# Konfigurierbare Systemsoftware (KSS)

## VL 1 – Einführung

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SS 14 – 2014-04-08

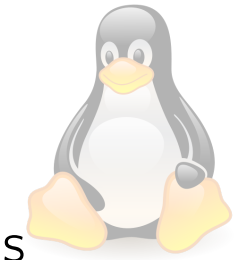
http://www4.informatik.uni-erlangen.de/Lehre/SS14/V_KSS

# Agenda



# 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]

$\notin$


# 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]

$\not\subset$

# 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");
}
```

# Agenda



# 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 to powerful?
  - supports many data types, formatting rules, ...
  - implementation requires a complex parser for the format string
- Let's try the much more specialized `puts()`!

# Reality Check: Granularity (Cont'd)

- 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 poweful?
  - buffered IO, streams
- Let's work directly with the OS file handle!

# Reality Check: Granularity (Cont'd)

- 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!

# Reality Check: Granularity (Cont'd)

- 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 ressort: 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 :-)**

# Reality Check: Lessons Learned

**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]

# Reality Check: Lessons Learned

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

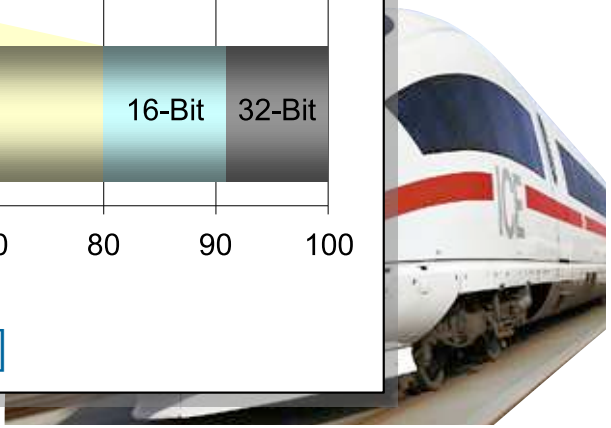
**What about other domains?**

# Agenda



# A Different Domain: Embedded Systems








CPU/DSP sales in **2002** [13]

# The ATmega $\mu$C Family (8-Bit)

| Type | Flash | SRAM | IO | Timer 8/16 | UART | $I^2C$ | 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 |

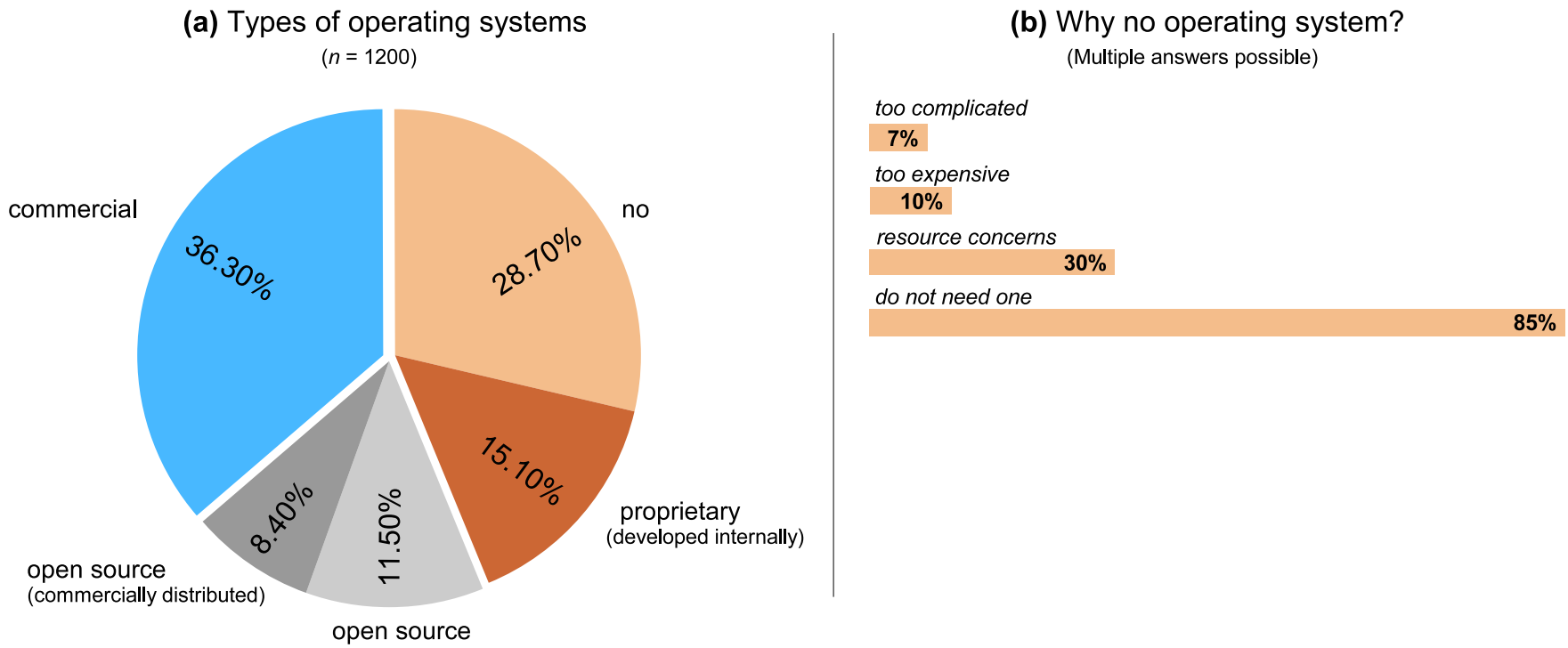
Bulk prices and features of ATmega variants (excerpt, DigiKey 2006)

## Limited Resources

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

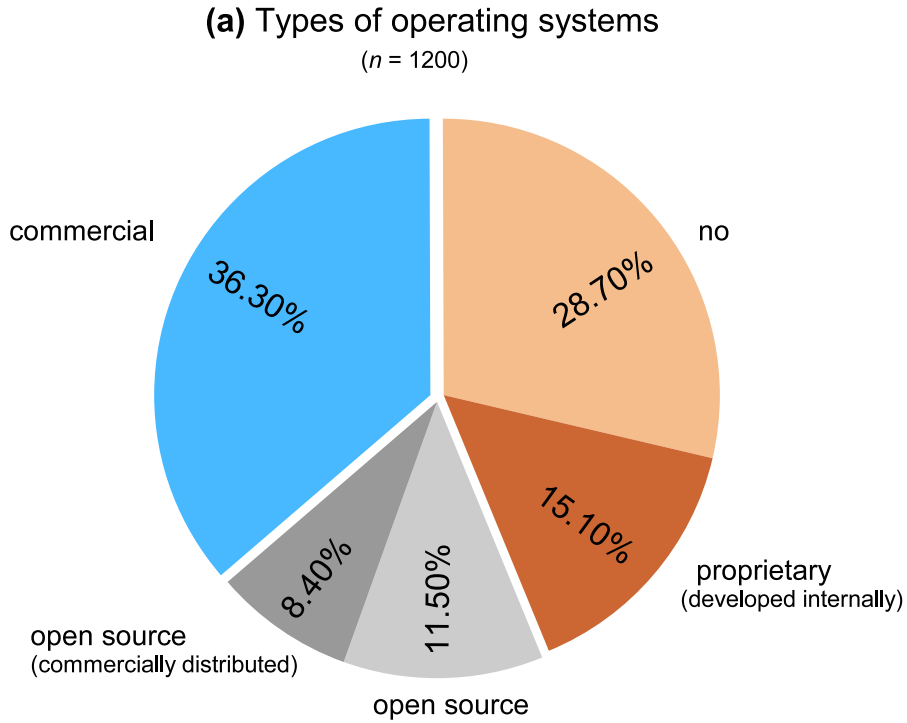
$\rightsquigarrow$ The "glibc approach" is **doomed to fail**!

# The Role of the Operating System




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

# The Role of the Operating System



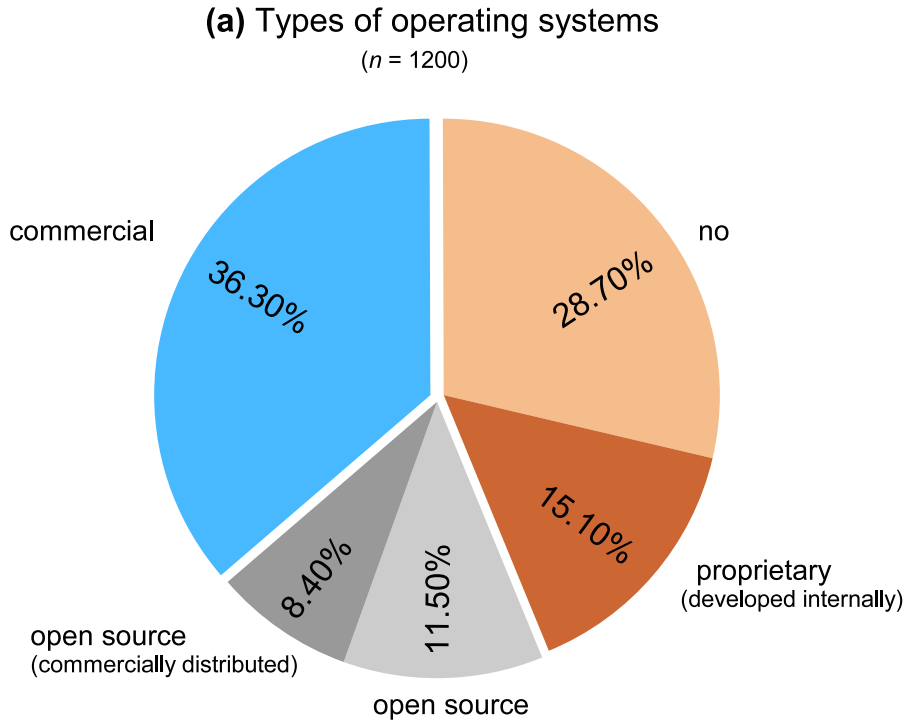

Operating systems (not) employed in embedded-system projects in 2006 [12]

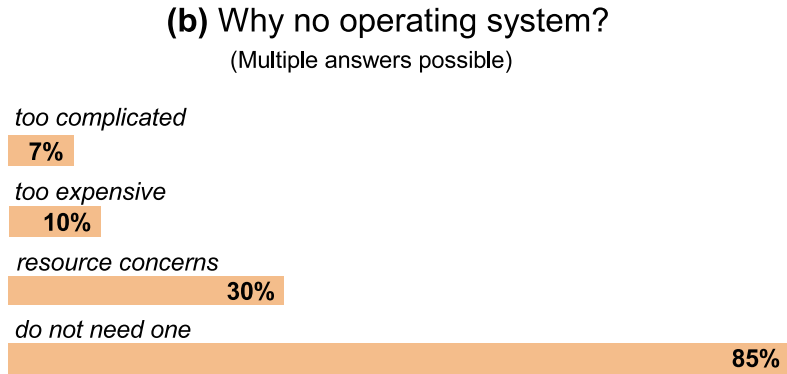
**> 40% of all projects use "in house" OS functionality!**

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




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, . . .

