

# TRANSFORMING AGRICULTURE WITH INTELLIGENT INFRASTRUCTURE: A U.S. PERSPECTIVE

**Shashi Shekhar**

*McKnight Distinguished University Professor, Univ. of Minnesota, Minneapolis*

*Tuesday, Dec. 17<sup>th</sup>, 2019*

*Workshop on Data Science for Agriculture and Natural Resource Management  
7<sup>th</sup> International Conference on Big Data Analytics*

- Details:** (a) **Intelligent Infrastructure for Smart Agriculture: An Integrated Food, Energy and Water System**, S. Shekhar et al., Computing Community Consortium whitepaper; arXiv preprint arXiv:1705.01993, 2017.
- (b) **Agriculture Big Data (AgBD) Challenges and Opportunities From Farm To Table**: A Midwest Big Data Hub Community Whitepaper, Ss. Shekhar et al, NSF Midwest Big Data Hub, December, 2017.

**Acknowledgements:** *Ranbeer Chandra (Microsoft), Chandra Krintz (U.C.S.B.), Kim Van der Waal & Philip Pardey (University of Minnesota), Midwest Big Data Hub, Computing Community Consortium.*  
*(Adapted from earlier talk in to 2018 American Association for Advancement of Sciences  
Session: Transforming Cities, Transportation, and Agriculture With Intelligent Infrastructure)*



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**Driven to Discover**<sup>SM</sup>



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# AGRICULTURE & UNIV. OF MINNESOTA


- Land Grant Mission
- Contributions
  - Honeycrisp Apple: **Research you can bite into**
  - People : Norman Borlaug

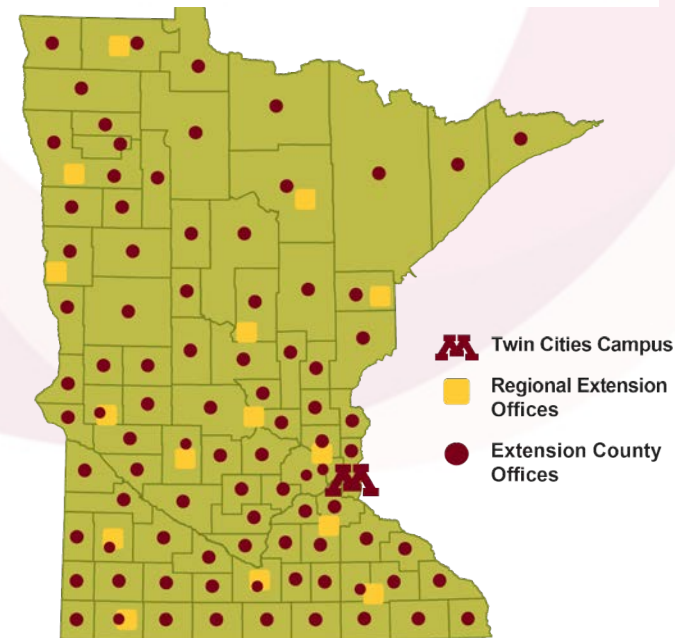
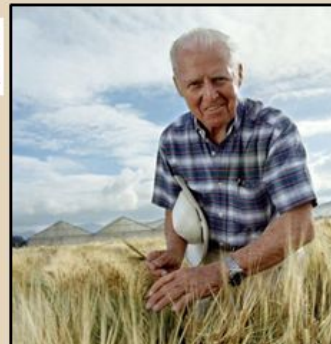
Crisp, juicy, sweet melting flavor.  
Developed by University of Minnesota.  
Consistently rated #1 in taste tests.



Honeycrisp

## Norman Borlaug

- Known as **“The father of the Green Revolution”**
- Nobel Peace Prize Winner
- **University of Minnesota** Graduate 
- Created varieties of high yield, disease resistant wheat crops
- **Result:** boost the production of wheat around the world.



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Success Stories

Transformative Opportunities

Discovery to Application

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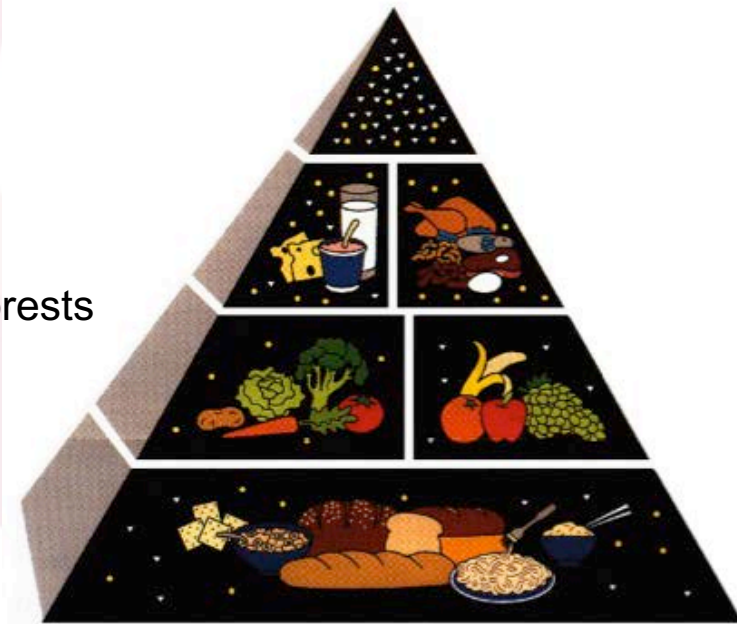
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# AGRICULTURE TODAY: SOCIETAL IMPORTANCE

- Agriculture nourishes us with
  - Food, Fiber, Fuel
- Economic Opportunities
  - 10% of U.S. Jobs
  - Helps rural America to thrive
  - Early adopter of technology, e.g., GPS, UAV, ...
- Stewart of natural resources
  - Healthy private working lands
  - Conservation, Improved Watersheds, Restored Forests

