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Real-Time and Security Requirements in IoT Operating Systems

Echtzeit 2016, Boppard, Germany

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Overview

- Dependable IoT
- Requirements for the IoT RTOSs
- Design choices for the IoT RTOSs
- Overview of existing OSs for the IoT
- Comparison of existing OSs for the IoT
- What is missing concerning IoT?
- Conclusion

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The Internet of Things

… will be everywhere!

- 50B+ connected devices by 2020
- Is one out of the "Ten most disruptive Technologies"
- Will impact the most critical areas of our daily life:
  - City management
  - Power grids & plants
  - Water management
  - Healthcare
  - Transportation (road, rail, air, water, space)
  - Infrastructure management, etc.

➔ The IoT must not fail ➔

- ➔ The IoT will itself become a new but highly critical infrastructure for our society

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The Internet of Things

… will be everywhere!

- We need to provide guarantees on *dependability*:
- **Security** (integrity, confidentiality)
  → no misuse or alteration
- **Safety**
  → no catastrophic consequences
- **Real-Time** (availability, reliability)
  → continuous correct, accurate and timely service
- **Maintainability**
  → flexible to adaptations and updates

- ➔ Cooperation across scientific disciplines to provide rigorous methods on designing, implementing and operating the IoT.

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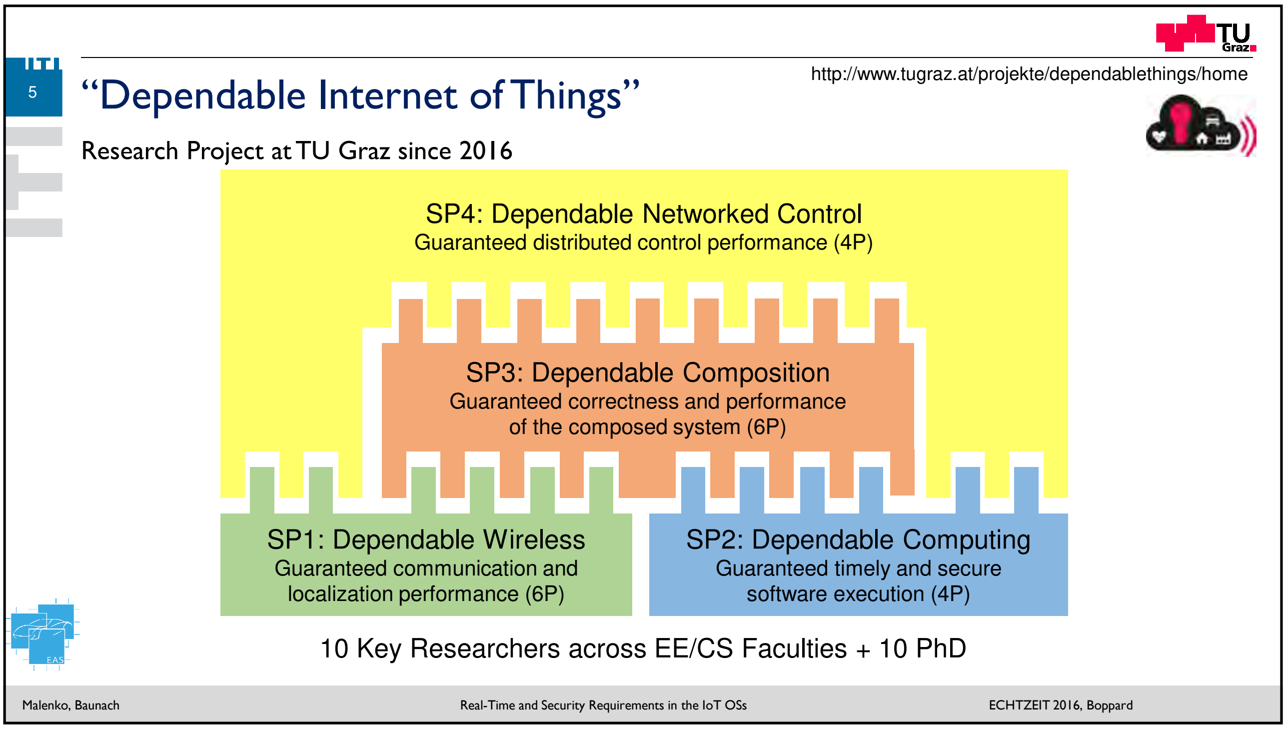

