Electrical Engineering and Computer Science at UC Berkeley: Another source of innovation for Silicon Valley

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Role of research universities in knowledge-based growth

- Focus of public policy in OECD, industrializing nations.
  - US “patent-based” policy, embodied in the Bayh-Dole Act of 1980, focused on patenting and licensing of academic research.
  - Bayh-Dole has been widely (if not always precisely) emulated by many other national gov’ts.
  - Numerous other policies adopted by US, other gov’ts to support “technology transfer” from universities since the 1980s.
- Topic of a large literature in economics, innovation studies.
  - Much of the empirical work focuses on “the countable,” especially patents and licenses.
  - A more modest case-study based literature has focused mainly on private US universities, especially MIT and Stanford.

Forthcoming volume on UC campuses' industry links and impacts

- Volume (Kenney & Mowery, eds.) of case studies of interaction between industrial and academic research that goes beyond patenting & licensing.
  - Focus on a public research university.
  - US public universities account for 69% of academic research activity, perform 60% of federally funded R&D, award 34% of bachelor's, 50% of PhDs as of 2009.
- Chapters on specific industries and UC campuses:
  - UC Davis and Napa Valley wine industry (James Lapsley & Daniel Sumner).
  - Semiconductors and UCLA, UCB, and UCSB (Christophe Lecuyer).
  - Biotech and UCSD, UCSF (Steve Casper).
  - Digital electron microscopes and UCSB (Cyrus Mody).
  - Wireless communications and UCSD (Mary Walshok & Joel West).
  - Information technology and UCB (Kenney, Patton, & Mowery).

Case studies highlight influence of industry on links with UC campuses

- 2-way interaction (intellectual, financial) between industry and academic research.
  - The links between academia and industry at several UC campuses were affected by large, research-intensive firms located near the campus.
    - Genentech (UCSF spinoff)
    - Qualcomm (UC San Diego)
    - Hybritech (UC San Diego spinoff).
    - Digital Instruments (UCSB spinoff).
    - IBM Almaden Research Labs (UC Berkeley).
  - University spinoffs are important, but established regional firms also were sources of spinoffs.
  - Researchers moving from industry to academia & vice versa play a key role in many of the interactions, innovations discussed in the volume.

Historical overview of the EECS department at UCB

- 1st faculty member specializing in electrical engineering joined UC "Department of Mechanics" in 1892.
- Department of EE established in 1958, nearly 60 years after MIT's EE department was founded in 1902.
- Computer Science, formed as a new UCB department in 1968, merged with EE in 1973 to form the EECS department.
- An intellectual backwater in the 1940s, UCB EECS department was ranked by US National Research Council in 2010 as #1 in US, tied with MIT and Stanford.

UCB EECS department's rise to national eminence paralleled transformation of EE

- Electrical engineering during the 1930s in US and at UCB consisted largely of practice-oriented electrical power engineering.
- Beginning in the 1940s, EE was transformed from a practice- to a theory-driven field.
- At UCB and other US universities, this transformation was influenced by federal support for defense-related research on radio, microwaves, and computing.
- Chapter on UCB EECS includes case studies of 7 major innovations, chosen to highlight channels of interaction.
  - Selection also influenced by availability of information.
  - Goal is description, rather than hypothesis testing.

California Digital Computer (CALDIC), 1948-54

- Funded by Office of Naval Research (ONR) as the 1st West Coast university-developed computer.
- Computer itself was never commercialized.
- Instead, project influenced regional industry through its training of engineers who went on to distinguished careers at IBM Almaden Research Labs in San Jose.
- CALDIC "graduates" led the IBM team that designed the disk-storage drive that was incorporated into the RAMAC computer, introduced in 1956.
  - Success of RAMAC's disk-drive technology led IBM Almaden labs to specialize in disk-drive technologies.
  - Subsequent growth of Bay Area disk-drive industry relied in part on people, ideas, and new firms from the IBM Almaden labs.
- Project's significant influence on industrial innovation was indirect: Employment in industry of talented students from the CALDIC project seeded the emergence of disk-drive industry in Silicon Valley.

