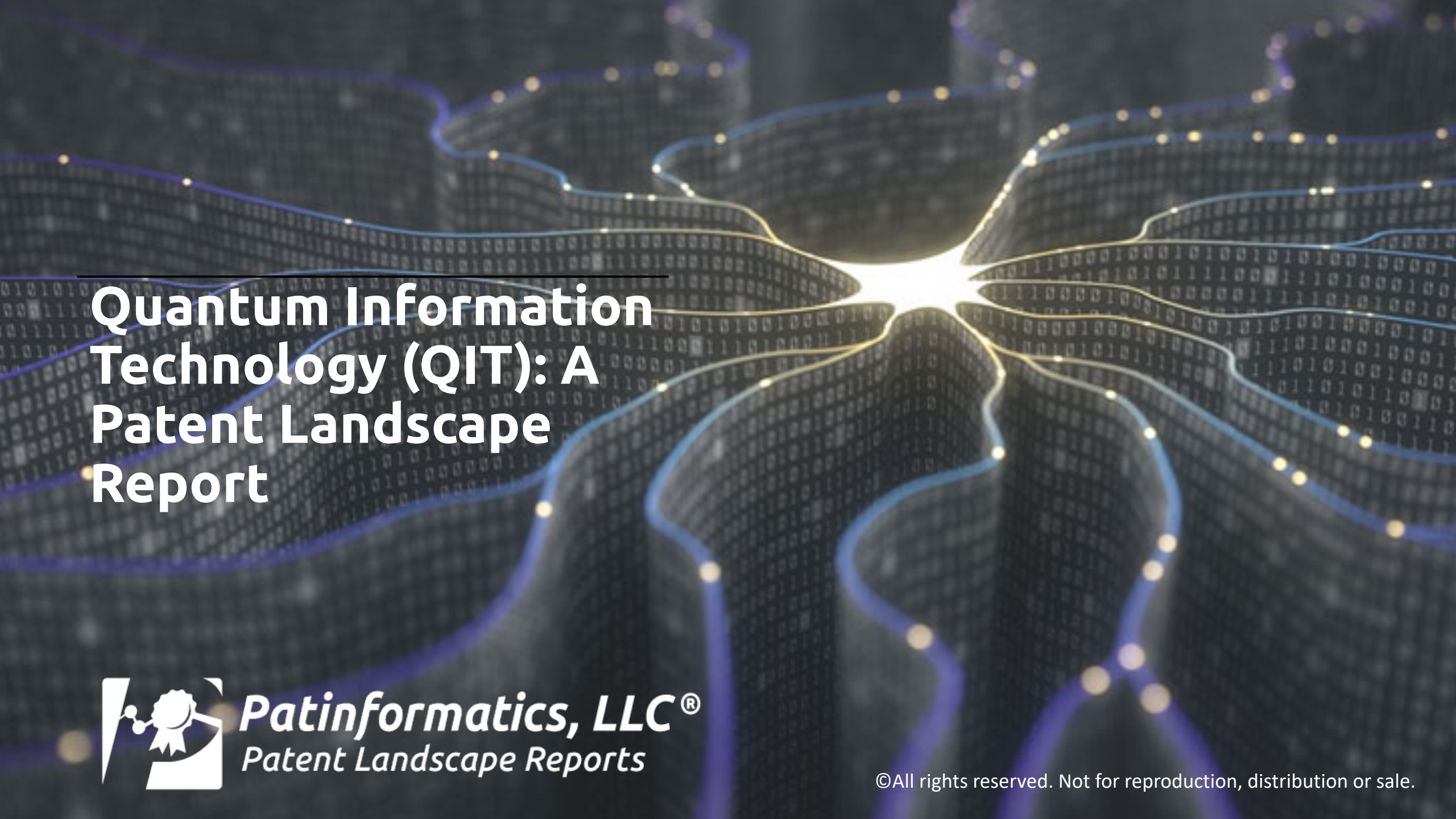

# Quantum Information Technology (QIT): A Patent Landscape Report

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# • Headlines

- Patenting in the field of Quantum Information Technology (QIT) has accelerated over the last three years.
  - Computer related patent family publications are projected to increase by 430% between 2014 and 2017.
  - Application related patent family publications are projected to increase by 350% between 2014 and 2017, but there are nearly twice as many quantum application patent families as there are families involving the quantum computers themselves.

- IBM is building an enormous portfolio in QIT, primarily in Qubit Technologies, and Hardware, and have had the most patent families published in the last two years. Their portfolios is one of the most influential.

- Northrup Grumman, HP, Raytheon, Qinetiq, and Magiq Technologies are North American companies who have substantial patent portfolios in the QIT space, and might make excellent partners, or patent acquisition targets as consolidation begins when the market grows, but Magiq stopped publishing patents in the area in 2012.

- Chinese organizations are dominating the patenting of quantum applications, and within QIT they have nearly two times as many patent families projected for 2017 as the United States, the next closest country – They are particularly interested in cryptology.

# • Headlines

- While D-wave still has the largest patent portfolio in the QIT field overall there are a number of Japanese companies that have also invested heavily in QIT including: NTT, Hitachi, Toshiba, Fujitsu and NEC.
- University backed start-ups are a significant source of potentially valuable patents, and portfolios. MIT, Yale, Harvard, and Stanford portfolios, or start-ups associated with them will be likely acquisition targets as the market grows, and larger players are looking to solidify their positions.
- Other smaller companies to consider for partnerships, or patent acquisition opportunities include: Quantum Circuits (Yale driven start-up), Qucor, Element 6, Rigetti Computing, and 1QB Information Technologies.
- Raytheon has a substantial, and potentially influential portfolio in Quantum Information Technology (QIT) – they have four Qubit Technology patent families, but most of their patenting is in applications, especially cryptology and communication

# • Headlines

- Chinese firms, Qasky, QuantumCTek, and Shenzhou Quantum are worth watching considering the enormous patent portfolios they are building.

- Approximately 72% of the academic patent families published in QIT since 2012 have been from Chinese universities. US universities are a distant second with 12%.

- Chinese universities like The University of Science and Technology of China, and The Chinese Academy of Sciences have significant portfolios associated with hardware aspects of quantum applications and will likely play a role in helping China to dominate quantum cryptology and communication within QIT. Beijing University is also contributing to this focus with a large portfolio in quantum algorithms.

- Quantum computer manufacturers tend to be based in North America while non-manufacturers, dominated by Asian organizations are focusing on quantum cryptology and communication within the QIT field.

- North American organizations may control the computer, but Asian organizations may end up controlling how those machines are used.

# *INTRODUCTION*

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# Introduction to Practical Quantum Computing

- The concept of quantum computing has been around, at least from a theoretical perspective, since the 1980's when Nobel prize-winning physicist Richard Feynman first spoke about the idea. Initially it was thought to be an impossible technology to harness due to the unstable nature of particles on the quantum scale, however due to technological advancements throughout the 1990's and 2000's not only has quantum computing become possible but it has transformed into one of the fastest growing industries in computer science. Some of the largest corporations around the world have devoted massive research and development dollars to the field along with many Universities and Government Institutions due to the enormous potential of this technology.
- Functional quantum computers will impact almost every area of science and technology. Below is a list of some areas that will experience the most disruption:
  - Cyber Security/National Defense – Most of the encryption systems employed around the world that are used to safeguard everything from personal data like banking information to highly confidential corporate and governmental data, are based on prime factorization of large numbers. For classical computers the task of factoring the encryption keys is nearly impossible, but this is not the case for quantum computers as they would be able to break every encryption method currently used. New quantum encryption methods will need to be employed to ensure that data is protected.
  - Artificial Intelligence – Machine learning is based heavily on pattern recognition algorithms that crunch massive amounts of data. Quantum computers will allow for exponentially more processing power that will lead to fundamentally more powerful forms of A.I. at a rate faster than most currently believe possible with conventional computing systems.

# Introduction to Practical Quantum Computing (cont.)

- Medicine/Chemistry – Quantum computing will allow scientists to to model complex molecular structures which is an extremely important aspect of new drug discoveries, and would even allow doctors to develop true patient-specific gene-therapy based treatments.
- Financial Industry – The finance industry could use the computational power of quantum computers to sort through enormous amounts of financial data, and use that information to optimize portfolios minute by minute.
- Climate Science – Quantum computers will give scientists the ability to model extremely complex weather patterns which will allow for more precise weather forecasts and could even lead to simulation-driven solutions to climate change.

- The reason Quantum Computers (QC) have the potential to disrupt so many different industries is because of the fundamental difference in how they operate compared to the supercomputers of today. Classical computing is built at a base level on bytes which are used to perform calculations and each bit represents either a 1 or 0. Quantum computing is built on quantum bits, known as qubits, and these particles not only represent 1's and 0's but due to the quantum mechanical property of superposition, can actually exist as both 1 and 0 at the same time and any combination in between. This means a small number of qubits grouped together would be able to do calculations exponentially faster than any of the supercomputers of today. In fact, it is estimated that a quantum computer that could successfully entangle as little as 50 qubits would be able to perform calculations faster than any classical computer, a level referred to as quantum supremacy, a mark companies like Google, IBM and Microsoft are actively trying to achieve. However there is not a consensus on the type of qubit that will be used to reach quantum supremacy.

