technische universität
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informatik 12

Embedded & Real-time Operating Systems

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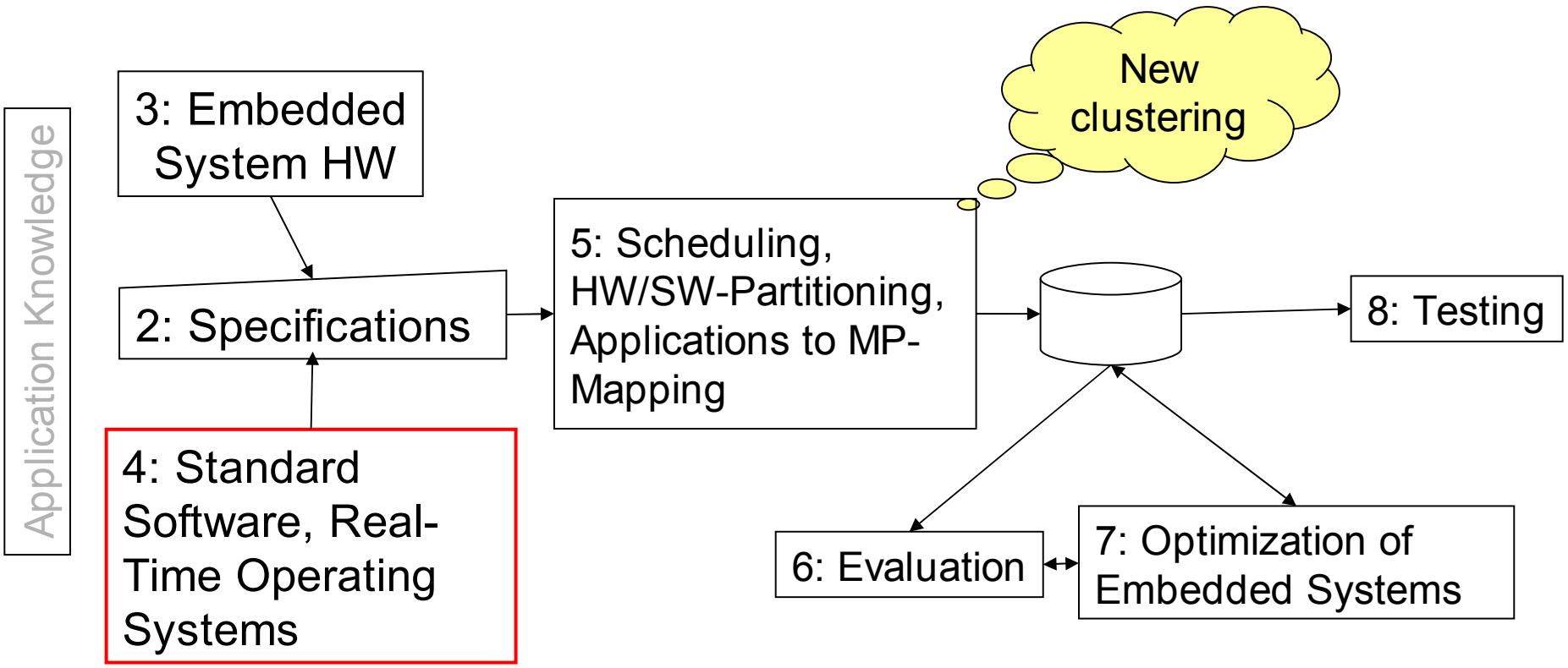
Structure of this course



Book chapter 4.3

Reuse of standard software components

Knowledge from previous designs to be made available in the form of **intellectual property** (IP, for SW & HW).

- Operating systems
- ….

