TDDD07 – Real-time Systems

Lecture 10: Real-time OS and wrapping up

Simin Nadjm-Tehrani

Real-time Systems Laboratory
Department of Computer and information Science

LINKÖPING UNIVERSITY

Reading Material

- Baskiyar (2005): main requirements and some examples – not so contemporary!
- Parts of Ch. 2 in Carlsson et al. may be useful as complementary text depending on your OS background

- Use the lecture slides as a guide, and for more details use a reference book e.g. chapter 10 in https://link.springer.com/book/10.1007/978-3-031-28701-5)

What have we learnt so far?

Summary of the course

During the course we have …

- Studied methods for allocation of CPU as a resource
  - Hard real-time systems: Three scheduling algorithms (Cyclic, RMS, EDF)
  - Soft real-time systems: Data centre scheduling (adaptation wrt load and energy optimisation)

Summary of the course

- We further looked at sharing multiple resources:
  - Single CPU case: Potential for deadlocks and starvation, a prevention technique (ICP)
  - Cloud CPUs & energy: Virtual machines
- As well as sharing resources in networked applications
  - Communication bus in hard real-time systems, dedicated applications (CAN vs. TTP scheduling)
  - Bandwidth, buffer space in IP/Multimedia networks

Different requirement types

- From "every deadline met" to QoS expressions
- Who enforces predictability?
  - **RTOS** in single CPU, Bus protocol in dist. system
  - Admission controllers, Packet schedulers, Buffer managers in soft real-time networked systems
- Relation between dependability and predictability
  - Faults models
  - Availability and some threats against it
    - Host crashes, Software process crashes, transients
  - Eliminating faults at design stage

The industry perspective

Ericsson speaker (Blas) talked about:

- Fast vs. Critical, Key Performance Indicators
  - Availability & accessibility
  - Degrees of reliability
- Moving from dedicated HW to COTS and virtualisation
- Replication of microservices (losing capacity but not capability)
- Uniform HW for simplicity (=no diversity!)

The industry perspective

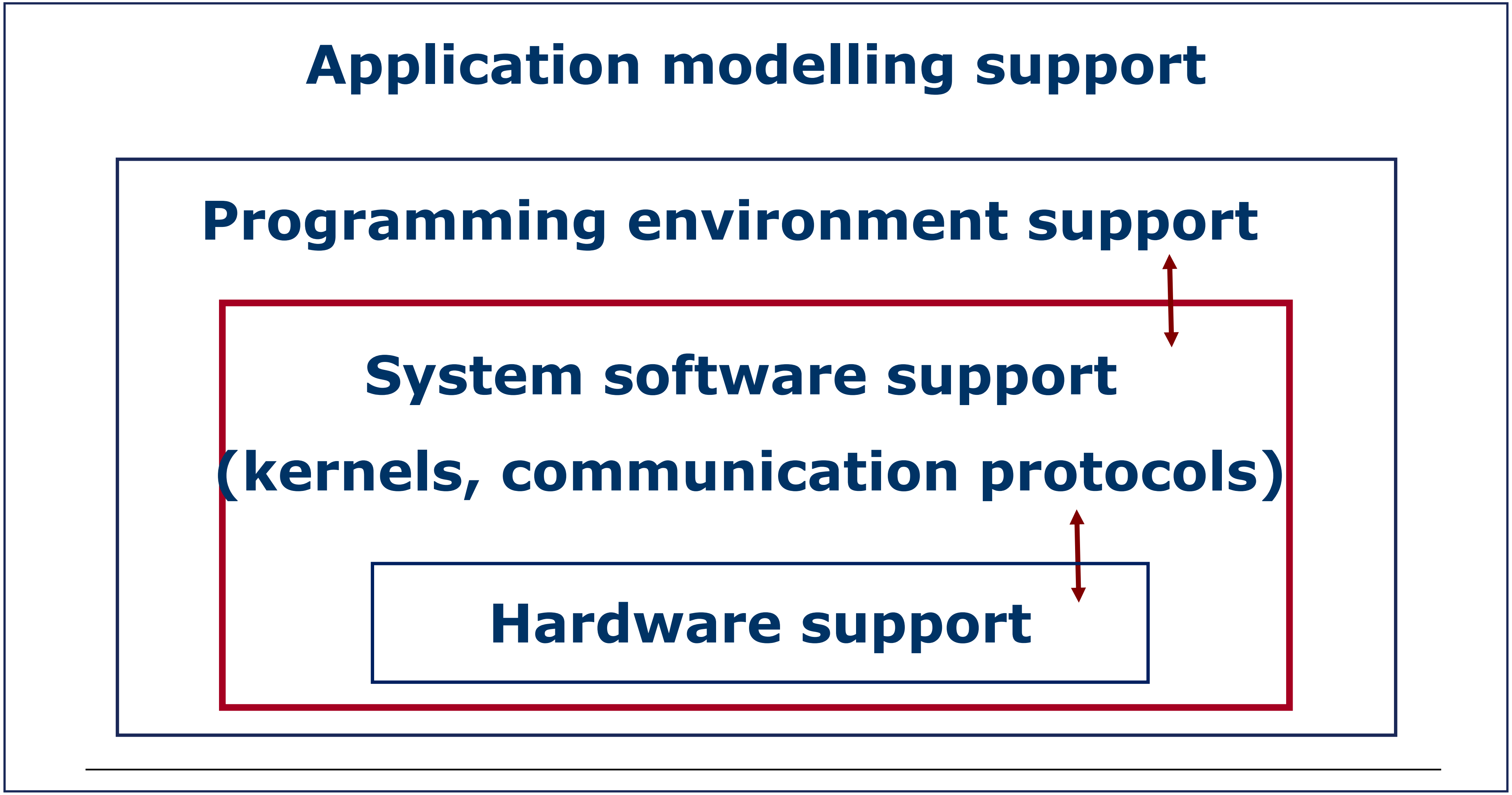
- Move from special purpose hardware to COTS
  - Makes benchmarking software from different vendors possible
  - Hard to make availability claims due to third party software on the same node
- Different performance indicators
- Core isolation for predictability

