

Konfigurierbare Systemsoftware (KSS)

VL 1 – Einführung

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http://www4.informatik.uni-erlangen.de/Lehre/SS14/V_KSS



- 1.1 Commodity Operating Systems Today
- 1.2 Reality Check: Granularity
- 1.3 The Domain of Embedded Systems
- 1.4 About KSS
- 1.5 KSS — Organization
- 1.6 References



The Operating System – A Swiss Army Knife?

Commodity operating systems provide a rich set of features to be prepared for all kinds of applications and contingencies:

- Malicious or erroneous applications
 - preemptive scheduling, address space separation, disk quotas
- Multi-user operation
 - authentication, access validation and auditing
- Multi-threaded and interacting applications
 - Threads, semaphores, pipes, sockets
- Many/large concurrently running applications
 - virtual memory, swapping, working sets



The Operating System – A Swiss Army Knife?

One size fits all?

↪ Variability

“ Clearly, the operating system design must be strongly influenced by the type of use for which the machine is intended. Unfortunately it is often the case with ‘general purpose machines’ that the type of use cannot be easily identified; a common criticism of many systems is that in attempting to be all things to all men they wind up being **totally satisfactory to no-one**. ”

Lister and Eager 1993: *Fundamentals of Operating Systems* [4]



The Operating System – A Swiss Army Knife?

Big is beautiful?

↪ Granularity

“Some applications may require only a subset of services or features that other applications need. These ‘less demanding’ applications should **not be forced to pay** for the resources consumed by unneeded features.”

Parnas 1979: “Designing Software for Ease of Extension and Contraction” [8]



Variability and Granularity

Variability

(Definition 1)

Variability of system software is the property that denotes the *range* of functional requirements that can be fulfilled by it.

Granularity

(Definition 2)

Granularity of system software is the property that denotes the *resolution* of which requirements can be fulfilled by it, in the sense that requirements are fulfilled but not overfulfilled.

- Can general purpose (GP) systems fulfill these demands?
- Reality check – a small study with `printf()` from `glibc`:
(Analogy: GP operating system $\longleftrightarrow$ GP library $\longleftrightarrow$ GP function)

```
int main() {  
    printf( "Hello World\n");  
}
```



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Reality Check: Granularity

■ The setup:

```
> uname -a
Linux faui48a 2.6.32-5-amd64 #1 SMP Mon Oct 3 05:45:56 UTC 2011 x86_64 GNU/Linux
> gcc -dumpversion
4.4.5
```

■ Experiment 1: `printf()`

```
> echo 'main(){printf("Hello World\n");}' | gcc -xc - -w -Os -static -o hello1
> ./hello1
Hello World
> size hello1
```

text	data	bss	dec	hex	filename
508723	1928	7052	517703	7e647	hello1

512 KiB!

- Maybe the general-purpose `printf()` is just too powerful?
 - supports many data types, formatting rules, ...
 - implementation requires a complex parser for the format string
- Let's try the much more specialized `puts()`!



■ Experiment 2: puts()

```
> echo 'main(){puts("Hello World");}' | gcc -xc - -Os -w -static -o hello2
> ./hello2
Hello World
> size hello2
```

text	data	bss	dec	hex	filename
508723	1928	7052	517703	7e647	hello2

512 KiB!

- That didn't help much!
- Maybe `puts()` is yet too powerful?
 - buffered IO, streams
- Let's work directly with the OS file handle!



■ Experiment 3: write()

```
> echo 'main(){write(1, "Hello World\n", 13);}' | gcc -xc - -Os -w -static -o hello3
> ./hello3
Hello World
> size hello3
```

text	data	bss	dec	hex	filename
508138	1928	7052	517118	7e3fe	hello3

512 KiB!

- 517703 compared to 517118 – a net saving of 585 bytes (0.1%) :-)

■ Experiment 4: empty program

```
> echo 'main(){}' | gcc -xc - -Os -w -static -o hello4
> size hello4
```

text	data	bss	dec	hex	filename
508074	1928	7052	517054	7e3be	hello4

Hm...

