IEEE COMPUTER SOCIETY

2022 Technology Predictions

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In This Report

SECTION 01

Introduction

Technology Predictions—from Hypothetical Exercise to Critical Planning

COVID-19 pandemic economic impact:[1]

- 272M COVID-19 cases by 15 December 2021
- 3–5% forecasted change in global GDP due to COVID-19 in 2021 (2.82Tn–4.69Tn in US$)

The pandemic had an impact on human lives, supply chains, work, unpredictable operations, and markets.

Counter-measures include cutting costs, repurposing assets, eliminating middle-men, and shifting to "as-a-Service" models.

The pandemic has created stress on our daily lives and values:

- Social distancing limited opportunities for social interaction.
- Future of work: many in-person workplaces and classrooms transitioned to virtual.
- AI was entrusted to assist in transportation, healthcare, eldercare, etc.

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

Technologies play an increasingly crucial role and are becoming essential.

Predictions go beyond a hypothetical exercise to encourage technologies to address pandemic concerns.

[1] https://www.statista.com/topics/6139/covid-19-impact-on-the-global-economy

SECTION 02

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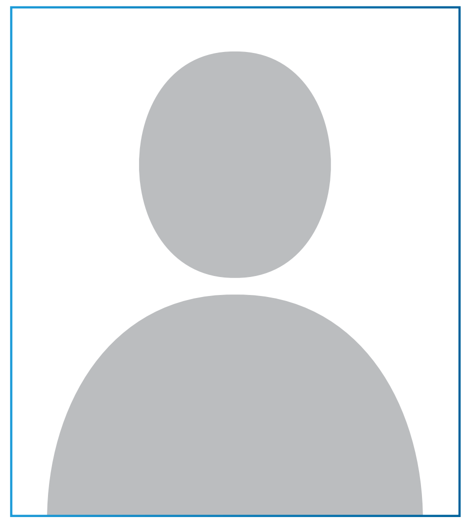

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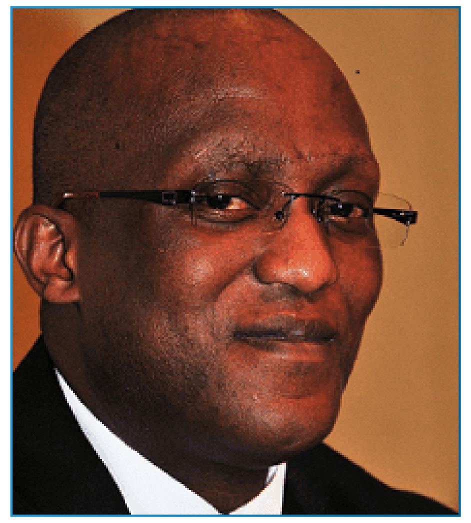

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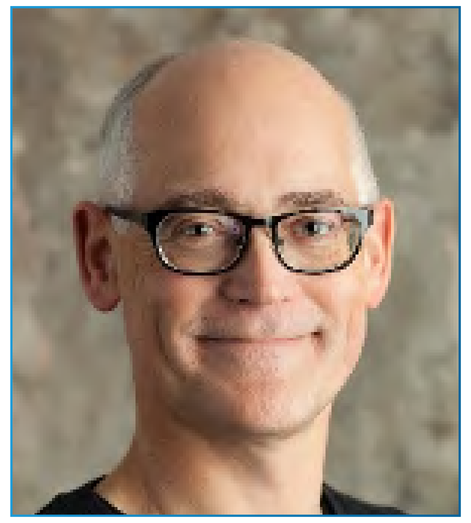

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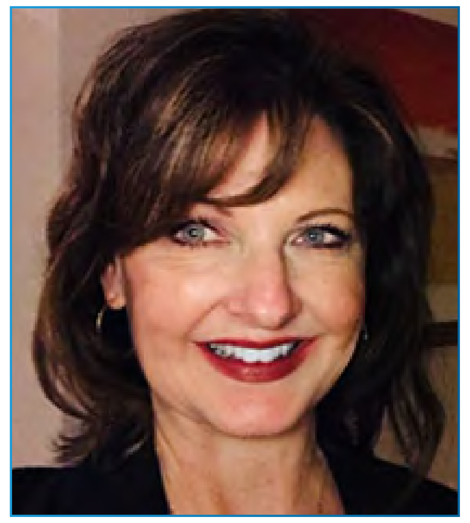

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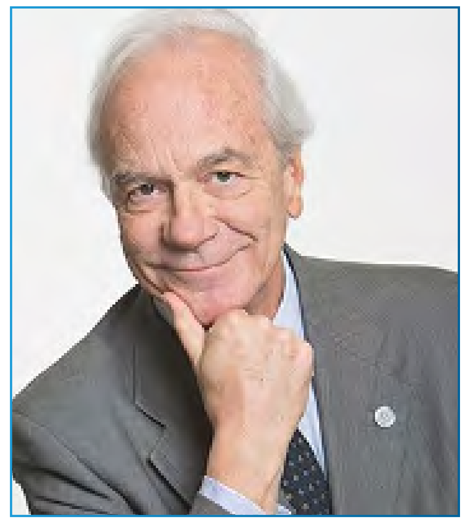

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Note: The statements expressed in this report do not represent the opinions of the authors' employers.

Process

This year, we expanded our team from 12 to 16 members, adding perspectives from Africa, Asia, Europe, and South America; we also improved diversity by including more women and adding one staff person.

16 authors made one or more predictions, resulting in 36 predictions. We combined 5, leaving us with 31.

We then down-selected to 11, by each author giving one of 12 votes to one technology, excluding the one(s) she/he proposed (this applied only to the first author if multiple authors proposed a technology).

The chair recommended adding the next closely voted 4 and also the 16th technology, and the team agreed.

In the second round, we graded each technology (A-F) for likelihood in succeeding and desirability. We also graded them for Technology Readiness Level (TRL) and impact using Total Addressable Market (TAM).

Because our estimates of both TAM and TRL came from disparate sources, we decided to not use them now. We will attempt to obtain more credible information on both in future years.

