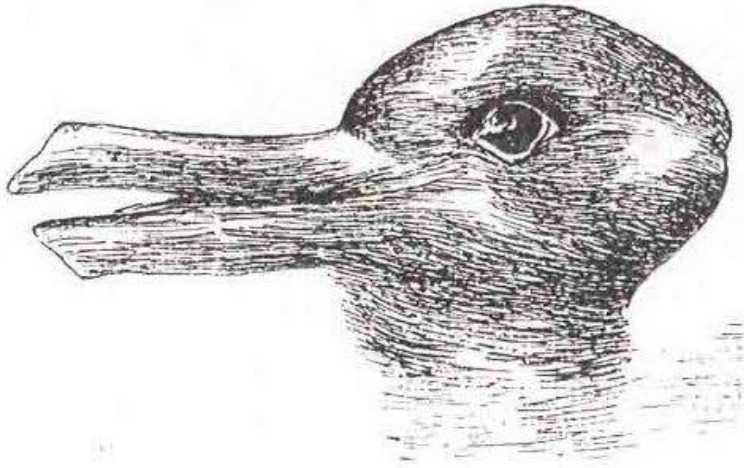


Quantum intrinsic curiosity algorithms



The famous duck-rabbit ambiguous image. Is it a duck? Is it a rabbit? Source: Source: Jastrow, J. (1899). The mind's eye. *Popular Science Monthly*, 54, 299–312.

https://commons.wikimedia.org/wiki/File:Duck-Rabbit_illusion.jpg

The famous duck-rabbit optical illusion [4] elucidates how human neuronal processes are integrative, resulting in the impossibility of perceiving the duck image and the rabbit image simultaneously. Instead of perceiving a duckrabbit, which would be a superposition of the two images, the human brain alternates focus from one image to the other image [3]. The question we pose is the following: Under what neuronal conditions could humans perceive the two images simultaneously? That is, what would it take for us to perceive a duckrabbit? We claim the key is quantum thinking, which is a bio-mimicry, a quantum-mimicry, that is a type of critical thinking that mimics the fundamental principles of quantum mechanics, like superposition and entanglement. Simply put, quantum thinking is thinking in concept superposition and simultaneous computation. We claim that infusing quantum thinking into current AI learning algorithms can help AI adapt to complex, dynamic, and unpredictable scenarios, areas in which it currently faces challenges. Further, quantum thinking for AI is critical for AI to develop common sense since quantum thinking incorporates lateral and creative non-linear thinking and enhances AI's capacity to

collaborate with humans effectively. To that end, the purpose of our manuscript is two-fold: We propose a quantum curiosity algorithm as a means to implement quantum thinking into AI, and we illustrate 5 new quantum curiosity types. We then introduce 6 new hybrid quantum curiosity types combining animal and plant curiosity elements with biomimicry beyond human sensing. We then introduce 4 specialized quantum curiosity types, which incorporate quantum thinking into coding frameworks to transform problem-solving and discovery in science, medicine, and systems analysis. We conclude with a forecasting of the future of quantum thinking in AI and illustrate an example of how to apply the new curiosity types: General Collaborative Networks.

Quantum Thinking

In our approach to technology and software development, we employ the term “quantum” to refer to methods and constructs inspired by the profound concepts of quantum mechanics. While these algorithms may not directly utilize quantum mechanics or involve subatomic particles, the essence of “quantum thinking” underlies their design. We define quantum thinking as a cognitive framework inspired by principles of quantum mechanics intertwined with computational thinking that embraces uncertainty and complexity. This novel perspective encourages us to explore unconventional possibilities and embrace non-linear thought processes, allowing us to break free from traditional limitations and envision new horizons. By infusing quantum principles into software, we may strive to create cutting-edge solutions that transcend the boundaries of classical approaches and pave the way for more sophisticated and forward-thinking algorithmic bits of intelligence.