The USDA Food Pyramid



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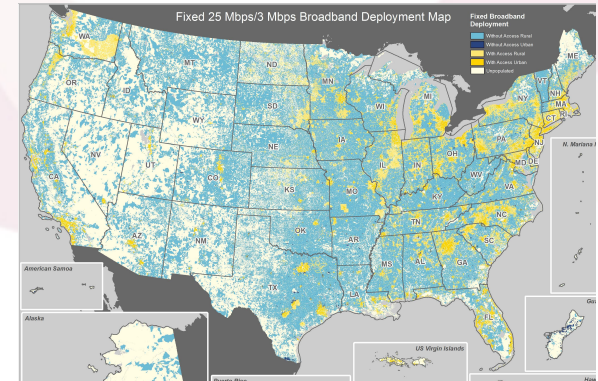
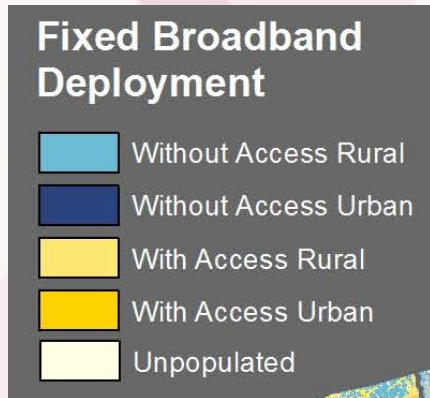
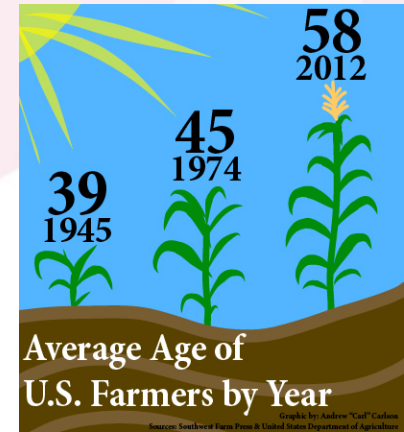


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# AGRICULTURE TODAY: CHALLENGES

- Social-Infrastructure
  - Aging workforce, Labor shortage
  - Low urban engagement of urban
- Environmental-Infrastrucure
  - Bee colony collapse
  - More intense rains & longer dry periods
- Cyber-Infrastructure Challenges
  - Broadband & cloud computing
  - Data: Yield & disease prediction



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# AN INTELLIGENT INFRASTRUCTURE SUCCESS STORY : PRECISION AGRICULTURE

- Transformed agriculture
  - Improves yield
  - Reduces fertilizer use & run-offs
- Intelligent Infrastructure
  - GPS, GIS, Remote Sensing, ...

Yield  
Monitors

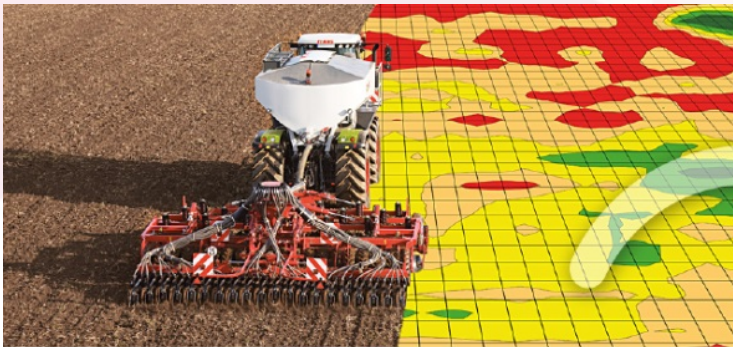
Direct &  
Remote  
Sensing

Precision  
Navigation

Variable  
Rate  
Technology

Global Positioning Systems

Geographic Information Systems



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# Deconstructing Precision Agriculture

#AgInnovates2015

Wednesday, March 4, 2015  
Reception | 5:00 to 7:00 pm

House Agriculture Committee Room,  
1300 Longworth House Office Building,  
Washington, DC

Think Moon landing.

Think Internet.

Think iPhone and Google.

Think bigger.

Come hear U.S. farmers, leading agriculture technology companies, and scientists tell how they work together to fuel U.S. innovation and the economy to solve this global challenge.

The event will exhibit three essential technologies of precision agriculture that originated from a broad spectrum of federally funded science: Guidance Systems and GPS, Data & Mapping with GIS, and Sensors & Robotics.

## Moderator

Raj Khosla, Professor of Precision Agriculture at Colorado State Univ.

## Farmers

David Hula, of Renwood Farms in Jamestown, Virginia

Rod Weimer, of Fagerberg Produce in Eaton, Colorado

Del Unger, of Del Unger Farms near Carlisle, Indiana

## Speakers

Mark Harrington, Vice President of Trimble

Carl J. Williams, Chief of the Quantum Measurement Division at NIST

Bill Raun, Professor at Oklahoma State Univ.

Marvin Stone, Emeritus Professor at Oklahoma State Univ.

J. Alex Thomasson, Professor at Texas A&M Univ.

Dave Gebhardt, Director of Data and Technology at Land O'Lakes/WinField

Shashi Shekhar, Professor at the Univ. of Minnesota

**RSVP**

<http://bit.ly/1CoOYoa>

Hosted by  
the Congressional Soils Caucus

In partnership with

Agricultural Retailers Association  
American Society of Plant Biologists

American Physical Society

American Society of Agronomy

Association of Equipment Manufacturers

Coalition for the Advancement of Precision Agriculture

Computing Research Association

CropLife America

Crop Science Society of America

PrecisionAg Institute

Soil Science Society of America

Task Force on American Innovation

Texas A&M AgriLife

Trimble

WinField



This is about feeding the world.



