

## Quantum Computing

EDGE | COUNTERPOINT GLOBAL TEAM | October 2020

Quantum computing was first theorized in 1981 as a way to address a subset of exponentially complex computing problems that classical computers can't solve. It has taken more than three decades, but we are now at the cusp of moving from scientific theory to commercial reality.

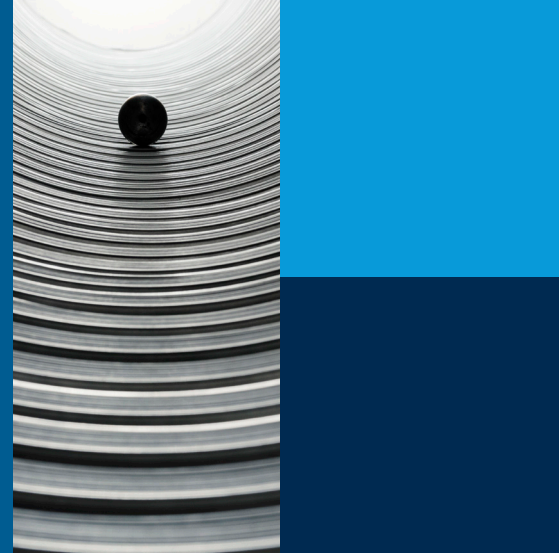
Quantum computers rely on quantum mechanical properties of matter to encode data and perform calculations. These effects, which include superposition and entanglement, occur only at atomic and subatomic scales. Because quantum computers process information in a fundamentally different way than classical computers do, they can tap an exponential increase in computing power. We are likely to achieve quantum supremacy, the point at which quantum computers can solve problems that classical computers cannot, in the next few years. This will move quantum computing from the realm of science project to solving real challenges.

### How It Works

Scientists including Albert Einstein, Max Planck, and Erwin Schrödinger developed the theory of quantum mechanics in the early 1900s. This new theory explained phenomena they saw in their experiments but were unable to reconcile with classical Newtonian physics. These phenomena enable quantum computing.

The fundamental building block in classical computing is the bit, which is either a 0 (the transistor is off) or a 1 (the transistor is on). Transistors, which were invented in 1947, are the building blocks of microprocessors and other computer chips. Computing power has continuously improved by shrinking the size of transistors but we are now running into physical limits.

The fundamental building block in a quantum computer is the quantum bit (qubit). As in classical computing, the qubit also takes the form of a 0 or a 1. But here is where it gets tricky. Due to the quantum phenomenon of superposition, a qubit can also be a 0 and a 1 at the same time. This enables a qubit to store more information than a bit. Quantum computers also benefit from the phenomenon of entanglement, or what Einstein called "spooky action at a distance." When qubits become entangled, they become intrinsically linked and hence no longer act independently. Acting



### WELCOME TO THE EDGE.

Morgan Stanley Investment Management's Counterpoint Global shares their proprietary views on a big idea that has the potential to trigger far-reaching consequences—ideas such as blockchain, autonomous vehicles, machine learning and gene editing.

Counterpoint Global's long-term ownership mindset emphasizes perspective, insight and thinking across categories, while our investment process focuses on identifying unique companies with sustainable competitive advantages. Through The EDGE, we share our framework for thinking about change and our process for recognizing patterns that may drastically alter the investment landscape over the longer term.

This work complements our team's more traditional, fundamental research to create a framework for long-term investing that is grounded in intellectual curiosity and flexibility, perspective, self-awareness and partnership.



on one qubit effectively acts on all the entangled qubits simultaneously. Superposition and entanglement allow quantum computers to process information simultaneously. This means that they have the potential to process massive amounts of data exponentially faster than can a classical computer.

Here's why quantum computing is so groundbreaking: With classical computers, computing power doubles as the number of bits doubles. With quantum computers, computing power doubles when an incremental qubit is added. Today quantum computing is in its infancy, similar to where classical computing was in the early 1950s. And challenges remain. For example, the transistor is the standard form factor for a bit in classical computing, but there is no standardized qubit in quantum computing. Scientists are pursuing multiple methods to build qubits, including superconducting circuits, ion

## Quantum computing is so potentially disruptive because the computing power doubles with every incremental qubit added to the computer.

traps, and silicon quantum dots. The largest quantum computers today have fewer than 100 qubits and are not yet capable of performing useful tasks. However, new applications will blossom as quantum computer hardware improves.