$\rightsquigarrow$ The "glibc approach" (one size fits all) **does not work**!

# Between a Rock and a Hard Place...

functional and nonfunctional *requirements*


tasks
sockets
file system
...
event latency
safety
...

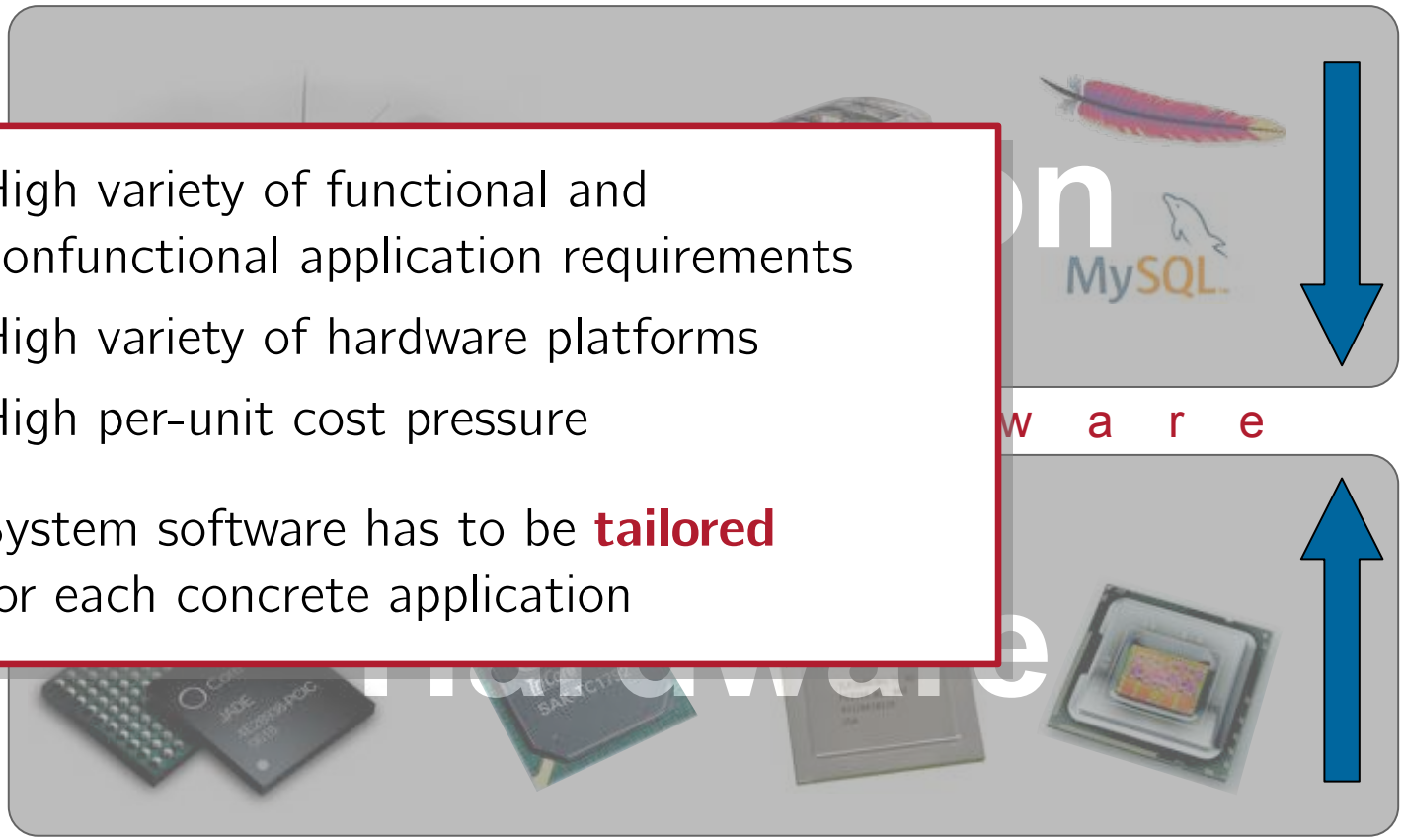
S y s t e m  S o f t w a r e


ISA
IRQ handling
MMU / MPU
...
cache size
coherence
IRQ latency
...

functional and nonfunctional *properties*

# 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
...
event latency
safety
...

ISA
IRQ handling
MMU / MPU
...
cache size
coherence
IRQ latency
...