Embedded operating systems
- Requirement: Configurability -

Configurability

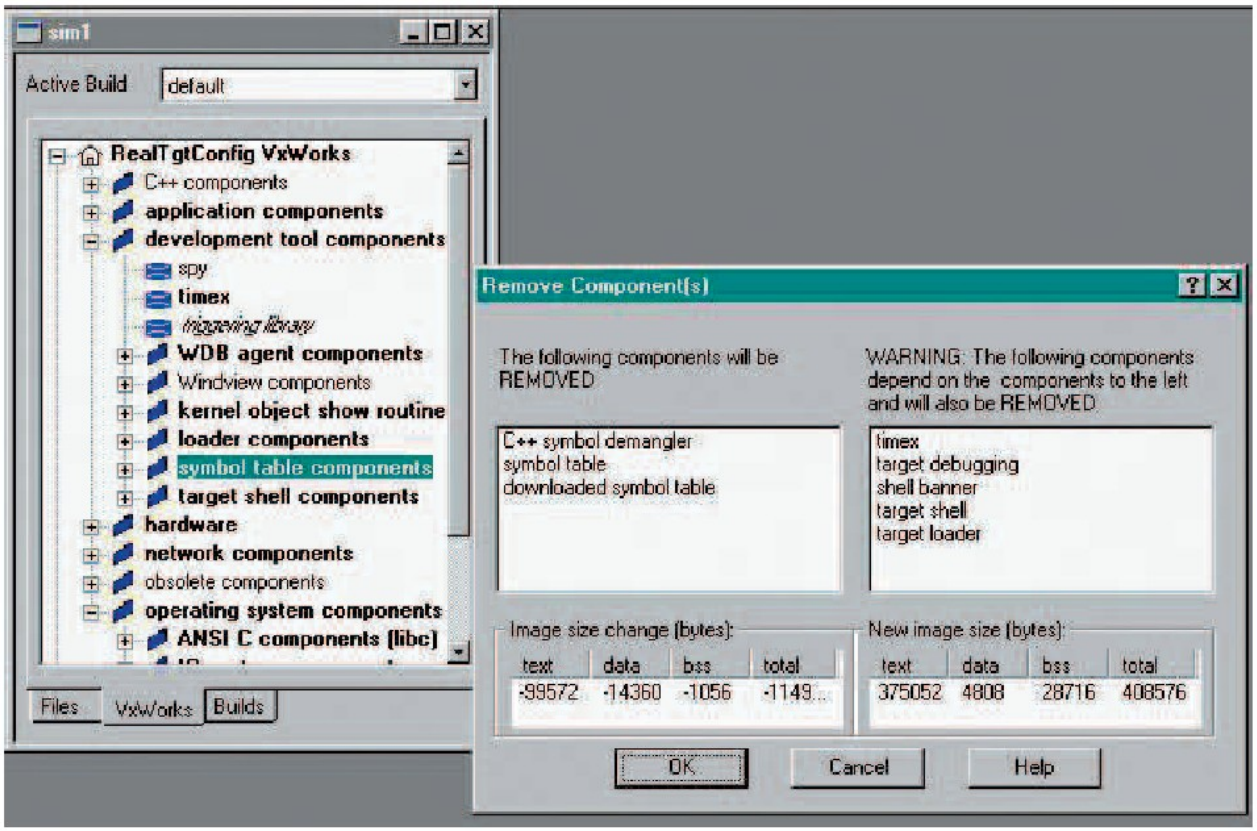
No single RTOS will fit all needs, no overhead for unused functions tolerated ☞ configurability needed.

- simplest form: remove unused functions (by linker ?).
- Conditional compilation (using #if and #ifdef commands).
- Dynamic data might be replaced by static data.
- Advanced compile-time evaluation useful.
- Object-orientation could lead to a derivation subclasses.

Verification a potential problem of systems with a large number of derived OSs:

- Each derived OS must be tested thoroughly;
- potential problem for eCos (open source RTOS from Red Hat), including 100 to 200 configuration points [Takada, 01].

Example: Configuration of VxWorks



Automatic dependency analysis and size calculations allow users to quickly custom-tailor the VxWORKS operating system.

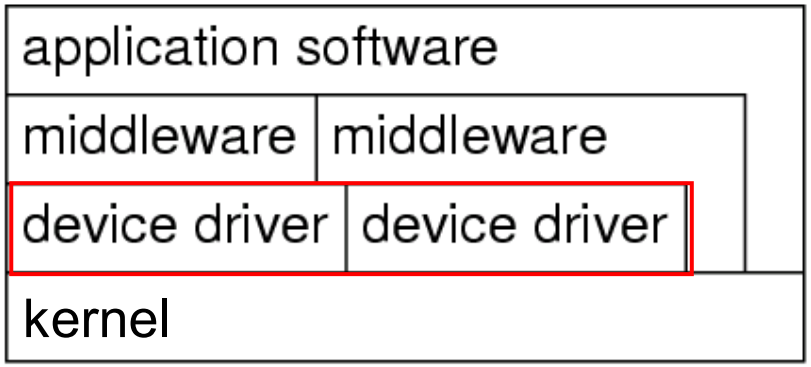
© Windriver

http://www.windriver.com/products/development_tools/ide/tornado2/tornado_2_ds.pdf

