A Retrospective on an Industrial Product-Line Project

(with longish detours dwelling on the question of the effectiveness of industry-research collaborations)

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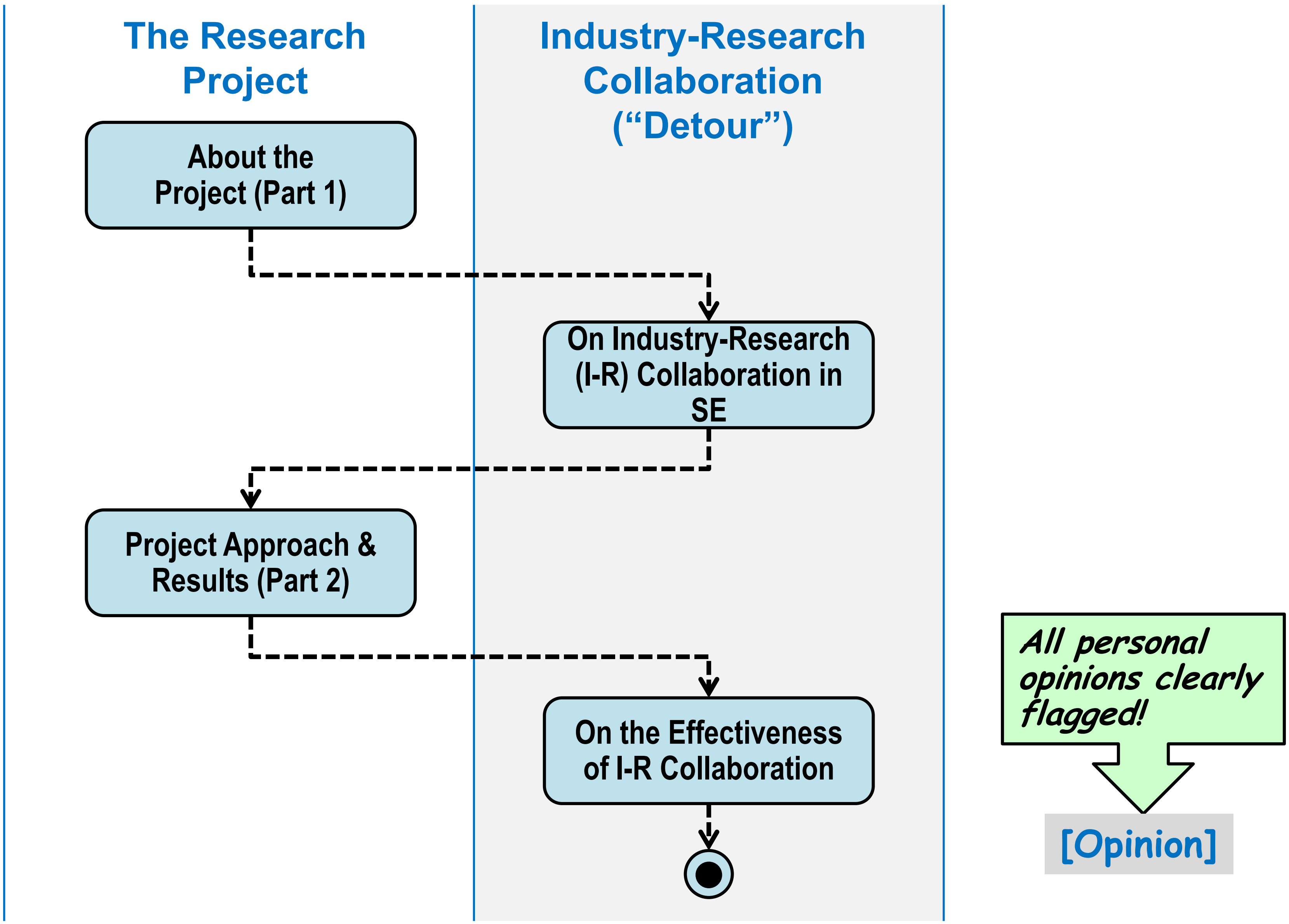
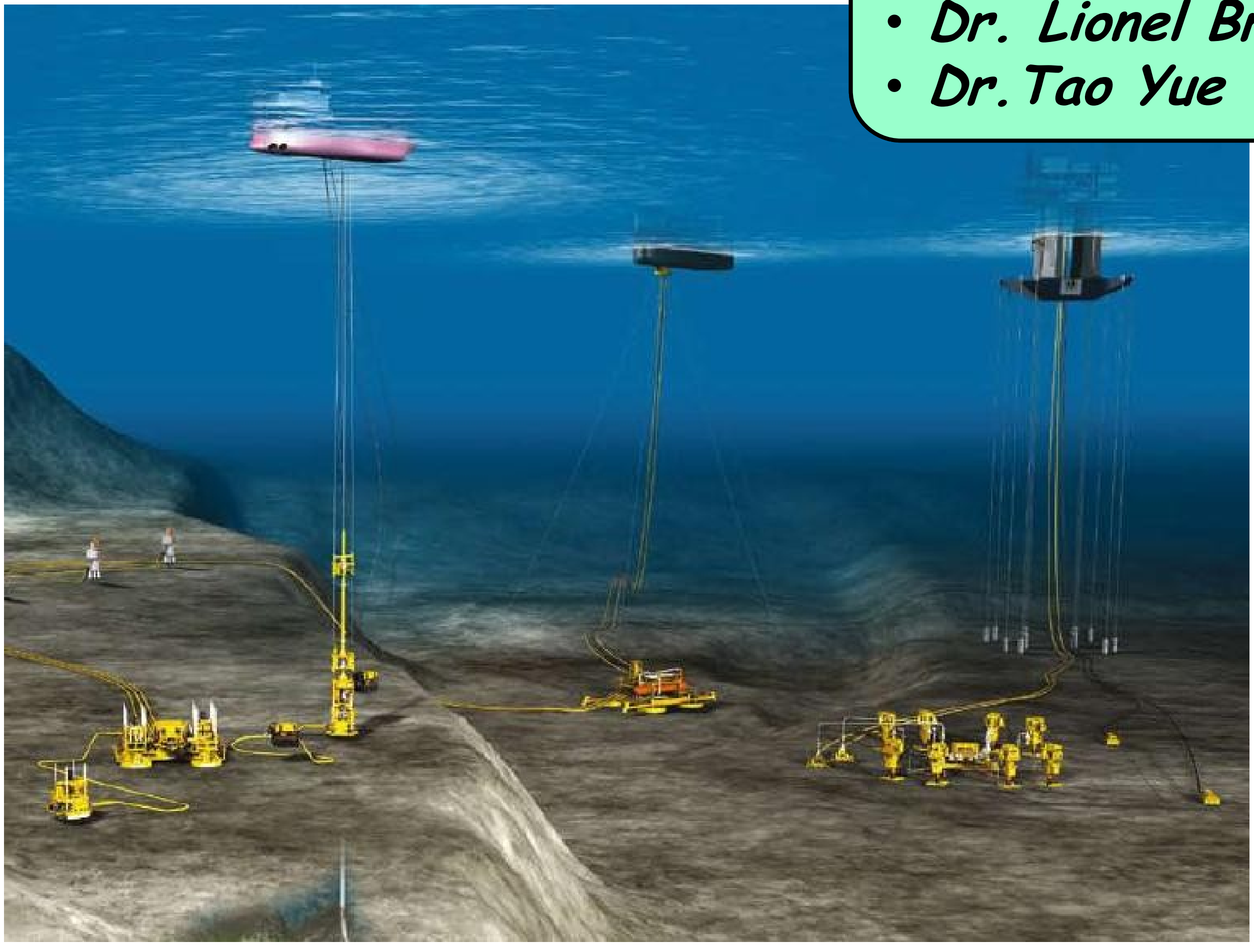
This Talk


The Research Project
Industry-Research Collaboration ("Detour")
About the Project (Part 1)
On Industry-Research (I-R) Collaboration in SE
Project Approach & Results (Part 2)
On the Effectiveness of I-R Collaboration
All personal opinions clearly flagged!
[Opinion]

Work done jointly with:

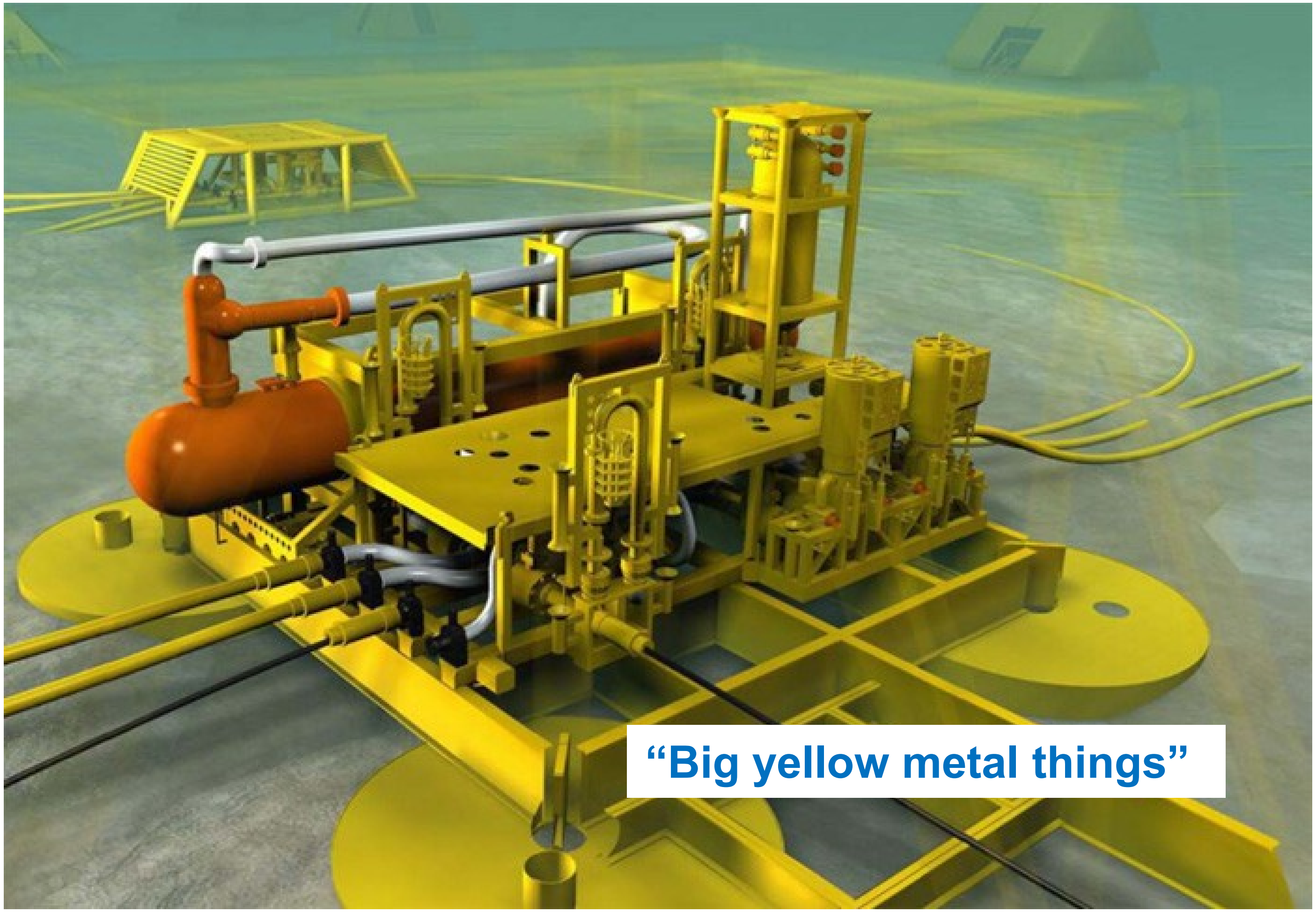
- Razieh Behjati (PhD)
- Dr. Lionel Briand
- Dr.Tao Yue



About the Project (Part 1)

The Domain: Subsea Production Systems

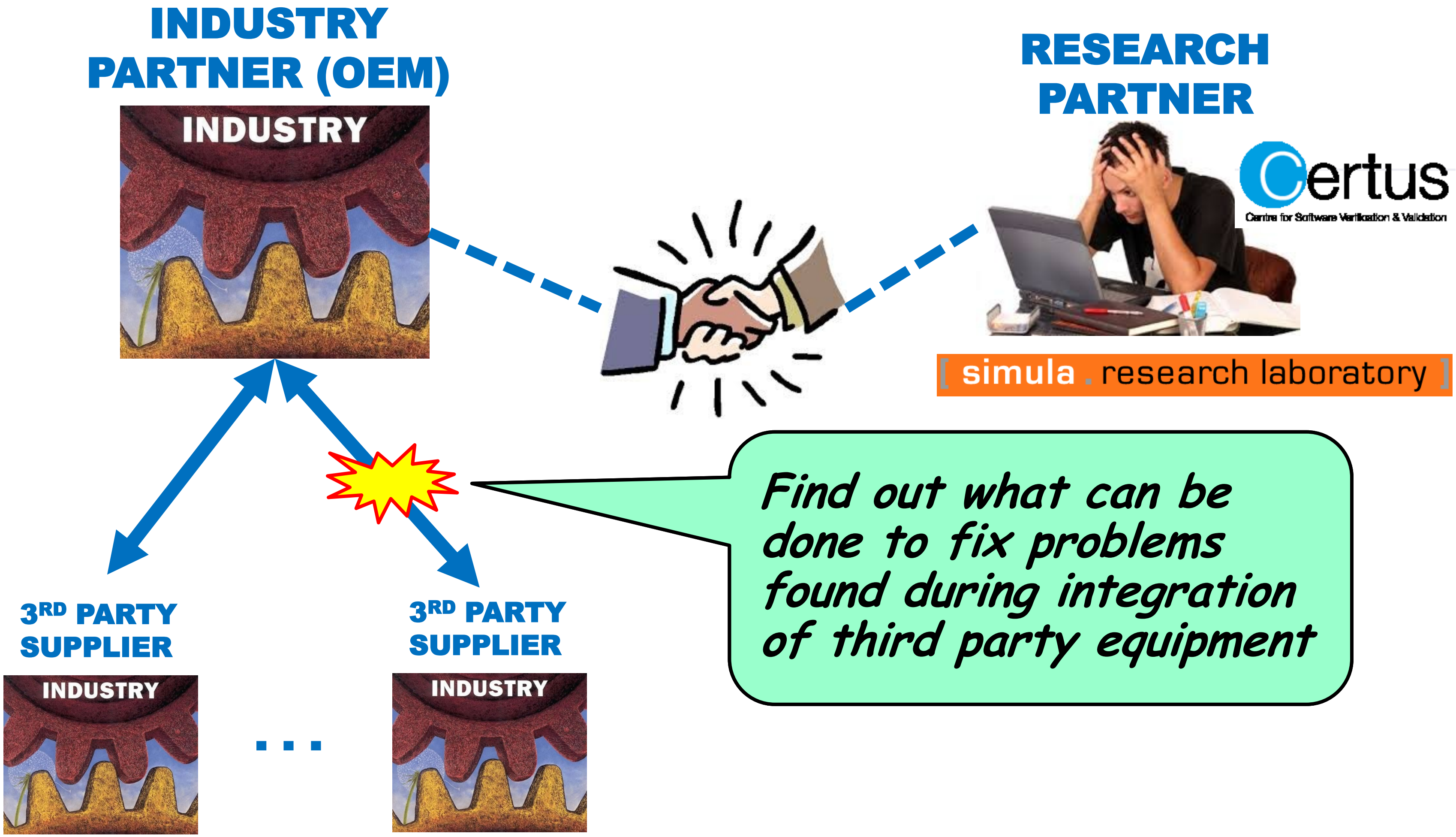
- Complex technologically heterogeneous systems:



Complex Heterogeneous Systems

- **Aerospace, automotive, manufacturing, medical equipment, nautical systems, office equipment, telecommunications, etc.**
  - Mature disciplines based on traditional engineering technologies and knowledge and mostly tangible artifacts
- **Software is generally a late-comer to this world**
  - Evolved from simple relay-logic replacements to fully-fledged integrated control systems (e.g., ~100MLoC)
  - A *key source of value add and market differentiation*
- **Unfortunately, it is still not fully understood in enterprises dominated by more traditional skills**
- ***Cyber-physical systems*: an approach advocating designing systems as a whole**

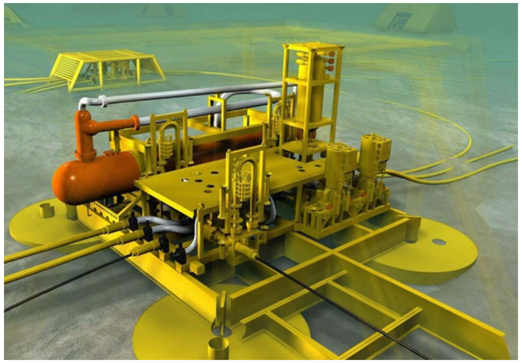
The Project



A typical industry-research collaboration project

Industry Partner

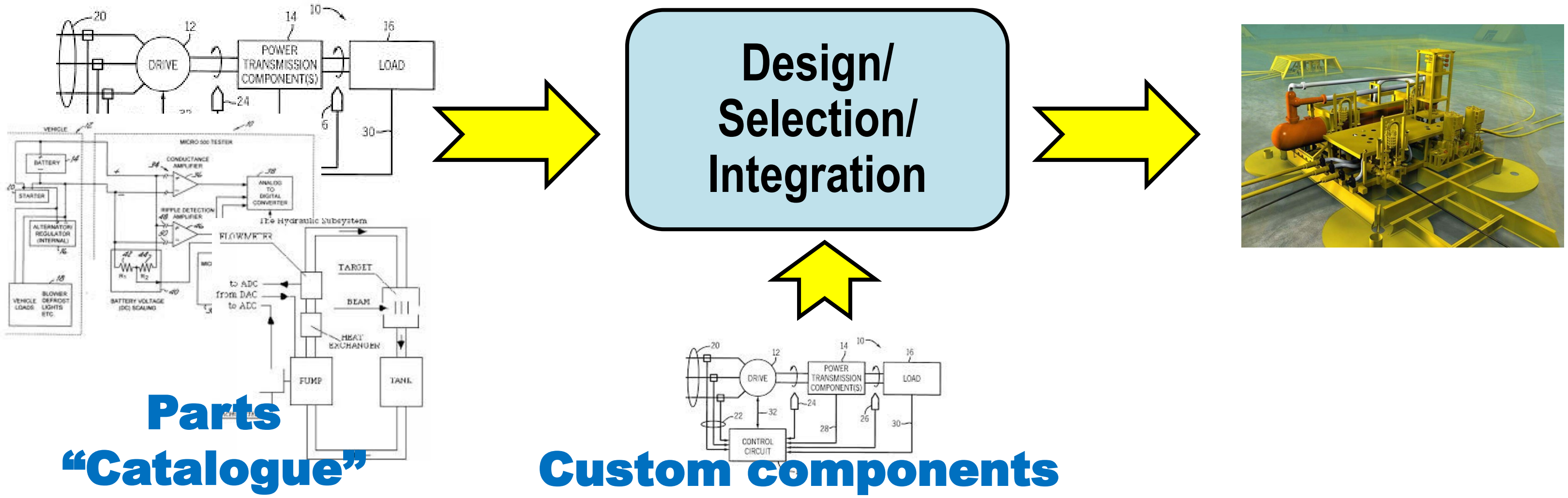
- **Market leader in subsea oil & gas extraction systems**
  - OEM (system integrator) role
  - Major development team in Norway



