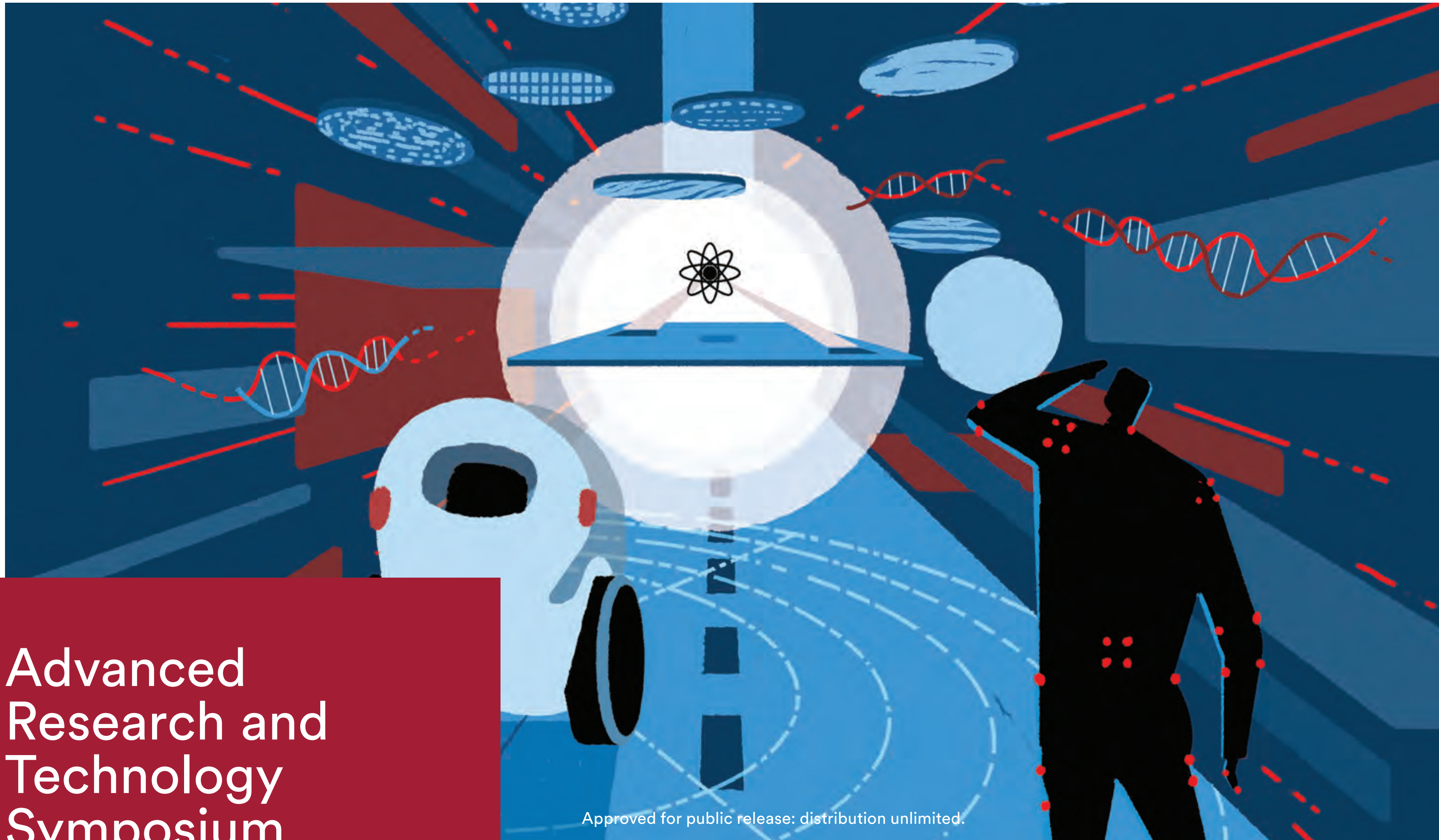
ARTS 2018



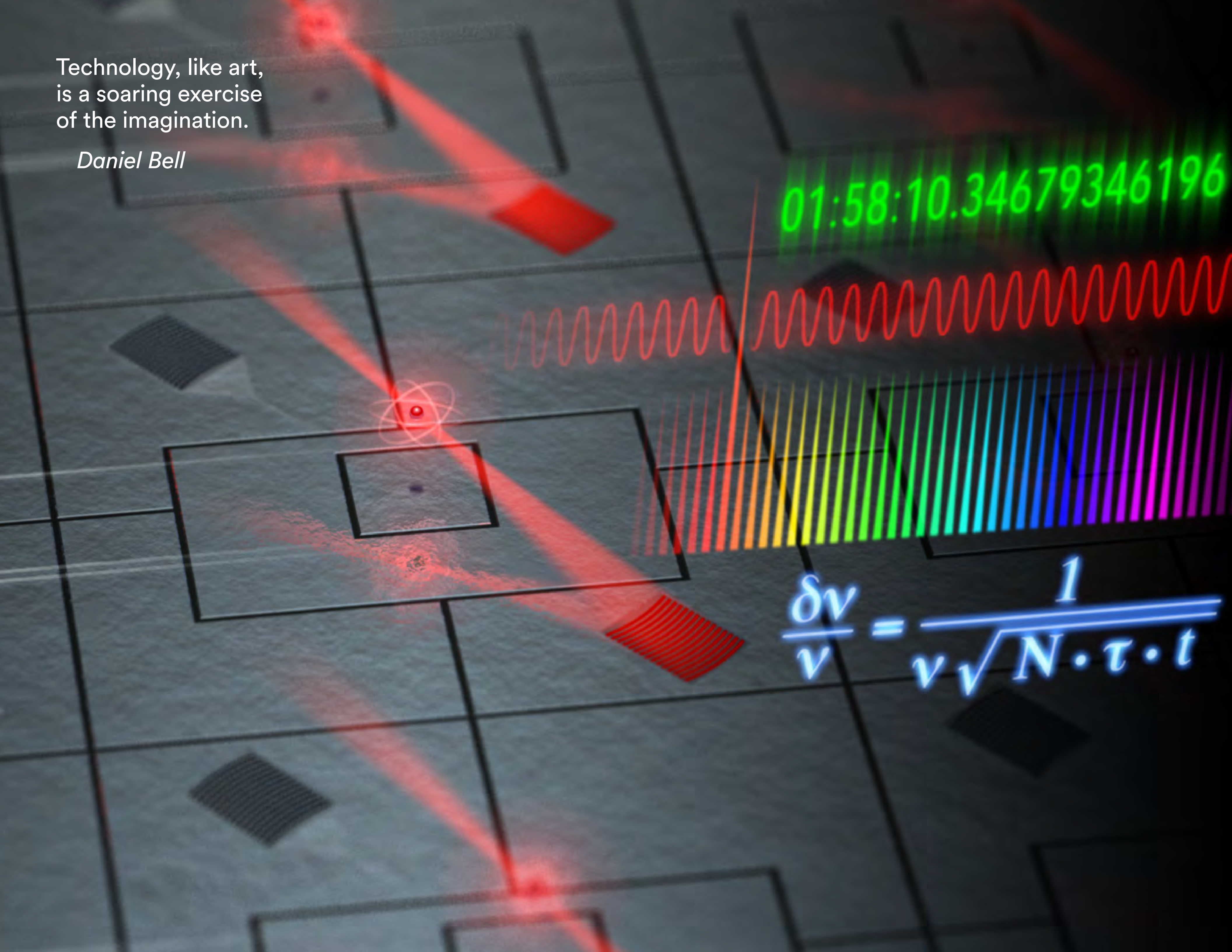
Advanced Research and Technology Symposium

5–6 March

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Technology, like art,
is a soaring exercise
of the imagination.

Daniel Bell



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A Letter from the Technology Office

Welcome to the Advanced Research and Technology Symposium (ARTS 2018) hosted by MIT Lincoln Laboratory, at the MIT Tang Center in Cambridge, MA, on March 5th and 6th.

MIT Lincoln Laboratory has a long history of advanced research and technology development focused on addressing critical technology gaps in national security. Recently, the pace of innovation has accelerated in part due to advances made by the private sector and academia. Working more closely with universities, the startup community, and small businesses is key to hastening the adoption of new technologies so they can be used effectively for national security. The major objective of this symposium is to reach out to academics, students, and entrepreneurs at MIT campus and in the New England area to encourage the development of advanced technologies in support of national security. The symposium will highlight some of the challenges confronting our nation's security and wellbeing, and how advanced technology can help address these challenges. Symposium discussions will stimulate interaction and suggest opportunities to develop new technologies, which will have both commercial and defense applications.

The 2018 symposium opens with a keynote address on technology for national security. The address is followed by several sessions that highlight recent technology challenges and revolutionary work that is ongoing at MIT's campus and MIT Lincoln Laboratory in the following areas:

- Data-starved artificial intelligence
- Smart super vehicles
- The future of advanced (secure) computing
- Revolutions in biotechnology
- Materials integration: from nanoscale to waferscale

Each session includes presentations by invited speakers and MIT Lincoln Laboratory staff, as well as a set of associated poster presentations. The poster sessions will showcase additional relevant and groundbreaking research projects and provide the audience with the opportunity to interact firsthand with the session speakers and their colleagues. The symposium wraps up with a ways-to-engage session that features a diverse panel of experts from government and federal laboratories who will facilitate a discussion on innovation in support of national security. The panel will explore ways to engage with Lincoln Laboratory and more broadly with the U. S. Government and related entities to develop research collaborations and other business opportunities.

This booklet provides a compilation of presentations and posters shared during the symposium. We hope you will find the symposium informative and stimulating, and look forward to your participation.

Thank you,

Bob Bond
Chief Technology Officer

Robert Bond

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The Lincoln Laboratory Mission

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

MIT Lincoln Laboratory is designated a Department of Defense federally funded research and development center (FFRDC) operated by the Massachusetts Institute of Technology. The Laboratory conducts research and development pertinent to national security on behalf of the military services, the Office of the Secretary of Defense, the intelligence community, and other government agencies. Projects undertaken by Lincoln Laboratory focus on the development and prototyping of new technologies and capabilities to meet government needs that cannot be met as effectively by the government's existing in-house or contractor resources. Program activities extend from fundamental investigations through design and field testing of prototype systems using new technologies. A strong emphasis is placed on the transition of systems and technology to the private sector.

Since 1951, Lincoln Laboratory has been providing the government with independent perspective on critical issues and technological solutions for both long-term interests and short-term, high-priority needs. On its 25th and 50th anniversaries, the Laboratory received the Secretary of Defense Medal for Outstanding Public Service in recognition of its distinguished technical innovation and scientific discoveries.

MIT Lincoln Laboratory
Lexington, MA

Massachusetts Institute of Technology
Cambridge, MA

Technology for National Security

Dr. Melissa Flagg

ARL Northeast

Former Deputy Assistant Secretary of Defense for Research, Office of the Assistant Secretary of Defense, Research & Engineering

Since 1945, the U.S. role in the world and the state of global science and technology have both changed greatly. We have seen a doubling of the U.S. population and a tremendous growth globally in those educated to understand and engage in S&T. The global investment has gone from amounts counted in millions to over $1.7 trillion and both our allies and our adversaries globally are steeped in access to technological knowledge and hardware. We go into this future with new challenges of speed and scale, the emergence of new areas of science that cut across our traditional disciplines and shake our institutional stovepipes, and a federal government that plays a radically different role in our country than it did 70 years ago. The security of our nation will require the ability to not only discover new knowledge, but to understand the potential of those discoveries, communicate it broadly, and integrate that knowledge into real solutions for challenges that generations before us never even imagined.

Biography
Dr. Melissa Flagg is currently the lead for the Army Research Laboratory Northeast. Previously, she was the founder and CEO of Flagg Consulting Services, LLC. She also worked with the University of Utah to re-examine the foundations of our scientific structures and served as an adjunct senior fellow in the Technology and National Security Research Program at the Center for a New American Security. Before starting her own company, she served as the Deputy Assistant Secretary of Defense for Research within the Department of Defense (DoD). Prior to that, she worked in various roles at the John D. and Catherine T. MacArthur Foundation, the U.S. DoD, the Office of Naval Research, and the U.S. Department of State. She received a BS from the University of Mississippi in 1996 and a PhD from the University of Arizona in 2000.

Data-Starved Artificial Intelligence

Recent breakthroughs in artificial intelligence (AI) and machine learning are transforming virtually every industry, including the national security technology landscape. Current advances in AI have relied on large amounts of labeled data, large amounts of computing power, and deep learning techniques to deliver performance rivaling that of humans on computer vision, speech, and text processing. However, some problem domains are data-starved—they either do not have sufficient labeled training data or deal with rare objects and events for which there is not enough data.

Humans and even animals can learn with very little “training” data using a computational resource (brain) that is very power-efficient. In addition, human intelligence is very good at reasoning about the world even in the presence of gaps in the sensory inputs or data. These characteristics of human and animal intelligence provide a direction for future AI research: learning in data-starved domains and learning in domains with scarce computational power. Furthermore, in addition to perception applications, next-generation AI must also focus on building machines with cognitive capabilities and the ability to reason based on imperfect observations of the world.

The session will begin with a keynote from Prof. Torralba, who is the director of the MIT-IBM Watson AI Lab. It will include talks by MIT Lincoln Laboratory researchers to highlight some of the challenges in the application of AI for national security missions, the work being done to advance computer vision, and applications of AI to cybersecurity. An invited talk by Dr. Mansinghka will focus on probabilistic inference. The poster sessions provide an opportunity to interact with MIT Lincoln Laboratory researchers. Posters will highlight some of the work in the area of explainable AI, computer vision, threat network detection, and cybersecurity. We look forward to engaging with our academic and industry partners in advancing the field of AI and helping to improve national security.

Dr. Sanjeev Mohindra

MIT Lincoln Laboratory

Data-Starved AI

Recent breakthroughs in the field of deep learning mark unprecedented progress toward creating artificial intelligence (AI) applications. Achievements in converting spoken language to text, categorizing images, and playing challenging board games such as Go demonstrate a versatility and utility in AI applications that stand to substantially transform society. The national security technology landscape will be similarly transformed, but facilitating this transformation introduces a new challenge. In this talk, we discuss methods developed under the Computer on Watch program that integrate the state-of-the-art in artificial intelligence via deep learning with imagery analysis applications. We: 1) demonstrate a prototype system, integrated into a modern DoD software framework, that can successfully identify various types of objects in overhead imagery in a scarce data setting; 2) describe a novel method for dramatically reducing the data requirements for training deep learning systems; and 3) report on research in automated visual reasoning, which lays the groundwork for creating a cognitive assistant that communicates using natural language.

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Biography

Dr. Sanjeev Mohindra is an assistant group leader in the Intelligence and Decision Technologies Group at MIT Lincoln Laboratory. The group is responsible for data analytics research activities. Dr. Mohindra manages part of the analytics portfolio for the group, including computer vision, natural language processing, graph analytics, and machine learning. His area of expertise is in building scalable systems for the exploitation of data using parallel and distributed computing technologies. Before coming to MIT Lincoln Laboratory, he worked with a startup developing smart storage technology with computing close to the hardware. Prior to that, he worked at Arthur D. Little Inc. in a technology-consulting role in both the Technology and Product Development and Environmental, Heath, and Safety divisions. He has a PhD from Cornell University and a BTech from the Indian Institute of Technology, Delhi, India.

Prof. Antonio Torralba

MIT

AI Horizons

The performance achieved by neural networks is remarkable and constitutes the state of the art on most recognition tasks. But why does it work so well? What is the nature of the internal representation learned by the network? I will discuss the importance of visualizations in order to understand how neural networks work. In particular, I will describe a procedure to automatically interpret the internal representation learned by a neural network. I will then discuss a particular task where a neural network is trained to predict the sounds associated to a video. By studying the internal representation learned, we show that the network learns to detect visual objects that make specific sounds like cars and sea waves, among many other things.

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Biography

Prof. Antonio Torralba is an assistant professor of electrical engineering and computer science and a member of the Computer Science and Artificial Intelligence Lab. He is a telecommunication engineer by the Technical University of Catalonia (Spain) since 1995. He received his PhD from Grenoble Institute of Technology (France) in 2000. His research interests span computer and human vision, computer graphics, and machine learning. His particular areas of interest include object and scene recognition, large image databases, applied machine learning, and the role of context in visual perception.

Mr. Arjun Majumdar

MIT Lincoln Laboratory

Computer-on-Watch

Recent breakthroughs in the field of deep learning mark unprecedented progress toward creating artificial intelligence (AI) applications. Achievements in converting spoken language to text, categorizing images, and playing challenging board games such as Go demonstrate a versatility and utility in AI applications that stand to substantially transform society. The national security technology landscape will be similarly transformed, but facilitating this transformation introduces a new challenge. In this talk, we discuss methods developed under the Computer-on-Watch program that integrate the state-of-the-art in artificial intelligence via deep learning with imagery analysis applications. We:
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2) describe a novel method for dramatically reducing the data requirements for training deep learning systems; and 3) report on research in automated visual reasoning, which lays the groundwork for creating a cognitive assistant that communicates using natural language.

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Biography

Mr. Majumdar is a technical staff member in the Intelligence and Decision Technologies Group at MIT Lincoln Laboratory. His research goal is to apply computer vision, machine learning, and artificial intelligence to solve real-world problems. He is currently working on developing machine learning solutions for low-resource domains. His interests range from active learning techniques to developing techniques for increasing trust in AI. Before coming to MIT Lincoln Laboratory, he was a principal engineer at Northrop Grumman's Automated Sensor Exploitation Technology Center where he developed algorithms and prototyped software for complex surveillance systems. He has a MS degree in electrical and computer engineering (ECE), with a concentration in computer vision and AI, and a BS in ECE from the University of Illinois at Urbana Champaign.

Dr. William Streilein

MIT Lincoln Laboratory

Teaming with the AI Cyber Warrior

As cyber attacks continue to grow in sophistication and impact, the cyber defender grows evermore overwhelmed in defending critical cyber assets. Artificial intelligence (AI) holds promise for shifting the balance of the cyber struggle in favor of the cyber defender by enabling early attack warning and pre-emptive mitigation deployment. “Teaming with the Cyber Warrior” challenges the reader to imagine a future for cyber security in which manual defensive processes relying upon technical solutions and using cyber-only data are replaced by deeper analyses of attacker intention and behavior to support machine-vs.-machine cyber combat using a range of multi-domain data sources. MIT LL is leveraging existing AI capabilities in online social media mining for early indications of cyber attack, as well as those for automated cyber decision, making an AI-enabled cyber warrior whose effectiveness at defending cyber systems is greatly enhanced. Please come and hear about our cyber-enabled cyber security future.

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Biography

Dr. William Streilein is the leader of the Cyber Analytics and Decision Systems Group at MIT Lincoln Laboratory, where he manages research and development programs in cybersecurity. His current research interests include the application of machine learning and modeling techniques to problems in cybersecurity. Other areas of interest include the investigation and development of quantitative metrics for cybersecurity, the exploration of moving target techniques to improve the resiliency of cyber and cyber-enabled systems, and automated techniques for discovering how government missions map to cyber infrastructure and for assessing risk to mission systems. Dr. Streilein holds a BA degree in mathematics from Austin College, an MM degree in electronic and computer music from the University of Miami, and a PhD degree in cognitive and neural systems from Boston University. He is a senior member of the IEEE. He has been at MIT Lincoln Laboratory since 1998.

Prof. Vikash Mansinghka

MIT

Probabilistic Computing for Data-Starved Artificial Intelligence

The recent successes of machine learning have centered on problems with three characteristics: 1) there are large real-world training data sets or good software simulators that can generate high-quality synthetic data; 2) the domain is described by well-understood rules; and 3) there are quantitative metrics for success and failure. The MIT Probabilistic Computing Project has been developing a new software and hardware stack for building probabilistic AI systems in domains where data is scarce, the domain itself is poorly understood, and the "right answer" may be inherently uncertain. This stack is based on novel integrations of probabilistic models, Monte Carlo inference, and deep neural networks with foundational abstractions from programming languages, system software, and microarchitecture. Examples will be drawn from real-world applications of probabilistic computing to problems in data science, and from new research on applications to problems in common-sense visual scene understanding.

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Biography

Prof. Vikash Mansinghka is a research scientist at MIT, where he leads the Probabilistic Computing Project. Prof. Mansinghka holds SB degrees in mathematics and in computer science from MIT, as well as an MEng in computer science and a PhD in computation. He also held graduate fellowships from the National Science Foundation and MIT Lincoln Laboratory. His PhD dissertation on natively probabilistic computation won the MIT George M. Sprowls dissertation award in computer science, and his research on the Picture probabilistic programming language won an award at CVPR. He served on DARPA's Information Science and Technology advisory board from 2010–2012, and currently serves on the editorial boards for the Journal of Machine Learning Research and the journal Statistics and Computation. He was an advisor to Google DeepMind and has co-founded two AI-related startups, one acquired and one currently operational.

Data-Starved Artificial Intelligence Posters

Mr. David Mascharka

MIT Lincoln Laboratory

Computer Vision in Low Resource Environments

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Recent breakthroughs in the field of deep learning mark unprecedented progress toward creating artificial intelligence (AI) applications. Achievements in converting spoken language to text, categorizing images, and playing challenging board games such as Go demonstrate a versatility and utility in AI applications that stand to substantially transform society. The national security technology landscape will be similarly transformed, but facilitating this transformation introduces new challenges.

This work addresses two key challenges in applying AI techniques to national security applications: low resource problems and stringent requirements for human-machine teaming. Data is often sparsely labeled in national security domains, and the burden on humans to label data is high. We present work in active learning, which minimizes the amount of labeling required for machine learning to be successful. In order to effectively utilize AI applications, operators need a flexible interface for interacting with machine systems and require an explanation for a machine's decision. Our work in visual question answering provides natural explanations and a flexible human-language interface for operators.

