Quantum Computation in Industry 4.0 Cyber-Physical Systems

Defensa Tesis Doctoral

Grupo Sistemas Complejos

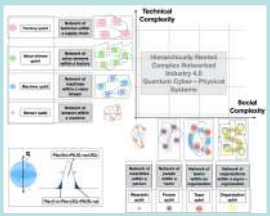
Autor. Javier Villalba—Diez

Director. Prof. Dr. Juan Carlos Losada González

Fecha. 25.03.2022

» Contents_

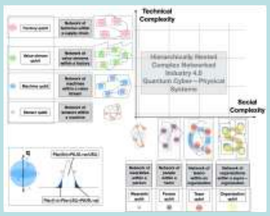
» Contents_



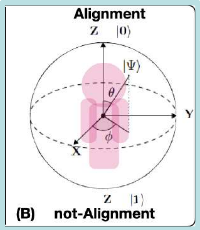
INTRODUCTION

» Contents_

- » INTRODUCTION
- » **QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)**
- » QSOD as QUANTUM MULTILAYERED NETWORKS (QMLN)
- » QSOD CASES
- » QUANTUM JIDOKA
- » QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)
- » CONCLUSIONS, FINAL REMARKS (CF)

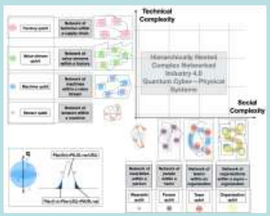


INTRODUCTION

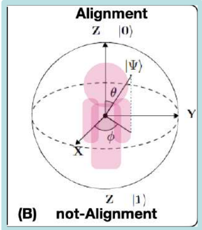


QSOD

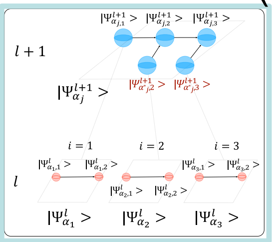
» Contents_



INTRODUCTION



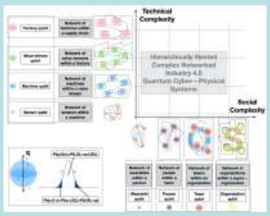
QSOD



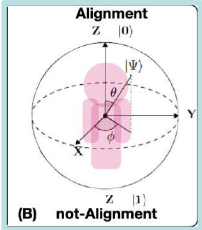
QSOD QMLN

» Contents_

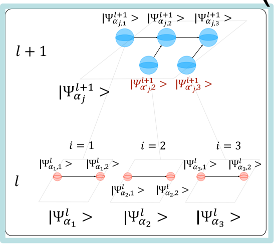
- » INTRODUCTION
- » QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)
- » QSOD as QUANTUM MULTILAYERED NETWORKS (QMLN)
- » **QSOD CASES**
- » QUANTUM JIDOKA
- » QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)
- » CONCLUSIONS, FINAL REMARKS (CF)



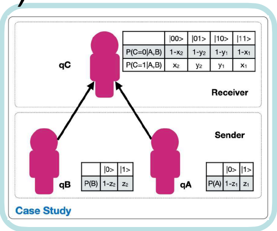
INTRODUCTION



QSOD



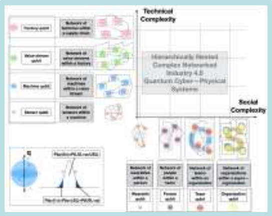
QSOD QMLN

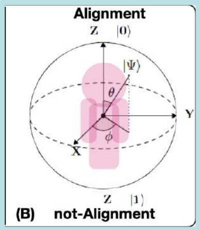


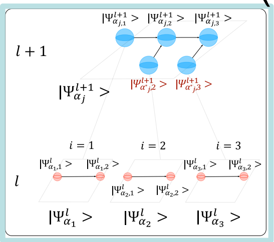
QSOD CASES

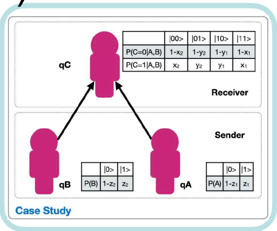
» Contents_

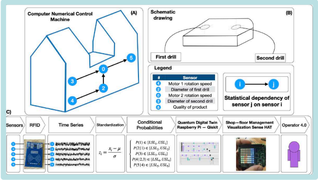
- » INTRODUCTION
- » QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)
- » QSOD as QUANTUM MULTILAYERED NETWORKS (QMLN)
- » QSOD CASES
- » **QUANTUM JIDOKA**
- » QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)
- » CONCLUSIONS, FINAL REMARKS (CF)







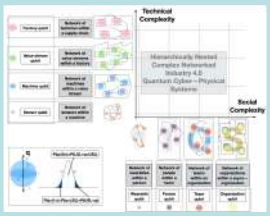




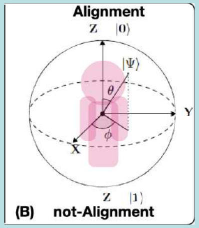
INTRODUCTION | QSOD | QSOD QMLN | QSOD CASES | QSOD JIDOKA

» Contents_

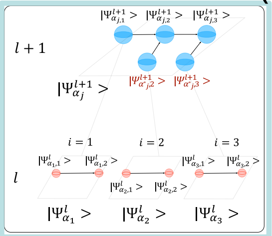
- » INTRODUCTION
- » QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)
- » QSOD as QUANTUM MULTILAYERED NETWORKS (QMLN)
- » QSOD CASES
- » QUANTUM JIDOKA
- » **QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)**
- » CONCLUSIONS, FINAL REMARKS (CF)



