System-Level Programming

1 Introduction

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http://sys.cs.fau.de/lehre/ss24

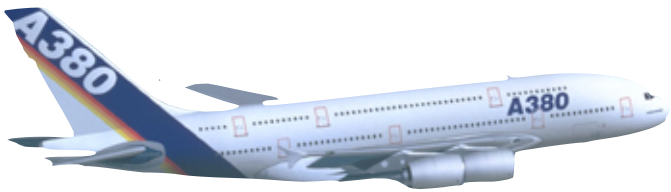
Introduction

- **Deepen** knowledge of concepts and techniques of computer science and software development
  - Starting point: Algorithms, Programming, and Data Representation
  - Main focus: System-Level Programming (SLP) in C
- **Development** of software in C for a μController (μC) and an operating-system platform (Linux)
  - SPiCboard learning development platform with an ATmega-μC
  - Practical experience in hardware and system-level software development
- **Understanding** of technological language and hardware basics for the development of system-level software
  - Being able to understand and assess the language C and
  - Dealing with concurrency and hardware proximity
  - Dealing with the abstractions of an operating system (files, processes, ...)

Motivation: Embedded Systems







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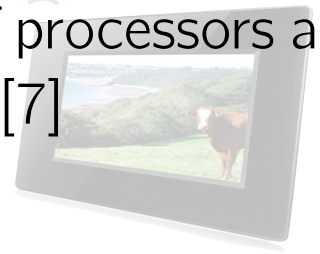
- **Omnipresent:** **98–99 percent** of processors are being used in **embedded systems** [7]









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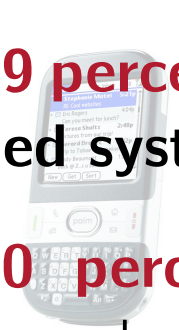
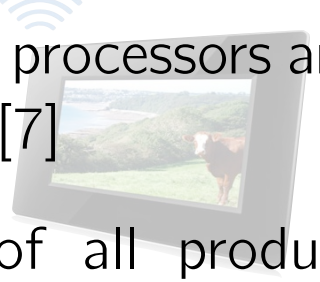
- **Omnipresent:** **98–99 percent** of processors are being used in **embedded systems** [7]
- **Cost-sensitive:** **70–80 percent** of all produced processors are DSPs and μController, based on **8-bit architecture or lower** [7, 8]



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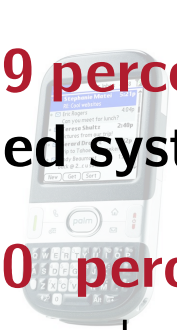
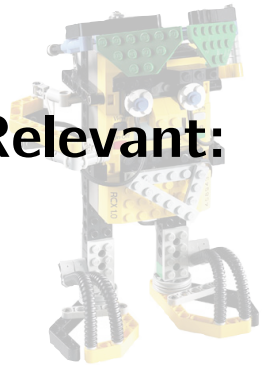
- **Cost-sensitive:** **70–80 percent** of all produced processors are DSPs and μController, based on **8-bit architecture or lower** [7, 8]
- **Relevant:** **25 percent** of job offers for EE engineers do contain the terms *embedded* or *automotive* (`http://stepstone.com`)