Computer Vision in Low Resource Environments

Background and Motivation

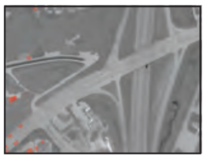
- Deep learning algorithms perform near human level on a diverse set of benchmark tasks
- There is a global push for dominance in all areas of AI research
- Machine learning research can and should be leveraged for national security domestically and abroad

Challenges for AI in National Security

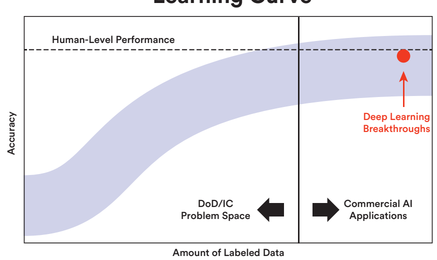
Limited Resource Challenges

- Data insufficiently labeled for machine learning
- Data is difficult to collect because content of interest is rare


Data Difficult to Collect

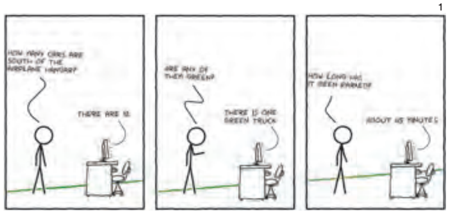

Data Insufficiently Labeled

Learning Curve



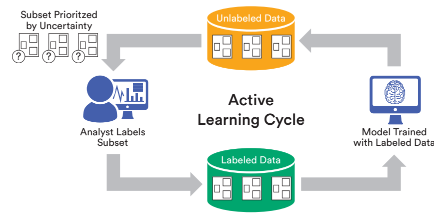
Human-Machine Teaming

- Require flexible interface to interact with machine systems
- Evidence is required for decision-making as a "sanity check"
- Explanations are necessary for building confidence in machine decisions


[1]

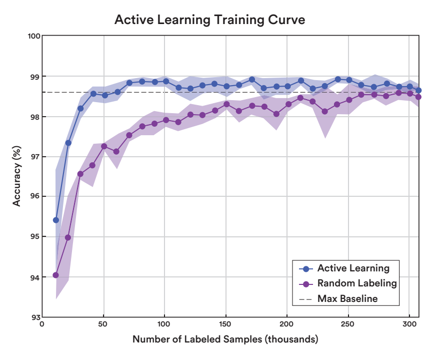
Limited Resource Challenges – Active Learning

- In an active learning framework, the computer identifies challenging samples of data for human annotation
- This subset of data is highly effective for training the computer



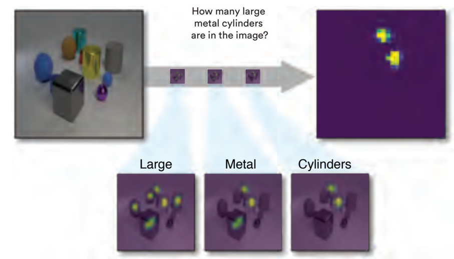
- *Limitation*: Standard deep learning models lack reliable measures of uncertainty
- *Solution*: Utilize Bayesian CNNs,[2] which provide a mathematically grounded estimate of uncertainty
- The images with highest uncertainty are most beneficial for learning

- Prioritizing the most confusing samples reduces the data requirement for learning
- Only about 1/6 of the data needs to be labeled for maximum performance
- Equivalent to reducing labeling time by about 109 hours (from 188 to 79)*

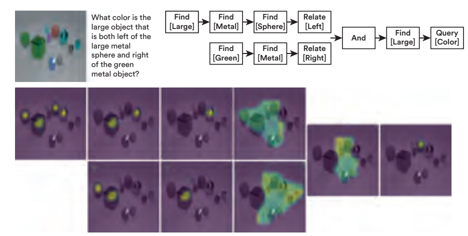


Human-Machine Teaming – Visual Reasoning

- Visual Question Answering (VQA) requires reasoning over text and an image
- Our approach is to
  - Break each question into a series of subtasks
  - Train a neural network (module) to solve each subtask
  - Compose these modules into a question-specific network
- Modules can be mixed and matched to answer a wide variety of questions
- *Transparency by Design networks*[3] are built around a visual attention mechanism



- Each module produces an *attention mask*
- Composing attention masks allows for inspection of each step in the reasoning process
- Our method performs at the state of the art while providing unrivaled interpretability



Future Direction

- Extend visual question answering to visual dialog
- Explore open-set active learning
- Combine active learning and visual reasoning approaches into a unified framework

David Mascharka, Ryan Soklaski, and Arjun Majumdar – MIT Lincoln Laboratory

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*Based on a rate of 10 seconds per sample and accounting for repeated samples from data augmentation

1. Comix I/O, http://cmx.io
2. Yarin Gal and Zoubin Ghahramani. "Bayesian Convolutional Neural Networks with Bernoulli Approximate Variational Inference." International Conference on Learning Representations (2016).
3. David Mascharka, Philip Tran, Ryan Soklaski, and Arjun Majumdar. "Transparency by Design: Closing the Gap Between Performance and Interpretability in Visual Reasoning." The IEEE Conference on Computer Vision and Pattern Recognition (CVPR). 2018.

Dr. William Streilein

MIT Lincoln Laboratory

Teaming with the AI Cyber Warrior

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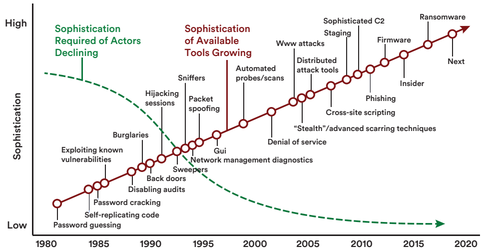
As cyber attacks continue to grow in sophistication and impact, the cyber defender grows evermore overwhelmed in defending critical cyber assets. Artificial intelligence (AI) holds promise for shifting the balance of the cyber struggle in favor of the cyber defender by enabling early attack warning and preemptive mitigation deployment. “Teaming with the AI Cyber Warrior” challenges the reader to imagine a future for cybersecurity in which manual defensive processes relying upon technical solutions and using cyber-only data are replaced by deeper analyses of attacker intention and behavior to support machine-vs.-machine cyber combat using a range of multi-domain data sources. MIT Lincoln Laboratory is leveraging existing AI capabilities in online social media mining for early indications of cyber attack, as well as those for automated cyber decision making, an AI-enabled cyber warrior whose effectiveness at defending cyber systems is greatly enhanced. Please come and hear about our cyber-enabled cybersecurity future.

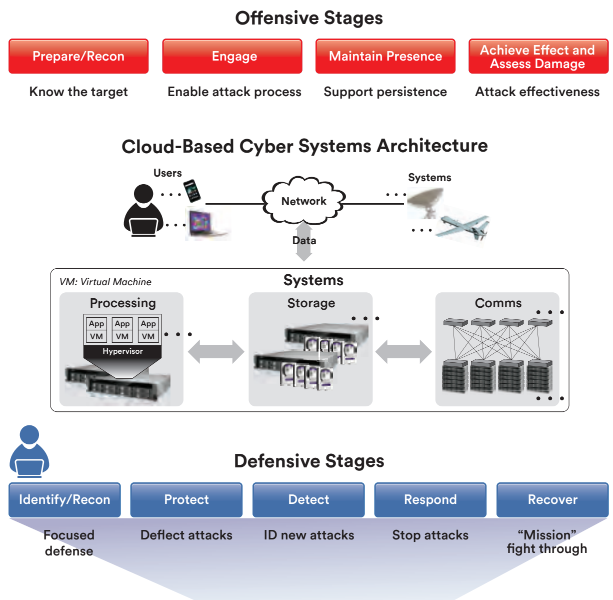
Teaming with the AI Cyber Warrior

The Threat Continues to Grow
Sophisticated Attacks Easier with Automation

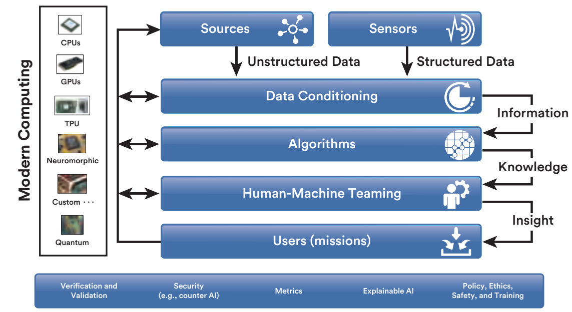


Some Numbers
- 250K new malware programs are registered each day
- There were 357M new email malware variants in 2016 – up 36% from 2014
- There were 463M new variants of ransomware in 2016 – up 36% from 2015
- 99 days to detect compromise – adversary gains access in three days
- Internet of Things/Cloud are hot targets (e.g., Mirai botnet) – two minutes to compromise
- Projected cyber-attack costs in 2019: $2.1T

Attack and Defense of a Cyber System



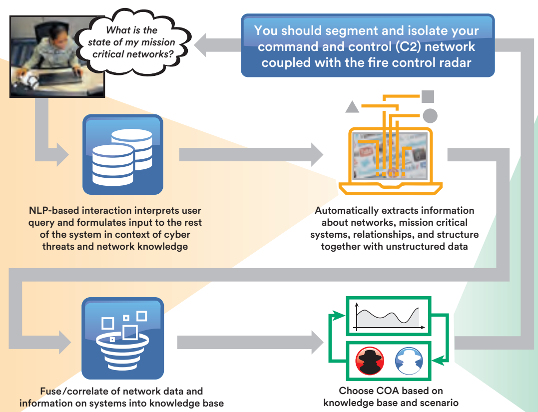
AI for Cybersecurity



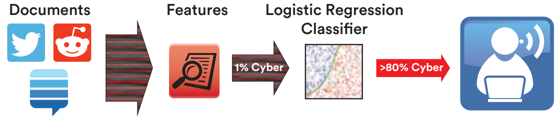
Global Trends

Today	Future
• AI not considered feasible • Purely technical solutions • Manual vulnerability discovery • Cyber-data only	• Increasing adoption of AI and automation for cybersecurity • Attacker intention and behavioral analysis • Machine-vs.-machine cyber combat • Multi-domain data sources

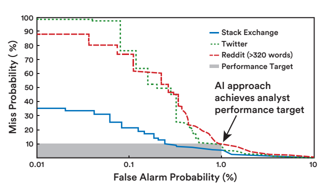
AI Cyber Warrior



CHARIOT*: Leverage Human Language Technology (HLT) to Improve Signal-to-Noise Ratio (SNR) for Cyber Analysis



- Source-dependent extraction/processing
- Future generation
  - Word stemming (hack, hacker, hacks, hacking)
  - Term Frequency–Inverse Document Frequency (TF–IDF)
- Logistic Regression Classifier

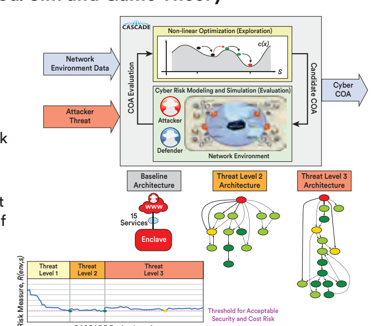


* Cyber HLT Analysis, Reasoning, and Inference for Online Threats

Automated Cyber Decision Making via Mod/Sim and Game Theory

CASCADE – Cyber Adversarial SCenario modeling and Automated Decision Engine

- Dynamically quantifies risk in the face of an adaptive adversary
- Considers mission context to select optimal course of action (COA)
- Prototype applied to configuration of network segmentation defense



William Streilein – MIT Lincoln Laboratory

Dr. Jonathan Su

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Adaptable Interpretable Machine Learning

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The adage “no trust, no use” summarizes the importance of trust in automation, and it resonates strongly for automation involving machine learning (ML) as the spread and consequences of ML grow explosively. This program seeks to gain trust by developing supervised classifiers that are interpretable—designed to be human-understandable—and/or adaptable—able to learn from new data and user feedback, while providing competitive performance. This program is a collaboration with Prof. Cynthia Rudin at Duke Univ., CS, EE, & Statistics and has two areas. First, for structured data in which the features are already understandable, we are developing Recursive Bayesian Rule Lists (RBRL), an adaptable extension of interpretable classifiers known as Bayesian Rule Lists. Via an analogy between classifier adaptation and tracking, RBRL can efficiently retrain on new data, and it can accept user feedback on the features that led to a prediction, rather than just additional labeled examples. Second, for unstructured data like images, where the features are not obvious, we are developing interpretable neural networks, including a prototype-layer network presented at AAAI 2018. In this network, the prototype neurons can be visualized as archetypal training examples, and a prediction can be understood by the weighted combination of each prototype neuron to each class.

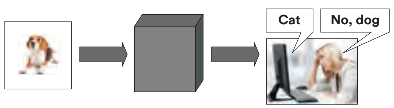
Adaptable Interpretable Machine Learning

Motivation, Trends, and Context

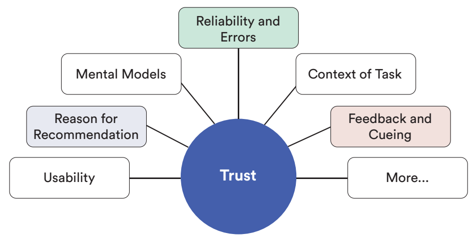
Growth and Reach of Automation and Machine Learning (ML)

Automation with ML becoming more prevalent and consequential

Problem: Most ML uses "black-box" algorithms that humans do not understand

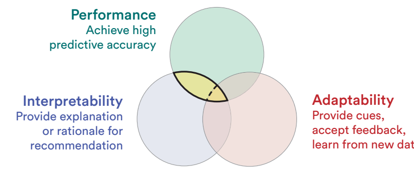


Many Factors Influence Trust: No Trust = No Use



Goal

Create algorithms that users can understand and that keep learning so users will trust them and actually use them