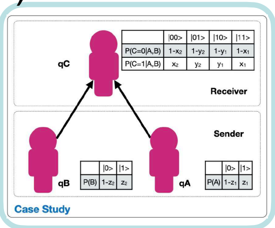
INTRODUCTION



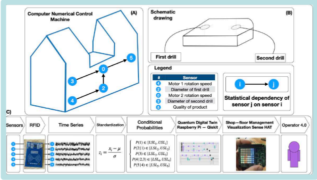
QSOD



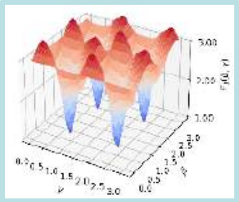
QSOD QMLN



QSOD CASES

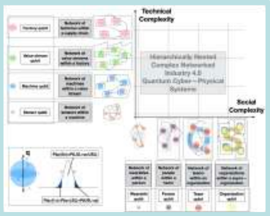


QSOD JIDOKA

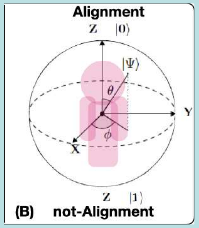


QAOA

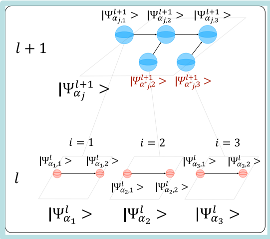
» Contents_



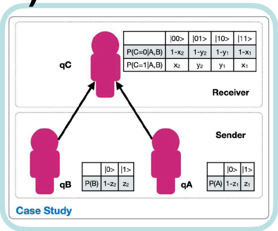
INTRODUCTION



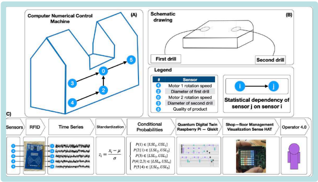
QSOD



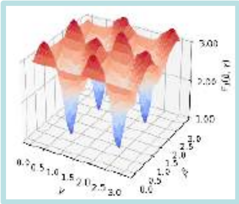
QSOD QMLN



QSOD CASES



QSOD JIDOKA



QAOA

CFO

GOAL

THE MAIN GOAL OF THIS THESIS IS TO PROPOSE EFFICIENT QUANTUM COMPUTATION ALGORITHMS FOR REAL--TIME STRATEGIC DESIGN OF LEAN COMPLEX CYBER--PHYSICAL INDUSTRIAL NETWORKED ORGANIZATIONS AND THEIR PRACTICAL IMPLEMENTATION AND, THEREFORE, SUPPORT THE LEADERS OF ORGANIZATIONS IN THEIR DECISION--MAKING PROCESS.

» Contents_

» **INTRODUCTION**

- » **MOTIVATION**
- » **QUANTUM INDUSTRY 4.0 CYBER—PHYSICAL FRAMEWORK**
- » **OBJECTIVES**

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

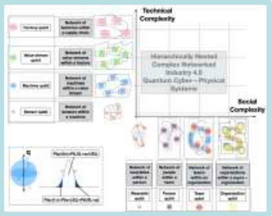
» QSOD as QUANTUM MULTILAYERED NETWORKS

» QSOD CASES

» QUANTUM JIDOKA

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

» CONCLUSIONS, FINAL REMARKS (CF)

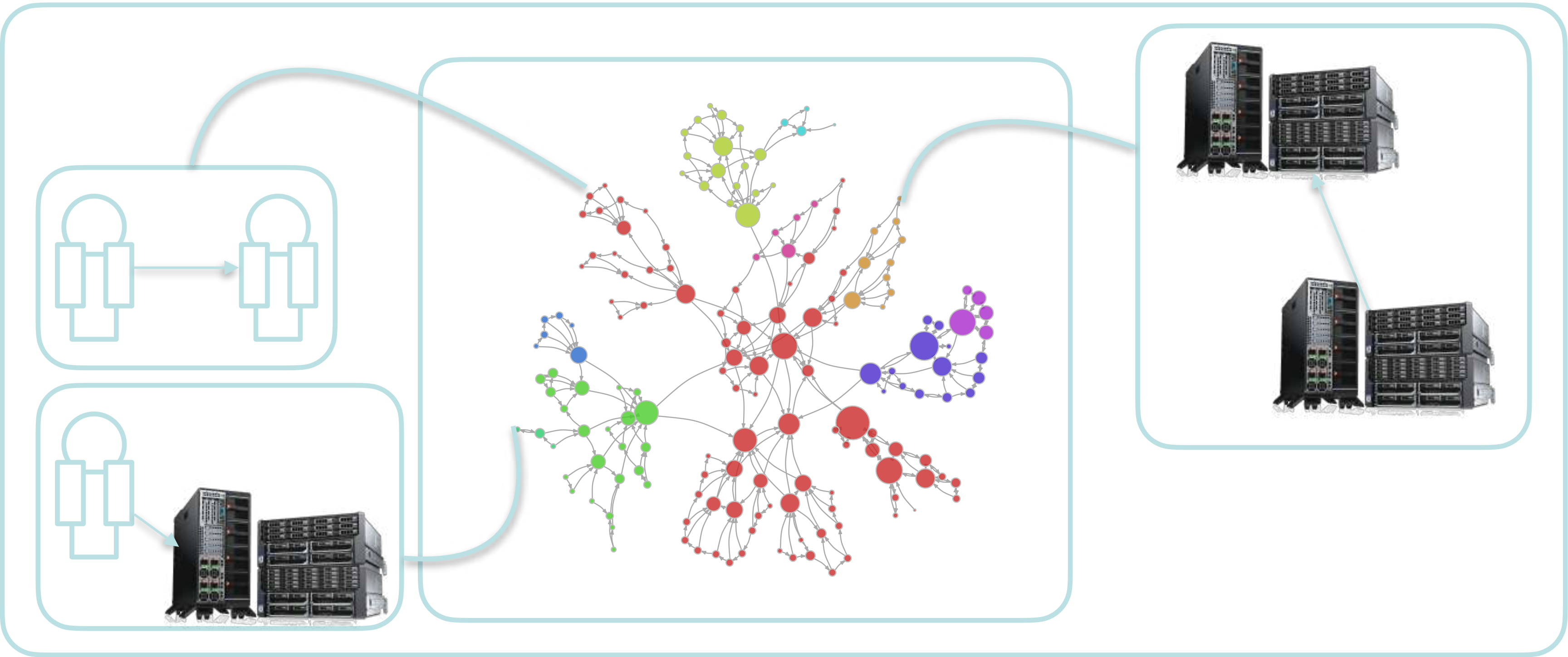


INTRODUCTION

» INTRODUCTION

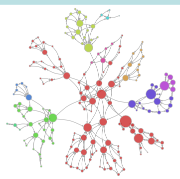
» MOTIVATION

INDUSTRY 4.0 CYBER—PHYSICAL SYSTEMS FORM **COMPLEX NETWORKS** THAT CAN BE UNDERSTOOD AS TIME-DEPENDENT GRAPHS $\Omega(T)=[\Gamma(T), E(T)]$ GIVEN BY A LISTS OF $\Gamma(T)$ **HUMAN AND CYBER-PHYSICAL NODES** AND **STANDARD COMMUNICATION EDGES** $E(T)\subset\Gamma(T)X\Gamma(T)$.



