



15 min



10+ years

# Classical Error Detection and Correction

Exploring how computers find and fix errors

## Learning Goals

- Understand how a classical computer detects and correct errors.
- Detect and correct errors using one strategy that classical computers use.

## Importance in Quantum Computing

This activity introduces participants to the binary system and error detection and correction in classical computing. Quantum computers also need to be able to detect and correct errors, but use different methods.



## Materials

- ❑ Surface with a grid, such as a checkers board or white board
- ❑ Items to populate the grid that differ in one aspect (e.g., sticky notes with Xs and Os, checkers pieces in red and black)
- ❑ Copies of Error Detection worksheet

## Preparation

- If necessary, draw a 6 by 6 grid on a white board or piece of chart paper.



## Background Knowledge

In this activity, participants will use a two-dimensional grid or array of binary objects and learn one way to detect errors within an array. Classical computers do not use all the digits we are accustomed to in math—0 through 9—they use only 0s and 1s. The 0s and 1s in a computer can also be interpreted as on (1) or off (0). The storage in a classical computer only recognizes on or off, so the circuits in a computer function like the circuits controlling a light in your home—it switches on or off. This system of 0s and 1s is called **binary**, and each 0 and 1 is a **binary digit**. Everything the computer does requires storing information through binary digits, or **bits**. It is also important for quantum computers to be able to detect and correct errors in the quantum bits, or qubits. However, qubits can be 1 and 0 simultaneously – this doesn't exist in classical computing – and change when measured, so this method does not work.

## Facilitating the Activity

### ENGAGE

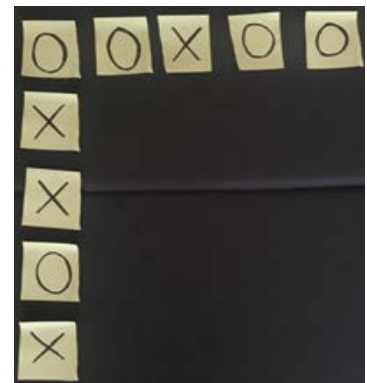


Literacy  
Connection

1. Look through the images in one of the following books, or something similar, with participants. Ask them to identify the image on each page that does not match the others. What is similar about them? What is different? Facilitate a discussion of how they identified the error on each page. What clues did they use to find the error? How would they correct it so it matches the other images on the page?
  - a. *Undercover: One of These Things is Almost Like The Others, Food Hide and Sneak, or Vehicles Hide and Sneak* by Bastien Contraire
  - b. *The Odd One Out* by Britta Teckentrup
2. Ask participants what they know about how computers are made and how they work. Check that they know the following:
  - a. Computers are comprised of a series of circuits, just like circuits in a building that allow a light to be either on or off. Inside a computer, the circuits can be either on or off, which are stored as the binary digits (“bits”) 1 or 0.
  - b. Classical computers are based on a binary system of 0s and 1s.
3. Tell participants that computers sometimes make errors and the relative simplicity of binary (only 2 digits) means that finding the errors is relatively easy. Ask participants if they know what a computer does when an error occurs in the bits in the hard drive. For example, if a bit that is supposed to be a 0 is recorded as a 1, or vice versa. It would be more difficult if computers used all ten digits we use for math.
4. Tell participants that you have an activity that shows how a classical computer finds small errors and corrects them, so they don’t accumulate and turn into bigger problems for the user.

### ACTIVITY

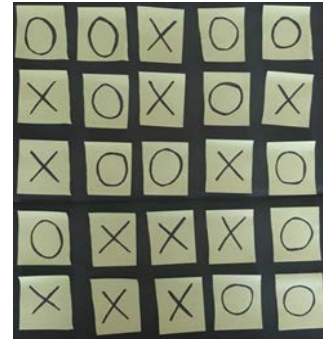
1. Fill in one row of 5 with a mix of your objects and one column of 5, as shown in the example to the right. Randomly choose the value of each position.



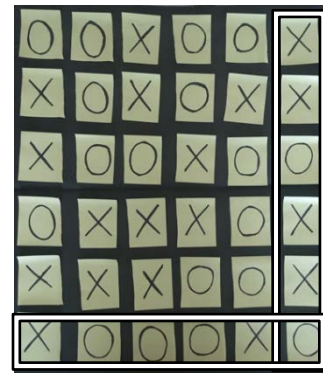
*Differentiation Note: For younger participants, consider starting with a 3x3 grid and building it to a 4x4 grid.*

## Classical Error Detection

2. Ask a participant to complete the rest of the 5x5 grid with a mix of the objects, as shown in the example to the right.
3. Tell participants that maybe 5x5 is too easy for you, and add another row and column to make the grid 6x6. Your new objects will not be randomly chosen, but don't tell this to participants. Use the following rule to place the remaining objects.