Program Area 1

Structured Data: Bayesian Rule Lists

- Features already human interpretable
- Examples
  - Medical records
  - Job, loan, visa applications
  - Criminal history
- Develop interpretable classifier that accepts user feedback on features, supports interactive ML

```
M, 43, 5- 8, 150, O+
F, 51, 5- 2, 125, A-
F, 30, 5- 3, 130, B+
M, 62, 6- 0, 180, B+
...
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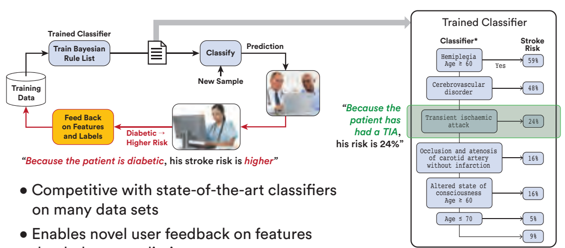
Adaptable Decision Lists

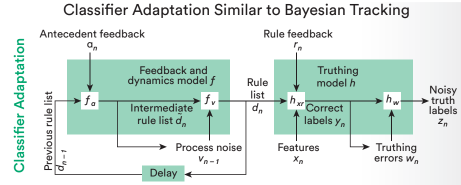
Making Bayesian Rule Lists* Adaptable



- Competitive with state-of-the-art classifiers on many data sets
- Enables novel user feedback on features that led to a prediction
  - Add/remove rule; reorder rules; modify threshold

Tracking Analogy

Classifier Adaptation Similar to Bayesian Tracking

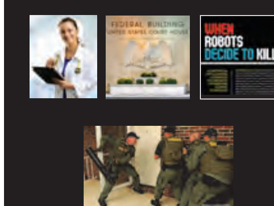


Benefits

- Recursive: New data only, no growing storage
- Non-iterative adaptation
- Feature feedback
- Dataset shift
- Multiple noisy truth labels

The Future

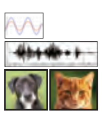
- ML development or applications where human understanding of the prediction process is paramount and black box is insufficient
- Structured or unstructured data program area
- Human interaction with interpretable ML



Program Area 2

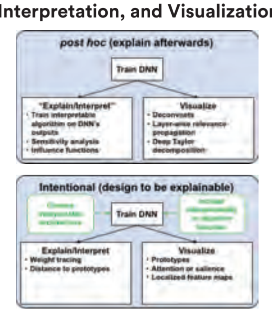
Unstructured Data: Deep Neural Networks

- Good features unclear or unknown
- Powerful black-box ML algorithm
- Extremely difficult to understand, interpret, or explain
- Examples
  - Time series
  - Audio or speech
  - Images, video

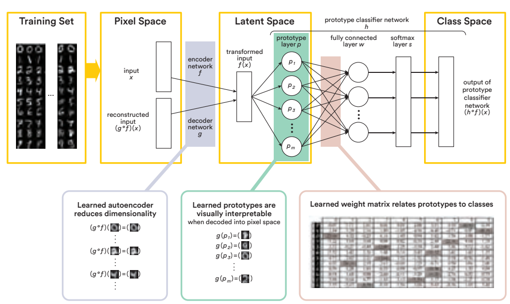


Explaining Deep Neural Networks

Two Main Approaches to Explanation, Interpretation, and Visualization



"A Neural Network That Explains Its Predictions"**



Performance Comparison

- Explainability gained with no loss in predictive accuracy

	Accuracy %
Autoencoder and prototype-layer DNN	99.22
Replace autoencoder with fully connected layer	99.24
Omit autoencoder and use CNN	99.23
LeNet 5 [Lecun et al. 1998]	99.20

Jonathan Su – MIT Lincoln Laboratory

* B. Letham, C. Rudin, T.H. McCormick, D. Madigan, "Interpretable classifiers using rules and Bayesian analysis: Building a better stroke prediction model," *Ann. Appl. Stat.*, vol. 9, no. 3, pp. 1350–1371, 2015
** O. Li, H. Liu, C. Chen, C. Rudin, "Deep Learning for Case-based Reasoning through Prototypes: A Neural Network That Explains Its Predictions," *AAAI* 2018, 11 pp. Oct. 2017

Dr. Olga Simek

MIT Lincoln Laboratory

Threat Network Detection: Countering Weaponization of Social Media

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Social media is now used by the majority of individuals across the industrialized world. This large-scale growth of worldwide social media networks is built upon their essential features of universal access, immediacy, and power to communicate with and influence others. However, these key design features have also created a potent new medium and an enabling technology for disinformation and propaganda. Terrorist organizations actively engage in global radicalization and recruitment on social media, targeting people of diverse backgrounds. State actors conduct hostile influence operations that involve weaponized information technologies as a component of gray zone warfare. We study jihadist as well as influence operations threat networks using an approach consisting of targeted network sampling to collect relevant data, natural language processing and graph-based narrative classification to detect activities of interest, and causal inference and network roles estimation to characterize threat networks. We present novel approaches and results for radicalization detection, influence operations detection, network role classification, and causal influence estimation.

Threat Network Detection: Countering Weaponization of Social Media

Motivation

1. Terrorist organizations actively engage in global radicalization and recruitment on social media, targeting people of diverse backgrounds.

2. State actors engage in hostile influence operations that involve weaponized information technologies as a component of gray zone warfare.

Technical Challenges

- Targeted data collection
- Dynamic network construction
- Network role classification
- Bot detection
- Narrative characterization
- Credibility estimation
- Radicalization detection
- Influence estimation
- Trend prediction

Future Work

- Predict and model outcomes and responses of individuals in an influence network
- Learn evolving and emerging themes in streaming media
- Estimate veracity of events, users, and posts in social media
- Characterize the role and use of bots in narrative propagation

Collaborations

Massachusetts Institute of Technology

Harvard

Techniques

Targeted Network Sampling[1]

Approach

- Lists of seed accounts
- Hashtags
- Keywords
- Supervised machine learning algorithms for relevance prediction

Natural Language Processing and Graph-Based Narrative Classification

Objectives

- Identify existing narratives, temporal changes and sentiment
- Detect emerging narratives
- Predict trends
- Estimate credibility
- Quantify use of bots

Causal Influence and Network Roles Estimation

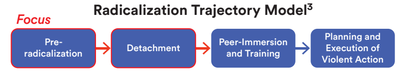
Novel Methods

- Influence estimation reveals important accounts that are not obvious through basic statistics
- Impact is the additive number of messages per user, due to exposure to the account[2]: **Average$_i$ (Exposed$_i$ – Control$_i$)**
- Machine learning and rule-based algorithms are designed for role classification

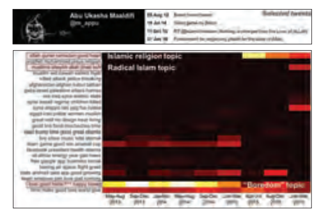
Extremist Recruitment and Propaganda

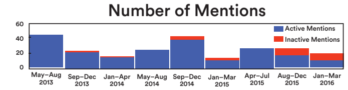
Cue on Known Extremists and Discover Network

Radicalization Detection



Example: Combining a user's network features and topic trends to identify potential recruits



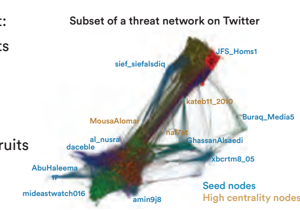


Increasing portion of suspended accounts over time in user's mentions network

Estimation Problem: Roles[4]

Roles to detect:

- Propagandists
- Fans
- Fighters
- Recruiters
- Potential recruits

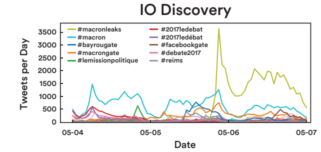


Influence Operations (IO)

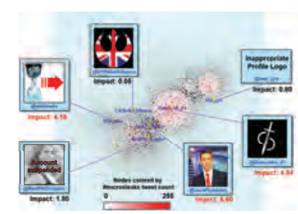
Cue on Known Propaganda Outlets and Discover Amplifiers

Detection of Influence Operations

Example Narrative: Hacking attack on a candidate in 2017 French presidential elections



Estimation Problem: Influence



Olga Simek, Steven Smith, Danelle Shah, and Ed Kao, MIT Lincoln Laboratory

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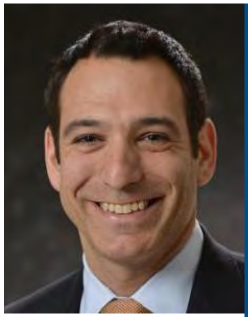
[1] S.T. Smith et al. "Network Discovery Using Content And Homophily," *ICASSP*, 2017.
[2] E.K. Kao. "Causal Inference Under Network Interference: A network potential outcome framework with Bayesian imputation," *preprint*.
[3] Klausen et al. "Toward a Behavioral Model of 'Homegrown' Radicalization Trajectories," *Studies in Conflict & Terrorism*, Nov 2015.
[4] O. Simek et al. "Threat Network Detection," *Graph Exploitation Symposium*, 2017.

Smart Super Vehicles

Improved performance of the underlying technologies required for autonomous vehicles has led to an exponential increase in their capabilities and their usage for both civilian and military applications. Improvements in energy storage, sensing, communications, and onboard processing have enabled the development of more fully autonomous behaviors in small agile platforms that would not have been feasible only 5 to 10 years ago. Large numbers of small, low-cost, autonomous vehicles are poised to transform the nature of future combat.

In this session, we will discuss both the applications and unique considerations for the use of autonomous systems in the national security environment. We will discuss how the U.S. military can maintain its edge in this critical area through investments in advanced technologies for energy, communications, and autonomy while bridging the innovation gap between university research and military use. The poster session will cover human-machine teaming, decentralized coordination, and novel sensors for undersea vehicles. Close collaboration between universities, innovative small companies, and the military will be essential for maintaining leadership in autonomous systems, and we look forward to working together in the future.



Mr. Scott Van Broekhoven

MIT Lincoln Laboratory

Building Smart Super Vehicles

Improved performance of the underlying technologies required for autonomous vehicles has led to an exponential increase in their capabilities and their usage for both civilian and military applications. Improvements in energy storage, sensing, communications, and onboard processing have enabled the development of more fully autonomous behaviors in small agile platforms that would not have been feasible only five to 10 years ago. Large numbers of small, low-cost, autonomous vehicles are poised to transform the nature of future combat.

This briefing will outline several methods to speed the development of smart super vehicles, including investments in key technologies, approaches that bridge the innovation gap between university research and military use, and better models for training the workforce of the future.

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Biography

Mr. Scott Van Broekhoven is the group leader of the Advanced Capabilities and Systems Group at MIT Lincoln Laboratory. In this role, he oversees a multidisciplinary team developing novel system and technology concepts that address the nation's critical security challenges. Projects range from the analysis and prototyping of tactical military optics and radar systems to the investigation of novel communication, navigation, and autonomous systems. Prior to his current role, Scott led R&D programs in both small satellites and aircraft-deployable micro-air vehicles. He is a recipient of Lincoln Laboratory's Early Career Technical Achievement Award.

Mr. Van Broekhoven earned a BS degree in mechanical engineering from Northwestern University and an MS degree in engineering systems from MIT.

Prof. John Hansman

MIT

Preliminary Development of the "Firefly" Rocket Powered UAV

This briefing will outline the development of a new class of small high-speed UAVs. The requirement to operate at transonic Mach numbers necessitates the development of a long-endurance slow-burn solid rocket prolusion system, which is tightly integrated into the vehicle design. The tight integration has stimulated a number of technical innovations that will be briefly described, including: new rocket chemistry; 3D-printed titanium rocket motor case; scheduled variable thrust; advanced thermal management; and a laser-based ignition system.

rjhans@mit.edu | 617-253-2271

Biography

Prof. R. John Hansman is the T. Wilson Professor of Aeronautics & Astronautics at MIT, where he is the director of the MIT International Center for Air Transportation. He conducts research in advanced technologies for operational aerospace systems. He led the founding Beaver Works capstone project class and has led several student-driven innovative UAV designs. Professor Hansman holds seven patents, has authored over 300 technical publications, and has over 6000 hours of pilot in-command. He chairs the U.S. Federal Aviation Administration Research Engineering & Development Advisory Committee (REDAC). He is co-director of the national Center of Excellence in Aviation Sustainability Center (ASCENT). He is a member of the U.S. National Academy of Engineering (NAE), is a fellow of the AIAA, and has received numerous awards, including the AIAA Dryden Lectureship in Aeronautics Research, the ATCA Kriske Air Traffic Award, a Laurel from Aviation Week & Space Technology, and the FAA Excellence in Aviation Award.

Prof. Douglas Hart

MIT

A Safe High-Energy Source of Hydrogen

This briefing will describe a novel aluminum fuel that readily reacts with water to produce hydrogen, heat, and aluminum hydroxide. Using a fuel cell, the hydrogen can be converted to electricity with an overall energy density on par with diesel generators, but with the advantages that it scales down to low power levels while maintaining high conversion efficiencies and requires far less oxygen then traditional combustion processes. The fuel processing involves a simple surface treatment and has been demonstrated using a variety of feedstocks including scrap aluminum. The resulting fuel is >98% aluminum and reacts to completion. This fuel far exceeds the energy density of traditional lithium batteries and will be an enabling technology for a new generation of small long-endurance undersea vehicles.

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Biography

Douglas P. Hart is an MIT professor of mechanical engineering and co-founder of three venture-backed biotechnology companies. He has a history of successful inventions from within and outside of academia and serves as a technical advisor for numerous companies and professional organizations. He has been involved in the commercial development of technologies ranging from satellite propulsion and unmanned drones to surgical robots. Prof. Hart received his BSc degree in aeronautical/astronautical engineering from the University of Illinois, his SM degree in mechanical engineering from the Massachusetts Institute of Technology and his PhD in mechanical engineering from the California Institute of Technology.

Dr. Scott Hamilton

MIT Lincoln Laboratory

Undersea Communications

Optical propagation through the ocean encounters significant absorption and scattering. The impact is exponential signal attenuation and temporal broadening, limiting the maximum link range and the achievable data rate, respectively. MIT Lincoln Laboratory is developing narrow-beam lasercom for the undersea environment, where a collimated transmit beam is precisely pointed to the receive terminal. This approach directly contrasts with the more commonly demonstrated approach, where the transmit light is sent over a wide angle, avoiding precise pointing requirements but reducing the achievable range and data rate. Two advantages of narrow-beam lasercom are the maximization of light collected at the receiver and the ability to mitigate temporal broadening by spatial filtering. Precision pointing will be accomplished by bi-directional transmission and tracking loops on each terminal, a methodology used to great effect in atmospheric and space lasercom systems. By solving the pointing and tracking problem, we can extend the link range and increase the data throughput.

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Biography

Dr. Scott A. Hamilton is the leader of the Optical Communication Technology Group at MIT Lincoln Laboratory. In this role, he is responsible for multiple R&D programs to develop free-space optical, undersea lasercom, and quantum communication technologies for fielded hardware prototyping efforts. He began his career at the Laboratory in 2000 researching all-optical signal processing for high-speed optical networks and photon-efficient transceiver technologies for challenging spaceborne user applications. Before moving to New England, he spent time in China Lake, CA working to develop F-4 supersonic drones and in the Clandestine Information Technology Office at the CIA. Dr. Hamilton studied at the University of California, Davis and earned the BS, MS, and PhD degrees in electrical engineering.

Prof. Sertac Karaman

MIT

Next-Generation Augmented Reality and Virtual Reality Development Environments for UAV Research

The development of fast, agile micro unmanned aerial vehicles (UAVs) has been limited by 1) on-board computing hardware restrictions; 2) the lack of sophisticated vision-based perception and vision-in-the-loop control algorithms; and 3) the absence of development environments where such systems and algorithms can be rapidly and easily designed, implemented, and validated. In this talk, we discuss novel UAV systems and development environments for UAV research that help overcome these challenges. The new development environments bring virtual reality and augmented reality to UAV research by utilizing state-of-the-art rendering engines, and allow us to design, test, and validate algorithms safely and efficiently. The new UAVs combine high-rate high-resolution sensing with powerful embedded computing capabilities. The new algorithms leverage these on-board sensing and computing capabilities for agile flight at operational speeds in a priori unknown complex environments.

sertac@mit.edu | 617-324-4254

Biography

Sertac Karaman is an associate professor of aeronautics and astronautics at MIT (since Fall 2012). He has BS degrees in mechanical engineering and computer engineering from the Istanbul Technical University, Turkey, in 2007; an SM degree in mechanical engineering from MIT in 2009; and a PhD degree in electrical engineering and computer science from MIT in 2012. His research interests lie in the broad areas of robotics and control theory. In particular, he studies the applications of probability theory, stochastic processes, stochastic geometry, formal methods, and optimization for the design and analysis of high-performance cyber-physical systems. He delivered the Robotics: Science and Systems Early Career Spotlight Talk in 2017. His awards include an IEEE Robotics and Automation Society Early Career Award in 2017, an Office of Naval Research Young Investigator Award in 2017, and an Army Research Office Young Investigator Award in 2015.

Smart Super Vehicles Posters

Mr. Mark Donahue

MIT Lincoln Laboratory

Verification for Tactile Intelligence in Motion (V-TIM)

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Verification for Tactile Intelligence in Motion (V-TIM) is exploring verification and validation (V&V) for systems with inherent machine learning by integrating machine learning algorithms with geometry-based touch sensor data. This work is in collaboration with MIT Professors Rus, Tedrake, and Adelson and leverages their expertise in simultaneous learning of and evaluation of system constraints for complex adaptive, dynamical systems as well as their expertise in novel touch sensing.

Verification for Tactile Intelligence in Motion (V-TIM)

Background

Motivation

Develop verification methods for autonomous systems that have complex dynamics and that interact with the physical world

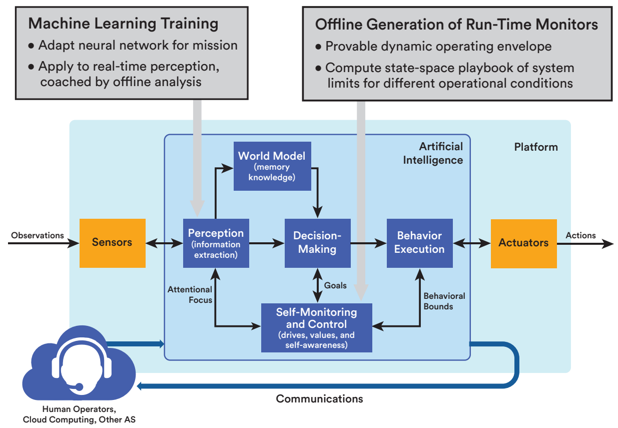



Challenges

- Autonomy in motion is a compound hardware-software-physics problem
- Verification of autonomy in motion does not have widely adopted formal tools
  - Impossible to provide test coverage for every possible scenario
  - Too expensive to achieve statistical relevance in hardware alone
  - Combinatorial number of contact conditions, solving big optimizations

Overview

Canonical Autonomy Architecture



Agile V&V Test Bed for Tactile Intelligence in Motion

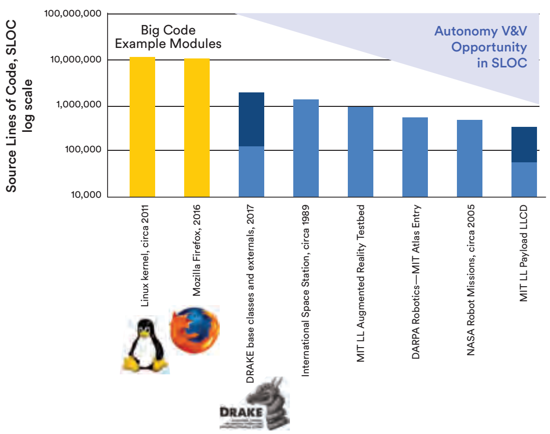
Verification
Did we build the system **right**?

Validation
Did we build the **right** system?

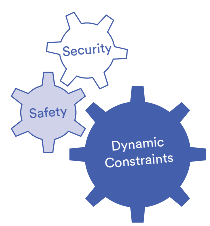
Dependability
Incorporates reliability (MTBF), trust, resiliency, and availability

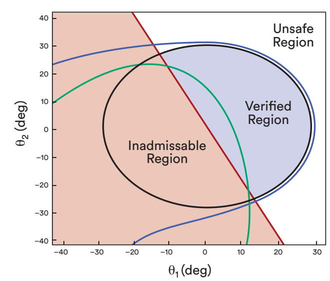
Usability
Common mental model for understanding the system

Leveraging Software Verification & Validation (V&V) Tools



Better V&V Tools for Autonomous Applications





Model-based optimization tools to address added complexity of Dynamic Constraints upon traditional "big-code" Safety and Security verification rules

Path Forward

- Adapt DRAKE to expose and leverage the structure within system models for systems with dynamic constraints
- Demonstrate dexterous, mobile manipulation by integrating machine learning with a novel, geometry-based touch sensor
- Develop general applicability work flows for using model-based design tools for autonomous systems with complex dynamics

Mark Donahue – MIT Lincoln Laboratory; Daniela Rus, Russ Tedrake, Edward Adelson – MIT

Mr. John (Dan) Griffith

MIT Lincoln Laboratory

Decentralized Coordination of Autonomous Systems

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Teams of autonomous systems are being developed for both military and non-military use and require the ability to cooperate in uncertain, complex, and dynamic environments. Decentralized control is critical to maintaining performance in communication-constrained or contested environments. A significant hurdle to realizing teams of autonomous systems that can operate in these environments is the lack of coordination methods that reason about uncertainty, communication limitations, and adversarial opposition, and also scale to problems of national interest.

This research is developing principled methods for multi-robot coordination. We use a generic model that represents multi-robot cooperative planning in the presence of stochasticity, uncertain sensing, and communication limitations. Using a generic model enables the framework to be applied to a wide variety of cooperative multi-robot problems. Our specific contributions include developing advanced methods of coordination that scale better to large problems than previous approaches and demonstrating these methods on problems of national interest.

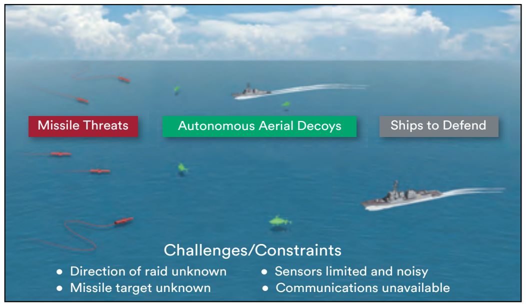
Decentralized Coordination of Autonomous Systems

ARTS

Motivation

Teams of autonomous systems often require cooperative planning in uncertain, complex, and dynamic environments where communications may be contested or constrained

Example Problem:
Defend 2 ships with 1 to 4 autonomous aerial decoys against a 5-missile raid



A significant technical hurdle is the lack of planning algorithms that are robust to uncertainty and communication limitations, and scalable to complex problems

Technology Landscape

Planning Algorithms

Online (Real Time) — Decision making algorithms executed in real time to determine best task allocation

- **Implicit Coordination**
  - All vehicles communicate to align their world estimates
  - Each agent searches for a global task allocation
- **Plan Consensus**
  - Each vehicle guesses at a global task allocation
  - All vehicles communicate to align task allocations

