Quantum Computing Education Scenarios

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Abstract — Quantum computers are one of the frontier teachings at this stage. The main purpose of this paper is to demonstrate how we design the quantum computing education scenarios. This paper mainly discusses the course content of quantum computing education. Also we have covered and initiated the motivation plan and perspective survey. This paper is the following work of " Teaching High School Quantum Computing Scenarios". For some well-known problems (such as factorization large numbers), quantum computers are clearly big winners compared to classic computers. The number of quantum computers that work can be factored down in a day can take millions of years for a classic computer.

Keywords - Quantum Computing, Education, Motivation for Quantum Computing Teaching, Quantum Scenario Analysis, Extra Curriculum Design.

I. INTRODUCTION

In this current research, we have outlined studies to find out the design for quantum computing education. In order to combine quantum computing with either high school computer science courses or extra-curriculum format, we have implemented the course content correlated to quantum computing.

Limitation: Our teaching scenario content is on the trail stage which requires practical trail to prove it if efficient.

Context: This paper outlines the implementation and design for quantum education scenarios. Quantum computing will give teenager programmers the tools to solve certain problems, we have designed specific course content for education, in that case the problem is how to program quantum computers to make a simple prototype. Specifically the deliverables for this research project will consist of the following:

•Explanation for a list of functional and usability properties that a quantum computing theme should have. A list of this sort has been concluded in the project, making it for different scenarios how to determine what a quantum programming technique needs to accomplish for different scenarios.

•Motivation for High School Quantum Computing teaching: Proofs and illustrations that show that the proposed teaching plan satisfies the functional and usability properties for High School student teaching.

•An implementation of the quantum computing education courses as a proof of concept, although this implementation may not necessarily be complete. We regard it as version 1.2.

•Scenarios Setup: The team has developed a series of quantum computing scenarios set up and planned to test it by designing extra-curriculum quantum computing activities.

Here, the quantum world and the classic world are different. In the classic world, we can only have one state at the same time. For example, if we have the 001 state, we can't have the 010 state at the same time. This is because the voltages of the two states are superimposed. If we have both states, we can only get the 011 state. But in the quantum world, we can get superposition states. Specifically, the state of the system can be at the same time.

	Bits (classical)	Qubits (quantum)
Subsets of n bits	Always have states	Generally have no states
Can state be learned from bits?	Yes	No, measurement collapses
To get information	Look at them	Measure them
Information acquired	X	x with probability $\left|\alpha_x\right|^2$
State after information acquired	Same, x	Different, $\left|x\right\rangle$, due to collapse

Figure 1. Comparision of bits and qubits.[1][2]

Today's computers use standard (or "classical") computational models to perform computational and processing information, dating back to Turing and Von Neumann period. In this model, all information can be reduced to bits, one bit can take a value of either 0 or 1 - and all processing can be done by simple logic gates (and, or, NOT, NAND) Execution, these logic gates act on one or two bits at a time. At any point in the calculation process, the state of the classical computer is determined by the state of all its bits, such that a computer with n bits can have 2^n possible states, ranging from 00...0 (all zeros) to 11...1 (all 1). [3]

At the same time, the power of a quantum computer lies in its rich and rich state. A quantum computer also has bits, just

like any computer. But its qubits, also known as qubits, do not represent 0 and 1, but can represent 0, 1 or both 0, 1 (ie a (0, 1) vector), this Attributes are called super-positions. This doesn't help for itself. Since a computer may have an intermediate position between 0 and 1, it is an analog computer that is simply not as powerful as a normal digital computer. Quantum computers utilize a special kind of superposition so that a number of exponential levels of logic are allowed at a time, all states from $|00...0\rangle$ to $|11...1\rangle$. This is a powerful skill and can be achieved without any classic computer. The vast majority of these quantum super-positions, and the most useful for quantum computing, are entangled—the states of the entire computer that do not correspond to any digital distribution and do not correspond to the analog state of a single qubit. Although there is no powerful exponential number of classic computers, a quantum computer is much more powerful than any classic computer—whether it is deterministic, probabilistic, or analog. [4]
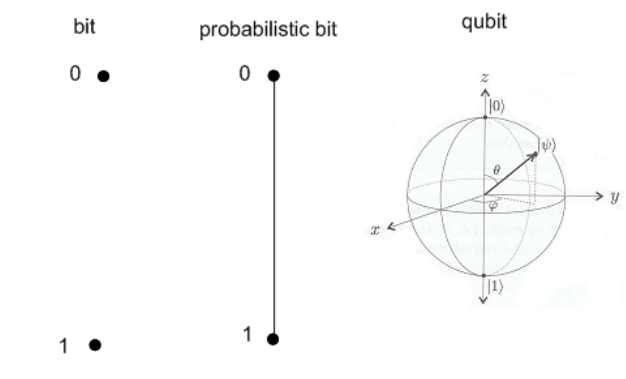

