CONTOURS OF INFORMATICS

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Agenda

- Aims & Objectives
- CVs
- Informatics – A Delineation — Syntax
- The Disciplines of Informatics — Semantics
  - ⋆ The Computer & Computing Sciences and Mathematics
  - ⋆ Linguistics/Semiotics and Philosophy
  - ⋆ Knowledge & Domain Engineering: A Domain Description Example
  - ⋆ IT Applications and Software Engineering
- On Methods and On Formal Techniques
- On Informatics Engineering:
  - ⋆ On Professionalism,
  - ⋆ CS, CS & SE
  - ⋆ On Obstacles to Professional SE
  - ⋆ A New Kind of Software Engineer
- Informatics — A New Universe
- Conclusion

Aims & Objectives

Aims

- To let you in on my way of thinking about my field of study —
- an approach that has obviously determined
  - ⋆ my teaching, my research and hence
  - ⋆ the structure and contents of my 3-volume book,
- and an approach and a view that pleads for a central rôle of the new field of domain science and engineering

Objectives

- To, perhaps, get you to think and act along a similar line —
- and maybe to put some more Informatics into DTU/IMM
- and some more interest in domain science and engineering.

CVs
Syntax

- MSc EE, Jan. 1962, PhD CS, Jan. 1969
- **IBM** Devt.: Stockholm, Hursley (UK) and San Jose (Calif.)
  - ⋆ Hardware Design, March 1962 — June 1969 Wonderful years
- **IBM** Research:
  - ⋆ Calif., July 1969 — April 1973 Wonderful years
  - ⋆ Wien: May 1973 — Aug. 1975 Wonderful and decisive years
- Vis.Prof.:
  - ⋆ **UC Berkeley** 1971–72
  - ⋆ **DIKU** Sept. 1975 — Aug. 1976
  - ⋆ **Kiel** Spring/Summer 1980
  - ⋆ **NUS**, Singapore 2004/2005
  - ⋆ **JAIST** (Japan) 2006
- Professor at **DTU**: Sept. 1976 — March 2007
- Co-founder (w/ **Chr. Gram**) and Sci. Advisor: **DDC**: Sept. 1979 — Dec. 1989
- Founding and First UN Director: **UNU-IIST**: Feb. 1992 — June 1997

CVs (Continued)
Semantics

- Computer Architectures and Machine Organisation 1962 – 1969
  IBM 1070, IBM 1800, ACS-1
- With (the late) John W. Backus: Red-1, Red-2 $\Rightarrow$ ffp 1969 – 1971
- With (the late) Ted Codd: DSL-α $\Rightarrow$ SQL 1971 – 1973
- Semantics of Programming Languages: IBM's PL/I, etc. $\Rightarrow$ VDM 1973 – 1975
- VDM: The Vienna Development Method 1973 – 1984
  formal, mathematics-based staged devt. of provably correct software
- Use of VDM for CHILL, Ada, etc. 1978 – 1984
- R&D of RAISE: Rigorous Approach to Industrial Softw. Eng. 1985 – ...
- Influence:
  - ⋆ *J. McCarthy, P. Landin, Dana Scott, (the late) C. Strachey, ... 1964/1973 – ...*
  - ⋆ *The IBM Vienna Group (Lucas, (the late) Bekič, Walk, Jones) 1973 – 1975 – ...*
  - ⋆ *IFIP WG2.3: (the late) E.W. Dijkstra, C.A.R. Hoare, M.A. Jackson, ... 1979 – ...*
  - ⋆ *(the late) Søren Prehn, Chris George, ... 1984 – ...*

Informatics — A Delineation (Syntax)

Software development requires many more proficiencies than "just programming":

- **Informatics**

  $=$ Computer Science $\oplus$ Computing Science *Datalogi*

  $\oplus$ Mathematics

  $\oplus$ Linguistics/Semiotics $\Rightarrow$ Philosophy

  $\oplus$ Software Engineering *Datamatik*

  $=$ **Domain Engineering**

  $\oplus$ Requirements Engineering

  $\oplus$ Software Design

  $\oplus$ IT Applications

Computer Science (I of II) — Rough Delineation

There are, pragmatically speaking two rather distinct sciences involved here:

- Comput**er** science
  - ⋆ is the study and knowledge about
  - ⋆ which "kind of things"
  - ⋆ can "exist inside" computers —
  - ⋆ including investigating the issues
    - ◇ "what are computers", "what does exist mean".