We define *likelihood* of succeeding as the progress the technology will make during 2022 in terms of advancement or adoption (subject to its current Technology Readiness Level).

We define *desirability* as how desirable this technology is to humanity (individuals, groups, countries).

We calculated our confidence as Standard Deviation in voting, for both likelihood and desirability.

For each of 16 technologies, the proposer(s) wrote a slide discussing problems/demand, opportunities, impact, and sustainable solution/business opportunity.

For each technology, we primarily focused on its computer science aspects.

Technology Predictions

1. **Data-centric AI** will increase focus on improving data quality and on data fabrics to make data available everywhere. (A-, B+)
2. **Remote medicine** will enable remote medical assistance, remote procedures, and consultations with remote experts. (A-, A-)
3. **Health, safety, and wearable biomedical technologies** will enable new home health services from wearables, bio-sensors, home diagnosis, etc. (A/B, A/B)
4. **Cybersecurity of critical infrastructure** and biological/medical supply chains will remain critical. (A/B, A-)
5. **Convergence of HPC/AI/HPDA** delivered as a Service will continue, fueled by heterogeneous hardware and serverless. (B+, A/B)
6. **AI at the edge will provide federated learning** with the support of the cloud, and will enable analysis of data at its point of origin (B+, B+)
7. **3D printing in healthcare** will enable prosthetics, protective equipment, custom surgical equipment, patient sample collection, and safer implants. (B+, A/B)
8. Safety, reliability, and resilience will improve for **intelligent autonomous systems,** fueled by pandemic-spurred growth in autonomous systems. (B+, A)
9. **Digital twins in manufacturing** will create a blended reality experience where simulation and reality overlap through integration of IoT, 5G, AI, and XR. (B, B+)
10. **Trustworthy AI** will continue to increase in importance, as AI/ML developers focus on explainable and trustworthy tools, code, and hardware. (B, A-)
11. **Disinformation detection and correction** will be of critical importance in politics, business, and social media. (B, A/B)
12. **Commoditization of space travel** will result in more companies sending technology to space, with rapidly decreasing barriers to entry. (B, B)
13. **Low-code/no-code** programming techniques will be more widely adopted for non-skilled (citizen) programmers. (B-, B+)
14. Despite trustworthiness concerns, **non-fungible tokens (NFTs)** will increase in adoption, enabled by blockchain for digital assets. (B-, C/D)
15. **Metaverse**/next-gen remote presence will evolve existing tech and introduce new senses (touch/haptic, olfactory, taste). (B-, B-)
16. **Confidential computing** will evolve as privacy-enhanced and secure computing delivered through a hybrid cloud model. (B/C, A-)

Broader Areas of Predicted Technologies

Productivity Tools	Low-Code/No-Code	Metaverse/Next-Gen Remote Presence	
Industry Verticals	Commoditization of Space Travel	Digital Twins in Manufacturing	
Pandemics, Healthcare	Health, Safety, and Wearable Biomedical Technologies	Remote Medicine	3D Printing in Healthcare
AI	Data-Centric AI	Trustworthy AI	AI at the Edge
Reliability	Safety, Reliability, and Resiliency Enabling Highly Autonomous Intelligent Systems		
Security	Cybersecurity (Critical Infrastructure and Biomedical Supply Chains)	Disinformation Detection and Correction	Confidential Computing
Core Technologies	Converged HPC/AI/HPDA Delivered on Heterogeneous	Non-Fungible Tokens (NFTs)	

Data-Centric AI

There is an increased demand to make data available everywhere and an increased focus on data-centric machine learning.

Problems/Demand

- AI models growing at an aggressive rate cause enormous computing pressure. Emerging data-centric practices improve the data quality rather than growing the models, and enable more efficient and incremental "active learning" approaches.
- Real-world training data are often biased, and it is difficult to avoid privacy violations when collecting data related to human behavior.
- Deep learning systems are inherently data-hungry systems, and providing them with enough quality data is challenging.
- For autonomous systems, data collection comes with a safety risk.
- Manually curating data is both time-consuming and costly.

Opportunities

- Improved tools and methodologies for cleansing, improving, and validating ML data.
- Self-learning metadata platforms that can infer data patterns from usage, enable capturing data transformations, versions, and provide links to ML pipeline stages.
- Data-centric AI approaches to specific verticals, such as manufacturing, health and life sciences, or financial services.
- Generating synthetic data free of bias and privacy concerns.
- Improved methods for data acquisition.
- Masking of personal-identifiable data.

Impact

- Relieves the infrastructure pressure and democratizes AI for those who cannot afford massive training runs.
- Eases the deployment of data-centric AI by reducing the dependency on ML model developers, which are a scarce resource and are a major source of adoption delays.
- Improves performance and accuracy of AI systems.
- Systems free from privacy and bias concerns.
- Systems with transparent decision-making.
- Safer systems.

Sustainable Solution/Business Opportunity

- **Enablers:** The emergence of open metadata platforms (like DVC) and a data-centric AI movement, cloud-scale compute and storage solutions, progress in machine learning techniques, improved data acquisition through IoT and 5G, data pipeline and simulation tools.
- **Inhibitors:** Proprietary platforms, like those offered in some cloud service providers; slow adoption of AI data practices and creation of de-facto incompatible standards; inability to define "unbiased"; synthetic data are too expensive and too removed from reality; lack of skilled "data workers"; lack of trust in manipulated and synthetic training data.

Remote Medicine

Remote medicine will enable patients to obtain remote medical assistance and physicians to perform procedures and consult with remote experts.

Problems/Demand

- Remote medical services have already been offered to the public for quite a long time, but with limited success.
- The appearance of COVID-19 made remote medicine more attractive (e.g., people worried about being exposed to other patients avoided going to medical centers; safety rules prevent physician from physically approaching patients).
- Fast-moving medical threats prevent training medical teams with new techniques and tools; remote medicine can help close such a gap.

