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DARPA AND THE US CONNECTED SCIENCE MODEL FOR INNOVATION - WHERE IS IT NOW?

I. INTRODUCTION – FUNDAMENTALS OF TECHNOLOGY DEVELOPMENT

- *Carlotta Perez (Schumpeterian economist) – industrial and therefore societal transformation roughly every half century starting with the emerging industrial revolution in Britain in 1770, and based on long innovation waves; military power transformed as well, and world military leadership parallels industrial leadership
- *US led last three innovation waves (IT is the most recent); will this continue? If it doesn't, then over time the US loses economic leadership
- *Deep interaction in US between war and technology – war has greatly influenced technology evolution, but the converse is also true.
- DARPA good example of that interaction

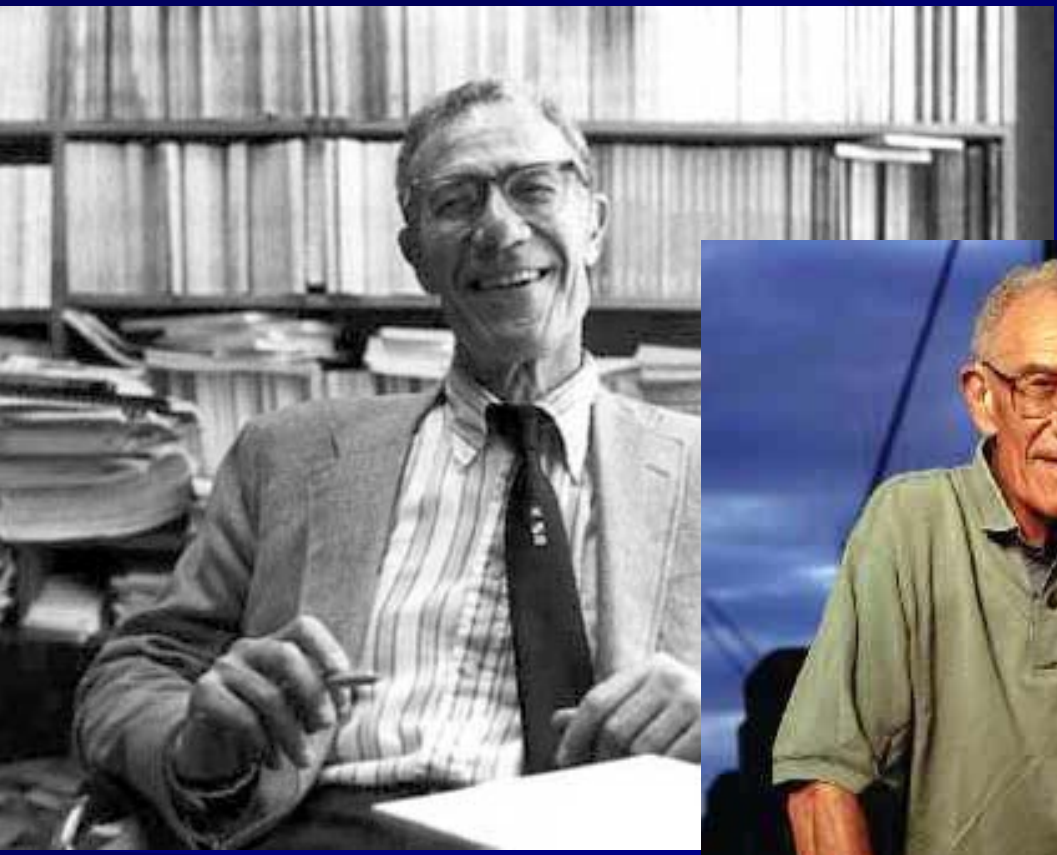
Introduction, Con't

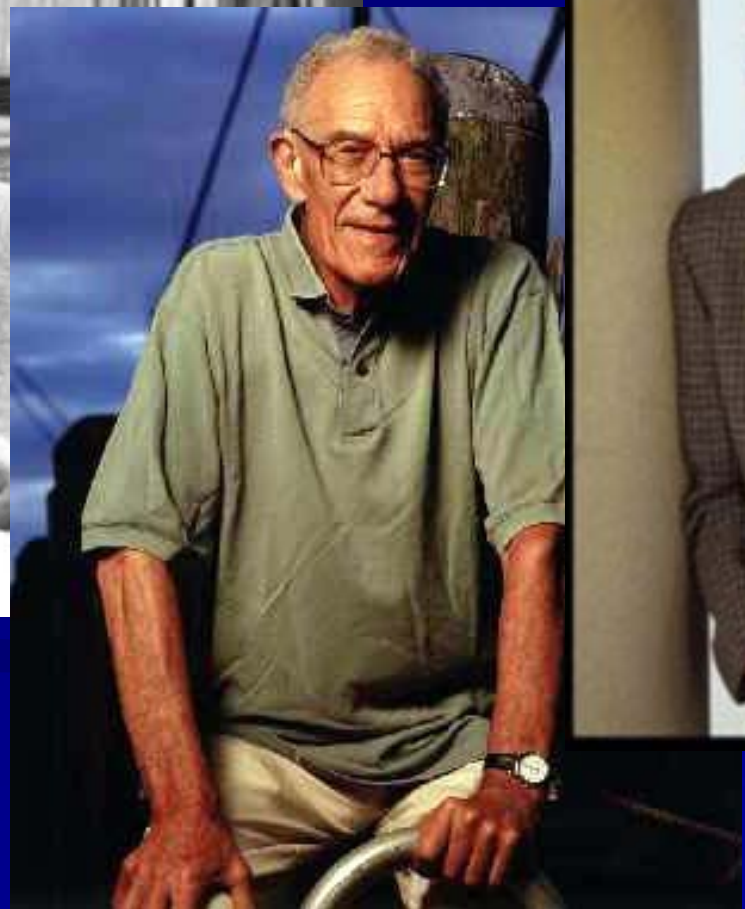
- Concerning DARPA, can't talk about US defense technology separate and apart from the technology that is driving the US economy – they are both part of the same technology paradigms.
- *If technology innovation is a driving force in US economic progress (and also for US military capability), we need to understand what are the causal factors behind innovation.
- *One of the factors is critical institutions. Arguably, there are critical technology and science institutions that can introduce not simply inventions or applications, but significant elements of entire innovations.
