The Role of DARPA in Seeding and Encouraging Technology Trajectories: Pre- and Post- Tony Tether in the New Innovation Ecosystem

Erica R.H. Fuchs

Assistant Professor

Department of Engineering and Public Policy

Carnegie Mellon University

erhf@andrew.cmu.edu

Plato's Cave: It's not about the funding.

"Are you familiar with the allegory of the Cave?"
(Plato, *The Republic*)

"… It's the same thing with (trying to deduce technology directions from) funding. The technology direction is a separate thing."

(Lead Technologist)

Background: Innovation and the (U.S.) State

- Unlike other countries, whom have open and explicit developmental policies (Chalmers 1982; Wade 1990; Amsden 1989, 1994, 2001, 2003; Breznitz 2007, Block 2007)
- Strong prevalence of free-market thinking in U.S. (Harcourt 1980)
- Despite extensive historical documentation of the importance of federal agencies in technology development
- Developmental state largely "hidden" (Hughes 2005, Block 2007)

Little research unpacking the underlying *processes* by which the U.S. state influences technology trajectories.

DARPA: Pioneer

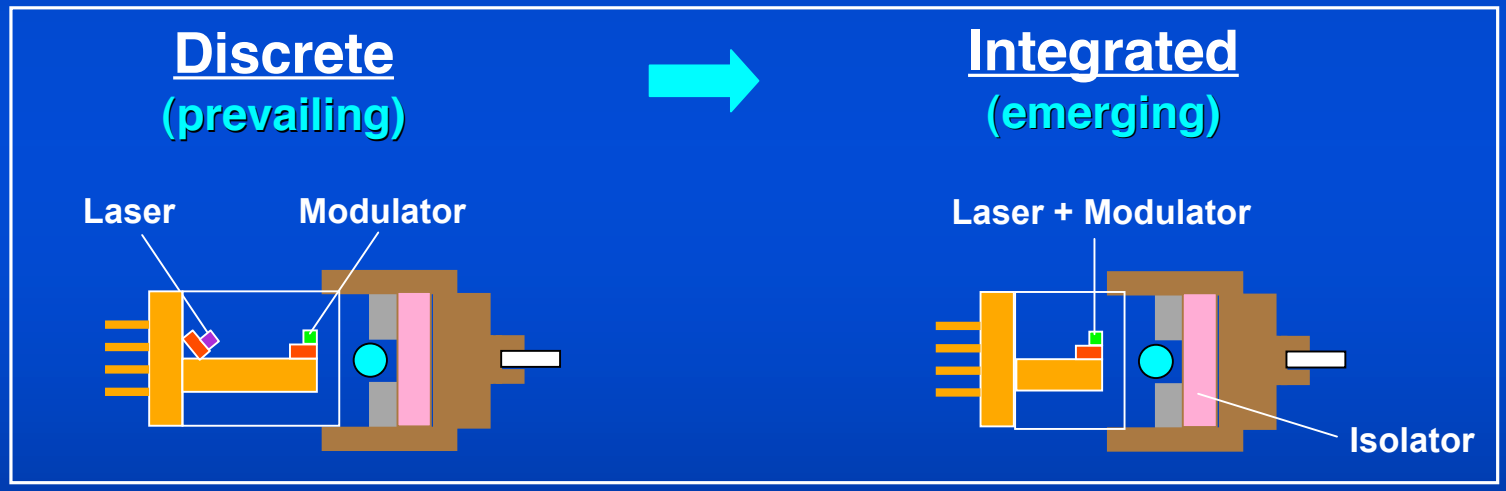
- Founded 1958 (ARPA), Sputnik
  - Prevent technological surprises
  - Overcome inter-service rivalry
- Pioneer of U.S. “Developmental Network State”
- Since its inception
  - Hailed: Internet, PC, Laser… The West Wing
  - Criticized: Lazowski/Patterson 2005, 90s, 80s, 70s…
  - Copied:
    - 1998: ARDA/DTO (Intelligence Community)
    - 1999: 'In-Q-Tel (CIA)
    - 2002: HSARPA (Homeland Security)
    - 2006: IARPA (Intelligence)
    - 2007: ARPA-E (Department of Energy)

What are the processes by which DARPA seeds and encourages new technology trajectories?

