Georgia Tech
CREATING THE NEXT

Ensemble of Diverse Mappings:

Improving Reliability of Quantum Computers by Orchestrating Dissimilar Mistakes

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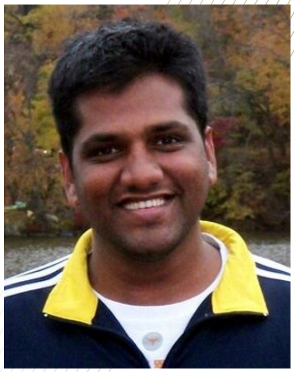
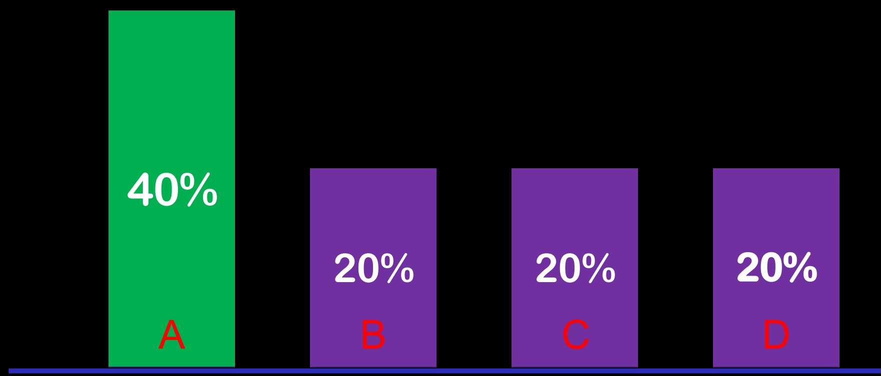




Don’t Know Correct Answer

Know Correct answer

Where was first MICRO located ?

A. Bedford, MA

B. Phoenix, AZ

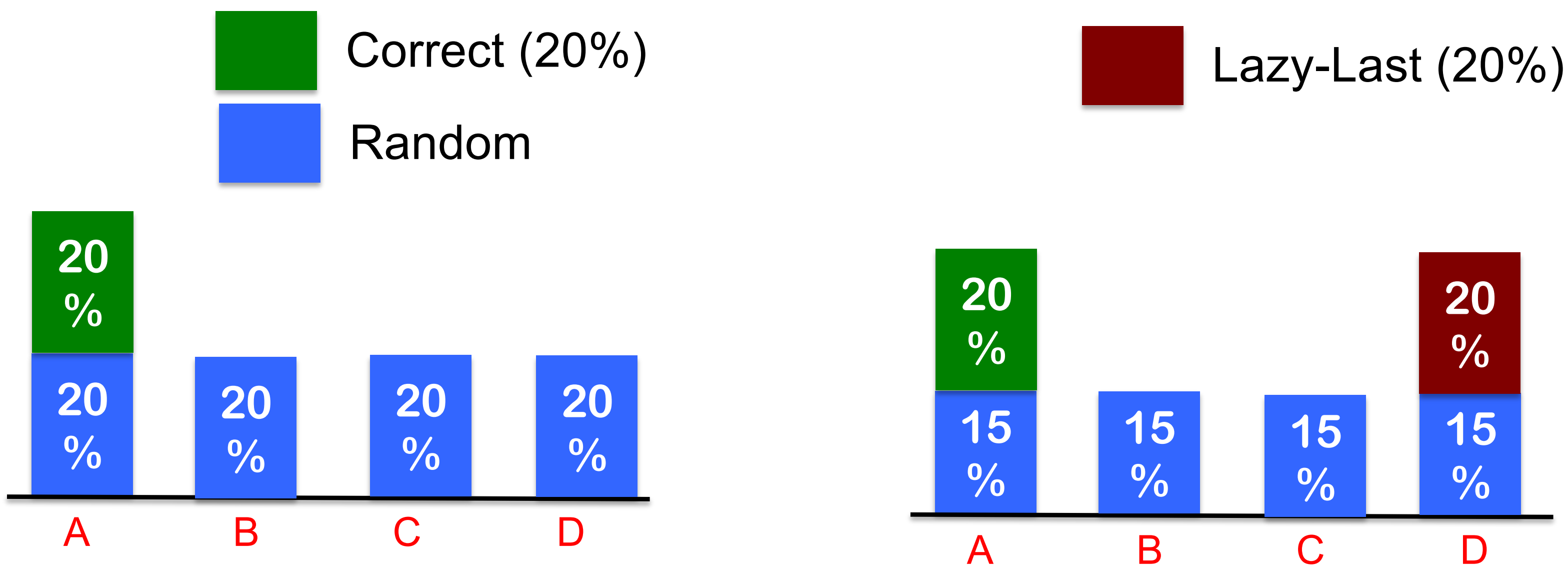
C. Urbana-Champaign, IL

D. Santa Cruz, CA

Lazy Audience → Correlated Mistakes

People who don’t know answer tend to select easiest option

Impact of Correlated Mistakes on Voting



Wrong answers randomly distributed

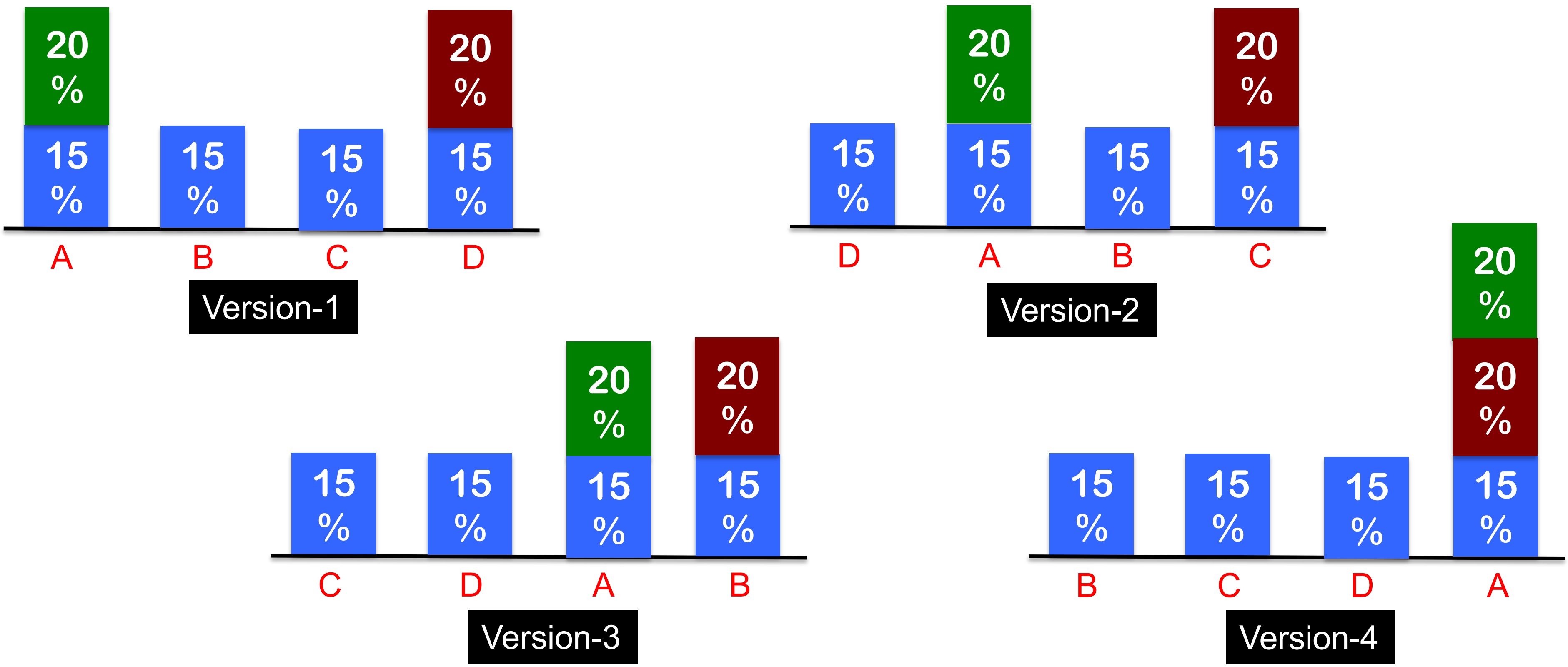
20% of audience lazy ➔ Always selects last option