- *We will focus on aspects of the U.S. innovation system supported by DARPA – Eisenhower creation; primary inheritor of WW2 connected science model; disproportionate postwar technology role
- *Further, we will attempt to understand where DARPA came from, and ask, how strong does it remain, as a way of focusing on the continuing strength of the US innovation system. Will also note DARPA clones.

SUMMARY OF MAJOR POINTS

- AS WE REVIEW THIS QUESTION OF THE INTERACTION BETWEEN US ECONOMIC LEADERSHIP AND TECHNOLOGY LEADERSHIP, AN INITIAL QUESTION IS:
- GROWTH ECONOMISTS SOLOW AND ROMER HAVE POSITED TWO DIRECT INNOVATION FACTORS – R&D/TALENT
- INDIRECT INNOVATION FACTORS
- IS THERE A 3RD DIRECT INNOVATION FACTOR? S&T ORGANIZATION?
- INNOVATION SYSTEMS OPERATE AT THE INSTITUTION LEVEL, AND AT THE PERSONAL LEVEL
- AT THE PERSONAL LEVEL WE WILL EXPLORE THE NATURE OF THE INNOVATION CULTURES AT:
- EDISON AT MENLO PARK
- VANNEVAR BUSH AND ALFRED LOOMIS – THE RAD LAB AT MIT
- BARDEEN, BRATAIN, SHOCKLEY AT BELL LABS
- THEN WE WILL TURN TO AN ARGUABLY UNIQUE INSTITUTION:
- DAPRA, THAT OPERATES AT BOTH THE PERSONAL AND INSTITUTIONAL LEVELS
- AT DARPA WE WILL REVIEW THE STORY OF
- JCR LICKLIDER AND THE DARPA CULTURE – PERSONAL COMPUTING, THE INTERNET; GREAT GROUPS AND GREAT INSTITUTIONAL CONNECTEDNESS
- WE WILL CLOSE WITH A LOOK AT, WHERE IS DARPA NOW?
- AND WE WILL NOTE THE DARPA CLONES THAT ARE EMERGING AT OTHER US R&D AGENCIES

