



IGROVERMIND>

30TH AUGUST 2021



UNIVERSITÄT BONN

800
1222-2022
ANNI



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

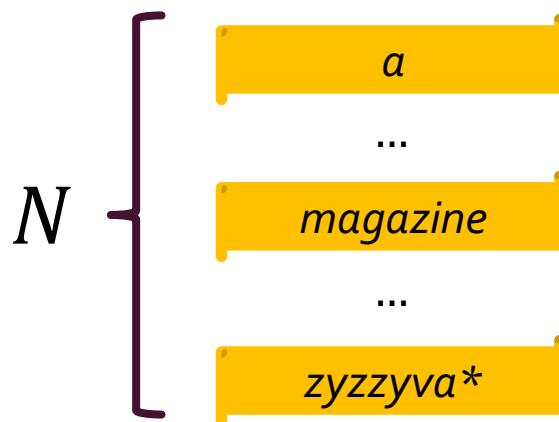
OUTLINE

- Grover's algorithm
- QCHack 2021
- The Mastermind Game
- Q# implementation
- $|GroverMind\rangle$ 2.0
- Summary and conclusions

SEARCH ALGORITHMS

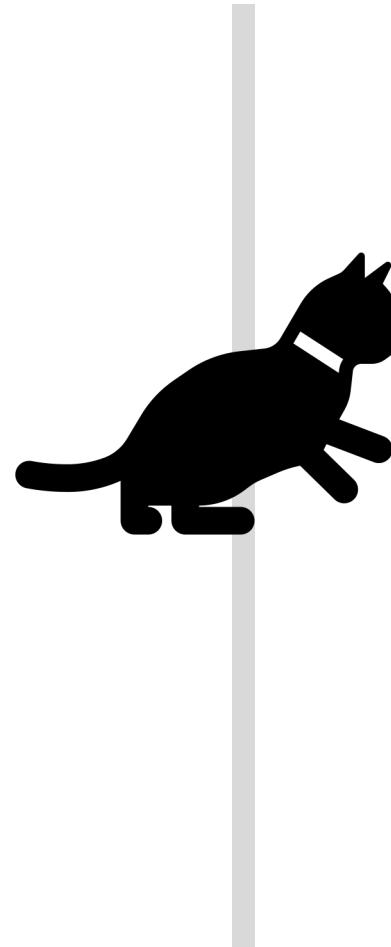


STRUCTURED

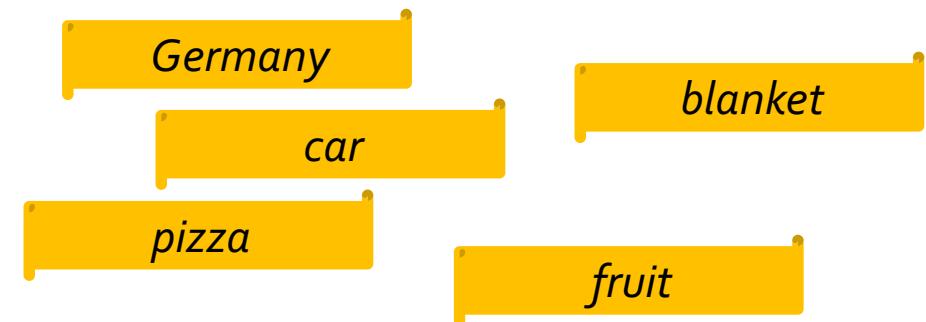


$$\sigma(\log_2(N))$$

*last word in the English dictionary



UNSTRUCTURED



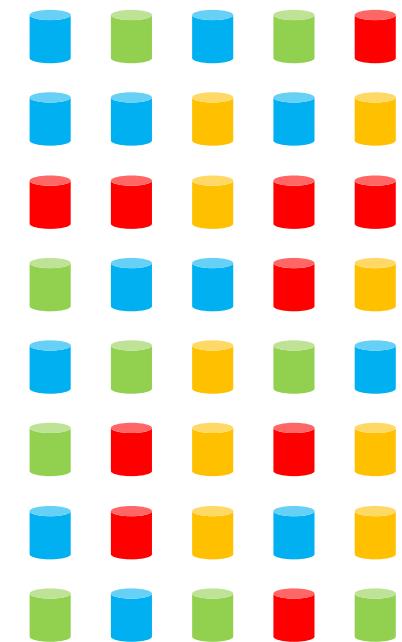
Classical
 $\sigma(N - 1)$

worst case

GROVER'S ALGORITHM

There are computational problems in which it is **difficult to find** a solution, but relatively **easy to verify** a solution.

$$f(x): \{0,1\}^n \rightarrow \{0,1\}$$
$$\left\{ \begin{array}{ll} 1 & \text{if } x = \omega \\ & x \in \{0,1\}^n \text{ will encode a sequence of pegs} \\ 0 & \text{if } x \neq \omega \end{array} \right.$$

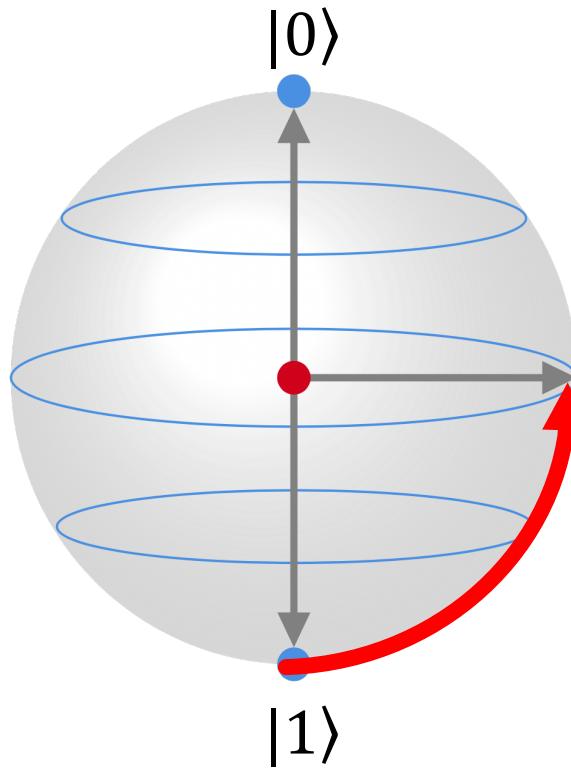


WHAT ABOUT QUBITS?

