U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Dr. Alexander Kott

Chief Scientist

DEVCOM Army Research Laboratory

Controlled by: U.S Army

Controlled by: DEVCOM ARL

CUI Category: N/A

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POC: Alexander Kott, 301-394-1507

WHY A LABORATORY

1. Create scientific knowledge for market advantage

2. Exploit scientific knowledge for market advantage

3. Advise leadership about future threats and opportunities

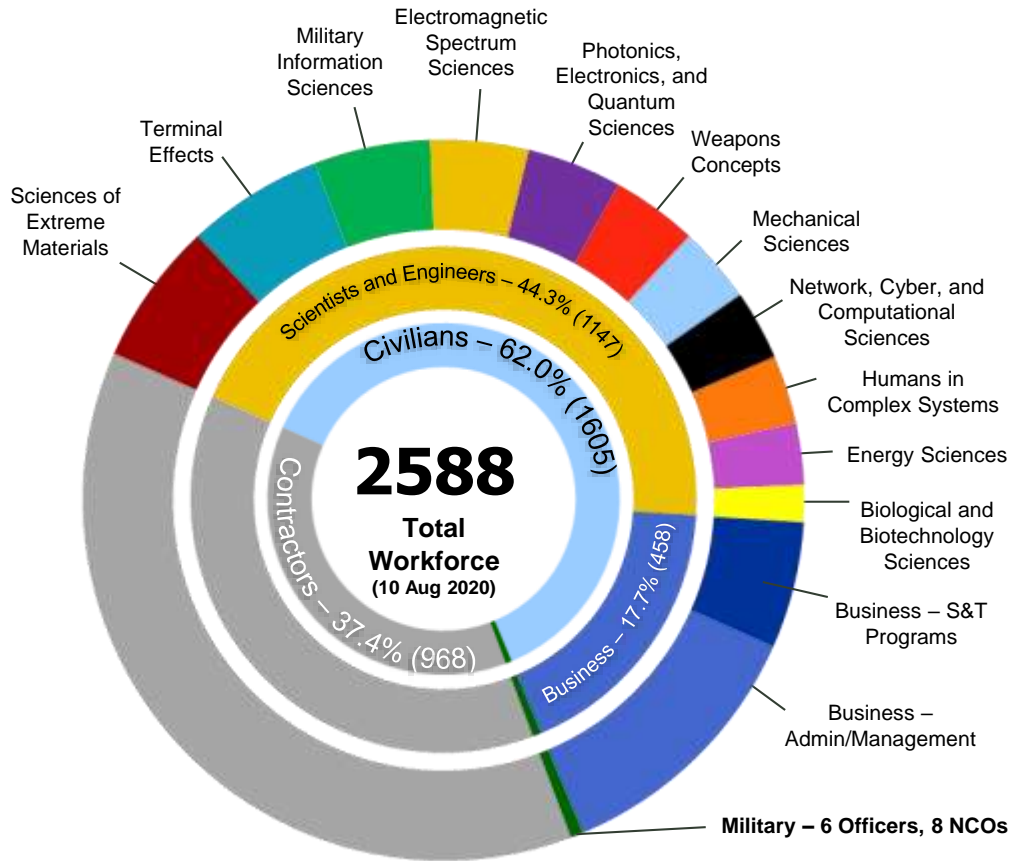OPERATIONALIZING SCIENCE FOR TRANSFORMATIONAL OVERMATCH

NOW ⟵ EVERY SINGLE DAY ⟶ 2050

WHO WE ARE: ARL'S PEOPLE AND FACILITIES

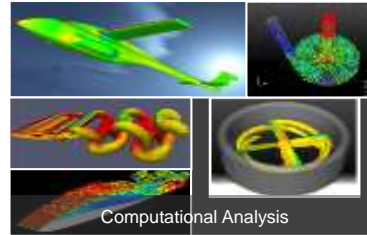## People – Diverse Elite Talent

2588 Total Workforce (10 Aug 2020)

Civilians – 62.0% (1605)
Scientists and Engineers – 44.3% (1147)
Contractors – 37.4% (968)
Business – 17.7% (458)
Military – 6 Officers, 8 NCOs

Categories: Sciences of Extreme Materials, Terminal Effects, Military Information Sciences, Electromagnetic Spectrum Sciences, Photonics, Electronics, and Quantum Sciences, Weapons Concepts, Mechanical Sciences, Network, Cyber, and Computational Sciences, Humans in Complex Systems, Energy Sciences, Biological and Biotechnology Sciences, Business – S&T Programs, Business – Admin/Management

