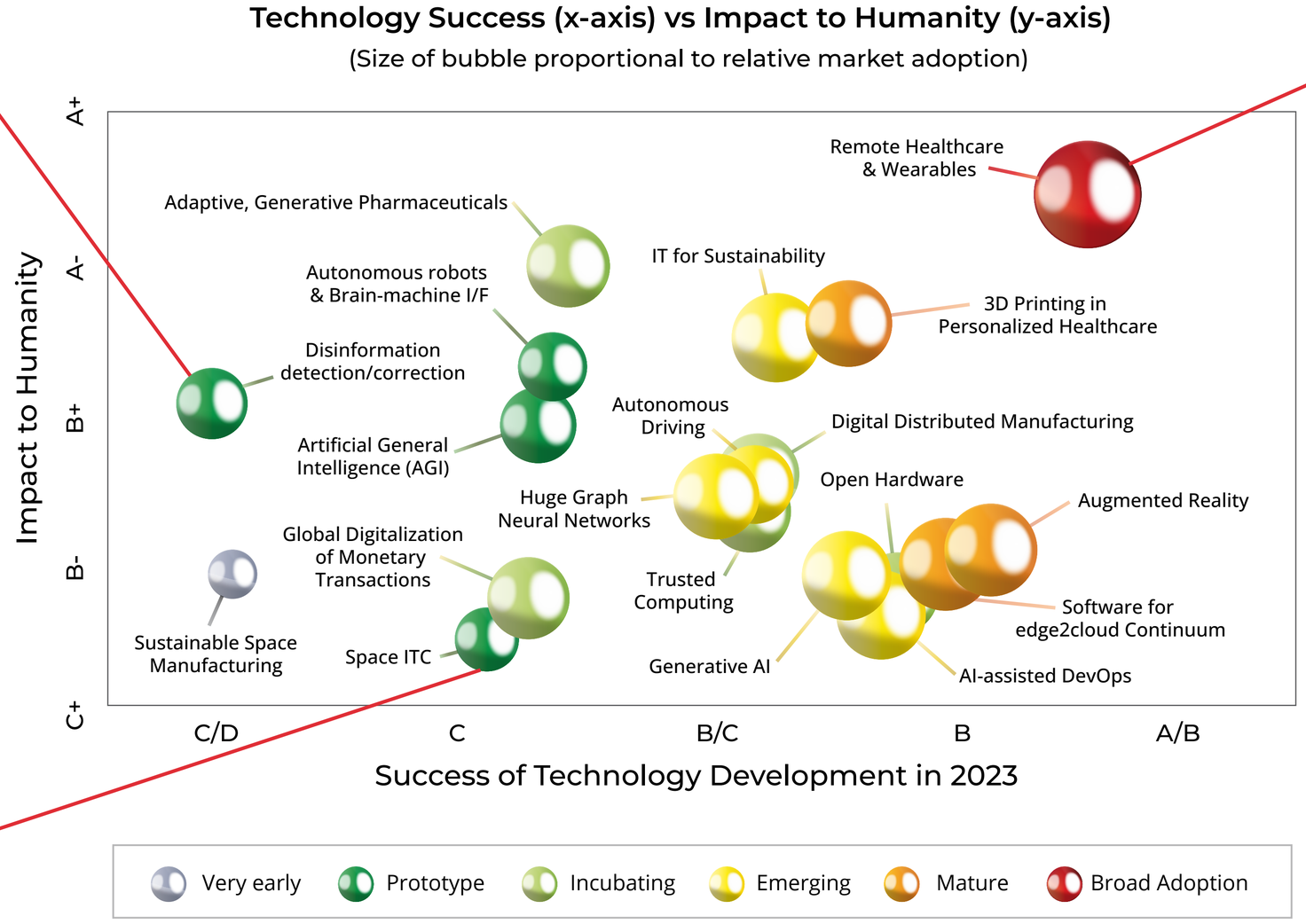
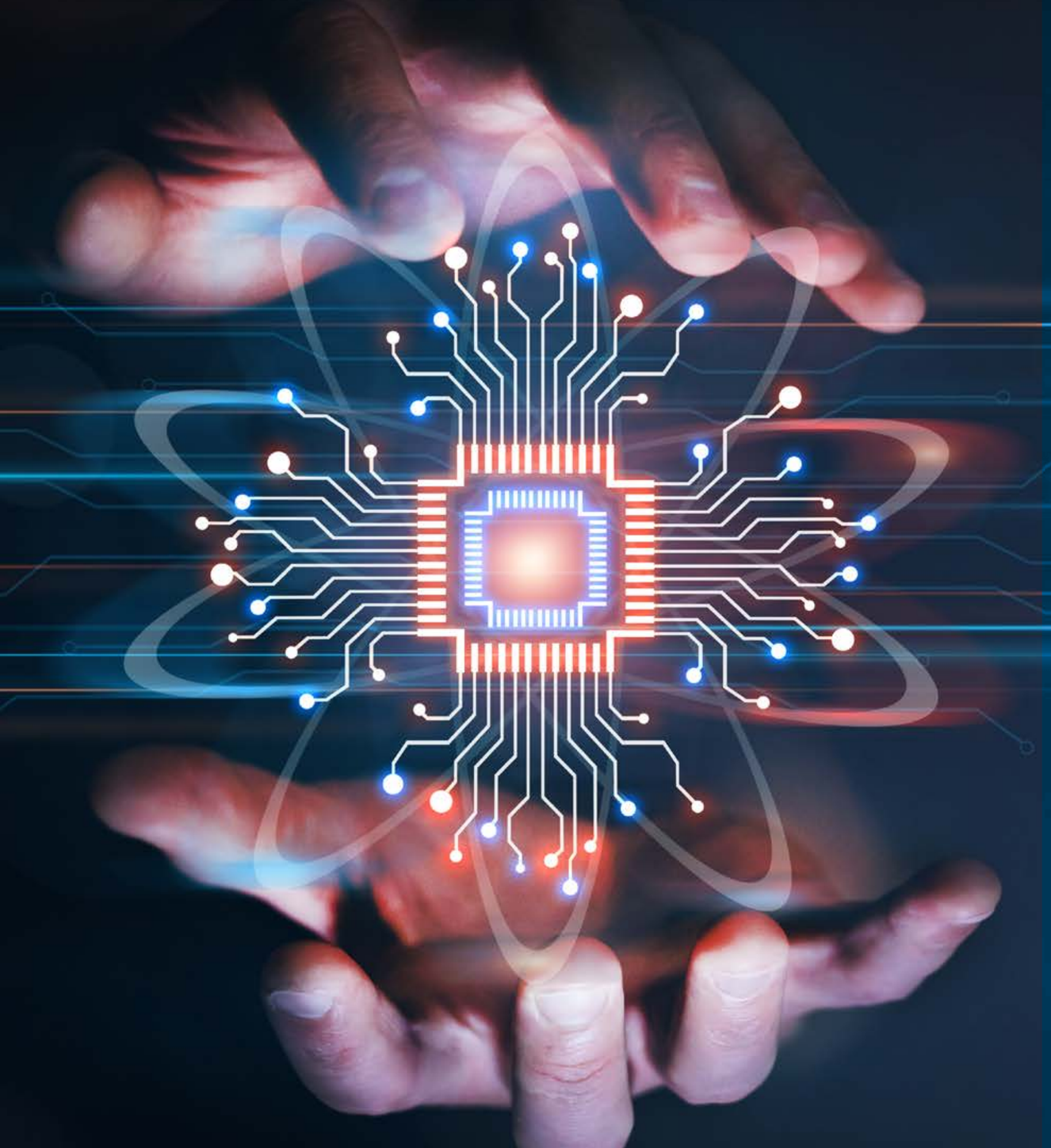
Comparing 2023 Technology Predictions, Clusters

Lowest chance of success

Highest chance of success and largest impact on humanity



Lowest impact on humanity



IEEE COMPUTER SOCIETY

2023 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]

- As of 28 December 2022, 663,666,629 affected (6,692,552 deaths) (https://www.worldometers.info/coronavirus).
- The GDP downturn in 2020 and 2021 (estimated 3–5%) has seen in 2022 a recovery to 2019 levels in the 40 more developed countries. Less developed countries and poor ones are still affected.

Pandemic had impact on human lives, supply chains, work, unpredictability of operations and markets.

Counter-measures: cutting costs, repurposing assets, eliminating middle-men, shift 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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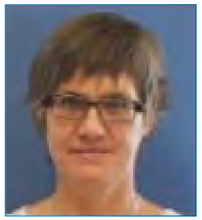

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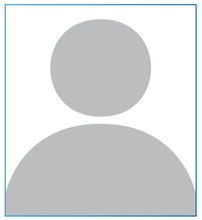

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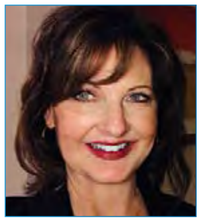

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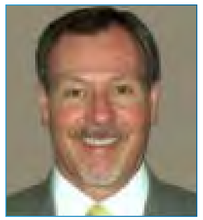

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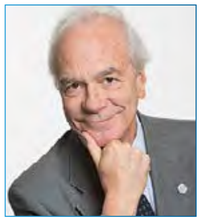

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Note: The statements expressed in this report do not represent the opinions of the authors' employers.

SECTION 03

Process

Continued Improvements Over Previous Years

Selection

- This year we expanded our team from 16 (2022) and 12 (2021) to 35 members, adding perspectives from Middle East and Australia and further expanding insights from Africa, Asia, Europe, and Latin America.
- We also further improved our diversity both in terms of authors and the covered areas.
- Authors made one or more predictions, resulting in 59 predictions; we merged several, leaving us with 30 that we voted upon.
- We then down-selected to 20, by each author giving one of 16 votes to one technology.
- We then did another careful merging of some proposals and ended up with 19.

Grading:
In the second round we graded each technology

- (A-F) for: a) Predicted Technology Success in 2023; b) (Potential for) Impact to Humanity; c) Predicted Maturity in 2023; d) Predicted Market Adoption in 2023.
- (1 year, 3y, 5y, 10y, 15y) for Horizon to Commercial Adoption.
- Intent was to present impact to humanity as a function of technology advancement, also qualifying those by relative maturity, market adoption, and positioning in time-to-adoption.
- We also calculated a) our confidence as standard deviation in voting; and b) bias as a correlation between individual grades.
- Finally, we did final tweaking and optimizing until the last moment, with the end customer (you the reader ☺) on our mind as a priority.

