QueueBits: Adding uncertainty to a 4-in-a-row game

Explore how *superposition* and *measurement* affect strategy

Learning Goals

- Understand that working with data in superposition affects strategy.
- Understand that the timing of measurement affects strategy.

Quantum Computing Tie-In

Superposition is one key to QC. Superposition and measurement timing affect algorithm design.

Materials

❏ Online Queue Bits game

Preparation

- Watch video on the QueueBits game

Background Knowledge

Superposition: Objects exist in a state of superposition when they can be more than one thing at once. In quantum computing, quantum bits ("qubits") can exist in multiple states at the same time. The different states can add together and interfere with each other to define the overall state of the qubit. In classical computing, bits have one of two values (zero or one). A qubit, however, can be zero or one or anywhere in between. The real power of superposition arises when more than one qubit is involved because the number of possible combinations grows exponentially, rather than linearly. This is often referred to as the quantum advantage. Getting this advantage requires creatively operating on data in superposition.

Measurement: Usually when something is measured, it is the same before and after we measure it. If you measure the length of a book using a ruler, the book is the same before and after measurement. Sometimes, however, measurement can change the thing we are measuring. For example, we might want to know how many licks it takes to get to the center of a Tootsie Pop; licking the Tootsie Pop until you get to the center means the Tootsie Pop changes as we measure it. In science, it is often important that the method of measurement does not "intrude" on what you are measuring. Classical (ordinary) computers store simple values in memory, and storage devices are able to both measure and retain the value when you read out of memory. Quantum computers, however, have a very complex, fragile state at the molecular level. No measurement device exists that can measure quantum states without fundamentally changing what is being stored. As a result, measurement is often delayed, affecting how we design algorithms for quantum computers.

Engage

1. Explain that today the class is going to do some activities that introduce students to the concepts of superposition and measurement, two of several critical concepts for quantum computing. What is quantum computing? You have some short videos to introduce the topic.
2. Play the first video, which introduces quantum information science (< 3 minutes)
3. Play the second video, which introduces quantum computing (< 5 minutes)

Activity

4. Explain that they are going to play a familiar game, Connect 4, but with a twist. Explain the basics of Connect 4:
    a. Two players will play against each other.
    b. The players take turns dropping a token into the game. The token always falls as far down as it can.
    c. The goal is to make a row, column, or diagonal of four of your tokens in a row.
5. Explain some differences between QueueBits and Connect 4 because we are introducing a topic critical to quantum computing into the game.
    a. Instead of playing another classmate, you will be playing the computer.
    b. Instead of having a piece that is definitely your color, some of the pieces you drop are *likely* to be your color but *may* end up being the opponent's color. Before you place them, they are in "superposition" because they are both your color and your opponent's color. The probability it will be your color, and when the measurement to determine which it is occurs, may influence where you place the piece. So pay close attention to how your thinking and strategy changes when we introduce superposition in the second level.
    c. Depending on what level you're playing, *when* the measurement occurs changes. In the first set of levels, the piece is measured right when it is played, so you know what it is by the time you play other pieces. But in higher levels, the board gets filled, and measurement occurs at the end.
6. Show the screenshot video introducing QueueBits (1 minute)
7. Send students to: (URL released April 11) and click "Go" button under QueueBits picture.
8. Set a timer for 30 minutes and have students play the game. They can play the same level multiple times.
9. Discuss with the students what they thought of the game.
    a. Did their game play change depending on
        i. Probability of the piece (why or why not?)
        ii. Timing of measurement (why or why not?)
    b. Was there anything challenging about the game? Would they have played more had they had the chance? Would they like to see more levels?

10. Play the final video that ties the game mechanics to quantum systems.

Additional QuanTime, April 2022 FAQ

1. When does QuanTime take place?
URL will be active April 11th through May 31st

2. How long does the activity take?
The activity takes approximately 45-60 minutes.

3. What discussions should teachers have with students?
The discussion prompts are in the facilitation guide

For additional questions about the activities, contact Diana Franklin and dmfranklin@uchicago.edu