Correlated errors limit the ability to infer the correct answer

Use Diversity to Break Correlation

Different versions, each with diverse option subjected to error

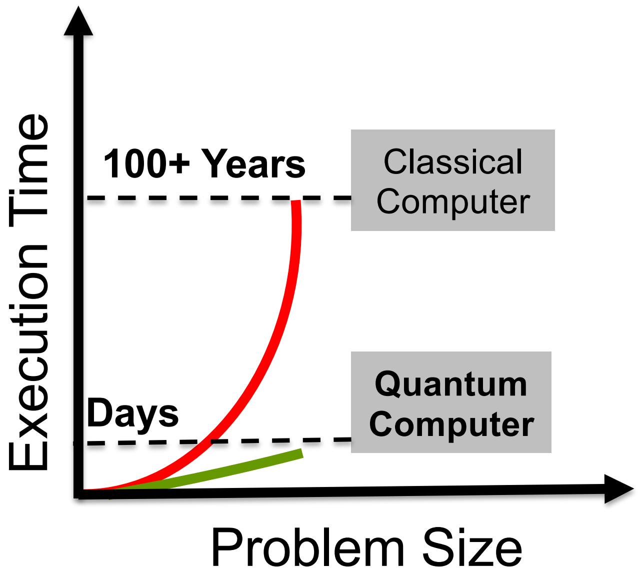
Use Diversity to Break Correlated Errors



Have different versions, each with diverse option subjected to error

Quantum Computers are Here!

Quantum computers can speedup hard problems



Recent demonstrations

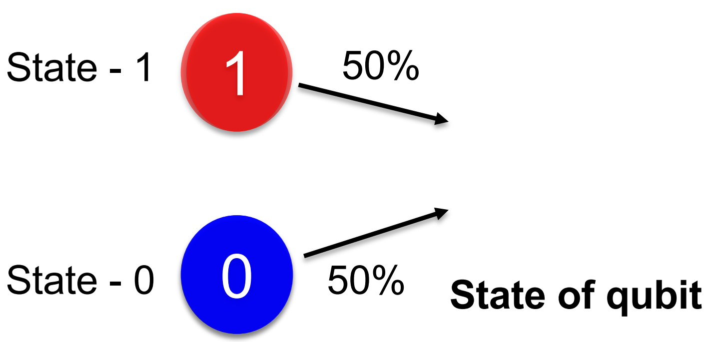
Quantum Machine	Number of Qubits*
Google	72
IBM	50
Intel	49
Rigetti	19
IonQ	11

* Under test , fabricated, or announced

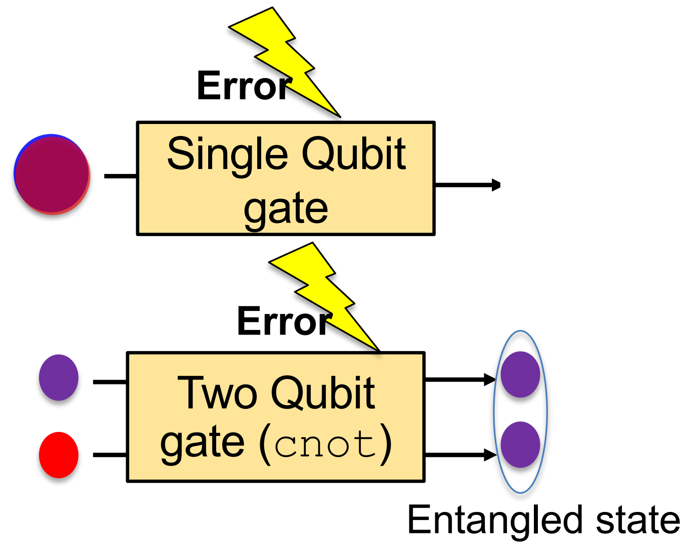
QC with 50+ qubits are here, QC with 100+ qubits expected soon

Quantum Computing: Background

QC operates on principles of entanglement and superposition



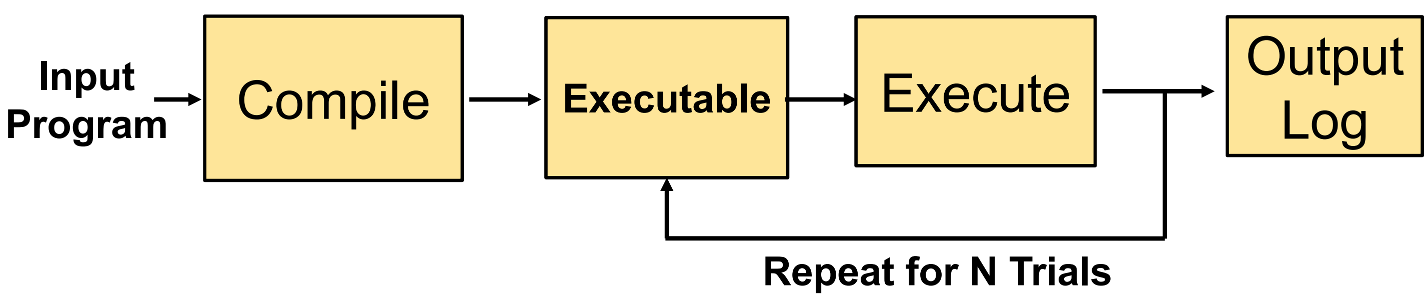
State of qubit is a superposition of state "0" and state "1"



Gate operations modulate state of the qubit

NISQ Programming Model

- Quantum Error Correction is expensive (20x-50x qubits)
- Noisy Intermediate Scale Quantum Computer (NISQ) [Preskill'18]
  - Run program without any error correction



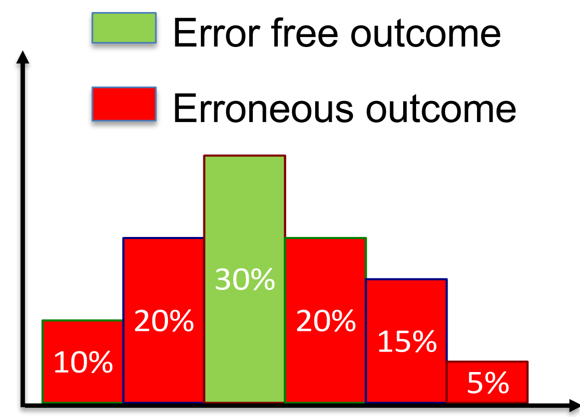


Figure of Merit: Probability of Successful Trial (PST)