# AN INTELLIGENT INFRASTRUCTURE SUCCESS STORY: PRESCRIPTIVE FARMING

CLIMATE  
**FIELDVIEW**

Seamless Field Data Collection



Customized Insights for Decision Making

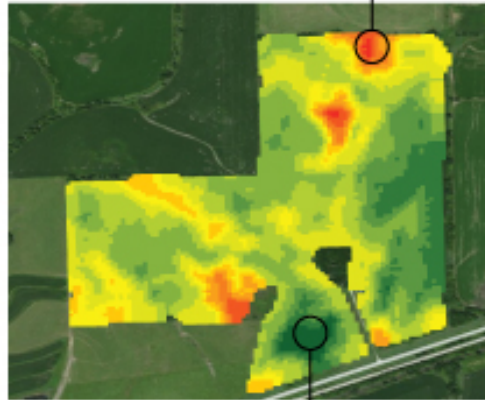
## Monsanto, DuPont and others are pitching 'prescriptive planting' services to increase crops

How data-driven planting services work:

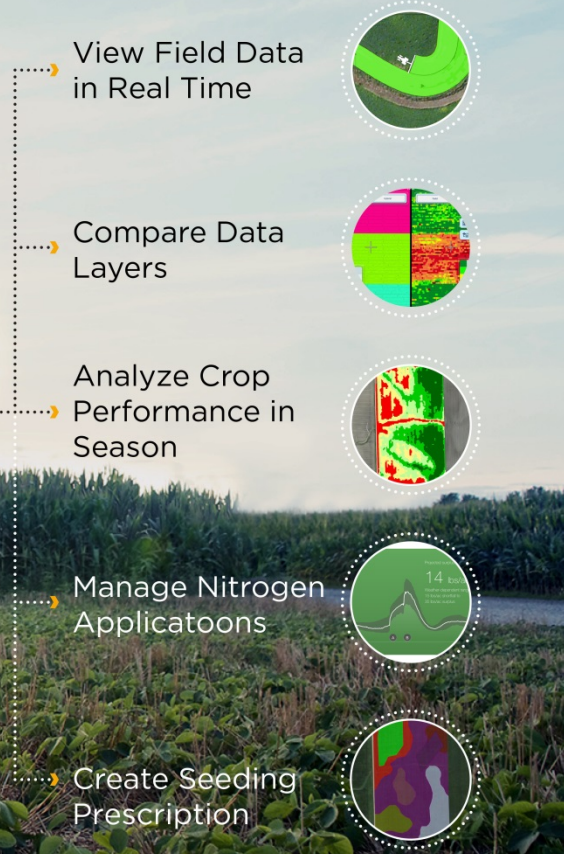
1. The farmer provides field boundaries, historic crop yields, soil conditions and other data to a company.
2. The company analyzes the data and its own information about seed performance in different areas and soil types.
3. The company sends a computer file with recommendations back to the farmer, who uploads it into a planter.
4. The farmer's equipment then plants based upon the recommendations. The company monitors weather and other factors, advising farmers on how to manage crops as they grow.

A cornfield analysis in Iowa:

**Red areas:** Lower number of seeds per acre recommended



**Green areas:** Portions of the field that can grow more corn and can take more seeds per acre



Source: Monsanto

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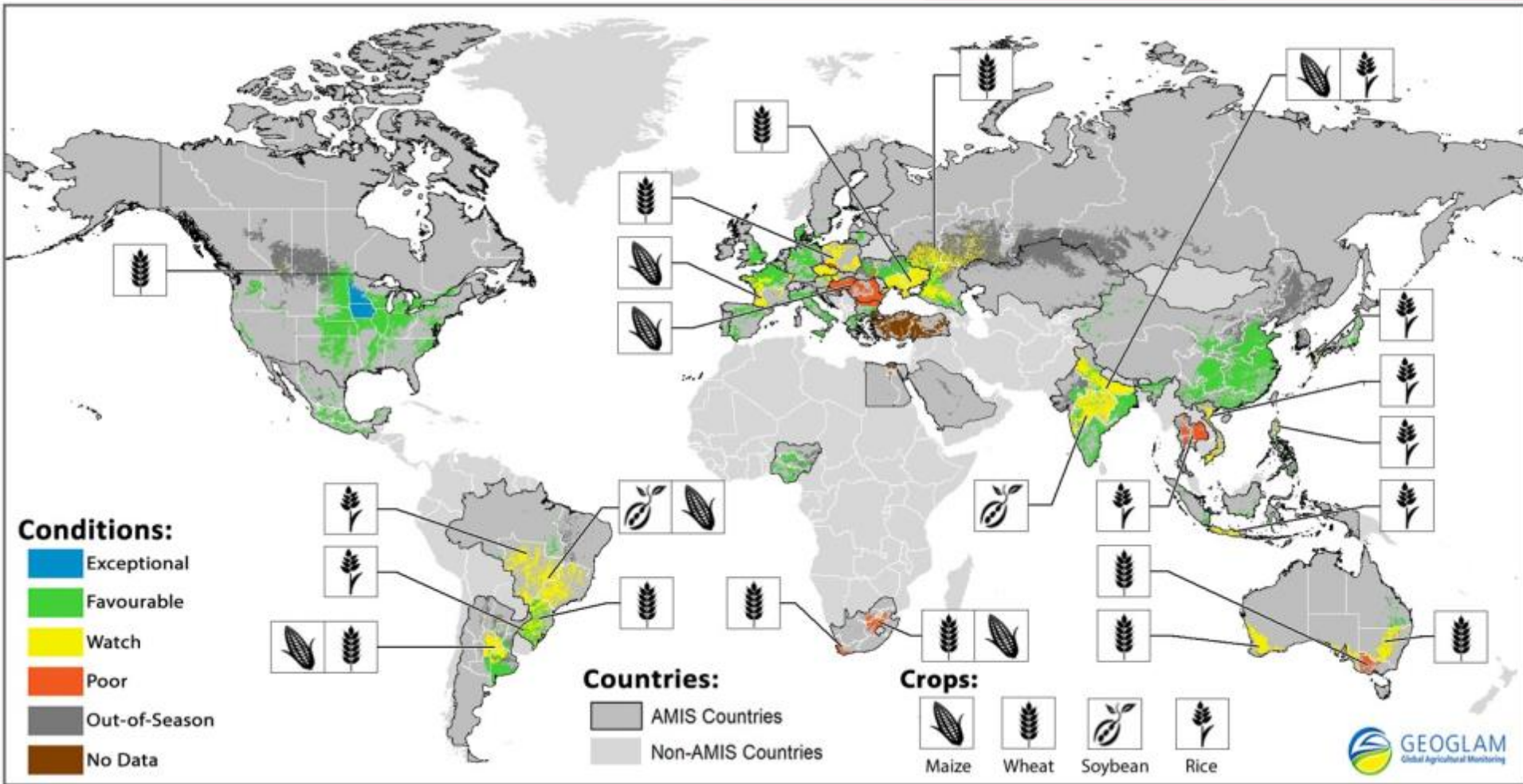
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# (BI-WEEKLY) CROP MONITORING & YIELD PREDICTION





