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

AI-enabled Multi-Domain Processing & Analytics for Decision Making

UDRC SSPD, 14-15 September 2021

SSPD Conference

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Army Research Laboratory

DISTRIBUTION STATEMENT A

TOPICS

Background

- ARL Mission and Research Competencies
- AI in Complex Multi-modal Environments

AI & ML Exemplars

Collaborations & Opportunities

THE ARMY'S CORPORATE RESEARCH LABORATORY

CCDC ARL MISSION: Operationalizing Science for Transformational Overmatch

Disruptive Foundational Research leading to U.S. Army modernization

Possess, create, and apply **leading niche and cross-cutting competencies**

Cultivate and optimize diverse talent in new areas for the modernized Army Team

Army's primary collaborative **link to the World-Wide Scientific Community**

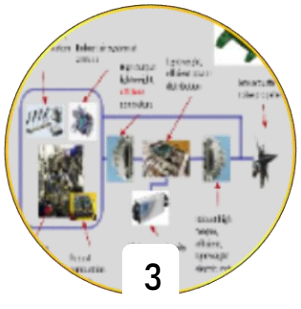
Shape Future Concepts and inform the future operating environment

***S&T in the Dirt:** *Bring research at the earliest possible stage (without waiting for maturity) into the most realistic environment possible, and collect relevant data.*

ARL RESEARCH COMPETENCIES

Biological and Biotechnology Sciences

Electromagnetic Spectrum Sciences



Energy Sciences

Humans in Complex Systems

Mechanical Sciences

Competencies ensure transformational overmatch for the Future Army

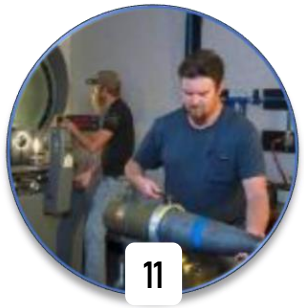
Military Information Sciences

Network, Cyber, and Computational Sciences

Photonics, Electronics, and Quantum Sciences

Sciences of Extreme Materials

Terminal Effects



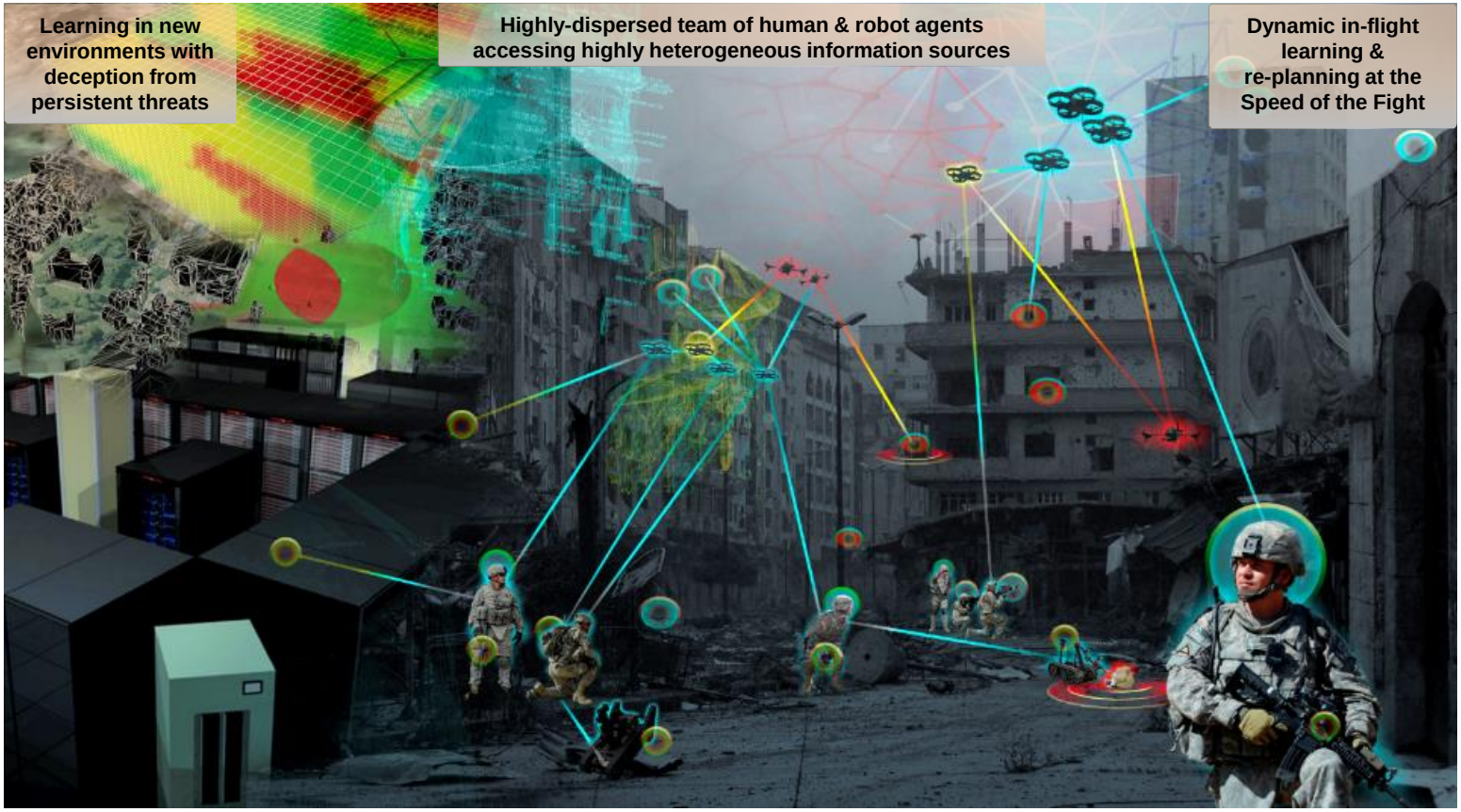
Weapons Sciences

Theory + Academic Outreach + Modeling + Experiment + Analysis

ARL has cross-cutting collaborative research programs to address **critical AI challenges** in **multi-modal analytics** and **IoT**, **networks** and **cyber security**, **autonomy** and **robotics**, and others

AI CHALLENGES IN COMPLEX ENVIRONMENT

Multi-Domain Operations (MDO) in Congested and Contested Environment



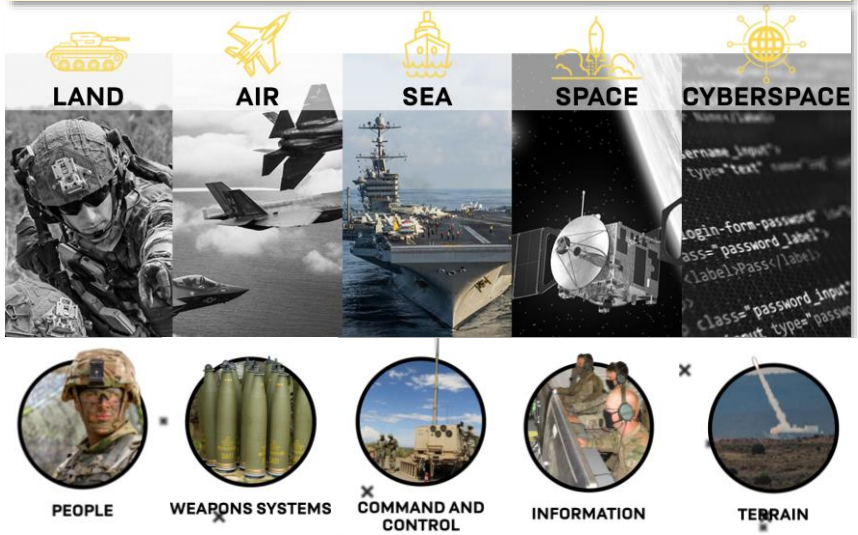
Technical Challenges

- **Learning in Complex Environment**
  - AI & ML with small samples, dirty data, high clutter
  - AI & ML with highly heterogeneous data
  - Adversarial AI & ML in contested, deceptive environment
- **Resource-constrained AI Processing at the Point-of-Need**
  - Distributed AI & ML with limited communications
  - AI & ML computing with extremely low size, weight, and power, time available (SWaPT)

MULTI-DOMAIN FORCE BY 2035

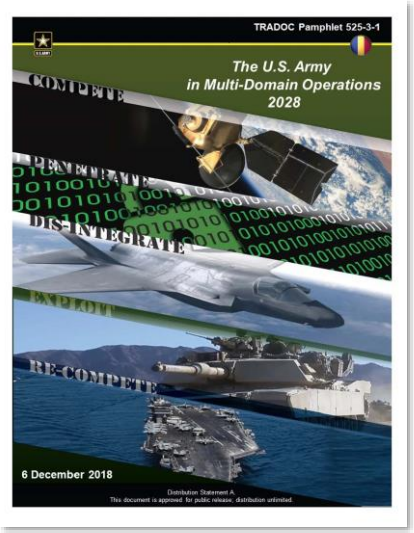
Project Convergence is a campaign of learning to aggressively pursue an **Artificial Intelligence and machine learning-enabled** battlefield management system.