Project GENIE and timesharing, 1964-68

- Defense Advanced Research Projects Agency (DARPA) supported work at MIT and UC Berkeley on computer time-sharing to facilitate access to then-scarce computing time.
  - MIT focused on mainframes, UCB on minicomputers.
- UCB researchers developed time-sharing SW for a Scientific Data Systems (SDS) minicomputer and gave the operating system to the company in 1965.
- Specialized timesharing computer services firm, Tymshare, founded in 1964 in Cupertino on basis of UCB-developed operating system.
- Success of Tymshare led 2 UCB faculty to establish a time-sharing firm, Berkeley Computer Corporation (BCC), with financial backing from UC system, in 1968.
  - BCC failed, but students trained in GENIE project and employed at BCC went to work at Xerox PARC, developed 1st "personal computer," the Alto.
- Tymshare's market position remained strong, but SDS dominance was eroded by minicomputers from Digital Equipment, and no strong Silicon Valley "cluster" in timesharing was established.

Relational Database SW, 1973-1980s

- Bay Area is a center for the modern database SW industry, and this regional dominance reflects work at UCB and IBM/San Jose.
- UCB professors, influenced by work on relational databases at IBM that led to SQL, obtained funding from DARPA and National Science Foundation to develop competing SW, QUEL.
  - UCB professors Stonebraker & Wong founded Relational Technology (renamed INGRES) to market QUEL.
  - IBM published its work, as did UCB faculty, who also provided QUEL to interested parties at no cost.
- IBM – UCB competition catalyzed rapid progress in this SW and led to foundation of many new relational-database SW firms in the Bay Area.
  - 22 of Stonebraker’s 32 students acknowledged in his account of the development of INGRES remain active in the Bay Area industry today.
- Competition between industry and academic research, along with the training of students, shifted the national “center of gravity” in the US relational-database SW to Bay Area from E. Coast.

Simulation Program for Integrated Circuit Engineering (SPICE), 1970-1990s

- EECS faculty member (Rohrer) returned from sabbatical at Fairchild SC, organized a class project to develop IC design SW in 1971.
  - Rohrer's efforts to commercialize his SW through new firm, Softech, were unsuccessful.
  - UCB colleague took over the academic research and developed SPICE, which he disseminated to all interested parties.
  - Availability of "free" design SW attracted industry participation (HP, IBM, Mentor) in further development, dissemination, accelerating progress & establishing SPICE as industry standard.
  - Industry researchers also spent time at UCB working on SPICE.
- UCB graduate student (Solomon) founded firm based on SPICE that grew into Cadence Design Systems, successful design SW firm.
- SPICE "standard" supported emergence of "fabless" semiconductor firms in Silicon Valley and globally.
  - Standard design SW facilitated collaboration between fabless design firms and "foundries" that produce their chips.
- Liberal dissemination of key innovation, training of students => rapid adoption, accelerated advances in a key SW "building block" of the US-based "fabless" SC industry in the 1990s.

Reduced Instruction Set Computing (RISC) microprocessors, 1970s – 1980s

- Stanford, IBM, UCB researchers independently began work on simplifying microprocessor architecture during the 1970s in order to accelerate computing speed for engineering workstations.
  - Stanford (Hennessey) and UCB (Patterson) researchers developed competing architectures, MIPS and SPARC.
  - Patterson worked with former student (Bill Joy) at Sun Microsystems to adopt SPARC (consulting, but no formal license); Hennessey helped found MIPS Computer Systems to commercialize MIPS architecture through Silicon Graphics.
    - Both Sun and Silicon Graphics located in Silicon Valley.
- SPARC and MIPS architectures ultimately lost market position to lower-cost Intel MPUs, but RISC architecture remains key to ARM microprocessors, widely used in cell phones and handheld devices.
- UCB "informal" transfer of technology to industry was facilitated by employment of student (Joy) at Sun Microsystems.
  - Competition between Stanford and UCB researchers arguably accelerated progress.
  - 2-way flow of ideas, people, some $$ between industry and academia also key.