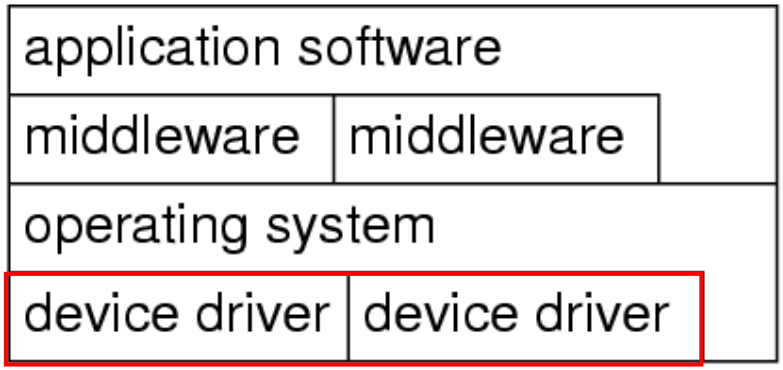
Embedded operating systems
-Requirement: Disc and network handled by tasks-

- Disc & network handled by tasks instead of integrated drivers. Relatively **slow** discs & networks can be handled by tasks.
- Many ES without disc, a keyboard, a screen or a mouse.
- **Effectively no device that needs to be supported by all versions of the OS**, except maybe the system timer.