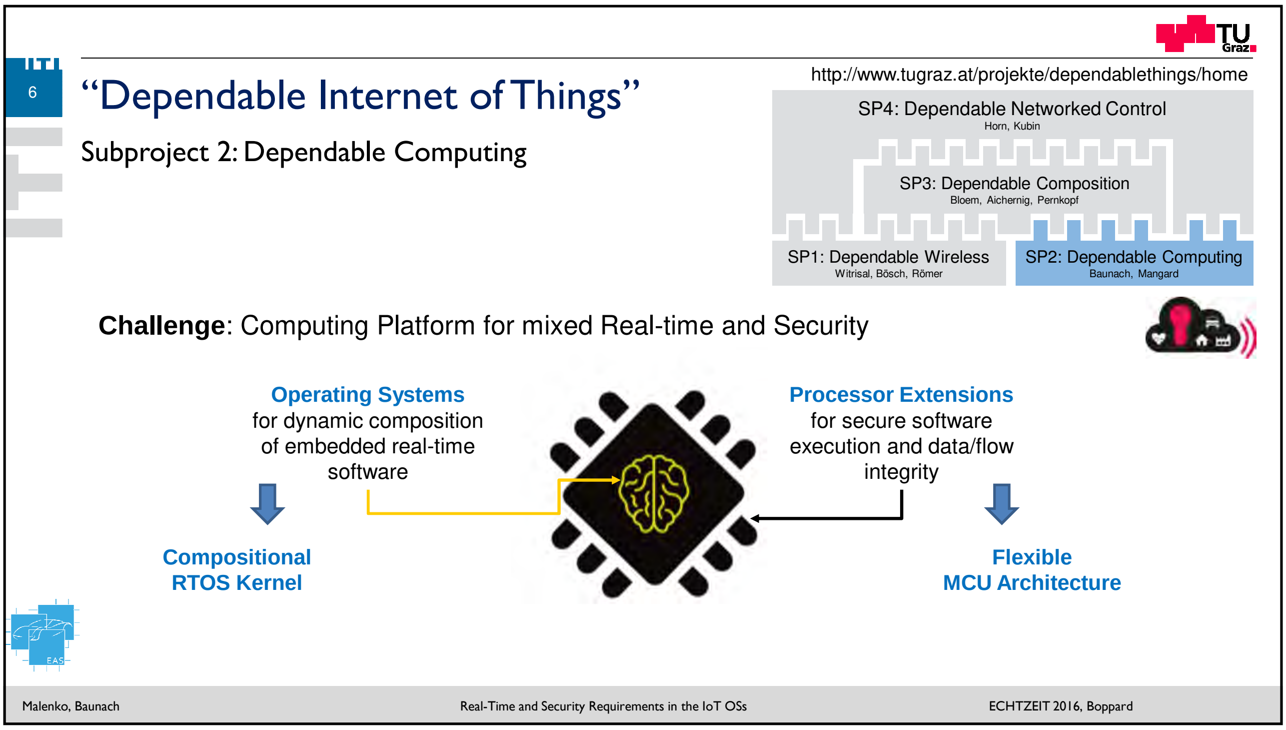

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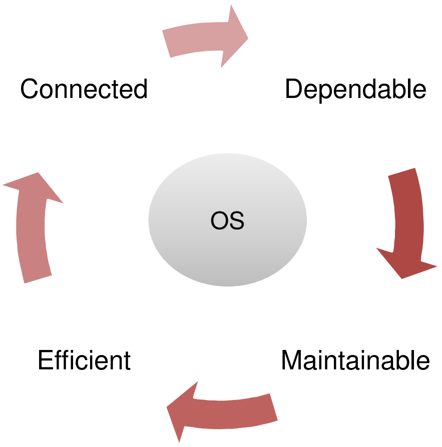
Requirements for the IoT RTOSs

- What makes a good IoT RTOS?
  - Dependable
    - Real-time
    - Security
    - Safety
  - Maintainability
    - Modular
    - Portable
  - Efficient
    - Resources
    - Usability
  - Connected



- State of the art
  - RTOSs often neglect security
  - RTOSs often neglect dynamical composition

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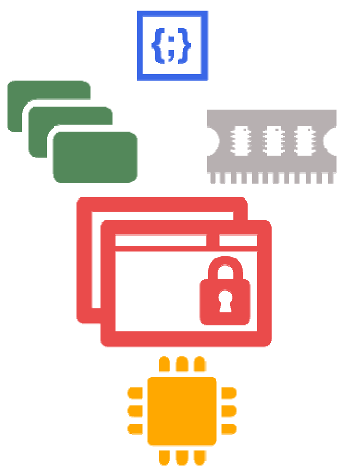
Design choices for the IoT RTOSs