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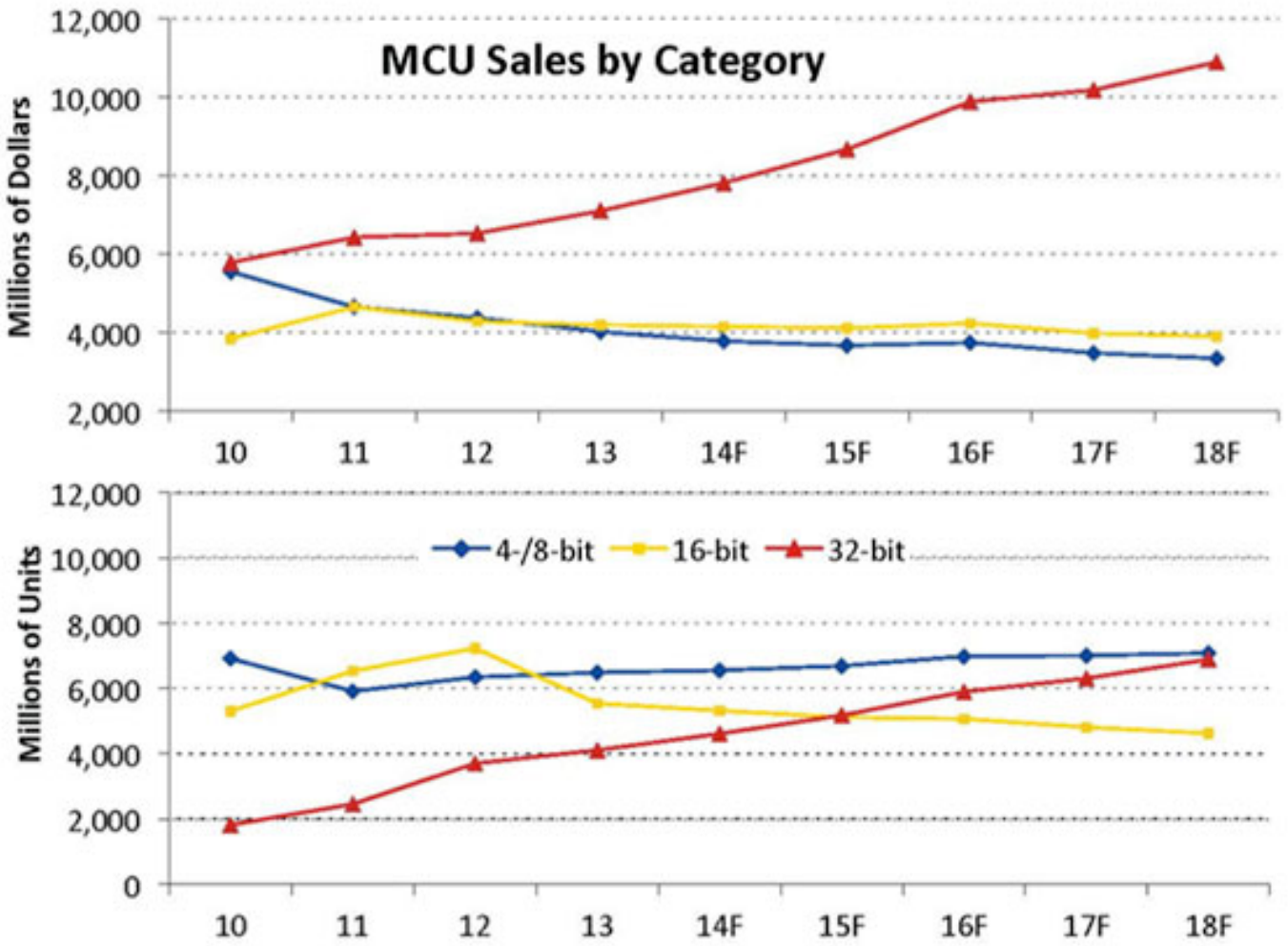

Source: IC Insights 2014 *McClean Report*

Motivation: The ATmega-μC Family (8-bit)

Type	Flash	SRAM	IO	Timer 8/16	UART	SPI	ADC	PWM	EUR
ATTINY13	1 KiB	64 B	6	1/-	-	-	1*4	-	**2,20**
ATTINY2313	2 KiB	128 B	18	1/1	-	1	-	-	**2,99**
ATMEGA48	4 KiB	512 B	23	2/1	1	1	8*10	6	**2,40**
ATMEGA16	16 KiB	1024 B	32	2/1	1	1	8*10	4	**6,40**
ATMEGA32	32 KiB	2048 B	32	2/1	1	1	8*10	4	**5,40**
ATMEGA64	64 KiB	4096 B	53	2/2	2	1	8*10	8	**–**
ATMEGA128	128 KiB	4096 B	53	2/2	2	1	8*10	8	**19,80**
ATMEGA256	256 KiB	8192 B	86	2/2	4	1	16*10	16	**15,50**

ATmega variants (selection) and market prices (Reichelt Elektronik, April 2023)