What has been the impact of the recent changes under Tony Tether, on the execution of these processes at DARPA?

Integration in Optoelectronic Transmitters

- Produce multiple functions on a single chip
- Originally, driven by telecom market
  - Improve network performance; reduce size, cost



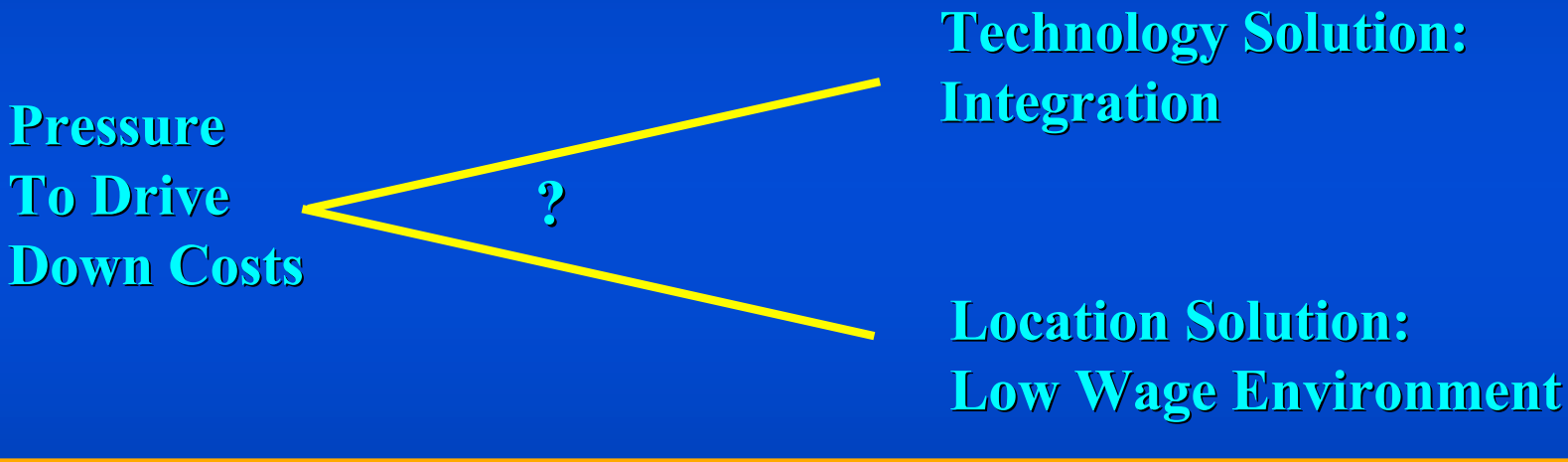
- Long term, address interconnect bottleneck
  - Computer optical bus: integration seven functions

Fuchs and Kirchain (2008) Design for Location: The Impact of Manufacturing Offshore on Technology Competitiveness. R&R with *Management Science.*

Dramatic Shift in Telecom Market

- In 2000, burst of telecom bubble

- Two options to reduce cost:



- 15 of 16 firms moved offshore (15 → 8)
- Cut R&D departments, ceased to push forward efforts in integration
- DARPA to the rescue? (UNIC Solicitation, 2006)

Fuchs and Kirchain (2008) Design for Location: The Impact of Manufacturing Offshore on Technology Competitiveness. R&R with *Management Science.*

Methods: Case Study Research

- Study Period: 1992-2008
  - Pre- and Post- Tether (2001)
- Microsystems Technology Office
  - Originally: Electronics Technology Office
  - Renamed: April 1999
- Technologies Relevant to Moore's Law
  - Pre-2001: SOI, Strained Si, SiGe, VCSELs, Lithography
  - Post-2001: Integrated photonics, 3D technology, atomic clocks, clockless logic