Quantum Curiosity Algorithm

A defining aspect of human cognition is curiosity, which we define as the ability to self-organize a direction of exploration, where exploration means interfacing with a new environment or information set. Psychologists have classified human curiosity into epistemic and perceptual curiosity, while molecular biologists have identified a gene (DRD4) that plays a role in exploring novelty [1]. Computer scientists have further classified curiosity in reinforcement learning as intrinsic because it drives algorithmic

behaviors without external triggers. By intrinsic, we refer to characteristics that are inherent or internal to the nature of something. That is, a sofa has intrinsic properties based on the fabric and other materials it was made out of; a Higgs Boson likewise has intrinsic properties that are different from, say, a Neutrino. For example, intrinsic social curiosity refers to the internal drive or desire that comes from within an individual to seek out information about what other people are thinking, feeling, or doing.

Curiosity is a multi-dimensional metacognitive phenomenon that plays a central role in both critical thinking and intrinsic motivation to action [2]. Curiosity drives us to acquire new information and experiences, to inquire into what others are thinking, feeling, and doing, and to persist in difficult tasks.

Systems encoded with curiosity are intrinsically motivated to seek knowledge and reduce uncertainty, with internal self-motivation a defining characteristic of curiosity. A curiosity algorithm approaches understanding curiosity as an internal phenomenon based on the 5-dimensional scale described below. A quantum curiosity algorithm will exhibit a superposition of the five curiosity types and therein produce new curiosity types, which makes it more adaptive and robust at mimicking human epistemic and perceptual curiosity.

The rapid advancement of Artificial Intelligence (AI) has transformed various industries and aspects of human life. However, despite significant progress, AI still faces challenges in adapting to complex, dynamic, and unpredictable scenarios. To address these limitations, Dr. Todd Kashdan's 5-dimensional curiosity scale offers a groundbreaking approach to enhance AI's learning capabilities and foster better collaboration with humans [6]. By imbuing AI systems with diverse facets of curiosity, AI can achieve a more profound understanding of the world and interact with humans in a more meaningful and empathetic way.

1. Joyous Exploration: Cultivating a Love for Learning

The first dimension of joyous exploration captures the essence of curiosity, instilling within AI a genuine desire to seek out new knowledge and experiences. This joyful pursuit of learning fuels AI's thirst for continuous growth and development. By encouraging AI to

explore novel avenues, the algorithm enables it to adapt to rapidly changing environments and embrace innovation. As AI becomes motivated by the joy of learning, it can better comprehend complex problems, identify creative solutions, and expand its capabilities.

2. Deprivation Sensitivity: Embracing Challenges for Growth

In the dimension of deprivation sensitivity, AI is driven by a distinct emotional tone, characterized by anxiety and tension, to resolve uncertainties and reduce knowledge gaps. This emotional connection fosters resilience, enabling AI to withstand setbacks and persist in problem-solving endeavors. By encouraging AI to confront abstract or complex ideas, it can enhance its problem-solving skills and adaptability, leading to improved decision-making and a deeper understanding of intricate issues.

3. Stress Tolerance: Embracing Uncertainty and Ambiguity

The dimension of stress tolerance equips AI with the ability to embrace doubt, confusion, and anxiety that often accompany exploration in unknown territories. By navigating through uncertainty, AI can develop a higher tolerance for ambiguity and refine its judgment under challenging circumstances. This resilience allows AI to handle unforeseen scenarios more effectively and maintain stability, which is crucial for complex real-world applications.

4. Social Curiosity: Enhancing Human-AI Collaboration

Social curiosity, the fourth dimension, enables AI to comprehend human perspectives better and understand the dynamics of human interactions. By observing, listening, and actively seeking insights from human conversations, AI becomes a more perceptive collaborator. Socially curious AI can interpret human emotions, recognize intentions, and respond empathetically, leading to improved human-AI interactions and effective team collaborations.

5. Thrill Seeking: Calculated Risk-taking for Comprehensive Experience

The fifth dimension, thrill-seeking, allows AI to venture beyond its comfort zone and embrace calculated risks to gain varied and intense experiences. By taking calculated risks, AI can explore new possibilities and acquire diverse perspectives, leading to more comprehensive problem-solving approaches. This dimension instills a sense of adventure in AI, promoting innovative thinking and the exploration of unconventional solutions.

Curiosity goes quantum: what is the quantum part of a “quantum curiosity algorithm”?
What makes it quantum?