functional and nonfunctional *properties*

# Customizing / Tailoring

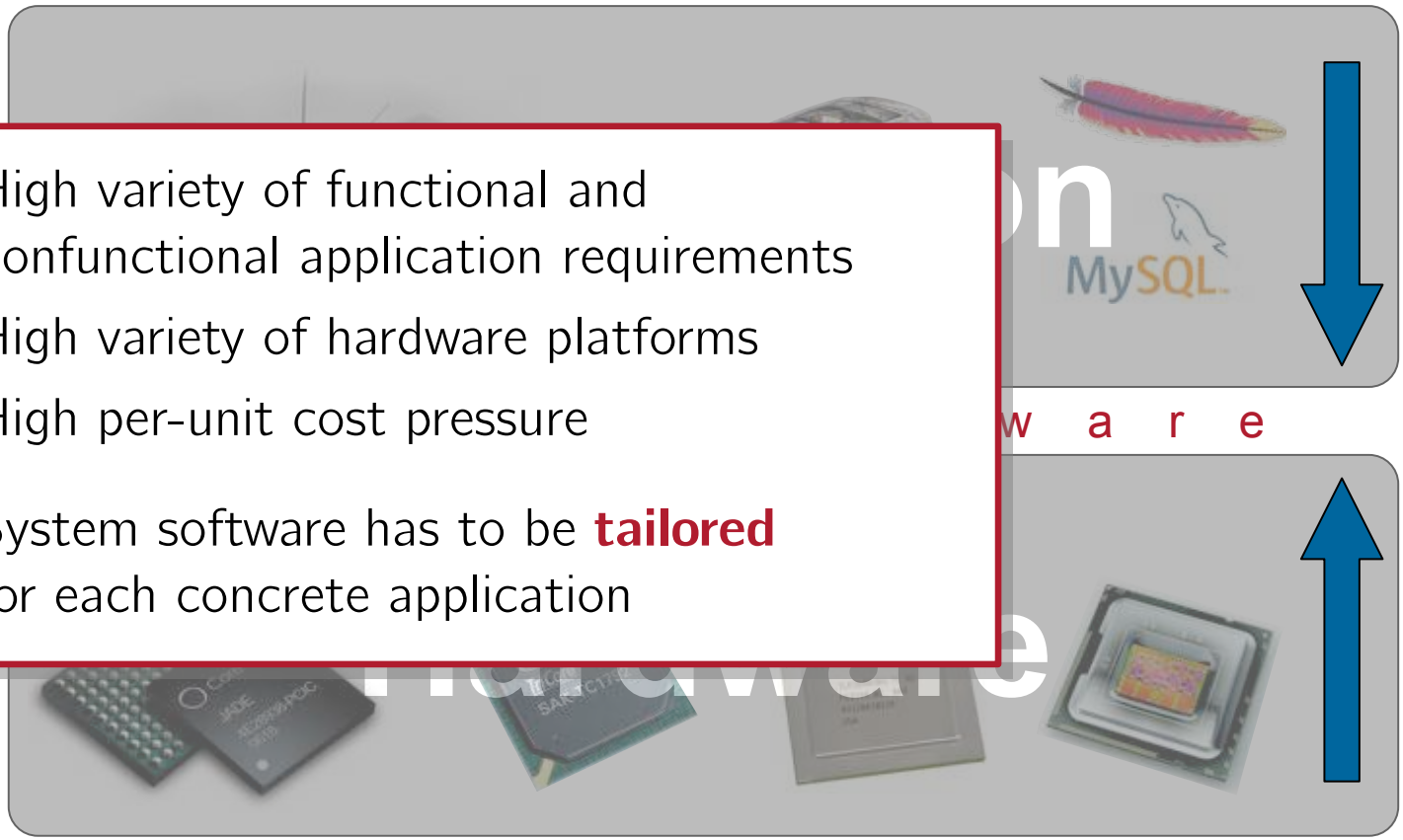
**Customizing/Tailoring** (Definition 3)

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...

functional and nonfunctional *requirements*

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functional and nonfunctional *properties*

# Agenda



# 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
    $\leadsto$ 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]
    $\leadsto$ `printf()` has become a "god method" [1]
- Reason: language and tool chain