Facilities – Unique Technical Infrastructure

Computational Analysis

Hover Cage

Network Science Research Laboratory

Information for Mixed Squads (INFORMS) Laboratory

Mechanical Sciences Research Laboratory

Cold Spray Laboratory

Network Science Research Laboratory

Specialty Electronic Materials and Sensors Cleanroom

Next Generation Squad Weapons Development

Energetics Laboratory

Rodman Materials Research Laboratory

ARL Center for Advanced Polymer Processing (ACAPP) Infrastructure

Synthesis

Transonic Experimental Facility

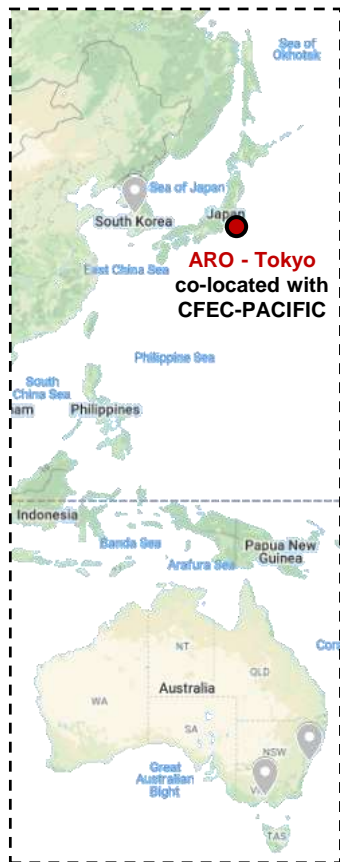Quantum Network Laboratory

Zahl Physical Sciences Laboratory

Additive Manufacturing Science Center

ARMY FOUNDATIONAL RESEARCH ECOSYSTEM: DIVERSE, DISTRIBUTED LOCATIONS & FACILITIES

ARL NATIONAL AND INTERNATIONAL

ARO - Tokyo
co-located with
CFEC-PACIFIC

ARO - London
co-located with
CFEC-ATLANTIC

ARO - Brazil
co-located with
CFEC-AMERICAS

ARL Northeast
Boston, MA
ISN UARC
A4I/A2I2 (CMU)
Cold Spray Technology
AC^2
DARPA Colosseum
USMA/West Point
DEVCOM Soldier Center

ARL West
Playa Vista, CA
ICB UARC
ICT UARC
FNC3 COE (UC-Riverside)
Tech Accelerators

ARL – White Sands Missile Range

ARL South
Austin, TX
Robotics CoE (UT Austin)
Cyber RIG (UTEP)
Innovation Proving Ground (TAMU)
Bell Innovation
Uber Elevate (Uber/UT Austin)
Rice University NSRA

ARL Central
Chicago, IL
ARL Center for UAS Propulsion (CUP)
AAMP-EM (Purdue)
Internet of Battlefield Things (IOBT) CRA

ARL – Aberdeen Proving Ground

ARL – Adelphi Laboratory Center *(Headquarters)*

ARL – Army Research Office RTP, NC

Legend:
- ARL Primary Lab Site
- ARL Regional Site
- ARL International Hub
- US Army Installation

Dropped Pins
1 – Color-coded by Regional Site (light: industry, dark: academia)
2 – Gray: Collaborative Agreements
(Single investigators and MURIs not shown)

ARL'S PAST ACHIEVEMENTS

2000 PATRIOT Assessments & Improvements

2001-2004 Infrasonic Arrays

2004 M829A3/4 Projectile Most lethal ammunition in the world

2004 Armor Survivability Kit for the HMMWV*

2004 UTAMS Mortar, Rocket, Explosion Locator*

2004 IED Countermeasure Equipment*

2005-2011 Rhino A vehicle mounted system for pre-detonating Improvised Explosive Devices (IEDs)

2005 Fido Explosives Detector*

2005 Persistent Surveillance

2006 Constant Hawk*

2006 OmniSense*

2006 Interim Fragment Kit 5*

2006 EM Armor Demonstration

2006 "Blow Torch" Counter – IED System*

2007 First Demonstration of Improved Ground Vehicle Mobility using Human Autonomy Teaming

2007-2008 IED Armor & Adv. Multi-threat Armor

2012 Weather Forecasting for Aerostat Operations

2009 - 2019 Vehicle Autonomy Software

2009-2011 Hazardous Aerosols Monitoring

2009 Improved Unmanned Ground Vehicle Mobility

2010 Autonomous System Technologies

2014 – 2019 Multimodal Transparency Based Interfaces for enhanced Human Autonomy Teaming

2010 - 2017 Micro-Autonomous System Technologies

2010 5.56 mm M855A1 millions fielded ** Lead Free Environmentally Friendly Ammunition

2011 Checkpoint Explosives Detection (CPEDS)

2012 Flexible Displays

2012 Apache AH-64E Transmission Face Gear Technology

2013 Strider Body Worn Detection System

2013 Brain Computer Interaction Technologies

2013 Fuel Cell-Powered Stalker UAS

2013 Serenity

2015 Auditory Hazzard Assessment Algorithm for Humans (AHAAH) in MIL-STD -1474E

2015 ARL Dari/Pashto keyboard software for "HYBRID" IED Reporting Device

2015 Gray Eagle-ER UAS Engine Calibration Method

2014 7.62 mm M80A1 100M fielded

2014 Weather Decision Aids

2014 Fielded Enhanced Combat Helmet

2016 Commercialized SIC Power Devices

2015 120 mm M829A4

2017 6.8 mm Concept For Next Gen Squad Weapon

2017 Information Security Continuous Monitoring (ISCM)

2018 Warrior Injury Manikin (WIAMAN) Worlds 1st Anthropomorphic Test Device to PEO STRI in time to meet AMPV testing

2019 7.62 mm Adv Armor Piecing M1158

2019 US IMPLEMENTATION of the 3-D Gridded Meteorology Message (METGM)

2019 Aqueous Lithium Ion Batteries

2019 RCV Fielding Identified opportunity & shaped CFT decision to accelerate RCV fielding by 2-4 years

2020 Opportunistic Sensing for AI/ML Applications

2020 Thermophotovoltaic (TPV) Battery Charger

2022 6.8 mm Ammo Special General and Purpose Projectiles

2000   2005   2010   2015   2020

*Army's Greatest Invention Award
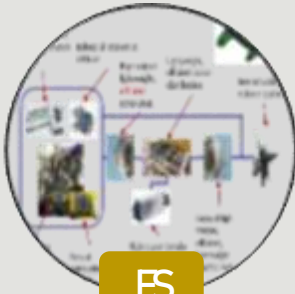** OSD Packard Award

ARL COMPETENCIES

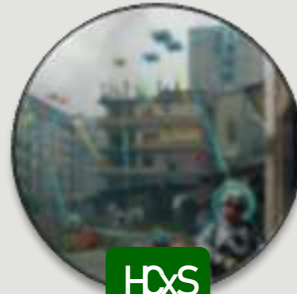
BBS
Biological and Biotechnology Sciences