Offline (In Advance) — Plans trained ahead of time using simulations, models, or data; plan executed quickly in real time

- **Open-Loop**
  - Generates a plan that is non-reactive to the environment
  - Each agent executes its piece of the plan
- **Closed-Loop**
  - Generates a plan that is reactive to the environment
  - Plan includes how to respond to sensor measurements

Centralized
- One global plan is generated
- A central agent (or decision maker) coordinates all agents

Decentralized
- Several individual plans are generated
- Each agent executes its own plan

Limitations Key
- Not robust to uncertainty
- Requires communication
- Computationally complex

Research required to overcome computational complexity limitations of decentralized coordination

Decentralized Coordinated Approach

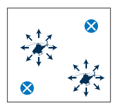
Formalize the Problem Specification	Optimize Coordinated Plans Offline to Maximize Reward	Execute Each Vehicle's Plan Online
• Vehicles, states, actions, sensor observations • Probabilistic transition and observation functions • A reward function	Considers outcome, sensor, and communication uncertainty	Plan defines action to take given previous sequence of actions, observations, and communications

General framework can be applied to a variety of problems

Advancements

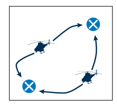
Prior Methods	New Methods

Model Representation



Plan over primitive actions *(e.g., move north, move east)*

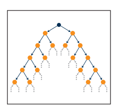
Issues:
- Requires a new decision each planning step
- Suffers significantly from curse of dimensionality



Plan over tasks *(e.g., navigate to waypoint)*

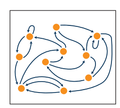
Benefits:
- Executing a task lasts several steps
- Plans can be generated for more complex environments

Data Structure for Plan



Represent plan as a tree *(one per agent)*

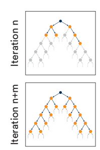
Issues:
- Tree grows exponentially with planning horizon
- Only a small tree can be stored in memory



Represent plan as a finite-state controller

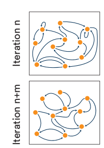
Benefits:
- Plan has a fixed memory size
- Plans can be generated for longer time horizons

Search Algorithm



Dynamic Programming

Issues:
- Requires a fully specified model description
- Scales poorly to large problems

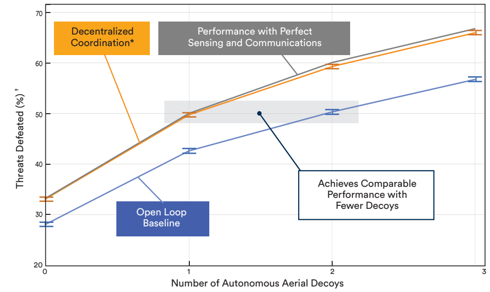


Sample-Based Planning

Benefits:
- Only requires access to simulator (often easier to specify)
- Demonstrated to generate higher quality plans

Numerous contributions now allow more complex problems to be solved

Selected Results



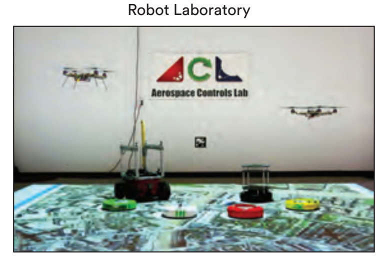
* Plans derived offline in 5-10 hours on a computing cluster
† Estimated from 10,000 Monte Carlo simulations (95% confidence intervals shown)

First demonstration of technology on problem of DoD interest

Future Work

Fleet Defense Training Tool

Robot Laboratory



- Scale coordination methods to larger teams
- Explore advanced optimization methods
- Demonstrate coordination techniques in more realistic environments outside the lab
- Establish a robotics-based multi-agent game for broader community engagement and competition

Dan Griffith and Reed Jensen – MIT Lincoln Laboratory, Technical Collaborators: Professor Jonathan How, MIT; Professor Christopher Amato, Northeastern University

Mr. Kevin Arsenault/Mr. Joshua Smith

MIT Lincoln Laboratory

Biomimetic Adaptive Sonar for Object Recognition

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The ability to detect, localize, and recognize undersea objects is a critical capability for missions such as mine countermeasures (MCM) and asset recovery. Unmanned undersea vehicles (UUVs) have been increasingly tasked with such missions, with the intention to eventually replace the dolphins that execute the mine-hunting task in the U.S. Navy Marine Mammal Program. UUV development for MCM has moved toward larger vehicles with more powerful and multi-modal sensors, to the point where next-generation UUVs are significantly larger and have more powerful sensors than dolphins. The size and expense of these larger UUVs will significantly limit their employment, motivating the search for a more cost-effective solution that more closely approximates a dolphin's capabilities. Dolphins rely on relatively modest sonar to detect and locate objects such as mines, but utilize it to great effect. In contrast to rigid UUV search procedures, dolphins employ a flexible, adaptive approach with respect to both sonar signaling and search route execution. In this work, the effectiveness of biomimetic sonar search and classification is investigated through four principal bio-inspired adaptations: click interval, source power, source frequency, and mobility. For this purpose, a custom UUV test bed was designed and built to provide the flexibility needed to evaluate the detection and classification benefits that these adaptive techniques may offer.

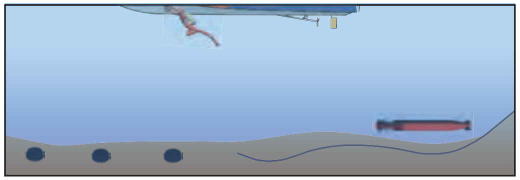
Biomimetic Adaptive Sonar for Object Recognition

ARTS

Background

Motivating Mission: Small Object Detection

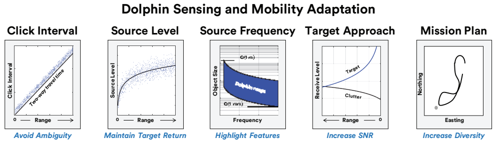
Detect, classify, localize, and neutralize undersea objects that pose a threat to U.S. assets and infrastructure (e.g., mines, divers, and undersea vehicles)



Past/Current Method: Marine Mammal Program

- Program was created by the Navy in early 1960s
- Sea lions and dolphins trained to detect, recover, or tag divers and mines
- Dolphins are highly effective despite relatively limited sonar
  - Limitation offset by cognitive ability to adapt signaling and movement
- Program began decommission in 2017 due to cost and animal welfare concerns

Dolphin Sensing and Mobility Adaptation



Current Method: Unmanned Undersea Vehicles (UUVs)

- Navy is planning to use torpedo-sized UUVs to carry out these tasks
- Despite better sonar, not yet as effective as dolphins (lacks cognitive ability)

General Dynamics Bluefin Robotics Knifefish UUV
($2.5+ million, 21" diameter × 19' length, 1,700 lbs)

https://americansecuritytoday.com/bluefin-21-auv-launches-sandshark-micro-uav-see-action/

Overview

Objective

- Leverage adaptive mobility and sonar sensing techniques (similar to dolphins) to improve detection and classification for UUVs
- Focus on smaller, less-expensive UUVs used to interrogate potential targets

Target Classification

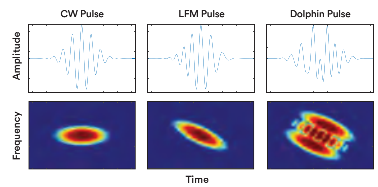
- Use adaptive techniques to minimize false targets (rocks, marine debris)
- Desire ability to classify object properties (material, shape, size, hollowness)
  - Unlike side-scan sonar imaging that mainly classifies on shape

Source Adaptations

Adapt the source signal to optimize response from a potential target

- Waveform type
- Frequency
- Bandwidth
- Pulse width
- Ping interval
- Source level

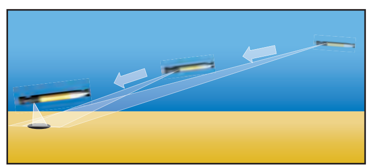
Enhance unique target features to improve discrimination



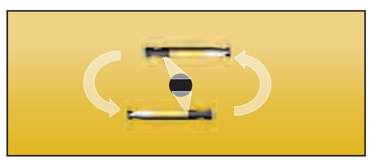
Platform Adaptations

Adapt platform motion to minimize noise and enhance target response

Changing aspect angle can provide target response diversity



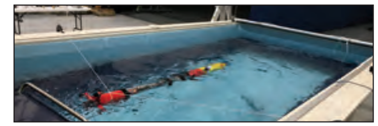
- Range
- Depth
- Aspect angle



Experimental Results

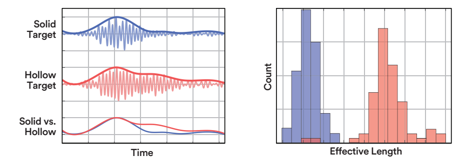
Custom-Built UUV Test Bed

- Custom 6' UUV provides flexibility needed for testing adaptive techniques
- Commercial Bluefin SandShark tail section for mobility
- Custom payload for sonar sensing and autonomy



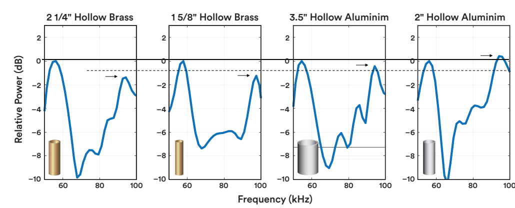
Temporal Classification Features

- Hollow targets have longer resonating tail than solid targets
- Solid vs. hollow classifier built using effective tail length (98% accurate)



Spectral Classification Features

- Target spectral response may provide additional information about the target, such as size or material composition



Path Forward

- Test bed improvements
  - Improve mobility by increasing fin size and/or decreasing payload size
  - Coherent array processing for additional gain and target bearing estimation
- Analysis
  - Model the response of various targets using a variety of source parameters
  - Perform additional data collections under controlled conditions
  - Demonstrate classification improvements using adaptive techniques
- Future directions
  - Investigate sharing sonar with other functions (e.g., communications)
  - Consider other applications for adaptive sonar techniques

Joshua Smith, Kevin Arsenault, Joe Edwards, and Andrew Wang – MIT Lincoln Laboratory

The Future of Advanced (Secure) Computing

Computing has become ubiquitous in society through advances in performance, power consumption, network connectivity, and cost. However, processor and data security is now a key factor that must be incorporated into future design strategies ranging from chip to enterprise levels. Effective and adaptive security technologies for computing must be developed to enable future commercial growth and drive new applications.

The keynote will address the question of how processor architecture needs to evolve to eliminate software and hardware attack surfaces and to reduce the trust we need to place on system and application software.

In this session, we will explore the future of computing with presentations on secure-by-design computer architectures and data networks, quantum computing, and novel data analytics architectures. The poster session will cover emerging probabilistic programming, Internet-of-Things, and big data-oriented technologies. With your help, we hope to define the next phase of advanced secure computing!

Dr. Paul Monticciolo

MIT Lincoln Laboratory

The Future of Advanced (Secure) Computing

Computing has become ubiquitous in society through advances in performance, power consumption, network connectivity, and cost. However, processor and data security is now a key factor that must be incorporated into future design strategies ranging from chip to enterprise levels. Effective and adaptive security technologies for computing must be developed to enable future commercial growth and drive new applications.

The keynote will address the question of how processor architecture needs to evolve to eliminate software and hardware attack surfaces and to reduce the trust we need to place on system and application software.

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Biography

Dr. Paul Monticciolo leads MIT Lincoln Laboratory's Embedded and Open Systems Group, which provides high-performance computing solutions for sensor signal processing, communications, and data analytics applications. He currently oversees advanced power-efficient technology developments, including novel co-designed computer architectures, custom ASICs, and heterogeneous parallel processing systems. He also leads an internal R&D thrust for DoD-oriented AI technologies. From 2010 to 2014, he held multiple roles at Mercury Systems including CTO and GM of Mercury Federal Systems. During his prior 20-year tenure at Lincoln Laboratory, he led multiple groups and became a recognized expert in ISR and communications technologies, including real-time embedded processing, digital signal processing, and RF systems. He also developed real-time process control systems while at Alcoa from 1981 to 1986. Dr. Monticciolo earned a BEE degree from The Cooper Union, an MSEE from Georgia Institute of Technology, and a PhD in electrical engineering from Northeastern University.

Prof. Srini Devadas

MIT

Challenges in Building Secure Hardware Platforms

Architectural isolation is central to ensuring application privacy and integrity when applications timeshare processor hardware. Unfortunately, architectural isolation can be broken when microarchitectural optimizations produce software side channels that can be exploited by an adversarial application. Even secure processors such as Intel SGX are not immune to software side channel attacks.

In this talk, I will describe the Sanctum secure processor architecture, which offers the same promise as SGX, namely strong provable isolation of software modules running concurrently and sharing resources, but protects against an important class of additional software attacks that infer private information by exploiting resource sharing. While the current Sanctum architecture is non-speculative and therefore immune to recent attacks that exploit speculative execution to leak secrets from kernel and application space, I will briefly describe a strategy for securing speculative execution processors from these attacks.

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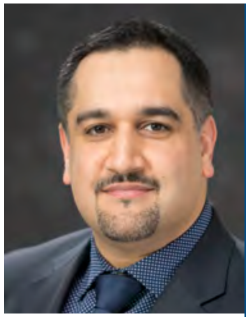
Biography

Srini Devadas is the Webster Professor of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology (MIT) where he has been on the faculty since 1988. Prof. Devadas's research interests span Computer-Aided Design (CAD), computer security, and computer architecture. He is a fellow of the IEEE and ACM. He received the 2014 IEEE Computer Society Technical Achievement award, the 2015 ACM/IEEE Richard Newton technical impact award, and the 2017 IEEE Wallace McDowell award for his research. Prof. Devadas is a MacVicar Faculty Fellow and an Everett Moore Baker teaching award recipient, which are considered MIT's two highest undergraduate teaching honors.



Dr. Hamed Okhravi

MIT Lincoln Laboratory

An Inherently Secure Computer

Mission-critical systems use commercial-off-the-shelf (COTS) components in their computing infrastructure (including processors, operating systems, and programming languages). But COTS components have vulnerabilities that expose the composite system to cyberattacks. These cyber vulnerabilities are often rooted in the legacy design. In this talk, we will describe an ongoing project to research and develop an inherently secure computer system that reduces attack surface by orders of magnitude, making it nearly impossible to break in and cause failure during finite mission duration. In close collaboration with MIT CSAIL, the project focuses on research into new processor designs, safe programming languages, and operating systems developed in safe languages, as well as development of a vision and architecture. Numerous previous efforts focused on security guarantees within individual layers of a computer system. This project will take a holistic approach. The idea is to preserve security properties throughout the software stack, which is the combined layers of software and hardware that constitute a computer system.

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Biography

Dr. Hamed Okhravi is a senior staff member in the Cyber Analytics and Decision Systems Group at MIT Lincoln Laboratory, where he leads programs and conducts research in the area of systems security. He is the recipient of the 2014 MIT Lincoln Laboratory Early Career Technical Achievement Award and 2015 Team Award for his work on cyber moving target research. He has served as the program chair for the ACM CCS Moving Target Defense (MTD) workshop 2017, the poster chair for the IEEE SecDev 2017, and is a program committee member for a number of academic conferences and workshops including ACM CCS, NDSS, RAID, IEEE SecDev, AsiaCCS, ACNS, and MILCOM. He has also served as the guest editor for the *IEEE Security & Privacy* magazine and the *Journal of Security and Communication Networks*. Dr. Okhravi earned his MS and PhD in electrical and computer engineering from the University of Illinois at Urbana-Champaign in 2006 and 2010, respectively.

Dr. Emily Shen

MIT Lincoln Laboratory

Data-Centric Secure Computing

An ever-increasing amount of sensitive and valuable data is being stored, processed, and sent around the world. Today's security approaches are generally designed to protect access to a system, with limited focus on protecting data once system access is granted, sometimes resulting in large-scale failures. We propose a data-centric approach to security, focusing directly on protecting data instead of systems. Our vision is for data to protect itself automatically at rest, in use, and in transit in distributed systems. Data-centric secure computing will use cryptographically secure storage and computation to enforce policies and will leverage data provenance and content-centric networking. This talk will describe the data-centric secure computing vision, examples of secure computing techniques and applications, and research challenges to address.

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Biography

Dr. Emily Shen is a technical staff member in the Secure Resilient Systems and Technology Group. She joined MIT Lincoln Laboratory in 2013. Her main research interest is applied cryptography. Her current work is in the areas of secure multiparty computation and cryptographically secure database storage and search.

Dr. Shen received a BS degree with distinction and honors in computer science from Stanford University in 2006. She received SM and PhD degrees in electrical engineering and computer science from MIT in 2008 and 2013, respectively, under the supervision of Prof. Ronald Rivest.

Dr. Eric Dauler

MIT Lincoln Laboratory

Quantum Computing

The development of quantum computers is motivated by their potential to perform computations that are not feasible using classical computing hardware and algorithms. However, entirely new technologies are needed to build a quantum computer, starting with the fundamental quantum bit, or qubit, that is used to store and manipulate the information. Several quantum technologies are being pursued for this purpose and two of these approaches—superconducting qubits and trapped ions—will be described to illustrate the challenges and progress in this field. Finally, the successful development of a quantum computer will rely upon advances in many areas, from material science to algorithms, so some key opportunities for collaborations and supporting products will be highlighted.

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Biography

Dr. Eric A. Dauler is the leader of the Quantum Information and Integrated Nanosystems Group. Upon joining MIT Lincoln Laboratory in 2001, Dr. Dauler first worked in the Optical Communication Technology Group advancing superconducting nanowire single photon detectors and related technologies for high-sensitivity optical communication receivers. From 2009 to 2013, he and his colleagues incorporated these detectors into the Lunar Laser Communication Demonstration and several quantum optics experiments. More recently, Dr. Dauler worked for two years in the MIT Lincoln Laboratory Technology Office, which is responsible for managing the Laboratory's internal R&D portfolio. His work on single-photon detectors was patented and has been recognized by the Laboratory's 2009 Best Invention Award and an R&D 100 Award. In 2010, Dr. Dauler was named R&D Magazine's Young Innovator of the Year. Dr. Dauler earned his SB, MEng, and PhD degrees from the Massachusetts Institute of Technology, all in electrical engineering and computer science.

Mr. Vitaliy Gleyzer

MIT Lincoln Laboratory

DataSToRM: Data Science and Technology Research Environment

Information, such as protein interactions or social networks, can be represented with a data structure called a graph. By analyzing these graphs using specialized analytics, complex relationships and deeper insight can be extracted from the raw information. This concept has been widely used across different fields and application, including analyzing customer buying habits for targeted recommendations and finding new medical applications for existing drugs. This talk will provide a systems perspective on enabling future innovation in the area of scalable graph analytics and offer insight on several technologies and efforts at the Laboratory focusing on accelerating analysis of real-world graphs that contain billions to trillions of edges.

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Biography

Mr. Vitaliy Gleyzer has been a staff member in the Embedded and Open Systems Group at MIT Lincoln Laboratory for 10 years. Prior to joining the Laboratory, he received his master's degree in electrical and computer engineering from Carnegie Mellon University, with a research concentration on network architecture and network modeling. His current work and research interests are primarily focused on high-performance hardware architectures, graph analytics, and multichannel communication systems. Over the years at the Laboratory, Mr. Gleyzer has been the lead software and hardware architect, as well as the principal developer, for several advanced communication radio technologies, distributed processing clusters, novel network recovery algorithms, and RF geolocation systems. Most recently, he has been leading the architecture and development of a scalable, high-performance graph processing hardware platform targeted to accelerating large-scale graph analytics.

The Future of Advanced (Secure) Computing Posters

Dr. Siddharth Samsi/Dr. Vijay Gadepally

MIT Lincoln Laboratory

Big Data Processing for DoD IoT and AI

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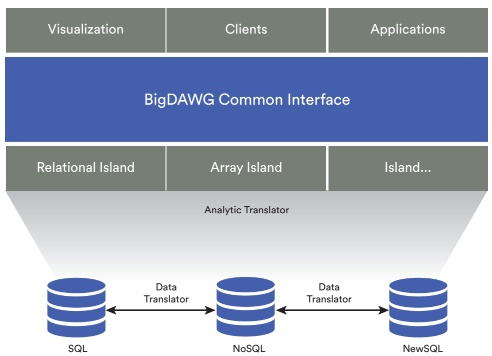
The explosion of sensor data in the DoD brings a unique set of challenges, including the sheer number of devices, diversity of data, and the varied defenses required to protect them. Building machine learning and AI tools that leverage this big data efficiently requires tools for labelling, curating, and managing this data, along with massive high-performance computing (HPC) resources to process these data. Traditionally, the DoD has developed hundreds of stovepiped interfaces and been limited to commercial off-the-shelf (COTS) processors for deployment on low-resource or otherwise constrained environments. MIT Lincoln Laboratory has been developing technologies to address these challenges in collaboration with our academic partners. The BigDAWG architecture aims to bridge the gap between different storage and data management technologies by providing a single interface for many database and storage engines. We developed a BigDAWG prototype that has been applied to a large medical dataset and demonstrated that a polystore database solution can significantly reduce computational time without excessive overhead. We are also developing theory for sparse deep learning algorithms and applying them to new and emerging hardware architectures. The GraphBLAS standard defines standard building blocks for graph algorithms in the language of linear algebra and enables the development of efficient algorithms on modern hardware. Our future research goals include the development and integration of new databases for streaming and sparse array storage, optimization of core libraries for AI systems, and support the development of new hardware architectures.