Opportunities

- The growth of fast communication means, such as 5G, allows extensive use of advanced communication technologies such as video conferencing, remote MRI, remote sensors, and more.
- The wide use of cloud computing allows small medical centers to perform computations that require vast compute power.
- Governments and insurance companies are willing to spend vast amounts of money on R&D, which is related to COVID-19 in general and to remote medicine in particular.
- New classes of machine learning algorithms will allow physicians to be more efficient and serve more patients.

Impact

- Better ways to provide medical assistance.
- Technologies that have been developed for COVID-19 will be useful for treating other diseases.

Sustainable Solution/Business Opportunity

- Unfortunately, forecasts predict that different types of epidemics will continue to occur.
- **Enablers:** Fast communication, new ML algorithms, and new types of accelerators that allow performing sophisticated computations at the edge.
- **Inhibitors:** Cost, the need for explainable ML algorithms, regulatory and insurance reimbursement models.

Health, Safety, and Wearable Biomedical Technologies

03

Small electronic, wireless, autonomous devices that capture, analyze, and aggregate biofeedback or other sensory physiological functions related to health, well-being, and fitness and that can be worn on the human body (or in the human body with versions such as micro-chips or smart tattoos)

Problems/Demand

- Demand for wearable technologies is growing in response to increasing healthcare costs, aging populations, and the burden of chronic disease.
- The COVID-19 pandemic increased the desire for advanced technologies to detect, monitor, and treat COVID symptoms.
- AI, ML, and big data analytics in cost-efficient, power-efficient electronics and software have enabled the usefulness of sensor data.

Opportunities

- Data security, trust issues, and potential ethical hurdles to protect and limit access to health and personal information.
- Connectivity improvements, additional types/scopes of sensors, and further miniaturization to reduce cost and expand usefulness.
- Recurring costs from batteries, chips, and sensors that require periodic replacement.

Impact

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

Sustainable Solution/Business Opportunity

- Integration of wireless charging and energy harvesting.
- More integrated analytics to provide reliable insights from the data being collected.
- Improved reliability and accuracy of sensor data & information analytics.
- Expansion of the application & use of wearable technology.
- **Enablers:** Electronics miniaturization, battery efficiency, advanced sensors, microfluidics, and advances in commercial IoT market.
- **Inhibitors:** Regulatory requirements (e.g., HIPAA, pre-market approval, biocompatibility testing), data privacy and categorization, parts obsolescence/life-cycle, and data processing.

Cybersecurity of Critical Infrastructure and Medical/Biological Supply Chains

04

Securing digital vulnerabilities in our critical infrastructure, data, and medical resources

Problems/Demand

- Rising reliance on IoT control of critical infrastructure, medical devices, experimental equipment, and data collection increases vulnerabilities due to hacking or bugs.
- Digital vulnerabilities in turn can lead to destruction or disabling of infrastructure such as power sources, water sources, dams, air traffic, ground transportation, shipping, hospitals, military bases/equipment, and environmental monitoring.
- Digital vulnerability of collected experimental data can subject us to false conclusions and harmful or ineffective treatment or public health guidance.
- Digital vulnerability of medical/biological supply chains and medical devices can result in unavailable, ineffective, or harmful medical components, diagnostics, and treatments.

Opportunities

- More tamper-proof independent monitoring of critical infrastructure.
- IoT security improvements.
- Distributed, better-secured production of medical supplies.
- Open infrastructure that is more secure than proprietary solutions, due to peer review and independent verification.

Impact

- Less likelihood of disasters that cause large-scale loss of life.
- Critical infrastructure remains understood and controllable.
- Safe medical products remain available.
- Higher confidence in experimental data guiding public health responses.

Sustainable Solution/Business Opportunity

- IoT cybersecurity and monitoring.
- Biology lab cybersecurity and monitoring.
- Verification of actuation systems involved in experimental procedures and data collection.
- Tamper-proof provenance of medical supplies, components, and devices.
- Continual building, rebuilding, and optimization of infrastructure and equipment, lest we lose our understanding of it and ability to control it.
- **Enablers:** New focus on supply chain modeling and initiatives, open-source software security initiatives (such as OpenSSF), cryptography for tamper-proof chain of custody and provenance, formal verification efforts for IoT platforms and protocols.
- **Inhibitors:** Increased coupling and interdependence of almost all components in distributed systems, channels for fixing deployed IoT platforms are also attack surfaces, loss of manufacturing knowledge, loss of software maintenance knowledge, immature cybersecurity understanding for bio labs.

05

Converged HPC/AI/HPDA

Delivered as a Service on Heterogeneous Hardware & Serverless

Heterogeneity continues to emerge to overcome the end of Moore's Law, and serverless continues evolution of finer-grain and higher-level abstraction of virtualization from bare metal to VMs, to containers, and now Functions as a Service (FaaS).

Problems/Demand

- Scaling of traditional HPC applications declined, introducing adoption of AI/ML/DL techniques; similar is true for High Performance Data Analytics (HPDA).
- End of Moore's Law triggered specialized accelerators, which introduced complexity in system programming/managing.
- To improve developer productivity, virtualization evolved towards Functions as a Service, further abstracting systems.

Opportunities

- Cross-leverage techniques from three independent areas (HPC, AI, HPDA) for overall growth of all three.
- Uncovering new algorithms and data structures that can benefit all three.
- Improved programmer productivity due to the use of serverless hiding heterogeneity.
- Scaling traditional HPC/HPDA applications beyond supercomputer scale.
- Increased system efficiency using FaaS and heterogeneous accelerators.

Impact

- Solving problems that humanity is facing beyond the scale that was possible in the past.
- Quicker time to solution due to improved development productivity.
- More sustainable infrastructure due to higher system efficiency.
- Improved speed of reaction due to shortened software stack.
- Increased speed to innovation.

Sustainable Solution/Business Opportunity

- Standardizing on a plethora of diverging heterogeneous accelerators.
- Developing new programming model(s) and tools that better integrate traditional HPC/HPDA (MPI/PGAS) and AI (Python-based).
- **Enablers:** Huge market opportunity, as AI and HPDA have higher growth than HPC; increased need for addressing pandemics, climate change, etc.; increased use of data lakes; cybersecurity needs; and a large number of startups in the space.
- **Inhibitors:** Proprietary designs; complexity in handling heterogeneity; and vertical SW/HW stacks that hide innovation.