Figure 2. The difference between bits, probabilistic bits, and qubits.
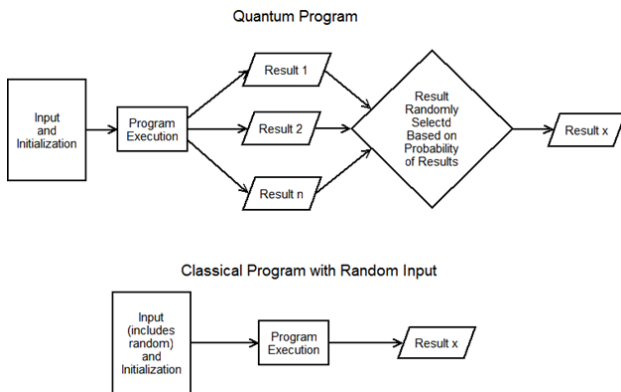

Figure 3. A quantum versus a classical program.

We can see from Figure 3 that the quantum computer generates multiple results, but only one of those is selected as becomes the output. Once the classical program is seeded with random input its execution and result are deterministic. As a result, when seeded with the same input a quantum program may generate different results from execution to execution, but a classical program will execute the same given the same input.[5]

II. MOTIVATION FOR HIGH SCHOOL STUDENT

Our research team has started a survey for multiple schools. Include some high school students from online participation, this survey analysis focus on the received result from the "WJX", the website we apply to get the survey result. According to the survey, we can conclude the willingness to have a 3 months courses and 2 years continuing projects is an ideal choice for the high school student. In that case, we have decided to design the teaching courses as a comprehensive 2 years project for the high school student. To unify the evaluation standard, we choose to initiate the 3 months Quantum Computing courses and 2 years perspective extracurricular projects for them. As shown in Figure 4 and Figure 5.

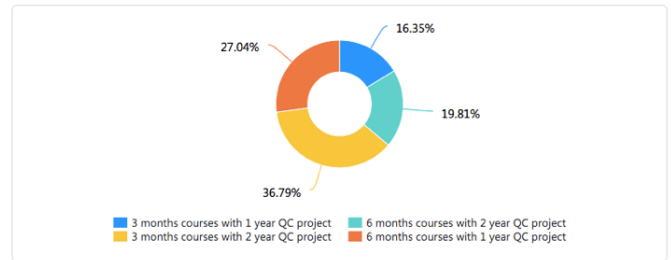**Figure 4. Which format of teaching is the most acceptable choice.**

Figure 5. Graph for Survey Results

A. Motivation Plan

To implement the teaching high school student procedure, we need to make the whole program more convincing and practical for high school student. Most high school student devoted a lot of time for their high school extra-curriculum activity. As shown in the Figure 6. The best way to motivate the high school student is to help them design the learning procedure as an extra-curriculum. This method will also promote their future study in the area which they can apply quantum computing as a tool to help them understand and learn the knowledge in the different disciplinary. [6]
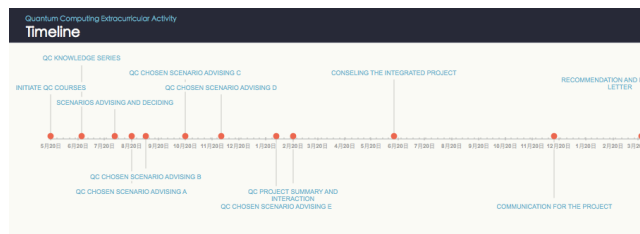
Figure 6. Timeline for Quantum Computing Extracurricular Activity.