Qualifying

- For each of the 19 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

Sorted by Likelihood of Success

1. **Remote Healthcare & Wearables (B+):** Remote healthcare with advanced wearables will enable patients to obtain remote medical assistance, physicians to perform procedures and consult with remote experts, and both to have access to vital health information.
2. **Augmented Reality (B):** Seamless integration between the real world and cyberspace will increasingly materialize.
3. **Software for Edge2Cloud Continuum (B):** New software for the development and deployment of next-generation computing components, systems, and platforms that enable a transition to a compute continuum with strong capacities at the edge and far edge in an energy-efficient and trustworthy manner.
4. **Open Hardware (B):** From open systems (OCP) to ISAs (RISC-V) and interconnects (CXL, UCIe) the open-source movement has expanded into hardware.
5. **AI-Assisted DevOps (B):** The traditional DevOps approach will be improved to address the increasing complexity of software systems.
6. **3D Printing in Personalized Healthcare (B-):** 3D printing in healthcare will evolve toward customized additive manufacturing for individuals.
7. **Generative AI (B-):** In the next few years, generative AI will be used even more, increasing effectiveness and enabling new services. It is also bound to raise ethical and societal issues. Expect strong impact on business (short term), on education (long term) and on society (medium to long term).
8. **IT for Sustainability (B-):** Technology will evolve from sustainable IT to novel uses of IT for sustainability, clean energy, and a green economy.
9. **Autonomous Driving (B/C):** Self-driving vehicles in controlled environments are starting to gain adoption at scale, backed by strong business cases.
10. **Digital Distributed Manufacturing (B/C):** Digital Distributed Manufacturing will reduce the energy and environmental footprint and increase the resilience of supply chains.
11. **Trusted Computing (B/C):** There will be increased public awareness and attention to trusted/assured computation across all industry sectors. Governments will increase focus on legislative actions to ensure that public facing systems can be trusted.
12. **Huge Graph Neural Networks (B/C):** Applications that use huge models, such as chatGPT, have demonstrated a real impact on a substantial set of problems. Graph Neural Networks can represent complex, “real-world” structures. We predict that huge GNN models will widely be used in machine learning.
13. **Adaptive, Generative Pharmaceuticals (C+):** Advances in nanotechnology and AI could shorten the time to vaccine development and broaden their efficacy.
14. **Autonomous Robots & Brain-machine I/F (C+):** Pervasive uptake of robotic platforms will take place, including as extensions of the human body.
15. **Artificial General Intelligence (AGI) (C+):** Advances in AI will lead to AGI systems that can understand or learn any intellectual task that a human being can perform.
16. **Global Digitalization of Monetary Transactions (C+):** Digital transformation of monetary transactions will open new disruptive opportunities in global markets.
17. **Space ITC (C):** As more companies send technology to space, the barriers to entry are decreasing rapidly.
18. **Sustainable Space Manufacturing (C/D):** Space manufacturing and recycling technologies and services will improve sustainability, resilience, and cost of the space ecosystem.
19. **Disinformation Detection/Correction (C/D):** Improving the reliability of information in public health, politics, and science will improve public information required for sound decisions from personal to societal levels.

Predicted Technologies

Financial

Manufacturing

Industry Verticals

Healthcare

Robotics

- Global Digitalization of Monetary Transactions
- Digital Distributed Manufacturing
- Sustainable Manufacturing in Space
- Remote Healthcare & Wearables
- Adaptive, Generative Pharmaceuticals
- 3D Printing in Personalized Healthcare
- Autonomous Driving
- Autonomous robots & Brain-machine I/F

Productivity Tools

- AI-assisted DevOps
- Augmented Reality

AI

- Artificial General Intelligence (AGI)
- Generative AI
- Graph Neural Networks

Security

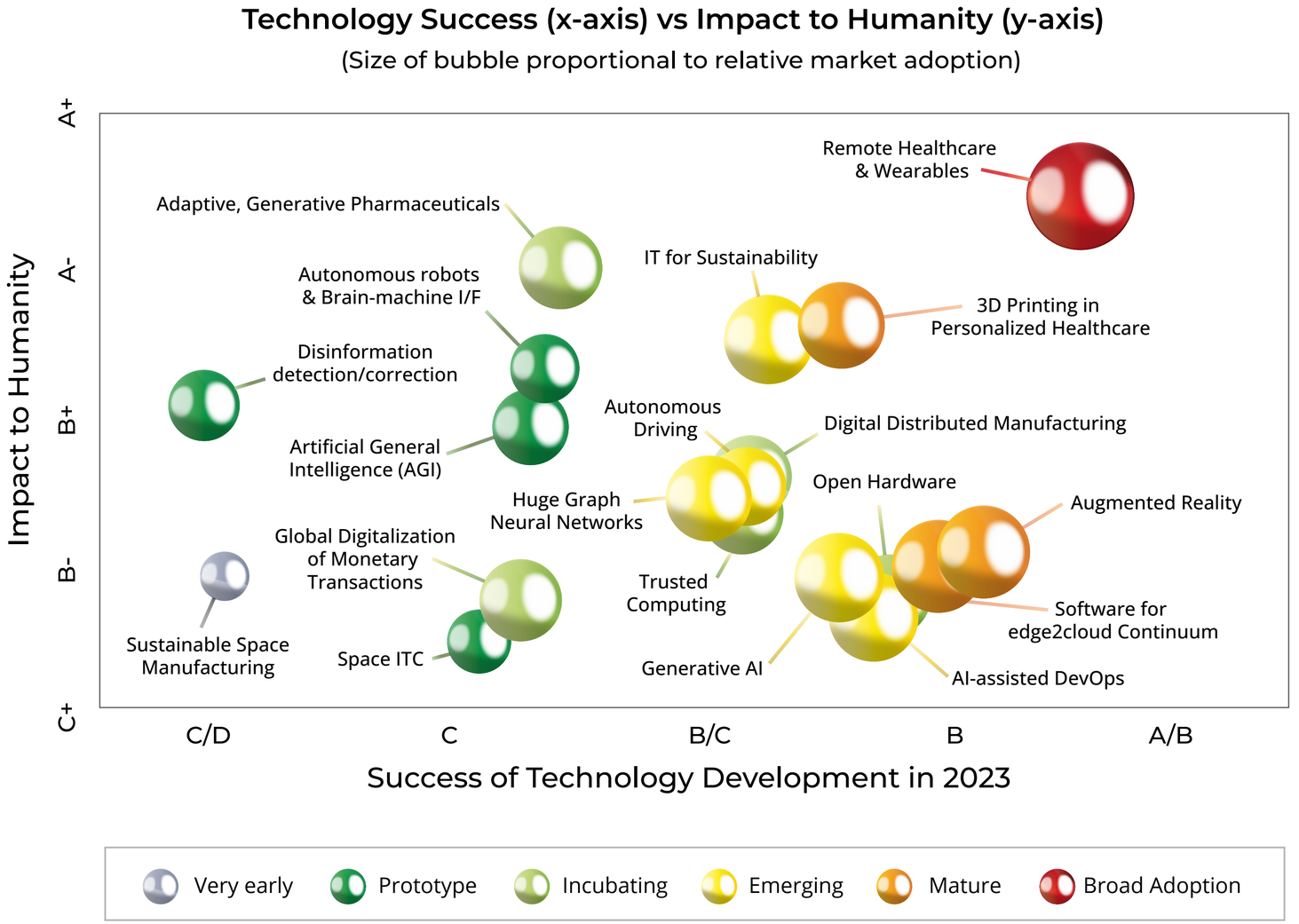
- Trusted Computing
- Disinformation detection & correction

Core Technologies

- Open Hardware
- IT for Sustainability
- Space ITC
- Software for the Edge-to-cloud continuum