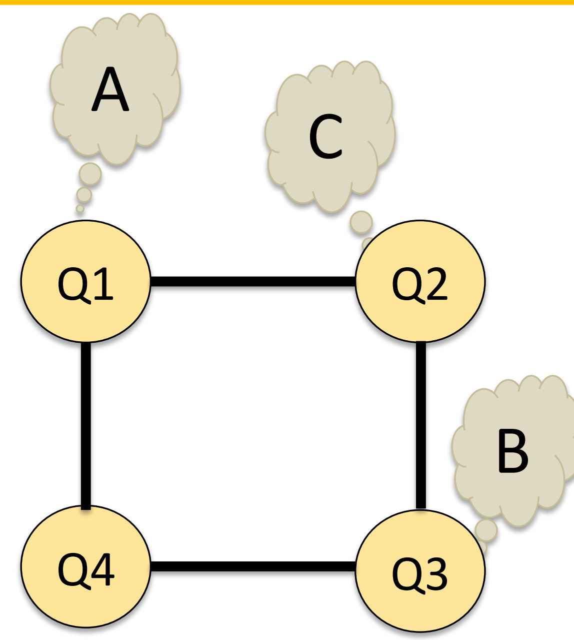
Limited Connectivity and the Mapping Policy

```
CNOT A,C
CNOT B,C
CNOT A,B
```

Not Possible no coupling link Between A and B

```
CNOT A,C
CNOT B,C
SWAP B,C
CNOT A,B
```

link between A and B, CNOT can be performed



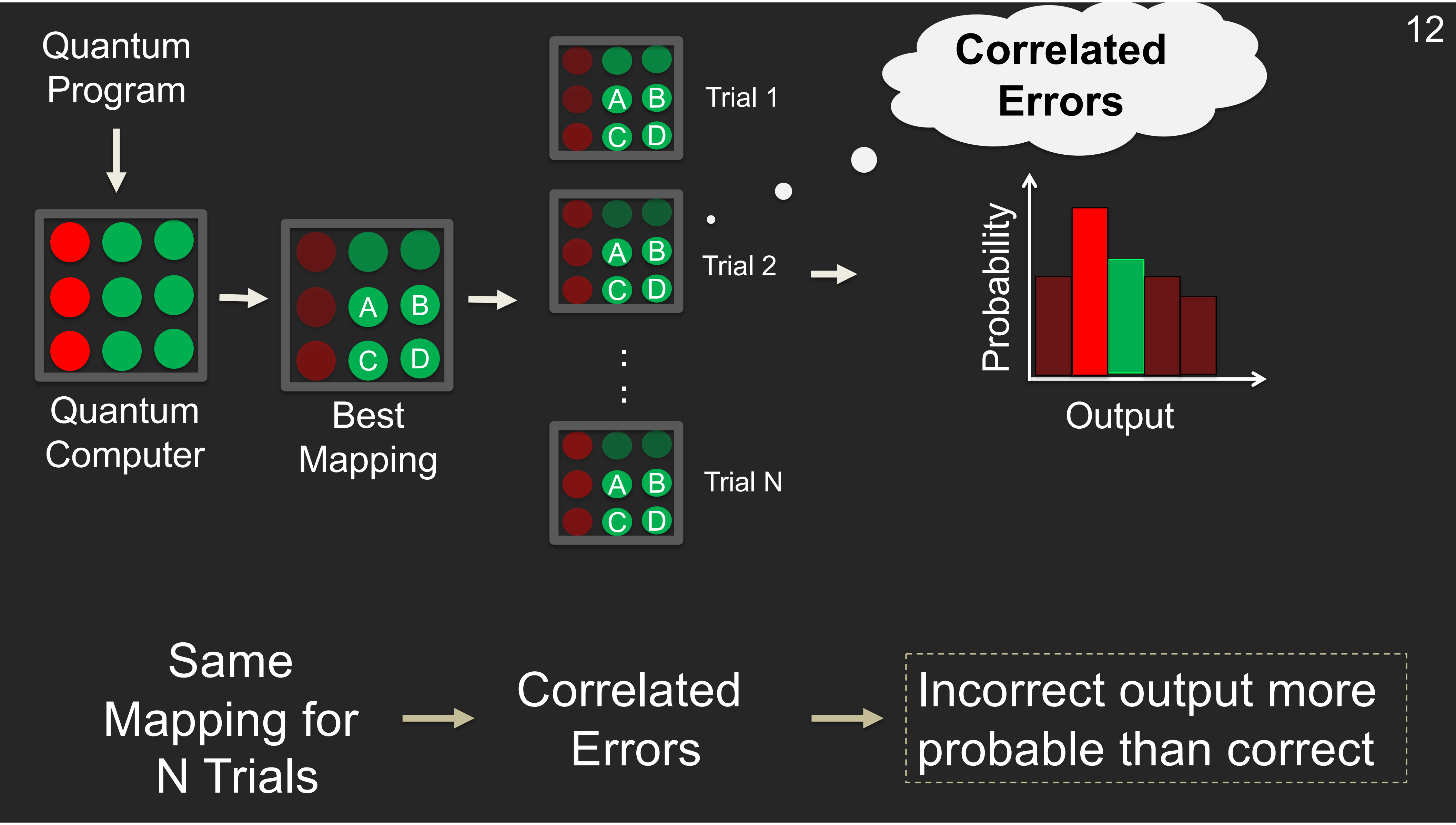
SWAP facilitate data movement

Compiler insert SWAPs → SWAPs are extra instructions which can also fail

Qubit Mapping Policies

SWAP Minimizing Mapping
Maslov et. al (2007) [U Waterloo]
Shafaei et. al (2013) [USC]
Paler et. al (2014) [JKU]
Siraichi et. al. (2018) [FUMG]
Li et. al (2019) [UCSB]
Itoko et. al (2019) [IBM] … many more

All of the above use same mapping for all trials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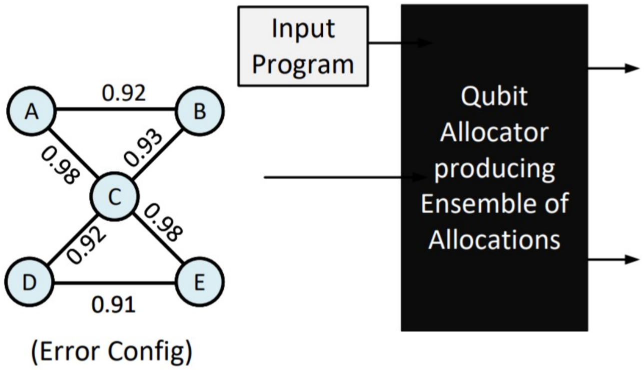
Quantum Program
Quantum Computer
Best Mapping
A B C D
Trial 1
Trial 2
Trial N
Correlated Errors
Probability
Output
Same Mapping for N Trials
Correlated Errors
Incorrect output more probable than correct

Goal

Design Mapping Policy that Mitigate Correlated Errors to Improve Inference

Can We Suppress Incorrect Answers with Diversity?



