Creating Capability Surprise

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21 April 2009

*This work was sponsored by the Department of the Air Force under contract FA8721-05-C-0002. "Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government*
The Surprise Exemplar: 4 October 1957

"SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U.S."

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"All the News That’s Fit to Print"

The New York Times, Late City Edition

VOL. 234 NO. 165 NEW YORK, SATURDAY, OCTOBER 5, 1957

FIVE CENTS

SIGNALS FROM THE SATELLITE
Ham operator Roy Welch of Dallas, seated, plays a tape-recorded signal from the Russian space satellite for fellow hams at the State Fair of Texas. Welch recorded the signals on a receiver at his home.
The Extension of Asymmetric Surprise

Using existing systems in radically new and asymmetrical ways can have enormous impact.

Terrorist Attack

Suicide Vest

Explosive Cell Phone

Vehicle-Borne IED
Examples Abound

Pearl Harbor  Kamikazes
Bay of Pigs
Cuban Missile Crisis
China enters Korea
Sputnik
Iran Hostages
Tet Offensive
Beirut Barracks Bombing
Victor 3/Akula Quieting
Soviet Bio-weapons Program
Khobar, Cole, Nairobi
Kuwait Invasion
’93 WTC
9/11
PRC ASAT
IEDs in OIF
PRC Force-down of EP-3
...and happened for a variety of reasons

- Thought we could respond without doing anything new
- Knew it was likely, understood the magnitude of the implications, but didn’t pursue it appropriately
- Believed they were not up to it
- Believed they wouldn’t dare
- Knew it might happen, but were trapped in our own paradigms
- Didn’t imagine or anticipate the strategic impact
- Lost in the “signal to noise” of other possibilities
- Imagined it, but thought it was years away
- Were willing to take the risk that it wouldn’t happen

In most cases the indications were there, but with nothing to differentiate a given possibility from others and compel a decision to act
Three Tiers of Technology Innovation

- **Ferment**
  - Technology Disruption

- **Takeoff**
  - Fielding of New Systems
  - New Operational Methods

- **Maturity**
  - Discontinuity

Technology Development vs. Time
Outline

• Introduction

• Sources of Technology Capability Surprise
  – New operational methods
  – Transition and fielding
  – Adaption of new technologies

• Summary
The Symmetric Timeline

Conventional Warfare
SEAD / DEAD Example

- Suppression of enemy air defense (SEAD)
- Destruction of enemy air defense (DEAD)

Response loop measured in years
The DoD 5000 Integrated Defense Acquisition, Technology and Logistics Life Cycle Management Process

10 yrs from concept to capability
Changing Political and Economic Landscape

- Connectivity growth (CNN, internet)
- Ease of global transportation
- Emergence of US as sole superpower
- Disintegration of Soviet Union
- Insertion / maintenance of US military in Middle East
- Explosion of drug traffic
- Partnering of narcotics / terrorist organizations
- Resurgence of violent ethnic and ideological groups
- Worsening income inequity
- Declining standard of living
- Clash over religious influence in third world
- Safe havens in Africa, Asia, South America
- Readily available small arms & weapons

Variety of socio-economic and political conditions providing “kindling” for likely explosion of 4th generation warfare

† Map by Adrian White, University of Leicester (2006)
The Timeline Has Collapsed!

Conventional Warfare
SEAD / DEAD Example

USAF Capability
High Altitude Aircraft
Electronic Countermeasures
Endgame Countermeasures
Engage SAM

Response loop measured in years

Adversary Capability
High Altitude SAM
Monopulse SAM
SAM with ECCM

Counter-Insurgency Warfare
Iraq Example

US Capability
Jammers
Monopulse SAM
Mine Resistant Ambush Protected (MRAP) Vehicle
Advanced Technology

Adversary Capability
High Altitude Aircraft

Response loop measured in months or weeks
Red Team / Blue Team Process

Red Team

- Modeling
- Threat Prototyping
- Testing

Red Threat Assessment

Blue Team

- Modeling
- Prototype Development
- Testing

US Vulnerability Assessment

- Identify gaps in US technology
- Set goals for US technology development

- New US fielded capability
- Rapid transition to user
Three Tiers of Technology Innovation

- Ferment
- Takeoff
- Maturity

New Operational Methods

Fielding of New Systems

A lot of good engineers

Technology Disruption

Technology Development

Time
Concerning Trends

- Knowledge-intensive industries are reshaping the world economy.
- Industry R&D in manufacturing and services is expanding and increasingly crossing borders.
- R&D in the United States is robust and dominated by industry.
- Advanced training in natural sciences and engineering is becoming widespread, eroding the US advantage.
First University Degrees, by Selected Country: 1985–2005

**Natural Sciences**

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</table>

Notes: Natural sciences include physical, biological, earth, atmospheric, ocean, agricultural, and computer sciences and mathematics. German degrees include only long university degrees required for further study.