Because whoever can see, understand, and act first will win.



Through the **Project Convergence framework**, we are demonstrating technologies … **Demonstrations will consist of *multi-domain operational* environments**, where the Army will demonstrate **artificial intelligence** and networked lethality technologies that augment human sensing and decision making in order to improve the warfighter's lethality and pace of battle.

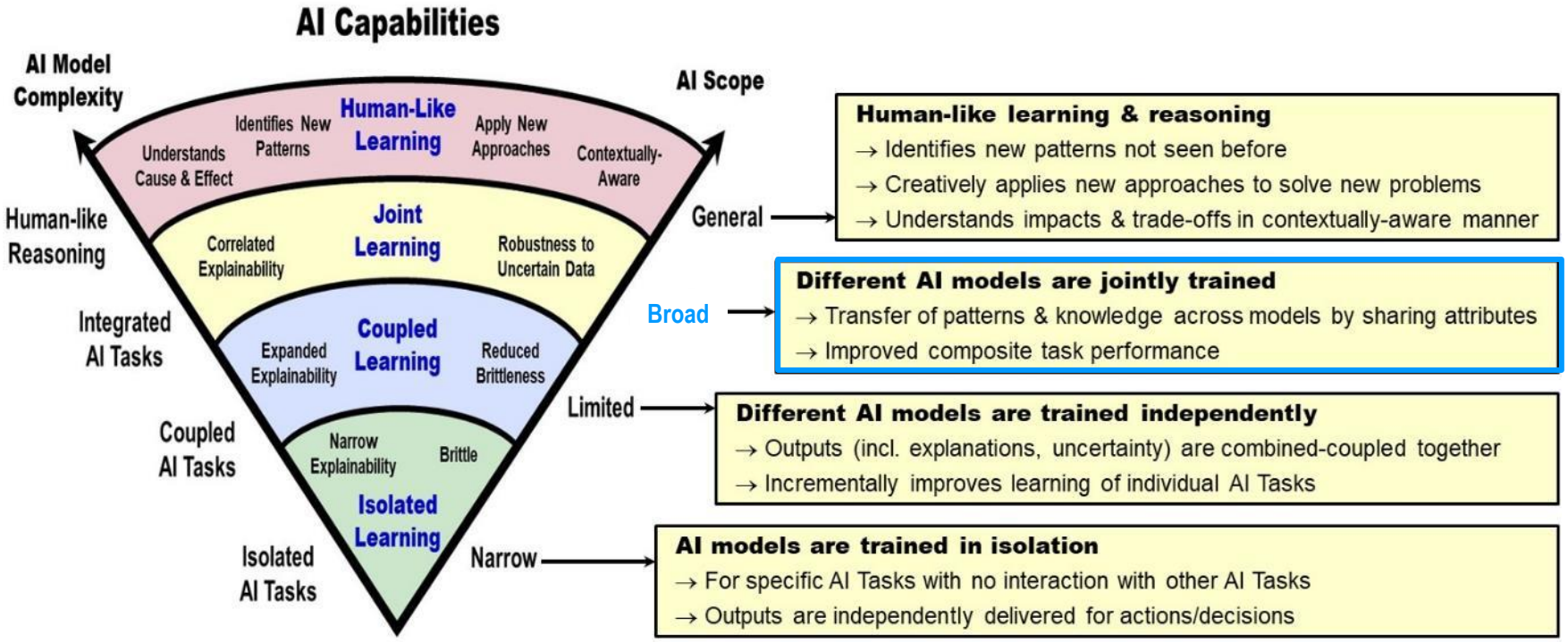
https://armyfuturescommand.com/convergence/



https://www.tradoc.army.mil/Portals/14/Documents/MDO/TP525-3-1_30Nov2018.pdf

https://www.nscai.gov/

AI CAPABILITIES FOR MDO



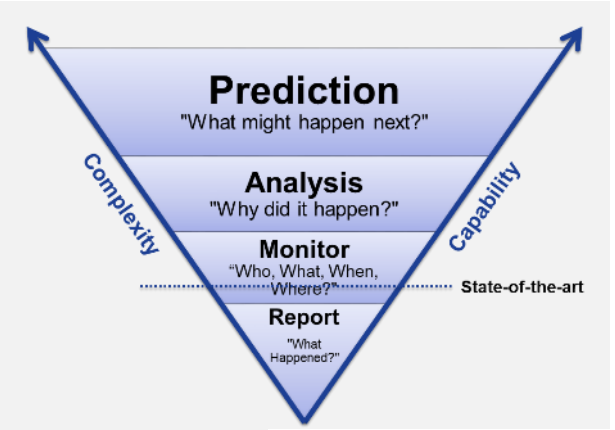
- **Resource-constrained AI** Operating in austere environments
- **Resilient AI** For operational adaptability to adapt to new situations
- **Robust AI** Dealing with complex, uncertain, dynamically-changing data
- **Adversarial AI** For obtaining resilience to adversarial manipulations
- **Distributed AI** To overcome computational & storage constraints
- **Federated AI** Collaborative training without training data exchange
- **Explainable AI** Human understanding of AI for trustworthy decisions
- **Causal AI** Understanding cause & effect in AI to achieve broad AI

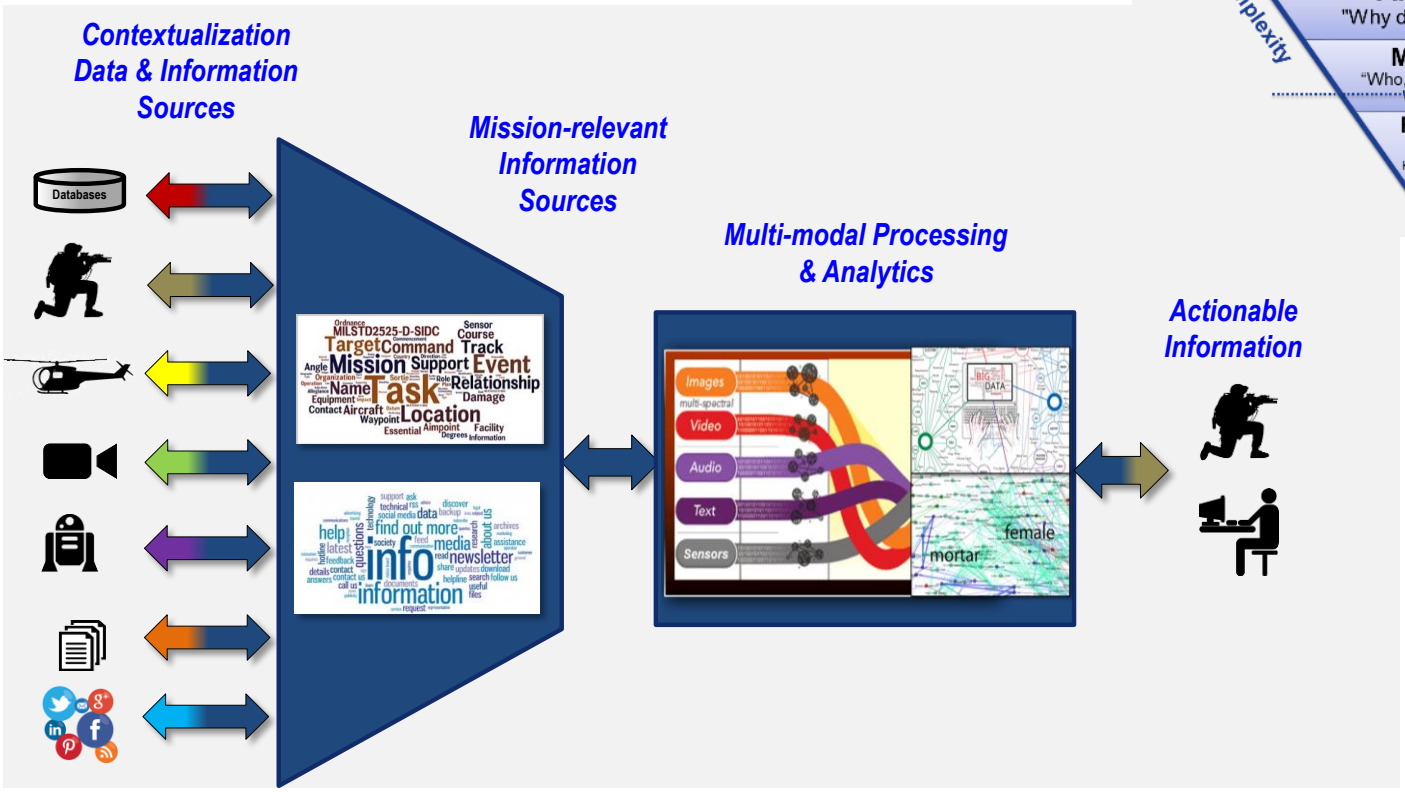
Key Publications: G. Cirincione and D. Verma, *Federated Machine Learning for Multi-Domain Operations at the Tactical Edge,* 2019 SPIE Conference on "Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications," Baltimore, MD, 15-17 Apr 2019.