Comparing Predictions

Comparing 2023 Technology Predictions, Four Ways

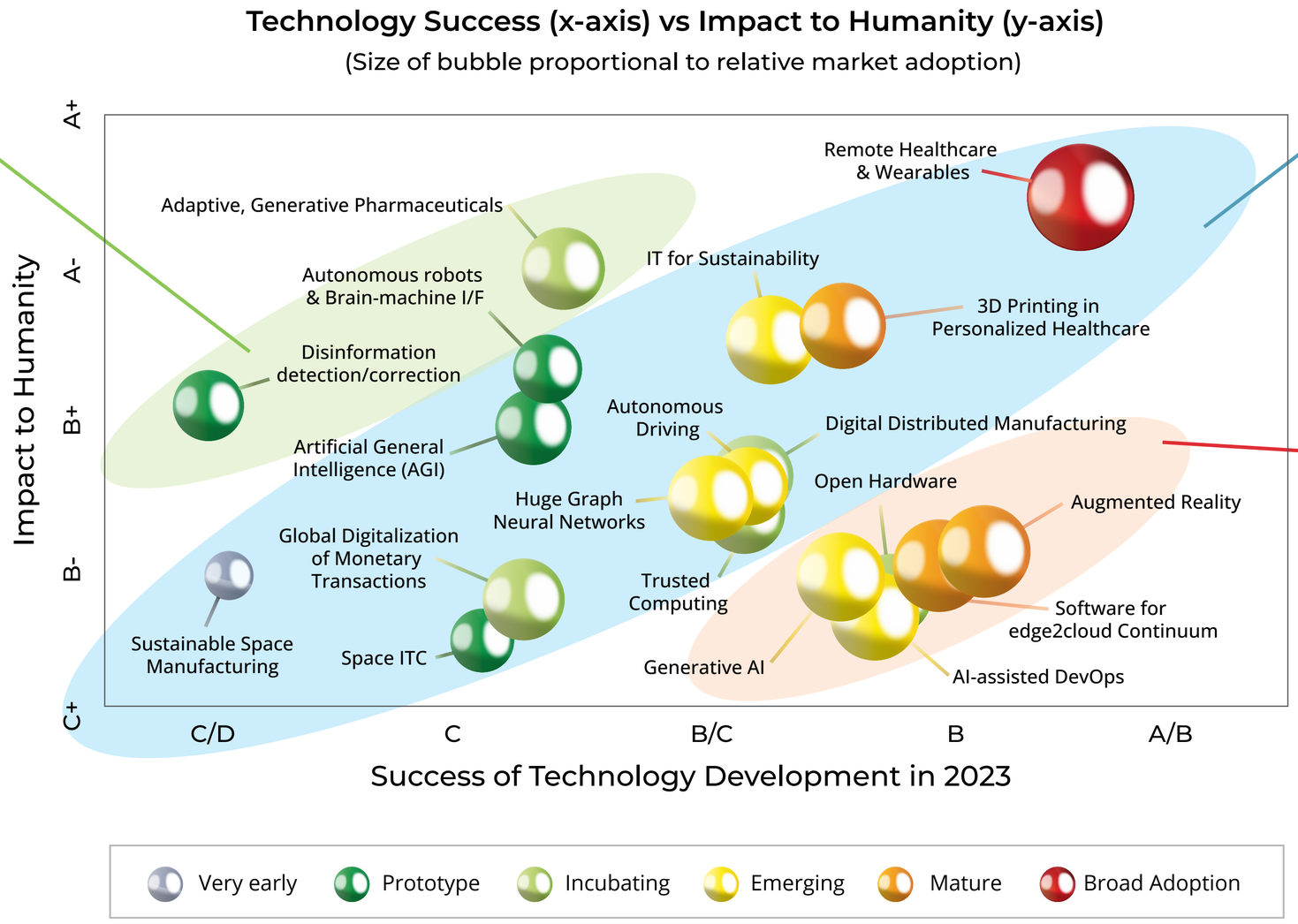


Comparing 2023 Technology Predictions, Clusters

Impact on humanity higher than chance of success (worth investing in)

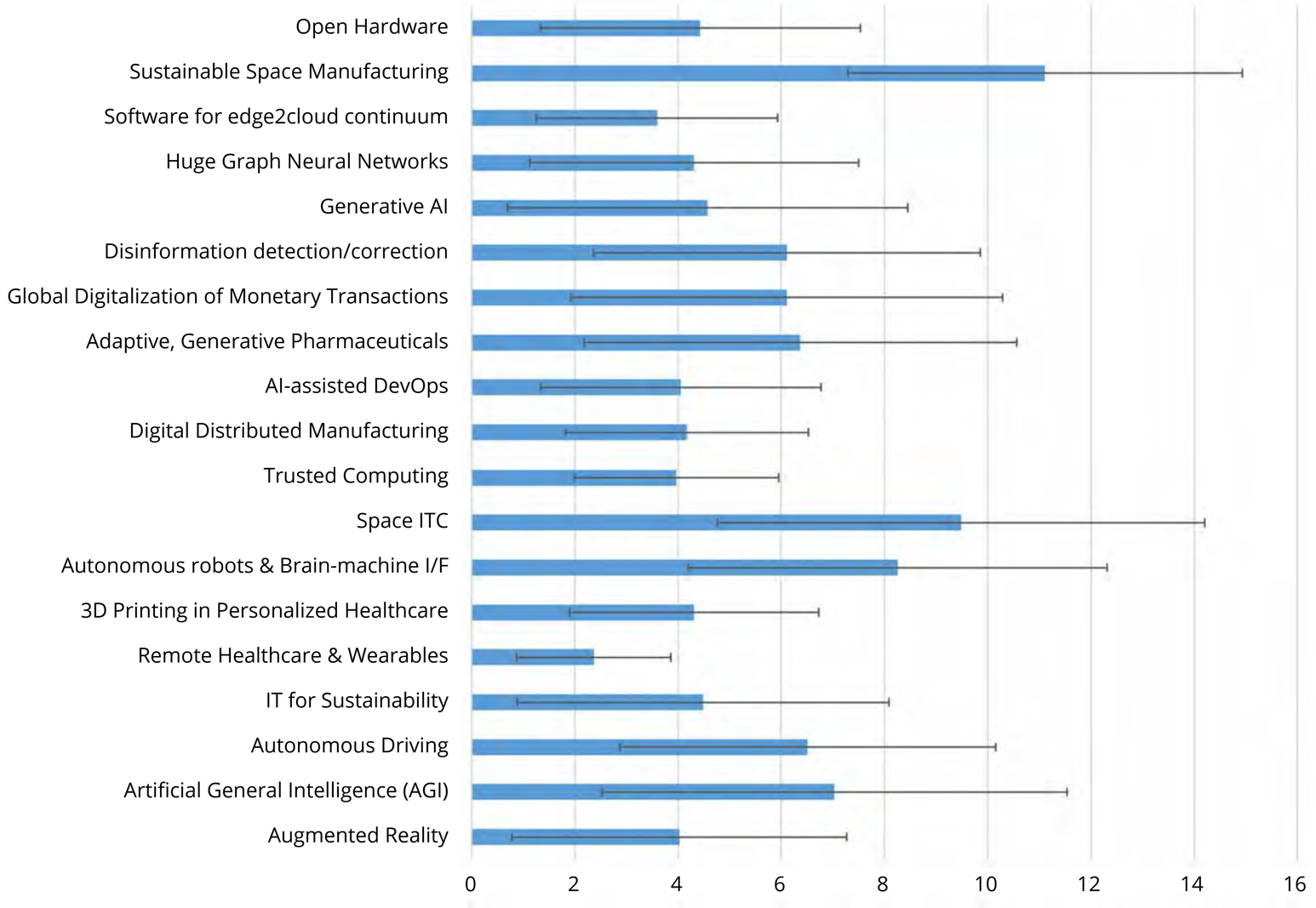
Chance of success correlates to impact on humanity

Chance of success higher than impact on humanity



SECTION 05: COMPARING PREDICTIONS

Horizon to Commercial Adoption (in Years)



Technology Predictions, Comparison

Technology	Success in 2023		Impact to Humanity		Maturity in 2023		Market Adoption in 2023		Horizon to Commercial Adoption	
	rank	grade	rank	grade	rank	grade	rank	grade	rank	#years
Augmented Reality	2	B	12	B-	2	B-	3	B-	4	4.03
Artificial General Intelligence	15	C+	7	B+	16	C-	15	C	16	7.03
Autonomous Driving	9	B/C	8	B	13	C+	14	C+	15	6.51
IT for Sustainability	8	B-	4	A/B	5	B/C	4	B/C	10	4.49
Remote Healthcare & Wearables	1	B+	1	A	1	B	1	B+	1	2.37
3D Printing in Personalized Healthcare	6	B-	3	A/B	3	B/C	8	B/C	7	4.31
Autonomous robots & Brain-machine I/F	14	C+	5	A/B	15	C-	17	C-	17	8.26
Space ITC	17	C	19	B/C	17	C-	18	C/D	18	9.49
Trusted Computing	11	B/C	11	B	11	C+	7	B/C	3	3.97
Digital Distributed Manufacturing	10	B/C	9	B	8	B/C	11	C+	6	4.17
AI-assisted DevOps	5	B	18	B/C	7	B/C	6	B/C	5	4.06
Adaptive, Generative Pharmaceuticals	13	C+	2	A-	14	C	13	C+	14	6.37
Global Digitalization of Monetary Transactions	16	C+	17	B/C	10	C+	12	C+	12	6.11
Disinformation detection/correction	19	C/D	6	B+	18	C-	16	C	12	6.11
Generative AI	6	B-	14	B-	6	B/C	5	B/C	11	4.57
Huge Graph Neural Networks	12	B/C	10	B	9	B/C	10	C+	7	4.31
Software for edge2cloud continuum	3	B	13	B-	3	B/C	2	B-	2	3.60
Space Manufacturing	18	C/D	14	B-	19	D+	19	D	19	11.11
Open Hardware	4	B	16	B/C	12	C+	9	B/C	9	4.43

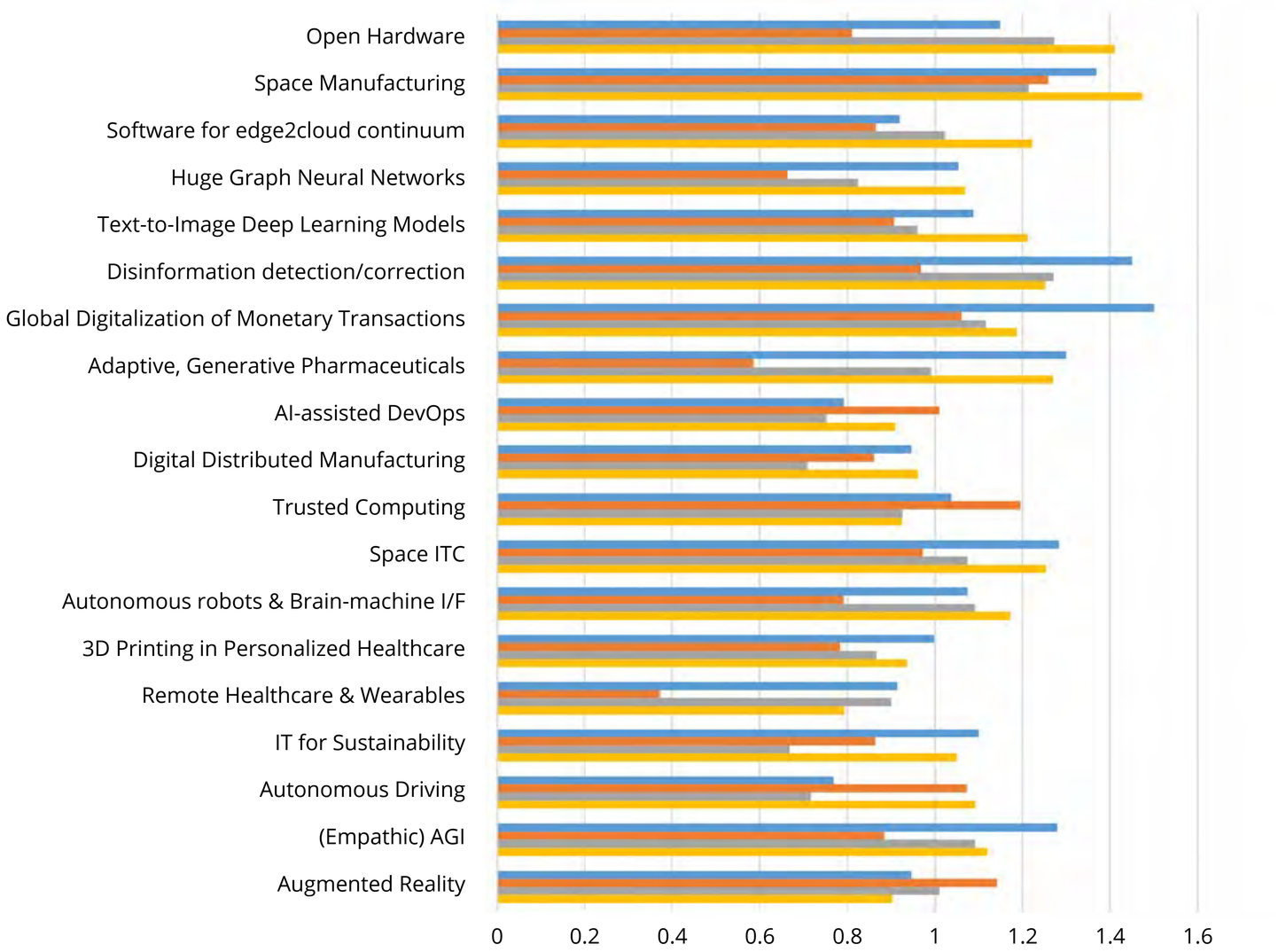
Correlation and Average & Range (across Technologies)