Big Data Processing for DoD Internet of Things (IoT) and Artificial Intelligence (AI)

Overview

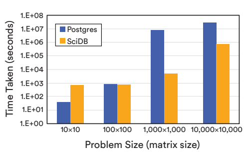
- The explosion of sensor data in the DoD brings a unique set of challenges
  - Number of devices
  - Diversity of data
  - Varied defenses required to protect assets
- Building machine learning and AI tools that leverage this big data efficiently requires
  - Labelled and curated data
  - Tools for data management
  - Massive high performance computing resources
- Solving these challenges on the tactical edge requires
  - Low-resource processing
  - Ability to function well in constrained environments
- MIT Lincoln Laboratory has been developing technologies to address these challenges in collaboration with our academic partners

BigDAWG Common Interface

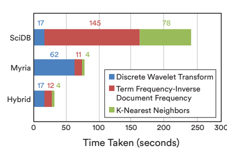


A polystore system is any database management system (DBMS) that is built on top of multiple, heterogeneous, integrated storage engines

Efficient Data Processing Using Federated Databases

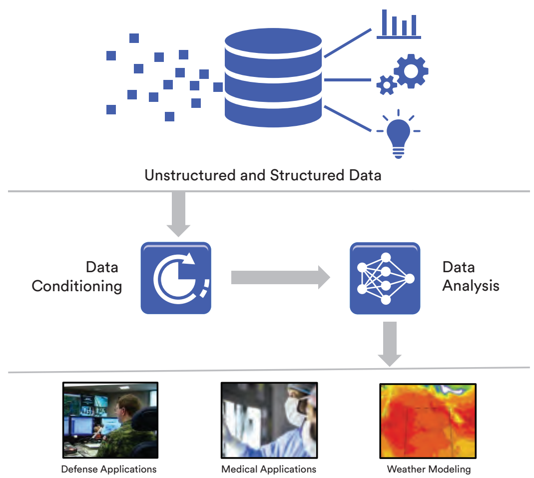


Comparing matrix-multiplication performance in different databases



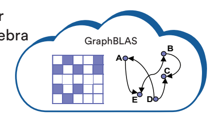
Performance of different databases for document analysis

Big Data Processing System Pipeline

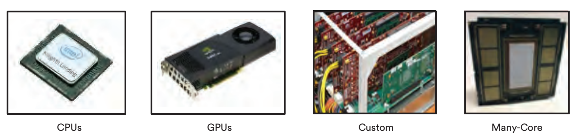


GraphBLAS-Based Processing for Big Data Graphs

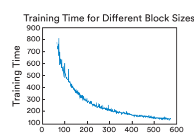
- GraphBLAS defines standard building blocks for Graph Algorithms in the language of Linear Algebra
- Generalizes linear algebra computations to extend the range of these primitives to support a wide range of parallel graph algorithms



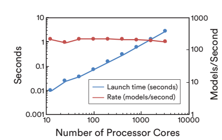
Big Data and Machine Learning on Diverse Platforms



Measuring launch and training performance of Deep Learning models across heterogeneous computing architectures



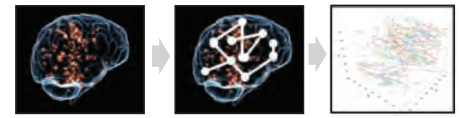
Tuning AI/Machine Learning Models for Optimal Performance



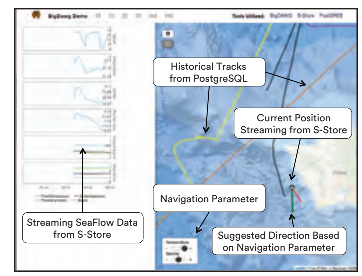
Launch Time for High Performance Machine Learning on 40,000+ Cores

Emerging Applications

Brain Mapping



Ocean Metagenome Analysis

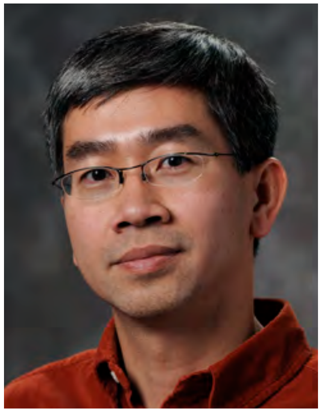


Future Work

- Develop and integrate new databases for streaming and sparse array storage
- Develop and optimize core libraries to enable efficient big data processing and AI systems on new and emerging processing architectures
- Develop new algorithms for decision support at the tactical edge
- Support the development of new algorithm techniques and define new processing architectures

References:
Brattain, Laura, et al. "A cloud-based brain connectivity analysis tool." IEEE, HPEC 2017.
Tim Mattson, et al. "Demonstrating the BigDAWG Polystore System for Ocean Metagenomics Analysis," CIDR 2017

Siddharth Samsi and Vijay Gadepally – MIT Lincoln Laboratory



Dr. Karen Gettings/Dr. Huy Nguyen

MIT Lincoln Laboratory

Efficient Computing for the Internet of Things

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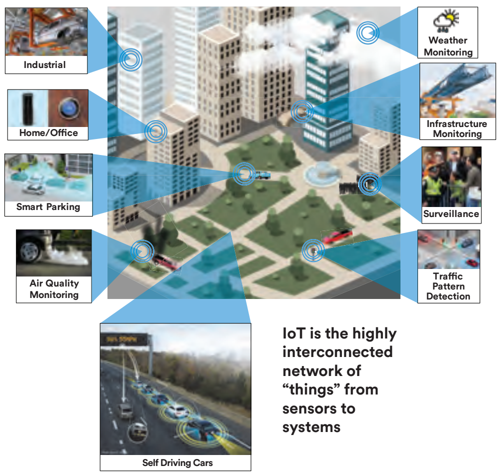
All of our interconnected devices comprise the Internet of Things (IoT). Due to rapid growth, the future of this technology needs to address critical issues such as communication bandwidth, data storage, and security, while being mindful of the power consumption of untethered (i.e., battery operated) devices. Our poster highlights enabling technologies that attempt to solve some of these issues. One of these technologies is passive or near-powerless smart sensor systems that are continually sensing the environment for an event of interest using artificial intelligence-based techniques. There are also power-efficient algorithms that allow for selective data processing using machine learning, sometimes trading accuracy for large power savings. Additionally, we illustrate how using dedicated accelerators with programmable logic can help enhance the computational efficiency while still allowing for flexibility, shorter time to market, and cost. Looking ahead, we identify several areas where work can immediately impact the future of IoT: creating infrastructures for distributed computing, using processors that can autonomously adapt from approximate to exact computing to maximize power efficiency and accuracy, and using advanced system integration to efficiently couple heterogeneous systems, such as sensors, processors, and security systems, for IoT solutions that are optimized for size, processing capabilities, and energy efficiency.

Efficient Computing for the Internet of Things (IoT)

Motivation

- Advances in efficient computing can increase the functionality and applicability of the IoT
  - Leads to greater proliferation of sensor systems and associated data processing that can improve our well being



IoT is the highly interconnected network of "things" from sensors to systems

Efficient Computing Technology Gaps Across IoT Architecture Layers

Application
Distributed network of large number of nodes with autonomous adaptability and machine learning

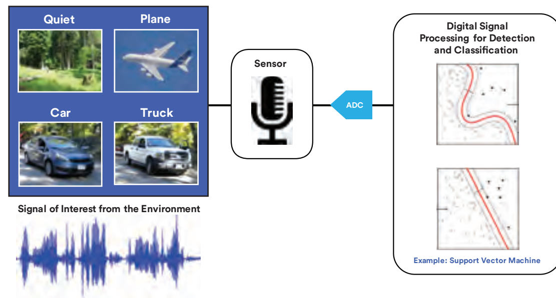
Cloud and Edge Computing
Balance of processing in the cloud, local network (edge) and in the device (thing)

Compute/Energy
Small, low power optimized compute algorithm and energy solutions for all platforms

Communications
Fully interconnected network with security for data protection at rest and during transit; large bandwidth but low power operation

Enabling Technology Examples

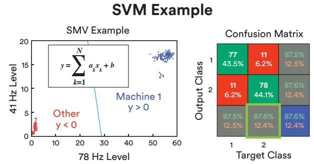
Passive Sensing and Processing



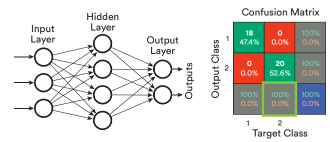
Passive or near-powerless smart sensor systems that are continually sensing to detect a specific event

Efficient Algorithms for Edge Computing

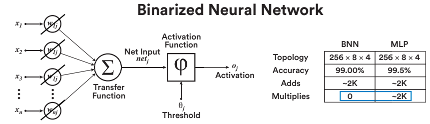
SVM Example



Neural Network Classifier



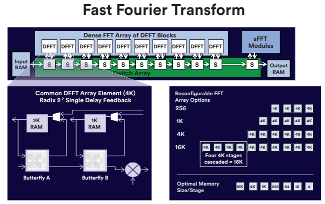
Binarized Neural Network



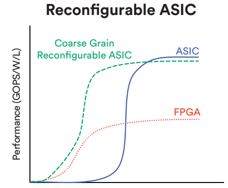
Novel low-power machine learning algorithms can resolve tasks such as detection and discrimination efficiently so they can operate at the sensor or network edge instead of the cloud

Reconfigurable ASICs with Highly Efficient Accelerators

Fast Fourier Transform



Reconfigurable ASIC

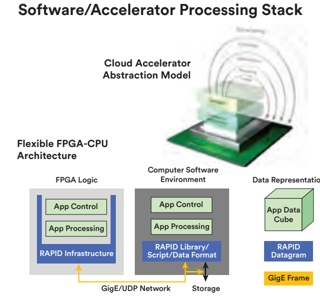


Reconfigurable ASIC system-on-chip implementations provide the flexibility of coarse grain reconfiguration with near ASIC performance, with the ability of expanding for creating even more powerful systems

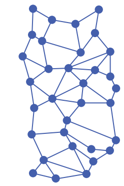
A Way Forward

Computing Infrastructure for Distributed Edge Operation

Software/Accelerator Processing Stack

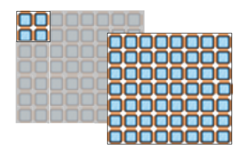


Distributed Network



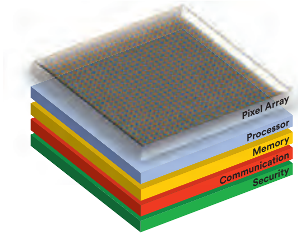
Adaptability and Reconfigurability

Approximate to exact computing using reconfiguration, autonomously adapting to the processing needs



Advanced System Integration

Heterogeneous structure integration to minimize area and power



Conclusion

- MIT Lincoln Laboratory is developing technology to advance IoT edge computing
- There is enormous potential for power savings
- Possibility to tailor solutions to complex problems with fast turnaround times
- University collaboration could help to address technology gaps for the future IoT

Karen Gettings and Huy Nguyen – MIT Lincoln Laboratory

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Dr. Michael Hurley/Dr. William Song

MIT Lincoln Laboratory

Custom Processor Architectures for Probabilistic Programming

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Probabilistic programming enables decision making in the presence of uncertainty by creating statistical inference models. Recent advances in probabilistic programming have enabled the rapid development of specific applications in many fields such as machine vision, semantic language processing, and financial analysis. Unfortunately, most implementations are poorly suited to time-critical decision-making because of inefficient execution caused by poor matches between the computations common in probabilistic programming and the computational structures, memory systems, and communication networks found in conventional computers. MIT Lincoln Laboratory has started to investigate whether custom processor architectures can dramatically accelerate probabilistic programming algorithms, thus enabling their use in a wider array of time-critical applications. To start, we conducted a small number of conceptual case studies focused upon the Markov Chain Monte Carlo (MCMC) algorithm, which is one of the most commonly used inference algorithms. The preliminary results indicate that some versions of the MCMC algorithm can be significantly accelerated with custom processor architectures constructed through algorithm-architecture co-design. Going forward, we plan to explore key enabling kernels that can accelerate a broad class of probabilistic programming algorithms as well as identify the relevant time-critical applications that could most benefit from custom-processor-enabled acceleration.

Custom Processor Architectures for Probabilistic Programming

ARTS

Motivation

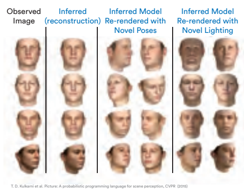
Computational Acceleration of Probabilistic Programming

Probabilistic programming is computationally inefficient for complex time-critical applications

- Conventional processors are not optimized for probabilistic processing, memory usage, and data flow

Current state of applications

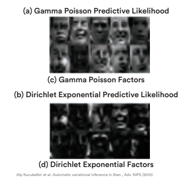
- Some non-time-critical applications
  - Computer vision
  - 3D face/road models from 2D images
  - Semantic language processing
  - Space object identification
- Few time-critical applications
  - Only possible with simple models and small data sets



Analytic and Sampling Techniques

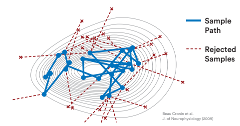
Analytic techniques

- Belief propagation
- Expectation maximization
- Expectation propagation
- Laplace's method
- Variational Bayesian methods
- Variational message passing

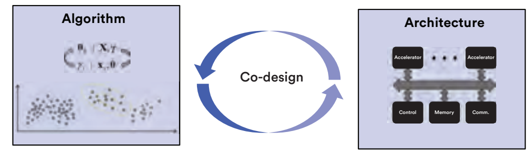


Sampling techniques

- Enumeration query
- Function inverse query
- Rejection sampling
- Importance sampling
- Markov chain Monte Carlo



Algorithm/Architecture Co-Design Approach

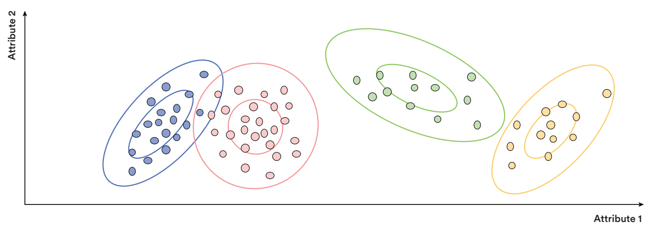


- Joint optimization of algorithm and architecture
  - New algorithms and architectures developed to work together
- Order(s) of magnitude higher optimization possible over single domain optimization
- Requires team personnel that are well versed in both algorithm and architecture
  - Much more efficient optimization possible over two teams of experts

Markov Chain Monte Carlo (MCMC) Example Case Studies

MCMC-Based Probabilistic Clustering

- Probabilistic clustering identifies the structure of data
  - Models data as mixtures of distributions (e.g., Gaussian mixture model)

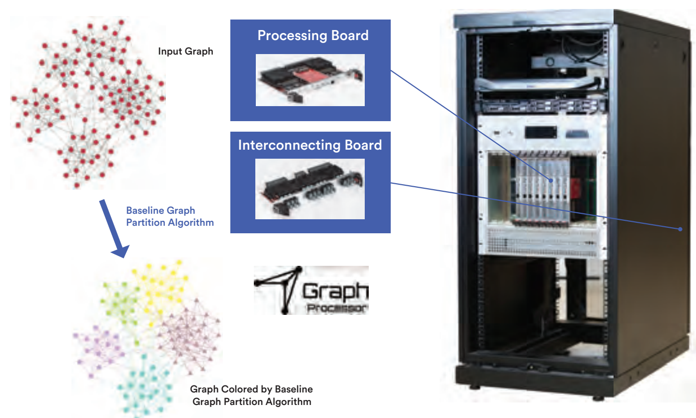


- Probabilistic clustering, with principled inference, is more rigorous than other clustering approaches
  - Estimate the parameters of each cluster
  - Assign each data point to cluster(s)
  - Determine optimal number of clusters with well-founded criteria
    - Bayesian information criterion, entropy minimization, and more
- Preliminary computational analysis indicates that custom processor architectures may be able to accelerate the processing significantly

$$\theta_k \mid \mathbf{X}, \gamma$$
$$\gamma_i \mid \mathbf{x}_i, \theta$$

Iterative MCMC Update

MCMC-Based Graph Partitioning



Number of edges between block t_1 and t_2 according to partition b on graph G

$$p(\mathbf{b}|G) \propto \sum_{t_1, t_2} M_{t_1 t_2} \ln\left(\frac{M_{t_1 t_2}}{d_{t_1} d_{t_2}}\right)$$

Number of edges in block t_1 and t_2

- Custom processor architectures can speed up processing significantly
  - MIT Lincoln Laboratory Graph Processor well suited for the task

Future Research Directions

- Faster processing times enabled by custom processor architectures to enable many time-critical applications for probabilistic programming
- Co-design of algorithm and architecture to provide significant performance and power-efficiency gains
- Optimized processor architecture for key probabilistic programming kernel implementations to be used across diverse applications
- Optimized hardware and software with user-friendly interfaces to speed up application adoptions

William Song, Edward Kao, Cem Sahin, Mike Hurley, Paul Monticciolo, and Sanjeev Mohindra – MIT Lincoln Laboratory

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Revolutions in Biotechnology

Advances in biotechnology are increasing at a rapid pace with applications in human health and performance that would seem to come from science fiction. Synthetic biology and genome editing are curing inherited diseases, such as sickle cell anemia, as well as certain forms of cancer. A deeper understanding of brain structure, wiring, and function is enabling new insights and treatments for neurotrauma, neurodegenerative diseases, and psychological disorders. Advances in sensors and analytics are enabling better quantification of human physiology. Meanwhile, our service members are confronted with multiple threats on the battlefield, including extreme environmental conditions, trauma, and PTSD. This session will focus on multiple biotechnologies being developed at MIT Lincoln Laboratory that will improve insights into the brain, human behavior, and the microbiome, and how they will improve the health and performance of our service members.

The session will begin with a keynote from Dr. Joseph Bolen, Chief Scientific Officer at PureTech Health. Dr. Bolen will discuss the dynamic interactions across the brain and body and how the PureTech Health family of companies is tackling key health challenges. The presentations and posters include neural sensing technologies, brain/computer interface, sensorimotor tracking of neurological disorders, and an artificial gut for microbiome R&D. We look forward to engaging with our academic, clinical, and industry partners in applying these new technologies to improve health and performance.

Mr. Edward Wack

MIT Lincoln Laboratory

Warfighter Health and Performance

Advances in biotechnology are increasing at a rapid pace with applications in human health and performance that would seem to come from science fiction. Synthetic biology and genome editing are curing inherited diseases such as sickle cell anemia as well as certain forms of cancer. A deeper understanding of brain structure, wiring and function is enabling new insights and treatments for neurotrauma, neurodegenerative diseases, and psychological disorders. And advances in sensors and analytics are enabling better quantification of human physiology. Meanwhile our service members are confronted with multiple threats on the battlefield including extreme environmental conditions, trauma, and PTSD. This session will focus on multiple biotechnologies being developed at MIT Lincoln Laboratory that will improve insights into the brain, human behavior, and the microbiome, and how they will improve the health and performance of our service members.

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Biography

Edward C. Wack is assistant division head of the Homeland Protection and Air Traffic Control Division at MIT Lincoln Laboratory. In this role, he shares responsibility for research, development, evaluation, and technology transfer of advanced technologies and systems for chemical and biological defense, bioengineering, and biomedical systems. Prior to this position, Mr. Wack was the leader of the Bioengineering Systems and Technologies Group, which focuses on innovative advanced technology programs in biodefense, forensics, and biomedical research. Mr. Wack was also the director of future acquisition at the Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD) within the Department of Defense. Before joining the JPEO-CBD, Mr. Wack spent 13 years at Lincoln Laboratory, including as assistant group leader in the Sensor Systems and Applications Group. Mr. Wack earned a BA degree in mathematics from the College of the Holy Cross and an MS degree in bioinformatics from Brandeis University.

Dr. Joe Bolen

PureTech Health

The Brain–Immune–Gut Super System and the Emergence of Human Chronic Disease

Chronic diseases—such as diabetes, obesity, cancer, heart disease, depression, arthritis, schizophrenia, and Alzheimer's disease—represent the most common and costly of all health problems. The primary influences governing chronic disease risk are age and environmental exposures, which together outweigh the contribution of an individual's inherited genetic content.

Two of the human body's organ systems—the nervous system and the immune system—represent the major adaptive systems responsible for interacting with the environment. Together they comprise the sensory interfaces that recognize, assimilate, and respond to environmental changes. While these systems have historically been viewed as functionally independent, it is now recognized that the nervous system and immune system can be more accurately considered an integrated adaptive super system. These new insights raise the possibility that the basis of many complex chronic human diseases may in fact represent pathologies created through the disruption of allosteric response balance with the nervous–immune adaptive super system.

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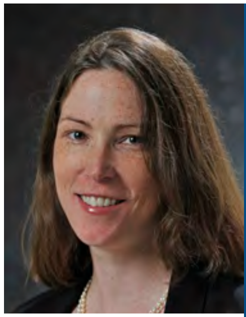
Biography

Dr. Joe Bolen is chief scientific officer at PureTech Health, where he works with the company's discovery and preclinical team to identify and pursue promising new technologies. Dr. Bolen has more than 30 years of industry and research experience and has been at the forefront of cancer and immunology research. He began his career at the NIH, where he contributed to the discovery of a class of proteins known as tyrosine kinase oncogenes as key regulators of the immune system. Dr. Bolen most recently oversaw all aspects of R&D for Moderna Therapeutics as president and chief scientific officer. Previously, he was chief scientific officer and global head of Oncology Research at Millennium: The Takeda Oncology Company. Dr. Bolen graduated from the University of Nebraska with a BS degree in microbiology and chemistry and a PhD in immunology and conducted his postdoctoral training in molecular virology at the Kansas State University Cancer Center.



Dr. Danielle Braje

MIT Lincoln Laboratory

Diamond Sensors for Brain Imaging

Understanding the inner workings of the human brain remains a relatively uncharted frontier. Consciousness, thought, emotions, and decisions originate from electrical currents generated by and propagating through complex maps of neurons. Non-invasive detection of neuronal activity requires picking up minute electromagnetic signals. Current magnetoencephalography systems typically employ cryogenic sensors in a magnetically shielded facility to achieve this. We are building a diamond-based, room-temperature sensor, designed to sense the magnetic signatures of impulses generated by neurons. Using quantum systems in the diamond could allow an alternative to existing magnetoencephalography techniques, potentially enabling evaluation of neuronal signals beyond a shielded room. This type of advance may help propel magnetoencephalography into a more widely-used diagnostic tool to help address neurological disorders including epilepsy and post-traumatic stress disorder.

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Biography

Dr. Danielle A. Braje is an assistant leader of the Quantum Information and Integrated Nanosystems Group at MIT Lincoln Laboratory. With a focus on quantum sensing, her group applies the fundamental stability of quantum systems to the sensing arena. Current development focuses on advanced quantum control for small, portable solid-state systems, such as nitrogen vacancies in the diamond lattice. Her research interests span from atomic physics and low-light-level nonlinear optics to atom interferometry and quantum coherence. Prior to joining Lincoln Laboratory, Dr. Braje was a faculty member at Reed College, working in coherent effects in laser-cooled atoms and as a scientist at the National Institute of Standards and Technology (NIST)–Boulder developing compact laser frequency combs. She earned her BS degree in physics from the University of Arizona and her PhD degree in applied physics from Stanford University.

Dr. Albert Swiston

MIT Lincoln Laboratory

Microelectronics Interfacing Neural Devices (MIND)

Interfacing electronic and biological systems has been a long intractable problem, leading in vivo medical devices to suffer from biofouling, short lifetimes, size-weight-power constraints, and low sensitivity. Many of these issues arise from the mismatch between the biotic-abiotic interface, and can be significantly reduced if devices are fully wireless, extremely small, and mechanically soft. The MIND program seeks to build such a device: the world's smallest, mixed-signal, single-channel, neural signal acquisition and communication system, capable of measuring and reporting action potentials from individual nerves and neurons, while being placed in the body via facile injection rather than surgical implantation. This device will allow for greater spatio-temporal understanding of the nervous system, and could lead to better-guided interventions for a wide range of neurological and inflammatory diseases.

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Biography