Methods: Data Collection

- **Fieldwork:**
  - **50 semi-structured interviews**
    - **DARPA program managers (pre-/post- 2001)**
    - **Intel, AMD, IBM, HP, Sun, Cray, Start-ups**
    - **University professors**
    - **Government labs (Lincoln Labs, Lawrence Livermore)**
  - **Participant observation of DARPA UNIC team**
  - **Participation in industry conferences**
    - **Microphotonics Consortium 2007, Photonics North 2007, OIDA Annual Forum 2008, OIDA Manufacturing and Innovation in the 21st Century 2008, IEEE computing industry workshop**

- **Triangulated with Archival Data:**
  - **Online biographies, CV and bio of all interviewees**
  - **DARPA budgets, annual reports, meetings, technical reports**
  - **Congressional testimonies, legislation**
  - **New releases: DARPA, Companies, Industry journals**

DARPA: The Institution (representative of '90s)

A Culture Which Supports Risk-Taking

(At DARPA you can) "…place bets with enormous risk, and very few penalties of failing. It's probably better to have *spectacular failures* than just lots of failures"

(DARPA Program Manager)

"NSF is much more peer-review… so you kind of get the lowest common denominator funded. But with DARPA, they'll take flyers."

(University Professor)

DARPA: The Institution (representative of '90s)

Lean, Connected Organizational Structure

- Little hierarchy
  - Two steps: Office Director, DARPA Director
- Significant organizational turnover
  - DARPA Director: Average 2.7 years (Mode: 2 yrs)
  - Program Manager: 3-5 years

What processes does DARPA use to influence technology development?

"It really comes down to the program manager. A program manager that has a passion for an idea, that understands the technical elements of an idea, and has some vision for where it might go."

- Taken from the existing research network
  - Government, industry, academia
- A step-ladder in one's career

Pull on their existing social networks

"… I knew there was a chance they wouldn't make it. But at the time, I was betting on the person. Usually, I'd bet on a few people."

(DARPA Program Manager)

"And then he touched on people like (professor) and others who he knew well, and said, hey, help me, give me the ideas. So, he touched on (professor), he touched on other key leaders in the field that he knew and he trusted."

(University Professor)

"Good venture capitalists do very good due diligence. …. They're tough on making you show what you really have. DARPA doesn't do any of that. Relationships are important in the VC community, but DARPA is more about relationships."

(Start-up Company)

Generating Ideas, Identifying Directions

"..."

(DARPA Program Manager)

- Informal
- And Formal
  - Defense Science Board, ISAT, Symposiums, Workshops

Gaining Momentum around an Idea

“…”

(DARPA Program Manager)

Building Community

- Early-Stages: Increasing Information Flows
  - Star scientists protective, institutionally isolated
  - Seeding disparate researchers
  - Bring together in workshops formal, informal conversations
- Later Stages: Growing Communities
  - Workshops
  - Conferences

Validating Directions: Other Funding Agencies

"**See, once you've gotten funding from DARPA,** you have an issue resolved, and so on, **then you go right ahead and submit an NSF proposal.** By which time your ideas are known out there, people know you, you've published a paper or two. And then the guys at NSF say, yeah, yeah, this is a good thing. … So **NSF funding usually comes in a second wave.** DARPA provides initial funding. … **So DARPA *plays a huge role in selecting key ideas*.**

(University Professor)

…that can't be accomplished with peer review?

Validating Directions: Industry

"So the DARPA piece, while large, was the validation for (company A) to spend their own money. The same way for the (company B) piece. You know, (company B) certainly looked at that project, and then (company B) ended up funding it internally, but the fact that DARPA went back to them 3 and 4 times …it got high enough that they set up a division to do this."

(DARPA Program Manager)

But not sustaining the technology

"…we were doing great stuff, really good science. But the tipping point, … is the fact that (company) saw the value in this to the point that they started investing in it."

(DARPA Program Manager)

The State Seeding and Encouraging New Technology Trajectories?

