

A 20-Year Community Roadmap for Artificial Intelligence Research in the US

Executive Summary

March 2019

Co-chairs: Yolanda Gil and Bart Selman

Decades of artificial intelligence (AI) research have produced formidable technologies that are providing immense benefit to industry, government, and society. AI systems can now translate across multiple languages, identify objects in images and video, converse about order placement, and control cars. The ubiquitous deployment of AI systems has not only created a trillion dollar AI industry that is projected to quadruple in three years, but has also exposed the need to make AI systems fair and trustworthy as well as more competent about the world in which they (and we) operate. Future AI systems will be rightfully expected to handle complex tasks and responsibilities, engage in meaningful communication, and improve their awareness through experience.

The next generation of AI systems have the potential for transformative impact on society. For example, lifelong personal assistants will enable an elderly population to live longer independently, AI health coaches will provide advice for lifestyle choices, customized AI tutors will broaden education opportunities, and AI scientific assistants will dramatically accelerate the pace of discovery. Recognizing that AI will be a major driver of the economy over the next several decades, Asia and Europe are making multi-billion dollar AI investments. With strategic investments, the US can remain the preeminent leader in AI and benefit from its broad societal and economic impacts.

Achieving the full potential of AI technologies poses research challenges that will require significant sustained investment and a radical transformation of the AI research enterprise. This is the main finding of a recent study by leading AI experts carried out by the Computing Community Consortium and the Association for the Advancement of Artificial Intelligence to formulate a roadmap for AI research and development over the next two decades.

The 20-year research roadmap for AI envisions three major areas of significant potential impact:

- *Integrated intelligence*, including foundations for principled combination of modular skills and capabilities, contextualization of general capabilities to suit particular uses, and creation and use of open shared repositories of machine understandable world knowledge.
- *Meaningful interaction*, comprising productive collaboration, diverse communication modalities, responsible and trustworthy behaviors, and fruitful online and real-world interaction.
- *Self-aware learning*, ranging from robust and trustworthy learning, learning from few examples and through instruction, developing causal and steerable models from numerical data and observations, and real-time intentional sensing and acting.

Underlying these research directions is the quest to understand intelligence in all forms (artificial, human, animal) and contexts. The AI community is eager to pursue this research agenda, but there are major impediments to making substantial headway.

First, the field of AI has reached a maturity level that goes beyond the initial academic focus on algorithms and theories and into embracing live instrumented deployments, continuous data collection, social and interactive experimentation, dynamic environments, and massive amounts of knowledge about a constantly changing world. This requires new facilities that do not exist in academia today. Although major AI innovations have roots in academic research, universities now lack the massive resources (unique datasets, special-purpose computing, extensive knowledge graphs, well-trained AI engineers, etc.) that have been acquired or developed by major IT companies. These are fundamental capabilities to build forward-looking AI research programs. This also puts universities at a serious disadvantage in terms of attracting talented graduate students and retaining influential senior faculty. Moreover, because AI resources in major IT industry labs are generally proprietary, this uneven playing field also negatively affects smaller businesses and non-IT industry sectors, as well as government organizations, all of which have traditionally benefitted from the open nature of academic research.

Second, research requires highly interdisciplinary teams that can only succeed in long-term sustained programs that are currently rarely available. AI challenges span all areas of computer science, as well as cognitive science,

psychology, biology, mathematics, social and natural sciences, engineering safety, public policy, ethics, education, and communication, to name a few.

Third, the overwhelming demand and excitement surrounding data-rich machine learning has caused a redirection of faculty, students, and curricula towards this particular area of AI, at the expense of other AI areas that are crucial for a broader research roadmap.

Fourth, the need for AI expertise surpasses current production of university graduates with AI skills at the undergraduate, masters, and PhD levels. Many PhD level AI graduates in the US find attractive opportunities abroad. Although there is great demand for AI practitioners and data scientists, universities lack the facilities to prepare students properly for industry settings.

Achieving this vision will require a reinvention of the AI research enterprise to create a comprehensive national AI infrastructure and to re-conceptualize AI workforce training. The 20-year AI research roadmap includes the following specific recommendations:

I --- Create and operate a National AI infrastructure to serve academia, industry, and government through four interlocking capabilities:

- a) *Open AI Platforms and Facilities*: a vast interlinked distributed collection of “AI-ready” resources (growing datasets, software libraries, knowledge repositories, instrumented homes and hospitals, robotics environments, cloud services, etc.) contributed by and available to the research community as well as to industry and government.
- b) *Sustained Community-Driven AI Challenges*: organizational structures that coordinate the formulation by researchers of well-defined challenge roadmaps to jointly address key problems, reformulate them in unison with new advances, promote integration and well-engineered systems, and create shared resources in the Open AI Platforms and Facilities.
- c) *National AI Research Centers*: concentrations of first-class researchers, including multi-year funded Faculty Fellows affiliated with a range of academic institutions and Industry Resident Fellow positions from other organizations. Together, these will create critical mass to address core AI research challenges and facilitate technology transfer to industry.
- d) *National AI Laboratories*: government organizations that will provide sustained capabilities and AI experts to support the Open AI Platform and AI Challenges, and address vertical sectors of public interest such as health, policy, education, and science.

II --- Re-conceptualize and train an all-encompassing AI workforce

- a) *Recruitment programs for AI*, including grants for talented students to obtain advanced graduate degrees, retention programs for doctorate-level researchers, and engagement of underrepresented groups.
- b) *Broadening AI curriculum and incentivizing non-traditional and interdisciplinary AI studies*, with priority to AI policy and law, as well as AI safety engineering.
- c) *Training highly skilled AI engineers and data scientists* through the Open AI Platform, thereby significantly growing the pipeline through community colleges and workforce retraining programs.

The combination of shared infrastructure capabilities and a massive skilled workforce will put the United States in a unique position to continue to be the world’s leader in AI research, development, and technology transfer, by 1) pursuing the forward-looking AI research that will lead to sustained and broad innovations in AI; 2) creating unique, comprehensive, and effective AI capabilities; 3) attracting and retaining the best talent in fertile research settings; 4) creating extensive human capital in this crucial technology area; and 5) driving AI technologies to address important problems in sectors less favored by industry, such as scientific discovery, education, and public policy.

This is the result of the community road mapping effort which took place in the fall 2018 and winter of 2019. Information about the AI road mapping effort can be found here (<https://cra.org/ccv/visioning/visioning-activities/2018-activities/artificial-intelligence-roadmap/>). This material is based upon work supported by the National Science Foundation under Grant No. 1136993. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

A 20-Year Community Roadmap for Artificial Intelligence Research in the US

Yolanda Gil (USC) and Bart Selman (Cornell), co-chairs

AI LANDSCAPE

Exploiting data with AI/ML highly effective but limited use

Industry push of AI mostly for consumer products

Piecemeal funding programs and academic projects

IT giants amassing significant proprietary resources and experts

Rest of industry, government, academic lack access to large AI infrastructure and engineering resources

AI-driven capabilities:

- Mental and behavioral health coaches
- Accurate models of water resources
- Speed up materials science experiments
- Augment education for remote students
- Resolve supply chain delays
- At-home robot caregivers/helpers
- Response for natural disasters
- Collaborative omics discoveries
- Train for robot repair jobs
- Businesses innovation in personal devices
- Game design startups
- Scientific models from theories and data
- Improve law enforcement and training
- Resolve food insecurity and distribution
- Resilient cyber-physical systems

ASPIRATIONS

Reduce healthcare cost

Accelerating scientific discovery

Universal personalized education

Unprecedented innovation for businesses

Evidence-driven social opportunity

AI challenges not solvable as piecemeal academic research projects

AI challenges not a priority for big AI/IT industry players

AI RESEARCH PRIORITIES

Integrated intelligence

- Science of integrated AI
- Contextualized AI
- Open knowledge repositories
- Understanding intelligence

Meaningful interactions

- Collaboration
- Trust and responsibility
- Diversity of interaction channels
- Improved interaction between people

Self-aware learning

- Robust and trustworthy learning
- Deeper learning for challenging tasks
- Integrating symbolic and numeric representations
- Learning in integrated AI/Robotic systems

RECOMMENDATIONS

Audacious AI Research

National AI Infrastructure

Workforce Training

Interdisciplinary AI

AI faculty and student retention

Broadening AI research priorities

AI engineers workforce (retraining, CC, MS)

EPIC-2019-001-002682

National AI Labs

National AI Research Centers

Open AI Platforms and Facilities

Sustained community-driven challenges

Developing a 20-Year AI Research Roadmap for the US

CRA Computing Community Consortium,
Association for the Advancement of Artificial Intelligence (AAAI),
and the computing research community

Roadmap Co-Chairs:

Yolanda Gil, University of Southern California, AAAI President

Bart Selman, Cornell University, AAAI President-Elect



May 2, 2019



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Societal Drivers

Evidence-Driven
Social Policy

Reduce Cost of
Healthcare

Personalized
Education

Business
Opportunities

Accelerating
Science

Technical Areas

Integrated
Intelligence

Meaningful
Interaction

Self-Aware
learning

Identifying Societal Drivers

1. **Boost Health and Quality of Life:** Prevention of illness and elderly ailments, mental/behavioral health, reducing cost (25+% feasible) while improving care, remote patient care.
2. **Lifelong Education and Training:** Personalized, scalable education support. Improve the AI knowledge and skills of people who will lose jobs. Training next generation of AI specialists, data scientists, and software engineers
3. **Reinvent Business Innovation and Competitiveness:** Evidence-driven companies, which would increase productivity and value and open new sectors/products
4. **Accelerate Scientific Discovery and Technological Innovation:** Biomedical, environmental, new materials, personalized services, robotics, self-driving cars, etc.
5. **Social Justice and Policy:** Engaging and empowering disadvantaged communities. Improving civic and political discourse
6. **Transform Cyber Defense and Security:** AI driven systems can compensate for a relatively small cyber defense workforce, adversarial reasoning

Research Priorities

- **Integrated Intelligence**

- Science of integrated intelligence
- Contextualized AI
- Open knowledge repositories
- Understanding human intelligence

- **Meaningful Interaction**

- Collaboration
- Trust and responsibility
- Diversity of interaction channels
- Improving online interaction

- **Self-Aware Learning**

- Robust and trustworthy learning
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Significant Scientific Advances Are Driven by Substantial Long-Term Investments

- Other sciences have had significant US infrastructure and research investments with phenomenal outcomes
 - Most were high-risk investments (eg LIGO)
- AI has become a mature science
 - But lacks substantial investments to reach new levels
- AI investments would be low-risk high-return



Apollo Program
1960-'72: 25 Billion
2019: 144 Billion



Hubble Telescope
1990: \$1.5 Billion
2019: \$3 Billion

Human Genome Project
1991: \$2.7 Billion
2019: \$5 Billion



LIGO and Gravitational Waves
1992: largest NSF-funded project
2019: \$1.1 Billion



Major International AI Investments

- Just in 2019, China is establishing at least 4 National AI R&D Centers of Excellence. Each with \$50M/yr support and affiliated with major universities (e.g. Peking U and Tsinghua). Each center will employ hundreds of AI scientists and software developers.
- Total Chinese AI R&D investments over the next 5 years is in the billions of dollars.
- Goal: To become world leader in AI by 2030.