B. Plan Performing

Previous research on motivation for extracurricular activities in high school usually examined the relationship between student attributes and specific extracurricular activities, but the study of more "voluntary" or behavioral attributes related to extracurricular activities that students liked was limited. By increasing the possibility of high school students choosing their own future quantum computing applications in their favorite fields, organize to participate in academic or quantum computing clubs.

For the practice schools, we will initiate 3 months Quantum Computing Courses. According to the knowledge series determined by the lecturer, high school student will receive scenarios advising meeting. Then we will have five scenarios advising session to help student learn corresponding algorithm, utilization and quantum computing basics. During the last year of the extra-curricular activity, student will finish the chosen scenarios summary and interact with the instructor. The whole procedure will constitute a comprehensive extra-curricular activity that will greatly increase their admission rate for college application. At the same time, it will help them get prepared for the college academics.

C. Advantages

As to extra-curricular activity motivation, we have following four advantages:

1. The QC project has long enough time frame.

2. The Quantum Computing learning procedure has in-depth influence for high school students future study in the college.

3. A combination of activity and extraordinary recognition. All scenarios will be persuasive for the college for the reason that it is an original computer science based activity.

4. Unique. At the same time Seidenberg School of CSIS has finished the trial for teaching high school student and the student has finished their unique extra-curricular activity that will influence the academic for their college study.

We can also initiate a perspective research to see the difference between the student who has taken Quantum Computing courses and the student who has taken different kinds of activity in the same learning areas performance.[7]

D. The course setup of Quantum Computing Teaching in High School

Course production is a prerequisite for the implementation of the Quantum Computing. For the production of quantum computing courses, we can import knowledge from before class, focus on important concept and knowledge understanding for elementary principle of quantum computing as shown in Figure 2.

1. The knowledge absorption and other aspects are carried out through team-based project. In the knowledge introduction stage before the class, the teacher needs. It should be produced according to the key points and difficult points of the quantum computing.

2. The process of deciding scenario based project, it should be combined with the students' learning ability to avoid difficulties. After the introduction of the IBM QC platform, the teacher can use the form of online simulator to emphasize the teaching. As to extra-curriculum project: divided points and difficult points to simplify the use of complex quantum computing knowledge. [8]

3. Typical quantum computing application examples to guide students to master the rules of quantum computing learning and deepen their studies. During the class, teachers can create a brief introduction video for students, the main content of the video would expand on how to quickly master the function of quantum computing. Demonstrate the process of quantum computing utilization, let students learn while watching the video for the lesson.[14]

E. During the process of teaching course setup of Quantum Computing Teaching in High School.

1. Under the Quantum Computing teaching mode, teachers can make the key points in teaching Quantum Computing into hands-on simulator, allowing students to practice in the classroom. After trying the simulator, the students can ask questions that they have encountered during the practice process, and the teachers will explain them in the classroom to improve the efficiency of the classroom teaching. In addition, teachers can also share the Quantum Computing method on the school's website, and students can download it under the class to facilitate students to study anytime, anywhere.

2. Taking the picture teaching in real scenarios Finance Industry as an example, in the classroom learning of the computer, the teacher can explain the knowledge in the form of how to utilize Quantum Computing in Finance Industry. Given the interdependence of thousands of assets, quantum computing can help identify attractive portfolios. In addition, quantum computing technology can be used to more effectively identify critical fraud flags. When learning the content of the picture in World, the teacher displays the scenario related method to the student in the form of simulator through the form of either Python or IBM Simulator. At the end of the each class or project meeting, the teacher reserves a portion of the question time for the student to help the student solve the

problem encountered during the Quantum Computing process. After solving the students' questions, the teacher organizes the students to carry out practical utilization exercises, so that the students can apply the theoretical knowledge to the actual operation and deepen the students' knowledge mastery.[9]

III. TEACHING SCENARIOS AND MANAGEMENT OF THE CONTENT

Quantum Computing Basics Understanding for Different Scenario Design

In the experimental teaching, the students are the main body, emphasizing the leading role, organization and management of teachers in experimental quantum computing teaching. Before each scenario experiment, the teacher briefly lectures on the theoretical knowledge points, experimental purposes, experimental content, experimental focus and operational difficulties related to corresponding quantum computing experiment. The remaining time students conduct experiments. During the experiment, the teacher strengthens the inspection, and the quantum computing scenario should generally be determined by the students. After the experiment is completed, students are first required to write an experimental report, summarize the experimental process and analyze the experimental results. Then the teacher summarizes according to the student's experimental report and experimental process, so that students can accumulate experience from the experiment, gain more experimental skills, and deepen their understanding of quantum computing theoretical knowledge.

