The P vs NP Problem from a Quantum Mechanical Perspective: Distinguishing Between Process-Centric and Outcome-Centric Superpositions

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Summary

This paper approaches the P vs NP problem from a quantum mechanics perspective, specifically introducing the concepts of "Process-Centric Superposition" and "Outcome-Centric Superposition" to reinterpret the essence of the problem. Using classical NP problems such as Sudoku and Minesweeper, the paper examines the nature of 'superposition' inherent in each. Through this analysis, we differentiate between types where the stages of problem-solving are intertwined (process-centric) and those where only the outcome is verified (outcome-centric), highlighting the intrinsic differences in problem characteristics. In particular, applying the quantum concepts of observational dependence and superposition suggests that some problems involve multiple true/false states from the start, strongly implying that P might not equal NP. Conversely, some cases show that the result itself may not be clear or that one conclusion could contain multiple possibilities, making the concept of proof itself difficult to establish. This context ultimately suggests that the P vs NP problem should be considered not merely as a computational complexity issue but within a broader philosophical and physical context.

I. Introduction

The P vs NP problem is one of the oldest and most important unsolved problems in computational complexity theory, summarized by the question, "Can all problems that are quickly verifiable also be quickly solvable?" Traditionally, this problem has been approached from the perspective of algorithmic computation time and efficiency, and the relationship between P and NP has not yet been conclusively determined mathematically. However, this paper aims to reinterpret this classical problem from a quantum mechanics perspective. In quantum mechanics, the concept of

superposition exists, where a single state can hold multiple possibilities simultaneously, which offers new insights into what we understand as 'problem-solving paths' or 'clarity of results.'
In particular, we classify problems into process-centric problems and outcome-centric problems, and analyze the manner and location of superposition inherent in each. The former involves superposition occurring in the problem-solving path, while the latter pertains to cases where the result itself is superposed.
Sudoku and Minesweeper are chosen as examples representing these characteristics. Sudoku is a process-centric NP problem, where superposition occurs in all attempts leading towards the solution. On the other hand, Minesweeper is an outcome-centric problem, where true/false superposition occurs while verifying the pre-given results (the locations of the mines).
This paper connects the concept of quantum superposition with computer science's complexity theory and argues that "the superposition of the process is evidence of P ≠ NP, and the superposition of the result provides a basis for the impossibility of proof." Through this, we propose a new interpretation of the P vs NP problem and explore the physical and philosophical extensions beyond complexity theory.

II. Background Knowledge

2-1. Overview of the P-NP Problem

The P-NP problem is one of the most fundamental unsolved problems in computational complexity theory, summarized by the question, "Can all verifiable problems also be efficiently solvable?" Here, P represents the set of problems that can be solved in polynomial time, while NP represents the set of problems whose solutions can be verified in polynomial time. If P = NP holds, problems that are currently hard to solve but easy to verify would also be efficiently solvable. However, the fact that this problem remains unproven suggests that the relationship between these two sets is not merely a matter of computational ability.
This paper aims to analyze this problem not merely from the perspective of mathematical computational complexity but by introducing the concepts of process and outcome superposition, reinterpreting how we understand and verify problems.

2-2. The Concept of Superposition in Quantum Mechanics

In quantum mechanics, superposition refers to a phenomenon where multiple states exist simultaneously until observed, offering intriguing interpretations not only in physics but also in information theory, epistemology, and logic. For instance, a qubit can simultaneously exist in both the 0 and 1 states, and this parallelism is foundational to quantum computing.

When applied to computational problems, this concept suggests that the solution or solution path may exist in a superposed state, and upon observation (i.e., computation or selection), it collapses into a single determined solution. This provides a new perspective on NP problems, where one must search among multiple possible paths to determine which one is the correct solution, presenting the notion of "process superposition."

2-3. Process-Centric and Outcome-Centric Superposition

This paper posits that NP problems can be divided into two categories based on their structural differences: process-centric problems and outcome-centric problems.

Process-Centric Problems are those in which the search paths themselves are superposed. A representative example of this is a puzzle like Sudoku. In such cases, each path undergoes a truth/false evaluation, and the superposition of these paths hinders a clear definition of the path while searching for the solution. This structure provides an intuitive basis for $P \neq NP$.

