DARPA/DSO 101

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Director
Defense Sciences Office

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DARPA's Mission

Breakthrough Technologies and Capabilities for National Security

Precision Guidance & Navigation

Communications/Networking **IR Night Vision**

Stealth **Radar Arrays** **UAVs**

1960s	1970s	1980s	1990s	2000s	2010s	2020s

Microelectronics: VLSI, CAD, manufacturing, IR, RF, MEMS

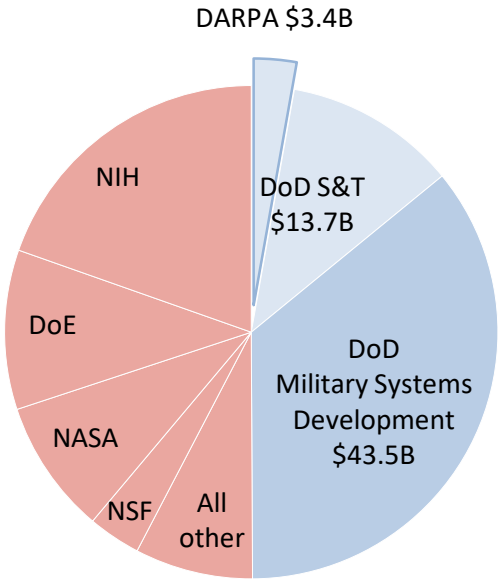
ARPAnet/Internet

Information Technology: timesharing, client/server, graphics, GUI, RISC, speech recognition

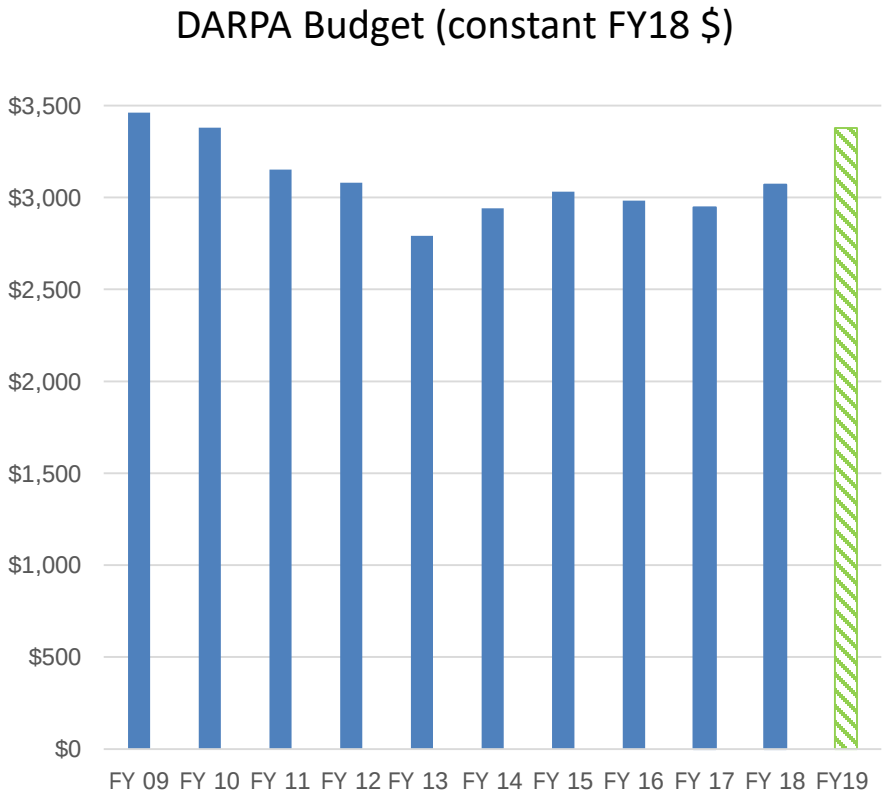
Materials Science: semiconductors, superalloys, carbon fibers, composites, thermoelectrics, ceramics

DARPA's role: Pivotal early investments that change what's possible

DARPA Budget



Federal R&D
FY 2019 President's Budget Request
$118B



92% of funding to projects

67% to industry

17% to universities

25% of total DoD S&T funding

DARPA Inside

People

DARPA program managers

- Exceptional technologists and researchers
- Typically serve 3-5 years

Mission-driven support staff

Processes

DARPA programs

- High-impact objective
- $10-100M over 2-5 years

DoD, Administration, and Congress support mission and autonomy

DARPA Culture

Drive for off-scale impact

Risk taking

Honor in public service

Major Factors Shaping DARPA Investments Today

Wide range of threats to the nation:

Enemy states, non-state actors, shifting networks, WMT

Peer competitions on land (Europe), at sea (Asia), and in the EM and space domains

Continuous and persistent counter-terrorism and counter-insurgency operations world-wide

Powerful, globally available technologies

set a fast pace

WMT – Weapons of Mass Terror
EM - Electromagnetic

DARPA's Portfolio

Multi-varied threats to the nation

Defend the homeland

Cyber deterrence
Bio threat detection and mitigation
Defense against WMT
Countering hypersonic weapons

Peer competitor confrontations in Europe and Asia

Deter and prevail against high-end adversary

Adaptive lethality for air, land & sea
Control of the EM spectrum
Long range effects
Robust space

Continuous counter-terrorism and counter-insurgency operations

Effectively prosecute stabilization efforts

Gray warfare experimentation
Behavior modeling & influence
3D city-scale operations
Warrior performance

Foundations

Understanding complexity, composable systems, advanced materials and electronics, trusted hardware and software, human-machine symbiosis, 3rd wave artificial intelligence, data and social science, new computing, and engineered biology

Increasing the pace of developing technologies and capabilities for the US and allied warfighter

DARPA Technical Offices

BTO — BIOLOGICAL TECHNOLOGIES OFFICE

Biology for Security
- Outpacing Infectious Disease
- Neurotechnology
- Gene Editing & Synthetic Biology