- **Characteristics:**
  - Dominated by traditional engineering culture
  - The role and significance of software in products growing rapidly
  - But, still perceived as a *follow-on component* component

The Product Line and Products

- Structured "catalogue" of mechanical, hydraulic, electronic, communications, and computing components



- A particular system (product) is constructed by a <u>customer-specific configuration</u> of standard and custom components produced by the OEM and subcontractors

Research Partner: Simula Research Laboratory

[simula . research laboratory]

- **A specialized research institute owned and funded by the government of Norway**
  - Focus on software and communications technologies
  - Established in 2001 and conceived as an unfettered institution for researchers
    - No teaching duties, no funding proposals, minimal admin overhead
  - ~35 research staff
- **Several research departments**
  - Includes the Certus Centre within the Software Engineering department

The Certus Centre (1)

Certus
Centre for Software Verification & Validation

- **An 8-year project funded by the Research Council of Norway**
  - ~16 people (primarily senior researchers and PhD candidates)
  - ~75M NOK (~$13M or $2.6M/yr)
  - Head: Dr. Arnaud Gotlieb (previously: Dr. L. Briand)
- **One of 16 Norwegian Centres for Research-Based Innovation (SFI)**
  - Created to "encourage enterprises to innovate through collaboration with advanced research groups"
  - i.e., *industrially-relevant research*

The Certus Centre (2)

Certus

Centre for Software Verification & Validation

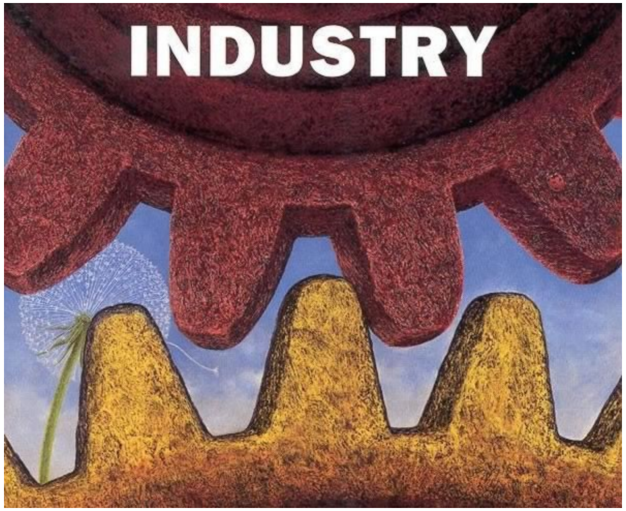
- Focus on verification and validation of software
- 4 main projects (involving user partners)
  - *Model-based engineering of highly configurable systems*
  - Safety analysis and certification of embedded systems
  - Testing of data-intensive systems
  - Testing of real-time embedded systems
- Characteristics:
  - 5 user partners (1 government, 3 industry, 1 tool vendor)
  - Partners only need to provide in-kind contributions ⇒ practically free *government-funded research*

Detour (1): On Industry-Research Collaborations in Software Engineering Research

Who Am I to Talk About Research?

- **Most of my career (40+ years in software engineering) has been in industry**
  - Some academic experience (teaching, adjunct)
- **I have been and am currently involved in industry-research collaboration projects and know from experience that they can be highly successful:**
  - Worked in and with a number of research institutes
  - Directly involved as an industry participant in numerous industry-research collaboration projects
  - Acted as expert referee/reviewer of many research proposals and evaluations in Europe and North America
  - Previously: on Board of Directors of three research funding bodies

Key Question



RESEARCH

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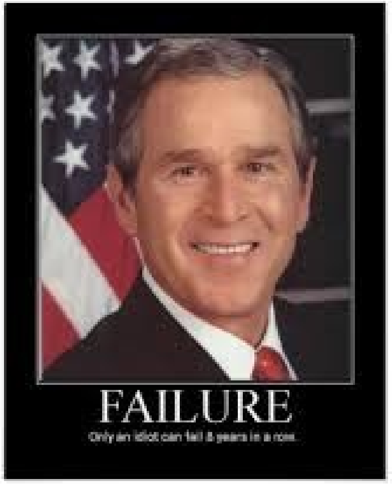
What makes an industry-research collaboration projects successful?



Industry-Research Collaboration Projects

Technical projects in which:
(a) one or more industry partners define the problem and provide domain expertise and
(b) an institution specializing in research seeks to provide a solution

- **Rationale: Industry might be lacking**
  - Resources (time, budget) needed to conduct research
  - Technical expertise:
    - Not a question of ability, but of a systematic and comprehensive understanding of the state of the art

Objectives: Industry Partner

- Fixing specific point problems not satisfactorily solvable by current practices or technologies
- Improving productivity and/or product quality (i.e., doing things better)
- Demonstrating technical leadership: public relations (PR) benefit
- Identifying new technical/product opportunities
- Gaining a systematic and comprehensive understanding of the problem and solution spaces
- Access to potential highly-qualified hires

Objectives: Research Partner

- Increasing likelihood of future funding
- Working on technical challenges that may advance the state of the art
- Enhancing own scientific reputation
  - generally supplements the first two items
- Training of highly-qualified personnel
  - PhD, MSc, postdoc
- Solving industry partner problems

Types of (Software) Research Institutions

- Corporate (in house) research groups
  - Large enterprises: IBM Research, Bell Labs, Google, Microsoft Research, Tata Consultancy Services, etc.
  - SME advanced technology departments
- Independent research groups
  - Academic (university) research teams
  - Government-supported specialized research institutes

Corporate Research Groups: Analysis

- (Pro) Intellectual property protected
- (Pro) Tighter interworking with industry partner
- (Con) Expensive
- (Con) Often disconnected from corporate mainstream
  - In some cases, exist primarily for corporate PR value (little interest in research results)
  - Not seen by production teams as a primary source of advanced solutions ⇒ self-fulfilling prophecy
- Strong corporate pressure to be "relevant"
  - Frequently turn into specialized product development shop
  - But, typically *more expensive than development*

Independent Research Groups: Analysis

- (Pro) Cheaper and more easily directed than corporate (for industry partners)
- (Con) IP concerns
- Industry-relevant research is often deemed "second rate" by academics
  - "Insufficiently "scientific", "tainted by commercialism"
    - E.g., separate proceedings for "industrial tracks"
  - Concern that pragmatic concerns will obscure the essence

⇒ Many academics avoid this type of research (pro/con?)

- Conversely, research institutes often favour this type of research
  - Typically part of their mandate

Challenge: Engaging Suitable Industry Partners

- **Despite all their advantages, independent research institution usually have difficulties to:**
  - Find partners willing to commit resources to research
    - Especially if a cash contribution is required
  - Get access to industry experts at required levels
  - Transfer research results to industry partners
- **Why?**

