Levels of Specialization in Real-Time Operating Systems

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Embedded Systems are Special-Purpose Systems

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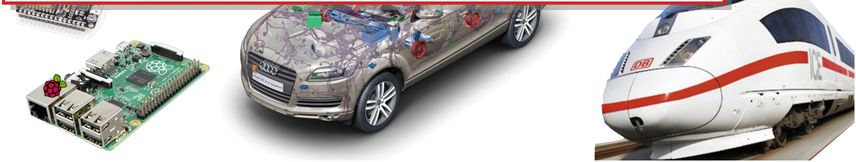
Applications are special-purpose systems.

RTOS can be a special-purpose system, too!



Agenda

- Motivation
- Specialization
- Levels of System-Software Specialization
- Case Study: GPSLogger
- Benefits and Challenges
- Summary

“Between a Rock and a Hard Place”

functional and nonfunctional **requirements**

functional and nonfunctional **properties**

"Between a Rock and a Hard Place"

functional and nonfunctional **requirements**

Knowledge

functional and nonfunctional **properties**

"Between a Rock and a Hard Place"

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Knowledge

functional and nonfunctional **properties**

Method: Static/Dynamic Analysis

"Between a Rock and a Hard Place"

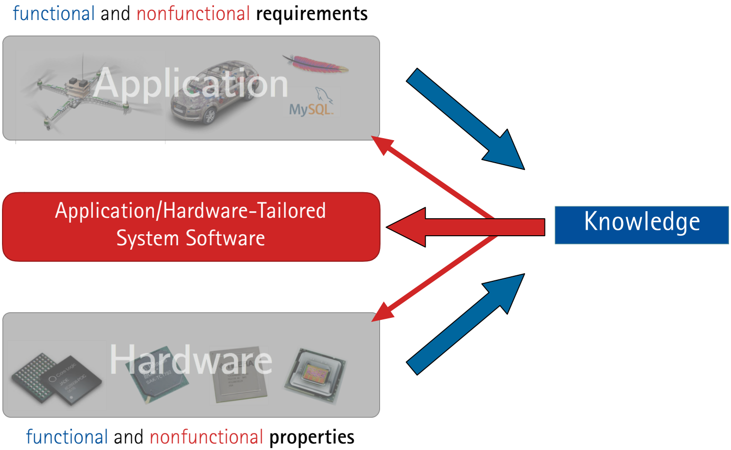
functional and nonfunctional **requirements**

Application/Hardware-Tailored System Software ← Knowledge

functional and nonfunctional **properties**

Technique: Compilation and Generation

"Between a Rock and a Hard Place"



Technique: Compilation and Generation

"Between a Rock and a Hard Place"

functional and nonfunctional **requirements**

Improved nonfunctional properties?

Application/Hardware-Tailored System Software

Knowledge

functional and nonfunctional **properties**

Technique: Compilation and Generation

System-Software Specialization

- **Specialization:** Subsetting to “what is actually needed” by exploiting a-priori knowledge.

  ↪ There is always more knowledge than you think!

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- **Levels:** Taxonomy of three subsequent levels of specialization.

  1. **Abstraction** — *What* functionality is used.
  2. **Instance** — *Which* entities use that functionality.
  3. **Interaction** — *How* do they use that functionality.

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  1. **Abstraction** — *What* functionality is used.
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  3. **Interaction** — *How* do they use that functionality.

- **Knowledge:** The more we know, the deeper we can specialize.

