries
    |   |-- libxal.a
    |   `-- loader.lds
    `-- sha1sum.txt
```

Listing 5.2: XAL subtree.

A XAL partition can:

- Be specified as "system" or "user".
- Use all the XtratuM hypercalls according to the type of partition.
- Use the standard input/output "C" functions: `printf`, `sprintf`, etc. The available functions are defined in the `include/stdio.h`.
- Define interrupt handlers and all services provided by XtratuM.

An example of a Xal partition is:

```
#include <xm.h>
#include <stdio.h>

#define LIMIT 100

void SpentTime(int n) {
   int i,j;
   int x,y = 1;
    for (i= 0; i <=n; i++) {
        for (j= 0; j <=n; j++) {
            x = x + x - y;
        }
    }
}

void PartitionMain(void) {
    long counter=0;

    printf("[P%d] XAL Partition \n",XM_PARTITION_SELF);
      counter=1;
      while(1) {
        counter++;
        SpentTime(2000);
        printf("[P%d] Counter %d \n",XM_PARTITION_SELF, counter);
    }
      XM_halt_partition(XM_PARTITION_SELF);
}
```

Listing 5.3: XAL partition example.

In the xal-examples subtree, the reader can find several examples of XAL partitions and how these examples can be compiled. Next is shown the `Makefile` file.

```
# XAL_PATH: path to the XTRATUM directory
XAL_PATH=/......./xal

# XMLCF: path to the XML configuration file
XMLCF=xm_cf.sparcv8.xml
```

```
# PARTITIONS: partition files (xef format) composing the example
PARTITIONS=partition1.xef partition2.xef ....

all: container.bin resident_sw
include $(XAL_PATH)/common/rules.mk

partition1: dummy_xal.o
    $(LD) -o $@ $^ $(LDFLAGS) -Ttext=$(call xpathstart,1,$(XMLCF))
......

PACK_ARGS=-h $(XMCORE):xm_cf.xef.xmc \
    -p 0:partition1.xef\
    -p 1:partition2.xef\
    .....

container.bin: $(PARTITIONS) xm_cf.xef.xmc
    $(XMPACK) check xm_cf.xef.xmc $(PACK_ARGS)
    $(XMPACK) build $(PACK_ARGS) $@
    @exec echo -en "> Done [container]\n"
```

Listing 5.4: Makefile.

5.4 The "Hello World" example

Let's start with a simple code that is not ready to be executed on XtratuM and needs to be adapted.

```
void main() {
    int counter =0;

    xprintf(``Hello World!\n'');
    while(1) {
        counter++;
        counter %= 100000;
    }
}
```

Listing 5.5: Simple example.

The first step is to initialise the virtual execution environment and call the entry point (`PartitionMain` in the examples) of the partition. The following files are provided as an example of how to build the partition image and initialise the virtual machine. 1315

`boot.S`: The assembly code where the headers and the entry point are defined.

`traps.c`: Required data structures: PCT and trap handlers.

`std_c.c`, `std_c.h`: Minimal "C" support as `memcpy`, `xprintf`, etc.

`loader.lds`: The linker script that arranges the sections to build the partition image layout.

The `boot.S` file: 1320

```
#include <xm.h>
#include <xm_inc/arch/asm_offsets.h>
//#include <xm_inc/hypercalls.h>

#define STACK_SIZE 8192
#define MIN_STACK_FRAME 0x60

.text
.align 8

.global start, _start

_start:
start:
        /* Zero out our BSS section.
             */
        set _sbss, %o0
        set _ebss, %o1

1:
        st %g0, [%o0]
        subcc %o0, %o1, %g0
        bl 1b
        add %o0, 0x4, %o0

        set __stack_top, %fp

        mov %g1, %o0
        call init_libxm
        sub %fp, MIN_STACK_FRAME, %sp

#if 0
        //set 0xfa000002, %sp
        sub %sp, 4, %sp
        save
        save
        save
        save
        save
        save
        save
        save

        restore
        restore
        restore
        restore
        restore
        restore
        restore
        restore
#endif
        ! Set up TBR
        set sparc_write_tbr_nr, %o0
        set _traptab, %o1
        __XM_HC

        call PartitionMain
        sub %fp, MIN_STACK_FRAME, %sp

        set ~0, %o1
        mov halt_partition_nr, %o0
        __XM_HC

1:      b 1b
        nop

ExceptionHandlerAsm:
        mov sparc_get_psr_nr, %o0
        __XM_AHC
        mov %o0, %l0
!       set sparc_flush_regwin_nr, %
      o0
!       __XM_AHC
        sub %fp, 48, %fp
        std %l0, [%fp+40]
        std %l2, [%fp+32]
        std %g6, [%fp+24]
        std %g4, [%fp+16]
        std %g2, [%fp+8]
        st %g1, [%fp+4]
        rd %y, %g5
        st %g5, [%fp]

        mov %l5, %o0
        call ExceptionHandler
        sub %fp, 0x80, %sp
        ld [%fp], %g1
        wr %g1, %y
        ld [%fp+4], %g1
        ldd [%fp+8], %g2
        ldd [%fp+16], %g4
        ldd [%fp+24], %g6
        ldd [%fp+32], %l2
        ldd [%fp+40], %l0
        add %fp, 48, %fp
        mov %l0, %o1
        mov sparc_set_psr_nr, %o0
        __XM_AHC
        set sparc_iret_nr, %o0
        __XM_AHC

ExtIrqHandlerAsm:
        mov sparc_get_psr_nr, %o0
        __XM_AHC
        mov %o0, %l0
!       set sparc_flush_regwin_nr, %
      o0
!       __XM_AHC
        sub %fp, 48, %fp
        std %l0, [%fp+40]
        std %l2, [%fp+32]
        std %g6, [%fp+24]
        std %g4, [%fp+16]
        std %g2, [%fp+8]
        st %g1, [%fp+4]
        rd %y, %g5
        st %g5, [%fp]
        mov %l5, %o0
        call ExtIrqHandler
        sub %fp, 0x80, %sp
        ld [%fp], %g1
        wr %g1, %y
        ld [%fp+4], %g1
        ldd [%fp+8], %g2
        ldd [%fp+16], %g4
        ldd [%fp+24], %g6
        ldd [%fp+32], %l2
        ldd [%fp+40], %l0
        add %fp, 48, %fp
        mov %l0, %o1
        mov sparc_set_psr_nr, %o0
        __XM_AHC
        set sparc_iret_nr, %o0
        __XM_AHC
```

```
HwIrqHandlerAsm:
        mov sparc_get_psr_nr, %o0
        __XM_AHC
        mov %o0, %l0
!       set sparc_flush_regwin_nr, %
    o0
!       __XM_AHC
        sub %fp, 48, %fp
        std %l0, [%fp+40]
        std %l2, [%fp+32]
        std %g6, [%fp+24]
        std %g4, [%fp+16]
        std %g2, [%fp+8]
        st %g1, [%fp+4]
        rd %y, %g5
        st %g5, [%fp]
        mov %l5, %o0
        call HwIrqHandler
        sub %fp, 0x80, %sp

        ld [%fp], %g1
        wr %g1, %y
        ld [%fp+4], %g1
        ldd [%fp+8], %g2
        ldd [%fp+16], %g4
        ldd [%fp+24], %g6
        ldd [%fp+32], %l2
        ldd [%fp+40], %l0
        add %fp, 48, %fp
        mov %l0, %o1
        mov sparc_set_psr_nr, %o0
        __XM_AHC
        set sparc_iret_nr, %o0
        __XM_AHC

.data
.align 8
__stack:
        .fill (STACK_SIZE/4),4,0
__stack_top:

.previous


#define BUILD_IRQ(irqnr) \
        sethi %hi(HwIrqHandlerAsm), %
             l4 ;\
        jmpl %l4 + %lo(
             HwIrqHandlerAsm), %g0 ;\
        mov irqnr, %l5 ;\
        nop

#define BUILD_TRAP(trapnr) \
        sethi %hi(ExceptionHandlerAsm
             ), %l4 ;\
        jmpl %l4 + %lo(
             ExceptionHandlerAsm), %g0
              ;\
        mov trapnr, %l5 ;\
        nop            ;

#define BAD_TRAP(trapnr) \
1:      b 1b    ;\
        nop     ;\
        nop     ;\
        nop

#define SOFT_TRAP(trapnr) \
1:      b 1b    ;\
        nop     ;\
        nop     ;\
        nop

#define BUILD_EXTIRQ(trapnr) \
        sethi %hi(ExtIrqHandlerAsm),
             %l4 ;\
        jmpl %l4 + %lo(
             ExtIrqHandlerAsm), %g0 ;\
        mov (trapnr+32), %l5  ;\
        nop

.align 4096
_traptab:
! + 0x00: reset
t_reset: b start
        nop
        nop
        nop

! + 0x01:
     instruction_access_exception
        BUILD_TRAP(0x1)

! + 0x02: illegal_instruction
        BUILD_TRAP(0x2)

! + 0x03: privileged_instruction
        BUILD_TRAP(0x3)

! + 0x04: fp_disabled
        BUILD_TRAP(0x4)

! + 0x05: window_overflow
        BUILD_TRAP(0x5)


! ..........
```

Listing 5.6: user/examples/sparcv8/boot.S

The __xmImageHdr declares the required image header (see section 6) and one partition header[2]: __xmPartitionHdr.

The entry point of the partition (the first instruction executed) is labeled start. First off, the bss section is zeroed; the stack pointer (%sp register) is set to a valid address; the address of the partition header is passed to the libxm (call InitLibxm); the virtual trap table register is loaded with the direction of __traptab; and finally the user routine PartitionMain is called. If the main function

[2]Multiple partition headers can be declared to allocate several processors to a single partition (experimental feature not documented).

returns, then an endless loop is executed.

The remaining of this file contains the trap handler routines. Note that the assembly routines are only provided as illustrative examples, and **should not be used on production application systems**. These trap routines just jump to “C” code which is located in the file `traps.c`:

```
#include <xm.h>
#include <xm_inc/arch/paging.h>
#include "std_c.h"

extern void start(void);

static xm_u8_t _pageTable[PAGE_SIZE*32] __attribute__((aligned(PAGE_SIZE)
    )) __attribute__ ((section(".bss.noinit")));

struct xmImageHdr xmImageHdr __XMIHDR = {
    .sSignature=XMEF_PARTITION_MAGIC,
    .compilationXmAbiVersion=XM_SET_VERSION(XM_ABI_VERSION,
        XM_ABI_SUBVERSION, XM_ABI_REVISION),
    .compilationXmApiVersion=XM_SET_VERSION(XM_API_VERSION,
        XM_API_SUBVERSION, XM_API_REVISION),
    .pageTable=(xmAddress_t)_pageTable,
    .pageTableSize=32*PAGE_SIZE,
    .noCustomFiles=0,
#if 0
    .customFileTab={[0]=(struct xefCustomFile){
            .sAddr=(xmAddress_t)0x40105bc0,
            .size=0,
        },
    },
#endif
    .eSignature=XMEF_PARTITION_MAGIC,
};

void __attribute__ ((weak)) ExceptionHandler(xm_s32_t trapNr) {
    xprintf("exception 0x%x (%d)\n", trapNr, trapNr);
    //XM_halt_partition(XM_PARTITION_SELF);
}

void __attribute__ ((weak)) ExtIrqHandler(xm_s32_t trapNr) {
    xprintf("extIrq 0x%x (%d)\n", trapNr, trapNr);
//   XM_halt_partition(XM_PARTITION_SELF);
}

void __attribute__ ((weak)) HwIrqHandler(xm_s32_t trapNr) {
    xprintf("hwIrq 0x%x (%d)\n", trapNr, trapNr);
    // XM_halt_partition(XM_PARTITION_SELF);
}
```

Listing 5.7: user/examples/common/traps.c

Note that the “C” trap handler functions are defined as “`weak`”. Therefore, if these symbols are defined elsewhere, the new declaration will replace this one.

The linker script that arranges all the ELF sections is:

```
/*OUTPUT_FORMAT("binary")*/
OUTPUT_FORMAT("elf32-sparc", "elf32-sparc", "elf32-sparc")
OUTPUT_ARCH(sparc)
ENTRY(start)

SECTIONS
{
  .text ALIGN (8): {
        . = ALIGN(4K);
        _sguest = .;
        *(.text.init)
        *(.text)
  }

  .rodata ALIGN (8) : {
        *(.rodata)
        *(.rodata.*)
        *(.rodata.*.*)
  }

  .data ALIGN (8) : {
        _sdata = .;
        *(.data)
        _edata = .;
  }

  .bss : {
        *(.bss.noinit)
        _sbss = .;
        *(COMMON)
        *(.bss)
        _ebss = .;
  }

  _eguest = .;

  /DISCARD/ :
  {
        *(.note)
        *(.comment*)
  }
}
```

Listing 5.8: user/examples/sparcv8/loader.lds

The section `.text.ini`, which contains the headers, is located at the beginning of the file (as defined by the ABI). The section `.xm_ctl`, which contains the PCT table, is located at the start of the `bss` section to avoid being zeroed at the startup of the partition. The contents of these tables has been initialized by XtratuM before starting the partition. The symbols `_sguest` and `_eguest` mark the Start and End of the partition image.

The ported version of the previous simple code is the following:

```
#include "std_c.h"          /* Helper functions */
#include <xm.h>
```

```
void PartitionMain () {     /* ``C'' code entry point. */
    int counter=0;

    xprintf(``Hello World!\n'');
    while(1) {
        counter++;
        counter %= 100000;
    }
}
```

Listing 5.9: Ported simple example.

Listing 5.10 shows the main compilation steps required to generate the final container file, which contains a complete XtratuM system, of a system of only one partition. The partition is only a single file, called `simple.c`. This example is provided only to illustrate the build process. It is advisable to use some of the Makefiles provided in the `xm-examples` (in the installed tree).

```
# --> Compile the partition souce code: [simple.c] -> [simple.o]
\$ sparc-linux-gcc -Wall -O2 -nostdlib -nostdinc -Dsparcv8 -fno-strict-aliasing \
    -fomit-frame-pointer --include xm_inc/config.h --include xm_inc/arch/arch_types.h \
    -I[...]/libxm/include -DCONFIG_VERSION=2 -DCONFIG_SUBVERSION=1 \
    -DCONFIG_REVISION=3 -g -D_DEBUG_ -c -o simple.o simple.c

# --> Link it with the startup (libexamples.a)
\$ sparc-linux-ld -o simple simple.o -n -u start -T[...]/lib/loader.lds -L../lib \
    -L[...]xm/lib --start-group `sparc-linux-gcc -print-libgcc-file-name ` -lxm -lxef \
    -lexamples --end-group -Ttext=0x40080000

# --> Convert the partition ELF to the XEF format.
\$ xmeformat build -c simple -o simple.xef

# --> Compile the configuration file.
\$ xmcparser -o xm_cf.bin.xmc xm_cf.sparcv8.xml

# --> Convert the configuration file to the XEF format.
\$ xmeformat build -c -m xm_cf.bin.xmc -o xm_cf.xef.xmc

# --> Pack all the XEF files of the system into a single container
\$ xmpack build -h [...]/xm/lib/xm_core.xef:xm_cf.xef.xmc -p 0:simple.xef container.bin

# --> Build the final bootable file with the resident sw and the container.
\$ rswbuild container.bin resident_sw
```

Listing 5.10: Example of a compilation sequence.

The partition code shall be compiled with with the flags `-nostdlib` and `-nostdinc` to avoid using host specific facilities which are not provided by XtratuM. The bindings between assembly and "C" are done considering that not frame pointer is used: `-fomit-frame-pointer`.

All the object files (`traps.o`,`boot.o` and `simple.o`) are linked together, and the `text` section is positioned in the direction 0x40050000. This address shall be the same than the one declared in the XM_CF file:

```
<SystemDescription xmlns="http://www.xtratum.org/xm-3.x" version="1.0.0"
    name="example">
        <HwDescription>
          <MemoryLayout>
             <Region type="rom" start="0x0" size="4MB" />
             <Region type="stram" start="0x40000000" size="4MB"/>
```

```
            <Region type="sdram" start="0x60000000" size="1MB"/>
          </MemoryLayout>
          <ProcessorTable>
            <Processor id="0" frequency="50Mhz">
              <CyclicPlanTable>
                <Plan id="0" majorFrame="2ms">
                  <Slot id="0" start="0ms" duration="1ms" partitionId="0"/>
                  <Slot id="1" start="1ms" duration="1ms" partitionId="1"/>
                </Plan>
              </CyclicPlanTable>
            </Processor>
          </ProcessorTable>
          <Devices>
            <Uart id="0" baudRate="115200" name="Uart"/>
            <MemoryBlock name="MemDisk0" start="0x4000" size="256KB" />
            <!--
               <MemoryBlock name="MemDisk0" start="0x40100000" size="256KB"
                   />
               <MemoryBlock name="MemDisk1" start="0x40150000" size="256KB"
                   />
               <MemoryBlock name="MemDisk2" start="0x40200000" size="256KB"
                   />
               -->
          </Devices>
        </HwDescription>
        <XMHypervisor console="Uart">
          <PhysicalMemoryArea size="512KB"/>
          <Container device="MemDisk0" offset="0x0" />
        </XMHypervisor>

        <!-- <track id="hello-xml-sample">-->
        <PartitionTable>
          <Partition id="0" name="Partition1" flags="system" console="Uart"
              >
            <PhysicalMemoryAreas>
              <Area start="0x40080000" size="512KB"/>
            </PhysicalMemoryAreas>
            <TemporalRequirements duration="500ms" period="500ms"/>
          </Partition>
          <Partition id="1" name="Partition2" flags="system" console="Uart"
              >
            <PhysicalMemoryAreas>
              <Area start="0x40100000" size="512KB" flags=""/>
            </PhysicalMemoryAreas>
            <TemporalRequirements duration="500ms" period="500ms"/>
            <HwResources>
              <Interrupts lines="4"/>
            </HwResources>
          </Partition>
        </PartitionTable>
        <!-- </track id="hello-xml-sample">-->
</SystemDescription>
```

Listing 5.11: XML configuration file example

In order to avoid inconsistences between the memory @Area attribute of the configuration and the parameter passed to the linker, the examples/common/xpath tool[3] can be used, from a Makefile, to extract the information from the configuration file.