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- Becomes visible: **resource scarcity**
  - **Flash** (storage for program code and constant data) is **scarce**
  - **RAM** (storage for runtime variables) is **extremely scarce**
  - few bytes "wasted" $\rightsquigarrow$ significantly higher cost per piece

Motivation: C as a Language

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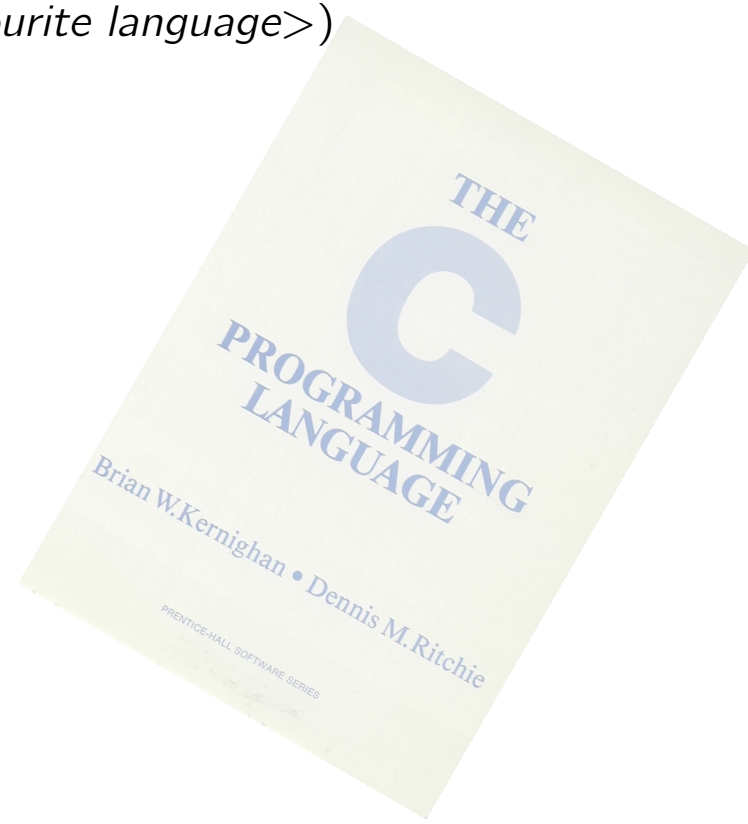
  - **Why C?** (and not Python/Java/Scala/<*favourite language*>)



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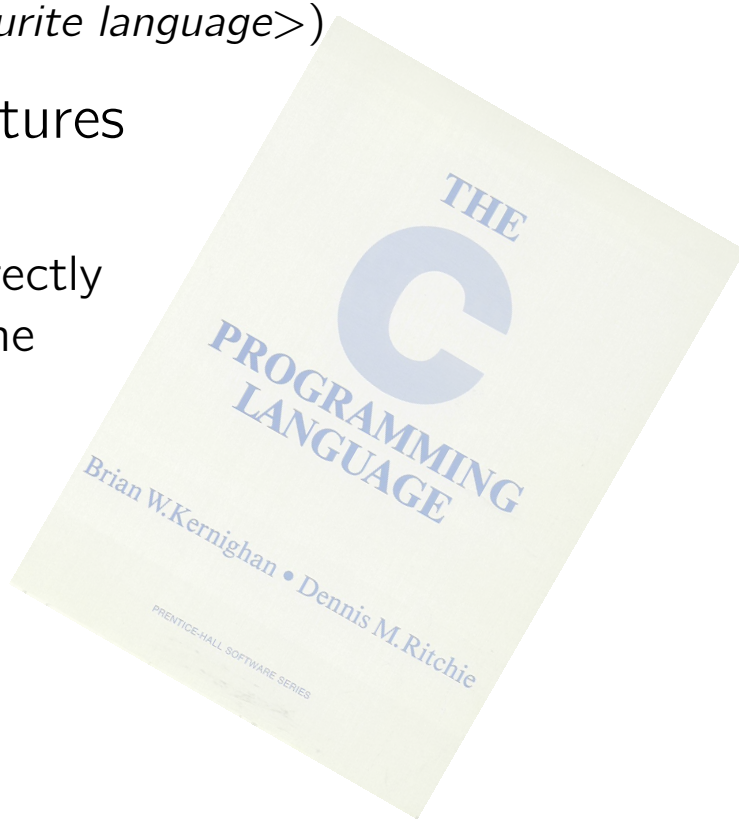

