CLASS 8: DARPA as the Connected Model in the Innovation System - Gov't-Private Sector Interaction and the Example of Computing

William B. Bonvillian

MIT: STS.081/17.395

"Innovation Systems for Science, Technology, Mfg., Energy and Health"

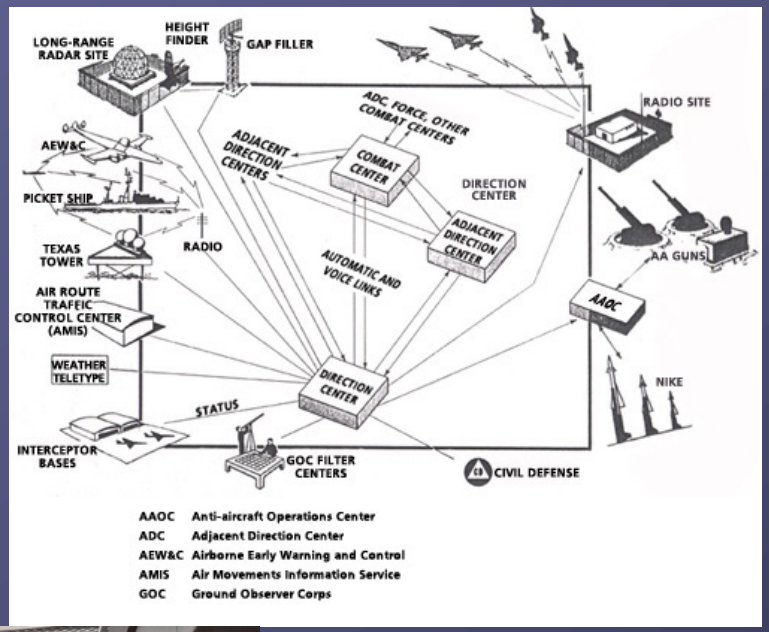
Here's what it's like before Licklider comes to computing:

- "Present-day computers are designed primarily to solve preformulated problems or to process data according to predetermined procedures. The course of the computation may be conditional upon results obtained during the computation, but all the alternatives must be foreseen in advance. ... The requirement for preformulation or predetermination is sometimes no great disadvantage. It is often said that programming for a computing machine forces one to think clearly, that it disciplines the thought process. If the user can think his problem through in advance, symbiotic association with a computing machine is not necessary." – JCR Licklieder
- But suppose you can't think through every variable in advance for every question you face? Main-frame pre-programmed computing won't work well – this is the problem that drives Licklider

Whirlwind and SAGE at MIT

SAGE consoles & light guns

SAGE network



IBM SAGE system

M.Mitchell Waldrop, "The Dream Machine, J.C.R. Licklider and the Revolution that Made Computing" (Viking 2001)

- **CHAPTER FIVE:**
- FIRST STEPS - USAF Whirlwind/SAGE at MIT
  - DOD sponsored computer projects –single application
  - SAGE did have desk consoles &CRT monitors, network connected over phone lines
  - But built team of experts at MIT
  - Ken Olsen, Wes Clark, Harlan Anderson become DEC
    - -- build TX-0, light pen, transistor-based, CRT monitor
    - Draw, play games, move toward interactive computing

COMPUTING OUTLOOK LIMITED:

- Not interactive – not fun or exciting – behind glass walls, white-coat technicians
- Forbidding – built for large number-processing bureaucracies in business and gov't
- IBM – builds on its tradition of mechanical tabulators for business and accounting – punchcards/batch processing
- Emphasis on bigger and bigger computers

Waldrop on Pre-Licklider computing:

- "More than a decade will pass before personal computers emerge from the garages of Silicon Valley, and a full thirty years before the Internet explosion of the 1990s.
- "The word computer still has an ominous tone, conjuring up the image of a huge, intimidating device hidden away in an overlit, air-conditioned basement, relentlessly processing punch cards for some large institution: *them*."
  - Waldrop, Dream Machine (2001).
- Watch this 1972 film of what ARPANET was trying to do: http://www.youtube.com/watch?v=aY4vsHWe25c

ENTER JCR LICKLIDER:

- Man-machine interface/TRAINED AS PSYCHOLOGIST
- Psychologist – has idea of man-machine role from WW2 acoustic work
- Realizes 85% of thinking time is spent getting into position to think, to make a decision, to learn elements needed – clerical mechanical aspects
- "The hope is…human brains and computing machines will be coupled together very tightly and the resulting partnership will think as no human has ever thought and process data in a way not approached by the information handling machines we have today"
- Humans: perception, goal-setting, judgment, insight
  - These qualities surpass machines - these are "heuristic" qualities
- So: Licklider leaves MIT psychology dept.
- Joins BBN – acoustic consultants
  - Brings BBN into computing

LICKLIDER: THE ROLE OF SYNTHESIZER

- Licklider's role:
  - He's a psychologist – can see need to have computing serve people
  - Electronic expert – knows technology
  - Provides a roadmap into the future of computing
  - Licklider is ideas not inventions -- innovation req's vision
- 1960 ARTICLE – ***MAN MACHINE SYMBIOSIS*** (IEEE magazine) - the seminal, breakthough piece
- Fig tree pollenated by wasp – Lick's metaphor of symbiotic relationship
- Must be relationship/partnership between computer and man – perform complementary functions
- This partnership must be in real time – can't be based on "batch processing"
- Computer is to relieve people of the 85% drudgery factor

LICKLIDER ROLE– MAN/MACHINE SYMBIOSIS, Con't.

- Time-sharing – computer must serve many users – interactive – like windows for each user
- Would be an online learning or "thinking center" (the www)-later calls it the Inter-GalacticNetwork
- Sees a "network" of thinking centers, connecting users in a continental scale" – the Internet
- See memory storage need
- AI offers the most direct path to understanding intellectual processes
- Envisions a personal desk console linked by phone lines
- Sees "thinking center" as a public utility – compute at center surrounded by users

LICKLIDER ROLE: MAN/MACHINE SYMBIOSIS, Con't.:

- Sees interactive computers participating in wide range of intellectual tasks including education itself [writes early educational software]
- Sees programming as a science – a process yielding both practical applications and profound insights – like mathematics itself
- Sees programming and computing as a way to understand the structure of ideas and way to grasp intellectual process – so: model for cognitive science
- Sees computing role in "dynamic modeling" –
  - Take static models (data) and
  - Let user play with them into dynamic modeling
  - User could "feel" and change model and parameters

LICKLIDER ROLE: MAN/MACHINE SYMBIOSIS, Con't.:

- Sees that computing will help manage the great problem of complexity - the multitude of variables
- With online access for numerous users, computers can bring many minds to bear on dynamic modeling – early idea of groupware
- Computer could create and manage the "system of systems"
  - Ex: combat theatre operations center or computer-aided design/manufacturing process

LICKLIDER ROLE: MAN/MACHINE SYMBIOSIS, Con't.:

- Invents the idea of the "electronic library" –a digital library where vast data could:
  - be stored – online library
  - be organized and accessed through a search process
  - It would be both library and reference librarian
- SO: computer is the key tool for getting past the "brain-desk barrier" and extracting real knowledge
- Envisions "new science" of computing as an intellectual enterprise of high order

LICKLIDER ROLE: MAN/MACHINE SYMBIOSIS, Con't:

- So, in summary: 15 years before the PC, 30 years before the internet (p.186) Licklider envisions:
  - Graphics-rich personal work stations
  - Idea of human computer symbiosis
  - Time sharing, ie, interactive computer-aided collaborative work
  - Networks and idea of online community
  - Online libraries, with instant ,universal access to knowledge
  - Computer language, and new digital medium of expression

LICK=VISIONARY; DARPA= VISION CHAMPION?

- By 1961 – Licklider unfolds the whole next 50 years of computing – the **VISIONARY** of computing as we are still realizing it
- But: there is no **VISION CHAMPION**
  - MIT is stumbling along supporting visionaries
  - BBN, DEC, MIT tinkering with hardware and software
- Then: DARPA emerges as a possible "Vision Champion" with R&D funding resources to build the vision
- Licklider comes to DARPA to play this role
- Unique moment - visionary becomes vision enabler

Chapt. 6: THE FOUNDING OF DARPA

- 1957 – Shock of Sputnik
  - Eisenhower – creates formal Science Advisor
  - Massive new R&D investments
  - ARPA founded by Eisenhower to perform space R&D since stove-piped services were failing
  - But months later selects NASA to do civilian space
- By 1960 – services recapture defense space programs from DARPA
- DARPA - left doing revolutionary science R&D projects:
  - Ballistic missile defense (at MIT's Lincoln Labs)
  - Nuclear test detection
  - Materials science
- Jack Ruina – Director and MIT Prof. – saw DARPA as a force for "technical excellence"
- Ruina starts to handle "Presidential Issues" – subjects a Secretary of Defense wants to understand