### **Why It's Disruptive**

Ironically, one of the first likely applications of quantum computing is to break encryption on classical computers. The secure transfer of data over the internet relies on public key cryptography, which uses a public key to encrypt data and a private key to decode it. Public key cryptography is currently based on prime number

factoring. The principle is that it is very easy for a computer to multiply two prime numbers together to produce a third number, but exceedingly difficult for a computer to start with the third number and determine its prime factors. The private key is derived from the prime numbers while the public key is derived from their product. Users can make data secure by making the prime numbers so large that factoring their product through brute force is intractable for even the most powerful supercomputers.

Peter Shor, a professor of mathematics at MIT, invented his eponymous algorithm in 1994 that demonstrated

that quantum computers would excel at this factoring problem. A quantum computer could crack a 2048-bit RSA encryption, the gold standard today, in as little as eight hours.<sup>1</sup> RSA-2048 remains secure because the quantum hardware needed to break it does not yet exist. But it could in theory be broken with a perfectly functioning quantum computer of just 4,100 qubits. Based on the present rate of progress, it is likely that a quantum computer will exist within the next decade that will be able to crack today's public key cryptography. Companies, governments, and organizations that rely on public key cryptography (i.e., anyone who sends or receives data via the internet) will therefore need to transition to security protocols that quantum computers can't crack. This change might present cybersecurity companies opportunities and risks and could provide a pathway for new entrants into the field.

While quantum computing is still in the early stage of research, it shows promise in other areas as well. It was originally proposed as a way to model quantum physics and chemistry and those remain promising applications. Classical computers have difficulty modeling the behavior of molecules accurately because a molecule's complexity increases exponentially with the number of electrons in the molecule. For example, caffeine ( $C_8H_{10}N_4O_2$ ), is too complex to model on a classical computer even though it is not a large molecule. This complexity arises because the laws of quantum mechanics govern the behavior of electrons. Electrons are exceedingly difficult to model on classical computers as they can exist in superposition and become entangled.

Here is where quantum computing has a huge advantage. A quantum computer superposes and entangles its own qubits, which innately models

the behavior of electrons in the molecule. This allows a quantum computer to process significantly more data than a classical computer can. The hope is that scientists can fundamentally understand how molecules work on a subatomic level, which will allow them to design better materials, catalysts, and drugs. For instance, bacteria convert atmospheric nitrogen into ammonia using the enzyme nitrogenase more efficiently than do humans, who use the Haber-Bosch process. Scientists know that nitrogenase catalyzes the reaction but still do not understand how. They hope that a better understanding of nitrogenase will allow them to design a more efficient process for making ammonia, the key raw material for nitrogen fertilizers. Producing ammonia more efficiently would not only lower costs but would also reduce greenhouse gas emissions. This type of modeling, made possible by quantum computers, will enable scientists to design everything from better batteries to more efficient solar panels to high-temperature superconductors.

Quantum computing has other potential applications. It could shorten the time required to perform an internet search. It could tackle all sorts of optimization problems such as scheduling, routing, and options pricing. Quantum computing may even apply to machine learning. In each of these domains, quantum computing should be significantly faster than classical computing but may not demonstrate the same exponential increase in processing speed as in cryptography and quantum simulation.

## Challenges

Quantum computing is still in its infancy and there are still a lot of challenges. The incredible power

of quantum computers comes from their ability to harness superposition and entanglement. But these quantum phenomena are very fragile. Decoherence (i.e., losing superposition through the quantum computer's interactions/entanglement with the external environment) causes the quantum computer to lose information to its external environment, similar to how a cooling stove loses heat to its surroundings. This introduces errors into the computer's calculations. Preventing decoherence requires extreme measures such as chilling computers to absolute zero and isolating them from all forms of electromagnetic radiation and sound.

Even with these extraordinary efforts, a quantum computer may have only milliseconds to perform calculations before decoherence renders its results useless. Scientists need to increase coherence time for quantum computers to be truly useful. Quantum computers by nature are error prone because noise can creep into the calculations even without full decoherence when qubits are exposed to the slightest perturbation. Classical computers, by contrast, are discrete and predictable. Scientists are working on error mitigation and error correction strategies simultaneously in order to make quantum computers more practical.