# QIT Patent Landscape Report

- The present patent landscape report (PLR) covers worldwide published patent applications and grants in the space of quantum information technology (QIT), which is meant to encompass the entire quantum computing and information field including qubit technologies, quantum computer hardware, and quantum applications, especially cryptology and communication. This collection was built from two previous reports that looked at quantum computing, and quantum applications separately. See https://patinformatics.com/quantum-computing-report/ for a copy of the other reports.

- These results provide a broad overview of the QIT field as a whole. Details specific to the sub-categories within quantum computers, and quantum applications can be found in the previous reports.

- Spatial concept maps labeled by the main concept areas have been generated with colored highlights based on the key patent assignees by organization type.

- The forward citation network map generated is based on the entire collection of more than 4,000 patent families found in both reports that have forward citations associated with them.

# *GENERAL STATISTICS*

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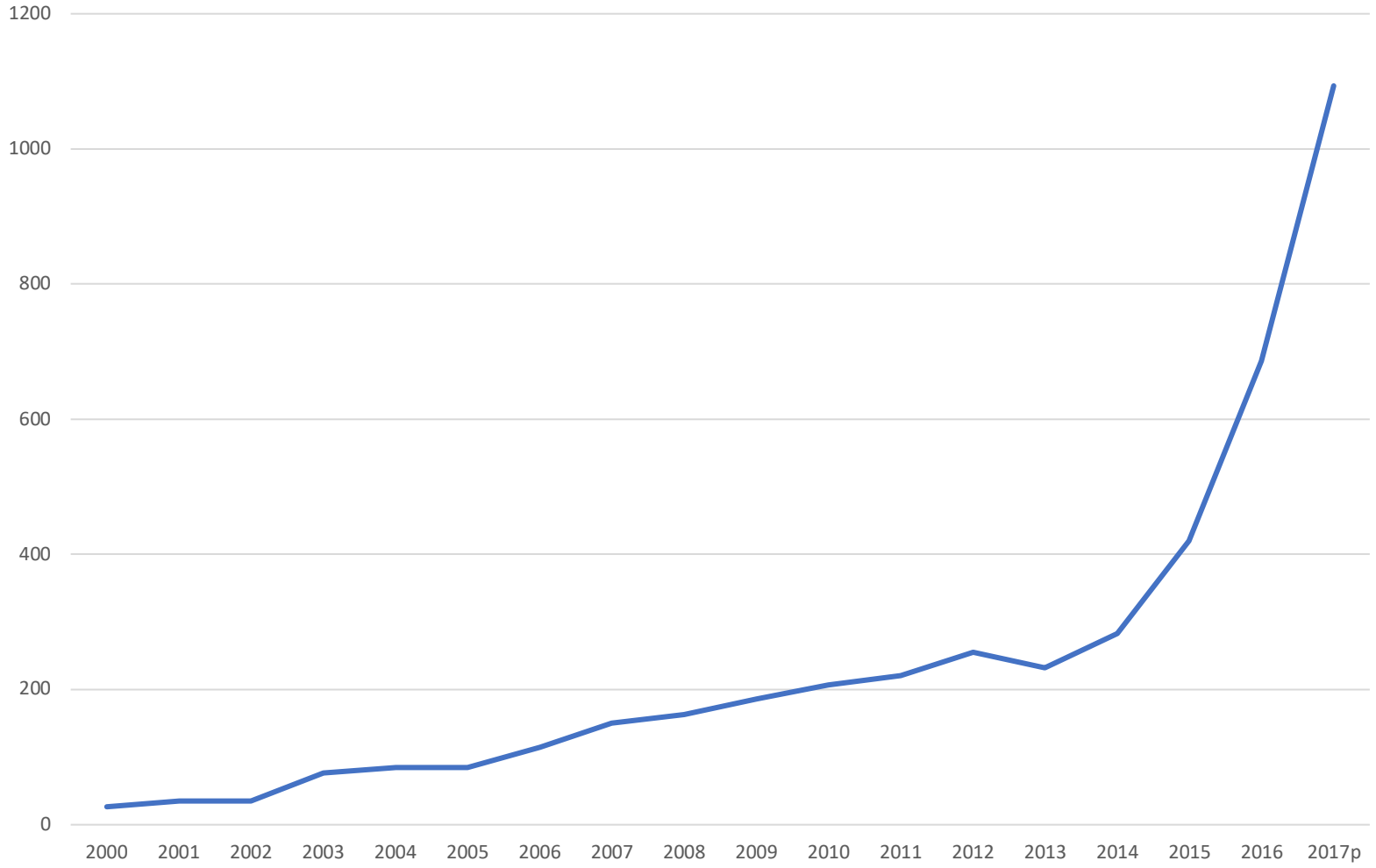
# Overall Quantum Information Technology Patent Families by Publication Year

- After a slight decline in patent publications in 2013, the quantum information technology field has experienced exponential growth over the last two years which projects to continue through 2017
- Steady growth in this field began in 2003 and has continued through the explosion in growth that began in 2014
- The number of filings has increased by over 380% since 2014

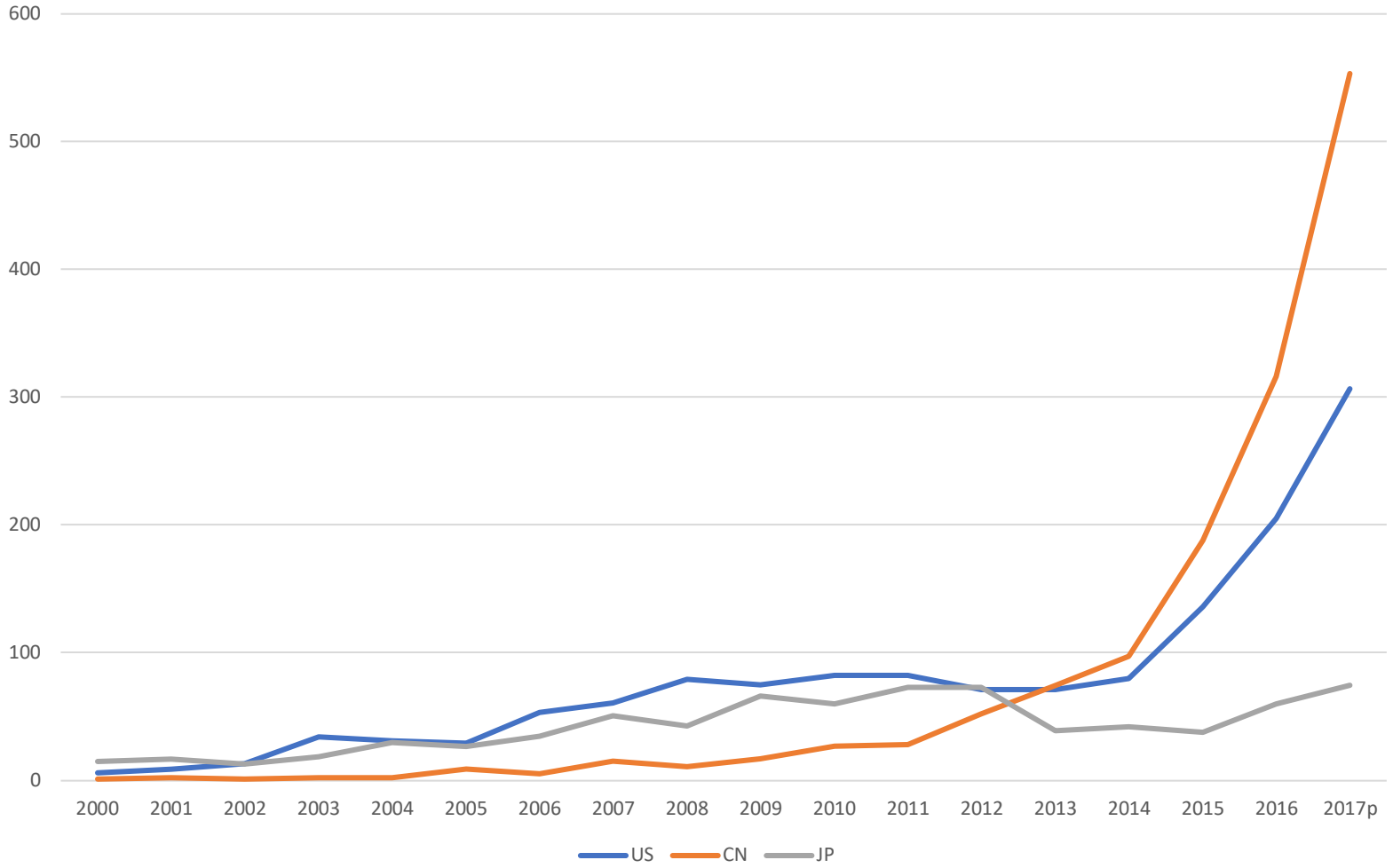



Note: Based on 4,072 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country; Currently 820 documents for 2017.

