Reflections on Software Engineering Research Collaborations:

From Ottawa to the Software Engineering Institute to Silicon Valley

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Abstract — This paper outlines challenges, practices and successes in establishing and sustaining software engineering research collaborations between academia and industry. These activities were observed over a period of 25 years while in a variety of research tech transfer and change agent roles at Cisco, Qualcomm, and BNR/Nortel. This experience was complemented by serving as a Visiting Scientist for one year at Carnegie Mellon University's Software Engineering Institute (SEI) while on loan from BNR/Nortel. Research collaborations were incubated, brokered, and sustained through: the cultivation of internal relationship sponsorship by executives and company experts, tech scouting to identify relevant projects, information sharing, seed funding (gift and sponsored research agreements), and talent migration to accelerate technology transfer.

***Index Terms*— research, collaboration, industry, university.**

I. Introduction

The translation of an invention into a useful innovation with business value can be challenging. Many inventions – while useful and practical – have failed to be adopted, becoming fads rather than fashion. Dyer *et al.* [1] suggested that innovation is driven by a mix of skills including: associating; questioning; observing; networking; and experimenting. However, these are different skills from those required to translate innovation into practice. Rogers in his seminal work [2] views the "translation" process as one of diffusion – where the process of communicating the attributes of innovation to a community through relevant channels is an essential ingredient for success. Rogers observed that the diffusion process depends on a variety of factors including information sharing, social proof (and other influence mechanisms) and knowledge clustering to leverage a critical mass of expertise. Greg Orr [3] commented that "... as our communication networks become denser through technological advance, the diffusion process is happening faster and faster". Sandy Pentland [4] has confirmed this observation in his recent book *Social Physics: How Good Ideas Spread – The Lessons from a New Science*.

Observations reported in this paper are derived from experiences at Cisco, Qualcomm, and BNR/Nortel – companies developing software, hardware and systems to deliver communications equipment and IT services (Table I).

TABLE I. Company Experience Context Summary

	BNR/Nortel *1987-2002*	**Qualcomm** *2005-2007*	**Cisco** *2007-2013*
Author's Role	S/W Researcher; SEI Visiting Scientist; Mgr Process Engineering; Sr Mgr External Research	Sr Staff, Learning Center	Director, Research Center
Software Focus	Real-Time: Telephony Communications Systems	Real-time: Mobility + Wireless Systems	Real-time: Collaboration + IT Data Systems
Region	Canada/US, Global	San Diego, Global	San Jose/US, Global
System Info	~25k engineers >10 global sites >> 10 MLOC ~15 yrs	~8k engineers ~5 global sites >> 10 MLOC ~20 yrs	~25k engineers >10 global sites >> 10 MLOC ~25 yrs
Process	Waterfall	Early agile transition	Broad agile transition

Industry-university relations go far beyond setting the context for research collaborations and the translation of invention to innovation. Some motivating perspectives are summarized in Table II.

TABLE II. Industry-University Motivations for Collaboration

	Industry	**University**
Innovation Grand Challenges + Inspiration	Explore and leverage technologies beyond company perspectives and avoid dead ends	Explore market challenges through industry partners
Calibration + Benchmarking + Vendor Visibility	University consortia enable benchmarking in a pre-competitive environment	Industry partnerships provide real world scale and scope to calibrate research
Policy + Talent Development	Curriculum and policy influence	Industry input and internships or sabbaticals
Talent Migration (Recruiting)	Tech transfer skills and knowledge through full-time hires of new grads	Industry opportunities (jobs) for graduating students and academic consulting
Funding strategy + Intellectual Property Rights (IPR)	Outsourcing opportunity for the acquisition of intellectual property rights (IPR)	Funding in absence of other sources and an opportunity for IPR spin-out revenue
Philanthropy	Benefactor of community goodwill	Recipient of community goodwill

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II. BNR/NORTEL COLLABORATIONS

The role of the author at BNR (Bell Northern Research the research arm of Northern Telecom, later rebranded as Nortel) was initially that of a researcher embedded in an exploratory tools group researching new software applications and processes. Research on approaches to software reuse was initiated in 1987 and documented in [5]. The first cycle of software reuse research focused on a tool assisted process for the identification of appropriate classes and methods in the Smalltalk class libraries. The initial challenge was to reduce the learning curve of new team members unfamiliar with either the standard Smalltalk library or project-specific additions to the library. A keyword indexing approach was implemented based on the descriptive variable names and documentation found in method headers.