- 0

- 1

BIT



QUBIT

$$H|1\rangle = \frac{|0\rangle - |1\rangle}{\sqrt{2}}$$



GROVER'S ALGORITHM – ORACLE

Apply the function via a **quantum oracle** (unitary operator)

$$U|x\rangle|q\rangle = |x\rangle|q \oplus f(x)\rangle$$

$|q\rangle$ is the **oracle qubit** initialized to $|0\rangle$
and $|x\rangle \equiv |x_1\rangle|x_2\rangle\dots|x_n\rangle$

$$\begin{cases} U|x\rangle|0\rangle = |x\rangle|0\rangle & \text{if } x \neq \omega \\ U|x\rangle|0\rangle = |x\rangle|1\rangle & \text{if } x = \omega \end{cases}$$

MARKING ORACLE



GROVER'S ALGORITHM – ORACLE

It is **convenient** to apply the quantum oracle when the oracle qubit is initialized to $|q\rangle = \frac{|0\rangle - |1\rangle}{\sqrt{2}} = |- \rangle$

$U_\omega|x\rangle|- \rangle = -|x\rangle|- \rangle \quad \text{if } x = \omega$ The oracle marks the solution by **shifting its phase**

PHASE ORACLE

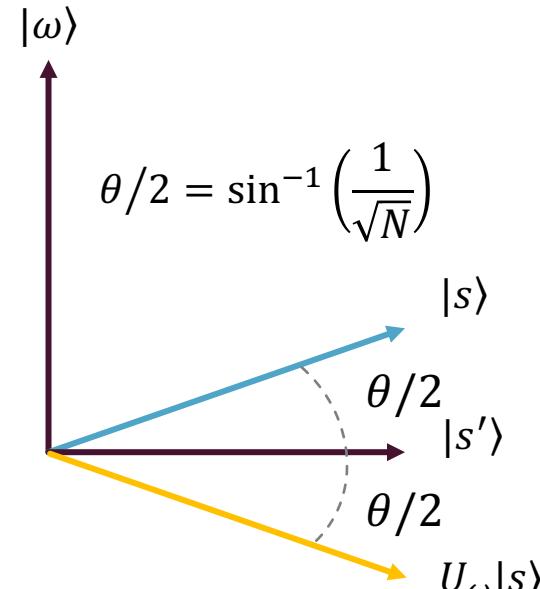
GROVER'S ALGORITHM – ITERATIONS



$$|s\rangle = \frac{1}{\sqrt{N}} \sum_{x=0}^{N-1} |x\rangle \quad |s'\rangle = \frac{1}{\sqrt{N-1}} \sum_{x \neq \omega} |x\rangle$$

First reflection $U_\omega = I - 2|\omega\rangle\langle\omega|$

$$\begin{cases} U_\omega |s'\rangle = (I - 2|\omega\rangle\langle\omega|)|s'\rangle = |s'\rangle - 2|\omega\rangle\langle\omega|s'\rangle = |s'\rangle \\ U_\omega |\omega\rangle = (I - 2|\omega\rangle\langle\omega|)|\omega\rangle = |\omega\rangle - 2|\omega\rangle\langle\omega|\omega\rangle = -|\omega\rangle \end{cases}$$



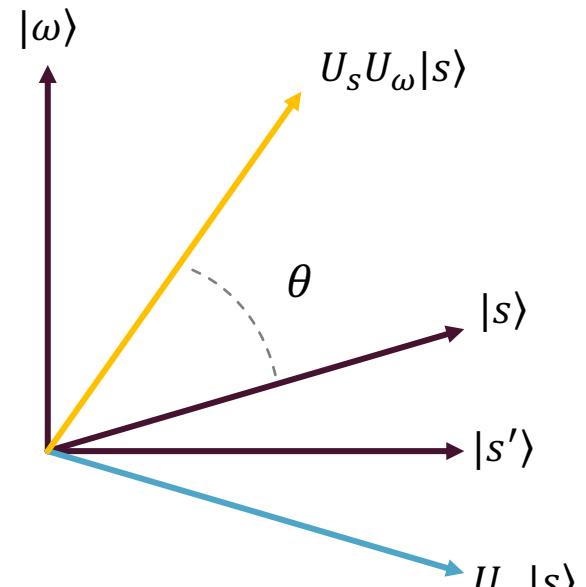
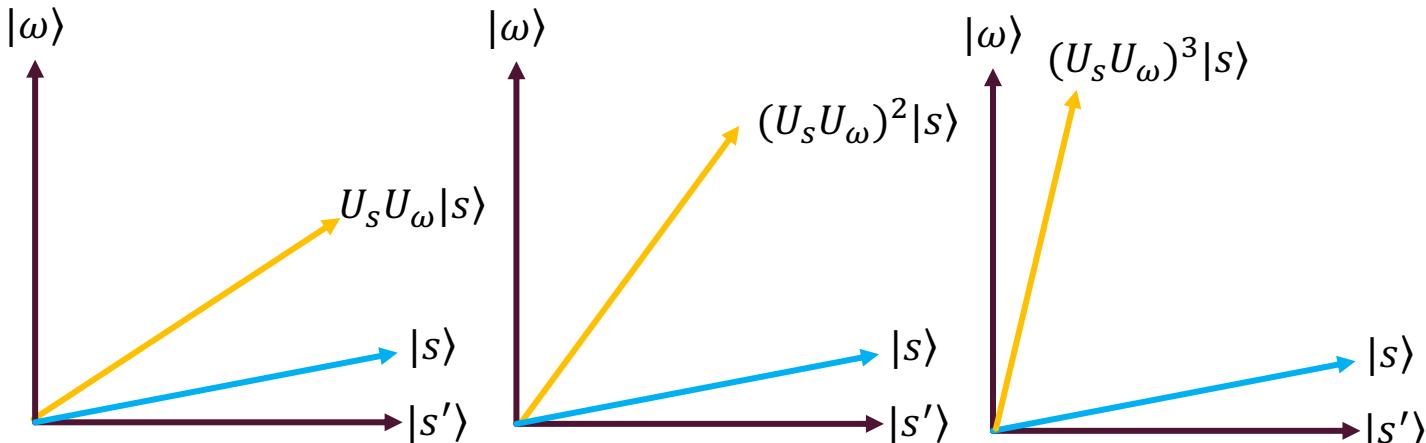
...but the chance of measuring ω is still $\frac{1}{N} = \frac{1}{2^n}$



GROVER'S ALGORITHM – ITERATIONS



Second reflection $U_s = 2|\omega\rangle\langle\omega| - I$



Stop after r iterations: $r \theta = \frac{\pi}{2} \rightarrow r = \frac{\pi}{4} \sin^{-1} \left(\frac{1}{\sqrt{N}} \right) \approx \frac{\pi}{4} \sqrt{N}$



WHAT IS QCHACK?

Quantum Coalition Hack

10–11 April 2021

Open to everyone

Yale x Stanford Hosted

Information for Students | Sponsors

2.1K participants | 80 countries | 200 projects

Sign-up below to get an invite to the Quantum Coalition

Discord and to stay tuned for QC Hack 2022!

Join the Quantum Coalition



Google
Quantum AI



Q-CTRL

IBM Quantum

Main Partners | 100 Qubit Sponsors



Microsoft



IONQ



qBraid

10 Qubit Sponsors



$\langle Q | FARM \rangle$



1 Qubit Sponsors

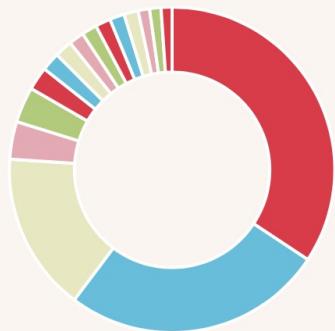
*Interested in **sponsoring** or **partnering** with the Quantum*

Coalition? Schools and companies please sign up [here](#).

Verify certificates [here](#).

WHAT IS QCHACK?