# Quantum Information Technology Patent Families by Priority Country and Publication Year

- Since 2013, the number of publications that listed China as the priority country have grown by almost 750% which clearly demonstrates China's commitment to research in the quantum information technology field

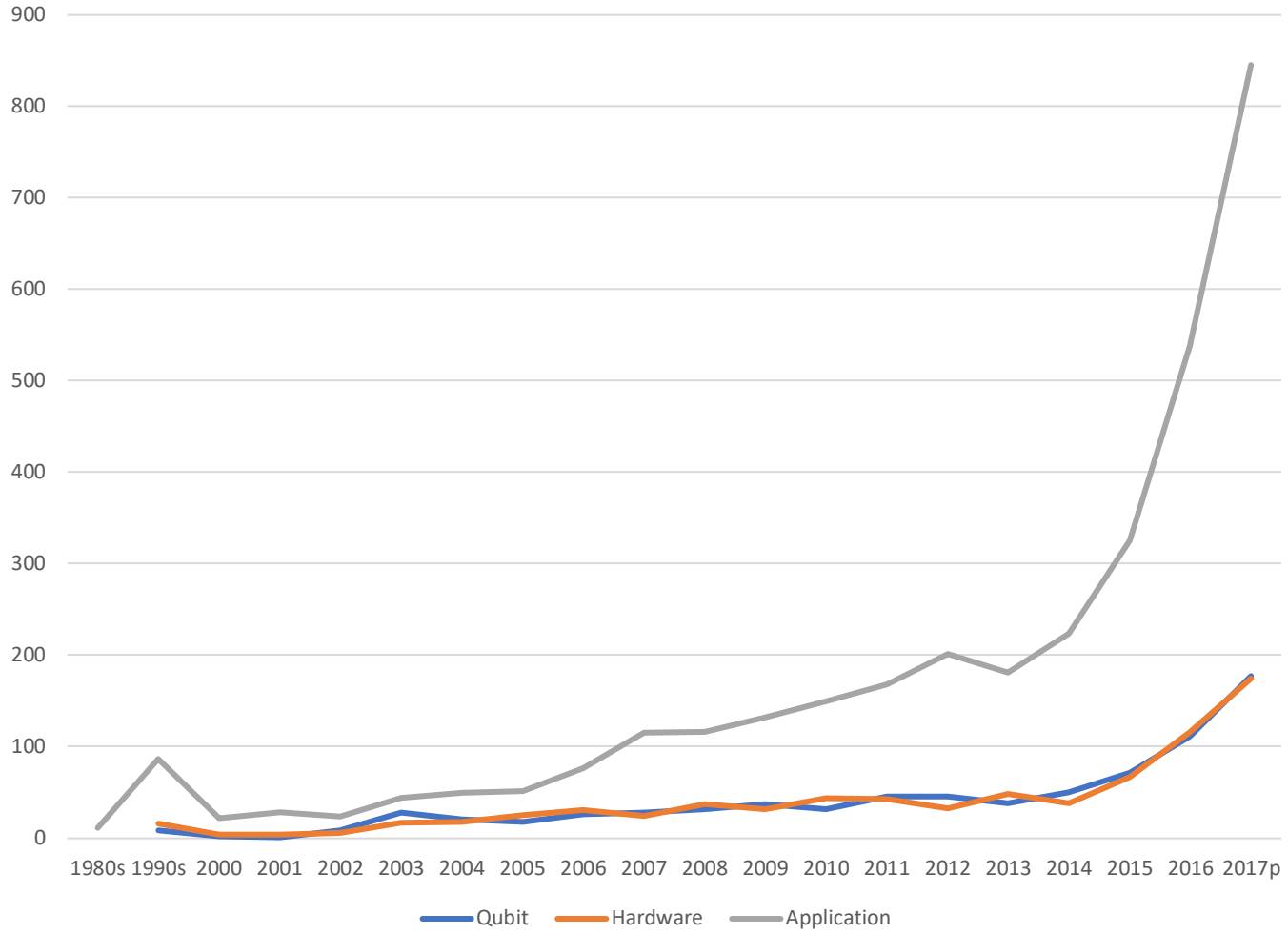
- After nearly a decade of sustained interest levels, publications that listed the United States as the priority country have grown by more than 300% over the last three years




Note: Based on 3,366 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country; Currently 701 documents for 2017.

# Quantum Information Technology Patent Families by Category and Publication Year

- Even before the advent of realistic quantum computer devices organizations have been heavily interested in the applications, methods, and protocols that would be used in conjunction with this new type of computational device
- Steady growth in applications began in 2005 and has continued through the explosion in growth that began in 2014
- Work in qubits and other quantum hardware began in the 1990s, but has experienced an acceleration in growth over the last two years that projects to continue through 2017




Note: Based on 4,645 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country; Currently 898 documents for 2017.

# *ORGANIZATION DISCUSSION*

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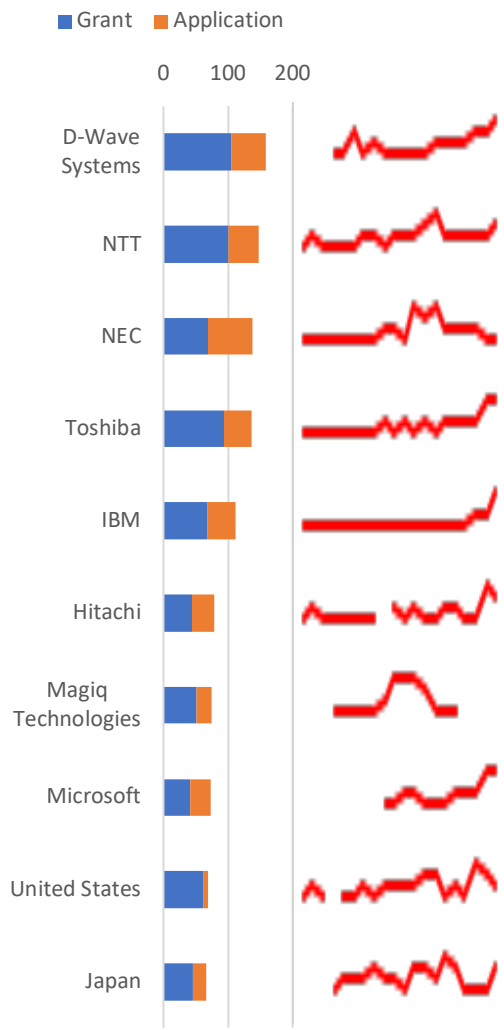
# • Quantum Information Technology Patent Families by Top Organization

- Half of the top ten organizations in the quantum information technology field are Japanese; These organizations have been working in the QIT field on average longer than other organizations
- IBM, D-Wave, Toshiba and Microsoft (highlighted in red) appear to be investing heavily in the quantum information field as all are projected to publish over 20 documents in 2017
- Hitachi, NTT and the Japanese Gov. have also shown an increase in activity related to QIT over the last two years, just not to the same degree as the top five organizations
- The United States has been decreasing activity while MagiQ has not published anything in QIT since 2012

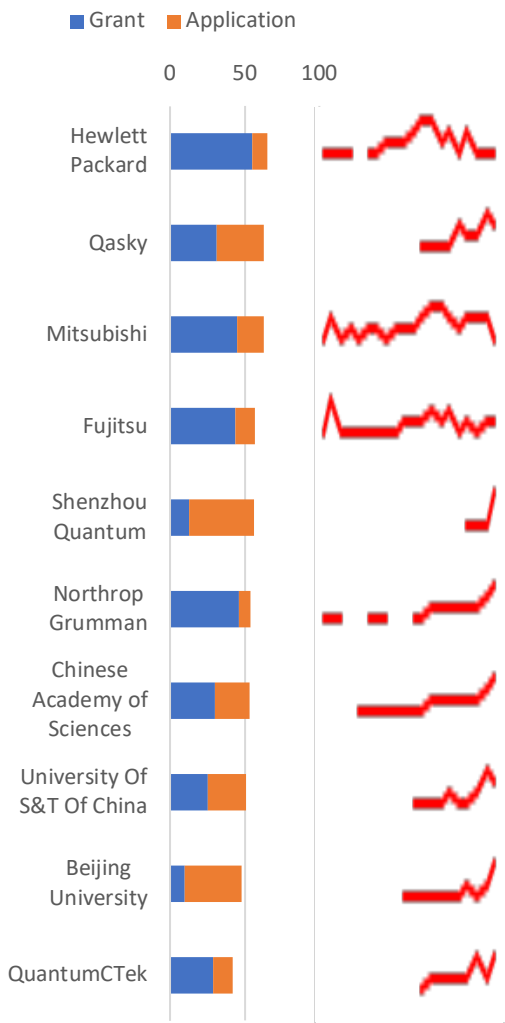



| | 1980s | 1990s | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D-Wave Systems | | | | | 1 | 18 | 7 | 9 | 5 | 5 | 5 | 5 | 2 | 13 | 12 | 9 | 8 | 19 | 18 | 29 |
| NTT | | 6 | 4 | 1 | | 3 | 7 | 6 | 2 | 7 | 10 | 11 | 12 | 23 | 11 | 8 | 10 | 10 | 6 | 15 |
| NEC | 3 | 5 | 5 | 2 | 1 | 3 | 2 | 1 | 6 | 9 | 3 | 21 | 11 | 21 | 10 | 10 | 10 | 6 | 5 | 5 |
| Toshiba | | 1 | | | 1 | 6 | 1 | 4 | 8 | 2 | 10 | 6 | 9 | 4 | 11 | 8 | 12 | 12 | 22 | 27 |
| IBM | | 4 | | 3 | 2 | 3 | | | 1 | | 3 | 3 | 1 | 4 | 6 | 1 | 4 | 15 | 16 | 60 |
| Hitachi | 1 | 7 | 1 | 1 | 1 | 2 | 2 | 1 | | 7 | 4 | 5 | 4 | 4 | 7 | 6 | 2 | 2 | 14 | 11 |
| Magiq Technologies | | | | | 1 | 1 | 1 | 3 | 7 | 14 | 14 | 17 | 11 | 4 | 2 | | | | | |
| Microsoft | | | | | | | | | | 1 | 5 | 5 | 1 | 4 | 2 | 8 | 5 | 8 | 19 | 21 |
| United States | | 4 | | | | 1 | 3 | | 5 | 3 | 3 | 4 | 8 | 7 | 1 | 4 | 1 | 12 | 9 | 5 |
| Japan | | | | | 3 | 4 | 3 | 6 | 5 | 5 | 2 | 7 | 7 | 3 | 10 | 6 | | | 1 | 5 |

Note: Based on 1,054 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country; Currently 133 documents for 2017.