Solow and Romer





II. ROLE OF TECHNOLOGY INNOVATION AND TALENT IN GROWTH

- What do we know about the nature of innovation in economic transformation? what are the causal factors in economic growth?

Professor of Economics Robert Solow, MIT --

Solow's Basic Growth Theory:

- NOBEL PRIZE IN 1987; FIRST OF THE GROWTH ECONOMISTS
- ATTACKS CLASSICAL ECONOMICS GROWTH MODEL AS STATIC MODEL - BASED ON CAPITAL AND LABOR SUPPLY
- FOUND MORE THAN HALF OF U.S. ECONOMIC GROWTH WAS CREATED THROUGH TECHNOLOGICAL AND RELATED INNOVATION
- DYNAMIC MODEL – WE CAN CREATE GROWTH AND THEREFORE SOCIETAL WELLBEING BY FOSTERING INNOVATION
- DIRECT (OR EXPLICIT) INNOVATION FACTOR #1: R&D

Professor of Economics Paul M. Romer, Stamford Univ.

Romer's Basic Growth Theory

- If economic growth occurs primarily through technological and related innovation,
- Then: the key factor behind that innovation is "HUMAN CAPITAL ENGAGED IN RESEARCH"
- Has a "Prospector Theory" of Innovation

SO: TWO KEY DIRECT OR EXPLICIT GROWTH FACTORS:

- R&D THAT YIELDS TECH INNOVATION (Solow)
- TALENT ENGAGED IN R&D (Romer)
- THESE TWO ECONOMIC GROWTH FACTORS CREATE AN INNOVATION SYSTEM ---

INDIRECT INNOVATION FACTORS

- Note: also part of Innovation Systems are Indirect/Implicit Innovation Factors:
- **INDIRECT FACTORS SET BY GOV'T:**
- Fiscal/tax/monetary policy
- Trade policy
- Technology standards
- Technology transfer policies
- Gov't procurement (for mission agencies)
- Intellectual Property protection system
- Legal/Liability system
- Regulatory system (environment, health, safety, market solvency and market transparency, financial institutions, etc.)
- Accounting standards (via SEC through FASB)
- Export controls, ETC.
- **INDIRECT FACTORS SET BY PRIVATE SECTOR:**
- Investment Capital –
- angel,
- venture,
- IPO;s,
- equity, lending
- Markets
- Management & Management Organization, re: innovative and competitive quality of firms
- Talent Compensation/Reward, ETC.

III. QUESTION: IS THERE A THIRD DIRECT/EXPLICIT INNOVATION FACTOR?

- ANSWER: ARGUABLY, YES -
- THE ORGANIZATION SCIENCE AND TECHNOLOGY –
- THE WAY THE R&D AND THE R&D TALENT COME TOGETHER IN AN INNOVATION SYSTEM
- ARGUABLY, INNOVATION ORGANIZATION OPERATES AT AT LEAST TWO LEVELS – THE INSTITUTIONAL LEVEL AND THE PERSONAL, FACE TO FACE LEVEL – WE WILL EXPLORE THESE IN SUCCESSION.