Scaling is a related obstacle. Adding more qubits to a computer increases challenges with decoherence and can add errors into calculations. Figuring out how to increase the number of qubits while reducing errors is a huge focus of research. Finally, scientists need to develop new algorithms to unlock potential applications for quantum computers because they work completely differently than classical computers do.

<sup>1</sup>Emerging Technology from the arVix. (May 30, 2019). How a quantum computer could break 2048-bit RSA encryption in 8 hours. Retrieved from <https://www.technologyreview.com/s/613596/how-a-quantum-computer-could-break-2048-bit-rsa-encryption-in-8-hours/this>.

## Conclusion

The notion that Moore's Law, the idea that classical computing capability doubles every two years, is dead has gained traction in recent years. Quantum computing offers a possible path to continue the improvement in computing. While still nascent, quantum computing has the potential to improve much faster than the rate suggested by Moore's Law. In fact, quantum computing is said to follow Neven's Law, which states,

"Quantum computing is experiencing doubly exponential growth relative to conventional computing." If Neven's Law proves true, we can expect to see huge advances in quantum computing over the next decade. Quantum computing offers the potential to improve our lives by enabling everything from better renewable energy technologies to new drugs to cure complex diseases. Quantum computing could become a foundational technology in the decades ahead.



### Other Disruptors

Other themes the team is currently researching include

- Blockchain
- Autonomous vehicles
- Machine learning
- Automation/robotics

# Counterpoint Global

INVESTORS	FUNDAMENTAL RESEARCH RESPONSIBILITIES	YEARS OF EXPERIENCE	YEARS WITH FIRM	YEARS WITH TEAM
DENNIS LYNCH	Lead Investor   Head of Counterpoint Global	31	27	27
SAM CHAINANI	Head of Counterpoint Global ~ New York, Technology	29	29	25
JASON YEUNG	Health Care	28	23	21
ARMISTEAD NASH	Business Services, Software	25	23	21
DAVID COHEN	Consumer	37	32	26
ALEX NORTON	Consumer, Industrials, Technology (ex Software)	30	25	25
MANAS GAUTAM	Head of Global Endurance, Generalist	13	10	10
ANNE EDELSTEIN	Co-Head of Vitality, Health Care	14	7	7
JENNY LEEDS	Co-Head of Vitality, Health Care	9	6	6
ABHIK KUMAR	Software, Media	16	6	6
JOSHUA JARRETT	Director of Research, Generalist	20	5	5
RUOBING CHANG	Internet	13	9	5
ALEKS SAMETS	Payments	5	5	5
BETH FIFER	Health Care	13	4	4
MUHAMMADRAZA PANJU	Internet	6	4	4
PETE STOVELL	Generalist	31	4	4
MICHAEL MORITZ	Generalist	7	3	3
GINO GRAZIADIO	Generalist	1	1	1
<b>CONSILIENT RESEARCH</b>				
MICHAEL MAUBOUSSIN	Head of Consilient Research	39	5	5
DAN CALLAHAN	Consilient Research	20	5	5
<b>DISRUPTIVE CHANGE RESEARCH</b>				
STAN DELANEY	Big Ideas, Emerging Themes	24	24	21
SASHA COHEN	Big Ideas, Emerging Themes	8	8	8
JUSTIN AMEZQUITA	Big Ideas, Emerging Themes	5	5	5
<b>SUSTAINABILITY RESEARCH</b>				
THOMAS KAMEI	Head of Sustainability Research, Tailwinds	13	13	13
DERRICK MAYO	Sustainability Research	20	11	4
<b>CLIENT RELATIONSHIP &amp; BUSINESS MANAGEMENT</b>				
MARK TODTFELD	Chief Operating Officer	30	20	6
KERRY ANN JAMES	Head of Client Relations, Portfolio Specialist	28	8	4
PRAJAKTA NADKARNI	Portfolio Specialist	21	18	14
MICK MORAN	Portfolio Specialist	11	11	3
MCKENZIE BURKHARDT	Portfolio Specialist	22	22	22
XAVIER SALAZAR	Portfolio Analyst	7	7	3
KATHRYNE HORAN	Portfolio Specialist ~ Global Endurance	13	13	3
EARL PRYCE	Portfolio Administrator	25	25	18
CHAYSE MORGAN	Portfolio Administrator	5	5	5
ERICA CASARENO	Portfolio Administrator	3	3	3
AMBER YANG	Business Management	15	7	4

"Investor" refers to an analyst or portfolio manager of Counterpoint Global.