Ensemble of Diverse Mapping: Design

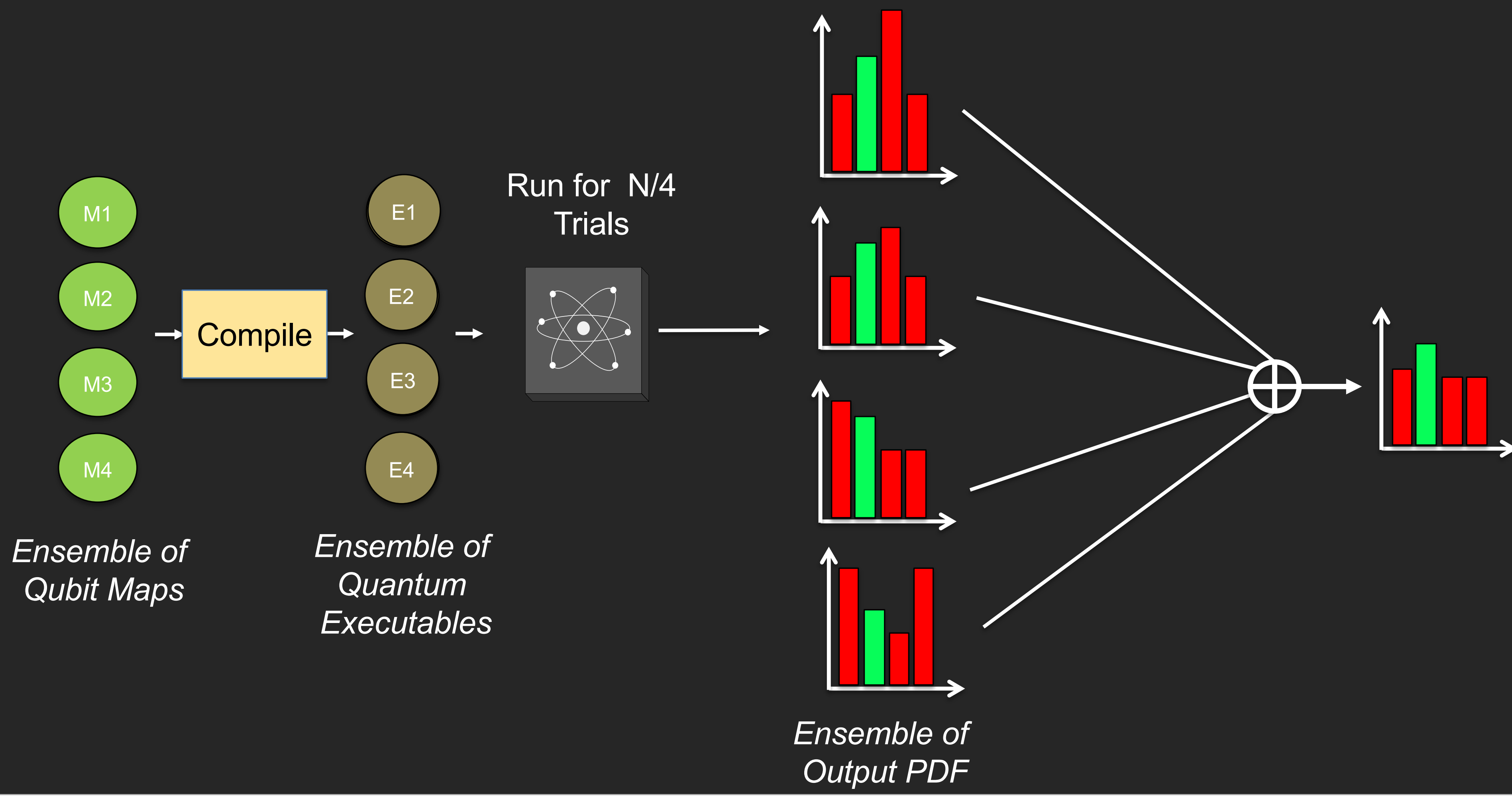
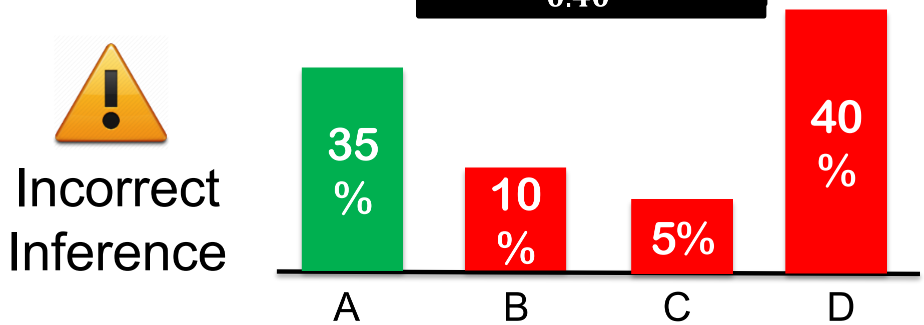


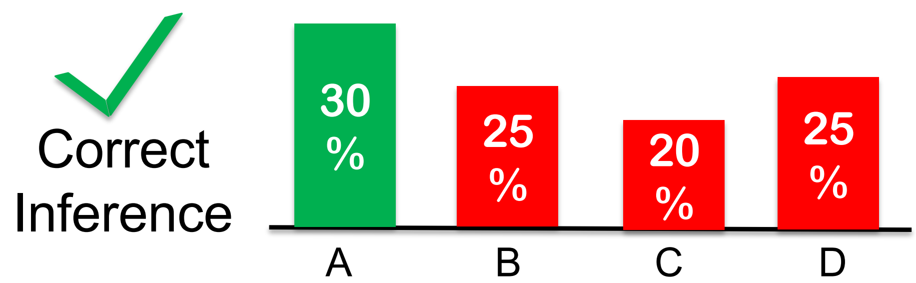
Figure of Merit: Inference Strength (IST)

$$IST = \frac{\textit{Probability of Erorr Free Output}}{\textit{Probability of Erroneous Output with Highest Frequency}}$$

$$\text{IST} = \frac{0.35}{0.40} = 0.87$$



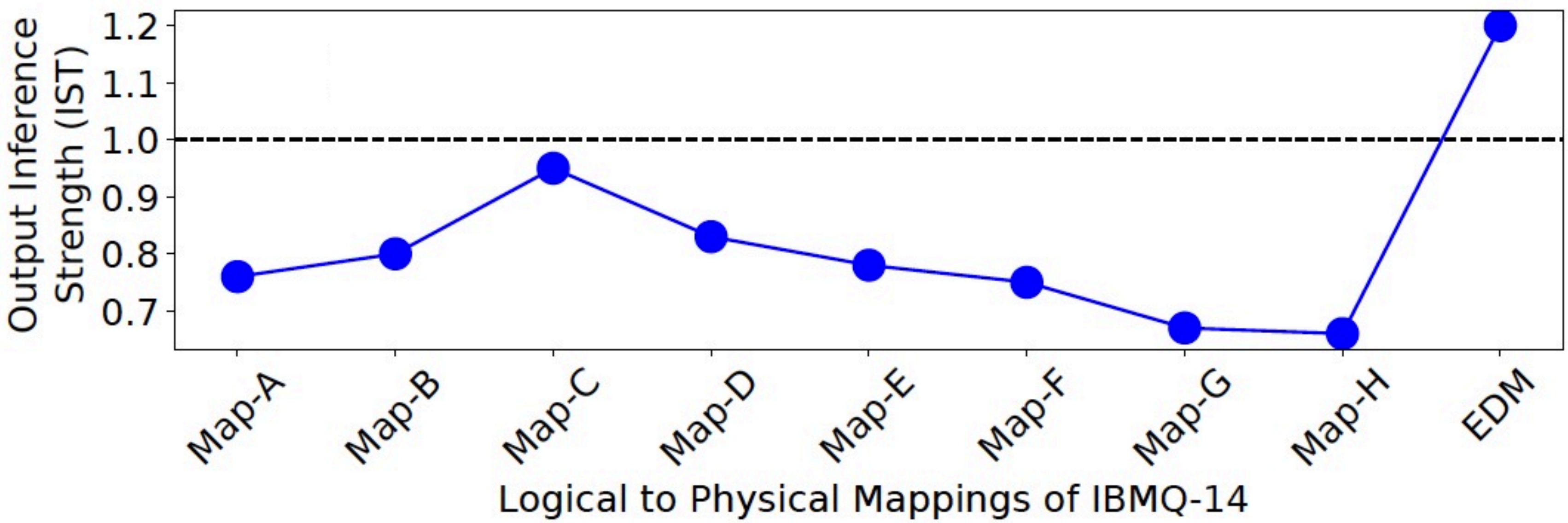
$$\text{IST} = \frac{0.3}{0.25} = 1.25$$