	Success in 2023	Impact to Humanity	Maturity in 2023	Market Adoption in 2023
Success in 2023	1	0.08944	0.91997	0.87544
Impact to Humanity	0.0894	1	0.1306	0.2776
Maturity in 2023	0.92	0.1306	1	0.94076
Market Adoption in 2023	0.8754	0.2776	0.9408	1

Success in 2023		Impact to Humanity		Maturity in 2023		Market Adoption in 2023		Horizon to Commercial Adoption (#years)	
Average	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**
B/C	[B+, C/D]	B	[A, B/C]	C+	[B,D+]	C+	[B+, D]	5.54	[2.4-11.1]

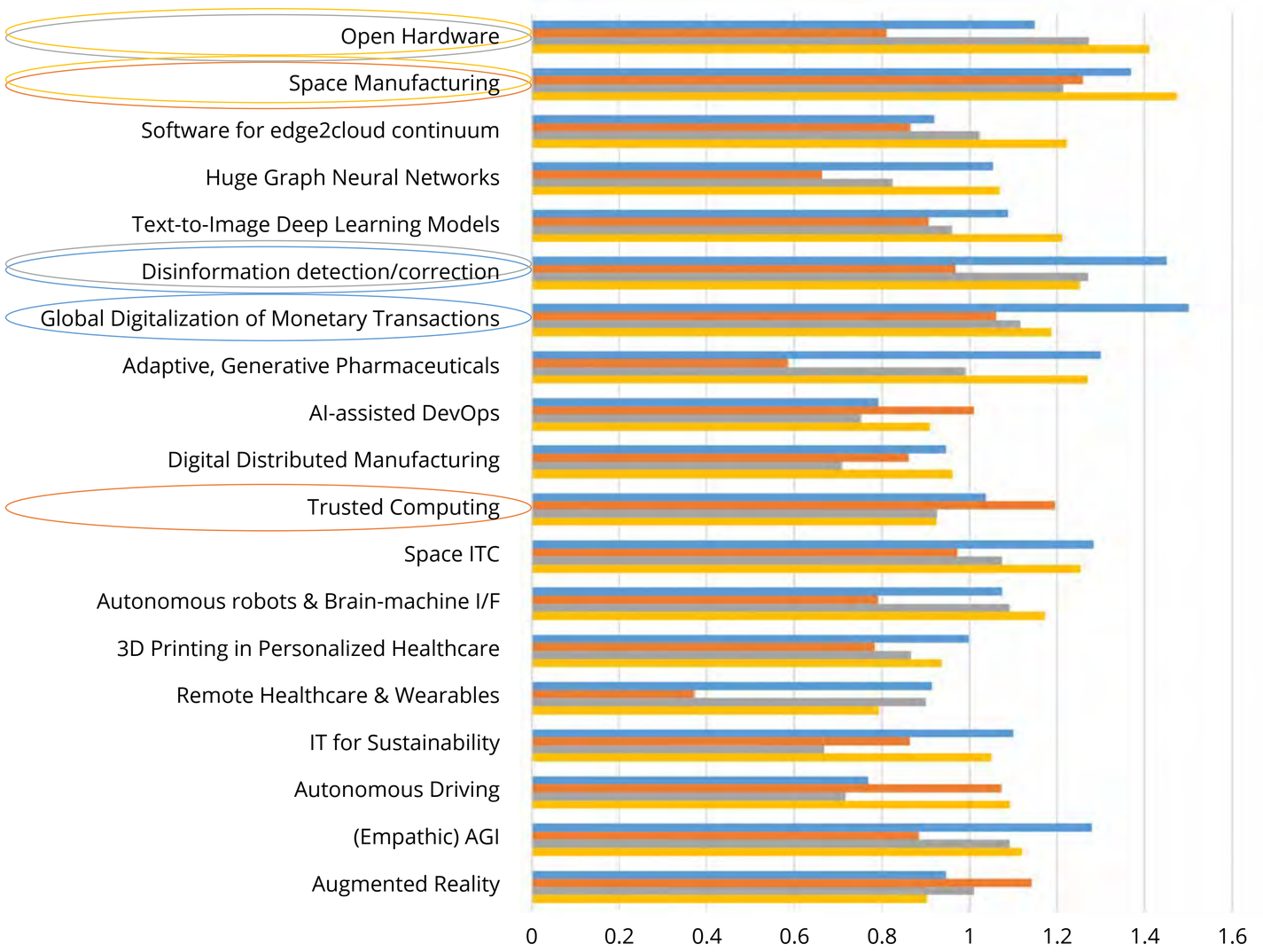
SECTION 05: COMPARING PREDICTIONS

Standard Deviation



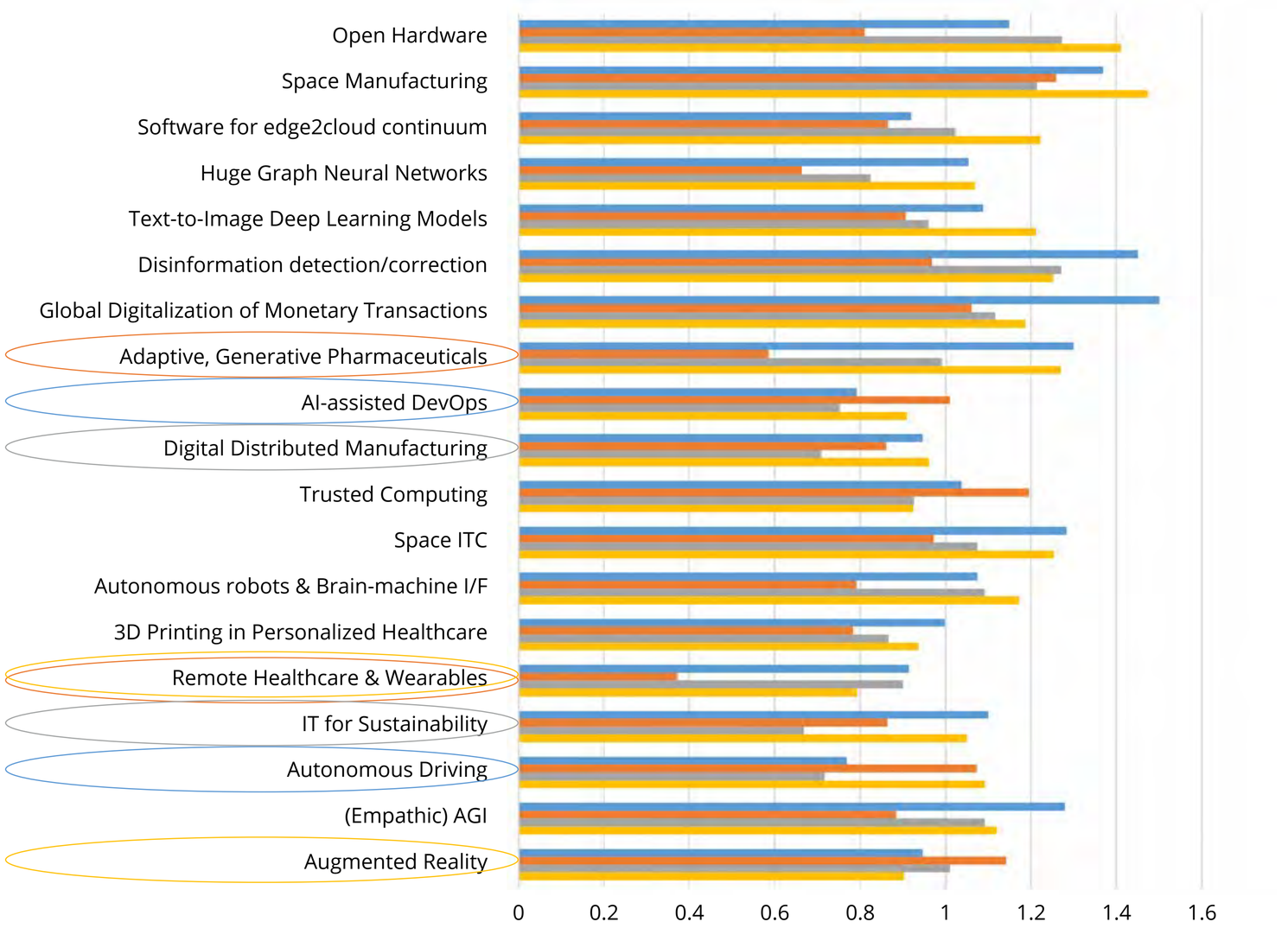
SECTION 05: COMPARING PREDICTIONS

Standard Deviation, Largest (Least Confidence)