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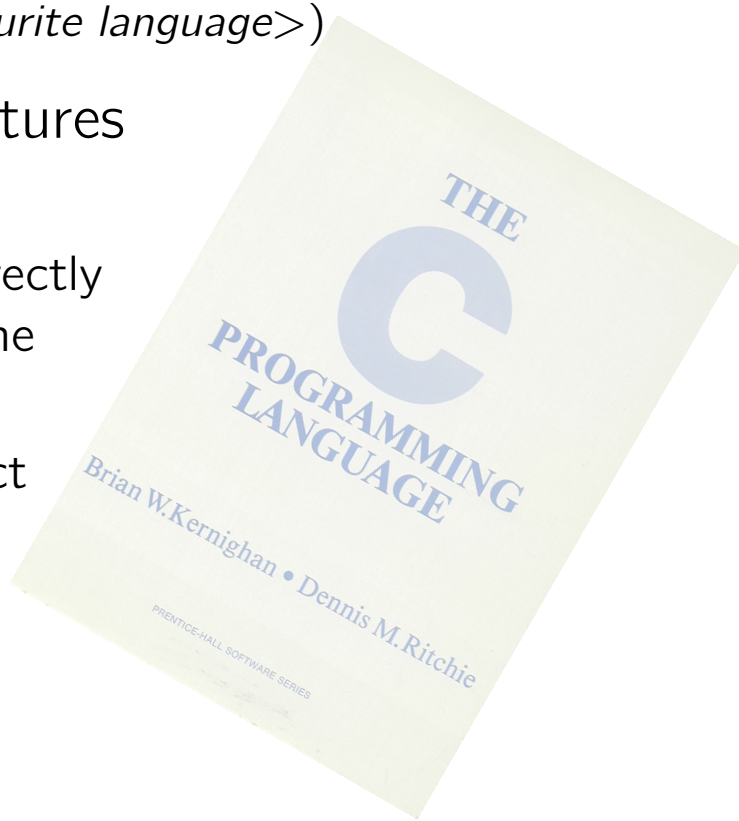

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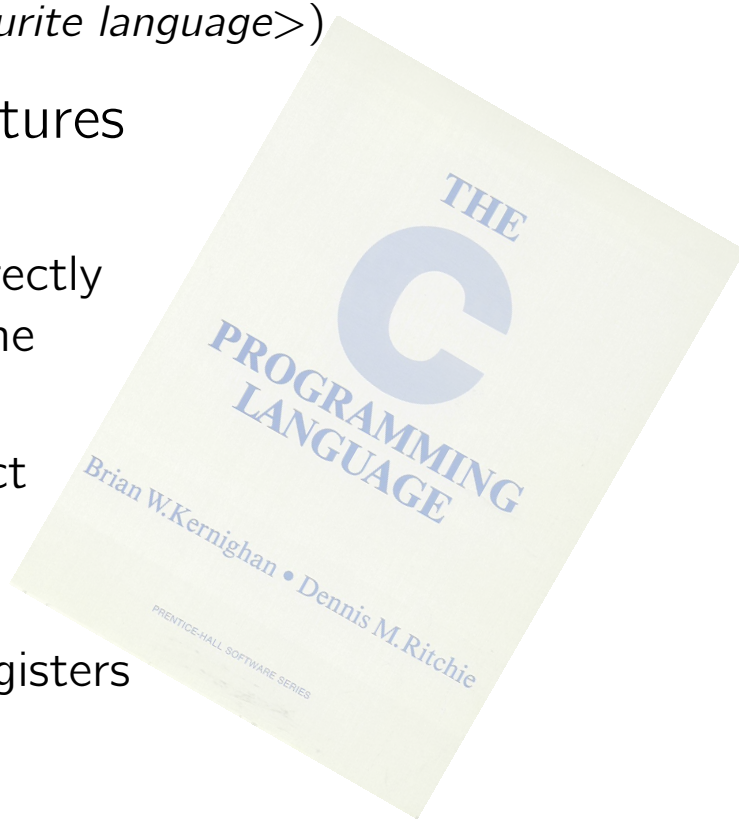