- Kernel architecture
  - Monolithic kernel
    - Modular kernel
  - Microkernel
  - Exokernel
- Programming model
  - Event-driven
  - Multithreading
- Scheduling model
- Memory management
- Portability
- Security



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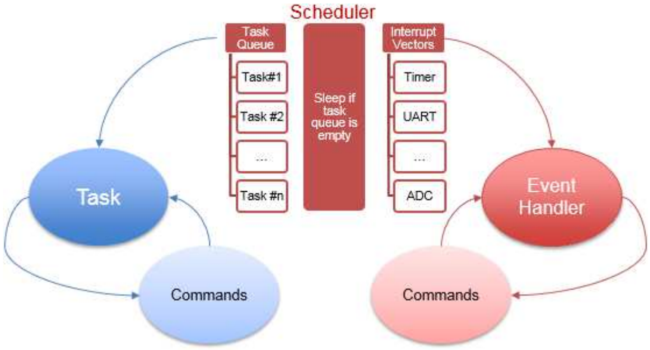
TinyOS

- Monolithic kernel
- Programming model
  - Event-driven
  - Implemented in nesC
- Two – level scheduling
  - RTC tasks
  - Event handlers
- Static memory allocation
- Optional
  - Preemprive TOSThreads
- Support for several network stacks



Energy and memory efficient
Portability (components)
Modularity

Real-time
Programming model
Dynamic memory management
Security

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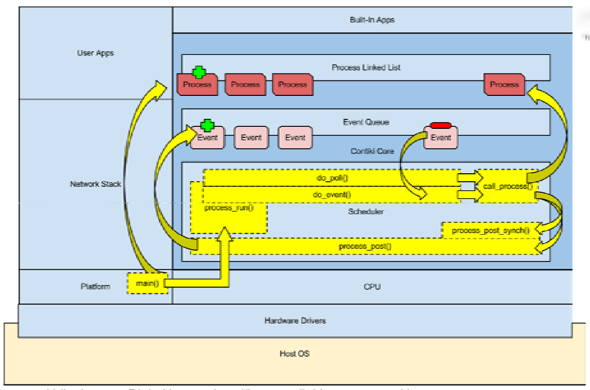
Contiki

- Modular kernel
- Programming model
  - Event-driven
- Two – level scheduling
  - Event handlers
  - Interrupts
- Dynamic memory management
- Optional
  - Preemptive multithreading
- Support for several network stacks



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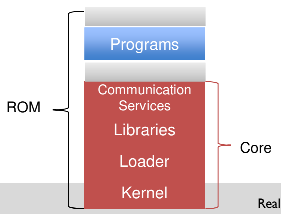

Dynamic loading
Modularity
Efficiency (application)

Portability
Programming model
Real-time
Security

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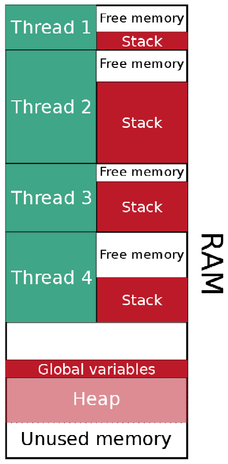
RIOT

- Microkernel
- Programming model
  - Multithreading
- Scheduler
  - Preemptive, fixed priority
  - Tickless scheduler
- Memory management
  - Static memory allocation in the kernel
  - Dynamic memory allocation for applications
- Support for different communication stacks



Modularity
Efficiency
Portability
Real-time
Programming model

Dynamic composition
Security

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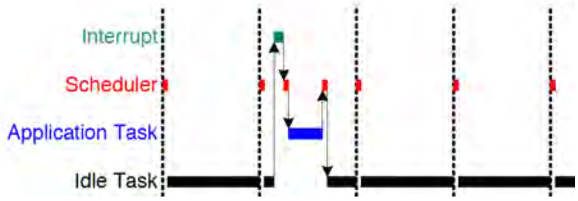
FreeRTOS

- Minimalistic microkernel
- Programming model
  - Multithreading(multitasking)
- Scheduler
  - Preemptive, and cooperative
  - Fixed-priority tasks
- Memory management
  - Allocate memory once for all
  - On demand allocate and free memory
    - Constant sized
    - Variable sized
- No own network stack
- SafeRTOS