- `objdump -D --reloc hello4 | grep printf | wc -l` yields still **2611** matches!
- It's the startup code!



■ Experiment 5: `write()`, no startup code

```
> echo '_start(){write(1, "Hello World\n", 13);_exit(0);}' | gcc -xc - -Os -w  
-static -nostartfiles -o hello5  
> size hello5  
   text    data     bss      dec     hex filename  
   597       0        4     601     259 hello5  
> ./hello5  
Segmentation fault
```

0.5 KiB :-|

but segfault :-|

- Even a simple `write()` cannot be issued without the complete initialization.
- Last resort: invoke the syscall directly!

■ Experiment 6: `SYS_write()`

```
> echo '_start(){syscall(4, 1, "Hello World\n", 13);_exit(0);}' | gcc -xc - -Os  
-w -static -nostartfiles -o hello6  
> size hello6  
   text    data     bss      dec     hex filename  
   293       0        4     297     129 hello6  
> ./hello6  
Hello World
```

0.25 KiB :-)



297 $\longleftrightarrow$ 517703 Bytes!

On Linux/glibc, a simple “Hello World” application takes **1750 times** more memory than necessary!

- However, is this a problem?
 - The glibc has been designed for a “standard case”
 - Large, multithreaded, IO-intensive UNIX application
 - Assumption: every program uses `malloc()`, `printf()`, ...
 - Variability has been traded for Granularity

Every Program?

“ I know of no feature that is always needed. When we say that two functions are almost always used together, we should remember that “almost” is a euphemism for “not”. ”

Parnas 1979: “Designing Software for Ease of Extension and Contraction” [8]



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 - Large, multithreaded, IO-intensive UNIX application
 - Assumption: every program uses `malloc()`, `printf()`, ...
 - Variability has been traded for Granularity
- Assumption: The GP operating system will compensate for it...
 - Virtual memory $\rightsquigarrow$ memory is not an issue (but is that a reason to waste it?)
 - Shared libraries $\rightsquigarrow$ memory is actually shared between processes (unless we relocate the symbols, e.g., for address-space randomization...)

What about other domains?

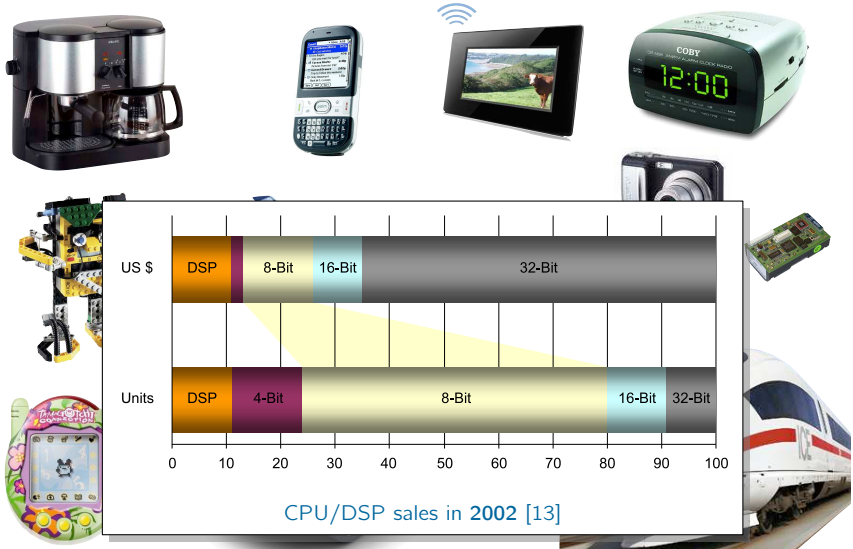


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A Different Domain: Embedded Systems



The ATmega μ C Family (8-Bit)