  - Compiler/linker work on the granularity of symbols or even object files
    $\leadsto$ dead code is not effectively eliminated

# What to do?

297 $\longleftrightarrow$ 517703 Bytes! **Why?**

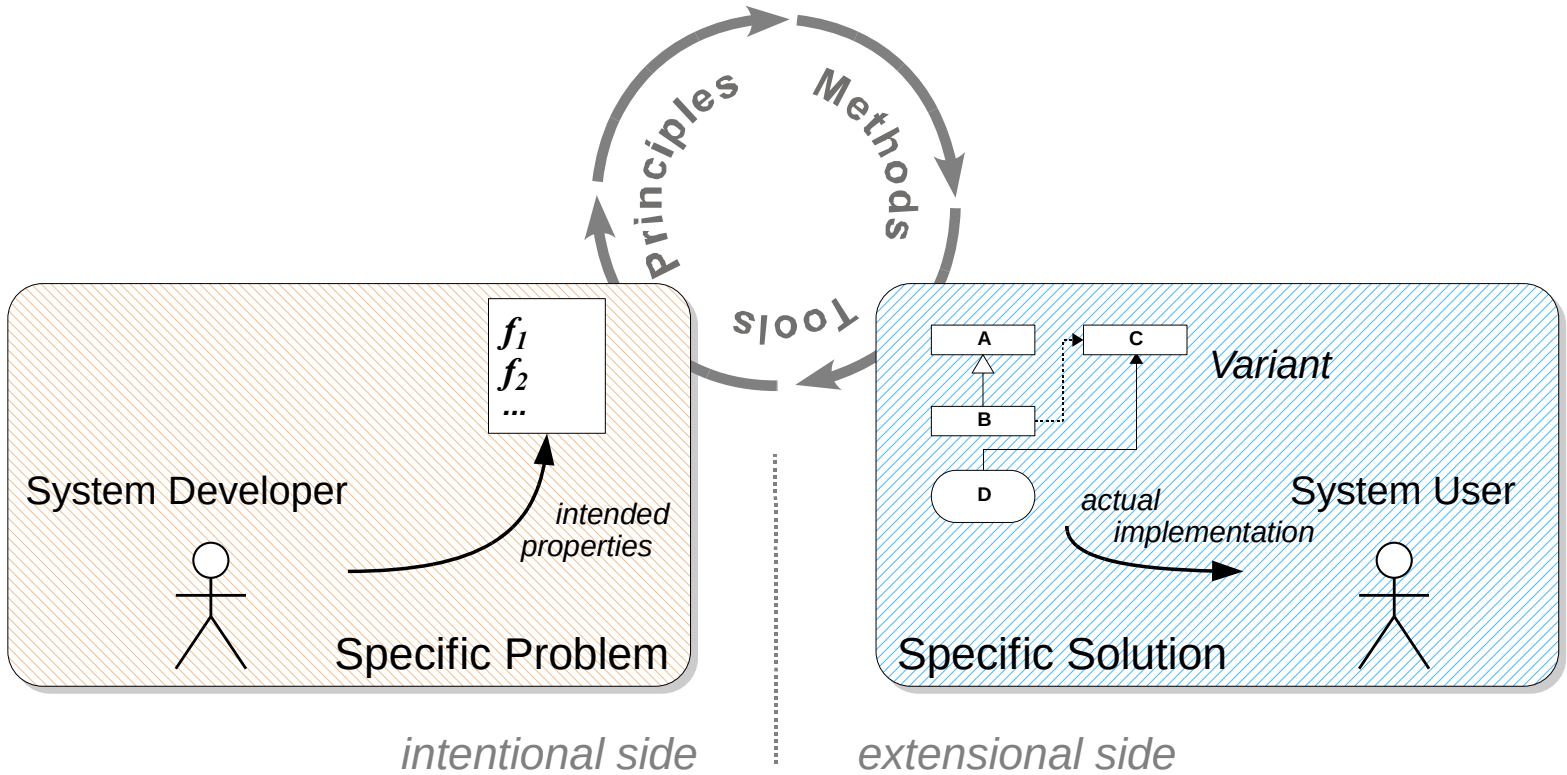
On Linux/glibc, a simple "Hello World" application takes **1750 times** more memory than necessary!

## $\rightsquigarrow$ Konfigurierbare Systemsoftware – KSS

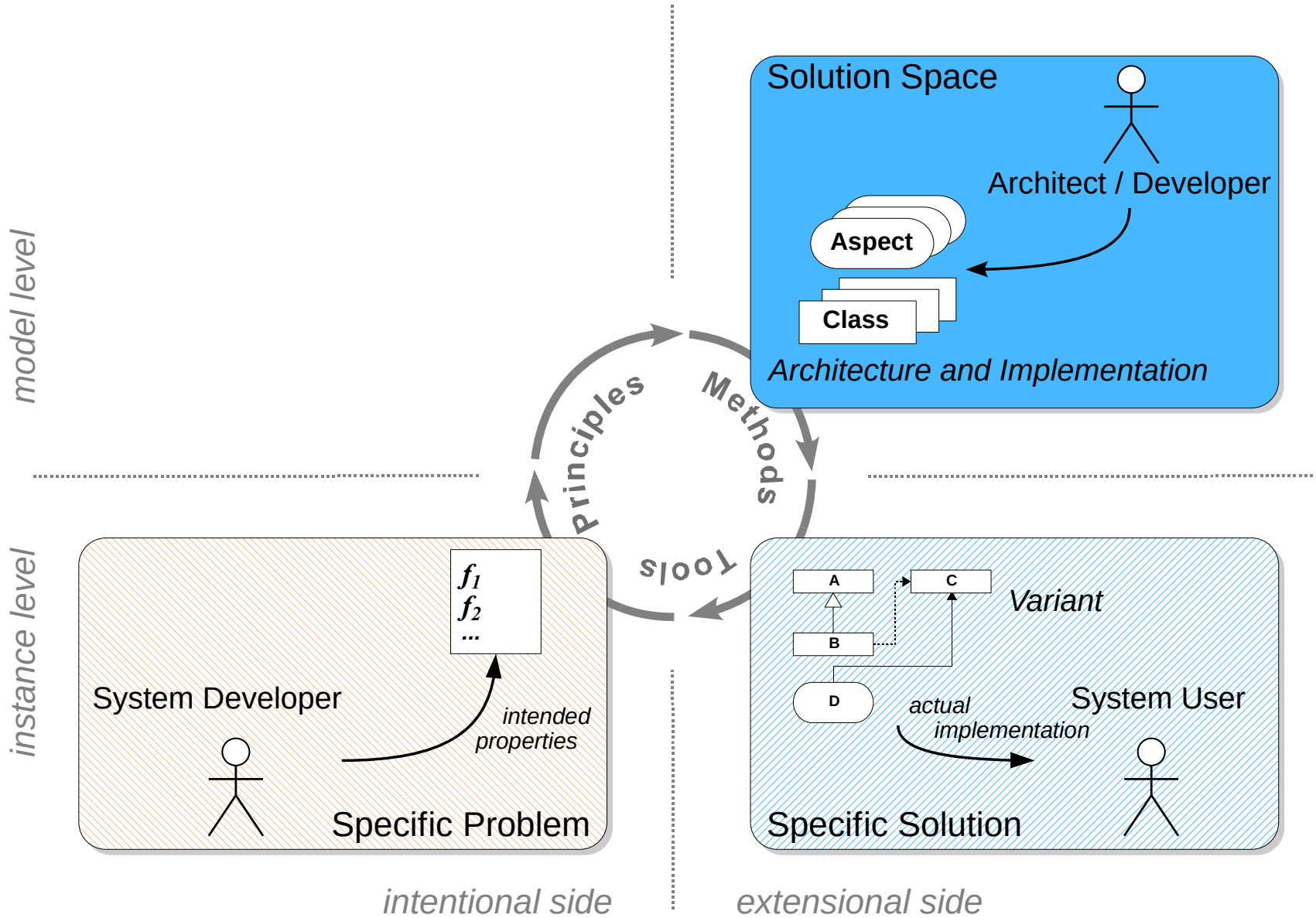
Througout the software development cycle, **variability** and **granularity** have to be considered as primary design goals from the very beginning!