Innovation Systems at the Institutional Level

- WW2 – Vannevar Bush heads OSRD and NRDC – science/tech is integrated
- Post-WW2 – Bush's "Endless Frontier" – gov't role is to fund basic research – pipeline model – segregation of research stages
- R&D are separated
- Plethora of agencies when NSF set up late
- Result – Legacy of disconnected science
- Note: No other nation organizes science this way

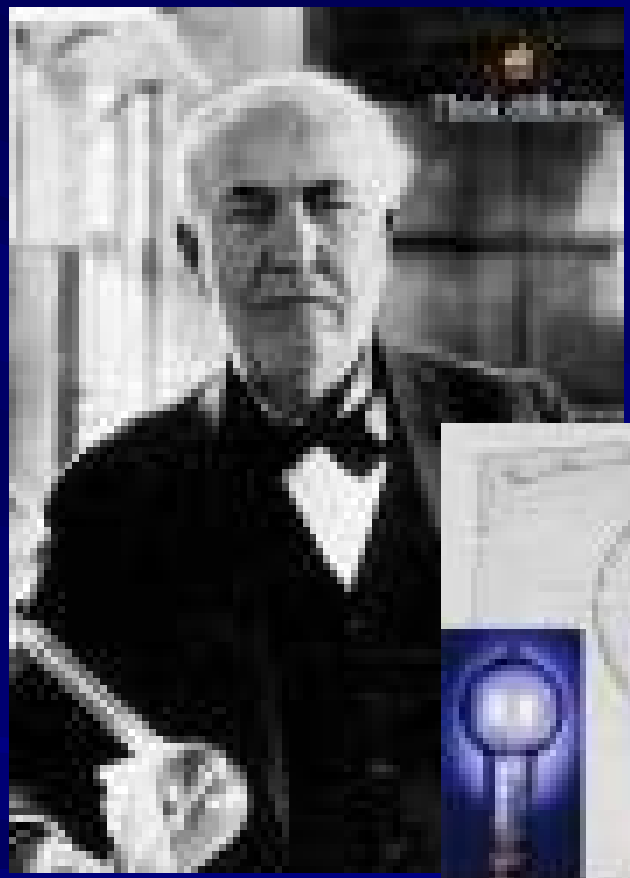
Innovation Systems at the Personal Level – Great Groups

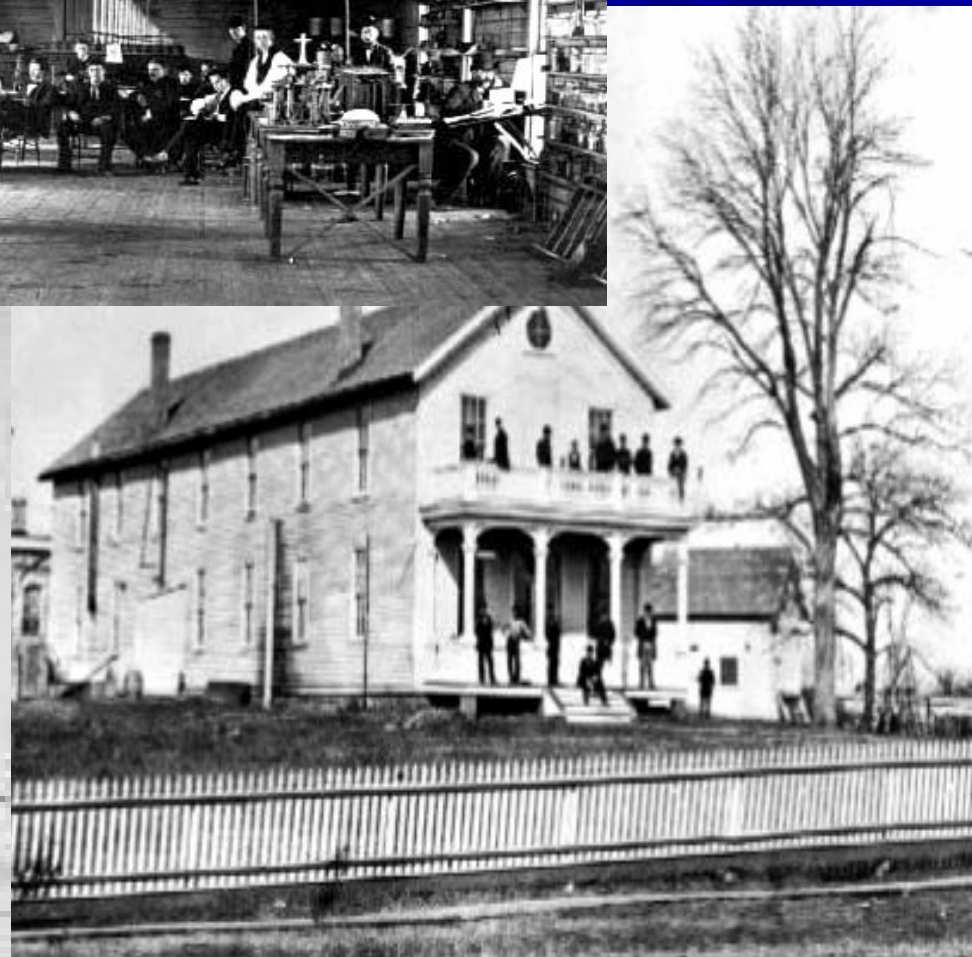
- People innovate not institutions.
- It's not only the process of creating connected science at the institutional level – what about at the personal level, the face to face level?