Initial research collaborations were developed through conference contacts. However, most contacts were industry based – or academics with existing industry partnerships.

As a result of feedback from the internal BNR development community, the focus of our work on software reuse changed from the microscopic (code and indexing strategies) to a macro scale focus on process, communication, team organization, and learning. Two mechanisms were applied to promote software reuse *via* organizational learning:

(1) For small software teams, a workshop process [6] was adapted from John Warfield's Interpretive Structural Modeling (ISM) work at George Mason University as detailed in [7]. Professor Warfield provided consulting services to assist with the introduction of the workshop customization. ISM was used to enable teams to:
- identify shared norms, beliefs, and ideas related to software best practices;
- structure, categorize, and prioritize activities specific to individual teams; and
- propose, plan and review "next-steps".

(2) For large software development organization, an internal (proprietary) technical conference (the "Design Forum") was developed at BNR/Nortel to:
- identify and share BNR/Nortel best practices in design and technology;
- provide feedback to authors through a double-blind peer review (used to avoid the negative influences of hierarchy and seniority) and presentations (for accepted contributions);
- provide a platform to create visibility for academic partners (keynotes or tutorial presenters);
- publish proceedings to capture and preserve organizational memory; and
- foster technical staff internal networking.

Both strategies had tangible results. For example, a workshop revealed the cost implications ($22M) of a contractual penalty while another workshop uncovered system duplications. Similarly, thanks to a summary presentation at a "Design Forum" on a recently completed project – plans for costly duplicate development were nipped in the bud.

Inspirational Design Forum keynote speakers from academia included David Parnas, Mary Shaw, Fred Brooks, Barry Boehm, Tony Hoare, Jeannette Wing, Bonnie John, Laurie Williams, and other pioneers – while industry keynotes included Grady Booch, Steve McConnell, Kent Beck, Ted Biggerstaff, Adele Goldberg, James Gosling, and Bill Joy. As a result of keynote interaction – speakers often became research and/or company consulting partners. A summary of the values and attributes of proprietary tech forums appears in Table III.

Following the presentation of [6] reporting on the results of the BNR/Nortel software reuse program, the author was invited to serve as a Visiting Scientist at the SEI (Software Engineering Institute) a Federally Funded Research and Development Center (FFRDC) on the campus of Carnegie Mellon University in 1994. The year was spent prototyping and piloting team approaches to domain engineering (software reuse for products). Engagement with the SEI led to an increased external visibility for BNR/Nortel and for the ISM based workshop methodology. SEI work also contributed to an increased critical mass of company staff engaged in domain engineering (software reuse) across multiple BNR/Nortel labs. The work connected the author to the leaders of what was to become the agile software community through an ongoing series (50+) of workshops, panels, and forums. These interactive community learning sessions were organized at software conferences including ACM's OOPSLA (SPLASH), IEEE's ICSE, and the European XP20NN series [8].

The SEI partnership was facilitated by Nortel's Global External Research group which helped finalize approval for the SEI/Nortel contractual requirements. Funding in the form of research gifts, sponsored research agreements (to support researcher release time, conference travel, graduate student assistantships, etc.) – facilitated collaborations with university researchers including: Gail Kaiser (Columbia University) and her "MARVEL" tool/process program; and Laurie Williams' research into Pair Programming at NC State.

Another fruitful university partnership developed by six Ontario universities collaborating to support a Software Engineering Master's program. The *Consortium for Graduate Education in Software Engineering (ConGESE)* enabled company staff to follow an industry relevant curriculum, on company campuses within accelerated timeframes.