Team members may change without notice from time to time. Years of Experience listed above refers to Industry Experience.

Years of Experience, Years with Firm and Years with Team are as of February 2025.

## Risk Considerations

There is no assurance that a Portfolio will achieve its investment objective. Portfolios are subject to **market risk**, which is the possibility that the market values of securities owned by the Portfolio will decline and that the value of Portfolio shares may therefore be less than what you paid for them. Market values can change daily due to economic and other events (e.g. natural disasters, health crises, terrorism, conflicts and social unrest) that affect markets, countries, companies or governments. It is difficult to predict the timing, duration, and potential adverse effects (e.g. portfolio liquidity) of events. Accordingly, you can lose money investing in this Portfolio. Please be aware that this Portfolio may be subject to certain additional risks. In general, **equities securities'** values also fluctuate in response to activities specific to a company. Investments in **foreign markets** entail special risks such as currency, political, economic, market and liquidity risks. The risks of investing in **emerging market countries** are greater than risks associated with investments in foreign developed countries. **Privately placed and restricted securities** may be subject to resale restrictions as well as a lack of publicly available information, which will increase their illiquidity and could adversely affect the ability to value and sell them (liquidity risk). **Derivative instruments** may disproportionately increase losses and have a significant impact on performance. They also may be subject to counterparty, liquidity, valuation, correlation and market risks. **Illiquid securities** may be more difficult to sell and value than public traded securities (liquidity risk).

## IMPORTANT INFORMATION

There is no guarantee that any investment strategy will work under all market conditions, and each investor should evaluate their ability to invest for the long-term, especially during periods of downturn in the market.

**A separately managed account may not be appropriate for all investors. Separate accounts managed according to the Strategy include a number of securities and will not necessarily track the performance of any index. Please consider the investment objectives, risks and fees of the Strategy carefully before investing. A minimum asset level is required.**

**For important information about the investment managers, please refer to Form ADV Part 2.**

The views and opinions and/or analysis expressed are those of the author as of the original publication date and are subject to change at any time due to market or economic conditions and may not necessarily come to pass. Furthermore, the views will not be updated or otherwise revised to reflect information that subsequently becomes available or circumstances existing, or changes occurring, after the date of publication. The views expressed do not reflect the opinions of all investment personnel at Morgan Stanley Investment Management (MSIM) and its subsidiaries and affiliates (collectively "the Firm"), and may not be reflected in all the strategies and products that the Firm offers.

Forecasts and/or estimates provided herein are subject to change and may not actually come to pass.

This material is a general communication, which is not impartial and all information provided has been prepared solely for informational and educational purposes and does not constitute an offer or a recommendation to buy or sell any particular security or to adopt any specific investment strategy. The information herein has not been based on a consideration of any individual investor circumstances and is not investment advice, nor should it be construed in any way as tax, accounting, legal or regulatory advice. To that end, investors should seek independent legal and financial advice, including advice as to tax consequences, before making any investment decision.

This material has been prepared on the basis of publicly available information, internally developed data and other third-party sources believed to be reliable. However, no assurances are provided regarding the reliability of such information and the Firm has not sought to independently verify information taken from public and third-party sources.

This material is not a product of Morgan Stanley's Research Department and should not be regarded as a research material or a recommendation.

The Firm has not authorised financial intermediaries to use and to distribute this material, unless such use and distribution is made in accordance with applicable law and regulation. Additionally, financial intermediaries are required to satisfy themselves that the information in this material is appropriate for any person to whom they provide this material in view of that person's circumstances and purpose. The Firm shall not be liable for, and accepts no liability for, the use or misuse of this material by any such financial intermediary.

This material may be translated into other languages. Where such a translation is made this English version remains definitive. If there are any discrepancies between the English version and any version of this material in another language, the English version shall prevail.

The whole or any part of this material may not be directly or indirectly reproduced, copied, modified, used to create a derivative work, performed, displayed, published, posted, licensed, framed, distributed or transmitted or any of its contents disclosed to third parties without the Firm's express written consent. This material may not be linked to unless such hyperlink is for personal and non-commercial use. All information contained herein is proprietary and is protected under copyright and other applicable law.