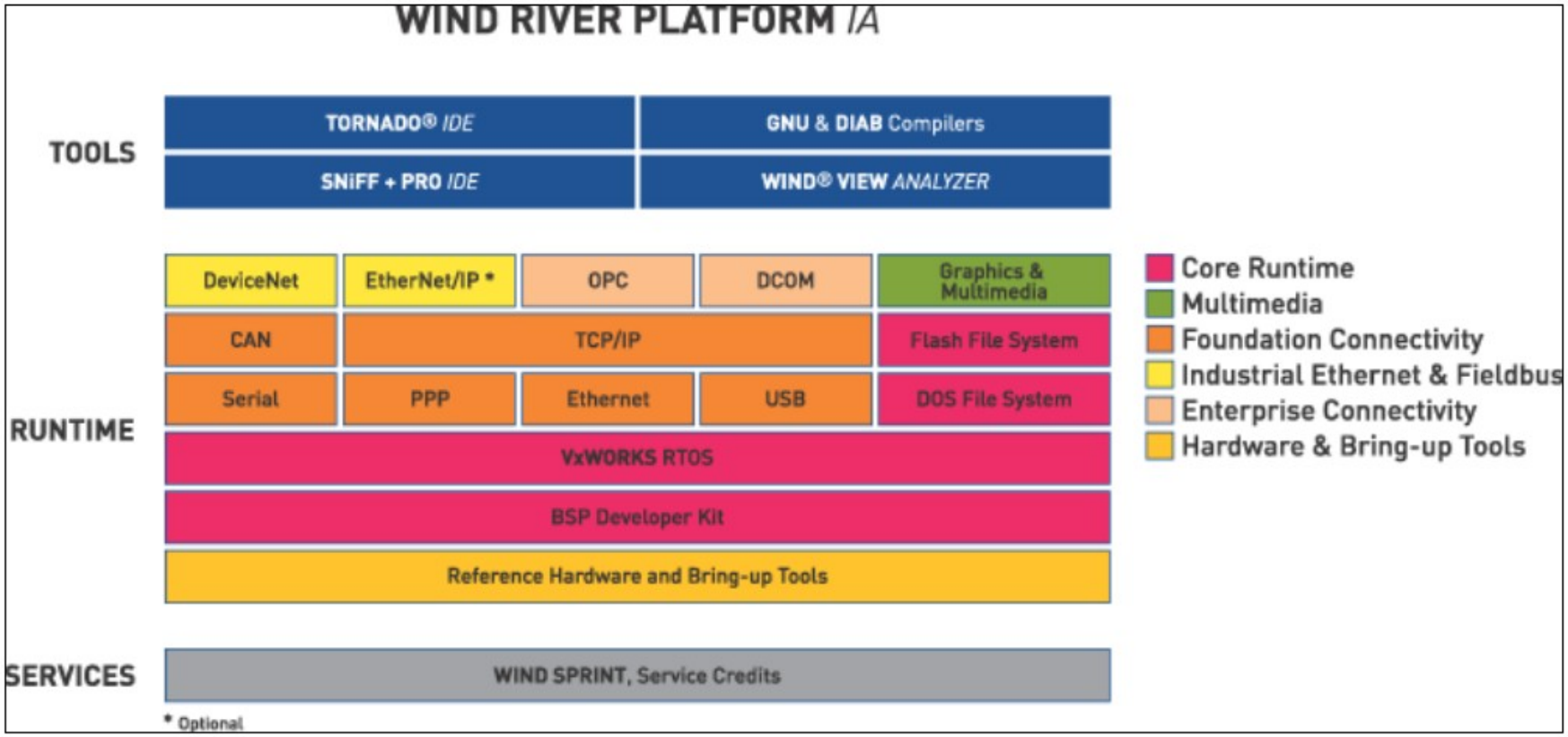
Embedded OS



Standard OS



Example: WindRiver Platform Industrial Automation



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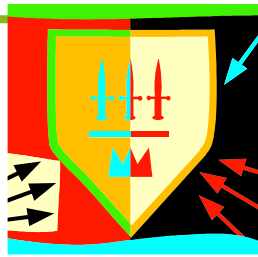
Embedded operating systems
- Requirement: Protection is optional-



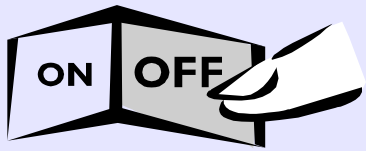
Protection mechanisms not always necessary:
ES typically designed for a single purpose,
untested programs rarely loaded, SW considered reliable.
(However, protection mechanisms may be needed for safety and security reasons).

Privileged I/O instructions not necessary and
tasks can do their own I/O.

Example: Let **`switch`** be the address of some switch
Simply use

```
load register,switch
```

instead of OS call.



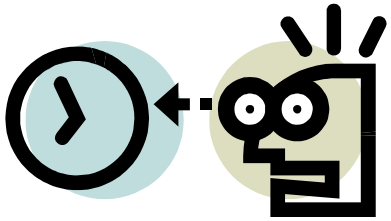
Embedded operating systems
- Requirement: Interrupts not restricted to OS -

Interrupts can be employed by any process
For standard OS: serious source of unreliability.
Since

- embedded programs can be considered to be tested,
- since protection is not necessary and
- since efficient control over a variety of devices is required,
- it is possible to let interrupts directly start or stop tasks (by storing the tasks start address in the interrupt table).
- More efficient than going through OS services.
- Reduced composability: if a task is connected to an interrupt, it may be difficult to add another task which also needs to be started by an event.

Embedded operating systems
- Requirement: Real-time capability-

Many embedded systems are real-time (RT) systems and, hence, the OS used in these systems must be **real-time operating systems (RTOSes).**



Real-time operating systems
- Real-time OS (1) -

Def.: *(A) real-time operating system is an operating system that supports the construction of real-time systems*

The following are the three key requirements

3. **The timing behavior of the OS must be predictable.**
   ∀ services of the OS: Upper bound on the execution time!
   RTOSs must be deterministic:
   - unlike standard Java,
   - short times during which interrupts are disabled,
   - contiguous files to avoid unpredictable head movements.

[Takada, 2001]

Real-time operating systems
- Real-time OS (2) -

1. **OS must manage the timing and scheduling**
   - OS possibly has to be aware of task deadlines; (unless scheduling is done off-line).
   - OS must provide precise time services with high resolution.

[Takada, 2001]

Time services

Time plays a central role in “real-time” systems.

Actual time is described by real numbers.

Two discrete standards are used in real-time equipment:

- **International atomic time TAI**
  (french: *temps atomic internationale*)
  Free of any artificial artifacts.
- **Universal Time Coordinated (UTC)**
  UTC is defined by astronomical standards

UTC and TAI identical on Jan. 1st, 1958.