TABLE III. COMPANY TECH FORUM ATTRIBUTES

Value	a) Corporate wide visibility for innovation/research b) Foster internal networking and collaboration c) Promote organizational learning and talent retention d) Desktop participation options reduce travel costs
Format	Presentations, panels, workshops, tutorials, keynotes
Content	a) Emergent based on internal "call for participation" b) Invited "keynotes" – including academic partners
Audience	a) Technical staff, to break down organizational silos b) Non-technical staff, to increase visibility for research
Selection Process	Double-blind peer review selection process, to avoid the influence of hierarchy and seniority on content
Modularity	Registration/attendance options by session, day, or forum
Feedback Cycle	Authors/presenters receive feedback from reviewers and through their presentations
Transmission	"Live" and "recorded" video streams to reach a global mobile (virtual) corporate audience across time-zones
Keynotes	Recognized experts and innovators anchor program
Expert Forum	Foster internal talent networking, mobility, and retention
Proceedings	Provide a "corporate memory" with a directory of topics and internal experts – with links to external researchers

It became apparent that the dual approach of staff-up ("grass-roots") and C-Level-Executives-down was more effective than either approach in isolation. From experience, starting a technology initiative with a virtual, geographically distributed "vocal grass-roots network" helps secure an enthusiastic following and makes the benefits subtly more visible to executives. Executive edict is less likely to meet with success unless matched by "grass-roots" enthusiasm and motivation. Executive support helps secure budgets and staff, while the effectiveness of program initiatives can be negatively impacted by executive change and broader organizational churn.

III. Qualcomm Collaborations

Complementing traditional lecture-based training (i.e. short courses) – several programs were initiated in the context of introducing "Software Best Practices" to the Qualcomm software engineering community including:

- A "branded" series of talks by invited experts (researchers or "PIs" – as in "Principal Investigators") from academia and industry;
- A proprietary technical conference (the *QTech Forum*) with a double-blind peer review process and visible executive sponsorship; and
- Technical reading circles – discussing and reviewing books such as Fred Brooks' "The Mythical Man Month" [9] and planning change.

The scheduling of talks and lectures proved to be a major challenge. Not surprisingly, talks or short-courses scheduled weeks or months in advance often come into conflict with critical project work. A technology talk or training course has a low priority for most engineers (and their managers) when compared to urgent customer needs or previously unscheduled corporate events which might demand "all hands on deck."

Video streaming is an attractive mechanism for technology transfer at a reduced cost (both time and money) per viewer – particularly for companies with multiple locations (including within the same city, campus, or building). However, using video effectively is a challenge when it comes to audience interaction since the medium is much more limiting than a live lecture. Although video streaming is a convenient way to support a large distributed audience participating from desktops across the corporation and around the world, the technology is not a panacea. Video talks are limiting, because it is more difficult for participants to really "be involved", and because speakers generally perform better in front of a "live audience" who can "shout out" questions in real time.

Similarly, a live talk in an auditorium with two hundred empty seats is not very effective, even if there is also an online audience of two hundred desktops. Attracting participants for both virtual and physical seats emphasizes the need to incorporate both in-person and virtual influence strategies to maximize participation.

Influence strategies have been described by [10] and [11] and may include:

- Authority: motivation by hierarchy or regulation
- Consistency: by personal commitment
- Liking: persuasion by personal influence
- Reciprocity: one good favor deserves another
- Reward: motivation through incentives
- Scarcity: influence by "limited" offers
- Social Proof: the influence of crowd behavior
- Inspiration: attraction to a "new" innovation

Influence strategies may be implemented as follows:

- Organizational edict – with the desired behavior tied to individual performance management (driven by Human Resources) and achievement of documented personal milestones (tying "authority" and "consistency").
- Inspiration from respected leaders (e.g. technical gurus, organization leads – a mix of "liking" and "social proof").
- Providing "free" headcount from "corporate" in return for a product work group piloting a new technology and/or partnering with researchers.
- T-shirts and other *tchotchke* are useful "giveaways" to increase in-person attendance at talks (and all the more attractive if available only to the first N attendees – building on the influence of scarcity).
- Testimonials by influential participants (social proof).

The influence factors above – used in concert at the right time [2] – proved effective in attracting and sustaining interest in the adoption of software technologies at Qualcomm. Visible CTO and CEO participation in programs such as the QTech Forum also proved invaluable.