Type	Flash	SRAM	IO	Timer 8/16	UART	I ² C	AD	Price (€)
ATTINY11	1 KiB		6	1/-	-	-	-	0.31
ATTINY13	1 KiB	64 B	6	1/-	-	-	4*10	0.66
ATTINY2313	2 KiB	128 B	18	1/1	1	1	-	1.06
ATMEGA4820	4 KiB	512 B	23	2/1	2	1	6*10	1.26
ATMEGA8515	8 KiB	512 B	35	1/1	1	-	-	2.04
ATMEGA8535	8 KiB	512 B	32	2/1	1	1	-	2.67
ATMEGA169	16 KiB	1024 B	54	2/1	1	1	8*10	4.03
ATMEGA64	64 KiB	4096 B	53	2/2	2	1	8*10	5.60
ATMEGA128	128 KiB	4096 B	53	2/2	2	1	8*10	7.91

Bulk prices and features of ATmega variants (excerpt, DigiKey 2006)

Limited Resources

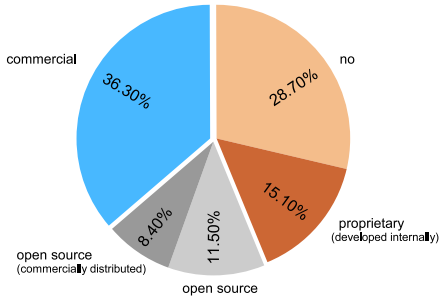
- Flash is limited, RAM is extremely limited
- A **few bytes** can have a **massive impact on** per-unit **costs**

→ The “glibc approach” is **doomed to fail!**



The Role of the Operating System

(a) Types of operating systems
(n = 1200)



(b) Why no operating system?
(Multiple answers possible)

too complicated

7%

too expensive

10%

resource concerns

30%

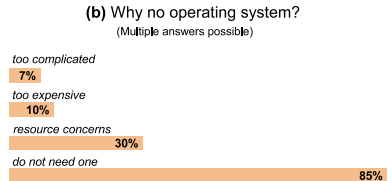
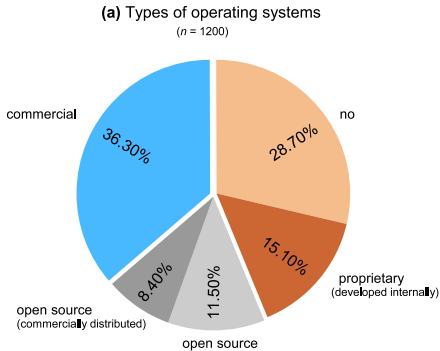
do not need one

85%

Operating systems (not) employed in embedded-system projects in 2006 [12]



The Role of the Operating System



Operating systems (not) employed in embedded-system projects in 2006 [12]

> 40% of all projects use “in house” OS functionality!

Wide-spread fear of the resource overhead of GP operating systems

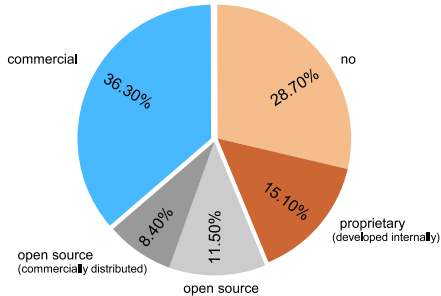
- OS functionality is developed “side-by-side” with the applications
- This leads to very high “hidden” development costs

[14]

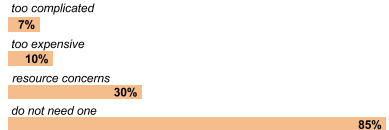


The Role of the Operating System

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(Multiple answers possible)



Operating systems (not) employed in embedded-system projects in 2006 [12]

Rest spreads over **hundreds of different** operating systems!

..., C{51, 166, 251}, CiAO, CMX RTOS, Contiki, C-Smart/Raven, eCos, eRTOS, Embos, Ercos, Euros Plus, FreeRTOS, Hi Ross, Hynet-OS, LynxOS, MicroX/OS-II, Nucleus, OS-9, OSE, OSEK {Flex, Turbo, Plus}, OSEKtime, Precise/MQX, Precise/RTCS, proOSEK, pSOS, PURE, PXROS, QNX, Realos, RTMOSxx, Real Time Architect, RTA, RTX{51, 166, 251}, RTXC, Softune, SSXS RTOS, ThreadX, TinyOS, Tresos, VRTX, VxWorks, ...