# TRANSFORMATIVE OPPORTUNITIES: SOCIAL INFRASTRUCTURE

- Challenges: Aging workforce, Labor shortage, Low urban engagement
- Intelligent Infrastructure Opportunities
  - Tele-operation
  - VR-based Training Environment



Source: Autonomous Solutions Inc. and CNH Industrial unveil concept Autonomous Tractor, Aug. 30, 2016, asirobots.com



Source: L. Mathew, There is now a \$300 joystick built for Farming Simulator, geek.com, 06.12.2015.

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# TRANSFORMATIVE OPPORTUNITIES: ENVIRONMENTAL

- Challenges: Bee colony collapse, Rainfall Variability
- Intelligent Infrastructure Opportunities
  - Robot Bees
  - Cyber-Physical Systems for Smart Water management
    - Water sensors + data analytics + control



Source: Researchers using AI to build robotic bees, D. Harris, GigaOm, Oct 1, 2012.



Source: Smart Irrigation: 10 Companies to Watch in 2018, A. Shiffler, disruptorDaily.com, Dec. 27<sup>th</sup>, 2017.

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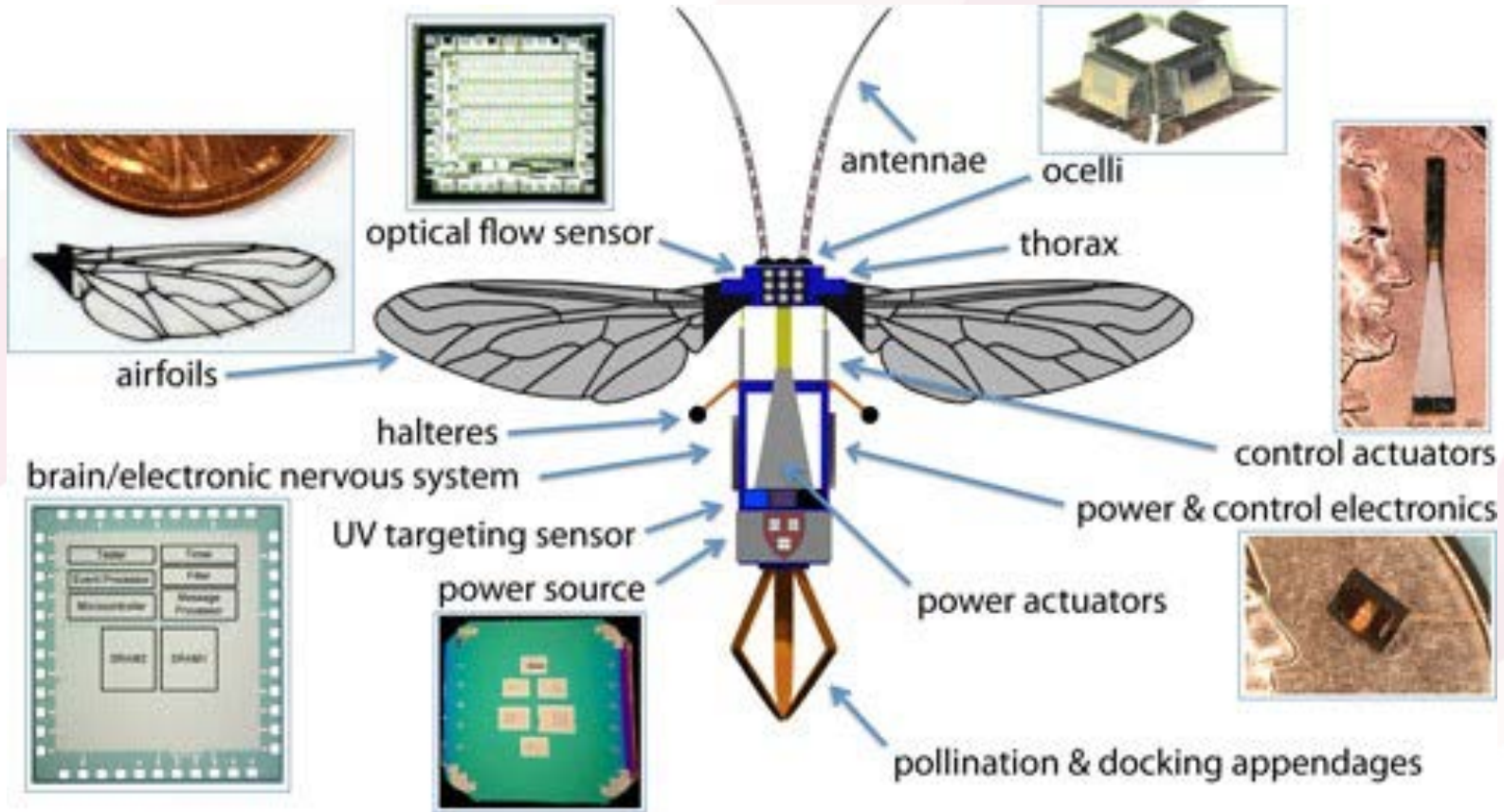


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# ROBOTIC POLLINATORS

- Robo-Bees (Harvard U, National Science Foundation):



Source: Researchers using AI to build robotic bees, Derrick Harris, GigaOm, Oct 1, 2012.