DSO — DEFENSE SCIENCES OFFICE

- Frontiers in Math, Computation & Design
- Limits of Sensing & Sensors
- Complex Social Systems
- Anticipating Surprise

I2O — INFORMATION INNOVATION OFFICE

- Symbiosis: Partner with Machines
- Analytics: Understand the World
- Cyber: Deter Cyber Attack

MTO — MICROSYSTEMS TECHNOLOGY OFFICE

- Electromagnetic Spectrum
- Tactical Information Extraction
- Globalization

STO — STRATEGIC TECHNOLOGY OFFICE

Win In Any Environment via Adaptive Kill Webs
- Sensing
- Comms, Command, Control
- Effects

TTO — TACTICAL TECHNOLOGY OFFICE

Enterprise Disruption: Platforms, Systems, and Technologies that Enable New Warfighting Constructs

Crosscutting Themes
- Eliminate High-Value Assets
- Exploit Cross-Domain Seams
- Enable Decision-Making Asymmetry

DARPA and the Defense Sciences Office

DARPA: Create and prevent strategic surprise

- DARPA's DARPA
- Everywhere the rest of DARPA is, and more
- Mission-informed research

DSO: The Nation's first line of defense against <u>scientific</u> surprise

Program Managers

Anne Fischer
Chemical Systems

Jan Vandenbrande
Math, Design, & Production Automation

John Paschkewitz
Systems, Design, & Materials

Bill Carter
Materials Science

Michael Fiddy
Electromagnetic waves, scattering & structures

Tatjana Curic
Quantum Information Science

James Gimlett
Physics

John Main
System Frontiers

Adam Russell
Behavioral/Social Sciences

Alé Lukaszew
Physics/Materials

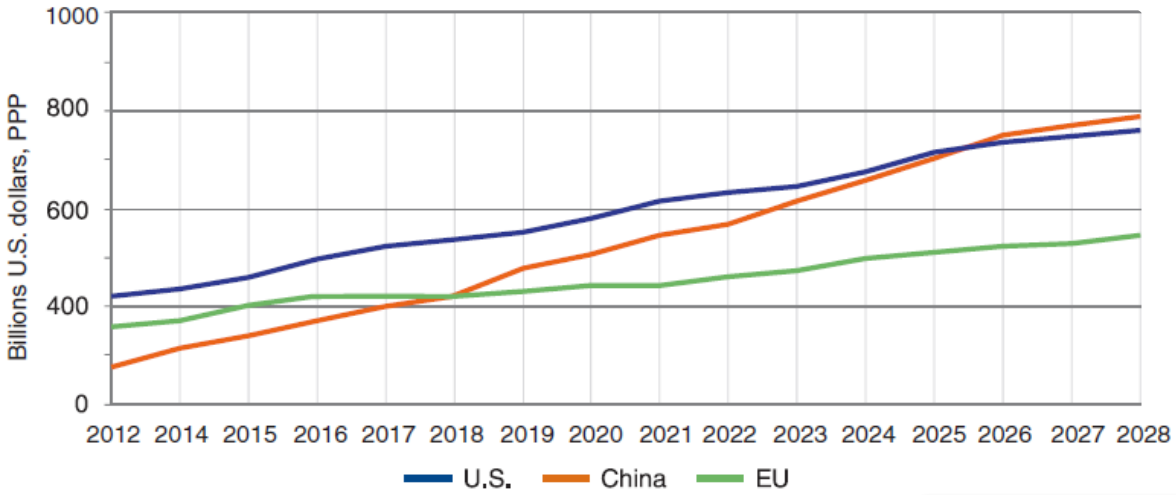
MAJ David Lewis
Physics

Ted Senator
Artificial Intelligence

Vincent Tang
Applied Physics

Trends & Opportunities: Increasing the Pace

Globalization and proliferation of technology (peer, non-peer and non-state actors) implies that U.S. can no longer rely on having/keeping technological advantage



China's 2017 (R&D) growth is basically twice the percentage change and twice the dollar amount of change as the growth forecast for U.S. 2017 R&D spending †

Defense Implications

- Reduced time to:
  - o Identify new Science & Technology (S&T)
  - o Effectively assess value
  - o Exploit for DoD
- Counter new S&T even as it is being exploited for its own use
  - o Equal access to emerging technologies will disrupt future conflicts

Technical Opportunities

- Early identification of S&T with potential to significantly disrupt operational paradigms
- S&T breakthroughs to mitigate the use of emerging technologies by our adversaries

†ASR R&E EXCOM Presentation (30 Jan 2018)

Trends & Opportunities: Escalation Options

Adversaries are increasingly using measured escalation to expand their influence and/or control

Armed men without insignia (so-called "little green men") in Simferopol Airport, 28 February 2014.
http://www.voanews.com/content/us-britain-no-zero-sum-

U.S. responses are limited by the lack of an ability to tailor a "just right" force at the "just right" place.

