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Images of Quantum Computing: Taking Stock and Moving Forward

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IMAGES OF QUANTUM COMPUTING: TAKING STOCK AND MOVING FORWARD

Research Paper

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Abstract

Quantum computing is attracting increasing attention due to both the threats and the opportunities it may present. Nonetheless, the technology is still nascent and thus far lacks substantive commercial applications that can demonstrate, let alone validate, its potential impact. This uncertainty challenges organizations' ability to make strategic decisions concerning quantum computing. In this study, we explored the practitioners' discourse about quantum computing and the metaphors used to describe the technology and its prospective value. Building on a thematic analysis of 140 video presentations by quantum computing practitioners, we identified ten distinct metaphors of quantum computing. Subsequently, we sorted the metaphors based on the perceived feasibility and strategic potential of the technology to reveal four ways quantum computing may impact the prevailing digital logic. These findings shed light on the alternative development paths of quantum computing business applications and extend the theoretical foundation of this incipient discourse.

Keywords: Quantum technology, Quantum computing, Future research, Metaphors.

1 Introduction

Quantum computing is emerging as a novel technology with the potential to introduce new ways of computing and, perhaps, the next golden age of software engineering (Piattini et al., 2021). While this technology is still in the early stages of development, rising interest from the public sector can be seen in the rapid growth in the number of projects and funding opportunities related to the development of quantum computing in the European Union (Mlynek, 2021; Riedel et al., 2019), the United States (Raymer and Monroe, 2019), and China (Wang et al., 2021). The private sector has also invested heavily in developing quantum computing solutions that could obtain and capture business advantages by radically improving performance for known business problems, exploring new potential applications that were previously not possible, and defending against business adversaries (Jenkins et al., 2022). Interest in quantum computing extends not only to a growing number of start-up companies but also to large digital incumbents, such as IBM, Google, and Microsoft, that are each working towards the first commercial quantum computer (Castelvecchi, 2017; Galanis et al., 2022), as well as to large non-digital incumbents, such as Toyota, that view the technology as a means to improve battery performance (Russell, 2021).

Academic research in quantum computing shows a growing number of publication outputs. Since 2019, more than 18,000 scholars have published quantum-computing-related research in physics and astronomy, materials science, engineering, computer science, mathematics, and chemistry (Wang et al., 2021). Much of this research focuses on hardware development for quantum computing, though some work is also concerned with potential software applications. This is not surprising, because we need to develop commercial-grade functioning quantum computers before we are able to define pertinent business problems and specialized applications to address them. Subsequently, the discussion about the applicability and impact of quantum computing has remained more of a speculative discussion based on thought experiments than an evidence-based debate. Although the principles of quantum computing have been established, we still lack a clear understanding of its relationship with the prevailing computing paradigm and of the types of problems quantum computers are likely to solve more effectively than their digital counterparts (Coveney and Highfield, 2020).

Making sense of quantum computing is challenging because it operates on a radically different functional logic than the familiar digital systems (Ashktorab et al., 2019). With this in mind, how do practitioners make sense of potential new quantum computing systems and applications when these new systems are premised on unfamiliar assumptions? We argue that practitioners utilize metaphors of quantum computing to relate quantum computing to, and contextualize it within, a familiar lived experience. In other words, the metaphors used to describe quantum computing are the key to understanding what quantum computing means to practitioners and how they will appropriate resources for its further development and conceptualization. Thus, this study explores the following research question: *What metaphors of quantum computing are used by practitioners?*

To answer this question, we conducted an exploratory qualitative study of 140 YouTube videos related to the public discourse of practitioners in the field of quantum computing. Following an inductive perspective, we conducted a thematic analysis to identify latent metaphors. The findings reveal ten distinct common metaphors of quantum computing. Subsequently, we sorted the metaphors based on perceived feasibility and strategic potential to reveal four potential ways that quantum computing may impact the prevailing digital logic. These findings shed light on the possible development paths of quantum computing business applications and extend the theoretical foundations of this incipient literature.

