



Technology Predictions 2021

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IEEE Industry
Engagement
Committee

In This Report

SECTION 01

Broader Technology Predictions Team



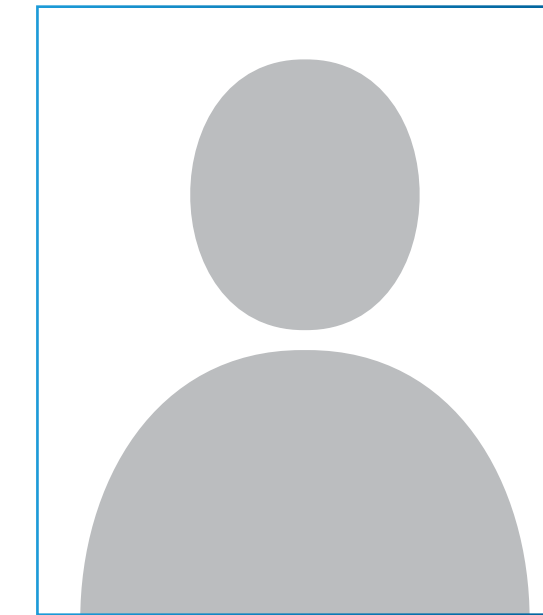
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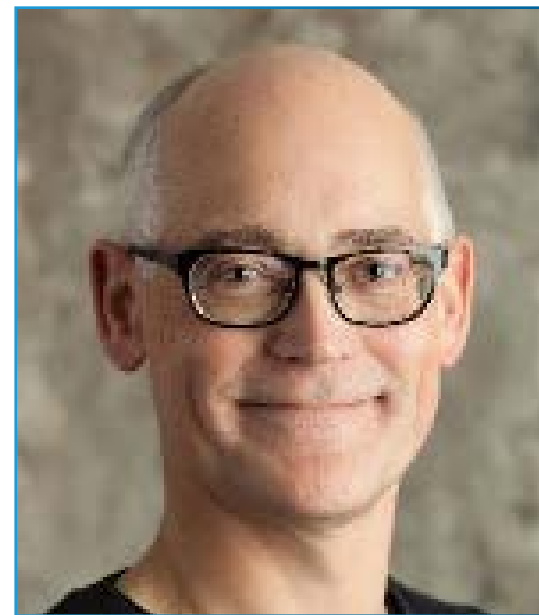
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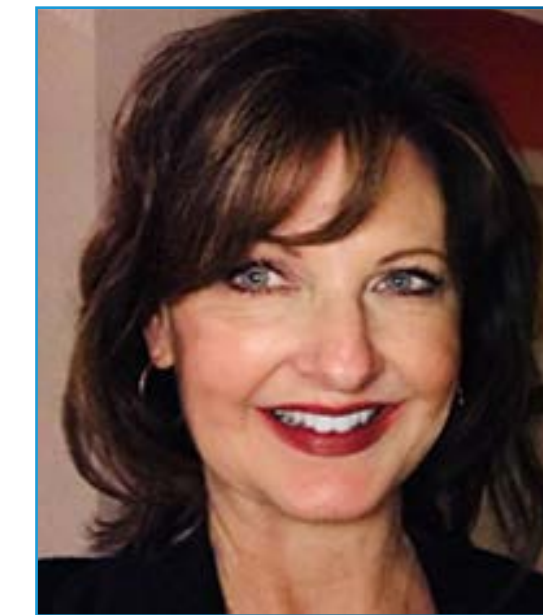
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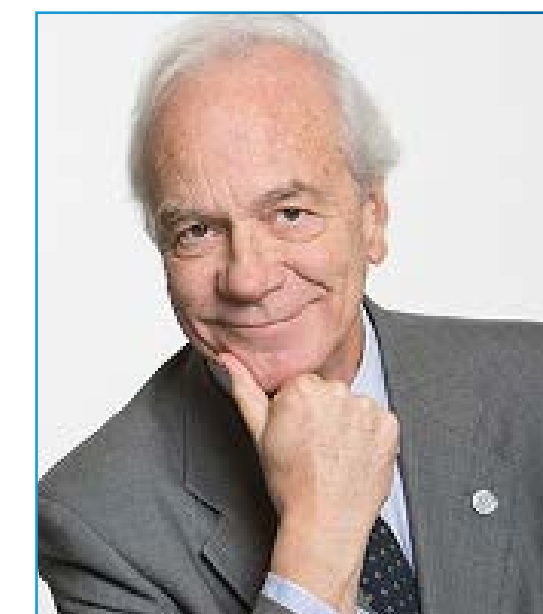
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Roberto Saracco
IEEE FDC



Jeffrey Voas
NIST, IEEE Computer EIC

SECTION 02

Introduction

Technology Predictions from Hypothetical Exercise to Critical Planning

The pandemic data¹

- 28 Trillion \$ loss in 2020, unevenly distributed across regions and sectors
- Recovery time estimated at 2 to 4 years; market and priorities reshaped
- Up to 10% of GDP in jobs support, good portion is “wasted” money

The pandemic had impact on: human lives, supply chains, workforce, unpredictability of operations and markets

Counter-measures: cutting costs; repurposing assets; eliminating the middle-man; shift to “as-a-Service” models

Pandemics have created STRESS on current humankind existence, values, and daily lives