# • Quantum Information Technology Patent Families by Top Organization Continued…

- Six of the organizations ranked 11th-20th from an overall portfolio size are Chinese, which is even more impressive considering only the Chinese Academy of Sciences was active in this field prior to 2008.
- Shenzou Quantum is a relatively new company in quantum information technology, and already projects to have over 50 publications in 2017 alone (only IBM has a larger projection)
- Both Hewlett Packard, and Mitsubishi appear to be slowing down in this field unlike Northrop Grumman who has been steadily increasing their interest over the last three years



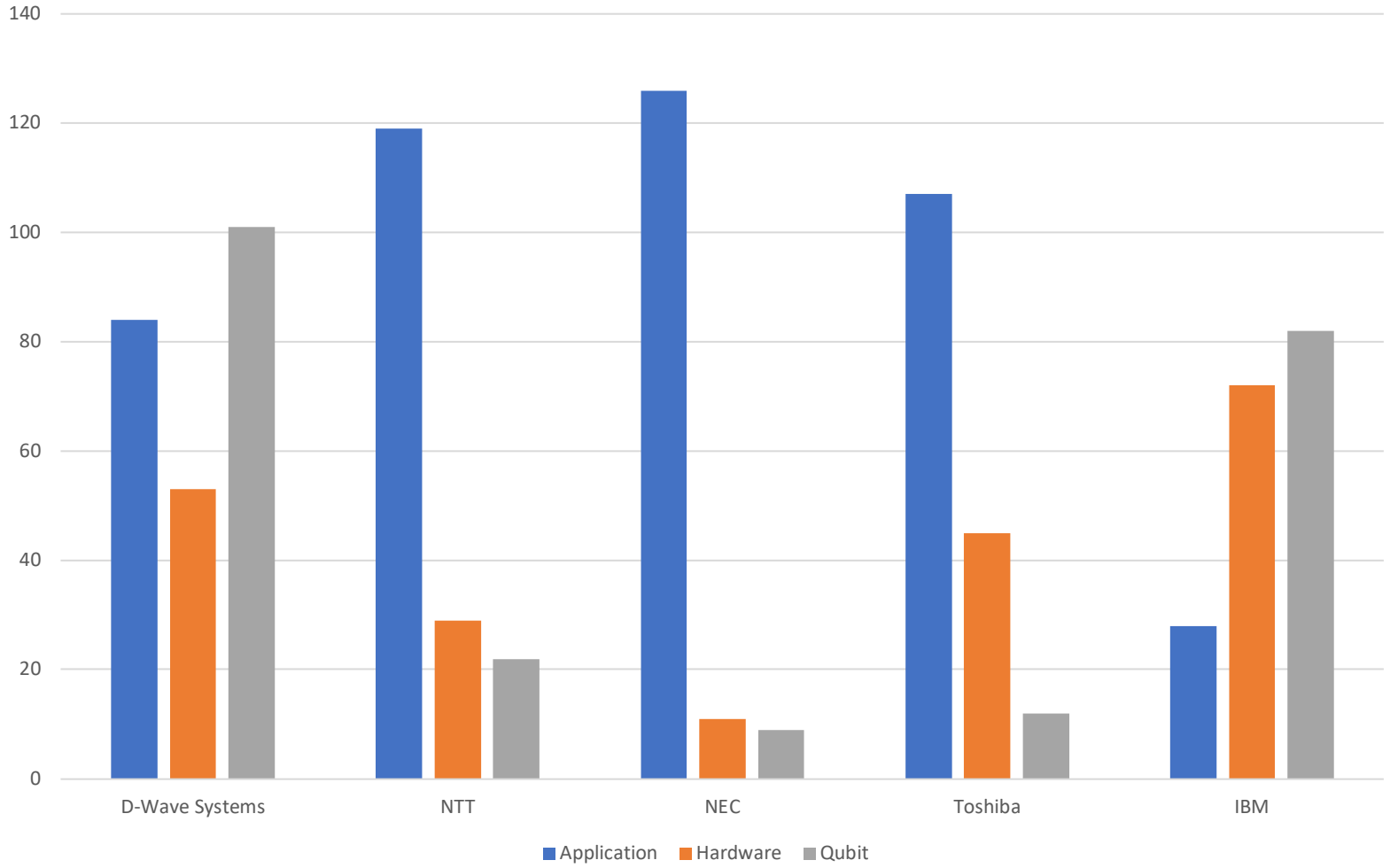

| | 1980s | 1990s | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hewlett Packard | | 1 | 1 | | | | 1 | 3 | 5 | 3 | 7 | 11 | 10 | 4 | 8 | 2 | 7 | 1 | 1 | |
| Qasky | | | | | | | | | | | | | 2 | 2 | 1 | 12 | 7 | 9 | 20 | 13 |
| Mitsubishi | 1 | 5 | | 3 | | 2 | 3 | 1 | 3 | 3 | 3 | 4 | 6 | 7 | 5 | 2 | 5 | 4 | 5 | 1 |
| Fujitsu | 2 | 11 | 1 | | | 1 | 2 | 1 | | 3 | 4 | 5 | 8 | 3 | 6 | | 3 | | 3 | 5 |
| Shenzhou Quantum | | | | | | | | | | | | | | | | | | 7 | 8 | 55 |
| Northrop Grumman | | 1 | | | | | 1 | | | | | 1 | 4 | 4 | 4 | 5 | 5 | 7 | 11 | 15 |
| Chinese Academy of Sciences | | | | | | 1 | | 1 | | 1 | | 2 | 4 | 4 | 6 | 4 | 6 | 6 | 9 | 12 |
| University Of S&T Of China | | | | | | | | | | | | 1 | 2 | 1 | 5 | 3 | 4 | 6 | 20 | 12 |
| Beijing University | | | | | | | | | | | 1 | | 2 | 5 | | 4 | 9 | 3 | 8 | 21 |
| QuantumCTek | | | | | | | | | | | | | 5 | 5 | 4 | 4 | 3 | 10 | 3 | 11 |

Note: Based on 552 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country; Currently 109 documents for 2017.

# • Quantum Information Technology Patent Families by Organization and Category

- D-Wave and IBM are clearly more interested in qubit technology as well as quantum hardware than any of the other Japanese companies which illustrates that their interests lie more in practical quantum computers