The Command and Control Problem:

- Kennedy/MacNamara: Cuban missile crisis illustrates profound "command and control" problem
- Ruina brings in Licklider before Cuban missile crisis but this becomes driver for Lick's efforts
- DOD's command and control needs match Licklider's agenda for for computing
  - DARPA contributions to computing project:
    - "White Elephants": 4 surplus Sage computers
    - Orphan: Systems Dev. Corp. – Rand spinoff from SAGE – USAF wanted to keep its team
    - Crisis in Command and Control
- Ruina had never thought of the link between behavior and computing, but liked Lick's ideas that merged these two

1) THE RULES OF DARPA

*Why DARPA becomes DARPA – "the greatest venture capital firm in the history of the world" – unique new R&D model – what are its organizing principles?

- "Technical excellence" – great talent
- DARPA's Director: anti-micromanagement (p. 205)
- DARPA uses its potential competitors at DOD (service R&D, service labs) as its contracting agents and collaborators (p.206)
- DARPA "coordinates the stovepipes" via inter-agency monthly meetings – group has no charter, only sharing info. (p.206)
- SO: potential bureaucratic enemies become friends
- DARPA nurtures satellites of extremely talented researchers – sponsors the research community (p.206)

2) RULES OF DARPA:

- DARPA uses high-speed flexible contracting– "just do it"- high speed – develops "other transactions" authority (p. 221)
  - Charlie Hertzfeld, DARPA Dir.: someone with a good idea can get $1m in a day; Robert Taylor gets $1m for the Arpanet in 20 minutes
- DARPA project directors "mentor not micromanage" (p.238)
- DARPA funds not only hardware technology but those who develop the intellectual and conceptual framework for the tech advances – not just hardware but thinking (p.240)
  - Ex.- Carnegie Tech – early computer science dept. funded by Lick – defines computer sci. very broadly – "the phenomena surrounding computers" – from physics of IC's, to math algorithms, to human interface design, to social ferment around DARPA community – works on overlaps between cognitive science and computer science
- "creating an explosive intellectual environment is a lot like planning a successful party" (p.219)(quality attendees/quality activity)

3) RULES OF DARPA:

- Uses collaborative partners from both Univ.'s and industry – ex's: BBN, SDC, Rand/MIT,Utah, UCLA, etc.
- Summer Study mechanism [from Tuxedo Park model] enables researcher collaboration (p.222)
- Talented project directors stay several years and move on, but to get continuity name their successors –mix of management change, continuity and ongoing expertise
  - – Licklider, to Ivan Sutherland, to Bob Taylor, to Larry Roberts, etc.
- Grand Challenge idea = Long-term commitment to nurture an outstanding research base to meet major tech challenge – in interactive computing, commitment lasts well over a decade – radical not incremental change
- Tech Demo– ex., Englebart's fall '68 demo (p.288) to computing world (see below)

LICK'S/DARPA'S SATELLITES OF GREAT GROUPS:

- Systems Data Corp. (SDC) (Jules Schwartz) – time sharing/interactive
- Carnegie Tech (Alan Newell, Herbert Simon, Alan Perlis) – computing as a science, LISP software - expansive
- RAND Corp. – software: "General Problem Solver" for time sharing
- Stanford (John McCarthy) – time sharing
- Berkeley (Ed Feigenbaurm) – time sharing

- And – Doug Engelbart & MIT – next slides

LICK'S/DARPA'S GREAT GROUPS, CON'T.:

- Doug Engelbart (Stanford Research Inst.)
- Was Navy radar operator in the Philipines
- 10/62 – Augmenting the Human Intellect, A Conceptual Framework" – picks up man-machine symbiosis
- Word processing
- Computer-based framework for human-computer learning:
  - "concept manipulation" – raw ideas, concepts
  - "symbol manipulation" – representing concepts with symbols
  - "manual external symbol manipulation" – ways to graphically represent symbols – writing, drawing
  - "automated external symbol manipulation" – computers can aid humans by adding a different kind of knowledge – 3 dimensional graphics that can be played with, etc.
- "knowledge augmentation library" (Lick's framework)