Outcome-Centric Problems are those where only the validity of a predefined answer is judged. Games like Minesweeper are representative of such problems. In these cases, the solution itself is not superposed; instead, the observed state exists in a probabilistic mixture of true/false. This demonstrates the limitations of mathematical proof or random distributions.

This binary distinction, when applied through the lens of quantum mechanics' superposition and collapse concepts, enables a reinterpretation of the P-NP problem beyond computational efficiency, extending it into philosophical and logical realms.

2-4. The P-NP Problem and Impossibility of Proof

Gödel’s incompleteness theorem showed that some mathematical propositions cannot be proven within their system. Similarly, the P-NP problem might have a logical or structural nature that makes its proof inherently impossible. In particular, in outcome-centric problems, where the solution's distribution exists in a random or superposed state, the existence of the solution may depend more on probabilistic convergence or inductive observation than on formal proof within the system.

Thus, this paper posits the following premises:

Process-centric NP problems have superposed solution paths, which may serve as the logical foundation for $P \neq NP$.

Outcome-centric NP problems have superposed solutions themselves, which leads to issues of impossibility of proof or non-convergence..

III. Main Content

3-1. Superposition Structure in Process-Centric Problems and P ≠ NP

3-1-1. Conceptual Definition

A process-centric problem is one where the focus is not on the solution itself, but rather on the path taken to find the solution.

These paths are in a superposed state of true/false during the search, and until the solution is reached, it is impossible to definitively determine which path leads to the correct answer.

This superposition makes it inefficient for classical computers to resolve sequentially, explaining the 'search cost' characteristic of NP problems.

3-1-2. Example: Sudoku Problem

The search space of Sudoku is made up of interdependent constraints, requiring backtracking through trial and error.

Each attempt corresponds to an observation that collapses one of the superposed states.

→ Python backtracking code or a simulation showing success probabilities by number of attempts could be included here.

3-1-3. Conclusion

The structure where the path to the solution is superposed rather than the solution itself can serve as evidence for P ≠ NP.

Although direct proof is difficult, the structural imbalance suggests that it is impossible to find the solution in polynomial time.

3-1-4. Local Reduction from NP to P: Collapse of Dimensional Axes

Generally, process-centric NP problems like Sudoku involve a 3D search structure, consisting of a 9×9 grid and the combinations of numbers from 1 to 9.

There are three axes: rows, columns, and the numbers that can be placed in the cells.

However, if all paths to the solution are valid (i.e., every potential placement leads to a valid solution), the search structure becomes irrelevant.

This means that if the problem's state collapses to all paths being true, the need for searching disappears.

Example:

In a 9×9 Sudoku, if placing any number in any cell does not violate the rules, that cell is no longer a subject of search.

If this condition holds for all cells, the problem is reduced from a search problem to a sequential placement problem, which is solvable in polynomial time, i.e., a P problem.

Conclusion:

This phenomenon does not contradict the P ≠ NP claim but instead suggests that certain NP problems can be reduced to P under special conditions.

This indicates that some subsets of NP can be reduced to P in specific cases, and in these instances, the dimension of computational complexity is 'compressed.'

3-2. Superposition Structure in Outcome-Centric Problems and Impossibility of Proof

3-2-1. Conceptual Definition

An outcome-centric problem is one where, instead of the process of finding the solution, only the existence of a solution is verified in the given state.

In this case, the solution is in a superposed state of multiple possibilities.

Since the existence of the solution is revealed only upon observation, the true/false distribution does not converge mathematically.

3-2-2. Example: Minesweeper Problem

The presence of mines at specific coordinates is probabilistically determined, and as the game progresses, the system reaches a state where the probabilities are logically indeterminate.

The previously created 'high-dimensional array convergence simulation code' could be included to show that the true/false distribution does not converge with the number of observations.

3-2-3. Conclusion

In this case, since the solution cannot be defined until observed, the possibility of proof may not hold.

This can be likened to Gödel's incompleteness theorem, where without an observation outside the logical system, it is impossible to determine true/false.