Real-time operating systems

An overview

LINKÖPING UNIVERSITY

This lecture: Real-time OS



The role of OS

Depends on who you ask:

- The bare machine people
- The buy-kernel-and-complete people
- The sector-dependent OS people
- The language-dependent OS people
- The off-the-shelf OS people
- The reconfigurable OS people
- The middleware people

If you're serious about doing real-time why do you want an operating system?

OSEK

Ada

POSIX-compatible

ThreadX
uClinux
FPGA

Variations remain

- The 20-year perspective:

https://www.embedded.com/how-embedded-software-development-has-evolved-over-20-years/

Shows a clear trend from commercial OS to open-source OS (see Figure 5)

Sector interoperability

- Keeping competitive advantage but sharing interfaces (Application APIs)
  - AUTOSAR: 20 years in 2023

https://www.autosar.org/standards/classic-platform

- Did you look at the Toyoto Oklahoma court ruling from 2013?
  - Mentioned OSEK standard and Misra-C

Linux alternatives

- Co-kernel approach
  - e.g. Xenomai.org
- Running PREEMPT-RT Linux (patch) extensions enabled for support of real-time services
- See the overview (figure 1) in section 2, Reghenzani et al. 2019

  https://doi.org/10.1145/3297714

Game changer?

November 2023

- Microsoft makes its RTOS ThreadX open source through eclipse foundation

- https://www.embedded.com/what-open-source-azure-rtos-means-to-developers/

Let’s start with basics

Main functions of an OS

From Nanokernels
to Kernels

- Task management
- Inter-task communication and synchronisation
- Timer services
- Interrupt services
- Memory management (DMA)
- Device I/O management

Task management

May be:

- Time-driven
  - At each tick of a clock the kernel checks if some tasks need to be queued, a task should start to run, or a task should stop running
- Event-driven
  - When an I/O operation is completed, or a task signals completion, the kernel checks …

Task attributes

- On creation of threads RT kernels allow specification of attributes such as
  - Start time
  - Deadline
  - Priority
  - …
- Used for releasing, aborting, and scheduling

Event-based task switching

Upon arrival of an event:

- Determine whether the current running task should continue (based on scheduling policy)
- If not, determine the next task to be run
- Save the environment of the preempted task
- Prepare the selected task to be run

… in deterministic time!

Basic operations

- Search, insert and delete tasks in ready queue
- Restore the state of the highest priority task

Recall our assumption of zero overhead!

