Quantum computing state-of-play and the future of the Internet of Things

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• Background / context
• Key terms
• Quantum computing state-of-play
• Internet of Things state-of-play
• Opportunities quantum computing technologies could create for IoT
• Possible unknowns posed by quantum computing technologies to the emerging IoT ecosystem
• Possible trajectories of development for quantum computing and IoT
• Implications for the future
Background / context
The basis for this talk

- Ongoing research about quantum technologies, key players, market conditions, roadmaps, and trajectories of development
- Connect academic, scientific research with market analysis (including key players, venture capital and hedge fund investment scenarios)
- First paper titled ‘Assessing the quantum computing landscape’ published in the Communications of the ACM October 2022 issue. DOI: 10.1145/3524109
- Parts of this talk build on that paper in conjunction with ongoing research and analysis
- This is a non-expert view of quantum computing and IoT developments as seen by researcher(s) with classical computing, technology, and industry backgrounds
Quantum computing

• Quantum computing is a computational model that leverages the capabilities of quantum mechanics
• Quantum states like superposition, interference and entanglement play a pivotal role in quantum computing
• The "quantum" in quantum computing describes the use of quantum mechanics to derive results
• In physics, the term “quantum” also refers to the smallest possible unit of a physical object. It also contains references from atomic and subatomic particles like electrons, neutrons, and proton

Source: IBM
The Internet of Things or IoT is a system of interconnected devices and networks that help process, transfer, and store data. IoT uses sensors and unique identifiers (UIDs) to mitigate human-to-human and human-to-machine interference requirements. The “thing” in the Internet of Things refers to a user, device, or network that connects to the internet. Businesses from various industries use IoT to execute multiple tasks with maximum efficiency to deliver quality solutions, services, and products.
Quantum computing state-of-play
Known limitations of current-day quantum computing technologies

• The technology is at a very early stage of development
• Equivalent to 1940s classical analogue computers
• Key challenges include
  • Error correction
  • Managing decoherence (impact of external environment),
  • Scaling up hardware
  • Lack of software
  • Practical usefulness

Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109
Google and IBM have demonstrated computers capable of up to 100 qubits of operations.

Google famously claimed quantum supremacy in 2019, a claim contested by IBM.

D-Wave has built quantum annealers (computers that solve only specific problems) having thousands of annealing qubits.

Notable start-ups include:

- Rigetti, IonQ: Integrated chips
- PsiQuantum: Fault-tolerant computers (due mid-2020s)
- ETH-led Quantum Engineering Initiative (QEi): analogue and digital control electronics and device fabrication
- Quantum computers developed in China: Jiuzhang and Zuchongzhi.
  - Jiuzhang is claimed to have quantum supremacy.

Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109
Market readiness of quantum computing technologies: Software

- **Software tools**
  - Microsoft: Q#
  - IBM: Qiskit
  - Google: Cirq
  - Rigetti: Forest and pyQuil
  - Cambridge Quantum Computing (Quantinuum): tket and pytket
  - ETH: Silq
  - Open Source: QuTip
- **Cloud computing services**
  - Microsoft: Azure Quantum
  - IBM: Quantum Experience
  - Amazon: Amazon Braket with the hardware from D-Wave, IonQ, and Rigetti as the back-end
  - Alibaba offers cloud computing access

Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109
• **US and China** are leaders with billions of dollars committed to research
• EU, UK, and Australia have committed hundreds of millions of dollars
• Japan, South Korea, Russia, Sweden, and India are the other countries with tens of million dollars committed

Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: [10.1145/3524109](https://doi.org/10.1145/3524109)
Reported levels of investment in quantum computing technologies: Private sector

- **Big tech companies** do not break out their numbers – this makes it difficult to assess their level of investment.
- **North America** is the leader in venture capital (VC) funding.
- **China** has an active state-led VC funding but limited details are available.
- Notable start-ups which have raised funding:
  - Rigetti, IonQ, Zapata Computing, and PsiQuantum (US)
  - D-Wave and IQBit (Canada)
  - Cambridge Quantum Computing (now Quantinuum) (UK)
  - QuantumCTek, Qasky (China)

Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: [10.1145/3524109](https://doi.org/10.1145/3524109)
Internet of Things state-of-play
IoT use cases

- **Healthcare**: Wearables, ingestibles, health and wellbeing
- **Retail and hospitality sector**: Stores, banks, restaurants etc.
- **Workplaces**: energy management, health and safety, security
- **Production environments**
  - Standard: Manufacturing plants, hospitals, farms
  - Custom: Mining, construction, oil & gas exploration
- **Connected devices**: associated with smart homes
- **Connected vehicles**: Cars, trucks, ships, airplanes, trains
- **Connected places**: Smart cities, smart meters, traffic control etc.
- **Outdoor settings**: Railroad tracks, airports, shipping ports