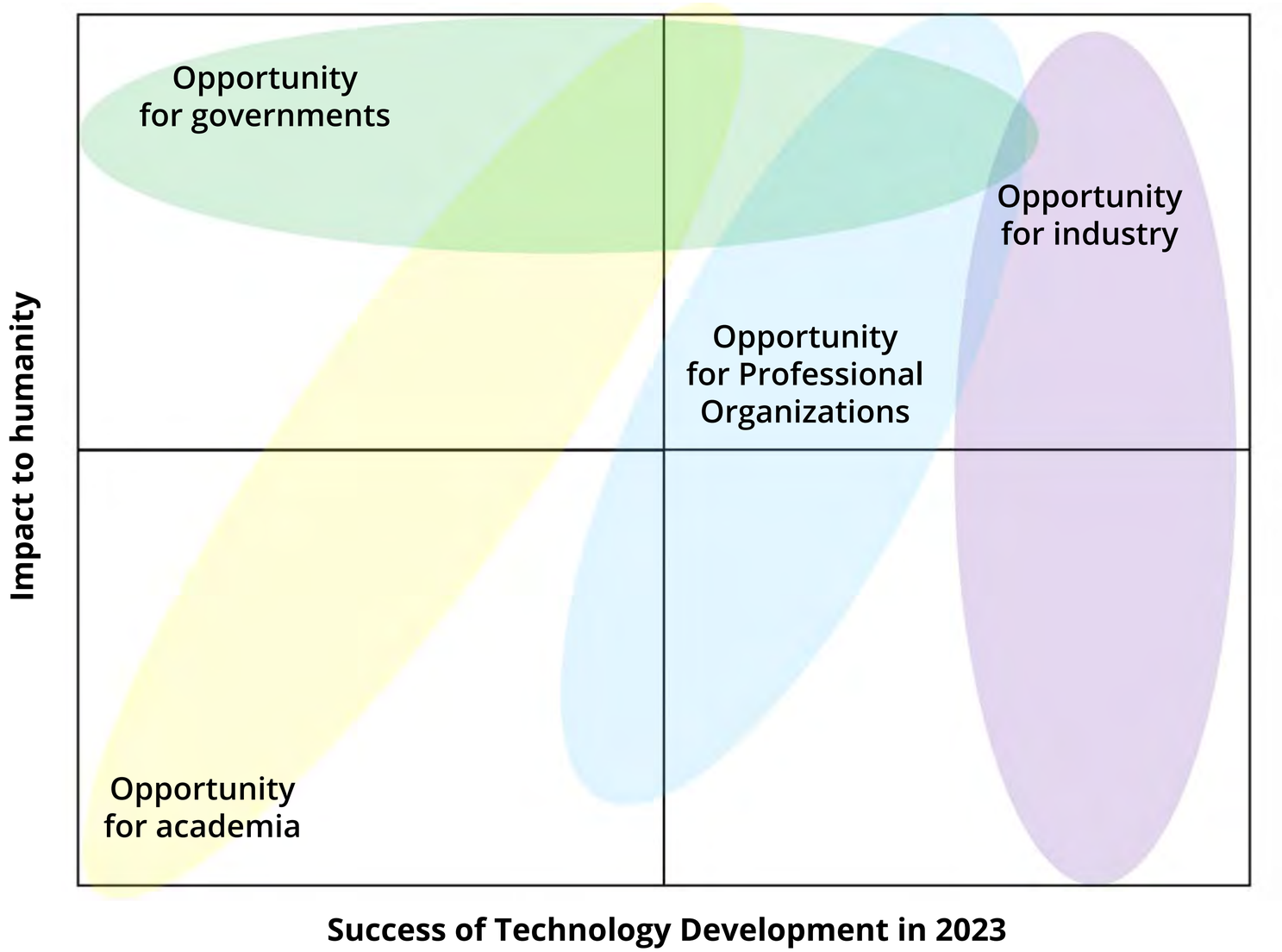


SECTION 05: COMPARING PREDICTIONS

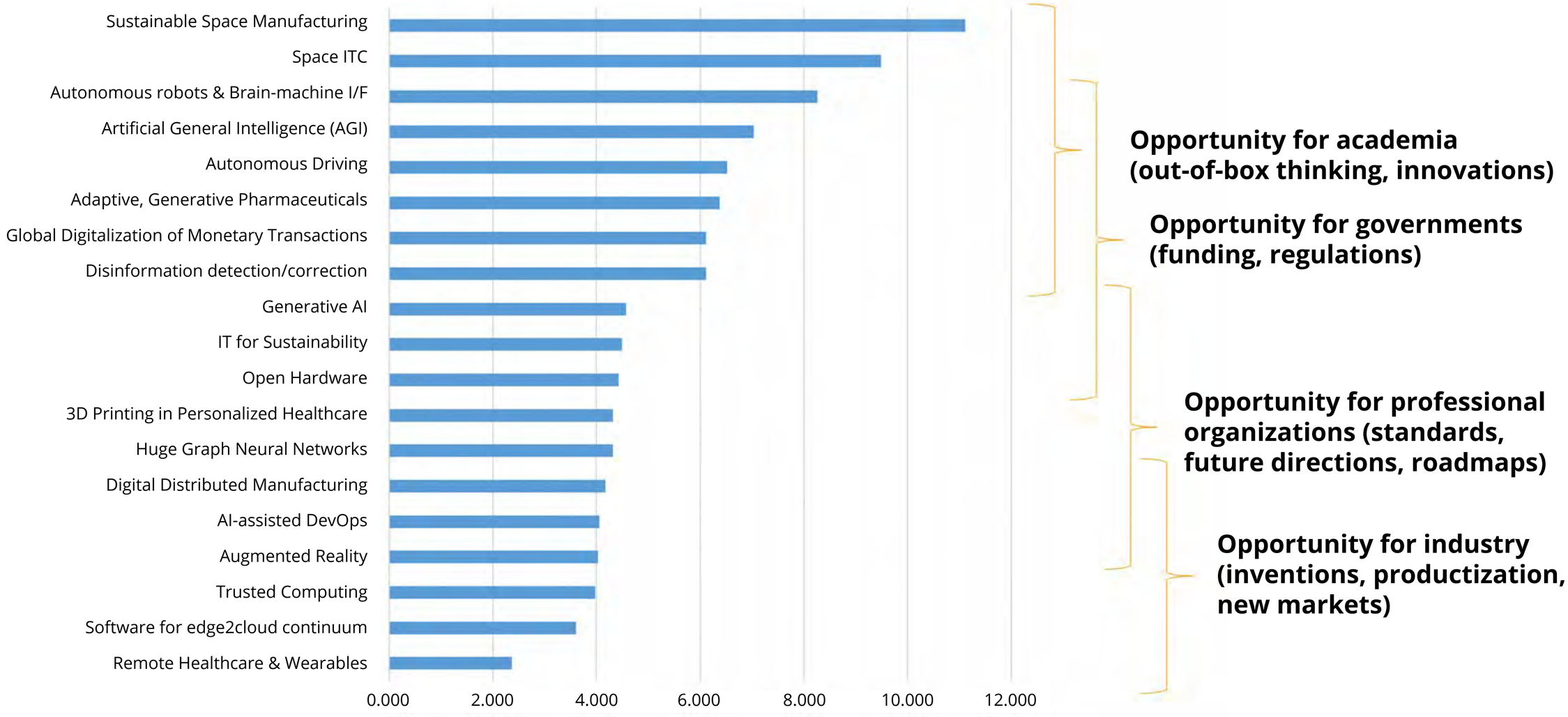
Standard Deviation, Smallest (Most Confidence)



How to Use Results, Technology-to-Humanity Quadrants



How to Use Results, Horizons to Commercial Adoption



SECTION 06

Insights and Opportunities

- Clear predicted success is Remote Healthcare & Wearables (in terms of technology advance **and** impact to humanity).
- Business opportunities are a are cluster of technologies which will likely succeed (augmented reality, software for edge to Cloud, etc.)
- Concerns are technologies with large impact to humanity but less chances for technological success (disinformation detection, adaptive generative pharmaceuticals).
- Long-term opportunities are space technologies and global monetization.
- “AI will eat the world” (Mark Andreessen paraphrase). Almost all of the technologies benefit from or crucially rely on advances in AI.
  - Without AI, there’s much less (in these areas).
  - We’re also predicting advances in AI proper, which feeds back into the loop, accelerating all the other technologies.
  - This suggests that nearly all the slides could have an enabler and inhibitor in the form of “advances in AI”.
- Fear, Uncertainty and Doubt (FUD, all forms of mistrust).
  - The world is unfortunately ruled by FUD.
  - FUD can be countered by technologies–directly (trusted computing, disinformation), or indirectly (AI-related, Openness).
- Opportunities for industry
  - Health industry (remote, wearables, custom 3D printing)
  - Augmented reality
  - IT for sustainability
  - Open hardware
- Opportunities for governments
  - Regulate: Disinformation detection, generative pharmaceuticals
  - Fund: Space technologies
- Opportunities for academia
  - Space technologies (ITC, manufacturing, recycling)
- Opportunities for professional organizations
- AI-related, Sustainability, Space

SECTION 07

Summary

Outlook

- Technologies will continue to be critical in addressing and preventing pandemics, wars, and natural disasters.

Predictions

- We made nineteen predictions in four areas (core technologies, security, AI, productivity tools) and four industry verticals (healthcare, robotics, manufacturing, and financial).
- We graded our predictions in terms of likelihood of technology success, impact to humanity, maturity in 2023, market adoption in 2023, and horizon to commercial adoption.
- Predicted technologies show a degree of correlation, but with a more diverse roster this year we experienced less correlation.

Future Work

- We continue to eliminate bias, as demonstrated by correlation and standard deviation.
- We are exploring collaboration with market analysts to include the total addressable markets of technologies.
- In the future, we plan to devise recommendations to industry as a function of our predictions.
- At the end of the year, we will prepare a scorecard on how technologies succeeded against our predictions.

Remote Healthcare & Wearables

Remote healthcare and advanced wearables will enable patients to obtain remote medical assistance, physicians to perform procedures and consult with remote experts, and both to have access to vital health information.