2 Theoretical Foundations

2.1 Quantum Physics

Much of the "classic" or "Newtonian" physics taught in schools is arguably intuitive through everyday experiences: an apple falling from a tree can demonstrate gravity, or a car sliding on ice can demonstrate friction (Himsworth, 2022). However, in the early twentieth century, scientists started conducting more experiments to understand the properties of atoms and elements. The scientific community realized that many findings from these experiments are counterintuitive in the context of classical physics, leading to the development of a new field known as quantum physics (California Institute of Technology, 2022). This new branch of physics studies phenomena at atomic scales (Adlam, 2021) and has been responsible for the discovery of many novel and radical new ideas. Noteworthy examples include the "uncertainty principle", which states that we cannot precisely measure the position and the momentum of a particle simultaneously when observing phenomena at atomic scales (Busch et al., 2007); "superposition", which states that an object can be in a combination of multiple states simultaneously until it is measured (California Institute of Technology, 2022); and "entanglement," which states that two particles may be in such a strong correlation that, even if they are physically separated, any change in one will immediately affect the other (Singh and Singh, 2016). In other words, quantum entanglement refers to the property of two or more correlated particles whose states cannot be described independently of the state of the other, thus becoming not individual particle states but an inseparable whole (Zou et al., 2022). While these concepts present a challenge to human comprehension, they have nevertheless provided significant breakthroughs in the study of the physical universe (Laloe, 2019). They have also formed the theoretical basis for a range of important innovations, such as the laser, electric signals, and nuclear magnetic resonance for resonance imaging (Jiang and Chen, 2021).

2.2 Quantum Computing

Arguably one of the most promising applications of quantum principles is the design and development of quantum computing (Himsworth, 2022). Quantum computing may have the potential to revolutionize how digital systems do computation, with the result that the computational power of systems could make a radical jump (Pérez-Castillo et al., 2021; Piattini et al., 2021). Simply put, quantum computers are technologies that operate following the rules of quantum physics instead of the traditional physics assumed by standard digital computers (Ashktorab et al., 2019). This change of modus operandi requires new machines that work under very specific conditions (e.g., cryogenic temperatures), and process information in a very different manner compared to traditional computers, thanks to the superposition and entanglement of qubits (Kietzmann et al., 2021).

Nevertheless, developing a commercial quantum computer is still challenging. Traditional computers store and process information using bits that can only be in the form of one of two physical states ("1" or "0"). In contrast, quantum computers use qubits as a fundamental unit that can be in the form of one of the two physical states ("1", "0"), or also in a linear combination of these two states to conform with the quantum superposition principle (Kietzmann et al., 2021). Attaining stable qubits' superposition unlocks the power of quantum computers to work on millions of computations simultaneously and thus more efficiently than the traditional counterparts (Popkin, 2016). However, this is not easy to do because qubits are affected by the environment that makes the superposition states unstable and fragile. The need to isolate quantum computers from the environment is one of the reasons new hardware solutions like cryogenic machines are developed. If qubits interact with the environment, they lose coherence and therefore lose their quantum advantage (Gill et al., 2022). From a business perspective, the improved hardware capabilities of quantum computing provide opportunities to solve large-scale optimization problems more quickly and cheaply than digital computers, such as portfolio optimization in finance or the development of new drugs and materials in chemistry (Bova et al., 2021). Quantum computing may also open up new areas like molecule simulation for faster and more accurate drug discovery, as well as new forms of communication by restructuring the current satellite-based infrastructure (Hassija et al., 2020).

For these reasons, while still under development and not fully understood, quantum computing has become a key strategic concern for organizations worldwide. Some of the biggest economies, like Europe, the United States, and China, have been investing heavily in quantum-related research as part of strategic national initiatives, collectively funding more than US $12 billion in research and development (Mlynek, 2021). Many public and private organizations are also interested in the strategic power of quantum computing, creating a battle to reach "quantum supremacy"—a milestone at which quantum computing performs computational tasks that would be impossible for digital technologies to solve in a reasonable amount of time (Thanasilp et al., 2021).

Quantum supremacy is a critical milestone in the race for gaining a competitive advantage. Google claimed to achieve it in 2019 when their Sycamore quantum processor using 53 qubits solved a computational problem in 200 seconds that they claimed would have taken 10,000 years for a traditional computer (Arute et al., 2019). After Google's announcement, IBM showed it was possible to solve the problem with a conventional computer in 2.5 days (Pednault et al., 2019), refuting Google's claim of quantum supremacy.

Despite these organizations' sizable investments, quantum computing remains a complex and uncertain technology to many of them, with progress slowed by entry barriers, such as the sparsity of quantum physics knowledge among businesspeople, the lack of experts available to assist in development, and the low standardization and high costs of development (Rietsche et al., 2022).