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# SMART IRRIGATION: CYBER-PHYSICAL SYSTEMS

- Cyber-Physical Systems = sensors + data analytics + control



Source: This smart irrigation and water management system is controlled by your smartphone, Derek Markham, treehugger.com, July 19, 2013.

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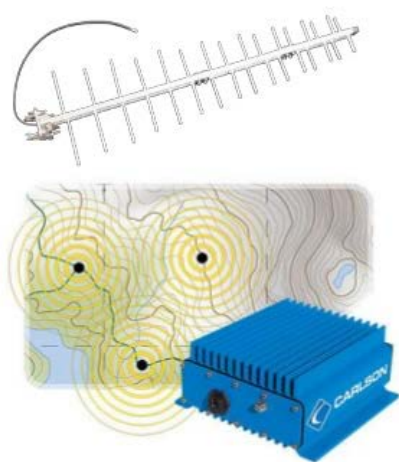
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# TRANSFORMATIVE OPPORTUNITIES: CYBER-INFRASTRUCTURE

- Challenges: Limited broadband, sensing, data & computing
- Intelligent Infrastructure Opportunities
  - TV Whitespace Spectrum for rural broadband
  - Geospatial Cloud & Edge Computing for farms
  - Spatial Data Science to monitor disease & predicting yield

## RuralConnect: TV White Space Radio



Client Station

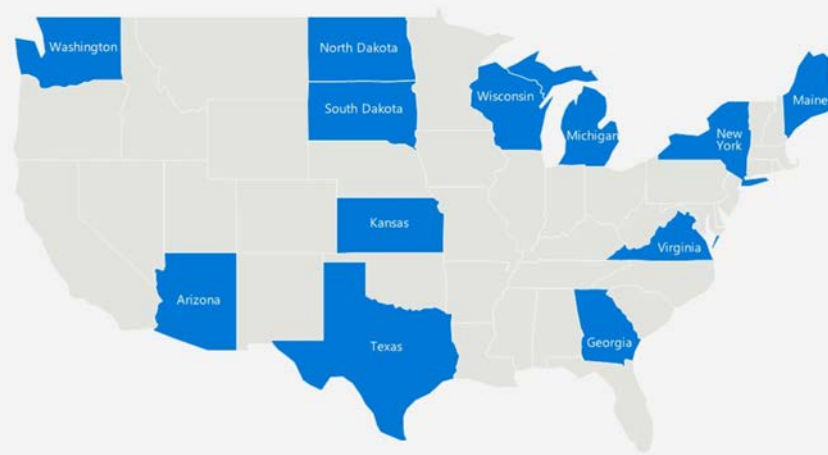


Base Station

[www.CarlsonWireless.com](http://www.CarlsonWireless.com) | 707.822.7000 | [Sales@CarlsonWireless.com](mailto:Sales@CarlsonWireless.com) | [f](#) [t](#) [in](#) [v](#)

## Microsoft TV White Spaces Pilot Projects

12 projects up and running in 12 states in the next 12 months



Source: Microsoft wants to close the rural broadband gap with TV white spaces, T. Warren, theverge.com, July 11, 2017.

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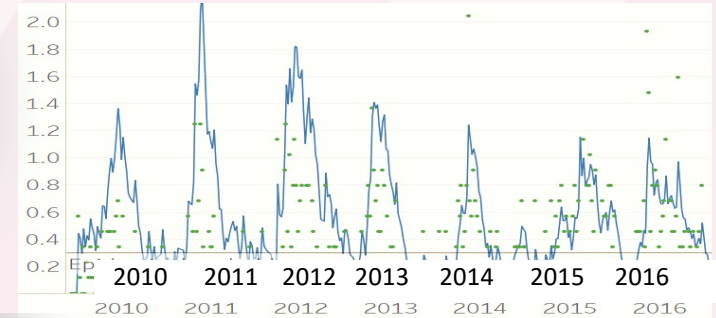
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# (WEEKLY) SWINE MONITORING & DISEASE FORECAST

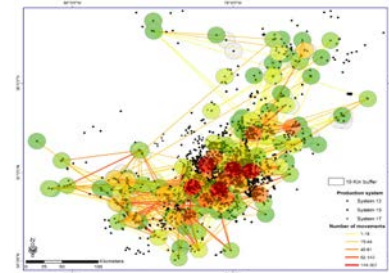
- **Track** weekly infection status
  - 50% of U.S. sow population
  - PRRS & PED virus
- **Forecast virus spread**
  - from pig **movement** across farms
- **Model** regional spread
  - Identify **super-spreaders**
- **Early Warning System**
  - Altered disease dynamics Detection
- **Challenge: Data Sharing**
  - During **Epidemics** (similar to E-911)
  - Protect property rights, privacy, ...