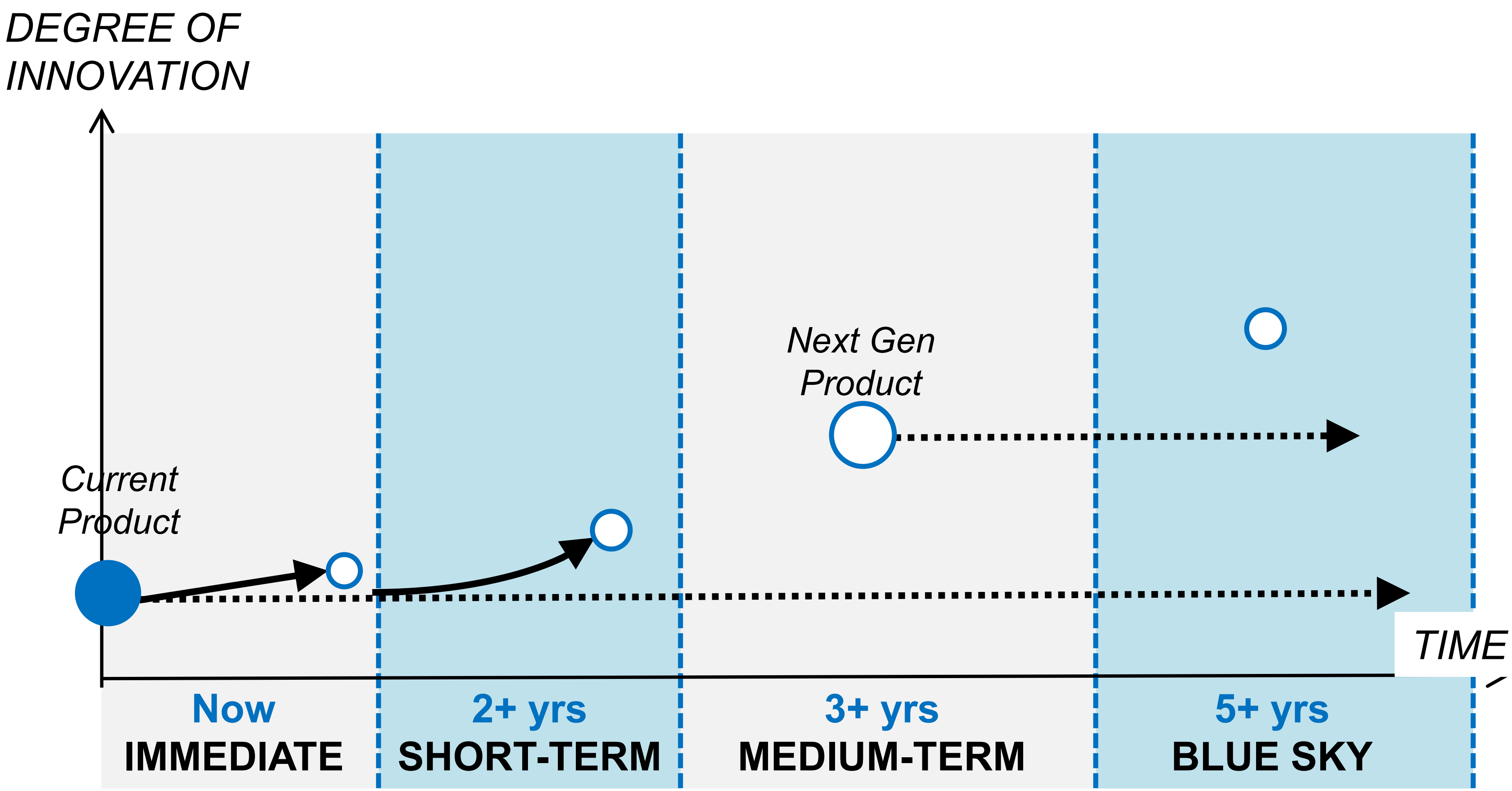
Hurdles

- Need to find strong insider advocates who:
  - Understand the need for research
  - Have necessary corporate leverage to commit
  - Are persistent
- The significance of software is still not sufficiently understood by many corporate decision makers
  - Traditional engineering culture with minimal software training
  - Value proposition not sufficiently understood
- IP leakage and ownership concerns
- Short-term corporate mindset/culture...

The Research vs Short-Term Profit Conundrum

- **Corporations, particularly publically-traded ones, face strong market pressures to meet <u>quarterly</u> profit projections**
  - Focus is on short-term results
  - Research value is hard to prove
    ("Making predictions is hard, especially about the future" -- Y. Berra)
  - Draws resources away from research
  - *"Do I sacrifice my project (and my bonus) or the corporate future?"*

Categories of Industrial Research



NB: Provisional informal categorization

Immediate Type Research

- Scope: within 1-2 years
- Address current problems in existing products
- Practitioners often lack requisite overview of the problem space and/or available solutions
  - Point (vs. "systematic") solutions to problems
  - Researchers can provide a systematic and comprehensive view
- Possibly the "sweet spot" for industry-research collaboration (for both parties)
  - Greatest likelihood of results being adopted in practice
  - But, is it "research"?
  - Tends to be respected less in academia

Short-Term Research

- Scope: 2-4 years
- Address near-term anticipated problems and developments related to existing products
  - e.g., possible new features, scalability/performance problems, introduction of new technologies, new methods and tools
- Typically lower corporate commitment to adoption than short-term research
  - Issues less pressing
- Better suited to academic research groups

Next-Gen Product (Medium-Term) Research

- Invariably undertaken by <u>corporate</u> research groups (due to IP concerns)
- Usually work on a 3+ year horizon
  - Proof-of-concept technological prototypes
  - New product architecture
- [Experience] Most next-gen ***<u>projects</u>*** are abandoned!

- In practice, most next-gen ***<u>products</u>*** are conceived and realized by development groups (vs. research groups)
  - Greater corporate leverage (and experience)
  - Seen as a lower risk option by decision makers
  - But, proposed technological advancement often either
    [1] undershoots ("same old") or
    [2] overshoots ("the second system syndrome")

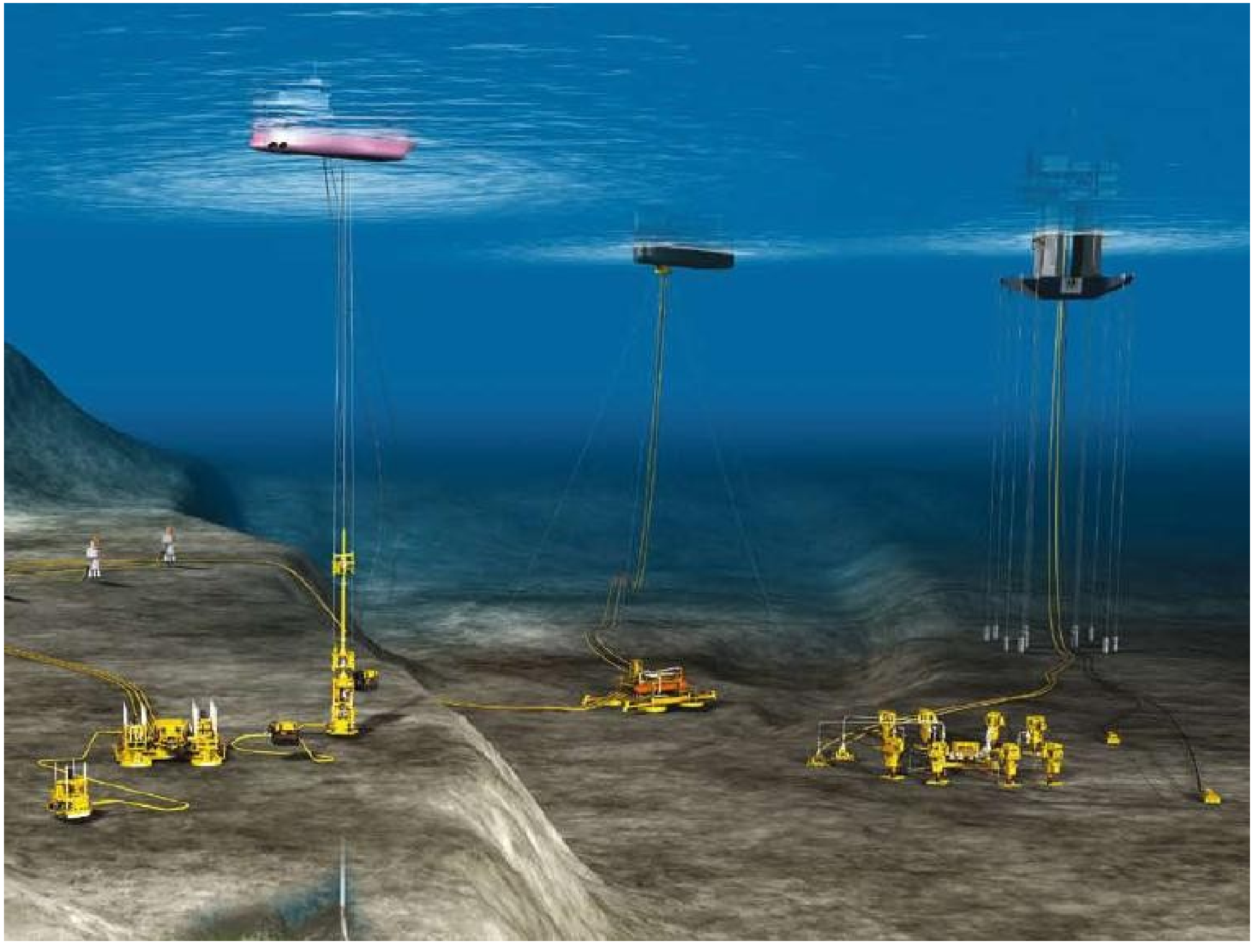
Blue Sky (Long-Term) Research

- Scope: 5-10 years and beyond
- Deals with topics that are not necessarily directly related to current products
  - Usually by corporate research groups (e.g., Bell Labs, IBM Research, Google)
- [Opinion] Corporate PR value is often primary motivation (particularly for large enterprises)
- Good opportunity for academic researchers
- But, funding for such projects is difficult to secure

What About Research Consortia?