**80 Countries
Represented**



- India ■ United States ■ Other
- Canada ■ United Kingdom
- Turkey ■ Germany ■ Vietnam
- China ■ Mexico ■ Romania
- Pakistan ■ Australia ■ Brazil
- Spain ■ Italy

2.1K Registered

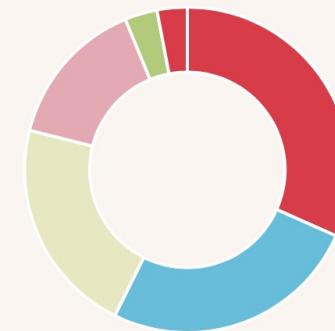
1.4K Unique Viewers

1K Discord Members

200 Projects Created

22 Hours of Content

**Diversity of
Backgrounds**



- Computer Science ■ Physics
- Engineering ■ Math ■ Chemistry
- Non-STEM

OUR TEAM



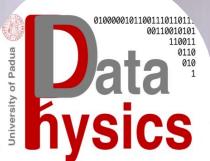
University of Padua
**Data
physics**



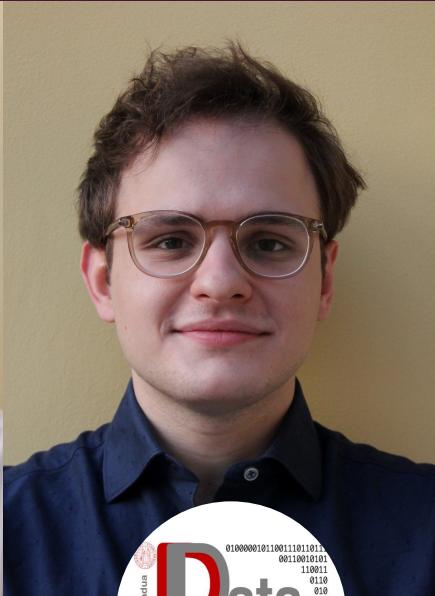
ALESSANDRO MARCOMINI



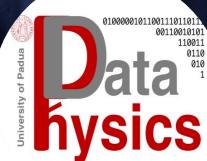
University of Padua
**Data
physics**



TOMMASO FAORLIN



University of Padua
**Data
physics**



SAMUELE PICCINELLI



University of Padua
**Data
physics**



GIULIA CAMPESAN



 Erasmus Mundus
JMD on
Nuclear Physics

FILIPPO ANGELINI

OUR QCHACK 2021



4 problems

+

Creative challenge

- *Use of Q#*
- *Educational value*

Brainstorming



- New to Q#
- Simplify game rules

Work*



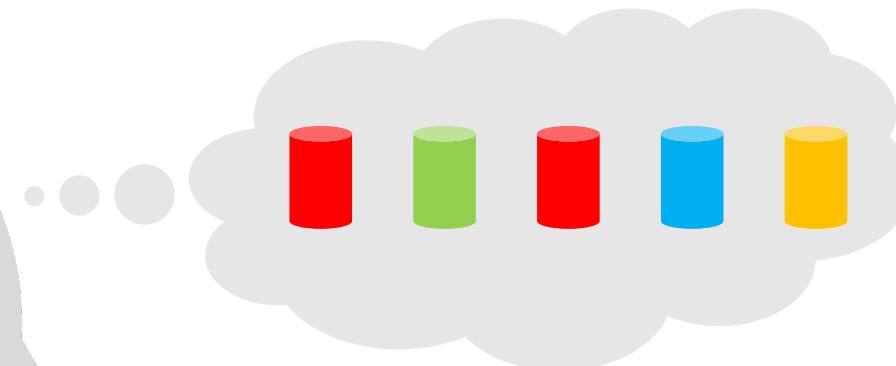
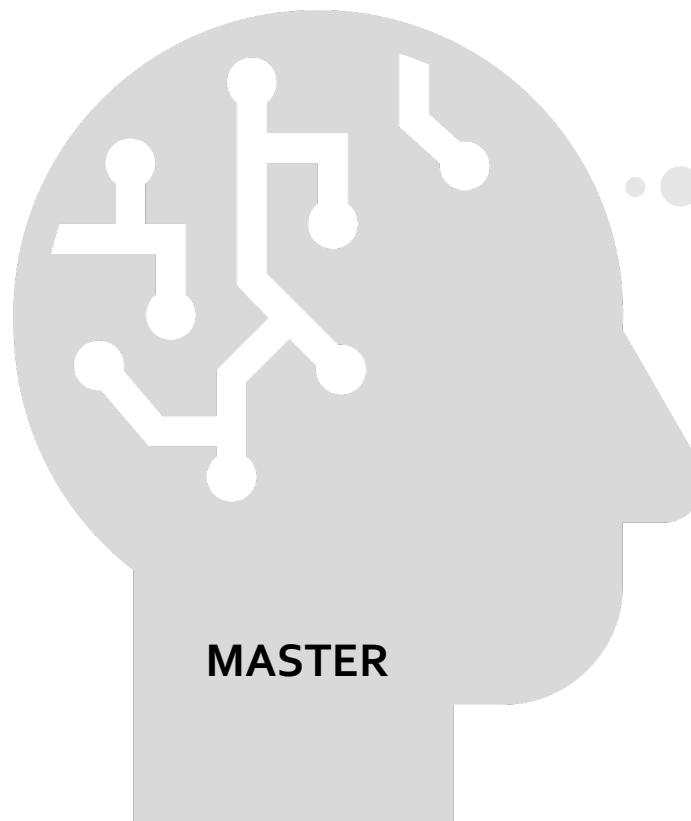
IGROVERMIND⟩ @ QCHACK 2021