Computing Science (I of II) — Rough Delineation

- Comput**ing** science
  - ⋆ is the study and knowledge about
  - ⋆ how to construct "those things."

Computer Science (II of II) — Examples

- Examples of computer science topics:
  - ⋆ computability, computational models
  - ⋆ abstract complexity theory
  - ⋆ automata theory and formal languages
  - ⋆ *&c.*

Computing Science (II of II) — Foundational Examples

- Examples of computing science topics:
  - ⋆ Algorithmics, searching, sorting, ...
  - ⋆ Functional, logic, imperative and parallel programming
  - ⋆ Abstraction and modelling, refinement calculi
  - ⋆ Verification, model checking, (formal) testing *&c.*

Computing Science (II of II (Continued)) — Application Examples

- Semantics of programming languages
  and "their" interpreters and compilers
- Semantics of information (database) systems
  and their database management systems
- Semantics of process systems
  and their management (operating) systems
- Semantics of data movement
  and its management (data communication) systems
- Semantics of the Internet and the Web concept,
  Internet systems, Web programming, *&c.*
- *&c.*

Mathematics

Informatics is not based in the natural science.
Informatics has a main base in mathematics.

- **"Pure" Mathematics** **foundations and practice**
  - ⋆ Discrete Math.:
    - ◇ Logic **but not in the classical sense of math. logic**
    - ◇ Algebra **but not in the classical sense of algebra**
    - ◇ Graph Theory and Combinatorics, ...
  - ⋆ Meta-Mathematics (λ-Calculus, Recursive Function Theory)
  - ⋆ Calculus, Probability Theory, Statistics, ... *sometimes forgotten*
- **"Applied" Mathematics** **practice**
  - ⋆ Operations Research, ...

Linguistics/Semiotics

Informal narrative descriptions, prescriptions and specifications go hand-in-hand with formal such.

And: descriptions, prescriptions and specifications cover the below facets of semiotics:

- **Pragmatics**
  SEs tend to "hide" the pragmatics
- **Semantics** *Can be formalised*
- **Syntax** *Can be formalised*
  CS Depts. tend to focus mostly on syntax

Philosophy

- What can exist ?
- What can be described and what is a description ?

- **Mereology:** *theory of parts (and wholes)*
- **Espistemology:** *the study of knowledge and justified belief*
  - ⋆ epistemology is about issues
    - ◇ having to do with the creation and dissemination of knowledge
    - ◇ in particular areas of inquiry;
  - ⋆ translates into issues of scientific methodology:
    - ◇ how can one develop theories or models
    - ◇ that are better than competing theories ... ?
- **Ontology:** *specification of a conceptualization*

The Domain Engineering Dogma

- *Before* **software** *can be* **design***ed*
- *we must understand its* **requirements**.
- *Before* **requirements** *can be expressed*
- *we must understand the (application)* **domain**.