What is a (correct) Specialization

$$RTS(\vec{I}) = \vec{O}$$

RT-system **specification**
defines system input $\vec{I}$,
defines correct output $\vec{O}$

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Concrete **implementation** consumes input $\vec{I}$, produces output $\vec{O}$

What is a (correct) Specialization

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What is a (correct) Specialization

Specification determines correctness

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What is a (correct) Specialization

Specification determines correctness

Specialization: modify implementation remove flexibility

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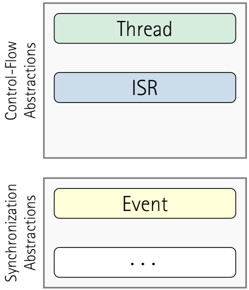
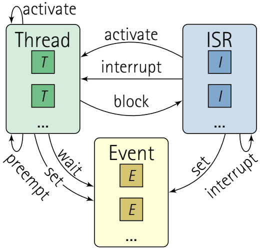
OS Specialization: **0 – Standard/API**

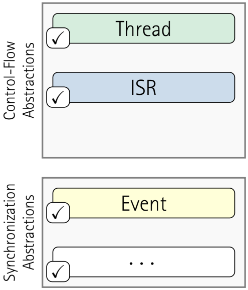


not specialized



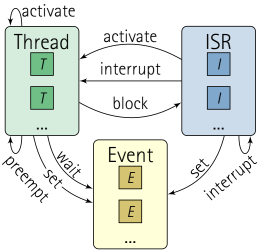
supports any application

OS Specialization: **1 – Abstraction-Level Specialization**



Abstractions

subsetting of available abstractions/features



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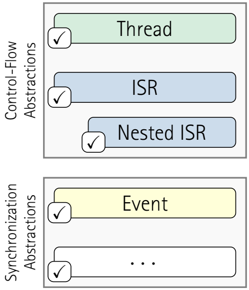

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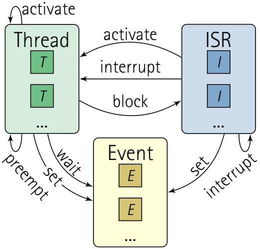

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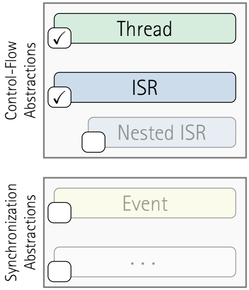

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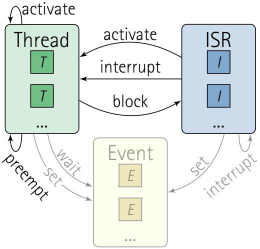
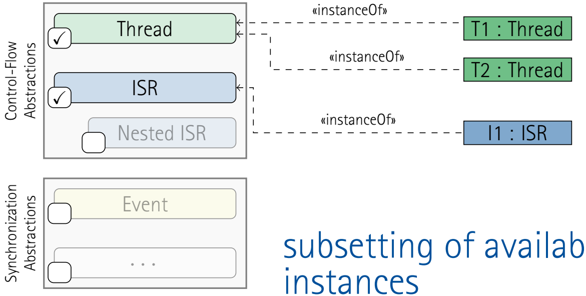


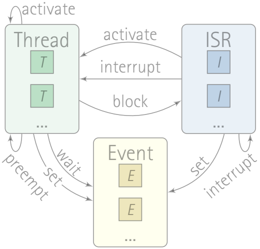
class of applications

OS Specialization: **2 – Instance-Level Specialization**

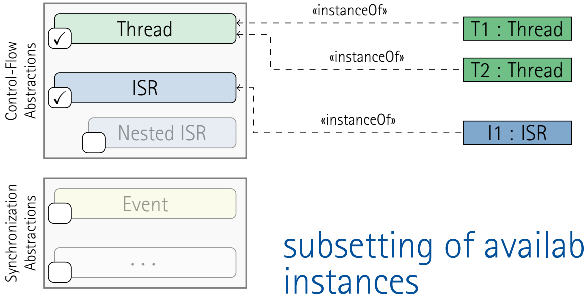


subsetting of available instances

Abstractions Instances



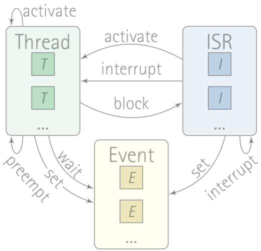
OS Specialization: **2 – Instance-Level Specialization**