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

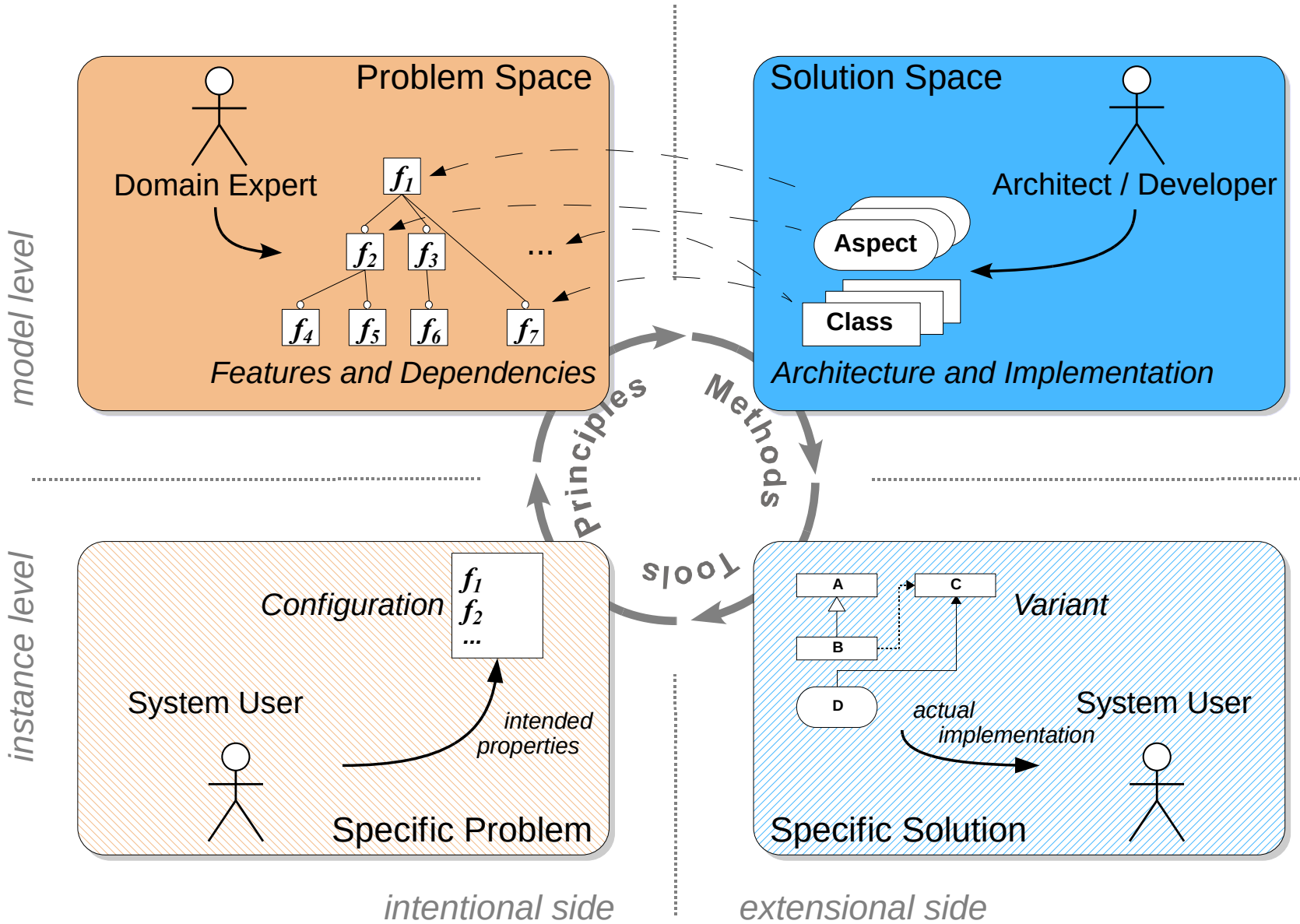
# Individually Developed Software Product



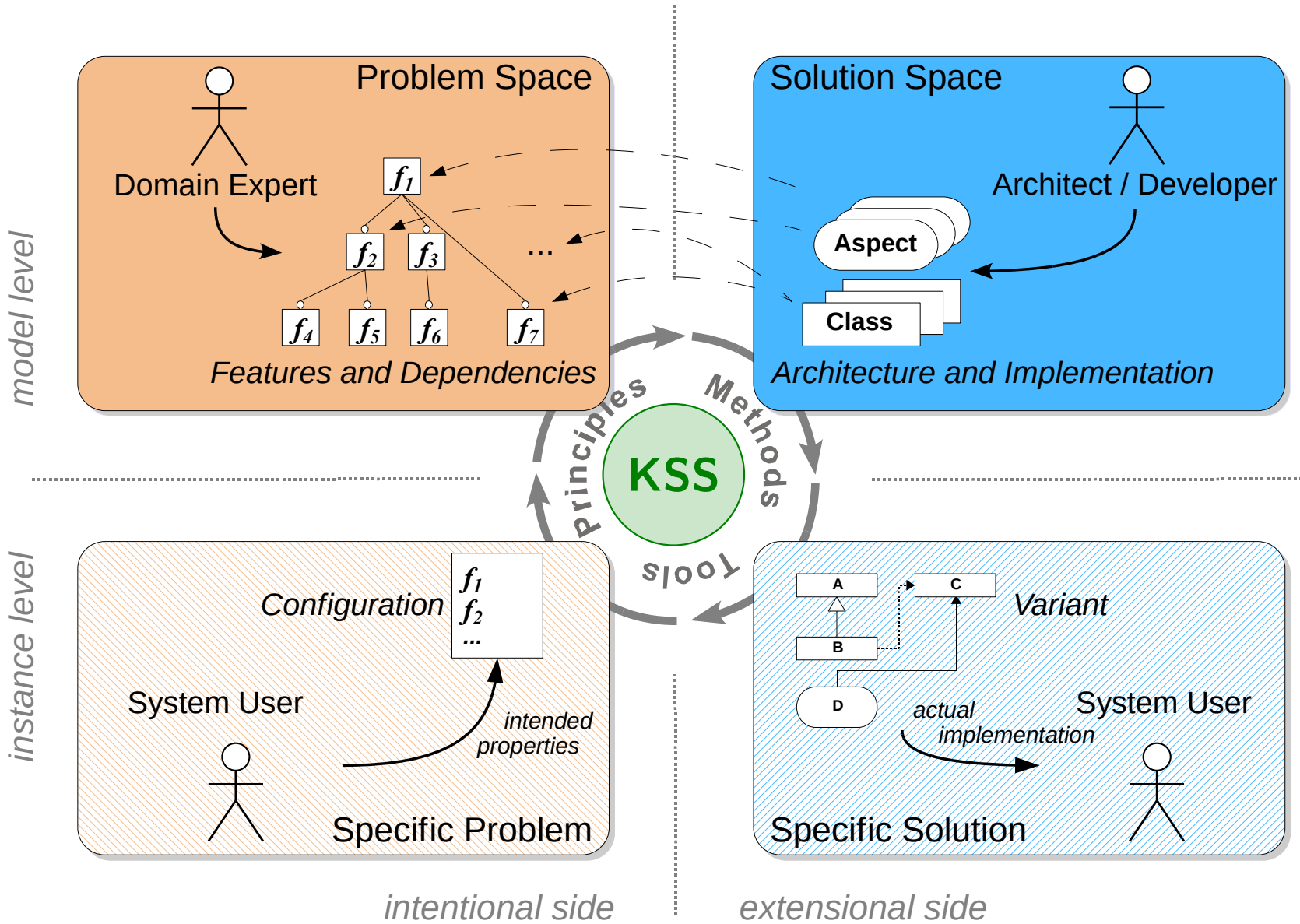
# Software Product Derived from Reusable Assets



# Configurable Software – Software Product Line



# Configurable Software – Software Product Line



# Agenda



# Learning Objectives

- **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!

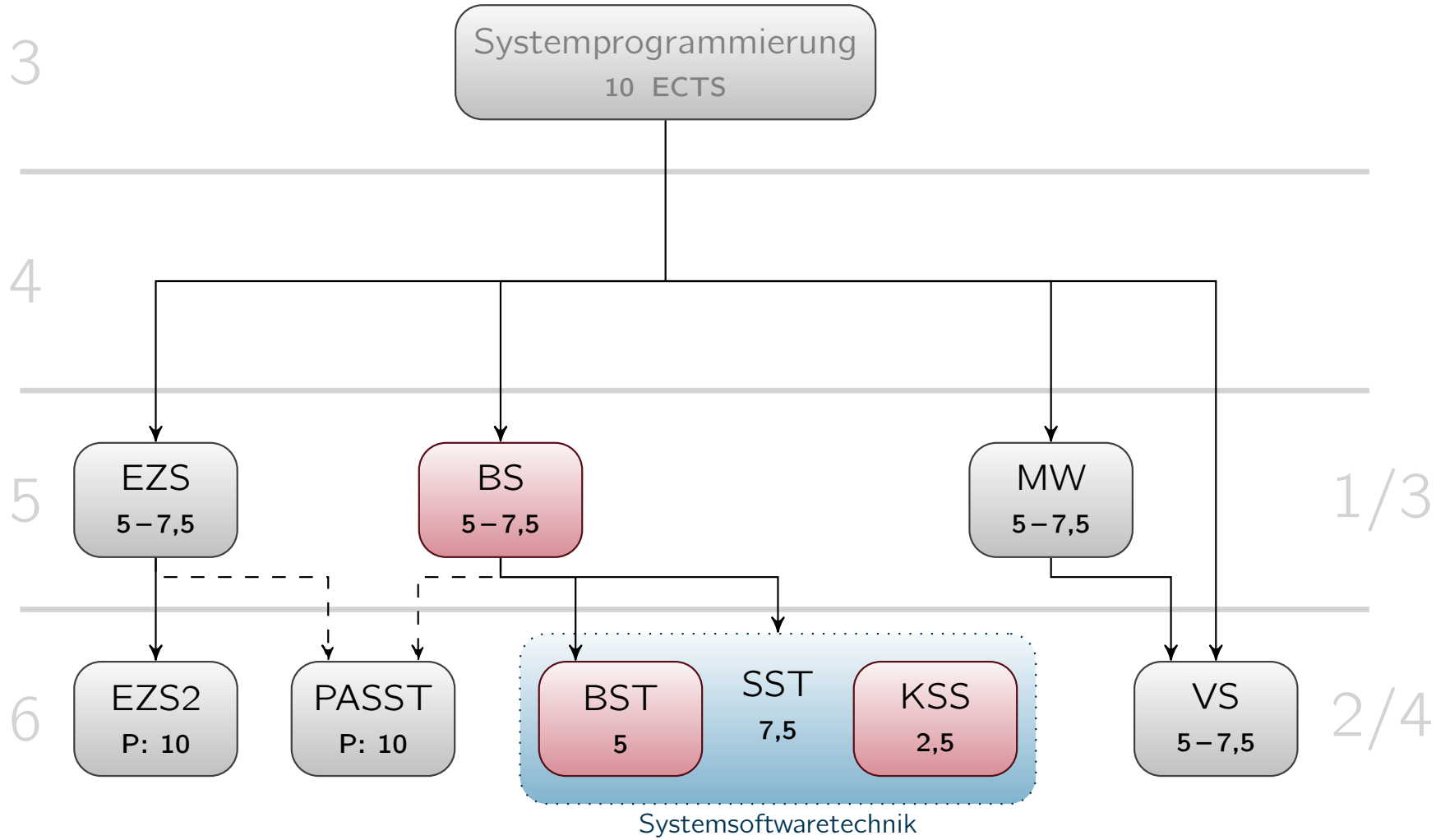
# Topics

KSS $\mapsto$ Konfigurierbare Systemsoftware

- Software engineering
  - Variability
  - Product Lines
  - Aspects
  - Generators
- Operating systems
  - eCos [6]
  - CiAO [5]
  - Sloth [2]
  - Linux [11]

# KSS – Einordnung

(Bachelor/Master)




# Organisation: Systemsoftwaretechnik (SST)

- 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
- $\leadsto$ KSS kann **nur zusammen mit BST** belegt werden!
  - Es gibt keine 2.5 ECTS Module...
  - Wenn Bedarf besteht, wird KSS auf 5 ECTS erweitert