Defense Implications

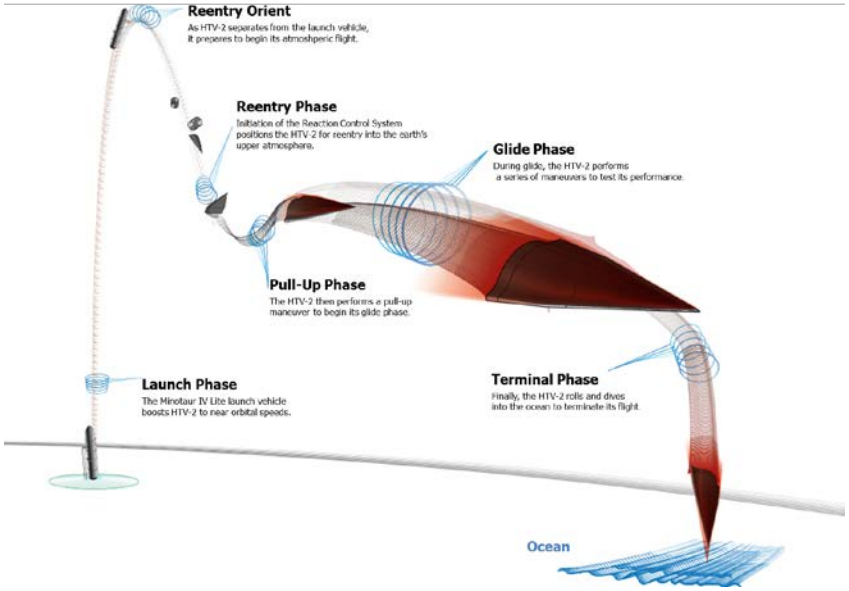
- Develop capability to effectively match and control escalation to achieve a specific adversary response (e.g., de-escalation)
- Develop capability to restore geopolitical influence and power projection in regions proximate to peer adversaries

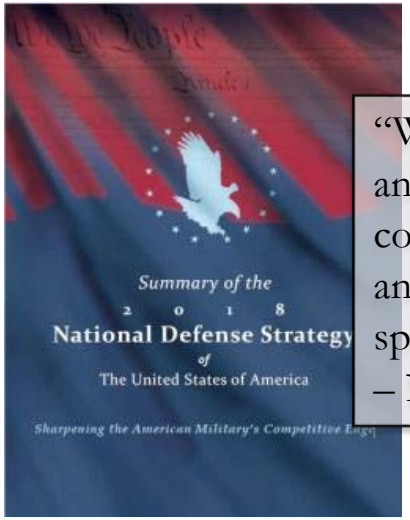
Technical Opportunities

- Capabilities to predict consequences of DoD actions by understanding and modeling intent and reactions of adversaries and allies
- New options for measured DoD escalation or mitigating adversaries' escalation
- Technologies to enable distributed operations/Mosaic Warfare (e.g., manufacturing, communication)

Trends & Opportunities: Need for Speed

The speed/complexity of military engagement is increasing





"We face an ever more lethal and disruptive battlefield, combined across domains, and conducted at increasing speed and reach"
– National Defense Strategy

Defense Implications

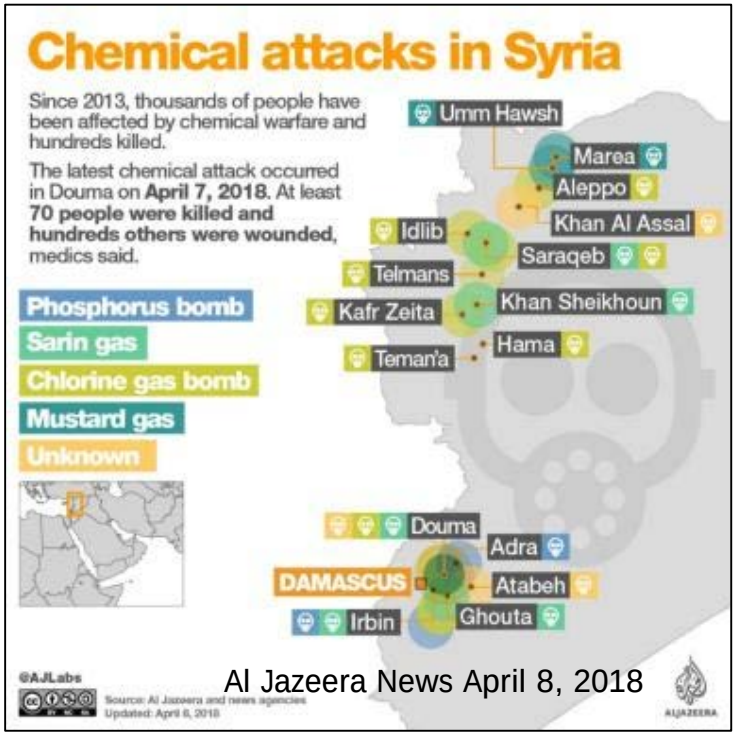
- Compression of DoD's OODA loop
  - o Fidelity of the input critical
  - o Trusted decision making at increased speed and calculable confidence
- Greater payoff to disruption/delay of our adversaries information/decisions processes

Technical Opportunities

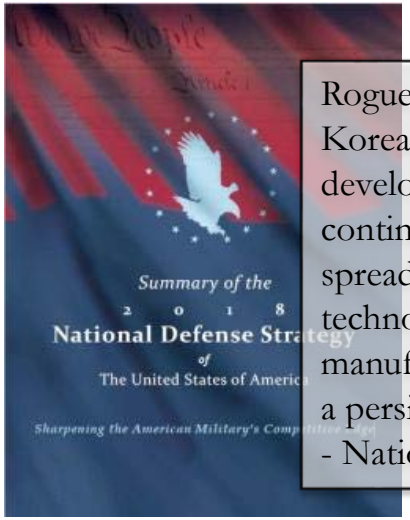
- New sensors and sensor modalities to rapidly incorporate unique information
- Accurate models of physical, environmental and social effects to support decision making across multiple domains
- Alternatives to traditional computing/machine learning for faster, more robust decisions
- Approaches to impose complexity on adversary

Trends & Opportunities: Counter WMD

Proliferation of weapons of mass destruction (WMD), including short range/tactical nuclear



Al Jazeera News April 8, 2018



Rogue regimes, such as North Korea, continue to seek out or develop [WMD] … Terrorists … continue to pursue WMD, while the spread of nuclear weapon technology and advanced manufacturing technology remains a persistent problem.
- National Defense Strategy