2.3 Metaphors

Metaphors are essential to making sense of quantum computing, due to its complex and unintuitive nature that does not easily relate to our lived experience. Metaphors are widely used in research and practice, as they help people to construct views about a topic and to understand how people make sense of things and how discourse may shape actions (Berente, 2020). Metaphors are figures of speech used as a comparative tool to create meaning by using a familiar object or image to illustrate the essence or certain characteristics of an unfamiliar object or image (Morgan, 1998). From a more practical perspective, metaphors can be used to explain a concept by offering different views that help to broaden the understanding of the concept and defy the existing assumptions around it (Oates and Fitzgerald, 2007). Metaphors help to open up abstract concepts and make them more digestible to the audience by drawing comparisons to familiar ideas (Hekkala et al., 2018), and generally promote generativity and genre pluralism (Avital et al. 2017). As Lakoff and Johnson (1980) explain, metaphors help people to understand and experience one complex term or concept by using another one and its properties. For example, in the field of information systems, to model and understand the different layers, components, and relationships of IT systems in organizations, the metaphor of enterprise architecture is widely used, as it helps to simplify the complexities through the image of a planning process (Haki and Legner, 2021). Enterprise architecture is not architecture in its literal sense, whereby one defines the design and planning of a physical structure for a specific use. Nonetheless, the metaphor of architecture makes it easier to understand that the IT systems of a company involve different components and relationships that need to be modeled in a way that makes sense and fills a purpose before they are implemented.

Research about metaphors and their use has been widely undertaken in organizational and management fields (Cornelissen, 2005; Cornelissen et al., 2008; Lakoff, 1980; Morgan, 1998; Schön, 1979). From an organizational perspective, metaphors are presented as tools for animating organizations by compressing their complexity and making them capable of being understood (Cornelissen et al., 2008). In the same vein, the information systems literature has also made use of metaphors to understand how team members and managers make sense of IS development projects (Hekkala et al., 2018) or how control-based approaches to project management are counterproductive and can be compared with a chimpanzee tea party (Drummond and Hodgson, 2003). Some other approaches have also been taken, like developing new methodologies to understand the organizational context of information systems development (Oates and Fitzgerald, 2007) or focusing on the limits of metaphors in explaining the role and nature of IS theory (Alter, 2017). In sum, metaphors are of research interest as they play an essential role in the sensemaking process people go through to make the world come alive (Schön, 1979), particularly in unprecedented or unfamiliar contexts (Maitlis and Christianson, 2014).

3 Research Design

3.1 Data Collection

For this exploratory study, a qualitative method was applied to reveal the quantum computing metaphors used in the public discourse of this emerging context. The study builds on publicly available YouTube videos of experts presenting and discussing quantum computing in practitioners' venues. Table 1 displays a detailed list of all data sources. Considering the lack of research related to the perception of quantum computing technologies, we selected the videos following a purposeful sampling, focusing on identifying and selecting videos offering rich data (Suri, 2011). We followed three selection criteria. First, the video had to cover quantum computing-related topics intended for a business practitioner audience. Second, the video had to be openly available on YouTube as part of the public discourse. Third, the video had to be offered by organizations and not individuals to ensure quality control and compliance with business standards. Overall, 140 videos from different organizations covering a total of 52 hours were transcribed and analyzed (see Table 1).

Sources	Details	Videos (#)	Sub-Total
Business Consulting Firms	Accenture YouTube Channels	13	36
	AI Summit UK 2022	1	
	BCG YouTube Channels	2	
	Capgemini YouTube Channels	7	
	Deloitte Quantum Marketplace Seminar	7	
	Deloitte YouTube Channels	3	
	JP Morgan YouTube Channels	2	
	MLT Artificial Intelligence YouTube Channel	1	
Research and Development Firms	AWS Summit ANZ 2022	1	74
	AWS YouTube Channels	3	
	D-Wave Qubit Conference	2	
	D-Wave YouTube Channels	6	
	Google Quantum Summer Symposium 2021	3	
	Google YouTube Channels	9	
	IBM Qiskit Seminar Series	3	
	IBM Seminar Quantum Series	1	
	IBM YouTube Channels	22	
	Intel YouTube Channels	3	
	Microsoft YouTube Channels	21	
General Media	ABC Australia	1	30
	CNBC	1	
	Commercializing Quantum 2022 – The Economist (CQ22)	20	
	QB2 Event 2019, 2020, 2021	4	
	TED Talks	1	
	The Qubit Guy Podcast	1	
	WIRED	1	
	World Economic Forum 2022 (WEF22)	1	
		TOTAL	**140**

Table 1: Data Sources

3.2 Data Analysis

We selected a metaphorical analysis approach, which helps to develop a systematic reflection around and through the perception and communication in a specific context (Myers, 2013). Subsequently, we conducted a thematic analysis to identify and report patterns within the data (Braun and Clarke, 2006). Following an inductive thematic analysis approach (Boje, 2001), we initiated the process with data familiarization, reading and noting the initial ideas presented in the transcriptions of the videos. Next, we followed the approach of Gioia et al. (2013) to ensure a systematic representation of both the informants' and the researchers' perspectives on the topic (see Figure 1). We first identified illustrative semantics that characterized recurring narratives in the discourse. For instance, many speakers discussed the "destruction of current encryption methods" when referring to the risks of quantum computing. Next, we compared and grouped illustrative semantics across the different narratives to form an abstraction of these narratives, specifically in relation to the implicit or explicit use of metaphors. This resulted in ten latent metaphors, for which we defined differentiating descriptive labels. As we developed these labels, we continuously summarized the main ideas embedded in them. We also noted which groups of speakers were using each of the metaphors. Table 2 displays the distribution of metaphors across each group.

