Guest Editors' Introduction

Quantum Visual Computing

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Quantum computing is emerging as a transformative force in computer science, offering significant advantages in speed and efficiency over classical computing methods. Despite this promise, the practical application of quantum computing to visual computing faces numerous challenges, including the complexity of quantum algorithms and the limitations of current quantum hardware. These challenges underscore the necessity for focused research and collaboration in this interdisciplinary area. This special issue of IEEE Computer Graphics and Applications, "Quantum Visual Computing," aims at drawing attention to these challenges and bringing together pioneering research at the intersection of quantum and visual computing. By fostering dialogue and innovation between these fields, we hope to inspire new solutions and advance the state of the art in both domains.

Quantum computing holds the promise of revolutionizing various fields within computer science, offering unprecedented speed and efficiency compared to classical computing methods. This special issue of IEEE Computer Graphics and Applications, "Quantum Visual Computing," focuses on how quantum computing can benefit the field of visual computing—and vice versa—in applications such as image processing, rendering, games, and education.

The core of quantum computing lies in its use of registers of quantum bits, so-called *qubits*, which can exist in a superposition of multiple states and are capable of entanglement. These properties enable quantum computers to solve certain problems more efficiently than classical computers. For visual computing, this could mean improvements in rendering techniques, faster image processing, and more advanced machine learning models in computer vision. Conversely, visual computing techniques can aid in better understanding and faster development of quantum algorithms through better visualizations and interactive tools.

Quantum visual computing is an emerging field with significant potential. Evidence of the current interest in quantum computing from computer graphics and visual computing in general can be seen in introductory quantum computing courses being offered at SIGGRAPH 2023 [1] and 2024 [2], Dario Gil's 2023 keynote on "What's next in Quantum Computing"[a], the Quantum Computer Vision and Machine Learning workshops at CVPR 2023 and ECCV 2024[b] and the importance of quantum computing in NVIDIA keynotes over the past years[c]. Just last year, Bethel et al. [3] predicted disruptive changes resulting from quantum computing and visualization in IEEE CG&A. This special issue brings together research that explores these intersections. The goal is to foster a deeper understanding of how quantum computing and visual computing interact and to stimulate collaboration between experts in these fields. By understanding how quantum computing can enhance visual computing, and how visual computing can aid quantum computing, we can pave the way for novel solutions to complex problems. We hope this special issue provides valuable insights into the intersection of quantum and visual computing and inspires future research in this promising area.

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[a] https://history.siggraph.org/learning/siggraph-2023-opening-session-keynote-dario-gil-whats-next-in-quantum-computing-by-gil

[b] https://qcvml.github.io

[c] https://youtu.be/DiGB5uAYKAg?t=754

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CHALLENGES IN QUANTUM VISUAL COMPUTING

Quantum visual computing, the intersection of quantum computing and visual computing—an umbrella term for all fields of computing involving visual data, such as computer graphics, computer vision, image processing, visualization, and (serious) games—poses a number of unique and non-trivial challenges.

Interdisciplinary Knowledge Gap

Combining quantum computing and visual computing requires a unique blend of expertise that spans both domains. However, there is often a knowledge gap between researchers and practitioners in these fields. Many computer science curricula still do not include quantum computing courses, as quantum computing was previously mostly considered a subdomain of physics, but this is changing with many universities beginning to offer such courses. Bridging this gap is essential to advance quantum visual computing. This can be achieved through targeted educational initiatives, collaborative research projects, and the development of accessible tools and platforms that facilitate cross-disciplinary learning and innovation.

Algorithm Development

One of the foremost challenges in quantum visual computing lies in the inherent complexity of quantum algorithms and the difficulty in developing an intuitive understanding of quantum computing. Developing efficient quantum algorithms for tasks such as image processing, rendering, and machine learning poses significant difficulties. With novel visualization techniques and educational games, visual computing can assist in developing such an intuition. At the same time, computer science in general can assist in developing better abstractions than the low-level quantum circuits commonly used to describe quantum algorithms.

Visualization of Quantum States

Visualizing quantum states themselves presents a unique set of challenges. Quantum states and phenomena such as superposition and entanglement are not easily represented using conventional visualization techniques, as the number of variables increases exponentially with the number of qubits. Developing intuitive and effective methods for visualizing quantum states—especially during execution of quantum algorithms—is crucial for both understanding and communicating quantum concepts. This challenge extends to creating visualizations that can aid in debugging and optimizing quantum algorithms, as well as making quantum computing more accessible to non-experts.

Hardware Limitations

Current quantum hardware is still in the early stages, characterized by limited qubit counts, high error rates, and decoherence issues. These factors are why quantum computing is currently considered to be in the NISQ era—the Noisy Intermediate-Scale Quantum era. These limitations significantly impact the practical implementation of quantum visual computing applications. To realize the full potential of quantum visual computing, advancements in quantum hardware are essential. This includes increasing the number of stable qubits, improving error correction methods, and extending coherence times. However, quantum computer vendors expect significant improvements in the near future and hardware limitations do not limit the theoretical development of algorithms. Additionally, this opens up a large space for research into robust and hybrid algorithms, as well as approaches using more specialized hardware such as quantum annealers.

ARTICLES IN THE SPECIAL ISSUE

After rigorous review and revisions, we have selected three papers—out of an initial seven submissions—for publication in this special issue. The three papers in this issue contribute to the broader theme of quantum visual computing in various ways.

They illustrate the diverse applications of quantum computing in visual computing and vice versa. By addressing different aspects of the field—from game development to image segmentation and educational tools—they provide a comprehensive view of the current state and future possibilities of quantum visual computing.

A Chronicle of Quantum Technologies in Game and Software Development

The first paper provides a survey of the application of quantum technologies in game development. It explores how quantum phenomena can be used to create new gaming experiences and discusses the potential for future advancements. This work is crucial for understanding the practical applications of quantum computing in interactive media and software development, and how these applications can enrich visual computing. It also provides readers from the field of visual computing with a rough idea of what quantum computing is and how they can benefit from it.

Q-Seg: Quantum Annealing-Based Unsupervised Image Segmentation

The second paper introduces Q-Seg, a novel image segmentation method that leverages quantum annealing. By framing the segmentation problem as a graphcut optimization task, the authors demonstrate how quantum hardware can be used to solve complex image processing problems more efficiently. This paper highlights the potential of quantum computing to enhance image processing, making them faster and more scalable, thus showing direct benefits of quantum computing for visual computing.

Quantum Machine Learning Playground
The third paper discusses an interactive visualization tool designed to help users understand quantum machine learning (QML) algorithms. It draws parallels between classical machine learning tools and QML, providing an accessible entry point for those new to the field. This paper emphasizes the importance of visualization in making complex quantum concepts more comprehensible, thereby aiding education and research in quantum computing. This demonstrates how visual computing can contribute to quantum computing by making it more accessible and easier to learn.

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DISCLAIMER

Peer review and decision-making for “Quantum Machine Learning Playground” by Pascal Debus, Sebastian Issel, and Kilian Tscharke as well as another submission by authors who work or worked at Fraunhofer institutes were handled by the non-conflicted guest editors Vladislav Golyanik and Tolga Birdal; Johannes Mueller-Roemer had no role in determining the outcome of this article.

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