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Student's chosen quantum computing experimental organization and management： According to the existing experimental equipment and environment, for the experimental content of the quantum computing, the experiment was carried out by combining independent experiment and group experiment according to the application of quantum computing knowledge toward the project. Group experiments can enhance mutual learning, coordination and cooperation among students. The seven scenarios we purposed will accelerate the knowledge understanding period and help students to develop the project as their own research-based extra-curriculum activities.

A. Financial Service

Financial analysts often rely on algorithms consisting of probabilities and assumptions expressed by markets and portfolios. Quantum computing can help eliminate blind spots in data and prevent losses from unfounded financial assumptions.

B. Healthcare

Quantum computers can help speed up the process of comparing the interactions and effects of different drugs on a range of diseases to determine the best drug.

In addition, quantum computing can bring true personalized medicine, using advanced technology in genomics to tailor treatment plans for each patient. Protein Folding and Drug Discovery. Simulated annealing is an algorithm currently used to predict the effects of potential treatments while optimizing for non-adverse effects. Quantum computing can replace some of these technologies, and there may be large-scale improvements over the next few years, such as improved drug design.

C. Network Security

Quantum computers can be used to break the passwords we use today to protect sensitive data and electronic communications. However, quantum computers can also be used to protect data from quantum hacking, which requires a technique called quantum cryptography. [12]

D. Manufacture

Supply Chain and Procurement. There are various aspects of supply chain optimization, such as procurement, production, and distribution. As quantum computing improves, it will evolve from being able to solve one-time scenarios, such as "shelf maps" or "truck loads," to large-scale system scenarios, such as storage tiers.

E. Resources Distribution

Asset Depreciation Modeling and Application Distribution Optimization. Today, by examining operational real-time data based on rules or machine learning models, we are able to identify potential problems that affect usability. Quantum computing continues to provide recommendations for optimizing critical systems to save costs.

F. Media

Maximizing ad scheduling and advertising revenue. Systems are often tailored to each customer's situation. These systems collect hundreds of attributes about consumer

preferences that need to be mapped to product affinity and presented as a chart. Ultimately, the optimization of this chart is the best decision to show customers what kind of advertising. Quantum computers are great for dealing with such problems.

G. Agriculture

Quantum computers can help us make fertilizers more efficiently. Almost all the fertilizers that help to feed us are made of ammonia. The ability to produce ammonia (or substitutes) more efficiently means less expensive, less energy-consuming fertilizers. Easier access to better fertilizers will benefit the environment and help feed the growing population of the planet. However, little progress has been made in improving the process of manufacturing or replacing ammonia, as the number of possible catalyst combinations is unlimited. [13]

IV. METHODOLOGY

Knowledge-based quantum computing curriculum content:

Part 1

1. Traditional computing

First consider traditional computing, which is useful for understanding quantum computing. We are accustomed to modern digital computers and their ability to execute many different applications. Our desktops, laptops, and smartphones can run spreadsheets, live video, let us chat with people on the other side of the world, and immerse us in a very real 3D environment. However, all digital computers have something in common. They all perform simple arithmetic operations. Their ability to do this comes from their extremely fast speed. Computers perform billions of operations per second. These operations are performed very quickly, they allow us to run very complex advanced applications. Traditional digital calculation can be summarized using the chart shown in Figure 7.
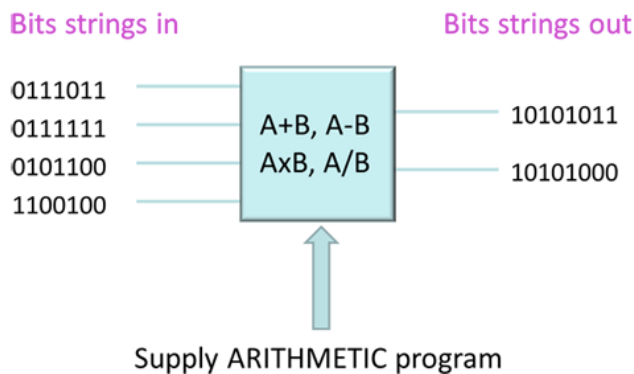

Figure 7. Data flow in traditional computers

Although traditional computers are good at many tasks, computing in some fields is still very difficult. Examples of these areas are: image recognition, natural language (use your own language instead of a programming language, let the computer understand what we mean), and the computer must learn from experience to do better specific tasks. Although a lot of research and efforts have been carried out in this field in the past few decades, our progress in this area is still very slow. The prototypes we make usually require very large supercomputers to run and consume a lot of Space and energy.