01

Problems/Demand

- COVID-19 made remote medicine more attractive (e.g., many people worried about being exposed to other patients and 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 helps close such a gap.
- Demand for wearable technologies is growing in response to increasing healthcare costs, aging populations, and the burden of chronic disease.
- AI, ML and big data analytics in cost-efficient, power-efficient electronics and software enable the usefulness of sensor data.

Opportunities

- Increasing availability of faster communications enables extensive use of video conferencing, remote MRI, remote sensors, etc.
- Cloud computing allows small medical centers to perform computations that require vast compute power.
- Government and insurance company R&D investments will help advance sensors, research, and remote medical infrastructure.
- New classes of machine learning algorithms allow physicians to be more efficient and serve more patients.
- Connectivity improvements, additional type/scope of sensors and further miniaturization to reduce cost and expand usefulness.

Impact

- Broader access to customized solutions and medical assistance
- Technologies that have been developed for COVID-19 will be useful for treating other diseases.

Sustainable Solution/Business Opportunity

- Integration of wireless charging, energy harvesting, make-on-demand sensors, real-time data analytics.
- Improved reliability and accuracy of sensor data & information analytics.
- Expansion of the application & use of wearable technology.
- The unfortunate likelihood of continuing and future global health crises.
- **Enablers:** Data bandwidth, storage, and access; new ML algorithms and new accelerators to perform sophisticated computations, including at the edge; electronics miniaturization, battery efficiency, advanced sensors, microfluidics, advances in commercial IoT market.
- **Inhibitors:** Cost, the need for explainable ML algorithms, health insurance models/ infrastructure, regulatory requirements (e.g., HIPAA, pre-market approval, biocompatibility testing), data privacy & categorization, parts obsolescence / life-cycle, data processing.

Augmented Reality

Seamless integration between the real world and cyberspace will increasingly materialize.

Problems/Demand

- Hybrid reality bringing together real and virtual reality.
- Renewed post COVID-19 and due to 5G (leading to 6G, 2030).
- Augment knowledge, capability, options, experiences.

Opportunities

- Inclusivity (differently-abled, geographic, cultural, etc.).
- Changing the world of work.
- Augment reality with data, multiple input, simulations, etc.
- Events and Entertainment (conferencing, gaming, movies, tours, art exhibitions, gambling, etc.).
- Education (broader access, broader exposure to ideas).
- Wellness (interactive gym, mental wellbeing, etc.).
- Healthcare (robotic surgeries, remote consultations...).
- Social (metaverse).
- Retail, sports, real estate and architecture, tourism.

Impact

- Redefining the future world of work, entertainment, etc.
- Innovation and Inclusion through a hybrid world.

Sustainable Solution/Business Opportunity

- Low-cost headsets/hardware.
- Education.
- Miniaturization.
- **Enablers:** Mind-set post COVID-19, 5G, reduced bandwidth (relative to VR), youth population in emerging economies.
- **Inhibitors:** Mind-set (both enabler and inhibitor), digital inequality, lack of standardization, cost of firmware development/maintenance (initial investment or technology adoption —ahead of time), privacy and other legislation/regulatory framework (particularly in a transnational world), data validity (what is accurate, truthful, best), health concerns.

Software for Edge2Cloud Continuum

03

New software for the development and deployment of next-generation computing components, systems, and platforms that enable a transition to a compute continuum with strong capacities at the edge and far edge in an energy-efficient and trustworthy manner.

Problems/Demand

- Recent developments in sensor networks, cyber-physical systems, and the ubiquity of the Internet of Things (IoT), connected to centralized resources such as commercial clouds and HPC centers.
- Development and deployment of the next generation computing components, systems and platforms that enable this transition to a compute continuum with strong capacities at the edge and far edge in an energy efficient and trustworthy manner.
- The logistic of wide-area, multistage workflows that move back and forth across the computing continuum.
- Need for new basic software (operating systems), programming models and tools to support this new infrastructure.

Opportunities

- Processing the data where is produced (sensors, instruments).
- Low latency operations, resilient, privacy-preserving (data processed at edge and not transmitted).
- Support for federated learning.
- New ways of computing (swarm approach).
- Democratization of compute, and distributed data processing and AI.
- Seamless management to allow services and data to be processed across various providers, connectivity types, and network zones.
- Migratory computing (moving compute to appropriate resources to meet processing demands).

Impact

- Reduction of required network bandwidth and enlarging processing capabilities.
- Reduction of power required to transfer data.
- Maximized social and economic benefits from the wider and more effective use of data.
- Different business model (compared to traditional centralized one).
- No loss of science! (ability to capture the most important observations/events).

Sustainable Solution/Business Opportunity

- Distributed systems with more efficient data processing.
- New meta-operating systems that orchestrate the distributed set of resources.
- **Enablers:** Maturity and vast adoption of IoT and edge devices, need for hyper-distributed applications, new methodologies for distributed AI.
- **Inhibitors:** Cloud providers interested on keeping centralized solutions.

Open Hardware

04

From open systems (OCP) to ISAs (RISC-V) and interconnects (CXL, UCIe) the open-source movement will expand into hardware.

Problems/Demand

- The last decade has seen a constant shift from proprietary hardware systems to open ecosystems, following a similar path of open-source software.
- Starting from system-level specs (OCP), we have seen emergence of open ISAs (RISC-V), and interconnects (component-level, CXL and chip-to-chip, UCIe).
- Open hardware standards allow for better interoperation among different blocks, and open up software innovation, and democratize hardware access.

Opportunities

- Open standards allow for fair competition among the different players on the hardware and chip market.
- Open ISA extensions allow to target specific needs and create domain-specific hardware to increase performance at slowing process improvements.
- More freedom in the design of chips and systems.

Impact

- Allows a strategic industry (processors and hardware systems) to be less dominated by few players.
- Broaden access to hardware to smaller universities and boosts education opportunities without massive funding.
- Open standards enable and boost software innovations.

Sustainable Solution/Business Opportunity

- An enormous opportunity for the whole digital industry from processor design, to SoCs, systems, and software development (operating systems and middleware).
- **Enablers:** RISC-V and the several organizations behind it, open interconnect standards (CXL and UCIe), institutional and government funding initiatives.
- **Inhibitors:** Compatibility with existing standards and ISAs, dependence on proprietary tools (e.g., CAD, EDA), still need massive investments to build hardware.

05

AI-assisted DevOps

The traditional DevOps approach will be improved to address the increasing complexity of software systems.

Problems/Demand

- Increasing complexity of datacenter hardware technologies and software stacks presents exponential explosion of the configuration management space, leading to errors and upgrade delays, impacting downtime, and operational costs.
- As the software systems became more complex, the support process to help the developers needs improvements.
- The adoption of microservices helped on the development of individual services, but there is a lack of support for the interaction and evolution among them (maybe too specific).

Opportunities

- AI tools/models shown effective for the types of detection and recommendation problems.
- The problem space can leverage advances in AI technologies targeting a broad consumer space (speech, visual, etc. assistance).
- Provide better hints to the developers on how to improve and deploy software.
- Shorten the cycle between bug finding and its correction
- Help understanding possible software architecture issues.

Impact

- Impact on curtailing operational costs, time to adoption of new technologies in production systems.
- Impact on improved operating efficiency and error/ downtime reduction.
- Provide better support for software development in an holistic way based on the enormous base of free software already available.

Sustainable Solution/Business Opportunity

- Tools allowing teams to have better productivity.
- **Enablers:** Continued advances in AI, open-source Community, Git related support tools.
- **Inhibitors:** Training cost, need to further advances in explainable AI. Bad source code available, inappropriate use of not open-source code.

3D Printing in Personalized Healthcare

Printing in healthcare will evolve towards customized additive manufacturing for individuals.

Problems/Demand

- One-size-fits-all orthotics and protheses can be inefficient, uncomfortable, and cause unnecessary side-effects.
- Centralized manufacturing of medical supplies leads to fragile supply chains.
- Centralized lab production of personalized “human-ware” suffers bottlenecks.
- Low-volume/high-mix manufacturing is very expensive.

Opportunities

- Lower-cost development.
- Localization of manufacturing.
- Customized to the individual (3D scanning).
- Inclusion for the differently-abled.
- Medical education and research.
- Availability of low-volume medical devices.

Impact

- Better body fitment solutions lead to better health.
- More flexible supply chains.
- Availability of life-saving devices too expensive to create otherwise (e.g., 3D-printed ingestible capsule customized for drug delivery).

Sustainable Solution/Business Opportunity

- New manufacturing markets (printers, materials, etc.).
- New 3D design tools.
- New scanning technologies.
- Education.
- **Enablers:** Greater awareness of health benefits post COVID-19 (e.g., ventilator valves, nasal swabs); Open Access/Source community; new approaches to highly complex, highly customized 3D design for body fitment.
- **Inhibitors:** Environment sustainability, medical approvals (regulatory variation between countries is diverse), medical ethics.

Generative AI

07

In the next few years, generative AI will be used even more, increasing effectiveness and enabling new services. It is also bound to raise ethical and societal issues. Expect strong impact on business (short term), on education (long term) and on society (medium to long term).

Problems/Demand

- Till recently, AI created results based on a discriminative process and through inference, i.e., it DERIVED the results from the inputs. The progress in machine learning have led to self-learning and the possibility of creating new results, e.g., the creation of an image of a flying horse, where there is no flying horse in the training parameters but there are concepts of flying and of horse. This empowers AI to address new problem areas and respond to the demand of more flexible behavior of robots (autonomous robots) to face unexpected situations.
- For Text-to-Image: Illustration and design demand exponentially increasing due to increase of digital channels and social-media outlets, TV and visual ads globally. Brands and entities (across industry) are struggling to have the perfect illustrations and designs on their digital channels. The time to illustrate and design a storyline within an app, a website or an ad is high, impacting time to market. Business requirements and briefs is challenging when done manually.

Opportunities

- A whole new area of applications opens up with generative AI. It goes beyond the possibility to increase autonomy of machines. It can support human creativity.
- It can be used in areas like writing articles, novels, creating music, paintings.
- It will be used to explore business opportunities, understanding market interests.
- Faster, more accurate and broader options to illustrations and story lines. Text-to-Image Engines provide new aspects and horizons in designs and illustrations.
- Time-To-Market will be significantly decreased. Help designers to illustrate faster, and help businesses improve their digital channels and marketing.

