Internet of Battlefield Things

COLLABORATIVE RESEARCH ALLIANCE

IoBT REIGN

U.S.ARMY

DEVCOM ARMY RESEARCH LABORATORY

IoBT CRA RMB

Way Ahead

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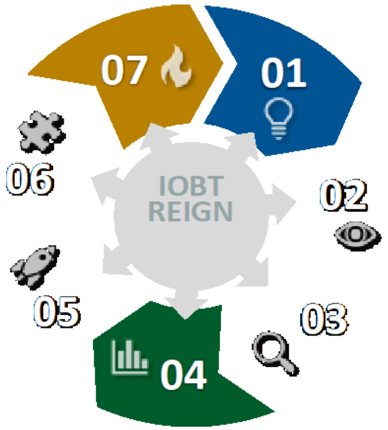
March 18, 2022

ILLINOIS | USC University of Southern California | UCLA | UMass Amherst | Carnegie Mellon University | Georgetown University | SRI International | Stanford University | The University of Texas at Austin

CURRENT IOBT CRA THRUSTS

Towards Efficient and Resilient Tactical Edge Analytics for the Sensing-to-Decision (MDO Effect) Loop



Research Areas (Year 1-3)

Agile Synthesis of Large-Scale IoBTs

Reflexes for Self-aware IoBTs

Intelligent Battlefield Services

Sharpen Multi-disciplinary Collaboration

Thematic Thrusts
Aligned with Value Proposition and Application
(Year 4-5)

Edge Efficiency (Time is a Weapon)

Enable efficient, real-time synthesis, communication, and data processing in large-scale, dynamic networks

Resiliency (of Decision Loop Analytics)

Offer strong assurances of correctness in the face of adversarial disruption

Tailored Intelligence (at the Point of Need)

Tailor multimodal services for the distributed tactical edge

1. Assess & Detect
2. Identify
3. Locate & Track
4. Aggregate & Synthesis
5. Distribute
6. Decide
7. Effect / Actuate

Developed in Collaboration with FCC. (Maj Adam Taliaferro)

Tarek Abdelzaher (UIUC), Adam Taliaferro (FCC), Paul Sullivan (ARL), Stephen Russell (ARL), "**The Multi-domain Effects Loop: From Future Concepts to Research Challenges**," In Proc. SPIE Defense + Commercial Sensing, April 2020.

MOVING THE NEEDLE

DEVCOM ARMY RESEARCH LABORATORY

	Prior to IoBT CRA (2017)	With IoBT CRA (Today)
Edge Efficiency	New more accurate but **heavyweight machine analytics** • *Edge performance limitations* running (neural-network-based) inference on embedded hardware • Network *synthesis is slow* and limited in problem space	**Efficient edge** (faster sensing-to-effect loop) • *Theory of rapid network synthesis* for rich, expressive classes of problems with optimality guarantees; *highly scalable* • *10x-100x more efficient edge-AI* for the sensor-to-effect pipeline; *new compression bounds* for neural models • *Quickest change detection*
Resiliency (of Decision Loop Analytics)	**Data attacks on machine analytics**. "Cat and Mouse" game between attacks and defenses • Neural network *vulnerabilities* • Sensor attack *detection too slow* for a real-time implementation; not always possible in a decentralized manner • Off-policy *confidence in mean behavior only*	Foundations of **tactical resiliency** and risk prediction • Accuracy *correctly predicted even for adversarial inputs* • Sensor attack *detection 10x faster*. New decentralized algorithms for different network topologies • Confidence intervals for risk relevant statistics (tail of distribution) to *bound worst-case outcomes* in off-policy evaluation
Tailored Intelligence at the Point of Need	**Stovepiped intelligent application pipelines** (e.g., Amazon Echo, Autonomous cars, etc) • Stovepiped processing pipelines and growing diversity of hardware • Machine learning inference on relatively *resource-rich computing* • *Limited AI uncertainty* models for the edge	Tailored services for **the distributed edge** • Distributed *heterogeneous sensing and computing*; adapts to wireless and resource dynamics • Multimodal sensing and *opportunistic exploitation* (e.g., use of *radios as sensors*) • Theory for *quantifying uncertainty* in deep learning

FOCUSED EXCURSION
Operational Hypotheses and Takeaways

Operational Hypotheses

IoBT will help commanders distill prioritized information from vast amounts of data faster for decision making by providing efficient, real-time processing