Metaphor Distribution	**Group**		
	Business Consulting Firms	R&D Firms	General Media
Mirage	14	30	18
Yo-Yo	0	2	7
Elephant in the Room	7	46	19
AI Demon	5	22	11
Crypto Buster	12	36	18
Supercomputer	29	63	25
Hive	2	13	20
Casino	6	20	14
Silver Bullet	25	56	17
Teleportation Machine	4	20	6

Table 2: Distribution of metaphors among groups of speakers

4 Findings

This section describes ten commonly used metaphors that emerged from the data. Each of these metaphors captures not only a distinct way of conceptualizing quantum computing but also a characteristic attitude toward the potentially destabilizing impact of the technology.

4.1 Quantum Computing as a Mirage

The first metaphor used in the sampled discourse was that of quantum computing as a Mirage. Speakers frequently mentioned their uncertainty regarding what might happen, how to set business goals and develop roadmaps, and when the technology would become available. Moreover, speakers using this metaphor expressed skepticism and caution and were reluctant to give specific commitments or timelines. Thus, speakers compared quantum computing to a Mirage that appears real at first glance but does not exist in reality. The Mirage metaphor reveals skepticism about quantum computing as an unrealistic hope or wish with no specific process for successful achievement. The level of uncertainty about what is possible is critical in this context. The Mirage metaphor is illustrated in a panel talk by one of the chairs of the editorial board at the Financial Times, who said:

> *For most of us, it's very hard right now to work out what is hype, what is real, how it affects all of us in different fields. (WEF22 19.07.2022 3.10.2022)*

4.2 Quantum Computing as a Yo-Yo

The Yo-Yo metaphor is related to the fluctuations in people's expectations of quantum computing. The technology raises organizations' interests, but as soon as they encounter challenges, skepticism appears and their curiosity about or attraction to quantum computing begins to vanish. This metaphor also reveals the skepticism regarding quantum computing. However, in this metaphor the skepticism is directed not necessarily towards the technology but, rather, towards organizations' ability to remain committed once they realize how challenging it will be to develop the resources to make use of the technology. The VP of Biologics at Amgen raised this metaphor in a panel talk, saying:

> *So there's a lot of shiny objects that we could be paying attention to. And there is a tendency in our industry and many others to pay a short amount of*

> *attention to each shiny object and then stop paying attention as soon as something goes wrong. So there's this Yo-Yo effect: "We're all in. Oh, well, it didn't really work as we thought it would, so we're not all in anymore." (CQ22 20.05.2022)*

4.3 Quantum Computing as an Elephant in the Room

Analysis of the quantum discourse revealed some reluctance among speakers when they were asked about, for example, how long it would take for quantum computing to become available or what specific use cases will be seen in the near future. These situations are at the center of the Elephant in the Room metaphor. Many speakers are celebrating quantum computing and hyping up the potential impact of the technology, but fewer speakers are as forthcoming about the remaining challenges they face to make the technology feasible. This approach threatens to oversimplify the concept and undermine the credibility of those advocating quantum computing. Thus, the skepticism this metaphor represents is based on the sense that some speakers either are being irresponsibly optimistic as they become swept up in the hype of a new technology or even may be deliberately evading some scrutiny of their claims by providing only vague details about the progress made thus far. This metaphor is illustrated by a professor of physics at the University of California, who said:

> *I think one of the big problems is it's just not talked about very clearly and transparently. […] I want to see a histogram, you know, a number of qubits and things like that. Now, maybe that's not appropriate here, but this is what the field has to do to give people confidence that we're making progress. (CQ22 20.05.2022)*

4.4 Quantum Computing as an AI Demon

Quantum computing as an AI Demon is a metaphor that focuses on the present concerns regarding the threats that quantum computing will pose when available at full scale in the future. It builds on the idea that human brains operate on quantum-based processes, which explains why we can still outperform supercomputers in terms of decision making in unforeseen circumstances and the ability to innovate. The AI Demon metaphor refers to the science-fiction literature that foresees superior humanoids or enhanced artificially intelligent agents operating without strong regulations to protect societies from misuse and abuse. In the wrong hands, and without proper regulation, quantum computing could become dangerous in the future, especially combined with other technologies like AI. The AI Demon metaphor was illustrated by a postdoctoral researcher at UNSW Sydney, who said:

> *Will we be prepared before a researcher manages to build a full-scale quantum computer that could speed up progress towards superhuman AI? The quantum future is approaching faster than we think. We need to choose whether the AI will liberate or enslave humankind. (ABC Australia 20.05.2022)*

4.5 Quantum Computing as a Crypto Buster

A large group of speakers expressed concerns about the impact quantum computing might have on cybersecurity. While they do not consider the current state of the technology a problem for cybersecurity today, they see it as a potential existential threat for cybersecurity in the future. The metaphor of quantum computing as a Crypto Buster is based on the idea that the technology could abruptly shatter the foundational computational assumptions of cryptography and cybersecurity. Interestingly, this threat is presented as two competing threats of quantum computing to the precarious present balance of cryptography: either it will be able to decrypt all current messages using traditional cryptography, or it will make communications so secure that it would be impossible to decrypt potential threats like terrorist attacks. As an example of this metaphor, a head of industries at Capgemini Quantum Lab said:

> *Mature quantum computers would probably break much of the cryptography that we use today all over the Internet, and that's a real risk. (Capgemini YouTube Channel 21.12.2021)*

4.6 Quantum Computing as a Supercomputer

The Supercomputer metaphor builds on a more optimistic approach toward quantum computing in the near future. It focuses on the idea that by using quantum properties like superposition and entanglement, it will be possible to boost the performance of traditional computing, refining the quality and speed of the analysis we conduct today in classical machines. The central point in this metaphor is the improvement quantum computing brings to classical computing. The Supercomputer metaphor is exemplified by a senior manager of Quantum Research at IBM, who said:

> *We think that quantum computing is going to be used to accelerate the kinds of things that are really hard for classical machines. (WIRED 25.06.2018)*

4.7 Quantum Computing as a Hive

A recurrent topic in the discourse around quantum computing is the leading role of the collaboration between the different participants of the ecosystem. The idea here is that, because quantum computing is still a novel and complex technology, it requires the support of different actors in the community, thinking and acting collectively like bees in a Hive. The conclusion of this idea is that only through this Hive-like approach to developing this technology will organizations achieve their business goals with the technology. The Hive metaphor focuses on the evolutionary perspective on quantum computing, building on an optimistic vision of this technology in the near future. This view is supported by several partnerships between private and public organizations seeking to enhance access to quantum knowledge and other resources. A VP of Quantum Software at Microsoft raised this metaphor when she mentioned:

> *We need to fill the gap between today and our quantum future. And this requires our collective genius. And more importantly, it requires all of you [referring to the participants of the panel session]. It requires you to help unlock quantum discovery and find out how this amazing technology can help move your business forward. (CQ22 20.05.2022)*

4.8 Quantum Computing as a Casino

The Casino metaphor is related to the "bets" placed on quantum computing. The idea here is that the technology is still in a stage where significant risks prevail due to the number of unknowns surrounding the technology, but the risks seem worthwhile considering its potential and the opportunities it might generate. Just as not all the games in a Casino are equal, the same is true of quantum computing. Today, it looks like a slot machine, where anything might happen, and some of the advances seem like mere luck. However, some specialists have mentioned the need to build a "quantum intuition," deepening our understanding of this technology today so that we can practice and prepare for the future. This scenario seems more similar to games like blackjack and poker, where technique and experience can be more relevant than luck. This metaphor emerges from the vision of the short-term tasks and bets that can be made to achieve the opportunities quantum computing is expected to bring. The Casino metaphor can be observed in the statement of a journalist from CNBC:

> *Venture capital investors are pouring hundreds of millions of dollars into quantum computing startups, even though practical applications are years or even decades away. By 2019, private investors have backed at least 52 quantum technology companies around the world since 2012, according to an analysis by Nature [the journal]. Many of them were spun out of research teams at universities in 2017 and 2018. (CNBC 10.01.2020)*