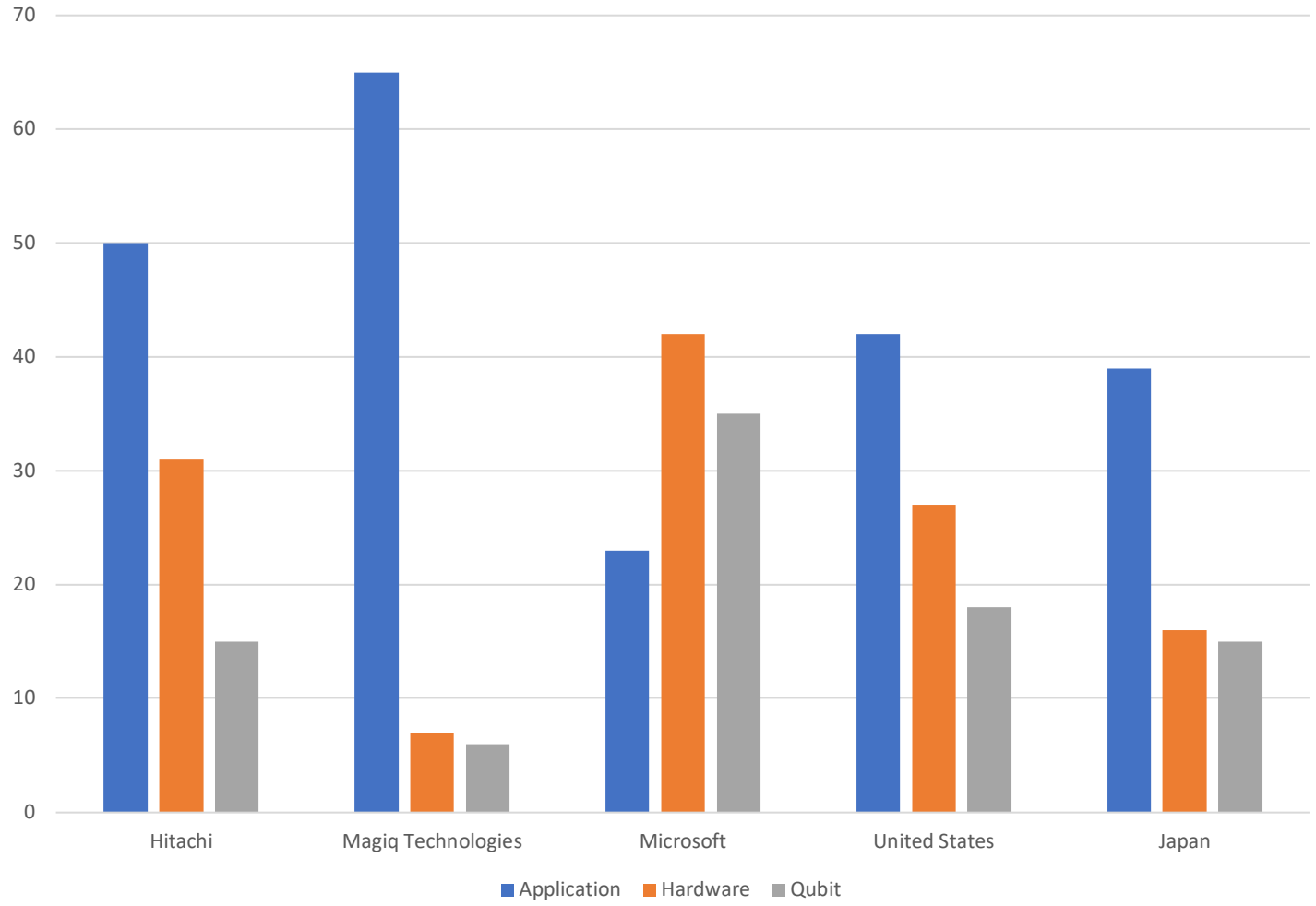
- NTT, NEC and Toshiba are all primarily working in applications of quantum technologies and more specifically quantum communication and cryptology




Note: Based on 900 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Quantum Information Technology Patent Families by Organization and Category

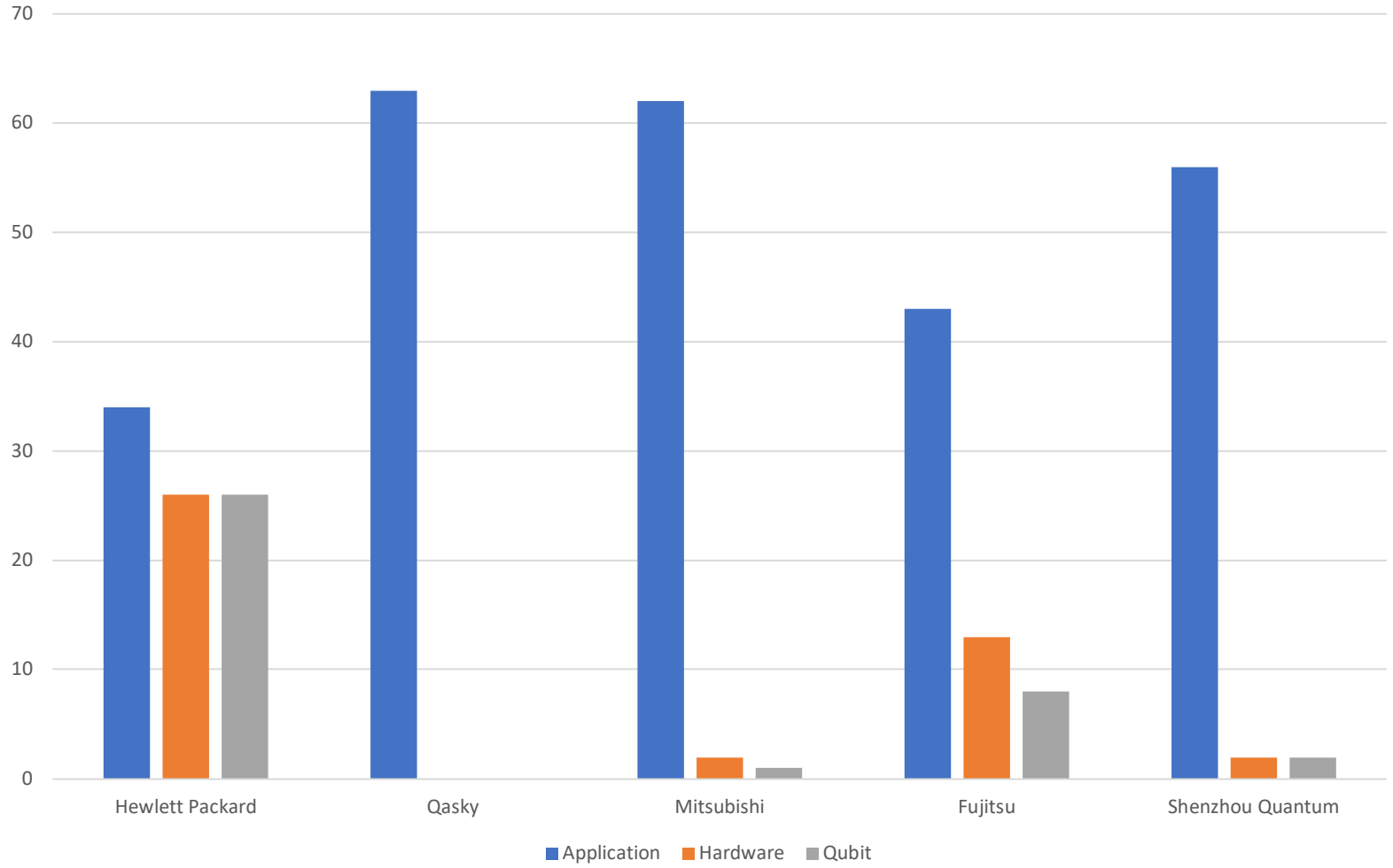
- Similar to IBM and D-Wave, Microsoft has a greater interest in qubits and quantum hardware, which illustrates their interest in building a practical quantum computer
- Hitachi and the Japanese government have similar portfolios in that both are more focused on applications, yet they also include a decent number of documents related to qubit technology, and in particular they are both interested in quantum dot technologies
- The United States has a substantial collection of documents related to superconducting qubits, however they are also working heavily in applications
- MagiQ is a quantum application driven company




Note: Based on 431 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# • Quantum Information Technology Patent Families by Organization and Category

- Qasky, Shenzhou Quantum, Mitsubishi and Fujitsu are all primarily working in quantum applications, and more specifically quantum communication and cryptology
- Hewlett Packard has a relatively even distribution across all three categories which demonstrates that they have a portfolio that is emphasizing both practical quantum computers as well as their interest in quantum communication and cryptology