IoBT capabilities that provide robustness, resiliency, and adaptive services in the face of adversarial disruption and deception in conjunction with camouflaged sensing and communication, are essential to maintain commander confidence in data and reduce risk

IoBT will increase situation awareness tempo by exploiting ubiquitous,- multimodal sensors, unconventional sensing, and edge computation in the operating environment

IoBT, with rigorous testing and training, will enable trust despite a contested and dynamic environment by providing performance guarantees, uncertainty quantification and the ability to explain

Key Takeaways

Potential High Impact Research Priorities:

- **Efficiency at scale** in the presence of vast amounts of data
  - Semantic compression; processing at the edge
  - Prioritization and filtering of data push
  - Optimal network usage and network inference
- **Reconfigurable and adaptable algorithms** to induce **flexibility** (flexibility empowers creative alternatives)
  - Dynamic tuning to changing priorities/objectives
  - Resilience, safety, and risk mitigation (a distribution-tail challenge)
  - Fast optimization
- Information verification by exploitation of **multi-modal and multi-vantage sensing** for joint inference
  - Hybrid analytics – ML and rule-based; multiple time-scales
- **Uncertainty quantification** of network or analytics composition (in the presence of open/commercial sources)

WAY AHEAD

Phase I

Edge Efficiency

Resiliency
(of Decision Loop Analytics)

Tailored Intelligence at the Point of Need

Guidance: Focused Excursion (DEVCOM + FCC + IoBT Research SMEs)

Operational Gaps/Concepts

Technical Opportunities

Scale

Dynamics

Coordination

Phase II

Efficiently managing (spatial and temporal) scale

- *Optimal network usage/sharing*
- *Prioritization and filtering to meet CCIRs*
- *Efficient uncertainty quantification*

Reconfigurable and adaptable systems to induce flexibility (perpetually-transient systems)

- *Processing, communication, and synthesis strategies to adopt to evolving objectives*
- *Foundations of resiliency, safety, risk analysis*
- *Fast multi-objective optimization*

Tactical coordination (for the heterogeneous, multimodal edge)

- *Flexible heterogeneous multi-vantage sensing*
- *Multi-modal confirmation/verification*
- *Distributed hybrid ML at multiple timescales*

FUTURE ROADMAP: THE SCALE GAP
EFFICIENTLY MANAGING SCALE OF THE IOBT

Capability: Efficient management and control of large-scale data-rich IoBT systems to support ubiquitous sensing, processing, communication, and prioritization

Gap: Cannot offer long-lasting large-scale distributed edge AI capabilities on resource-limited devices (can't last whole mission)

Approach: Hyper-efficiency (an additional 10x-100x reduction in resource consumption) via a combination of innovations

- ***Prioritize early:*** Enhance prioritization and semantic compression of information from vast amounts of sensor data; Push mission-based filtering and prioritization closer to the sensor
- ***Break functional barriers:*** Optimal network usage and sharing of computational resources; A unified framework for joint sensing and communication
- ***Uncertainty quantification:*** Extend confidence estimation to multi-modal/multi-vantage resources and the presence of mostly non-sympathetic (e.g., commercial or open) sources

FUTURE ROADMAP: THE DYNAMICS GAP

RECONFIGURABLE AND ADAPTABLE SYSTEMS TO INDUCE FLEXIBILITY

Capability: **Enhanced resiliency & speed of operations in complex highly dynamic adversarial (DDIL) environment**

Gap: **Lack of theoretical understanding of resiliency, risk mitigation and optimization in persistently transient systems**

Approach: New theoretical foundations for optimization, resilience, and risk analysis in persistently transient distributed systems, with a focus on the tactical edge

- Understanding tunable system parameters; dynamic network synthesis, processing and communication strategies in the presence of fast dynamics and *adapting to different and quickly evolving objectives*
- Foundations of resiliency, safety, risk-analysis and optimization in persistently transient (ultra fast-changing) systems
- Fast mixed (discrete-continuous) distributed optimization across latency, energy and accuracy, computing, sensing and communication devices and placements at scale

FUTURE ROADMAP: THE COORDINATION GAP

TACTICAL EDGE COORDINATION

Capability: Increased situational awareness & information validation to improve confidence