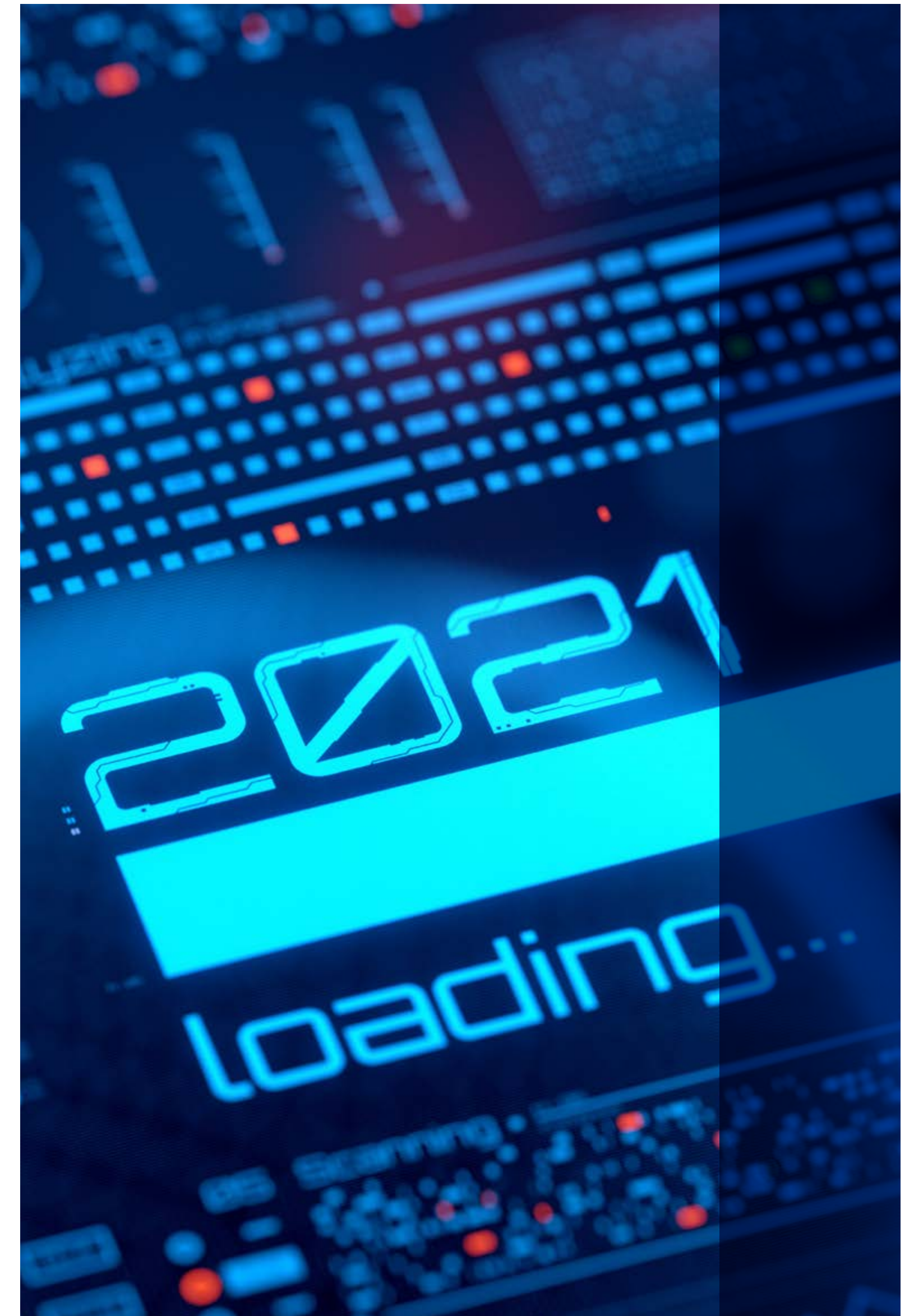
- Societal distancing vs depleting individuals’ social credits
- Future of workforce
- Forced to trusting AI to assist in transportation, healthcare, elderly, etc.

Acceleration of the Digital Transformation was forced upon work, education, and private life

Technologies increasingly play crucial role in all of this and are becoming essential for our survival

Predicting technologies helps addressing pandemics, it goes well beyond hypothetical exercise

¹ From Roberto Saracco, Industry Advisory Board report to IEEE Future Directions Committee