Real-time
Efficiency
Portability
Dynamic memory management

Dynamic composition
Scalability
Security

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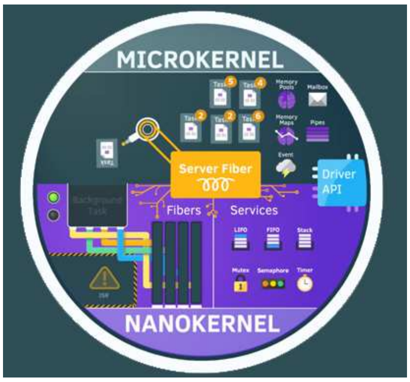
Zephyr

- Minimal hybrid micro/nanokernel
- Programming model
  - Cooperative fibers in nanokernel
  - Multithreading (multitasking) in microkernel
- Scheduler
  - Cooperative, priority-based fibers in nanokernel
  - Preemptive, priority-based tasks in microkernel
- Memory management
  - Microkernel supports dynamic memory allocation
- Support in mind for many networking protocols



Digital image. *https://www.zephyrproject.org*. Web. 15 Nov. 2016.

Modularity
Efficiency
Real-time

Dynamic composition
Security

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seL4

- Microkernel
- The first-ever OS kernel that has been formally verified for
  - Functional correctness
  - Data confidentiality
  - Data integrity
  - Temporal integrity
- seL4 concepts:
  - Capabilities
  - Kernel services (threads, IPC, capability spaces, interrupts)
  - Kernel objects (CNodes, TCBs, IPC endpoints, VA objects, interrupt objects, untyped memory)
    - Fixed size after creation
    - Untyped memory object used to create new typed objects
  - Preemptive, RR scheduler

Security
Portability
Real-time
Reusing untyped memory

Efficiency

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Commercial OSs

- Real-time
- Safety and security features
- POSIX-compliant

- QNX Neutrino
  - Microkernel
  - Built-in security features
- VxWorks
  - Monolithic kernel
  - Certified for real-time, reliability and security
- LynxOS
  - Monolithic kernel
  - LynxOS-178 – safety-critical
  - LynxSecure – security-critical

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Comparison

- Designed with low-level constrained embedded devices in mind
- Developed in C
  - Except TinyOS
- Mostly microkernel design
  - Less prone to errors, modular, easier verification
- Real-time
  - Except TinyOS and Contiki
    - Event-based programming
- Support multiple network protocols and multiple processor architectures
- No memory protection
  - Except seL4

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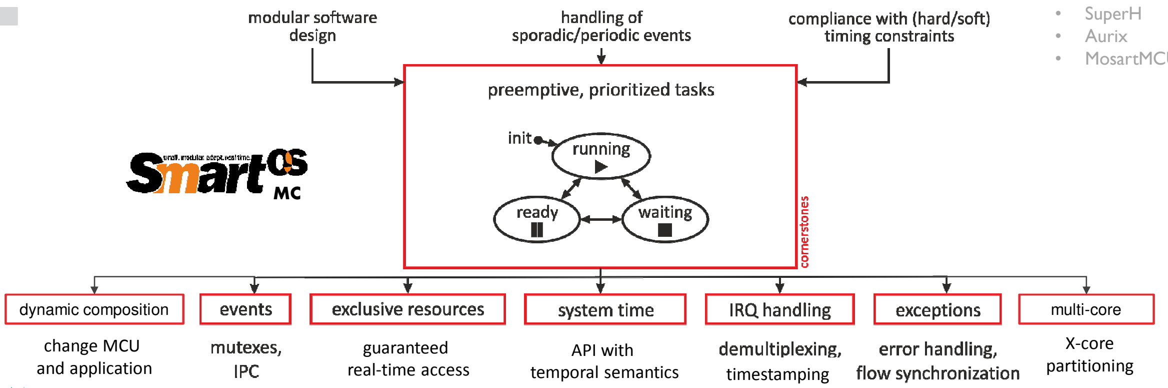
SmartOS

2005 - …

A multi-tasking & multi-core operating system
for compositional embedded applications:

Ports:
- Atmega128
- MSP430
- SuperH
- Aurix
- MosartMCU



Malenko, Baunach: *„Real-Time and Security Requirements for the Internet of Things Operating Systems"*
Baunach, Gomes, Mauroner: *„Collaborative Resource Management for Multi-Core AUTOSAR OS"*
Baunach: *"Advanced Timestamping for pairwise Clock Drift Detection in Wireless Sensor/Actuator Networks"*
...

Conclusion

- IoT imposes new requirements
- Existing RTOSs lack many IoT functionalities

- Challenges to be met
  - Dynamic composition of applications and services
    - Guarantee compatibility and interoperability
  - Dynamic Resource Sharing
  - Security risks

- An RTOS must evolve to deliver **sustainability**

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