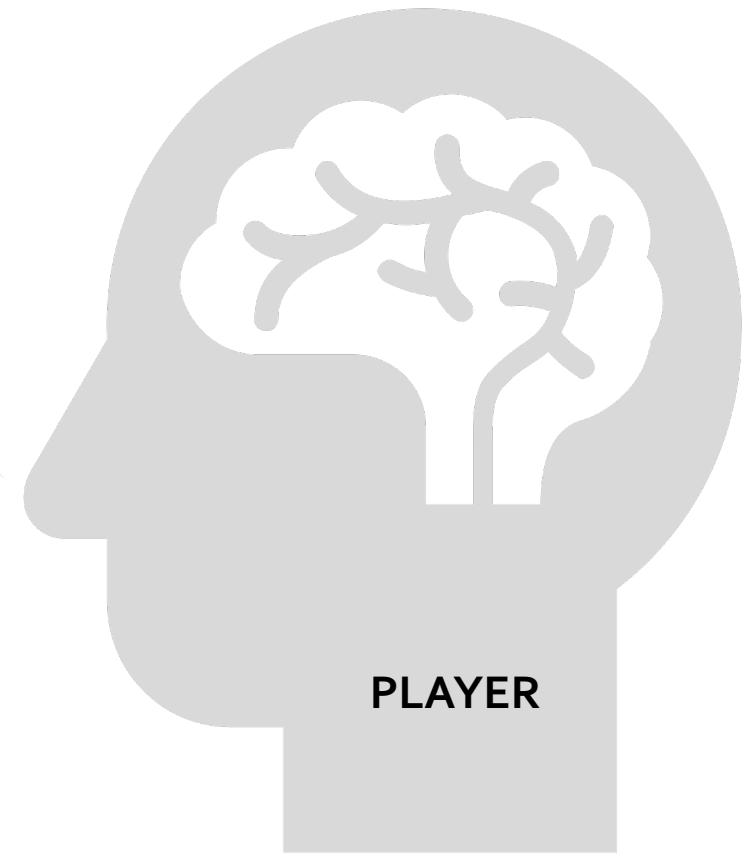
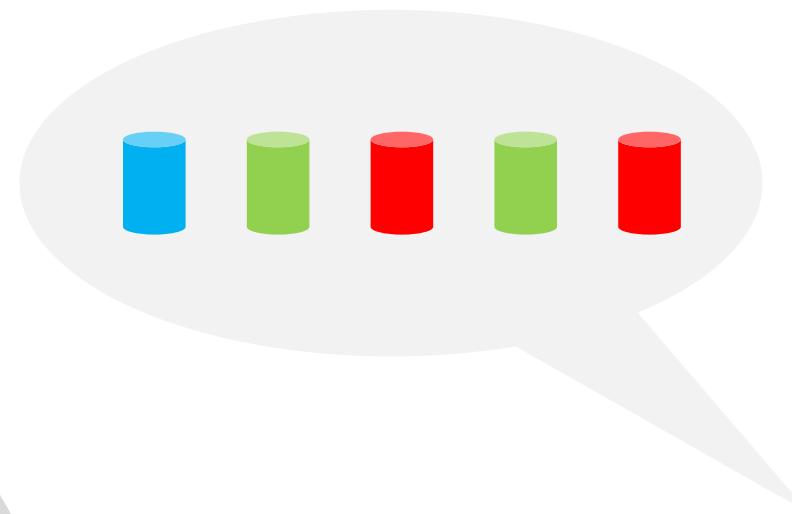
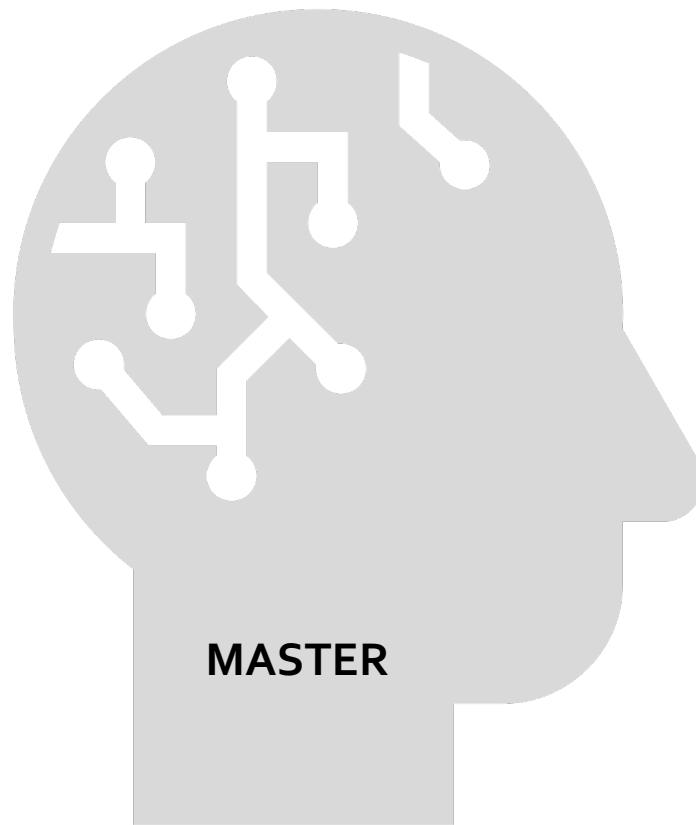
THE MASTERMIND GAME



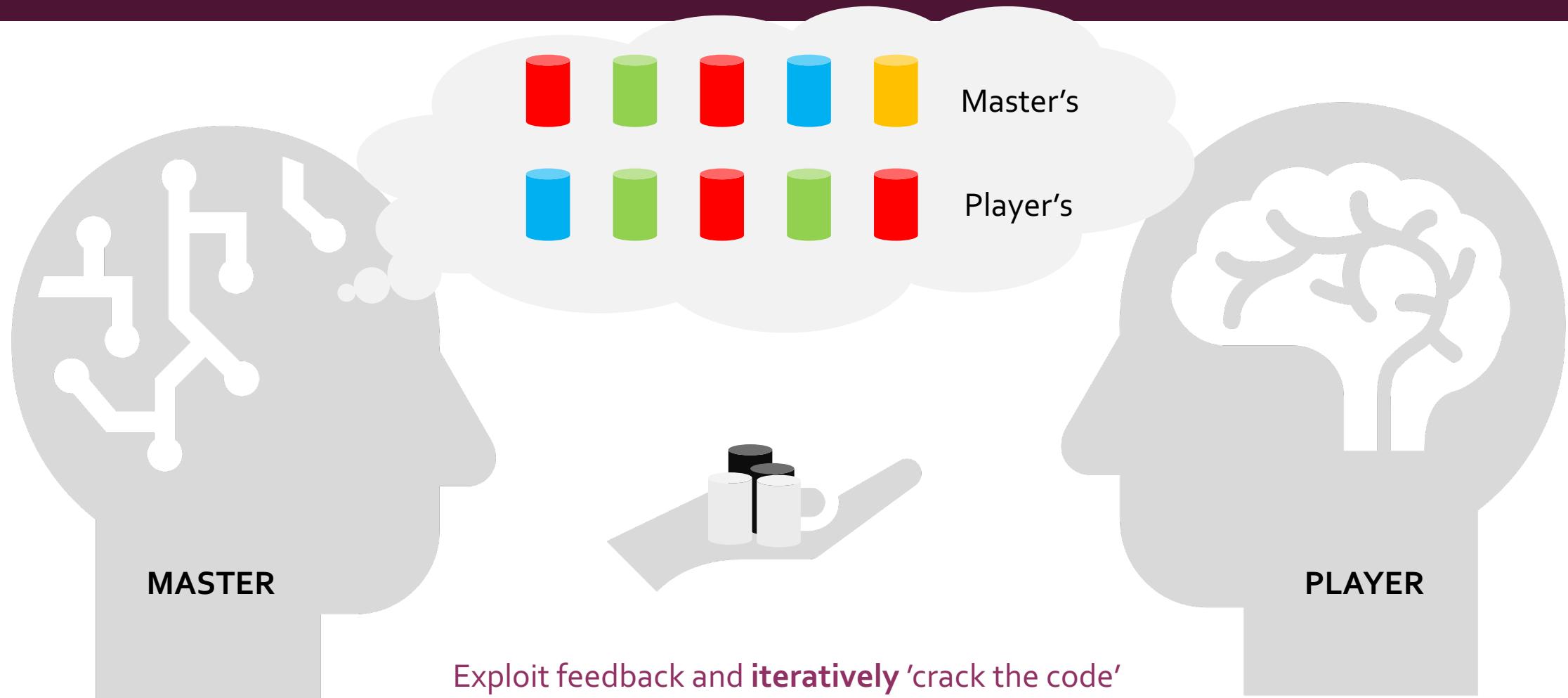
Player's goal is to **guess correctly** an **unknown sequence** of colors, within a **fixed number** of trials



