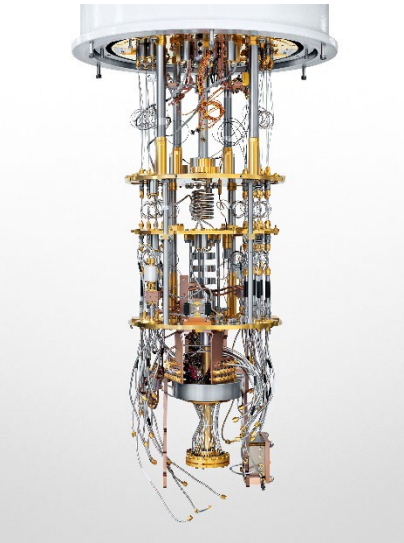
The Quantum Leap
March 7, 2022

Learning More about Quantum Computing



RIGETTI COMPUTING - CHANDELIER

As I've interacted with readers of the Quantum Leap, I'm continually awed by the diversity and openness of so many of the folks involved in the Quantum Computing (QC) field. However, I still find that many people are still put off or intimidated by the concepts covered. While I have tried to orient my posts so that non-technical readers can still benefit, it seems that many well intended, intelligent readers are still baffled by most things "Quantum". And while I don't have a monopoly on the best learning resources, I've been on a pretty long and deep dive in my own quantum journey, so wanted to provide links to some resources to help my readers accelerate their own quantum educations.

In addition, I'll provide some guidance as follows:

- **Easy** items include topics where ZERO math, physics or prior technical knowledge is needed.
- **Moderate** items provide a bit more technical detail but should be approachable for those intellectually curious enough to dig in a bit deeper. Many refer to some advanced concepts such as Entanglement and Superposition, but no formal math or physics training is required to understand the fundamental details.
- **Advanced** items will be reserved for resources that are more technical in nature and/or would take a longer time to get through.

Finally, there are a plethora of resources available on the Internet including articles, podcasts, blogs, interactive learning resources, classes, lectures, seminars, academic papers, etc., so I will also point out a variety of resources and media. Fortunately, there are many resources, delivered in a variety of ways, so I encourage you to try a few and if they don't resonate or feel helpful, skip to the next one. I hope these items accelerate your understanding and spur further learning.

Essentials of Quantum Computing

For an **EASY** introduction, consider the following:

- Article: How to get started in quantum computing, *Nature*, by David Matthews, March 1, 2021: This was my starting point for jumping into the QC world, which provides a good summation as well as a few more learning resources.

- Article: What is quantum computing? Everything you need to know about the strange world of quantum computers, *ZDNet*, by Daphne Leprince-Ringuet, July 29, 2021: An excellent and approachable overview of the landscape with zero math or Greek notation.
- Article: Commercialising quantum computers, *The Economist*, September 26, 2020: Another approachable summary article.
- Online Tutorial: LinkedIn Learning "Introduction to Quantum Computing" is a relatively brief set of videos and interactive quizzes covers a broad range of introductory concepts in a mostly non-technical way.
- Book: Quantum Computing: How it works, and why it could change the world, my Amit Katwala, published in 2021 by *Wired* magazine: No graphs, equations, physics or algebra, just a common language overview.

For a more Moderate introduction, the following are included largely because they are longer and therefore take more time to review. They contain some intermediate concepts but are generally still introductory and should be readable to nearly anyone curious about QC:

- Research Piece: The Next Decade in Quantum Computing – and How to Play, by Philipp Gerbert and Frank Ruess, *Boston Consulting Group*, November 2018: a good overview including some technical details and potential use cases.
- Research Piece: The Coming Quantum Leap in Computing, by Anant Thaker and Suhare Adam, *Boston Consulting Group*, May 16, 2018: Mostly non-math oriented although there are some graphics depicting speedup, which some intermediate math concepts. That said, you should be able to absorb the full content without any math background.
- Research Piece: What Happens When 'If' Turns to 'When' in Quantum Computing, by Jean-Francois Bobier, Matt Langione, Edward Tao, and Antoine Gourevitch, *Boston Consulting Group*, July 2021: Another good overview with use cases and some details on various hardware approaches where math is not required.
- Research Piece: Quantum computing: An emerging ecosystem and industry use cases, *McKinsey & Company*, December 2021: Another broad overview with details on players and use cases, heavy on details but light on math.
- Research Piece: Economic-technological revolution through Quantum 2.0: New super technologies are within reach, by Dr. Hermann Rapp, *Deutsche Bank*, December 17, 2021: A detailed compendium broadly covering QC with very modest levels of technical details or math.
- Research Piece: Broad Interest in Quantum Computing as a Driver of Commercial Success, by Bob Sorensen, *Hyperion Research* (sponsored by D-Wave), November 2021: A focus on use cases and potential commercial users.
- Article: Inside the race to build the best quantum computer on earth, by Gideon Lichfield, *MIT Technology Review*, February 26, 2020: A broad overview with a deep dive into IBM's QC history.
- Article: What is Quantum Computing, *CB Insights*, January 7, 2021: A good mix of some modest technical details and examples along with a broad overview of use cases.
- Online Tutorial: Q-CTRL's Black Opal, a hands-on tutorial with excellent visualizations and short sessions. There is also a fantastic "Practice" section which is a very visual tool for understanding how gates act on qubits (including animations). There are three

"beginner" modules on Superposition, Qubits and Measurement which I have included here as "intermediate" level. More advanced modules are shown below.

- YouTube: "Quantum Computing, Software and Tech" by Anastasia Marchenkova: A charming and approachable series of short videos on various introductory topics and concepts.
- Book: Quantum Computing for Everyone, by Chris Bernhardt, published 2019: Another good intro book although the "for Everyone" in the title is a bit misleading since it digs in a bit on quantum theory and math.
- Book: Quantum Boost, by Brian Lenahan, published 2021: A good intro book covering the basics of QC along with some specific applications.

And here are a bit more **advanced** introductions. While you don't need formal linear algebra or physics backgrounds, these get a more technical and introduce some rudimentary linear algebra in the context of describing qubit gates.

- Article: The Need, Promise and Reality of Quantum Computing, by Jason Roell, published in *Medium* February 1, 2018: Some good introductions to exponential speed-up, details on qubits, superposition and entanglement and quantum volume.
- Article: Quantum Computing, by Sarvesh Patil, published in *Medium* May 16, 2021: Dense but strong overview.
- Book: Quantum Computing: An Applied Approach, by Jack D. Hidary, published 2019: a great foundational overview with a practical approach to programming and detailed appendices focusing on the QC-specific applications of linear algebra. There is a more recent new addition as well as a great companion GitHub site (http://github.com/jackhidary/quantumcomputingbook).
- Book: Quantum Computation and Quantum Information, by Michael Nielsen and Isaac Chuang, 10th Edition published 2010: This is one of the most cited books in physics of all time and is a standard college course textbook often referred to as "Mike & Ike". I have not read this yet but hope to this year, and include it based on its nearly-universal mention by advanced QC users.
- Online Tutorial: Q-CTRL's Black Opal, the hands-on tutorial with excellent visualizations and short sessions noted above. There are three "Intermediate" modules on Circuits, Entanglement and Noise which I have included here as "advanced" level.
- Online Tutorial: Quantum County, by Andy Matuschak and Michael Nielson (of "Mike & Ike" fame), has a novel and engaging method of introducing complex quantum principles including their own "mnemonic" approach which they hope will help users retain the information longer. While this is included in the "advanced" section of this post, I highly recommend this for readers with some basic working understanding of quantum mechanics.

Hardware/Software/Key Players/Use Cases

While some of these topics are broadly covered in the resources noted above, here are some additional resources which drill down further on specific players and uses.

For **EASY** summaries, the following provide a broad overview:

- Article: QC companies of 2021: Guide based on 4 ecosystem maps, by Cem Dilmegani, published in *AI Multiple*, December 17, 2019 and updated February 4, 2022: A good summary of extracts from BCG, Tracxn, Everest Group and Tractics. There are also a number of hyperlinks to additional details.
- Article: Commercial applications of quantum computing, by Francesco Bova, Avi Goldfarb and Roger Melko, *EPJ Quantum Technology*, 2021: Another good summary article also with an extensive list of hyperlinked endnotes.
- Article: Quantum Software Development Kits in 2022, by Cem Dilmegani, published in *AI Multiple*, April 11, 2021 and updated February 8, 2022: A short but dense listing of the key players in QC software development.
- Article: Eight ways quantum computing is going to change the world, by Daphne Leprince-Ringuet, *ZDNet*, December 21, 2021: Plain language descriptions of some key applications of QC.