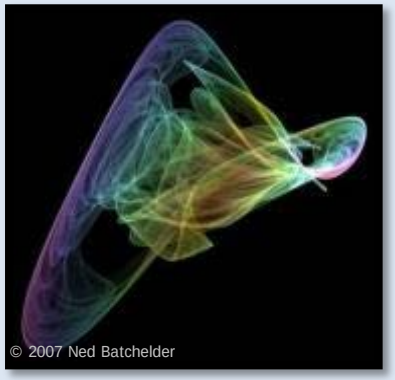
Defense Implications

- Counter the use of WMD
- Prevent proliferation
- Respond to the use of WMD via early warning and maintenance of operations

Technical Opportunities

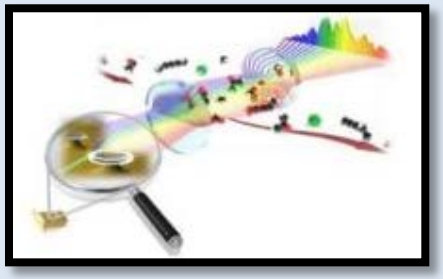
- Sensors and sensor networks that can warn early enough to avoid and/or treat
- Capability to understand adversaries' intent to use WMD in order to thwart "left of boom"
- Approaches that reduce the value to the adversary of using WMD

Current Areas of DSO Focus



Frontiers in Math, Computation & Design

Limits of Sensing & Sensors



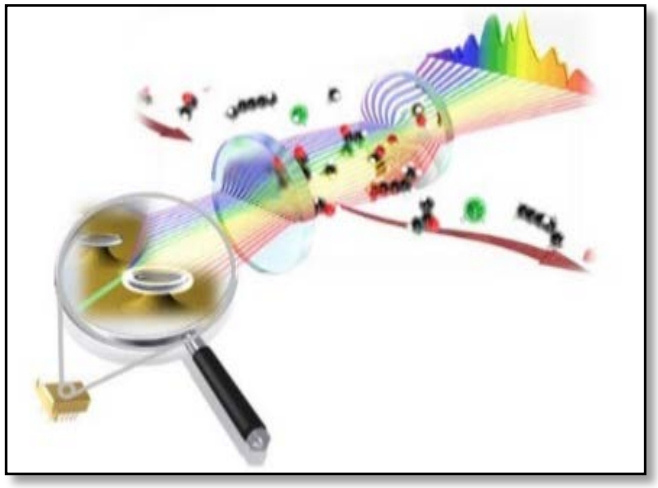
Complex Social Systems

Anticipating Surprise

Limits of Sensing & Sensors

Motivation: Sensing and measurement of various signals are ubiquitous to military systems and missions

- ISR
- PNT
- Health monitoring
- Target ID/tracking



Limits of Sensing & Sensors is exploring both fundamental and practical limits of novel DoD sensors

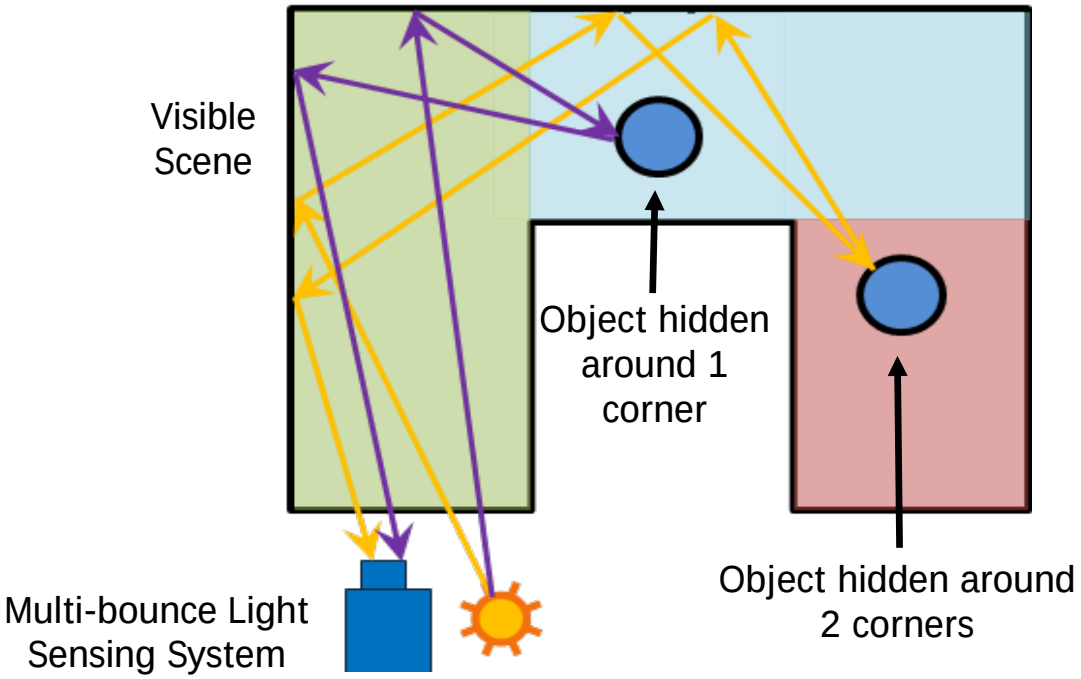
Topics of interest:

- New sensing modalities
- Engineered materials that enable novel optics and imaging capabilities
- Quantum sensing and metrology
- New materials and architectures for memory and logic processing

Revolutionary Enhancement of Visibility by Exploiting Active Light-fields (REVEAL)