- **Groupings of research institutions and industry partners working on a common project**
  - E.g., EC funded research projects
  - Creates critical mass that impresses funding agencies

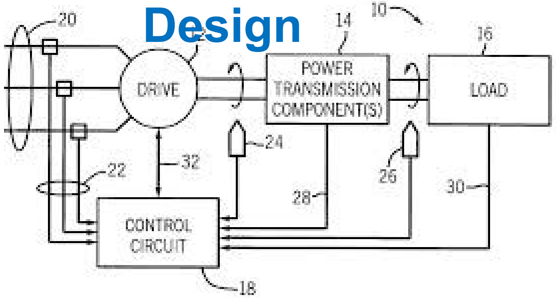
- **[Opinion] Weak synergy**
  - Once the funding is secured, very little technical collaboration
  - The “bank robbery syndrome”
  - Research groups enter with their established specialties and biases ⇒ impedes effective synergy
- **[Opinion] *industry partners typically get very little value-add out of consortia-type research projects***



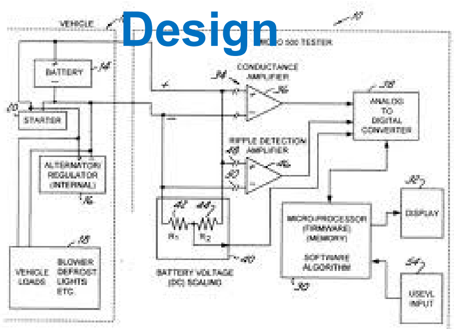
Project Approach and Results (Part 2)

Development Artifacts

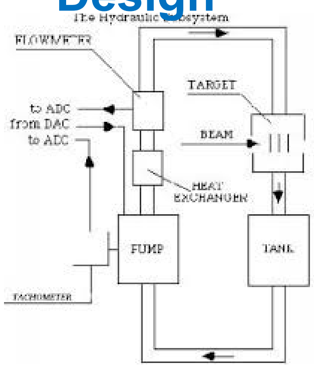
Mechanical Design

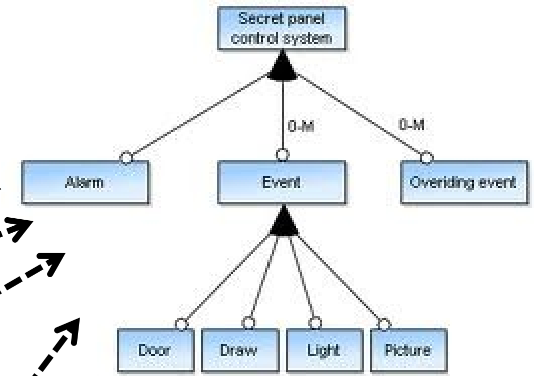


Electrical Design



Hydraulic Design

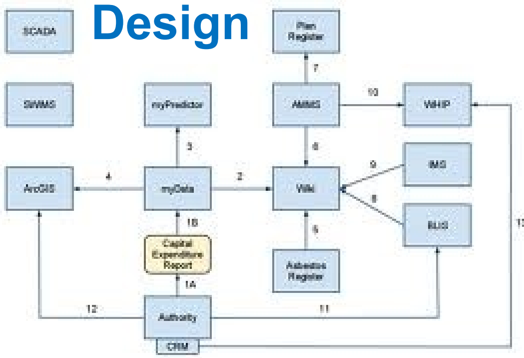




Configuration System Design

Emerges from collected input data

Software Design



Root Cause Analysis

- "Integration problems"
- Analysis methods:
  - Intensive study of system design documents, requirements documents, error reports, test results
  - Numerous meetings and interviews with domain experts
  - Polls/questionnaires
- Conclusions:
  The vast majority (~50%) of "integration" problems turned out to be errors in configuration
  - e.g., wrong software driver configured for hardware device
  - Not directly perceived as such by industry partner

⇒ *A systematic approach to configuration needed*

Main Sources of Configuration Errors

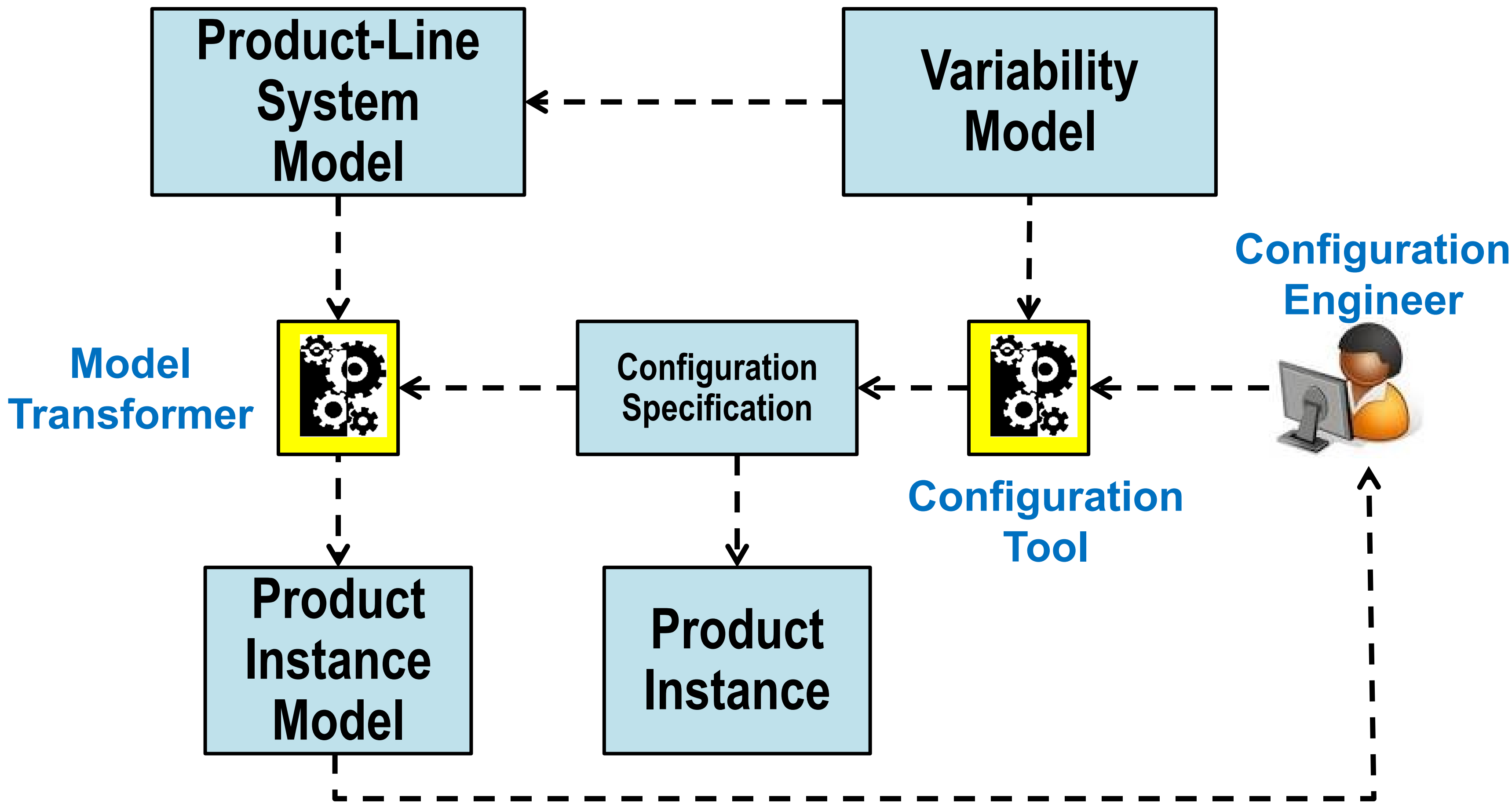
- **Configuration engineers need to have an in-depth understanding of both hardware components and software**
  - Difficult to extract from documentation and designers
- **Insufficient methodological guidance for configuration engineers**
  - Guidelines exist, but: incomplete, unclear, complex, outdated
- **No easy way to verify configuration**
  - Tens of thousands of configuration parameters
- **Manual methods for:**
  - Detecting dependencies between configuration parameters
  - Detecting consequences of design changes
- **Insufficient support for configuration debugging**
- **Insufficient support for configuration reuse**
  - Clone-based reuse

Solution Approach Taken

- Model-based engineering
  - Formal (computer-analyzable) representation of the fully integrated system
- Use of industry standards
  - Modeling languages: UML, OCL, MARTE, and a custom UML profile-based configuration-specific DSL
  - Taking advantage of available expertise and tooling
- Automation wherever possible
  - Interactive verification of configuration choices
  - Interactive guidance through the configuration process
  - Automated enforcement of derived configuration choices