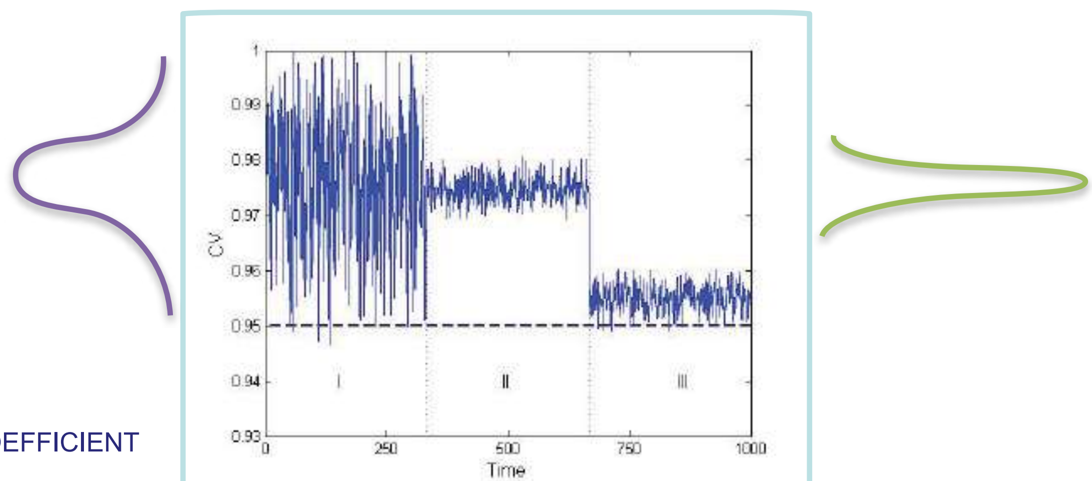
» INTRODUCTION

» MOTIVATION



CYBER--PHYSICAL SYSTEMS FORM **COMPLEX NETWORKS** CAN BE UNDERSTOOD AS TIME-DEPENDENT GRAPHS Ω(T)=[Γ(T), E(T)] GIVEN BY A LISTS OF Γ(T) **HUMAN AND CYBER-PHYSICAL NODES** AND **STANDARD COMMUNICATION EDGES** E(T)$\subset\Gamma$(T)XΓ(T).

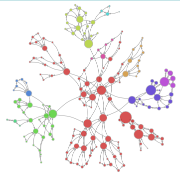
WE AIM TO **DECREASE VARIABILITY** OF THE **KEY PERFORMANCE INDICATORS** (KPI) MEASURING THE INDUSTRIAL VALUE CREATION WITHIN THESE CYBER—PHYSICAL NETWORKS.



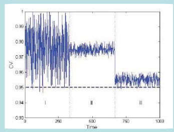
KPI = C.V. VARIATION COEFFICIENT

» INTRODUCTION

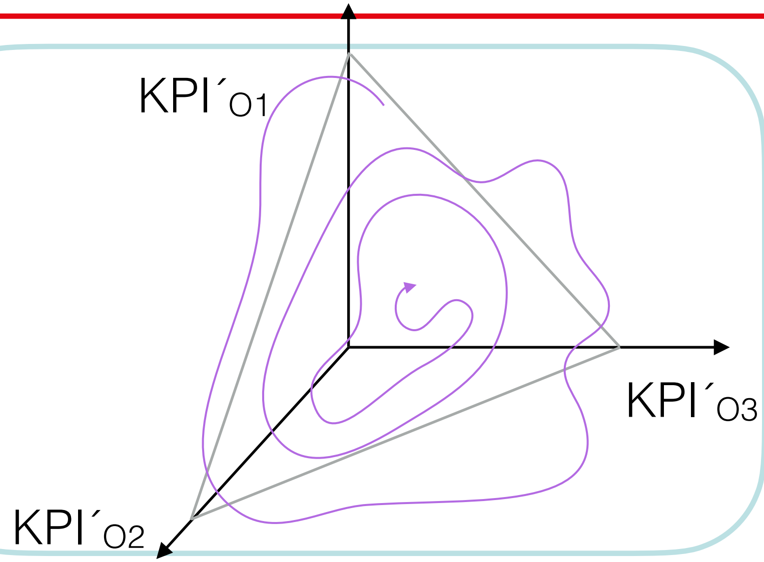
» MOTIVATION



CYBER--PHYSICAL SYSTEMS FORM **COMPLEX NETWORKS** CAN BE UNDERSTOOD AS TIME-DEPENDENT GRAPHS $\Omega(T)=[\Gamma(T), E(T)]$ GIVEN BY A LISTS OF $\Gamma(T)$ **HUMAN AND CYBER-PHYSICAL NODES** AND **STANDARD COMMUNICATION EDGES** $E(T)\subset\Gamma(T)X\Gamma(T)$.



WE SEEK SYSTEMATICALLY TO **DECREASE VARIABILITY** OF THE **KEY PERFORMANCE INDICATORS** MEASURING THE INDUSTRIAL VALUE CREATION WITHIN THESE CYBER PHYSICAL NETWORKS.



SUCH KEY PERFORMANCE INDICATORS ARE INTERDEPENDENT AND DESCRIBE CERTAIN TRAJECTORIES IN A N--DIMENSIONAL **PHASE SPACE**.