EMSS
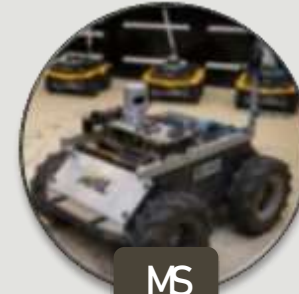Electromagnetic Spectrum Sciences
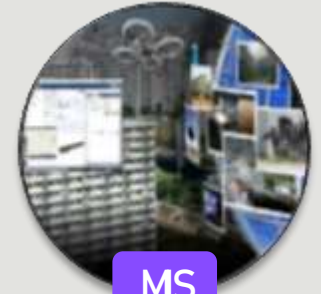
ES
Energy Sciences

HCxS
Humans in Complex Systems

MS
Mechanical Sciences

MS
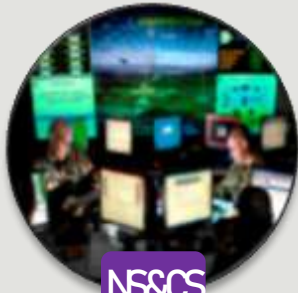Military Information Sciences

Competencies are the source of all technical work to ensure **transformational overmatch**

NS&CS
Network, Cyber, and Computational Sciences
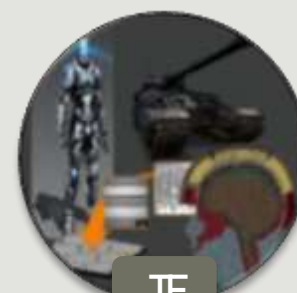
PE&QS
Photonics, Electronics, and Quantum Sciences

SEM
Sciences of Extreme Materials

TE
Terminal Effects

WS
Weapons Sciences

Theory + **Academic Outreach** + **Modeling** + **Experiment** + **Analysis**
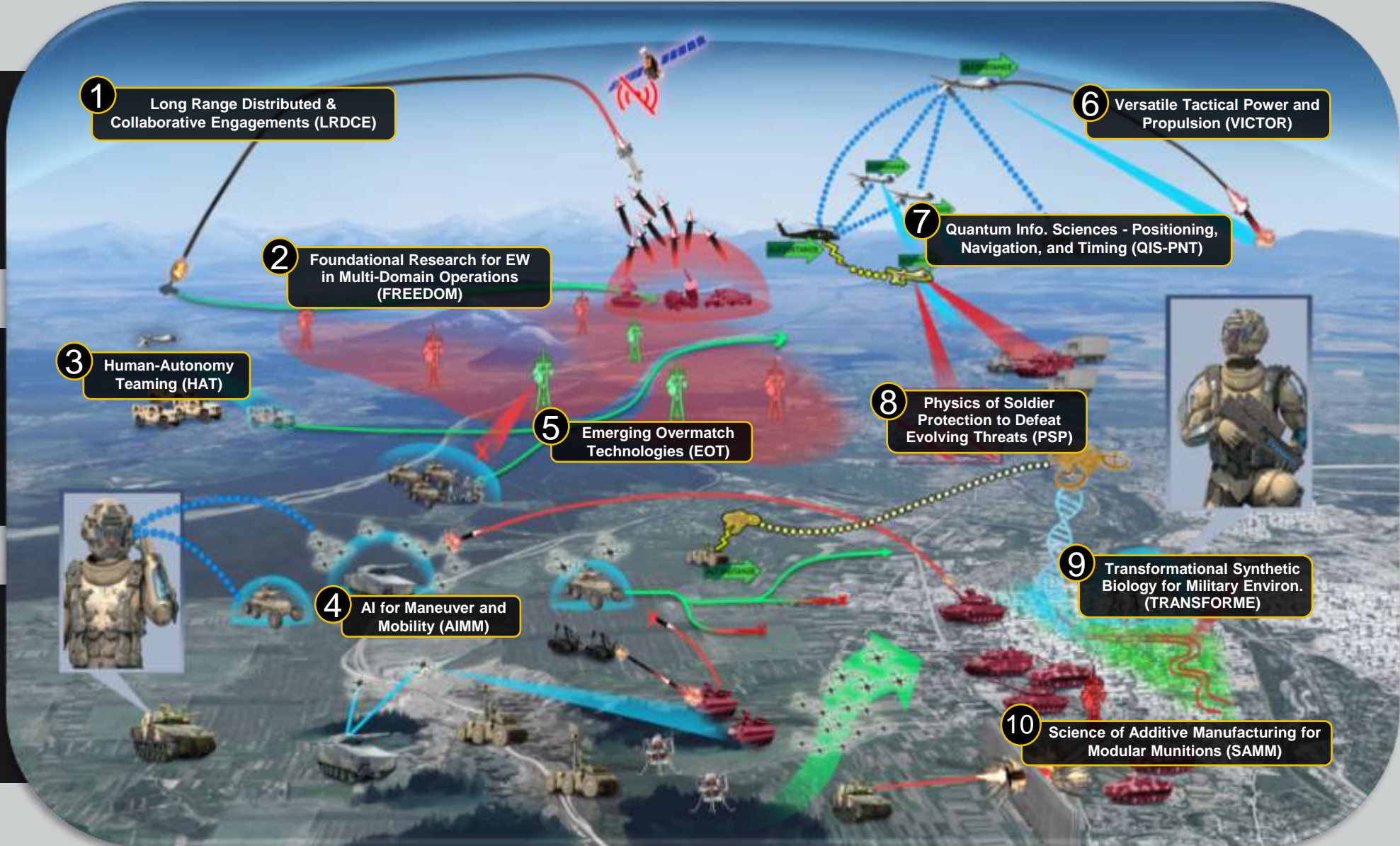
ARL ESSENTIAL RESEARCH PROGRAMS (ERPS)