IST captures quality of inference. IST > 1 ensures correct answer is strongest

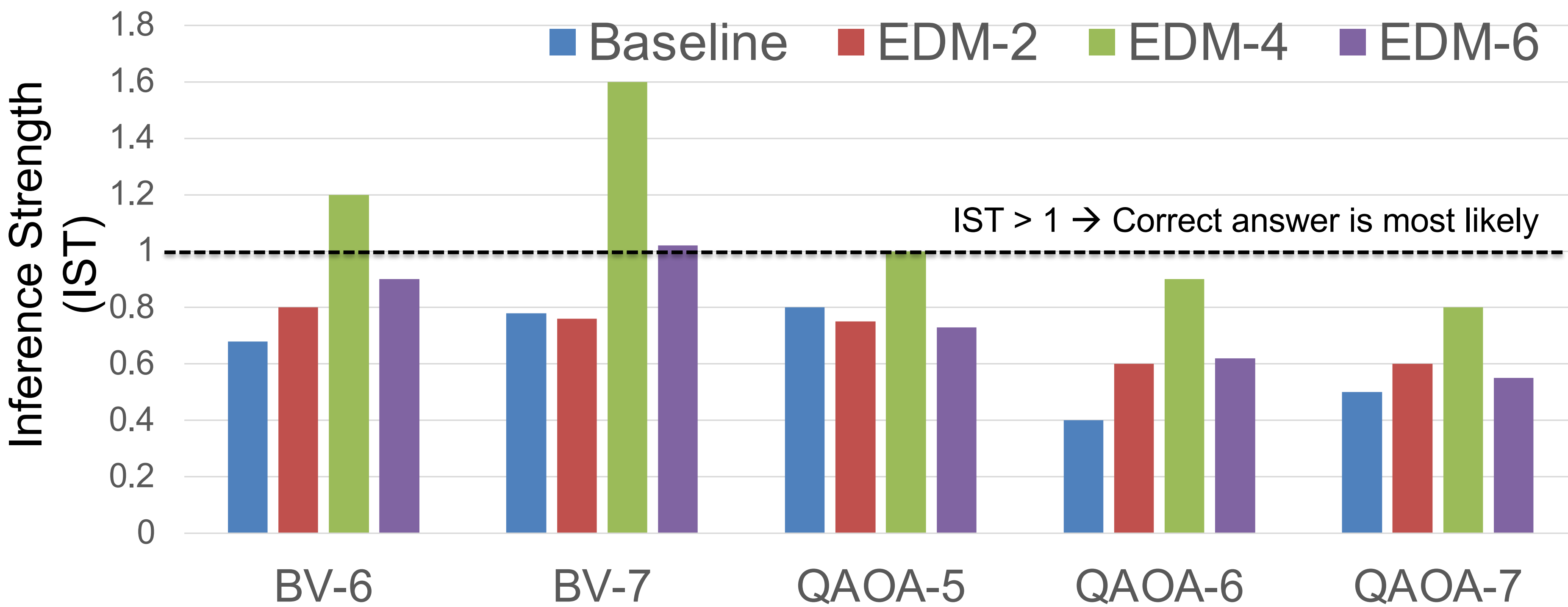
Ensemble of Diverse Mappings: Experiment

EDM creates four copies of the program using mappings A, B, C, and D



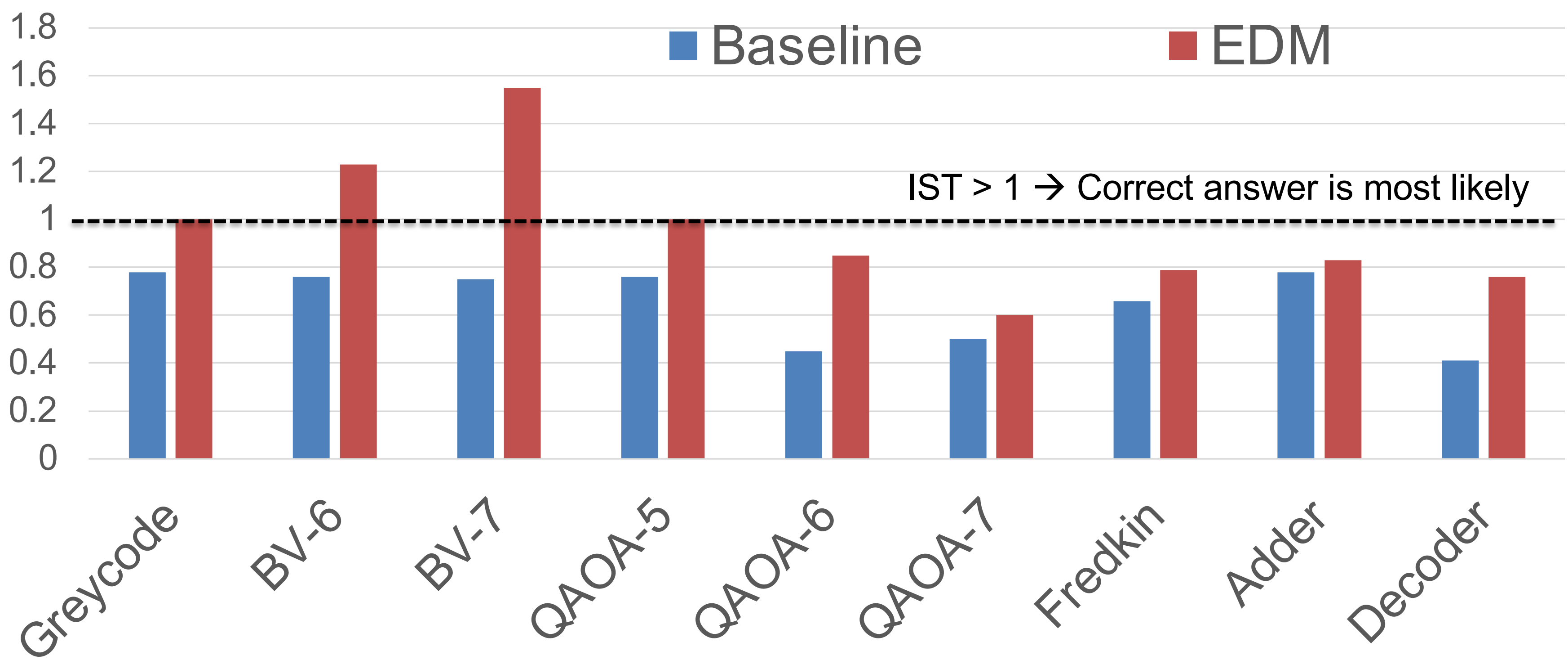
With diverse set of mappings we can orchestrate dissimilar mistakes

How Many Members in the Ensemble?