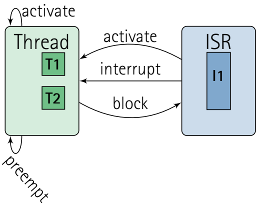


subsetting of available instances

Abstractions

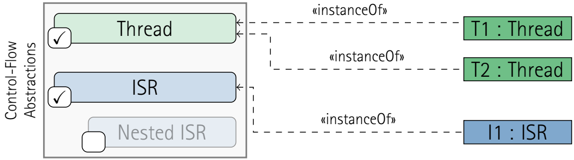
Instances

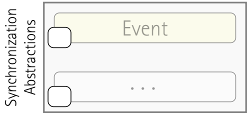


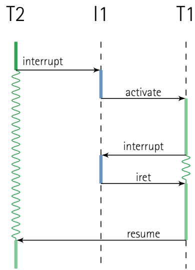


specific application

OS Specialization: **3 – Interaction-Level Specialization**

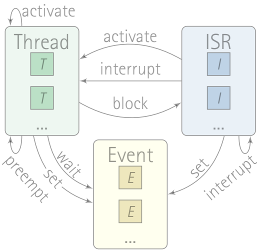


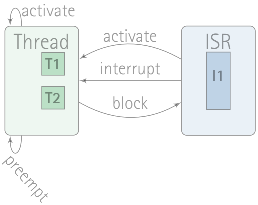


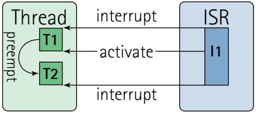


subsetting of possible instance interactions

Abstractions | Instances | Interactions







specific application implementation

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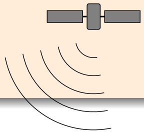
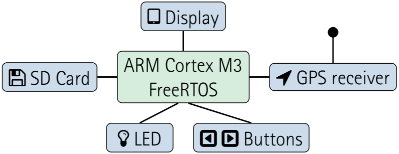
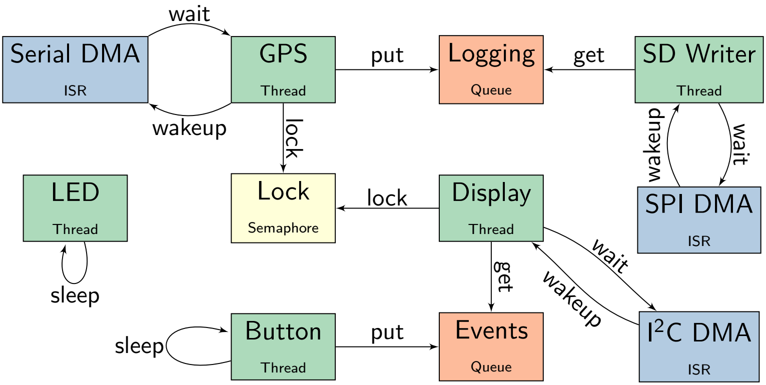




https://github.com/grafalex82/GPSLogger

Case Study: GPSLogger



- Abstractions: Already done by CPP macros

	Abstractions
Text segment (bytes)	91,084
Data & BSS segment (bytes)	18,328
Startup time (cycles)	60,426

Case Study: GPSLogger

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- Instances: Threads and queues statically instantiated

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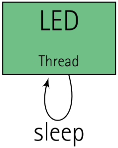
Text segment (bytes)	91,084	91,196
Data & BSS segment (bytes)	18,328	17,472
Startup time (cycles)	60,426	53,827

Case Study: GPSLogger



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- Interactions: LED task inlined in ISR

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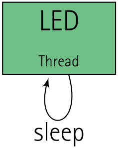

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	Abstractions	Instances	Interactions
Text segment (bytes)	91,084	91,196	90,572
Data & BSS segment (bytes)	18,328	17,472	16,712
Startup time (cycles)	60,426	53,827	51,029

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Benefits

- Memory footprint reduction
  - CiAO [ISORC '14]