Dr. Albert Swiston is a principal investigator in the Bioengineering Systems and Technologies Group at MIT Lincoln Laboratory. Dr. Swiston's research focuses on novel medical devices and physiological signals analysis for military and civilian applications. His work has been published in Nature Materials, Science Translational Medicine, PLoS, and IEEE journals. He served as a National Security Scholar in the U.S. Intelligence Community and as a Science and Technology Policy Fellow at the National Academies' Committee on Science, Engineering, Medicine, and Public Policy. Dr. Swiston earned BS/MSE degrees from Johns Hopkins University and a PhD in materials science and engineering from MIT.

Dr. Catherine Cabrera

MIT Lincoln Laboratory

Microbiome

Engineering the human microbiome has shown emerging potential to address health and performance without major ethical concerns. Current research in the "gut-brain axis" has linked gut dysfunction to a wide variety of neurologic and cognitive disorders, including those associated with Parkinson's disease. A lack of methods to rapidly test engineered microbiomes has drastically slowed down development of potential therapies and high-throughput studies of the microbiome. MIT Lincoln Laboratory has been developing a wide range of in silico and in vitro tools for studying the microbiome through devices that mimic the complex environment of the human gut. MIT Lincoln Laboratory has leveraged its expertise in engineering, modeling, and prototyping to develop an artificial gut (ArtGut), which focuses on oxygen gradients and the role of mucus. Through the ArtGut program, we have shepherded together a collaborative network to tackle Parkinson's disease head-on.

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Biography

Dr. Catherine R. Cabrera is assistant leader of the Bioengineering Systems and Technologies Group at MIT Lincoln Laboratory. She received her BA degrees in biochemistry and chemical engineering from Rice University and her PhD in bioengineering from the University of Washington. Dr. Cabrera joined the Laboratory in 2002, initially working on hardware and software development for biowarfare agent ID, particularly for field-forward applications. In 2010, Dr. Cabrera was promoted to assistant group leader and became part of the team leading the Laboratory's efforts to expand biomedical R&D and is the current lead of the biomedical Line. Dr. Cabrera currently oversees a portfolio of 20+ projects, which include molecular biomarkers for heath and performance, engineered biological systems, and advanced DNA forensics.

Revolutions in Biotechnology Posters

Dr. Laura Brattain

MIT Lincoln Laboratory

Large-Scale Brain Mapping

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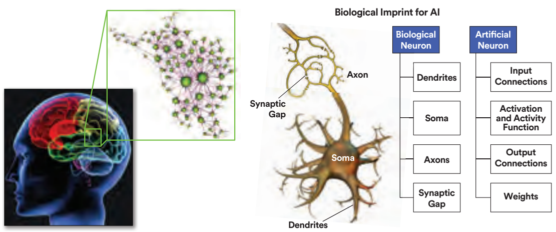
Large-scale brain mapping is hampered by the lack of automated image processing algorithms. MIT Lincoln Laboratory is working with MIT Chung Lab to develop the capability for long-range neuron tracing and large-scale connectivity analysis in the human brain. By building a detailed brain map, we aim to gain insight into brain disorders (e.g., mTBI and PTSD) and seek new ways for treatment. Through leveraging MIT Lincoln Laboratory advanced technologies, such as object tracking in dense scenes, novel machine learning algorithms, and supercomputing resources, we have developed a platform for automated dense neuron tracing that achieves orders of magnitude speed-up when compared to current state of the art. The image processing pipeline lays the groundwork for constructing high-resolution brain maps and characterizing the many neuron types still unknown. This work has great potential in making an impact in the neuroscience community as a whole.

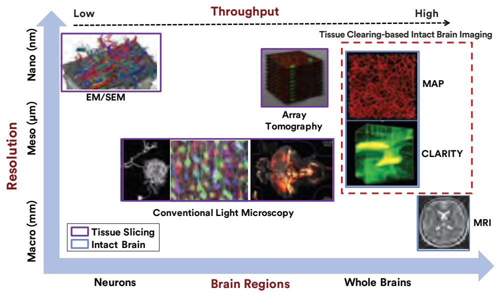
Large-Scale Brain Mapping

Motivation

- Human brain: 86 billion neurons and 100 trillion synapses
- Bridge the link between functional connectivity and anatomical connectivity
- Elucidate structural abnormality in brain disorders (e.g., PTSD, TBI, or depression) and seek new ways for treatment
- Decipher the brain's algorithms to revolutionize machine learning



Brain Imaging at Different Scales

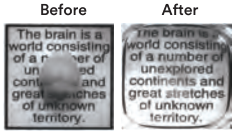


CLARITY/MAP Intact Brain Imaging*

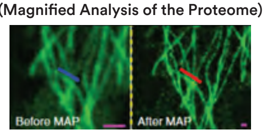
- CLARITY/MAP: High throughput (~1 TB/hr) and high resolution (cellular)
- Challenges: Efficient and fast analysis of massive brain imageries

CLARITY

Before After



MAP
(Magnified Analysis of the Proteome)

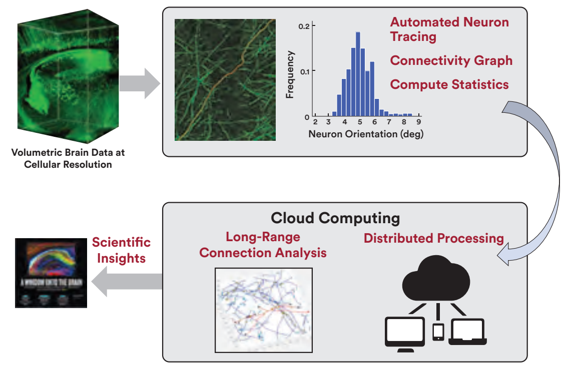


- Enable volumetric imaging
- Track long-range projections
- Resolve cellular structures
- Perform molecular phentotyping

- Expand linearly by four-fold
- Preserve overall architecture
- Resolve subcellular structures

Goals

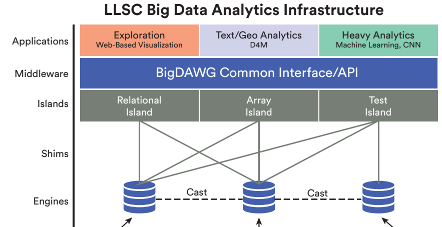
- Build a new platform to reconstruct brain connectivity from high-throughput, high-resolution, and large field-of-view microscopy brain images
- Analyze brain connectivity to gain deeper insights on brain functions



Approach
Leverage Advanced Technology

- Provides a flexible backend using a hybrid of databases (text, image, graph, etc.)
- Utilizes a common user interface/API
- Facilitates data sharing and collaborations with campus and the neuroscience community worldwide

LLSC Big Data Analytics Infrastructure

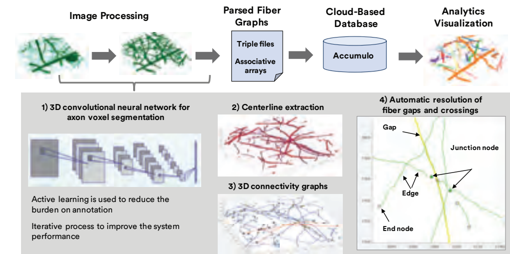


PostgreSQL
- Image metadata
- Optics/microscope metadata
- Biological metadata (tissue type, staining technique, etc.)

SciDB/TileDB
- 3D MAP/CLARITY image data
- Fiber tracks

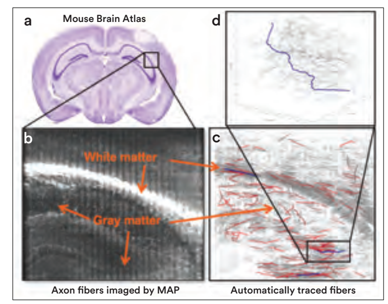
Accumulo
- Graph data from fiber tracks
- Connectivity analysis

MIT Lincoln Laboratory Brain Imagery Processing Pipeline**



- Learning-based image processing algorithms
- High performance cloud computing platform

Dense Axon Tracing

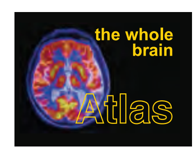


- 220,000 traced fibers in a 250 GB volume
- 10 hrs on LLSC (as opposed to months if done manually)
- Total length ~34 m
- Longest fiber is ~2 mm

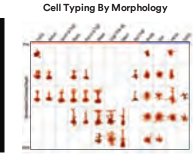
Exciting Applications

Goals
- Build a high-resolution whole brain atlas
- Enable cell typing by morphology and connectivity
- Map the structure to function
- Compare healthy and diseased brains

Challenges
- Novel algorithms for large-scale cell detection and co-registration
- To further improve the processing speed on the cloud
- Novel user interface to support interactive analytics



Cell Typing By Morphology



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*Chung et al. Nature 2013, Ku et al. Nature Biotechnology 2016
**Brattain et al. ISBI 2017, Brattain et al. HPEC 2017, Hernandez et al. ISBI 2018

Dr. Christopher Smalt

MIT Lincoln Laboratory

A Brain Computer Interface for Hearing Aid Design

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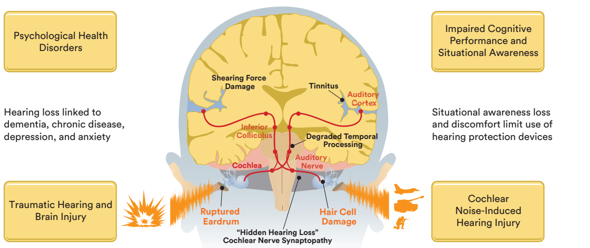
Hearing impairment and challenging listening environments reduce auditory situational awareness and speech intelligibility. These impairments can threaten a warfighter's operational performance, mission success, and survival, and have well-established, negative physical and economic consequences for warfighter health post-deployment and in retirement (VA, 2016). Hearing loss is permanent, so hearing aids often are employed in an attempt to restore auditory performance. Hearing aids notoriously do not work well in restoring communication ability—particularly in environments with a high amount of background noise or multiple speakers—because they cannot identify or selectively amplify the signal of interest (the talker).

Our aim is to reduce the cognitive burden of isolating a single speaker in background noise and thus improve communication ability. The approach for auditory attention decoding (AAD) relies on a brain-computer interface to determine the attention of the listener, then isolate and enhance the acoustic signals of interest. We will leverage a long history of speech separation and enhancement algorithms developed at MIT Lincoln Laboratory, as well as deep neural networks (DNNs), to decode attention from noninvasive electroencephalography (EEG) measurements. Talkers in the environment are separated through acoustic beamforming or other techniques, then fed into a DNN to predict the measured EEG, and thus the attention of the listener. Finally, the intended talker is played back over an earpiece to the listener.

A Brain Computer Interface for Hearing Aid Design

Background

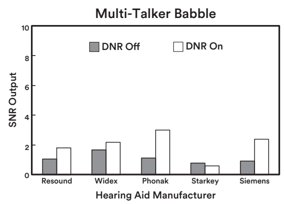
- Over 230,000 new cases of auditory disabilities reported by the VA in 2016
- Over 5% of the world's population – 360 million people – has disabling hearing loss
- Hearing aid market expected to be $10B by 2024



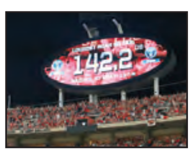
Hearing Aids Amplify Sound But Don't Restore Hearing Like Glasses Correct Vision

- Limited bandwidth
- Limited noise reduction
- Limited ability to differentiate signal from noise, particularly in multi-talker scenarios

DNR: Digital Noise Reduction (Source: Professor Andrea Pittman, ASU)



Noisy environments with many talkers present challenges to hearing impaired and normal listeners.



Problem: New technologies are needed that can improve intelligibility in these challenging environments

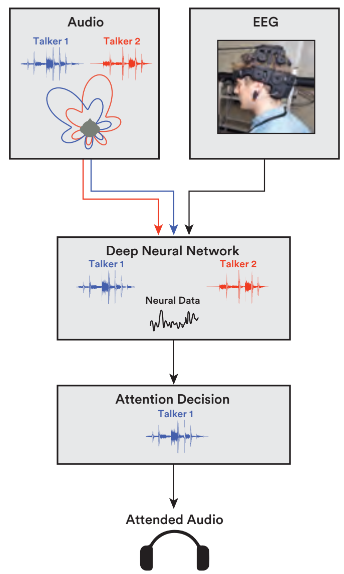
MIT Lincoln Laboratory Approach: Auditory Attention Decoding

Goal: Use a brain computer interface to extract noninvasive neural signals (EEG) and automatically decide which of two talkers a listener is focusing on and incorporate into a hearing enhancement system

MIT Lincoln Laboratory collaborators at Columbia University pioneered this technique using invasive neural recordings (Mesgarani and Chang, 2012, *Nature*) and more recently using EEG (O'Sullivan, 2014, *Cerebral Cortex*).

MIT Lincoln Laboratory Super Hearing Aid Design

- Improved speaker separation and enhancement using microphone beamforming
- Deep neural network algorithm to predict attention, i.e., decode which talker the listener is focusing on, using EEG and acoustic signals
- Select the appropriate enhanced acoustic signal based on attention, present audio to the listener



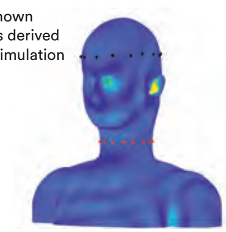
Speaker Separation

- Beamforming and spectral separation techniques can be used to isolate the audio of each talker in the environment
- Initial microphone layouts are shown below with beamformer weights derived from boundary element (BEM) simulation

BEM Simulation
(45° Azimuth)

● Microphone positions for forehead array

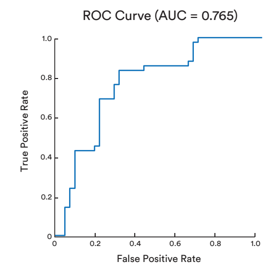
● Microphone positions for neck array



Auditory Attention Decoding Results

- EEG collection in progress for both normal hearing and hearing impaired individuals
- Initial study uses 64 electrodes, with the ability to downselect the number of EEG channels being used in offline processing

- Preliminary classifier performance results are shown below, for predicting which of two talkers in the environment the listener is focusing on



Future Work and User's Technology Outlook

- Knowledge of the user's attention can provide opportunities for acoustic signal enhancement for hearing aids, increased perceptual ability
- Machine learning techniques, including deep neural networks, provide a high-performance technique when coupled with on-body sensor information, including EEG, audio, vision
- This approach can be utilized for other modalities and senses, providing increased situational awareness, decreased cognitive burden, and enhanced performance

Christopher Smalt – MIT Lincoln Laboratory

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Dr. Megan Blackwell

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Wearable System for Near-Infrared Brain Imaging

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Advanced imaging technology developed at MIT Lincoln Laboratory can be transformative for other fields of use, such as medical imaging. This project is optimizing the design of single-photon sensitive detectors, previously demonstrated in laser radar and laser communication applications, for non-invasive brain imaging.

A new technique developed by our collaborators at the Martinos Center for Biomedical Imaging at Massachusetts General Hospital uses pulsed near-infrared light through the skull to simultaneously estimate blood flow and changes in both oxy- and deoxy-hemoglobin concentrations related to brain activity. This technique is called time-domain diffuse correlation spectroscopy (TD-DCS). Measuring both hemoglobin concentration and blood flow enables the estimation of cerebral oxygen metabolism, which provides a more robust estimate of neuronal activity than other techniques, such as functional magnetic resonance imaging, which measure signals affected by changes in blood flow or deoxyhemoglobin concentration alone.

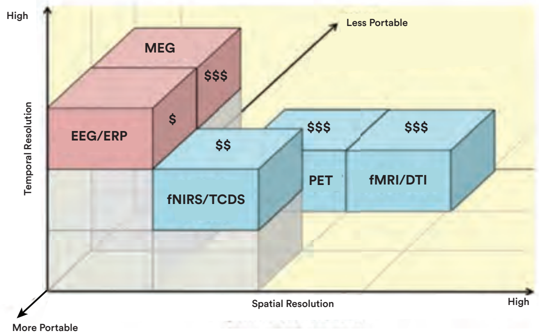
In close collaboration with the Martinos Center, a Laboratory team is constructing a TD-DCS test bed to better understand the optical phenomenology to inform the design of future single photon detectors. Time-gating the detectors to collect photons after a specific delay sensitizes the measurement to brain activity, as reflections from cortical brain tissue will take longer to propagate than reflections off the superficial layers of the scalp and skull. The end goal of the project is to develop a wearable array of up to 128 sensing nodes that would cover the head and, at the same time, permit measurements of subjects performing more natural behaviors than presently permitted with other imaging methods.

Wearable System for Near-Infrared Brain Imaging

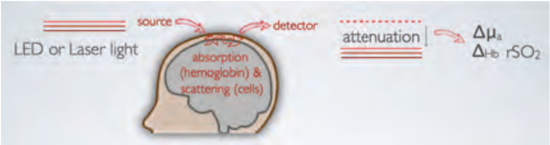
ARTS

Background

Functional near-infrared spectroscopy (fNIRS) is an inexpensive, portable means of noninvasively imaging brain function. Because of its low cost and adequate spatial and temporal resolution, fNIRS is gaining popularity as a tool to study the normal and pathological brain.

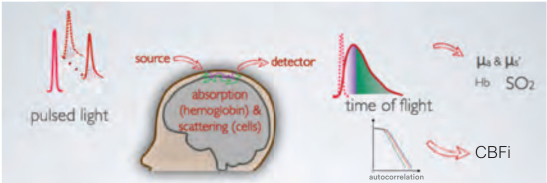


Most fNIRS techniques use a continuous-wave laser source and single-photon detectors to measure changes in blood volume and hemoglobin oxygenation in response to brain function.



Continuous-Wave Near-Infrared Spectroscopy

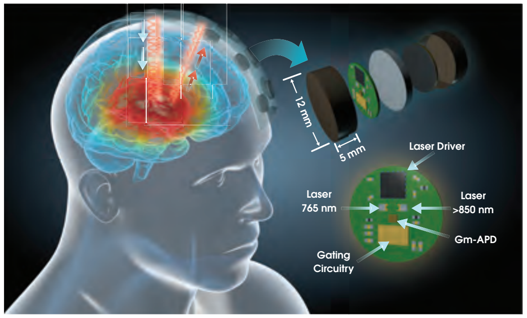
By using a train of long-coherence length laser pulses and gated single-photon detectors, Lincoln Laboratory can simultaneously measure blood volume, blood oxygenation, and blood flow.



Time-Domain Diffuse Correlation Spectroscopy

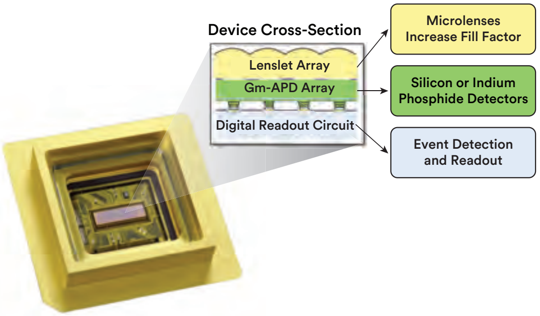
Novel Approach

In close collaboration with the Martinos Center for Biomedical Imaging, Lincoln Laboratory is creating the first wearable system for time-domain diffuse correlation spectroscopy (TD-DCS).



Our vision is to create a cap containing 128 optodes, each having two pulsed laser sources and MIT Lincoln Laboratory (MIT LL)-designed Geiger-mode avalanche photodiodes.

MIT Lincoln Laboratory is a world leader in Geiger-mode APDs and has developed large arrays that have been demonstrated in high-performance photon-counting applications, such as ladar imaging test beds and laser communications.



Geiger-mode APDs provide

- Single-photon sensitivity
- Gated detection → greater sensitivity to brain
- Lots of current → easy digitization
- Fast breakdown → excellent (sub-ns) time resolution
- Scalability to large array formats → cost-effective approach to whole-brain imaging

Advantages

The MIT Lincoln Laboratory novel TD-DCS system uses pulsed long-coherence length lasers and time-gated photon-counting detectors and offers several advantages over standard fNIRS approaches:

- Improved spatial localization of brain activity
- Greater optode density in portable packaging
- Cost-effective approach to whole-brain imaging
- Less contamination by scalp, skull, and cerebrospinal fluid
- A more robust measure of neuronal activity
  - Measuring both cerebral blood flow and cerebral oxygenation enables the estimation of cerebral oxygen metabolism ($CMRO_2$)

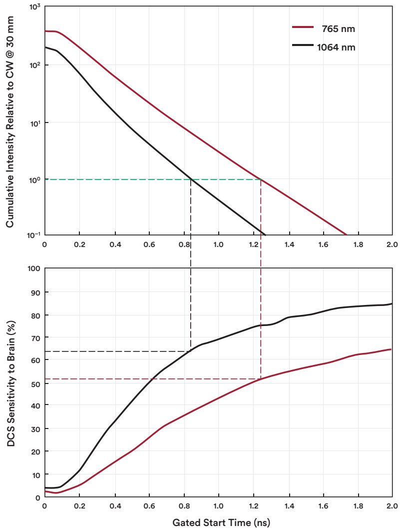
Next Steps

Recent discoveries have motivated investigation of sources and detectors at longer wavelengths.

Although at longer wavelengths water absorption is higher, scattering is lower and permits a greater penetration depth and improved resolution. A two-compartment Monte Carlo model estimates a 20–30% increase in brain sensitivity at 1064 nm compared to 765 nm.

Lincoln Laboratory is currently designing APD test chips for operation at 765 nm and 1064 nm and evaluating optode packaging approaches.

Monte Carlo Simulation of Two-Compartment Phantom



Megan Blackwell – MIT Lincoln Laboratory

Dr. Adam Lammert

MIT Lincoln Laboratory

Sensorimotor Tracking of Neurological Disorders: Mild Traumatic Brain Injury (mTBI)

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MIT Lincoln Laboratory (MIT LL) has been developing noninvasive biomarkers of neurological conditions based upon observable human behaviors. These biomarkers have been successful for assessing a variety of neurocognitive conditions, such as depression, Parkinson's disease, and traumatic brain injury (TBI). TBI is prevalent in civilians and service members, and is associated with a diverse set of cognitive and sensorimotor symptoms. As such, there is a pressing need to go beyond the typical coarse severity classifications (i.e., mild, moderate, severe) when diagnosing patients with TBI. It is essential to develop technologies with the ability to disambiguate mild TBI (mTBI) phenotypes, which in turn should facilitate the design of enhanced patient care systems for monitoring and targeted intervention. Recent advances in virtual reality—embodied in the virtual environment at the MIT LL STRIVE Center—have enabled increasingly immersive sensorimotor provocative tests, which can challenge subjects with situations that elicit underlying deficits. Pairing provocative tests with neurologically relevant, mechanical models of sensorimotor control—developed at MIT LL—provides a neurocomputational substrate that can aid in establishing causal relationships between impaired pathways and observed behaviors. Ultimately, individualized, mechanical models of sensorimotor control may aid in designing novel physiological assessments, as well as predicting outcomes associated with rehabilitation interventions for people who have suffered a TBI.

Sensorimotor Tracking of Neurological Disorders: Mild Traumatic Brain Injury (mTBI)

Brain-Related Disorders Affect Quality of Life for Millions Worldwide

- Prevalent in military and civilian populations
- Leading contributor to global disease

Examples

Traumatic Brain Injury Characteristics

Primary Causes

- Civilians: falls, motor vehicle accidents, sport injuries
- Servicemembers: blast injury

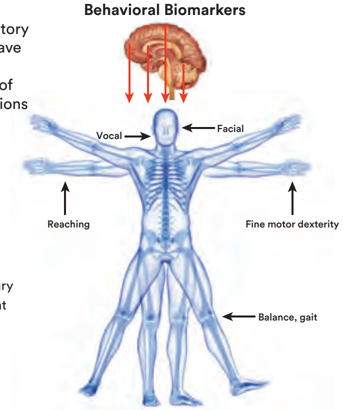
Impairments

- Dizziness and balance problems, attention and memory deficits, weakness, speech impairment, reduced problem-solving
- Affects 1.7 M/yr in civilian population, total lifetime cost of $60B/yr
- Mild TBI (mTBI, or concussion) is most common

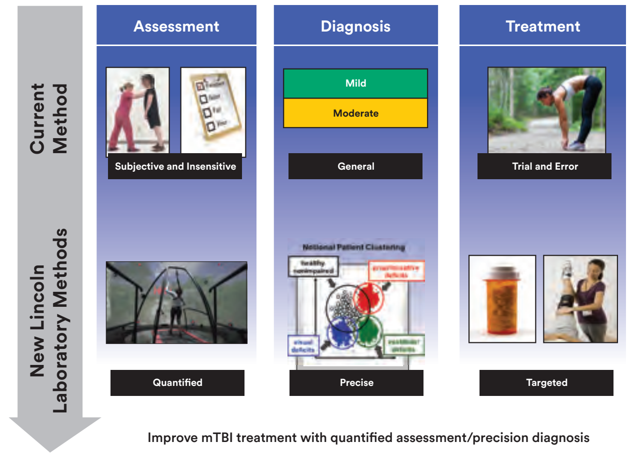
Behavioral Biomarkers as a Method for Assessing Neurological Disorders

- Pioneering work at MIT Lincoln Laboratory using biomarkers have been successful at assessing a variety of neurological conditions
- Prior work focused on depression
  - Parkinson's disease
  - TBI
- Continuing work focuses on three broad areas
  - Psychological health
  - Neuro-traumatic injury
  - Cognitive impairment

Behavioral Biomarkers



Diagnosing mTBI through Quantified Human Movement



Improve mTBI treatment with quantified assessment/precision diagnosis

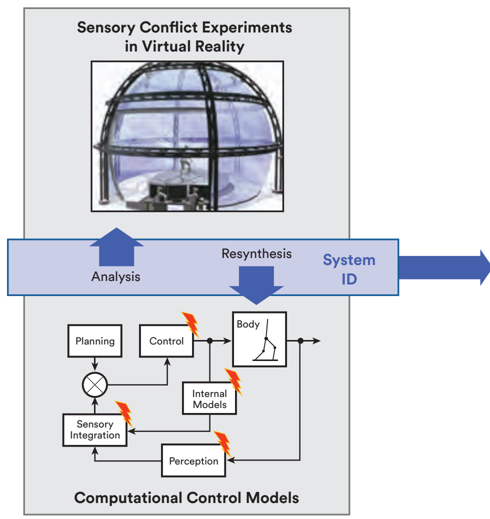
Assessment

Sensorimotor Provocative Tests at STRIVE

- Fully immersive virtual environment system
- 24-foot immersive dome offers a 360° visualization screen surround sound
- 18 camera motion capture system dual-belt, instrumented treadmill mounted on a 6 degrees-of-freedom motion platform
- Real-time software injects visual changes of scene in a flexible manner

Diagnosis

Individualized Understanding of TBI Symptoms



Mechanism	Value	Normal?
Visual Feedback	1.3	✓
Vestibular Feedback	2.1	✗
Proprioceptive Feedback	0.7	✓
State Prediction	0.2	✓
Motor Planning	1.1	✓

Analysis-by-Synthesis for System Identification

Treatment

Practical Impacts

- Wide applicability
  - Methods may be useful for assessing preclinical onset of Parkinson's disease, Lou Gehrig's disease
- Improved outcomes
  - Determining mechanisms of impairment can facilitate targeted treatment
- Enhanced assessment
  - Individualized models can be used to design focused clinical tests

STRIVE Center Capabilities

- Virtual prototyping of human-autonomous system teaming
- AI-enabled human performance enhancement
- Rapid, multisensory human physiological modeling
- Early-stage testing and evaluation of novel wearables

Adam Lammert, Thomas Quatieri, Michael Nolan, Gregory Ciccarelli, Ryan McKindles, Jeffrey Palmer – MIT Lincoln Laboratory; P. Bonato, A. O'Brien, G. Vergara-Diaz, R. Zafonte – Spaulding/MGH/Harvard

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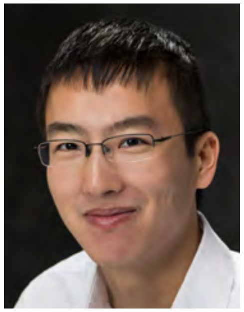


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Inhalable Nanosensors for Rapid Breath-Based Pathogen Identification in Respiratory Infection

Acute respiratory infections are the third most common cause of death worldwide and are caused by a number of pathogens. Current standards for pathogen identification, such as microbiological cultures, take at least one to two days. In the interim, empirical treatment, often involving broad-spectrum antibiotics, is administered. Thus, delays in pathogen identification contribute to antibiotic overuse, the rise of drug resistance, and increased risk for infection-associated morbidity or mortality. To potentially diagnose and monitor diseases rapidly, we engineered inhalable nanosensors that release volatile reporters into the breath in the presence of proteases upregulated during infection. These “synthetic breath biomarkers” circumvent many difficulties with using endogenous volatiles (e.g., high environmental background). In a proof-of-principle, we synthesized a neutrophil elastase nanosensor to assess differentiating healthy and bacterial-pneumonia-infected mice. Detection was done using a vapor detection mass spectrometer developed at MIT Lincoln Laboratory. Reporter release was specifically triggered in vitro by purified neutrophil elastase and ex vivo by elevated neutrophil elastase levels in infected lung homogenates. When administered in vivo, infected mice could be identified within 20 minutes after nanosensor inhalation. Future work includes developing a nanosensor 10-plex to generate signatures specific to pathogens such as Mycobacterium tuberculosis and investigating handheld detection devices.