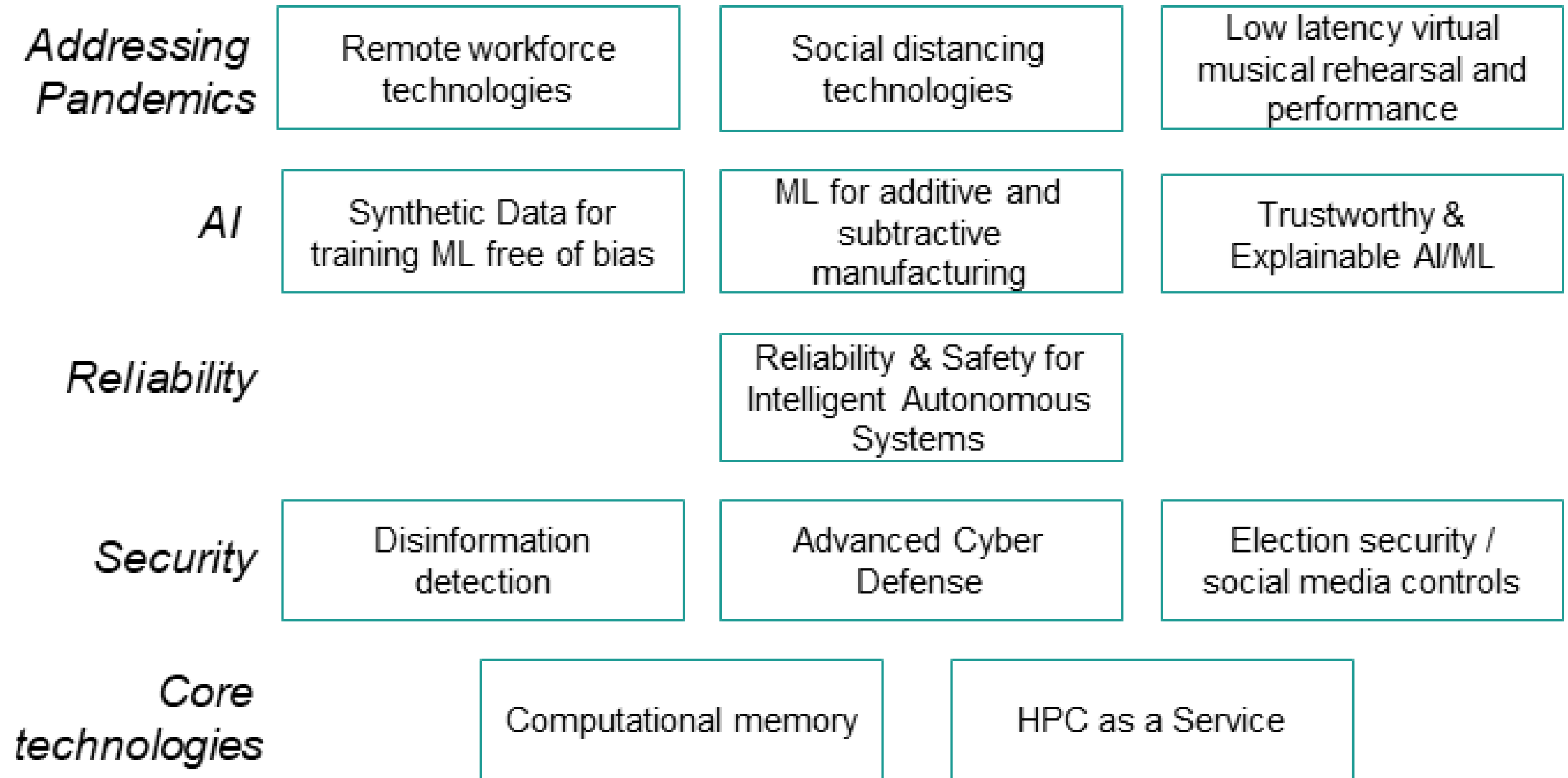


Technology Predictions at the Times of Pandemics

12 Predictions Landscape

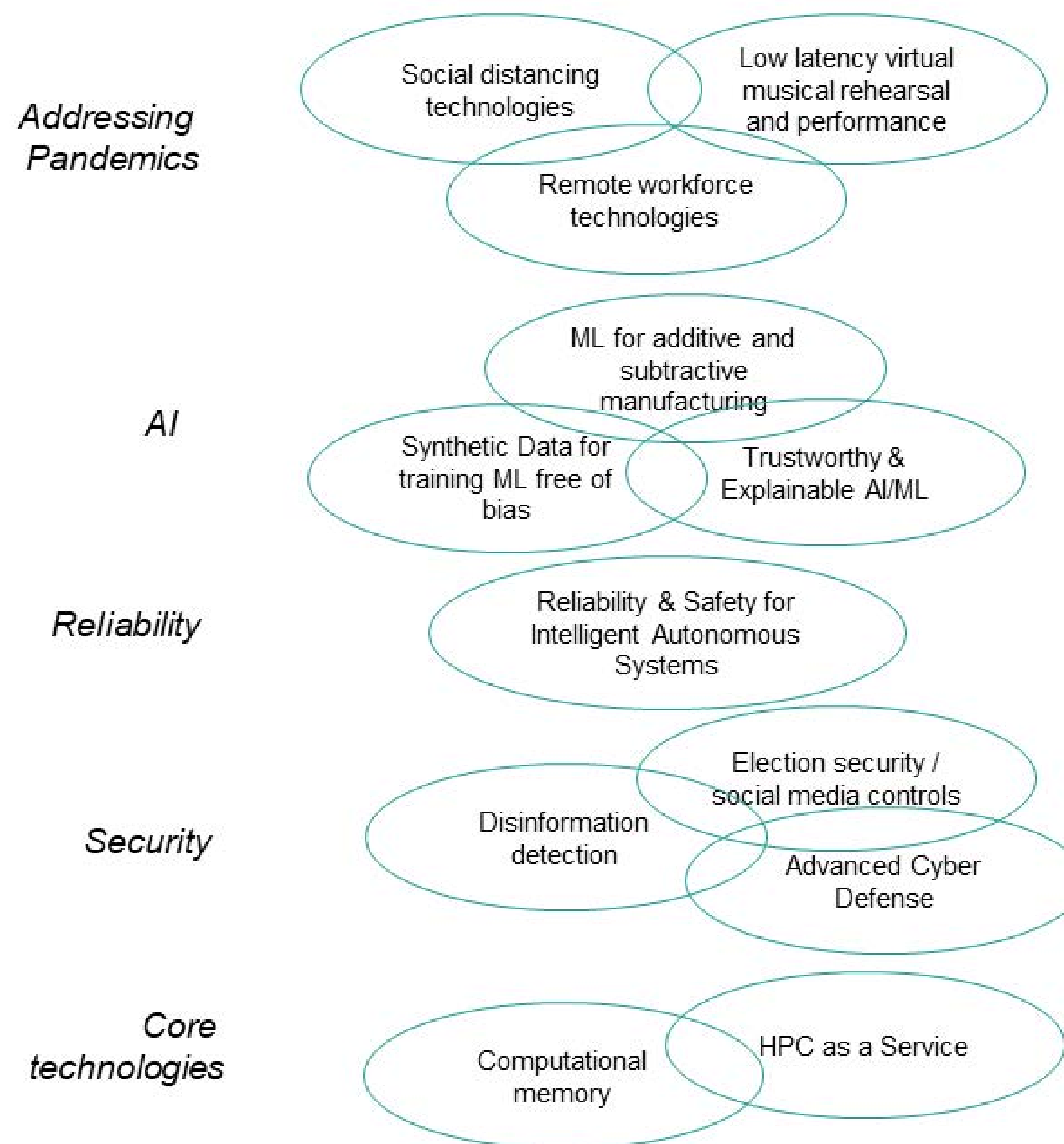
1. Remote workforce technologies
2. Social distancing technologies
3. Reliability/Safety for Intelligent Autonomous Systems
4. Synthetic Data for training ML systems free of bias
5. Disinformation detection
6. HPC as a Service
7. Election security / social media controls
8. Trustworthy & Explainable AI/ML
9. Low latency virtual musical rehearsal and performance
10. Computational memory
11. AI for additive & subtractive manufacturing
12. Advanced Cyber Weapons

Relationship Between Predicted Technologies



SECTION 03

In Reality ...



SECTION 04: INDIVIDUAL 12 PREDICTIONS

Remote Workforce

Tools, policies, and regulations for remote work will evolve rapidly, improving existing remote roles and expanding to use cases that don't currently have ideal solutions, such as education, manufacturing, and healthcare.



Problems/demand

- The pandemic required social distancing, which in turn created an immediate explosion in remote work, especially for white-collar industries
- The vast majority of remote work uses preexisting technology, such as video conferencing and virtual private networks
- But there are many important workplace interactions that don't currently have a great technological solution and are ripe for innovation

Opportunities

- Technology to facilitate proximity-based or spontaneous collaboration, substituting for the office environment
- Technology to facilitate effective teaching and learning with rich communication, substituting for the classroom environment
- Technology to facilitate effective large-scale meetings, substituting for the conference environment (short-term)

Impact

- Customized remote work environments and Improved accommodation of workers with different needs.
- A more inclusive work environment, policy, and culture
- Growth in remote-based services such as tele-health.
- Adoption of remote collaboration, hiring, and training.

Sustainable solution/business opportunity

- A permanent transition to a remote or hybrid work model in white-collar industries.
- Increase in worker mobility and geographical diversity.
- Improvements in diversity, equity, and inclusion of the workforce.
- **Enablers:** tech & app innovations; AR/VR, regulation
- **Inhibitors:** company policy, lack of financial support and buy-in

More details at <https://doi.org/10.36227/techrxiv.13278092>

SECTION 04: INDIVIDUAL 12 PREDICTIONS

Social Distancing

A host of technology is converging, creating streams of data that will be processed locally and globally creating a framework of massively distributed intelligence with impact on apps, wearables, and sensors.



Problems/demand

- The pandemic required social distancing, which in turn created an immediate explosion in remote work, especially for white-collar industries
- The vast majority of remote work uses preexisting technology, such as video conferencing and virtual private networks
- But there are many important workplace interactions that don't currently have a great technological solution and are ripe for innovation

Opportunities

- Societal Distancing Techniques can increase service quality and decrease cost by leveraging alternative ways to turn distance into closeness (by creating a feeling of presence)
- On the business side they open up new opportunities, as demonstrated by the number of tools for managing virtual meetings and by the rapid evolution of their features.
- Social distances techniques, when duly addressed, provide tools that foster the digital transformation

Impact

- The impact of Social Distancing is substantial. Humans are social animals, psychologically against "distancing".

Closeness provides a sense of safety in case of perceived danger.

- The negative aspects of social distancing can be decreased by improving technologies to overcome separation (e.g. VR/AR).
- The growing awareness at personal & social level can stimulate specific behavior and foster proactive healthcare. Social Credits growth was noticed in China.

Sustainable solution/business opportunity

- We can expect emergence of new and improvement of existing wearable devices. Existing smartphones improve sustainability (reuse), like the adoption of GPS/Wireless, Bluetooth
- The leverage of data is also in line of sustainability, opening up biz opportunity, e.g. adoption of existing data frameworks like Electronic Health Records (EHR)z
- The need to create personal data space goes hand in hand with the evolution trends of Digital Twins and Personal Digital Twins that in turn is likely to foster new biz opportunity
- **Enablers:** VR/AR technologies, social credits
- **Inhibitors:** distancing enforcement, poor technology support

SECTION 04: INDIVIDUAL 12 PREDICTIONS

Reliability and Safety for Intelligent Autonomous Systems

Fueled by the pandemic, substantial growth in autonomous systems will further improve reliability and safety of such autonomous systems.

