Saving Schrödinger's Cat

Joint work with Laur Nita, Helen Cramman, and Laura Mazzoli-Smith and others

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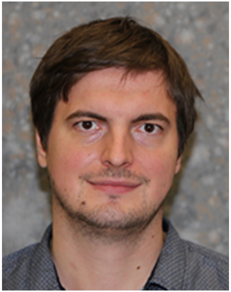
A student led project

Laurentiu Nita, my PhD student led the project



- Also collaboration with Helen Cramman and Laura Mazzoli-Smith in Durham Education, and some of their students
- Laur runs a company which produces a related video game (more on this later)

Representing quantum operations visually

Why?

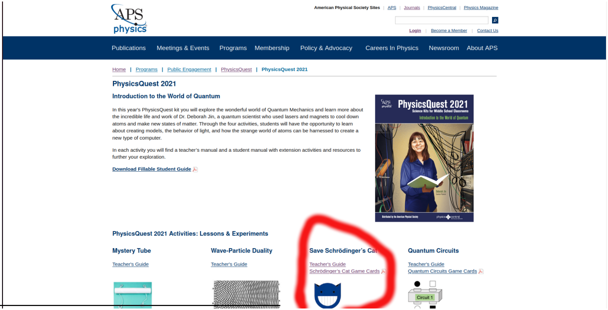
- Matrix algebra can be intimidating
- Stereotypes about who should and shouldn't be "good at math"
- Some people may think better visually than in equations
- Add an element of fun/gamification to learning

We originally made a video game (Quantum Odyssey) to do this

Physics Quest: from video game to card game

American Physics Society approached us about making the game part of their "Physics Quest"* outreach package , but...

- Not all classrooms would have computers available
- Even those that do would have different software/operating systems
- These barriers would likely select for more well-off schools
- Make a card game instead to avoid these limitations



*https://www.aps.org/programs/outreach/physicsquest/pq21.cfm

What makes quantum mechanics different

Classical probabilities

- Probabilities can only add, never subtract
  - Example: Consider the probability my shoes can get wet (first think only about rain)
  - The fact that there are sprinklers on my route home can only make this probability go up

Quantum probability *amplitudes*

- Probability amplitudes can add or subtract (even cancelling completely)
  - Example to come later: Hong-Ou-Mandel
  - A property called **phase** determines whether they add or subtract

Three ingredients to represent a quantum system

(1) Amplitudes for each state

- Needs to include phase information
- List of amplitudes describing a state
- Represented by game tokens

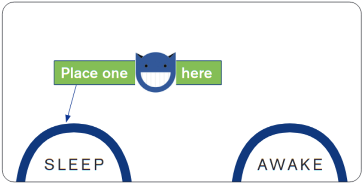
(2) Operations can be performed on the system

- Represented by the cards within the game

(3) Rules for how amplitudes interfere (do they add or subtract)

- These are the rules for adding complex numbers
- We do this visually with card game rules

Ingredient # 1: states*



Two states: cat is asleep or awake (can also be in a superposition)

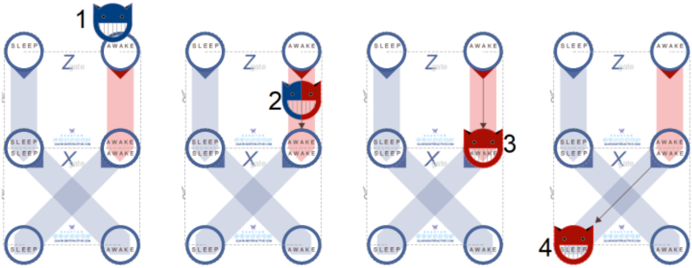
- Token(s) only on left side= asleep
- Token(s) only on right side= awake
- Tokens on both= **quantum superposition**

Four colours of tokens, also allowed to have pairs of tokens

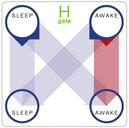
- Four single coloured states
- Four allowed pairs
- Can represent eight different phases

*mathematically these are known as "state vectors" but not important for the purpose of the talk

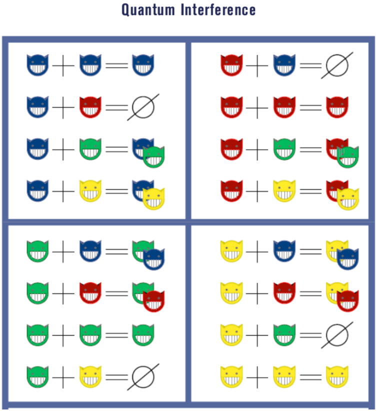
Ingredient # 2: Quantum operations (aka gates)



- Coloured edges change colour (phase)
- Edges can flip from asleep to awake and vice-versa
- Can also join and split paths, but need ingredient # 3 for this

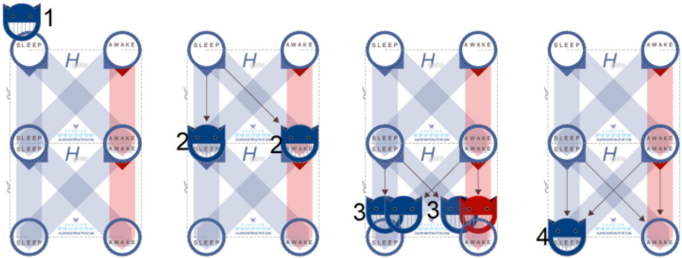


Ingredient # 3: Interference rules



- Sometimes add together (constructive interference)
- Sometimes disappear completely (destructive interference)