IV. Cisco Collaborations

As Director of the Cisco Research Center (CRC) the author focused on: scouting emerging technologies, innovation outreach with customers, brokering relationships with university researchers, facilitating technology transfer – and recruiting PhD/Post-Docs.

Cisco collaboration vehicles fell into four broad categories with strengths and weaknesses as outlined in Table IV.

- Consortia/Center research programs were based on broad, multi-year agreements with organizations including MIT's Media Lab, UC Berkeley's AMP Lab, Stanford's Clean Slate, UCSD's CNS, and other centers.
- Sponsored research agreements (SRAs) were based on statements of work (SOWs), with anticipated company intellectual property rights (IPR) including: reports, software, prototypes, benchmarking results, etc. As an aside, to ensure that product groups had "skin-in-the-game" Cisco Business Units (BUs) were required to contribute 50% of contract costs to be matched by CRC operational expense funding – in contrast to research gifts which were generally fully funded from the corporate philanthropy research budget.
- Research gifts were based on PI proposals in response to RFPs (Request for Research Proposal) published on the Research Center web portal at www.cisco.com/research
- Chairs/Fellowships were proposed by students, departments, and universities – as context relevant.

TABLE IV. RESEARCH COLLABORATION VEHICLES

	Consortia (Centers)	SRAs (contracts)	Research Gifts	Chairs, Fellowships
Governance	Company Sponsors + Consortia PIs; University Guidelines	Subject to SRA Terms; University Guidelines	Arm's length; University Guidelines	Arm's length; University Guidelines
Project Selection	Center Selects from PI Proposals	Company Negotiates with PI/University	Company Selects from PI Proposals	PI/Student, Department, Dean Proposal
Payments	Annual Fees	Specified by SRA Payment Schedule	Determined by Company	Fee set by Department or University
Term	Flexible – Often Self-Renewing	Specified in SRA Terms	Generally Fixed term (~1 Year)	Varied: Fellow ~ 1 yr, Chair – depends on University
Strengths	Critical Mass, Tech Sensing, IPR Sharing, Publicity, Good Will, Tax Benefit*	Tangible IPR Deliverables, Tax Benefit*	Exploration, Good Will, Publicity, Lower Overheads, Tax Benefit*	Talent Development, Good Will, Tax Benefit*
Weaknesses	Expense, Lack of Influence on Project Selection	Overhead costs, Lengthy Negotiations	Arm's Length Nature of Relationship	Difficult to Leverage Results, Expense
Risks	Possible Company IPR Contamination	Indemnification Issues, 3rd Party Rights	Gift Ethics, Tax Issues, Compliance + Overhead Issues	Contractual Issues

**Possible Government Research or Philanthropic Tax Benefit*

A. Research Gifts

Research gifts complicate research relationships. "Gifts" must be given with no expectation of reciprocity. Gift funded exploratory research may have community benefit, since "successful" research will generally bear fruit in the form of tangible IPR benefits. This can be problematic for the donor company which will be challenged by the perception (and reality) of reciprocity if they benefit directly and immediately following their gift – in contrast to other companies which can benefit directly since they were not a party to the gift.

If benefits flow to the community, for all to leverage – and the gifting process follows clearly established guidelines on ethics and process – then research gifts are a valuable research community funding mechanism as long as the:

- Research is done at arm's length, i.e. there is no donor company direction – e.g. prioritization of desired results
- Results are publicly communicated – and the donor company does not receive private pre-public results

Both universities and companies require due diligence when entering into gift agreements to ensure compliance with appropriate laws and in some countries (e.g. the US) – guidelines concerning research overheads. While SRAs (research contracts) in the US have attracted overheads approaching 75% or more, gifts have traditionally required smaller administrative overheads under 10%. Companies may also identify and partner with external partner philanthropic foundations to:

- Simplify accounting and manage gift processing
- Ensure "arm's length" compliance, particularly important when there is a duality of relationship (e.g. donor, vendor)
- Separate operational funds from gift funding to decouple research collaborations from quarterly corporate cycles

B. Project Solicitation, Selection, and Follow-up

Projects (contract research or gift funded) were selected from proposals received in response to published RFPs (request for research proposal); through campus visits – e.g. consortia research review meetings, guest lectures, conference interactions, *etc.;* and through discussions between PIs and Cisco Engineers. In some cases, proposals were solicited through business partnerships – for example, the Video Aware Wireless Networking (VAWN) partnership with Intel and Verizon Wireless [12].