The MIT Great Group – Project MAC ("Multiple Access Computing")

- Project MAC is timesharing (pp.220-224)
- Lick's and Bob Fano's Train Ride – 1961
  - Greenbriar Resort to Wash., DC
  - Fano buys Lick's symbiosis and interactive computing and agrees to head new MIT "Tiger Team" effort funded by DARPA
- The conflict in MIT – 2 separate competing computing approaches – DARPA supports both:
  - Licklider's (and Larry Corbato's) Project MAC man/machine symbiosis idea, computers complement human intelligence, verses:
  - MIT (Marvin Minsky) Artificial Intelligence (AI) Lab
    - Built on idea computer thinking would be superior to man's, not just complementary
  - MIT joke: "MAC" means: "Minsky Against Corbato"

MAC: THE "VIRTUAL COMMUNITY"

- Industrial Revolution–hierarchical, class- creating; Information Revolution–inherently democratic, empowering, leveling
- Project MAC – electric utility analogy used – power flows one way from power plant to user; in info. Utility, POWER FLOWS BOTH WAYS (pp.227-232)
- MAC's CTSS (Computer time sharing) – set up as OPEN SYSTEM – users can extend and modify system – becomes user's own system not imposed system - commons theory
  - Software is posted and shared – early word processor, archive, file, email, file exchange, games – creative MIT types keep adding to the system, build it jointly
  - Users keep adding and sending out to other users – it's a 2-way utility – users dominate, system secondary
  - Idea: creativity within standards/framework – key step

MAC: THE VIRTUAL COMMUNITY

- This MUTUAL BUILDING DYNAMIC is a kind of "shareware"
- Uses "Public Data Repository" that becomes a "TOWN SQUARE, ROMAN FORUM, ATHENIAN AGORA" – where "citizens" talk, exchange ideas, argue, build better ideas
- This is a social revolution not just a technology revolution
- Didn't HAVE to go this way - computing could have just extended the Industrial Revolution (IBM vs. Licklider)
- SELF-GUIDED, NOT TOP DOWN – opposite of industrial tool approach of batch processing
- Open System model enables creativity to flow throughout the system – the joint creativity builds a much stronger and powerful system
  - Irony of IBM now championing open systems, Linnux, verses MS closed systems approach
- But: openness requires trust – have to have faith in system quality ("Murphy was an optimist")
  - Fault toleration, firewalls, backup files, passwords
  - Privacy vs. "hackers" (MIT model train club term) in AI project

LICK PUSHES THE INTERNET:

- "Intergalactic Computer Network" – Lick in 1963 (p.225)
  - Concept of "network" for his DARPA supported community – people at the heart of his idea
    - Lick Saw Project MAC developments and wanted to push that virtual community model nationwide
  - Q: How to convey whole vision and progress to each researcher? A: Link each group's timesharing computers
  - Lick's DARPA memo envisions the internet in more detail
  - Motive -To build an ongoing tech revolution, need a network of mutually supporting researchers
    - Alternative – Tech Tower of Babel – scattered researchers and disconnected computers
  - Lick foresaw connecting all DARPA's timesharing computers into a single national network
  - Builds on his network of "thinking centers" idea
- Lick's DARPA 3 research priorities:
  - 1) Timesharing (interactive),
  - 2) Graphics/Modeling (Ivan Sutherland),
  - 3) Networking (Bob Taylor)
- Lick saw need for all 3

The Inevitable Confrontation: MIT's Project MAC vs. IBM System 360

- IBM's new System 360
  - A "bet the company" $5B initiative for IBM
  - Idea: replace all previous computers with single line of computers for all levels of need
  - Term "360" conveys full circle of computers
  - Idea: Share common software program for small and large computers
  - Idea: new programming language (PL/1) and same operating system (OS/360) for whole 360 line of computers of mixed size/speed
  - IBM: basic organizational theme: one powerful processing unit at the center of a spider's web of users

IBM vs. PROJECT MAC at MIT

- Market reaction to System 360?
  - Companies love the idea of software compatibility – ends nightmare cycle of disruptive redo of new programming for every computer upgrade
  - 360 is a watershed of computing history – assures computers are integrated into every corp. and gov't operation
  - System 360 then 370 become the defacto standard for mainframe architecture into the 90's
  - Note: Emmanuel Piore – builds brilliant IBM R&D Center – ex.-IBM hardrive is breakthrough for memory and storage that enables interactive computing
- BUT: MIT wanted MANY central processing units operating at once to serve timesharing network–more reliable, if one down, rest work, and can keep expanding the system by adding CPU's
  - MIT's Project MAC-fundamental contradiction to System 360