Cross competency programs designed to operationalize science

Leading to transformational overmatch at the speed of relevance

Leveraging tailored engagements across the ecosystem

1. Long Range Distributed & Collaborative Engagements (LRDCE)
2. Foundational Research for EW in Multi-Domain Operations (FREEDOM)
3. Human-Autonomy Teaming (HAT)
4. AI for Maneuver and Mobility (AIMM)
5. Emerging Overmatch Technologies (EOT)
6. Versatile Tactical Power and Propulsion (VICTOR)
7. Quantum Info. Sciences - Positioning, Navigation, and Timing (QIS-PNT)
8. Physics of Soldier Protection to Defeat Evolving Threats (PSP)
9. Transformational Synthetic Biology for Military Environ. (TRANSFORME)
10. Science of Additive Manufacturing for Modular Munitions (SAMM)

AUTONOMOUS INTELLIGENT CYBER-DEFENSE AGENTS

- **Growing focus on AI, autonomy, and issues of human trust in AI**

- **Cyber is exceptionally ripe for strong AI; autonomous yet human-managed agents for cyber operation**

- **Malware is growing in autonomy and sophistication**

- **Current manual and semi-manual approaches grossly inadequate**

- **Needed are autonomous agents that:**
  - actively patrol the friendly network
  - detect and react to hostile activities far faster than human reaction time
 - trusted and controlled by humans

MEASURING CYBER RESILIENCE

- You cannot improve what you cannot measure

- All sciences and engineering blossomed only when measurements tools appeared

- Analogy: indicator diagram. James Watt found it so important for development of steam engines, it so crucial to improving his steam engines, he kept it secret

- We need tools for measuring cyber resilience: rigorous, repeatable, and statistically meaningful

- Red teams and qualitative assessments are important. But no substitute for high throughput automated testing, for multiple operational and threat scenarios

MEASURING RESILIENCE
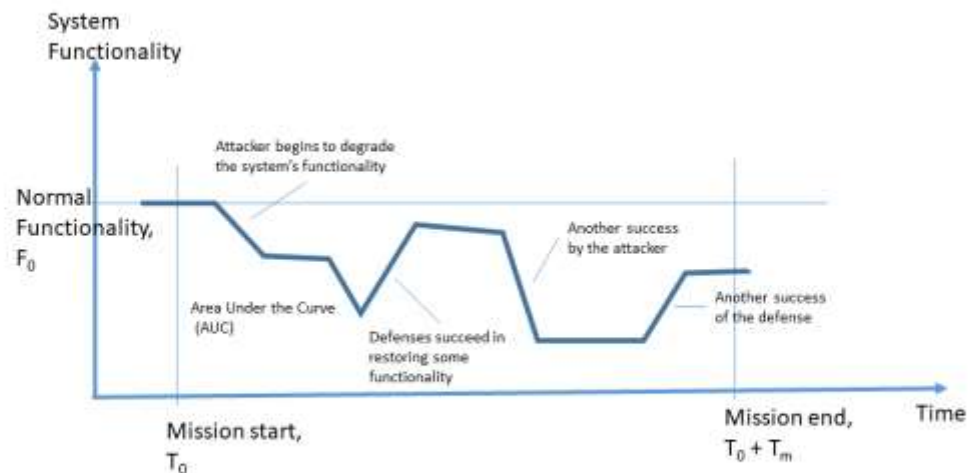
Quantification of resilience through integral of system functionality F(t) over the total mission time Tm. The resilience quantity is $R = (AUC)/(F0*Tm)$

- **Execute series of experiments with real system, in representative missions**
- **Apply pressure of diverse, representative attacks**
- **Quantify actual degradation of mission-relevant functionality**

REFERENCES

- A. Kott and I. Linkov, "To Improve Cyber Resilience, Measure It," in Computer, vol. 54, no. 2, pp. 80-85, Feb. 2021
- Kott, A., & Linkov, I. (Eds.). (2019). Cyber resilience of systems and networks (pp. 381-401). New York, NY: Springer International Publishing.
- A. Kott, J. Ludwig, and M. Lange, "Assessing mission impact of cyberattacks: Toward a model-driven paradigm," IEEE Secur. Privacy, vol. 15, no. 5, pp. 65–74, Jan. 2017
- E. J. M. Colbert, A. Kott, and L. P. Knachel, "The game-theoretic model and experimental investigation of cyber wargaming," J. Def. Model. Simul., vol. 17, no. 1, pp. 21–38, 2020
- Kott, A., & Theron, P. (2020). Doers, not watchers: Intelligent autonomous agents are a path to cyber resilience. IEEE Security & Privacy, 18(3), 62-66.
- Kott, A., Théron, P., Drašar, M., Dushku, E., LeBlanc, B., Losiewicz, P., ... & Rzadca, K. (2018). Autonomous intelligent cyber-defense agent (aica) reference architecture. release 2.0. arXiv preprint arXiv:1803.10664.