AI at the Edge

Distributed federated learning with support of the cloud; real use cases available.

Problems/Demand

- Many companies are evaluating the use of edge computing for data collection, processing, and online analytics to reduce applications latency and data transfers.
- A growing number of use cases (e.g., predictive maintenance, machine vision, and healthcare) can benefit from AI applications spanning edge-to-cloud infrastructures.
- Other use cases with privacy, confidentiality, or legal requirements may require processing at the edge.

Opportunities

- Novel tools for developing AI applications (including machine learning and deep learning applications, and large-scale analytics) that exploit resources in the computing continuum.
- Advanced strategies to design and optimally partition AI models given model accuracy, application performance, and security and privacy constraints.
- New methodologies to support continuous model training.

Impact

- AI services with reduced latency.
- New solutions for environments with minimal available bandwidth.
- Faster and simpler methodologies to train better neural networks.
- Lower-cost digital infrastructure.

Sustainable Solution/Business Opportunity

- Opportunities for subject matter experts to develop solutions to specific problems for edge devices. Enablement of new methodologies such as ultraprecision agriculture.
- **Enablers:** Novel frameworks for developing and operating AI applications, together with their data, exploiting computing continuum environments.
- **Inhibitors:** Interoperability problems among devices and cloud technologies.

Applications of Additive Manufacturing in Healthcare

07

3D printing parts and components for existing or new healthcare solutions, such as prosthetics, personal protective equipment, customized surgical equipment, parts for patient sample collection, and safer implants and ingestible devices

Problems/Demand

- Demand for physical technologies in healthcare is growing, to counteract increasing healthcare costs, pandemic supply chain issues, and rising levels of chronic disease.
- Desire for reduced lead times.
- Need for higher confidence that printed parts meet regulatory and safety requirements.
- Need for easier and faster customization of designs.

Opportunities

- Local production of unavailable medical supplies.
- Tamper-proof provenance tracking of manufactured parts.
- Affordable solutions customized to individual patient needs.
- Previously unachievable solutions based on new printable materials.

Impact

- Products remain available in the face of global disruption.
- Better fit to individual patients.
- Safer, more comfortable, and less invasive treatments.
- New interventions.
- Higher confidence around part provenance.

Sustainable Solution/Business Opportunity

- Individual patient data collection for customization of parts.
- Improvement of materials for different types of solutions.
- Better distribution of certified digital solutions for local physical production.
- **Enablers:** 3D printing of new materials such as tissue, coatings for ingestible probes, anti-bacterial materials, and lighter and more robust materials.
- **Inhibitors:** Regulatory certification (e.g., materials safety testing and approval), data privacy, and large-scale patient studies.

Safety, Reliability, and Resilience for Intelligent Autonomous Systems

08

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

Problems/Demand

- Expected market growth for intelligent autonomous systems (e.g., mobile robots and vehicles) with high level of autonomy.
- To enable high levels of autonomy, stringent requirements for the reliability/ safety of their components must 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, resilience, and safety should be guaranteed with respect to transient faults and aging phenomena in the field.

Opportunities

- Intelligent, autonomous systems proved very helpful in facing the pandemic (e.g., robots to disinfect infected areas autonomous vehicles transporting COVID-19 tests).
- Moving towards fully autonomous systems will significantly help humans by preventing exposure to risky health 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 and monitoring 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, resilience, safety, security, and time determinism constraints.
- Applicability to environmental monitoring and catastrophe prediction and avoidance.
- **Enablers:** Innovative approaches for enhanced reliability, resilience, and safety; new international standards in the field; and regulations for ethical responsibility.
- **Inhibitors:** Technical challenges and regulations.

Digital Twins in Manufacturing + Industrial Metaverse

Integration of IoT, 5G, AI, and XR to create a blended reality experience where simulation and reality overlap

Problems/Demand

- A Digital Twin (DT) is an exact virtual representation of a real-world system or object. It pairs the virtual and the real world and allows for analysis and monitoring in real time.
- DTs can enhance an organization's ability to make data-driven decisions, increasing efficiency and avoiding potential shortcomings.
- DTs enable experimenting with the future by exploring various scenarios safely, economically, and sustainably.

Opportunities

- Test and verification of functionality before a system or product is actually built.
- Iterative improvements and optimizations by data exchange between the virtual and the physical worlds.
- Enabling predictive maintenance.

Impact

- Accelerating innovative product and process design.
- Broad scenario exploration to improve usability and safety.
- Solving problems before they occur.
- Increased adoption of autonomous systems.

Sustainable Solution/Business Opportunity

- Potential business opportunity with substantial impact in product/process quality improvement, with reduced operation costs.
- **Enablers:** 3D virtual environments, machine learning, cloud-scale storage and computing, sensors for data collection, and networks to transport vast amounts of sensor data.
- **Inhibitors:** Bridging the gap between the virtual world simulation and the real world—most notably the ability to model physical properties accurately.

Trustworthy AI

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

10

Problems/Demand

- Today's AI practices and tools are designed for performance and scalability, but lack transparency and accountability.
- They may introduce or amplify bias due to training data quality.
- They are not capable of explaining the decision process.
- They are executed by hardware that can be affected by faults and age with usage.
- Hardware protection techniques are only partially adopted to limit costs.
- 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 and faults/aging affecting the hardware.
- Design to be respectful of privacy: data should be gathered with consent and discarded when no longer needed or protected from unanticipated use.
- Design for fairness: systems should be able to measure and mitigate bias.