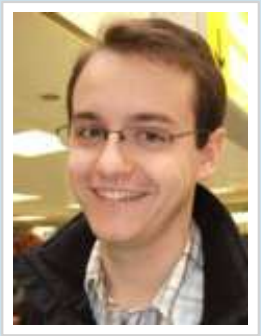
# Organisation: Beteiligte

## Vorlesung

Daniel Lohmann

## Übung

Daniel Danner



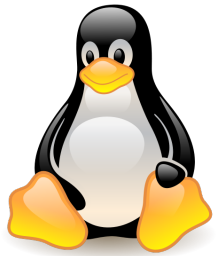
Gabor Drescher

## Projekt

Daniel Danner

Martin Hoffmann

Jens Schedel



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# Semesterplanung

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

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

# Referenzen


[1] Martin Fowler and Kendall Scott. *UML konzentriert*. 2nd ed. Addison-Wesley, 2000. ISBN: 3-8273-1617-0.

[2] Wanja Hofer, Daniel Lohmann, Fabian Scheler, et al. "Sloth: Threads as Interrupts". In: *Proceedings of the 30th IEEE International Symposium on Real-Time Systems (RTSS '09)*. (Washington, D.C., USA, Dec. 1–4, 2009). IEEE Computer Society Press, Dec. 2009, pp. 204–213. ISBN: 978-0-7695-3875-4. DOI: `10.1109/RTSS.2009.18`.

