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

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Advait Deshpande

School of Computing & Communications

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Agenda

- 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

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Key terms

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

Internet of Things

- 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

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- Source: Oracle

Quantum computing state-of-play

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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

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- Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109

Market readiness of quantum computing technologies: Hardware

- 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

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- Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: [10.1145/3524109](https://doi.org/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

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- Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109

Reported levels of investment in quantum computing technologies: Nation states

- **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

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 1QBit (Canada)
    - Cambridge Quantum Computing (now Quantinuum) (UK)
    - QuantumCTek, Qasky (China)

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- Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109

Internet of Things state-of-play

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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

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- 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

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- 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

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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

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Possible unknowns posed by quantum computing technologies to the emerging IoT ecosystem

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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

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Possible trajectories of development for quantum computing and IoT

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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

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- Source: Assessing the quantum computing landscape, CACM, October 2022. DOI: 10.1145/3524109

IoT

- 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

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- Source: Ericsson; McKinsey; Matter 2022

Implications for the future

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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

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Thank you

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