Inhalable Nanosensors for Rapid Breath-Based Pathogen Identification in Respiratory Infection

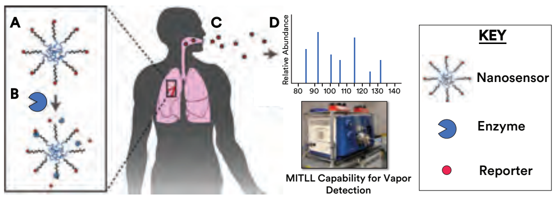
Introduction

Challenge

- Current pathogen identification methods are time-consuming (days-weeks)
- Rapid pathogen identification can reduce antibiotic use and improve health outcome

Goal and Technical Concept

- Accelerate pathogen identification using inhalable, multiplexable, nanosensors that release reporters in response to disease-related enzyme activity

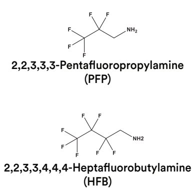


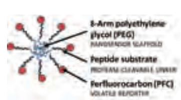
Inhalable nanosensors for pathogen identification in respiratory infection.

A) Nanosensors containing the reporters are inhaled. B) Disease-related enzyme activities process the nanosensors to release volatile reporters. C) The reporters are exhaled. D) The reporters are detected for diagnosis.

Methods

Develop Neutrophil Elastase (NE) Nanosensor

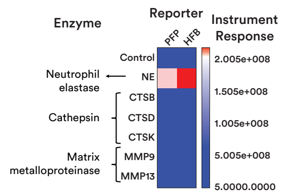




Perfluorocarbon (PFC) reporters were conjugated to 8-arm polyethylene glycol (PEG) with peptide substrate recognized by the **enzyme neutrophil elastase (NE).**[1] Reporter release was detected using a real-time vapor analysis mass spectrometer.[2]

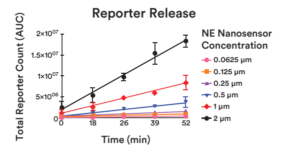
Results

Nanosensor Specificity



Screening against multiple enzymes shows that reporter release is specific to NE

Reporter Release Kinetics



	k_{cat}, s^{-1}	K_m, µM	k_{cat}/K_m, $M^{-1} \cdot s^{-1}$
NE sensor (PFP)	2.60	25.7	1.01×10^5
NE sensor (HFB)	0.218	1.53	1.43×10^5

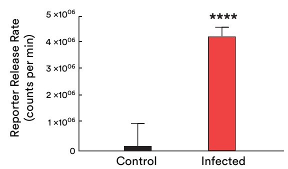
The rate constant (k_{cat}) and the dissociation constant (K_m) were calculated

Ex Vivo Test on Dissected, Homogenized, Mouse Lung

t = 0 h
Infect CD-1 mice with 1.5 × 10^6 cfu PAO1/mouse

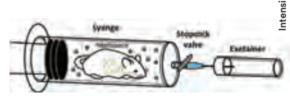
t = 24 h
Euthanize mice
Prepare lung homogenate

t = 26 h
Mix homogenates with nanosensors and measure reporter in headspace over time



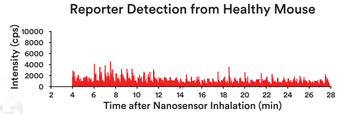
Faster reporter release from *P. aeruginosa* infected lung homogenates was observed

In Vivo Test on Mouse Breath

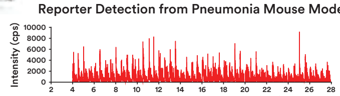


Higher reporter levels were measured in breath collected from pneumonia mouse models

Reporter Detection from Healthy Mouse



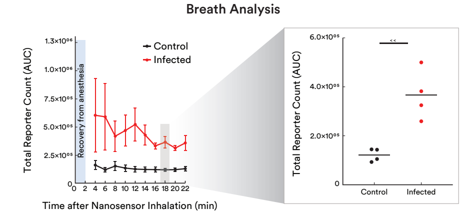
Reporter Detection from Pneumonia Mouse Model



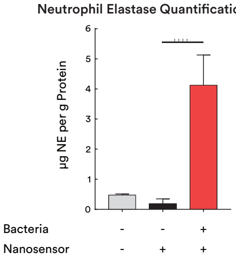
Results Continued

Differentiate Healthy and Infected Mice

Breath Analysis



Neutrophil Elastase Quantification



Reporter levels are 3-fold greater in infected breath than in healthy breath 18 min after nanosensor inhalation (p = 0.0035). ELISA confirms higher NE concentration in infected mouse lungs

Conclusions and Future Work

- Conclusions
  - Developed nanosensors with volatile reporters that responds to upregulated neutrophil elastase activity during infection
  - Demonstrated rapid distinction between healthy and infected mice via breath

Future Work and Potential Collaboration Opportunities

- New applications
  - Develop nanosensors for *Mycobacterium tuberculosis*, which currently takes weeks to diagnose
  - New pathogen categories (e.g., fungal and viral)
  - New diagnostic challenges (e.g., drug resistance, wound infection, etc.)
- Improved detection performance
  - Nanosensor 10-plex to improve specificity
  - Pair nanosensors with a portable, low-cost VOC detector

Acknowledgments

This work is funded by the Massachusetts General Hospital Global Health Innovation Partnership and MIT Lincoln Laboratory.

Leslie Chan[1], Melodi Anahtar[2], Ta-Hsuan Ong[3], Kelsey Hern[1], Roderick Kunz[3], and Sangeeta Bhatia[1,2,4,5]

[1]Institute for Medical Engineering and Science, [2]Harvard-MIT Division of Health Sciences and Technology, [3]MIT Lincoln Laboratory, [4]Koch Institute for Integrative Cancer Research, [5]Howard Hughes Medical Institute

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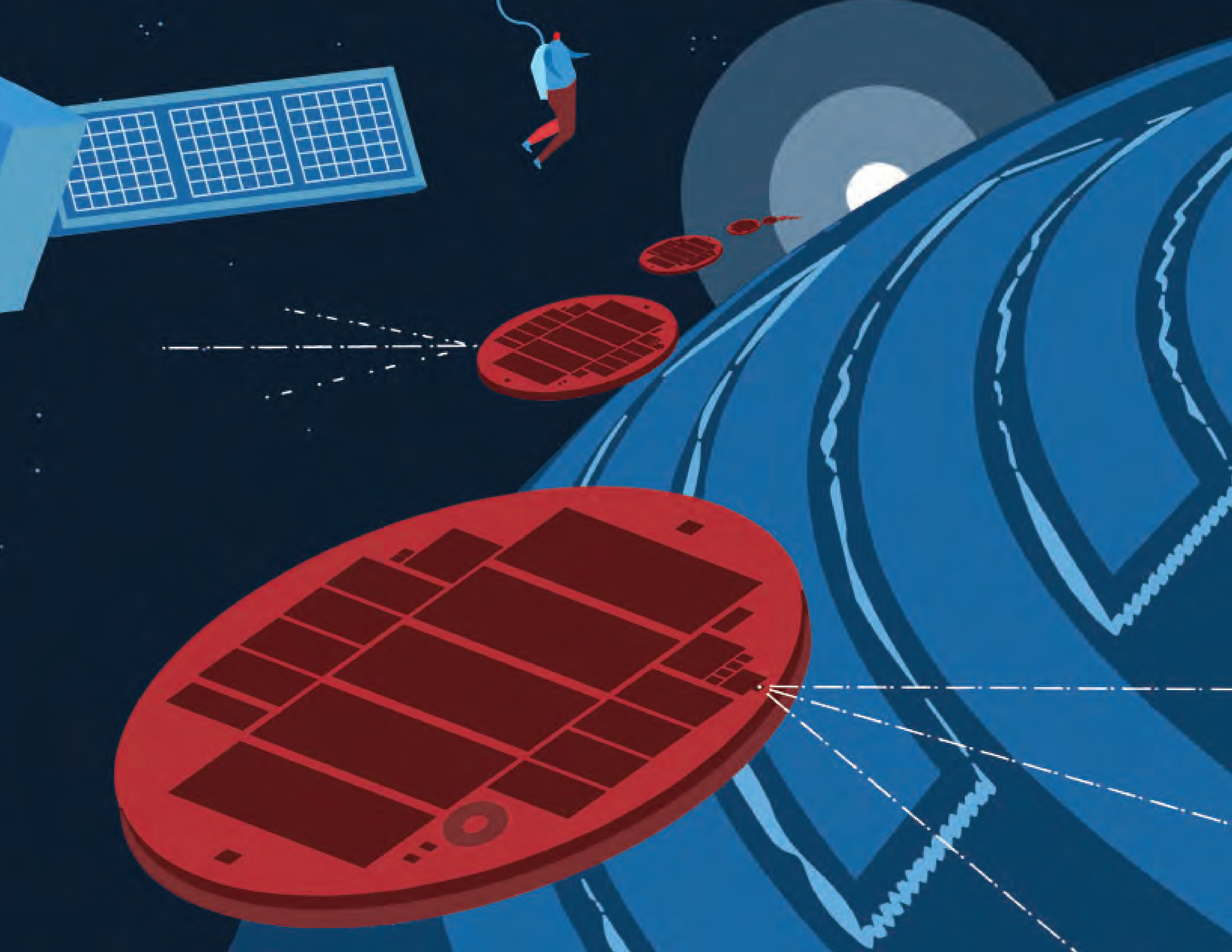
1. Kasperkiewicz, P. et al. Design of ultrasensitive probes for human neutrophil elastase through hybrid combinatorial substrate library profiling. *PNAS* 111, 2518–2523 (2014).
2. Ong, T. et al. Use of Mass Spectrometric Vapor Analysis to Improve Canine Explosive Detection Efficiency. *Anal. Chem.* 89, 6482–6490 (2017).



Materials Integration: from Nanoscale to Waferscale

The maturation of electronics packaging is a key element in the electronics miniaturization revolution that has taken place in the past decade. As part of this trend, packaging linewidths have gotten narrower, circuit boards have gotten thinner, and levels of integration have increased greatly, but the basic approach of placing electronic components on printed circuit boards remains unchanged. There are emerging approaches that break the conventional printed circuit board paradigm by integrating the system instead of just the electronics—thereby providing even more user capability in ever-smaller form factors. In this session, we will discuss these emerging approaches and aim to find synergies among them, with the goal of identifying breakthrough capabilities.

The presentation's topics include photonic integrated circuits; nanoscale fabrication for biological nanofluidic systems; micrometer-scale hydraulic motors; micrometer-scale additive manufacturing with controlled dielectric, electronic, and elastic properties; wafer-scale satellites for distributed-aperture systems in space; and polymer and optical fibers with integrated electronics and sensors for "functional-fiber" microsystems. MIT's Carl Thompson will also be joining as an invited speaker to discuss materials for microsystems.

Dr. Mark Gouker

MIT Lincoln Laboratory

Materials Integration: from Nanoscale to Waferscale

Microelectronics technology is a hugely successful invention and has impacted most aspects of our daily routines. The maturation of this field has created the mobile electronics revolution and the Internet of Things that will further entrench electronics into our lives. As prevalent as this has been, we are on the verge of a new and even more powerful era of microsystems that will incorporate microelectronics, microfluidics, integrated photonics, microactuators, and more. This presentation sets the stage for the session and a discussion on how we can form new synergies and boldly leverage these emerging capabilities.

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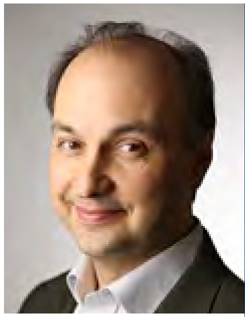
Biography

Dr. Mark Gouker is an assistant division head in the Advanced Technology Division at MIT Lincoln Laboratory. In this role, he oversees the operation of the Laboratory's Microelectronics Lab and guides the internal investments and external program development. Previously he led the Quantum Information and Integrated Nanosystems Group. This group has a number of core technology elements that include superconducting and trapped ion quantum computing, solid-state quantum sensing, superconducting and CMOS electronics, and integrated photonics. Dr. Gouker's technical interests lie in developing microsystems that incorporate these core technologies.



Prof. Vladimir Bulović

MIT

Squitch: Nano-Engineered Squeezable Electro-Mechanical Switch

Abrupt switching behavior and near-zero leakage current are advantageous properties of nanoelectromechanical (NEM) switches, but typical NEMs structures require high actuation voltages and can prematurely fail through permanent adhesion (defined as stiction) of device electrodes. A new NEM switch, which we termed a “squitch,” could overcome these challenges. It is designed to electromechanically modulate the tunneling current through a nanometer-scale gap defined by an organic molecular film sandwiched between two electrodes. When voltage is applied across the electrodes, the generated electrostatic force compresses the sandwiched molecular layer, thereby reducing the tunneling gap and causing an exponential increase in the current through the device. The presence of the molecular layer avoids direct contact of the electrodes during the switching process, leading to zero net stiction and recoverable switching. An optimized squitch design can enable large on-off ratios, beyond six orders of magnitude, with operation in the sub-1 V regime and with nanoseconds switching times.

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Biography

Prof. Vladimir Bulović holds the Fariborz Maseeh Chair in Emerging Technology and is the MIT School of Engineering’s Associate Dean for Innovation. He co-directs the MIT Innovation Initiative and is the faculty leading the design and construction of MIT’s new nanofabrication, nanocharacterization, and prototyping facility. He also co-directs the Eni-MIT Solar Frontiers Center, one of MIT’s largest sponsored research programs. He leads the Organic and Nanostructured Electronics Laboratory (ONE Lab), which he developed as a unique open nanotechnology facility. Prior to joining the School of Engineering leadership, Prof. Bulović directed the MIT Microsystems Technology Laboratories (MTL), which during his tenure grew to support over 700 investigators and $80M of research programs from across the Institute. His research interests include studies of physical properties of organic and inorganic nanostructured films and structures and their applications in novel optoelectronic devices. His academic papers have been cited over 10,000 times, while his 60 U.S. patents and numerous patent disclosures have been licensed and utilized by both start-up and multinational companies.

Dr. Jakub Kedzierski

MIT Lincoln Laboratory

Microhydraulic Actuators: Artificial Muscle and More

Microhydraulics is a new technology developed at MIT Lincoln Laboratory to enable microsystems and small components to move. Microhydraulic actuators are designed to enable precise motion in systems that are too small to allow for the integration of an electromagnetic motor. The actuators work by integrating surface tension forces produced by electrowetting electrodes acting on scaled droplets along the length of a thin ribbon, for linear motion, or disk, for rotational motion

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Biography

Dr. Jakub T. Kedzierski is a senior staff member in the Chemical, Microsystem, and Nanoscale Technology Group. At MIT Lincoln Laboratory, he has led the work on low-power electronics, two-dimensional electronic materials, and microfluidics. He served as the assistant group leader in the Advanced Silicon Technology Group, where he designed an ultra-low-power subthreshold CMOS technology, built one of the world's first top-gated graphene transistors, and helped to initiate the microfluidic research program in the Advanced Technology Division. Prior to joining the Laboratory, Dr. Kedzierski worked at the IBM T. J. Watson Research Center, where he studied advanced electronic devices, metal-gate integration, and technology scaling. Dr. Kedzierski received his PhD degree in electrical engineering from the University of California at Berkeley in 2001, where he co-invented the FinFET transistor, a technology currently adopted for advanced logic electronics by Intel and Taiwan Semiconductor Manufacturing Company (TSMC).

Dr. David Kharas

MIT Lincoln Laboratory

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Prototype Photonic Integrated Circuit (ProtoPIC) Platform and Applications

Silicon-based photonic integrated circuits (PICs) are seeing rapid adoption in datacom, enabling data rates beyond 100 Gb/sec. These PICs leverage silicon (Si) waveguides operating at near-infrared wavelengths (1300 to 1600 nm) where Si is transparent. For photonic applications outside of telecom, including lidar, bio-photonics, and atomic systems where wavelengths spanning near UV to IR are of interest, PICs based on silicon-nitride (SiN) waveguides can be utilized. Since neither Si nor SiN components emit light efficiently, light sources need to be integrated with these platforms using fiber coupling or heterogeneous integration techniques. There is a desire to combine the best-of-breed active devices (e.g., lasers, semiconductor optical amplifiers (SOAs), modulators, photodetectors) typically fabricated in III-V material systems with the Si and SiN platforms. We present a hybrid integration platform developed at MIT Lincoln Laboratory that enables flip-chip die attach of a wide variety of III-V photonic components with our SiN PIC platform.

Biography

Dr. David Kharas is a member of the technical staff in MIT Lincoln Laboratory's Quantum Information and Integrated Nanosystems Group, where he is working in the Integrated Photonics Team in a process integration role. Dr. Kharas leads the Photonics Team's device fabrication activities across a number of technology platforms, including silicon and nitride PICs, hybrid integration of III-V components, and MEMS and microfluidic devices. Prior to joining the Laboratory, Dr. Kharas led the AlInGaP Technology Group at Philips Lumileds. He holds a BS in applied physics from UMass Lowell, and holds MS and PhD degrees in materials science from SUNY Stony Brook.

Dr. Livia Racz

MIT Lincoln Laboratory

Wafer-Scale Satellites

Interest in small-space systems has grown significantly in the past decade, driven primarily by the desire to reduce launch costs. Aggressively miniaturized CubeSat platforms have been made possible by the shrinkage of many of the required component technologies. However, CubeSat fabrication is still performed one at a time, mostly by hand, which makes it difficult to achieve economies of scale. MIT Lincoln Laboratory, in collaboration with MIT campus, is developing a radically different wafer-scale satellite platform that enables the manufacture of complete, disaggregated satellite constellations quickly and easily, leveraging the economies of scale that the semiconductor industry has perfected over the past 40 years.

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Biography

Dr. Livia M. Racz is assistant leader of the Chemical, Microsystem, and Nanoscale Technologies Group, where she is currently focused on advanced materials and their application of micro- and nanotechnology in order to enable unique capability in scaled-down systems. In addition, she leads the MIT Lincoln Laboratory research portfolio in Advanced Materials and Processes. Dr. Racz joined Lincoln Laboratory in February 2015 after eight years at Draper Laboratory, where she held positions of principal technical staff, distinguished technical staff, Laboratory technical staff, group leader, and division leader. She has also spent time in two early-stage startups and in academia, in each case focused on some novel aspect of miniature electronic systems. Dr. Racz received her SB and PhD degrees in materials science and engineering from MIT and worked at the German Aerospace Research Center (DLR) in Cologne, Germany as an Alexander von Humboldt fellow.

Dr. Alexander Stolyarov

MIT Lincoln Laboratory

Functional Fiber Microsystems

For millennia, fibers and fabrics have remained virtually unchanged from a materials and functionality standpoint. In recent years, however, the development of new materials processing approaches has emerged, enabling a new class of multimaterial fibers—ones containing semiconductors, insulators, and metals—opening an era of fiber devices and fabric systems. This presentation will focus on recent breakthroughs in fiber and fabric materials and functionality achieved through a collaboration between MIT Lincoln Laboratory, Prof. Yoel Fink's group at MIT, and the Advanced Functional Fabrics of America (AFFOA) USA Manufacturing institute. Fibers and fabrics with controlled spectral signatures, electrically controlled reflectivity, and diode-containing structures will be discussed. The Defense Fabric Discovery Center (DFDC), a national security-focused, end-to-end advanced fabric prototyping facility located at MIT LL, stood up in collaboration with Natick Soldier Systems Center, the Commonwealth of Massachusetts, and AFFOA, will be introduced and current projects at the DFDC will be highlighted.

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Biography

Dr. Alexander (Sasha) Stolyarov is a member of the technical staff in the Chemical, Microsystem, and Nanoscale Technologies group in the Advanced Technology Division and leads MIT Lincoln Laboratory's initiatives on multifunctional fiber and fabric technology. In 2017, Sasha spearheaded the founding of the Defense Fabric Discovery Center (DFDC), an end-to-end prototyping facility focused on developing advanced fiber and fabric technology for national security, stood up in collaboration with MIT LL, Natick Soldier Systems Center, the Commonwealth of Massachusetts, and the AFFOA Manufacturing USA Institute. Sasha conducted his graduate and postdoctoral training at MIT, where he developed advanced fabrication capabilities for multimaterial fiber devices and systems. He has co-authored 20 peer-reviewed journal articles and holds four U.S. patents in this emerging field. Sasha earned a PhD in applied physics from Harvard University in 2012 and a BS in physics from the University of Texas at Dallas in 2005.

Materials Integration: from Nanoscale to Waferscale Posters

Dr. Bradley Duncan

MIT Lincoln Laboratory

Additive Manufacturing with Electronic Materials

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Additive manufacturing of radio frequency (RF) components offers an attractive strategy to generate complex devices that traditional fabrication methods cannot achieve. Three-dimensional printing of composites offers advantages over single-component systems by synergistically combining the properties of the matrix and filler components. To date, there has been limited success in printing composite structures with suitable electromagnetic characteristics for operation in the millimeter-wave range (>30 GHz). Here, we describe a generalized block copolymer-based strategy to incorporate ceramic and conductive materials into 3D-printable inks. The behavior of these inks can be tuned by altering the filler-particle-to-polymer ratio in a plug-and-play fashion and can be deposited with both positional and compositional control using a custom active mixing printing nozzle. Using these inks, we have fabricated a variety of RF structures with graded dielectrics as well as conductive and dielectric metamaterials.

Additive Manufacturing with Electronic Materials

3D Printable Electronic Materials

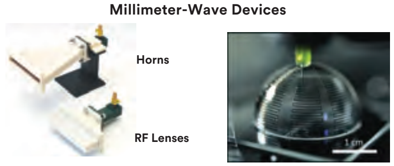
The limited number of materials that can be 3D printed restricts the designing of innovative electronic devices

- Developed a family of low-loss dielectric and conductive inks to create RF devices
- Inks can be combined on-the-fly with a custom printing nozzle to control electromagnetic properties at the voxel level
- Generated devices/components that are difficult or impossible to make by conventional manufacturing

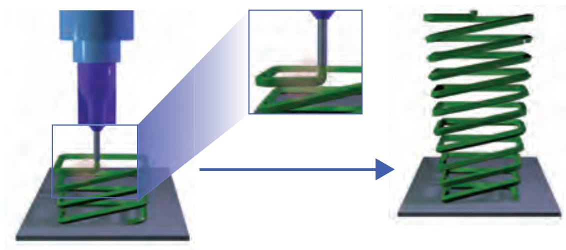
3D printing advantages for millimeter wave:

- Feature resolution, accuracy, and surface roughness difficult for machining
- Print complex internal paths and undercut structures, dielectrics and metal designs, and dielectric gradients

Millimeter-Wave Devices



Solvent Casting Direct Ink Writing



Solvent Casting Direct Ink Writing

- Electronic materials must be formulated with proper rheological and viscoelastic properties to be printable
- Printing nozzle location is robotically controlled
- Thermoplastic material dissolved in a volatile solvent is extruded
- Solvent rapidly evaporates leaving rigid structures

Conductive Metal Composites

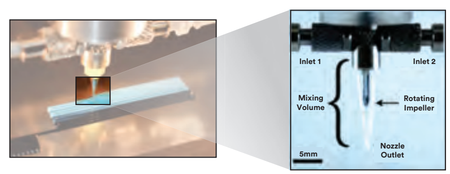
Allows for the rapid generation of metallic interconnects and embedded conductive structures

- Our polymeric ink formulations generate conductive traces that do not require high-temperature sintering
- Compatible with printed dielectrics

Material	Resistivity (Ω•m)	Conductivity (S/m)	% of Bulk Silver Conductivity
Bulk Silver	1.6×10^{-8}	6.3×10^{7}	100
Commercial Silver Ink	7.4×10^{-6}	1.4×10^{5}	0.2
Silver Flake Ink	1.8×10^{-7}	5.7×10^{6}	9.1
Gold Flake Ink	8.3×10^{-7}	1.2×10^{6}	1.9

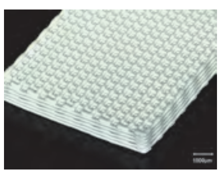
Active Mixing Nozzle Development

Active mixing allows for the printing of materials in a compositionally and geometrically controlled fashion

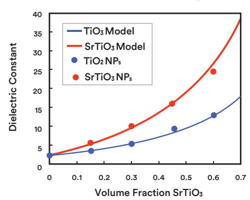


Composite Dielectric Inks

Printed 45 vol.% TiO_2/SIS ink



Dielectric Constants of Composites



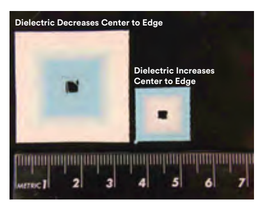
Material (vol. %)	Dielectric Constant (ε') (34 GHz)	Loss Tangent (ε"/ε') (34 GHz)
SIS Polymer	2.2	0.002
TiO_2/SIS (30 : 70)	5.9	0.012
TiO_2/SIS (60 : 40)	13.8	0.028
$SrTiO_3$/SIS (30 : 70)	10.1	0.032
$SrTiO_3$/SIS (60 : 40)	24.8	0.060

Material (vol. %) Dielectric Constant (_') Loss Tangent (_"/_')
34 GHz) (34 GHz)

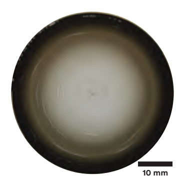
Commercial nanoparticles were functionalized for compatibility with our polymer system

Printable, low-loss ink with a dielectric constant >24 is higher than reported in literature at comparable frequencies

3D Printed Gradient Patterns



Polymer – Blue (ε = 2.2)
TiO_2 composite ink – White (ε = 9.9)



Spiral structure is backlit to show transparency of inner polymer rings

Polymer – Clear (ε = 2.2)
TiO_2 composite ink – White (ε = 13.8)

Gradient dielectric printing established opening up new frontiers in RF device and antenna design

Conclusions

Copolymer and composite-based dielectric inks

- Can print a wide variety of shapes and devices