CiAO

CiAO is Aspect-Oriented

90% less code
50% less RAM usage

ISE SRA

Benefits

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- Memory footprint reduction
  - CiAO [ISORC '14]
- Security and safety improvements
  - CADOS [HotDep '12]

CiAO

CiAO is Aspect-Oriented

10% less code with CVE entries
5× more robust against bitflips

Benefits

- Memory footprint reduction
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- Security and safety improvements
  - CADOS [HotDep '12]
- Better exploitation of hardware
  - SLOTH [RTSS '09; RTSS '12]

171× less dispatch latency

Benefits

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- Better exploitation of hardware
  - Sloth [RTSS '09; RTSS '12]
- Reduction of jitter and kernel latency
  - OSEK-V [LCTES '17]

OSEK-V

81% less cycles for dispatch

Benefits

- Memory footprint reduction
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  - CADOS [HotDep '12]
- Better exploitation of hardware
  - Sloth [RTSS '09; RTSS '12]
- Reduction of jitter and kernel latency
  - OSEK-V [LCTES '17]
- Analyzability and testability
  - SysWCET [RTAS '17]
  - SysWCEC [ECRTS '18]

15% better WCRT bounds

Challenges

- You have to know what you need

17000 features in Linux

Challenges

- You have to know what you need
- You have to be able to express what you need

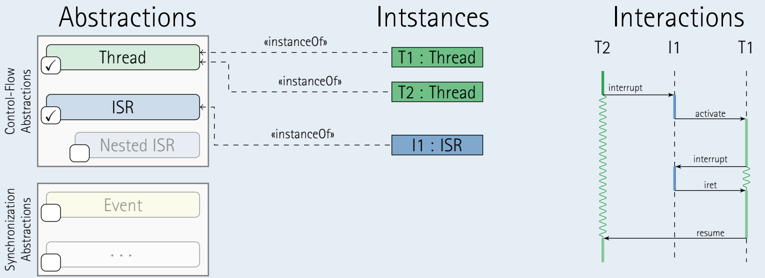
POSIX style

Challenges

- You have to know what you need
- You have to be able to express what you need
- Testability and certifiability

Costs

Levels of specialization



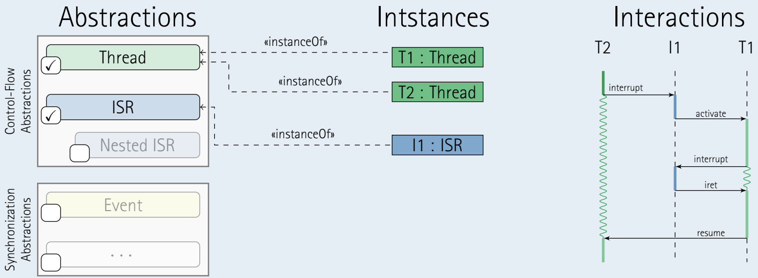
Summary

Levels of specialization

- Specialization significantly improves nonfunctional properties
- Manual specialization: too costly and time-consuming

Summary

Levels of specialization



- Specialization significantly improves nonfunctional properties
- Manual specialization: too costly and time-consuming

↪ Automation

↪ Integration in toolchain

Summary

Levels of specialization

- Specialization significantly improves nonfunctional properties
- Manual specialization: too costly and time-consuming

↪ Automation

↪ Integration in toolchain

There always is more to specialize than you'd expect

References I

Christian Dietrich, Peter Wägemann, Peter Ulbrich, and Daniel Lohmann. "SysWCET: Whole-System Response-Time Analysis for Fixed-Priority Real-Time Systems". In: *Proceedings of the 23rd IEEE International Symposium on Real-Time and Embedded Technology and Applications (RTAS '17)*. Washington, DC, USA: IEEE Computer Society Press, 2017, pp. 37–48. ISBN: 978-1-5090-5269-1. DOI: `10.1109/RTAS.2017.37`.

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