AI TECHNOLOGY CHALLENGE

Develop AI-enabled multi-modal analytics capabilities for

- Multi-Domain situational understanding
- Real-time decision making toward the tactical edge





TOPICS

Background

AI & ML Exemplars

- Robust Inference and Machine Learning
- Human-Centered Machine Learning
- Neural Network Compression
- Information Extraction from Knowledge Networks
- Distributed Video Analytics

Collaborations & Opportunities

ROBUST INFERENCE & MACHINE LEARNING

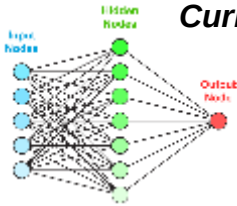
Enabling Robust AI

Outcomes:

- Machine learning that can characterize uncertainty in light of the similarity of the test sample with the sparse training data

Research Areas:

- Characterization and quantitative formulation of types of uncertainty
- Uncertainty-aware learning
- Isolating and explaining causes of uncertainty



Current ML approaches

High probability an army is attacking

Uncertainty is close to one with little belief of an attacking army

Uncertainty-aware ML approach

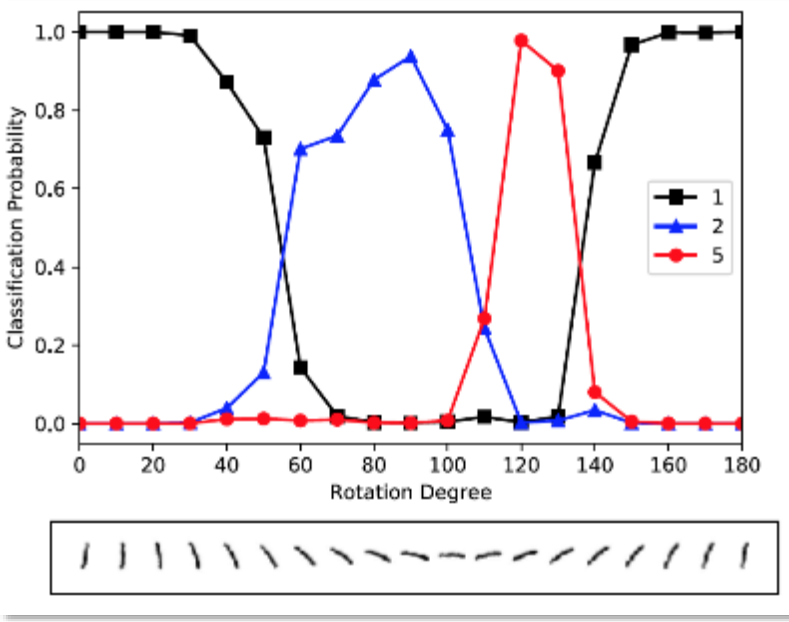
Payoff:

- Mitigate the risk of poor decisions due to unexpected events and/or observations
- Effective teaming with human agents through explanations of uncertainty

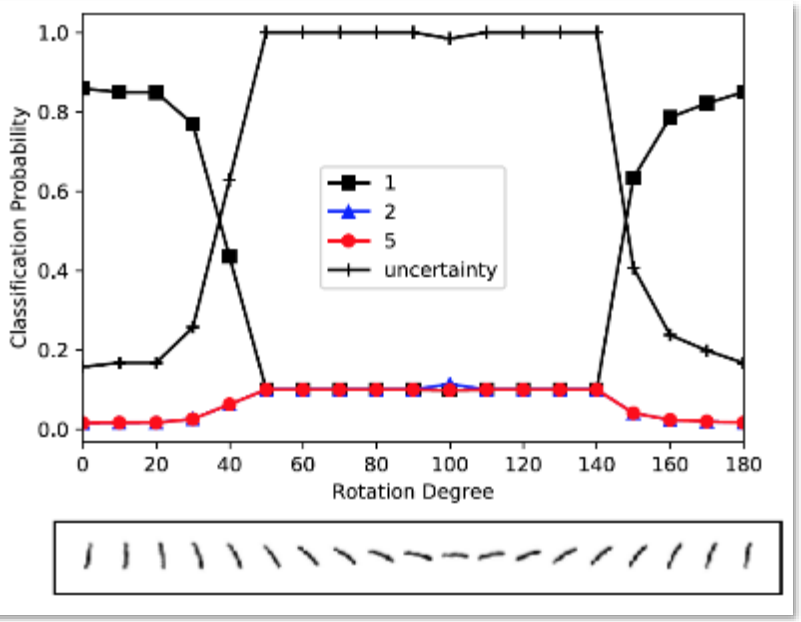
EX: EVIDENTIAL NEURAL NETWORKS

Innovation: Output layer of the NN is interpreted as Dirichlet parameters and trained using a loss function that balances prediction accuracy against accrual of conflicting evidence

Misclassifications via softmax



Evidential Neural Network



ML that recognizes its limits due to novel events or significant changes to the environment

Key Publications:

- M.Sensoy, M.Kandemir, L. Kaplan, *Evidential Deep Learning to Quantify Classification Uncertainty,* NIPS 2018
- Sensoy, M., Kaplan, L., Cerutti, F., & Saleki, M. (2020). Uncertainty-Aware Deep Classifiers Using Generative Models. Proceedings of the AAAI Conference on Artificial Intelligence, 34(04), 5620-5627.

HUMAN-CENTERED MACHINE LEARNING

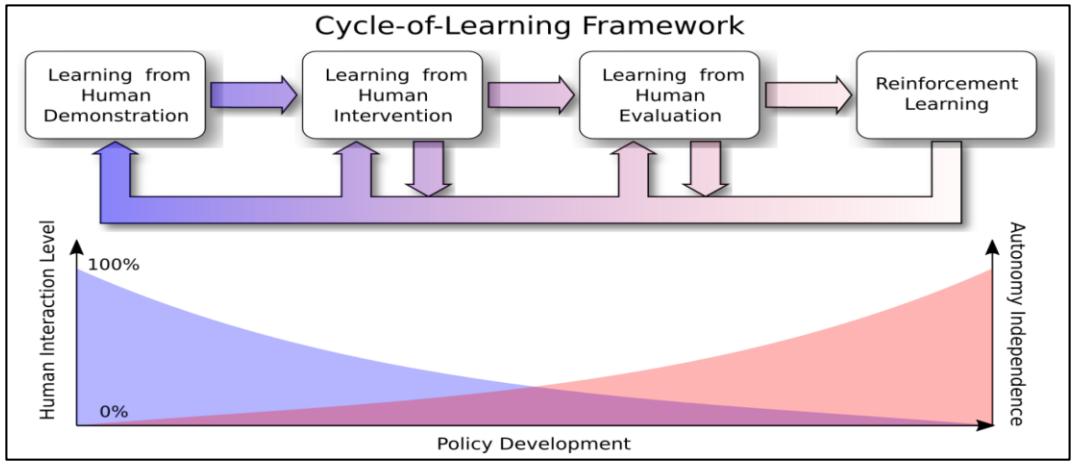
Enabling Resilient AI and Causal AI

Outcomes:

- Artificial autonomous systems that can be trained, modified, or repaired by Soldiers as opposed to system designers.