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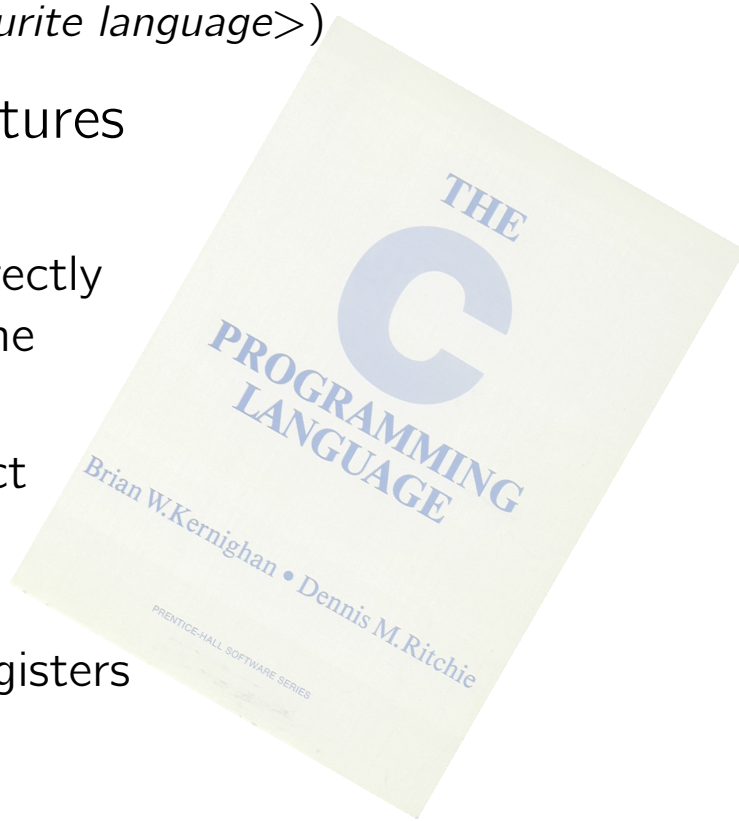
  - Portability
    - There is a C compiler for **every** platform
    - C was "invented" (1973), to implement the OS UNIX portable [4, 6]



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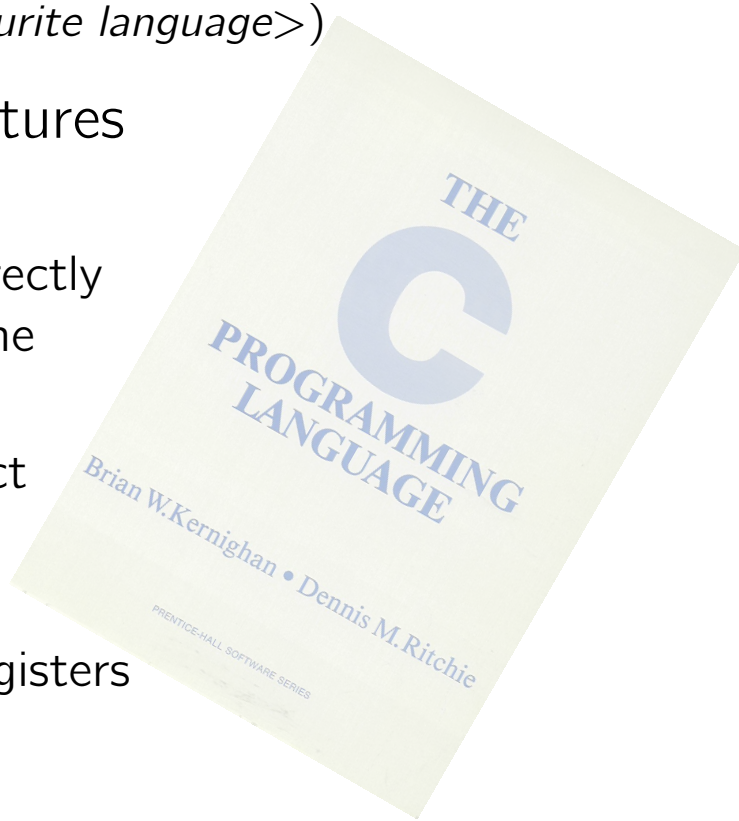


↝ **C** is the **lingua franca** of system-level programming!