~ The “glibc approach” (one size fits all) **does not work!**



Between a Rock and a Hard Place...

functional and nonfunctional requirements



S y s t e m S o f t w a r e



functional and nonfunctional properties

tasks
sockets
file system

...
event latency
safety

...

ISA
IRQ handling
MMU / MPU

...

cache size
coherence
IRQ latency

...



Between a Rock and a Hard Place...

functional and nonfunctional requirements

- High variety of functional and nonfunctional application requirements
- High variety of hardware platforms
- High per-unit cost pressure
- ↪ System software has to be **tailored** for each concrete application

tasks
sockets
file system

...
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safety

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cache size
coherence
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...

functional and nonfunctional properties



Customizing/Tailoring

(Definition 3)

Customizing or tailoring is the activity of modifying existing system software in order to fulfill the requirements of some particular application.

This calls for **granularity** and **variability**!



Between a Rock and a Hard Place...

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What to do?

297 $\longleftrightarrow$ 517703 Bytes!

Why?

On Linux/glibc, a simple “Hello World” application takes **1750 times** more memory than necessary!

- Reason: software structure
 - Trade-off between **reuse** $\longleftrightarrow$ **coupling**
 - $\rightsquigarrow$ by extensive internal reuse, glibc has become an all-or-nothing blob
- Reason: software interface
 - C standard defines **printf()** as a swiss army knife [3, §7.19.6]
 - $\rightsquigarrow$ **printf()** has become a “god method” [1]
- Reason: language and tool chain
 - Compiler/linker work on the granularity of symbols or even object files
 - $\rightsquigarrow$ dead code is not effectively eliminated



What to do?

297 $\longleftrightarrow$ 517703 Bytes!

Why?

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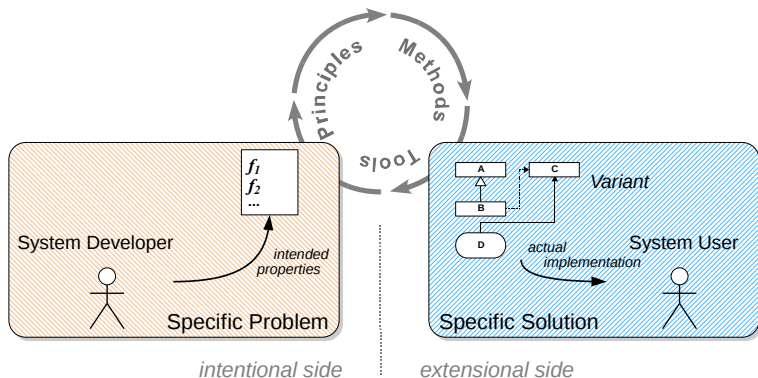
~> Konfigurierbare Systemsoftware – KSS

Throughout the software development cycle, **variability** and **granularity** have to be considered as primary design goals from the very beginning!

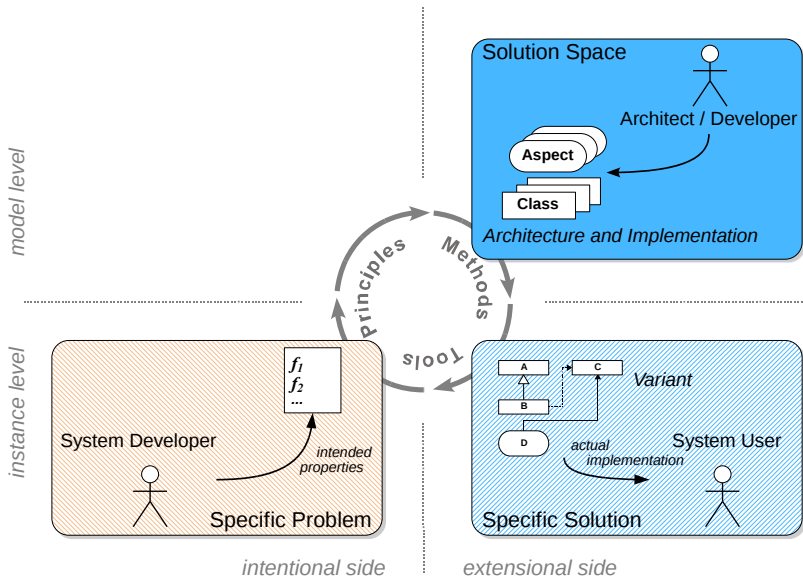
In KSS you will learn about **principles**, **methods**, and **tools** to achieve this.