“Berkeley UNIX” (BSD Unix), 1973-1995

- UNIX developed in 1969 at Bell Labs by an EECS alumnus to support multitasking, time-sharing.
  - UCB faculty member learned about UNIX through a conference presentation, then licensed the SW from AT&T in 1973 & modified it to operate on a DEC minicomputer.
  - UCB and Bell Labs researchers worked closely to improve UNIX.
  - Bell Labs UNIX developer spent a sabbatical at EECS, taught a class on UNIX that led students to modify UNIX to produce the “Berkeley Software Distribution UNIX” (BSD UNIX).
  - BSD UNIX distributed to all parties requesting a copy.
- DARPA required that the Internet SW protocol developed under its sponsorship (TCP/IP) be integrated with UNIX in the ARPANET to ensure compatibility among different computers on the network.
  - DARPA supported UCB researchers’ work on BSD UNIX integration into what became the networking protocol underpinning the Internet.
- Lawsuits between AT&T and UC system over UNIX license produced a settlement that allowed for continued distribution of modified version of BSD UNIX.
- UNIX, the SW foundation for the WorldWideWeb, emerged from a complex interaction among academic and industrial researchers, aided by funding from both industry and federal gov’t.
  - Personnel flows and informal interactions between industry and academic researchers, including students, also important in development and diffusion of this SW innovation.
  - University sued to protect “freedom to invent,” rather than seeking to strengthen its ownership of faculty-developed IP.

Redundant Arrays of Inexpensive Disks (RAID), 1987

- Important advance in computer architecture that demonstrated feasibility of today's "server farms."
- 2 UCB EECS faculty & a graduate student published an influential paper in 1987 positing a tradeoff between very large disk-storage systems utilizing small # of expensive disks and an alternative architecture relying on large #s of inexpensive disks.
  - SW-enabled architecture made possible exploitation of rapid advances in low-cost storage technologies developed for PCs.
  - Researchers built a 192-disk prototype array in 1990.
- DEC, IBM, EMC, along with numerous new firms, commercialized technologies based on this architecture during 1990s.
  - New firms clustered in Silicon Valley, based in part on spinoffs from IBM Almaden Research facilities.

Other channels of U-I interaction at EECS

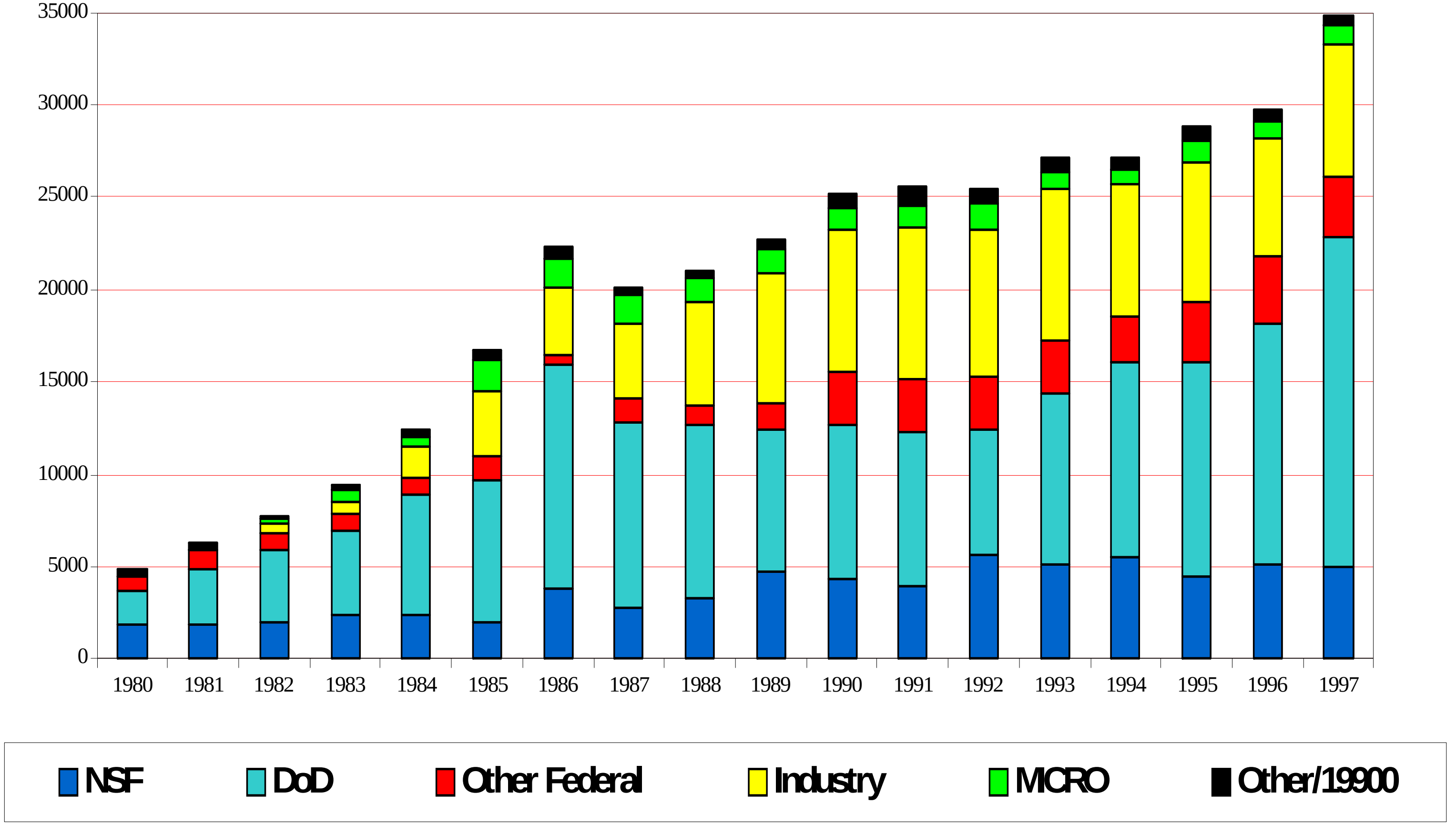
- New-firm formation:
  - 53 new firms founded by EECS faculty or students immediately after graduation; all but 2 located in Bay Area.
  - EECS faculty serve as advisors or in management at 78 other firms, 13 of which are located outside of the region.
- Patents & licensing:
  - Patents historically have been less important economically or technologically in IT than in other fields (e.g., biomedical).
  - UC EECS faculty have patented relatively few inventions, based on view that patenting can obstruct informal collaboration and knowledge exchange with industry.
  - Royalty income from licensing of UCB EECS patents historically has been modest.