AI for Command & Control (C2)
of Multi Domain Operations (MDO)

Premise: Existing tools that support C2 will overload human cognitive ability in MDO

Explore technologies for AI-supported C2 Systems

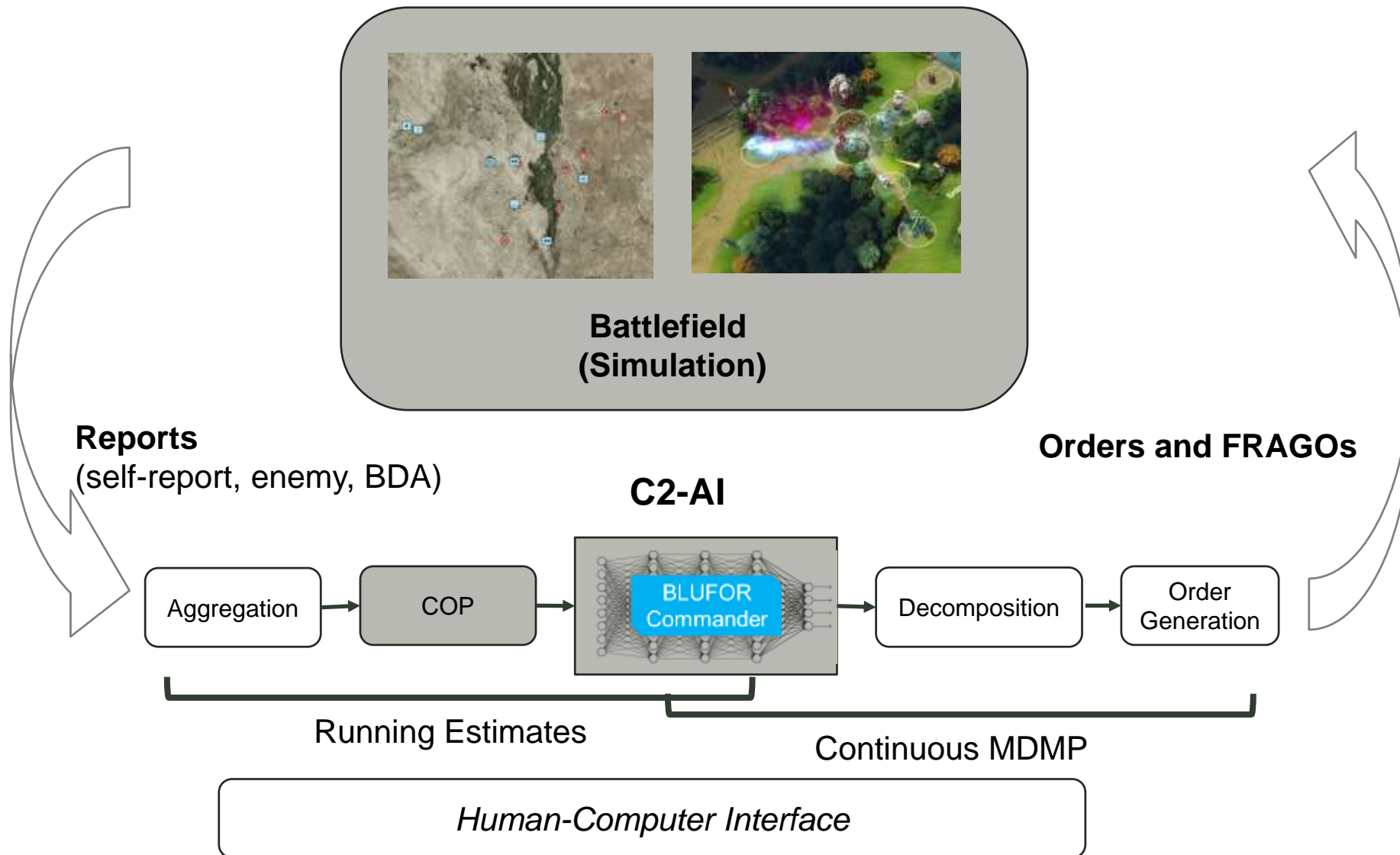| AI-enabled C2 to respond to WoS	Rapid synchronization Across echelon, domain, assets	C2 of future robotic-heavy forces

AI has previously overpromised
and under-delivered

- The "representation problem" hobbled AI since 1960s. Can we achieve realistic C2 with manageable level of detail in representation?

- Both OpenAI and DeepMind relied on enormous computational resources, long learning. Is this a show-stopper for AI C2?

- No evidence yet that DRL can adapt to new features in the game, in real time. Could it? If not – is it truly critical?

- Doubts remain about strategic (look-ahead) abilities of DRL players. Does DRL produce implicit look-ahead, or not?

- Little evidence yet that DRL can deal with deception. Can it?

- Claims emerge that DRL shows rigid, predictable style. Is it so?

Experimental Testbed
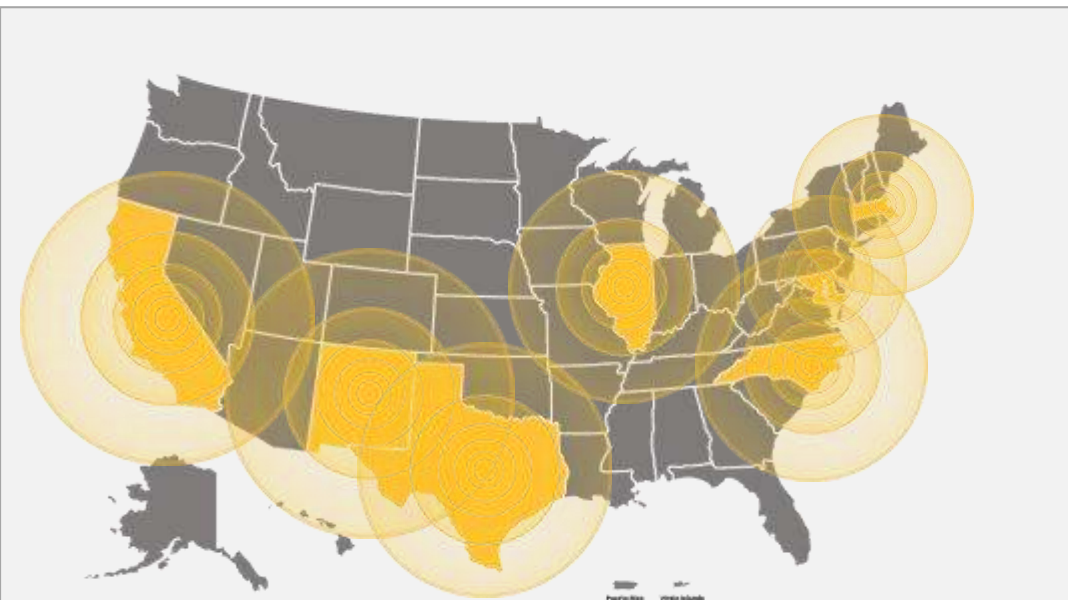

Battlefield (Simulation)