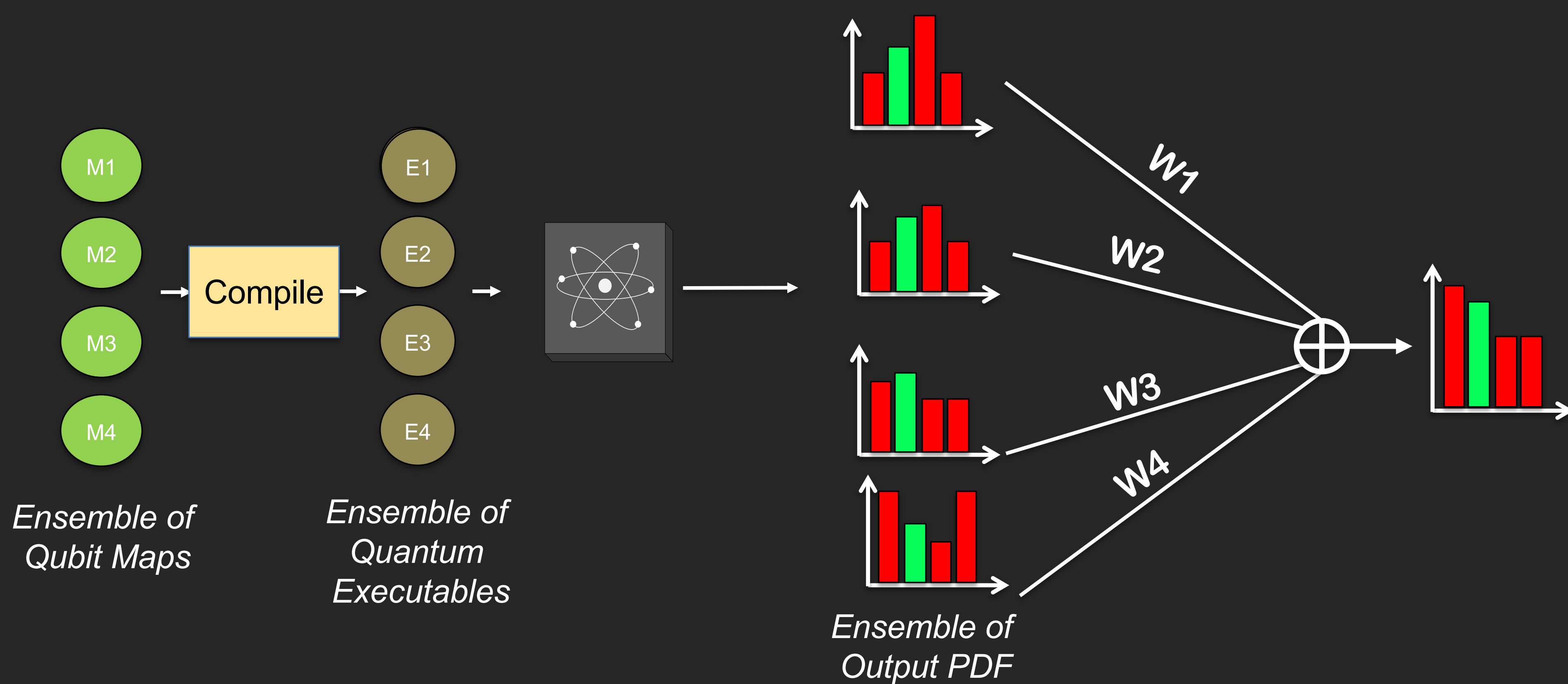
Tradeoff: Increasing ensemble size increases diversity in errors but exposes program to weaker qubits adding more errors

EDM: Evaluations on IBM-Q14 system



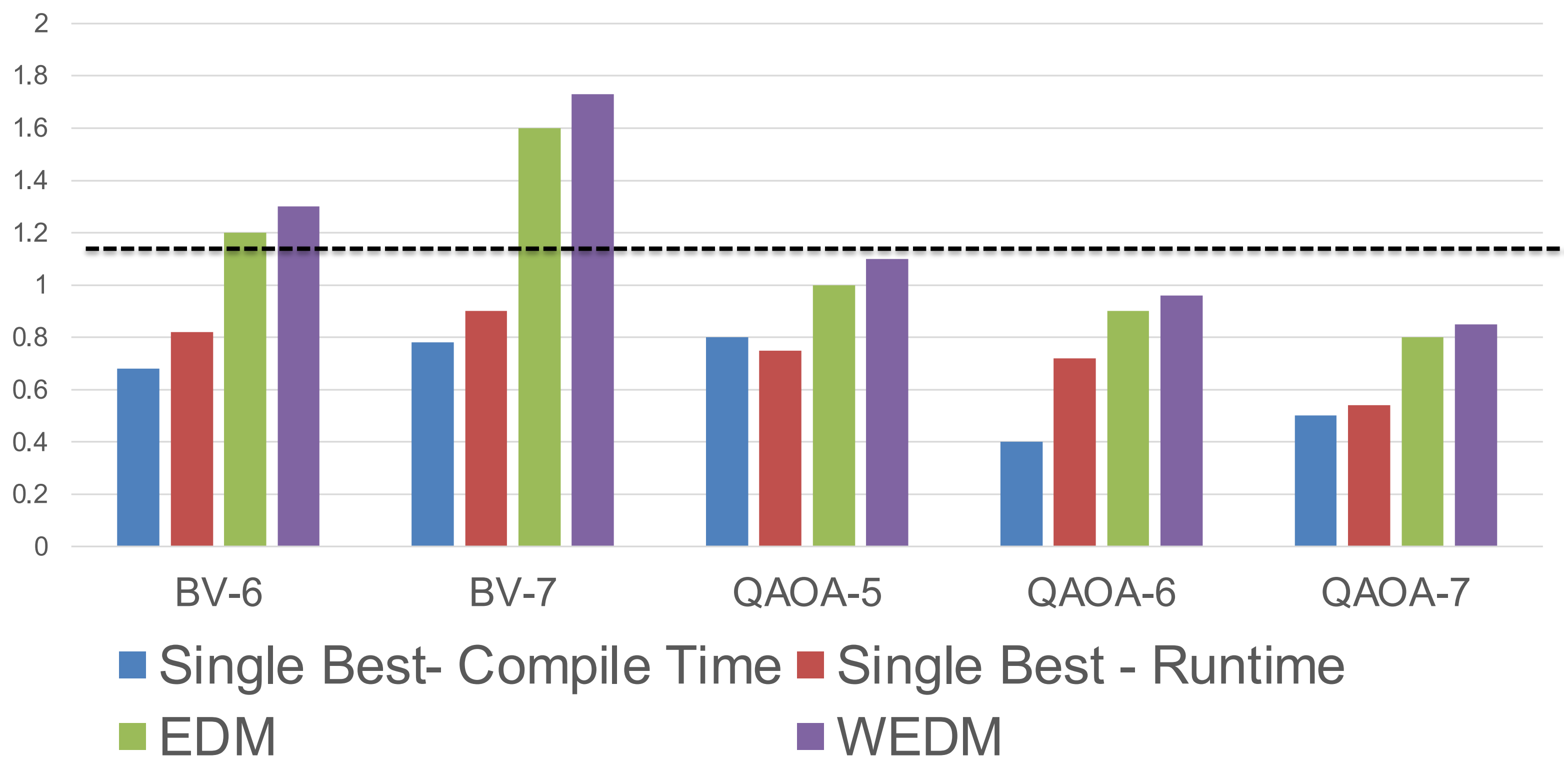
For current quantum kernels, EDM improves the IST by up to 1.5x

Weighted EDM: Design



Weighted EDM → Use Weighted average of an Ensemble such that unique output has more weight

WEDM Evaluations on IBM-Q14 system

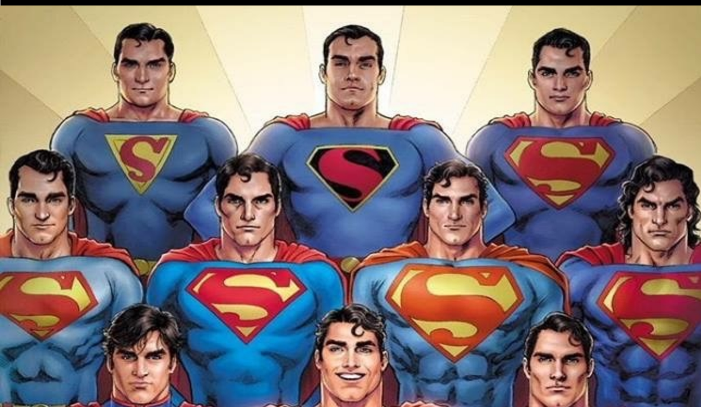


For current quantum kernels, EDM improves the IST by up to 1.73x

Summary

- ❖ Correlation in qubit errors degrade inference quality on NISQ
- ❖ Prior work: single best mapping for all trials → correlated errors
- ❖ EDM: divide trials into groups, use different mapping for each group
- ❖ EDM Improves the quality of inference up to 2X on IBMQ-14 machine