US Congressional Report

Report: China will outspend US on AI research by end of 2018



In a separate initiative, the MOE also plans to launch a new five-year AI talent training program to train 500 more AI instructors and 5,000 more top students at top Chinese universities.⁴²

A 20-Year AI Research Roadmap for the US

European Union To Invest 20 Billion Euros in AI

AI Hub Europe

nature

Europe's next €1-billion science projects:
six teams make it to final round

AI enhancement included in the shortlist

each funded to the tune of around €1 billion over 10 years

Bloomberg

U.K. Unveils \$1.4 Billion Drive Into Artificial Intelligence

U.S. tech giants, European telecoms firms, Japanese venture capital and the U.K. government has put together a 1 billion-pound (\$1.4 billion) investment into the U.K. artificial intelligence industry, as governments weigh how to compete with China.

The deal comprises a total of 300 million pounds of private financing, 300 million pounds of new government spending in addition to 400 million pounds the state has already announced.

Interim report, 2 May 2019

REUTERS

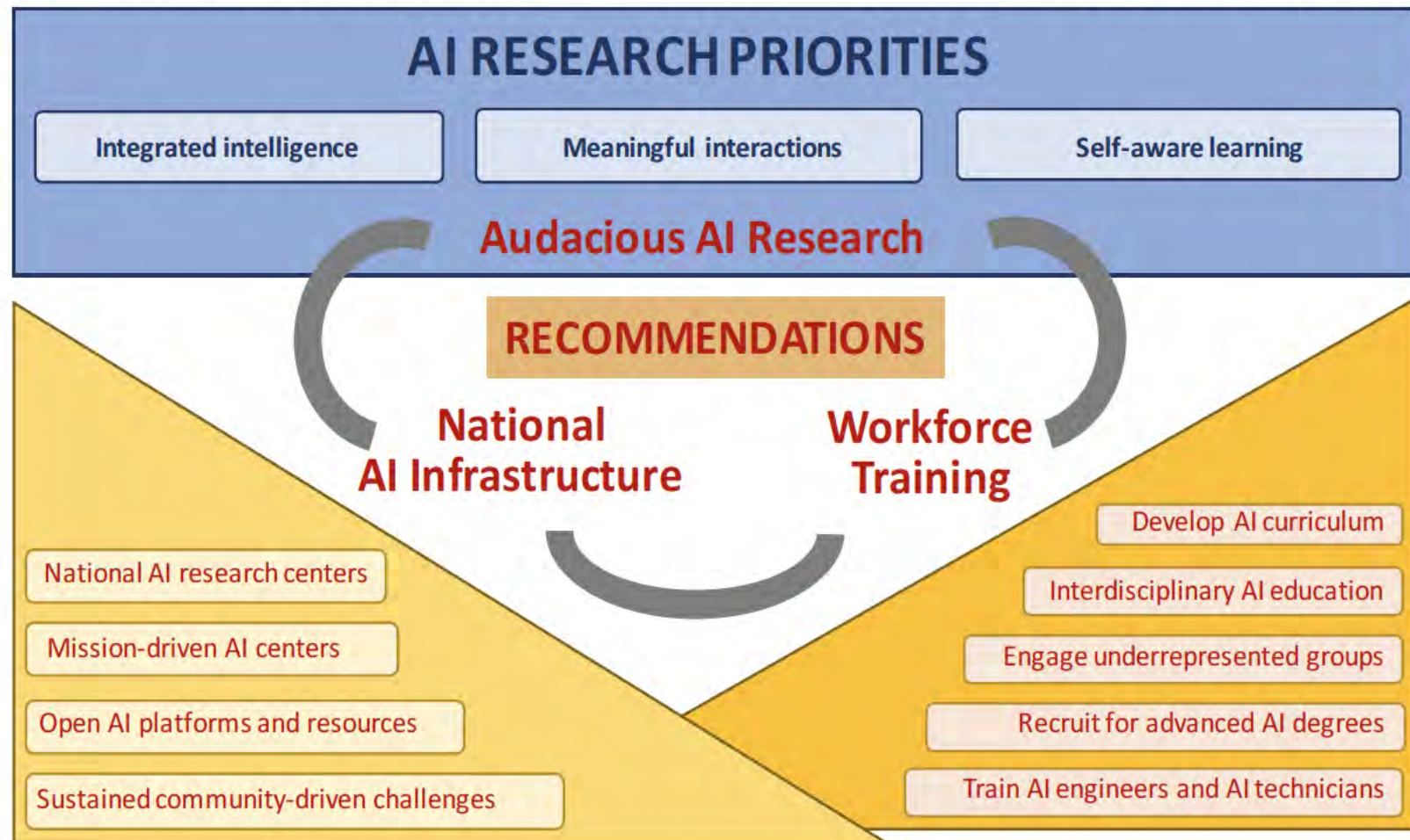
Germany plans 3 billion in AI investment

WIRED

The French government will spend €1.5 billion (\$1.85 billion) over five years to support research in the field, encourage startups, and collect data that can be used, and shared, by engineers.

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Overview of Research Priorities and Recommendations



A 20-Year AI Research Roadmap for the US

Interim report, 2 May 2019

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Key Recommendations: National Infrastructure for AI and Workforce Training

AI Research Centers

- Focused on cross-cutting research themes
 - Examples: Center on AI Trust and Responsibility, Center on Integrated Intelligence, etc.
- Resources in each center would include *at least*:
 - 100 full time faculty (in AI and other relevant disciplines)
 - 50 visiting faculty fellows and industry fellows
 - 200 AI engineers
 - 500 full time students (graduate and undergraduate)
 - Computing and infrastructure support
- Multi-university centers with affiliates
- Multi-decadal funding at \$100M/yr levels
- Train students at all levels
- Small-scale example models: Allen Institute for AI, CMU's SEI, USC's ICT

Mission-Driven AI Centers

- Focused on societal drivers
 - Examples: AI-ready hospitals, AI-ready homes, AI-ready schools, VR/Robotics labs, etc.
- Living laboratories for hands-on research and collection of unique data
- Operations as well as workforce training
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Community-Driven AI Challenges

Open AI Platforms and Resources

All-Encompassing Workforce Training in High Demand

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Interim report, 2 May 2019

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Developing a 20-Year AI Research Roadmap for the US

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May 2, 2019



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Important Note

- **This presentation gives an overview of ongoing efforts to create a 20-Year AI Research Roadmap for the US. It summarizes current views, and introduces preliminary ideas for potential recommendations.**
- **The presentation captures interim ideas, and is intended to promote community input and discussion.**

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Center for a
New American
Security

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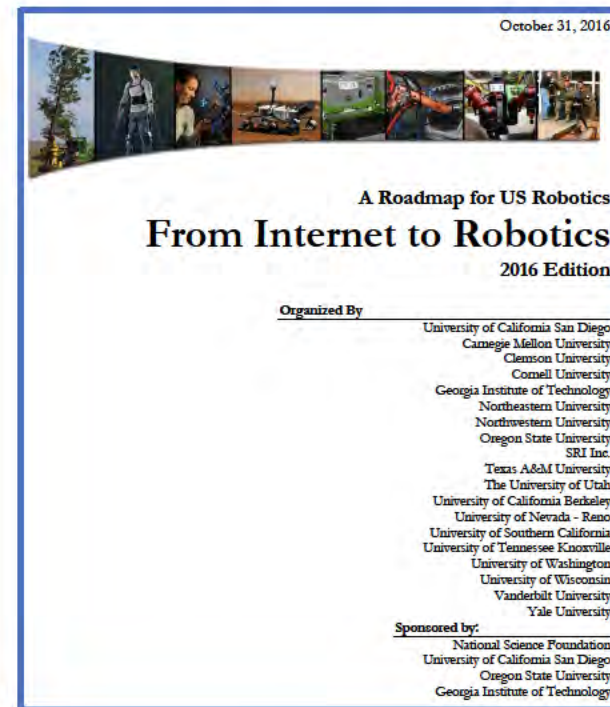
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A 20 Year AI Research Roadmap for the US

- Objectives
 - 10 - 20 year research roadmap
 - Guidance for funding agencies and Congress
 - Relate to:
 - AI research in industry
 - International AI initiatives
- Computing Community Consortium with support from US National Science Foundation
 - CCC has developed prior research roadmaps, such as the Robotics Roadmap that led to the US National Robotics Initiative
 - In collaboration with the Association for the Advancement of Artificial Intelligence (AAAI)
 - Premier scientific society for AI, more than 250 elected fellows