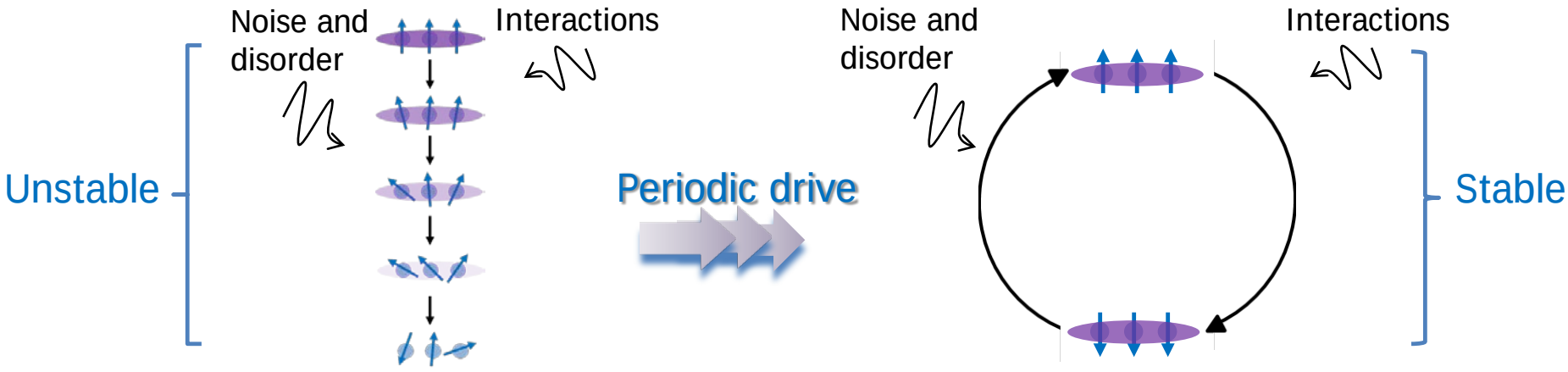
Theoretical framework to enable maximum information extraction from complex scenes using all photon pathways and leveraging light's multiple degrees of freedom

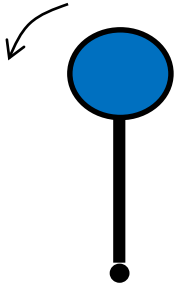
Typical Corridor or Hallway



REVEAL aims to develop new imaging technologies capable of full 3-D scene reconstruction from a single viewpoint

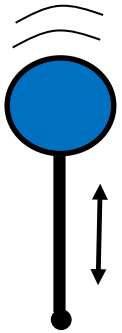
DRIven and Non-equilibrium Quantum Systems (DRINQS)





Unstable

CONVENTIONAL PENDULUM



Stable

KAPITZA PENDULUM

Enhancing coherence time to improve time keeping and magnetometers

Complex Social Systems

Motivation: Understanding the dynamics of complex social networks is critically important for many military operations

- Stability and deterrence
- Counter-terrorism
- Training and mission planning
- Wargaming

Complex Social Systems is addressing challenges in leveraging social behavior science innovation for DoD

- Reproducibility/replicability in DoD scenarios
- Planning for heterogeneous teams of humans and machines

Topics of interest:

- Scientifically validated models of the social dynamics underlying different kinds of conflict
- Capabilities to improve understanding of causality in social systems
- Tools that enable human-machine symbiotic decision-making
- New concepts in war-gaming & conflict simulation
- Social media tools to expedite discovery

Systematizing Confidence in Open Research and Evidence

Automated tool to quantify the confidence DoD should have in social and behavioral science (SBS) research claims

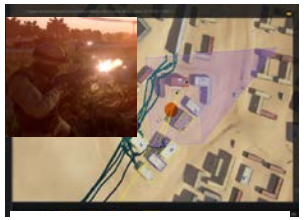
Reproducibility: The extent to which results can be computationally reproduced by others

Replicability: The degree to which results can be replicated by others

SCORE aims to develop and demonstrate automated capabilities for assigning Confidence Scores (CSs) for Reproducibility and Replicability of different SBS research claims

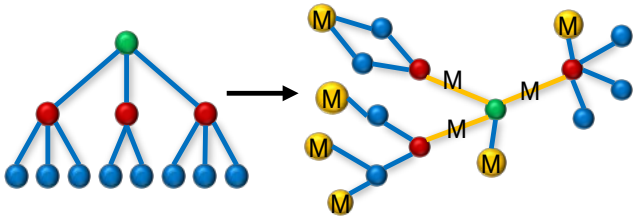
Agile Teams (A-Teams)

Discover, test, and demonstrate predictive and generalizable mathematical abstractions and algorithms for the design of agile hybrid teams. A *hybrid team* combines humans with intelligent machines to realize complex and dynamic collective goals.



Infantry platoon operations virtual testbed

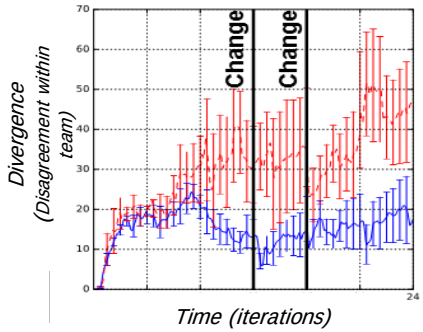
How to compose and structure a hybrid team to solve a complex problem?



M = AI-enabled machine element

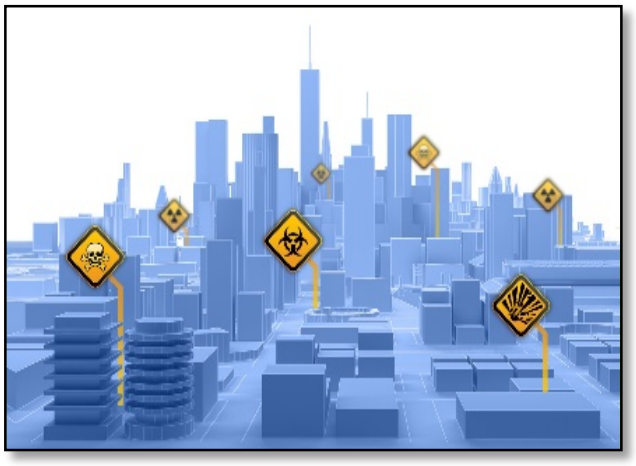
How can a hybrid team solve a changing problem together most effectively?