Source: Prof. Kim VanderWall, Univ. of Minnesota

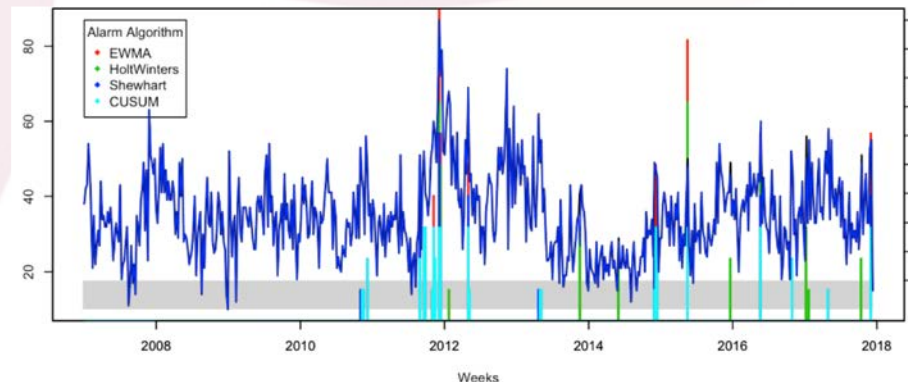
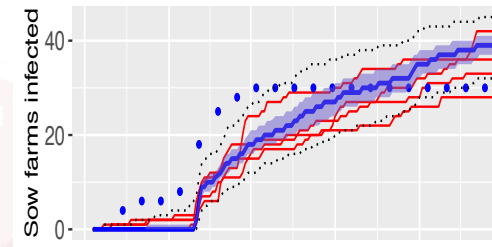
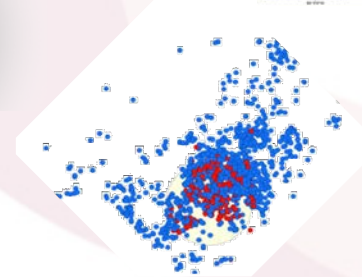
*Industry participation*



*Spatial analysis & Simulation*



*Machine Learning*





# CYBER-INFRASTRUCTURE NEEDS IN DATA-DRIVEN FARMS

- Challenges: Limited broadband, sensing, data & computing

## Data-Driven FARMs small and smart

### Computing Resources

#### Farm Dashboard & DSS



#### Privacy-Protected Shared FARMING DATA & Pattern Mining

The farm generates vast quantities of rich and varied data. This is stored in the cloud. Data can be used as digital evidence reducing time spent completing grant applications or carrying out farm inspections saving on average £5,500 per farm per year.

#### Nano-satellites & SURVEY DRONES

Aerial drones survey the fields, mapping weeds, yield and soil variation. This enables precise application of inputs, mapping spread of pernicious weed blackgrass could increase Wheat yields by 2-5%.

#### Sensor Network & FLEET OF AGRIBOTS

A herd of specialised agribots tend to crops, weeding, fertilising and harvesting. Robots capable of microdot application of fertiliser reduce fertiliser cost by 99.9%.

### Broadband Network

#### TEXTING COWS & GPS Collars

Sensors attached to livestock allowing monitoring of animal health and wellbeing. They can send texts to alert farmers when a cow goes into labour or develops infection increasing herd survival and increasing milk yields by 10%.

#### Smart Water

#### Tele-operated SMART TRACTORS

GPS controlled steering and optimised route planning reduces soil erosion, saving fuel costs by 10%.

Adapted from S. Chakravarty, [History of scientific farming in India](http://www.geospatialworld.net), June 6, 2017, [www.geospatialworld.net](http://www.geospatialworld.net)

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# INTELLIGENT INFRASTRUCTURE OPPORTUNITIES

- **More examples** in community whitepaper:

S. Shekhar et al., [Intelligent Infrastructure for Smart Agriculture: An Integrated Food, Energy and Water System](#), Computing Community Consortium whitepaper; arXiv preprint arXiv:1705.01993, 2017.

Areas	Intelligent Infrastructure and Research Needs
Workforce Development	Augmented reality; Teleoperation
Cyber Physical Systems & Robotics	Robust high-precision positioning; Automation for labor intensive tasks
Spatiotemporal Machine Learning, Data Analytics	Using high resolution satellite data to monitor crops; Optimize resource allocation
Security, Privacy, Safety	Secure, privacy-protected farm-data sharing; Economic models to promote data sharing
Networking, Internet of Farm Things	Improving Broadband Network Access in Rural Farming Areas
Decision Support	Advanced spatiotemporal image, and video analysis techniques
Citizen Engagement	Social Media; Apps

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# ADVANCING SCIENCE DISCOVERY TO APPLICATION

- Knowledge **co-production** with users
  - **Co-Visioning**
  - **Co-define Problems**
  - **Co-select Science Questions**
  - **Co-Evaluate Discoveries**
- **Co-production Initiatives**
  - CRA/CCC Visioning Workshops
  - (Midwest) Big Data Hubs & Spokes
  - NSF Sustainability Research Networks
  - NSF Smart & Connected Community
- **Co-Production Examples** in my work
  - 2005: **Evacuation Planning**: MN local governments
  - Current: **NSF SCC** Project: counties, cities in MN, FL



Source: The Sheffield Mental Health Guide, sheffieldflourish.co.uk, 5 Apr 2017.



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# KNOWLEDGE CO-PRODUCTION: EVACUATION PLANNING (2005)

- **Team:** US DHS, MN Dept. of Transportation, URS Corp.
  - Emergency Mangers, Police, Fire Fighters, Natl. Guard
- **Co-Visioning** via monthly meetings
  - Challenges: evacuees & traffic maps
  - Police: focus on what can be done!
- **Problem Co-Definition**
  - 1-mile scenarios: 5 sites, work-day or night-time
- **Co-Discovery**
  - For 1st mile, walking faster than driving
- **Co-Evaluation**
  - Walk selected routes : avoid wooden bridge near E
  - Lock parking garages during evacuation ?