30 seconds had to be added since then.

Not without problems: New Year may start twice per night.

Internal synchronization

Synchronization with one master clock

- Typically used in startup-phases

Distributed synchronization:

3. Collect information from neighbors
4. Compute correction value
5. Set correction value.

Precision of step 1 depends on how information is collected:

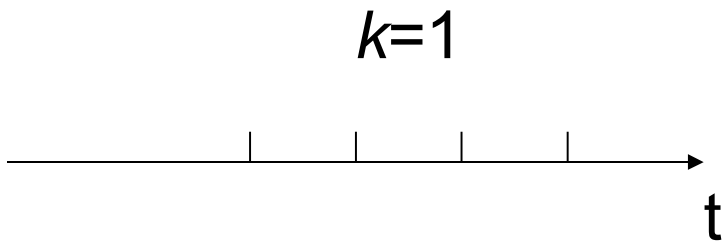
Application level: ~500 µs to 5 ms

Operation system kernel: 10 µs to 100 µs

Communication hardware: < 10 µs

Byzantine Error

Erroneous local clocks can have an impact on the computed local time.
Advanced algorithms are fault-tolerant with respect to Byzantine errors. Excluding *k* erroneous clocks is possible with 3*k*+1 clocks (largest and smallest values will be excluded.
Many publications in this area.



External synchronization

External synchronization guarantees consistency with actual physical time.
Recent trend is to use GPS for ext. synchronization
GPS offers TAI and UTC time information.
Resolution is about 100 ns.

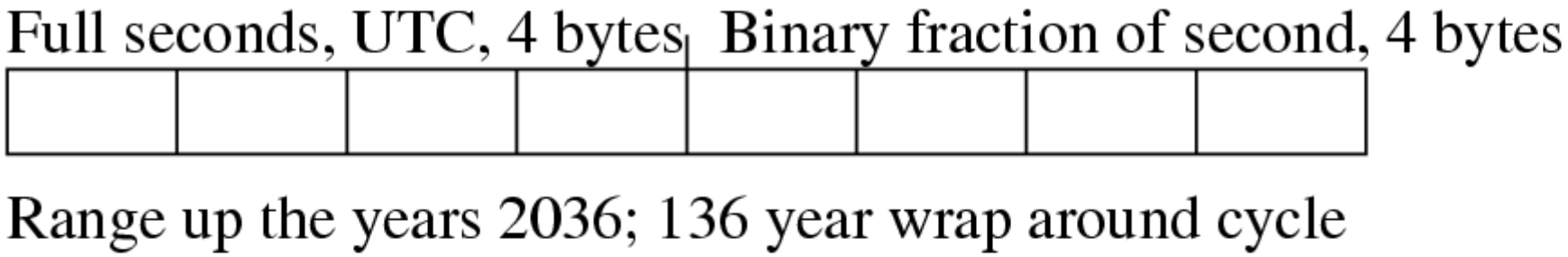
GPS mouse

© Dell

Problems with external synchronization

Problematic from the perspective of fault tolerance:
Erroneous values are copied to all stations.
Consequence: Accepting only small changes to local time.

Many time formats too restricted;
e.g.: NTP protocol includes only years up to 2036



For time services and global synchronization of clocks synchronization see Kopetz, 1997.

Real-time operating systems
- Real-time OS (3) -

1. **The OS must be fast**

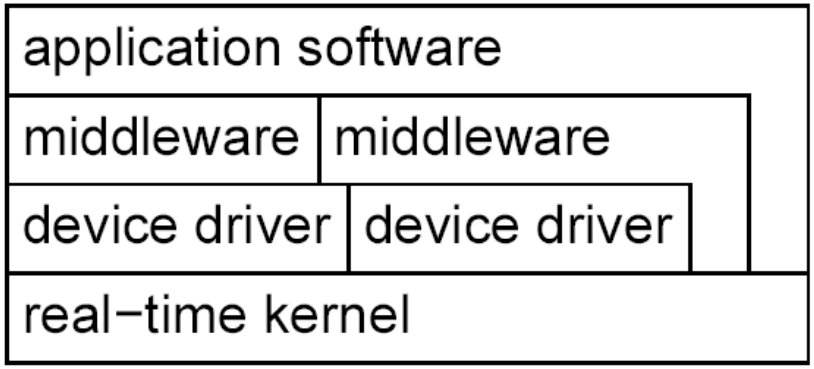
   Practically important.