THE MASTERMIND GAME



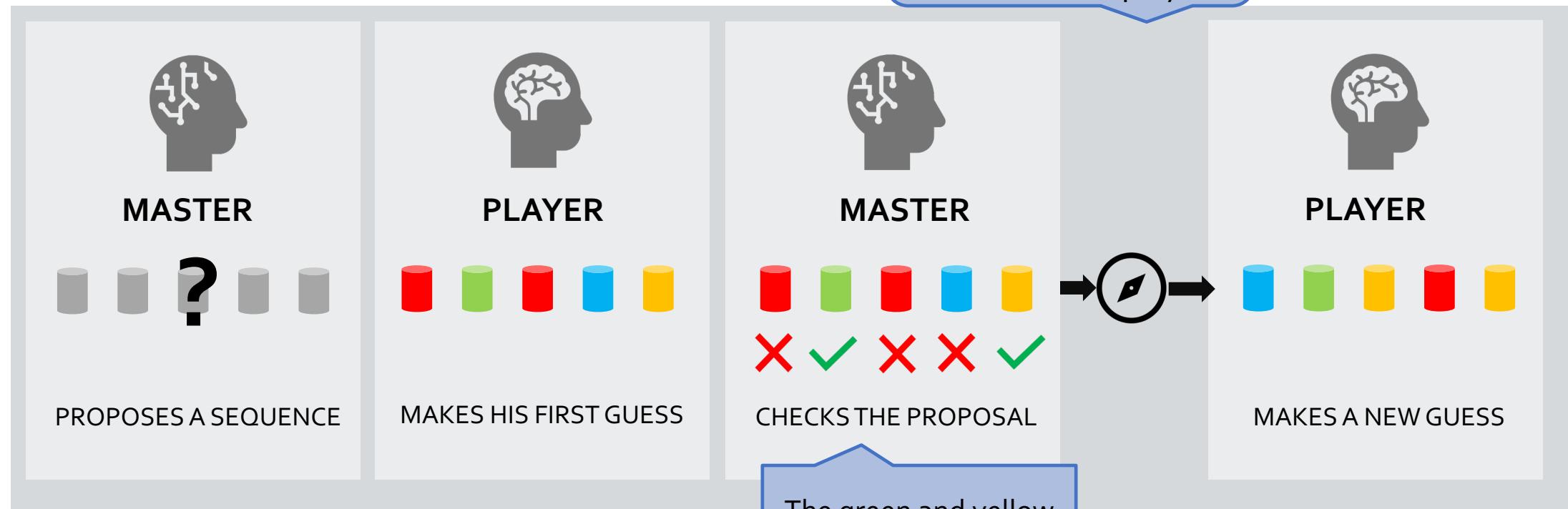
THE MASTERMIND GAME



Exploit feedback and **iteratively** 'crack the code'