1) ARPANET - Lick's Third Stage – Networking through Arpanet

- CHAPT. 7:
- Lick & Robert Taylor envision computing as a communications device –
- how to do? Dial-up phone connections too slow
- Taylor and Larry Roberts at DARPA develop 2-way model – ARPA nodes have to hook up, but also new way for users to contribute ideas
- Again – open system – creativity within standards/protocols/framework
- Robert Taylor's & Larry Robert's Arpanet Model:
  - Packetswitching over phone lines
  - Network of central computers protected by small routing computer ("IMP") at each node

2) Arpanet, Con't

- DARPA picks BBN to implement the technology
- In parallel – same packetswitching idea developed by Donald Davies in Britain, but British Postal Service refuses to allow implementation – so he advises DARPA
- In parallel – Paul Baran of RAND writes of need to solve huge command and control problem of a nationwide communications system that would survive a nuclear attack
- DARPA uses 2 rationales for Arpanet:
  - Critical to computer science advance - connects computers at DARPA's computer sci. research univ's
  - Helps solve major command and control issue

3) Arpanet, Con't.– Engelbart Demos Amazing Applications

- Doug Engelbart/SRI – Fall '68 Menlo Park Computer Conf. – demo of interactive computing – makes case for Arpanet
  - Demonstrates: the mouse, full screen text editing, cut and paste, outlining, hypertext, on-line windows, on line collaboration, prototype email, etc.
  - Audience transfixed – spontaneous standing ovation – the "defining moment for interactive computing"
- Internet Stood Up by BBN in Sept. 1969 (nine month contract)

4) Arpanet, Con't – email is the Critical Application

- Frank Heart, BBN –Arpanet is stood up but is a network in name only. "It was like picking up the phone and calling France. Even if you could get the connection to work, if you don't speak French you've got a problem."
- Computers connected to the net can't really use it
- Robert Kahn and Vint Cerf (DARPA) lead protocol effort to make Arpanet smooth - TCPIP
- Ray Tomlinson creates protocols to put email on Arpanet
- Larry Roberts persuades DARPA Dir. Steve Lukasik to use email – he loves it; makes it the mandatory communications system in DARPA - teletypes at all desks
- Email becomes the critical communications system for all of the Arpanet community – links all nodes
- And the number of nodes keeps expanding

5) WHY DOES ARPANET SUCCEED?

- "One of the great experiments in science"-- Len Kleinrock, UCLA
- Credit to DARPA Leadership – Evolve and Protect DARPA Model of Innovation
  - Charles Herzfeld, Steve Lukasik and Johnnie Foster (at DDR&E) protect the project and give it extraordinary "freedom to make mistakes"
- Credit to DARPA IPTO Project Directors: Licklider, Ivan Sutherland, Bob Taylor, Larry Roberts – "want progress not progress reports"
  - Get users involved in the creation process
  - Hyper-democratic bottom-up decision making
  - Open model within framework/standards
- Credit to incredible talent team in the Arpanet modes who collaborate

Licklider Back at MIT:

- Sets up MIT's "Dynamic Modeling" Research Group
  - Focus on the software problem – goal: slash errors
  - solve by better interactive computing
  - Goes after graphical, interactive programming system all can use
- Backs student plan to give all MIT undergrads computer access – sells idea to MIT Pres. Jerry Weisner
  - Puts thousands on the Arpanet
  - Games at MIT take off – Pong, Spacewar

Bonvillian and Weiss, *Technological Innovation in Legacy Sectors* (2015)

- Chapt. 8, pp 119-134
re: DARPA model

Two Topics:

1) DARPA as a unique institutional model operating a personal and institutional levels
2) DARPA's Organizational Ruleset

Bonvillian&Weiss, **DARPA *Role***

- Defense is a classic legacy sector
  - Contains a series of legacy sector features
- DARPA originated most of the technology advances that enabled the "Revolution in Military Affairs" (RMA)
  - Precision Strike
  - Stealth
  - UAVs
- Operated as a "Change Agent" – critical to Legacy Sector innovation
- Allied with Office of Secretary of Defense