Inform and validate models in testbeds with diverse cognitive tasks, uncertainty, dynamics and complexity



Anticipating Surprise

Motivation: Ensure that U.S. warfighters have access to the most advanced technologies



Anticipating Surprise invests in “leap ahead” capabilities for specific current and/or future threats

- WMD/WMT
- Robust space situational awareness
- Hypersonics
- Etc.

Topics of interest:

- Materials for harsh environments
- Defense against WMD/WMT
- Exploitation of COTS technology to achieve increased lethality
- Energetic materials
- Concepts in ultra-rapid, high-magnitude energy transduction

SIGMA+

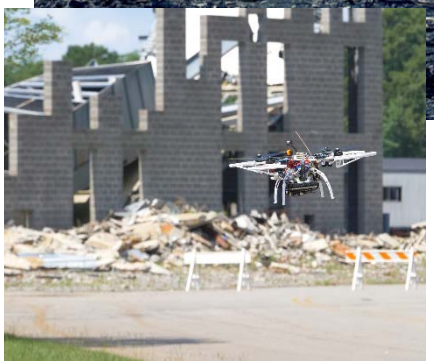
Scalable, high capability, fully automated CBRNE early detection systems remain a grand challenge for national security

SIGMA+ aims to develop and demonstrate a transformative CBRNE early detection system by leveraging advances in sensing, data fusion, analytics, and social sciences

Chemical, biological, radiological, nuclear and explosive (CBRNE)

Fast Lightweight Autonomy

Increased effectiveness and expanded mission capability of high-speed autonomous systems

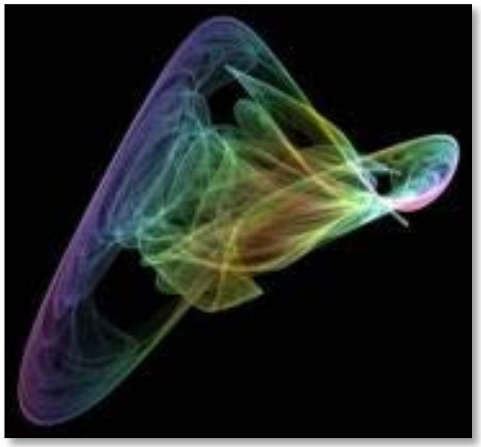


- **Novel sensing**
- **Aggressive, high-speed controls**
- **Robust state estimation**
- **Visual odometry**
- **Monocular perception**
- **Biologically-inspired perception and control**
- **Aerial autonomy**

Minimalistic algorithms for high-speed autonomous navigation in cluttered environments without prior knowledge, remote control, or GPS

Frontiers in Math, Computation & Design

Motivation: DoD operational environments are increasingly technologically sophisticated, fast-paced, complex and dynamic



Frontiers in Math, Computation & Design is addressing challenges in how we design and plan for future military needs:

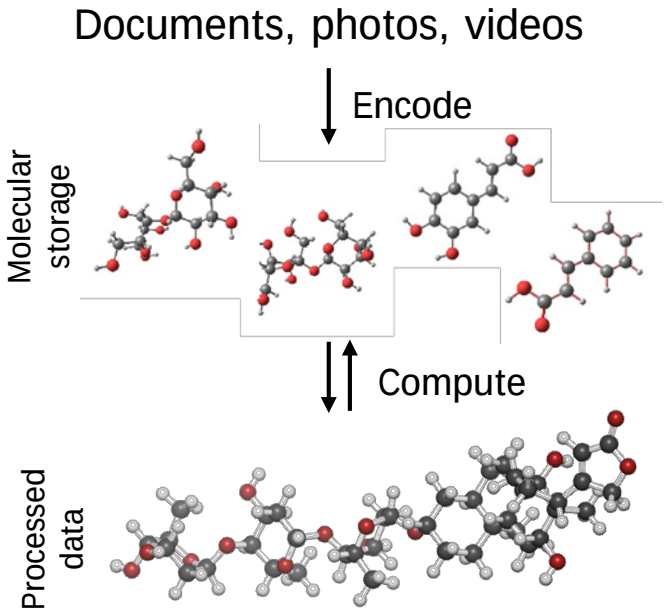
- Materials
- Platforms
- Systems

Topics of interest:

- Mathematical, computational, and design frameworks and tools that provide robust solutions to challenging planning and optimization problems
- Fundamental scientific underpinnings and limits of artificial intelligence and machine learning
- Alternative computing models, architectures, and substrates for faster, more robust decision making
- Advanced design tools

Molecular Informatics

Novel capabilities to exploit molecules for ultra-dense information storage and processing



Addressing:

Search | Classification | Optimization

Signal processing | Primitives

Molecular Informatics aims to couple ultra-dense data storage with novel molecular informatics as a new paradigm in scalable, high-throughput information processing

Space Environment Exploitation

Predict the space environment with sufficient precision & accuracy to provide space operational support to enable counterspace capability

Situational awareness for helping a commander prepare the operational battle space

Young Faculty Award (YFA)

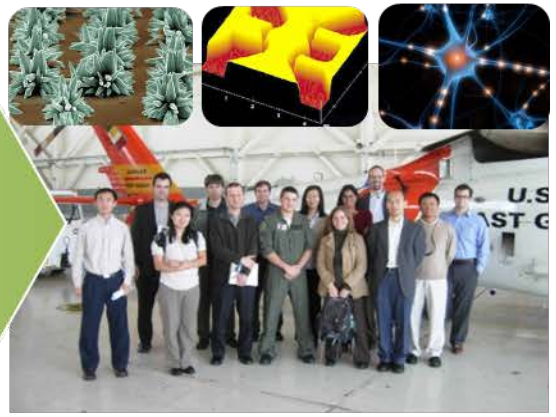
Identify and engage **rising stars** in junior research positions, emphasizing those without prior DARPA funding, and expose them to DoD needs and DARPA's program development process