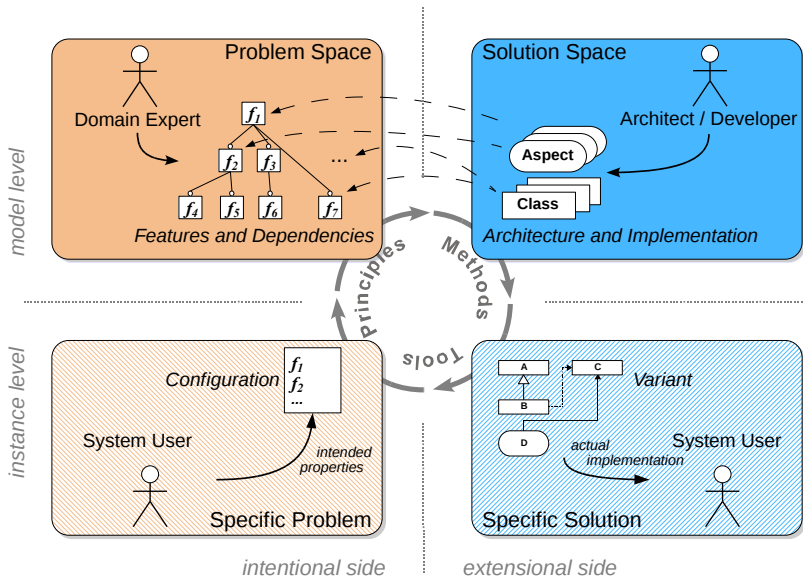
Individually Developed Software Product



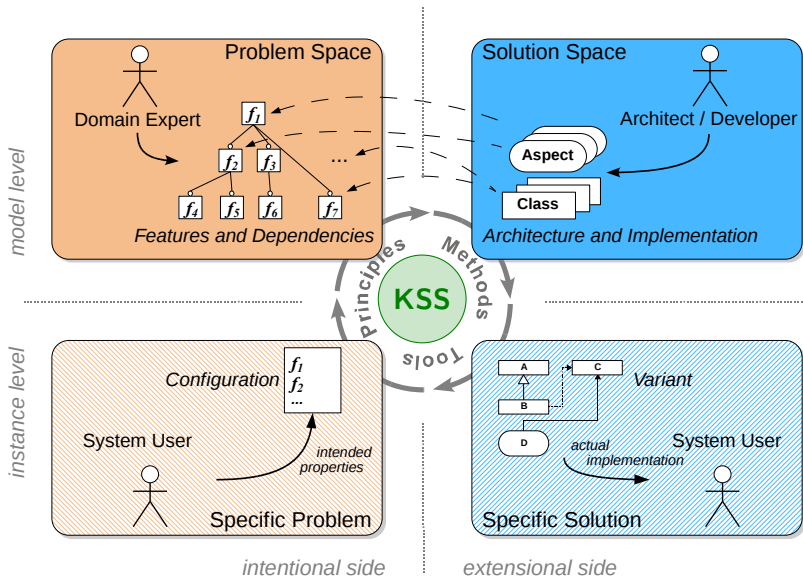
Software Product Derived from Reusable Assets