Reports
(self-report, enemy, BDA)

Orders and FRAGOs

C2-AI

Aggregation → COP → BLUFOR Commander → Decomposition → Order Generation

Running Estimates

Continuous MDMP

Human-Computer Interface

ARL CONNECTS THE ARMY TO EXTRAMURAL RESEARCH

ARL is the Army's primary collaborative link to the Academic Scientific Community.

Researchers execute **cutting edge programs** and are aware of both science and technology strategy and **Army application**.

Extramural Program Managers are **subject matter experts** that also **have funding authority**.

The ARL Team *proactively* identifies promising science and **emerging technology** and brokers new diverse teaming relationships.

ARL Teams with intellectual capital of industry and academic institutions

ARL brokers relationships between the Army and these institutions to build focused scientific *networks* – not a pipelines. **The intention is to operationalize scientific knowledge**, which leads to game-changing Army application and economic viability.

These networks extend to support the training, education, and development of the **next scientific generations** – effectively using Army Science to help shape the future of the **National Security and economic base**

50
States

28
Countries

575
Institutes of Higher Learning
(CONUS and OCONUS)

as of 15 JULY 2021
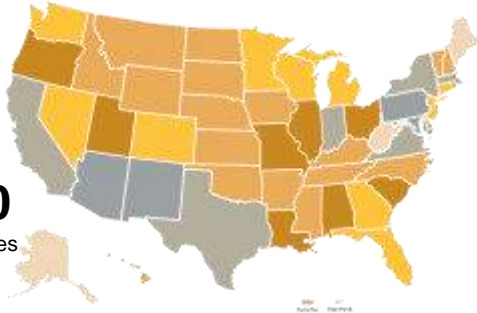
ARL EXTRAMURAL PROGRAMS OVERVIEW

Extramural Basic Research
Single Investigator, MURI, DURIP, PECASE

ARO FY21 Funding ($s)

575

Institutes of Higher Learning
(CONUS and OCONUS)

50 States

Total/cumulative award amounts for ARO-managed agreements active in FY21

- 0–$1M
- 0–$10M
- $10M–$25M
- $25–$50M
- $50M–$100M
- >$100M

28 Countries

Quantum Technology Center

Quantum research for applications in security, decision aids, sensing, and PNT

2

UWBG RF Electronics Center

"Diamond and beyond" UWBG RF electronics, semiconductor materials via first principles theory, experiment, physics-informed AI, and iterative device design methodology

9

Internet of Battlefield Things (IoBT)

Research in IoBT Phenomena Applicable to Tactical Environments

Distributed Collaborative Intelligent Systems and Technology (DCIST)

Extend Reach, Situational Awareness, and Operational Effectiveness of Intelligent System/Soldier Teams vs. Dynamic Threats in Complex & Contested Environment.

3

Advanced Energetics Center

Energetic materials for tailorable effects, specific impulse properties, and with higher energy density

7

Army Center for Synthetic Biology

Predictive design of engineered biological materials and biological control of cellular systems in competitive environments

5

Cyber Security

Cyber Science for Army Networks

Army Artificial Intelligence Innovation Institute (A2I2)

Accessible Data, Repository of AIML Algorithms & Software Tools, and Military-Relevant Challenge Problems for Autonomous Maneuver in MDO

3

A2I2

University Affiliated Research Centers

ICB
XSN
MIT

MIT UCSB — Soldier Survivability

Biotechnology

USC Institute for Creative Technologies

Caltech — Immersive Environments

Strengthening Teamwork for Robust Operations in Novel Groups (STRONG)

Enhance Strengths of Individual Humans and Agents to Optimize Team-level States and Processes

MHP

Select Cooperative Agreements

Advanced Materials and Wireless Networks — RICE

Novel Agile Development Processes — TEXAS A&M

Robotics & Robotics-Enabled/Technologies — TEXAS

Multi-Scale Materials

Materials in Extreme Dynamic Environments

Multi-Scale Multidisciplinary Modeling of Electronic Material

6

Centers of Excellence

UC RIVERSIDE — NC4RSA CoE

HOWARD UNIVERSITY — AI/ML CoE

Delaware State University — Quantum CoE

TUSKEGEE UNIVERSITY — Aerospace CoE

HAMPTON — STEM Edu. CoE

Spelman College — Minority Women in STEM CoE

ARMY PRIORITY RESEARCH AREAS (PRAS)

1 Hypersonic Flight	**2** Quantum	**3** Artificial Intelligence
4 Autonomy	**5** Synthetic Biology	
6 Material by Design	**7** Disruptive Energetics	**8** Science of Additive Manufacturing
9 RF Electronic Materials)	**MHP** Maximizing Human Potential	

How Prospective PIs
Can Engage with ARO

CRITICAL QUESTIONS TO CONSIDER WHEN PITCHING IDEAS

Is it basic research?

- What's the <u>scientific</u> question?
- What foundational knowledge is not currently available about the workings of the universe?
- Proposals focused on specific devices/components/technologies are beyond the scope of ARO's mission.

Is it hard?

- If an "old" question, why haven't we found an answer yet?
- If a "new" question, where's the sticky part?

Why you? Why now?

- What's been done before? Why wasn't it successful?
- What's novel about your skills/abilities/ approach that makes you think there's a shot at an answer?
- What new advance provides opportunity to make new progress?