Research Areas:

- Learning from human **demonstration, intervention**, and **feedback**.
- **Integrating** multiple sources of human feedback.



Payoffs:

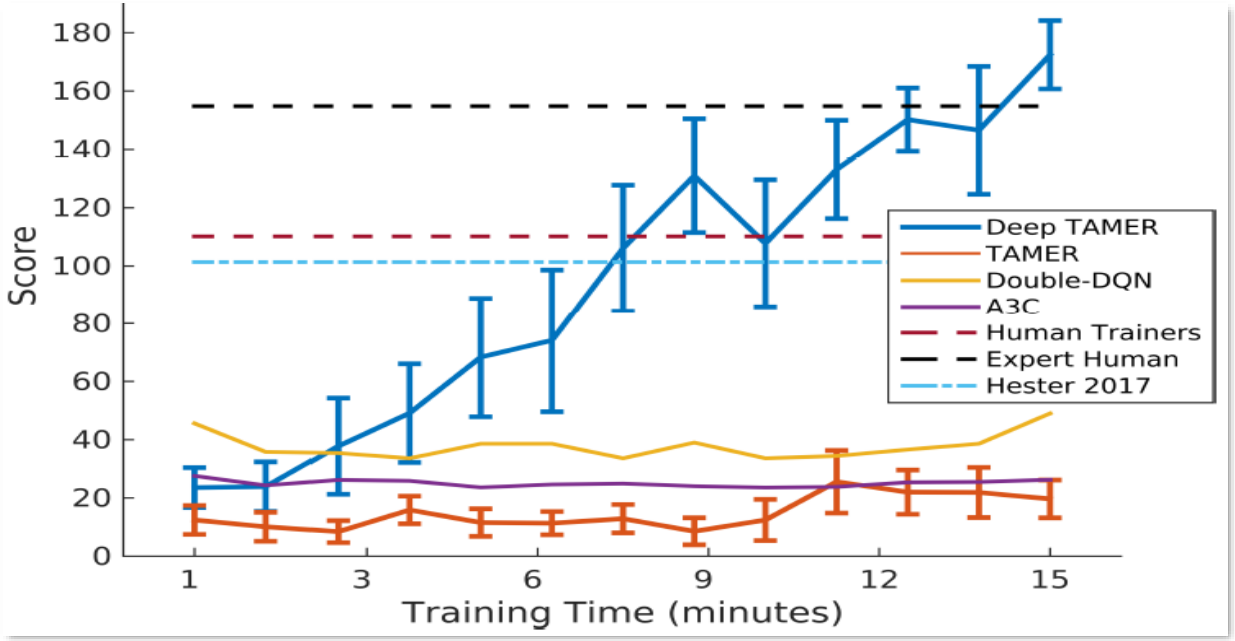
- **Fast**, **robust**, and possibly **superhuman** task learning.
- Training and adaption by **non-expert** users.
- Learning tasks that are otherwise **difficult or impossible to encode**.
- **Personalized** artificial systems which **may increase trust**.

E. Stump et al., *Discovery enabler concept of operations: Human-centered machine learning to enable autonomy,* (in preparation) DEVCOM Army Research Laboratory Technical Report. 2021.
N. Waytowich, **V. Goecks, V. Lawhern**. *Cycle of learning for autonomous systems from human interaction*, AAAI FSS. 2018.

EX: LEARNING FROM EVALUATIVE HUMAN FEEDBACK

Innovation: *Human-in-the-loop reinforcement learning* system to provide improve decision-making in *dynamically-changing environments*, where data availability and computational resources are limited

Reinforcement-learning AI solution using real-time human input to solve the unsolved Atari™ Bowling task



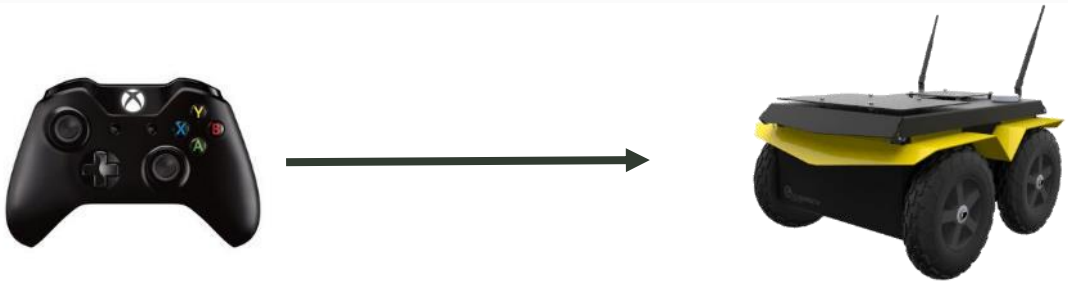
Reconceiving human-technology roles in the future Battlefield

Key Publications:

- Warnell et al. *Deep TAMER: Interactive Agent Shaping in High Dimensional State Spaces*, AAAI 2018
- F. Torabi et al. "Imitation learning from video by leveraging proprioception." International Joint Conference on Artificial Intelligence, 2019

EX: ADAPTIVE PLANNER PARAMETER LEARNING

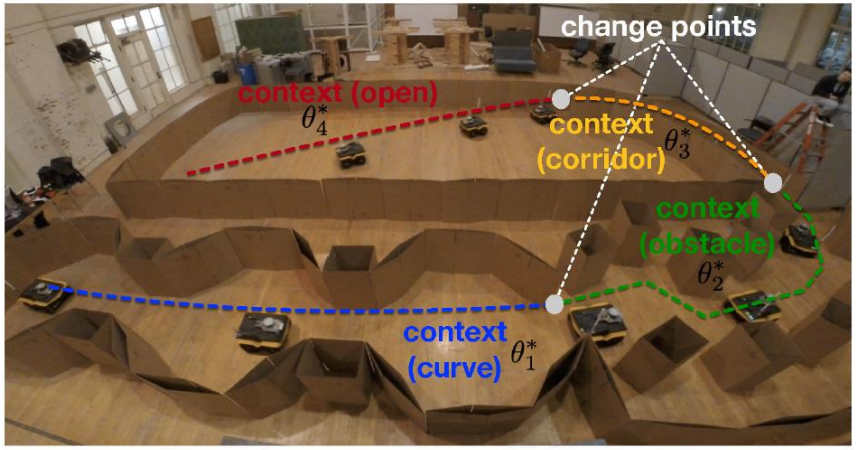
Innovation: *Human-centered machine learning* techniques for improving autonomous navigation across a spectrum of user interaction modalities .



Data from Human Interaction **More Robust Autonomous Navigation**

Supported Interaction Modalities:

- Full demonstrations (teleoperation)
- Spot interventions (teleoperation)
- Feedback only (button presses)



Example research environment: Constrained spaces such as these are relatively easy for human operators to navigate, but surprisingly challenging for autonomous systems. Our APPL algorithms allow operators to “fix” the autonomous navigation system through simple system interactions.

Key Publications:

X. Xiao, B. Liu, **G. Warnell**, **J. Fink**, P. Stone. *APPLD: Adaptive planner parameter learning from demonstration*, IEEE RA-L. July 2020.
Z. Wang, X. Xiao, B. Liu, **G. Warnell**, P. Stone. *APPLI: Adaptive planner parameter learning from interventions,* ICRA 2021.
Z. Xu, G. Dhamankar, A. Nair, X. Xiao, **G. Warnell**, B. Liu, Z. Wang, P. Stone. *APPLR: Adaptive planner parameter learning from reinforcement,* ICRA 2021.
Z. Wang, X. Xiao, **G. Warnell**, P. Stone. *APPLE: Adaptive planner parameter learning from evaluative feedback,* IROS 2021.