A NODE IS TO BE IN **ALIGNMENT** AT ANY GIVEN MOMENT IN TIME IF THE KEY PERFORMANCE INDICATOR'S **TRAJECTORY PRESENTS ASYMPTOTIC STABILITY AT THIS POINT IN TIME.**

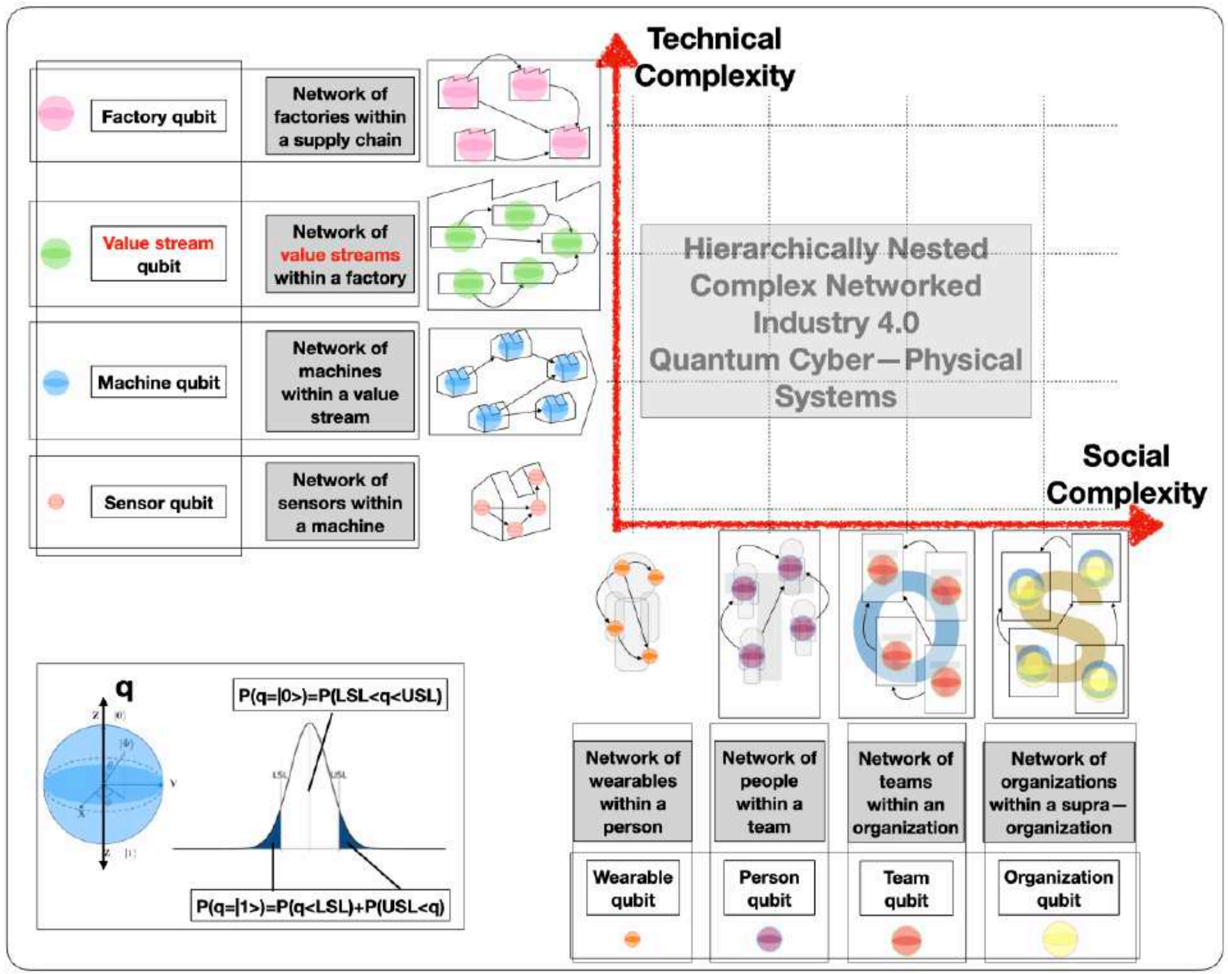
ALIGNMENT IS THUS A BINARY PROPERTY OF EACH CYBER--PHYSICAL NODE.

» INTRODUCTION

» QUANTUM INDUSTRY 4.0 CYBER—PHYSICAL FRAMEWORK

THE **INDUSTRY 4.0 CYBER—PHYSICAL FRAMEWORK** DESCRIBES A **SOCIO—TECHNICAL NESTED NETWORKED SYSTEM** IN WHICH THE ELEMENTS ARE REPRESENTED BY **COMPUTATIONAL UNITS WITH TWO POSSIBLE STATES**: ALIGNMENT AND NON—ALIGNMENT.

THERE IS A PROBABILITY THAT THESE COMPUTATIONAL UNITS FIND THEMSELVES IN THE SPECIFICATION LIMITS GIVEN BY THE VALUE CREATING PROCESS.



» INTRODUCTION

» OBJECTIVES

O1

PROPOSE A NOVEL QUANTUM STRATEGIC ORGANIZATIONAL DESIGN CONFIGURATION OF DISTRIBUTED QUANTUM CIRCUITS IN MULTI--LAYERED COMPLEX NETWORKS THAT ENABLE THE EVALUATION OF INDUSTRY 4.0 LEAN COMPLEX NETWORKS.

» INTRODUCTION

» OBJECTIVES

O1

PROPOSE A NOVEL QUANTUM STRATEGIC ORGANIZATIONAL DESIGN CONFIGURATION OF DISTRIBUTED QUANTUM CIRCUITS IN MULTI--LAYERED COMPLEX NETWORKS THAT ENABLE THE EVALUATION OF INDUSTRY 4.0 LEAN COMPLEX NETWORKS.

O2

PROPOSE DIFFERENT MECHANISMS FOR THE INTEGRATION OF INFORMATION BETWEEN CIRCUITS OPERATING AT DIFFERENT LAYERS, ANALYZE AND COMPARE THEIR BEHAVIOR WITH THE CLASSICAL CONDITIONAL PROBABILITY TABLES LINKED TO THE BAYESIAN NETWORKS.

» INTRODUCTION

» OBJECTIVES

O1

PROPOSE A NOVEL QUANTUM STRATEGIC ORGANIZATIONAL DESIGN CONFIGURATION OF DISTRIBUTED QUANTUM CIRCUITS IN MULTI--LAYERED COMPLEX NETWORKS THAT ENABLE THE EVALUATION OF INDUSTRY 4.0 LEAN COMPLEX NETWORKS.

O2

PROPOSE TWO DIFFERENT MECHANISMS FOR THE INTEGRATION OF INFORMATION BETWEEN CIRCUITS OPERATING AT DIFFERENT LAYERS, ANALYZE AND COMPARE THEIR BEHAVIOR WITH THE CLASSICAL CONDITIONAL PROBABILITY TABLES LINKED TO THE BAYESIAN NETWORKS.