- Warren Bennis, "Organizing Genius" (1997) – writes about the rule sets for "great groups"

- Let's review the organizing elements of three US "great groups"
  - Edison at Menlo Park
  - Vannevar Bush and Alfred Loomis at the Rad Lab at MIT
  - The transistor team at Bell Labs

Edison and the “Invention Factory” at Menlo Park





1) Edison at Menlo Park

- Edison assembles dozen plus artisans and a few trained scientists at 100 foot wood frame building on his New Jersey farm – calls it his “Invention Factory”
- They work 24/7 – have pies at midnight, sing songs, recite poems
- Invent the light bulb, but then have to invent whole electrical infrastructure – generators, public utility model, fire safety, wiring
- Use Challenge Model – trying to solve specific challenge, goal, apply both practical and basic science to get there – Edison creates connected model tying invention to innovation – all stages
- Edison stands up non-hierarchical, relatively flat, 2-level, collaborative operation
- Mix of experimentalists and theorists, artisans and trained scientists/engineers
- Edison Effect – Edison has to derive electron theory to explain results – leads to atomic physics advances
- Lesson – science is not a linear pipeline going from basic to applied – it goes both ways: basic to applied and applied to basic – and have to have team that can collaborate in both ways

Bush and Loomis and the Rad Lab at MIT

Alfred Lee Loomis 1887-1975

MIT’s Rad Lab

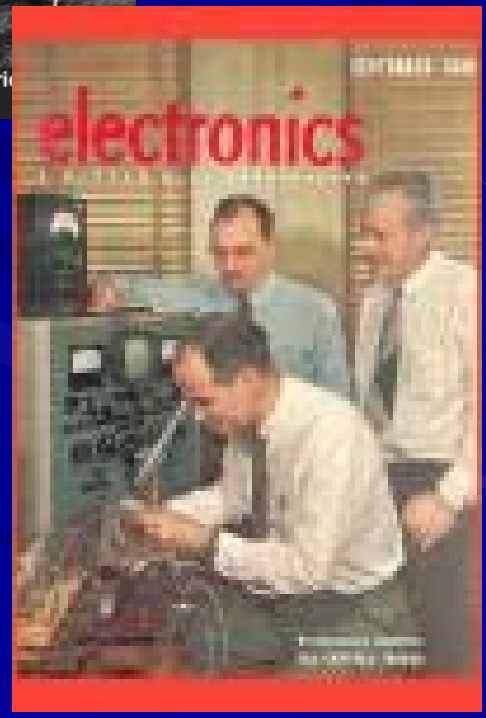
2) Vannevar Bush and Alfred Loomis and the Rad Lab At MIT– 1940-1945