Bonvillian&Weiss --- DARPA AS A UNIQUE MODEL – COMBINING INSTITUTIONAL CONNECTEDNESS AND GREAT GROUPS

- We have discussed the concept of innovation organization as a third direct innovation factor, and noted that it operates at both the institutional level and the personal level. Unlike the four DARPA-supported personal level models we have discussed above, DARPA itself has operated at both the institutional and personal levels.
- Eisenhower's initial 1957 creation ended up as a unique entity. It got around the post WW2 dismantlement of the connected science model, and the end of the "Great Group" culture at the Rad Lab.
- DARPA becomes a bridge organization connecting these two organizational elements, unlike any other R&D entity stood up in government.

Bonvillian&Weiss - **DARPA RULES**

- **Small and flexible** –100/150 professionals – "100 geniuses connected by a travel agent";
- **Flat organization -** no hierarchy, 2 levels;
- **Substantial autonomy and freedom** from bureaucratic impediments – operates outside civil service hiring and gov't contracting rules;
- **Technical staff drawn from world-class** scientists and engineers with representation from industry, universities, government laboratories and Federally Funded Research and Development Centers (FFRDC's);
- **Technical staff hired or assigned for 3-5 years** and rotated to assure fresh thinking and perspectives;

- **Project based –CHALLENGE MODEL -**
- all efforts typically 3-5 years long with strong focus on end-goals. Major technological challenges may be addressed over much longer times but only as a series of focused steps.
- The end of each project is the end. It may be that another project is started in the same technical area, perhaps with the same program manager and, to the outside world, this may be seen as a simple extension. For DARPA, though, it is a conscious weighing of the current opportunity and a completely fresh decision. The fact of prior investment is irrelevant;

Bonvillian&Weiss, **DARPA RULES**, Con't

- **Necessary supporting personnel (technical, contracting, administrative) are "hired" on a temporary basis** to provide complete flexibility to get into and out of an area without the problems of sustaining the staff. This is by agreement with Defense or other governmental organizations (military R&D groups, National Aeronautics and Space Administration, National Science Foundation, etc.) and from System Engineering and Technical Assistance (SETA) contractors – builds collaboration and leverages help across DOD stovepipes;

- **Program Managers (the heart of DARPA) are selected to be technically outstanding and entrepreneurial.** "The best DARPA Program Managers have always been freewheeling zealots in pursuit of their goals";

- **Management** is focused on basic stewardship of taxpayer funds but imposes little else in terms of rules. Management's job is to **enable the Program Managers – empowerment model;**

- **A complete acceptance of failure** if the payoff of success was high enough – high risk model for breakthrough opportunity

Bonvillian&Weiss - **DARPA RULES**, Con't

- Oriented to **Revolutionary Technology breakthroughs** – Radical not Incremental Innovation – emphasis on High Risk Investment
- Fundamental through prototype – hands off production to services OR commercial sector
- Employes **technology "visioning**"
- Usually works on solutions to Joint Service problems – works across DOD's stovepipes – and leverages them

- Typical project:
- $10-40m over 4 years
- Single DARPA Project Manager controls
- Other Defense R&D agency or outside contractor manages administrative side–buy in
- Typically combines private co's and Univ's, all aimed at common goal - Hybrid model

Bonvillian&Weiss, DARPA's Role on the Front End of the Defense Innovation System

- DARPA is not simply a research-only agency
- It plays a key role in moving technologies toward implementation:
  - Form critical innovation institutions – of great talent and capability; DARPA rules a good model
  - Use the Island-Bridge Model – DARPA uses ties to the Office of the Secretary
  - Build a "thinking community" – need a volume of talent on the task; Romer prospectors rule
  - Link technologists to operators – key to designing the technology for implementation

GLENN FONG, ARPA DOES WINDOWS; THE DEFENSE UNDERPINNING OF THE PC REVOLUTION (2001)

- Apple's Lisa then MacIntosh came from Xerox PARC's Alto
- Microsoft's Windows came from Apple's Mac
- Key staff from PARC went to Apple and Microsoft
- DARPA underwrote PARC:
  - Vannevar Bush's "Memex" envisions personal libraries on a desktop
  - Licklider envisions the PC and internet and funds the enabling technologies at DARPA