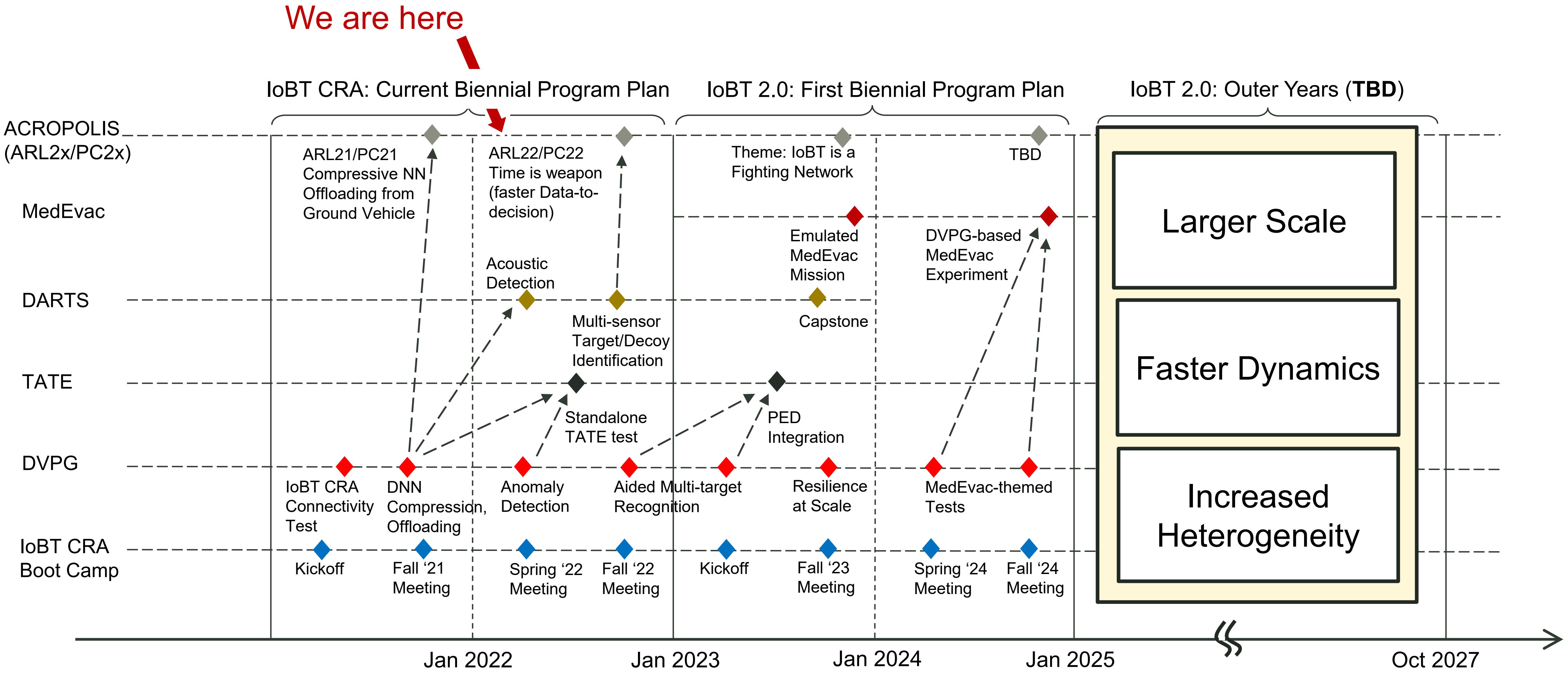
Gap: Current (neural-network-based) analytics **do not offer plug-and-play functionality** with respect to highly **heterogeneous underlying hardware and sensing modalities**, and do not compose well across different time-scales

Approach: Solutions for plug-and-play functionality, coordination among entities, and compositionality at the tactical edge

- Flexible exploitation of heterogeneous and multi-vantage sensing for joint inference
- Multi-modal verification to improve prediction confidence
- Distributed hybrid (rule-based plus data-based) ML to incorporate extant knowledge; composability at multiple timescales

JOINT INTEGRATED EXPERIMENTATION

Notional avenues for experimental validation
(Live experiments with emulation-based augmentation for scale)



SUMMARY

DEVCOM ARMY RESEARCH LABORATORY

- IoBT was a new high-risk area when we started the program
  - Exciting new results and potential capabilities
- New basis and set of thrusts for IoBT, based on FE, CRA & community research, and engagement with stakeholders
- Joint integrated experimentation – being expanded
- Increasing integration within ARL enterprise
- Emerging transitions

Recommend that IoBT CRA be extended for an additional five years

IOBT CRA RMB REVIEW

Questions?

To view read-ahead material visit:

https://iobt.illinois.edu/RMB22-Readahead