A Retrospective on an Industrial Product-Line Project
(with longish detours dwelling on the question of the effectiveness of industry-research collaborations)

Bran Selić
Malina Software Corp. CANADA
Simula Research Laboratory, NORWAY
University of Toronto, CANADA
bselic@simula.no
selic@acm.org
This Talk

The Research Project

About the Project (Part 1)

Industry-Research Collaboration (“Detour”)

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]
About the Project (Part 1)

Work done jointly with:
• Razieh Behjati (PhD)
• Dr. Lionel Briand
• Dr. Tao Yue
The Domain: Subsea Production Systems

- Complex technologically heterogeneous systems: “Big yellow metal things”
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

INDUSTRY PARTNER (OEM)

RESEARCH PARTNER

3RD PARTY SUPPLIER

3RD PARTY SUPPLIER

Find out what can be done to fix problems found during integration of third party equipment

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 customer-specific configuration of standard and custom components produced by the OEM and subcontractors
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)

- 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)

- 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
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

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 $\Rightarrow$ 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 quarterly 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

DEGREE OF INNOVATION

Current Product

Now
IMMEDIATE

2+ yrs
SHORT-TERM

3+ yrs
MEDIUM-TERM

5+ yrs
BLUE SKY

Next Gen Product

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

Act NOW!
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 corporate 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 projects are abandoned!
- In practice, most next-gen products 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)
“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
· 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
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):

- «hwComponent» AbsFTComponent
  - «systemDesignView»
  - p1

- «hwComponent» RedundantComponent
  - e1:R
  - e2:R
  - p1

- «hwComponent» TMRComponent
  - v:Voter
  - d1:P
  - d2:P
  - d3:P
  - p1
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)
[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
- \(\Rightarrow\) Funding contributions tend to be small and infrequent
Likelihood of industry Adoption

DEGREE OF INNOVATION

Current Product

Now IMMEDIATE

2+ yrs SHORT-TERM

3+ yrs MEDIUM-TERM

5+ yrs BLUE SKY

TIME

CAVEAT: Opinion based on personal experience

© Copyright Malina Software 2013-2014
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?

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)
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?