NEURAL NETWORK COMPRESSION

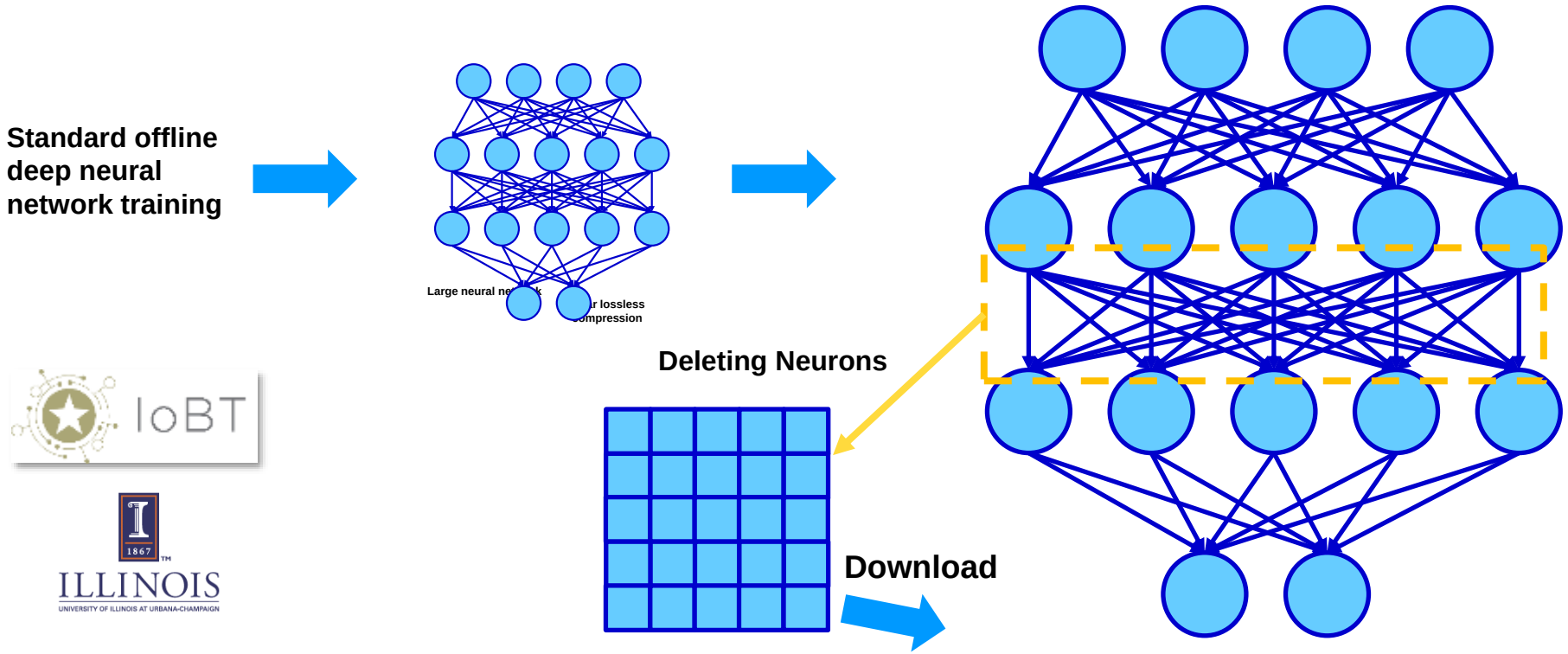
Enabling Resource-Constrained AI

Outcomes:

- Algorithms for compressing large trained neural networks to fit within resource-constrained sensor-side/field devices (without losing inference accuracy)

Research Areas:

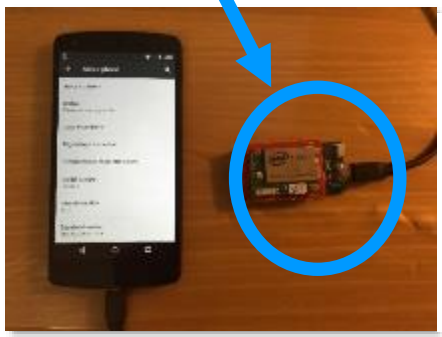
- **Deep learning** for **resource-constrained (IoBT) environments**
- Analysis of **compressibility** of deep neural networks
- **Robustness/performance trade-offs** in neural network compression



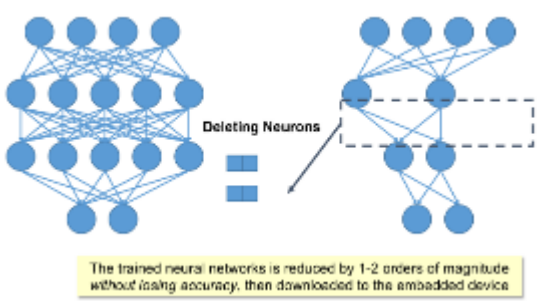
EX. : IMAGE RECOGNITION WITH DEVICE-SIDE COMPRESSED NN

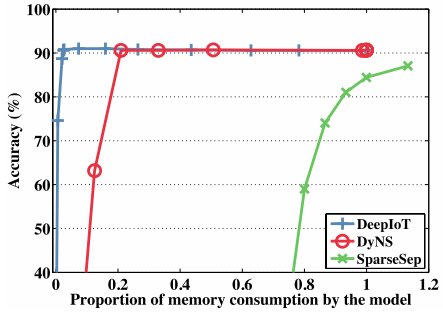
Innovation: Developed *novel NN compression techniques* that reduce the original trained NN size by *up to two orders of magnitude* with no degradation in inference accuracy.

Low-end embedded processor



Compression of a Deep Neural Network for Image Recognition (VGGNet)





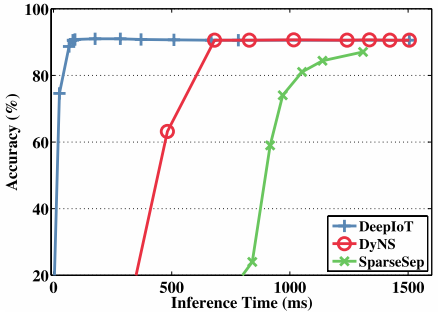


Figure shows one-to-two orders of magnitude reduction in inference time, inference energy, and memory footprint of deep neural network inference (after compression with the new *DeepIoT* framework) without loss of image recognition accuracy, outperforming the state of the art (measured on an Intel Edison embedded processor)

Potential: *Intelligent edge-device services* for situation understanding in complex high-tempo battlefield environments

Key Publications:

- Yao et al (2018). *"Deep Learning for the Internet of Things,"* IEEE Computer, Vol. 51, No. 5, May 2018.
- Yao et al (2018b). *"FastDeepIoT: Towards Understanding and Optimizing Neural Network Execution Time on Mobile and Embedded Devices,"* In Proc. 16th ACM Conference on Embedded Networked Sensor Systems (SenSys), Shenzhen, China, November 2018
- Yao et al (2018c*). "ApDeepSense: Deep Learning Uncertainty Estimation Without the Pain for IoT Applications,"* In Proc. IEEE International Conference on Distributed Computing Systems (ICDCS), Vienna, Austria, July 2018.