We can ask the question: Is there a fundamentally different way to design computer systems in this world? If we could start from scratch and do something completely different, it would be better to accomplish tasks that are difficult for traditional computers. So how do we set about building a new type of computer?

2. A new way of calculation

The traditional method transforms the bit strings of groups 0 and 1 into another group, and the method of quantum computing is quite different. In quantum computing, everything changes. The physical layer of the information bits we understand and the equipment that operates them are completely different. The way we manufacture this equipment is different, requiring new materials, new design rules, and new processor architectures. Finally, the way we program these systems is completely different. This document will explore the source of these problems, that is, how to replace the traditional bits (0 or 1) with a new kind of information-qubits, which can change the way we think about computing.

3. Light Switch Game

Before learning quantum computing, it is also important to understand why we can use traditional computers to solve certain problems. Let us consider a mathematical problem called a light switch game, which can explain the key point well.

The light switch game involves trying to find the best setting among a bunch of switches. Here is a picture that introduces this problem as an example:

Figure 8. Light Switch Game

Let's imagine that each light switch has a number that is closely related to it and is for you to choose (you don't want to change this). We call this number the "deviation value". All you have to do is to select whether each light switch is on or off. In our game, open means 1 and close means -1. We then multiply the deviation values of all switches by the

corresponding on / off values. This will produce a result. The intent of this game is to set all switches on and off to find the minimum value. Mathematically, we define the deviation value of every switch as hi, and the switch setting is called Si.

$$E(\mathbf{s}) = \sum_i h_i s_i$$

OFF
-1

ON
+1

+0.2

h = 'bias' value associated with each switch

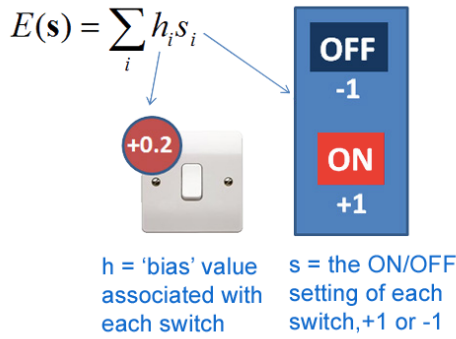s = the ON/OFF setting of each switch,+1 or -1

Figure 9. To play the light switch game, multiply the deviation value of each switch by their set value (you must choose) and add up.

Therefore, depending on which switch we set to +1 (open) and which switch we set to -1 (closed), we will get a different score. You can try this game. I hope you will find it easy because there is a simple winning rule:
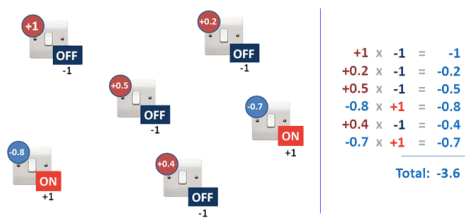
+1 OFF -1

+0.2 OFF -1

+0.5 OFF -1

-0.7 ON +1

-0.8 ON +1

+0.4 OFF -1

+1 x -1 = -1
+0.2 x -1 = -0.2
+0.5 x -1 = -0.5
-0.8 x +1 = -0.8
+0.4 x -1 = -0.4
-0.7 x +1 = -0.7

Total: -3.6

Figure 10. Answer the special "conjecture" set for this switch.

We found that if we set all the switches with positive deviations to off, turn on the switches with negative deviations, and then add up, we will get the smallest value. Is it easy? I can give you as many switches with different deviation values as possible, and you only need to turn these switches on and off according to this rule.