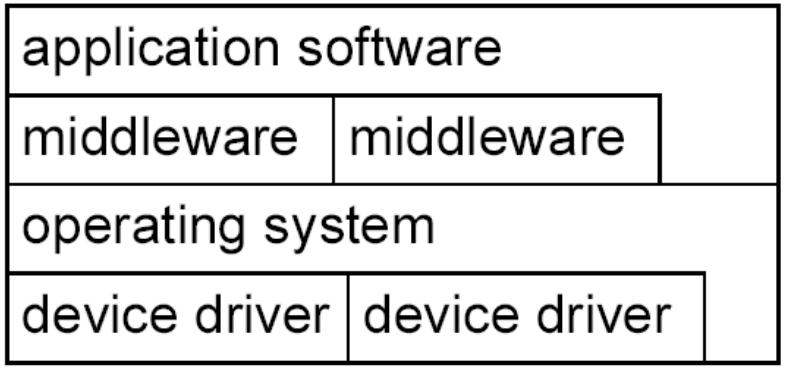
[Takada, 2001]

RTOS-Kernels

Distinction between

- real-time kernels and modified kernels of standard OSes.





Distinction between

- general RTOSes and RTOSes for specific domains,
- standard APIs (e.g. POSIX RT-Extension of Unix, ITRON, OSEK) or proprietary APIs.

Functionality of RTOS-Kernels

Includes

- processor management,
- memory management,
- and timer management;

} resource management

- task management (resume, wait etc),
- inter-task communication and synchronization.

Classes of RTOSes according to R. Gupta
1. Fast proprietary kernels

Fast proprietary kernels

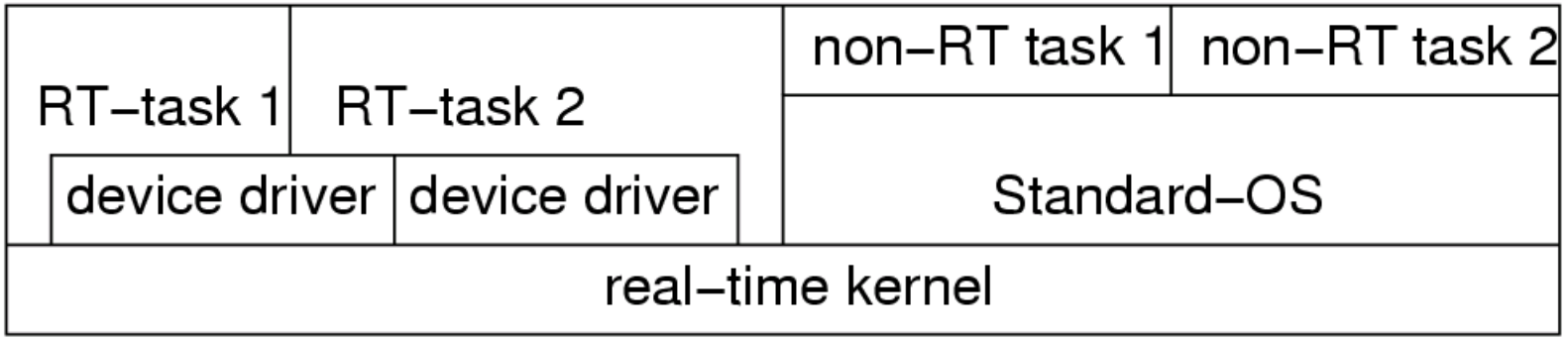
For complex systems, these kernels are inadequate, because they are designed to be fast, rather than to be predictable in every respect

[R. Gupta, UCI/UCSD]

Examples include
QNX, PDOS, VCOS, VTRX32, VxWORKS.