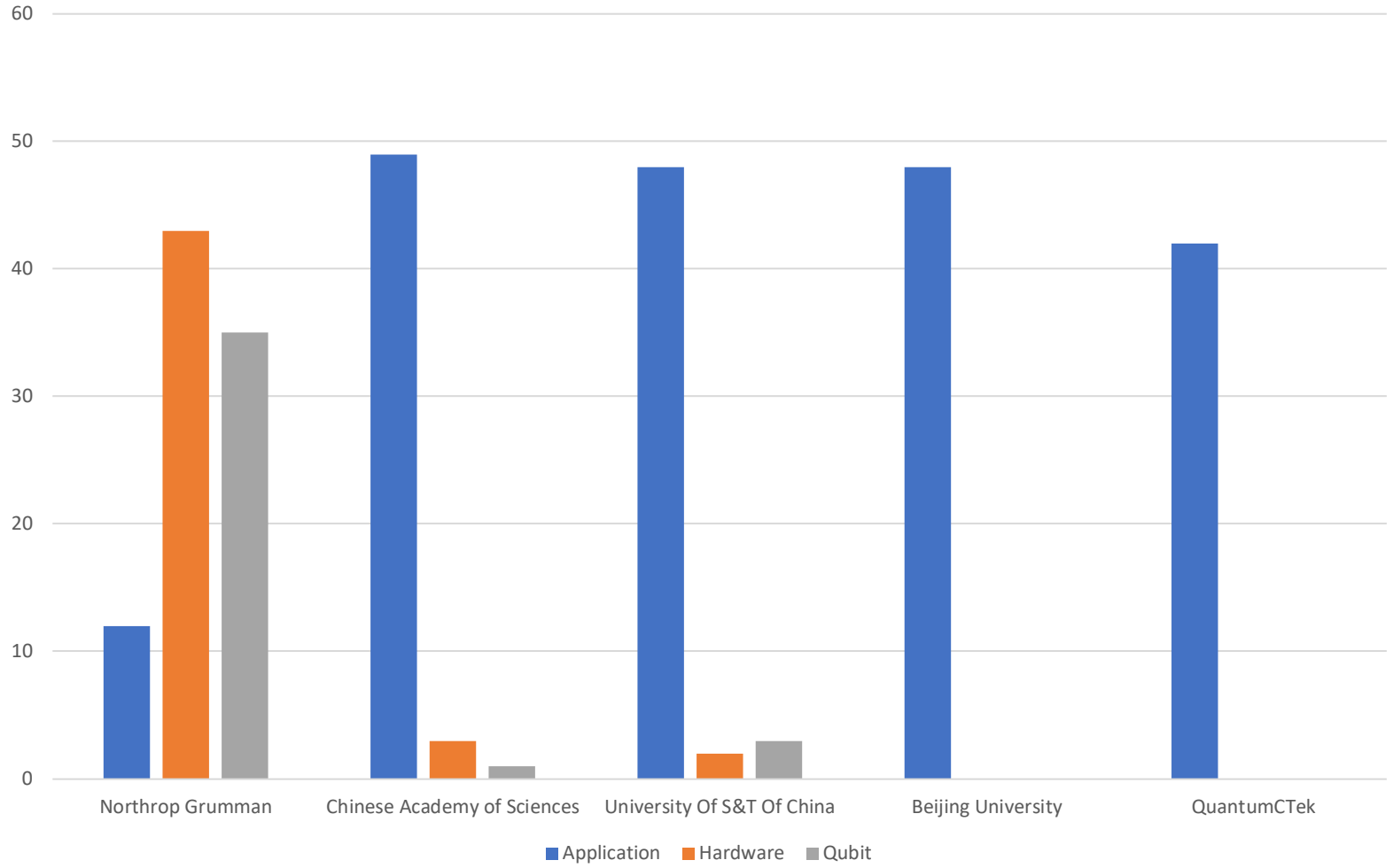



Note: Based on 338 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Quantum Information Technology Patent Families by Organization and Category

- Northrop Grumman has the third largest collection of documents related to qubit technologies as well as a substantial number of quantum hardware publications indicating they are more focused on building practical quantum computers using superconducting qubits

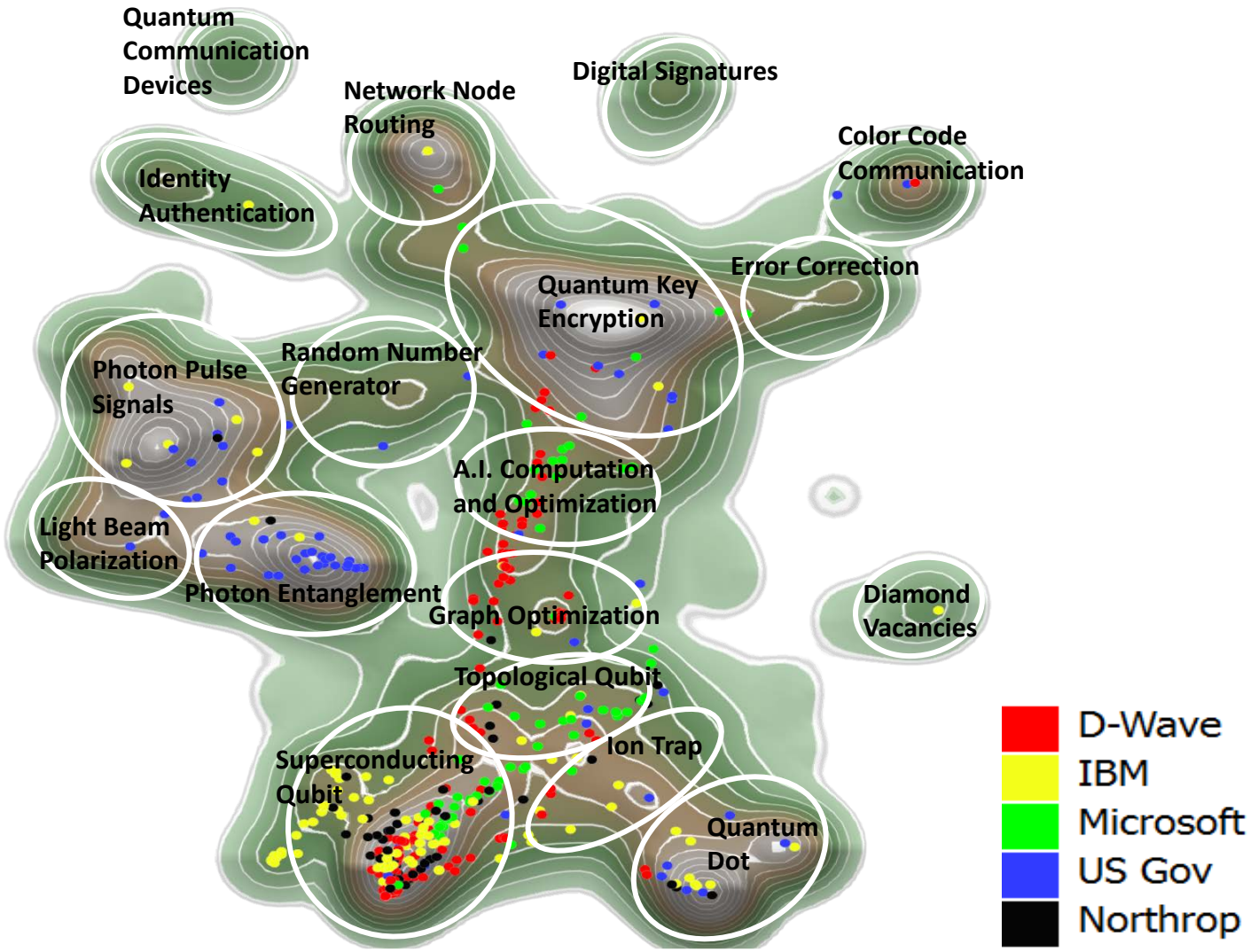
- Beijing University, and QuantumCTek are almost exclusively interested in quantum communication and cryptology, but The Chinese Academy of Sciences and Univ. of Sci. & Tech. have hardware interests as well




Note: Based on 286 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Quantum Information Technology Patent Families Spatial Concept Map by Top North American Organizations

- The North American organizations have a high cluster density down in the qubit technology section of the map indicating these organizations are primarily focused on building quantum computers
- D-Wave, apart from their concentration in superconducting qubits, also appears to be working within the A.I. computing and graph optimization areas
- Both IBM and Northrop Grumman are primarily working in superconducting qubits
- Microsoft, like D-Wave also has an interest in A.I. computing and graph optimization in addition to their work on topological qubits
- The United States shows dense clustering within photon entanglement as well quantum key encryption indicating a strong interest in communication and cryptology

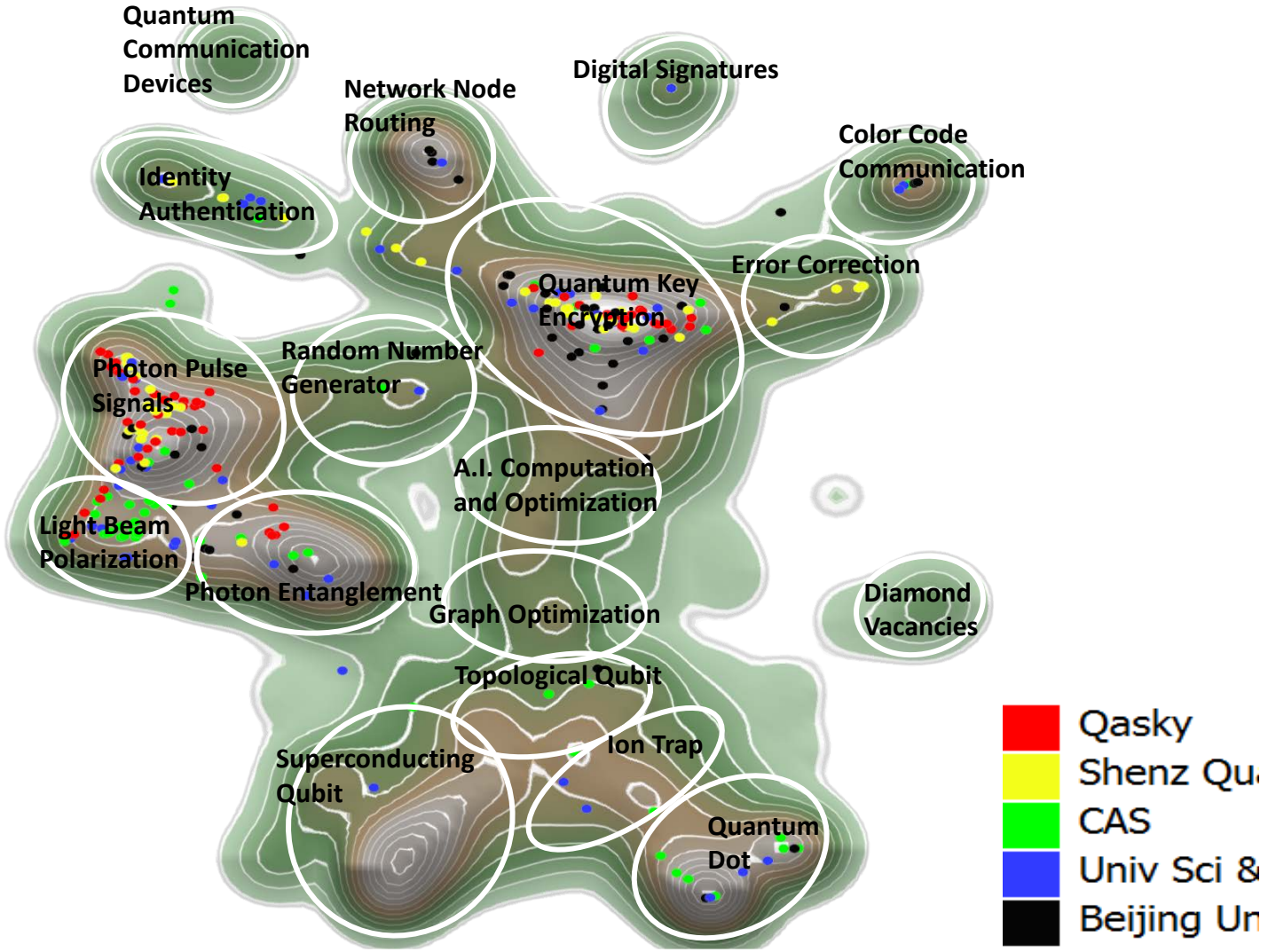



Note: Based on 465 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Quantum Information Technology Patent Families Spatial Concept Map by Top Chinese Organizations