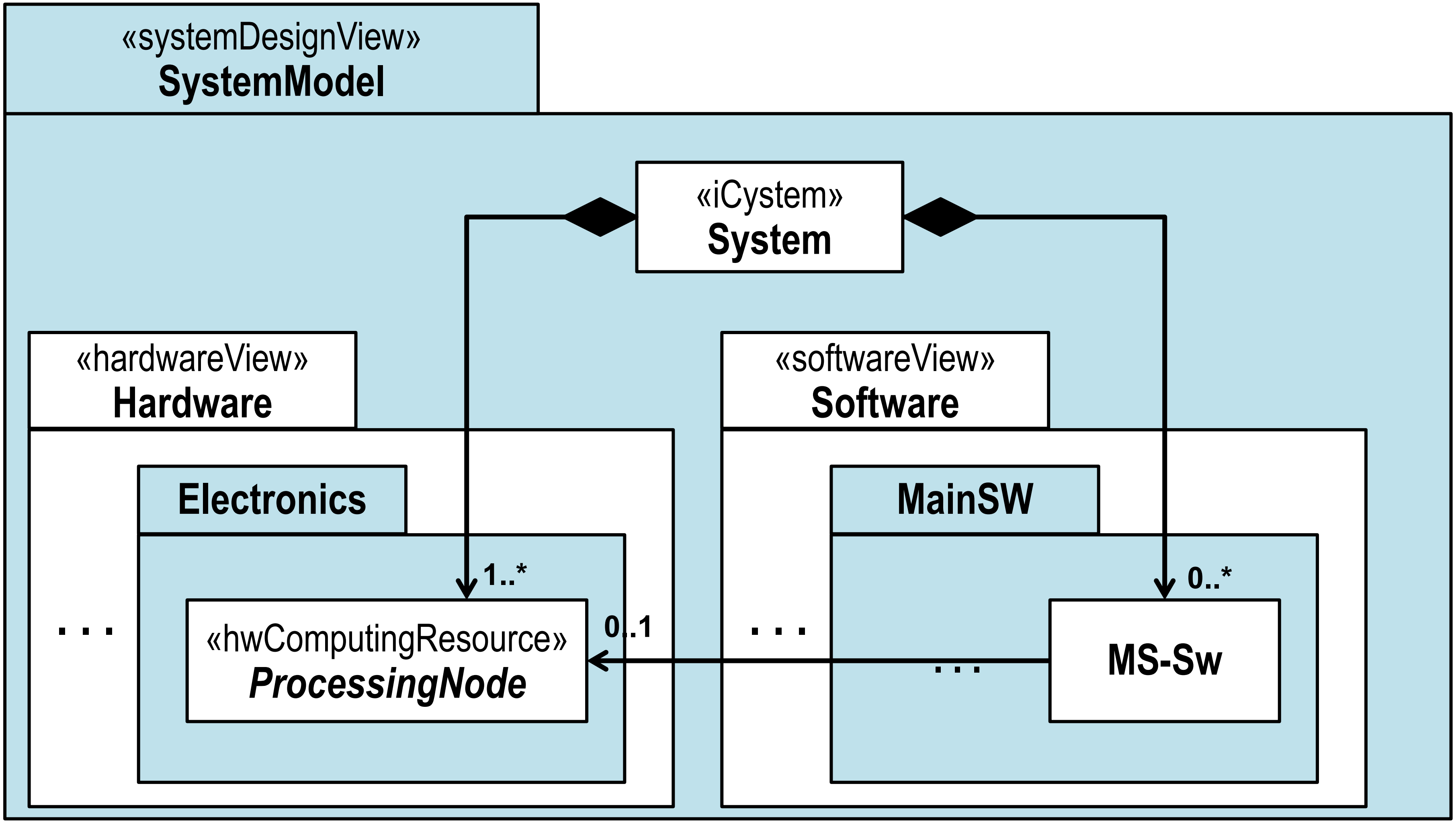
Solution Architecture

- **Very similar to recent CVL standard:**
  - Unfortunately, CVL was not yet available during the project



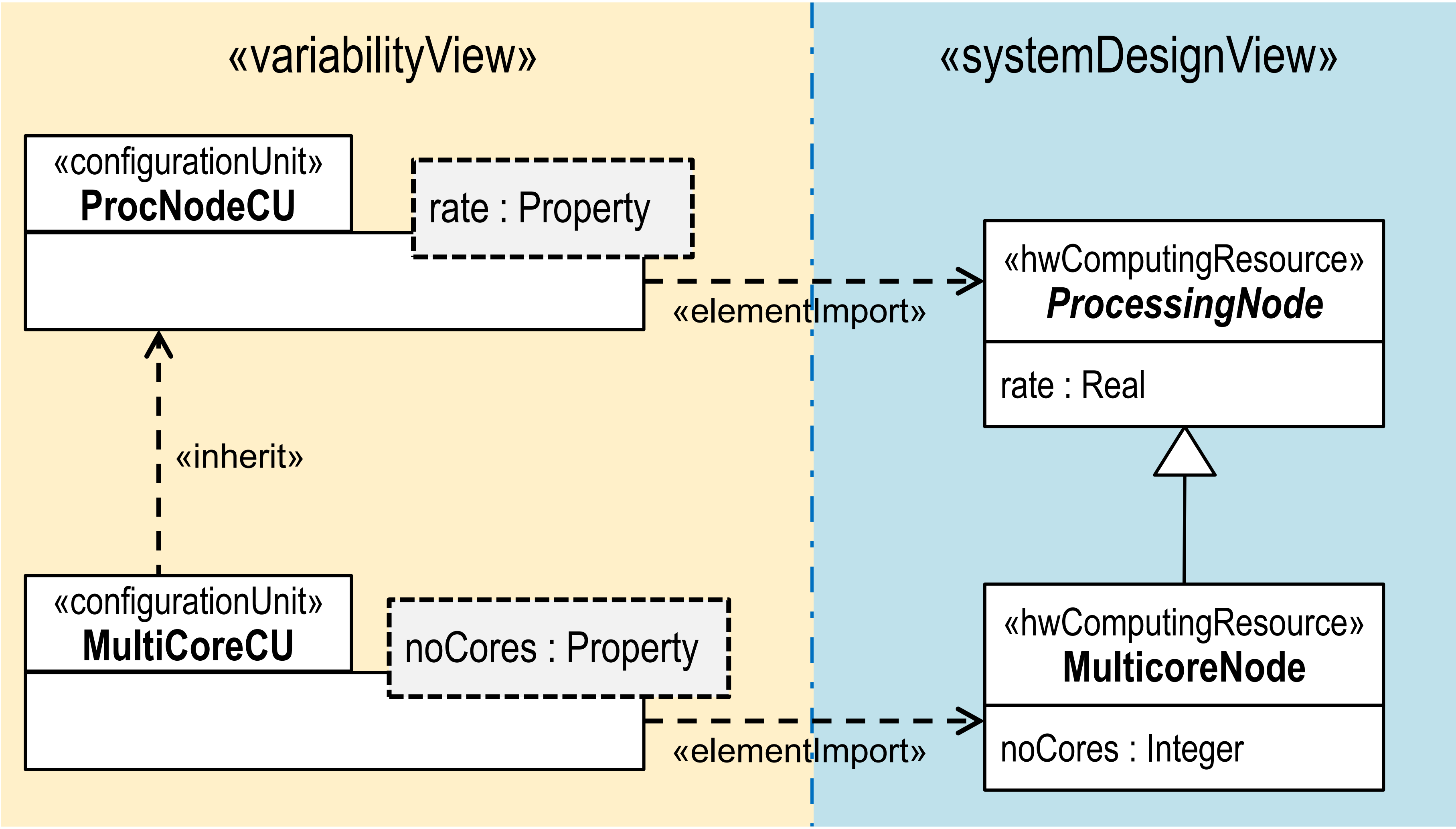
Product-Line System Model

- Using standard UML class modeling (structure only)



Variability Modeling Approach (1)

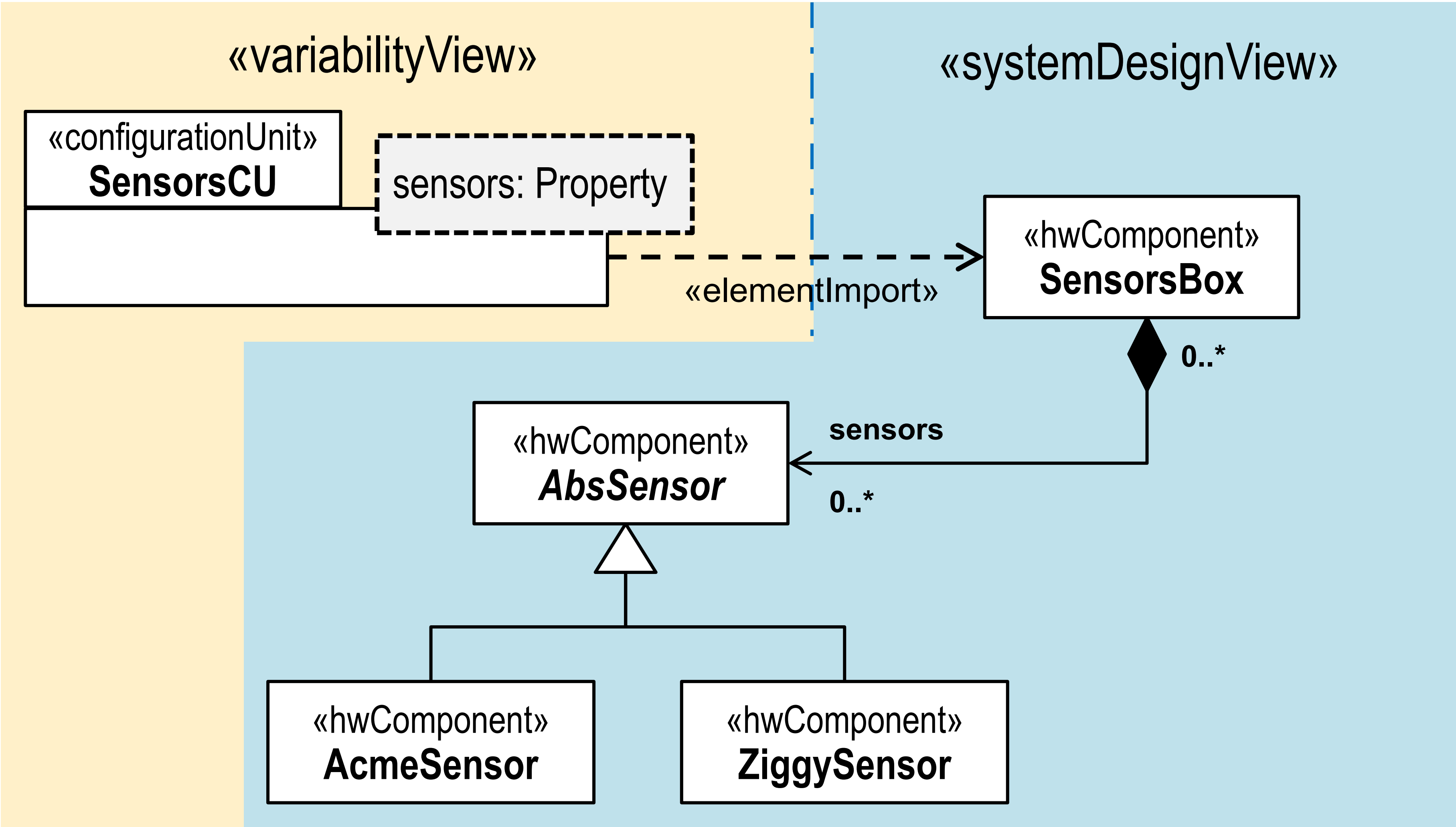
- Using the UML package template mechanism*