Although there were inevitably failures, historical evidence these processes worked really well…

-Bromberg (1991) The Laser in America
-NAS (1992) The Government Role in Civilian Technology
-Sternberg (1992) Photonic Technology & Industrial Policy
-Malone (1995) The Microprocessor: A Biography
-NAS (1999) Funding a Revolution
-Fong (2000) "Breaking New Ground…"
-Fong (2001) "ARPA Does Windows"
-Allan (2001) A History of the Personal Computer
-Newman (2002) Net Loss
-Roland (2002) Strategic Computing
-Hecht (2005) Beam: The Race to Make the Laser

The State Seeding and Encouraging New Technology Trajectories?

- Generating Ideas
  - Bringing researchers together to brainstorm on program goals
- Gaining Momentum
  - Providing seed funding to disparate researchers working on similar goals
- Building Community
  - Program workshops
  - Conferences
- Providing Third Party Validation
  - Funding agencies
  - Industry
- Not Sustaining the Technology

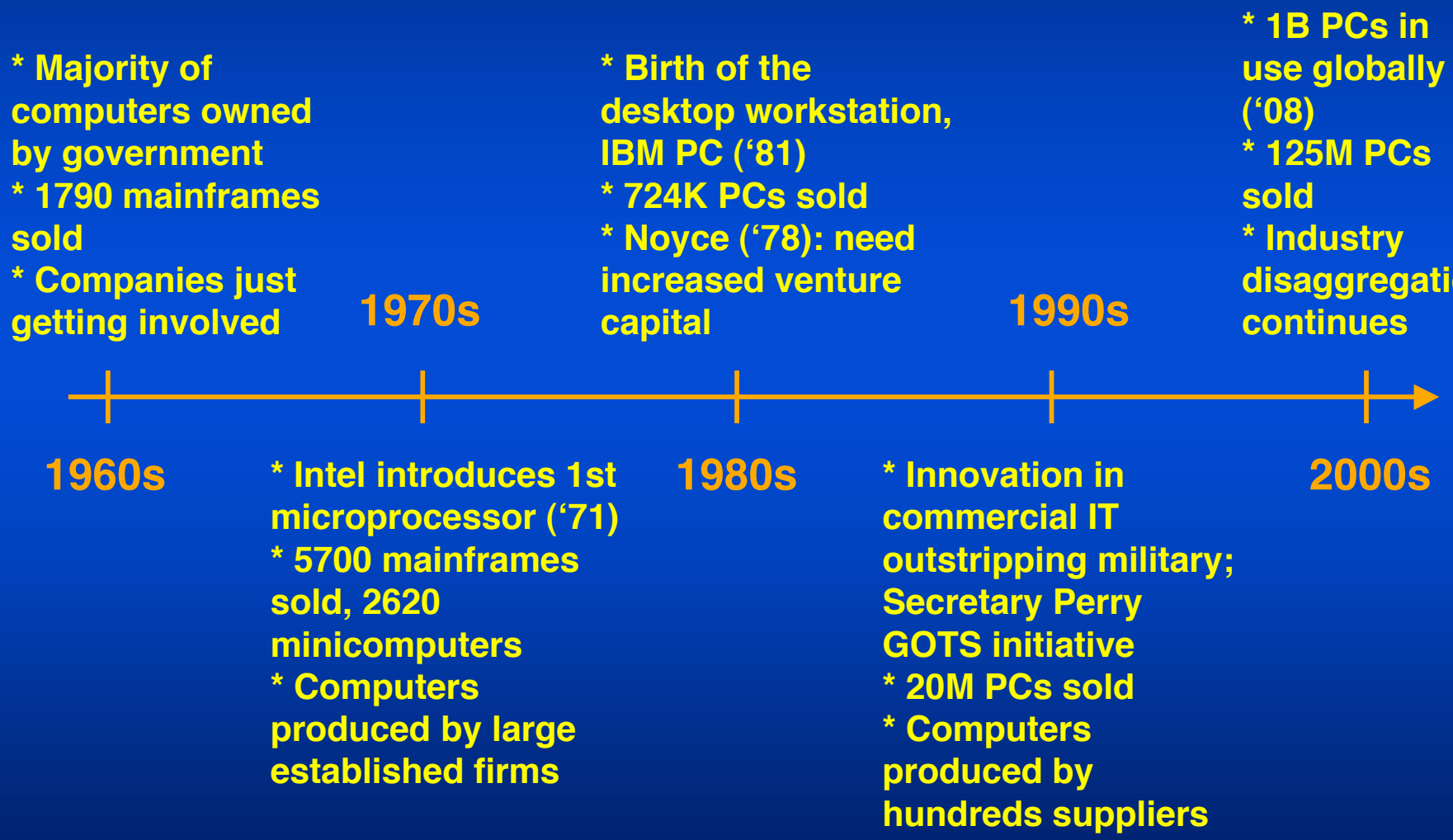
What about the “new DARPA”?

