The Nano-Enabled Internet of Things Research Community

Current Members

MANTH (lead)
CNF
SENIC
NNF
KY-NNIN

NNCI Annual Meeting
October, 2022

National Nanotechnology Coordinated Infrastructure

What is the Nano-Enabled Internet of Things?

It is our conjecture that many devices and applications for the Internet of Things will be enabled by nanotechnology

- The IoT 'things' may in many cases comprise small-scale structures, sensors, and actuators (MEMS)
- The IoT 'things' may need to process and collect data, requiring on-board electronics
- The IoT 'things' will need to communicate with the Internet, requiring communication protocols in multiple bands exploiting a diversity of modalities

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The Nano-IoT Research Community Vision

- Our vision is that the ubiquitous sensing potential of the Nano-Enabled Internet of Things (**Nano-IoT)** will:
  - provide the input necessary for data mining/big data processing to understand complex system behavior
  - augment the interaction environment in future workplaces
  - be the transducers that can monitor living things from agriculture to medicine
  - catalyze the convergence of researchers from many intellectual backgrounds
  - …
- **Nano-IoT** encompasses several of the themes of the NSF Ten Big Ideas, including: Future of Work, Growing Convergence Research, Understanding the Rules of Life, and Harnessing the Data Revolution.

Nano-IoT Research Community Plans

- Our original plan was to hold the first symposium in October of 2020
- First workshop late spring of 2021 as a virtual Nano-IoT RC meeting
  - Day-long event
  - Invited Speakers
  - Presentation from each RC member site of Nano-IoT research highlights going on at their site

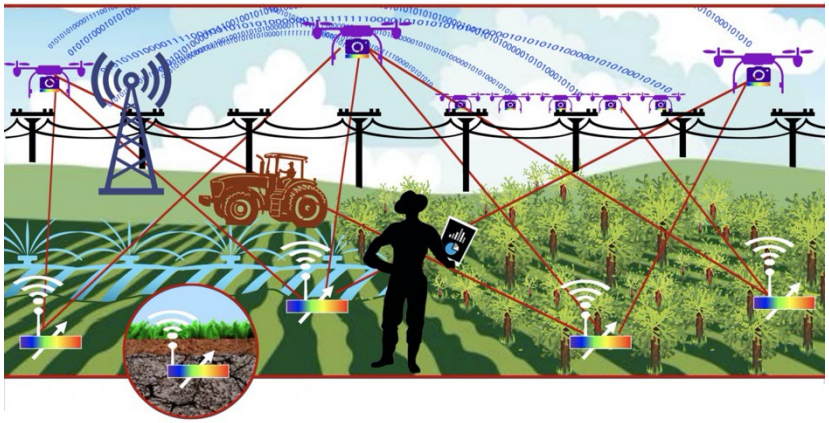
Example: Precision Agriculture

Key message: "… it is critical that productivity growth not rely on more cultivated land, water, or energy, but instead harness the power of innovation and technology."

Key message: "Digital technologies have the potential to improve efficiency, equity, nutrition and health, and sustainability in the food system."

NSF ERC for the Internet of Things for Precision Agriculture (IoT4Ag)

Penn (lead), Purdue, University of California (Merced), University of Florida
Director: Prof. Cherie Kagan



Theme: **IoT4Ag** researchers will create miniature soil-based sensors and swarms of aerial and ground-based robots, find new ways to network them together in communication-constrained environments and develop high-level data science techniques that will allow data from different sensors in the field to be integrated with data from weather reports and commodity markets, synthesizing it into actionable information.

Thrust 1: Agricultural Sensor Systems (Eshani, Rowland)
Thrust 2: Communication and Energy Systems (Allen, Love)
Thrust 3: Decision and Response Systems (Buckmaster, Mangharam)

The convergence of plant science, distributed sensors, communications, data science, agricultural practices, and robotic surveillance/interrogation

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NSF

New NSF-Funded STC Center

cropps
Center *for* Research on Programmable Plant Systems

Participating Institutions

- **Cornell University (CU) – lead**
- **Boyce Thompson Institute (BTI)**
- **University of Arizona (U of A)**
- **University of Illinois Urbana-Champaign (UIUC)**