  - Structures with high dielectric values, >24, with low-loss in Ka band
  - Structures with ~9% bulk silver conductivity without the need to sinter
- Structures generated that vary both geometrically and compositionally
- Devices performed as designed

Research Opportunities

- Antenna and device designers needed
- Introducing custom nanoparticles to expand the functionality of our printed devices
- Understanding the structure activity relationships between nanomaterials and polymers

Theodore Fedynyshyn and Bradley Duncan – MIT Lincoln Laboratory

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Dr. Cheryl Sorace-Agaskar/Dr. Josue Lopez

MIT Lincoln Laboratory/MIT

Planar-Lens-Enabled Beam Steering for Chip-Scale LIDAR

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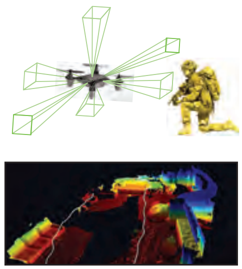
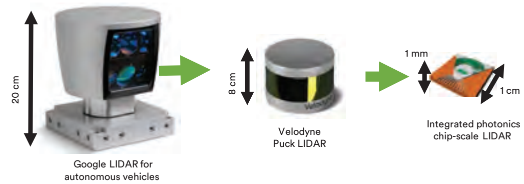
Light detection and ranging (LIDAR) is an important tool across a variety of application spaces including 3D mapping and autonomous navigation. In particular, there is demand for a compact, non-mechanically steered sensor with lower size, weight, and power (SWaP) requirements. Integrated photonics is uniquely suited to meet this challenge. However, current leading chip-based LIDAR solutions, which use 1D or 2D phased-array antennas to steer a coherent beam bi-directionally, still suffer from a number of drawbacks in complexity, power consumption, and stability. Herein, for the first time, we explore a lens-enabled chip-scale beam steering device that overcomes many of these drawbacks. It allows for wide steering angles and very low SWaP in a simple, easy-to-control system, which can be scaled up, through tiling, in aperture size, number of resolvable points, and output power. We experimentally demonstrate an initial device with azimuthal, $\phi = 38.8°$, and polar, $\theta = 12.0°$, beam steering, and outline a path for future improvement.

Planar-Lens-Enabled Beam Steering for Chip-Scale LIDAR

Motivation

- Autonomous machines
- 3D mapping
- Commercial systems are aimed at automotive industry
- Requirements differ for other platforms like UAVs
- Desire even further reductions in size, weight, and power (SWaP)





Concept

- On-chip beam-steering solution based on integrated lens and grating
  - In-plane steering determined by choice of input waveguide, out-of-plane steering done with wavelength

Benefits

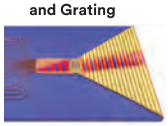
- All-electronic beam steering
- Wide angle steering
- Scalability, power, wavelength flexibility (blue – IR)
- Tx/Rx
- Compared to integrated phased arrays
  - Greatly reduced power requirements (>10×)
  - Reduced control complexity
  - Faster, more flexible scans (×10–100)

LIDAR Performance Goals

FOM	Spec
In-plane field of view	90°
In-plane resolvable points	128
Out-of-plane field of view	12°
Out-of-plane resolvable points	140
Aperture size	1–10 mm^2
Range resolution	1–2 mm
Output power	100 mW
Chip area	~2 cm^2
Power dissipation	~2.5 W

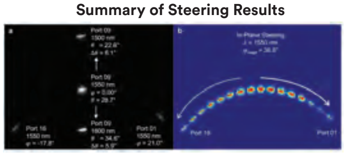
Initial Demonstration

Diagram of Lens and Grating



Microscope Image of Fabricated Lens and Grating

Summary of Steering Results



Demonstrated Steering

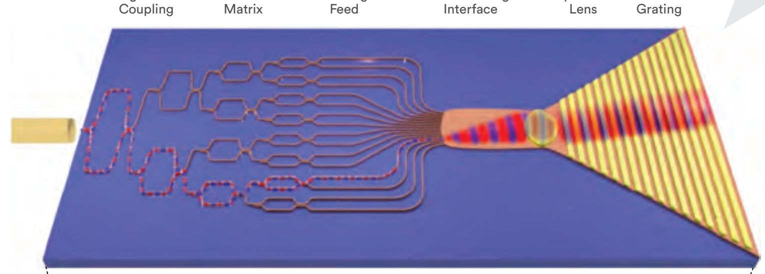
In-Plane

Out-of-Plane

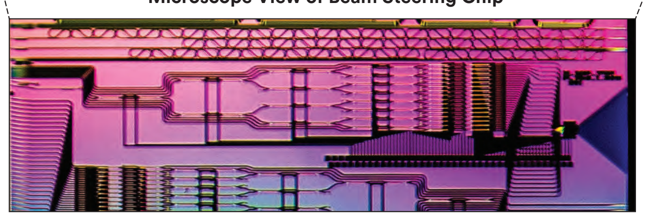
Rendering of Beam Steering Chip

SiO_2 Silicon Nitride PolySilicon

Edge Fiber Coupling | MZI Switch Matrix | Wavelength Feed | Slab-Wavelength Interface | Aplanatic Lens | 1D Grating



Microscope View of Beam Steering Chip

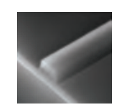


Integration Platform

- Fabricated in MIT Lincoln Laboratory 90 nm node CMOS foundry
- Uses our flexible, low-loss SiN platform
  - Available modifications include multiple layers, Al_2O_3 blue-light waveguides, III-V device bonding, ultralow loss or low temperature deposition

Measured Losses

Wavelength [nm]	Measured Loss [dB/cm]
Silicon Nitride	
1550	0.2
1092	<0.1
633	0.2
461	6–7
Al_2O_3	
461	0.8
405	1.6
369	2.9



Future Work

- Integrate rest of LIDAR system, including receive functionality onto chip and into low-SWaP package
- Scale to larger apertures and/or powers
- Determine best wavelength and waveform
- Explore non-wavelength steering options
- Determine best or novel phase-shifter technology (non-thermal)

Cheryl Sorace-Agaskar, Dave Kharas, Jeffrey Herd, Paul Juodawlkis – MIT Lincoln Laboratory; Josue Lopez, Scott A. Skirlo, Jamison Sloan, Marin Soljacic – MIT – MIT Lincoln Laboratory

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Dr. Melissa Smith

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Biological Nanofluidic Systems

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High-density arrays of nanochannels present unique opportunities ranging from fundamental studies of nanofluidics and interfaces to high-throughput lab-on-chip applications such as sequencing, chromatography, and drug delivery. Two challenges of developing nanochannels for these applications are (1) their integration with solid-state electronic and photonic components to enable massively parallel processing in complex nanofluidic circuits and (2) determining the dimensions of the nanochannels and the measuring of their fill-state accurately and non-destructively.

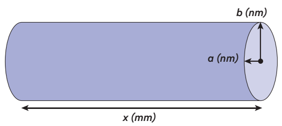
We addressed both challenges by first fabricating long, dense arrays nanochannels, which are suitable for the aforementioned applications, with a CMOS-compatible tool set. The nanochannels were 40 nm wide, 140 nm tall, and 6 mm long. The arrays consisted of 10,000 nanochannels with pitches ranging from 200 nm to 240 nm. We validated our fabrication approach by loading different fluids into the nanochannels and verifying that the fluid dynamics follow the well-accepted Washburn Equation for fluid flow in capillaries. Lastly, we coupled spectroscopic ellipsometry with rigorous coupled wave analysis simulations to extract the dimensions of the nanochannels with nanoscale accuracy and detect percent-level changes in volumetric fill-fraction.

Notably, our fabrication and measurement techniques require only the fine-tuning of the capabilities of an advanced CMOS tool set while providing a platform for integration into functional chips.

Biological Nanofluidic Systems

Motivation

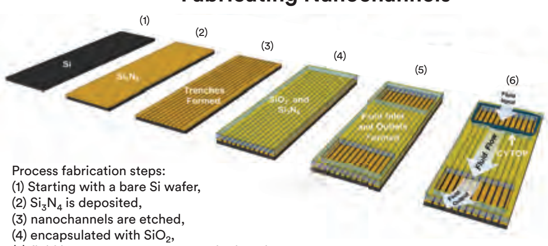
- Nanochannels with high aspect ratios are useful for single molecule manipulation and study, i.e., elongating DNA for sequencing
- Integrating nanochannels with solid-state devices can have meaningful impacts in drug delivery, chromatography, filtration, and computation
- Integration is challenging as it is difficult to fabricate high-density arrays with processes that are CMOS-compatible



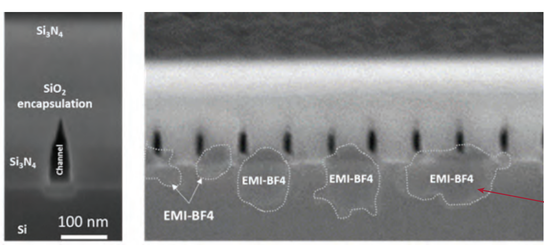
Reported Nanochannel Architectures

Source	Aspect Ratio (Length/Width)	Suitability for Complex Integration
Sobolev et al. J. Colloid Interface Sci.,2000, 222, 51-54.	~300,000	Low
Liang et al. Nano Lett., 2007, 7, 3774-3780.	~300,000	Med
Alibakhshi et al. Scientific Reports, 2016, 6.	3	High
Wang et al. ACS Nano, 2015, 9, 1206-1218.	~200	High
This Work	*~500,000*	*High*

Fabricating Nanochannels

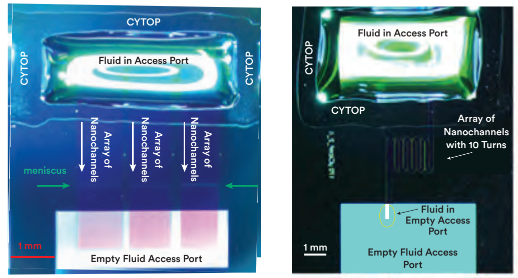


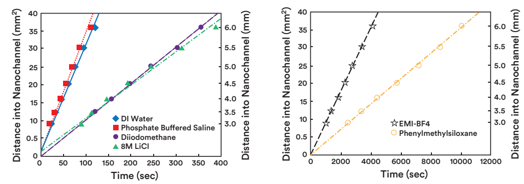
Process fabrication steps:
(1) Starting with a bare Si wafer,
(2) Si_3N_4 is deposited,
(3) nanochannels are etched,
(4) encapsulated with SiO_2,
(5) fluid input/output ports are etched, and
(6) CYTOP is applied around the fluid access ports.



SEM cross-section of the nanochannels loaded with EMI-BF4. After cleaving the sample, the EMI-BF4 leaks from the interior of the channels onto the face of the cross-section.

Loading Fluids into Nanochannels





From the equation (below), the slope of the lines (above) contains comprehensive information about the surface tension (γ), viscosity (η), and wettability (θ) on SiO_2 of fluids that can be loaded into the channels, as well as channel geometry (a and b). The experimental slope can be extracted for each fluid and compared to the theoretical slope.

$$x^2 = \left[\frac{\gamma\cos\theta(ab)^2}{2\eta(a^2+b^2)}\left(\frac{1}{a}+\frac{1}{b}\right)\right]t$$

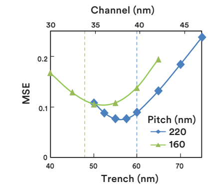
Fluid	*Contact Angle, θ (°)	Surface Tension, γ (N/m)	Viscosity, η (cP)	Calculated Slope (mm^2/s)	Experimental Slope (mm^2/s)
DI Water	70	0.0720	0.89	0.3	0.3
Phosphate Buffered Saline	62	0.065	1.0	0.3	0.3
8M LiCl	40	0.0727	2	0.3	0.09
Diiodomethane	45	0.0508	2.6	0.1	0.1
EMI-BF4	65	0.054	37	0.007	0.009
Phenylmethylsiloxane	10	0.037	37	0.01	0.004

*Measurements were taken on a flat surface, after access port etch but prior to O_2 plasma cleaning

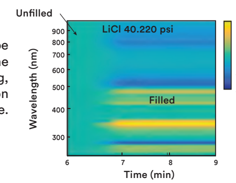
Characterizing Nanochannels

By combining spectroscopic ellipsometric scatterometry, with rigorous electromagnetic simulations, channel dimensions and channel fill state can be determined accurately and nondestructively.

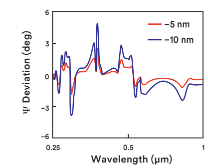
Compare the psi parameter from experimental data to simulation data and calculate the mean-square-error. The experimental channel dimensions can be determined from the comparison with the smallest mean-square-error



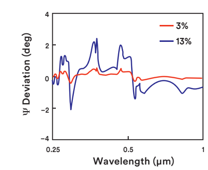
Change in the fill state can be determined by measuring the psi parameter during filling, and observing its evolution with time.



Dimensions can be determined with an accuracy of 5 nm



Filling percent can be detected with 1% accuracy on the timescale of seconds



Future Work

Technical Directions
- Loading particles or molecules into the channels
- Controlling fluid flow
- Fabricating channels in different material sets (metals and organics)

Possible Applications
1. Miniaturized CRYO-TEM/soft x-rays of biological samples
2. In-line competitive binding assays
3. Integrated nanofluidics and photonics

Melissa Smith – MIT Lincoln Laboratory

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Electronically Reconfigurable Phase Change IR Metasurfaces

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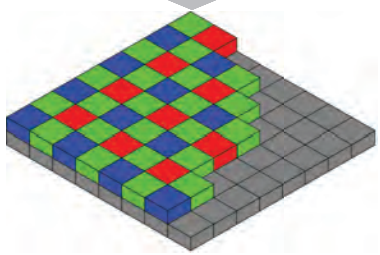
Traditional opto-mechanical systems use bulky and slow components to mechanically displace individual optical elements. The large sizes and slow speeds become an impediment in compact systems such as in drones or handheld systems. In this poster, we present our work on a solid state tunable phase change material that can be digitally programmed into any optical element, such as switching between varying lenses, gratings, and holograms. With our collaboration with Prof. Juejun Hu at MIT, we have developed a novel transparent phase change material that works across the entire IR spectrum, from the SWIR to LWIR wavelengths.
In this poster, we present the thermal, optical, and electrical switching results of this novel material.
One demonstration is a rewritable lens for beam steering applications.

Electronically Reconfigurable Phase Change IR Metasurfaces

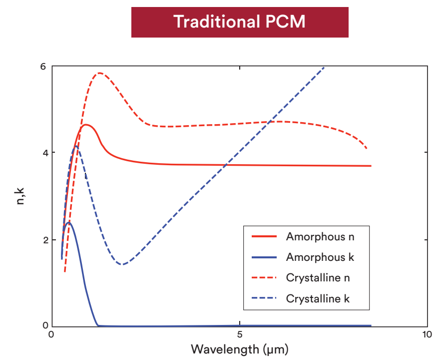
Objective

Replace bulky optical mechanical components

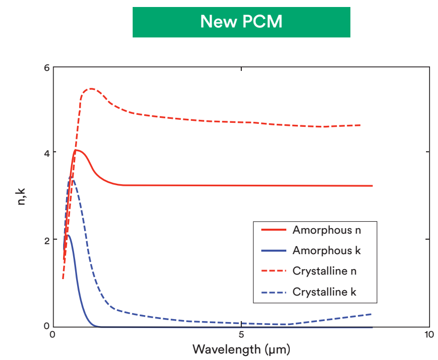


With a solid state thin film system

New Transparent Phase Change Material: $Ge_2Sb_2Se_4Te_1$ (GSS4T1)



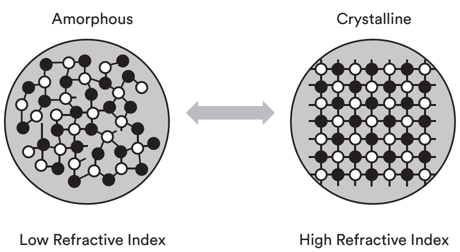
Traditional PCMs have too much loss in the IR to be usable



Our new PCMs have lower loss by a factor of 31 in the LWIR

Method

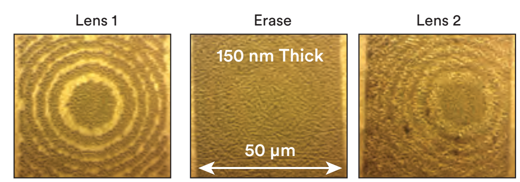
Utilize Phase Change Materials (PCMs)

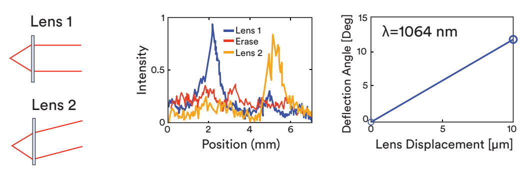


Extreme Refractive Index Contrast of

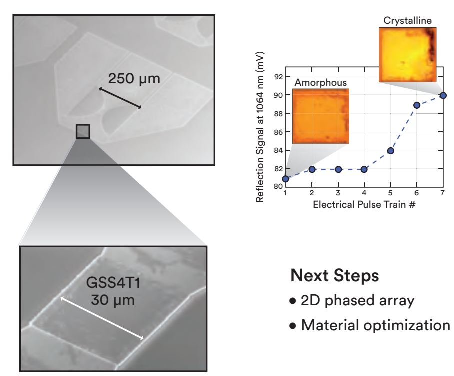
$\Delta n=2$

Reconfigurable Beam Steering





Electrical Switching



Next Steps

- 2D phased array
- Material optimization

Jeffrey Chou and Vladimir Liberman – MIT Lincoln Laboratory

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Ways to Engage

The Advanced Research and Technology Symposium highlights some of the most pressing challenges confronting our nation's security and well-being. Part of the symposium will discuss how to pursue opportunities for new partnerships that develop advanced technologies to address these challenges. The pace of innovation has accelerated in part due to advances made by the private sector and academia. Working more closely with universities, the startup community, and small businesses is key to hastening the adoption of new technologies so they can be used effectively for national security.

The Ways-to-Engage session features a diverse panel of experts from government and federal laboratories to facilitate a discussion on innovation in support of national security. The panel will explore ways to engage with Lincoln Laboratory and more broadly with the U. S. Government and related entities to develop research collaborations and other business opportunities. This session includes time for participants to ask questions and for a discussion between the experts and the audience. There also is time to follow up with the researchers who have presented their technologies throughout the symposium.

Dr. Israel Soibelman

MIT Lincoln Laboratory

Innovation in Support of National Security

Dr. Israel Soibelman is the Assistant to the Director for Strategic Initiatives at MIT Lincoln Laboratory. His responsibilities include assisting in the development of Laboratory-level strategic planning and leading and helping grow external strategic relationships.

Prior to his appointment as the Assistant to the Director, Dr. Soibelman served as the Head of the Homeland Protection and Air Traffic Control Division at the Laboratory, directing programs in homeland air defense, chemical and biological defense, homeland security, and air traffic control.

Dr. Soibelman holds a BS degree in mechanical engineering from Columbia University and a PhD degree in applied mathematics from the California Institute of Technology.

Dr. Bernadette Johnson

DIUx

Dr. Bernadette Johnson currently serves as the Chief Science Officer of Defense Innovation Unit Experimental (DIUx), a DoD organization stood up to accelerate commercial innovation for national security. She joined DIUx in 2016 after serving as the Chief Technology Officer at MIT Lincoln Laboratory, where she managed the Laboratory's internal research and development portfolio. Prior to that, she was a researcher and member of senior leadership in areas related to laser-based propagation and sensing, biodefense, and homeland security. She holds degrees in various branches of physics from Dickinson College, Georgetown University, and Dartmouth College, and is currently a member of the National Academies' Naval Studies Board.

Mr. Warren Katz

Techstars Boston

Mr. Warren Katz co-founded MÄK Technologies in 1990, a leading global vendor of military simulation software. In December 2006, MÄK was acquired by VT Systems of Alexandria, Virginia. Mr. Katz is an avid mentor and angel investor at both Techstars and Bolt, with expertise in how to fund companies using government contracts. He is a noted industry advocate of open interoperability standards and commercial business models in Department of Defense procurement. He was a six-term chairman of the Simulation Interoperability Standards Organization, the international not-for-profit consortium that develops standards for synthetic environments. From 1987 to 1990, he worked for Bolt, Beranek, and Newman as a drive train simulation expert, responsible for mathematical modeling of physical systems. He holds dual bachelor's degrees in mechanical and electrical engineering from Massachusetts Institute of Technology. Some of his investments include Harmonix, GrabCAD, Oblong, Organic Motion, and PetNet.

Dr. Charlene Stokes

MITRE

Dr. Charlene Stokes holds a PhD in Industrial-Organizational & Human Factors Psychology. She recently joined The MITRE Corporation to expand their human-machine team (HMT) capabilities and grow their Innovation Bridging activities. Prior to joining MITRE, she was a cognitive behavioral scientist with the Air Force Research Laboratory, where she served as a program manager and principal investigator on internally and externally funded programs. She established and directed the Human-Machine Social Systems (HMSS) Lab as an AFRL resource at Yale University from 2011 to 2016. She then moved the HMSS Lab from Yale to a Boston accelerator, MassRobotics, in an effort to increase engagement with the commercial sector and the robotics startup community. She continues to direct the HMSS Lab at this location under MITRE. Her primary research focus is on the social dynamics of human-machine interaction.

Dr. Nathan Wiedenman

Draper

Dr. Nathan Wiedenman began his Army career leading armored units at the platoon and company level. He spent the majority of his career leading technology research and development in various roles across the Department of Defense. These included assistant professor at the U.S. Military Academy at West Point, deputy chief scientist at the Army's Tank Automotive Research and Development Center, science and technology advisory team lead in Afghanistan, and program manager with the Defense Advanced Research Projects Agency (DARPA) in Washington, D.C. He retired from the Army as a Lieutenant Colonel in 2014. Nathan is currently the director of the Sembler Office for entrepreneurship at Draper in Cambridge, MA. He holds degrees from Harvey Mudd College in Claremont, CA (BS, engineering), the University of California at Berkeley (MS, mechanical engineering), and the Massachusetts Institute of Technology (PhD, mechanical engineering).

Ways to Engage Poster

Dr. Brian Tyrrell

MIT Lincoln Laboratory

Advanced Concepts Committee: Supporting Breakthrough Ideas

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781-981-5496

The Advanced Concepts Committee (ACC) provides seed funding as well as technical and programmatic guidance for the development of advanced concepts that address important technical problems. Collaborative efforts involving diverse teams from both Lincoln Laboratory and MIT campus are encouraged.

The ACC funds highly innovative, high-risk research that, if successful, has enormous impact on the Laboratory's mission areas. Identification of immediate follow-on sponsors is not expected for this type of research. The ACC will consider funding innovative proposals on any topic that promotes technology in support of national defense.

Advanced Concept Committee: Supporting Breakthrough Ideas

The Advanced Concepts Committee (ACC) provides funding and technical and liaison support for developing advanced concepts that address high-priority national problems. These concepts may enable new systems or promote significant improvement of current practice. The proposed concepts need not be in the current Lincoln Laboratory mainstream. ACC efforts often involve some collaboration with management and with other divisions and, where indicated, additional activity will be directed toward possible program initiation. In addition, the ACC funds studies and research and development on campus in areas of programmatic importance to Lincoln Laboratory.

The ACC funds:

- Novel high-risk ideas enabling major technical advances, or which create new project areas leading to follow-on funding
- Projects typically lasting 6–12 months and cost up to $125K for Lincoln Laboratory, and up to $125K for MIT campus staff support

Committmeee Points of Contact

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Vice Chair
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Prof. Jonathan How,
MIT Campus Liaison
jhow@mit.edu

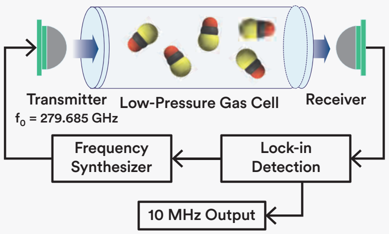
Example Projects Supported by the ACC

All-Electronic sub-THz/mm-wave Molecular Clock

Principal Investigators:
Bradford Perkins, MIT LL
Professor Ruonan Han, MIT

The primary goal of the project is to demonstrate a working high-precision molecular clock. A novel THz chip emitter and receiver provides high power and narrow line widths that are used to lock an output reference frequency to a highly stable molecular rotational transition. Future plans include an effort to miniaturize the components in a CMOS architecture to provide a low-cost, size, weight, and power precision time-keeping device.

THz Molecular Clock

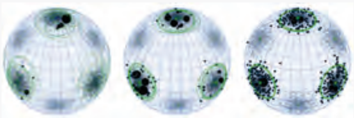


Speed and Reliability for d Nonparametric Bayesian Clustering

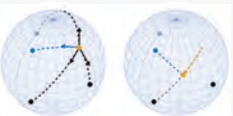
Principal Investigator:
Tamara Broderick, MIT

The goal of this project is to probabilistically cluster extremely large data sets with guarantees on performance so as to rapidly assess unstructured packet capture data. We pre-process data to find a "Bayesian coreset"—a small, weighted subset of the data—and then run standard algorithms on the core set rather than the full data.

Clustering Demonstration



Directional Clustering



Greedy Geodesic Selection

Balloon Enabled Atmospheric Convection Observation Network (BEACON)

Principal Investigators:
David Patterson, Zachary Palmer, John Lessard, MIT LL
Earle Williams, MIT

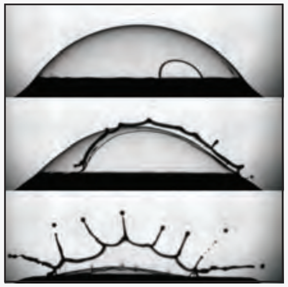
Inference of the charge state of a storm system via radar returns would revolutionize flight safety decisions for aircraft and spacecraft operations. This is likely possible, but will require high-resolution E-field measurements throughout the storm lifecycle for model development. The BEACON project has developed and demonstrated an instrument capable of taking those measurements; designed to be deployed in clusters, the BEACON instrument enables significant advancements in airborne E-field measurement resolution, dynamic range, and density.

In-Weather Launch with the National Severe Storms Lab

How Bubbles Burst

Principal Investigators:
Assistant Professor Lydia Bourouiba, MIT
Dr. William Lawrence, MIT LL

The dynamics of bubble formation and collapse to form aerosol droplets play a critical role in disease transmission and air contamination. This project combined theoretical and experimental approaches to examine the fundamental mechanisms that trigger water bubble bursts and to characterize the effect of contaminants on the burst to address issues of disease transmission, and contaminated aerosol suspension and transport.



High-Speed observation of surface changes in a bursting bubble

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