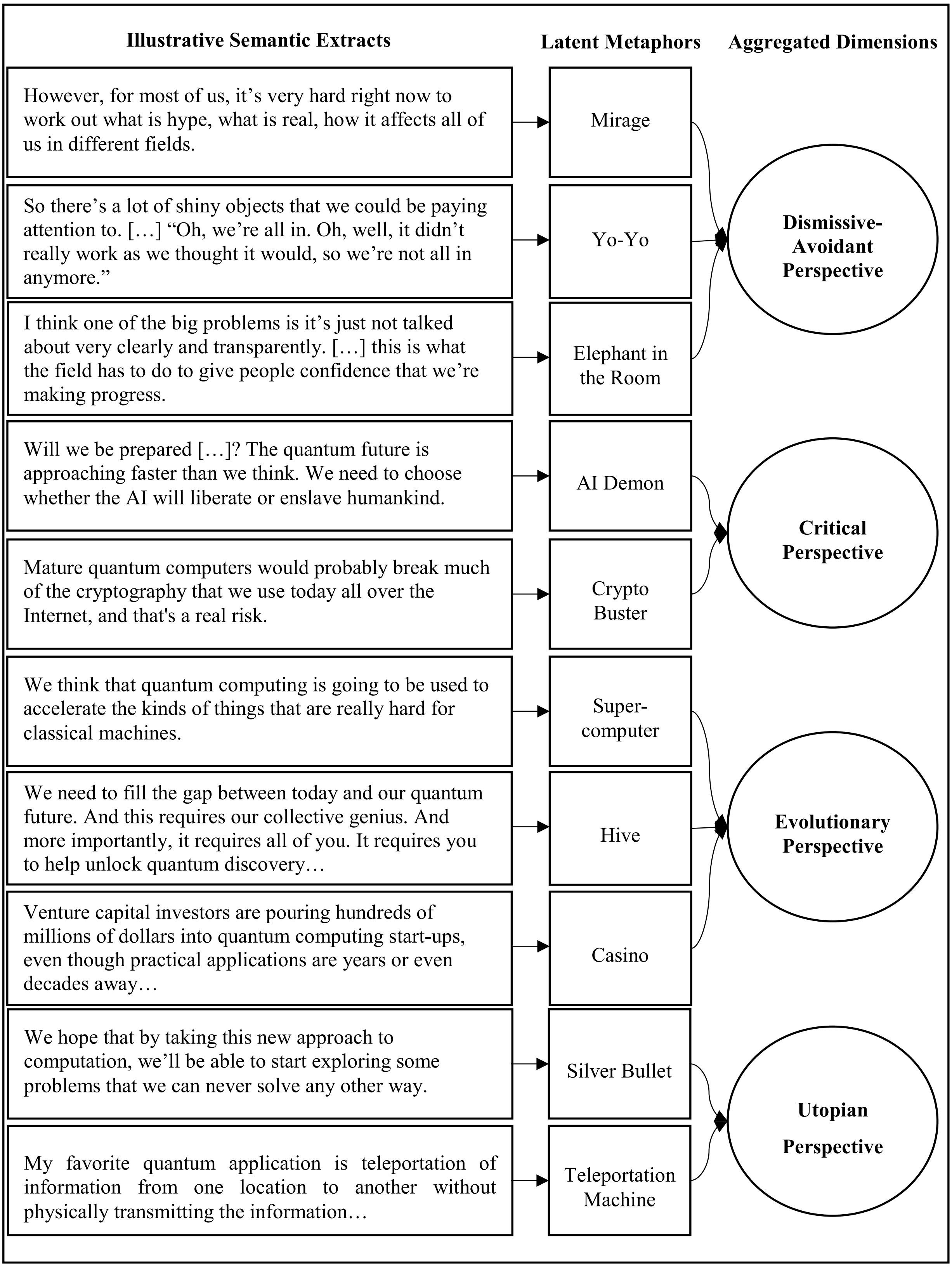

Figure 1: Data structure of quantum computing metaphors and aggregated dimensions

4.9 Quantum Computing as a Silver Bullet

The Silver Bullet metaphor represents the idea that quantum computing is the solution to all complex problems in the world. The idea here is that several complex problems cannot be simulated on classical systems. Therefore, a quantum computer seems the natural solution to address this situation. This metaphor focuses on the idealistic vision of the future associated in which quantum computing will be used to handle and solve all the problems that are impossible to solve today with classical computing. The Silver Bullet metaphor is illustrated by a senior manager of Quantum Research at IBM, who said:

> *We hope that by taking this new approach to computation, we'll be able to start exploring some problems that we can never solve any other way. (WIRED 25.06.2018)*

4.10 Quantum Computing as a Teleportation Machine

The quantum computing discourse entertains several futuristic ideas. The Teleportation Machine metaphor signifies potential opportunities for the future. Instead of focusing on solving complex problems like the Silver Bullet metaphor, this metaphor builds on the idea that quantum computing will open new frontiers in human societies. For example, the ability to teleport physical objects and living entities through space and perhaps time as well. The Teleportation Machine metaphor is demonstrated by the Director of the Centre of Women in Science, who said:

> *My favorite quantum application is teleportation of information from one location to another without physically transmitting the information. Sounds like sci-fi, but it is possible. (Ted Talks 01.02.2019)*

5 Discussion

The metaphors described in the previous section shed light on how practitioners perceive and conceptualize quantum computing in order to make sense of the various possibilities before the technology is actually ready to deploy. These metaphors also represent varying attitudes toward quantum computing and the scale and nature of its possible impact. This section aggregates these latent metaphors into four mutually exclusive perspectives based on their respective relationship to the feasibility and strategic potential dimensions. Sorting the metaphors into these archetypical categories provides a top-level view of the potential commercial development paths of quantum computing.