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Source: National Science Board, Science and Engineering Indicators 2008
Critical National Security Threats

1. Computer Network Attack/Exploit
2. Quiet Submarines
3. Unguided Battlefield Rockets
4. Chemical/Biological Attack
5. IED/Insurgents
6. Maneuvering Ballistic Missile (MaRV) Against Carrier Battle Group (CBG)
7. Containerized Nuclear Weapon
8. Anti-Satellite (ASAT)
9. Cruise or Short-Range Ballistic Missile Launch off Barge
10. Anti-cryptography (QC)
S&T Initiatives to Address Top National Security Threats

High Priority Initiatives

- Early Warning
- Medical Treatments
- Speed-of-Light Weapons
- Container Monitoring/Tracking
- Active Radiological Detection
- Pre-detonation
- Cultural Training
- Persistent Surveillance
- Counter-media
- Authentication, Trust, Access
- Network Attack
- Attack Detection & Response
- Network Hardening
- Platform Hardening
Three Tiers of Technology Innovation

- Adaption of New Technologies
  - Information Technology
  - Nanotechnology
  - Biotechnology

“Three Queens of Research”

- Ferment
- Takeoff
- Maturity

New Operational Methods

Fielding of New Systems
### Defense Technology Timeline

<table>
<thead>
<tr>
<th>40s</th>
<th>50s</th>
<th>60s</th>
<th>70s</th>
<th>80s</th>
<th>90s</th>
<th>00s</th>
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</thead>
<tbody>
<tr>
<td>Nuclear weapons</td>
<td>Digital computer</td>
<td>Satellite comm.</td>
<td>Airborne GMTI/SAR</td>
<td>GPS</td>
<td>Wideband networks</td>
<td>GIG</td>
</tr>
<tr>
<td>Radar</td>
<td>ICBM</td>
<td>Integrated circuits</td>
<td>Stealth</td>
<td>UAVs</td>
<td>Web protocols</td>
<td>Armed UAVs</td>
</tr>
<tr>
<td>Proximity fuze</td>
<td>Transistor</td>
<td>Phased-array radar</td>
<td>Strategic CMs</td>
<td>Night vision</td>
<td>Precision munitions</td>
<td>Optical SATCOM</td>
</tr>
<tr>
<td>Sonar</td>
<td>Laser technology</td>
<td>Defense networks</td>
<td>IR search and track</td>
<td>Personal computing</td>
<td>Solid state radar</td>
<td>Data mining</td>
</tr>
<tr>
<td>Jet engine</td>
<td>Nuclear propulsion</td>
<td>Airborne surv.</td>
<td>Space track network</td>
<td>Counter-stealth</td>
<td>Advanced robotics</td>
<td>Advanced seekers</td>
</tr>
<tr>
<td>LORAN</td>
<td>Digital comm.</td>
<td>MIRV</td>
<td>C2 networks</td>
<td>BMD hit-to-kill</td>
<td>Speech recognition</td>
<td>Decision support</td>
</tr>
</tbody>
</table>

- Quantum
- Nanoscale
- Engineered Bio
Quantum Computing

- Cryptanalysis
  - Factorization of prime numbers
  - Unsorted database searches
- Simulation
  - Fluid flow problems
  - Atomic interactions
  - Material Sciences
  - Modeling quantum systems
- Nobody knows whether we can build one big enough to be useful

Quantum computers are significantly faster than classical computers for certain classes of problems.
The Nanometer Scale

**Things Natural**
- Dust mite ~500 µm
- Human hair 10-50 µm dia.
- Ant ~5 mm
- Fly ash ~10-20 µm dia.
- Red blood cells with white cell 2-5 µm dia.
- DNA 2.5 nm dia.
- ATP synthesis ~10 nm dia.
- Atoms in silicon 0.2 nm spacing