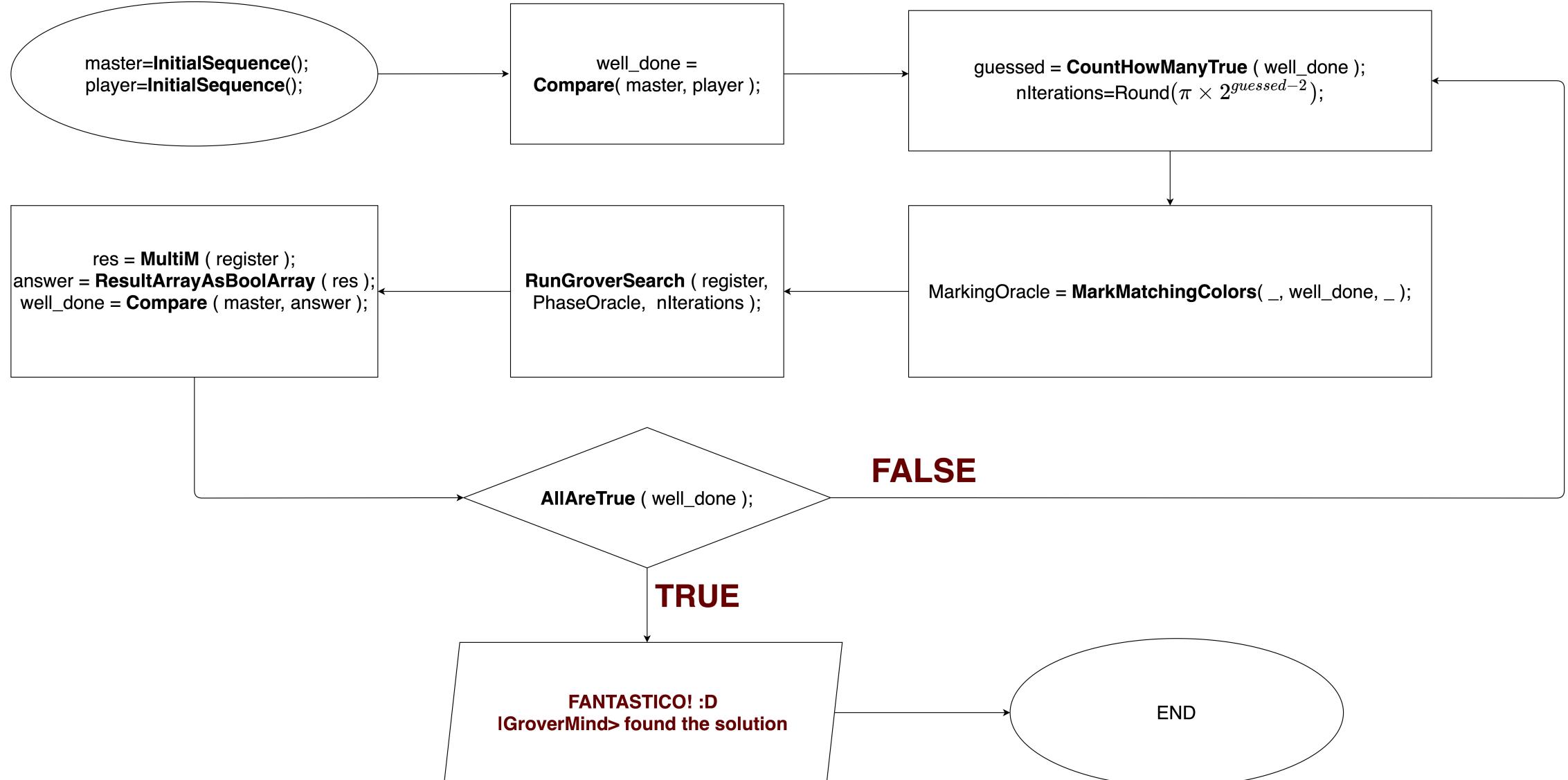
|GROVERMIND⟩

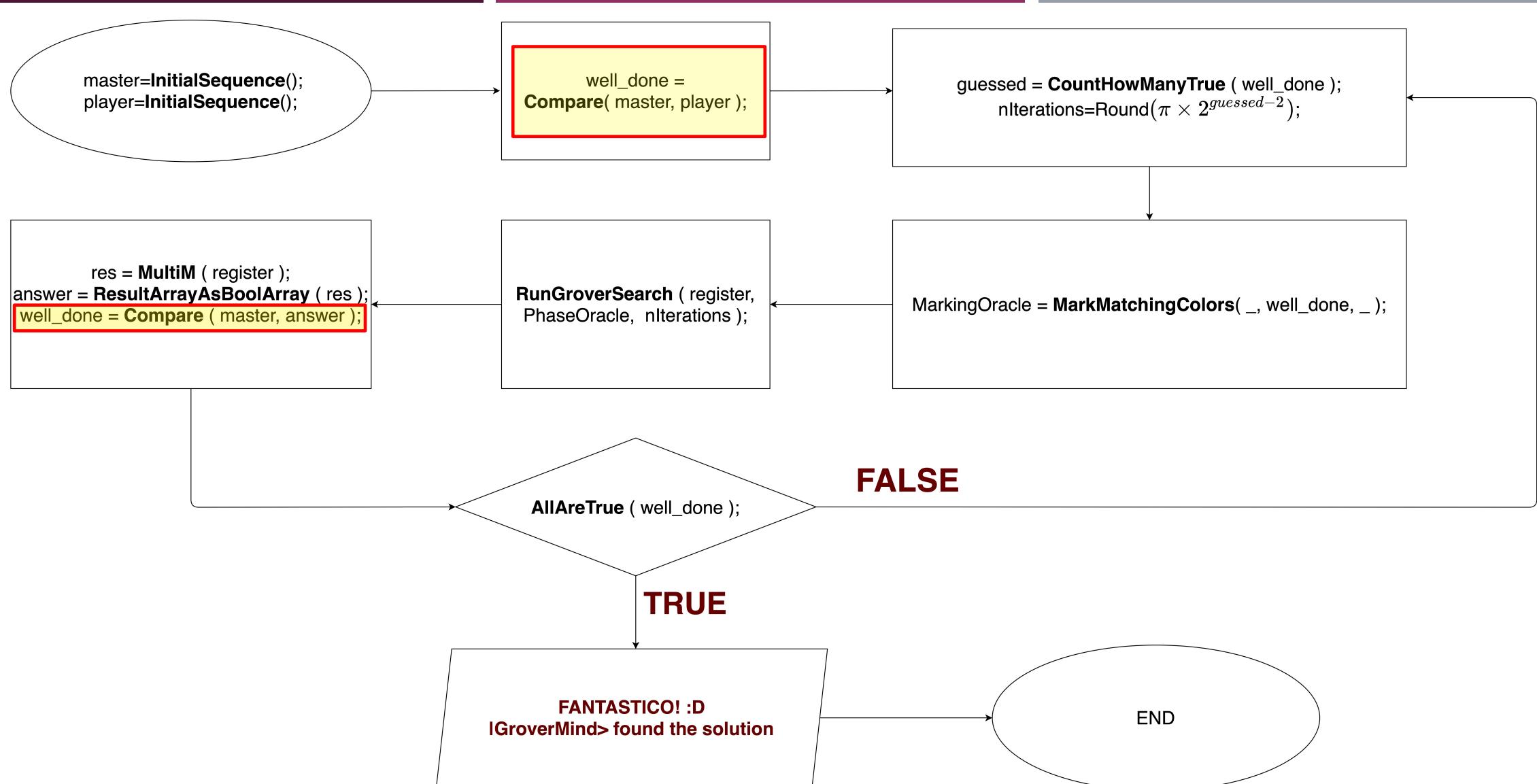
Here Grover's algorithm comes into play



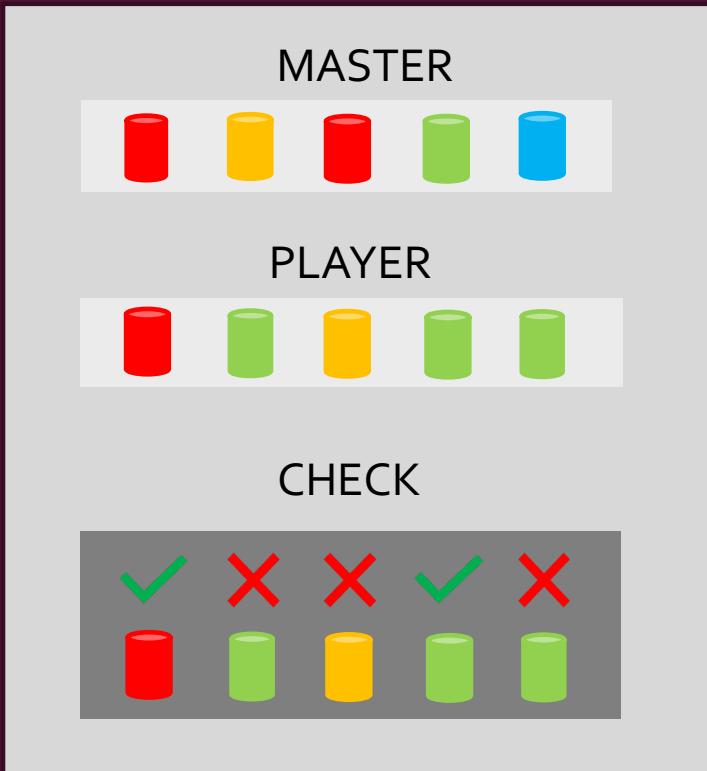
OK BUT...
PRACTICALLY
SPEAKING?