The Post Tony Tether Era…

Change in U.S. Innovation Ecosystem

- New Industrial R&D Model
  - Shift away from corporate R&D labs (Mowery 2000, NAS 2006)
  - To venture-funded small and medium sized enterprises (NAS 2006)
  - Large firms outsource innovation needs to smaller firms and universities through technology alliances and acquisitions (Cohen 1990, Lamb 1997, Chesbrough 2003)
  - Complex networks of firms, universities, government labs (NRC 1999, Powell and Grodal 2005)
  - Interdependent innovation trajectories (Mowery 2000)
- New Challenges for Technology Development
  - Alignment of incentives (Casaadesus-Masanell)
  - Coordination across firms (Gawer 2002, Iansiti 2004)
  - Supporting long-term research (Macher 2000)

Change in the Computing Industry



Changes in the Computing Industry

1960s-1980s	1990s-present
Industry Structure	
Few, pioneering firms supplied computers	Hundreds loosely linked suppliers (Breshnan 2000)
Market Structure	
Primary demand government contractors	Primary demand (high volumes) commercial applications
Government Contracting	
Contractors order customized products	Contractors customize commercial products

Changes in DARPA (1990s to Present)

1992-2001	2001-2008
Broad Area Announcements Open-ended solicitations	Phases: 12-16 mo intervals Funds tied to go/no-go reviews linked to specific deliverables [1, 2, 3]
Funding primarily of universities	Funding shifted from universities to established vendors Many preclude universities, small start-ups as prime contractors; require formation of teams [4]

- Met severe criticism from computer science community[1, 2, 3]

[1] Joint Statement of the Computing Research Community. House Science Committee Hearing on The Future of Computer Science Research in the U.S. May 12, 2005.
[2] Lazowska, E. and Patterson, D. Editorial: An Endless Frontier Postponed. *Science Magazine*. Vol. 308. May 6, 2005.
[3] Markoff, John. Pentagon Redirects is Research Dollars. *New York Times*. April 2, 2005
[4] Defense Science Board Task Force. High Performance Microchip Supply. Feb. 2005

DARPA: HPC, EPIC, and UNIC Programs

Vision: "Moore's Law for Photonics and Beyond"

- **Phase I (February 2006)**
  - **Super-seedling, validity demonstration, 9 months**
  - **Five Teams: HP, IBM (with Luxtera), Sun Microsystems (with Luxtera), MIT I (with BAE), MIT II (with primary contractor)**
- **Phase II (November 2006)**
  - **2 years funding**
  - **Four Teams: HP (with Intel), IBM (with Luxtera), Sun Microsystems (with Luxtera), MIT I (with BAE)**
- **Phase III (March 2008)**
  - **5 1/2 year, $44M Funding of Sun Microsystems (with Luxtera and Kotura, Stanford, UCLA)**

Gathering momentum around an idea.

"So we worked with … the DARPA program manager, and they got interested in the field, and they got a program out of this. They got a bunch of other people involved in the program."

(Start-up Company)

Validating Directions: Bringing Credibility to New Ideas

"Investors are highly motivated to see the company succeed. **DARPA funding and ATP funding have the added benefit of communicating to a third party a validation of the technology"**

(Start-up Company)

Building Community: Coordinating technology directions across companies?

"I can tell you what you'll find. I was there (at the DARPA workshop), and they're all presenting to each other what they're going to do. They're all talking to each other. And they're all doing the same thing."