**Things Man-Made**
- Head of a pin 1-2 mm
- Microelectromechanical devices 10-100 µm wide
- Red blood cells Pollen grain
- Nanotube electrode
- Nanotube transistor
- Carbon nanotube ~2 nm diameter
- Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip - Corral diameter 14 nm

Source: National Research Council
Nanotechnology Classes

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Nano-Structures</th>
<th>Nano-Devices</th>
<th>Nano-Enabled Systems</th>
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</thead>
<tbody>
<tr>
<td>Functionalized plasmonic structures</td>
<td>Chemical nanosensors</td>
<td>Distributed nanosensor arrays</td>
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<tr>
<td>Computing</td>
<td>Graphene films</td>
<td>Graphene transistors</td>
<td>Ultrafast computers</td>
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<tr>
<td>Electronics</td>
<td>Carbon nanotubes</td>
<td>Field emitting devices</td>
<td>High-efficiency displays</td>
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<td>Energy</td>
<td>Semiconductor nanodots</td>
<td>Thermoelectric materials</td>
<td>Efficient thermoelectric generators</td>
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<tr>
<td>Biotechnology</td>
<td>Protein nanotubes</td>
<td>Drug-containing nanotubes</td>
<td>Drug delivery systems</td>
</tr>
<tr>
<td>Materials</td>
<td>Metallic-dielectric nanostructures</td>
<td>Negative-index metamaterials</td>
<td>Cloaking coatings</td>
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Explosion of Biological Capability*

- *E. Coli* was the first bacterial genome sequenced, in 1997
- The Human Genome was sequenced in 2003; it took 10 years and $3 billion
- In 2007 the genome of James Watson (co-discoverer of DNA) was sequenced; it took 2 months and $1 million
- The $1000 genome is imminent, and it is projected to become a common diagnostic procedure.
- In 2006, a patent application was filed for the first synthetic organism
- In 2007 recombinant genetic methods were used to alter the species of a bacterial strain

There are many “Moore’s Law” equivalencies for DNA and synthetic biology, and we are just at the beginning of the curves

*Courtesy D. Galloway, DTRA JSTO*
Enabling Technology: Engineered Organisms

• A range of organisms (bacteria, fungi, yeast, eukaryotic cells) have been engineered in a variety of ways
  – Biosensors (ex. CANARY)
  – Protein production (ex. insulin from yeast and bacteria)

• How is this done?
  – Selection under stringent conditions (predominantly used for bioremediation applications)
  – Genetic engineering – insert desired genes into genome of organism (ex. CANARY)

(1) Pathogens crosslink antibodies
(2) Biochemical signal amplification releases Ca$^{2+}$
(3) Ca$^{2+}$ makes aequorin emit photons
(4) Detect photons

As we learn more about cellular systems and “-omics”, we can engineer more elaborate systems
The Shifting Research Base

Number of Full-Time Equivalent Researches (Millions)

<table>
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<th>Region</th>
<th>1995</th>
<th>2002</th>
<th>Yearly Growth</th>
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<td>North America</td>
<td>1.02</td>
<td>1.35</td>
<td>3.7%</td>
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World Total = $813

Notes: R&D estimates from 91 countries in billions of purchasing power parity dollars. Percentages may not add to 100 because of rounding.
Monitoring People in Research Communities is Also Important

Adapted from 2008 Defense Science Board Study on Capability Surprise
**Tech Watch / Horizon Scan**

- Scientometric analysis of published work
- Identify emerging technical communities
- Identify movement of authors
- Detect new technical concepts

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- **Reminders**
  - Prime candidates for research

- **Wait for COTS**
  - Probably requires no direct funding; integrate into ongoing roadmaps & future programs

- **Weak Signals/Wildcards**
  - Should be further assessed—very short pre-cursor studies

- **Back-burner**
  - Can be revisited at a later time

- **Highlights**

- **Technometric analysis of published work**
- **Identify emerging technical communities**
- **Identify movement of authors**
- **Detect new technical concepts**

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Summary

• Capability surprise results from both “known surprises” and “surprising surprises”

• The changing landscape is likely to result in more capability surprises
  – Growing strength of foreign S&T enterprise
  – Global diffusion of technology
  – Global pull on US S&T ideas and workforce
  – Changing nature of innovation

• Sources, examples, and methods for countering each of the technology surprise categories were presented