Impact

- Trustworthiness of AI encourages private sector investment in AI-enabled solutions.
- 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, and to overcome faults/aging affecting the hardware.
- **Enablers:** Several world-wide initiatives towards a converged set of AI ethics principles (e.g., secure, private, inclusive, human, responsible, robust)[1]; research on faults/aging affecting AI/ML hardware.
- **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; hardware cost pressures; and the need to explain deep mathematics and technology to lawmakers requesting compliance

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

Disinformation Detection and Correction

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

Problems/Demand

- Oxford Dictionaries declared "post-truth" its 2016 word of the year.
- Nearly 80% of US consumers have reported seeing fake news on the coronavirus outbreak. Such disinformation (and unintentional misinformation) has caused confusion and limited the success of public health initiatives.
- Disinformation affects perceived credibility of news sources and sows mutual distrust between constituencies on different sides of an issue.
- Consumers make judgments about trustworthiness based on reviews and critics claiming to be "objective," despite being paid (directly or indirectly).

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."
- Technologies for profiling and understanding market demands and needs (currently focused on commercial purposes) can be used to detect fake news and false information.
- Researchers are using advanced machine learning and data mining techniques to detect false information.

Impact

- Minimizing provably false information in the public discourse.
- More reliable detection of "fake" information and people can positively impact social governance.
- Improved quality of products and services.

Sustainable Solution/Business Opportunity

- Industry investment in advanced AI/ML technology to improve content monitoring, classification, and filtering.
- Better regulations and laws that will mitigate the use and spread of false data and false information.
- An increase (or possibly decrease) of trust in traditional social media products; room for arrival of new entrants.
- **Enablers:** Regulation, advanced machine learning algorithms, technology &and application innovations; and provenance technologies like blockchain.
- **Inhibitors:** Legislators, politicians, perceived commercial interests of existing players, and inability to define "disinformation"; many people get their news from social media, where "opinion" and "news" are represented interchangeably.

Commoditization of Space Technology

More companies are sending technology to space, and the barriers to entry are decreasing rapidly.

Problems/Demand

- Private companies such as SpaceX and Blue Origin can send people and satellites to space. Even nonprofits like Copenhagen Suborbitals can launch rockets now.
- Increased competition can drive down costs, accelerate technology developments, and reduce the barrier to entry for customers wishing to utilize space.
- The "democratization" of space technology can lead to an explosion of new applications.

Opportunities

- Acceleration of scientific discovery in areas such as cosmology, biology, and low-gravity manufacturing.
- Increased global connectivity at lower cost.
- New applications and inventions, including mitigation of climate change.

Impact

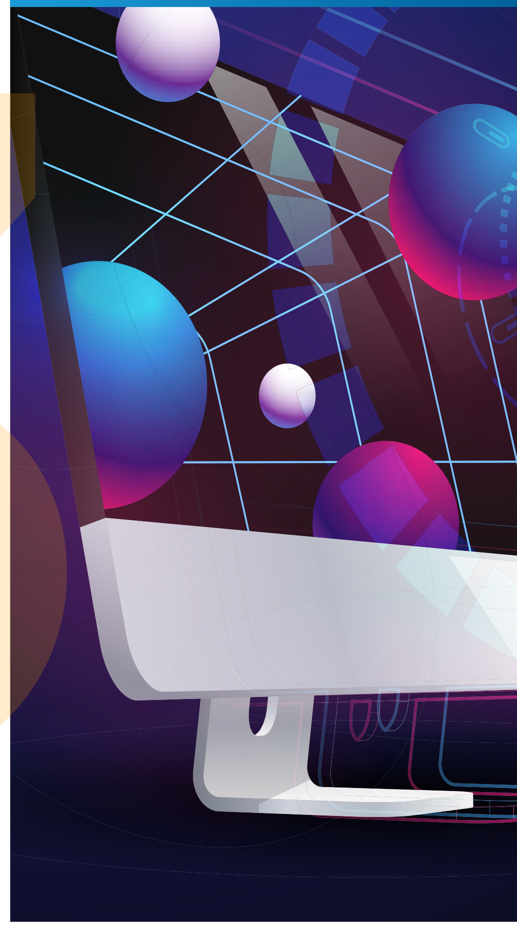
- Bringing more countries and more people into space: technologies, science, and natural resources.
- Planet-scale technologies that could affect everyone.
- Potential for increased carbon footprint with commoditized launches, or reduced footprint with sustainable fuels.

Sustainable Solution/Business Opportunity

- So far, only capital-intensive companies are providing commercial space services, but if they can serve smaller clients, it can open up opportunities for upstarts, like the cloud has done for scalable computing.
- As a shared resource that had so far been only accessible to a few state superpowers, the "democratization" of space offers opportunities and risks for global cooperation and regulation.
- **Enablers:** Reduced cost and carbon footprint of launching; scalable business models.
- **Inhibitors:** Regulation; unfair distribution of shared space "resources."

Low-Code/No-Code Programming Techniques

13



The wide adoption of computer systems in almost every facet of our lives requires some degree of programming, but not everyone is skilled or even aware of programing languages and environments. Low-code/no-code enables novice users to achieve their programming needs without being skilled in programming.

Problems/Demand

- Systems: Growing complexity of programming heterogeneous systems delivered in a distributed fashion.
- Software: Complexity of frameworks, applications and increased adoption of AI.
- Consumables: Increased adoption of programmable devices that require configuration and functional adaptation for use.

Opportunities

- Providing guidance to novice users in terms of compliance, security, reliability.
- Use in the area of Robotic Process Automation (RPA).
- Application to workflow development, which already has limited options.
- Adoption by non-technical users (citizen developers) as well as by Small and Medium Businesses (SMBs).
- Conversion of existing processes and their automation.