Problems/demand

- Expected market growth for intelligent autonomous systems (e.g. mobile robots, vehicles) with high level of autonomy
- To enable high levels of autonomy, stringent requirements in terms of reliability/safety of their components have to be met
- The ability to reach a safe state in a fully autonomous way (thanks to reliable components) has to be guaranteed in case of hazardous conditions
- High reliability and safety should be guaranteed with respect to transient faults and aging phenomena occurring in the field

Opportunities

- Intelligent, autonomous systems proved very helpful in facing the pandemic emergency (e.g., robots to disinfect infected areas, autonomous vehicles transporting Covid19-tests, etc).
- Moving towards fully autonomous systems will significantly help humans by preventing exposure to health's risky conditions
- Applications are pandemic support, environmental monitoring, post-earthquake management, space exploration, etc.

Impact

- Significant reduction of humans' work risks
- Improvement of humans' health
- More efficient healthcare, surveillance, and better services
- Technological boost

Sustainable solution/business opportunity

- Significant research investment (academia and industry) in high reliability and safety solutions for highly autonomous intelligent systems
- Research needed to investigate interaction among reliability, safety and security and time determinism constraints
- Applicability to environmental monitoring, catastrophes' prediction and avoidance
- **Enablers:** Innovative approaches for enhanced reliability and safety; new international standards in the field; regulations for ethical responsibility
- **Inhibitors:** technical challenges; regulations

For more details, please join the IEEE Computer Society Special Technical Community (STC) on Reliable, Safe, Secure and Time Deterministic Intelligent Systems at <https://www.computer.org/communities/special-technical-communities/rsstdis>

Synthetic Data for Training ML

We shall see a substantial increase in the adoption of synthetic data for training ML in the coming year.



Problems/demand

- Real-world data often embed strong biases found throughout society thus allowing AI algorithms to amplify those undesirable biases
- Real-world data is difficult to gather and very expensive to manually label hence limiting the use of ML
- Real-world data often raise privacy concerns which may severely limit its application
- Real-world data can sometimes not be collected in a certain environment due to safety reasons

Opportunities

- Synthetic data can be generated in infinite amounts at extremely low cost
- Synthetic data is automatically perfectly labelled
- Synthetic can be engineered to be free of bias and promote inclusion
- Synthetic data can easily be shared and used in collaborative environments
- Generating behavioral data such as in robotics simulations at speeds much higher the wall clock
- Greater variation in data including black swan events

Impact

- More and better training data at order of magnitude lower cost
- Creating training data reflecting the world as we want to see it rather than the biased world we live in
- Eliminate the risk of model overfitting
- Disrupting model accuracy through active learning and dynamic data generation in a virtuous feedback loop
- Democratization of AI/ML by lowering barriers of entry for ML practitioners

Sustainable solution/business opportunity

- Low-cost smart cameras with computer vision
- Improved AI functionality in Augmented Reality
- ML Models as-a-Service
- Testing ML systems with anonymized data
- Improve limited real-world datasets with synthetic data
- **Enablers:** Push for Responsible AI; privacy concerns; bias prevention; inclusion; low cost; scalability; and flexibility
- **Inhibitors:** Limited technology offerings; awareness; insufficient skills & knowledge of complex data theories; and deep rooted skepticism to data not originating from real-world events; legal uncertainty

Disinformation Detection

Critical importance of having accurate information will trigger techniques to determine disinformation in politics, business, and social media.



Problems/demand

- 'Post-truth' declared word of the year by Oxford Dictionaries, 2016
- Twitter Has Flagged 200 of Trump's posts as 'Disputed' or Misleading since election day and the CNN refused to broadcast some of his statements. Based on what tools/information they are making their decision?
- People are making judgments about trustworthiness based on reviews and critics of claiming to be "objectives". Apparently, many of them are being paid directly or indirectly to vote for or against the product/service.

Opportunities

- The current technology of profiling and understanding market demands and needs are focusing on commercial purposes, but the same technology can be used to detect disinformation
- Recently, quite a new researchers are using advanced machine learning and data mining techniques to achieve that goal

Impact

- More reliable detection of "fake" people and information can positively impact social governance
- It will improve the quality of products and services we are getting

Sustainable solution/business opportunity

- We need better regulations and laws that will mitigate the use and the spread of false data and false information
- We need to develop more reliable tools to detect false data – tools that people can trust
- **Enablers:** regulation; advanced machine learning algorithms; tech & app innovations
- **Inhibitors:** legislators, politicians, perceived commercial interests of existing players

SECTION 04: INDIVIDUAL 12 PREDICTIONS

HPC as a Service (HPCaaS)

During 2021, we will see increasing progress towards delivering medium HPC systems as a Service.



Problems/demand

- Not everyone can afford Supercomputer, delivering high end HPC hardware on as needed basis eliminates CAPEX
- HPC is converging towards AI¹ and most of AI is executed in the Cloud or on aaS platforms
- However, HPC applications still require high parallelism and specialized, noise-free interconnects, as well as HPC-specific tools (schedulers, libraries, etc.)

Opportunities

- Applications in the Cloud have evolve their workflow and tool chains in a more superior fashion than HPC
- Security models are better in the Cloud with shared infrastructure
- Scale-out models in the Cloud are proved to be more cost-efficient than on-premise

Impact

- Making HPC more broadly available can democratize many high end applications and also foster innovation

- HPC platforms will modernize and new programming models beyond MPI & multi-threading will evolve
- Entirely new applications may evolve from tighter convergence of HPC and AI fueled by HPCaaS

Sustainable solution/business opportunity

- International governments embracing HPC as a Service
- HPCaaS Adoption for Engineering solutions in oil and gas, finance, etc. (mid- to low-end HPC)
- We need to develop more reliable tools to detect false data – tools that people can trust.
- **Enablers:** growth of AI accelerators; concerted efforts by US DoE; push by top tier Cloud providers
- **Inhibitors:** legacy HPC applications are still dominated by MPI and multi-threaded models; very high end systems and highly parallel applications will demand on-premise

¹R. Stevens, J. Nichols, K. Yellick, "AI for Science," DoE Report. <https://publications.anl.gov/anlpubs/2020/03/158802.pdf>

SECTION 04: INDIVIDUAL 12 PREDICTIONS

Election Security and Disinformation

Technological tools and new laws will develop to safeguard election security, increase trust and confidence in the democratic process, and curb the spread of disinformation.