- a. **There must be an even number of one of the two objects in each row and each column.** In the example shown, there is one X in the first row. Another X needs to be added in the sixth position of that row to make an even number of Xs. Similarly, the third column has 4 Xs, so an O needs to be added to the sixth position in that column to maintain an even number of Xs.

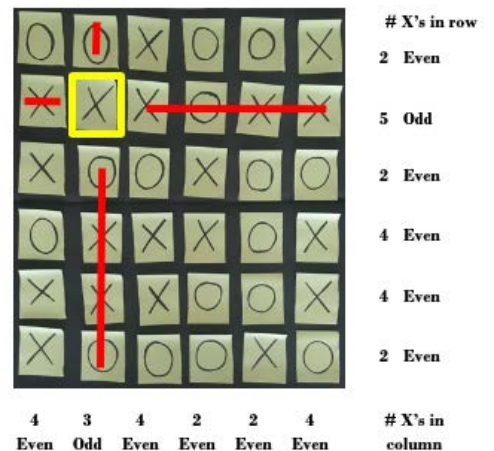


4. Ask a participant to change one of the objects (e.g., from X to O, or from red to black) while you have your back turned. Tell them that you will be able to tell which card was changed when you turn around. Ask other visitors to watch and confirm that you have not cheated.

*Facilitation Note: If a second facilitator is available, have them help the participant successfully change the object. Common problems the participants have include using an object that is not one of the two options, placing an object outside of or out of line with the grid, replacing an object with the same object (so there is no change), or switching two objects already on the grid (resulting in 2 errors).*



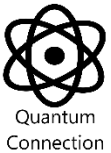
5. When you turn around, look for the row and column that no longer have an even number of your object. The object that they have in common is the one that was changed. Show participants the object you believe was changed and ask if you are correct. Participants might think you made a lucky guess, so return the object to the correct state and ask another participant to change another object while you are not looking.



*Facilitation Note: Be sure to change the object back to the original state before you repeat the “trick.” You must ensure that the rows and columns have an even number before starting. This process does not work if 2 bits have been changed because it’s assumed that double errors are rare.*

### DISCUSSION

1. Ask the participants for their ideas about how you figured out which object was changed.
  - a. If a participant has the right idea, have them come up and demonstrate their strategy.
  - b. If no participants have the right idea, give them a hint by saying that you’re using a pattern in the grid to identify which object changed. Ask for someone else to change an object and again find the change.
  - c. If participants still need a hint, tell them that the key is in the 6th row and 6th column that you placed, rather than in the original 5x5 grid that the participant created.
2. If most participants are still struggling after seeing the activity multiple times, do it once more while walking them through the process.
  - a. Explain your reasoning for choosing either X or O for the 6th row and 6th column, as described above. To further illustrate this, you can construct a new 5x5 grid and walk them through constructing the 6th row and 6th column.
  - b. Explain the process you used to identify the changed object. Show participants how you identify the problematic row and column, and how that will always lead you to the single object that was changed.
3. After all participants understand the process, ask one or more to come up and try it out, both creating the 6th row and 6th column as well as identifying the changed object. With this logical method, anyone can do the “trick!”
4. Tell participants that the error detection and correction method they just learned only applies to classical computer, not a new kind of computer called a quantum computer. There are 2 reasons that this doesn’t work for quantum computers.
  - a. In this error correction method, we observe bits, which are either a definite 1 or a definite 0. How can you look for an even number of 1s if you don’t even have a certain number of 1s to begin with?
  - b. This error correction method relies on an observer actually looking at (or measuring) the bits in the array. Qubits, on the other hand, are sensitive to any form of measurement to the extent that if qubits are even exposed to light, their state will be altered. In quantum computer, error detection and correction cannot include observing qubits because observing changes the state of the qubit.



## Classical Error Detection

5. Another method of classical error correction involves cloning bits in succession to identify error. For example: Instead of sending a 0, you send five 0s consecutively, 0-0-0-0-0. If you receive 0-0-0-1-0, the 1 is most likely the error and should be a 0, because it's very unlikely the four zeros are errors and the 1 is correct. The reverse works if you want to send 1 by coding 1-1-1-1-1 and receive 1-1-0-1-1. This method is also incompatible with quantum computing. First, qubits are more complex than bits, as they can be 0 and 1 at the same time and carry other information. Moreover, it's impossible to clone a qubit. To clone a qubit, you would first have to measure it, and by measuring, you change the state of the qubit.
6. Ask participants to complete the Error Detection worksheet and find the errors.

### Connections to Standards

*Next Generation Science Standards\**

Crosscutting Concept: Patterns

Science and Engineering Practices: Using Mathematics and Computational Thinking

### Acknowledgements

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This activity was adapted from the [Quick Card Flip Magic](#) activity developed by [CS Unplugged](#), a project by the [CS Education Research Group](#) at the [University of Canterbury, NZ](#)

\*Next Generation Science Standards is a registered trademark of Achieve. Neither Achieve nor the lead states and partners that developed the Next Generation Science Standards were involved in the production of this product, and do not endorse it.