*Source: McKinsey Insights 2022*
Key players and sectors of activity

- **Amazon**: IoT devices, cloud computing for IoT
- **Apple**: Consumer IoT products (design and manufacturing)
- **Advanced Micro devices (AMD)**: Semiconductors for industrial market, transportation, supply chain, finance, healthcare, retail, and energy sectors
- **NVIDIA**: Graphics processing unit (GPU) designer for IoT devices
- **Qualcomm**: Semiconductor designers and chip manufacturers for IoT, IoT-as-a-Service provider
- **Intel**: Semiconductors for IoT devices that are used in cars, healthcare, retail, and energy
- **Cisco**: Communications equipment provider for IoT
- **Texas Instruments**: Microcontrollers, processors, sensors, and power management chips for IoT devices

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**Source**: Yahoo Finance 2022
Key players and sectors of activity

- **NXP Semiconductors**: Microcontrollers, application processors for IoT devices
- **IBM**: Software solutions provider for IoT (including cloud computing platform to access live data and generate analytics)
- **Johnson controls**: Smart home products such as heating controls, building management, fire detection, and other systems
- **Garmin**: Wireless device manufacturer and seller of products such as smart watches, fitness bands, and activity tracking equipment
- **Sensata Technologies**: Sensors and controllers for devices such as position and thermal management sensors
- **STMicroelectronics**: Semiconductors for products such as automotive, industrial and consumer appliances, and sensors
- **ABB**: Electrification, process automation, motion, and robotics

Source: Yahoo Finance 2022
Market conditions 2021 and 2022

- In 2021, end-user spending for IoT reached an estimated US$423.4 billion
- **Key sectors:** Manufacturing, Supply chain, and Automotive (connected vehicles)
- **Key use cases:** Smart homes, Healthcare, and IoT security
- **Potential growth areas:** Connectivity management, Software-defined vehicles, and wireless power
- **Key issues**
  - Geopolitical and economy uncertainty
  - Global supply chain disruption
  - Cooling off in VC funding
  - Lower exit values in IoT start-ups for VC companies

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*Source: Pitchbook annual IoT report 2021 and 2022*
Opportunities quantum computing technologies could create for IoT
IoT issues and what quantum computing could offer

- **IoT security concerns** a critical challenge
- Current cryptographic algorithms rely on public key schemes
- Continued growth in IoT devices increases risk of exposure
- Possible areas where quantum computing could address bottlenecks affecting IoT are:
  - **Increased computational capabilities** to process heavy volumes of data generated by IoT
  - **Speed improvements** in authentication and verification
  - **Improvements to communication security** through quantum cryptography techniques
Possible unknowns posed by quantum computing technologies to the emerging IoT ecosystem
IoT ecosystem and the unknowns posed by quantum computing

- **New ecosystem of policy issues**
  - Ethics of data collection, storage, and processing
  - Interoperability between connected places, devices, and vehicles
    - Legacy, classical IoT devices and quantum-powered IoT
  - Connected places, devices, and vehicles and security concerns
  - Connected places, devices, and vehicles and issues of privacy and surveillance
  - Commercial practices for consumer, industrial, and public sector stakeholders (including defence)
  - Adoption of quantum hardware capabilities in IoT devices
  - Adoption of quantum software capabilities in IoT devices
  - **Unknown timelines in terms of readiness of quantum computing**
    hardware and software for universal, functional computations
Possible trajectories of development for quantum computing and IoT
Quantum computing

• Actual addressable market of the technology in practice is highly limited (as of 2022-23)
• Priority areas for quantum computing breakthroughs: improvements in the quality of qubits, error correction, and demonstrable set of practical applications
• Niche, first market-ready applications to focus on problems which classical computers cannot solve or take too long to solve
• Focus on hybrid computing combining classical and quantum computers
• Cloud computing to be the prevalent form of access
• Industries focussed on data to be the drivers of investment and adoption
• Public sector funding crucial for research
• Risks of quantum winter

Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109
• Semantic interoperability (shared sense of meaning for data exchange)
• Matter standard
  • Growth of interoperable smart devices and sensors
  • Inter-device connectivity between manufacturers
  • Lowered barriers to adoption of smart home
• Improvements to security standards (including standardised labelling)
  • Increased legislation and regulation of IoT devices
• Internet of Healthcare Things
  • Growth in the use of wearables and in-home sensors for healthcare management
• Industrial IoT

Source: Ericsson; McKinsey; Matter 2022
Implications for the future
Looking ahead

• Need to dissociate and distance from the hype when the near-term impact of quantum computing on IoT is considered
• Quantum computing contributions are likely to be niche, small-scale, and incremental combined with uses of classical computing software/hardware
• The use cases for IoT and areas of investment/development for quantum computing offer some clues
  • Improving security, including encryption based on post-quantum cryptography
  • Internet of Healthcare Things, subject to how advancements in quantum computing enable big data processing in drug discovery and development
  • Quantum-inspired optimisation algorithms to improve data analysis in real-time for connected devices, vehicles, places
Thank you