[3] International Organization for Standardization. *ISO/IEC 9899:TC2: Programming languages — C*. Geneva, Switzerland: International Organization for Standardization, 2005. URL: `http://www.open-std.org/JTC1/SC22/wg14/www/docs/n1124.pdf`.

[4] A.M. Lister and R.D. Eager. *Fundamentals of Operating Systems*. 5th. Macmillian, 1993. ISBN: 0-333-46986-0.

[BS] Daniel Lohmann. *Betriebssysteme*. Vorlesung mit Übung. Friedrich-Alexander-Universität Erlangen-Nürnberg, Lehrstuhl für Informatik 4, 2011 (jährlich). URL: `http://www4.informatik.uni-erlangen.de/Lehre/WS11/V_BS`.


# Referenzen (Cont'd)


[5] Daniel Lohmann, Wanja Hofer, Wolfgang Schröder-Preikschat, et al. "CiAO: An Aspect-Oriented Operating-System Family for Resource-Constrained Embedded Systems". In: *Proceedings of the 2009 USENIX Annual Technical Conference*. Berkeley, CA, USA: USENIX Association, June 2009, pp. 215–228. ISBN: 978-1-931971-68-3. URL: `http://www.usenix.org/event/usenix09/tech/full_papers/lohmann/lohmann.pdf`.

[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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