Software Engineering

- Ideally
  - ⋆ first: $\mathcal{D}$**omain Engineering**
  - ⋆ then: $\mathcal{R}$**equirements Engineering**
  - ⋆ finally: $\mathcal{S}$**oftware Design**
- such that $\mathbf{D}, \mathbf{S} \models \mathbf{R}$

Domain Science and Engineering

- **By a domain we understand a universe of discourse.**
- Examples of domains:
  - ⋆ *airports* (**Changi**)
  - ⋆ *air traffic* (**Pearl River Delta**)
  - ⋆ *container logistics* (**Maersk, SG**),
  - ⋆ *documents* (**Fuji Xerox, IBM**)
  - ⋆ *financial services*
  - ⋆ *health care (incl. EPJ)*
  - ⋆ *Internet (ubiquitous computing)*
  - ⋆ *IT security* (**IBM TRL**)
  - ⋆ *robotics (1991 paper,* **Kyushu** *[2006])*
  - ⋆ *transportation, as such, or*
    - ◇ *electronic road pricing* (**Singapore**)
    - ◇ *railways*
    - ◇ *road traffic*

  &c.
- **By domain engineering we understand the R&D of domain descriptions.**
- **By domain science we understand the study and knowledge about domain descriptions.**

Domain Engineering — Why Not ?

- All other, i.e., the classical, engineering disciplines builds on (the natural) sciences.
- No-one would hire a $\mathcal{Y}$ engineer unless that person was strong in science $\mathcal{X}$, where $\mathcal{X}$ provides the foundation for $\mathcal{Y}$.
- But as for domain $\mathcal{A}$ software engineers, no-one asks for competence in science $\mathcal{B}$, where science $\mathcal{B}$ could be the domain science of for example
  - ⋆ air traffic,
  - ⋆ container logistics,
  - ⋆ financial services,
  - ⋆ health care,
  - ⋆ transportation,
  - ⋆ or other.

Example of a Domain Description

- A multi-modal transport net consists of one or more segments and two or more junctions.
- With segments [junctions] we can associate the following attributes:
  - ⋆ segment [junction] identifiers,
  - ⋆ the identifiers of the two junctions to which segments are connected [the identifiers of the one or more segments connected to the junction],
  - ⋆ the mode (road, rail, air-lane, shipping lane) of a segment [the modes of the segments connected to the junction].

type

N, S, J, Si, Ji, M

value

obs_Ss: N $\longrightarrow$ S-**set**, obs_Js: N $\longrightarrow$ J-**set**

obs_Si: S $\longrightarrow$ Si, obs_Ji: J $\longrightarrow$ Ji

obs_Jis: S $\longrightarrow$ Ji-**set**, obs_Sis: J $\longrightarrow$ Si-**set**

obs_M: S $\longrightarrow$ M, obs_Ms: J $\longrightarrow$ M-**set**

axiom

$\forall$ n:N $\cdot$ **card** obs_Ss(n) $\geq 1 \wedge$ **card** obs_Js(n) ≥ 2

$\forall$ n:N $\cdot$ **card** obs_Ss(n) $\equiv$ **card** {obs_Si(s)|s:S $\cdot$ s $\in$ obs_Ss(n)}

$\forall$ n:N $\cdot$ **card** obs_Js(n) $\equiv$ **card** {obs_Ji(c)|j:J $\cdot$ j $\in$ obs_Js(n)}

...

type

Nm, Co, Ye

value

obs_Nm: N $\longrightarrow$ Nm, obs_Co: N $\longrightarrow$ Co, obs_Ye: N $\longrightarrow$ Ye

Software Engineering

- Software Engineering

  $=$ **Domain Engineering**

  $\oplus$ Requirements Engineering

  $\oplus$ Software Design

- We have yet to more fully understand the interplay between knowledge engineering and domain engineering (K&DE).
- Is knowledge engineering a proper part of domain engineering ?
- Maybe K&DE is one discipline ?

Requirements Engineering

- Requirements Engineering

  $=$ **domain requirements engineering**

  $\oplus$ **interface requirements engineering**

  $\oplus$ **machine requirements engineering**

- is about
  - ⋆ systematic to formal ways
  - ⋆ of "turning" oftentimes **non-computable** domain and knowledge descriptions
  - ⋆ into prescriptions for **computable** software.

Software Design

- Software design is about
  - ⋆ systematic to formal ways
  - ⋆ of "turning" abstract requirements prescriptions
  - ⋆ into
    - ◇ **correct** and
    - ◇ **efficiently executable**

  program code.