- The Chinese organizations are clearly concentrated in the quantum communication and cryptology areas on the map with very little coverage in qubit technology

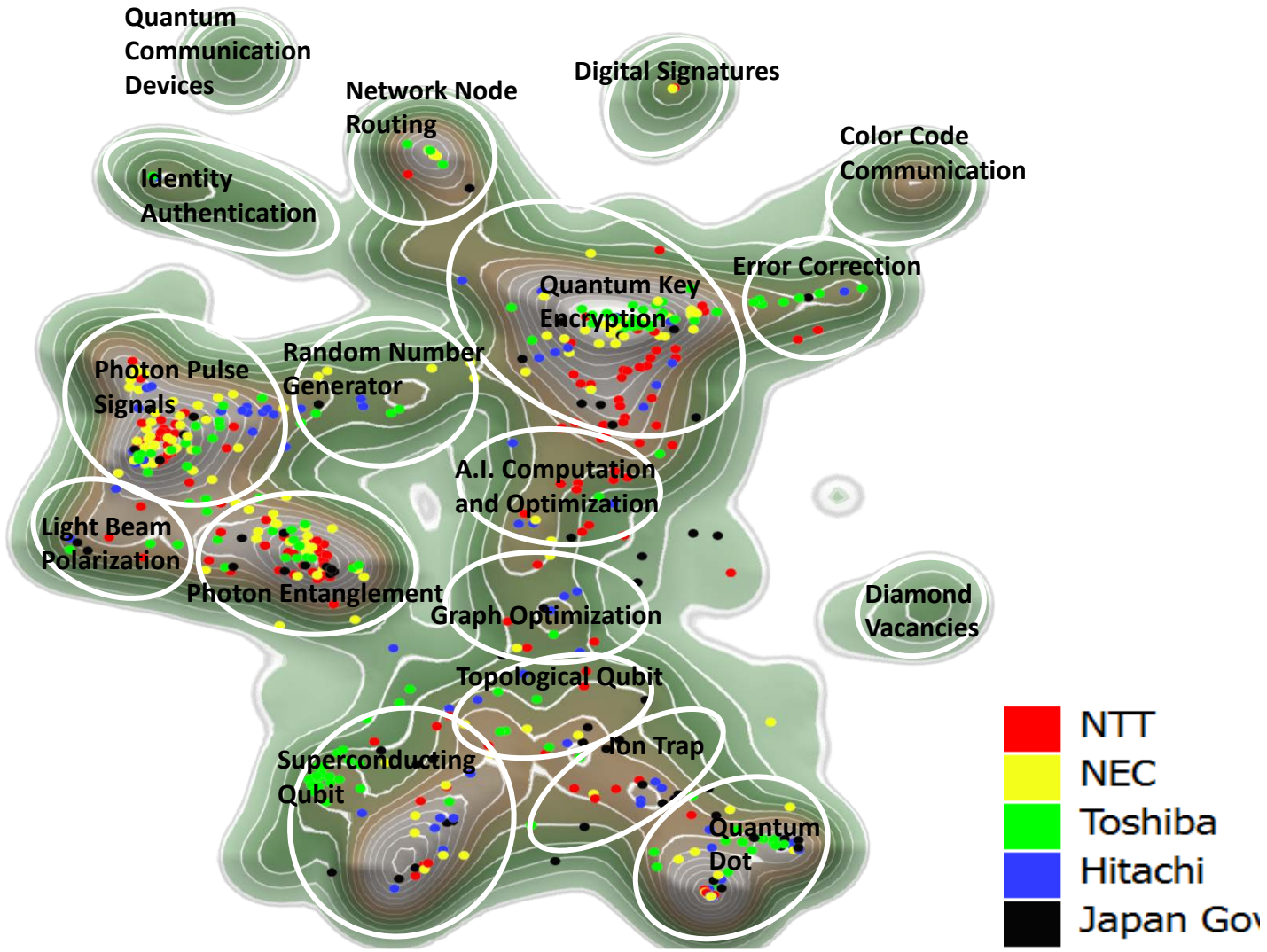
- The Chinese Academy of Sciences and the University of Science and Technology of China both have some interest in qubit technologies despite primarily working in quantum communication and cryptology unlike Qasky and Shenzhou Quantum who are overwhelmingly focused across the communication and cryptology areas of the map




Note: Based on 271 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Quantum Information Technology Patent Families Spatial Concept Map by Top Japanese Organizations

- Overall the Japanese organizations have the highest concentration density throughout the quantum communication and cryptology areas of the map but they also have relatively large collection of documents relating to qubit technology. This differs from the top North American and Chinese organizations who have a clear focus on one or the other
- NEC, NTT and Toshiba have very similar distributions throughout the map with dense clustering throughout photonic communication and the quantum key fields. NEC and NTT are also evenly distributed throughout the qubit area of the map while Toshiba has dense clusters in superconducting qubits and quantum dots




Note: Based on 568 Quantum Information Technology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# *CITATION NETWORK ANALYSIS*

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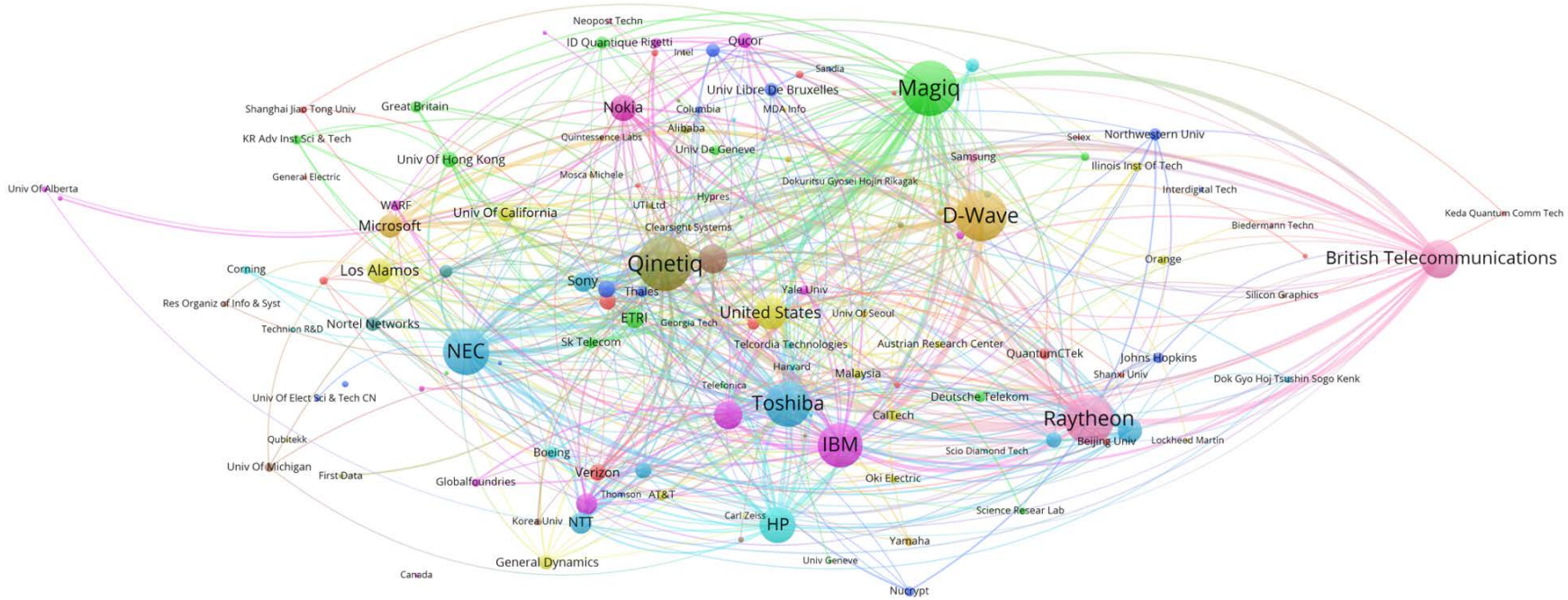
# • Quantum Information Technology Forward Citation Network Map

- The portfolios of D-Wave, MagiQ, Qinetiq, Raytheon, NEC, Toshiba, British Telecom and IBM have the largest number of forward citations (based on the size of their circles) indicating they include potentially influential patent families within the quantum information field