3-3. Integrated Implications

3-3-1. Reinterpretation of Superposition Structure and Computational Complexity

Process-centric superposition → Provides tangible grounds for the complexity difference (P ≠ NP possibility)

Outcome-centric superposition → Logical indeterminacy regarding the existence of the solution (impossibility of proof)

3-3-2. Philosophical/Theoretical Conclusion

The P-NP problem can be understood as an ontological issue beyond discrete mathematical propositions.

Certain NP problems inherently contain proof impossibility within their logical systems.

Therefore, the P = NP problem may not be a straightforward proposition but a complex structure where truth, falsehood, and agnosticism coexist, depending on the classification of the problem.

IV. Experiment

4-1. Superposition Probability Formula

In this study, we define the probability

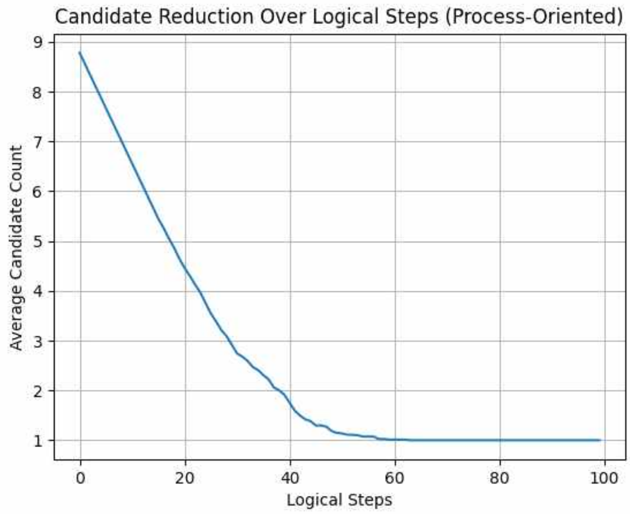
of a superposition state for both process-oriented and result-oriented problems using the following formula:
P.superposition = 1 − 1 / N^k

Where:
P.superposition : Probability of superposition of true and false states
N: Number of conditions of the problem or the number of trials
k: Number of dimensions of the problem

This formula suggests that as the number of conditions increases, or as the problem structure becomes more complex (i.e., as N or k increases), the probability of not converging to a single solution but rather remaining in a superposition state increases.

4-2. Process-Oriented Problem Experiment

Example: Sudoku Solution Process
Sudoku is a puzzle where you place the numbers 1 to 9 in a 9×9 grid such that no number repeats in any row, column, or region. The solving process involves checking and verifying numerous candidate solutions. The results of simulating this process are as follows:



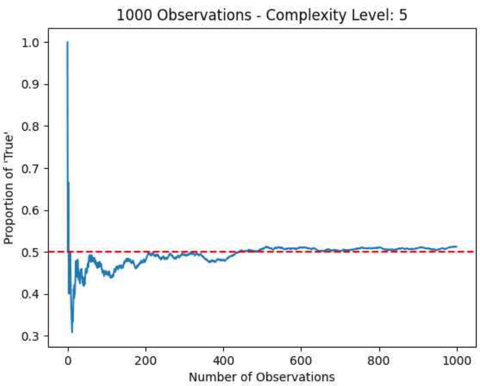
The experiment is based on 9 numbers (N=9) and 3-dimensional constraints (k=3). In this case, the superposition probability is:
P.superposition = 1 - 1/9^3 = 1 - 1/729 ≈ 0.9986
This means that during the solution process, multiple possible solutions remain in a superposition state, and it does not converge to a single solution. Furthermore, in process-oriented problems, the closer the superposition probability is to 1, the more likely that false solutions are mixed in with the true ones.
In Sudoku, if even one number violates the rule, the entire solution is invalid. Therefore, if there is falsehood mixed in the process, it means that the final solution is more likely to be incorrect. As the superposition probability approaches 1, the likelihood of reaching the correct solution

rapidly decreases. This provides experimental evidence supporting the possibility that process-oriented problems may not be solvable in polynomial time—i.e., P ≠ NP.