Morgan Stanley Investment Management is the asset management division of Morgan Stanley.

## DISTRIBUTION

**This material is only intended for and will only be distributed to persons resident in jurisdictions where such distribution or availability would not be contrary to local laws or regulations.**

**MSIM, the asset management division of Morgan Stanley (NYSE: MS), and its affiliates have arrangements in place to market each other's products and services. Each MSIM affiliate is regulated as appropriate in the jurisdiction it operates. MSIM's affiliates are: Eaton Vance Management (International) Limited, Eaton Vance Advisers International Ltd, Calvert Research and Management, Eaton Vance Management, Parametric Portfolio Associates LLC, and Atlanta Capital Management LLC.**

This material has been issued by any one or more of the following entities:

## EMEA

This material is for Professional Clients/Accredited Investors only.

In the EU, MSIM and Eaton Vance materials are issued by MSIM Fund Management (Ireland) Limited ("FMIL"). FMIL is regulated by the Central Bank of Ireland and is incorporated in Ireland as a private company limited by shares with company registration number 616661 and has its registered address at 24-26 City Quay, Dublin 2, DO2 NY19, Ireland.

Outside the EU, MSIM materials are issued by Morgan Stanley Investment Management Limited (MSIM Ltd) is authorised and regulated by the Financial Conduct Authority. Registered in England. Registered No. 1981121. Registered Office: 25 Cabot Square, Canary Wharf, London E14 4QA.

In Switzerland, MSIM materials are issued by Morgan Stanley & Co. International plc, London (Zurich Branch) Authorised and regulated by the Eidgenössische Finanzmarktaufsicht ("FINMA"). Registered Office: Beethovenstrasse 33, 8002 Zurich, Switzerland.

Outside the US and EU, Eaton Vance materials are issued by Eaton Vance Management (International) Limited ("EVMI") 125 Old Broad Street, London, EC2N 1AR, UK, which is authorised and regulated in the United Kingdom by the Financial Conduct Authority.

**Italy:** MSIM FMIL (Milan Branch), (Sede Secondaria di Milano) Palazzo Serbelloni Corso Venezia, 16 20121 Milano, Italy. **The Netherlands:** MSIM FMIL (Amsterdam Branch), Rembrandt Tower, 11th Floor Amstelplein 1 1096HA, Netherlands. **France:** MSIM FMIL (Paris Branch), 61 rue de Monceau 75008 Paris, France. **Spain:** MSIM FMIL (Madrid Branch), Calle Serrano 55, 28006, Madrid, Spain. **Germany:** MSIM FMIL Frankfurt Branch, Große Gallusstraße 18, 60312 Frankfurt am Main, Germany (Gattung: Zweigniederlassung (FDI) gem. § 53b KWG). **Denmark:** MSIM FMIL (Copenhagen Branch), Gorrissen Federspiel, Axel Towers, Axeltorv2, 1609 Copenhagen V, Denmark.

## MIDDLE EAST

**Dubai:** MSIM Ltd (Representative Office, Unit Precinct 3-7th Floor- Unit 701 and 702, Level 7, Gate Precinct Building 3, Dubai International Financial Centre, Dubai, 506501, United Arab Emirates. Telephone: +97 (0)14 709 7158).

This document is distributed in the Dubai International Financial Centre by Morgan Stanley Investment Management Limited (Representative Office), an entity regulated by the Dubai Financial Services Authority ("DFSA"). It is intended for use by professional clients and market counterparties only. This document is not intended for distribution to retail clients, and retail clients should not act upon the information contained in this document.

This document relates to a financial product which is not subject to any form of regulation or approval by the DFSA. The DFSA has no responsibility for reviewing or verifying any documents in connection with this financial product. Accordingly, the DFSA has not approved this document or any other associated documents nor taken any steps to verify the information set out in this document, and has no responsibility for it. The financial product to which this document relates may be illiquid and/or subject to restrictions on its resale or transfer. Prospective purchasers should conduct their own due diligence on the financial product. If you do not understand the contents of this document, you should consult an authorised financial adviser.