O3

DEMONSTRATE THAT QUANTUM CIRCUITS CAN IMPROVE THE PERFORMANCE OF CLASSIC ALGORITHMS IN DESCRIBING CERTAIN COMPLEX INDUSTRIAL PROCESSES BY SOLVING SIMPLE PRACTICAL CASES OF CHAINS OF COMMAND AND DEPENDENCY IN INDUSTRIAL PROCESSES.

» INTRODUCTION

» OBJECTIVES

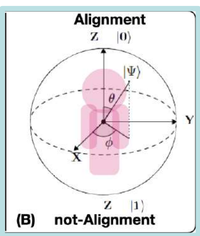
O1 **PROPOSE** A NOVEL QUANTUM STRATEGIC ORGANIZATIONAL DESIGN CONFIGURATION OF DISTRIBUTED QUANTUM CIRCUITS IN MULTI--LAYERED COMPLEX NETWORKS THAT ENABLE THE EVALUATION OF INDUSTRY 4.0 LEAN COMPLEX NETWORKS.

O2 **PROPOSE** TWO DIFFERENT MECHANISMS FOR THE INTEGRATION OF INFORMATION BETWEEN CIRCUITS OPERATING AT DIFFERENT LAYERS, ANALYZE AND COMPARE THEIR BEHAVIOR WITH THE CLASSICAL CONDITIONAL PROBABILITY TABLES LINKED TO THE BAYESIAN NETWORKS.

O3 **DEMONSTRATE** THAT QUANTUM CIRCUITS CAN IMPROVE THE PERFORMANCE OF CLASSIC ALGORITHMS IN OPTIMIZING CERTAIN COMPLEX INDUSTRIAL PROCESSES BY SOLVING SIMPLE PRACTICAL CASES OF CHAINS OF COMMAND AND DEPENDENCY IN INDUSTRIAL PROCESSES.

O4 **IMPLEMENT** THE THEORETICAL DEVELOPMENT BASED ON QUANTUM PRINCIPLES IN A DEVICE THAT ALLOWS TO DISCERN IN REAL TIME THE NEED TO MODIFY AN INDUSTRIAL PROCESS DUE TO THE PRESENCE OF PRODUCTION ERRORS AND TO ACHIEVE AN INTUITIVE INTERFACE FOR THE OPERATOR WHO USES IT.

» Contents_



QSOD

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

TRADITIONAL COMPUTING EMPLOYS BOOLEAN CIRCUIT COMPONENTS.

QUANTUM COMPUTING EMPLOYS TYPICALLY UNITARY OPERATIONS, I.E. OPERATING IN AN INFINITE SET, ON ONE OR MORE TWO—STATE SYSTEMS TO REALISE QUANTUM CIRCUITS.

Classical computing

$$x_j; j = 1,\ldots,n \in \mathbf{B}^{\mathbf{n}} = \{0,1\}^n$$

Quantum computing

$$\otimes\, |x_j > ; j = 1,\ldots,n \in \mathbf{B}^{\mathbf{n}}$$

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

$x_j;\, j = 1,\ldots,n \in \mathbf{B^n} = \{0,1\}^n$ Classical computing

$\otimes \,|x_j>\,;\, j = 1,\ldots,n \in \mathbf{B^n}$ Quantum computing

TRADITIONAL COMPUTING EMPLOYS BOOLEAN CIRCUIT COMPONENTS.

QUANTUM COMPUTING EMPLOYS TYPICALLY UNITARY OPERATIONS, I.E. OPERATING IN AN INFINITE SET, ON ONE OR MORE TWO—STATE SYSTEMS TO REALISE QUANTUM CIRCUITS.

A QUANTUM COMPUTER WORKS WITH A FINITE SET OF OBJECTS CALLED **QUBITS**.

EACH QUBIT HAS **TWO SEPARATE STATES** |0> AND |1> THAT FORM A BASIS IN A SPACE OF STATES.

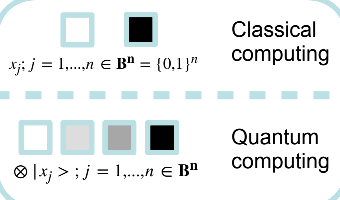
ARBITRARILY LINEAR COMBINATIONS OF THE BASIS STATES, WITH COMPLEX COEFFICIENTS THAT PRESERVE THE NORM DESCRIBE THE SYSTEM $|\psi>$.

$$|\Psi> = \sum c_{x_1,x_2,\ldots,x_n} |x_1, x_2, \ldots, x_n>$$

$$\sum |c_{x_1,x_2,\ldots,x_n}|^2 = 1$$

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS



TRADITIONAL COMPUTING EMPLOYS BOOLEAN CIRCUIT COMPONENTS.

QUANTUM COMPUTING EMPLOYS TYPICALLY UNITARY OPERATIONS, I.E. OPERATING IN AN INFINITE SET, ON ONE OR MORE TWO—STATE SYSTEMS TO REALISE QUANTUM CIRCUITS.

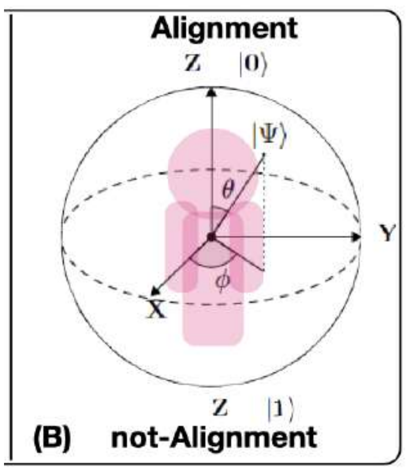
$$|\Psi> = \sum c_{x_1,x_2,\ldots,x_n} |x_1, x_2, \ldots, x_n>$$

$$\sum |c_{x_1,x_2,\ldots,x_n}|^2 = 1$$

A QUANTUM COMPUTER WORKS WITH A FINITE SET OF OBJECTS CALLED **QUBITS**.

EACH QUBIT HAS **TWO SEPARATE STATES** |0> AND |1> THAT FORM A BASIS IN A SPACE OF STATES.