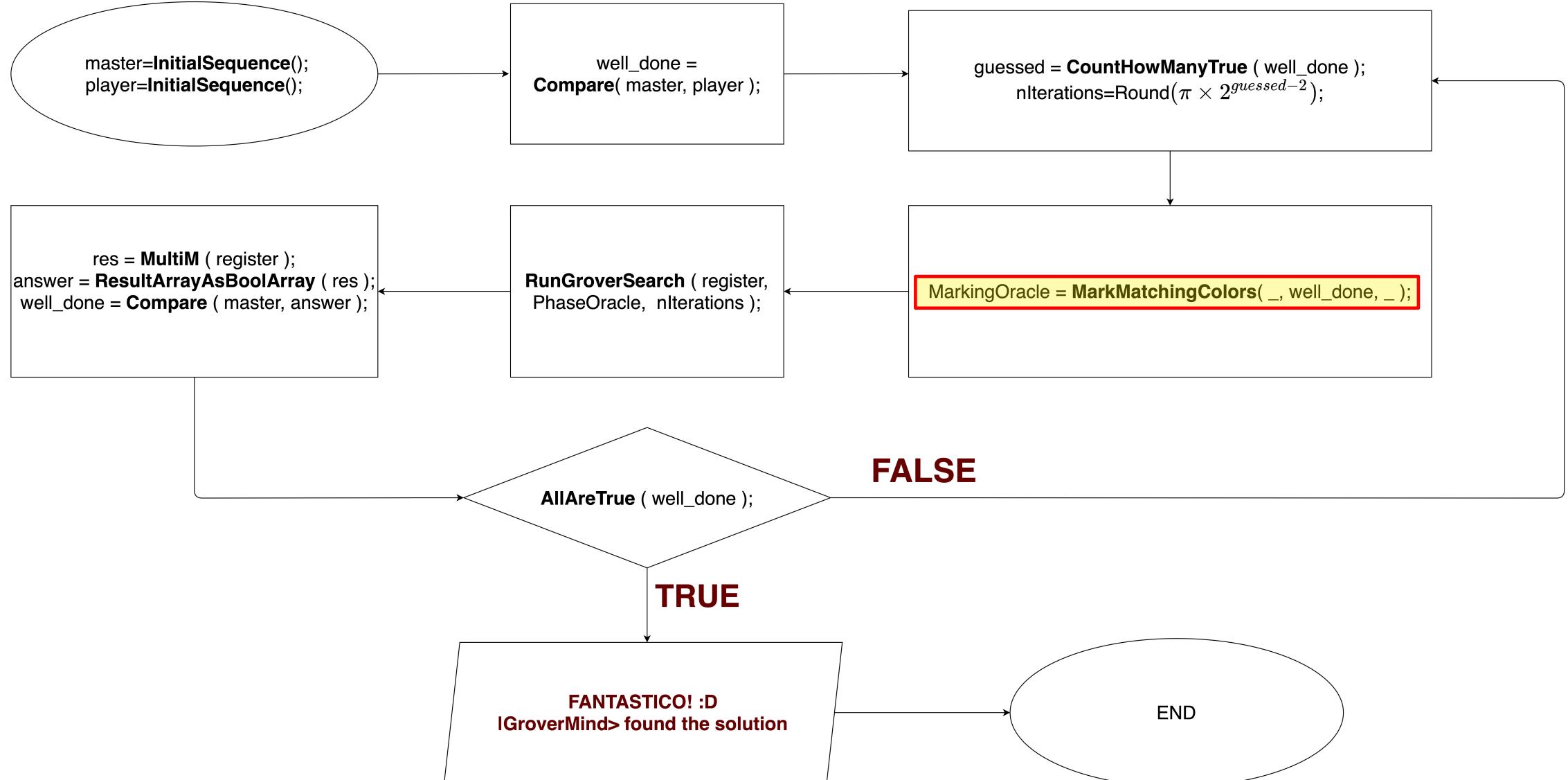




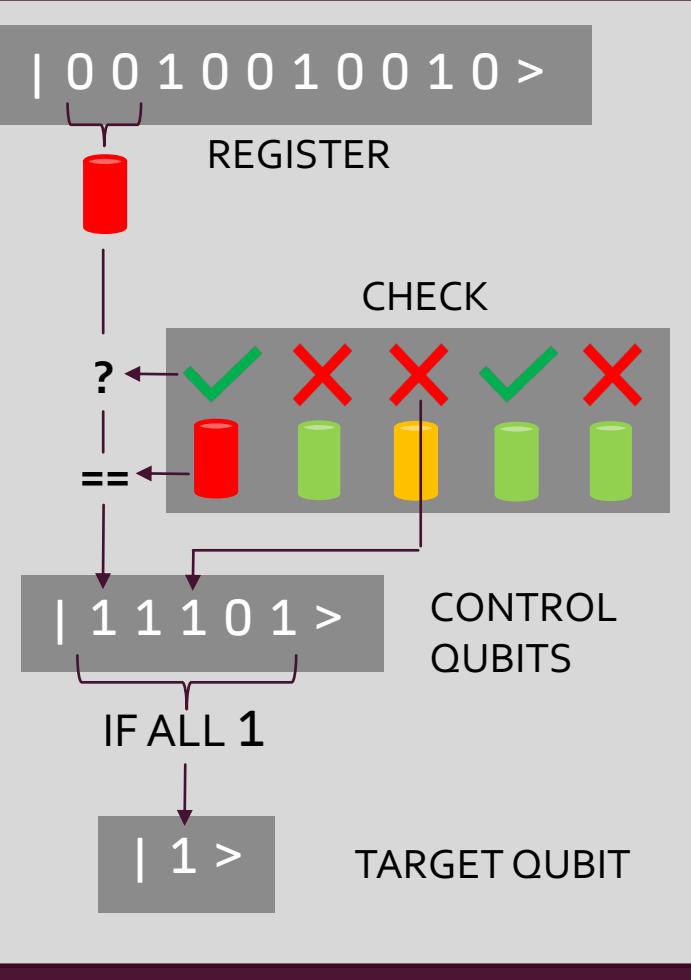
COMPARISON



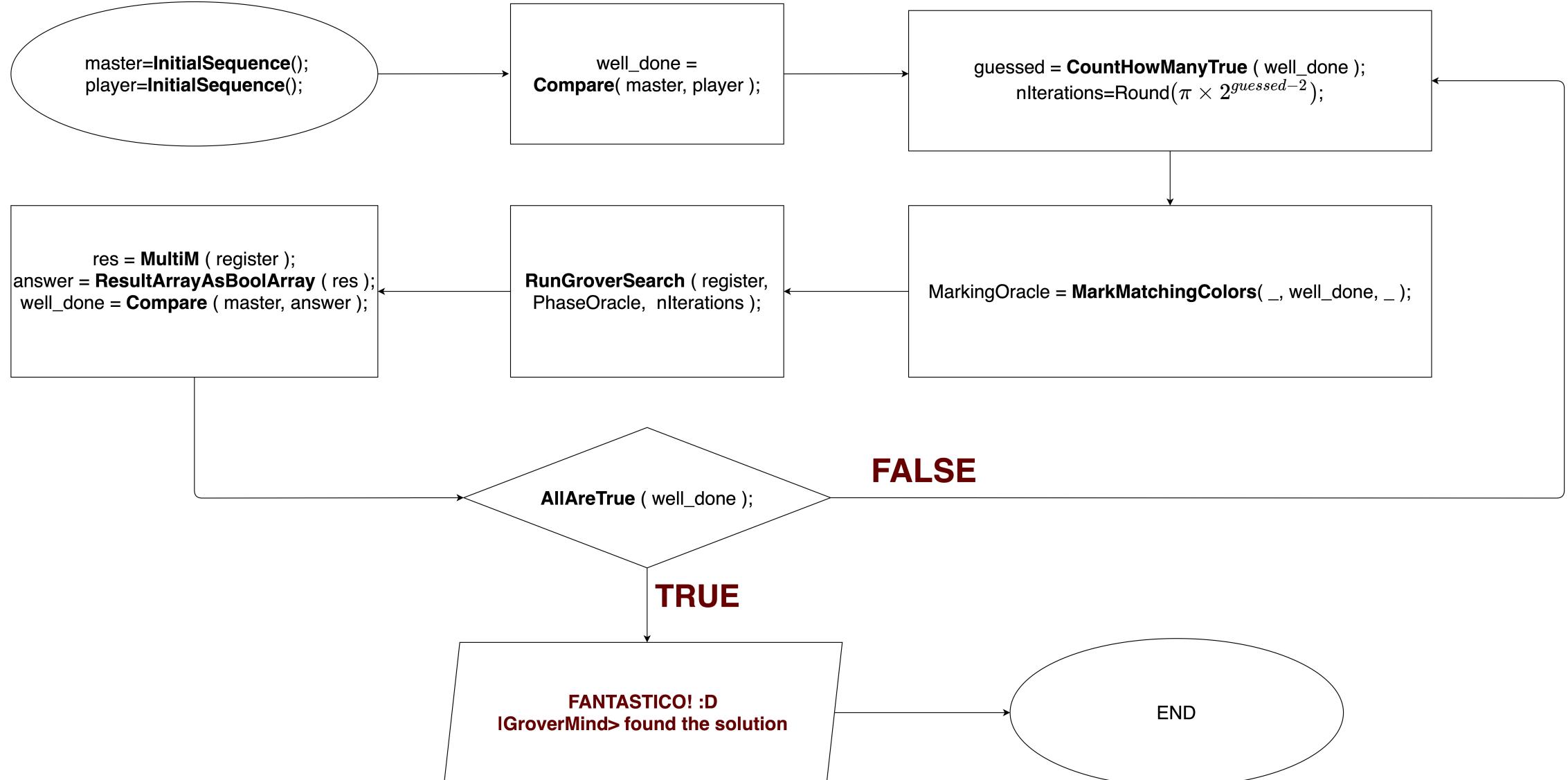
```
function Compare(master : Int[], player : Int[]) : (Bool,Int)[] {  
    //Compares the two sequences of colors.  
    //For each position in the grid, returns a tuple containing a boolean (true if the colors are matching,  
    //false otherwise) and the color of the player sequence.  
    mutable check = new (Bool,Int)[5];  
    for i in 0 .. 4 {  
        let control = master[i] == player[i];  
        set check w/= i <- (control, player[i]);  
    }  
    return check;  
}
```