5.1 Perspectives on Quantum Computing

Taking into consideration the ten different metaphors presented in our findings, we observe that while some of these metaphors focus on the threats that quantum computing might present, others focus on the opportunities that the technology might generate. Further, the ten metaphors also differ according to their temporal focus. While some metaphors focus on what can be done with the technology in the realizable near future through the interaction of quantum computing with existing systems, others focus on the imaginable distant future and the interaction of quantum computing with as-yet unknown future systems. With these dimensions in mind, it is possible to classify the different metaphors into four perspectives (see Table 3 and Table 4).

The "Dismissive-Avoidant" perspective includes metaphors that focus on the realizable near future threat. People that adopt this perspective are "Skeptics"; specifically, they are skeptical of the ability to actually apply and evolve quantum computing (Mirage), skeptical of the value quantum computing will generate if it can be applied (Yo-Yo), or skeptical of the specific opportunities and challenges that are being anticipated due to the lack of transparency related to complex topics (Elephant in the Room).

The "Evolutionary" perspective includes metaphors that focus on the realizable near future opportunity. People that adopt this perspective can be called "Believers"; they believe that quantum computing represents the next leap forward in computational power (Supercomputer), the belief that quantum computing represents the next leap forward in terms of connectivity and collaborations (Hive), or the belief that quantum computing and "quantum intuition" represent the next leap forward in terms of approaches to problem solving (Casino).

Feasibility			
	Imaginable Distant Future	**Critical Perspective** **(The Concerned)** • AI Demon • Crypto Buster	**Utopian Perspective** **(The Dreamers)** • Silver Bullet • Teleportation Machine
	Realizable Near Future	**Dismissive-Avoidant Perspective** **(The Skeptics)** • Mirage • Yo-Yo • Elephant in the Room	**Evolutionary Perspective** **(The Believers)** • Supercomputer • Hive • Casino
		Threat	Opportunity
		Strategic Potential	

Table 3: Perspectives on Quantum Computing

The "Critical" perspective includes metaphors that focus on the imaginable distant future threat. People adopting this perspective can be called "Concerned"; that is, they are concerned about the detrimental misuses and abuses of the technology due to the lack of regulations to protect societies (AI Demon) or about the potential destruction of traditional cybersecurity measures and the new forms of potential attacks that quantum computing could enable (Crypto Buster).

Finally, the "Utopian" perspective includes metaphors that focus on the imaginable distant future opportunity. People adopting this perspective can be called "Dreamers"; they dream that quantum computers will help to solve important problems that are considered impossible to solve today (Silver Bullet) or even that quantum computing will open radical new frontiers in what is possible, like teleportation (Teleportation Machine).

Additionally, the analysis identified a connection between these four perspectives and the potential impact that quantum computing could have on the future development path of the prevailing digital logic and consequent technologies. Following Yoo et al. (2010), digital technologies are characterized by common logic. First, they are reprogrammable (i.e., the functional logic of digital technology is separated from the physical element that executes it). Second, their data are homogeneous (i.e., all digital data can be combined with other digital data, as well as stored, transformed, and transmitted, eliminating product boundaries). Third, they are self-referential by nature (i.e., we need digital technologies to create more digital technologies). Our analysis shows that quantum computing may have implications for this assumed logic (see Table 4).

The extent of this change in logic varied across perspectives. Skeptics adopting the Dismissive-Avoidant perspective did not indicate that quantum computing would fundamentally challenge the current digital logic. Instead, it is often implicit within this perspective that quantum computing may fail because it requires new technological capabilities that do not seem likely to arrive.

Believers adopting the Evolutionary perspective implied that quantum computers will help to expand and improve what is possible to do with current digital technologies, such as training digital computers using quantum principles and expanding the knowledge and intuition of current digital specialists through learning and collaboration. According to this perspective, while quantum computers cannot integrate with digital systems directly, they can expand the digital logic by adding another layer to the existing "stack" of technologies on which digital systems build.

Perspective	Implications for Digital Logic
Dismissive-Avoidant (Skeptics)	None
Evolutionary (Believers)	Expansion of the current digital logic
Critical (Concerned)	Collapsing of the current digital logic
Utopian (Dreamers)	New logic creation: quantum logic

Table 4: Implications of each perspective for the prevailing digital logic

Concerned speakers adopting the Critical perspective assumed that the use and application of quantum principles through quantum computing could destroy or collapse the digital logic. This is not only because quantum computing presents a distinct logic but also because the capabilities of this new logic undermine some of the environmental constraints that the digital logic has treated as constants. An important example is the previously unattainable computational power that is needed to overcome cryptography based on RSA encryption.