ARBITRARILY LINEAR COMBINATIONS OF THE BASIS STATES, WITH COMPLEX COEFFICIENTS THAT PRESERVE THE NORM DESCRIBE THE SYSTEM |ψ>.



BLOCH'S SPHERE IS COMMONLY USED TO GEOMETRICALLY REPRESENT A QUBIT. OF UNITARY RADIUS, THE Z-AXIS IS THE COMPUTATIONAL AXIS AND ITS POSITIVE DIRECTION COINCIDES WITH THE STATE |0>, AND THE NEGATIVE WITH STATE |1>.

A QUBIT CAN BE REPRESENTED AS A POINT ON THE BLOCH SPHERE WITH THE HELP OF TWO PARAMETERS θ AND φ: $|\Psi> = cos\left(\frac{\theta}{2}\right)|0> + e^{i\phi} sin\left(\frac{\theta}{2}\right)|1>$

WE DEFINE THE **QSOD QUBIT**, THE NODE OF A DECISION COMPLEX—NETWORKED CYBER-PHYSICAL LEAN MANAGEMENT SYSTEM, AS **A HUMAN OR CYBER—PHYSICAL ASSET** THAT IS **IN THE CENTER OF A BLOCH SPHERE**, IN WHICH THE STATE OF ALIGNMENT AND NOT-ALIGNMENT REFERENCES RESPECTIVELY WITH THE QSOD QUBIT |0> AND |1> COMPUTATIONAL STATES.

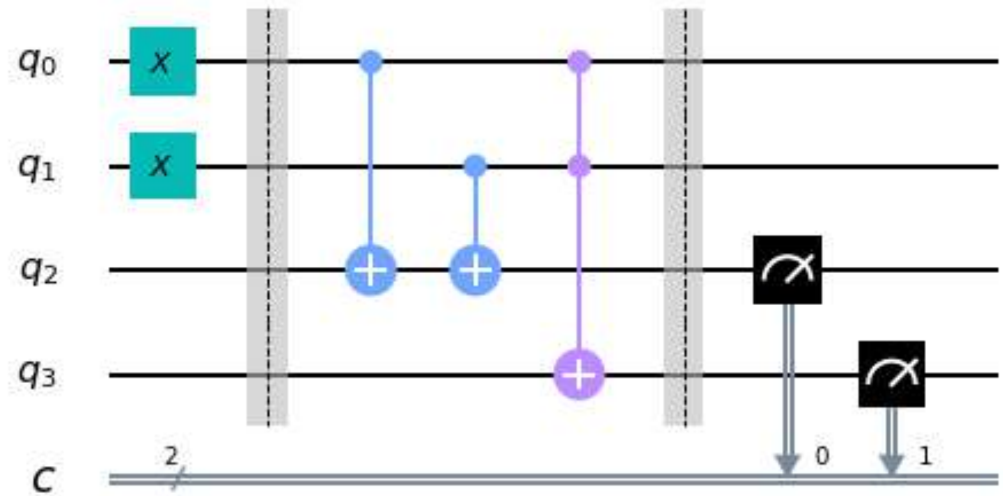
» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

A **QUANTUM CIRCUIT** IS A COMPUTATIONAL SEQUENCE.

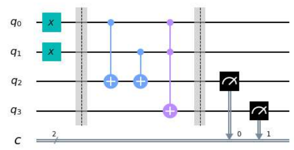
IT PERFORMS A SERIES OF COHERENT QUANTUM (UNITARY) OPERATIONS ON QUBITS. BY ORGANIZING THEM INTO AN ORDERLY SEQUENCE OF RESETS, QUANTUM GATES AND MEASUREMENTS.

RESETS QUANTUM GATES MEASUREMENTS



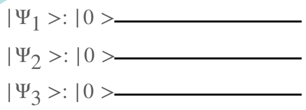
» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS



A **QUANTUM CIRCUIT** IS A COMPUTATIONAL SEQUENCE.

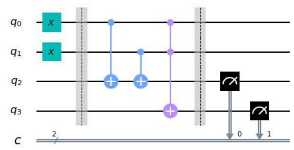
IT PERFORMS A SERIES OF COHERENT QUANTUM (UNITARY) OPERATIONS ON QUBITS. BY ORGANIZING THEM INTO AN ORDERLY SEQUENCE OF RESETS, QUANTUM GATES AND MEASUREMENTS.



THE INITIALIZATION AND RESET OF THE QUBITS IS TYPICALLY STANDARDIZED TO THE STATE |0> ON THE COMPUTATIONAL Z-AXIS.

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS



A **QUANTUM CIRCUIT** IS A COMPUTATIONAL SEQUENCE.

IT PERFORMS A SERIES OF COHERENT QUANTUM (UNITARY) OPERATIONS ON QUBITS. BY ORGANIZING THEM INTO AN ORDERLY SEQUENCE OF QUANTUM GATES, MEASUREMENTS, AND RESETS,.

$|\Psi_1>: |0>$
$|\Psi_2>: |0>$
$|\Psi_3>: |0>$

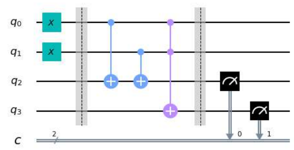
THE INITIALIZATION AND RESET OF THE QUBITS IS TYPICALLY STANDARDIZED TO THE STATE |0> ON THE COMPUTATIONAL Z-AXIS.

$$\theta = 2atan\sqrt{\frac{p(|1>)}{p(|0>)}}$$

FOR A **ROOT NODE**, THE CONDITIONAL PROBABILITIES TRANSLATE INTO QUBIT ROTATION ANGLES DEPENDING ON ITS DECISION NETWORK DEPENDENCIES.

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS



A **QUANTUM CIRCUIT** IS A COMPUTATIONAL SEQUENCE.

IT PERFORMS A SERIES OF COHERENT QUANTUM (UNITARY) OPERATIONS ON QUBITS. BY ORGANIZING THEM INTO AN ORDERLY SEQUENCE OF QUANTUM GATES, MEASUREMENTS, AND RESETS,.