Association for the
Advancement of Artificial Intelligence



CCC
Computing Community Consortium
Catalyst

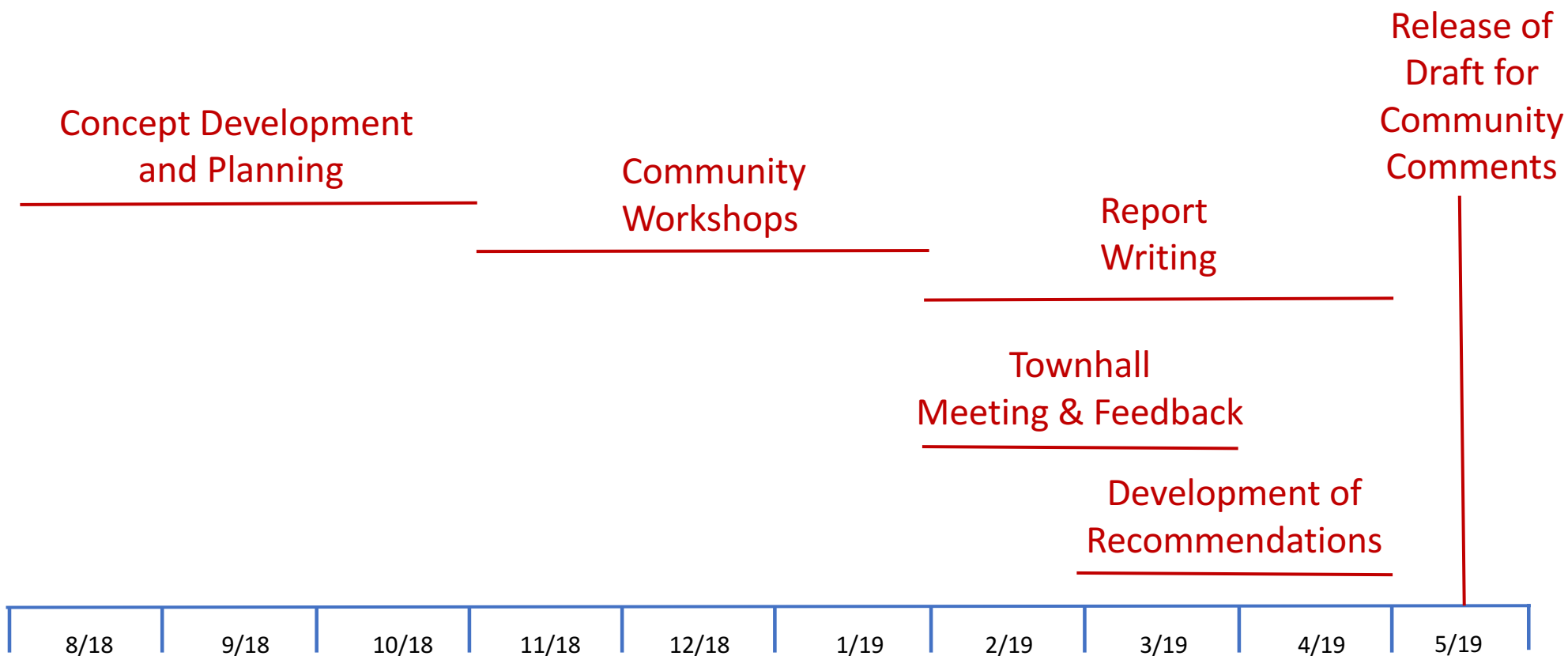


CRA
Computing Research
Association

A 20-Year AI Research Roadmap
A 20-Year AI Research Roadmap for the US

interim report, 2 May 2019

Timeline of AI Research Roadmap



Timeline for Development of AI Roadmap

- 3 small by-invitation workshops (Nov-Jan)
 - WS1: Integrated intelligence
 - WS2: Meaningful interaction
 - WS3: Learning and robotics
- Townhall at AAI (Jan)
- Executive summary release and feedback gathering (Feb-March)
- Report release and community feedback period (April)
- Final report (May)

Community Participation in the Development of Roadmap

- Workshops with diverse participation from the community
 - 41 academic institutions and 9 industry involved
 - Some participants with appointments in both academia and industry
 - Participants were asked to develop research agenda 20 years forward
 - Participants also reflected on related topics such as the historical evolution of the field of AI, the multidisciplinary of the AI research agenda, AI research infrastructure, the rapid growth of AI in industry labs and how it has affected academia, AI funding programs and agencies, and the public understanding and perception of AI technologies
- Executive summary released for comments
 - Feedback obtained from diverse stakeholders in university ranks, industry lab directors, government agencies, etc.

Core Reference Documents

- US National AI R&D Strategic Plan, 2016 (currently being updated)
 - https://www.nitrd.gov/news/national_ai_rd_strategic_plan.aspx
- US National Robotics Roadmap, 2009, revised 2016:
 - <https://cra.org/ccc/wp-content/uploads/sites/2/2016/11/roadmap3-final-rs-1.pdf>
- 100 year study of AI, 2016 report:
 - https://ai100.stanford.edu/sites/default/files/ai100report10032016fnl_singles.pdf

Identifying Societal Drivers

1. **Boost Health and Quality of Life:** Prevention of illness and elderly ailments, mental/behavioral health, reducing cost (25+% feasible) while improving care, remote patient care.
2. **Lifelong Education and Training:** Personalized, scalable education support. Improve the AI knowledge and skills of people who will lose jobs. Training next generation of AI specialists, data scientists, and software engineers
3. **Reinvent Business Innovation and Competitiveness:** Evidence-driven companies, which would increase productivity and value and open new sectors/products
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Societal Drivers

Evidence-Driven
Social Policy

Reduce Cost of
Healthcare

Personalized
Education

Business
Opportunities

Accelerating
Science

Technical Areas

Integrated
Intelligence

Meaningful
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Self-Aware
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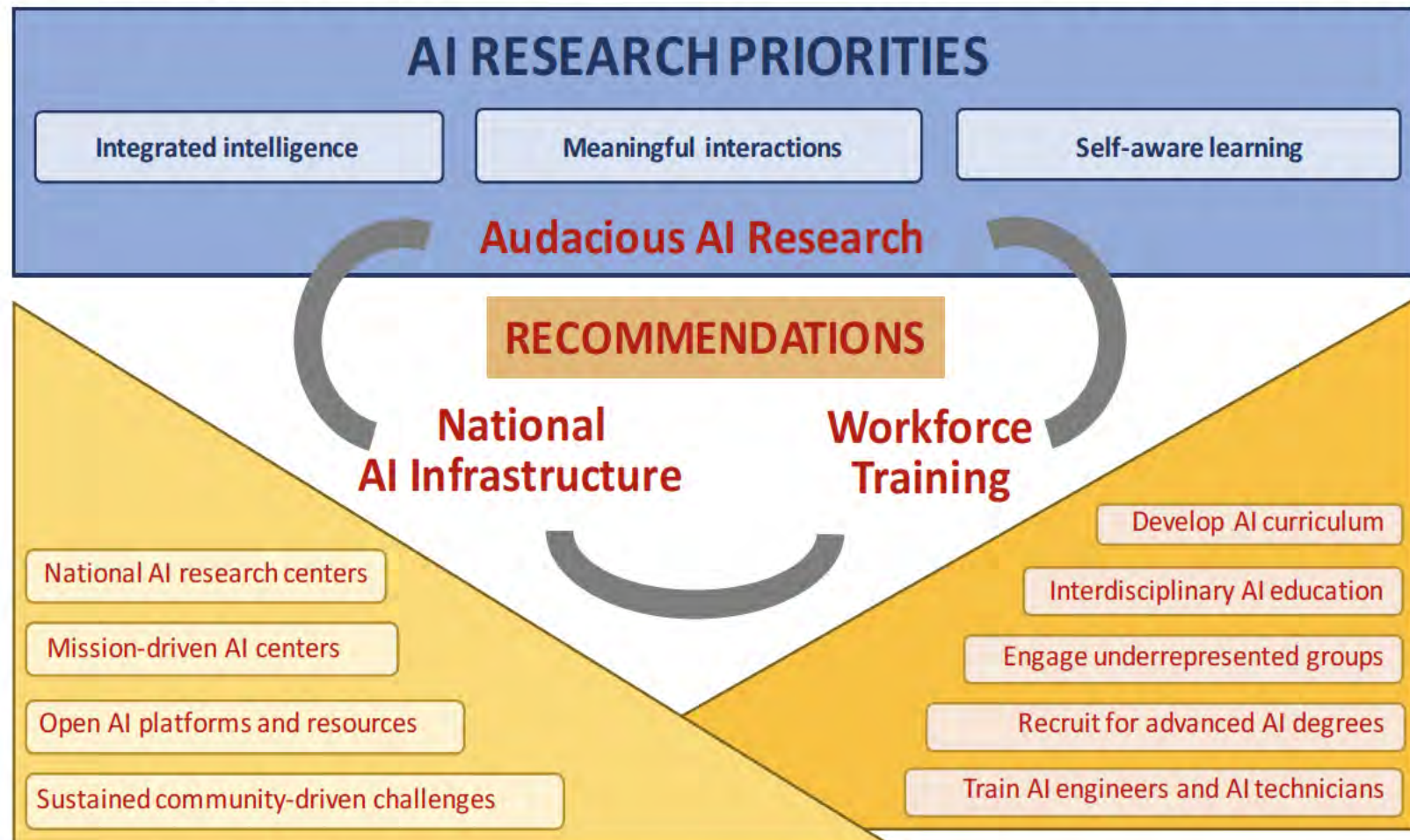
A New Era of **Audacious** AI Research



- Audacious AI research in roadmap tackles broader AI goals
 - More integrative, requiring significant resources and diverse expertise
 - Hard for individual PIs to stand the necessary research environments
- AI has become a mature science
 - Need for substantial experimental facilities in addition to theoretical research
- Other sciences have had significant infrastructure and concomitant research investments, but nothing so far for AI
 - Eg LIGO and LHC in particle physics
 - Eg Human Genome Project in medicine
 - Eg Hubble telescope in astronomy
- Need for substantial multi-decadal investments in AI



Overview of Research Priorities and Recommendations



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Mission-Driven AI Centers

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Community-Driven AI Challenges

Open AI Platforms and Resources

All-Encompassing Workforce Training in High Demand

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Main Recommendations

**[I] Create Comprehensive National AI R&D Infrastructure to
Develop the Next Generation of AI Technology**

[II] Re-Conceptualize and Train an All-Encompassing AI Workforce

[I] National Infrastructure for AI:

1) Open AI Platforms and Resources

- A shared ecosystem infrastructure for AI research
 - Components and services available for others to use and build on
- Open licenses, open source
- Example resources
 - An open knowledge network of knowledge about the world
 - Data repositories
 - Reproducible experimentation environments
 - Computational/cloud resources
- Wide range of contributors and contributions
 - Share research products
 - Experimental harness