I am in grade \_\_\_\_\_

## Detecting and Correcting Errors

Examine the grids below. Use the strategy you just learned to find the errors.

Circle any errors you find.

X	X	O	O
O	O	X	X
X	O	X	O
O	X	O	O

O	O	X	X	O	O
X	X	X	O	O	X
X	O	O	X	X	X
O	X	O	X	O	O
O	X	X	O	O	X
O	O	X	X	X	X

O	O	X	O	O	X	X	X
X	X	O	O	X	X	O	O
X	O	O	X	X	X	X	X
X	X	O	X	O	O	O	X
X	O	O	X	O	O	X	X
O	O	X	O	O	X	O	X
O	O	X	O	O	X	X	X
O	O	X	X	O	O	O	O

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X	X	O	O
O	O	X	X
X	O	X	O
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O	O	X	X	O	O
X	X	X	O	O	X
X	O	O	X	X	X
O	X	O	X	O	O
O	X	X	O	O	X
O	O	X	X	X	X

O	O	X	O	O	X	X	X
X	X	O	O	X	X	O	O
X	O	O	X	X	X	X	X
X	X	O	X	O	O	O	X
X	O	O	X	O	O	X	X
O	O	X	O	O	X	O	X
O	O	X	O	O	X	X	X
O	O	X	X	O	O	O	O



A PEEK INTO...

Handwritten notes on a piece of paper:

b) Ozeanil  
 c) Gausenru ✓

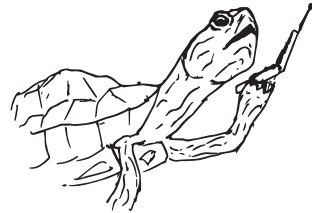
(5) Dillacosta formari so leau themon cooparates?  
 a) Quantum  
 b) Error ✓  
 c) Detection ✓

(6) Cembak le sultike, pro nos apizake le?  
 a) Angrostke  
 b) Zonallir

## What's That?

Sometimes it can be hard to hear letters over the phone.

Was that an "m" or an "n"?



The person on the other end of the line might make a mistake.

## Sending Extra Information Can Help Prevent Errors

"m" as in magic

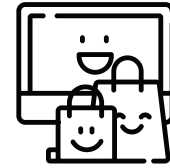


It takes a little longer to send the message, but it's more likely to be correct!

## What's in a UPC?

Barcodes on products have a UPC number.

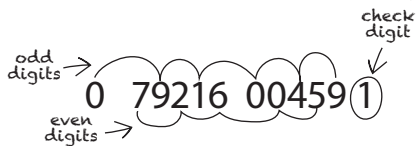
A UPC number is made up of 12 digits that have encoded information about a product and its manufacturer.



The last digit is called a check digit. It is used to know whether or not an item scanned correctly.



## How Does It Work?



Add the odd digits together.  $\frac{\text{odd total}}{23}$  Then, multiply the total by 3.  $\frac{\text{odd total}}{69}$

Add the even digits together.  $\frac{\text{even total}}{20}$

Add the even and odd totals together.  $\frac{\text{total}}{99}$

Add the even/odd total and check digit together.  $\frac{+1}{100}$



If the total is a multiple of 10, the UPC is valid!

## Error Detection in Classical Computers

Information is sent as bits with a value of 0 or 1.



Sometimes errors occur that cause a bit to flip.

To help detect errors, each bit can be sent multiple times.  $101 \rightarrow 111|000|111$

When the digits in a group of bits don't match, then we know we've detected an error!



error →  $110|000|101$  error

## Error Detection in Quantum Computers

Quantum bits (or qubits) are very fragile and errors are common.

Qubits can't be copied without losing information.

I'm very sensitive!

I'm too complex!



I think I've entered a new phase.

Bit flips aren't the only kind of error qubits encounter.



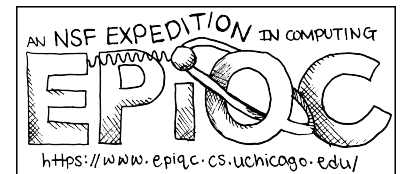
Quantum computers require new ways of detecting errors!

Find more Quantum Computing zines here:

<https://www.epiqc.cs.uchicago.edu/resources/>

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# Share what you've learned about error detection and correction!

- Explain to someone else what it means to detect and correct an error.
- Notice when you find and correct errors in your everyday life. Discuss your experiences with others.
  - What helped you to find the error?
  - What did you do to correct it?
  - How do you think you could make it easier to find errors?
- Try the classical error detection and correction “trick” with someone new! Can they figure out how you did it?