## Evacuation Planning System for Twin Cities Metro Area

Step 2 of 3: Adjust Scenario Settings [\(go home\)](#)

Zoom In (x4) Zoom In (x2) Zoom Out (x2) Zoom Out (x4)

## Evacuation Planning System for Twin Cities Metro Area

Step 3 of 3: Evacuation Route Plan [\(go home\)](#)

Zoom In (x4) Zoom In (x2) Zoom Out (x2) Zoom Out (x4)

Scenario Name:

User Defined

Evacuation Radius

Src Radius: 1 mile  
Dst Radius: 2 mile

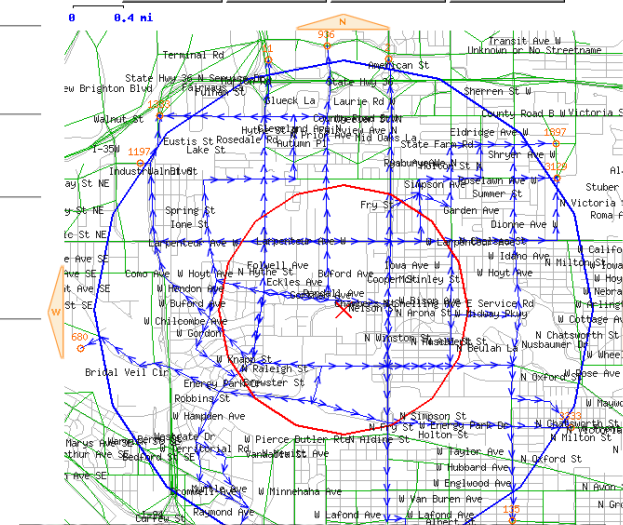
Population Estimate

Original Estimate: 14431 [\(details\)](#)  
Adjusted Estimate: 14431

Time of Day: Daytime

Analysis Result

Number of destinations: 45  
Evacuation Time: 3 hr(s) 16 min



Scenario	Population	Vehicle	Walking
A	143,360	4:45	1:32
B	83,143	2:45	1:04
C	27,406	4:27	1:41
D	50,995	3:41	1:20
E	3,611	1:21	0:36

Details: [FoxTV newsclip, Shashi Shekhar Disaster Area Evacuation Analytics](#),  
<https://www.youtube.com/watch?v=PR9k72W8XK8>

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# KNOWLEDGE CO-PRODUCTION: NSF SMART & CONNECTED COMMUNITIES GRANT 1737633 (2017-2020)

- **Team:** U of Minnesota, Purdue U, FL State U, U of WA
  - Schools, Counties (e.g., Hennepin), Cities (e.g., Minneapolis, St. Paul, Tallahassee);
  - MetroLab Network, National League of Cities, ICLEI-USA, Intl. City/County
- **Co-Visioning** via meetings
  - Communities planning infrastructure for driver-less, post-carbon future with climate change
  - Advance Environment, Health, Wellbeing & Equity via infrastructure refinement
- **Co-select Questions**
  - Understand **spatial equity in infrastructure & outcomes** (wellbeing, health, environment)?
  - How does **equity first approach** differ from average-outcome based approaches ?
- **Problem Co-Definition:** How to measure spatial equity? Well-being?
- **Co-Discovery**
- **Co-Evaluation**



- **Details:** [University of Minnesota secures \\$2.5 million grant to improve quality of life in cities](https://www.cs.umn.edu/news/filter/highlights/professor-shekhara-leads-u-m-team-granted-25-million-nsf-grant), October 20, 2017 (<https://www.cs.umn.edu/news/filter/highlights/professor-shekhara-leads-u-m-team-granted-25-million-nsf-grant>)



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# CONCLUSIONS & NEXT STEPS

- **Agriculture is societally important and facing challenges**
  - Importance: 10% of U.S. economy, ...
  - Challenges: Workforce, bee colony collapse, broadband, ...
- **Intelligent Infrastructure has already transformed Agriculture**
  - Precision Agriculture
- **Many Transformative opportunities lie ahead**
  - Workforce, Robo-bees, TV Whiteband, Spatial Data Science, ...
- **However, these will not material without**
  - Federal research funding
  - **Knowledge Co-production**: farmers, academics, businesses, policy-makers



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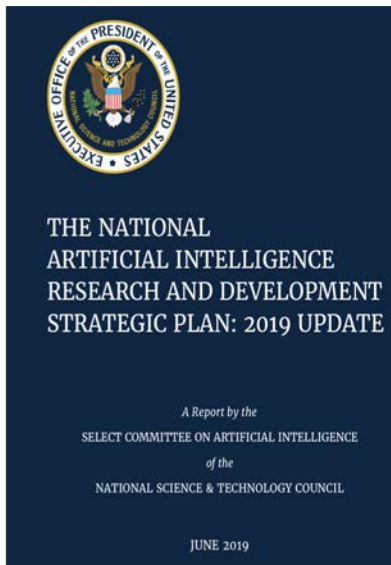
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# American AI Initiative

The [American AI Initiative](#) supporting national AI technology and innovation has spurred numerous efforts, including the [NITRD National AI R&D Strategic Plan \(2019 Update\)](#), the [AAAI/CCC 20 year community roadmap for AI research](#), [NIST plans for AI standards](#), [NSF National AI Research Institutes solicitation](#), and related initiatives in academia, industry and government.



## National Artificial Intelligence (AI) Research Institutes: Accelerating Research, Transforming Society, and Growing the American Workforce

### PROGRAM SOLICITATION NSF 20-503



#### National Science Foundation

- Directorate for Computer and Information Science and Engineering
- Directorate for Biological Sciences
- Directorate for Education and Human Resources
- Directorate for Engineering
- Directorate for Geosciences
- Directorate for Mathematical and Physical Sciences
- Directorate for Social, Behavioral and Economic Sciences
- Office of Integrative Activities



National Institute of Food and Agriculture



Department of Homeland Security, Science & Technology Directorate



U.S. Department of Transportation, Federal Highway Administration



U.S. Department of Veterans Affairs

**Anticipated Type of Award:** Standard Grant or Cooperative Agreement

**Estimated Number of Awards:** 9 to 14

NSF plans to make 1-6 Institute Awards and approximately 8 Planning Grants.