Impact

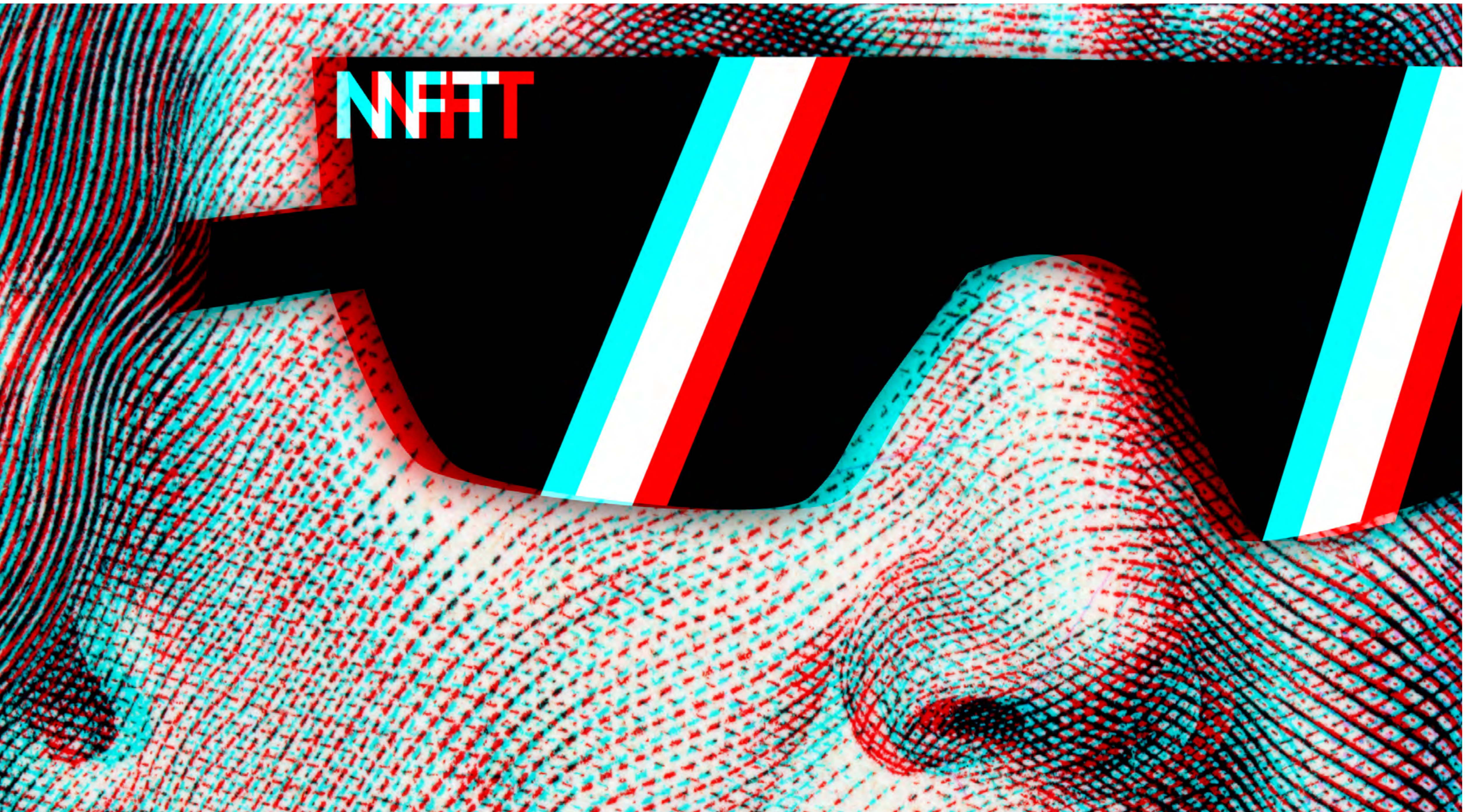
- Substantial improvements in ease of development and ease of use of growing number of applications, reducing the cost.
- Improved security through guided development.
- More efficient use of infrastructure through preconceived programs and programming models.

Sustainable Solution/Business Opportunity

- The world is becoming digital, and all solutions will need some amount of programming, configuration, and maintenance.
- **Enablers:** New frameworks and platforms; demand for online offerings (especially during pandemics) surpasses supply of programmers; automation and FaaS virtualization; security compliance.
- **Inhibitors:** Complexity of heterogeneous hardware with intricacies that percolate up the stack and require skilled programmers; security corner cases that are outside of cookie cutter choices.

Non-Fungible Tokens (NFTs)

Using blockchain technology for authentication and ownership of digital assets like art



Problems/Demand

- NFTs are (allegedly) attested through a unique ID on a blockchain (distributed ledger).
- NFTs are being used for the sale of digital artwork and other digital assets (e.g. pictures, videos, and game items).
- NFTs are being traded or sold by buyers and sellers on NFT marketplaces or through art auction houses (any of which may have vulnerabilities).

Opportunities

- NFTs are currently being used for buying and selling digital artwork and other digitized assets.
- NFTs are currently fueling a lucrative market in exchange of digital assets in virtual reality environments.

14

Impact

- NFTs are becoming popular for creating (allegedly) authenticated ownership of digital assets.
- NFTs will be important in promoting commerce in gaming, virtual reality, and mixed reality environments.

Sustainable Solution/Business Opportunity.

- Current NFTs are based upon computationally intense blockchain technology—non-computation-based blockchains would make this technology less energy-intensive.
- **Enablers:** A growing market of digital assets popularizing NFTs in certain markets, like art; perhaps space- and time-based blockchains could reduce the energy consumption for NFT blockchains.
- **Inhibitors:** Fraud and trustworthiness problems; legal ownership deficits/ uncertain legality—copyright, TM, rights of publicity; energy consumption of current blockchain technologies used for NFTs, security issues in NFT marketplaces, wallets, and with the tokens themselves.

Next-Generation Remote Presence ("Metaverse")

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Incremental progress in existing VR/AR technologies as well as new technologies involving senses beyond audiovisual are driving better and better immersion.

Problems/Demand

- The COVID-19 pandemic and the consequent need for physical distancing are driving demand for immersive remote-presence technologies.
- The increasing globalization of the workforce and the higher connectivity of people across distances are independently also driving this demand.
- This demand could be met with improved VR/AR technologies that help bridge physical distancing.

Opportunities

- Technology to facilitate proximity-based or spontaneous collaboration, substituting for the office environment.
- Technology to facilitate remote learning, substituting for the classroom environment.
- Technology to facilitate effective large-scale meetings, substituting for the conference environment.
- Large increase in recreational and social time spent in the virtual world.