Okay to make mistakes, but not the same one again and again



Team of all Kryptonians

Kryptonite →Identical Weakness

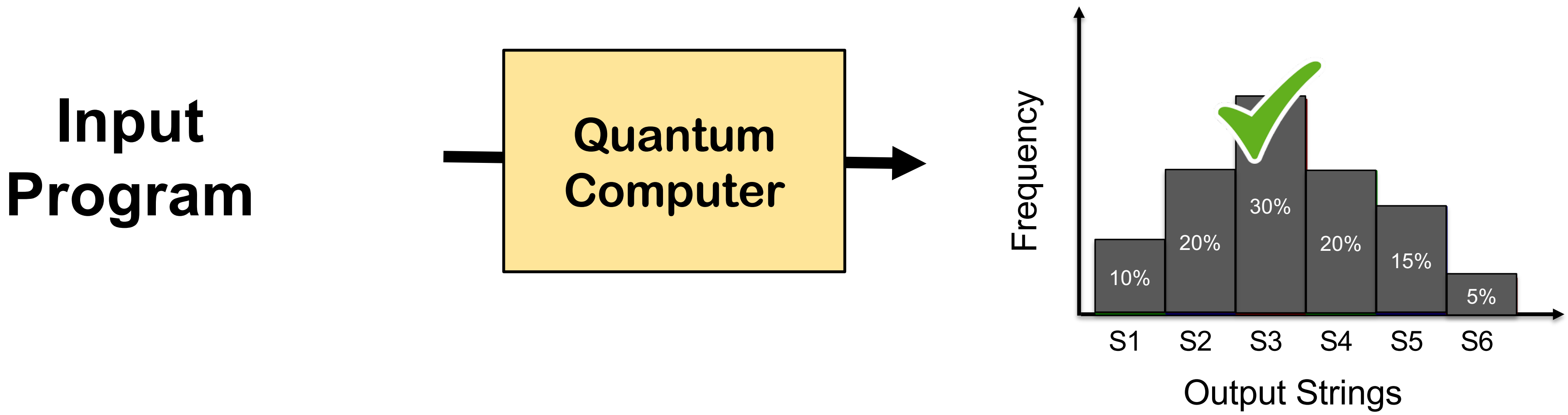
Justice League

Cover each others weakness

Thank you

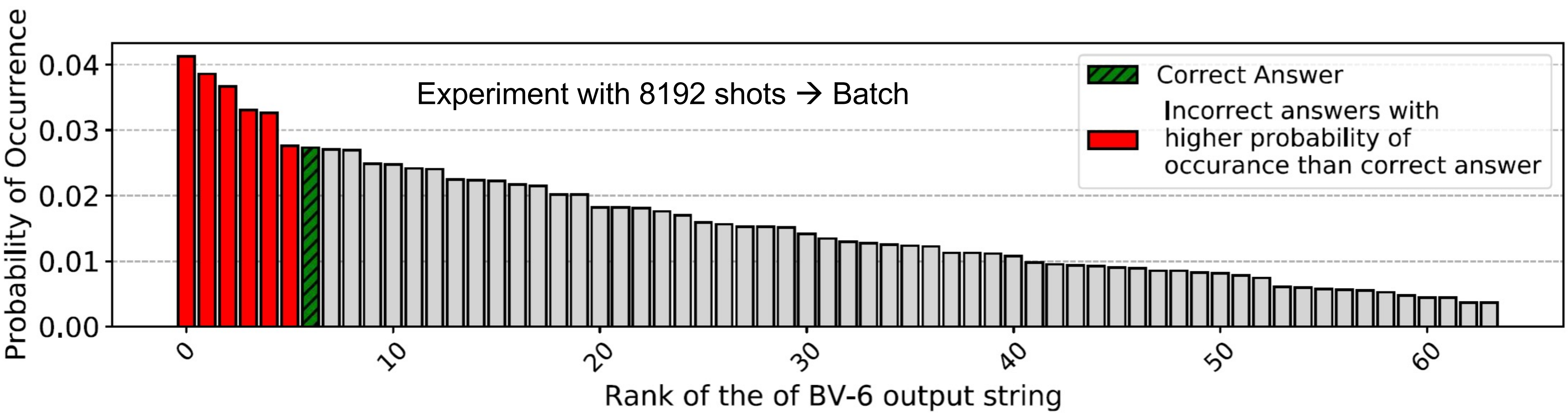
Backup Slides

Inferring Correct Answer with NISQ Model



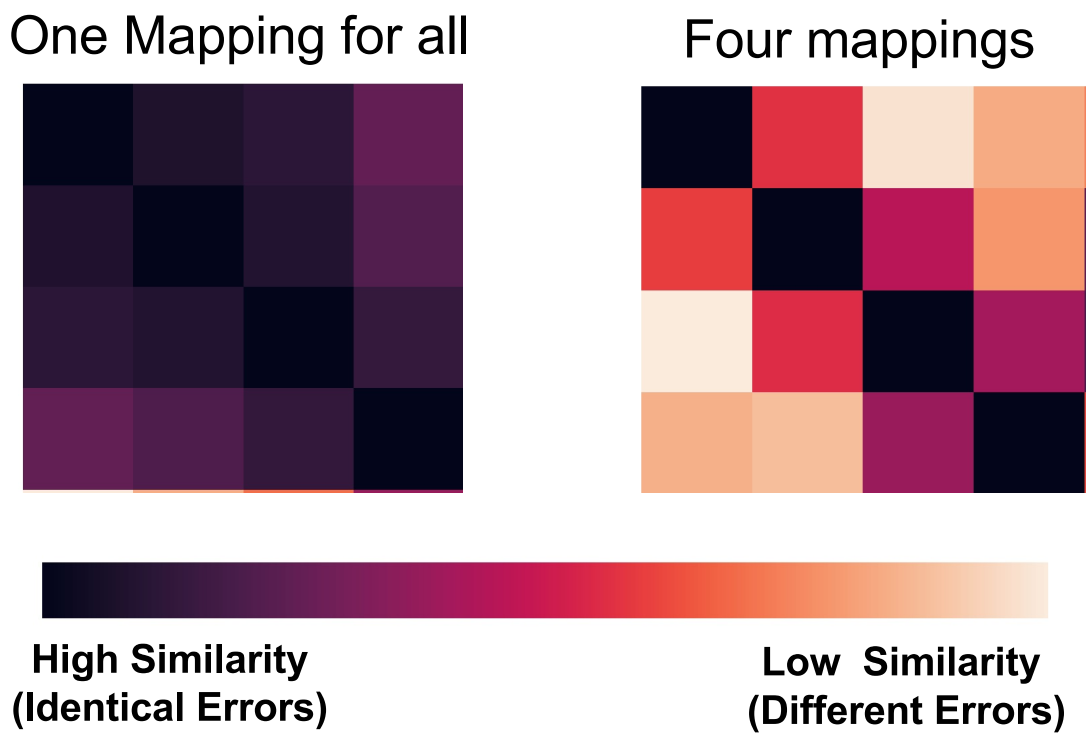
Inference: Pick output with highest frequency of occurrence