Configurable Software – Software Product Line



Configurable Software – Software Product Line



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Objectives

Einordnung

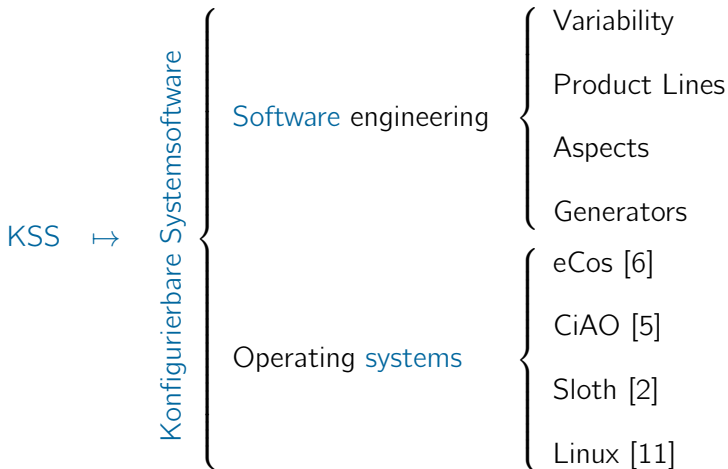
Semesterplanung

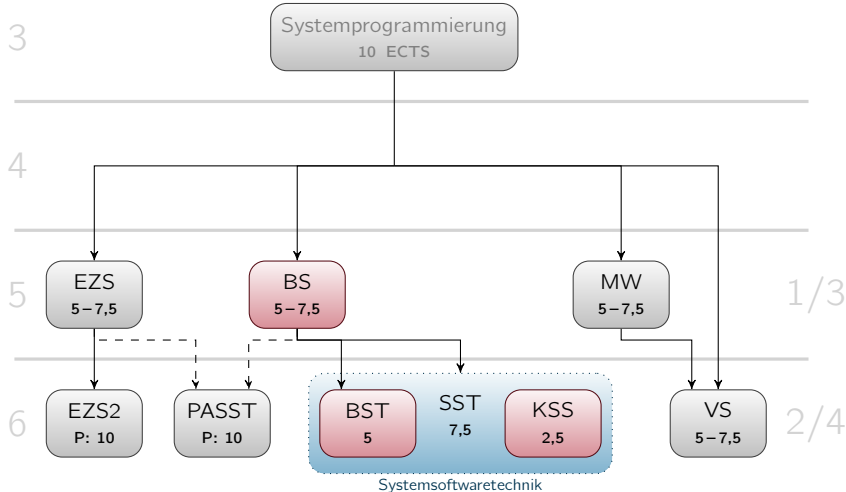
1.6 References



- **Improve** your understanding of the design and development of low-level system software
 - Starting point: “Betriebssysteme” [BS]
 - Focus: Static configuration and tailoring
- **Expand** your knowledge by new software engineering methods and language techniques for configurable system software
 - Software families and software product lines [7]
 - Aspect-oriented and generative programming in C/C++ [10]
- **Apply** these techniques in the context of current operating-system research projects
 - CiAO, SLOTH, VAMOS, DanceOS [2, 5, 9, 11]
 - Get prepared for a master thesis or project in the field!







- Modul Systemsoftwaretechnik (SST) 7.5 ECTS
 - ① Vorlesung Betriebssystemtechnik (BST) 2.5
 - Mo 12–14
 - 12–14 Vorlesungstermine
 - ② Übungen zu Betriebssystemtechnik (BST-Ü) 2.5
 - Di 10–12
 - 12–14 Übungstermine/Rechnerübungen
 - ③ Vorlesung und Übung **Konfigurierbare Systemsoftware (KSS)** 2.5
 - Do 14–16 (Vorlesung)
 - 7 Vorlesungstermine, 1 Übungsaufgabe, 1 Projekt
 - Übung integriert in BST-Übung / Rechnerübung
- ↪ KSS kann **nur zusammen mit BST** belegt werden!
 - Es gibt keine 2.5 ECTS Module...
 - Wenn Bedarf besteht, wird KSS auf 5 ECTS erweitert



Organisation: Beteiligte

Vorlesung



Daniel Lohmann

Übung



Daniel Danner



Gabor Drescher

Projekt



Daniel Danner



Martin Hoffmann



Jens Schedel



?