RFPs were drafted by Cisco staff and published on the Cisco Research Center web portal following an internal review for relevance and consistency with policy. New incoming project proposals were reviewed every corporate quarter with the goal of making and communicating funding decisions to PIs before the start of the next funding cycle. Following the completion of a research project, both the PI and the Cisco sponsor were invited to provide feedback on research outcomes – e.g. publications, students mentored, community value, etc. Quarterly investments and other Cisco Research Center key process indicators were communicated to senior management. However, drawing a cause-and-effect between funding and results was challenging.

C. Tech Transfer through PhD/Post-Doc Recruiting

Research projects provided attractive opportunities for post-graduate recruiting (PhDs/Post-Docs). Through skills, experience, connections, and passion – new grad PhD/Post-Docs were recognized as an effective form of tech transfer – to transition university research lab expertise into product development.

The PhD/Post-Doc "Cisco Choice Select" recruiting program was "talent-centric." The intent was to place exceptional full-time and intern candidates identified through university research collaborations. In contrast to a "requisition-centric" recruiting program where multiple candidates are interviewed to fill one role, "Cisco Choice Select" PhD/Post-Doc candidates interviewed for three to five roles which they would "select" from a list of 100+ available role descriptions.

Proposed PhD/Post-Doc role descriptions were solicited from company senior technical talent (e.g. distinguished engineers, fellows, CTOs, directors, managers) – with a track record of innovation, university research collaborations, and/or adjunct professorships. The program featured a consistently high hire rate (more than 50% of identified candidates).

When collaborating PhDs/Post-Docs new grads decided to remain in academia – this was seen as a different, but equally important opportunity to fund the new academics in their first university position – possibly leading to a career research relationship. The "downside" of the "Cisco Choice Select" process was that central funding was limited and only ~20% of the roles could be filled. The process "upside" was that candidates had a much greater choice of roles – and Cisco had increased opportunities to attract top candidates.

D. Software Research

Great interest was demonstrated by product teams (and executives) in the advances and value enabled by software technologies – e.g. Software Defined Networking (SDN), the Internet of Things (IoT), Video Collaboration, Security, Cloud Computing etc. This interest was in contrast to that shown for software process or tools research *per se*. Challenges also arose due to organizational churn which seemed to impact software organizations (e.g. those with a "meta" focus on process) more so than product organizations. This was also true at Nortel and is likely true of any organization whose budgets are optimized to deliver quarterly returns to meet shareholder expectations in contrast to anticipated "long-term returns" from the reduction of technical debt or software process improvement.

On joining Cisco in 2007, the author discovered that the Agile "revolution" was truly well under way – driven by enthusiast zeal and a curiosity for new effective approaches to engineering software. However, unlike the "early days of Agile" at the turn of the 21st Century – it was no longer a case of Agile consultants selecting projects – but rather the project staff driving agile [13] because of anticipated benefits. This contrasted to the days when "Extreme Programming" was "the" Agile methodology of choice and limited to single site and non-mission critical system development. Perhaps not surprisingly, Agile has been driven by industry experience rather than academic research as evidenced by the initial signatories to the Agile Manifesto [14].

As reported in [15] Cisco embarked on a program to introduce and standardize agile development processes beginning with the *Collaboration and Communications Group* (CCG) in November of 2009. In addition to instructor led courses, and mentoring – visiting experts and Cisco engineers contributed material to company conferences. Conferences included: *Agile @ Cisco*, an internal conference focused on agile software practices and tools; and the *CTech Forum*, a broad-based research and innovation conference with a double-blind peer review content selection process organized by the Cisco Research Center. Drivers for technology adoption included engineering staff – both from the "company mother ship" and from recently acquired companies; tool vendors; and program managers frustrated by "waterfall processes". As a result of much discussion and debate, standardized agile processes [16] were developed and deployed.