So what? Who cares?

- What impact will the research make on the scientific community?
- What papers will be written because of your efforts? What papers will stop being written?
- What are the potential implications for the future of technology?

Where's the risk?

- How confident are you that you're asking the right question?
- How will you know when you have an answer? If you find a different answer, will you still learn something?

What will it take?

- What resources (time, money, infrastructure, personnel, partnerships) are required to pursue the research?

ARO PROGRAM: HOW TO ENGAGE

Your 'menu' of ideas	Whitepaper	Proposal

Your 'menu' of ideas

- Suggested initial ideas to share with PM: 3-4 ideas, 1-2 Paragraphs each, 2 pages max

- 2 ideas aligned with the program (see the BAA)

- 1 idea outside the program

- 1 idea characterized as half-baked, super high-risk, possibly "crazy"

- Submit directly to PM any time via email. Feedback is relatively fast.

- Do not ask "what research does ARO want me to do"
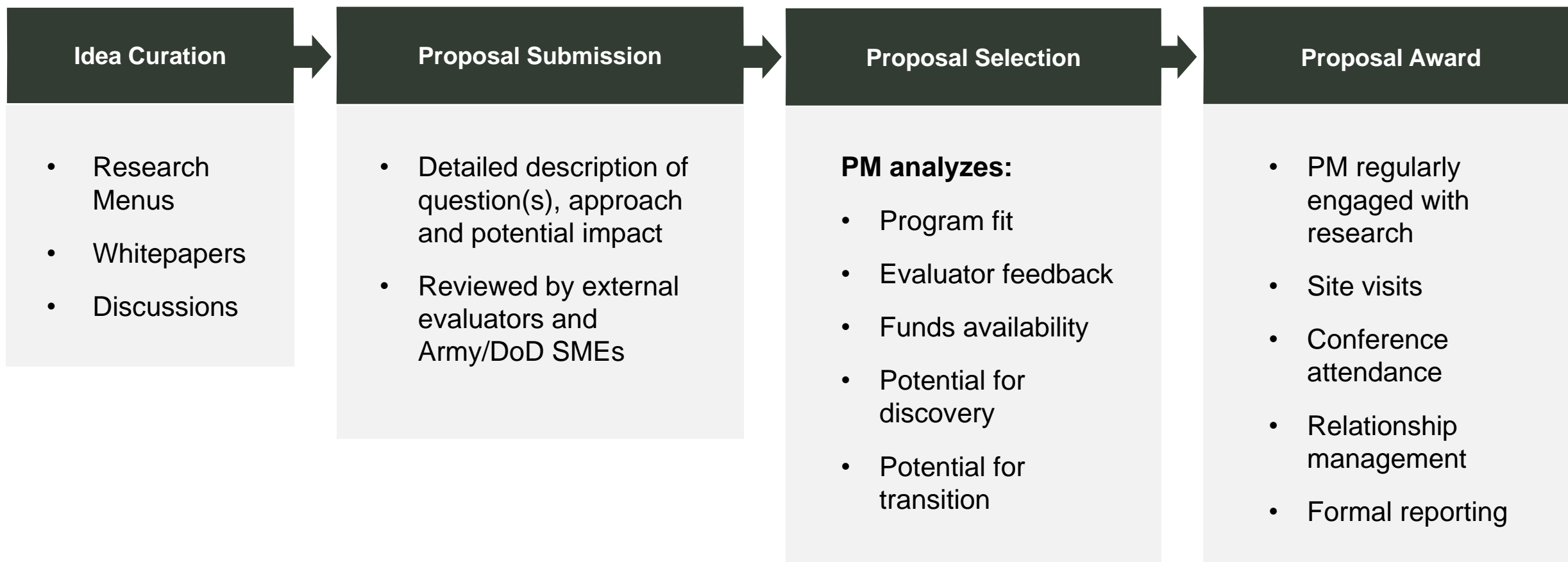
Whitepaper

- 5 pages max

- Provides a well-written scientific question and proposes a novel approach

- Describes the level of risk associated with the effort.

- Identifies the resources required to pursue the research (rough order of magnitude).

- Provides a short bibliography positioning the research in the body of knowledge.

- Submit any time via email.

Proposal

- Consult the ARO Core BAA for full details on requirements.

- Expands on the discussion in the whitepaper to adequately describe the proposed effort.

- Provides a reasonably self-contained description; expert reviewers should not have to heavily consult the literature or supplementary material to understand the question and the approach.

- Submit via grants.gov.

PROPOSAL PROCESS: FROM IDEA TO POST-AWARD

Idea Curation

- Research Menus
- Whitepapers
- Discussions

Proposal Submission

- Detailed description of question(s), approach and potential impact
- Reviewed by external evaluators and Army/DoD SMEs

Proposal Selection

PM analyzes:

- Program fit
- Evaluator feedback
- Funds availability
- Potential for discovery
- Potential for transition

Proposal Award

- PM regularly engaged with research
- Site visits
- Conference attendance
- Relationship management
- Formal reporting

ARL Outreach Programs

IMPORTANCE AND VALUE OF ACADEMIC RESEARCH TO THE ARMY

The scientific process is the foundation for **generating knowledge** of what is possible.

A **diversity of approaches** is key to discovery.

The Army's capacity for discovery and disruptive technology advances is expanded by **building a network**, not a pipeline.

Fundamental scientific knowledge opens new doors

- Army-Academic partnerships encourage use-inspired research otherwise unexplored.
- If I could tell you a new truth about the world, would it change the way you fight?
- If I had new understanding of how the world works, could I make it work in a new way?

Talent Development

- Students and research scientists become available to the Army.
- Annually, over 3,000 graduate students supported via CCDC partnerships. Over 45 Educational Partnerships Agreement are currently in place.