Semesterplanung

KW	Mo	Di	Mi	Do	Fr	Themen
15	07.04. BST VL1	08.04. KSS VL1	09.04.	10.04. KSS VL2	11.04.	BST VL1: Organisation und Einleitung KSS VL1: Introduction, Motivation and Concept KSS VL2: Software Families and Software Product Lines
16	14.04. BST VL2	15.04. TÜ BST A1	16.04.	17.04. Ostern	18.04.	BST VL2: Systemaufruf
17	21.04. Ostern	22.04.	23.04.	24.04. KSS VL3	25.04.	KSS VL3: Aspect-Oriented Programming, AspectC++
18	28.04. BST VL3	29.04. TÜ KSS A1	30.04.	01.05. 1. Mai	02.05.	BST VL3: Betriebssystemarchitektur
19	05.05. BST VL4	06.05.	07.05.	08.05. KSS VL4	09.05.	BST VL4: Hierarchien KSS VL4: Aspect-Aware Design, CiAO
20	12.05. BST VL5	13.05. TÜ BST A2	14.05. Abgabe BST A1	15.05. KSS VL5	16.05.	BST VL5: Adressraumverwaltung KSS VL5: Variability in the Large, VAMOS
21	19.05. BST VL6	20.05.	21.05.	22.05. KSS VL6	23.05.	BST VL6: Adressraummodelle KSS VL6: Generative Programming, Sloth
22	26.05. BST VL7	27.05.	28.05. Abgabe KSS A1	29.05. Himmelf.	30.05.	BST VL7: Sprachbasierung
23	02.06. BST VL8	03.06. TÜ BST A3	04.06.	05.06. Anstich	06.06.	BST VL8: Interprozesskommunikation
24	09.06. Pfingsten/Berg	10.06.	11.06.	12.06. KSS VL7	13.06.	KSS VL7: Conclusion, Summary
25	16.06. BST VL9	17.06.	18.06. Abgabe BST A2	19.06. Fronleich.	20.06.	BST VL9: Kommunikationsabstraktionen
26	23.06. BST VL10	24.06.	25.06.	26.06.	27.06.	BST VL10: Mitbenutzung
27	30.06. BST VL11	01.07.	02.07.	03.07.	04.07.	BST VL11: Bindelader
28	07.07. BST VL12	08.07.	09.07. Abgabe BST A3	10.07.	11.07.	BST VL12: Nachlese



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- [6] Daniel Lohmann, Fabian Scheler, Reinhard Tartler, et al. "A Quantitative Analysis of Aspects in the eCos Kernel". In: *Proceedings of the ACM SIGOPS/EuroSys European Conference on Computer Systems 2006 (EuroSys '06)*. (Leuven, Belgium). Ed. by Yolande Berbers and Willy Zwaenepoel. New York, NY, USA: ACM Press, Apr. 2006, pp. 191–204. ISBN: 1-59593-322-0. DOI: 10.1145/1218063.1217954.
- [7] Daniel Lohmann, Olaf Spinczyk, and Wolfgang Schröder-Preikschat. "Lean and Efficient System Software Product Lines: Where Aspects Beat Objects". In: *Transactions on AOSD II*. Ed. by Awais Rashid and Mehmet Aksit. Lecture Notes in Computer Science 4242. Springer-Verlag, 2006, pp. 227–255. DOI: 10.1007/11922827_8.
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- [9] Horst Schirmeier, Rüdiger Kapitza, Daniel Lohmann, et al. "DanceOS: Towards Dependability Aspects in Configurable Embedded Operating Systems". In: *Proceedings of the 3rd HiPEAC Workshop on Design for Reliability (DFR '11)*. Ed. by Alex Orailoglu. Heraklion, Greece, Jan. 2011, pp. 21–26.
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- [11] Reinhard Tartler, Daniel Lohmann, Julio Sincero, et al. "Feature Consistency in Compile-Time-Configurable System Software: Facing the Linux 10,000 Feature Problem". In: *Proceedings of the ACM SIGOPS/EuroSys European Conference on Computer Systems 2011 (EuroSys '11)*. (Salzburg, Austria). Ed. by Christoph M. Kirsch and Gernot Heiser. New York, NY, USA: ACM Press, Apr. 2011, pp. 47–60. ISBN: 978-1-4503-0634-8. DOI: 10.1145/1966445.1966451.
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