Impact

- AI's application to the area of RPA (Robotic Process Automation) is likely to improve effectiveness in shop-floor operation, provide more flexible manufacturing and a more reliable supply chain.
- It is going to become a new tool to increase human creativity and we have already seen concerns expressed and limited buy-in.
- Significant decrease in time-to-market, enabling designers/illustrators more varieties of creative designs.

Sustainable Solution/Business Opportunity

- Generative AI may decrease the need for intensive processing to train AI in any new area (second half of decade). Support for no/low-code.
- On the business side, it can be expected that generative AI will increase AI adoption and create new revenue streams.
- Text to Image Illustrations.
- **Enablers:** Chatbots, Engines. Machine Learning approaches such as Federated Learning will allow these technologies to be used securely at client's site while leveraging insights from large data sets.
- **Inhibitors:** It can support human creativity, which until now has been perceived as very core human characteristic. This potential represents a thread or concern. Illustrators/Designers, Creative Industries.

IT for Sustainability

Technology will evolve from sustainable IT to novel uses of IT for sustainability, clean energy, and a green economy.

Problems/Demand

- From UN: meeting the needs of the present without compromising the ability of future generations to meet their needs.
- IT can play two roles: reduce impact of IT, but more importantly improve the efficiency of the "green economy" (including clean energy) through technology, such as AI, HPC, and digital twins.
- High energy consumption of certain computing activities (e.g. social media, AI@scale, large data centers, supercomputing, crypto mining) negatively impact environment and energy costs.
- Governments are mandating energy efficiency in computing and datacenters.

Opportunities

- Reduce carbon footprint of computing activities, discover new ways to optimize computing.
- Data center waste heat reuse represents a major untapped potential in the green energy transformation.
- Ensure a positive environment impact for manufacturing, operation, and disposal of IT products.
- Aggressively deploy IT (e.g. HPC, big data, and AI) to improve the efficiency of generating, distributing, and storing renewable energy.
- Apply the three key "circular economy" design principles to IT
  - Eliminate waste and pollution
  - Circulate products and materials (at their highest value)
  - Regenerate nature

Impact

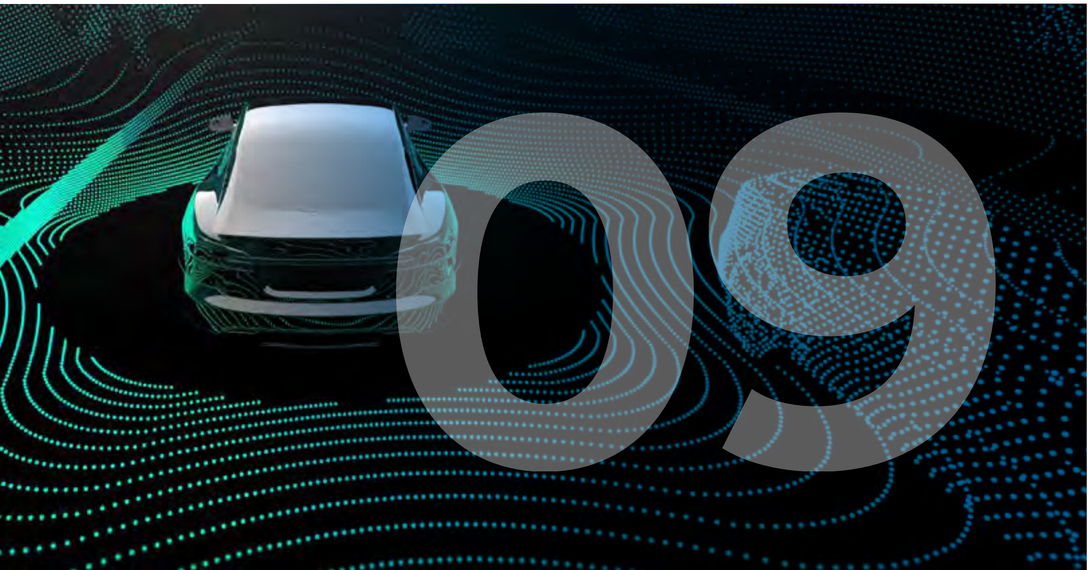
- Organizations are seeking sustainable solutions to create material benefits from reduced energy costs and greater resiliency.
- Reduced stress on the environment and cost savings.
- A more efficient, optimized and economically viable ecosystem for renewable energy generation, distribution and storage.

Sustainable Solution/Business Opportunity

- Potential new business — "green clouds."
- AI could render renewable energy cost-competitive with fossil fuels.
- Digital twins and AI could help optimize the distributed energy resources of a renewable micro-grid.
- **Enablers:** Existing optimization techniques for time/memory can be adapted for energy efficiency. Enterprises can improve ESG scores and brand image, customer satisfaction, and financial savings.
- **Inhibitors:** Traditional computing paradigm. IT accounts for 3% of global CO2 emissions. Footprint is growing, with rising demand for computing and data storage and the production/disposal of electronic devices. Massive increase in electricity needed to power digital technologies, including AI/ML systems and cloud that require more computing and storage. Need for greater understanding of the end-to-end environmental impact of IT.

Autonomous Driving

Self-driving vehicles in controlled environments are starting to gain adoption at scale, backed by strong business cases.



Problems/Demand

- Autonomous, Connected, Electric, Shared (ACES) vehicles are disrupting the transportation market.
- SAE International classifies autonomous driving levels 0 to 5. We are between 3 and 4. By 2030, vehicles will be L2 or above.
- Most accidents are a result of human driver error.
- Traffic congestion and parking are major problems.
- Self-driving, consumer vehicles in everyday traffic are still in test phase, and must overcome many challenges.

Opportunities

- Controlled environments (behind closed gates, such as airports, factories, warehouses, etc.) are likely the first adopters of L4-L5 autonomous vehicles.
- Commercial trucks on highways are the next large opportunity, followed by robo-taxis and shuttles.
- Self-driving can reduce driver related accidents, increase vehicle density, reduce operational costs.

Impact

- Reduce traffic deaths, improved vehicular safety.
- Increase efficiency (road utilization, occupancy, parking).
- Reduce carbon emissions and travel time.
- Reduce operational expenses of commercial operations.

Sustainable Solution/Business Opportunity

- The business case behind self-driving in controlled environments is strong, scalable, and fast to commercialize.
- Software is likely to remain a key control point and large business opportunity.
- Improved sensors and component reliability, including error free software, are necessary.
- Infrastructure and regulatory changes are needed to fully implement everyday autonomous driving.
- **Enablers:** AI, data science, edge computing, electric and connected vehicles, shared economy.
- **Inhibitors:** Social acceptance, regulations, large investments, at-scale commercialization.

Digital Distributed Manufacturing

Digital Distributed Manufacturing will reduce the energy and environmental footprint and increase the resilience of supply chains.

Problems/Demand

- Logistics/supply chain challenges.
- Increased energy costs of manufacturing and transportation.
- Supply chain flexibility across many components.
- Remote manufacturing.

Opportunities

- Just-in-time manufacturing: timely, local.
- Labor reduction for spare parts management.
- Rapid change in component production.
- AI-controlled real-time process adjustment using non-destructive evaluation and uncertainty quantification to meet spec.
- Multi-material/multi-functional components.
- Integrated components, sensors, actuators.

Impact

- Reduce energy/environmental footprint of speculative manufacture, ship, and store.
- Real time response to supply & demand.
- Component precision beyond conventional manufacturing.

Sustainable Solution/Business Opportunity

- Just-in-time automotive/aircraft carrier spare parts.
- Contract manufacturing: rapid change of output to meet highest demand.
- **Enablers:** Advances in printing precision, multi-source densification, AI repair of in-situ flaws.
- **Inhibitors:** Materials (cost of high-quality powders), microstructure control, cost and speed of manufacture, digital design security.

Trusted Computing

There will be increased public awareness and attention to trusted/assured computation across all industry sectors. Governments will increase focus on legislative actions to ensure that public facing systems can be trusted.

Problems/Demand

- Increased threat surface to governments, industry, and individuals.
- Integration (both intentional and unintentional) of numerous devices, software etc. with vulnerabilities.
- Users are demanding better guarantees of safe operations of devices, software, and systems.

Opportunities

- New technologies (e.g. blockchain, encryption algorithms).
- Greater awareness and support for R&D.

Impact

- Increased safety, security, and privacy.
- Increased citizen and consumer confidence.
- Cost savings (from losses incurred by attacks).
- Lower insurance costs.

Sustainable Solution/Business Opportunity

- Trusted clouds and service providers will be market leaders.
- **Enablers:** widescale support (popular and research funding).
- **Inhibitors:** Costs, increased time to market.

Huge Graph Neural Networks

Applications that use huge models, such as chatGPT, have demonstrated a real impact on a substantial set of problems. Graph Neural Networks can represent complex, “real-world” structures. We predict that huge GNN models will widely be used in machine learning.

Problems/Demand

- Many “real world” applications can be represented as graphs, e.g., relational data-based, the netlist of a chip, social networks, citation networks, Bot-detection, molecular biology, and many more.
- The use of Graph Neural Network (GNN) algorithms can help to better handle graph-related problems.

Opportunities

- GNN-related research needs to be extended to support more domain-specific areas and to include many more computational patterns, such as
  - hierarchical representations,
  - clustering,
  - Port-graphs and
  - More.
- Graph-based algorithms, e.g. Min-Max, spanning trees.
- Special hardware needs to be developed to handle huge GNNs in a more efficient way.

Impact

- We believe that GNN will be used as a keystone for many applications; many of them require the use of huge graphs to be efficient.
- It enables new classes of machine learning algorithms to be used for solving a wider range of applications.

Sustainable Solution/Business Opportunity

- **Enablers:** The use of GNN can help:
  - Better handling dynamic social networks
  - Representing inter/intra relationship between molecules in biology
  - Finding Hardware Trojan Horses (HTT) and
  - Many more domain-specific applications.
- **Inhibitors:**
  - It requires a vast amount of compute-resources.
  - Training may be costly.
  - Further research is still needed in order to expand the usability of the method.