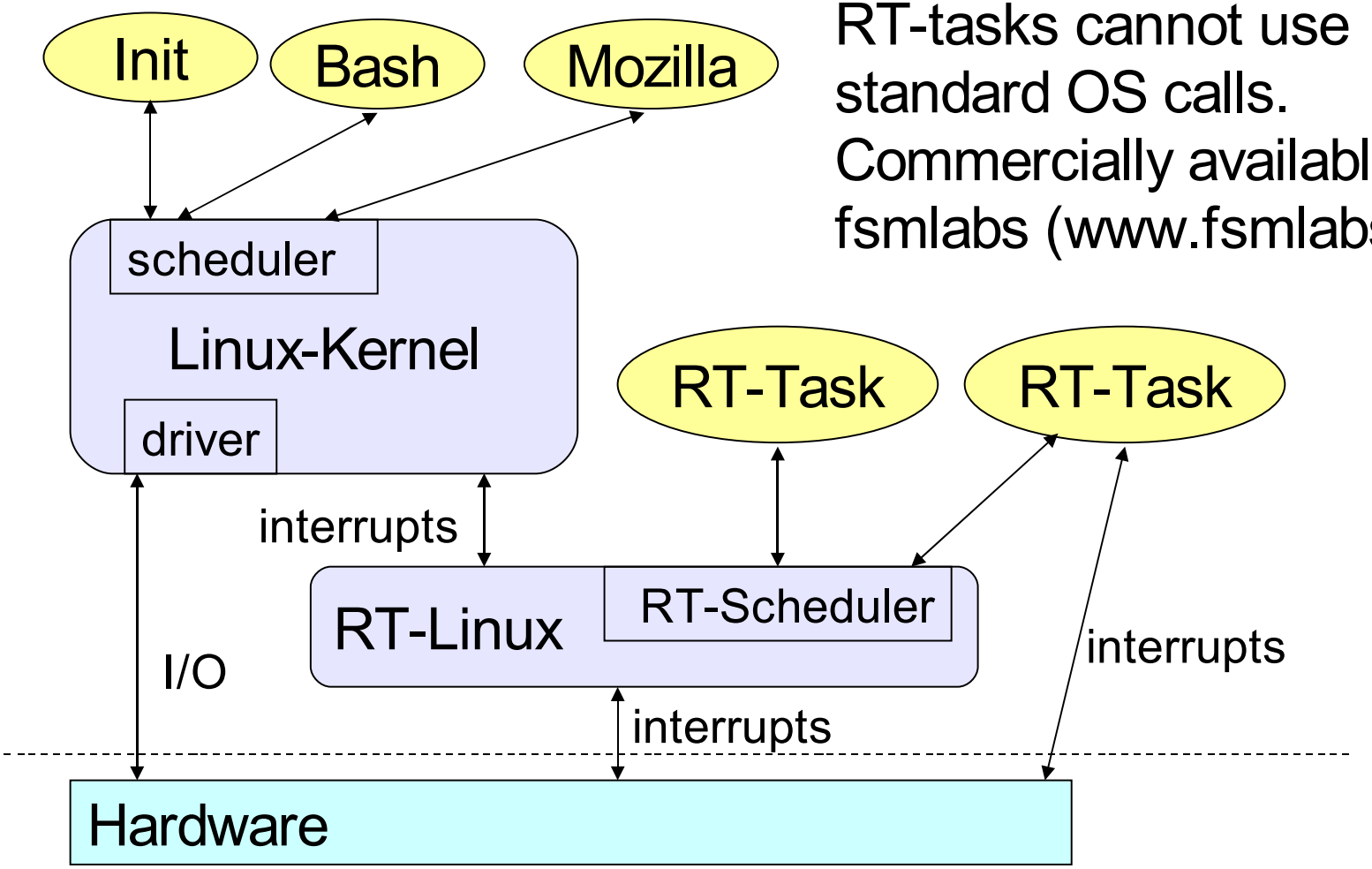
Classes of RTOSes according to R. Gupta
2. Real-time extensions to standard OSs

Real-time extensions to standard OSes:
Attempt to exploit comfortable main stream OSes.
RT-kernel running all RT-tasks.
Standard-OS executed as one task.