On Methods and Methodology

- Software artifacts are not manifest in the sense of being
  - ⋆ viewable,
  - ⋆ hearable,
  - ⋆ touchable,
  - ⋆ tastable,
  - ⋆ smellable
  - ⋆ or ... physically measurable.
- Their construction thus necessitates
  - ⋆ **a new approach** to **“methodiciy”**
  - ⋆ (being methodological).

On Methods and Methodology (Continued)

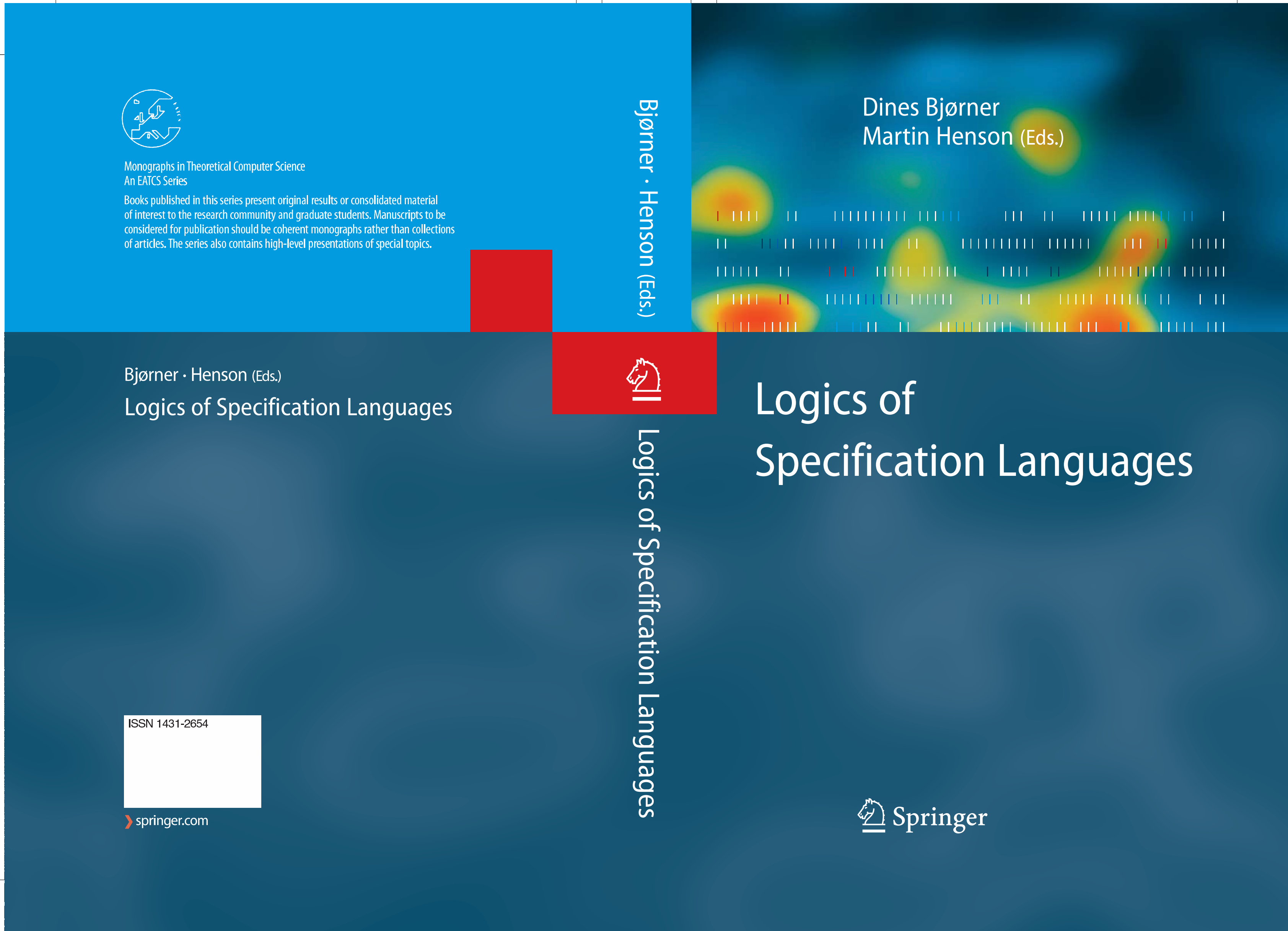
- By a **method** we shall understand a set of
  - ⋆ **principles** for
  - ⋆ **selecting** and **applying**
  - ⋆ **analysis** and **synthesis**
  - ⋆ **techniques** using a set of
  - ⋆ **tools.**
- By **methodology** we shall understand
  - ⋆ the study and knowledge of methods.
- The discipline of software engineering
  - ⋆ **is full of (many claims of) methods !**
- These **principles, techniques** and **tools** are of “a new kind” — different from classical engineering, we claim.