INFORMATION EXTRACTION FOR KNOWLEDGE NETWORK CONSTRUCTION

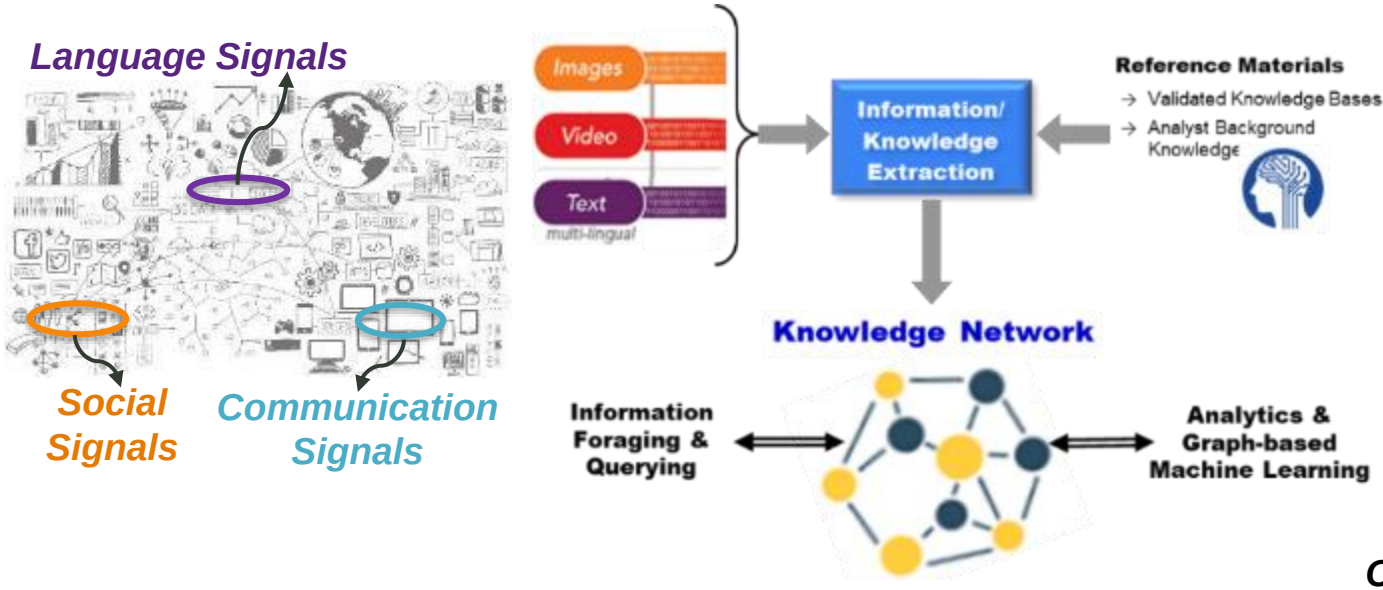
Enabling Multi-Modal AI and Distributed AI

Outcomes:

- Transforming unstructured data across multiple domains and modalities into common representation

Research Areas:

- Computational linguistic methods for high to low-resource domain adaptation
- Knowledge representations for complex events
- Semantics for semi-structured document analytics



For Relevant Shared Understanding

in support of Common Operating Picture

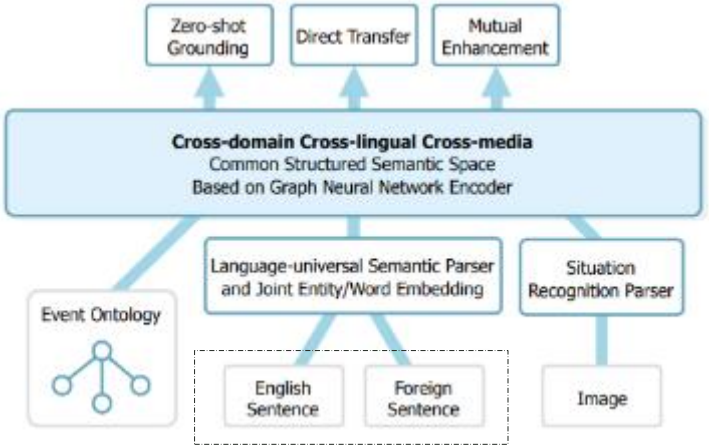
Payoff:

- Identify redundant information to mitigate against ever increasing data variety, velocity, volume
- Leverage recent advances in distributional semantics to extract & share information across modalities

EX: COMMON SEMANTIC SPACE FOR TRANSFER LEARNING

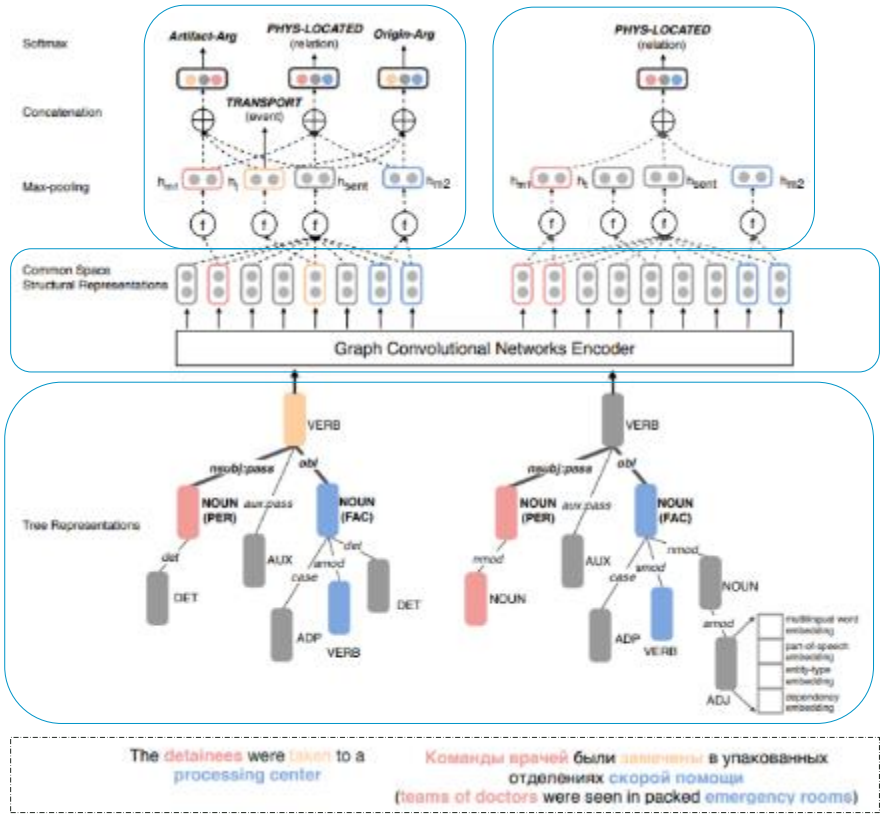
Innovation: Encoding multilingual text via *Graph Convolutional Networks* creates common semantic space where semantic structures from high-resource languages will transfer to low-resource languages

Share-and-Transfer Approach



This framework enhances the portability of event extraction across high-to-low settings, for example, across domains, languages (diagram at right), and modalities.

- The ***Share*** step constructs *Common Structured Semantic Space* (blue) with data from high-resource setting, combining symbolic and distributional representations of extracted event information.
- The ***Transfer*** step applies event extractors, pre-trained in common space, to target data from low-resource setting.



Multilingual common semantic space and cross-lingual structure transfer

Key Publication:

H. Ji and C. Voss. (Forthcoming) "Low-resource Event Extraction via Share-and-Transfer and Remaining Challenges:", *Computational Analysis of Storylines: Making Sense of Events*, Cambridge University Press.

DISTRIBUTED VIDEO ANALYTICS AT THE TACTICAL EDGE

Enabling Distributed AI

Outcomes:

- Machine Learning that can detect complex activities occurring in complex information environments at the tactical edge

Research Areas:

- Automated techniques for detection of complex actions on single sensor views
- Distributed algorithms for scheduling of video analytics between edge devices
- Transfer learning and validation of ML on various military relevant and operational datasets

Techniques to process information generated at the tactical edge

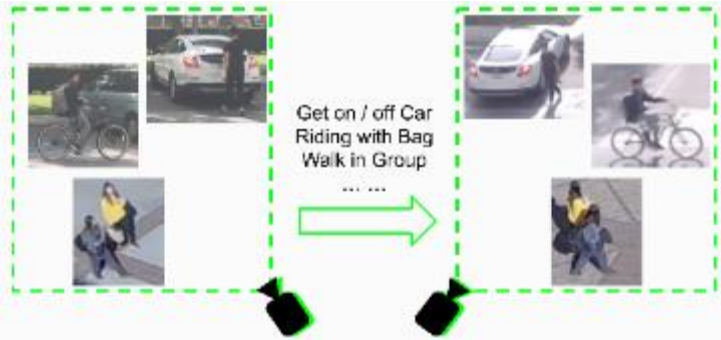
Identification of complex interactions of objects