* NOTE: minor differences from published version

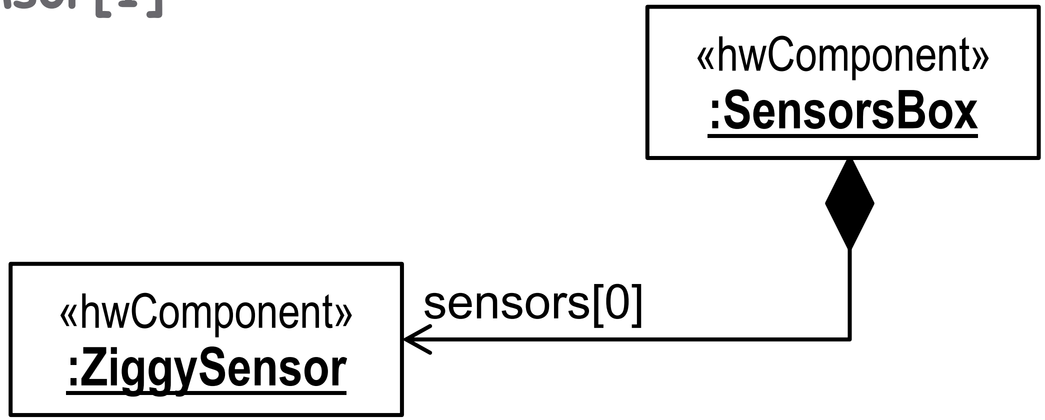
Variability Modeling Approach (2)

- Dealing with type variability



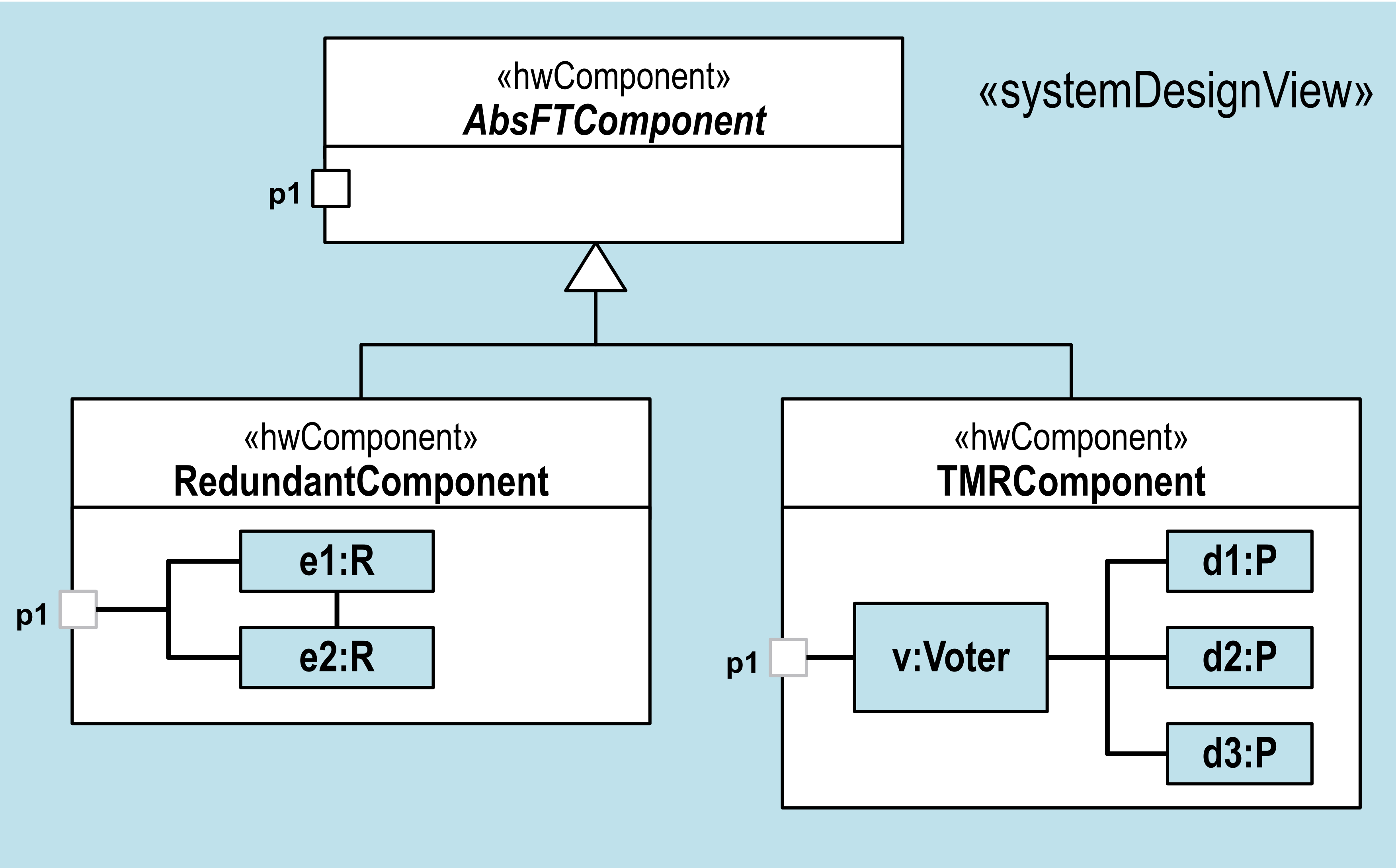
Generated Instance Model

- Generated from Configuration Specification data
- E.g., bind "sensor" template parameter to the Property:
  - sensor:ZiggySensor[1]



Variability Modeling Approach (3)

- **Dealing with topology variability (using type variability):**

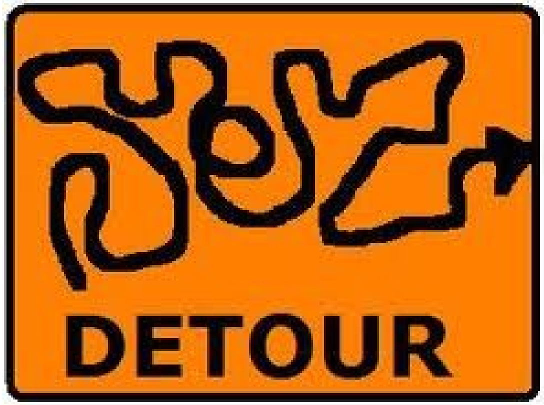


Empirical Evaluation & Summary

- Approach applied to a sample product line
  - *Simplified (but representative)* product-line model of the actual system was constructed and used in the evaluation
  - Real-world product-line models had ~ 450 variability points (resulting in 10's of thousands of configuration items)
  - Evaluation model had ~100 variability points (including 16 OCL constraints)
  - A *prototype* configuration tool was produced and used
- ***All evaluation models were verified with and confirmed by domain experts***

⇒ Evaluation indicates that the approach has potential

Q: Was this project successful?