(University Professor)

… competitors and suppliers

… 1984 National Cooperative Research Act

… 1987 Sematech

… 1990s further vertical disintegration

A Critical Role for DARPA?

"You need someone with a longer term horizon. Ten years from now, we want a teraflop of computing. But we don't have more than a six month time horizon."

(Company "A")

"Here, the technology is being driven by the systems companies. Very few companies have the resources to do system-level exploration without DARPA funding. DARPA funding is enabling system players to determine the direction of this technology. If you don't get the system guys involved, you end up getting widgets that don't work in the bigger picture."

(Company "B")

Avoiding DARPA Closer to the Market?

"So, (our company) as a whole has just shied away from government funding. … (Our research arm), or whatever, they'll get a little DARPA funding, but most of that is, has never produced anything of value, from a… commercial perspective. That wasn't saying it wasn't of value within industry, but just trying to delineate."

(Company "C")

"Sometimes I'm very nervous about getting too much focus on defense money. I don't want to lose track of the fact that I'm developing *products*, not technology. … (my company) is ideally placed for (today's products). But, admittedly, not necessarily for the long term."

(Start up Company)

-Allen 1978, Sirbu 1978, Zysman 1983
-NAS 2007 SBIR Assessment

Discussion

- The *process* matters.
- The old DARPA model: High-risk, high-reward, open-ended funding of universities
  - Seed and encourage new technology trajectories
  - Facilitating conversations, seeding disparate researchers, developing community, providing external validation
- The new DARPA model: Bridging the Gap.
  - Likely necessary given the dependency of the military on commercial products
  - Essential role in coordinating commercialization of research across universities, start-ups, and system contractors…?

Discussion

But with the decline of corporate R&D labs, and shift in DARPA funding away from universities, who is supporting early stages of the pipeline?

"… I want to fund those companies that will put Intel out of business. I'm not interested in driving Moore's Law. The ITRS roadmap exists, and everyone knows what it is. DARPA is not in the business of maintaining that roadmap. We're in the business of cutting a path across it."

(Former DARPA Program Manager, mid-90s)

Policy Implications

- **Generating Ideas**
  - Bringing researchers together to brainstorm on program goals *- who is helping identify directions?*
- **Gaining Momentum**
  - Providing seed funding to disparate researchers working on similar goals *- who is in your network?*
- **Building Community**
  - Program workshops *- who is sharing information?*
  - Conferences *- what community are you building?*
- **Providing Third Party Validation**
  - Funding agencies, Industry *- validation to whom?*
- **<u>Not</u> Sustaining the Technology**
  - *in a disintegrated system, is dependence necessary?*

The Changing Faces of DARPA

	1960s	1970s	1980s
Name	ARPA	'72: DARPA	
Era	Fundament. Research	Military Missions	Industrial Competitiveness
Influential President	Eisenhower, Kennedy	Nixon	Reagan
Legislative / Political Environ.	Sputnik '57, Cold War	Vietnam War, Mansfield Act '69	Japan Competit. National Cooper. Research Act '84
DARPA Director	Betts, Ruina	Heilmeier	Cooper
DARPA Environ.	Scientific merit over military; independence, intell. quality; best people	Mid-term exams, Success measures	Strategic Comp. '83, Sematech '87 Pyramid of tech., Connect academ. industry

The Changing Faces of DARPA

	1980s	1990s	2000s
Name	DARPA	'93-96 ARPA	DARPA
Era	Industrial Competitiveness	Competitiveness, Internationaliz.	Industry to Military
Influential President	Reagan	Clinton	Bush
Legislative / Political Environ.	Japan Competit. National Cooper. Research Act '84	Sematech weans off public asst., internationaliz.	Sept. 11, 2001 Iraq War '03 RAGS '05
DARPA Director	Cooper	Fernandez	Tether
DARPA Environ.	Strategic Comp. '83, Sematech '87 Pyramid of tech., Connect academ. industry	Priorities: people, competition, outreach, experimentation	Bridging the Gap, milestones, phases, accountability