07

Problems/demand

- The 2020 US presidential election shone a light on the oversized role of technology, in particular social media, on perceptions of election security
- Debate continues about the appropriate scope of intermediary responsibility and liability for disinformation and its viral spread
- Concerns about interference from foreign adversaries are real, and social media demonstrated continued influence operations

Opportunities

- Social media technologies and companies influence the views of millions. This influence can be harnessed for voter education and communication, rather than furthering viral spread of disinformation, distrust, and “echo chambers”.
- The commercial incentives of social media companies should align with the democratic interests and values of each country
- Opportunities exist to merge the conversation from election security with WHO’s inquiries into “infodemiology” and disinformation as a threat to public well-being

- Balancing diverse perspectives with responsible propagation of content challenges the continued fit of traditional legal approaches to intermediary protection

Impact

- Building trust in the democratic process and election results
- Potentially overlapping interests across the political aisle
- Minimizing provably false information in the public discourse

Sustainable solution/business opportunity

- Industry investment in advanced AI/ML technology to improve content monitoring, classification and filtering
- A new, possibly more restrictive regulatory climate for these companies
- An increase (or possibly decrease) of trust in traditional social media products; room for arrival of new entrants
- **Enablers:** Better content classification tech, regulation
- **Inhibitors:** conflicting perceptions of commercial and political interests

Trustworthy & Explainable AI/ML

In addition to performance, the AI/ML developers will start focusing on explainable and trustworthy tools and code.



Problems/demand

- Today's AI practices and tools are designed for performance, but lack transparency and accountability
- They introduce or amplify bias due to training data quality
- They are not capable of explaining the decision process
- They can't be used in compliance-sensitive or mission-critical applications

Opportunities

- Design for explainability: systems should be interpretable and observable
- Design for reproducibility: systems should be designed to act upon traits that are invariant
- Design for robustness: systems should be stable during training and inference, and robust against adversarial attacks
- Design for fairness: systems should be able to measure and mitigate bias

Impact

- Applicability of AI/ML to mission-critical processes
- Mitigation of biased decisions caused by AI technology
- Human-in-the-loop decision making process with validation and compliance

Sustainable solution/business opportunity

- Trustworthy AI toolkits and standard practices to design, analyze and measure AI solutions and technologies
- AI/ML technology that is "designed for trust" by construction, with built-in support to measure and analyze the important explainability metrics
- **Enablers:** several world-wide initiatives towards a converged set of AI Ethics principles (e.g., Secure, Private, Inclusive, Human, Responsible, Robust)¹
- **Inhibitors:** AI/ML center of gravity in consumer applications (e.g., recommenders) that are less sensitive to trust issues; emphasis on performance rather than trust.

¹ Example (IEEE): https://bit.ly/IEEE_AI_Ethics_Principles

SECTION 04: INDIVIDUAL 12 PREDICTIONS

Low Latency Virtual Music Collaboration

New technologies will enable vocal and instrumental ensembles to make collaborative music in real-time for instruction, rehearsal, and performance.

09

Problems/demand

- The pandemic has made it unsafe for singers and wind instrumentalists to rehearse together indoors. Outdoor rehearsals aren't always possible, due to weather.
- A large audience congregating for a live performance is dangerous
- Remote workforce technology adds significant latency and jitter, making it unusable for collaborative musical rehearsals and live performances

Opportunities

- Technologies to facilitate virtual rehearsals with low enough latency (< 25ms) to support collaborative music making for:
 - Musical instruction (e.g., individual or small group lessons)
 - Small ensemble rehearsals (e.g., chamber groups, jazz combos)
 - Larger ensemble rehearsals (e.g., choruses, concert bands)
- Technologies to facilitate live virtual performances of musical ensembles, with audience interactivity

Impact

- Enablement of collaborative music making for instruction, ensemble rehearsals, and performances
- Increased sense of community beyond individual artistic pursuits
- Potential for larger, more inclusive audiences than possible with in-person events
- Post-pandemic: reduced need for commuting to rehearsals and events
- New business models around remote, rather than in-person, delivery

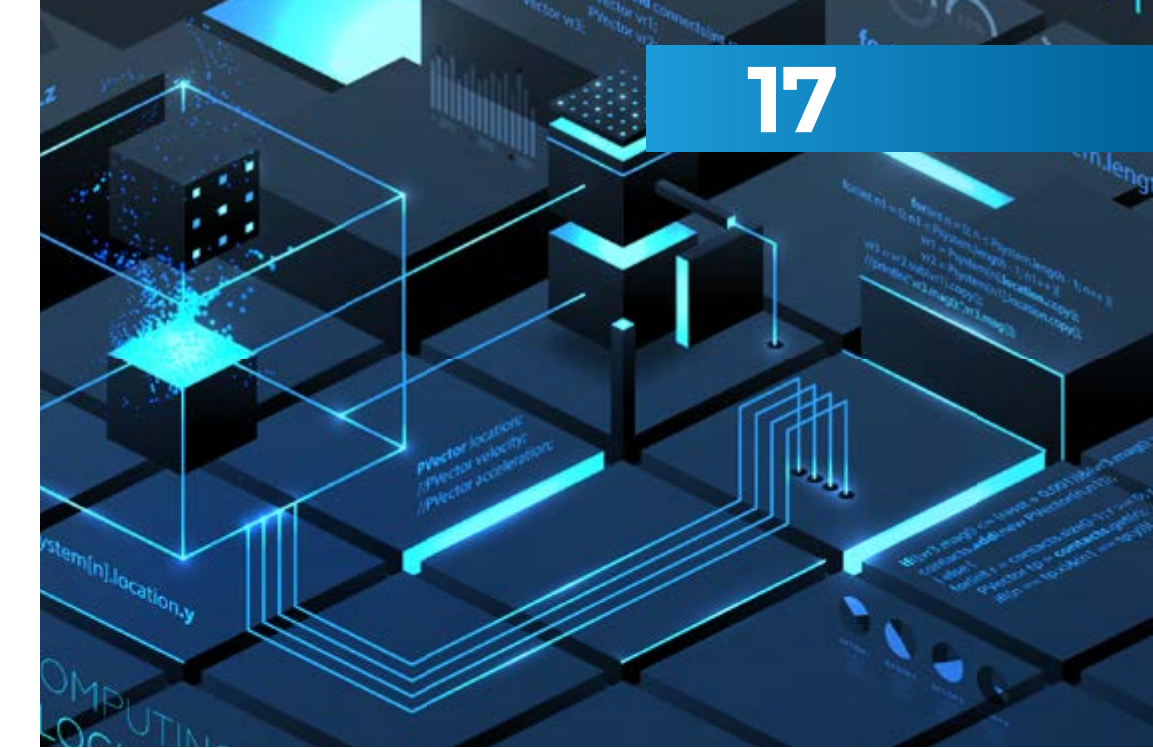
Sustainable solution/business opportunity

- Hardware and software support for low-latency, DVD-quality Internet audio and video processing
- Easy-to-use devices, applications, and cloud services to simplify configuration and management for non-technical users
- **Enablers:** several initiatives are exploring solutions for Internet music making. E.g: [JackTrip Foundation](https://www.jacktrip.org/) and [Jamkazam](https://jamkazam.com)
- **Inhibitors:** physics (speed-of-light delays limit geographic spread of musical collaborators), insufficient financial support for new arts-related technologies

¹ <https://www.jacktrip.org/>

² <https://jamkazam.com>

Computational Storage and In-Memory Processing



Increased deployment of IoT sensors with minimal power consumption will accelerate development and deployment of computational storage and in-memory processing devices, software stacks, and products.