[I] National Infrastructure for AI:

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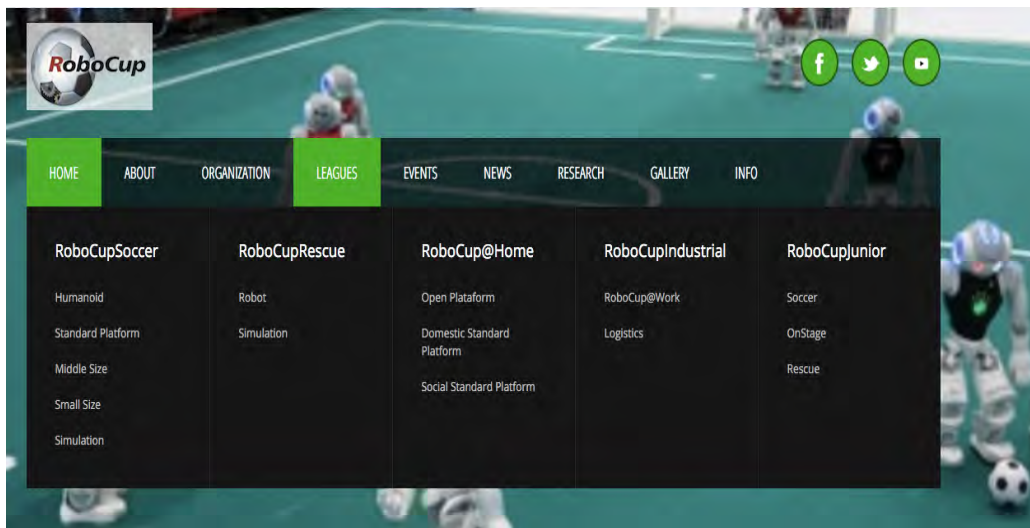
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[I] National Infrastructure for AI:

4) Community-Driven Research Challenges



- Challenges collaboratively designed by participants
- Challenges designed to drive research, address key tractable problems
- Governance: organizational structures to oversee activities and progress
- Break down complex problems in a divide-and-conquer timeline approach
- Design arch over a long period of time, adjust for advances
- Creation of shared resources when needed
- Embedded metrics and expertise: the community develops the metrics to measure progress and also provides expertise

[II] Training AI Workforce

Key elements:

- Recruitment programs
- Broadening AI curriculum
- Incentivizing interdisciplinary AI studies (incl. ethics, policy, law)
- Education and training of AI engineers and data scientists beyond the traditional BA/BS, e.g.,
 - Community college programs
 - Certificate programs
 - Online post-baccalaureate programs
- Faculty and student retention

Comments, Suggestions, Feedback?

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cccinfo@cra.org

ADDITIONAL DETAILS: RESEARCH PRIORITIES

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Societal Drivers

Evidence-Driven
Social Policy

Reduce Cost of
Healthcare

Personalized
Education

Business
Opportunities

Accelerating
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Technical Areas

Integrated
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Meaningful
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Self-Aware
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Integrated Intelligence

Chairs:

Marie desJardins, Simmons U

Ken Forbus, Northwestern U

Technical Areas

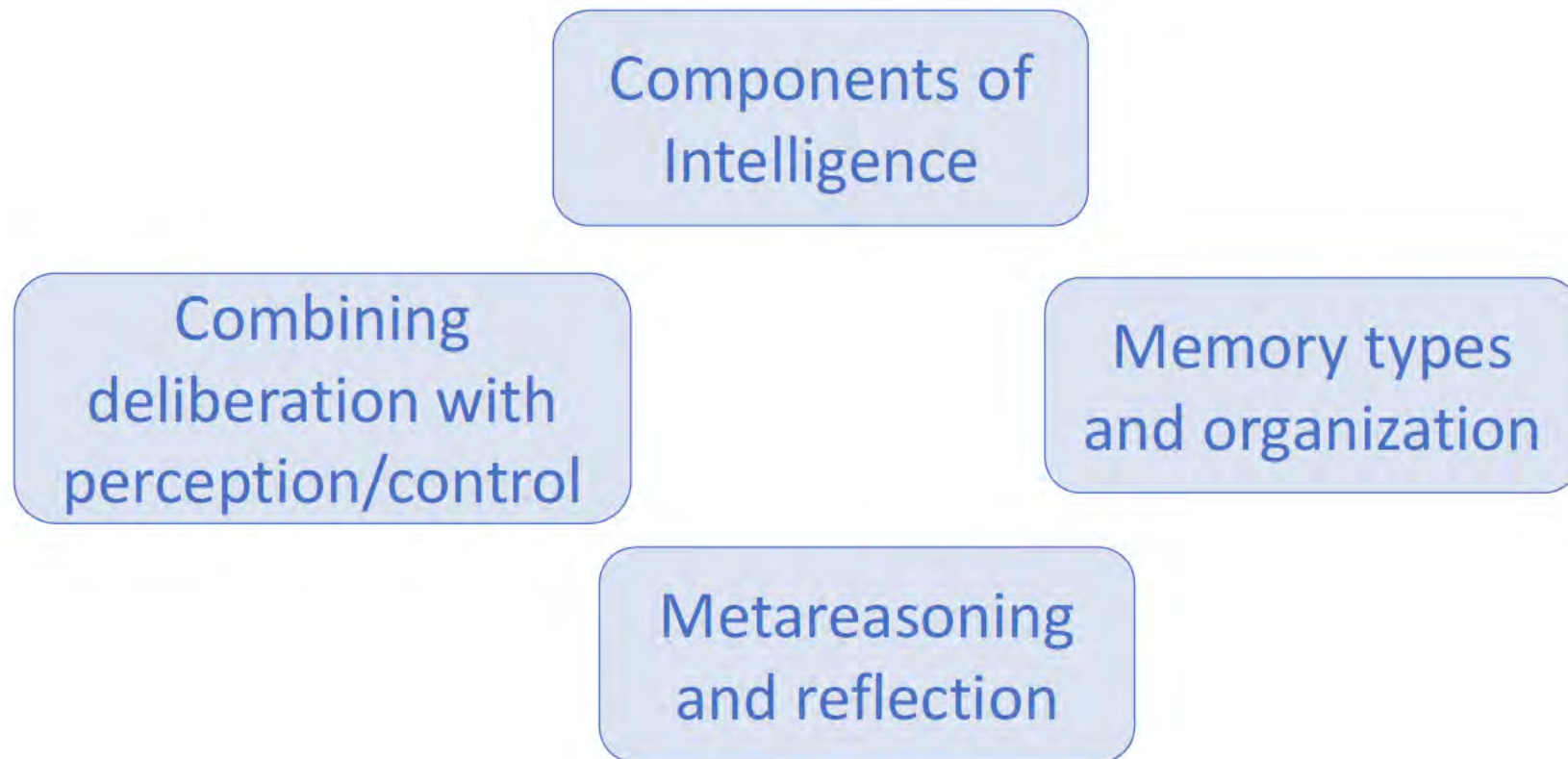
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3. Open knowledge repositories
4. Understanding human intelligence

Societal Driver Vignettes

- Mental and behavioral health coach
- Accurate models of water reserves
- Speed up vaccine experiments
- Students in remote rural settings
- Retrain factory workers
- Resolve supply chain delays

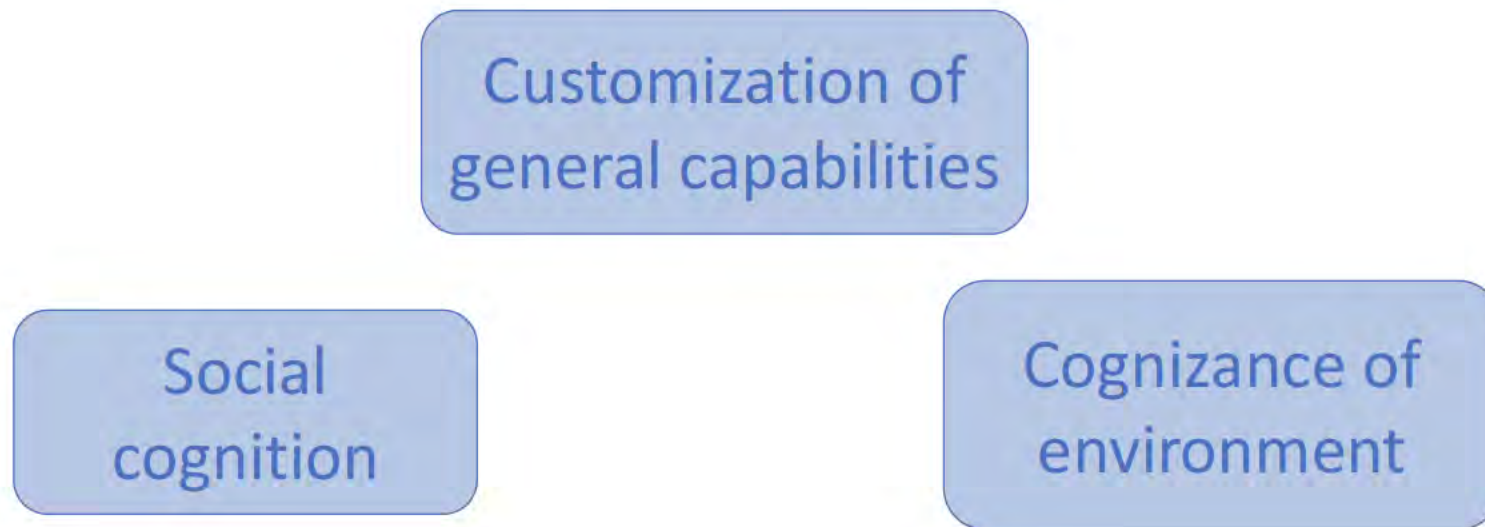
Integrated Intelligence:

1) Science of Integrated AI



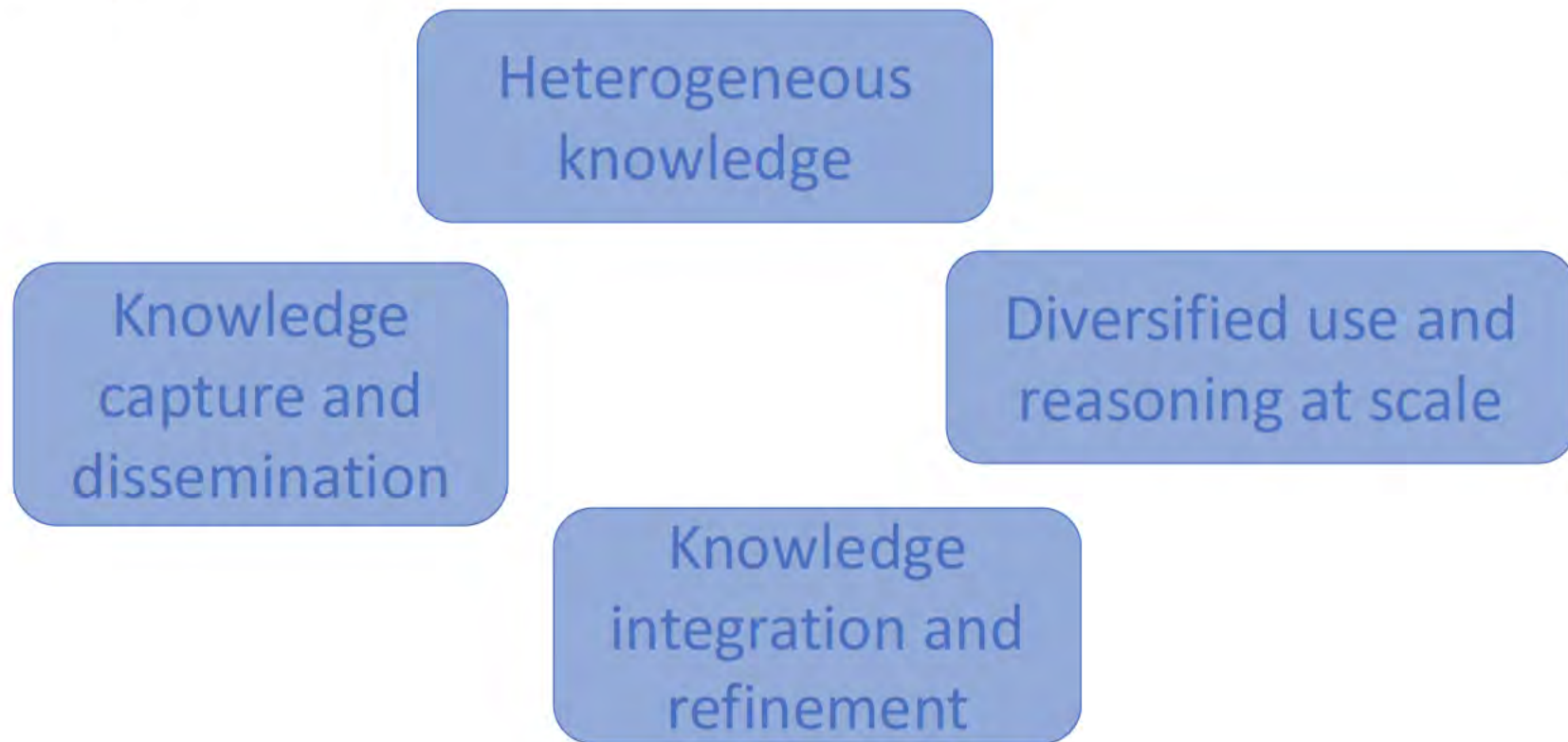
Integrated Intelligence:

2) Contextualized AI



Integrated Intelligence:

3) Open Knowledge Repositories



Integrated Intelligence:

4) Understanding Human Intelligence

AI inspired by
human intelligence

AI to understand
human intelligence

Unifying theories of
human and artificial
intelligence

Meaningful Interaction

Chairs:

Kathy McKeown, Columbia U

Dan Weld, U Washington

Technical Areas

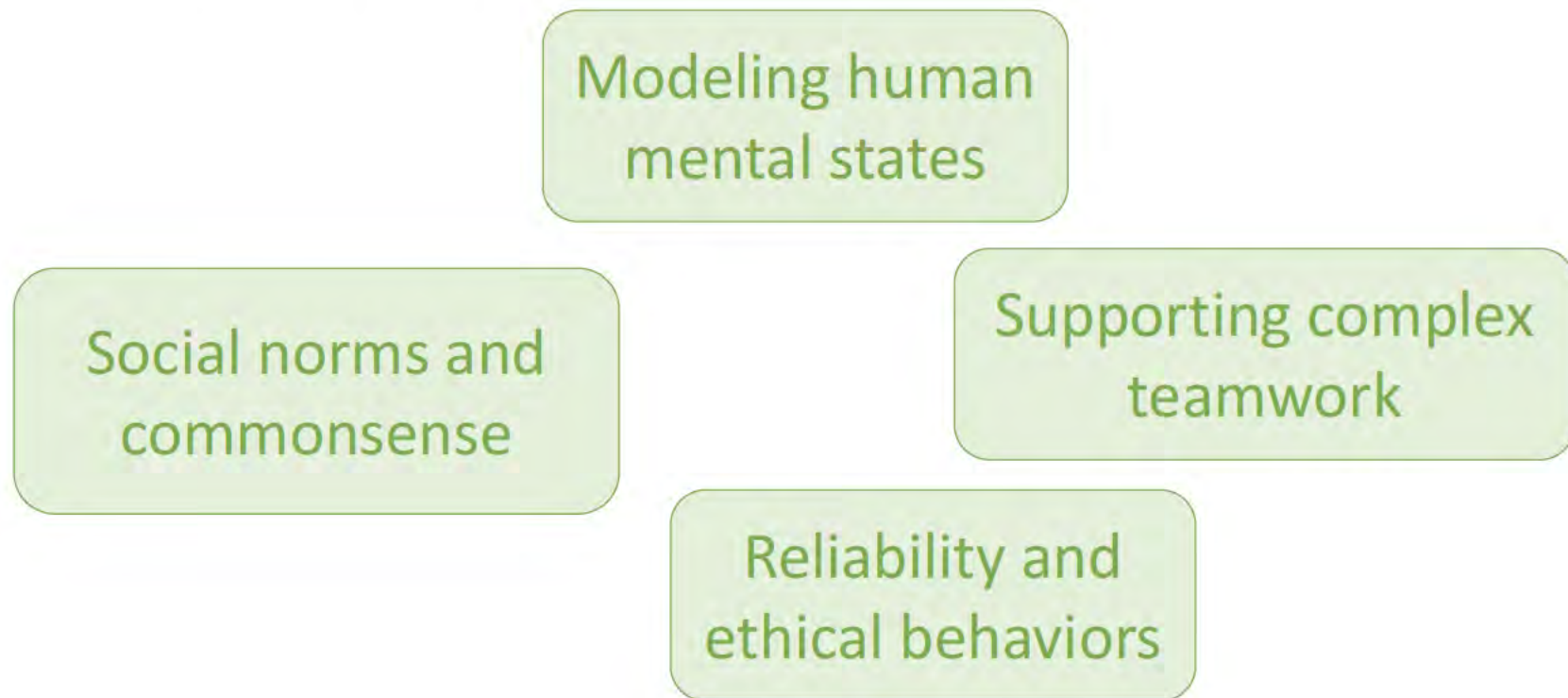
1. Collaboration
2. Trust and responsibility
3. Diversity of interaction channels
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Societal Driver Vignettes

- At-home robot caregiver/helper
- Collaborative materials discovery
- Training for robot repair jobs
- Custom personal devices business
- Spreading opportunities for homeless youth

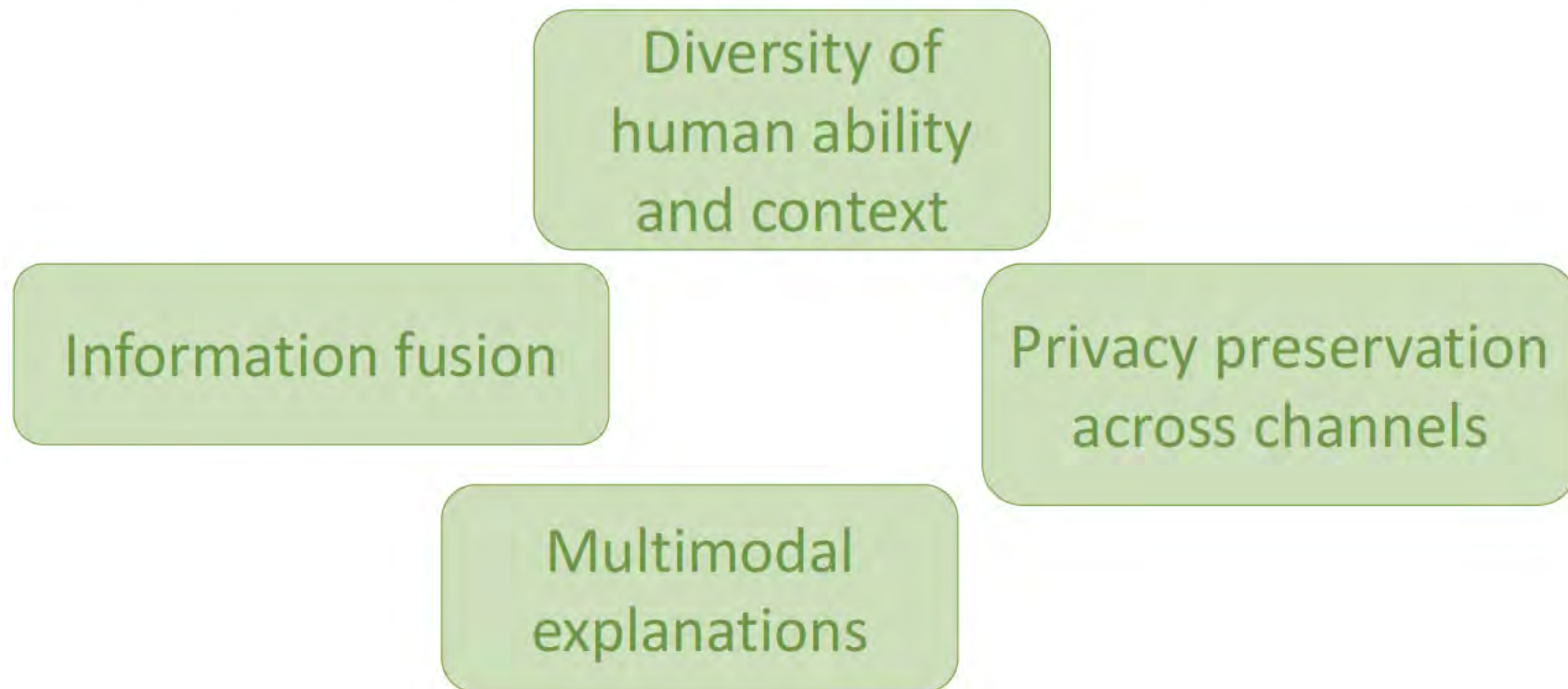
Meaningful Interaction:

1) Collaboration



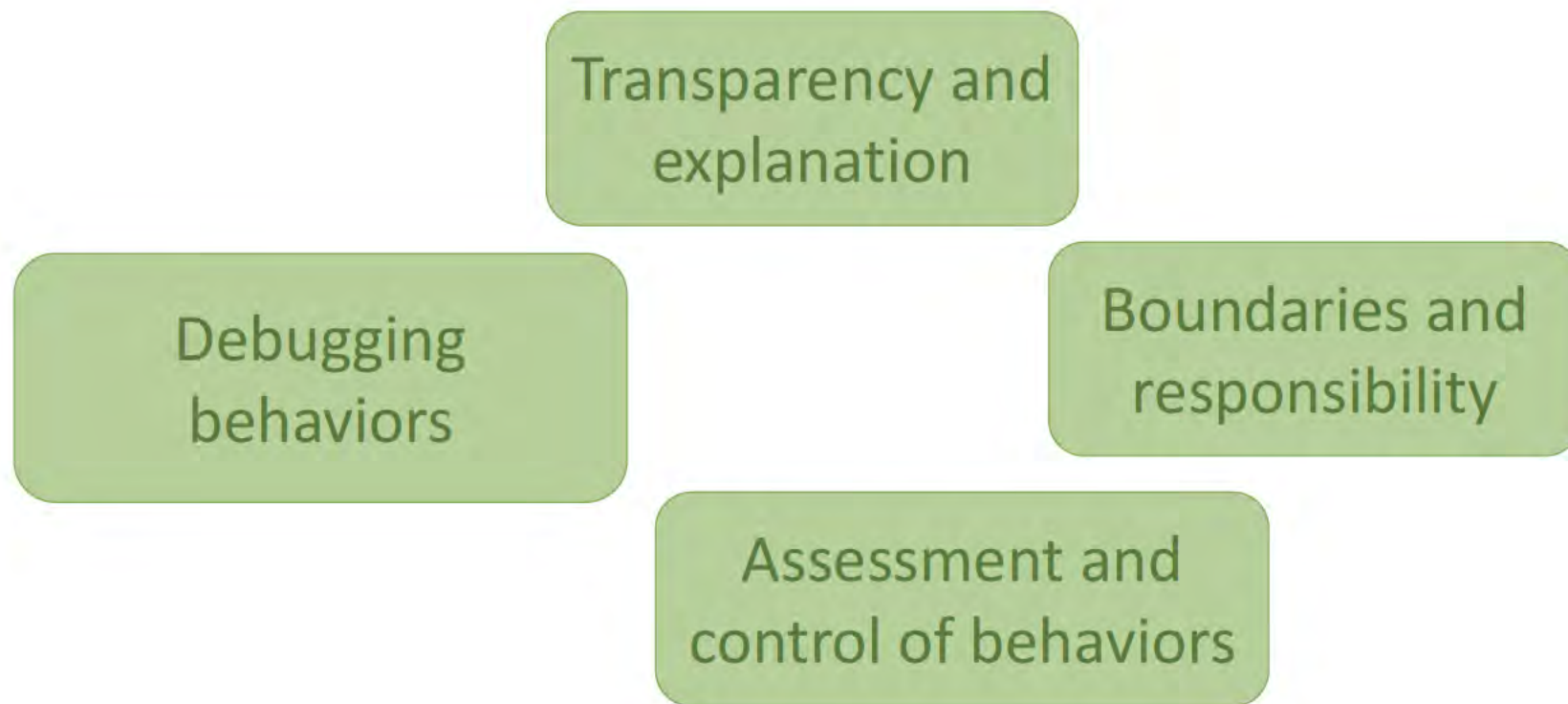
Meaningful Interaction:

2) Diversity of Interaction Channels



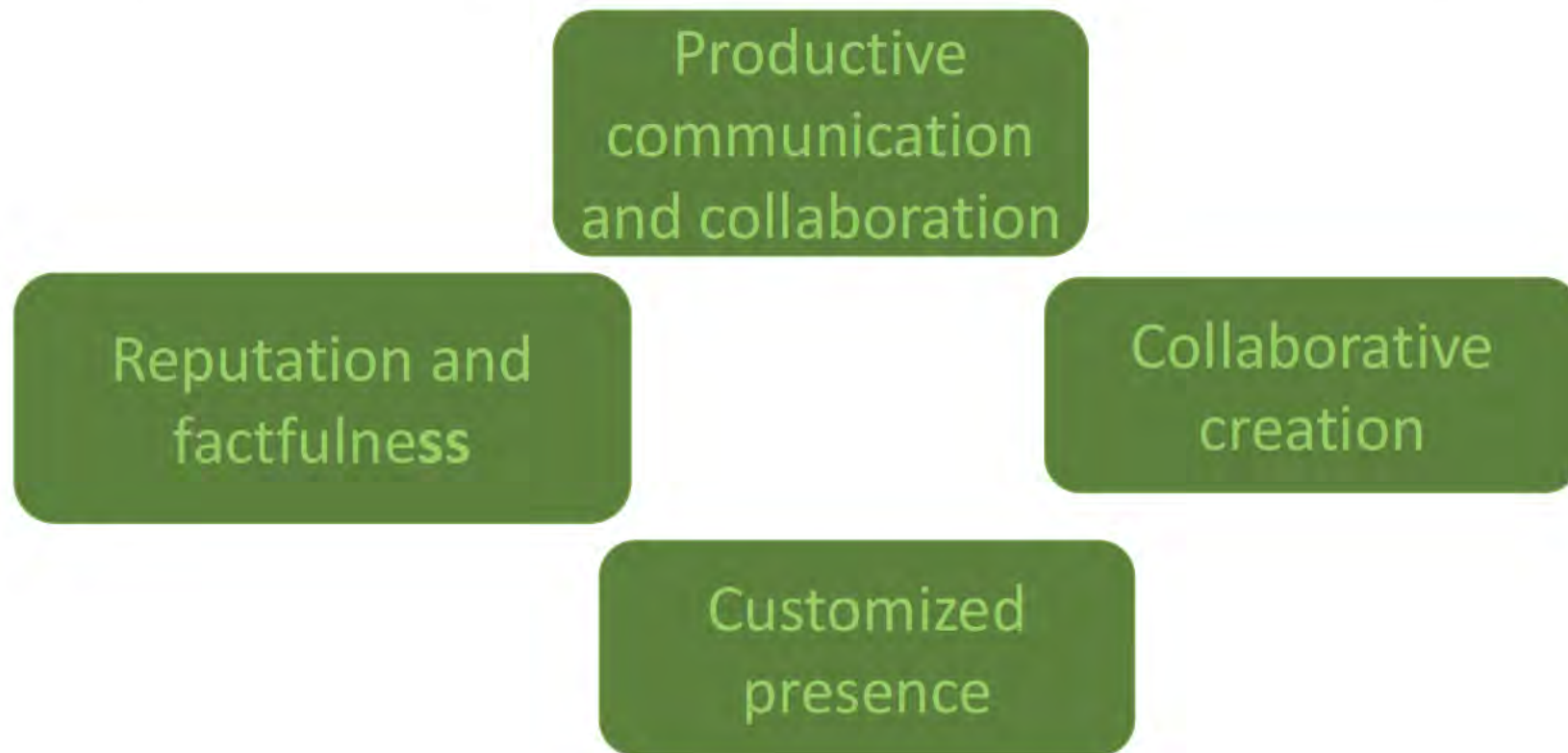
Meaningful Interaction:

3) Trust and Responsibility



Meaningful Interaction:

4) Improving Interactions Between People



Self-Aware Learning

Chairs:

Tom Dietterich, Oregon State U

Fei-Fei Li, Stanford U

Technical Areas

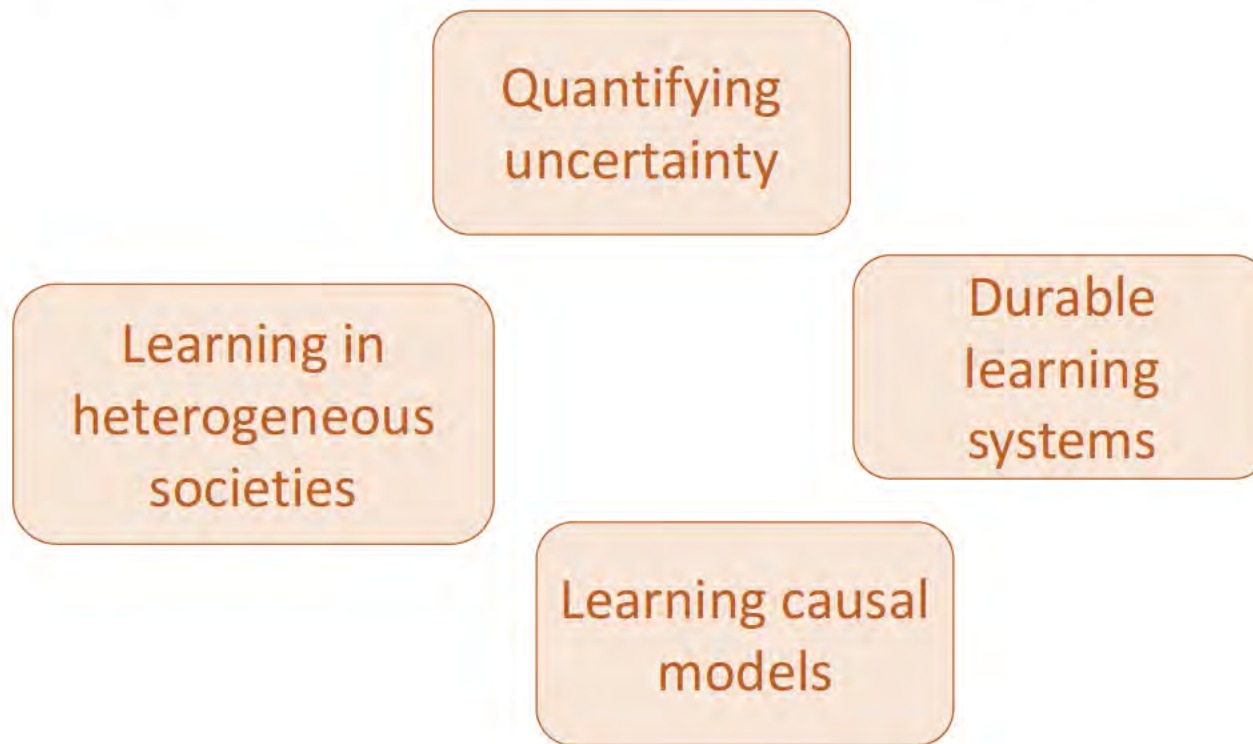
1. Robust and trustworthy learning
2. Deeper learning for challenging tasks
3. Integrating symbolic and numeric representations
4. Learning in integrated AI/Robotic systems

Societal Driver Vignettes

- Prevent opiate abuse
- Game design startup
- Climate models with physics and data
- Police training
- Food insecurity and distribution
- Resilient cyber-physical systems

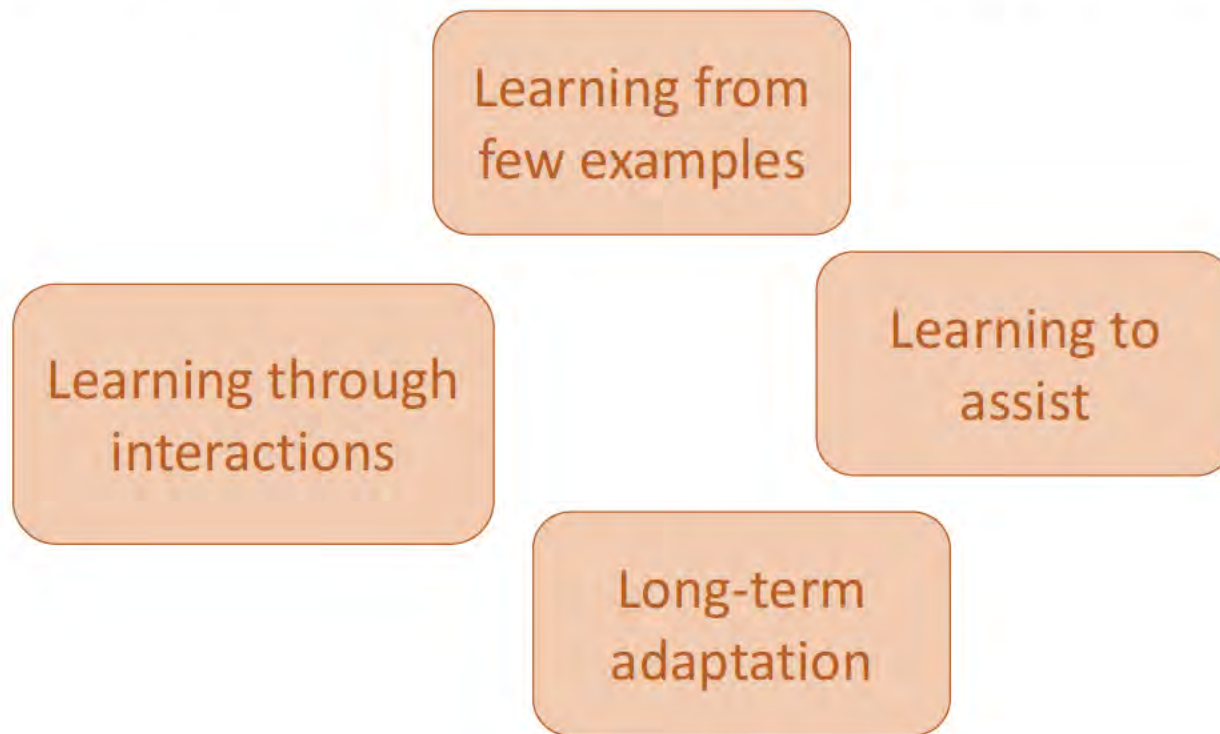
Self-Aware Learning:

1) Robust and Trustworthy Learning



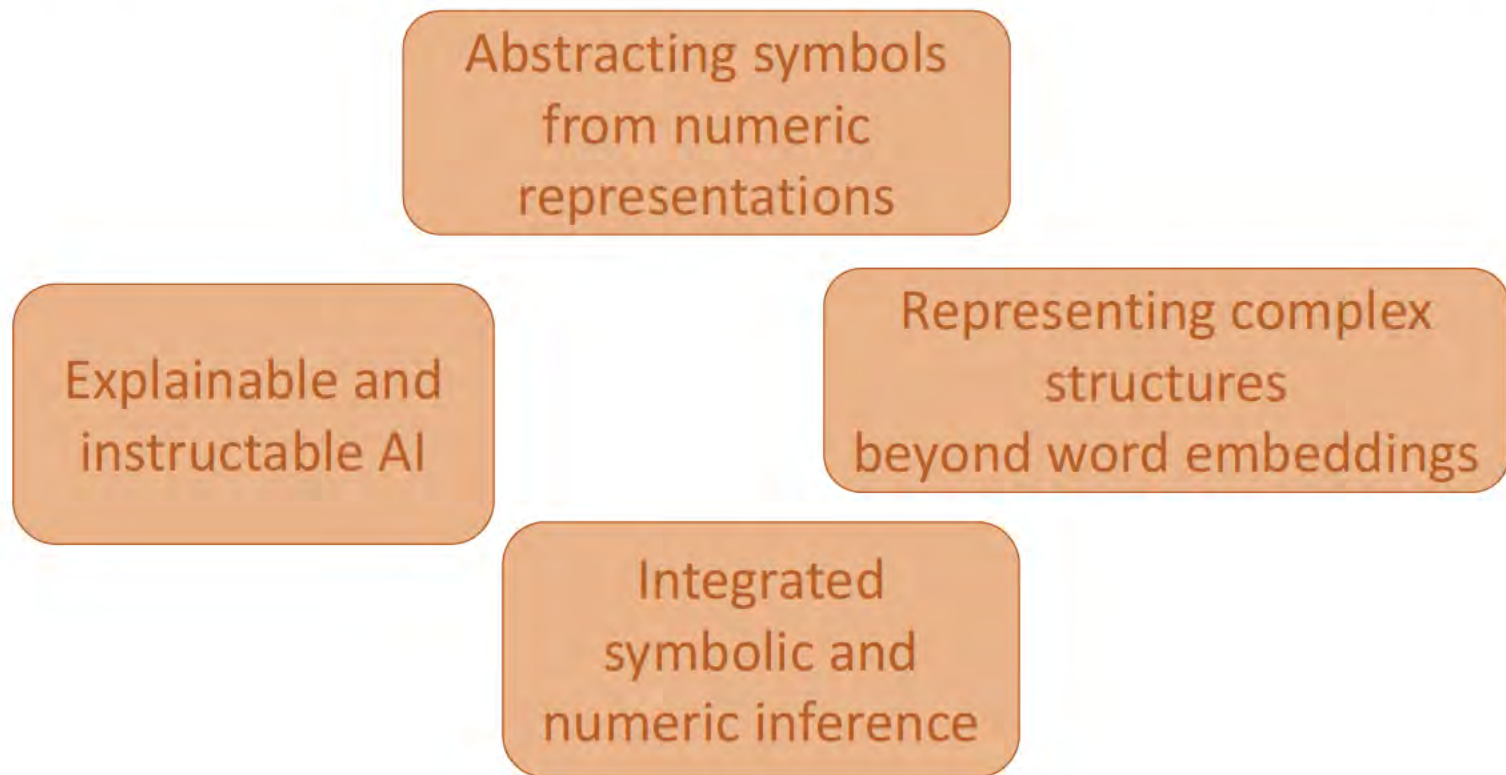
Self-Aware Learning:

2) Deeper Learning for Challenging Tasks



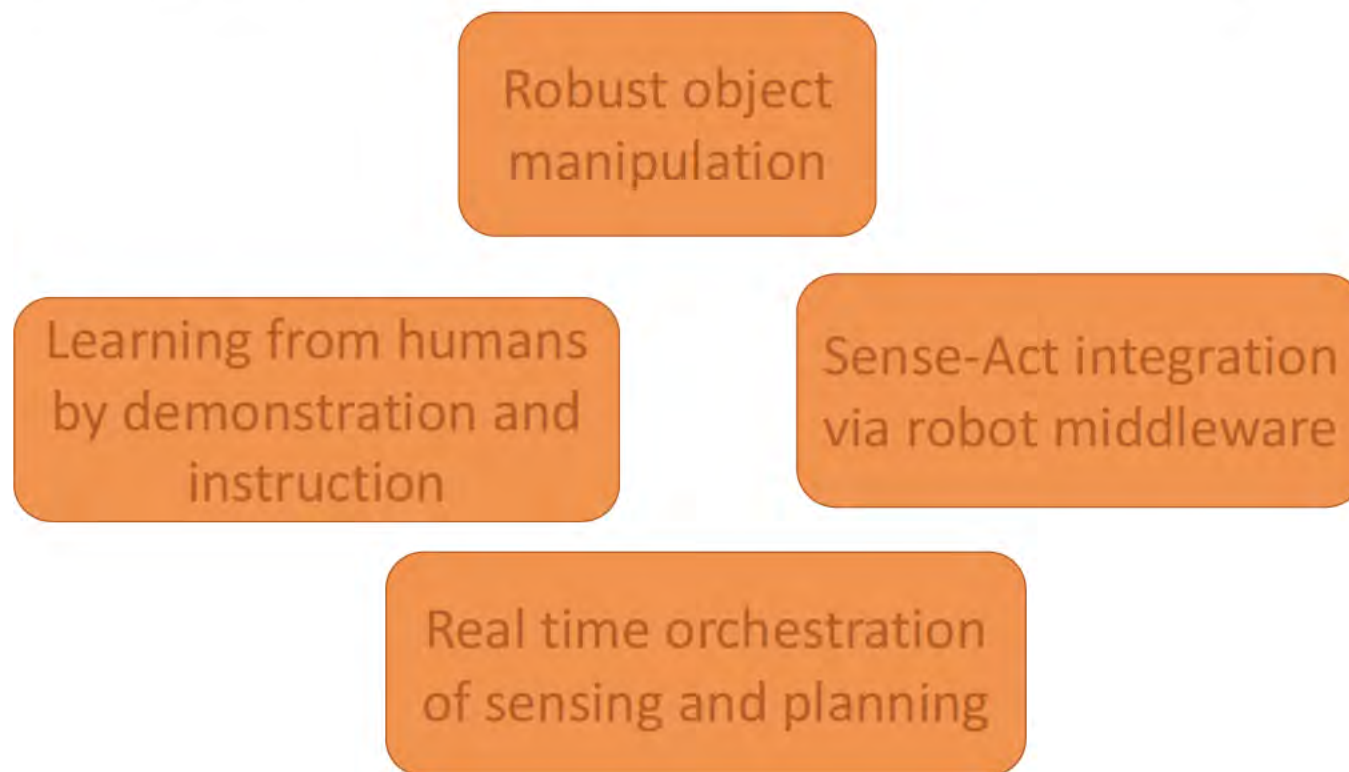
Self-Aware Learning:

3) Integrating Symbolic and Numeric Representations



Self-Aware Learning:

4) Learning in Integrated AI/Robotic Systems



ADDITIONAL DETAILS: BACKGROUND AND CONTEXT



MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: MICK MULVANEY
DIRECTOR, OFFICE OF MANAGEMENT AND BUDGET

MICHAEL KRATSIOS
DEPUTY ASSISTANT TO THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SUBJECT: FY 2019 Administration Research and Development Budget Priorities

FY 2019, 2020 R&D Budget Priorities Memo

“Continued leadership in AI, quantum information science (QIS), and strategic computing is critically important to our national security and economic competitiveness. Agencies should invest in fundamental and applied AI research, including machine learning, autonomous systems, and applications at the human-technology frontier.”



“...prioritize emerging technologies critical to economic growth and security, such as data science, encryption, autonomous technologies,... advanced computing technologies, and artificial intelligence. “

National Leadership in AI

Office of Science & Technology Policy (OSTP)



Lynne Parker, NSF
Assistant Director for AI



Jim Kurose, NSF
Former Assistant Director for AI

National Science and Technology Council (NSTC)

France Cordova, NSF
AI Select Committee
Co-chair (with DARPA,
OSTP)



Select Committee
on AI

Committee
on
Technology

...

Committee
on S&T
Enterprise

Erwin Gianchandani, NSF
Jim Kurose, NSF
MLAI co-chairs



Machine
Learning
and AI
(MLAI)

...

Networking
and Info.
Tech. R&D
(NITRD)

Subcommittees

AI R&D
Interagency
Working
Group

Working groups

Henry Kautz, NSF
NITRD AI WG co-chair

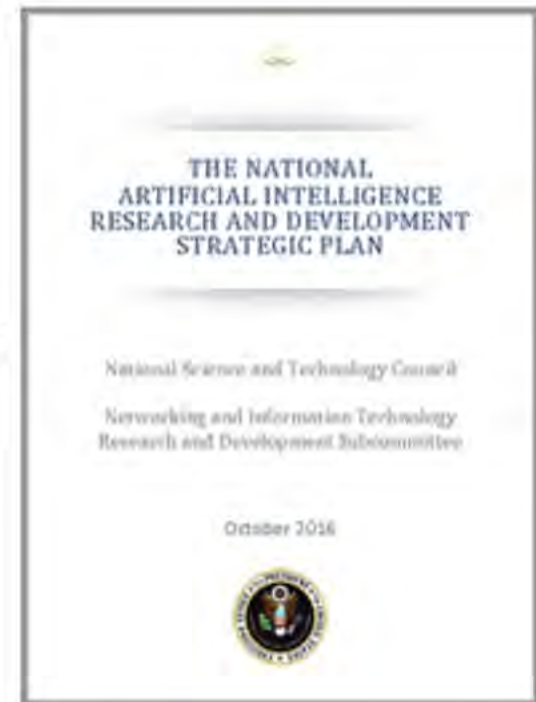


Jeff Alstott, IARPA
NITRD AI WG co-chair



US National AI Research & Development Strategic Plan

- NITRD Working Group of 40+ Federal Funding Agencies
- Co-Chairs: Henry Kautz (NSF) and Jeff Astott (IARPA)
- April 2019: Update to 2016 Plan and Implementation Report
- Updating 2016 National AI Research and Development Strategic Plan (RFI responses were due Oct 26)



AI Presence and Overall Trends in the US

- AI has gone from an academic research area to permeating our lives
 - Significant impact on society
 - Untapped potential
- Significant influence of AI in innovation and stimulating the economy
 - White house meeting in May 2018
- Concern about safety and transparency of this technology leads to questions for AI research community about how to establish policy
- Concerted initiatives in government and in academia
 - Joint AI Center
- Increases in federal funding investments (DARPA \$2B, NSF, etc)

US R&D Leadership: Driven by Major Investments

- **Moon Landing**
- **Human Genome Project**
- **Hubble Telescope**
- **LIGO Gravitational Waves**



Apollo Program
1960-'72: 25 Billion
2019: 144 Billion



Hubble Telescope
1990: \$1.5 Billion
2019: \$3 Billion



Human Genome Project
1991: \$2.7 Billion
2019: \$5 Billion



LIGO and Gravitational Waves
1992: largest NSF-funded project
2019: \$1.1 Billion

Major International AI Investments: China R&D

Chinese Views on the Importance of AI

1. China's leadership – including President Xi Jinping – believes that being at the forefront in AI technology is critical to the future of global military and economic power competition.

- Just in 2019, China is establishing at least 4 National AI R&D Centers of Excellence. Each with \$50M/yr support and affiliated with major universities (e.g. Peking U and Tsinghua). Each center will employ hundreds of AI scientists and software developers.
- Total Chinese AI R&D investments over the next 5 years is in the billions of dollars.
- Goal: To become world leader in AI by 2030.

4. Despite expressing concern on AI arms races, most of China's leadership sees increased military usage of AI as inevitable and is aggressively pursuing it. China already exports armed autonomous platforms and surveillance AI.

A 20-Year AI Research Roadmap for the US

Interim report, 2 May 2019

Forbes
**Artificial Intelligence, China And
The U.S. – How The U.S. Is Losing
The Technology War**



Steve Andriole Contributor @
Enterprise & Cloud

Opinion The New York Times

China's Challenge Is America's Opportunity

By L. Rafael Reif

Dr. Reif is president of the Massachusetts Institute of Technology.

US Congressional Report
**Report: China will outspend US
on AI research by end of 2018**

Major International AI Investments: China on Education

<https://www.cnas.org/publications/reports/understanding-chinas-ai-strategy>

action to improve the size and quality of China's AI talent pool.⁴⁰ In April 2018, China's Ministry of Education (MOE) launched its *AI Innovation Action Plan for Colleges and Universities*. Among other elements, the plan:

- Will create “50 world-class teaching materials for undergraduate and graduate studies” related to AI applications for specific industries;
- Will create “50 national-level high-quality online open courses”;
- Will establish “50 artificial intelligence faculties, research institutions, or interdisciplinary research centers.”⁴¹

In a separate initiative, the MOE also plans to launch a new five-year AI talent training program to train 500 more AI instructors and 5,000 more top students at top Chinese universities.⁴²

This program is in full operation. It's currently in its 2nd year.

Major International AI Investments: EU

AI Hub Europe
European Union To Invest
20 Billion Euros in AI

nature
Europe's next €1-billion science projects:
six teams make it to final round

AI enhancement included in the shortlist

The commission already supports three scientific mega-projects known as FET Flagships — on the brain, graphene and quantum technologies — which are each funded to the tune of around €1 billion over 10 years.

The high-profile projects aim to make paradigm-shifting advances in

WIRED
JOHN K. DELANEY BUSINESS 05.20.19 09:09 AM
FRANCE, CHINA, AND THE EU
ALL HAVE AN AI STRATEGY.
SHOULDN'T THE US?

REUTERS
Germany plans 3 billion
in AI investment

WIRED
The French government
will spend €1.5 billion
(\$1.85 billion) over five
years to support research
in the field, encourage
startups, and collect data
that can be used, and
shared, by engineers.

Bloomberg
U.K. Unveils \$1.4 Billion Drive Into
Artificial Intelligence

U.S. tech giants, European telecoms firms, Japanese venture capital and the U.K. government has put together a 1 billion-pound (\$1.4 billion) investment into the U.K. artificial intelligence industry, as governments weigh how to compete with China.

The deal comprises a total of 300 million pounds of private financing, 300 million pounds of new government spending in addition to 400 million pounds the state has already announced.

COMPUTING COMMUNITY CONSORTIUM

The **mission** of Computing Research Association's Computing Community Consortium (CCC) is to **catalyze** the computing research community and **enable** the pursuit of innovative, high-impact research.



Community Consortium

ASSOCIATION FOR THE ADVANCEMENT OF ARTIFICIAL INTELLIGENCE

The **Association for the Advancement of Artificial Intelligence (AAAI)** is an international scientific society devoted to promote research in, and responsible use of, artificial intelligence. It has more than 250 elected Fellows in diverse research areas of AI.

AAAI also aims to increase public understanding of AI, improve the teaching and training of AI practitioners, and provide guidance for research planners and funders concerning the importance and potential of current AI developments and future directions.