Fong, ARPA Does Windows, Con't

- DARPA's Bob Taylor led PARC, and DARPA-funded university research centers (at MIT, Berkeley, Stanford, SRI, Utah) supported and trained much of the rest of PARC's staff
- DARPA's leaders funded the enabling technologies behind PARC:
  - Doug Engelbart computerized personal storage, mouse, windows- the oN Line System (NLS)
  - Ivan Sutherland's Sketchpad - graphic interface, light pen for drawing

Fong, ARPA Does Windows, Con't

- Famous computer scientists supported by DARPA:
  - Wesley Clark (DEC)
  - Lnn Conway
  - Michael Dertouzos (MIT's CS Lab, Media Lab)
  - Ed Feignebaum
  - John Hennessey (MIT then Pres. of Stanford)
  - John McCarthy (MIT and Stanford)
  - Marvin Minsky (MIT's AI Lab)
  - Alan Newell (CM)
  - David Patterson (Berkeley)
  - Raj Reddy
  - Bob Metcalf (3COM)
  - John Warnock (Adobe Systems)
  - Edwin Catmull (Lucas Films)
  - Noland Bushnell (Utah - founded Atari)
  - Jim Clark (Utah - Silcon Graphics, Netscape)
  - Bill Joy (Berkeley, Sun Microsystems)
  - ETC.

Fong, ARPA Does Windows, Con't

- Stuart Card, Xerox PARC (1996) - "Government funding of advanced human-computer interaction technologies built the intellectual capital and trained the research teams for pioneer systems that, over a period of 25 years revolutionized how people interact with computers."
- The US gov't systematically supported the development of:
  - The computer chip
  - The mainframe
  - The supercomputer
  - The internet
  - The PC
  - In other words, it (largely DARPA) underwrote the IT revolution

Tammy Carleton, "The Value of Vision in Radical Technological Innovation" [DARPA Study] pp. 62-113 (Stanford 2010)

- **Process of radical technological innovation starts with vision**
- DARPA has led in creating a process model for radical innovation --- Six stages:
  - Recruitment of great talent
    - Talent hired (largely from DARPA network) - become PM's
    - recruitment and vision united
  - Vision formulation
  - Program Definition and Launch
  - Program manager (PM) handles Portfolio Management of vision projects – vision process tied to single PM who is responsible
  - PM also responsible for Tech Transfer (largely ties in military for initial commercialization)

Vision Formulation at DARPA:

- Vision formulation
  - Responsibility of PM – hired for this skillset
  - PM spurs innovation efforts in teams they fund and foster
  - Four Criteria:Must be “DARPA Hard
    - Technically challenging – must extend beyond current limits of technology and knowledge
    - Actionable – can be built and produced – not sci fiction
    - Multidisciplinary – draw on multiple experts and areas
    - Far-reaching – ambitious about grand scale change
  - Techniques to flesh-out vision :
    - Expert invitation-only workshops
    - Proof of concept (stand up a “seedling”)

Vision Program Definition:

- DARPA has no PM training – relies on culture and informal exchange to nurture visioning by PM's
- PMs standing up vision programs must be entrepreneurs and venture capitalists – advocates for their vision
  - DARPA needs visions, but funding enables vision enablers
- Decision to stand up vision programs –
  - no peer review, no "stage gates" as in industry, no review panels, no consensus decision-making
  - 2 Quick approvals- from office managers and Director
- PM is the vision champion (key role in innovation process)– carries project through early stage development and hand off

Importance of DARPA Vision Process:

- DARPA shows there is a relationship between tech visioning and creating radical innovation
  - "DARPA Hard" vision problems pursued – technically challenging, actionable, multidisciplinary, far-reaching
- Use of expert workshops and proof of concept (seedlings) are techniques to define vision
- DARPA culture and informal socialization are training system for PM's – no training
- Governance model – no consensus or peer review, just prompt OK from office dir. and DARPA director – very different from industry "stage gate" R&D mode
- DARPA starts with vision up front – very different from industry and other agency approaches

WRAP--UP – WALDROP - Gov't Role in Computing Tech. Development:

- Gov't role in computing:
  - Proving ground for new concepts, designs, architectures
  - Initial market for new products, services, industries
  - Expanded Univ. research capabilties
  - Trained computing talent base
  - Promoted technology advances so gov't mission agencies could meet their role req's – esp. Defense
- Supported efforts to build large systems:
  - SAGE – for early warning system air defense
  - Internet – packetswitching – DARPA/ then NSF
- Built on Industrial Research: industry not picking up so Gov't advanced key areas:
  - RISC computing
  - Relational databases, etc.