Problems/demand

- Creating value and enabling quick decisions from growing data stores while reducing energy consumption and cost will enable wide-spread applications that enhance public safety, improve health, and enable greater understanding
- It will allow us to experience the world and others in new ways and help create a true partnership between humans and machines

Opportunities

- Many IoT/AI real time applications (e.g. autonomous vehicles) benefit from processing at the edge
- Processing at endpoints or at the edge, often with embedded SoC devices, can improve latency, reduce network bandwidth and also reduce energy consumption
- Replacing volatile with non-volatile memory, emerging memory fabrics and domain specific processors to implement in-memory processors or computational storage to reduce movement of data
- Replacing volatile with non-volatile memory in industrial, civic and consumer embedded devices can reduce energy consumption and often provide more memory for AI and other applications, increasing their usefulness

Impact

- Local data processing makes IoT data more useful and reduces the impact of this data on baseband network bandwidth
- Local data processing with embedded devices using non-volatile memories can make power constrained applications possible, enabling new medical/health, AR/VR and many other apps
- In addition to saving power, greater use of non-volatile memory, domain specific processing and disaggregated and composable infrastructure could increase the overall data center efficiency

Sustainable solution/business opportunity

- Processing data locally saves energy, provides higher performance, saves network bandwidth and reduces latency
- New networking architectures and memory/storage strategies will create new opportunities for computing resources
- Low power embedded devices enable more apps and new packaging options—such as smart glasses with voice control
- **Enablers:** improving AI and nonvolatile memory enable local processing using less energy
- **Inhibitors:** Need higher volume lower cost non-volatile memories and implementation of new AI applications in embedded devices and data centers

AI for Digital Manufacturing

We will see further uptake of additive and subtractive manufacturing with lower design-to-production times, higher part quality, and increased customization opportunities provided via new applications of data science and ML.



Problems/demand

- Desire for faster ideation-to-production time for parts created through additive and subtractive manufacturing
- Need for higher confidence that parts meet functional constraints and quality requirements
- Need for easier and faster customization of designs
- Desire to open up design ideation and creation to any user

Opportunities

- Feedback/learning loops in manufacturing/testing equipment for higher quality and faster achievement of desired functionality
- Feedback/learning loops in design through consumer usage
- Learn from tagged design libraries and images of products to achieve desired aesthetics or functionality of new parts
- Human-centered, even verbal, input into design process

Impact

- Shorter time from need to production
- Higher quality solutions/parts
- Increased customization
- Designs created and produced by those who want them

Sustainable solution/business opportunity

- Data science for industrial manufacturing across and inside of factory workflows steps
- Data science for functional proof of produced parts
- AI for modeling and design by untrained users
- **Enablers:** advances in AI and physical calibration
- **Inhibitors:** lack of communication between different workflow components and consumer feedback

Advanced Cyber Defense

New autonomous and semi-autonomous security tools will emerge to defend against increasingly sophisticated attacks that are capable of causing significant physical harms and failures of critical infrastructure.



Problems/demand

- New and more innovative attack tools being developed
- Increased interconnectedness and ubiquity of computing enlarges attack surface.
- “Payoff” for success very large for low investment of effort
- Single individuals and small rogue groups can cause material losses due to information security harms

Opportunities

- Cross platform, application and device malware emerging
- AI technologies allow for evolving, adaptive and mutating malware
- State actors, rogue nations, terrorists, protest groups can easily create and deploy advanced attack tools and malware

Impact

- Physical harm (including loss of life) on massive scale

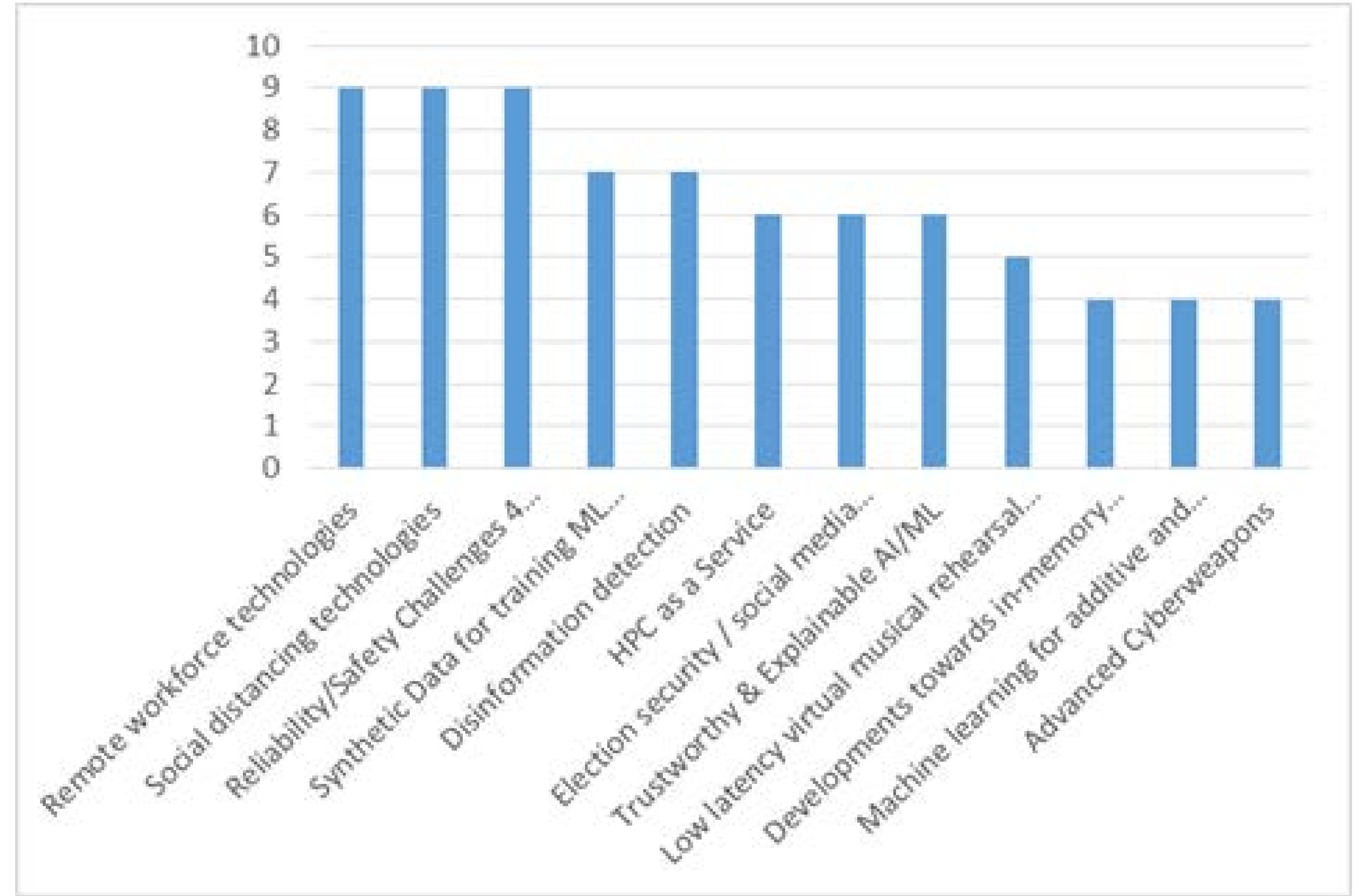
- Theft or corruption of vast amounts of data; massive financial harm to corporations, public entities, governments
- Widespread destruction, failure or malfunctioning of critical infrastructure systems with associated major societal damage
- A massive disruption of computing service triggering second and third order failures of computing and non-computing systems worldwide