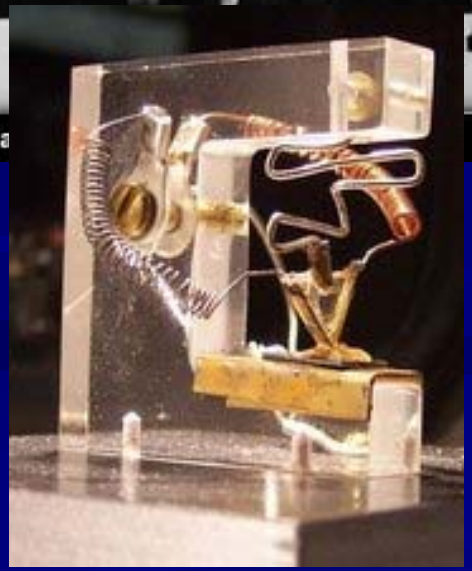
- see discussion in: Jennet Conant, Tuxedo Park (2004), Pascal Zachary, The Endless Frontier (1997)
- Bush and Loomis mobilize science for FDR on the eve of WW2
- Bush – Engineering Dean at MIT, then heads Carnegie Institution in Wash., DC – becomes FDR's science operative
- Loomis – loves science but becomes lawyer, leading Wall St financier for electric utilities in 20's, sells out in '28, sets up private lab at Tuxedo Park estate in 30's for who's who of pre-war physics
- Loomis' field of study – microwave physics
- Bush centralizes science under "ONE TENT" – makes all the key organizational decisions -heads NACA then NDRC then OSRD
- Bush brings in Loomis, Sec. of War Stimson's 1st cousin, to organize defense science
- Loomis stands up the Rad Lab at MIT – in weeks, after British hand over microwave radar to him at the Shoreham Hotel in DC

2) Con't – V. Bush and A.Loomis

- Loomis and his friend Ernest Lawrence of Berkeley call in the whole talent base of US physics into the Rad Lab
- Loomis personally funds it while gov't approvals are delayed
- Rad Lab – flat, non-hierarchical – project managers and teams, intense work around the clock, high spirits, purposely kept out of the military
- Develop microwave radar, proximity fuse – 11 Nobel prizewinners come out of Rad Lab, lays the foundations for modern US electronics
- Use Challenge Model – challenge based on fundamental breakthrough, connected to development, prototyping, and initial product market
- Both have the connection and authority to immediately go directly to the President and Sec. of War

Transistor Team at Bell Labs





Bell Labs

2) Transistor Team at Bell Labs

- Bell Labs' Murray Hill facility is consciously modeled pre-war on Edison's Menlo Park, and postwar by AT&T's VP Mervin Kelly on the great military labs of WW2 – the Rad Lab and Los Alamos
- When Bardeen arrives at Murray Hill in '45 his first act is to sell his patent rights to AT&T for $1 – "I really feel this is only fair. People can cooperate without worrying who is going to get the patent rights and this promotes a much freer exchange of ideas." - Bardeen
- Mervin Kelly and Shockley want a solid state physics team of 50 scientists and technicians – emphasis on fundamental research but with an eye to practical applications

3) Con't - Transistor Team

- Bardeen and Brattain developed profoundly close collaboration – scientific skills and intuition of each matched each other – one outgoing, one reflective – families are social friends - deep mutual respect
- Backed up by AT&T's rich industrial technical support system, with latest equipment and tech staff support
- "magic month" – mid-Nov. to Dec. 16, 1947 – they develop first transistor
- Shockley, their supervisor who provided initial project definition, working in secret at his home adds key features [Semiconductor sandwich vs. elec. contact point], and tries to preempt patent
- Shockley's secrecy wrecks the trio's collaboration

3) Con't - Transistor Team

- Before Shockley breaks up the collaboration:
- True Genius, p. 127 - "The solid-state group divided up tasks: Brattain studied surface properties such as contact potential; Pearson looked at bulk properties such as the mobility of holes and electrons; and Gibney contributed his knowledge of the physical chemistry of surfaces. Bardeen and Shockley followed the work of all members, offering suggestions and conceptualizing the work. 'It was probably one of the greatest research teams ever pulled together on a problem,' said Brattain."