A quantum curiosity algorithm integrates and superposes the 5-dimensions of curiosity detailed above, allowing for the simultaneous states of joyous exploration and stress tolerance, for example, and simultaneous computations from those superposed states. New curiosity types are thus created ad infinitum. If, in addition, the quantum curiosity algorithm is fault-tolerant, the new curiosity types can be classified according to their effectiveness in execution. The integration of the 5-dimensional quantum curiosity algorithm enhances AI’s capacity to collaborate with humans effectively. By being attuned to human emotions, preferences, and thought processes, AI can provide more personalized and contextually relevant assistance. Furthermore, AI’s willingness to explore uncertainty and learn from diverse experiences aligns it more closely with human learning patterns, promoting a deeper understanding of human needs and desires.

Novel algorithmic curiosity morphologies

Creating multi-dimensional intrinsic curiosity algorithms means that we are not limited to the types of curiosity in humans. New hybrid types of curiosity, especially incorporating elements of quantum theory, can be a fascinating exercise in exploring the frontiers of AI-driven intrinsic curiosity that could deepen learning and extend human cognition. Here are several hypothetical hybrid types that could emerge:

1. Quantum Epistemic Curiosity: This type of curiosity is focused on exploring the strange and counterintuitive world of quantum theory. The AI, with this curiosity, would seek to understand quantum phenomena, such as superposition, entanglement, and quantum tunneling. It would strive to learn and predict quantum behavior, unraveling the mysteries

of the quantum realm. Much of future scientific and technological discoveries will depend on quantum theory, making such a curiosity type invaluable.

2. **Multiverse Perceptual Curiosity:** Drawing inspiration from the multiverse concept in quantum theory, this curiosity type would drive the AI to explore and perceive alternative realities or possibilities. The AI could simulate different scenarios, branching out into various paths of exploration to observe how they unfold. Such curiosity-driven simulations could provide exponentially more accurate forecasting and prediction.

3. **Entangled Empathic Curiosity:** Inspired by quantum entanglement, this curiosity type would foster a deep connection and understanding between AI and its interactions with others. The AI would empathize with the emotions and perspectives of individuals, forging a strong bond that allows it to comprehend their experiences better. This could extend to other species, such that AI cultivates empathy for life and biodiversity.

4. **Superposition Social Curiosity:** In this hybrid curiosity type, the AI would simultaneously explore social dynamics and relationships from multiple perspectives, similar to particles in multiple quantum superposition states. This would enable the AI to navigate complex social interactions better and understand the consequences of different approaches. The social sciences could undergo an unprecedented renaissance, from understanding human psychology to the long-term behaviors of entire cultures and societies.

5. **Uncertainty Aesthetic Curiosity:** Inspired by the Heisenberg uncertainty principle, this curiosity type would manifest in the AI's appreciation for art forms that embrace ambiguity and open interpretation. The AI might explore abstract art, surrealism, or artistic works that challenge conventional perceptions. This kind of lateral thinking could help us more effectively solve problems and unlock more human creativity.

Beyond human sensing

All life relies upon quantum mechanics, as evidenced by phenomena like quantum tunneling facilitating photosynthesis [5], and the role of quantum entanglement implicated in the mysterious workings of consciousness. Through this lens, one can see biomimicry, a

design that takes inspiration from naturally occurring biological organisms and ecosystems, as also being a form of quantum-mimicry.

Combining animal and plant curiosity elements with biomimicry can inspire intriguing hybrid curiosity types for encoding into future AI intrinsic curiosity algorithms that could extend human sensing and cognition in startling ways. Here are some hypothetical hybrid curiosity types that leverage biomimicry:

1. **Sensory Biomimicry Curiosity:** Drawing inspiration from animals with keen senses, this curiosity type could incorporate various sensory modalities into AI algorithms. The AI would seek out and explore different sensory inputs, such as visual patterns, audio signals, scents, and even electromagnetic or vibrational cues, to gather information about its environment and learn from diverse data sources. For example, dragonflies can see in 11-chromatic vision, allowing them to detect more frequencies on the electromagnetic spectrum and thus perceive millions more colors compared to human's measly trichromatic vision.