V. Observations and Summary

University software engineering research collaborations were initiated through a variety of mechanisms that connected industry engineers to researchers – including:

- Industry visits to campus – for consortia/center reviews, seminars, or to attend other meetings, etc.
- Researcher visits to industry – to give talks, demos, etc.
- Unsolicited researcher proposals to industry
- Researcher proposals in response to industry RFPs (Request for Research Proposal)
- Researcher paper publications
- Conference interactions and collaborations (papers, panels, workshops, demos)

Table V summarizes programs that created visibility and led to sponsorship for research collaborations. One challenge at Cisco for researchers was the lack of a "research lab" with a sustained critical mass and a technical mission – in contrast to both Nortel and Qualcomm. This made it more challenging to transition PhD new-grads and Post-Docs directly into a product environment. However, some – including the CEO John Chambers – would argue that innovation by acquisition (of companies) was a better strategy than research lab investments – while others in the investor community might disagree [17].

The effective application of appropriate influence strategies is key to engaging staff, sustaining executive sponsorship, and brokering collaborations with university based researchers. Practices found useful to introduce technologies included: sponsorship at all levels – from "grass-roots" to C-Level executives; pilot projects; internal conferences to share and make visible results; peer mentoring; and research collateral (e.g. funding, the calibration of industry scope and scale) to identify and place top PhD/Post-Docs into relevant engineering roles.

"Open innovation" [18] strategies are an important factor for deploying software source libraries and sharing ideas – keeping in mind that the benefits of "openness" must be balanced against the obligations imposed by licensing restrictions. Recent books by Georges Haour and Laurent Miéville [19] *"From Science to Business: How Firms create Value by Partnering with Universities"* and Martin Kenney and David C. Mowery's [20] *"Public Universities and Regional Growth – Insights from the University of California"* report on a variety of open research collaborations and their economic impact. In contrast Jon Gertner's [21] "*The Idea Factory: Bell Labs and the Great Age of American Innovation*" reports on the fruits of proprietary research – funded by AT&T's telephone monopoly.

TABLE V. Summary of Research Collaboration Enablers

	BNR/Nortel *(1987-02)*	**Qualcomm** *(2005-07)*	**Cisco** *(2007-13)*
Internal Tech Forums	Design Forum	QTech Forum	CTech Forum
Expert Networks	X	X	X
Short Courses (by academics)	X	X	X
Tech Talks	X	X	X
Academic Sabbaticals	X	X	X
Industry Sabbaticals	X	X	X
External Conference Participation	X	X	X
Reading Circles	X	X	X
Research Labs	X	X	
Facilitated Workshops	X		
Industry Software Masters	X		
Research Institute (SEI) Pilot Projects	X		

A useful source of guidance may be found for partnerships between university and industry research managers in a forum hosted by the National Academy of Science in the US – namely the University Industry Demonstration Partnership (UIDP) [22]. The UIDP has published a number of relevant guides – including a "Researcher Guidebook" [23] and an "Intellectual Property Quick Guide" [24].

A concept useful for evaluating technologies and building relationships – which research collaborations play into – is that of a "Technology Radar" [25] which helps provide intelligence on innovation trends and support for innovation strategies.

Our experience garnered at three companies, confirms the importance of strategic migration of experts between industry and academia (and *vice versa*). We have observed that many of the "academic" software engineering researchers presenting their research or partnering with Cisco, Qualcomm, and BNR/Nortel had pre-existing industry experience. However, the same experience indicates that it is difficult to draw direct (absolute) cause-and-effect relationships between research collaborations and product/company success factors. That said, relative trends in "partner satisfaction", recruiting, and increased opportunities for tech transfer were observed.

Some catalyst programs required only limited resources for implementation, yet delivered wide "grass-roots" value, e.g. tech talks and reading circles. While face-to-face collaboration – at least initially – is preferred to leverage the proximity of researchers to industry scale and scope – collaboration tools including audio and video conferencing can be effective to sustain a virtual partnership. Even an informal just-in-time tech talk invitation might lead to a company's adoption of new technologies, tools, and processes – or it might connect for the acquisition [26] of a university spin-off. The power of collaboration should never be underestimated – whether planned or serendipitous.

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