If all solutions are true, the NP problem is reduced to a P problem, and the dimensional axis decreases. For example, in a 9×9 Sudoku, if any number can be placed in all cells without violating the rules, the need for further exploration is removed, and it effectively becomes a P problem.

4-3. Result-Oriented Problem Experiment

In result-oriented problems such as minesweeper, the final answer is determined by a single validation (or observation). Interpreting this experimentally, the following structure emerges:



The total number of possibilities is
N
N, and each has an independent
k
k-dimensional branching structure. Under these conditions, the probability of verifying a specific solution in a superposition state is defined as:

P.superposition = 1 - 1/N^k

This probability means that even if a solution exists, the search to verify it inherently begins in a superposition state. In other words, even in result-oriented problems, before reaching the solution, both true and false states coexist in an indeterminate state. As
N
N approaches infinity, the superposition probability converges to 1, indicating that "even though a solution exists, it may not be provable." This suggests that such situations may occur more frequently in result-oriented problems.

4-4. Superposition Convergence and Comparison with Computational Incomputability in Infinite Expansion

If the size N of the problem converges to infinity, the superposition state from a process-oriented perspective may lead to computational impossibility. This possibility can be discussed using minesweeper and Sudoku, as mentioned earlier.

Minesweeper: As N tends to infinity, the superposition probability converges to 1, meaning that true and false states coexist. This leads to a situation where it is computationally impossible to prove a solution.

Sudoku: As the N×N grid size grows infinitely, the problem becomes more complex than the number of solvable hint cells. In this case, the problem will converge to an "unsolvable Sudoku" where determining whether a solution exists is beyond our capability. Unless infinite hints are provided,

the solution to an infinitely expanded Sudoku cannot be approached in a computationally feasible manner, which means that the problem structure itself exists outside the realm of computational possibility.
In conclusion, even under the idealized expansion where $N \to \infty$, some problems may reach a state where determining true/false becomes meaningless, ultimately leading to a mathematically unprovable structure. This serves as an inductive argument for $P \neq NP$, suggesting that merely increasing computational resources will not resolve these problems.

V. Conclusion

In this paper, we reinterpreted the P vs NP problem from a quantum mechanical perspective by introducing the concepts of process-oriented superposition and result-oriented superposition, shedding new light on the nature of the problem. Through classical NP problems such as Sudoku and Minesweeper, we analyzed the distinct characteristics of superposition inherent to each type of problem, thereby providing a clearer structural distinction within the P vs NP landscape.
We demonstrated that in process-oriented problems, superposition arises during the solution path itself, suggesting an intuitive rationale for $P \neq NP$. The structure of problems like Sudoku, where multiple true/false paths remain superposed during the solving process, explains why these problems are unlikely to be solvable in polynomial time. From this perspective, the P vs NP problem is not merely an issue of computational time or algorithmic efficiency but reflects a deeper structural asymmetry rooted in the complexity of the solution process.
In contrast, result-oriented problems exhibit superposition in the existence of solutions themselves. Here, the solution remains in a probabilistic distribution of truth and falsehood until confirmed. Minesweeper, as a representative of this category, reveals how the solution can remain in a superposition state, making mathematical proof of the solution's existence inherently impossible in certain cases. Such result-oriented problems echo Gödel's incompleteness theorems, underscoring the presence of statements that may be true yet unprovable within a logical system.
This study does not confine the P vs NP problem to a purely mathematical conundrum but offers a new lens incorporating logical, philosophical, and physical perspectives. By leveraging the concept of superposition from quantum mechanics, we explored the intrinsic complexity and potential unprovability of NP problems, thereby re-examining the deep structural meaning embedded in the P vs NP question.
This paper proposes an alternative viewpoint on the P vs NP problem. By stepping beyond the traditional framework of computational complexity theory and embracing quantum-mechanical and philosophical thinking, we hope to lay the groundwork for future theoretical exploration.
P vs NP is not merely a computational question. It transcends mathematical limits, raising profound inquiries into existence and the nature of

knowledge itself. Thus, future research may need to extend beyond computer science to encompass philosophy, physics, and even the humanities. This attempt is a small step toward opening that possibility.