An example using these rules



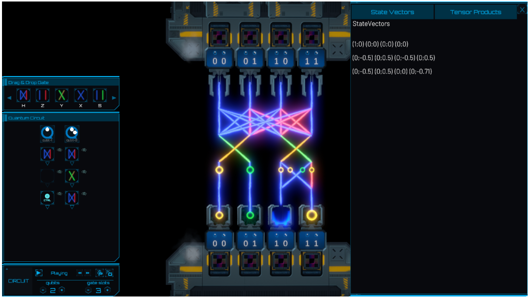
- Multiple edges split into multiple cat tokens
- interference rules (see earlier) need to be applied when multiple cat tokens come from different edges

Puzzles in the card game

1. Apply and “X” gate to go from asleep to awake
2. Go from asleep to awake without using “X”, use phase interference
3. Turn a superposition state into a single cat token
4. Change the colour of the cat token, what does this mean?
5. Which gates can be made from other gates?

Students are then challenged to make their own puzzles

Quantum Odyssey*



- Video game on which the card game is based
- Easier to collaborate with in an online setting, so what we will use today
- Can have more than one cat (qubit)

- Uses balls rather than cats and 0 and 1 rather than "asleep" and "awake", (feel free to still think of cats)

*Sold at https://www.quarksinteractive.com/

A Real World Example: Hong-Ou-Mandel*

Well known effect in quantum optics

1. Two identical photons enter a beam splitter "asleep" vs. "awake" $\rightarrow$ direction of travel
2. Four paths (neither reflect, 2 x one reflects, both reflect)
3. Paths cancel, both photons exit in same direction

Fundamentally different than identical classical balls (or cats), each can take one path (no superposition of asleep an awake):

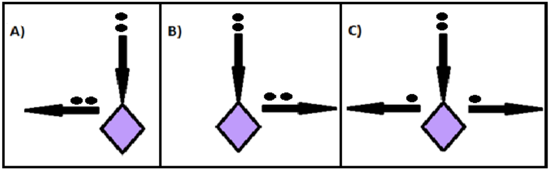


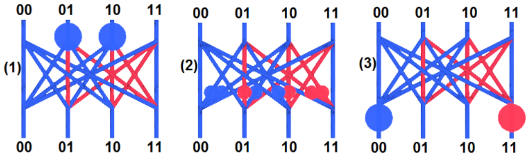
Figure 1: Balls are represented with the black dots and arrows show direction of bounce

A) 25% chance for both balls to bounce left.
B) 25% chance for both balls to bounce right.
C) 50% chance that each ball will bounce in an opposite direction.

*see: L. Nita et. al. Research in Science and Technology Education (2021) (arXiv:2004.07957)

Visualized with quantum odyssey*

1. Photon travel direction represented by 1 or 0 (think of two cats which can each be “awake” or “asleep”)
2. Start in a positive superposition (one cat awake, one asleep, but don’t know witch)
3. Beam splitters represented by “Hadamard” gates

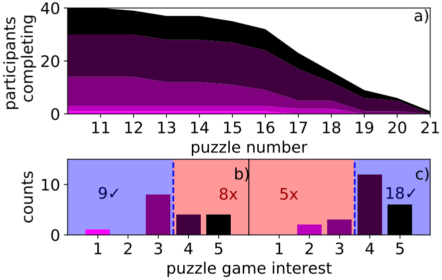


- Red and blue balls annihilate, representing interference
- Can see the effect working, no (traditional) mathematics required

*Note that we place the phases differently than traditional quantum optics to be more in line with quantum computing conventions

Additional research on this approach

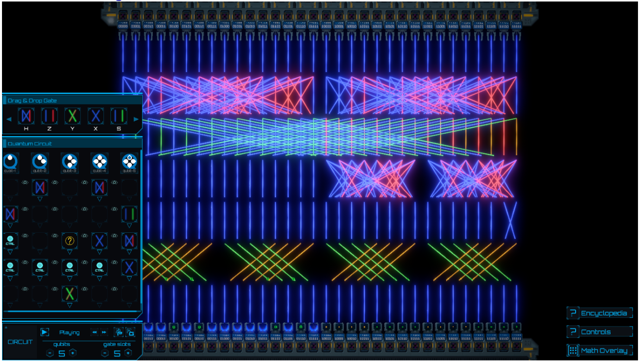
Paper studying the use of quantum odyssey in teaching https://arxiv.org/abs/2106.07077



Some key results:

- Interest in puzzle games was deciding factor in how participants performed
- No statistically significant effect from gender, quantum mechanics knowledge, interest in quantum computing
- Participants wanted to understand not just play

Let's give it a try!



Video games are more conducive to screen sharing so we have provided licenses for quantum odyssey

- Will divide into breakout rooms, myself and others will circulate to answer questions
- Don't want to be too prescriptive, explore as you like, but a few suggestions on the next slide

Suggested activities

1. Try to reproduce the puzzles in the card game with the video game
   - Perhaps follow along with the cards and tokens if you have them printed out
2. Play around with what you can do with a single qubit (the cat example in the card game)
   - Can you understand the rules the video game follows based on the card game rules?
   - Can you design puzzles to stump the people in the room with you?
3. Try some of the additional video game content, there is a lot to explore