On Formal Techniques

- Correctness of software is of overriding concern.
- To understand a domain, a set of requirements, and software
  - ⋆ we resort to a combination of
  - ⋆ precise **natural language** narratives and
  - ⋆ **formal**, mathematical **specification**s.
- By a **formal technique** we understand a technique
  - ⋆ which applies to formal specifications
  - ⋆ where these specs. have
    - ◇ a **formal syntax**,
    - ◇ a **formal semantics**, and
    - ◇ a **proof system**.
- Propagation of formal techniques (colloquially: "formal methods") seems to invoke **controversy**.

On Informatics Engineering
On Professionalism

- The professional informatics engineers possess the following skills:
  - ⋆ MSc level in computer & computing science,
  - ⋆ IE: knowledge, domain and requirements engineering and software design: $\mathcal{K}, \mathcal{D}, \mathcal{S} \models \mathcal{R}$,
  - ⋆ well-founded in the mathematics disciplines outlined above,
  - ⋆ clear understanding of the rôle of semiotics in SE,
  - ⋆ well aware of the philosophical issues outlined above,
  - ⋆ certified for work in one well-delineated domain, and
  - ⋆ pursues this work **also** using formal techniques:
    - ◇ that is, the professional informatics engineer is versant in varieties of formal techniques, say
      - ∘ *B, RAISE/RSL, VDM-SL, or Z,*
      - ∘ *DC, TLA+, or some other Temporal Logic,*
      - ∘ *Modal, Kripke, Epistemic, Deontic, etc., Logics, and*
      - ∘ *formal foundations of LSC, MSC, Petri nets, Statecharts, etc.*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The Professional Engineer

- The engineer **“walks the bridge”**
  - ⋆ between **science**
  - ⋆ and **technology** (in the sense of technological artifacts)
- The professional engineer
  - ⋆ designs technological artifacts based on scientific insight and
  - ⋆ studies technology in order to acquire new scientific knowledge.

CS, CS & SE

- But there are problems wrt. CS & CS !

  CS: Comput**er** Science, CS: Comput**ing** Science
- Most CS people confuse the two issues.
- Most CS people do not appreciate the work of the other CS people !
- Some CS people use mathematical-looking techniques
  where they could, and in MHO should, use formal specifications.
- Many CS papers suffer from unnecessary "mathematics" !
- The result is that most software engineers
  have a confused understanding of the rôle of foundational science.