MARKING ORACLE

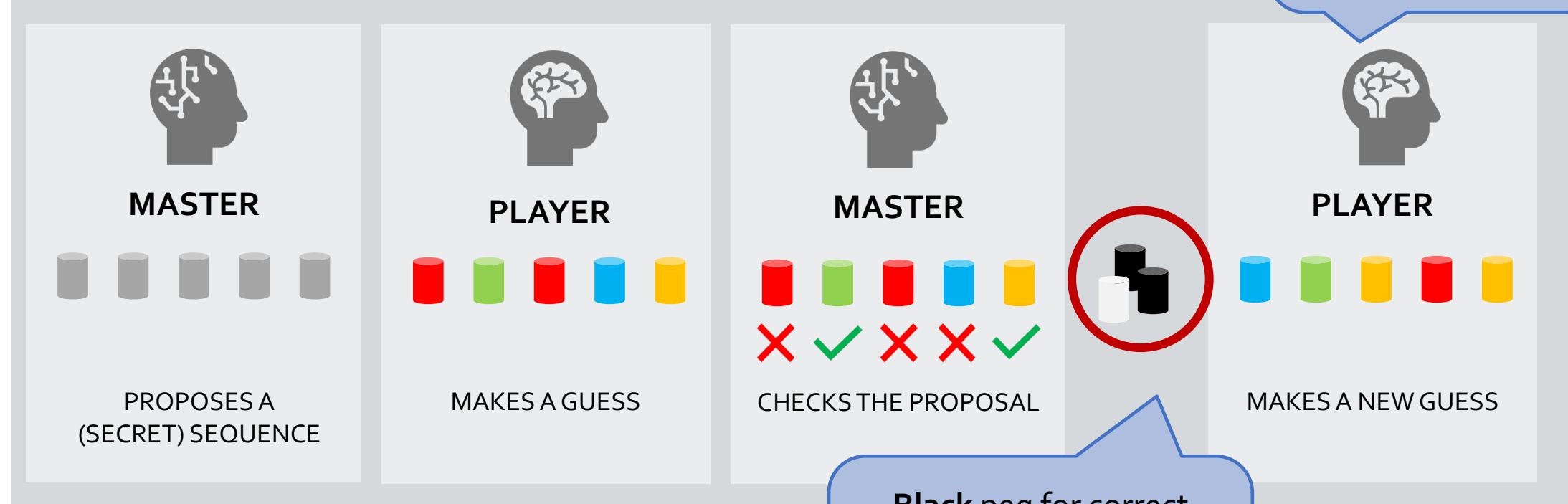


```
operation MarkMatchingColors(input : Qubit[], check : (Bool,Int)[], target : Qubit) : Unit is Adj {
    //GroverMind oracle
    let register_chunk = chunks(2,input);
    use controlQubit = Qubit[Length(input)/2];
    within {
        for ((guess, col), (q, control)) in Zipped(check, Zipped(register_chunk, controlQubit)){
            if guess{
                ControlledOnInt(col,X)(q,control);
            }
            else {
                X(control);
            }
        }
    } apply {
        Controlled X(controlQubit, target);
    }
}
```

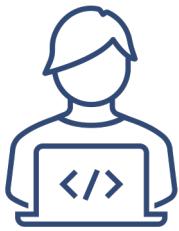
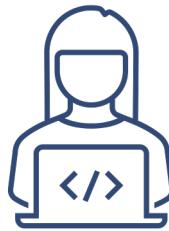


ONE STEP FURTHER: |GROVERMIND⟩ 2.0

Grover's algorithm narrows down the list of possible answers



IN SUMMARY



We implemented a **board game** in Q#



We **worked hard** and had fun together



We won a **Hackathon**



We met **new people** and **learned** a lot

```
117     if (H == null) { S = S + "S"; } else { S = S + "H"; }
118     if (X == null) { S = S + "S"; } else { S = S + "X"; }
119
120
121 DEMO TIME!
122
123     ApplyToEachA(H, register);
124     ApplyToEachA(X, register);
125 } apply {
126     Controlled Z(Most(register), Tail(register));
127 }
```

PROBLEMS OUTPUT TERMINAL DEBUG CONSOLE

1: powershell

Q#: Success! (0 errors, 0 warnings)

GroverMind -> C:\Users\samue\Desktop\Qsharp\qchack-microsoft-challenge\Part2\GroverMind> dotnet run

Build succeeded.

0 Warning(s)
0 Error(s)



Time Elapsed 00:00:20.94

PS C:\Users\samue\Desktop\Qsharp\qchack-microsoft-challenge\Part2\GroverMind> dotnet run

=====

ITERATION 1:

Master sequence: [Green,Green,Blue,Red,Green]

Player guess: [Green, Yellow, Green, Red, Red]

Thanks for the
attention!



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Backup slides

Q#

Google, IBM, and Intel have all shown off prototype quantum processors with around 50 qubits, and companies including Goldman Sachs and Merck are testing the technology. But thousands or millions of qubits are likely required for useful work. Much of a quantum computer's power would probably have to be dedicated to correcting its own glitches.

Microsoft has taken a different approach, claiming qubits based on Majorana particles will be more scalable, allowing it to leap ahead. But after more than a decade of work, it does not have a single qubit.

“From the fuller data, there’s no doubt that there’s no Majorana.”

— SERGEY FROLOV, UNIVERSITY OF PITTSBURGH