The YFA program provides:

- Research funding
- DoD contacts
- Military visits/exercises
- PM Mentor

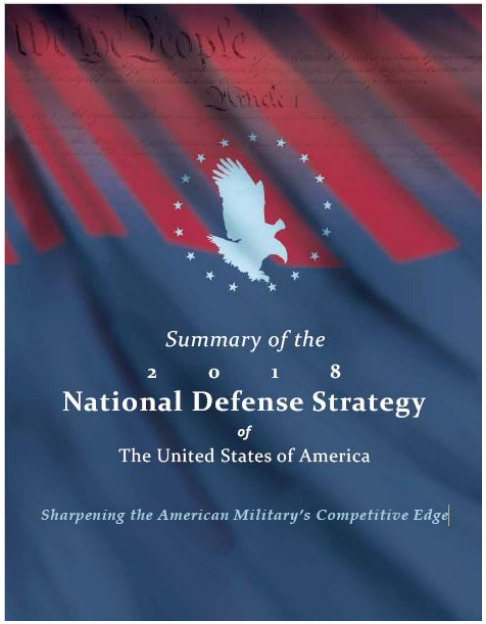
The YFA program yields:

- Insight into DoD problems
- Novel ideas
- Career development
- Future DARPA performers



Develop the next generation of academic scientists, engineers, and mathematicians who will focus a significant portion of their career on DoD and National Security issues

Disruptioneering



- "Harness and protect the National Security Innovation Base"
- "Deliver performance at the speed of relevance"

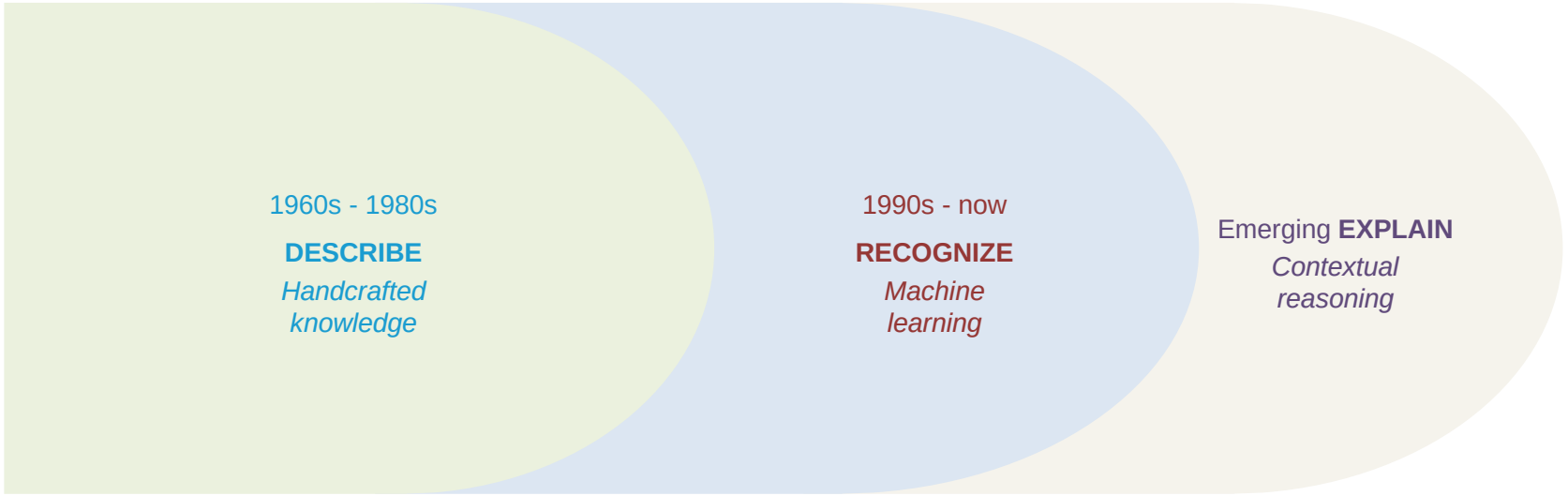
– National Defense Strategy

Disruptioneering is a DSO rapid acquisition approach to increasing the speed of innovation:

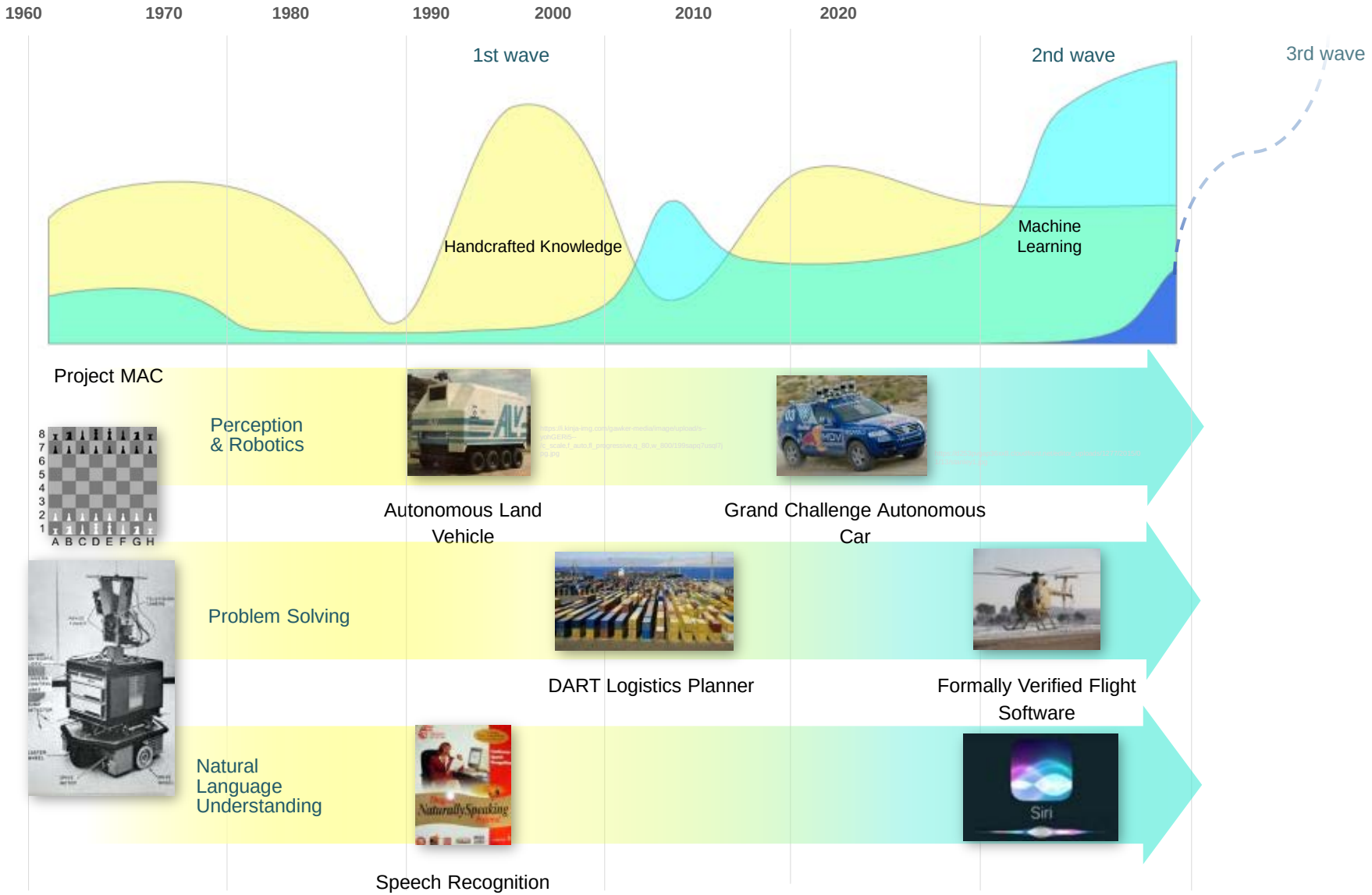
- High risk concept exploration
- Acquisition tailored to speed (idea to program in 90 days)

DARPA AI Strategy

Three waves of artificial intelligence R&D



A deep history of funding advances in AI



AI investment strategy

Computers as Tools → Computers as Partners

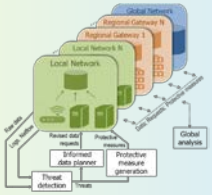
Collaborative operations in denied areas

Adaptive autonomous ISR

Assured Autonomy

Assurance for machine learning-enabled systems

Cyber Security

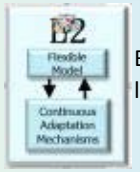


Cyber hunting at scale

AI Hardware

Neuro-morphic processor

Machine Learning



Biologically inspired lifelong learning machines

Explainable AI

This is a Russian tank, it has a rounded front fender.

Common-sense reasoning

- Theory of other minds (motivations of actors)
- Causal reasoning from naïve qualitative physics
- Representation and use of world knowledge

Theoretical foundations of machine learning

- Adversarial issues
- Performance and robustness characteristics
- Game theoretic aspects of autonomous systems

Application of AI to complex DoD problems

- Certification and accreditation of software
- Faster and more accurate security clearance
- Brain control of prosthetic limbs

Future funding directions

- Major programs
  - Multiple Broad Agency Announcements of new starts over the next 12 months
  - Advance the state of the art in: common sense reasoning, theoretical foundations, adversarial AI, reduction in data requirements for machine learning
- Funding pool for rapid execution of focused study efforts
  - Fund multiple, high-risk/high-payoff proof-of-concept study efforts
  - From proposal to award in less than three months
  - Quantify risks to accelerate new program starts
- Inspire research community to tackle challenging problems
  - Security clearance in a week
  - Software system accreditation in a day
  - Chip design 10x faster with fewer people
  - Spinal cord break bridging

Artificial Intelligence Exploration (AIE)

AIE will enable DARPA to fund pioneering AI research to discover new areas where R&D programs may be able to advance the state of the art

- The pace of discovery in AI science and technology is accelerating worldwide
- The AI Exploration (AIE) program is part of DARPA's broader AI investment strategy that will help ensure the U.S. maintains a technological advantage in this critical area

- Program Announcement (PA) release: July 20, 2018
  - https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-PA-18-02/listing.html

This new approach enables DARPA to go from idea inception to exploration in fewer than 90 days!

How We Think: The Heilmeier Catechism

Important questions to consider when approaching DARPA with ideas:

- What are you trying to do? Articulate your objectives using absolutely no jargon.
- How is it done today, and what are the limits of current practice?
- What is new in your approach and why do you think it will be successful?
- Who cares? If you are successful, what difference will it make?
- What are the risks?
- How much will it cost?
- How long will it take?
- What are the mid-term and final “exams” to check for success?

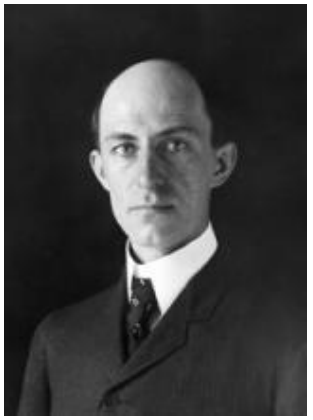
Revolutionary vs. Evolutionary R&D

"The flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanicians in from one million to ten million years"

- The New York Times
  - 9 October 1903

"We started assembly today"

- Orville Wright's Diary
  - 9 October 1903



Questions?