- However when factoring the size of each company's portfolio, Qinetiq and British Telecom become more interesting since their portfolios contain 17, and eight families respectively compared to D-Wave, or NEC who own 158, and 138 respectively



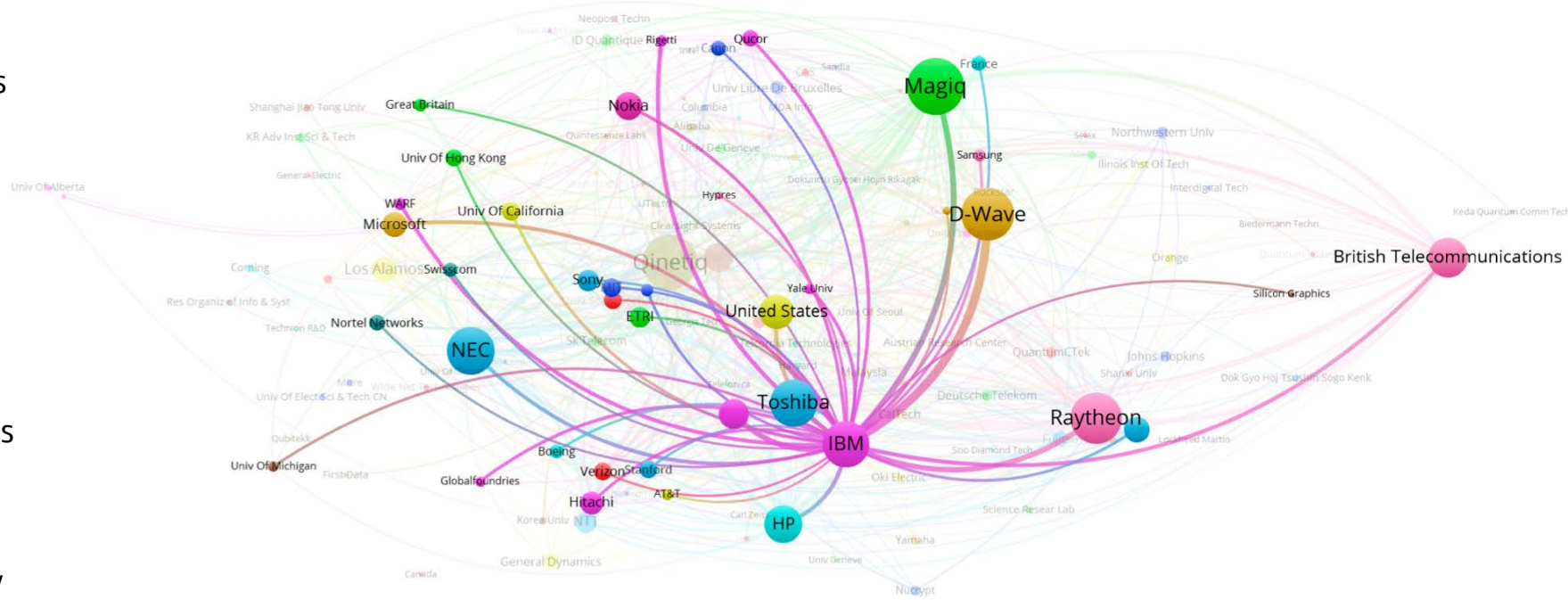

Note: Based on 1,780 Quantum Cryptology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# • Quantum Information Technology Forward Citation Network Map – Focus on IBM

- IBM has one of the most diverse portfolios with QIT, but they are primarily interested in manufacturing quantum computing devices, such as their IBM Q 20 superconducting qubit system that is currently available for users to develop applications on

- Their specific citation network, seen in this image in contrast to the entire QIT network is one of the most extensive involving almost all of the major players in the field

- This is a tangible demonstration of how influential the IBM portfolio is in QIT



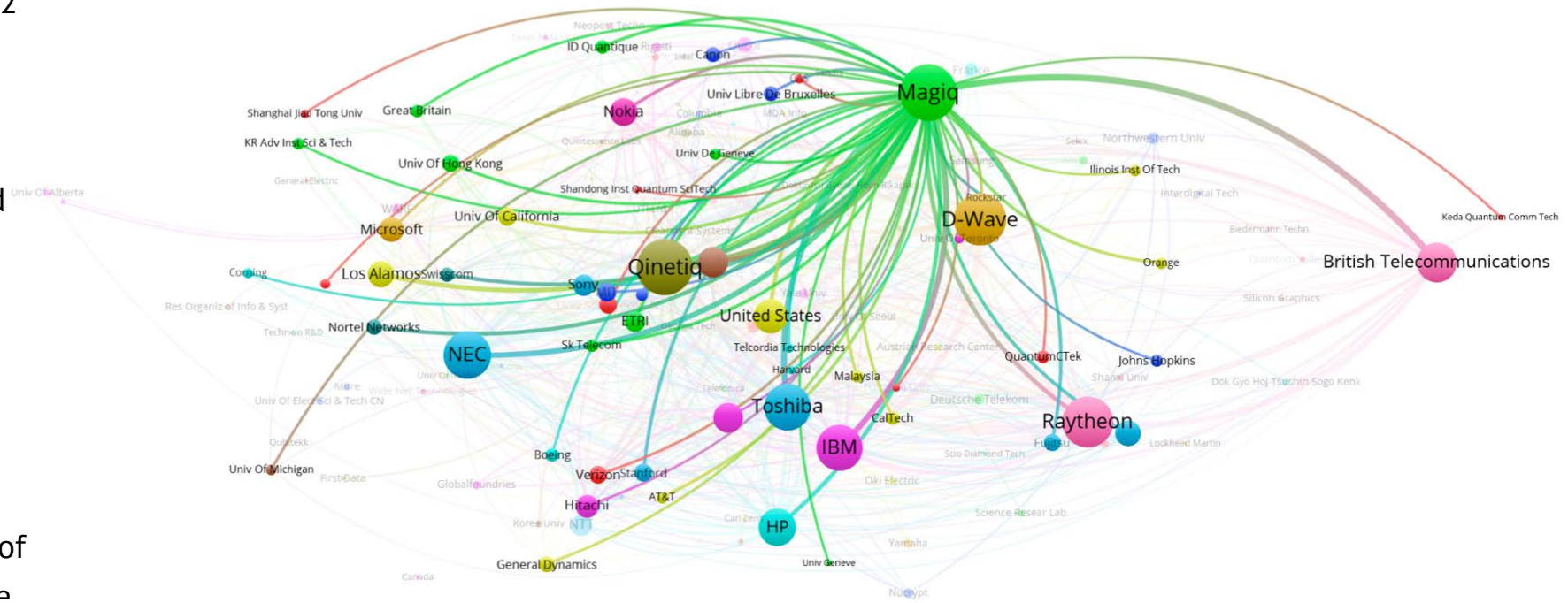

Note: Based on 1,780 Quantum Cryptology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Quantum Information Technology Forward Citation Network Map – Focus on Magiq Technologies

- Magiq Technologies is a bit of an enigma in QIT since they haven't published any patent documents in the area since 2012

- That being said they may have an even more influential portfolio than IBM considering the total number of forward citations associated with their families, and how many different companies are involved in their network

- They were a pioneer in the field of quantum key distribution, and they are positioned very well to take advantage of this technology as it continues to evolve and come to market




Note: Based on 1,780 Quantum Cryptology patent documents from a worldwide search in Derwent Innovation from Clarivate Analytics; limited to one document per family, based on DWPI with US as primary country.

# Collection methodology

- Searching was conducted in worldwide patent documents in Derwent Innovation for the following concepts:
  - IPC / CPC classes specific to quantum computing, nano-technology for information processing, or quantum communications, or encryption
  - For the concepts of quantum computer(s) or processor(s), or qubit(s), or quantum communication(s) or encryption(s), or algorithm(s), or computation(s) in the Titles, Abstracts, or Claims
- Collection was limited to one document per family using DWPI families
  - The US was retained as the primary country
- Categorization based on manual review or classification codes was conducted for these families based on the major categories and sub-categories
- Assignee names were standardized based on known mergers, acquisitions, and change of ownership

# • Acknowledgements


- Patinformatics would like to thank the following organizations for the use of data, or tools for the development of this study:

  - Clarivate Analytics — Derwent Innovation was used for searching, and for reviewing patent records for categorization and relevance

  - Evaluserve — the KMX Patent Analytics package was used for the creation of the spatial concept maps

  - The majority of the charts, and graphs used in this study were generated using Microsoft Excel


# The Analysts

Bryan Scanlon attended Ohio State University where he majored in finance. After Ohio State, Bryan accepted a consulting role at Accenture where he spent time working with AT&T on a number of projects including data analytics work. Now he works with Patinformatics in an analyst role helping clients drive business insights from intellectual property data.

Anthony (Tony) Trippe is Managing Director of Patinformatics, LLC. Patinformatics is an advisory firm specializing in patent analytics and landscaping to support decision making for technology based businesses. In addition to operating Patinformatics, Mr. Trippe is also an Adjunct Professor of IP Management and Markets at Illinois Institute of Technology teaching a course on patent analysis, and landscapes for strategic decision making.

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