Gov't Role in Computing Tech Advances, Con't:

- Gov't Agencies played central role:
  - Navy, Air Force, and esp. DARPA, at DOD; secondary:
    - NSF
    - NASA
    - DOE – esp. in supercomputing
- Gov't agencies sponsored Univ.-Industry collaboration – made these connections –
- Creating partnerships/networks became key gov't role in promoting advances
- Gov't role flexible – promote exploration, allow program managers to exercise discretion in supporting research advance

DARPA Model:

- Bonvillian & Weiss – DARPA uniquely combined innovation institutional model and innovation face-to-face model fostering great groups
  - DARPA RULESET
- Glenn Fong – DARPA played central institutional mobilization role for IT revolution
- Carleton – DARPA focus at the outset of technology visioning is key to its effectiveness

APPENDIX

- *NAS, "Funding a Revolution"*

OPTIONAL READING: National Research Council, "**Funding a Revolution**, Gov't Support for Computing Research" (Nat'l Aca. Press 1999)

- Chapt. 4: Organization of Federal Support:
- Deiverse agencies since WW2 – DOD, DOE, NASA, NSF
- Office of Naval Research – computing for missiles; Air Force Office of Scientific Research – similar role
- Nat'l Bureau of Standards – built computers for military, but ended this in 50's
- Project Whirlwind at MIT– Navy – aircraft simulator
- Project Sage at MIT– Air Force – air defense system – later: becomes Computer Reservation System for American Airlines
- Snow White & the 7 Dwarfs – IBM and Burroughs, Control Data, GE, Honeywell, NCR, RCA, Sperry Rand – sustained by DOD contracts
- '65- Computer Science Dept's at Carnegie Tech, Stanford; '68 - MIT

[Keys to DARPA Evolution:

DARPA management new model in science:

- Talented, technically trained Project Managers expert in the areas they were working in
- No peer-review; strong program managers
- Enough funding to shape coherent research programs over extended period
- Aimed at radical innovation not incremental - “order of magnitude difference” in advances
- Elitist – fund the very best Univ./industry programs, while NSF has to cope with geographical distributional req’s imposed by Congress
- Red tape cut to a minimum – flexible contracting

[DARPA in 70's-80's

- DARPA – under Director George Heilmeyer – focus on industry applications
- Very Large Scale Integrated Circuits (VSLIC's) – simplified circuit design to enable quick new IC designs, transferred over the Arpanet for quick low cost fabrication – led to US design leadership in IC's
- DARPA focus in computer architecture and system design, microelectronic fabrication efficiencies, talent education in computing, and fast turn-around fabrication, testing and evaluation
- RISC Architecture (reduced instruction set computing) and Processors – IBM led, but DARPA promoted, parallel processing, networking (SUN), design tools
- SEMATECH – manufacturing productivity breakthroughs for SC supplier sector (see below)
- Most computing advances in this period- DARPA support

[NSF – Role in Computing

- DARPA led the advance; NSF followed
- Initially saw computing as servant of existing science disciplines – mere supporting tool
- Erich Block – from IBM System 360 project – only industry head of NSF – 1986 – saw computing as a full science and put NSF there
- Brought in Gordon Bell from DEC – set up new Computer and Info Sciences and Engineering Directorate – funded computer science depts.
- Set up Science and Technology Centers at Univ.' s – step away from small grants and peer review
- Took over ARPANET making it NSFNET, spreading it to more Univ' s, then spinning it off to private sector in '95

[SEMATECH: DARPA SUPPORTED

- 80's - US about to lose memory chip (DRAMS) to Japan
- 14 Semiconductor industry firms found Sematech to collaborate; shared facilities to improve mfg. efficiency
- Focus on SC supplier firms – strengthen their mfg. process and productivity
- Joint industry-gov't cost shared effort – DARPA was gov't partner – It Worked – US dominance of semiconductors restored
- Late 80's Gov't program – High Performance Computing (Al Gore's bill)
- 90's Gov't computing program – Next Generation Internet – multiply internet speeds

STS.081J / 17.395J Innovation Systems for Science, Technology, Energy, Manufacturing and Health
Spring 2017