Finally, Dreamers adopting the Utopian perspective suggested that quantum computing represents a new quantum logic that is not only different from but also superior to the current digital logic. Dreamers argue that quantum computing introduces different rules that open new technological frontiers and new system goals that have previously seemed impossible. This will render the prevailing digital logic obsolete once quantum systems become practical, leading to a new era of design and innovation.

5.2 Contributions and research agenda

This study's contributions are both theoretical and practical. The paper explores the emergent perceptions around quantum computing that are present in the public discourse so as to make sense of this novel technology. From the data we obtained, we identified ten metaphors that illustrate how quantum computing is understood and envisioned: the Mirage, the Yo-Yo, the Elephant in the Room, the AI Demon, the Crypto Buster, the Supercomputer, the Hive, the Casino, the Silver Bullet, and the Teleportation Machine. We abstract from these metaphors into four perspectives on quantum computing: Dismissive-Avoidant, Evolutionary, Critical, and Utopian. At the heart of these different perspectives are contrasting views of quantum computing along two dimensions: the strategic potential in terms of threats and opportunities and the feasibility span in terms of realizable near future and imaginable distant future. Taken together, these dimensions, perspectives, and metaphors provide an empirical and theoretical foundation to encourage and position much needed further research on quantum computing.

Our analysis also raises questions about the compatibility of quantum computing with the existing digital logic. For those who believe quantum computing will have an impact, it appears that the arrival of quantum machines could expand the current digital logic, collapse it, or create a new quantum logic. These digital logics have played an important transformation role in recent decades (Baiyere et al., 2020). The implications of quantum computing for digital logic are therefore important for researchers to understand if we are to anticipate the possible impact of emerging quantum technologies.

In terms of practice, the contributions of this paper are concentrated on helping to develop a "quantum intuition." There is still a lack of knowledge, understanding, and skill development about quantum computing outside physics-related fields (Fox et al., 2020; Wang et al., 2021). The ten metaphors and four perspectives identified here offer a helpful starting point for practitioners and researchers to explore and analyze the different perceptions around quantum computing among business leaders. These perceptions are likely to change in the coming years as the capabilities of quantum computing become clearer. Future research efforts should thus take a longitudinal approach to observe these changes and the underlying shift over time across the different perspectives.

The rising investment in quantum computing from the public and private sectors (Mlynek, 2021; Riedel et al., 2019) supports the view that, while still in the early stages, quantum computing will evolve into a practical and useful technology. Linking the growing investment levels with specific metaphors and perspectives may also provide some insights into the ways those metaphors and perspectives are being used. For example, if the investment becomes more concentrated in the Evolutionary perspective, this may suggest that less revolutionary capabilities are maturing. In contrast, if the investment becomes concentrated in the Utopian or Critical perspective, this could signal that seemingly revolutionary capabilities are becoming more feasible.

5.3 Limitations

This study has multiple limitations to consider. First, we did not sample other sources of data, such as offline public discourses or digital public sources like blog posts and reports. Analyzing those other sources could help to capture the discourse from other populations of practitioners and thus mitigate the potential bias in the analysis.

Second, although we collected the data from a broad range of organizations, none of these organizations' discourses were analyzed over a longer period. A longitudinal analysis would help to identify potential changes and evolutions in the perspectives and could also help to identify how perceived self-interest impacts the way quantum computing is described. This limitation should be addressed in future studies by investigating the evolution of the narratives through time.

Third, while our discussion focused on how the perspectives might impact digital logic, we did not develop a reflection on how each metaphor relates to the academic debates around these topics. For some metaphors like the "Crypto Buster," the debate on post-quantum cryptography and quantum key distribution is receiving considerable attention (Lamacchia, 2022; Monroe, 2023; Tan, 2022). Future research should address this concern by analyzing the relation of the metaphors with the current debates in the academic field.

Finally, the context of quantum computing is still in the early stages, presenting different levels of experimentation and uncertainty of future applications. While this technology evolves, it is likely that the images of quantum computing will change accordingly, as new novel metaphors emerge while others fade away. Future research should continue investigating these discourses to examine how metaphors and perspectives change as quantum computing matures.

6 Conclusion

This study investigated the research question *What metaphors of quantum computing are used by practitioners?* To answer this question, we conducted an exploratory qualitative study of public discourse in 140 YouTube videos by various practitioners in the field of quantum computing (consultancy firms, research and development firms, and general media). The analysis identified ten common metaphors used to make sense of quantum computing, representing four archetypical perspectives on the technology. The findings also draw attention to the potential challenges that quantum computing may pose to the current digital logic and derivative technologies, by expanding them, destroying them, or perhaps even replacing them with a new quantum logic.

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