Well, we make this problem harder. Imagine that there are a lot of "pair" switches with an additional rule. The consideration here involves "pair" switches instead of one switch. We add a new deviation value (called J), we multiply it by the setting values of the two connected switches, and for all switches, we add the result value of each pair of switches. Still the same, what we need to do is how to choose whether the switch state is on or off to adapt to this new rule.
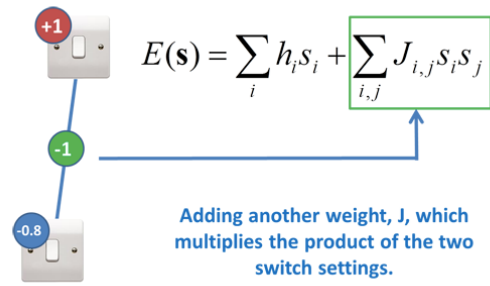
+1

-1

-0.8

$$E(\mathbf{s}) = \sum_i h_i s_i + \boxed{\sum_{i,j} J_{i,j} s_i s_j}$$

Adding another weight, J, which multiplies the product of the two switch settings.

Figure 11. Adding additional items that depend on the paired switch settings makes the game more difficult.

But now this is very, very difficult to decide which switch should be turned on or off, because the switch near it will affect it. Even simplified to the situation where there are only two switches as shown in the previous figure, you still can't use the previous rules, that is, set them to the opposite value of the deviation value according to the deviation value (you try). In front of a complex network where all switches have neighbors, it is very difficult for you to find the right combination to get the minimum value.

4. How Quantum Mechanics Works (Following Light Switch Game)

If you try all combinations for each pair of switches, there are four possibilities: [On, On], [On, Off], [Off, On], [Off, Off]. But as you increase the number of switches, the number of such possibilities will increase exponentially with the number of switches:

2 switches – 2^2 = 4 possible answers

10 switches = 2^{10} = 1024 possible answers

100 switches = 2^{100} = 1,267,650,600,228,229,401,496,703,205,376 possible answers

Figure 12. Exponential problems caused by light switch games

In fact, this problem is even difficult for most powerful supercomputers. It will take a very long time to store so many possible configurations in memory and send them to a traditional processor to calculate whether our guess is correct. Assuming 500 switches, there is not enough time in the universe to check all configurations.

The basic ability of quantum computers comes from the idea that you can put the qubits of information into a superimposed state. It has two states at the same time. Using quantum computers, our light switches can be turned on and off at the same time.
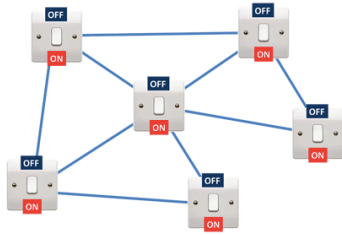
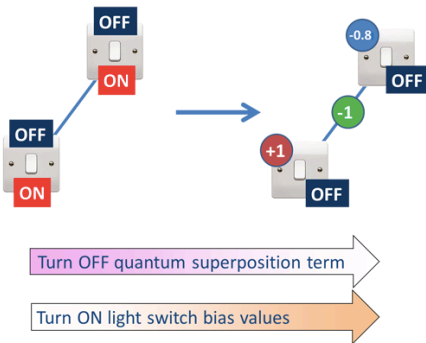**Figure. 13 A network of superposed states of qubits**

Figure. 14 The computer uses the superimposed state bit to start the calculation, and at the end generates the traditional normal bit stream, according to this method to find the answer

The information bit (Q bit) of the quantum mechanism can exist in a known superposition state. This superposition state has no choice whether to become +1 or -1 (in other words, you can think of it as +1 and it's -1)

Increase all deviations (h and J must be adjusted first). When this operation is performed, all switches will slowly jump out of their superimposed state and select a traditional state, that is, open or closed. Finally, each switch must select a state, open or closed. When you finally add them up, the quantum mechanism used inside the computer helps set the switch to the correct state to get the minimum value. Although N switches may produce 2^n possible configurations, it can also find the minimum value at the end and win the light switch game. So, we can know that quantum computers allow us to reduce expressions as follows:

$$[E(s) = \sum_i h_i s_i + J_{ij} s_i s_j]$$

Figure 15. Quantum Expression

It is very difficult (or impossible to complete) for traditional computers to operate.

Part 1 will help student solve the following problems:
How quantum mechanics gives us a new way to calculate
Similarities and differences between quantum computing and classical computing?
How the basic unit of quantum computing (qubits) is used to solve difficult problems ?

Why quantum computing is great for artificial intelligence and machine learning applications, and how quantum computers are used as "AI coprocessors?