Impact

- Faster transition from "back-to-the-office" to "work-anywhere" mentality.
- More effective social distancing to curb pandemics.
- Reduced travel and carbon footprint.
- Potential loss of privacy expectations from physical meetings.

Sustainable Solution/Business Opportunity

- Mitigation of the productivity hits from the loss of collaborative office work.
- Increased opportunity for a global and diverse workforce ("hire anyone, anywhere").
- **Enablers:** Low-latency immersive VR; enhanced sensory experience (smell, touch, taste); and reliable broadband.
- **Inhibitors:** Decreased personal privacy and freedoms; insufficiently reliable broadband may lead to VR that causes physical harm; inadequate immersion technology or device fatigue getting in the way; and cost to consumers.

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Confidential Computing

Privacy-enhanced and secure computing delivered through a hybrid cloud model

Problems/Demand

- Companies spend trillions per year on cybersecurity for traditional infrastructure, but they are facing new challenges as they move to a hybrid cloud model that spans on-premise and cloud data and compute.
- Cloud service providers have ramped up their “confidential computing” offerings by hardening their traditional infrastructure by a combination of hardware, software, and networking provisions that enforce isolation.
- The demand is growing to extend these secure capabilities to applications that can span across multiple clouds and on-premise environments and implement secure microservices.
- Several countries are advocating “sovereign clouds” to reduce dependence on foreign providers and enforce data governance systems: growing complexity of programming heterogeneous systems delivered in a distributed fashion.
- Software: Complexity of frameworks, applications, and increased adoption of AI.
- Consumables: Increased adoption of programmable devices that require configuration and functional adaptation for use.

Opportunities

- New hardware support for security, from traditional CPU trusted environments, to silicon root-of-trust architectures, to network-based security based on secure data-processing units (DPUs).
- New techniques to implement end-to-end security across multiple public and private clouds, different network overlays, and different data services.
- New tools and methodologies to assess, evaluate, and track security across diverse hybrid multi-cloud environments.