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3) Con't - Transistor Team

- "'I cannot overemphasize the rapport of this group. We would meet together to discuss important steps almost on the spur of the moment of an afternoon. We would discuss things freely. I think many of us had ideas in these discussion groups, one person's remarks suggesting an idea to another. We went to the heart of many things during the existence of this group, and always when we got to the place where something needed to be done, experimental or theoretical, there was never any question as to who was the appropriate man in the group to do it'" Brattain in Daitch and Huddelston, True Genius, pp. 127-128

SUMMARY FROM GREAT GROUPS:

- Teams are highly collaborative
- Flat, non-hierarchical and democratic
- Networked to the best thinking (for ex., Shockley and Bardeen travel for 2 mos in the summer of ’47 talking to the best European scientists in solid state area)
- Uses Challenge Model – fundamental science but breakthrough application in mind across basic, applied, prototype, development stages – you have “to ship”

IV. 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 personal level models we have discussed above, DARPA 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 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.

JCR Licklider - “Man-Machine Interface” / “Human-Computer Symbiosis”: "The hope is that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought.” -1960

JCR Licklider and the DARPA Model

- (see discussion in: Mitchell Waldrop, Dream Machine (2001)
- In 1960 Licklider writes about the "Man-Machine Interface" / "Human-Computer Symbiosis": "The hope is that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought."
- By 1960 – Licklider has envisioned both personal computing (as opposed to the then-dominant main-frame computing), the internet, the www, and nearly all the features we are still realizing
- Then Licklider goes to (D)ARPA – brought in to solve Kennedy's and MacNamara's command and control problem
- Rare case of the visionary being placed in the position of vision-enabler
- He funds, selects, organizes and stands up the support network of talent – researchers at Univ's and co's – that builds personal computing and the internet
- DARPA under Jack Ruina, Charles Herzfeld, and George Heilmeier back Licklider in creating the first and greatest success of the DARPA model
- Licklider creates a series of Great Groups – these in turn have the key features of Rad Lab, Los Alamos – Doug Englebart's Demo, Robert Taylor at Xerox Parc

Elements in the DARPA Model

- At the Institutional level – DARPA is able to do connected science – model requires:
- Revolutionary technology development - fundamental science connected through the development and prototyping stages
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- Other ways DARPA assures connectedness:
- -Cook-Deegan quote about DARPA role in the Pentagon bureaucracy – developed ability to make connections across the DOD stovepipes
- -Uses funding to leverage contributions from other DOD service tech development organizations, and promote service adaptation and production
- -Uses other DOD entities as its agents – promotes cooperation across the stovepipes – helps assure prototypes will move into production stage where DOD will create first market
-
- Other DARPA Characteristics – affect it's ability to operate at the Institutional and Great Group levels

The DARPA Model -

- **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;

The DARPA Model, 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

The DARPA Model, 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
- 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

V. DARPA TODAY – HOW HEALTHY IS THE MODEL?

- Arguably economic innovation sectors are best described as ecosystems and Marco Iansati and Roy Levien have argued (in The Keystone Advantage, Harvard Bus. Sch. Press 2005)) that within these systems are keystone firms that take on the task of sustaining the while ecosystem by connecting participants and promoting the progress of the whole system.

- Iansati has also argued that these innovation systems start to decline or shift elsewhere where the keystone firms cease being thought leaders and instead shift to what he calls "landlord" status. There, the landlord shifts to simply extracting value from the existing system rather than continuously attempting to renew and build the system. Does this analogy apply to DARPA?