```
\$ cd user/examples/hello_world
\$ ../common/xpath -c -f xm_cf.sparcv8.xml /SystemDescription/PartitionTable/
    Partition[1]/PhysicalMemoryAreas/Area[1]/@start
0x40050000
```

Listing 5.12: Using xpath to recover to memory area of the first partition.

The attribute /SystemDescription/PartitionTable/Partition[1]/PhysicalMemoryAreas/Area[1]/-@start is the xpath reference to the attribute which defines the first region of memory allocated to the first partition, which in the example is the place where the partition will be loaded.

5.4.1 Included headers

The include header which contains all the definitions and declarations of the libxm.a library is **xm.h**. This file depends (includes) also the next list of files:

```
user/libxm/include/xm_inc/config.h
user/libxm/include/xm_inc/autoconf.h
user/libxm/include/xm_inc/arch/arch_types.h
user/libxm/include/xm_inc/xmef.h
user/libxm/include/xm_inc/linkage.h
user/libxm/include/xm_inc/arch/linkage.h
user/libxm/include/xm_inc/arch/paging.h
user/libxm/include/xmhypercalls.h
user/libxm/include/xm_inc/hypercalls.h
user/libxm/include/xm_inc/arch/hypercalls.h
user/libxm/include/xm_inc/arch/irqs.h
user/libxm/include/xm_inc/arch/xm_def.h
user/libxm/include/xm_inc/arch/leon.h
user/libxm/include/arch/xmhypercalls.h
user/libxm/include/xm_inc/objdir.h
user/libxm/include/xm_inc/guest.h
user/libxm/include/xm_inc/arch/atomic.h
user/libxm/include/xm_inc/arch/guest.h
user/libxm/include/xm_inc/arch/processor.h
user/libxm/include/xm_inc/xmconf.h
user/libxm/include/xm_inc/arch/xmconf.h
user/libxm/include/xm_inc/devid.h
user/libxm/include/xm_inc/objects/hm.h
user/libxm/include/comm.h
user/libxm/include/xm_inc/objects/commports.h
user/libxm/include/hm.h
user/libxm/include/hmapp.h
user/libxm/include/xm_inc/objects/hmapp.h
user/libxm/include/hypervisor.h
user/libxm/include/arch/hypervisor.h
user/libxm/include/trace.h
user/libxm/include/xm_inc/objects/trace.h
user/libxm/include/status.h
user/libxm/include/xm_inc/objects/status.h
user/libxm/include/obt.h
user/libxm/include/xm_inc/objects/obt.h
```

[3]xpath is a small shell script frontend to the xmllint utility.

5.4.2 The "Hello World" example in multicore

In a multicore platform, when the partition is reset, the *virtual CPU*0 is booted and it is in charge of the initialisation of the other *virtual CPUs*. In the "Hello World" example, *vcpu*0 resets the other *vcpus*. 1790

```
#include "std_c.h"
#include <xm.h>

void PartitionMain(void) {
    extern struct xmImageHdr xmImageHdr;
    extern xmAddress_t *start;
    char str[]="Hello World";
    xm_s32_t i;

    xprintf("Hello World!\n");
    xprintf("This is Partition: %d vCPU: %d\n",
            XM_PARTITION_SELF, XM_get_vcpuid());
    if (XM_get_vcpuid()==0) {
        for (i=1; i<4; i++)
            XM_reset_vcpu(i, xmImageHdr.pageTable, (xmAddress_t)start, 0);
    }

    while(1) {
        counter++;
        counter %= 100000;
    }

    XM_halt_partition(XM_PARTITION_SELF);
}
```

Listing 5.13: Multicore simple example

5.5 Partition reset

A partition reset is an unconditional jump to the partition entry point. There are two modes to reset a partition: XM_WARM_RESET and XM_COLD_RESET (see section 2.3).

On a warm reset, the state of the partition is mostly preserved. Only the field resetCounter of the PCT is incremented, and the field resetStatus is set to the value given on the hypercall (see XM_partition_reset()). 1795

On a cold reset: the PCT table is rebuild; resetCounter field is set to zero; and resetStatus set to the value given on the hypercall; the communication ports are closed; the timers are disarmed.

5.6 System reset

There are two different system reset sequences:

Warm reset: XtratuM jumps to its entry point. This is basically a software reset.

Cold reset: A hardware reset if forced. (See section 8.3.5). 1800

The set of actions done on a warm system reset are still under development.

5.7 Scheduling

5.7.1 Slot identification

A partition can get information about which is the current slot being executed quering its PCT. This information can be used to synchronise the operation of the partition with the scheduling plan.

The information provided is:

Slot duration: The duration of the current slot. The value of the attribute "`duration`" for the current slot.

Slot number: The slot position in the system plan, starting in zero.

Id value: Each slot in the configuration file has a required attribute, named "`id`", which can be used to label each slot with a user defined number.

The id field is not interpreted by XtratuM and can be used to mark, for example, the slots at the starts of each period.

5.7.2 Managing scheduling plans

A system partition can request a plan switch at any time using the hypercall `XM_set_plan()`. The system will change to the new plan at the end of the current MAF. If `XM_set_plan()` is called several times before the end of the current plan, then the plan specified in the last call will take effect.

The hypercall `XM_get_plan_status()` returns information about the plans. The `xmPlanStatus_t` contains the following fields:

```
typedef struct {
    xmTime_t switchTime;
    xm_s32_t next;
    xm_s32_t current;
    xm_s32_t prev;
} xmPlanStatus_t;
```

Listing 5.14: core/include/objects/status.h

`switchTime`: The absolute time of the last plan switch request. After a reset (both warm and cold), the value is set to zero.

`current`: Identifier of the current plan.

`next`: The plan identifier that will be active on the next major frame. If no plan switch is going to occur, then the value of `next` is equal to the value of `current`.

`prev`: The identifier of the plan executed before the current one. After a reset (both warm and cold) the value is set to (`-1`).

5.8 Console output

XtratuM offers a basic service to print a string on the console. This service is provided through a hypercall.

```
   XM_write_console("Partition 1: Start execution\n", 29);
```

Listing 5.15: Simple hypercall invocation.

Additionally to this low level hypercall, some functions have been created to facilitate the use of the console by the partitions. These functions are coded in `examples/common/std_c.c`. Some of these 1835 functions are: `strlen()`, `print_str()`, `xprintf()` which are similar to the functions provided by a `stdio`.

The use of `xprintf()` is illustrated in the next example:

```
#include <xm.h>
#include "std_c.h"     // header of the std_c.h

void PartitionMain () {     // partition entry point
   int counter=0;

   while(1) {
   counter++;
   if (!(counter%1000))
      xprintf("%d\n", counter);
   }
}
```

Listing 5.16: Ported dummy code 1

`xprintf()` performs some format management in the function parameters and invokes the hypercall which stores it in a kernel buffer. This buffer can be sent to the serial output or other device. 1840

5.9 Inter-partition communication

Partitions can send/receive messages to/from other partitions. The basic mechanisms provided are sampling and queuing ports. The use of sampling ports is detailed in this section.

Ports need to be defined in the system configuration file `XM_CF`. Source and destination ports are connected through channels. Assuming that ports and channel linking the ports are defined in the configuration file, the next partition code shows how to use it. 1845

`XM_create_sampling_port()` and `XM_create_queuing_port()` hypercalls return *object descriptors*. An object descriptor is an integer, where the 16 least significant bits are a unique id of the port and the upper bits are reserved for internal use.

In this example partition_1 writes values in the `port1` whereas partition_2 reads them.

```
#include <xm.h>
#include "std_c.h"

#define PORT_NAME "port1"
#define PORT_SIZE 48

void PartitionMain () { // partition entry point
   int counter=0;
   int portDEsc;


   portDesc=XM_create_sampling_port(PORT_NAME, PORT_SIZE, XM_SOURCE_PORT);
   if ( portDesc < 0 ) {
      xprintf("[%s] cannot be created", PORT_NAME);
      return;
   }
```

```
    while(1) {
        counter++;
        if ( !(counter%1000) ){
            XM_write_sampling_message(portDesc,
                      counter, sizeof(counter));
        }
}
```

Listing 5.17: Partition_1.

```
#include <xm.h>
#include "std_c.h"

#define PORT_NAME "port2"
#define PORT_SIZE 48

void PartitionMain () {  // partition entry point
    int value;
    int previous = 0;
    int portDesc;
    xm_u32_t flags;

    portDesc=XM_create_sampling_port(PORT_NAME,PORT_SIZE, XM_DESTINATION_PORT);
    if ( portDesc < 0 ) {
        xprintf("[%s] cannot be created", PORT_NAME);
        return;
    }

    while(1) {
        XM_read_sampling_message(portDesc, &value, sizeof(value), &flags);
        if (!(value == previous)){
            xprintf("%d\n", value);
            previous = value;
        }
    }
}
```

Listing 5.18: Partition_2.

5.9.1 Message notification

When a message is sent into a queuing port, or written into a sampling port, XtratuM triggers the extended interrupt XM_VT_EXT_OBJDESC. By default, this interrupt is masked when the partition boots.

5.10 Peripheral programming

The LEON3 processor implements a memory-mapped I/O for performing hardware input and output operations to the peripherals. There are two hypercalls to access I/O registers: XM_{arch}_inport() and XM_{arch}_outport().

In order to be able to access (read from or write to) hardware I/O port the corresponding ports have to be allocated to the partition in the XM_CF configuration file.

There are two methods to allocate ports to a partition in the configuration file:

Range of ports: A range of I/O ports, with no restriction, allocated to the partition. The Range element is used.

Restricted port: A single I/O port with restrictions on the values that the partition is allowed to write in. The `Restricted` element is used in the configuration file. A restricted port includes the following information:

Address: Port address.

Mask: Port mask. Only those bits that are set, can be modified by the partition. In the case of a read operation only those bits set in the mask will be returned to the partition; the rest of the bits will be resetted.

The attribute (`mask` is optional. A restricted port declaration with no attribute, is equivalent to declare a range of ports of size one. In the case that both, the bitmap and the range of values, are specified then the bitmap is applied first and then the range is checked.

The implementation of the bit mask is done as follows:

```
        oldValue=LoadIoReg(port);
        StoreIoReg(port, ((oldValue&~(mask))|(value&mask)));
```

Listing 5.19: core/kernel/sparcv8/hypercalls.c

First, the port is read, to get the value of the bits not allocated to the partitions, then the bits that have to be modified are changed, and finally the value is written back.

The read operation shall not cause side effects on the associated peripheral. For example, some devices may interpret as interrupt acknowledge to read from a control port. Another source of errors may happen when the restricted is implemented as an open collector output. In this case, if the pin is connected to an external circuit which forces a low voltage, then the value read from the io port is not the same that the previous value written.

The following example declares a range of ports and two restricted ones.

```
<Partition ..... >
   <HwResources>
      <IoPorts>
         <Restricted address="0x3000" mask="0xff" />
      </IoPorts>
   </HwResources>
</Partition>
```

If the bitmask restriction is used, then the bits of the port that are not set in the mask can be allocated to other partitions. This way, it is possible to perform a fine grain (bit level) port allocation to partitions. That is a single ports can be safely shared among several partitions.

5.11 Traps, interrupts and exceptions

5.11.1 Traps

A partition can not directly manage processor traps. XtratuM provides a para-virtualized trap system called *virtual traps*. XtratuM defines 256+32 traps. The first 256 traps correspond directly with to the hardware traps. The last 32 ones are defined by XtratuM.

Specifically for LEON4 16 extended hardware interrupts are defined. These extended hardware interrupts are allocated from the 0x30 to 0x3F in the trap partition list. Next is shown the list of the mapping of extended hardware interrupts to traps.

```
#define EXT_HW_INTERRUPT_LEVEL_16 BASE_TRAP_EXT_HW_INTERRUPTS+15 //GRIOMMU // 31
#define EXT_HW_INTERRUPT_LEVEL_15 BASE_TRAP_EXT_HW_INTERRUPTS+14 //APBUART1 // 30
#define EXT_HW_INTERRUPT_LEVEL_14 BASE_TRAP_EXT_HW_INTERRUPTS+13 //APBUART0 // 29
#define EXT_HW_INTERRUPT_LEVEL_13 BASE_TRAP_EXT_HW_INTERRUPTS+12 //MEMSCRUBL2CACHE
     // 28
#define EXT_HW_INTERRUPT_LEVEL_12 BASE_TRAP_EXT_HW_INTERRUPTS+11 //AHBSTAT // 27
#define EXT_HW_INTERRUPT_LEVEL_11 BASE_TRAP_EXT_HW_INTERRUPTS+10 //GR1553B // 26
#define EXT_HW_INTERRUPT_LEVEL_10 BASE_TRAP_EXT_HW_INTERRUPTS+9 // GRETH_GBIT1 //
    25
#define EXT_HW_INTERRUPT_LEVEL_9 BASE_TRAP_EXT_HW_INTERRUPTS+8 // GRETH_GBIT0 //
    24
#define EXT_HW_INTERRUPT_LEVEL_8 BASE_TRAP_EXT_HW_INTERRUPTS+7 // SPWROUTER3 // 23
#define EXT_HW_INTERRUPT_LEVEL_7 BASE_TRAP_EXT_HW_INTERRUPTS+6 // SPWROUTER2 // 22
#define EXT_HW_INTERRUPT_LEVEL_6 BASE_TRAP_EXT_HW_INTERRUPTS+5 // SPWROUTER1 // 21
#define EXT_HW_INTERRUPT_LEVEL_5 BASE_TRAP_EXT_HW_INTERRUPTS+4 // SPWROUTER0 // 20
#define EXT_HW_INTERRUPT_LEVEL_4 BASE_TRAP_EXT_HW_INTERRUPTS+3 // GRGPIO3 // 19
#define EXT_HW_INTERRUPT_LEVEL_3 BASE_TRAP_EXT_HW_INTERRUPTS+2 // GRGPIO2 // 18
#define EXT_HW_INTERRUPT_LEVEL_2 BASE_TRAP_EXT_HW_INTERRUPTS+1 // GRGPIO1 // 17
#define EXT_HW_INTERRUPT_LEVEL_1 BASE_TRAP_EXT_HW_INTERRUPTS+0 // GRGPIO0 // 16
```

Listing 5.20: core/include/arch/irqs.h

The structure of the virtual trap table mimics the native trap table structure. Each entry is a 16 bytes large and contains the trap handler routine (which in the practice, is a branch or jump instruction to the real handler).

At boot time (or after a reset) a partition shall setup its virtual trap table and load the virtual `$tbr` register with the start address of the table. The `$tbr` register can be managed with the hypercalls: `XM_read_register32()` and `XM_write_register32()` with the appropriate register name:

```
#define TBR_REG32 0
```

Listing 5.21: Register name

If a trap is delivered to the partition and there is not a valid virtual trap table, then the health monitoring event `XM_EM_EV_PARTITION_UNRECOVERABLE` is generated.

5.11.2 Interrupts

In order to properly manage a peripheral, a partition can request to manage directly a hardware interrupt line. To do so, the interrupt line shall be allocated to the partition in the configuration file.

There are two groups of virtual interrupts:

Hardware interrupts: Correspond to the native hardware interrupts. Note that SPARC v8 defines only 15 interrupts (from 1 to 15), but XtratuM reserves 32 for compatibility with other architectures.

Interrupts 1 to 15 are assigned to traps 0x11 to 0x1F respectively (as in the native hardware).

Extended interrupts: Correspond to the XtratuM extended interrupts.

These interrupts are assigned from traps 0xE0 to 0xFF.

```
#define XM_VT_HW_FIRST          (0)
#define XM_VT_HW_LAST           (31)
#define XM_VT_HW_MAX            (32)
```

```
#define XM_VT_HW_INTERNAL_BUS_TRAP_NR (1+XM_VT_HW_FIRST)
#define XM_VT_HW_UART2_TRAP_NR    (2+XM_VT_HW_FIRST)
#define XM_VT_HW_UART1_TRAP_NR    (3+XM_VT_HW_FIRST)
#define XM_VT_HW_IO_IRQ0_TRAP_NR  (4+XM_VT_HW_FIRST)
#define XM_VT_HW_IO_IRQ1_TRAP_NR  (5+XM_VT_HW_FIRST)
#define XM_VT_HW_IO_IRQ2_TRAP_NR  (6+XM_VT_HW_FIRST)
#define XM_VT_HW_IO_IRQ3_TRAP_NR  (7+XM_VT_HW_FIRST)
#define XM_VT_HW_TIMER1_TRAP_NR   (8+XM_VT_HW_FIRST)
#define XM_VT_HW_TIMER2_TRAP_NR   (9+XM_VT_HW_FIRST)
#define XM_VT_HW_DSU_TRAP_NR      (11+XM_VT_HW_FIRST)
#define XM_VT_HW_PCI_TRAP_NR      (14+XM_VT_HW_FIRST)

#define XM_VT_EXT_FIRST        (0)
#define XM_VT_EXT_LAST         (31)
#define XM_VT_EXT_MAX          (32)

#define XM_VT_EXT_HW_TIMER      (0+XM_VT_EXT_FIRST)
#define XM_VT_EXT_EXEC_TIMER    (1+XM_VT_EXT_FIRST)
#define XM_VT_EXT_WATCHDOG_TIMER (2+XM_VT_EXT_FIRST)
#define XM_VT_EXT_SHUTDOWN      (3+XM_VT_EXT_FIRST)
#define XM_VT_EXT_SAMPLING_PORT (4+XM_VT_EXT_FIRST)
#define XM_VT_EXT_QUEUING_PORT  (5+XM_VT_EXT_FIRST)

#define XM_VT_EXT_CYCLIC_SLOT_START (8+XM_VT_EXT_FIRST)

#define XM_VT_EXT_MEM_PROTECT   (16+XM_VT_EXT_FIRST)

/* Inter-Partition Virtual Interrupts */
#define XM_MAX_IPVI            CONFIG_XM_MAX_IPVI
#define XM_VT_EXT_IPVI0        (24+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI1        (25+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI2        (26+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI3        (27+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI4        (28+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI5        (29+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI6        (30+XM_VT_EXT_FIRST)
#define XM_VT_EXT_IPVI7        (31+XM_VT_EXT_FIRST)
```

Listing 5.22: core/include/guest.h

Both, extended and hardware interrupts can be routed to a different interrupt vector through the `XM_route_irq()` hypercall, this hypercall enables a partition to select the most suitable vector to be raised.

All hardware and extended interrupts can be masked through the following hypercalls: `XM_clear_irqmask()` and `XM_set_irqmask()`. Besides, all these set of interrupts can be globally disabled/enable by using the `XM_sparc_get_psr()` and `XM_sparc_set_psr()` hypercalls, mimicking the way the underneath architecture works.

An example of interrupt management at partition level is:

```
#include "std_c.h"
#include <xm.h>

void IrqHandler(int irqnr) {
   xprintf("Hardware irq: %d\nHalting......\n", irqnr);
   XM_halt_partition(XM_PARTITION_SELF);
}
void ExtIrqHandler(int irqnr) {
   xprintf("Extended irq: %d\nHalting......\n", irqnr);
```

```
    XM_halt_partition(XM_PARTITION_SELF);
}

void PartitionMain(void) {
    xm_s32_t err;
    xmTime_t oneshoot;

    XM_get_time(XM_HW_CLOCK , &oneshoot);
    oneshoot += (xmTime_t)100000; // 1 second
    XM_set_timer(XM_HW_CLOCK , oneshoot, 0);

    XM_enable_irqs();
    err = XM_unmask_irq(XM_VT_EXT_HW_TIMER);
    xprintf("Unmask extirq XM_VT_EXT_HW_TIMER: %d\n", err);
    err = XM_unmask_irq( XM_VT_HW_IO_IRQ0_TRAP_NR );
    xprintf("Unmask hwirq 4: %d\n", err);

    while(1) {
        XM_idle_self();
    }
}
```

Listing 5.23: Virtual trap management example

5.11.3 Exceptions

Exceptions are the traps triggered by the processor in response to an internal condition. Some exceptions are caused by normal operation of the processor (e.g. register window over/underflow) but others are caused by abnormal situations (e.g. invalid instruction).

Error related exception traps, are managed by XtratuM thorough the health monitoring system.