$|\Psi_1>: |0>$ ———

$|\Psi_2>: |0>$ ———

$|\Psi_3>: |0>$ ———

THE INITIALIZATION AND RESET OF THE QUBITS IS TYPICALLY STANDARDIZED TO THE STATE |0> ON THE COMPUTATIONAL Z-AXIS.

$$\theta = 2atan\sqrt{\frac{p(|1>)}{p(|0>)}}$$

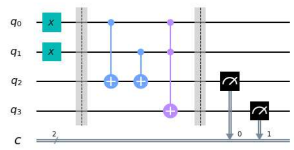
FOR A ROOT NODE, THE CONDITIONAL PROBABILITIES TRANSLATE INTO QUBIT ROTATION ANGLES DEPENDING ON ITS DECISION NETWORK DEPENDENCIES.

$$\theta = 2atan\sqrt{\frac{p(|1>|\prod\gamma_i = \prod\gamma_i^*)}{p(|0>|\prod\gamma_i = \prod\gamma_i^*)}}$$

FOR A **CHILD NODE** WITH “M” PARENTS THERE ARE ∏γI* POSSIBLE STATES.

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS



A **QUANTUM CIRCUIT** IS A COMPUTATIONAL SEQUENCE.

IT PERFORMS A SERIES OF COHERENT QUANTUM (UNITARY) OPERATIONS ON QUBITS. BY ORGANIZING THEM INTO AN ORDERLY SEQUENCE OF QUANTUM GATES, MEASUREMENTS, AND RESETS,.

$|\Psi_1>: |0>$

$|\Psi_2>: |0>$

$|\Psi_3>: |0>$

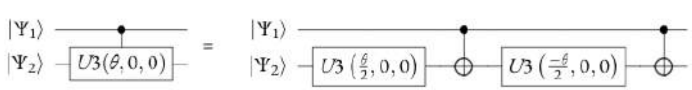
THE INITIALIZATION AND RESET OF THE QUBITS IS TYPICALLY STANDARDIZED TO THE STATE |0> ON THE COMPUTATIONAL Z-AXIS.

$$\theta = 2atan\sqrt{\frac{p(|1>)}{p(|0>)}}$$

FOR A ROOT NODE, THE CONDITIONAL PROBABILITIES TRANSLATE INTO QUBIT ROTATION ANGLES DEPENDING ON ITS DECISION NETWORK DEPENDENCIES.

$$\theta = 2atan\sqrt{\frac{p(|1> | \prod \gamma_i = \prod \gamma_i^*)}{p(|0> | \prod \gamma_i = \prod \gamma_i^*)}}$$

FOR A CHILD NODE WITH “M” PARENTS THERE ARE ∏γI* POSSIBLE STATES.



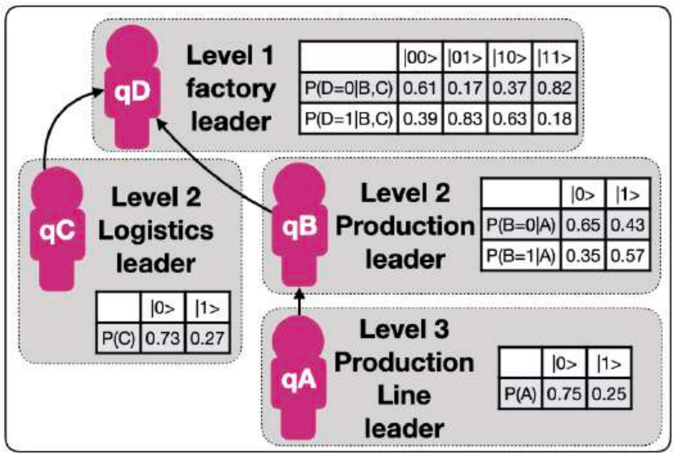
CONTROLLED ROTATIONS ARE NOT ELEMENTARY AND NEED TO BE DECONSTRUCTED.

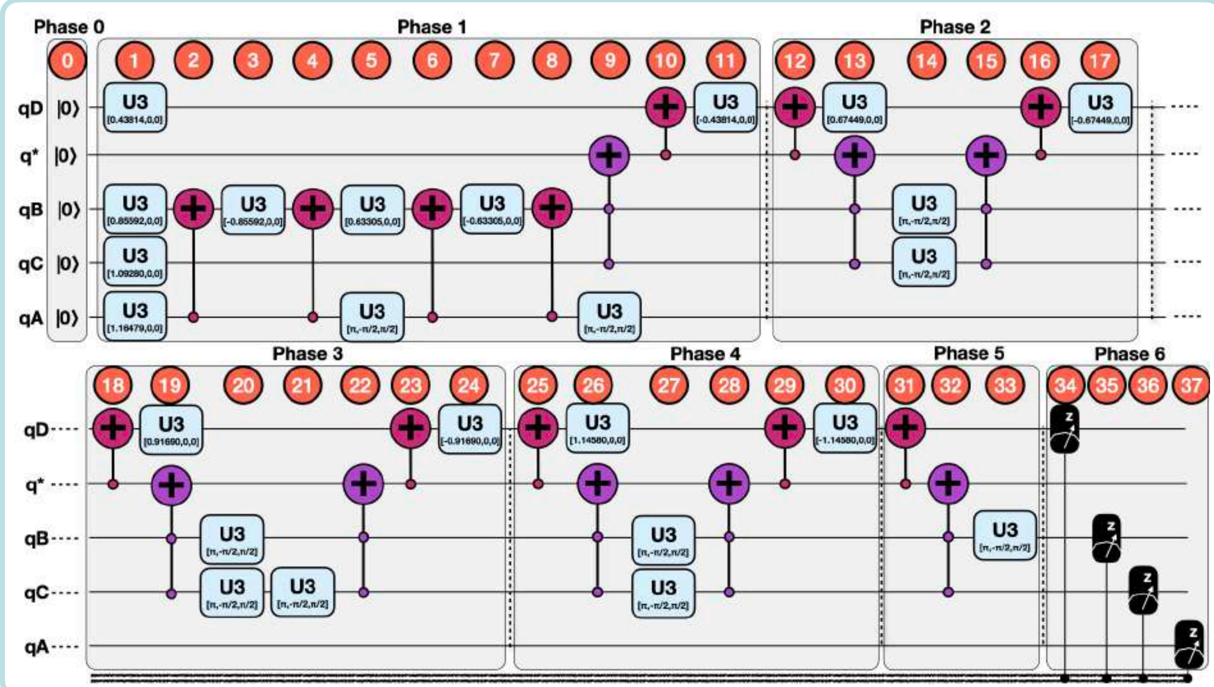
THIS METHOD WORKS: IF THE CONTROL $|\psi 1>$ IS IN STATE |0>, ALL WE HAVE IS U3(θ/2,0,0) FOLLOWED BY A U3(-θ/2,0,0) AND THE EFFECT IS TRIVIAL. IF THE CONTROL $|\psi 1>$ IS IN STATE |1>, THE NET EFFECT IS A CONTROLLED ROTATION U3(θ,0,0) ON THE $|\psi 2>$.