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Adaptive, Generative Pharmaceuticals

Advances in nanotechnology and AI could shorten the time to vaccine development and broaden their efficacy.

Problems/Demand

- Drug discovery is slow/time consuming.
- The cycle of sequencing pathogens, designing effective and broad vaccines, and testing them will accelerate using automation and AI.

Opportunities

- Quick response to new pathogens or mutations could create effective vaccines or treatments before they reach pandemic proportion.
- Eventually, tailored and adaptive gene therapy at the individual's genome level.
- 'Automation of science' bears the promise of making better decisions faster.
  - low error
  - high speed of execution
  - low consumption of materials
  - straightforward synthetic schemes for ease of compound production
  - potentially patentable compound
  - ease of instrument handling
  - ultimately, improved decision making for hit and lead candidate selection

Impact

- Life saving pharmaceuticals can be brought to market quicker.
- Significant reduction in premature deaths due to disease.
- Possibly new cures or treatments.

Sustainable Solution/Business Opportunity

- Avoidance of widespread economic impact of pandemics
- **Enablers:** Large-scale AI; cheap and accurate gene sequencing; nano-manufacturing and protein synthesis. Reducing errors in data annotation. Rely on suitable assays.
- **Inhibitors:** Getting the balance wrong between safety and regulation. Incompleteness of available drug discovery data. Erroneous assay readouts hamper accurate model building. Poor data curation or sharing can easily be a limiting factor for machine learning.

Autonomous Robots & Brain-machine I/F

Pervasive uptake of robotic platforms will take place, including as extensions of the human body.

Problems/Demand

- Increasing demand for highly autonomous robots capable of moving freely in space and interacting with humans, to replace humans in harsh environments and risky jobs.
- Robot programming and control is complex and often non-intuitive.

Opportunities

- **Increase humans' safety and security:** can replace humans in harsh environments and risky jobs (e.g., in mines, in space exploration missions, in some industrial production lines, etc).
- **Physically impaired people:** implanted BMIs can bypass and compensate for permanent neurological damage.
- **Consumer:** hands and voice –free interaction with robotics and prosthetics through wearable BMIs. Robotic platforms become an extension of the human body (augmented humans).
- **Defense/Space** (safer combat and exploration) and Remote medical technology (hands –free/wireless surgery).
- **Research/development:** need improved robotic "hands" for more human-like manipulation.

Impact

- Autonomous robots will impact humans' safety and security at work.
- New technical competences will be needed for workers to interact with autonomous robot colleagues.
- BMIs will gradually revolutionize the way we interact with robotics and electronics in general (peripheral –free).

Sustainable Solution/Business Opportunity.

- **Wearable** BMIs could be integrated with wireless charging and energy harvesting.
- **Low-power edge–computing** integration @ BMIs: maximum miniaturization and efficiency.
- **Enablers:** Techniques guaranteeing the safety and security of fully autonomous robots moving freely in the environment and autonomously interacting with humans.
- **Inhibitors:** Mandated standards guaranteeing high safety and security levels throughout the whole development and production process. Social concerns about "robot world take-over."

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Artificial General Intelligence (AGI)

Advances in AI will lead to AGI systems that can understand or learn any intellectual task that a human being can perform.

Problems/Demand

- With the increased proliferation of specialized or narrow AI systems it is becoming increasingly difficult for users to use the right combination of tools to solve complex problems.
- Narrow AI systems lack deep understanding of the user and their unique needs, feelings, and preferences.

Opportunities

- Improved decision-making: AGI could be used to analyze large amounts of data and make decisions that are more accurate and objective than those made by humans.
- Increased efficiency: AGI could be used to automate a wide range of tasks, leading to increased efficiency and productivity.
- Enhanced problem-solving: AGI could be used to tackle complex problems that are beyond the capabilities of humans, leading to new solutions and breakthroughs.
- Greater access to information: AGI could be used to process and understand vast amounts of information, making it more accessible and usable to people.
- Increased personalization: AGI could deliver highly personalized empathic services based on an individual's unique needs, feelings, and preferences.
- Trustworthiness: It is important for AGI to be accurate, transparent, secure, and ethical in order to build confidence in its use and ensure that it is used responsibly and ethically.

Impact

- The potential opportunities that could arise from the development of AGI are vast and varied, and it is difficult to predict exactly what they will be. However, it is clear that AGI has the potential to bring about significant benefits and change the way that we live and work.

Sustainable Solution/Business Opportunity

- Increased replacement and automation of information workers.
- New applications in robotics and autonomous systems.
- Improvements in energy efficiency in all aspects of life.
- Automation in science and technology research.
- **Enablers:** Computing power, Machine learning algorithms, Natural language processing (NLP), Computer Vision, Robotics, and Large Neural networks.
- **Inhibitors:** Lack of understanding of human intelligence, Limited data, Ethical concerns, Technological barriers, Economic barriers, and Environmental concerns.

Global Digitalization of Monetary Transactions

Digital transformation of monetary transactions will open new disruptive opportunities in global markets.

Problems/Demand

- Global legal banking and financial regulations for money exchange interactions, to certify compliance and resolve eventual discrepancy or dispute transaction disclaim.
- Secure trading through certified agents, avoiding fake transactions, fraudulent operators, money laundry, phishing, etc.

Opportunities

- Enormous globalization opportunities for trading services and goods with little limitations.
- Just like it happened with Uber or Airbnb, disruption in operations expanding from local to global, has the opportunity gap provided by legal frameworks designed only for “as-is” business, thus creating free frame to set new de-facto standards.
- Above problems are great opportunities to develop digital innovative monetary transactions systems under this gap shelter.

Impact

- New economy ‘soft’ vehicles enable broaden technology, knowledge, goods, and powerful collaboration worldwide.

Sustainable Solution/Business Opportunity

- First trusted traders in the market will monopolize top market share.
- **Enablers:** Global network system escalation has only local costs.
- **Inhibitors:** Local legal legacy regulation limitations for joining the trading network.

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Space ITC

As more companies send technology to space, the barriers to entry are decreasing rapidly.

Problems/Demand

- As humans expand their activities into outer space the delays in communicating with the earth will become a major issue for remote control and coordination.
- Demand for connectivity is giving rise to satellite-based solutions. Investment in computing infrastructure part of satellite deployments can be further amortized with other satellite-based services. Satellite-based computing reduces satellite backhaul demand, much like terrestrial edge.

Opportunities

- There is an opportunity to combine edge and full data centers in outer space, both in earth orbit as well as elsewhere in space.
- There are proposals to put data centers in earth orbit and in lava tubes on the moon (to archive earth's data as well as provide local data and communication resources for lunar and cis-lunar activities).
- Data centers will likely follow human exploration and development in space.
- This will also increase the demand for high bandwidth communication between these data centers and with the earth.
- Acceleration of scientific discovery in areas such as cosmology, biology, and low-gravity manufacturing.

Impact

- Local IT capability will enable more immediate work on data captured in outer space.
- This will expand the capabilities of machines and humans working in outer space.
- Local data centers could enable more effective AI for space activities.

Sustainable Solution/Business Opportunity

- Outer space IT will use locally harvested solar energy although radioactive decay or types of nuclear power plants could be used.
- In the long run, manufacturing of the IT components and systems done in space will reduce the impact of moving these components from earth.
- Earth observations, analysis and communications are being implemented for sustainable precision agriculture through new satellites.
- IT in outer space will generally support resource extraction and industry development in outer space, freeing the earth from environmental impact.
- **Enablers:** Inexpensive launch vehicles and IT equipment designed for use in space.
- **Inhibitors:** Costs of transportation to space and possible delays in human space development.

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Sustainable Space Manufacturing and Recycling

Space manufacturing and recycling technologies and services will improve sustainability, resilience, and cost of the space ecosystem.

Problems/Demand

- Launch cost
- In-space repair
- Construction of spacecraft and stations
- Satellite transportation and removal of debris
- Coordination among players
- Software-driven developments

Opportunities

- Replacement components
- Construction of space equipment using lunar materials
- Space tug services to replace expensive/ complex thruster and telemetry packages and remove orbital debris
- Longer lifetime through software-based architectures
- Cost reduction through system coordination
- Shorter time-to-deployment and time-to-operations

Impact

- Reduced cost for space equipment, craft, stations
- Ability to manage complicated repairs
- Replace thruster/telemetry packages with higher-end reusable systems
- Enhancement of verticals due to software-driven flexibility
- Space sustainability on the medium/long term

Sustainable Solution/Business Opportunity

- Space based manufacturing, repair, and logistics services
- **Enablers:** AI-based automation, AR/VR/digital twin, economy of scale of larger space efforts, high commercial potential, Artemis program. Software-defined Everything (networking, data centers, data storage, radio).
- **Inhibitors:** Cost, lack of standardization, complexity of manufacturing and service needs, large capital overhead. Resistance of many players to move form hardware- to software-based systems in the space realm.

Disinformation Detection/Correction

Improving the reliability of information in public health, politics, and science will improve public information required for sound decisions from personal to societal levels.

Problems/Demand

- Many online public sources contain information that is wrong, doesn't contain reliable confirmation or is misleading.
- Malicious players creating disinformation, including realistic computer-generated video.

Opportunities

- If we can create technology and/or programs that help determine veracity of public information and if this was widely used, people could make better decisions.
- Detecting and correcting disinformation could involve a combination of AI algorithms and crowdsourcing to determine whether a statement or piece of information is accurate or real.
- There could be economic and other value in verifying the true of information.
- Reduce propaganda in politics, public health.

Impact

- Success would reduce the ability to create social unrest by bad actors and bad decisions by individuals.
- With more accurate information, better personal and economic decisions are possible.
- This could also help with more fair elections.

Sustainable Solution/Business Opportunity

- There is great value to society, organizations and individuals to ensure that public information is true and accurate.
- Authenticity verification of arts, media, public statements.
- **Enablers:** Advanced AI and crowdsourced information verification, video, audio, and other media verification techniques.
- **Inhibitors:** Poor marketing and willing believers, unconvinced by facts, rapid escalation of falsification techniques.

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