- DARPA appears increasingly focused on a problem DARPA ran into the end of the Cold War and its higher levels of procurement – the breakdown of technology transition into services. However, rather than attempting build a new basis for revolutionary technology investment, DARPA has been retreating from radical innovation to incremental innovation, shifting investment into late stage development

Is DARPA Changing its Model?

- DARPA has also been growing its black programs, which has meant cutting back on Univ. ties and focusing on a much narrower group of innovators, largely in certain secure defense industries – this means greatly reduced mindshare in the technology community engaged on the problems DARPA must solve.
- So: Cutting back on breakthrough model, its historic mission

- Cutting way back on IT funding – down to around $140m – not pursuing breakthrough IT advance despite past leadership in this area. Budget analysts report that shorter term incremental work space launch and satellite "repair" are taking the growing part off the DARPA budget.

- "Up or out" review process – placing R&D on short term course with frequent policy reversals/turns that limits the ability to mount creative longer-term investment programs so important to past development.

- Heart of DARPA creativity in the past was in highly talented and empowered project managers. However, the role of project managers is now sharply curtailed by a centralized management approach

Is DARPA Changing its Model?

- DARPA has always been able to pick the brightest technologists in the nation, which has been crucial to its advances. However, critics are now saying that DARPA is now having trouble filling its positions.

- DARPA in the past has operated in both the civilian and defense economies, understanding they are the same economies. It has spun technology off to the civilian sector where it has further evolved enabling DOD to buy it back at radically lower costs and taking advantage of civilian advances, as in computing, or for defense only needs like Stealth, spun it off to the defense sector.

- Increasingly, DARPA appears less interested in civilian economy, despite DOD's increasing cost crisis and the need to take advantage of advances in that sector. Despite DARPA's historic role in successfully straddling both sectors, one DARPA leader has referred to advances in the civilian sector as "NSF's job" despite DARPA's need to play in both worlds.

- Danger that DARPA is retreating into Iansati's and Levien's "landlordism" – not renewing but living off past advances

Other Aspects of US Defense Technology Leadership – Also in Trouble?

- CSIS Report – disinvestment in fundamental science – leadership comes out of this area
- DSB Report – disinvestment in areas of critical advance in IT
- Defense Personnel problems – affects talent base
- Civilian Sector reports – Council on Competitiveness, National Innovation Initiative; NAS, Gathering Storm
- These issues not being dealt with at DOD

VI. DARPA CLONES EMERGE AT OTHER AGENCIES

- Homeland Security Dept. – HSARPA- in law for homeland security R&D
- Energy Dept. – Congress proposing DARPA model for DOE entity
- Cures Act from Congress – proposes HARPA at NIH – health advanced research connected to applied development
- Biothreats Act from Congress – proposes BARPA – for connected biothreat R&D

VII. CLOSING SUMMARY:

- Growth Economics posits two direct/explicit innovation factors:
- 1) R&D (Solow) and
- 2) S&T Talent (Romer)

- Is there a 3rd Direct/Explicit Innovation Factor?

- Arguably yes – the Organization of S&T – how you put together your R&D and Talent into a system
- Operates at Institutional and Personal Levels
- Looked at famous examples S&T organizational success for common threads
- Menlo Park, Vannevar Bush's and Alfred Loomis' Rad Lab at MIT, Transistor team at Bell Labs
- DARPA as a reprise of the connected challenge models at Rad Lab – operating at the institutional and personal level

Closing Summary, Con't

- These institutions are deeply collaborative, flat, feature close-knit talent, democratic, flexible, are oriented to breakthrough radical innovation
- They use a Challenge Model for R&D - move from fundamental back and forth with applied, connected to development, prototyping, and access to initial production
- Follow an innovation path not simply an invention path
- Like all human institutions, these organizational models are transitory
- DARPA as a unique model – operating at the institutional and personal level
- DARPA model has been the longest lasting – unique in the federal gov't – seemed to be the most capable of ongoing renewal
- But that DARPA model now may be being shifted – part of an issue over continued U.S. defense technology superiority
- Meanwhile, DARPA clones proposed in other agencies