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Programmable Plant Systems

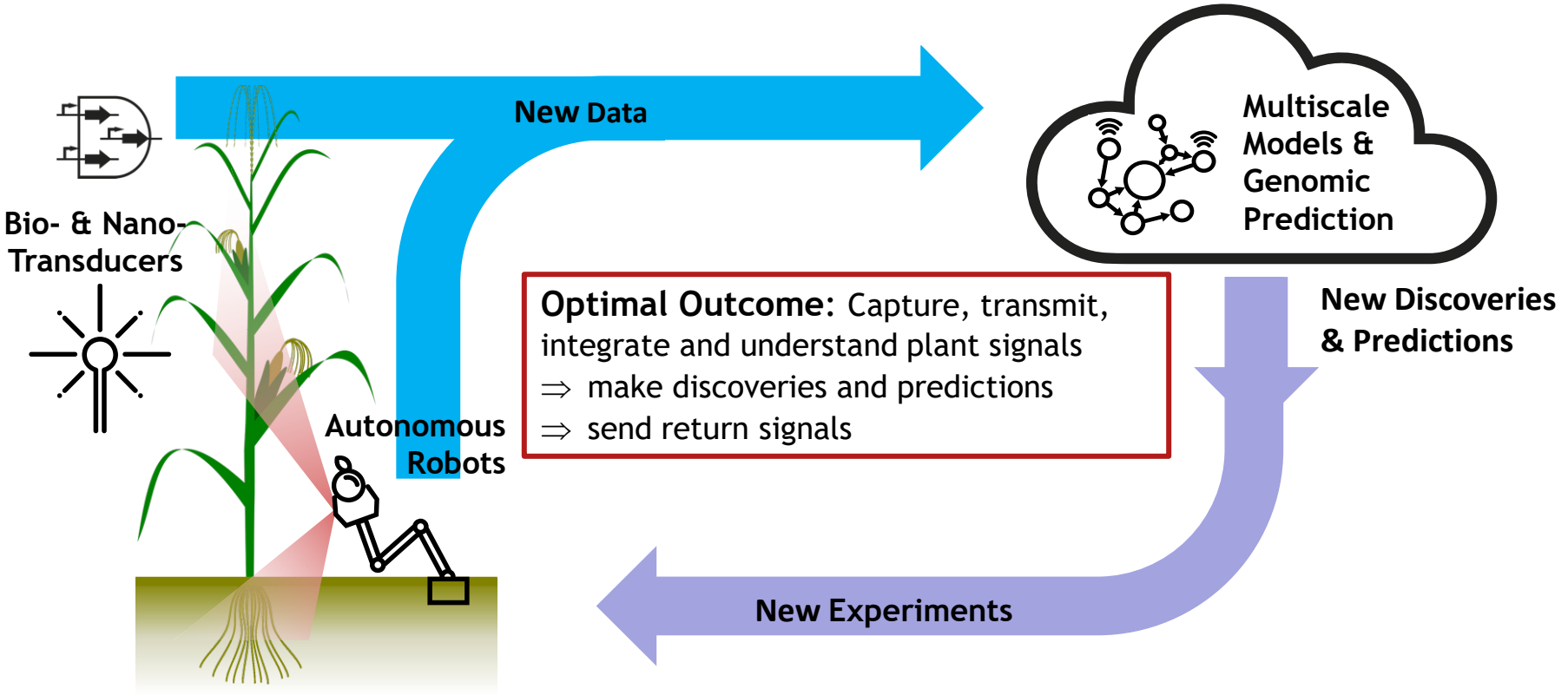

Image: Meagan Lang, Kelly Robbins, Amy Marshall-Colon

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Proposed Structure of our Research Community

- Nano-IoT members will hold or participate in a yearly, day-long symposium that will rotate among the community sites.
  - The major goal of the symposium is to summarize, inform, and exchange the work of NNCI users
  - New ideas to be introduced through invited external speakers
- Each member of the Research Community will send at least one speaker from their site to the rotating symposium, with the twin goals of
  - presenting research from their site; and
  - bringing back the knowledge of research going on at other sites, disseminated through local symposia
- Community members will subsequently hold a seminar at their home site for home users where the information discussed at the symposium will be disseminated.

Proposed Structure of our Research Community

- The host site will report out to the NNCI Annual Meeting
  - High level research highlights
  - lessons learned that could continually improve the information dissemination within the communities.
- Next workshop (2023) will be hosted by Christian Binek (NNF)

2022 Nano-IoT Workshop

- **Workshop registrant statistics**
- 43 people registered
  - 24 from Cornell University
  - 8 from Nano IoT RC sites
  - 5 from industry
  - 5 from other universities
  - 1 gov lab
- 21 attendees signed in for most of the day via zoom
- 15 attended in person

- Nano-IoT Technical Presentations by Invited Speakers (30 minutes each)
- Talks recorded and available.

Program:

10:15 a.m. Abraham D. Stroock, Smith School of Chemical and Biomolecular Engineering, Cornell; "Programmable Plants and the Internet of Living Things "- The Pulse of Plants

10:45 a.m. Mark Poliks, Center for Advanced Microelectronics Manufacturing, Binghamton University; "Flexing, Bending and Stretching Toward Advances in Electronics for Medical and Industrial Applications"

11:15 a.m. Scott Miller, Ph.D., Director of Technology, NextFlex; "Hybrid Electronics"

2:30 – 4:00 pm Nano IoT Panel and Discussion Summary

Moderator – Chris Ober and Ron Olson

Panelist; Scott Miller, Mark Poliks, Abe Stroock, Pat Watson

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Workshop Highlights

- Collaborations will be critical in order to bridge technological gaps between researchers/engineers
- New sensors and new devices could be developed through processes that make use of converging, classic cleanroom processes and advanced additive processes used in flexible hybrid electronics.
- Everyone agreed that developing a roadmap would help determine future directions for the Nano Internet of Things. A roadmap will address questions that are currently being raised and will help determine where the industry currently stands and what will be forthcoming.
- The discussion of how nanotechnology will transform the internet of things centered upon materials, processes and nanotechnology enabled devices. An understanding of new, complex tunable materials enabled by nanotechnology needs to be explored and mastered. These materials have the potential to enable new electronic structures with new properties and/or micromechanical attributes.