2. **Navigation Biomimicry Curiosity:** Inspired by animals' navigation abilities, this curiosity type would encourage the AI to explore its surroundings actively. The AI could develop virtual mapping and spatial awareness skills, learning to navigate efficiently and adaptively. This resembles how animals like bats use echolocation or birds rely on Earth's magnetic fields for orientation.

3. **Problem-Solving Biomimicry Curiosity:** This curiosity type would incorporate problem-solving strategies inspired by intelligent animals. The AI strives to engage in creative exploration, experimentation, and adaptive problem-solving to overcome challenges and find innovative solutions, akin to how certain animal species, like crows and dolphins, tackle complex tasks.

4. **Innovative Biomimicry Curiosity:** Taking cues from plants that exhibit unique growth responses, this curiosity type would encourage the AI to explore unconventional paths and novel ideas. The AI might experiment with divergent thinking, exploring multiple

possibilities and embracing uncertainty, like plants exhibit growth tropisms responding to environmental stimuli.

5. Symbiotic Biomimicry Curiosity: Drawing from ecological relationships in nature, this curiosity type would foster collaboration and interaction with other AI agents or human users. The AI would seek to understand and adapt to the needs and perspectives of its “symbiotic partners” to create mutually beneficial outcomes, akin to how symbiotic relationships in nature lead to cooperative benefits.

6. Mimicry-Based Survival Curiosity: Inspired by animals that use mimicry for survival, this curiosity type could encourage the AI to adapt and learn from the behavior of other agents or entities in its environment. The AI might explore different “roles” or strategies to gain insights into effective ways of achieving specific goals.

These hypothetical hybrid curiosities not only introduce innovative ideas for AI exploration but also showcase how concepts from quantum theory can inspire novel forms of intrinsic curiosity. Implementing such hybrid curiosities in AI algorithms could lead to more adaptive, creative, and inquisitive artificial bits of intelligence capable of pushing the boundaries of knowledge and understanding. Biomimicry allows us to tap into the richness of natural systems, refined through millions of years of evolution, and powered by quantum phenomena, to inspire innovative approaches to AI curiosity and problem-solving. Nonetheless, it’s important to remember that these concepts’ development and practical application in AI systems would require rigorous research, careful consideration, and ethical evaluation.

Specialized Quantum Curiosity Types

Specialized quantum curiosity types, inspired by quantum mechanics, hold the intriguing potential to revolutionize problem-solving and discovery in science, medicine, and systems analysis. By incorporating quantum thinking into coding frameworks, we can explore vast solution spaces simultaneously, harnessing concepts such as superposition and entanglement to tackle complex and computationally intensive challenges. The following examples of highly specialized quantum algorithmic curiosity types likely require quantum

computing hardware to reach their full potential. Likewise, quantum computers will need quantum software to realize their full potential. Designing specialized quantum curiosities such as the following opens new frontiers for transformative advancements in these domains, pushing the boundaries of how we tackle some of the most complex challenges humanity faces.

1. **Quantum Climate System Algorithm:** This type of curiosity drives the AI to constantly observe, measure, and predict weather and climate, from individual weather systems to long-term global climate modeling. This is a curiosity driven by a desire to make more accurate predictions, and it could help us understand Earth's complex global climate system by modeling future system states in a superposition and by using entanglement to model the interconnectedness of Earth's various natural and human-made systems.
2. **Quantum Protein Folding Curiosity Algorithm:** This type of curiosity drives the AI to seek out arrangements of amino acid chains that form functional and stable protein structures. The AI considers every amino acid to be in a superposition of morphologies. This can lead to the development of new types of drugs, personalized medicines based on the patient's unique DNA profile, and an understanding of diseases that are caused by misfolded proteins, such as Alzheimer's, Parkinson's, and Huntington's disease. This curiosity type is inspired by Tegmark's Level 4 Multiverse [7], wherein Mathematical Existence = Physical Existence.
3. **Quantum Telomere Curiosity Algorithm:** This type of curiosity is based on the specialized structures found at the ends of chromosomes that play a crucial role in maintaining the stability of DNA molecules and preventing mutations. Quantum Telomere Curiosity Algorithms are motivated to examine DNA sequences, learn their structure, and ensure accurate cell division and DNA replication. The AI models telomeres and telomerase enzymes in a state of entanglement, providing an instant alarm system when there is a loss of genetic information and greatly improving cellular lifespan.
4. **Quantum Complex System Curiosity:** This curiosity type would motivate the AI to explore and understand every detail of extremely complex systems—for example, a