Expanded Research Capacity for the Army

- New advances emerge from building collaborative relationships with partners.
- The process of discovery and disruption is highly non-linear, iterative, and relational.
- In FY20, the Army was partnered with 256+ distinct academic partners to advance scientific knowledge via a diverse set of mechanisms.

DEVCOM-ARL PORTFOLIO OF OUTREACH PROGRAMS

ARL Programs

K-12 Local Outreach Program

Summer Researcher Program

Student Orientation; Summer Student Professional Development Series; Summer Student Week; Summer Student Symposium

ARL/USMA Technical Symposium

ROTC Summer Program

USMA AIAD Summer Program

ORAU Research Associateship Program (RAP)

National Research Council (NRC)

Educational Partnership Agreements (EPAs)

Army Educational Outreach Program

Undergraduate Apprenticeship Program

Undergraduate Research Apprenticeship Program

Graduate-Postdoctoral Fellowship

High School Apprenticeship Program

Gains in the Education of Mathematics & Science (GEMS)

Junior Sciences and Humanities Symposium (JSHS)

eCYBERMISSION

Army/Customer Programs

National Defense Science and Engineering Graduate (NDSEG) Fellowship

Science, Mathematics and Research for Transformation (SMART)

Pathways Internship Program

Pathways Recent Graduate Program

STEM Student Employment Program

Army Civilian Training, Education and Development Systems (ACTEDS)

HBCU/MI Design Competition

DoD Summer Internship Program

Centers of Excellence

Spelman AI/ML Initiative

DTRA Faculty Fellow Research Team Program

*Managed by ARO   *Managed by ARL

2021 ARL SUMMER PROGRAM OFFERINGS

High School Apprentice Program

Matches practicing DoD scientists with talented high school students creating a direct mentor-student relationship that provides students with training that is unparalleled at most high schools. The program fosters desire in its participants to pursue further training and careers in STEM. This program is open to students meeting all the following requirements:
- Enrolled in the 10th, 11th, or 12th grade
- 16 years old at time of apprenticeship
- U.S. Citizens or Permanent legal resident

Duration: The program is primarily designed for summer experiences; however work study and year round experiences are also available.

Resources: Students receive an educational stipend.

Application: https://www.usaeop.com

Application Deadline: February 28th

Summer Student Experience Program

Provides opportunities for select scientists, engineers and students (Bachelor degree through pre-PhD level) to engage in their choice of research problems that are compatible with or contribute to ARL research efforts. SSE is open to students meeting all the following requirements:
- Enrolled student or non-PhD recent graduates in Science, Technology, Engineering, or Mathematics (STEM) majors
- U.S. Citizens, Permanent Resident, and Foreign Nationals

Duration: May 10–Sept 24, 2021

Resources: ARL can offer a stipend, health insurance stipend supplement, relocation allowance and travel allowance.

Application:
https://orau.org/arlfellowship/applicants/how-to-apply-summer-student-experience.htm

Application Deadline: February 28th

Army/Customer Programs

The ROTC Program is a summer enrichment program for ROTC college students in STEM related disciplines.

The Internship programs are leader development initiatives and a catalyst to help develop, retain, and ultimately commission quality ROTC Cadets as Second Lieutenants. All Cadets participating in these programs are volunteers and should be treated as junior staff officers.

Duration: Program runs 28 days during July through August. Students work 40 hours a week.

Resources: ROTC students are eligible to receive cadet pay based on academic and military rank. Transportation and housing resources are provided by cadet command.

Interested cadets should apply through their Brigade.

Application Deadline: December 1st

2021 ARL SUMMER PROGRAM OFFERINGS

Undergraduate Apprenticeship Program

Matches practicing DoD scientists with talented undergraduate students creating a direct mentor-student relationship, providing participants with training that is unparalleled at most colleges. This program is open to students meeting all the following requirements:

- Enrolled undergraduate students or recent graduates (within past six months)
- Science, Technology, Engineering, or Mathematics (STEM) majors
- U.S. Citizens or Permanent Residents

Duration: The program is primarily designed for greater than six month work study-internships and are available year round.

Resources: Students receive an educational stipend.

Application: https://www.usaeop.com

Post-College/Faculty/Senior Programs

ARL Fellowship Program

Provides opportunities for select scientists, engineers and students (Bachelor degree through pre-PhD level) to engage in their choice of research problems that are compatible with or contribute to ARL research efforts.

ARL Fellowships are managed through two cooperative agreements:

ORAU: www.orau.org/arlfellowship

NRC: sites.nationalacademies.org/pga/rap

Duration: The program operates year round to provide the Directorates maximum flexibility and ranges from a number of weeks to a year. Renewal option is available for most Fellows up to a maximum of three years.

Resources: Depending on the type of Fellowship and the needs of a specific Fellow, ARL can offer a stipend, health insurance stipend supplement, relocation allowance and travel allowance.

Oakridge Associate Universities (ORAU)

Postdoctoral: less that 5 years post-PhD

Senior Fellow: More than 5 years post-PhD

Short Term Fellow: A Postdoc or Senior Fellow at ARL for up to 20 weeks

Journeyman Fellow: A non-PhD (BA/BS or working on graduate degree)

Summer Student Experience: A summer student or non-PhD post-graduate

National Research Council (NRC)

Postdoctoral Fellow: less that 5 years post-PhD

Senior Fellow: More than 5 years post-PhD

Short Term Fellow: A Postdoc or Senior Fellow at ARL for up to 20 weeks

Davies Fellow: Teaches at USMA and conducts research at ARL

ARL Distringuished Fellow: Currently being established

- Three year program managed by ARL Fellows
- Awardee selected by ARL Fellows
- Awardee will select their technical research problem