Additional Resources

In addition to the articles, research pieces, on-line tutorials and books noted above, here are a few more places to continue your QC education:

Podcasts

Classiq publishes a weekly podcast called "The Qubit Guy's Podcast," hosted by CMO Yuval Boger, which I highly recommend (and for an added treat, make sure to check out his February 23rd interview of yours truly). Yuval has an excellent interview style and his podcasts are interesting and right-sized. I particularly recommend his interviews of Jack Hidary (Google/Sandbox/Alphabet), Dr. Robert Sutor (IBM) and Paul Lipman (Coldquanta), although all are worth listening to.

Inside Quantum Technology also showcases its own podcasts, hosted by Christopher Bishop, another highly skilled and interesting interviewer. I suggest his interviews of Chad Rigetti (Rigetti Computing) and Ilyas Khan (Quantinuum).

Aggregators

The Quantum Insider, led by Alex Challans and Evan Kubes, is a great starting point for general QC information and includes directories of Companies, Investors, Funding Rounds, Universities, Government Entities and Quantum Users among other details. They also publish a quarterly and an annual report as well as daily news aggregators.

Quantum Computing Report, put out by Doug Finke, is another aggregator that includes deep dives on players (segregated by Public Companies, Private Companies, Universities, Government and Venture) and hardware scorecards. Doug is a key intermediary in the quantum realm and he is available for a variety of consulting assistance.

Fact Based Insight, founded by David Shaw, is yet another compendium of broad QC information including links to lots of introductory content as well as a daily news aggregator and various company directories and summaries.

Inside Quantum Technology News, in addition to hosting the excellent podcasts noted above, IQT has a robust website, news aggregation and also hosts period industry events, like the upcoming Quantum Enterprise event May 10-12 in San Diego, CA.

The Qubit Report – Because Quantum is Coming, is another news aggregator with its finger on the pulse of current events, research, cybersecurity, software, business and technology among other important QC developments. Their regular LinkedIn posts are a great way to stay current on evolving events and announcements.

Quantum Strategy Institute, led by Brian Lenahan, has a lot of good content including position papers and links and is focused on connecting customers with its network of cross-domain experts to provide consulting services.

Linear Algebra

The bad news is that in order to really understand and appreciate the power of QC, some basic linear algebra is required. This is especially true when trying to understand how gates manipulate qubits. While you don't need to be an expert in all aspects of linear algebra, a working understanding of vectors, scalars, dot products (and orthogonal bases), matrix addition, matrix multiplication, eigenvalues and tensor products will enable a clearer understanding of gates and quantum algorithms. The good news is there are a ton or good resources available for self-learning. Here are two particularly good ones:

3Blue1Brown: a series of video lessons with excellent graphics to help visualize the concepts. The animation engine behind the graphics is a fantastic tool.

Khan Academy: Another resource for video lessons, with accompanying practice questions.

Other Resources

Medium: is a platform for self-publishing, used by a myriad of authors and readers. It doesn't have any particular industry focus, although it can be searched by topics and there are many excellent articles on Quantum Computing included. In addition, some users curate newsletters ("publications") aggregating content from various authors.

qBraid QuBes Course: qBraid is focused on helping high school students, but their content is well done, intuitive and thorough, combining video lectures with coding examples. While some topics dive in a bit beyond what might be approached by non-science users, since it is oriented towards high school students, you should be able to get through the material without a deep math or science background.

Qmunity.tech: Q-munity is a 501(c)(3) non-profit aiming to connect and teach young individuals about Quantum Computing. They offer a number free and paid courses on QC and while some have some technical details, they are geared towards high school students so should be relatively approachable.

***Disclosure**: I have no beneficial positions in stocks discussed in this review, nor do I have any business relationship with any company mentioned in this post. I wrote this article myself and express it as my own opinion.*

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Russ Fein is a venture investor with deep interests in Quantum Computing (QC). For more of his thoughts about QC please visit the link to the left. For more information about his firm, please visit Corporate Fuel. Russ can be reached at russ@quantumleap.blog.