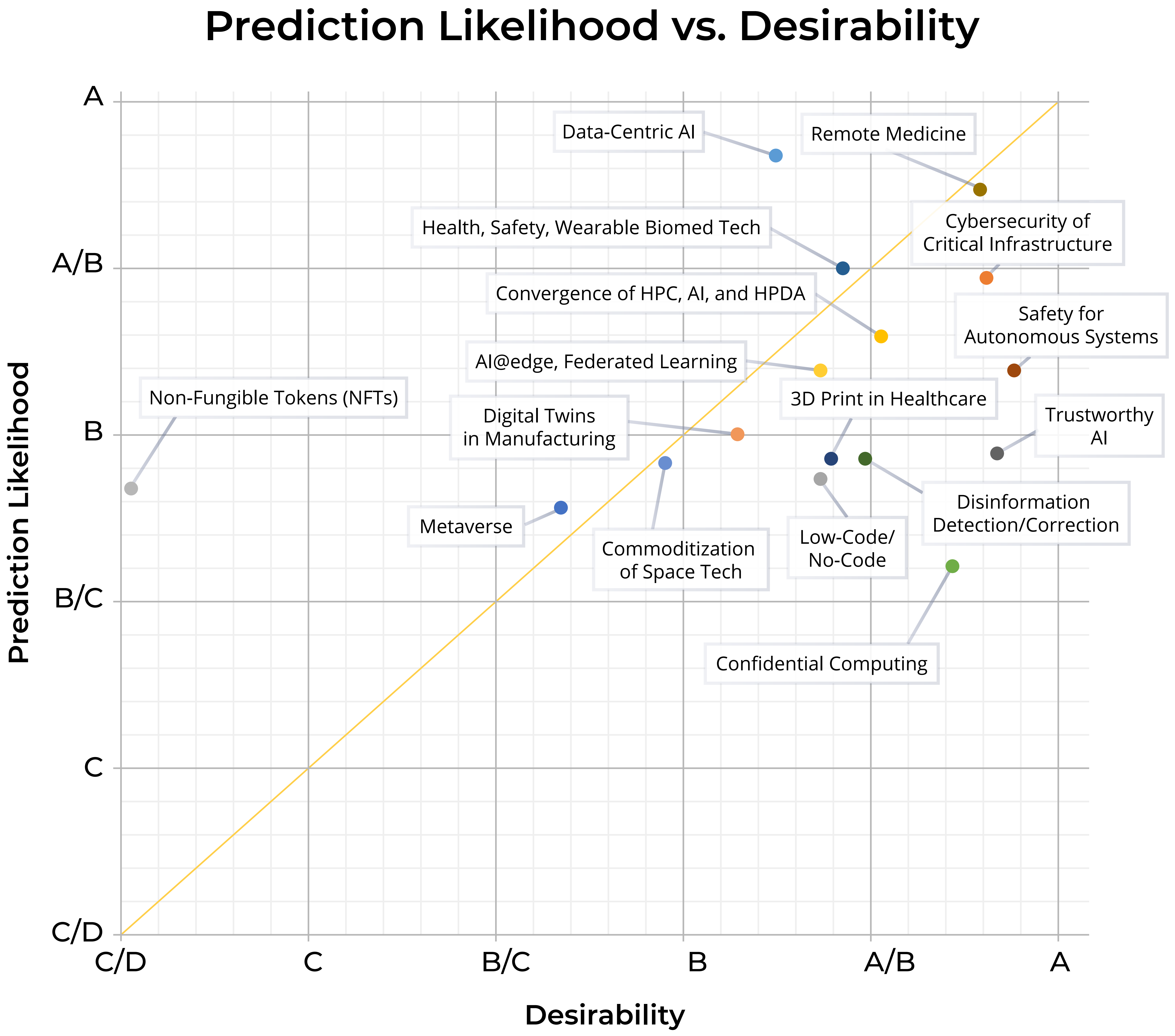
Impact

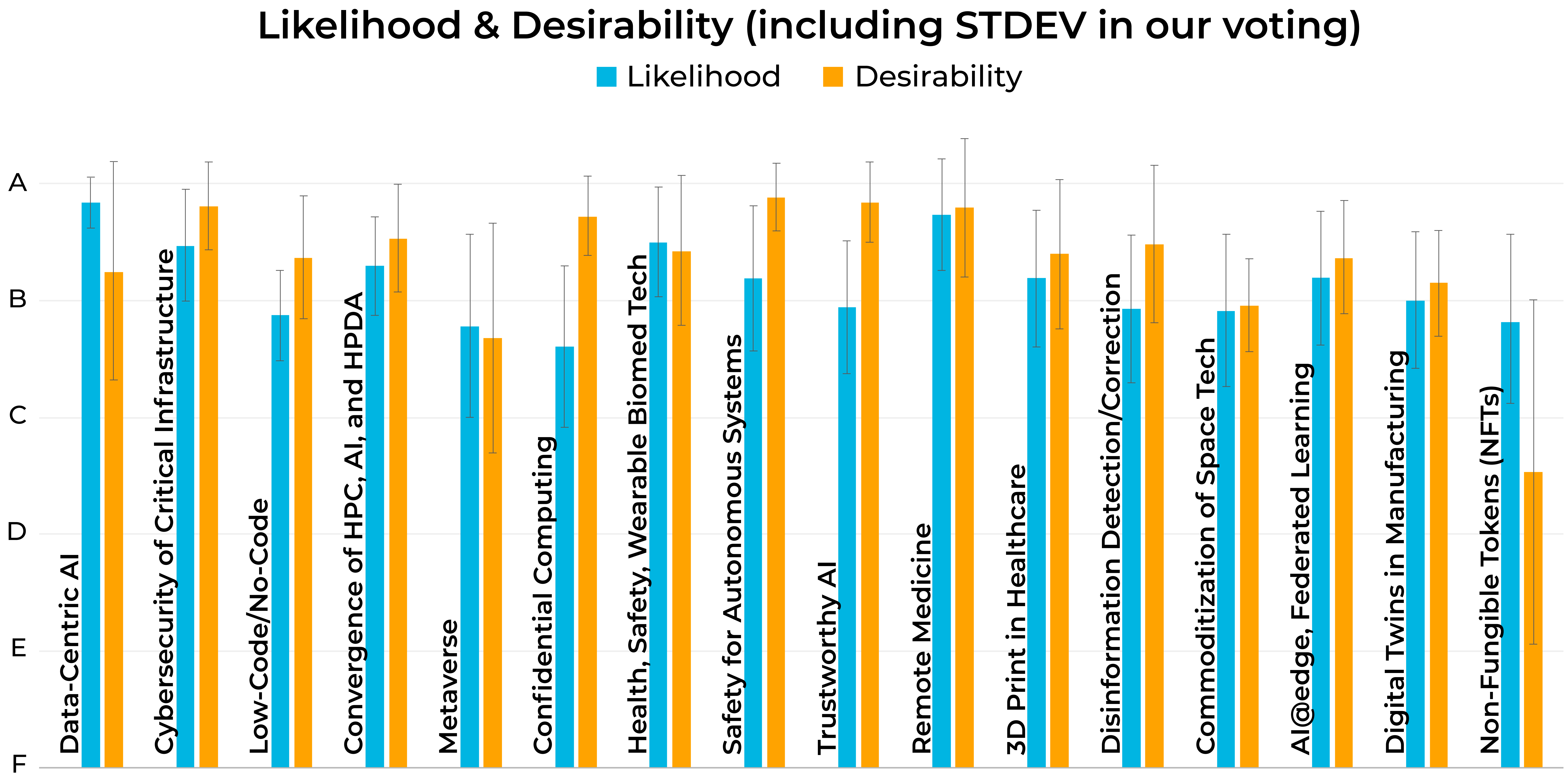
- Lower cybersecurity cost for applications that include cloud components and use cloud services.
- Faster evolution of mission-critical applications to take advantage of the rapid evolution of cloud computing services and practices.
- A secure multi-cloud environment can prevent lock-in and enable a smoother migration across private and public cloud providers.

Sustainable Solution/Business Opportunity

- Confidential computing has broad applicability across many industries including healthcare, finance, IoT, and government. Secure environments enable better data sharing without leaks and improve the collaboration opportunities across organization boundaries.
- **Enablers:** The emergence of strong hardware-based security technology to enforce a stronger VM separation at the compute, networking, and data levels.
- **Inhibitors:** The lack of a standardized way to implement confidential computing. Each cloud provider offers its own incompatible way to do so, and each hardware vendor provides a different mechanism. Fragmentation increases the vulnerability surface and multiplies the development and testing costs to support multiple clouds.

Comparing Predictions




Likelihood & Desirability (including STDEV in our voting)
Likelihood
Desirability
A
B
C
D
E
F
Data-Centric AI
Cybersecurity of Critical Infrastructure
Low-Code/No-Code
Convergence of HPC, AI, and HPDA
Metaverse
Confidential Computing
Health, Safety, Wearable Biomed Tech
Safety for Autonomous Systems
Trustworthy AI
Remote Medicine
3D Print in Healthcare
Disinformation Detection/Correction
Commoditization of Space Tech
AI@edge, Federated Learning
Digital Twins in Manufacturing
Non-Fungible Tokens (NFTs)

SECTION 06

Summary

Outlook

- Technologies will continue to be critical in addressing and preventing pandemics.

Predictions

- We made sixteen predictions in seven areas: core technologies, security, reliability, AI, pandemics and healthcare, industry verticals, and productivity tools.
- We measured our predictions in terms of likelihood and desirability: data-centric AI is the most likely, and remote medicine is the most desirable.
- Most technologies show correlation; they are similarly likely and desirable. However, there are some outliers, such as NFTs, which are much less desirable than likely, and confidential computing, which is much less likely than desirable.

Future Work

- We are exploring how to eliminate possible bias, as demonstrated by substantial correlation between likelihood and desirability.
- We are working to estimate impact through the total addressable markets of the individual technologies as well as their impact through technology readiness level.
- At the end of the year, we will prepare a scorecard on how technologies succeeded against our predictions.

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