Sustainable solution/business opportunity

- Cross government-industry solutions
- International alliances and information sharing
- **Enablers:** low barriers to entry, rogue governments and groups, enlarged attack surface due to ubiquity of computing elements and interconnectedness
- **Inhibitors:** prevention activities, preparedness, appropriate response/defense

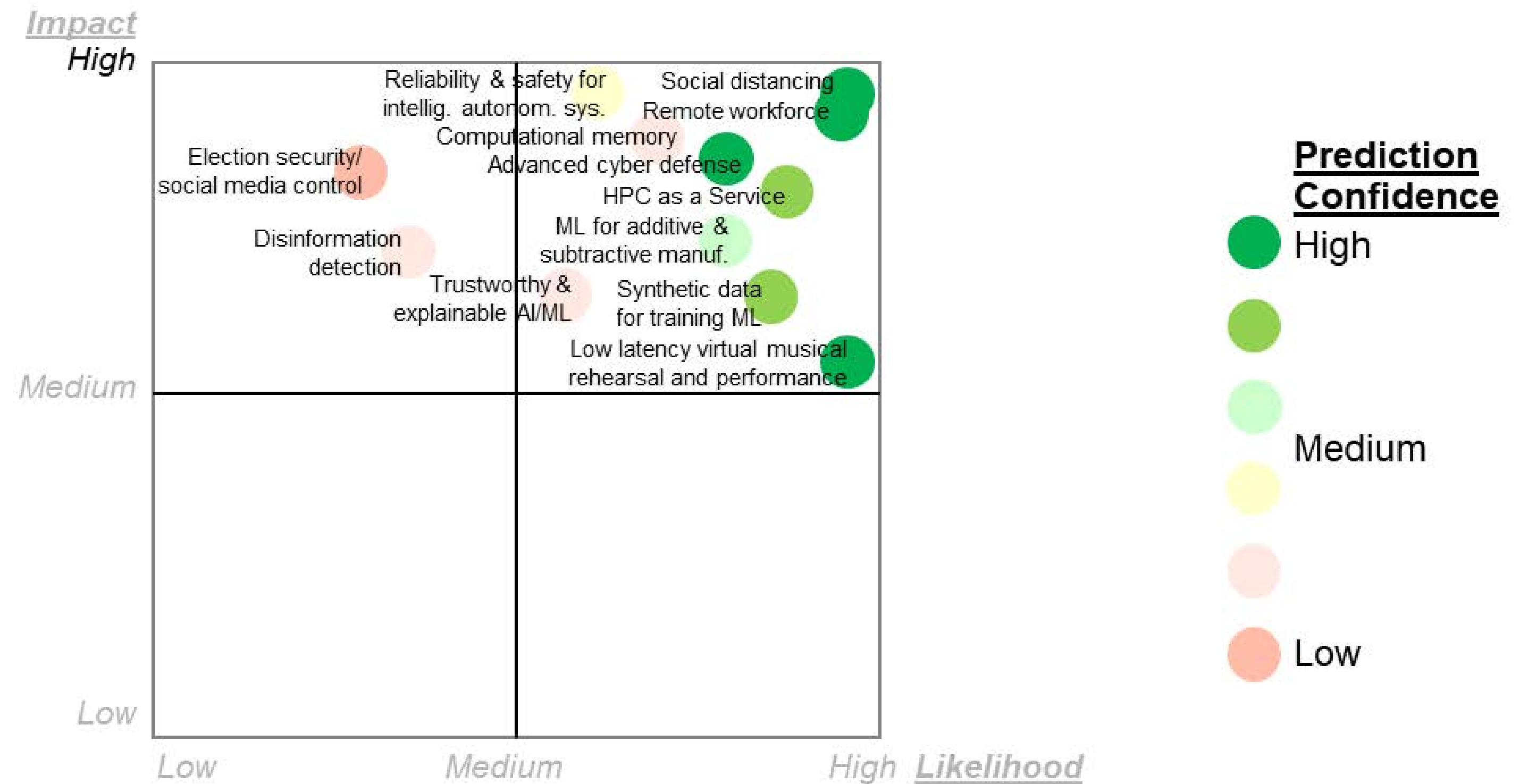
SECTION 04: INDIVIDUAL 12 PREDICTIONS

2021 Technologies Ordered by Predictions Team's Votes



Comparing Predictions

Impact, Likelihood, Confidence

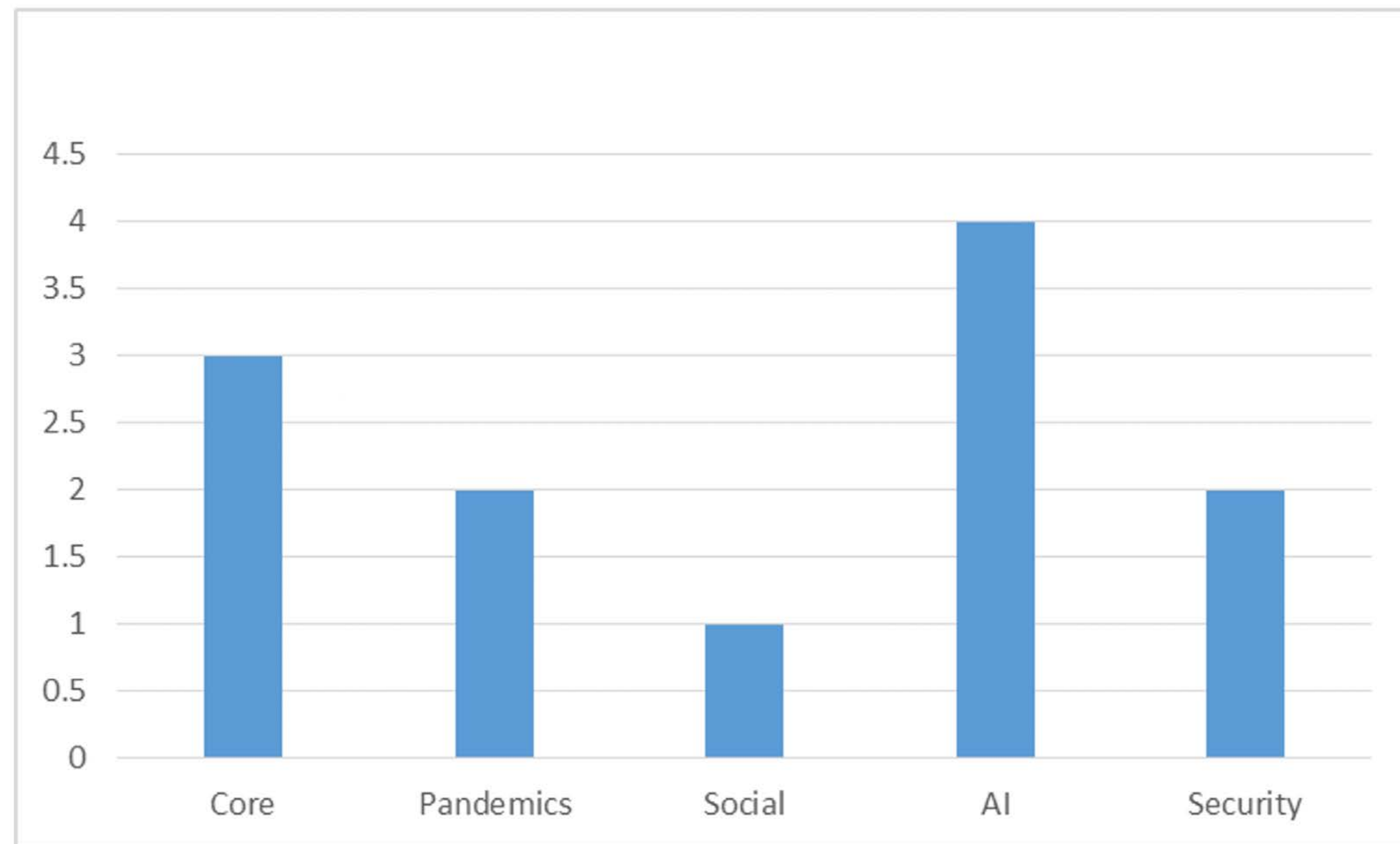


- 1) Likelihood was determined by the overall number of votes and consensus (average) among the committee, it defines probability of prediction happening
- 2) Impact is determined relative among different predictions
- 3) Prediction confidence describes our own confidence in prediction, and consensus (standard deviation), so it is different from 1) above



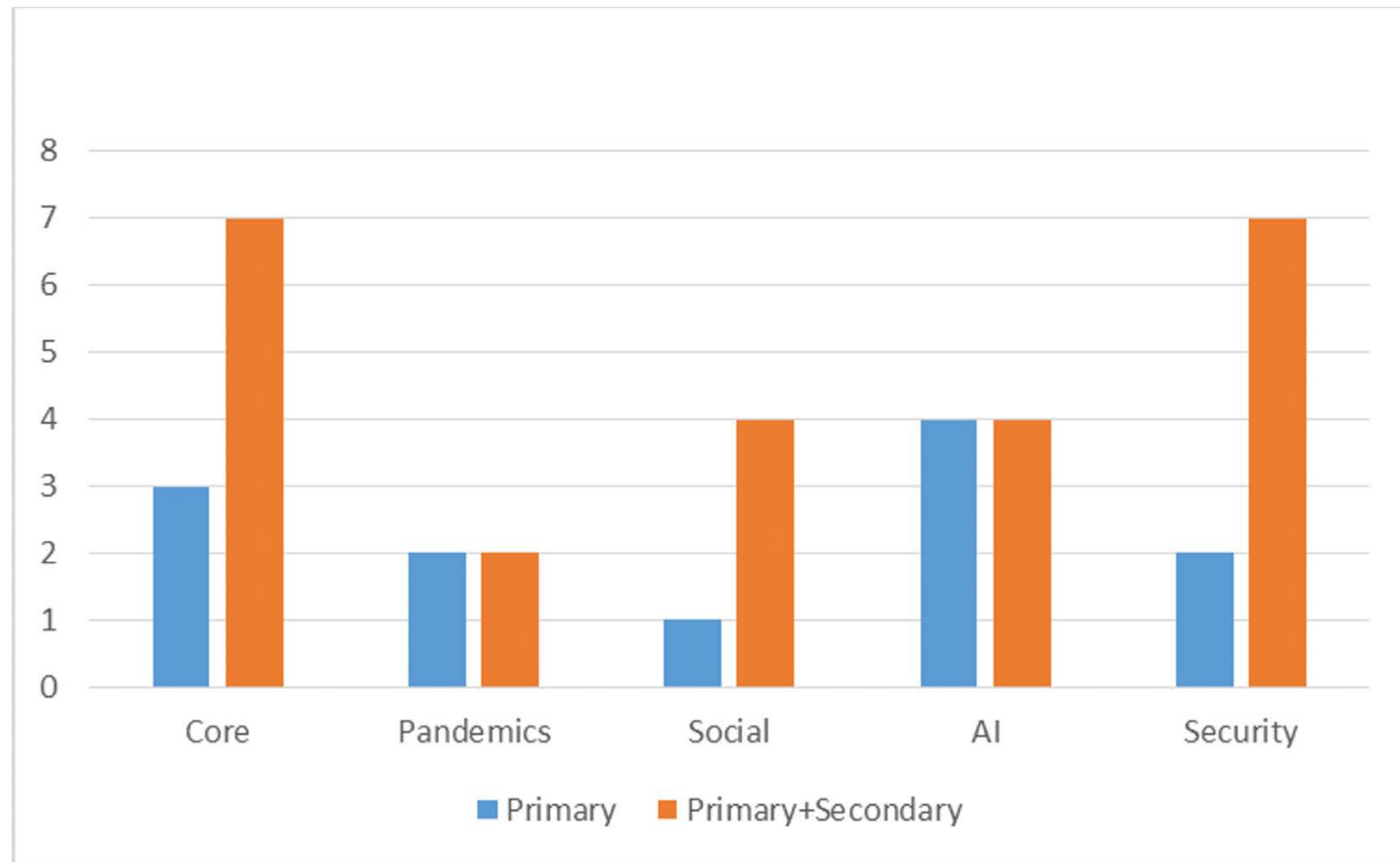
SECTION 05: COMPARING PREDICTIONS

#Predictions Categorized by Primary Focus



SECTION 05: COMPARING PREDICTIONS

#Predictions Categorized by Primary and Secondary Focus



SECTION 05: COMPARING PREDICTIONS

Some General Observations



Some of the industries are severely impacted by pandemics, dramatically reducing demand. Technology can help them too, but nothing can substantially reverse lack of demand, e.g.

- Transportation, especially air, cruises, taxis/lyft/uber, etc.
- Oil and gas, lack of travel drove down demand for oil (Oil future contract went negative)
- Tourism, hospitality, accommodation industry (hotels, AirBnB)

Some of the technologies and approaches are applicable across many fields

- AI/ML/DL techniques can be applied across all other technologies
- Cybersecurity is essential to protect against malicious behavior which is especially concerning in critical times
- Digital transformation is taking place in general and broadest sense
- Disaster recovery of manufacturing and supply chain very similar to data centers

SECTION 06

Overall Summary

The Pandemics

- Technology is critical in times of a pandemic, it helps overcome some of the negatives
- Pandemics also enable aggressive technology evolution. Necessity is mother of invention
- increasingly useful
- We continue to experiment with approaches and delivery models
- We are becoming more and more systematic and rigorous in our predictions

General

- Technology Predictions (or Trends) were always popular, now they are becoming
- Seeking Feedback
 - What do you think of our predictions? What have we missed, what is wrong, different?
 - Feel free to approach us with feedback, questions at k.mansfield@computer.org.



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