**Anticipated Funding Amount:** \$24,000,000 to \$124,000,000

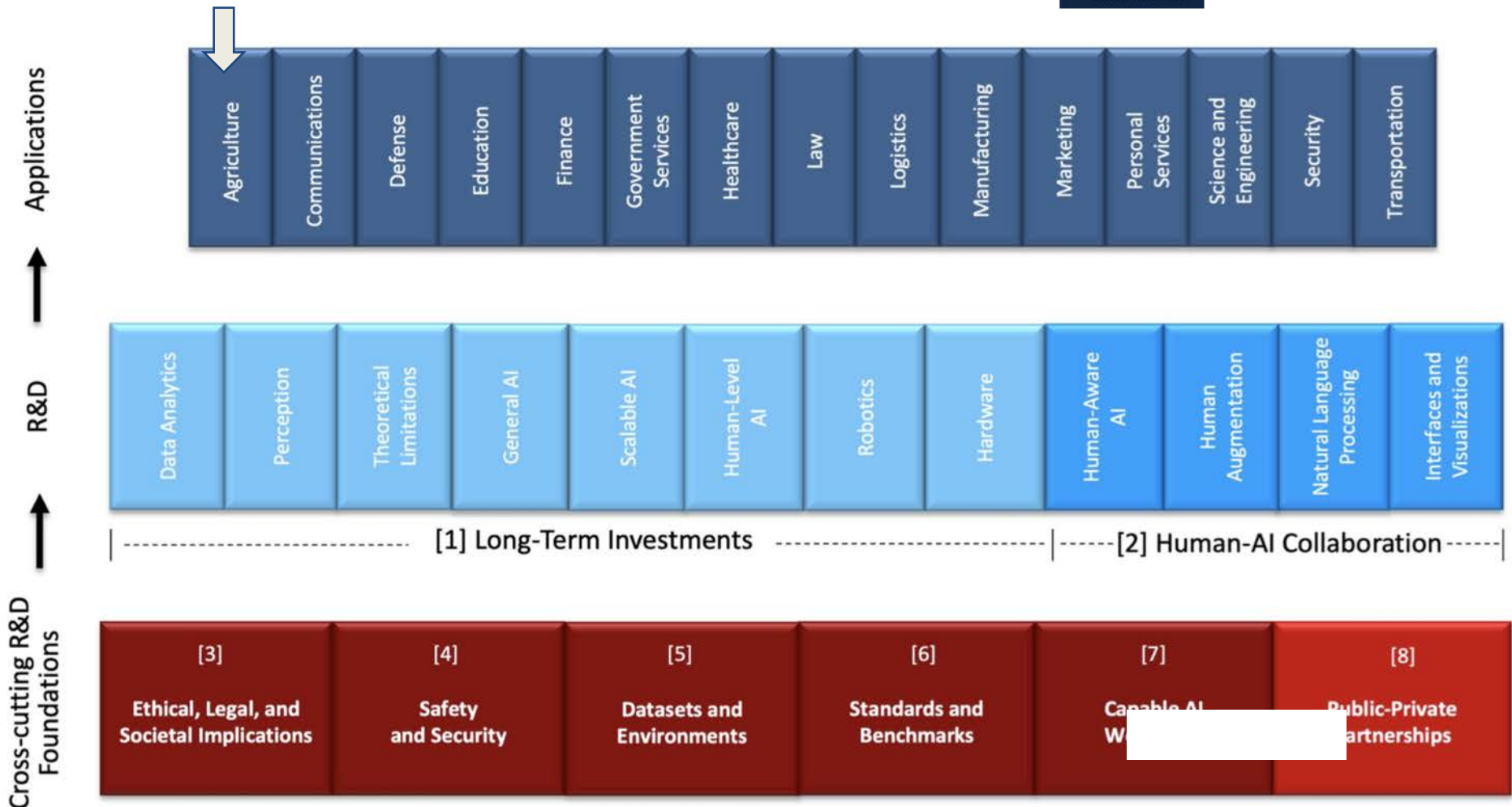


Figure 1. Organization of the AI R&D Strategic Plan (2019 update, to include Strategy 8). A combination of

# REFERENCES

1. S. Shekhar, J. Colletti, F. Munoz-Arriola, L. Ramaswamy, C. Krintz, L. Varshney, and D. Richardson, [Intelligent Infrastructure for Smart Agriculture: An Integrated Food, Energy and Water System](#), A Computing Community Consortium whitepaper; arXiv preprint arXiv:1705.01993, 2017.
2. S. Shekhar et al., [Agriculture Big Data \(AgBD\) Challenges and Opportunities From Farm To Table: A Midwest Big Data Hub Community Whitepaper](#), NSF Midwest Big Data Hub, December, 2017.
3. [Data Science for Food, Energy and Water: A Workshop Report](#), ACM SIGKDD Explorer, 18(2):1-4, December 2016. describes the highlights of the ACM SIGKDD [Workshop on Data Science for Food, Energy and Water](#), 2016.
4. [NSF Workshop to Identify Interdisciplinary Data Science Approaches and Challenges to Enhance Understanding of Interactions of Food Systems with Energy and Water Systems](#), Computing Research News (ISSN 1069-384X), Computing Research Association, 27(10), November 2015.
5. [Capitol Hill Presentation on Deconstructing Precision Agriculture](#), Computing Research News (ISSN 1069-384X), Computing Research Association, 27(4), April 2015.
6. [40 maps that explain food in America](#), E. Klein et al., 2014 (<https://www.vox.com/a/explain-food-america>).

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