Motivation: SLP – Syllabus and Concept

- **Teaching objective:** system-level programming in C
  - This is a really broad field: hardware programming, operating systems, middleware, data bases, distributed systems, compiler construction, ...
  - Additionally, we have the goal of learning the language C itself
- **Approach**
  - Concentration on two domains
    - μC programming
    - Software development for Linux system interface
  - Experience contrast μC-environment $\leftrightarrow$ operating system
  - Concepts and techniques get teachable and tangible with the help of various examples
  - **High relevance** for the target audience (EE, ME, ...)

Motivation: SLP

At the end of the lecture, everyone should be able to assess,

- what a μController can (not) do,
- how labor-intensive & beneficial its programming is,
- what an operating system does (not) provide,
- how labor-intensive & beneficial it is, to use one.

Everyone should be able to work with a computer scientist, if necessary...

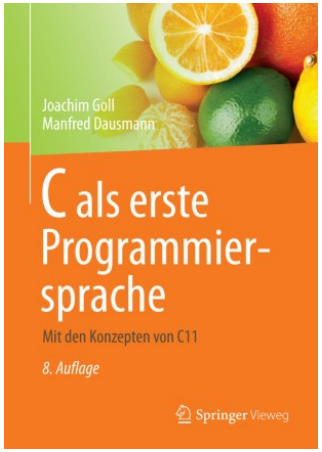
Lecture Notes

- This handout of the lecture notes will be provided online.
  - Chapters are available as individual files
  - The handout contains (some) additional information
- **However, the handout cannot be used as a substitute for making your own notes!**

Literature Recommendations

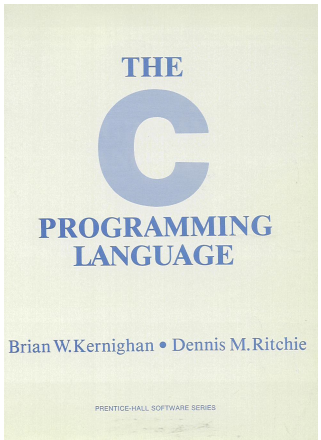
[3] Recommended for Beginners:

Joachim Goll und Manfred Dausmann. *C als erste Programmiersprache*. (Als E-Book aus dem Uninetz verfügbar). Springer Vieweg, 2014. ISBN: 978-3-8348-2271-0. URL: https://link.springer.com/book/10.1007/978-3-8348-2271-0



[5] The "classic" (more suitabe as a reference):

Brian W. Kernighan und Dennis MacAlistair Ritchie. *The C Programming Language (2nd Edition)*. Englewood Cliffs, NJ, USA: Prentice Hall PTR, 1988. ISBN: 978-8120305960



References

[2] Manfred Dausmann, Ulrich Bröckl, Dominic Schoop u. a. *C als erste Programmiersprache: Vom Einsteiger zum Fortgeschrittenen*. (Als E-Book aus dem Uninetz verfügbar; PDF-Version unter `/proj/i4spic/pub/material/`). Vieweg+Teubner, 2010. ISBN: 978-3834812216. URL: `https://www.springerlink.com/content/978-3-8348-1221-6/#section=813748&page=1`.

[4] Brian W. Kernighan und Dennis MacAlistair Ritchie. *The C Programming Language*. Englewood Cliffs, NJ, USA: Prentice Hall PTR, 1978.

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[7] David Tennenhouse. "Proactive Computing". In: *Communications of the ACM* (Mai 2000), S. 43–45.

[8] Jim Turley. "The Two Percent Solution". In: *embedded.com* (Dez. 2002). `http://www.embedded.com/story/OEG20021217S0039`, visited 2011-04-08.