```
#define DATA_STORE_ERROR 0x2b // 0
#define INSTRUCTION_ACCESS_MMU_MISS 0x3c // 1
#define INSTRUCTION_ACCESS_ERROR 0x21 // 2
#define R_REGISTER_ACCESS_ERROR 0x20 // 3
#define INSTRUCTION_ACCESS_EXCEPTION 0x1 // 4
#define PRIVILEGED_INSTRUCTION 0x03 // 5
#define ILLEGAL_INSTRUCTION 0x2 // 6
#define FP_DISABLED 0x4 // 7
#define CP_DISABLED 0x24 // 8
#define UNIMPLEMENTED_FLUSH 0x25 // 9
#define WATCHPOINT_DETECTED 0xb // 10
//#define WINDOW_OVERFLOW 0x5
//#define WINDOW_UNDERFLOW 0x6
#define MEM_ADDRESS_NOT_ALIGNED 0x7 // 11
#define FP_EXCEPTION 0x8 // 12
#define CP_EXCEPTION 0x28 // 13
#define DATA_ACCESS_ERROR 0x29 // 14
#define DATA_ACCESS_MMU_MISS 0x2c // 15
#define DATA_ACCESS_EXCEPTION 0x9 // 16
#define TAG_OVERFLOW 0xa // 17
#define DIVISION_BY_ZERO 0x2a // 18
```

Listing 5.24: core/include/arch/irqs.h

If the health monitoring action associated with the HM event is XM_HM_AC_PROPAGATE, then the same trap number is propagated to the partition as a virtual trap. The partition code is then in charge of handling the error.

5.12 Clock and timer services

XtratuM provides the XM_get_time() hypercall to read the time from a clock, and the XM_set_timer() 2045
hypercall to arm a timer.

There are two clocks available:

```
    #define XM_HW_CLOCK (0x0)
    #define XM_EXEC_CLOCK (0x1)
```
2050

Listing 5.25: core/include/hypercalls.h

XtratuM provides one timer for each clock. The timers can be programmed in one-shot or in periodic mode. Upon expiration, the extended interrupts XM_VT_EXT_HW_TIMER and XM_VT_EXT_EXEC_TIMER are triggered. These extended interrupts correspond with traps (256+XM_VT_EXT_HW_TIMER) and (256+XM-_VT_EXT_EXEC_TIMER) respectively. 2055

5.12.1 Execution time clock

The clock XM_EXEC_CLOCK only advances while the partition is being executed or while XtratuM is executing a hypercall requested by the partition. The execution time clock computes the total time used by the target partition.

This clock relies on the XM_HW_CLOCK, and so, its resolution is also 1μsec. Its precision is not as accurate as that of the XM_HW_CLOCK due to the errors introduced by the partition switch. 2060

The execution time clock does not advance when the partition gets idle or suspended. Therefore, the XM_EXEC_CLOCK clock should not be used to arm a timer to wake up a partition from an idle state.

The code below computes the temporal cost of a block of code.

```
#include <xm.h>
#include "std_c.h"

void PartitionMain() {
    xmTime_t t1, t2;

    XM_get_time(XM_EXEC_CLOCK, &t1);
    // code to be measured
    XM_get_time(XM_EXEC_CLOCK, &t2);
    xprintf("Initial time: %lld, final time: %lld", t1, t2);
    xprintf("Difference: %lld\n", t2-t1);
    XM_halt_partition(XM_PARTITION_SELF);
}
```

5.13 Processor management

Currently only the $tbr processor control register has been virtualised. This register should be loaded (with the hypercall XM_write_register32()) with the address of the partition trap table. This operation is usually done only once when the partition boots (see listing 5.4).

5.13.1 Managing stack context

The SPARC v8 architecture (following the RISC ideas) tries to simplify the complexity of the processor by moving complex management tasks to the compiler or the operating system. One of the most particular features of SPARC v8 is the register window concept, and how it should be managed.

Both, register window overflow and underflow cause a trap. This trap has to be managed in supervisor mode and with traps disabled (bit ET in the `$psr` register is unset) to avoid overwriting valid registers. It is not possible to emulate efficiently this behaviour.

XtratuM provides a transparent management of the stack. Stack overflow and underflow is directly managed by XtratuM without the intervention of the partition. The partition code shall load the stack register with valid values.

In order to implement a content switch inside a partition (if the partition is a multi-thread environment), the function `XM_sparcv8_flush_regwin()` can be used to flush (spill) all register windows in the current CPU stack. After calling this function, all the register windows, but the current one, are stored in RAM and then marked as free. The partition context switch code should basically carry out the next actions:

1. call `XM_sparcv8_flush_regwin()`
2. store the current “g”, “i” and “l” registers in the stack
3. switch to the new thread’s stack and
4. restore the same set of registers.

Note that there is no complementary function to reload (fill) the registers, because it is done automatically.

The `XM_sparcv8_flush_regwin()` service can also be used set the processor in a know state before executing a block of code. All the register windows will be clean and no window overflow will happen during the next 7 nested function calls.

5.14 Tracing

5.14.1 Trace messages

The hypercall `XM_trace_event()` stores a trace message in the partition’s associated buffer. A trace message is a `xmTraceStatus_t` structure which contains an *opCode* and an associated user defined data:

```
struct xmTraceEvent {
#define XMTRACE_SIGNATURE 0xc33c
    xm_u16_t signature;
    xm_u16_t checksum;
    xm_u32_t opCodeH, opCodeL;

// HIGH
#define TRACE_OPCODE_SEQ_MASK (0xfffffff0<<TRACE_OPCODE_SEQ_BIT)
#define TRACE_OPCODE_SEQ_BIT 4
#define TRACE_OPCODE_CRIT_MASK (0x7<<TRACE_OPCODE_CRIT_BIT)
#define TRACE_OPCODE_CRIT_BIT 1

#define TRACE_OPCODE_SYS_MASK (0x1<<TRACE_OPCODE_SYS_BIT)
#define TRACE_OPCODE_SYS_BIT 0

// LOW
#define TRACE_OPCODE_CODE_MASK (0xffff<<TRACE_OPCODE_CODE_BIT)
#define TRACE_OPCODE_CODE_BIT 16

// 256 vcpus
#define TRACE_OPCODE_VCPUID_MASK (0xff<<TRACE_OPCODE_VCPUID_BIT)
#define TRACE_OPCODE_VCPUID_BIT 8

// 256 partitions
#define TRACE_OPCODE_PARTID_MASK (0xff<<TRACE_OPCODE_PARTID_BIT)
#define TRACE_OPCODE_PARTID_BIT 0
    xmTime_t timestamp;
#define XMTRACE_PAYLOAD_LENGTH 4
    xmWord_t payload[XMTRACE_PAYLOAD_LENGTH];
} __PACKED;

typedef struct xmTraceEvent xmTraceEvent_t;
```

Listing 5.26: core/include/objects/trace.h

partitionId: Identify the partition that issued the trace event. This field is automatically filled by XtratuM. The value XM_HYPERVISOR_ID is used to identify XtratuM traces.

moduleId: For the traces issued by the partitions, this field is user defined.

For the traces issued by XtratuM, this field identifies an internal subsystem:

TRACE_MODULE_HYPERVISOR Traces related to XtratuM core events.

TRACE_MODULE_PARTITION Traces related to partition operation.

TRACE_MODULE_SCHED Traces concerning scheduling.

code: This field is user defined for the traces issued by the partitions. For the traces issued by XtratuM, the values of the code field depends on the value of the moduleId:

If moduleId = TRACE_MODULE_HYPERVISOR

TRACE_EV_HYP_HALT: The hypervisor is about to halt.

TRACE_EV_HYP_RESET: The hypervisor is about to perform a software reset.

TRACE_EV_HYP_AUDIT_INIT: The first message after the audit startup.

If moduleId = TRACE_MODULE_PARTITION

The field auditEvent.partitionId has the identifier of the affected partition. The recorded events are:

TRACE_EV_PART_SUSPEND: The affected partition has been suspended.

TRACE_EV_PART_RESUME: The affected partition has been resumed.

TRACE_EV_PART_HALT: The affected partition has been halted.

TRACE_EV_PART_SHUTDOWN: A shutdown extended interrupt has been delivered to the partition.

TRACE_EV_PART_IDLE: The affected partition has been set in idle state.

TRACE_EV_PART_RESET: The affected partition has been reset.

If **moduleId** = **TRACE_MODULE_SCHED**

The field `auditEvent.partitionId` has the identifier of the partition that requested the plan switch; or `XM_HYPERVISOR_ID` if the plan switch is the consequence of the `XM_HM_AC_SWITCH_TO_MAINTENANCE` health monitoring action.

The field `auditEvent.newPlanId` has the identifier of the new plan.

TRACE_EV_SCHED_CHANGE_REQ: A plan switch has been requested.

TRACE_EV_SCHED_CHANGE_COMP: A plan switch has been carried out.

criticality: Determines the importance/criticality of the event that motivated the trace message. Next, the intended use of it can be of the following levels:

XM_TRACE_NOTIFY A notification messages of the progress of the application at coarse-grained level.

XM_TRACE_DEBUG A detailed information message intended to be used for debugging during the development phase.

XM_TRACE_WARNING Traces which inform about potentially harmful situations.

XM_TRACE_UNRECOVERABLE Traces of this level are managed also by the health monitoring subsystem: a user HM event is generated, and handled according to the HM configuration. Note that both, the normal partition trace message is stored, and the HM event is generated.

Jointly with the `opCode` and the user data, the `XM_trace_event()` function has a bitmask parameter that is used to filter out trace events. If the logical `AND` between the bitmask parameter and the bitmask of the `XM_CF` configuration file is not zero then the trace event is logged; otherwise it is discarded. Traces of `XM_TRACE_UNRECOVERABLE` critically always raises a health monitoring event regarding the bitmask.

5.14.2 Reading traces

Only one system partition can read from a trace stream. A standard partition **can not read its own trace messages**, it is only allowed to store traces on it.

If the trace stream is stored in a buffer (RAM or FLASH). When the buffer is full, the oldest events are overwritten.

5.14.3 Configuration

XtratuM statically allocates a block of memory to store all traces. The amount of memory reserved to store traces is a configuration parameter of the sources (see section 8.1).

In order to be able to store the traces of a partition, as well as the traces generated by XtratuM, it has to be properly configured in the `XM_CF` configuration file. The `bitmask` attribute is used to filter which traces are stored.

```
<XMHypervisor console="Uart" healthMonitorDevice="MemDisk1">
   <Trace device="MemDisk0" bitmask="0x00000005"/>
</XMHypervisor>
<PartitionTable>
   <Partition console="Uart" flags="system" id="0" name="Partition0">
      <PhysicalMemoryAreas>
         <Area size="64KB" start="0x40080000"/>
      </PhysicalMemoryAreas>
      <Trace device="MemDisk0" bitmask="0x3"/>
      <TemporalRequirements duration="500ms" period="500ms"/>
   </Partition>
</PartitionTable>
```

Listing 5.27: Trace definition example

The traces recoded by XtratuM can be selected (masked) at module granularity.

In the example of listing 5.14.3, the TRACE_BM_HYPERVISOR and TRACE_BM_SCHED events will be recorded but not TRACE_BM_PARTITION.

5.15 System and partition status

The hypercalls XM_get_partition_status() and XM_get_system_status() return information about a given partition and the system respectively.

The data structure returned are:

```
typedef struct {
    /* Current state of the partition: ready, suspended ... */
    xm_u32_t state;
#define XM_STATUS_IDLE 0x0
#define XM_STATUS_READY 0x1
#define XM_STATUS_SUSPENDED 0x2
#define XM_STATUS_HALTED 0x3

    /* Number of virtual interrupts received. */
    xm_u64_t noVIrqs;               /* [[OPTIONAL]] */
    /* Reset information */
    xm_u32_t resetCounter;
    xm_u32_t resetStatus;
    xmTime_t execClock;
    /* Total number of partition messages: */
    xm_u64_t noSamplingPortMsgsRead; /* [[OPTIONAL]] */
    xm_u64_t noSamplingPortMsgsWritten; /* [[OPTIONAL]] */
    xm_u64_t noQueuingPortMsgsSent; /* [[OPTIONAL]] */
    xm_u64_t noQueuingPortMsgsReceived; /* [[OPTIONAL]] */
} xmPartitionStatus_t;
```

Listing 5.28: core/include/objects/status.h

```
typedef struct {
    xm_u32_t resetCounter;
    /* Number of HM events emitted. */
    xm_u64_t noHmEvents;            /* [[OPTIONAL]] */
    /* Number of HW interrupts received. */
    xm_u64_t noIrqs;                /* [[OPTIONAL]] */
    /* Current major cycle interation. */
    xm_u64_t currentMaf;            /* [[OPTIONAL]] */
    /* Total number of system messages: */
    xm_u64_t noSamplingPortMsgsRead; /* [[OPTIONAL]] */
    xm_u64_t noSamplingPortMsgsWritten; /* [[OPTIONAL]] */
    xm_u64_t noQueuingPortMsgsSent; /* [[OPTIONAL]] */
    xm_u64_t noQueuingPortMsgsReceived; /* [[OPTIONAL]] */
} xmSystemStatus_t;
```

Listing 5.29: core/include/objects/status.h

The field `execClock` of a partition is the execution time clock of the target partition. The rest of the fields are self explained.

Those fields commented as *[[OPTIONAL]]* contain valid data only if XtratuM has been compiled with the flag “Enable system/partition status accounting” enabled.

5.16 Memory management

XtratuM implements a flat memory space on the SPARC v8 architecture (LEON2 and LEON3 processors). The addresses generated by the control unit are directly emitted to the memory controller without any translation. Therefore, **each partition shall be compiled and linked to work on the designated memory range**. The starting address and the size of each partition is specified in the system configuration file.

Two different hardware features can be used to implement memory protection:

Write Protection Registers (WPR): In the case that there is no MMU support, then it is possible to use the WPR device of the LEON2 and LEON3 processors. The WPR device can be programmed to raise a trap when the processor tries to write on a configured address range.

Since read memory operations are not controlled by the WPR, it is not possible to enforce complete (read/write) memory isolation in this case. Also, due to the internal operation of the WPR device, all the memory allocated to each partition has to be contiguous and has to meet the following conditions:

- The size shall be greater than or equal to 32KB.
- The size shall be a power or two.
- The start address shall be a multiple of the size.

Memory Management Unit (MMU): If the processor has MMU, and XtratuM has been compiled to use it, then fine grain (page size) memory protection provided. In this case one or more areas of memory can be allocated to each partition.

The MMU is used only as a MPU (memory protection unit), i.e, the virtual and physical addresses are the same. Only the protections bits of the pages are used. As a result, each partition shall be compiled and linked to the designated addresses where they will be loaded and executed.

The memory protection mechanism employed is a source code configuration option. See section 8.1.

The memory areas allocated to a partition are defined in the `XM_CF` file. The executable image shall be linked to be executed in those allocated memory areas.

The `XM_get_physmem_map()` returns the set of memory areas allocated the partition. **Available since XtratuM 3.1**.

5.16.1 Configuration

A partition can statically allocates several memory areas to a partition. Memory areas have to be properly configured in the XM_CF configuration file in a coherent way with respect to the memory available and the allocation of memory areas to XtratuM, container, booter and other partitions.

An example of the memory areas definition in the XM_CF configuration file can be shown in 5.16.1.

```
<MemoryLayout>
  <Region type="stram" start="0x40000000" size="4MB"/>
  <Region type="sdram" start="0x60000000" size="8KB"/>
  <Region type="sdram" start="0xfffff000" size="4KB"/>
</MemoryLayout>
...

<XMHypervisor console="Uart" >
  <PhysicalMemoryArea size="512KB" />
</XMHypervisor>
...
<ResidentSw>
  <PhysicalMemoryAreas>
    <Area start="0x60300000" size="512KB"/>
  </PhysicalMemoryAreas>
</ResidentSw>
...
<PartitionTable>
  <Partition id="0" name="Partition0" console="Uart">
    <PhysicalMemoryAreas>
      <Area start="0x40100000" size="256KB" />
      <Area start="0x60200000" size="64KB" mappedAt="0x10000" />
      <Area start="0x60210000" size="64KB" mappedAt="0x20000" flags= "
          shared" />
      <Area start="0x60220000" size="64KB" flags= "uncacheable" />
      <Area start="0xfffff000" size="4KB" />
    </PhysicalMemoryAreas>
    <TemporalRequirements duration="500ms" period="500ms"/>
  </Partition>
  <Partition id="1" name="Partition1" flags="system" console="Uart">
    <PhysicalMemoryAreas>
      <Area start="0x40140000" size="256KB" mappedAt="0x40000000" />
      <Area start="0x60210000" size="64KB" flags= "shared read-only" />
      </PhysicalMemoryAreas>
    <TemporalRequirements duration="500ms" period="500ms"/>
  </Partition>
</PartitionTable>
..
```

Listing 5.30: Memory areas allocation example

The memory layout defined for the board is:

Memory type	Initial	End addres	Size
STRAM	40000000	403FFFFF	4 MB
SDRAM	60000000	607FFFFF	8 MB
STRAM	FFFFF000	FFFFFFFF	4 KB

The memory areas defined and the owners is detailed in the next table: 2315

NOTE: The container address is set in the XtratuM configuration process. In order to change it, a new XtratuM compilation and installation has to be performed.

In this example, Partition0 defines the following memory areas:

Component	Initial	End addres	Size	Attributes	Mapped at
XtratuM	40000000	400FFFFF	1 MB		
Partition0	40100000	4013FFFF	256 KB		
Partition1	40140000	4017FFFF	256 KB		
Partition0	60200000	6020FFFF	64 KB		10000
Partition0	60210000	6021FFFF	64 KB	Shared rw	20000
Partition1	60210000	6021FFFF	64 KB	Shared ro	
Partition0	60220000	6022FFFF	64 KB	Uncacheable	
RSW	60300000	6037FFFF	512 KB		
Container	60400000	6047FFFF	512 KB		
Partition0	FFFFF000	FFFFFFFF	4 KB		

- A memory area of 256Kb that is allocated to the physical memory ”0x40100000”.
- A memory area of 64Kb allocated in the physical memory at ”0x60200000” but mapped at ”0x1000”. So, internally the partition can access to this area using this virtual address.
- A memory area of 64Kb allocated in the physical memory at ”0x60210000” that is shared with other partitions. This partition can read and write on this area.
- A memory area of 64Kb allocated in the physical memory at ”0x60220000” that is not cacheable.
- A memory area of 4Kb allocated in the physical memory at ”0xfffff000” but mapped at ”0x2000”.

On the other hand, Partition1 defines:

- A memory area of 256Kb that is allocated to the physical memory ”0x40140000” and mapped at ”0x40000000”.
- A memory area of 64Kb allocated in the physical memory at ”0x60210000” that is shared with other partitions. This partition can only read on this area.

5.17 Releasing the processor

In some situations, a partition is waiting for a new event to execute a task. If no more tasks are pending to be executed, then the partition can become idle. The idle partition becomes ready again when an interrupt is received.

The partition can inform to XtratuM about its idle state (see `XM_idle_self()`). In the current implementation, XtratuM does nothing while a partition is idle, that is, other partition is not executed; but it opens the possibility to use this wasted time in internal bookkeeping or other maintenance activities. Also, energy saver actions can be done during this idle time.

Since XtratuM delivers an event on every new slot, the idle feature can also be used to synchronise the operation of the partition with the scheduling plan.

5.18 Partition customisation files

A partition is composed of a binary image (code and data) and, zero or more additional files (customisation files). To ease the management of these additional files, the header of the partition image (see section 6.4.1) holds the fields `noModules` and `moduleTab`, where the first is the number of additional files which have to be loaded and the second is an array of data structure which defines the loading address and the sizes of these additional files. During its creation, the partition is responsible for filling these fields with the address of a pre-allocated memory area inside its memory space.

These information shall be used by the loader software, for instance the resident software or a manager system partition, in order to know the place where to copy into RAM these additional files. If the size of any of these files is larger than the one specified on the header of the partition or the memory address is invalid, then the loading process shall fail.

These additional files shall be accessible by part of the loader software. For example, they must be packed jointly with the partition binary image by using the xmpack tool.

5.19 Assembly programming

This section describes the assembly programming convention, in order to invoke the XtratuM hypercalls.

The register assignment convention for calling a hypercall is:

%o0 Holds the hypercall number.

%o1 - %o5 Holds the parameters to the hypercall.

Once the processor registers have been loaded, a **ta** instruction to the appropriate software trap number shall be called, see section 6.2.

The return value is stored in register **%o0**.

For example, following assembly code calls the XM_get_time(xm_u32_t clockId, xmTime_t *time):