Payoff:

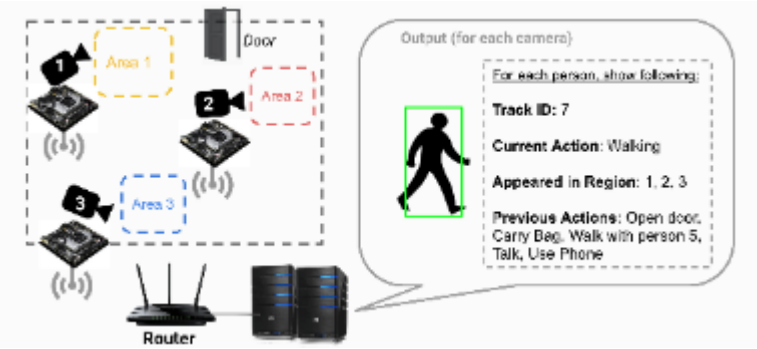
- Demonstration of complex activity detection algorithms deployed on tactical edge platforms
- Initial success on transfer learning between models (open source imagery → operational FMV; traffic camera → tactical UAV) tested on operational data using A2I2 infrastructure

EX: COMPLEX ACTIVITY DETECTION

Innovation: *Hybrid detection approach* using machine learning and rule sets, and efficient, near real-time execution on edge devices

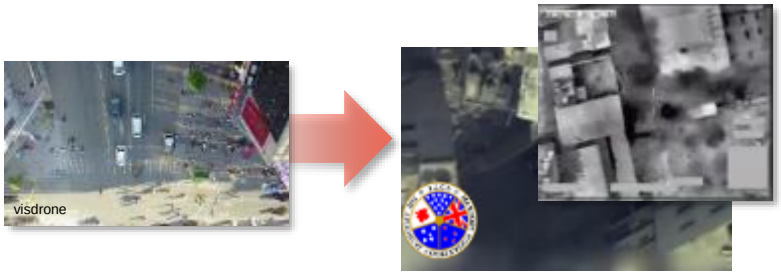


Capability that detects complex activities (objects and actions) of objects occurring over multiple non-overlapping scenes



Achieves ~15fps on edge platforms efficiently detecting over multiple devices and sensors

Validation of algorithms on open-source to operational data



Potential: Object and activity detection with increasingly semantic complexity that can be executed on distributed, tactical edge platforms for situation understanding in complex battlefield environments

Key Publications:

- Z. Lu, K. Chan, et al , “NetVision: On-demand Video Processing in Wireless Networks,” IEEE/ACM Trans. on Networking, 28(1), Feb 2020.
- X. Liu, et al, "Caesar: Cross-camera Complex Activity Recognition," Sensys'19, Nov 2019.

https://dais-ita.org/pub

TOPICS

Background

AI & ML Exemplars

Collaborations & Opportunities

- Bilateral Collaboration
- A2I2 & DVPG
- XTechSearch
- AI & ML for MDO Conference
- …

BILATERAL RESEARCH COLLABORATION

SIGNetS - *signal and information gathering for networked surveillance* - is jointly funded by US DoD & UK MoD under **Signal & Information Processing for Decentralized ISR** theme

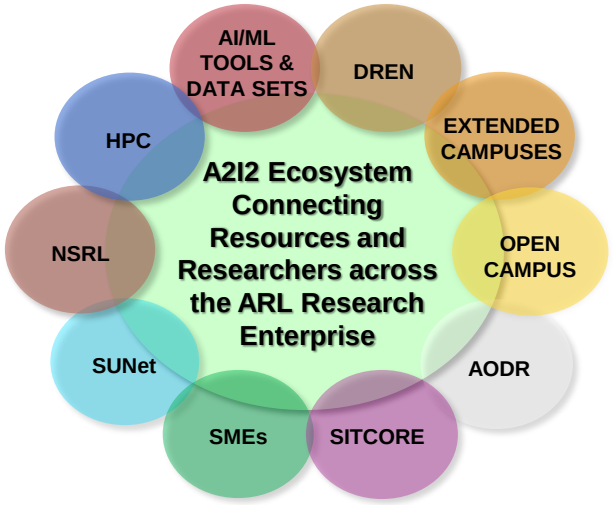
- WP1: **Uncertainty Quantification and Sensor Data Fusion** (Lead: Sheffield)
- WP2: **Learning & Intent Prediction in Scalable Networks** (Lead: Cambridge)
- WP3: **Autonomous Sensor Management & Communications** (Lead: Surrey)

SIGNetS

3-year joint US-UK research project

COLLABORATIONS VIA A2I2 & DVPG

Army AI Innovation Institute (A2I2)



Serve as focal point for Army AI & ML research

- Facilitate multi-disciplinary collaborative research with academia, industry and other government organizations
- Coordinate and sponsor joint experiments and demonstrations and share state-of-the-art results and lessons learned
- Transition new, advanced, robust AI & ML algorithms

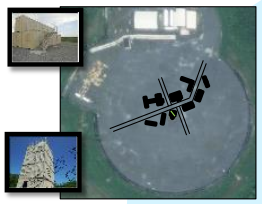
Access to:

- Relevant datasets from ARL, DoD, TTCP/NATO, Software tools, unclassified and classified data and computing resources
- Challenge problems and field experiment

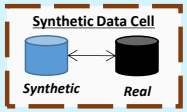
Distributed Virtual Proving Ground (DVPG)

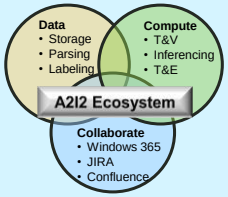
Federation of experimental testbeds with the capabilities to enabled simultaneous, virtualized experimentation by ARL and research collaborators

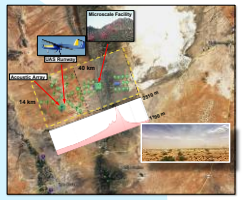
- DVPG boundaries are not limited to physical locations, systems, or assets, but rather is defined by interfaces, standards, and processes
- DVPG provides an adaptable architecture to enable ready-access to testbeds, data, and expertise across domains