On Obstacles to Professional SE

- **Academia:** *lack of scientific honesty | collegiality syndrome*
  - ⋆ We are not teaching professional software engineering
  - ⋆ We are not connecting computer science up to computing science
  - ⋆ Half the colleagues do not understand/appreciate the other half's work
  - ⋆ Academic staff are "barking up the wrong trees", "navel-fixated"
- **Industry:**
  - ⋆ Critical mass syndrome
  - ⋆ Unawareness *generation gap*
  - ⋆ Their own "watchdogs" do not prescribe professionalism — *as in & for other engineering disciplines: certification*
- **Customers** — do not demand professionalism
- **Public government**
  - ⋆ is not spearheading *why no academic 'Amanda' ?*
  - ⋆ no pathfinder projects *why no academic 'EPJ' ?*

A New Kind of Software Engineer
The Background Problem

- Major Software Development Projects Fail
  - ⋆ Exceed Estimated Development Costs
  - ⋆ Exceed Estimated Development Time
  - ⋆ Fail to Meet Customer Expectations
- Many Projects Fail
  - ⋆ The Danish EPJ project
    - ⋄ 17 different interpretations of the term ‘document’
    - ⋄ A number of existing EPJ systems cold not be “harmonised”
    - ⋄ Millions of $s are being wasted
  - ⋆ The Danish unemployment system was very problematic
- In the US of A alone an estimated US $ 20 bio is lost yearly

Software Development ⇒ Software R&D

- Many software development projects are actually research projects
  - ⋆ But many customers are “misled” by software houses
  - ⋆ And there is, in effect, no professional industry “watchdog”
- Software for “unfamiliar” domains need be R&D’ed
  - ⋆ Contracts need be flexible, “gliding”
  - ⋆ Research must account for “delays”, “failures”, “aborts”

A New Kind of Software Engineer

• Analogies — Somewhat "Stretched" •

- **Medical Profession**
  - ⋆ critical diseases treated at hospitals
  - ⋆ where some medical doctors
  - ⋆ are also researchers (profs. at univs.)
- **Architectural Profession**
  - ⋆ many leading designs done in architectural firms
  - ⋆ staffed by architects
  - ⋆ some of whom are also profs. at schools of architecture.
- *&c.*

• Software Scientists •

- Critical new software developments done at software house
- staffed by full-time industry and part-time academics
- where the latter thus have access to more foundational research

Informatics — A New Universe — Concluding Remarks

- I have "painted" an image of an engineering discipline.
  - ⋆ It is **not** based on the **natural sciences**.
  - ⋆ It is **more** based on **mathematics** — with supports from
    - ◇ linguistics cum semiotics and philosophy
- Informatics, I claim
  - ⋆ offers a universe of **intellectual quality**
  - ⋆ in contrast to classical engineerings' universes of **material quantity**
- I have introduced a new discipline, as part of informatics:
  - ⋆ **domain science and engineering:**
    - ◇ where the natural sciences study the universe as given to us,
    - ◇ domain science studies man-made universes:
      - ○ from infrastructure components *viz. transportation*
      - ○ to mechatronics/biological subsystems

Informatics — A Clarification

- **Classical Engineering Sciences**
  - ⋆ **Quantitative, Material**
    - ◇ smaller, faster,
    - ◇ higher capacity
    - ◇ lower energy,
    - ◇ less costly, etc.,
    - ◇ bound by laws of physics.
- **Informatics**
  - ⋆ **Qualitative, Intellectual**
    - ◇ correctness,
    - ◇ intellectual elegance,
    - ◇ fit to human psyche,
    - ◇ bound by laws of mathematics
    - ◇ and by "laws" of philosophy
- **Computing scientists are not gadget builders —**
  They build concepts and are not funded to implement these.