Detour (2): On the Effectiveness of Industry-Research Collaborations

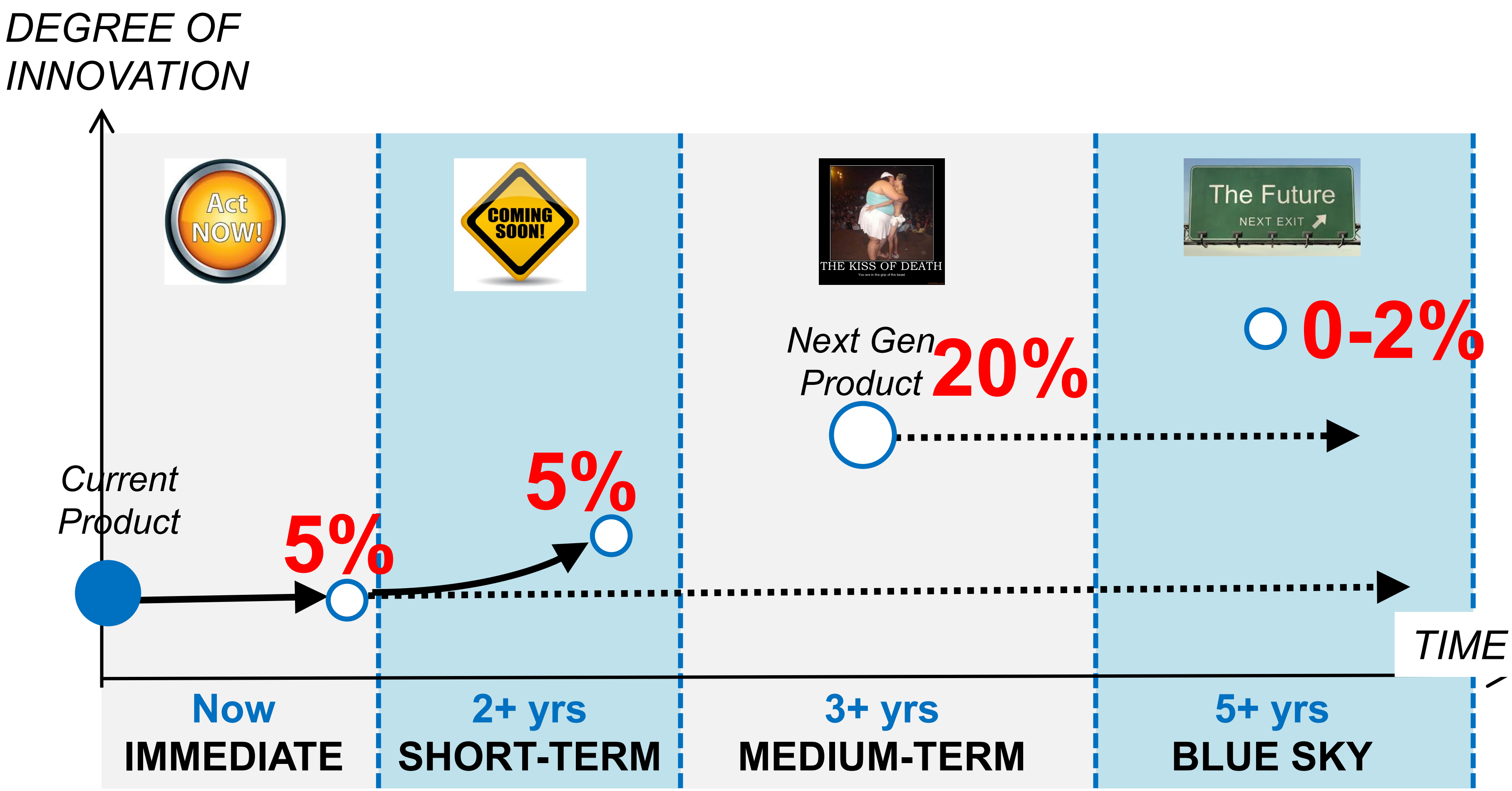
Project Success Criteria

- Subset of general research objectives
- Research partner:
  - Number of publications
  - Highly-qualified personnel trained
  - Research results transferred to industry partner
  - Patents
- Industry partner:
  - Research problem resolved in a way that can be exploited
  - Productivity and/or quality improvements (e.g., reduced development costs)
  - Potential for new product opportunities analyzed and understood
  - Highly-qualified personnel hired (from research team)

The Sum of It All

- [Opinion]: **The majority of industry-research collaborations**
  - Succeed from the perspective of the research partners, particularly in independent research institutions (academia, institutes)
  - Mostly fail to meet the expectations of the industry partners
- **So, why should industry partners bother?**
  - Requires taking resources away from product groups
  - Low probability of success
  - ⇒ Funding contributions tend to be small and infrequent

Likelihood of industry Adoption

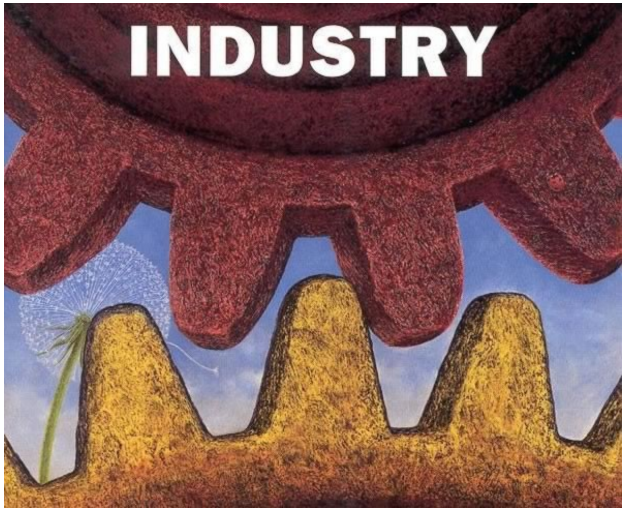


- ***CAVEAT:* Opinion *based on personal experience***

Key Questions

- What makes such a collaboration successful?
- How do we tell that it is likely to be successful?
- What can be done to increase the likelihood of success?
- How can we recognize projects that are unlikely to succeed?

What Is Success?



RESEARCH

Only if the expectations of both categories of participants are sufficiently met

How Can We Predict Success?

- Realistically assess, ahead of time, the likelihood that your success criteria will be met:

- **Research partner:**
  - Number of publications
  - Highly-qualified personnel trained
  - Research results transferred to industry partner
  - Patents
- **Industry partner:**
  - Research problem resolved in a way that can be exploited
  - Productivity and/or quality improvements (e.g., reduced development costs)
  - Potential for new product opportunities analyzed and understood
  - Highly-qualified personnel hired (from research team)

How Can We Increase Likelihood of Success?

- **Investigate carefully before committing**
- **Industry partner:**
  - Evaluate research partner: are they "academically" inclined or "industrially" oriented?
    - i.e., what do they qualify as a success
  - Must be prepared to commit promised resources
- **Research partner:**
  - What does the industry partner qualify as a successful project?
  - [Opinion]: *SMEs and government institutions tend to be far more receptive to applying results of research compared to large enterprises*

Conclusions

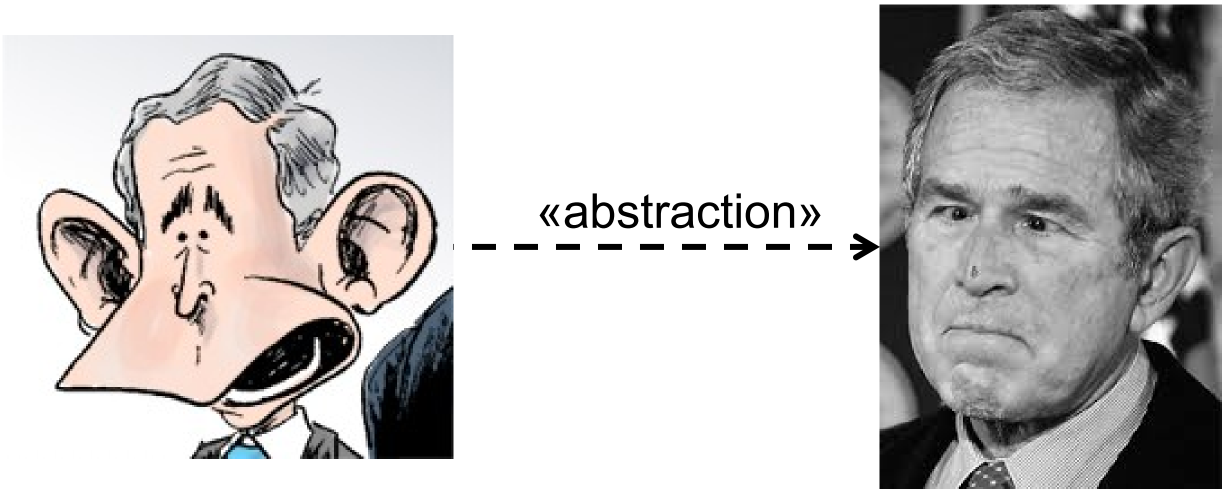
- [Opinion] The effectiveness of industry-research collaborations in the software domain is disappointing in terms of actual technical impact
  - Only a small percentage of research results actually find their way into practice
  - Most innovation in current practice comes from within the industry's own development teams (vs. their research teams)
- [Opinion] The primary benefit current industry-research collaborations seems to be the creation of highly-qualified personnel (HQPs)

…and the Emperor Strutted Merrily On

- These trends are known to most of those who are directly involved – but tend to be taken for granted
- [Opinion] It suits those who are more interested in public perceptions than technological benefits
  - E.g., research fund dispensers, (some) researchers
- It is not going to be easy to change

Have I Oversimplified Things?

- Perhaps I have, but...



- A good caricature is a typical example of good abstraction: it captures the essence and draws attention to it

Thank you, no more detours

Questions? Comments? Objections?

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