```
mov  0xa , %o0 ; __GET_TIME_NR
mov  %i0, %o1
mov  %i1, %o2
ta   0xf0
cmp  %o0, 0     ; XM_OK == 0
bne   <error>
```

In SPARC v8, the get_time_nr constant has the value "0xa"; "%i0" holds the clock id; and "%i1" is a pointer which points to a xmTime_t variable. The return value of the hypercall is stored in "%o0" and then checked if XM_OK.

Below is the list of normal hypercall number constants (listing 5.19) and assembly hypercalls (listing 5.19):

```
#define __MULTICALL_NR 0
#define __HALT_PARTITION_NR 1
#define __SUSPEND_PARTITION_NR 2
#define __RESUME_PARTITION_NR 3
#define __RESET_PARTITION_NR 4
#define __SHUTDOWN_PARTITION_NR 5
#define __HALT_SYSTEM_NR 6
#define __RESET_SYSTEM_NR 7
#define __IDLE_SELF_NR 8

#define __GET_TIME_NR 9
#define __SET_TIMER_NR 10
#define __READ_OBJECT_NR 11
#define __WRITE_OBJECT_NR 12
#define __SEEK_OBJECT_NR 13
#define __CTRL_OBJECT_NR 14

#define __CLEAR_IRQ_MASK_NR 15
```

```
#define __SET_IRQ_MASK_NR 16
#define __FORCE_IRQS_NR 17
#define __CLEAR_IRQS_NR 18
#define __ROUTE_IRQ_NR 19

#define __UPDATE_PAGE32_NR 20
#define __SET_PAGE_TYPE_NR 21
#define __INVLD_TLB_NR 22
#define __RAISE_IPVI_NR 23
#define __OVERRIDE_TRAP_HNDL_NR 24
#define __FLUSH_CACHE_NR 25
#define __SET_CACHE_STATE_NR 26

#define __SWITCH_SCHED_PLAN_NR 27
#define __GET_GID_BY_NAME_NR 28
#define __RESET_VCPU_NR 29
#define __HALT_VCPU_NR 30
#define __SUSPEND_VCPU_NR 31
#define __RESUME_VCPU_NR 32

#define __GET_VCPUID_NR 33

#define sparc_atomic_add_nr 34
#define sparc_atomic_and_nr 35
#define sparc_atomic_or_nr 36
#define sparc_inport_nr 37
#define sparc_outport_nr 38
#define sparc_write_tbr_nr 39
#define sparc_write_ptdl1_nr 40
```

Listing 5.31: core/include/arch/hypercalls.h

```
#define sparc_iret_nr 0
#define sparc_flush_regwin_nr 1
#define sparc_get_psr_nr 2
#define sparc_set_psr_nr 3
#define sparc_set_pil_nr 4
#define sparc_clear_pil_nr 5
#define sparc_ctrl_winflow_nr 6
```

Listing 5.32: core/include/arch/hypercalls.h

The file "core/include/sparckv8/hypercalls.h" has additional services for the SPARC v8 architecture.

5.19.1 The object interface

XtratuM implements internally a kind of virtual file system (as the /dev directory). Most of the libxm hypercalls are implemented using this file system. The hypercalls to access the objects are used internally by the libxm and shall not be used by the programmer. They are listed here just for completeness:

```
extern __stdcall xm_s32_t XM_get_gid_by_name(xm_u8_t *name, xm_u32_t
    entity);
extern __stdcall xmId_t XM_get_vcpuid(void);

// Time management hypercalls
extern __stdcall xm_s32_t XM_get_time(xm_u32_t clock_id, xmTime_t *time)
    ;
extern __stdcall xm_s32_t XM_set_timer(xm_u32_t clock_id, xmTime_t
    abstime, xmTime_t interval);

// Partition status hypercalls
```

```
extern __stdcall xm_s32_t XM_suspend_partition(xm_u32_t partition_id);
extern __stdcall xm_s32_t XM_resume_partition(xm_u32_t partition_id);
extern __stdcall xm_s32_t XM_shutdown_partition(xm_u32_t partition_id);
extern __stdcall xm_s32_t XM_reset_partition(xm_u32_t partition_id,
    xm_u32_t resetMode, xm_u32_t status);
extern __stdcall xm_s32_t XM_halt_partition(xm_u32_t partition_id);
extern __stdcall xm_s32_t XM_idle_self(void);
extern __stdcall xm_s32_t XM_suspend_vcpu(xm_u32_t vcpu_id);
extern __stdcall xm_s32_t XM_resume_vcpu(xm_u32_t vcpu_id);
extern __stdcall xm_s32_t XM_reset_vcpu(xm_u32_t vcpu_id, xmAddress_t
    ptdL1, xmAddress_t entry, xm_u32_t status);
extern __stdcall xm_s32_t XM_halt_vcpu(xm_u32_t vcpu_id);

// system status hypercalls
extern __stdcall xm_s32_t XM_halt_system(void);
extern __stdcall xm_s32_t XM_reset_system(xm_u32_t resetMode);

// Object related hypercalls

extern __stdcall xm_s32_t XM_read_object(xmObjDesc_t objDesc, void *
    buffer, xm_u32_t size, xm_u32_t *flags);
extern __stdcall xm_s32_t XM_write_object(xmObjDesc_t objDesc, void *
    buffer, xm_u32_t size, xm_u32_t *flags);
extern __stdcall xm_s32_t XM_seek_object(xmObjDesc_t objDesc, xm_u32_t
    offset, xm_u32_t whence);
extern __stdcall xm_s32_t XM_ctrl_object(xmObjDesc_t objDesc, xm_u32_t
    cmd, void *arg);
```

Listing 5.33: user/libxm/include/xmhypercalls.h

The following services are implemented through the object interface:

- Communication ports.
- Console output.
- Health monitoring logs.
- Memory access.
- XtratuM and partition status.
- Trace logs.
- Serial ports.

For example, the `XM_hm_status()` hypercall is implemented in the libxm as:

```
xm_s32_t XM_hm_status(xmHmStatus_t *hmStatusPtr) {
    if (!(libXmParams.partCtrlTab[XM_get_vcpuid()]->flags&XM_PART_SYSTEM))
        return XM_PERM_ERROR;

    if (!hmStatusPtr) {
        return XM_INVALID_PARAM;
    }
    return XM_ctrl_object(OBJDESC_BUILD(OBJ_CLASS_HM, XM_HYPERVISOR_ID, 0),
         XM_HM_GET_STATUS, hmStatusPtr);
}
```

Listing 5.34: user/libxm/common/hm.c

5.20 Manpages summary

Below is a summary of the manpages. A detailed information is provided in the document "*Volume 4: Reference Manual*".

System Management	
XM_get_system_status	Get the current status of the system.
XM_halt_system	Stop the system.
XM_reset_system	Reset the system.
Partition Management	
XM_get_partition_mmap	This function returns a pointer to the memory map table (MMT).
XM_get_partition_status	Get the current status of a partition.
XM_halt_partition	Terminates a partition.
XM_idle_self	Idles the execution of the calling partition.
XM_params_get_PCT	Return the address of the PCT.
XM_reset_partition	Reset a partition.
XM_resume_partition	Resume the execution of a partition.
XM_set_partition_opmode	Informs the internal status of the partition
XM_shutdown_partition	Send a shutdown interrupt to a partition.
XM_suspend_partition	Suspend the execution of a partition.
Multicore Management	
XM_get_vcpu_status	Get the current status of a *virtual CPU*.
XM_get_vcpuid	Returns the *virtual CPU* identifier of the calling partition
XM_halt_vcpu	Halts a *virtual CPU* for the partition invoking this service.
XM_reset_vcpu	Resets a *virtual CPU* for the partition invoking this service.
XM_resume_vcpu	Resumes a *virtual CPU* for the partition invoking this service.
XM_suspend_vcpu	Suspends a *virtual CPU* for the partition invoking this service.
Time Management	
XM_get_time	Retrieve the time of the clock specified in the parameter.
XM_set_timer	Arm a timer.
Plan Management	
XM_get_plan_status	Return information about the status of the scheduling plan.
XM_switch_sched_plan	Request a plan switch at the end of the current MAF.
Inter-Partition Communication	
XM_create_queuing_port	Create a queuing port.
XM_create_sampling_port	Create a sampling port.
XM_get_queuing_port_info	Get the info of a queuing port from the port name.

XM_get_queuing_port_status	Get the status of a queuing port.
XM_get_sampling_port_info	Get the info of a sampling port from the port name.
XM_get_sampling_port_status	Get the status of a sampling port.
XM_read_sampling_message	Reads a message from the specified sampling port.
XM_receive_queuing_message	Receive a message from the specified queuing port.
XM_send_queuing_message	Send a message in the specified queuing port.
XM_write_sampling_message	Writes a message in the specified sampling port.
Memory Management	
XM_memory_copy	Copy a memory area of a specified size from a source to a destination
Health Monitor Management	
XM_hm_read	Read a health monitoring log entry.
XM_hm_seek	Sets the read position in the health monitoring stream.
XM_hm_status	Get the status of the health monitoring log stream.
Trace Management	
XM_trace_event	Records a trace entry.
XM_trace_open	Open a trace stream.
XM_trace_read	Read a trace event.
XM_trace_seek	Sets the read position in a trace stream.
XM_trace_status	Get the status of a trace stream.
Interrupt Management	
XM_clear_irqmask	Unmask interrupts.
XM_clear_irqpend	Clear pending interrupts.
XM_raise_ipvi	Generate a inter-partition virtual interrupt (ipvi) to a partition as specified in the configuration file.
XM_route_irq	Link an interrupt with the vector generated when the
XM_set_irqmask	Mask interrupts.
XM_set_irqpend	Set some interrupts as pending.
Miscelaneous	
XM_get_gid_by_name	Returns the identifier of an entity defined in the configuration file.
XM_multicall	Execute a sequence of hypercalls.
XM_read_console	Print a string in the hypervisor console.
XM_write_console	Print a string in the hypervisor console.
XM_write_register32	Modify a processor internal register.
Sparcv8 specific	
XM_sparc_atomic_add	Atomic add.
XM_sparc_atomic_and	Atomic bitwise AND.
XM_sparc_atomic_or	Atomic bitwise OR.
XM_sparc_clear_pil	Clear the PIL field of the PSR (enable interrupts).
XM_sparc_flush_regwim	Save the contents of the register window.
XM_sparc_flush_tlb	The TLB cache is invalidated. Assembly hypercall.
XM_sparc_get_psr	Get the ICC and PIL flags from the virtual PSR processor register.
XM_sparc_inport	Read from a hardware I/O port.

XM_sparc_outport	Write in a hardware I/O port.
XM_sparc_set_pil	Set the PIL field of the PSR (disallow interrupts).
XM_sparc_set_psr	Set the ICC and PIL flags on the virtual PSR processor register.
XM_sparcv8_ctrl_winflow	Check manually the state of register windows.
Obsolete	
XM_hm_open	DEPRECATED
XM_mask_irq	Obsoleted by XM_set_irqmask().
XM_request_irq	Request to receive an interrupt.
XM_set_page_type	Changes the type of a physical page to a specific page type.
XM_sparc_flush_cache	Flush data cache. Assembly hypercall.
XM_update_page32	Updates an entry in the page table.

Chapter 6

Binary Interfaces

This section covers the data types and the format of the files and data structures used by XtratuM.

Only the first section, describing the data types, is needed for a partition developer. The remaining sections contain material for more advanced users. The `libxm.a` library provides a friendly interface that hides most of the low level details explained in this chapter.

6.1 Data representation

The data types used in the XtratuM interfaces are compiler and machine cross development independent. This is specially important when manipulating the configuration files.

XtratuM conforms the following conventions:

Unsigned	Signed	Size (bytes)	Alignment (bytes)
xm_u8_t	xm_s8_t	1	1
xm_u16_t	xm_s16_t	2	4
xm_u32_t	xm_s32_t	4	4
xm_u64_t	xm_s64_t	8	8

Table 6.1: Data types.

These data types have to be stored in big-endian format, that is, the most significant byte is the rightmost byte (`0x..00`) and the least significant byte is the leftmost byte (`0x..03`).

"C" declaration which meet these definitions are presented in the list below:

```
// Basic types
typedef unsigned char xm_u8_t;
#define MAX_U8 0xFF
typedef char xm_s8_t;
#define MAX_S8 0x7F
typedef unsigned short xm_u16_t;
#define MAX_U16 0xFFFF
typedef short xm_s16_t;
#define MAX_S16 0x7FFF
typedef unsigned int xm_u32_t;
#define MAX_U32 0xFFFFFFFF
typedef int xm_s32_t;
```

```
#define MAX_S32 0x7FFFFFFF
typedef unsigned long long xm_u64_t;
#define MAX_U64 0xFFFFFFFFFFFFFFFFULL
typedef long long xm_s64_t;
#define MAX_S64 0x7FFFFFFFFFFFFFFFLL
```

Listing 6.1: core/include/arch/arch_types.h

```
// Extended types
typedef long xmLong_t;
typedef xm_u32_t xmWord_t;
#define XM_LOG2_WORD_SZ 5
typedef xm_s64_t xmTime_t;
#define MAX_XMTIME MAX_S64
typedef xm_u32_t xmAddress_t;
typedef xmAddress_t xmIoAddress_t;
typedef xm_u32_t xmSize_t;
typedef xm_s32_t xmSSize_t;
typedef xm_u32_t xmId_t;
```

Listing 6.2: core/include/arch/arch_types.h

For future compatiblity, most data structures contain version information. It is a xm_u32_t data type with 3 fields: version, subversion and revision. The macros listed next can be used to manipulate those fields:

```
#define XM_SET_VERSION(_ver, _subver, _rev) ((((_ver)&0xFF)<<16)|(((
    _subver)&0xFF)<<8)|((_rev)&0xFF))
#define XM_GET_VERSION(_v) (((_v)>>16)&0xFF)
#define XM_GET_SUBVERSION(_v) (((_v)>>8)&0xFF)
#define XM_GET_REVISION(_v) ((_v)&0xFF)
```

Listing 6.3: core/include/xmef.h

6.2 Hypercall mechanism

A hypercall is implemented by a trap processor instruction that transfers the control to XtratuM code, and sets the processor in supervisor mode.

There are two kinds of hypercalls: normal and assembly. Each type of hypercall uses a different trap number:

```
#define XM_HYPERCALL_TRAP 0xF0
#define XM_ASMHYPERCALL_TRAP 0xF1
```

Listing 6.4: core/include/arch/xm_def.h

The XM_ASMHYPERCALL_TRAP hypercall entry is needed for the XM_sparcv8_flush_regwin(), XM_sparcv8_iret() and XM_sparcv8_get_flags() calls. In this case, the XtratuM entry code does not prepare the processor to execute “C” code.

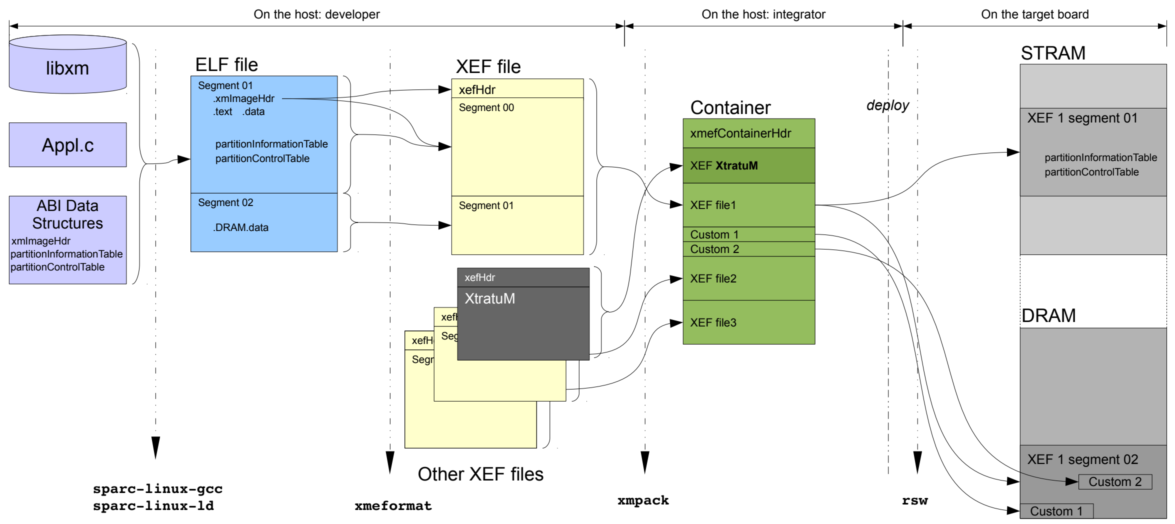


Figure 6.1: Executable formats.

6.3 Executable formats overview

XtratuM core does not have the capability to "load" partitions. It is assumed that when XtratuM starts its execution, all the partition code and data required to execute each partition is already in main memory. Therefore, XtratuM does not contain code to manage executable images. The only information required by XtratuM to execute a partition is the address of the partition image header (`xmImageHdr`). 2555

The partition images, as well as the XtratuM image, shall be loaded by a resident software, which acts as the boot loader.

The *XEF* (XtratuM Executable Format) has been designed as a robust format to copy the partition code (and data) from the partition developer to the final target system.

The XtratuM image shall also be in XEF format. From the resident software point of view, XtratuM is 2560
just another image that has to be copied into the appropriate memory area.

The main features of the XEF format are:

- Simpler than the ELF. The ELF format is a rich and powerful specification, but most of its features are not required.
- Content checksum. It allows to detect transmission errors. 2565
- Compress the content. This feature greatly reduce the space of the image; consequently the deploy time.
- Encrypt the content. Not implemented.
- Partitions can be placed in several non-contiguous memory areas.

The *container* is a file which contains a set of XEF files. It is like a tar file (with important internal dif- 2570
ferences). The resident software shall be able to manage the container format to extract the partitions (XEF files); and also the XEF format to copy them to the target memory addresses.

The signature fields are constants used to identify and locate the data structures. The value that shall contain these fields on each data structure is defined right above the corresponding declaration.

6.4 Partition ELF format

A *partition image* contains all the information needed to "execute" the partition. It does not have loading or booting information. It contains one *image header structure*, one or more *partition header structures*, as well as the code and data that will be executed.

Since multiple partition headers is an experimental feature (to support multiprocessor in a partition), we will assume in what follows that a partition file contains only one image header structure and one partition header structure.

All the addresses of partition image are absolute addresses which refer to the target RAM memory locations.

6.4.1 Partition image header

The partition image header is a data structure with the following fields:

```
struct xmImageHdr {
#define XMEF_PARTITION_MAGIC 0x24584d69 // $XMi
    xm_u32_t sSignature;
    xm_u32_t compilationXmAbiVersion; // XM's abi version
    xm_u32_t compilationXmApiVersion; // XM's api version
/* pageTable is unused when MPU is set */
    xmAddress_t pageTable; // Physical address
/* pageTableSize is unused when MPU is set */
    xmSize_t pageTableSize;
    xm_u32_t noCustomFiles;
    struct xefCustomFile customFileTab[CONFIG_MAX_NO_CUSTOMFILES];
    xm_u32_t eSignature;
} __PACKED;
```

Listing 6.5: core/include/xmef.h

`sSignature` and `eSignature`: Holds the **s**tart and **e**nd signatures which identifies the structure as a XtratuM partition image.

`compilationXmAbiVersion`: XtratuM ABI version used to compile the partition. That is, the ABI version of the libxm and other accompanying utilities used to build the XEF file.

`compilationXmApiVersion`: XtratuM API version used to compile the partition. That is, the API version of the libxm and other accompanying utilities used to build the XEF file.

The current values of these fields are:

```
#define XM_ABI_VERSION 3
#define XM_ABI_SUBVERSION 1
#define XM_ABI_REVISION 0

#define XM_API_VERSION 3
#define XM_API_SUBVERSION 1
#define XM_API_REVISION 2
```

Listing 6.6: core/include/hypercalls.h

Note that these values may be different to the API and ABI versions of the running XtratuM. This information is used by XtratuM to check that the partition image is compatible.

noCustomFiles: The number of extra files accompanying the image. If the image were Linux, then one of the modules would be the *initrd* image. Up to CONFIG_MAX_NO_FILES can be attached. The moduleTab table contains the locations in the RAM's address space of the partition where the modules shall be copied (if any). See section 5.18.

customFileTab: Table information about the customisation files.

```
struct xefCustomFile {
    xmAddress_t sAddr;
    xmSize_t size;
} __PACKED;
```

Listing 6.7: core/include/xmef.h

sAddr: Address where the customisation file shall be loaded.

size: Size of the customisation file.

The address where the custom files are loaded shall belong to the partition.

The xmImageHdr structure has to be placed in a section named ".xmImageHdr". An example of how the header of a partition can be created is shown in section 5.4.

The remainder of the image is free to the partition developer. There is not a predefined format or structure of where the code and data sections shall be placed.

6.4.2 Partition control table (PCT)

In order to minimize the overhead of the para-virtualised services, XtratuM defines a special data structure which is shared between the hypervisor and the partition called *Partition control table* (PCT). There is a PCT for each partition. XtratuM uses the PCT to send relevant operating information to the partitions. The PCT is mapped as read-only, allowing a partition only to read it. Any write access causes a system exception.

```
typedef struct {
    xm_u32_t magic;
    xm_u32_t xmVersion; // XM version
    xm_u32_t xmAbiVersion; // XM's abi version
    xm_u32_t xmApiVersion; // XM's api version
    xmSize_t partCtrlTabSize;
    xm_u32_t resetCounter;
    xm_u32_t resetStatus;
    xm_u32_t cpuKhz;
#define PCT_GET_PARTITION_ID(pct) ((pct)->id&0xff)
#define PCT_GET_VCPU_ID(pct) ((pct)->id>>8)
    xmId_t id;
    xmId_t noVCpus;
    xmId_t schedPolicy;
    xm_u32_t flags;
    xm_u32_t hwIrqs; // Hw interrupts belonging to the partition
    xm_s32_t noPhysicalMemAreas;
    xm_s32_t noCommPorts;
    xm_u8_t name[CONFIG_ID_STRING_LENGTH];
    xm_u32_t iFlags; // As defined by the ARCH (ET+PIL in sparc)
    xm_u32_t hwIrqsPend; // pending hw irqs
    xm_u32_t hwIrqsMask; // masked hw irqs

    xm_u32_t extIrqsPend; // pending extended irqs
    xm_u32_t extIrqsMask; // masked extended irqs

    struct pctArch arch;
    struct schedInfo schedInfo;
    xm_u16_t trap2Vector[NO_TRAPS];
    xm_u16_t hwIrq2Vector[CONFIG_NO_HWIRQS];
    xm_u16_t extIrq2Vector[XM_VT_EXT_MAX];
} partitionControlTable_t;
```

Listing 6.8: core/include/guest.h

The libxm call `XM_params_get_PCT()` returns a pointer to the PCT.

The architecture dependent part is defined in:

```
struct pctArch {
    xmAddress_t tbr;
#ifdef CONFIG_MMU
    volatile xmAddress_t ptdL1;
#define _ARCH_PTDL1_REG ptdL1
    volatile xm_u32_t faultStatusReg;
    volatile xm_u32_t faultAddressReg;
#endif
};
```

Listing 6.9: core/include/arch/guest.h

`signature`: Signature to identity this data structure as a PIT.

`xmAbiVersion`: The ABI version of the currently running XtratuM. This value is filled by the running XtratuM.

`xmApiVersion`: The API version of the currently running XtratuM. This value is filled by the running XtratuM.

`resetCounter`: A counter of the number of partition resets. This counter is incremented when the partition is WARM reset. On a COLD reset it is set to zero.

`resetStatus`: If the partition had been reset by a `XM_reset_partition()` hypercall, then the value of the parameter `status` is copied in this field. Zero otherwise.

`id`: The identifier of the partition. It is the unique number, specified in the `XM_CF` file, to unequivocally identify a partition.

`hwIrqs`: A bitmap of the hardware interrupts allocated to the partition. Hardware interrupts are allocated to the partition in the `XM_CF` file.

`noPhysicalMemoryAreas`: The number of memory areas allocated to the partition. This value defines the size of the `physicalMemoryAreas` array.

`name`: Name of the partition.

`hwIrqsPend`: Bitmap of the hardware interrupts allocated to the partition delivered to the partition.

`extIrqsPend`: Bitmap of the extended interrupts allocated to the partition delivered to the partition.

hwIrqsMask: Bitmap of the extended interrupts allocated to the partition delivered to the partition.

extIrqsMask:

In the current version there is no specific architecture data.

6.5 XEF format

The XEF is a wrapper for the files that may be deployed in the target system. There are three kind of files:

- Partition images.
- The XtratuM image.
- Customisation files.

An XEF file has a header (see listing 6.5) and a set of *segments*. Each segment, like in ELF, represents a block of memory that shall be loaded into RAM.

The tool `xmeformat` converts from ELF or plain data files to XEF format, see chapter 9.

```
struct xefHdr {
#define XEF_SIGNATURE 0x24584546
    xm_u32_t signature;
    xm_u32_t version;
#define XEF_DIGEST 0x1
#define XEF_COMPRESSED 0x4
#define XEF_RELOCATABLE 0x10

#define XEF_TYPE_MASK 0xc0
#define XEF_TYPE_HYPERVISOR 0x00
#define XEF_TYPE_PARTITION 0x40
#define XEF_TYPE_CUSTOMFILE 0x80

#define XEF_ARCH_SPARCv8 0x400
#define XEF_ARCH_MASK 0xff00
    xm_u32_t flags;
    xm_u8_t digest[XM_DIGEST_BYTES];
    xm_u8_t payload[XM_PAYLOAD_BYTES];
    xmSize_t fileSize;
    xmAddress_t segmentTabOffset;
    xm_s32_t noSegments;
    xmAddress_t customFileTabOffset;
    xm_s32_t noCustomFiles;
    xmAddress_t imageOffset;
    xmSize_t imageLength;
    xmSize_t deflatedImageLength;
    xmAddress_t pageTable;
    xmSize_t pageTableSize;
    xmAddress_t xmImageHdr;
    xmAddress_t entryPoint;
} __PACKED;
```

Listing 6.10: core/include/xmef.h

`signature`: A 4 bytes word to identify the file as a XEF format.

`version`: Version of the XEF format.

`flags`: Bitmap of features present in the XEF image. It is a 4 bytes word. The existing flags are:

- **`XEF_DIGEST`:** If set, then the `digest` field is valid and shall be used to check the integrity of the XEF file.
- **`XEF_COMPRESSED`:** If set, then the partition binary image is compressed.
- **`XEF_CIPHERED`:** (**future extension**) to inform whether the partition binary is encrypted or not.
- **`XEF_CONTENT`:** Specifies what kind of file is.

`digest`: when the `XEF_DIGEST` flag is set, this field holds the result of processing whole the XEF file (supposing the digest field set to 0). The MD5 algorithm is used to calculate this field.

Despite the well known security flaws, we selected the MD5 digest algorithm because it has a reasonable trade-off between calculation time and the security level [1] . Note that the digest field is used to detect accidental modifications rather than intentional attacks. In this scenario, the MD5 is a good choice.

`payLoad`: This field holds 16 bytes which can freely be used by the partition supplier. It could be used to hold information such as partition's version, etc.

The content of this field is used neither by XtratuM nor the resident software.

`fileSize`: XEF file size in bytes.

`segmentTabOffset`: Offset to the section table.

`noSegments`: Number of segments held in the XEF file. In the case of a customisation file, there will be only one segment.

`customFileTabOffset`: Offset to the custom files table.

`noCustomFiles`: Number of custom files.

`imageOffset`: Offset to the partition binary image.

`imageLength`: Size of the partition binary image.

`deflatedImageLength`: When the `XEF_COMPRESS` flag is set, this field holds the size of the uncompressed partition binary image.

`xmImageHdr`: Pointer to the partition image header structure (`xmImageHdr`). The `xmeformat` tool copies the address of the corresponding section in this filed.

`entryPoint`: Address of the starting function.

Additionally, analogically to the ELF format, XEF contemplates the concept of *segment*, which is, a portion of code/data with a size and a specific load address. A XEF file includes a segment table (see listing 6.5) which describes each one of the sections of the image (custom data XEF files have only one section).

[1]According to our tests, the time spent by more sophisticated digest algorithms such as SHA-2, Tiger or Whirlpool in the LEON3 processor was not acceptable. As illustration, 100 Kbytes took several seconds to be digested by a SHA-2 algorithm in this processor.

```
struct xefSegment {
    xmAddress_t physAddr;
    xmAddress_t virtAddr;
    xmSize_t fileSize;
    xmSize_t deflatedFileSize;
    xmAddress_t offset;
} __PACKED;
```

Listing 6.11: core/include/xmef.h

startAddr: Address where the segment shall be located while it is being executed. This address is the one used by the linker to locate the image. If there is not MMU, then physAddress=virtAddr.

fileSize: The size of the segment within the file. This size could be different from the memory required to be executed (for example a data segment (bss segment) usually requires more memory once loaded into memory).

deflatedFileSize: When the XEF_COMPRESS flag is set, this field holds the size of the segment when uncompressed.

offset: Location of the segment expressed as an offset in the partition binary image.

6.5.1 Compression algorithm

The compression algorithm implemented is Lempel-Ziv-Storer-Szymanski (LZSS). It is a derivative of LZ77, that was created in 1982 by James Storer and Thomas Szymanski. A detailed description of the algorithm appeared in the article "Data compression via textual substitution" published in Journal of the ACM.

The main features of the LZSS are:

1. Fairly acceptable trade-off between compression rate and decompression speed.
2. Implementation simplicity.
3. Patent-free technology.

Aside from LZSS, other algorithms which were regarded were: huffman coding, gzip, bzip2, LZ77, RLE and several combinations of them. Table 6.2 sketches the results of compressing XtratuM's core binary with some of these compression algorithms.

Algorithm	Compressed size	Compression rate (%)
LZ77	43754	44.20%
LZSS	36880	53.01%
Huffman	59808	23.80%
Rice 32bits	78421	0.10%
RLE	74859	4.60%
Shannon-Fano	60358	23.10%
LZ77/Huffman	36296	53.76%

Table 6.2: Outcomes of compressing the xm_core.bin (78480 bytes) file.

6.6 Container format

A *container* is a file which contains a set of XEF files.

The tool `xmpack` manages container files, see chapter 9.

A *component* is an executable binary (hypervisor or partition) jointly with associated data (configuration or customization file). The XtratuM component contains the files: `xm_core.bin` and `XM_CT.bin`. A partition component is formed by the partition binary file and zero or more customization files.

XtratuM is not a boot loader. There shall be an external utility (the resident software or boot loader) which is in charge of coping the code and data of XtratuM and the partition from a permanent memory into the RAM. Therefore, the the container file is not managed by XtratuM but by the resident software, see chapter 7.

Note also, that the container does not have information regarding where the components shall be loaded into RAM memory. This information is contained in the header of the binary image of each component.

The container file is like a packed filesystem which contains the file metadata (name of the files) and the content of each file. Also, the file which contains the executable image and the customisation data of each partition is specified.

The container holds the following elements:

1. The header (`xmefContainerHdr` structure). A data structure which holds pointers (in the form of offsets) and the sizes to the remaining sections of the file.
2. The component table section, which contains an array of `xmefComponent` structures. Each element contains information of one component.
3. The file table section, which contains an array of files (`xmefFile` structure) in the container.
4. The string table section. Contains the names of the files of the original executable objects. This is currently used for debugging.
5. The file data table section, with the actual data of the executable (XtratuM and partition images) and the configuration files.

The container header has the following fields:

```
struct xmefContainerHdr {
    xm_u32_t signature;
#define XM_PACKAGE_SIGNATURE 0x24584354 // $XCT
    xm_u32_t version;
#define XMPACK_VERSION 3
#define XMPACK_SUBVERSION 0
#define XMPACK_REVISION 0
    xm_u32_t flags;
#define XMEF_CONTAINER_DIGEST 0x1
    xm_u8_t digest[XM_DIGEST_BYTES];
    xm_u32_t fileSize;
    xmAddress_t partitionTabOffset;
    xm_s32_t noPartitions;
    xmAddress_t fileTabOffset;
    xm_s32_t noFiles;
    xmAddress_t strTabOffset;
    xm_s32_t strLen;
    xmAddress_t fileDataOffset;
    xmSize_t fileDataLen;
} __PACKED;
```

Listing 6.12: core/include/xmef.h

signature: Signature field.

version: Version of the package format. 2860

flags:

digest: Not used. Currently the value is zero.

fileSize: The size of the container.

partitionTabOffset: The offset (relative to the start of the file) to the partition array section.

noPartitions: Number of partitions plus one (XtratuM is also a component) in the container. 2865

componentOffset: The offset (relative to the start of the file) to the component's array section.

fileTabOffset: The offset (relative to the start of the container file) to the files's array section.

noFiles: Number of files (XtratuM core, the XM_CT file, partition binaries, and partition-customization files) in the container.

strTabOffset The offset (relative to the start of the container file) to the strings table. 2870

strLen The length of the strings table. This section contains all names of the files.

fileDataOffset The offset (relative to the start of the container file) to the file data section.

fileDataLen The length of the file data section. This section contains all the contents of all the components.

Each entry of the partition table section describes all the XEF files that are part of each partition. 2875
Which contains the following fields:

```
struct xmefPartition {
    xm_s32_t id;
    xm_s32_t file;
    xm_u32_t noCustomFiles;
    xm_s32_t customFileTab[CONFIG_MAX_NO_CUSTOMFILES];
} __PACKED;
```

Listing 6.13: core/include/xmef.h

id: The identifier of the partition. 2885

file: The index into the file table section of the XEF partition image.

noCustomFiles: Number of customisation files of this component.

customFileTab: List of custom file indexes.

The metadata of each file is store in the file table section:

```
struct xmefFile {
    xmAddress_t offset;
    xmSize_t size;
    xmAddress_t nameOffset;
} __PACKED;
```

Listing 6.14: core/include/xmef.h

`offset`: The offset (relative to the start of the file data table section) to the data of this file in the container.

`size`: The size reserved to store this file. It is possible to define the size reserved in the container to store a file independently of the actual size of the file. See the section 9.3.1 tool. 2900

`nameOffset`: Offset, relative to the start of the strings table, of the name of the file.

The strings table contains the list of all the file names.

The file data section contains the data (with padding if `fileSize<=size`) of the files.

Chapter 7

Booting

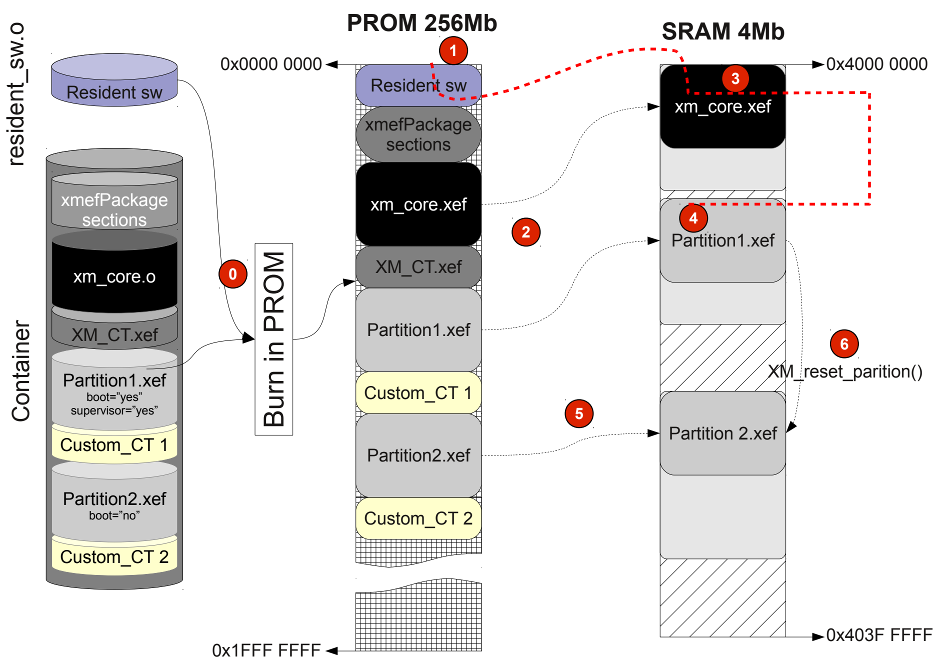


Figure 7.1: Booting sequence.

In the standard boot procedure of the LEON2 processor, the program counter register is initialized with the address 0x00000000. Contrarily to other computers, the PROM of the board does not have any 2905 kind of resident software-like booter[1] that takes the control of the processor after the reset.

We have developed a small booting code called *resident software*, which is in charge of the initial steps of booting the computer. This software is not part of the container produced by the xmpack tool. It is prepended to the container by the burning script.

2910 The board has two kind of RAM memory: SRAM (4Mb) and SDRAM (128Mb).

[1]Known as BIOS in the personal computer area.

7.1 Boot configuration

The *resident software* is in charge of loading into memory XtratuM, its configuration file (`XM_CT`) and any partition jointly with its customisation file as found in the container. The information hold by the `XM_CT` file is used to load any partition image. Additionally, the *resident software* informs XtratuM which partitions have to be booted.

⚠ After starting, XtratuM assumes that the partitions informed as ready-to-be-booted are in RAM/SRAM memory, setting them in running state right after it finishes its booting sequence

If a partition's code is not located within the container, then XtratuM sets the partition in HALT state until a system partition resets it by using `XM_reset_partition()` hypercall. In this case, the RAM image of the partition shall be loaded by a system partition through the `XM_memory_copy()` hypercall.

Note that there may be several booting partitions. All those partitions will be started automatically at boot time.

The boot sequence is sketched in figure 7.1.

(0) The deployment tool to burn the PROM of the board writes first the resident software and right after it the container, which should contain the XtratuM core and the booting partitions components. Note that the container can also contain the non-booting partitions.

(1) When the processor is started (reset) the resident software is executed. It is a small code that performs the following actions:

1. Initializes a stack (required to execute "C" code).
2. Installs a trap handler table (only for the case that its code would generate a fault, XtratuM installs a new trap handler during its initialisation).
3. Checks that the data following the resident software in the PROM is a container (a valid signature), and seeks the XtratuM hypervisor through container (a valid signature).
4. Copies the XtratuM hypervisor and booting partitions into RAM memory ((2)).
5. The address of the container (which contains the `ctCompTab`) is copied in the %g2 processor register. Jumps to the entry point of the hypervisor in RAM memory.

(3) XtratuM assumes no initial processor state. So, the first code has to be written in assembly (`code/kernel/sparcv8/head.s`), and performs the next actions: the %g2 register is saved in a global "C" variable; general purpose registers are cleared; memory access rights are cleared; PSR[2], WIM[3], TBR[4] and Y[5] processor control registers are initialized; sets up a working stack; and jumps to "C" code (`code/kernel/setup.c`).

The `setup()` function carries out the following actions:

1. Initializes the internal console.
2. Initializes the interrupt controller.
3. Detects the processor frequency (information extracted from the XML configuration file).
4. Initializes memory manager (enabling XtratuM to keep track of the use of the physical memory).

[2]PSR: Processor Status Register.
[3]WIM: Window Invalid Mask.
[4]TBF: Trap Base Register.
[5]Y: Extended data register for some arithmetic operations.

5. Initializes hardware and virtual timers.
6. Initializes the scheduler.
7. Initializes the communication channels. 2950
8. Booting partitions are set in NORMAL state and non-booting ones are set in HALT state.
9. Finally, the `setup` function calls the scheduler and becomes into the idle task.

④ Partition code is executed according to the configured plan.

⑤ A system partition can load from PROM or other source (serial line, etc.) the image of other partitions. 2955

⑥ The new ready partition is activated via a `XM_reset_partition()` service.

7.2 Booting process in LEON4

In the standard boot procedure of the LEON2/3 processors, the program counter register is initialized with the address `0x00000000`. In LEON4 processor, the program counter register is initialised with a specified address. The resident software has to be allocated from this address. 2960

The *resident software* is in charge of loading into memory XtratuM, its configuration file (`XM_CT`) and any partition jointly with its customisation file as found in the container. The information hold by the `XM_CT` file is used to load any partition image. Additionally, the *resident software* informs XtratuM which partitions have to be booted.

When the control is transfered from the resident software to XtratuM, the `setup()` function start the 2965 boot operation. Figure 7.2 sketches the booting sequences.

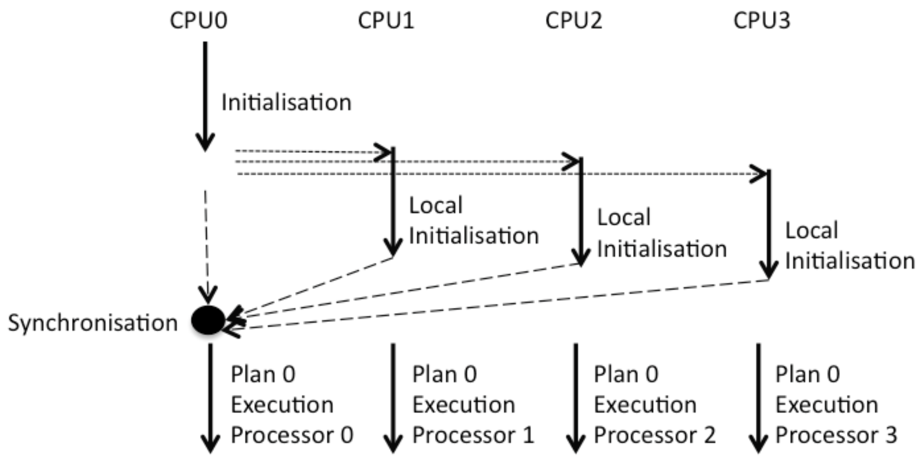

CPU0
CPU1
CPU2
CPU3
Initialisation
Local Initialisation
Local Initialisation
Local Initialisation
Synchronisation
Plan 0 Execution Processor 0
Plan 0 Execution Processor 1
Plan 0 Execution Processor 2
Plan 0 Execution Processor 3

Figure 7.2: Booting process.

After the hard reset, the CPU0 is started and a XtratuM thread is executed. This CPU0 thread performs a global initialisation and starts the execution of other CPUs by providing the entry point and stack area. Each started CPU executes a XtratuM thread performing a local initialisation of the internal local data structures. All CPU threads are synchonised in a specific point in order to guarantee a coherent 2970 initialisation before the scheduling plan execution.

The global initialisation consists on the following:

1. Initializes the internal console.
2. Initializes the interrupt controller.
3. Detects the processor frequency (information extracted from the XML configuration file).
4. Initializes memory manager (enabling XtratuM to keep track of the use of the physical memory).
5. Initializes hardware and virtual timers.
6. Initializes the scheduler.
7. Initializes the communication channels.
8. Wakes up other processors
9. Booting partitions are set in NORMAL state and non-booting ones are set in HALT state.
10. Opens the sync barrier
11. Finally, the setup function calls the scheduler and becomes into the idle task.

Other processors processors perform the local initialisation:

1. Sets up a valid virtual memory map
2. Initializes the timer
3. Waits in a sync barrier
4. Finally, calls the scheduler and becomes into the idle task.

These scheme implies an important design aspect with respect to the monocore version of XtratuM. The internal code of XtratuM is not a non preemptive code block like it is in the monocore version. The multicore design is fully preemptive. A set of low grain atomic sections have been defined in order to avoid race conditions between the internal threads of XtratuM.

7.2.1 Monocore partition booting

XtratuM provides *virtual CPU*s to the partitions. A monocore partition will use the *virtual CPU* identifed as vCPU0. Its operation is exactly the same as the monocore version of XtratuM.

After a partition reset, the vCPU0 is initialised to the default values specified in the configuration file.

Although the monocore partition uses the vCPU0, it can be allocated to any of the available

7.2.2 Multicore partition booting

Multicore partition can use several *virtual CPU*s (vCPU0, vCPU1, vCPU2, ...) to implement the partition. XtratuM follows the approach for *virtual CPU*s than the hardware provides.

At partition boot, XtratuM only starts vCPU0 for the partition. It is responsability of the partition code in the initialised vCPU0 thread to start the execution of the additional cores.

An important aspect to be considered is that the *virtual CPU*s are local to each partition. It means, each partition handles its *virtual CPU*s which are completely hidden to other partitions.

In order to handle *virtual CPU*s, XtratuM provides some services (hypercalls) to partitions to handle its *virtual CPU*s. These hypercall are:

Start a *virtual CPU* : the hypercall `XM_reset_vcpu()` permits to start the execution of a *virtual CPU* (identified by vcpuId in the call) from the entry point (entry address in the calling parameters) and using a stack address defined in the call.

Halt a *virtual CPU* : the hypercall `XM_halt_vcpu()` permits to halt the execution of a *virtual CPU*.

Suspend a *virtual CPU* : the hypercall `XM_suspend_vcpu()` permits to suspend the execution of a *virtual CPU*.

Resume a *virtual CPU* : the hypercall `XM_resume_vcpu()` permits to resume the execution of a *virtual CPU*.

Get the *virtual CPU* identifier : the hypercall `XM_get_vcpuId()` permits to know the *virtual CPU* where the calling partition thread is under execution.

This page is intentionally left blank.

Chapter 8

Configuration

This section describes how XtratuM is configured. There are two levels of configuration. A first level which affects the source code to customise the resulting XtratuM executable image. Since XtratuM does not use dynamic memory to setup internal data structures, most of these configuration parameters are related to the size, or ranges, of the statically created data structures (maximum number of partitions, 3020 channels, etc..).

The second level of configuration is done via an XML file. This file configures the resources allocated to each partition.

8.1 XtratuM source code configuration (`menuconfig`)

The first step in the XtratuM configuration is to configure the source code. This task is done using the same tool than the one used in Linux, which is commonly called "make menuconfig". 3025

There are two different blocks that shall be configured: 1) XtratuM source code; and 2) the resident sofware. The configuration menu of each block is presented one after the other when executed the "`$ make menuconfig`" from the root source directory. The selected configuration are stored in the files `core/.config` and `/user/bootloaders/rsw/.config` for XtratuM and the resident software respectively. 3030

The next table lists all the XtratuM configuration options and its default values. Note that since there are logical dependencies between some options, the menuconfig tool may not show all the options. Only the options that can be selected are presented to the user.

Parameter	Type	Default value
Processor		
SPARC cpu	choice	`[Leon2] [Leon3]`
Board	choice	`[TSim] [GR-CPCI-XC4V] [GR-PCI-XC2V] [SIMLEON]`
SPARC memory protection schema	choice	`[MMU]`
Support AMBA bus PnP	bool	`y`
Enable cache	bool	`y`
Enable cache snoop	bool	`n`
Enable instruction burst fetch	bool	`n`
Flush cache after context switch	bool	`n`

Continues...

Parameter	Type	Default value
Physical memory layout		
XM load address	hex	
XM virtual address	hex	
Enable experimental features	bool	`n`
Debug and profiling support	bool	`y`
Dump CPU state when a trap is raised	bool	`y`
Max. identifier length (B)	int	`16`
Hypervisor		
Enable voluntary preemption support	bool	`n`
Kernel stack size (KB)	int	`8`
MMU		
Drivers		
Reserve UART1	bool	`n`
Reserve UART2	bool	`n`
Enable early output	bool	`n`
CPU frequency (MHz)	int	
Early UART baudrate	int	
Select early UART port	choice	`[UART1] [UART2]`
Enable UART flow control	bool	`n`
DSU samples UART port	bool	`n`
Objects		
Verbose HM events	bool	`y`
Enable emulation of application HM events	bool	`y`
Enable XM/partition status accounting	bool	`n`
Enable partition id symbol on console write	bool	`n`

Sparc cpu: Processor model.

3035 **Board:** Enables the specific board features: write protection units, timers, UART and interrupt controller.

SPARC memory protection schema: Select the processor mechanism that will be used to implement memory protection. If MMU is available then it is the best choice. With WPR, only write protection can be enforced.

3040 **Enable cache:** If selected, the processor cache is enabled. All partitions will be executed with cache enabled unless explicitly disabled on each partition through the `XM_CF` file.

If this option is not selected, the cache memory is disabled. Neither XtratuM nor the partitions will be able to use the cache.

Flush cache after context switch: Forces a cache flush after a partition context switch.

3045 **DSU samples UART port:** If the UART port used to print console messages is also used by the DSU (Debugging Support Unit), then this option shall be set.

If the DSU is used, then the control bits of the UART does not change. In this case, bytes are sent with a timeout.

XtratuM load address: Physical RAM address where XtratuM shall be copied. This value shall be the same than the one specified in the `XM_CF` file. 3050

Console initial buffer length: Size of the internal console buffer. This buffer it used to store the messages written by XtratuM or by partitions using the `XM_console_write()` hypercall. The larger the buffer, the lower the chances of loosing data.

Enable voluntary preemption support:

Enable experimental features: Enable this option to be able to select experimental ones. This option does not do anything on itself, just shows the options marked as experimental. 3055

Kernel stack size (KB): Size of the stack allocated to each partition. It is the stack used by XtratuM when attending the partition hypercalls.

Do not change (reduce) this value unless you know what you are doing.

Debug and profiling support: XtratuM is compiled with debugging information (gcc flag "`-ggdb`") 3060 and assert code is included. This option should be used only during the development of the XtratuM hypervisor.

Maximum identifier length (B): The maximum string length (including the terminating "0x0" character) of the names: partition name, port name, plan, etc. Since the names are only used for debugging, 16 characters is a fair number. 3065

GCoverage support: Experimental.

Enable UART support: If enabled, XtratuM will use the UART to output console messages; otherwise the UART can be used by a partition.

Enable XM/partition status accounting: Enable this option to collect statistical information of XtratuM itself and partitions. 3070

Note that this feature increases the overhead of most of the XtratuM operations.

8.2 Resident software source code configuration (menuconfig)

The resident software (RSW) configuration parameters are hard-coded in the source code in order to generate a self-contained stand alone executable code.

After the configuration of the XtratuM source code, the "`$ make menuconfig`" shows the RWS configuration menu. The selected configuration is stored in the file `user/bootloaders/rsw/.config`. 3075

The following parameters can be configured:

Parameter	Type	Default value
RSW memory layout		
Container physical location address	hex	`0x4000`
Read-only section addresses	hex	`0x40200000`
Read/write section addresses	hex	`0x40090000`
CPU frequency (KHz)	int	`50000`
Enable UART support	choice	`[UART1] [UART2]`
Enable UART flow control	bool	`n`
UART baud rate	int	`115200`
Stack size (KB)	int	`8`
Stand-alone version	bool	`no`
Load container at a fixed address	bool	`y`

Stack size (KB):

Read-only section addresses: RSW memory layout. Read-only area. The resident software will be compiled to use this area.

Read/write section addresses: RSW memory layout. Read/write area used by the resident software.

CPU frequency (KHz): The **processor frequency** is passed to XtratuM via the `XM_CF` file, but in the case of the RSW it has to be specified in the source code, since it has no run-time configuration. The processor frequency is used to configure the UART clock.

Enable UART support: Select the serial line to write messages to.

UART baud rate: The baud rate of the UART. Note that the baud rate used by XtratuM is configured in the `XM_CF` file, and not in the source code configuration.

Stand-alone version: If not set, then the resident software shall be linked jointly with the container. That is, the final resident software image shall contain, as data, the container.

If set, then the container is not linked with the resident software. The address where the container will be copied in RAM is specified by the next option:

Container physical location address: Address of the container. In case of the stand-alone version.

8.2.1 Memory requirements

The memory footprint of XtratuM is independent of the workload (number of partitions, channels, etc.) The memory needed depends only on actual workload defined in the `XM_CF` file. The size of the compiled configuration provides an accurate estimation of the memory what will use XtratuM to run it. Note that it is not the size of the file, but the memory required by all the sections (including those not allocatable ones: `.bss`).

The resident software can be executed in ROM or RAM memory (if the ROM technology allows to run eXecute-in-Place XiP code). The resident software has no initialised data segment, only the `.text` and `.rodata` segments are required (the `.got` and `.eh_frame` segments are not used). The memory footprint of the RSW depends on whether the debug messages are enabled or not; and it can be obtained from the final resident software code (the file created with the `build_rsw` helper utility) using the `readelf` utility.

The next example shows where the size of the RSW code is printed (column labeled **`MemSiz`**):

```
# sparc-linux-readelf -l resident_sw
Elf file type is EXEC (Executable file)
Entry point 0x4020102c
There are 5 program headers, starting at offset 52

Program Headers:
  Type          Offset   VirtAddr   PhysAddr   FileSiz MemSiz  Flg Align
  LOAD          0x0000d4 0x00004000 0x00004000 0x196f0 0x196f0 RW 0x1 // 00 segment
  LOAD          0x0197c4 0x40090000 0x0001d6f0 0x00048 0x00048 RW 0x4 // 01 segment
  LOAD          0x019808 0x40090048 0x40090048 0x00000 0x02000 RW 0x8 // 02 segment
  LOAD          0x019810 0x40200000 0x40200000 0x01f44 0x01f44 R E 0x8 // 03 segment
  GNU_STACK     0x000000 0x00000000 0x00000000 0x00000 0x00000 RWE 0x4 // 04 segment

 Section to Segment mapping:
  Segment Sections...
   00     .container
   01     .got .eh_frame
   02     .bss
   03     .text .rodata
   04
```

Listing 8.1: Resident software memory footprint example.

The next table summarises the size of the resident software for different configurations:

Board type	Debug messages	size
LEON3	disabled	0x01f44
LEON3	enabled	0x01ff4
LEON2	disabled	0x01f44
LEON2	enabled	0x01ff4

8.3 Hypervisor configuration file (XM_CF)

The XM_CF file defines the system resources, and how they are allocated to each partition. 3105

For an exact specification of the syntax (mandatory/optional elements and attributed, and how many times an element can appear) the reader is referred to the XML schema definition in the Appendix A.

8.3.1 Data representation and XPath syntax

When representing physical units, the following syntax shall be used in the XML file:

Time: Pattern: "[0-9]+(.[0-9]+)?([mu]?[sS])"
Examples of valid times: 3110

```
9s      # nine seconds.
10ms    # ten milliseconds.
0.5ms   # zero point five milliseconds.
500us   # five hundred  microseconds  =0.5ms
```

Size: Pattern: "[0-9]+(.[0-9]+)?([MK]?B)" 3115
Examples of valid sizes:

```
90B    # ninety bytes.
50KB   # fifty Kilo bytes =(50*1024) bytes.
2MB    # two mega bytes =(2*1024*1024) bytes.
2.5KB  # two point five kilo bytes =2560B.
```
3120

It is advised not to use the decimal point on sizes.

Frequency: Pattern: "[0-9]+(.[0-9]+)?([MK][Hh]z)"
Examples of valid frequencies:

```
80Mhz     # Eighty mega hertz = 80000000 hertz.
20000Khz  # Twenty mega hertz = 20000000 hertz.
```
3125

Boolean: Valid values are: "yes", "true", "no", "false".

Hexadecimal: Pattern: "0x[0-9a-fA-F]+"
Examples of valid numbers:

```
0xFffffFfff, 0x0, 0xF1, 0x80
```

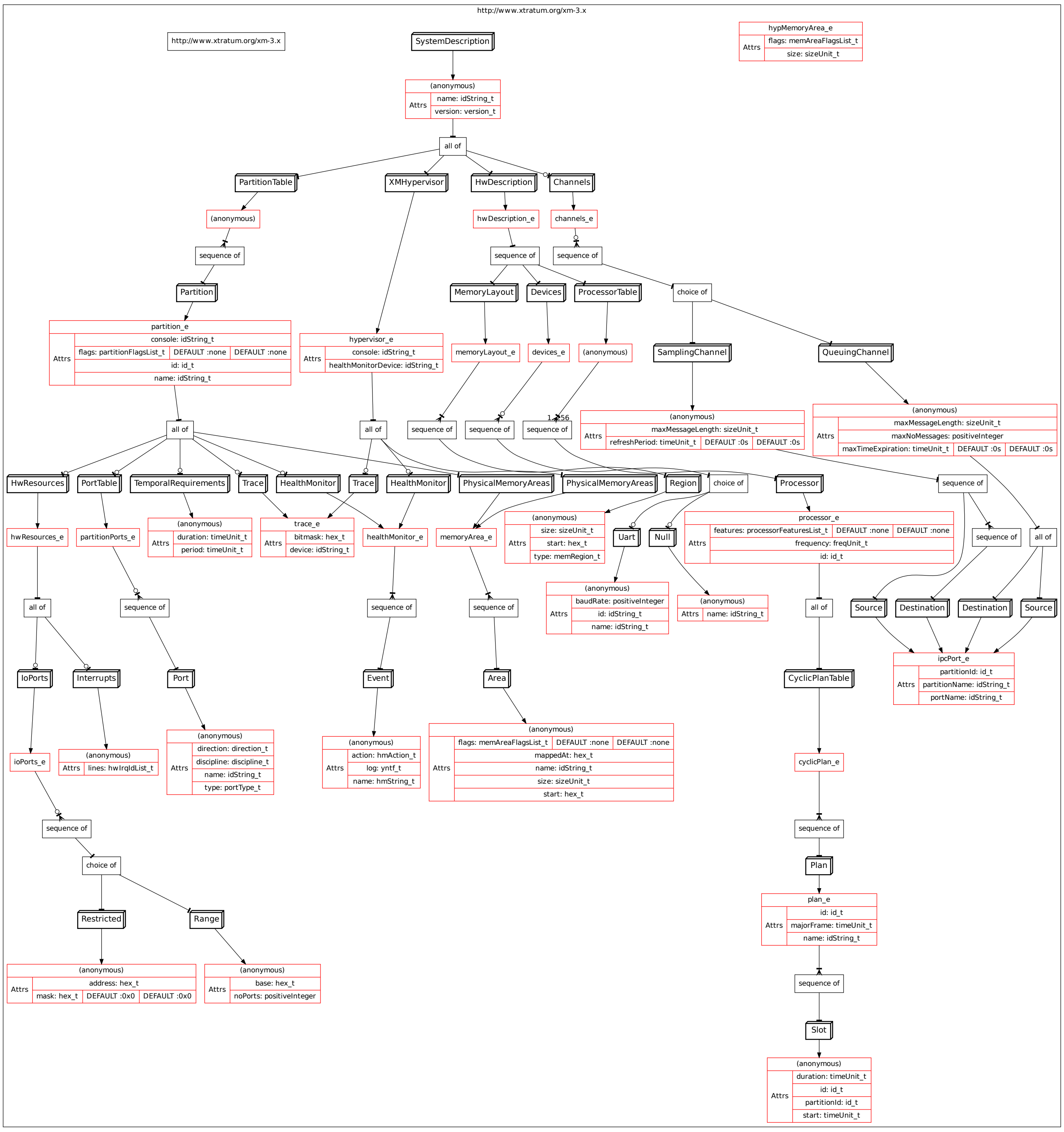

http://www.xtratum.org/xm-3.x
http://www.xtratum.org/xm-3.x
SystemDescription
hypMemoryArea_e
Attrs flags: memAreaFlagsList_t size: sizeUnit_t
(anonymous) Attrs name: idString_t version: version_t
all of
PartitionTable
XMHypervisor
HwDescription
Channels
(anonymous)
hwDescription_e
channels_e
sequence of
sequence of
sequence of
Partition
MemoryLayout
Devices
ProcessorTable
choice of
partition_e Attrs console: idString_t flags: partitionFlagsList_t DEFAULT :none DEFAULT :none id: id_t name: idString_t
hypervisor_e Attrs console: idString_t healthMonitorDevice: idString_t
memoryLayout_e
devices_e
(anonymous)
SamplingChannel
QueuingChannel
sequence of
sequence of
1..256 sequence of
(anonymous) Attrs maxMessageLength: sizeUnit_t refreshPeriod: timeUnit_t DEFAULT :0s DEFAULT :0s
(anonymous) Attrs maxMessageLength: sizeUnit_t maxNoMessages: positiveInteger maxTimeExpiration: timeUnit_t DEFAULT :0s DEFAULT :0s
all of
all of
HwResources
PortTable
TemporalRequirements
Trace
HealthMonitor
Trace
HealthMonitor
PhysicalMemoryAreas
PhysicalMemoryAreas
Region
choice of
Processor
sequence of
hwResources_e
partitionPorts_e
(anonymous) Attrs duration: timeUnit_t period: timeUnit_t
trace_e Attrs bitmask: hex_t device: idString_t
healthMonitor_e
memoryArea_e
(anonymous) Attrs size: sizeUnit_t start: hex_t type: memRegion_t
Uart
Null
processor_e Attrs features: processorFeaturesList_t DEFAULT :none DEFAULT :none frequency: freqUnit_t id: id_t
sequence of
all of
all of
sequence of
sequence of
sequence of
(anonymous) Attrs baudRate: positiveInteger id: idString_t name: idString_t
(anonymous) Attrs name: idString_t
all of
Source
Destination
Destination
Source
ipcPort_e Attrs partitionId: id_t partitionName: idString_t portName: idString_t
IoPorts
Interrupts
Port
Event
Area
CyclicPlanTable
ioPorts_e
(anonymous) Attrs lines: hwIrqIdList_t
(anonymous) Attrs direction: direction_t discipline: discipline_t name: idString_t type: portType_t
(anonymous) Attrs action: hmAction_t log: yntf_t name: hmString_t
(anonymous) Attrs flags: memAreaFlagsList_t DEFAULT :none DEFAULT :none mappedAt: hex_t name: idString_t size: sizeUnit_t start: hex_t
cyclicPlan_e
sequence of
choice of
sequence of
Plan
Restricted
Range
plan_e Attrs id: id_t majorFrame: timeUnit_t name: idString_t
sequence of
Slot
(anonymous) Attrs address: hex_t mask: hex_t DEFAULT :0x0 DEFAULT :0x0
(anonymous) Attrs base: hex_t noPorts: positiveInteger
(anonymous) Attrs duration: timeUnit_t id: id_t partitionId: id_t start: timeUnit_t

Figure 8.1: XML Schema diagram.

An XML file is organised as a set of nested elements, each element may contain attributes. The XPath syntax is used to refer to the objects (elements and attributes). Examples:

/SystemDescription/PartitionTable The element `PartitionTable` contained inside the element `SystemDescription`, which is the root element (the starting slash symbol).

/SystemDescription/@name Refers to the attribute **./@name** of the element **SystemDescription**.

./Trace/@bitmask Refers to the attribute **./@bitmask** of a **./Trace** element. The location of the element **./Trace** in the xml element hierarchy is relative to the context where the reference appears.

8.3.2 The root element: /SystemDescription

Figure 8.1 is a graphical representation of the schema of the XML configuration file. The types of the attributes are not represented, see the appendix A for the complete schema specification. An arrow ended with circle are optional elements.

Figure 8.2 on page 112 is a compact graphical representation of the nested structure of a sample XM_CF configuration file (the listing **??** is the actual xml file for this representation). Solid-lined boxes represent elements. Dotted boxes contain attributes. The nested boxes represent the hierarchy of elements.

The root element is "**/SystemDescription**", which contain the mandatory **./@version**, **./@name** and **./@xmlns** attributes. The xmlns name space shall be "`http://www.xtratum.org/xm-2.3`".

There are five second-level elements:

/SystemDescription/XMHypervisor Specifies the board resources (memory and processor plan) and the hypervisor health monitoring table.

/SystemDescription/ResidentSw This is an optional element which for providing information to XtratuM about the resident software.

/SystemDescription/PartitionTable This is a container element which holds all the **./partition** elements.

/SystemDescription/Channels A sequence of channels which define port connections.

/SystemDescription/HwDescription Contain the configuration of physical and virtual resources.

8.3.3 The /SystemDescription/XMHypervisor element

There are two optional attributes **./@console** and **./@healthMonitoringDevice**. The values of these attributes shall be the name of a device defined in the **/SystemDescription/HwDescription/Devices** section.

Mandatory elements:

./PhysicalMemoryAreas Sequence of memory areas allocated to XtratuM.

Optional elements:

./HealthMonitoring Contains a sequence of health monitoring event elements.

Not all HM actions can be associated with all HM events. Consult the allowed actions in the "Volume 4: Reference Manual".

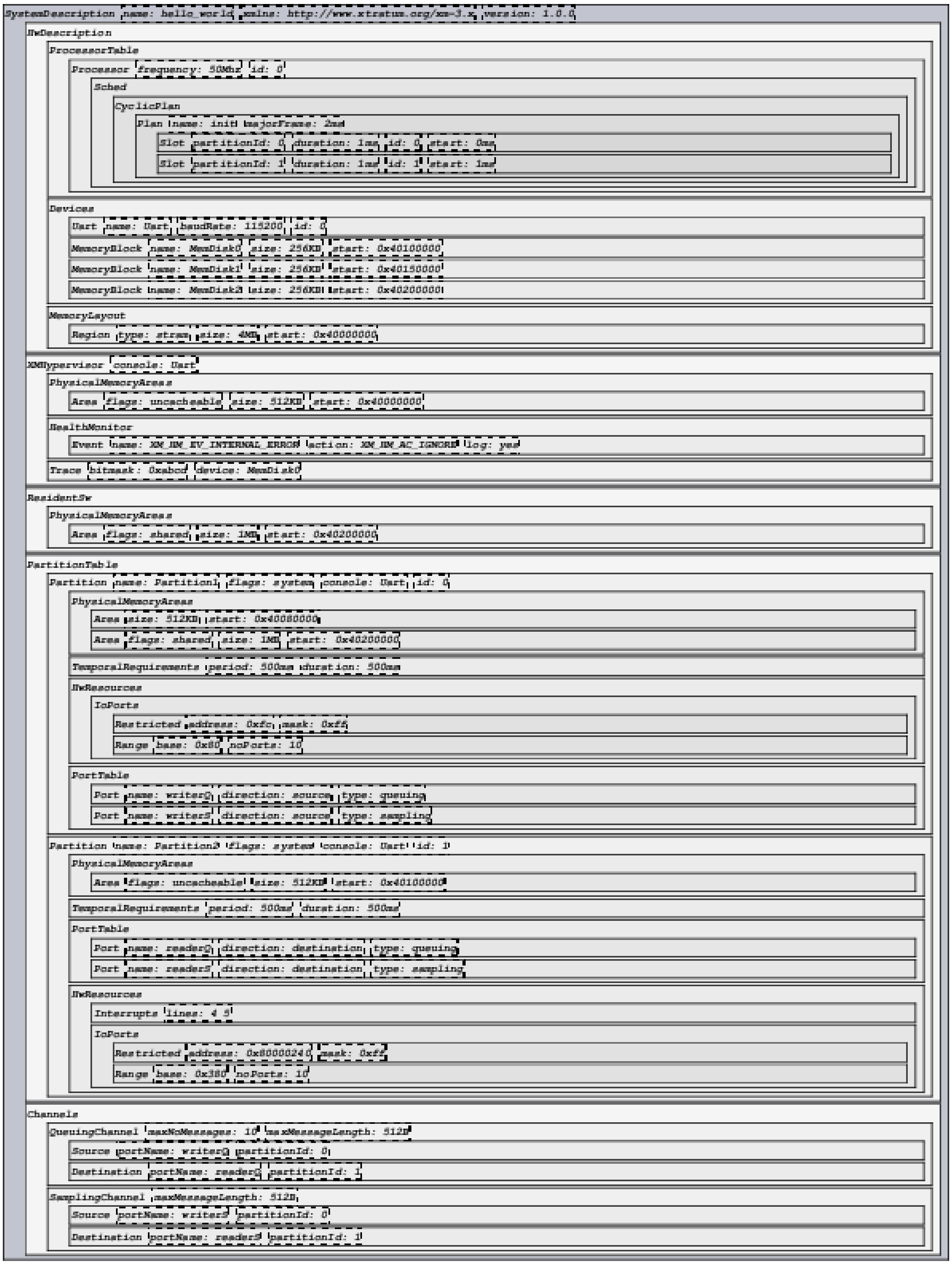

SystemDescription name: hello_world xmlns: http://www.xtratum.org/xm-3.x version: 1.0.0
HwDescription
ProcessorTable
Processor frequency: 50Mhz id: 0
Sched
CyclicPlan
Plan name: init majorFrame: 2ms
Slot partitionId: 0 duration: 1ms id: 0 start: 0ms
Slot partitionId: 1 duration: 1ms id: 1 start: 1ms
Devices
Uart name: Uart baudRate: 115200 id: 0
MemoryBlock name: MemDisk0 size: 256KB start: 0x40100000
MemoryBlock name: MemDisk1 size: 256KB start: 0x40150000
MemoryBlock name: MemDisk2 size: 256KB start: 0x40200000
MemoryLayout
Region type: stram size: 4MB start: 0x40000000
XMHypervisor console: Uart
PhysicalMemoryAreas
Area flags: uncacheable size: 512KB start: 0x40000000
HealthMonitor
Event name: XM_HM_EV_INTERNAL_ERROR action: XM_HM_AC_IGNORE log: yes
Trace bitmask: 0xabcd device: MemDisk0
ResidentSw
PhysicalMemoryAreas
Area flags: shared size: 1MB start: 0x40200000
PartitionTable
Partition name: Partition1 flags: system console: Uart id: 0
PhysicalMemoryAreas
Area size: 512KB start: 0x40080000
Area flags: shared size: 1MB start: 0x40200000
TemporalRequirements period: 500ms duration: 500ms
HwResources
IoPorts
Restricted address: 0xfc mask: 0xff
Range base: 0x80 noPorts: 10
PortTable
Port name: writerQ direction: source type: queuing
Port name: writerS direction: source type: sampling
Partition name: Partition2 flags: system console: Uart id: 1
PhysicalMemoryAreas
Area flags: uncacheable size: 512KB start: 0x40100000
TemporalRequirements period: 500ms duration: 500ms
PortTable
Port name: readerQ direction: destination type: queuing
Port name: readerS direction: destination type: sampling
HwResources
Interrupts lines: 4 5
IoPorts
Restricted address: 0x80000240 mask: 0xff
Range base: 0x380 noPorts: 10
Channels
QueuingChannel maxNoMessages: 10 maxMessageLength: 512B
Source portName: writerQ partitionId: 0
Destination portName: readerQ partitionId: 1
SamplingChannel maxMessageLength: 512B
Source portName: writerS partitionId: 0
Destination portName: readerS partitionId: 1

Figure 8.2: Graphical view of an example `XM_CF` configuration file (see the XML file in section **??**).

./Trace Defines where to store the traces messages emitted by XtratuM (the value of the attribute **./@device** shall be a the name of a device defined in **/SystemDescription/Devices**); and the hexadecimal bit mask to filter out which traces will not be stored (**./@bitmask**).

A health monitoring event element contains the following attributes:

./event/@name The event's name. See "2.13.1 HM Events" for the list of available HM events.

./event/@action The name of the action associated with this event. See "2.13.2 HM Actions" for the list of available HM actions.

./event/@log Boolean flag to select whether the event will be logged or not.

8.3.4 The /SystemDescription/HwDescription element

It contains three mandatory elements:

./HwDescription/ProcessorTable Which holds a sequence of **./Processor** elements. Each processor element describes one physical processor: the processor clock **./@frequency** (the frequency units has to be specified), **./@id** (zero in a mono-processor system), and an optional **./@features** attribute. The **./@features** attribute contains a list of specific processor features than can be selected. Currently, only the memory protection workaround ("XM_CPU_LEON2_WA1"), for the memory mapped processor registers bug[1].

Also, the **./ProcessorTable/Processor** element defines the scheduling plan of this processor. It is specified in the element **./Processor/Sched/CyclicPlan/Plan/**[2]. The **./Plan** element has the required attributes **./@name** and **./majorFrame**; and contains a sequence of **./Slot** elements.

Each **./Slot** element has the following attributes:

./Slot/@id Slot Id's shall meet the id's rules defined in section 2.7. This value can be retrieved by the partition at run time, see section 5.7.1.

./Slot/@duration Time duration of the slot.

./Slot/@partitionId Id of the partition that will be executed during this slot.

./Slot/@start Offset with respect to the MAF start.

Slots intervals shall not overlap.

./HwDescription/MemoryLayout Defines the memory layout of the board. All the memory allocated to partitions, resident software and XtratuM itself shall be in the range of one of these areas.

./HwDescription/Devices The device element contains the sequence the XtratuM devices. Currently XtratuM implements two types of devices: UART and memory blocks.

./Uart Has the required attributes **./Uart/@name**, **./Uart/@baudRate** and **./Uart/@id**. This element associates the hardware device **@id** with the **@name**, and programs the transmission speed.

./MemoryBlockTable This element contains a sequence of one or more **./Block** elements. A memory block device defines an area of RAM (ROM or FLASH) memory. This block of memory can then be used to store traces, health monitoring logs or the console output of a partition. Below is the list of attributes of the **./Block** element:

[1]Some key processor registers, needed to guarantee the spatial isolation, are mapped memory addresses which are not monitored/protected by the write protection mechanism. The workaround consists in protecting this register area using the watchpoint mechanism. The workaround is only applicable if the watchpoint facility is present.

[2]The large number of nested elements is for future compatibility with multiple plans and scheduling policies.

./MemoryBlockTable/Block/@name Required. Name which identifies the device. This name is only used to refer this device in the configuration file. Once compiled the configuration file this name is removed.

./MemoryBlockTable/Block/@start Required. Starting address of the memory block.

./MemoryBlockTable/Block/@size Required. Size of the memory block.

8.3.5 The `/SystemDescription/ResidentSw` element

The element **./PhysicalMemoryAreas** is used to declare the memory areas where the resident software will by located. This information is included in the configuration file for completeness (all the memory areas of the board shall be described in the configuration file) and used only to check memory overlaps errors.

Also the attribute **./@entryPoint** is used by XtratuM in the case of a cold system reset. In that case, XtratuM will give back the control of the system to the resident software by jumping to this address.

8.3.6 The `/SystemDescription/PartitionTable/Partition` element

Attribute description:

./@id Required. See the section 2.7 for a description on how to identify XtratuM objects.

./@name Optional.

./@console Optional. The console device where the output of the hypercall `XM_write_console()` is copied to.

./@flags Optional. List of features. Possible values are:

fp If set, the partition is allowed to use floating point operations. By default not set.

system If set, the partition has system privileges. By default not set.

Partition elements:

./PhysicalMemoryAreas Sequence of memory areas allocated to the partition.

./HwResources Contains the list of interrupts and IO ports allocated to the partition.

./PortTable Contains the sequence of communication ports (queuing and sampling ports) of the partition.

./Trace Configuration of the trace facility of the partition. Same attributes are that of the `/SystemDescription/XMHypervisor/Trace` element.

./TemporalRequirements An element which has two mandatory attributes: **./@period** and **./@duration**. **This data is not checked by XtratuM. Reserved for future use.**

Configuration of memory areas

The attributes are **@start**, **@size** and **@flags**. The **@flags** attribute is a list of the following values:

Value	Description
`unmapped`	Allocated to the partition, but not mapped by XtratuM in the page table.
`mappedAt`	It allows to allocate this area to a virtual address.
`shared`	It is allowed to map this area in other partitions.
`read-only`	The area is write-protected to the partition.
`uncacheable`	Memory cache is disabled.
`rom`	Not applicable in SPARC v8 boards. Only used in ia32 systems.

Configuration of I/O ports

There are two ways to allocate a port to a partition: using ranges of ports, and using the restricted port allocation. Both are declared by elements contained in the **`./Partition/HwResources/IoPorts`** element: 3235

`./Range` A range of port addresses is allocated to the partition. The attributes of a range element are:

- **`./Range/@base`** Required hexadecimal base address.
- **`./Range/@noPorts`** Required number of ports in this range. Each port is a word (4 bytes).

`./Restricted` An I/O port which is partially controlled by the partition. The attributes are:

- **`./Restricted/@address`** Required hexadecimal address of the port. 3240
- **`./Restricted/@mask`** Optional (4 bytes hexadecimal). The bits set in this mask can be read and written by the partition.

  Those bits not allocated to this partition (i.e. the bit not set in the bitmask) can be allocated to other partitions.

Configuration of interrupts

The element **`./Partition/HwResources/Interrupts`** has the attribute **`./@lines`** which is a list of 3245 the interrupt number (in the range 0 to 16) allocated to the partition.

8.3.7 The `/SystemDescription/Channels` element

This is an optional element with no attributes and which contains a list of channel elements. There are two types of channels:

`./SamplingChannel` Shall contain one **`./Source`** element and one or more **`./Destination`** elements. It has the following attributes: 3250

- **`./@maxMessageLength`** Required. The maximum message size that can be stored on this channel.
- **`./@refreshPeriod`** Optional. The duration of validity of a written message. When a message is read after this period, the validity flag will be false.

`./QueuingChannel` Shall contain one **`./Source`** element and one **`./Destination`** element. It has the 3255 following attributes:

- **`./@maxMessageLength`** Required. The maximum message size that can be stored on this channel.

./@maxNoMessages Required. The maximum number of messages that will be stored in the channel.

Note: The **./QueuingChannel/@validPeriod** attribute has been removed with respect to XtratuM-2.2.x versions.

The arguments `maxNoMsgs` and `maxMsgSize` of the hypercalls `XM_create_queuing_port()` and `XM_create_sampling_port()` shall match the values of the attributes **./@maxNoMessages** and **./@maxNoMessages**.

The XML schema which defines the configuration file is in the appendix A.

Chapter 9

Tools

This section describes the tools to assist the integrator and the partition developers in the process of building the final system file. They are:

`xmcparser`: System XML configuration parser.

`xmeformat`: Converts ELF files into XEF ones.

`xmpack`: Creates the container file.

`rswbuild`: Creates a bootable file image.

9.1 XML configuration parser (`xmcparser`)

The utility `xmcparser` translates the XML configuration file containing the system description into binary form that can be directly used by XtratuM.

In the first place, the configuration file is checked both, syntactically, and semantically (i.e. the data is correct). This tool uses the `libxml2` library to read, parse and validate the configuration file against the XML schema specification. Once validated by the library, the `xmcparser` performs a set of non-syntactical checks:

- Memory area overlapping.
- Memory region overlapping.
- Memory area inside any region.
- Duplicated Partition's name and id.
- Allocated CPUs.
- Replicated port's names and id.
- Cyclic scheduling plan.
- Cyclic scheduling plan slot partition ids.
- Hardware IRQs allocated to partitions.
- IO port alignment.
- IO ports allocated to partitions.
- Allowed health monitoring actions.

9.1.1 xmcparser

Compiles XtratuM XML configuration files

SYNOPSIS

xmcparser [-c] [-s xsd_file] [-o output_file] XM_CF.xml
xmcparser -d

DESCRIPTION

`xmcparser` reads an XtratuM XML configuration file and transforms it into a binary file which can be used directly by XtratuM at run time. `xmcparser` performs internally the folowing steps:

1. Parse the XML file.
2. Validate the XML data.
3. Generate a set of ”C” data structures initialised with the XML data.
4. Compiles and links, using the target compiler, the ”C” data structures. An ELF file is produced.
5. The data section which contains the data in binary format is extracted and copied to the output file.

OPTIONS

-d
Prints the dafault XML schema used to validate the XML configuration file.

-o file
Place output in file.

-s xsd_file
Use the XML schema xsd_file rather than the dafault XtratuM schema.

-c
Stop after the stage of ”C” generation; do not compile. The output is in the form of a ”C” file.

9.2 ELF to XEF (`xmeformat`)

9.2.1 xmeformat

Creates and display information of XEF files

SYNOPSIS

xmeformat read [-h|-s|-m] file
xmeformat build [-m] [-o outfile] [-c] [-p payload_file] file

DESCRIPTION

xmeformat converts an ELF, or a binary file, into an XEF format (XtratuM Executable Format). An XEF file contains one or more segments. A segment is a block of data that shall be copied in a contiguous area of memory (when loaded in main memory). The content of the XEF can optionally be compressed.

An XEF file has a header and a set of segments. The segments corresponds to the allocatable sections of the source ELF file. In the header, there is a reserved area (16 bytes) to store user defined information. This information is called user payload.

build

A new XEF file is created, using file as input.

-m

The source file is not an ELF file but a user defined customisation. In this case, no consistency checks are performed.

Customisation files are used to attach data to the partitions (See the xmpack command). This data will be accessible to the partition at boot time. It is commonly used as partition defined run-time configuration parameters.

-o file

Places output in file file.

-c

The XEF segments are compressed using the LSZZ algorithm.

-p file

The first 16 bytes of the file are copied into the payload area of the XEF header. The size of the file shall be at least 16 bytes, otherwise an error is returned.

The MD5 sum value is printed if no errors.

read

Shows the contents of the XEF file.

-h

Print the content of the header.

-s

Lists the segments and its attributes.

-m

Lists the table of custom files. This options only works for partition and hypervisor XEF files.

USAGE EXAMPLES

Create a customisation file:

```
$ xmeformat build -m -o custom_file.xef data.in
b07715208bbfe72897a259619e7d7a6d custom_file.xef
```

List the header of the XEF custom file:

```
$ xmeformat read -h custom_file.xef
XEF header:
  signature: 0x24584546
  version: 1.0.0
  flags: XEF_DIGEST XEF_CONTENT_CUSTOMFILE
  digest: b07715208bbfe72897a259619e7d7a6d
  payload: 00 00 00 00 00 00 00 00
           00 00 00 00 00 00 00 00
  file size: 232
  segment table offset: 80
  no. segments: 1
  customFile table offset: 104
  no. customFiles: 0
  image offset: 104
  image length: 127
  XM image's header: 0x0
```

Build the hypervisor XEF file:

```
$ xmeformat build -o xm_core.xef -c core/xm_core
```

List the segments and headers of the XtratuM XEF file: $ xmeformat read -s xm_core.xef Segment table: 1 segments segment 0 physical address: 0x40000000 virtual address: 0x40000000 file size: 68520 compressed file size: 32923 (48.05%)

```
$ xmeformat read -h  xm_core.xef
XEF header:
  signature: 0x24584546
  version: 1.0.0
  flags: XEF_DIGEST XEF_COMPRESSED XEF_CONTENT_HYPERVISOR
  digest: 6698cfcf9311325e46e79ed50dfc9683
  payload: 00 00 00 00 00 00 00 00
           00 00 00 00 00 00 00 00
  file size: 33040
  segment table offset: 80
  no. segments: 1
  customFile table offset: 104
  no. customFiles: 1
  image offset: 112
  image length: 68520
  XM image's header: 0x40010b78
  compressed image length: 32928 (48.06%)
```

9.3 Container builder (`xmpack`)

9.3.1 xmpack

Create an XtratuM system image container

SYNOPSIS

xmpack build -h xm_file[@*offset*]:conf_file[@*offset*] [-p *id*:part_file[@*offset*][:custom_file[@*offset*]]*]+ container

xmpack list -c container

DESCRIPTION

`xmpack` manipulates the XtratuM system container. The container is a simple filesystem designed to contain the XtratuM hypervisor core and zero or more XEF files. The container is an envelope to deploy all the system (hypervisor and partitions) from the host to the target. At boot time, the resident software is in charge of reading the contents of the container and coping the components to the RAM areas where the hypervisor and he partitions will be executed. Note that XtratuM has no knowledge about the container structure.

The container is organised as a list of *components*. Each component is a list of XEF files. A component is used to store an executable unit, which can be: the XtratuM hypervisor or a partition. Each component is a list of one or more files. The first file shall be a valid XtratuM image (see the XtratuM binary file header) with the configuration file (once parsed and compiled into XEF format). The rest of the components are optional.

`xmpack` is a helper utility that can be used to deploy an XtratuM system. It is not mandatory to use this tool to deploy the application (hypervisor and the partitions) in the target machine.

The following checks are done:

- The binary image of the partitions fits into the allocated memory (as defined in the XM_CF).
- The size of the customisation files fits into the area reserved by each partition.
- The memory allocated to XtratuM is big enough to hold the XtratuM image plus the configuration file.

build

A new *container* is created. Two kind of components can be defined:

-h to create an [H]ypervisor component:
The hypervisor entry is composed of the name of the XtratuM xef file and the binary configuration file (the result of processing the XM_CF file).

-p to create a [P]artition. The partition entries are composed of:
The *id* of the partition, as specified in the XM_CF file. Note that this is the mechanism to bind the configuration description with the actual image of the partition. The part_file which shall contains the executable image. And zero or more custom_files. There shall be the same number of customisation files than that specified in the field `noCustomFiles` of the `xmImageHdr` structure.

The elements that are part of each component are separated by ":".

By default, `xmpack` stores the files sequentially in the container. If the *offset* parameter is specified, then the file is placed at the given offset. The offset is defined with respect to the start of the container. The specified offset shall not overlap with existing data. The remaining files of the container will be placed after the end of this file.

list

Shows the contents (components and the files of each component) of a container. If the option **-c** is given, the blocks allocated to each file are also shown.

USAGE EXAMPLES

A new container with one hypervisor and one booting partition. The hypervisor container has two files: the hypervisor binary and the configuration table:

```
$ xmpack build build -h ../core/xm_core.bin:xm_ct.bin -p partition1.bin -o container
```

The same example but the second container has now two files: the partition image and a customisation file:

```
$ xmpack/xmpack build -h ../core/xm_core.bin:xm_cf.bin \
                      -p partition1.bin:p1.cfg \
                      -p partition2.bin:p2.cfg container.bin
```

List the contents of the container:

```
$ xmpack list container.bin
<Package file="container.bin" version="1.0.0">
  <XMHypervisor file="../core/xm_core.bin" fileSize="97188" offset="0x0" size="97192" >
      <Module file="xm_cf.bin" size="8976" />
  </XMHypervisor>
  <Partition file="partition1.bin" fileSize="29996" offset="0x19eb8" size="30000" >
      <Module file="p1.cfg" size="16" />
  </Partition>
  <Partition file="partition2.bin" fileSize="30292" offset="0x213f8" size="30296" >
      <Module file="p2.cfg" size="16" />
  </Partition>
</Package>
```

9.4 Bootable image creator (`rswbuild`)

9.4.1 rswbuild

Create a bootable image

SYNOPSIS

rswbuild contailer bootable

DESCRIPTION

`rswbuild` is a shell script that creates a bootable file by combining the resident software code with the container file. The container shall be a valid file created with the `xmpack` tool.

The resident software object file is read from the distribution directory pointer by the `$XTRATUM_PATH` variable.

USAGE EXAMPLES

```
rswbuild container resident_sw
```

Chapter 10

Security issues

This chapter introduces several security issues related with XtratuM which should be taken into account by partition developers. 3470

10.1 Invoking a hypercall from libXM

Invoking a hypercall requires a non-standard protocol which must be directly implemented in assembly code.

LibXM is a partition-level "C" library deployed jointly with XtratuM aiming to hide this complexity and ease the development of "C" partitions. 3475

From the security point of view, XtratuM implements two stacks for each partition: one managed by the partition (user context) and another, internal, managed directly by XtratuM (supervisor context). The partition stack is used by the libXM to prepare the call to XtratuM (pretty much like the gLibc does). Once the hypercall service is invoked, XtratuM changes the stack to its own stack. This second stack may contain sensitive information, but it is located inside the memory space of XtratuM (not exposed). 3480
It is normal to observe that the partition stack is modified when a hypercall is called, however this behaviour is far from being considered an actual security issue.

10.2 Preventing covert/side channels due to scheduling slot overrun

This version of XtratuM is non-preemptible: once the kernel starts an activity (e.g. a service), it cannot 3485
be interrupted until its completion. This behaviour includes any hypercall invocation: if a partition calls an hypercall just before a partition context switch must be performed, XtratuM will not carry out the action until the hypercall is finished. This overrun can be exploited to gain information. The information is obtained by measuring the temporal cost of the last hypercall. There are two types of information that can be retrieved: 3490

1. Whether the target partition was executing an hypercall at the end of the slot or not. If the spy partition start at the nominal slot start time or not.

2. In the case of being executing a hypercall, how much time XtratuM needed to attend it: the cost of the last hypercall.

In the case of a covert channel, the maximum bandwidth is determined by the duration of the longest hypercall divided by the clock resolution. A rough estimation (supposing that the maximum message length is 4096 Bytes) is 4 bits at each partition context switch.

In the case of a side channel, the bandwidth is drastically reduced due to the uncertainty/randomness introduced by the execution of the target partition.

There are several strategies to address this issue:

1. At integrator level: design a scheduling plan that lest some idle time before the end of a slot and the beginning of the next one. The Xoncrete scheduling tool is able to implement that solution automatically. Figure 10.1 shows two scenarios: scenario 1 where the integrator has not left spare time between one partition slot and the next one, enabling the partition in light grey overrunning the start of the dark gray one. Scenario 2 sketches the same case but leaving spare time between one slot and the next one. So, in this case, execution overruns can not occur.
2. At partition level: stop invoking hypercalls some time before the end of the slot. This way, there will be no hypercalls being executed when the slot end occurs, so the next partition will start always with no delay.
3. At hypervisor level:
   (a) Change the design of XtratuM to convert it preemptable. Hypercalls would be interrupted when the end of the slot is reached, and later resumed when the partition is active again.
   (b) Implement the partial preemptability in XtratuM (voluntary preemption). XtratuM is by default atomic (non-preemptable) but at some designated safe places in the code, the preemption is allowed.

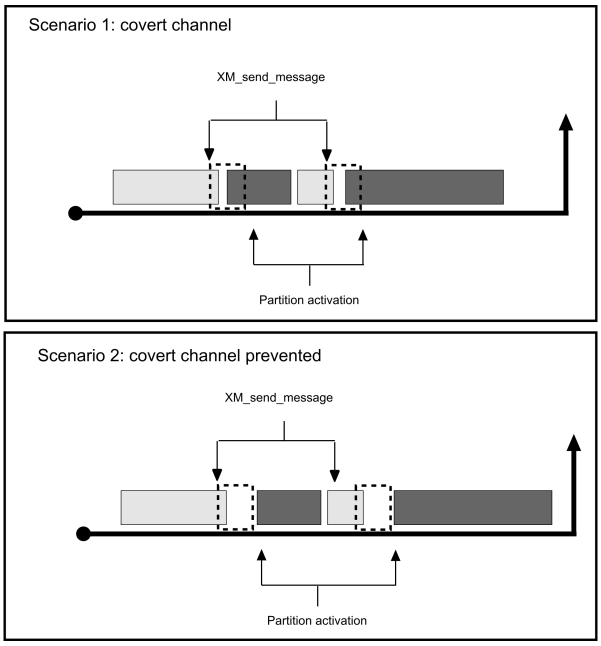


Figure 10.1: Covert channel caused by an incorrect scheduling plan and a solution.

Appendix A

XML Schema Definition

See attached document xm-4-usermanual-XML-spec.pdf.

GNU Free Documentation License

any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The “**Invariant Sections**” are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The “**Cover Texts**” are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A “**Transparent**” copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not “Transparent” is called “**Opaque**”.

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The “**Title Page**” means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, “Title Page” means the text near the most prominent appearance of the work’s title, preceding the beginning of the body of the text.

A section “**Entitled XYZ**” means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as “**Acknowledgements**”, “**Dedications**”, “**Endorsements**”, or “**History**”.) To “**Preserve the Title**” of such a section when you modify the Document means that it remains a section “Entitled XYZ” according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

2. VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

3. COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

4. MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.

B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.

C. State on the Title page the name of the publisher of the Modified Version, as the publisher.

D. Preserve all the copyright notices of the Document.

E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.

F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.

5. COMBINING DOCUMENTS

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled “History” in the various original documents, forming one section Entitled “History”; likewise combine any sections Entitled “Acknowledgements”, and any sections Entitled “Dedications”. You must delete all sections Entitled “Endorsements”.

6. COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

7. AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an “aggregate” if the copyright resulting from the compilation is not used to limit the legal rights of the compilation’s users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document’s Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

8. TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled “Acknowledgements”, “Dedications”, or “History”, the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

9. TERMINATION

Glossary of Terms and Acronyms

Glossary

hypervisor The layer of software that, using the native hardware resources, provides one or more virtual machines (partitions).

partition Also known as "virtual machine" or "domain". It refers to the environment created by the hypervisor to execute user code.

Abbreviated terms

Term	**Description**
ABI	Application Binary Interface.
API	Application Programming Interface.
IMA	Integrated Modular Avionics.
MMU	Memory Management Unit.
PCT	Partition Control Table.
PIT	Partition Information Table.
XML	eXtended Markup Languaje.

This page is intentionally left blank.