Closing Remarks

Closing Remarks — and Thanks

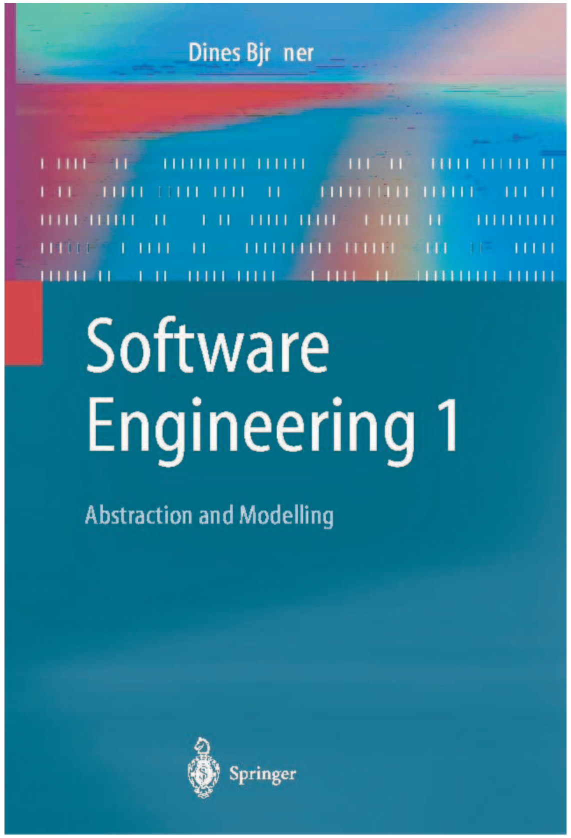
- An era, my era, at DTU; is "vorbei, zu ende". New eras are in sight.
- It was great fun — ... I am grateful to
  - ⋆ Prof. **Per Gert Jensen** for starting all this, "inviting me in"; to
  - ⋆ Prof. **Chr. Gram**

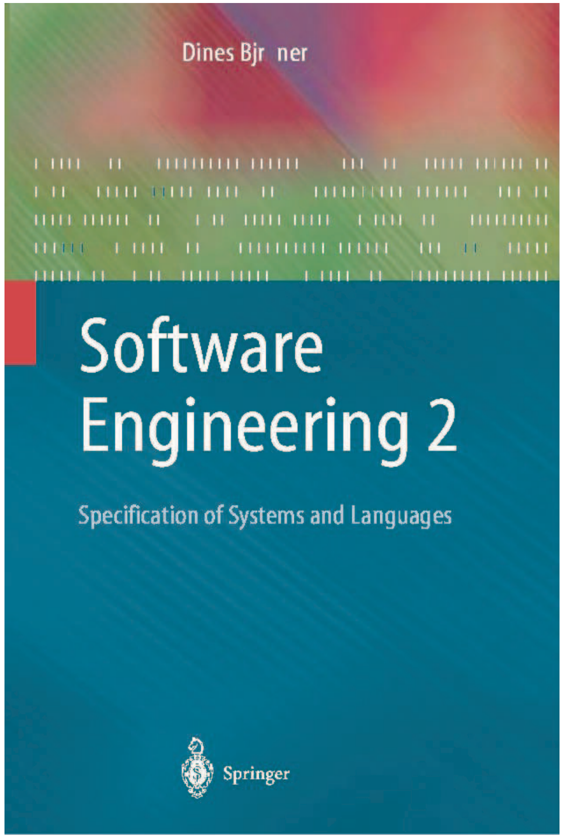
    for his gentle and fine leadership and for his co-starting DDC, providing leverage for much of "this"; to
  - ⋆ Prof. **Jørgen Fischer Nilsson**

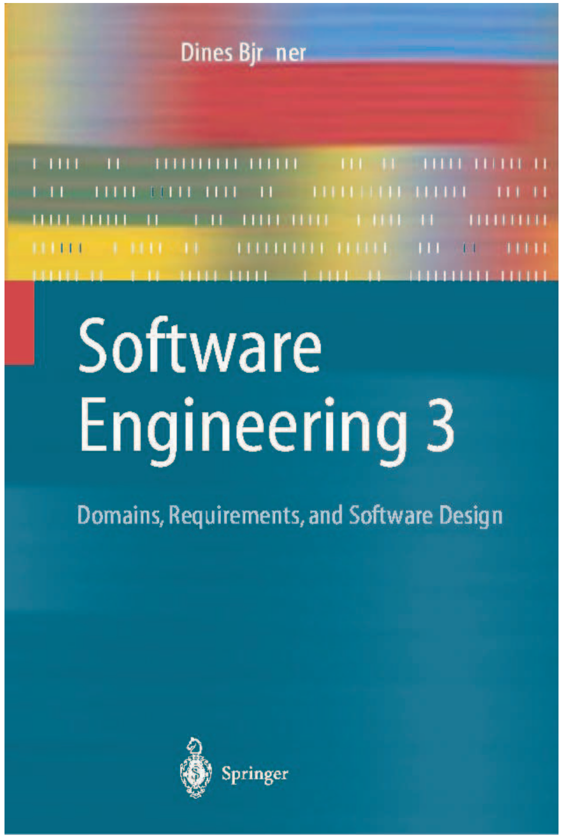
    for always stimulating talks, for steering a scientifically deep and relevant course — keep on, persevere; to
  - ⋆ Dr. **Ole N. Oest** DDCI, Phoenix, Arizona, USA