Part 2
1. It's a mathematical expression
The idea of finding an optimal binary variable configuration (such as a light switch game) is also at the core of solving many of our daily application problems. For example, some simple examples in the figure below. Even the concept of scientific exploration itself is a problem that needs to be constantly optimized (you are trying to find the best "configuration" of things, which helps to establish scientific equations that are consistent with actual observations).
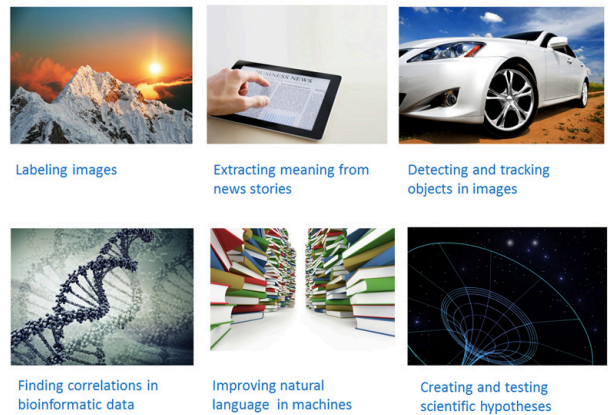

Figure 16. Scenario: The deep structure of some application examples requires an optimal "switch" configuration, and the use of quantum computers can be effectively solved

2. Energy Program

A group of qubits is initialized into their superimposed state, at which time energy planning (rather than logical planning) is applied to these groups. At the beginning of the calculation, the qubit is in an uncertain state. At the end of the calculation, it will be in a certain state of +1 or -1. So what is the energy planning process? In fact, it is the h and J that we set before-deviation setting. In the light switch game, we say that h and J are given. Then we now understand that they come from—they are defined by the problem you are trying to solve.
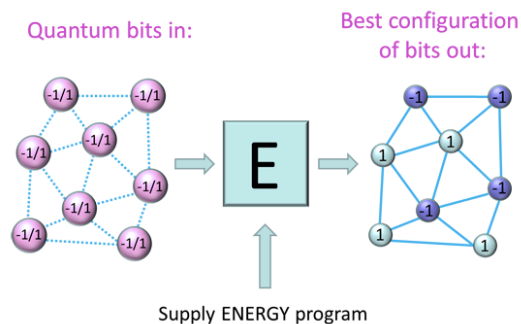
Figure 17. The basic operation of a quantum computer provides an energy planning program (a series of h and J values) so that the computer finds the optimal switch configuration (+1 and -1)

3.Uncertainty.

Another interesting point about quantum computers is that it is probabilistic, which also means that it may return multiple answers.

Some may be the answer you are looking for, some may not. At first, this didn't sound like a good thing. As a computer, when you ask the same question, the answer is different, it sounds like a bug! Nonetheless, multiple answers given by quantum computers can give us important information about computer reliability. Using the example of fruit recognition above, if we show the computer a picture, ask it what it is, ask it 100 times, and the answer it gives 100 times is an apple, then the computer is an apple on the fruit.

This matter is very confident. If the answer it gives is 50 times for Apple and 50 times for Raspberry, it means that the computer is not sure what exactly is on the picture you are showing. Of course, if the apple and raspberry are included in the picture you show, the computer is also correct. This kind of uncertainty is very useful when you are designing a system that requires complex judgment and learning capabilities for the world.)

IV.Conclusion

We have covered motivation plan, teaching scenarios and management of the content, and the methodology for the initiation of the project. As this is the continuous work for " teaching high school student quantum computing scenario", we typically gradually implement our comprehensive methodology with different versions.

Quantum computing gradually plays an important role in the future application in various scenarios. The purpose of the paper is to deepen quantum education reform and exploration is to improve the quality of quantum computing teaching at different education stages. The reform the scenario based quantum computing should focus on cultivating students' comprehensive analysis and design ability.

In the face of the constantly updated quantum computing and the differences in experimental teaching content, scenario implementation and student abilities of their future study, how to cultivate students' ability to continuously track and learn new quantum computing knowledge in the future remains to be explored. The high school computer science system needs to be continuously improved, and the quantum computing content and teaching methods will be continuously reformed and updated to improve the students' comprehensive application ability of computing and cultivate high-quality talents that are needed for the society. [15]

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