Main functions of an OS

- Task management
- Inter-task communication and synchronisation
- Timer services
- Interrupt services
- Memory management (DMA)
- Device I/O management

Task communication

- Shared memory and semaphores
  - Priority inversion
  - Deadlocks
- Message passing
  - Can above problems still arise?
- Deterministic time:
  - Locking and unlocking latency
  - Message passing delays

Yes! QNX Nuetrino uses inheritence to avoid it!

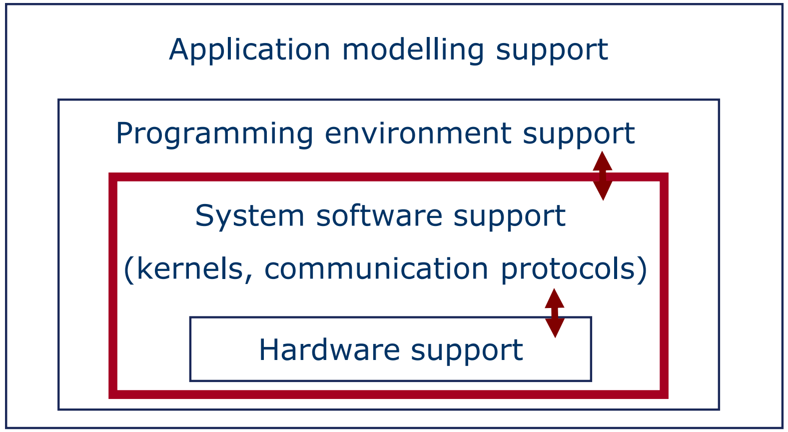
Can be made size-independent!

Main functions of an OS

- Task management
- Inter-task communication and synchronisation
- Timer services
- Interrupt services
- Memory management (DMA)
- Device I/O management

Time services

- Even event-driven OS need time services to construct timers and detect overruns
- OS may allow defining one or more high resolution clocks with get_value, set_value, get_resolution operations



- Timers can be defined to **signal** an event towards application processes after a particular period
- Real-time POSIX allows queued signals according to priority

Main functions of an OS

- Task management
- Inter-task communication and synchronisation
- Timer services
- Interrupt services
- Memory management (DMA)
- Device I/O management

Interrupt services

When an interrupt event is generated:

- State of the current running task is saved
- Interrupt handler – Interrupt Service Routine (ISR) – is executed
- Next task to be run (application task or the scheduler) is invoked

Deterministic interrupts

- RTOS vendor has to provide data on the timing determinism for the given steps
- Interrupt service routines (ISR) have to be short
- But also predictable!
- If several interrupts are to be serviced, the relative (fixed) priority determines the order

Main functions of an OS

- Task management
- Inter-task communication and synchronisation
- Timer services
- Interrupt services
- Memory management (DMA)
- Device I/O management

Memory allocation

Different views:

- Real-time programmer should have absolute control over resources used by the program
  - Dynamic memory allocation (malloc, free) not supported by RTOS
- Dynamic memory allocation takes non-deterministic time due to fragmentation and should be replaced by other mechanisms
  - Pools instead of heap
  - Control over garbage collection (GC) is an ingredient in real-time Java

Can GC be deferred?

- Swedish company Cinnober specialises Java programs to reduce non-deterministic access time when performing stock market transactions

- Uses replicated servers
- ”In most cases garbage collection will not take place in both servers at the same time.”

Computer Sweden 5 Dec 2013

https://www.idg.se/2.2683/1.536623/svenskar-bakom-java-genombrott

File system

- Traditional file systems not suitable for real-time OS!
- Those that support filing services also provide a mechanism for efficient locking of task data into main memory storage
- Avoiding unpredictable memory swaps!

Device controllers

- Initialise device interrupt information and disable/enable a device interrupt
- Upon generation of a hardware interrupt identify which device is involved

- Managing interrupt-driven I/O can be difficult unless the number of generated interrupts can be bounded

In addition to OS function and timing…

LINKÖPING UNIVERSITY

Other constraints

- So far, we only looked at timing constraints
- A general requirement for RTOS is low overhead, also from a memory *footprint* point of view
- Smallest embedded systems profile of POSIX.13, PSE51 can be written in thousands of lines of code
- Compare to Windows XP: ~30GB!
- Linux first release 10000 loc (2012:15m, 2022: 35m!)

Finally…

- Thank you for your attention!

- Hope you are better performance engineers and resource management experts after this course!

Questions?

http://www.ida.liu.se/~TDDD07/