    for co-initiating the DDC Ada Project, the one project that made DDC a household name on at least three continents; to
  - ⋆ Prof. **Kaj Madsen** for allowing my two sabbaticals; and to
  - ⋆ **DTU** for having provided, for many years, wonderful students and a proper academic and stimulating frame for serious work.

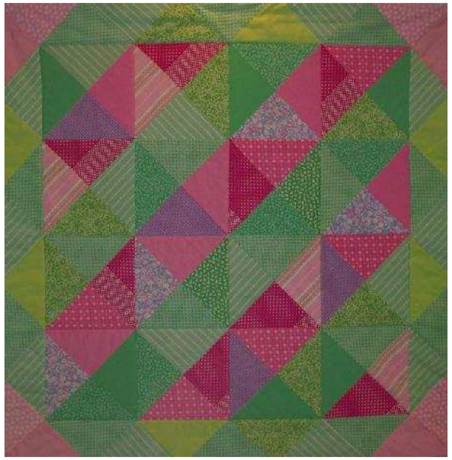
Buy — Read — Practice



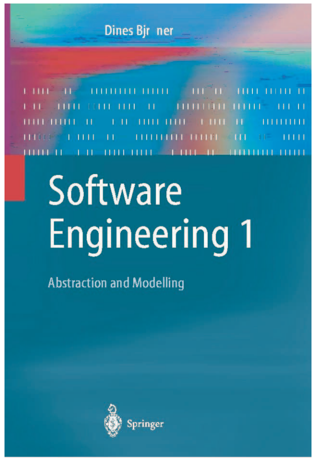


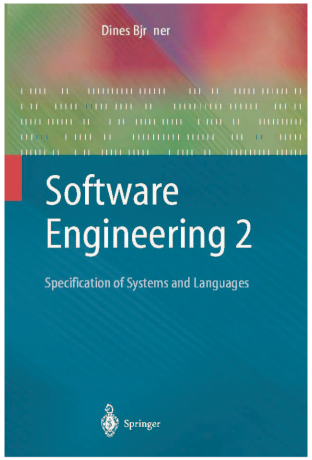


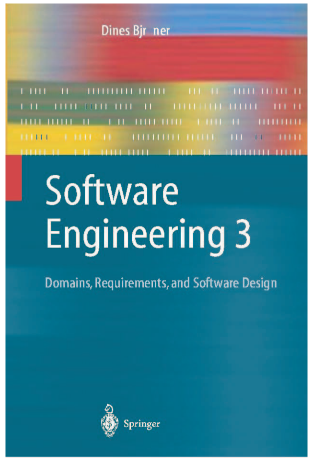
- Thanks to Christian Krog Madsen ↑ and Kirsten Mark Hansen ↑
- and also to Steffen Holmslykkke ↑



Thanks to Kari — the best thing that ever happened to me







Special Tak til Hans Bruun

Kære Hans,

⋆ **Uden Dig intet DDC.**

⋆ Uden Dit enorme arbejde og dybe indsigt intet DDC.

⋆ Mange er Dig taknemmelig

- for at Du på var fødselshjælper mmm. —
- for dem blev **DDC** en finest tænkelig karrierestart.