## U.S.

**NOT FDIC INSURED. OFFER NO BANK GUARANTEE. MAY LOSE VALUE. NOT INSURED BY ANY FEDERAL GOVERNMENT AGENCY. NOT A DEPOSIT.**

## LATIN AMERICA (BRAZIL, CHILE COLOMBIA, MEXICO, PERU, AND URUGUAY)

This material is for use with an institutional investor or a qualified investor only. All information contained herein is confidential and is for the exclusive use and review of the intended addressee, and may not be passed on to any third party. This material is provided for informational purposes only and does not constitute a public offering, solicitation or recommendation to buy or sell for any product, service, security and/or strategy. A decision to invest should only be made after reading the strategy documentation and conducting in-depth and independent due diligence.

## ASIA PACIFIC

**Hong Kong:** This material is disseminated by Morgan Stanley Asia Limited for use in Hong Kong and shall only be made available to "professional investors" as defined under the Securities and Futures Ordinance of Hong Kong (Cap 571). The contents of this material have not been reviewed nor approved by any regulatory authority including the Securities and Futures Commission in Hong Kong. Accordingly, save where an exemption is available under the relevant law, this material shall not be issued, circulated, distributed, directed at, or made available to, the public in Hong Kong. **Singapore:** This material is disseminated by Morgan Stanley Investment Management Company and should not be considered to be the subject of an invitation for subscription or purchase, whether directly or indirectly, to the public or

any member of the public in Singapore other than (i) to an institutional investor under section 304 of the Securities and Futures Act, Chapter 289 of Singapore ("SFA"); (ii) to a "relevant person" (which includes an accredited investor) pursuant to section 305 of the SFA, and such distribution is in accordance with the conditions specified in section 305 of the SFA; or (iii) otherwise pursuant to, and in accordance with the conditions of, any other applicable provision of the SFA. This publication has not been reviewed by the Monetary Authority of Singapore.

**Australia:** This material is provided by Morgan Stanley Investment Management (Australia) Pty Ltd ABN 22122040037, AFSL No. 314182 and its affiliates and does not constitute an offer of interests. Morgan Stanley Investment Management (Australia) Pty Limited arranges for MSIM affiliates to provide financial services to Australian wholesale clients. Interests will only be offered in circumstances under which no disclosure is required under the Corporations Act 2001 (Cth) (the "Corporations Act"). Any offer of interests will not purport to be an offer of interests in circumstances under which disclosure is required under the Corporations Act and will only be made to persons who qualify as a "wholesale client" (as defined in the Corporations Act). This material will not be lodged with the Australian Securities and Investments Commission.

## JAPAN

For professional investors, this material is circulated or distributed for informational purposes only. For those who are not professional investors, this material is provided in relation to Morgan Stanley Investment Management (Japan) Co., Ltd. ("MSIMJ")'s business with respect to discretionary investment management agreements ("IMA") and investment advisory agreements ("IAA"). This is not for the purpose of a recommendation or solicitation of transactions or offers any particular financial instruments. Under an IMA, with respect to management of assets of a client, the client prescribes basic management policies in advance and commissions MSIMJ to make all investment decisions based on an analysis of the value, etc. of the securities, and MSIMJ accepts such commission. The client shall delegate to MSIMJ the authorities necessary for making investment. MSIMJ exercises the delegated authorities based on investment decisions of MSIMJ, and the client shall not make individual instructions. All investment profits and losses belong to the clients; principal is not guaranteed. Please consider the investment objectives and nature of risks before investing. As an investment advisory fee for an IAA or an IMA, the amount of assets subject to the contract multiplied by a certain rate (the upper limit is 2.20% per annum (including tax)) shall be incurred in proportion to the contract period. For some strategies, a contingency fee may be incurred in addition to the fee mentioned above. Indirect charges also may be incurred, such as brokerage commissions for incorporated securities. Since these charges and expenses are different depending on a contract and other factors, MSIMJ cannot present the rates, upper limits, etc. in advance. All clients should read the Documents Provided Prior to the Conclusion of a Contract carefully before executing an agreement. This material is disseminated in Japan by MSIMJ, Registered No. 410 (Director of Kanto Local Finance Bureau (Financial Instruments Firms)), Membership: the Japan Securities Dealers Association, The Investment Trusts Association, Japan, the Japan Investment Advisers Association and the Type II Financial Instruments Firms Association.