Industry-funded research and philanthropy

- Over time, the establishment of strong links between this academic department and industry (both regional and global) was associated with growth in industry funding of academic research and industry philanthropic support of the department.
  – But industry funding never equaled federal research support (Figure) during 1980s and 1990s.
- 1980-97 data (Figure) show increasing share of EECS department research funding coming from industry.
  – CA state-sponsored MICRO program included mix of industry, state gov't funds.
- Industry also provided significant donations of equipment.
- "Industrial liaison program" involves payments from firms for conferences, lab-visit programs: US$3.1 million in 2012.
- US$18 million raised from industry for new EECS building in 1995.

Electronics Research Laboratory, UC Berkeley

Expenditures by Source ($K), 1980-97



Conclusion

- Intra-regional competition between firms and between research universities (UCB and Stanford) provided an impetus to innovation.
- Liberal disclosure and dissemination of IP limited licensing-based financial returns but yielded significant regional economic benefits and benefits for UCB EECS.
- 2-way flow of researchers and ideas between universities and industry is another important element in these innovations.
  - Placement of graduates in industry and exploitation of a large alumni "network" supports these flows of people and ideas.
  - Established high-tech firms played an important role in funding academic research, supplying new ideas and people, absorbing academic innovations, employing graduates, and spinning off new firms.
  - In a number of cases, university research facilities functioned as a joint facility for performance of (nonproprietary) research by faculty and industry researchers.
- Public R&D funding was critical in laying the foundations for the EECS department's rise to international eminence and public project-level support contributed to many of these innovations.

Conclusion (2)

- Development of strong 2-way links between EECS and industry was associated with growth in industry funding share within an expanding pool of research funds.
  – Not limited to UCB EECS: UC systemwide net licensing revenues are dwarfed by industry-funded sponsored research (in early 2000s, annual net license revenues averaged US$37million, but industry sponsored research was US$225 – 250 million).
- Relationships are dynamic and path-dependent, changing over time with evolution of research fields, regional firms, funding levels & sources.
- Factors & institutions outside of academic institutions influenced the interaction between university and industrial research and innovation.
- No single set of “metrics” captures these dynamic, numerous, complex links between EECS and regional industry.
- Patents are of limited importance in university-industry linkages in UCB EECS, consistent with other studies of IT field:
  – Agrawal & Henderson for MIT.
  – Cohen et al. surveys of industry R&D managers.
  – Nelson et al. surveys of R&D managers.