Robotics Research Collaboration Campus (R2C2) at Graces Quarters, MD





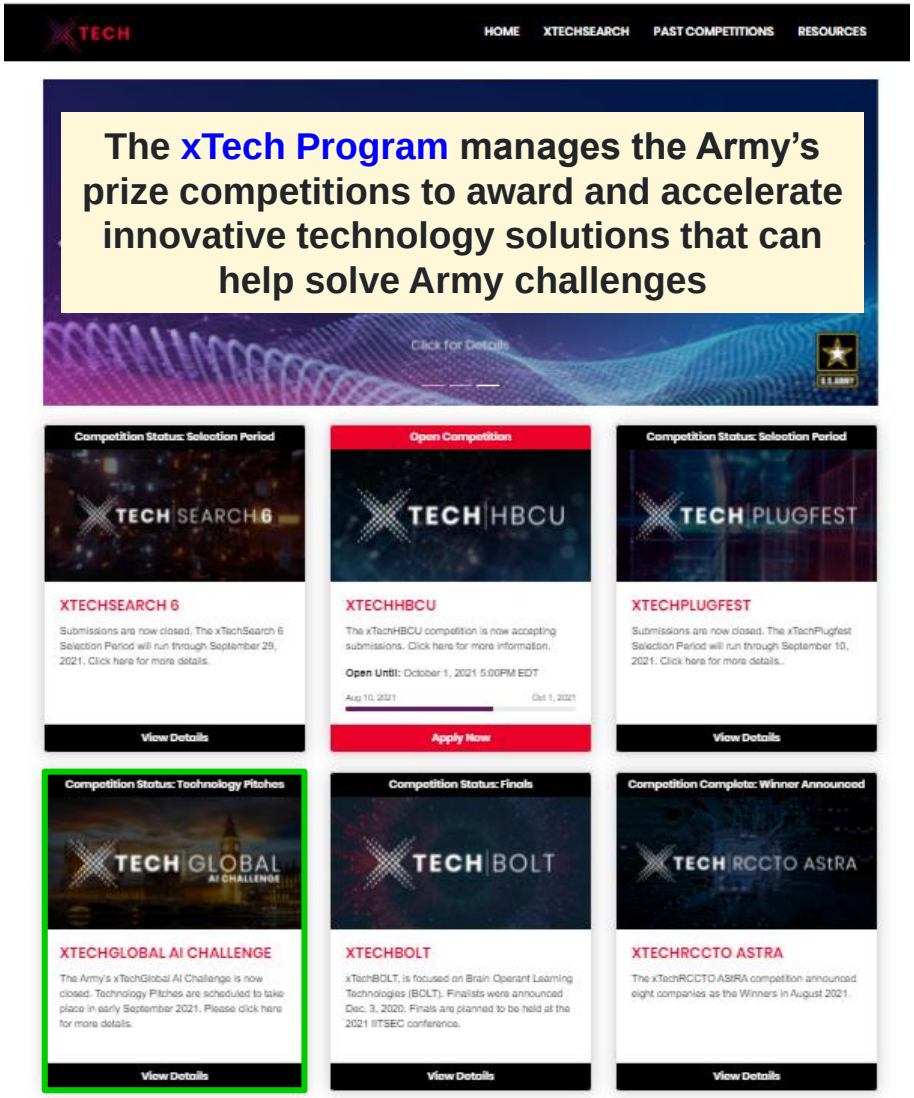


Multi-Purpose Sensing Area (MSA) White Sands, NM

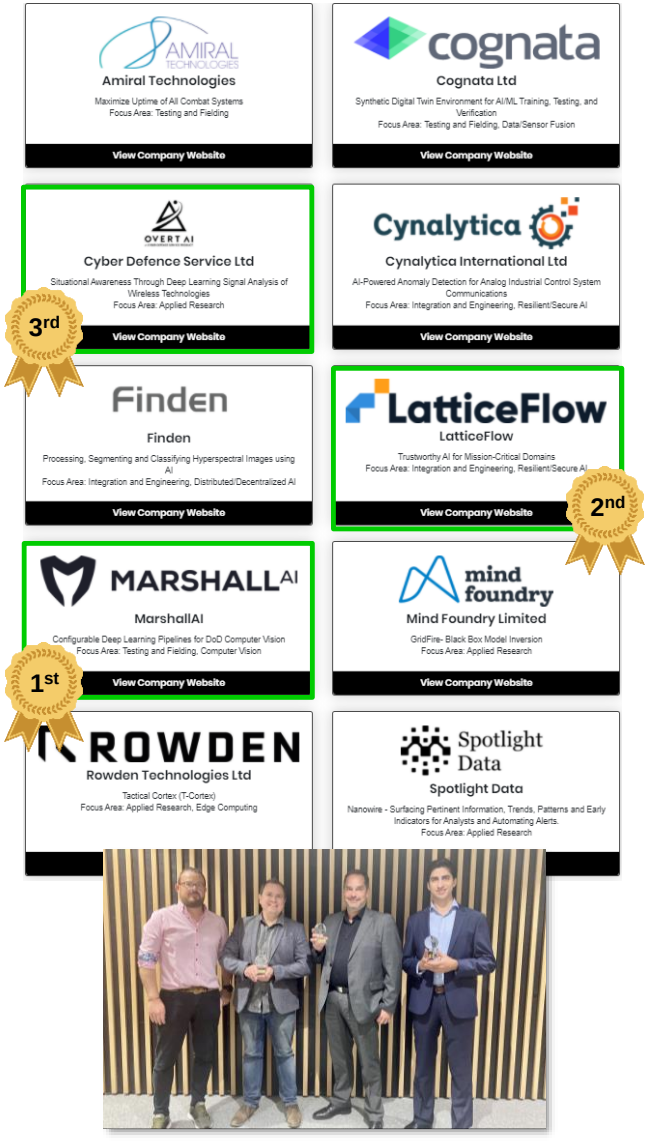
RELLIS Research Facility College Station, TX

University System of Maryland

ARMY XTECH PROGRAM

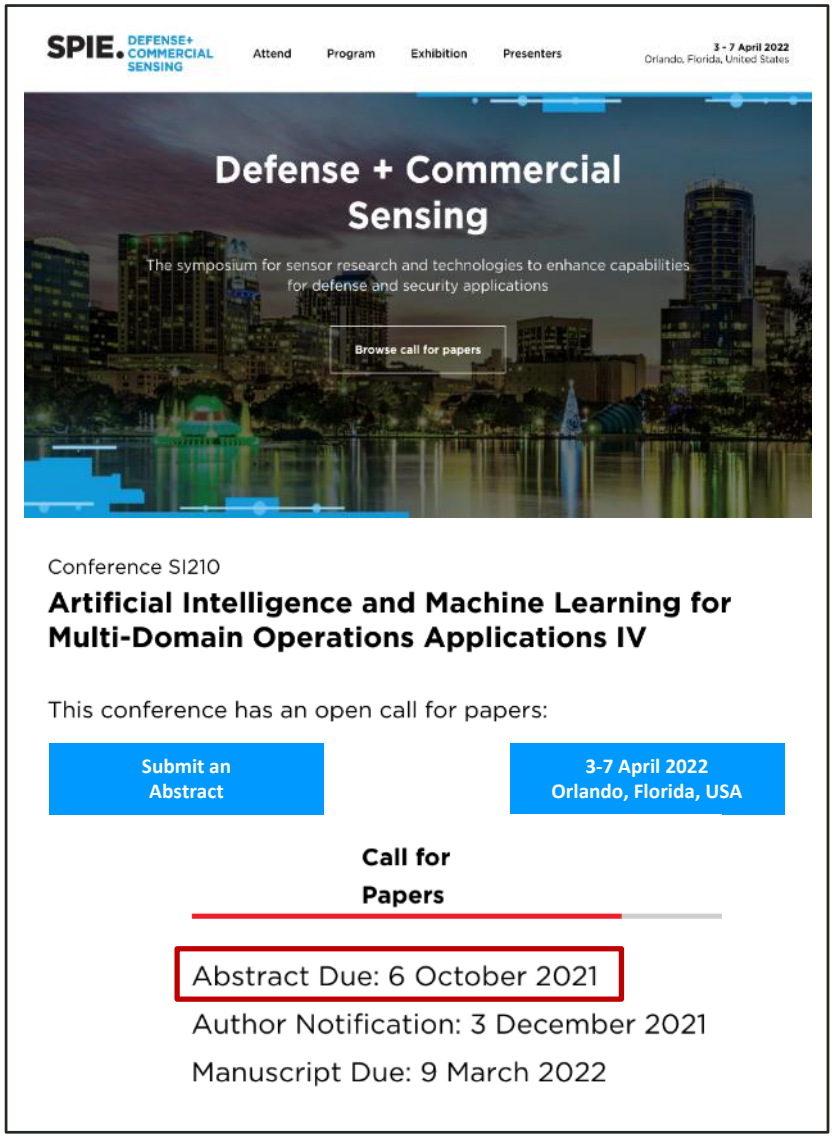


https://www.arl.army.mil/xtechsearch/index.html



XTechGlobal – AI Challenge Pitch Event: I-HUB, London, UK, 9-10 Sep 2021

AI & ML FOR MDO APPLICATIONS CONFERENCE



Goals: (i) To promote understanding of near-term and far-term implications of AI & ML for MDO and (ii) to gain awareness of R&D activities in AI & ML that are applicable to MDO.

Topics include but are not limited to the following:

- Learning and reasoning with small data samples, dirty data, high clutter, and deception
- Autonomous maneuver in complex environments
- Federated/distributed AI & ML
- Human agent teaming
- AI-enable context-aware decision making
- Resource-constrained AI processing at the point-of-need
- Adversarial machine learning
- Interpretable and explainable AI
- Novel AI & ML algorithms, frameworks and applications
- Modeling & Simulation Platforms for AI
- Safety, ethics and governance
- Future trends in AI to including 5G and AI, EW and AI, broad AI, quantum AI, AI with additive manufacturing, AI with synthetic biology…

https://spie.org/SI22/conferencedetails/artificial-intelligence-and-machine-learning-for-multi-domain-battle-applications?enableBackToBrowse=true

THANK YOU

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