Running Bernstein Vazirani (BV) on IBMQ-14

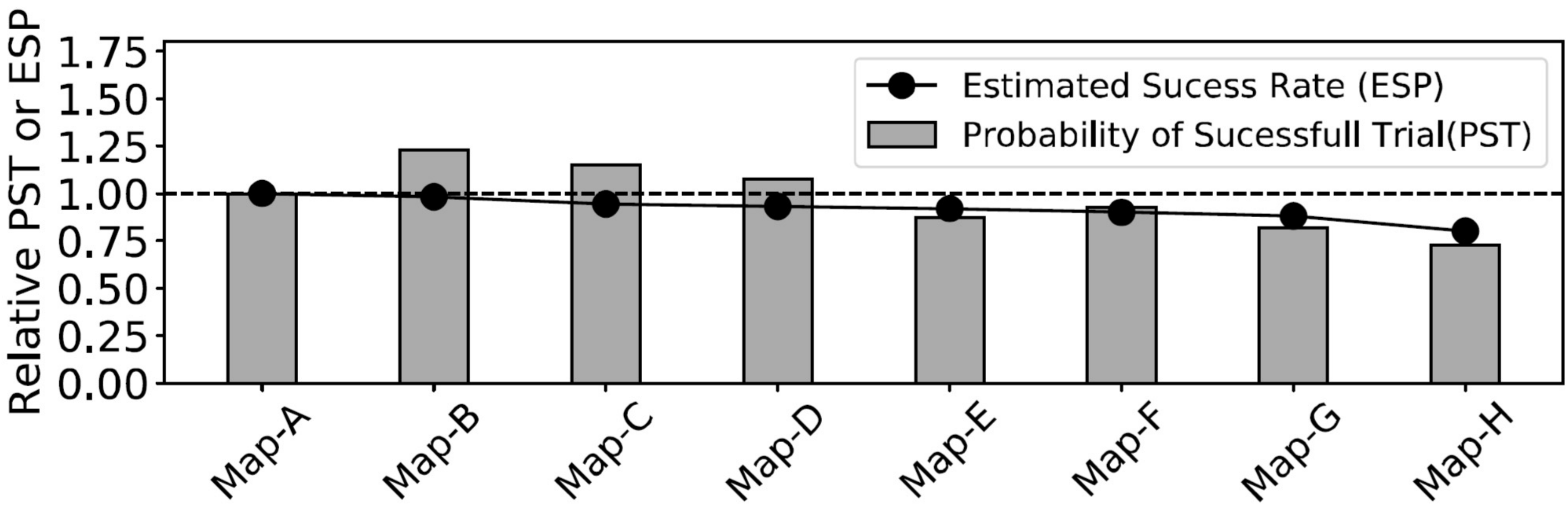


BV-6 → Bernstein Vazirani Algorithm with 6-bit Key

Heatmap – Diversity in Mapping



ESP vs PST


Relative PST or ESP
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Estimated Sucess Rate (ESP)
Probability of Sucessfull Trial(PST)
Map-A
Map-B
Map-C
Map-D
Map-E
Map-F
Map-G
Map-H

ESP vs PST

$$ESP = \prod_{i=1}^{N_{gates}} g_i^s * \prod_{j=0}^{N_{meas}} m_i^s$$

$$g_i^s = (1 - g_i^e) \quad m_i^s = (1 - m_i^e)$$

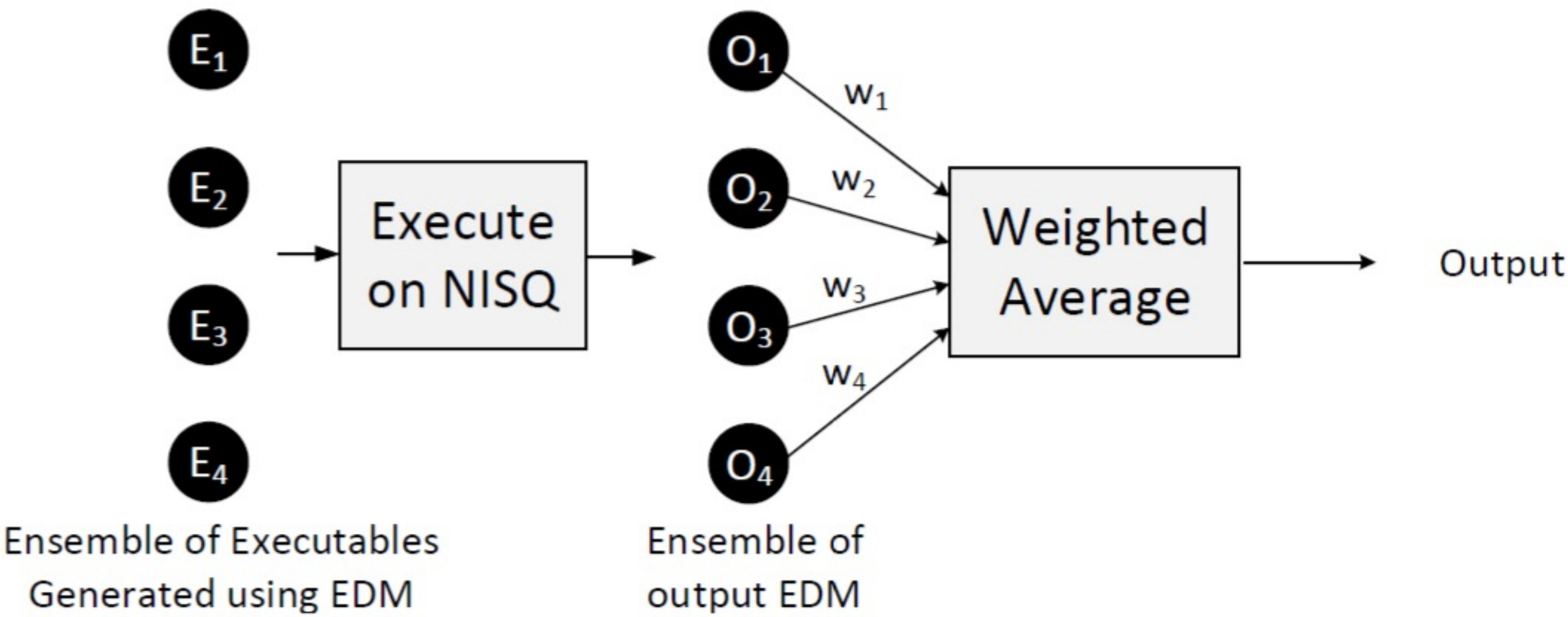
g_e → gate error

m_e → Measurement error

Benchmarks

Benchmark Name	Benchmark Description	Output	Number of Gates
Greycode	Greycode decoder	output: 001000	SG: 13, CX: 5, M: 6
bv-6	Bernstein-Vazirani	key: 110011	SG: 13, CX: 7, M: 5
bv-7	Bernstein-Vazirani	key: 1101011	SG: 13, CX: 11, M: 6
qaoa-5	max-cut 5 node graph	cut: 10101	SG: 24, CX: 8, M: 5
qaoa-6	max-cut 6 node graph	cut: 101010	SG: 30, CX: 10, M: 6
qaoa-7	max-cut 8 node graph	cut: 10101010	SG: 36, CX: 12, M:7
Fredkin	Fredkin gate	output:110	SG: 26, CX: 13, M:3
adder	1bit adder	output:011	SG: 12, CX: 15, M:3
Decode-24	2:4 Decoder	output: 100000	SG:119, CX:71, M:6

Weighted EDM



Weighted EDM

$$O_{WEDM} = \sum_{i=0}^{i=N} \overline{W_i} * O_i$$

$$W_i = \sum_{j=0}^{j=N} SD_{KL}(O_i, O_j) \qquad \& \qquad \overline{W_i} = \frac{W_i}{\sum_{i=0}^{i=N} W_i}$$