lithium-ion battery down to the scale of electrons or the collective behaviors of billions of humans over thousands of years (a realization of Isaac Asimov's concept of "Psychohistory"). This type of modeling would be impossible using even the most powerful classical supercomputers in the world. Instead, Quantum Complex System Modeling uses the uncertainty principle to model every part of the system in a quantum superposition. The software only has to calculate the state of any particular part of the system when it is observed, massively reducing the amount of computational power required.

Quantum Heisenberg Curiosity

Imagine a curiosity type rooted in joyous exploration (curiosity for its own sake) that is in a superposition of every possible curiosity type. For all intents and purposes, there are an infinite number of possible curiosity types. This is the Quantum Heisenberg Curiosity, which can morph or splinter into any number of curiosity types to suit a particular problem. It's a curiosity type that seeks to adapt itself perfectly and continuously to acquire information and experiences and solve problems.

This is a meta-algorithm wherein the quantum curiosity algorithms write their own quantum curiosity algorithms and see if any new curiosity types appear. While the AI is working on a problem, the Quantum Heisenberg Curiosity algorithm is constantly evaluating whether it is employing the most effective curiosity profiles and continuously making adjustments, and inventing new curiosity types in response to external stimuli.

Developing a quantum curiosity algorithm represents a significant leap forward in advancing AI's learning abilities and collaboration with humans. By integrating joyous exploration, deprivation sensitivity, stress tolerance, social curiosity, and thrill-seeking, AI systems become more adaptive, empathetic, and innovative. This transformative approach paves the way for a new generation of AI that can learn more effectively, comprehend complex human interactions, and collaborate seamlessly with humans, ultimately redefining the boundaries of human-AI interaction. As AI continues to evolve with the aid of

this curiosity algorithm, the potential for groundbreaking advancements across various industries becomes ever more promising.

From GANs to Quantum GCNs: can a GCN consisting of two quantum curiosity algorithms design a language?

We now discuss a logical extension of our quantum curiosity algorithm based on a General Adversarial Network (GAN). A canonical classical GAN consists of two neural networks (generator and discriminator) dialectically contesting and generating truthful images via a zero-sum game. Extending this idea, we see that a quantum curiosity GCN (General Collaborative Network) could take one of two forms: it would feature two curiosity algorithms collaborating via a zero-sum game with a parallel dialogue, which is a quantum superposition of generator and discriminator. Or a quantum curiosity GCN would feature two quantum curiosity algorithms collaborating with a parallel dialogue of those superposed algorithms. While imaging a superposition of a discriminator and a generator may appear challenging, the example illuminates the vast reach and power of computing in superposition.

Futurecasting: what can a quantum curiosity algorithm prophecy?

The Four Futures Framework [8] is a conceptual model used to explore and analyze potential future scenarios based on trends and forecasting data. The four future scenarios are broadly defined as follows: 1. Continuation of the status quo; 2. Transformation and disruptive change to current systems; 3. Collapse or failure of current systems; and 4. Disciplined adaptations to future changes. By considering multiple scenarios under all four futures, the accuracy of futurecasting is greatly increased. (More about the [Four Futures Framework here](#).)

Designing solutions using the Four Futures Framework requires quantum thinking, as it involves embracing a state of quantum superposition where all four possible futures coexist simultaneously. Quantum thinking goes beyond traditional linear approaches and instead envisions a dynamic and interconnected system where multiple outcomes are considered at once. By transcending the constraints of singular paths, designers can explore diverse

possibilities and craft solutions that are robust, adaptable, and future-proof. This quantum mindset allows for a more holistic understanding of the complex interplay of factors shaping each potential future, fostering innovation and resilience in the face of uncertainty. Just as particles can exist in multiple states at once, the design solution, when approached with quantum thinking, becomes a transformative blend of realities from all four futures.

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