+ Crash of standard-OS does not affect RT-tasks;
- RT-tasks cannot use Standard-OS services;
  less comfortable than expected

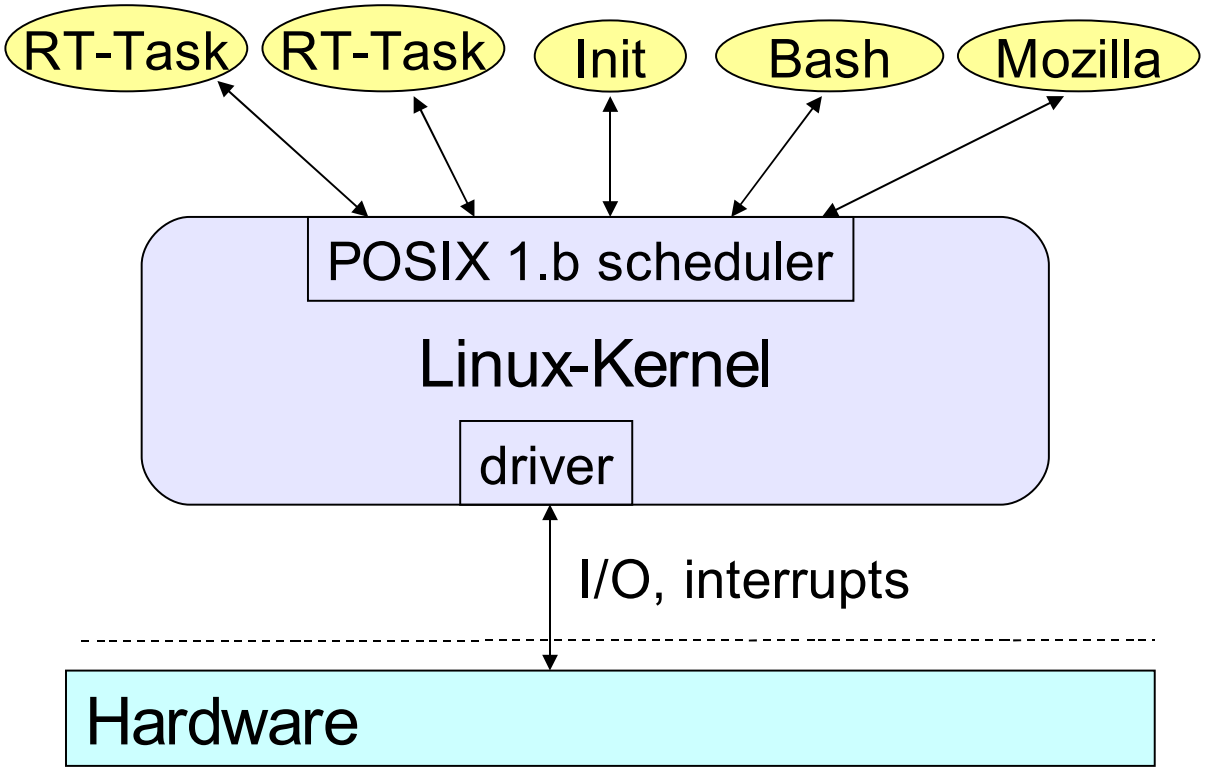
Example: RT-Linux



RT-tasks cannot use standard OS calls. Commercially available from fsmlabs (www.fsmlabs.com)

Example: Posix 1.b RT-extensions to Linux

Standard scheduler can be replaced by POSIX scheduler implementing priorities for RT tasks



Special RT-calls and standard OS calls available.
Easy programming, no guarantee for meeting deadline

Evaluation (Gupta)

According to Gupta, trying to use a version of a standard OS:
not the correct approach because too many basic and inappropriate underlying assumptions still exist such as optimizing for the average case (rather than the worst case), ... ignoring most if not all semantic information, and independent CPU scheduling and resource allocation.
Dependences between tasks not frequent for most applications of std. OSs & therefore frequently ignored.
Situation different for ES since dependences between tasks are quite common.

Classes of RTOSes according to R. Gupta
3. Research systems trying to avoid limitations

Research systems trying to avoid limitations.
Include MARS, Spring, MARUTI, Arts, Hartos, DARK, and Melody

Research issues [Takada, 2001]:

- low overhead memory protection,
- temporal protection of computing resources
- RTOSes for on-chip multiprocessors
- support for continuous media
- quality of service (QoS) control.

Competition between

- traditional vendors (e.g. Wind River Systems) and
- Embedded Windows XP and Windows CE

Market

Summary

- General requirements for embedded operating systems
  - Configurability, I/O, interrupts
- General properties of real-time operating systems
  - Predictability
  - Time services, synchronization
  - Classes of RTOSs, device driver embedding