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

EXAMPLE





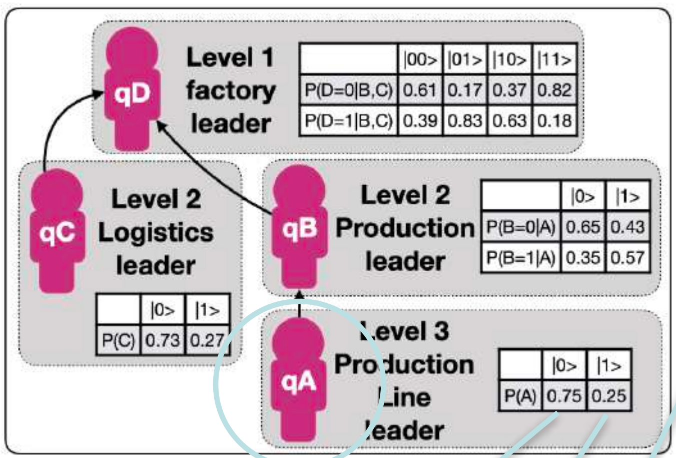
PAPER PUBLISHED

- **Villalba-Diez, J., & Zheng, X. (2020).** Quantum Strategic Organizational Design: Alignment in Industry 4.0 Complex-Networked Cyber-Physical Lean Management Systems. *Sensors, 20(20), 5856*. https://doi.org/10.3390/s20205856

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

EXAMPLE

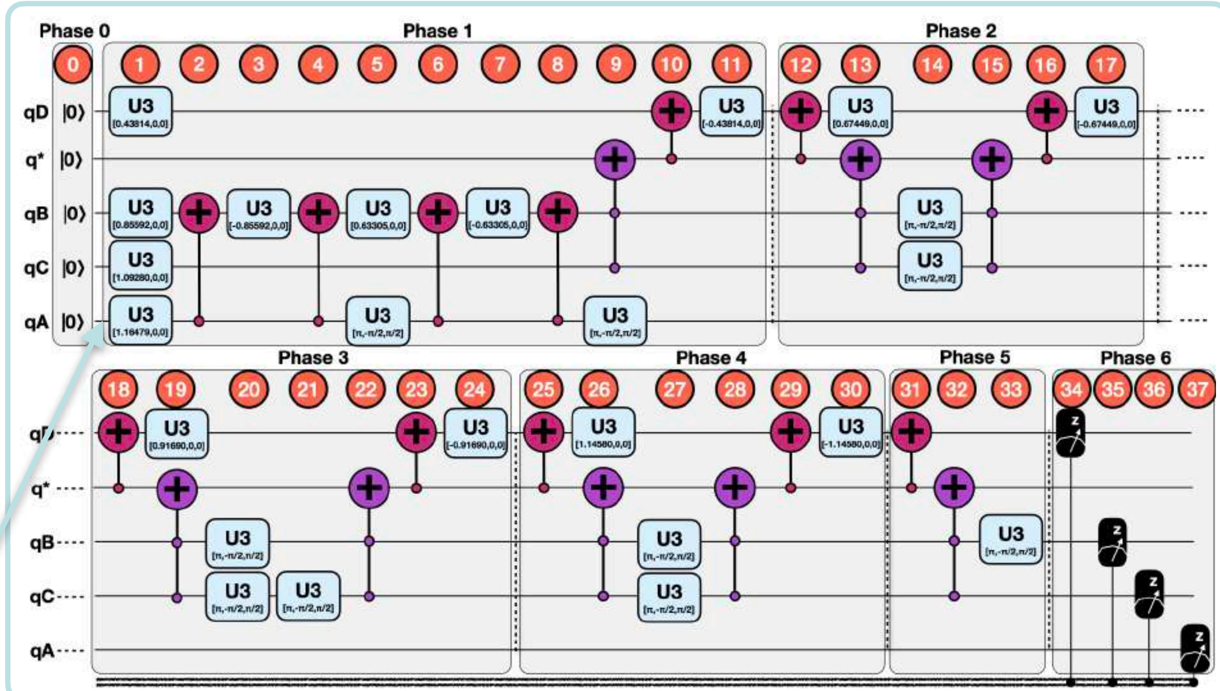


	|00>	|01>	|10>	|11>
P(D=0|B,C)	0.61	0.17	0.37	0.82
P(D=1|B,C)	0.39	0.83	0.63	0.18

	|0>	|1>
P(C)	0.73	0.27

	|0>	|1>
P(B=0|A)	0.65	0.43
P(B=1|A)	0.35	0.57

	|0>	|1>
P(A)	0.75	0.25



ROOT NODE ANGLE

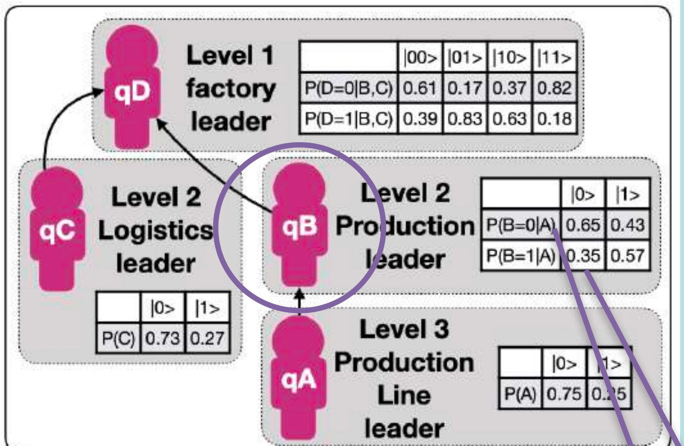
$$\theta_A = 2\arctan\sqrt{\frac{0.25327658}{0.74672341}} = 1.16479$$

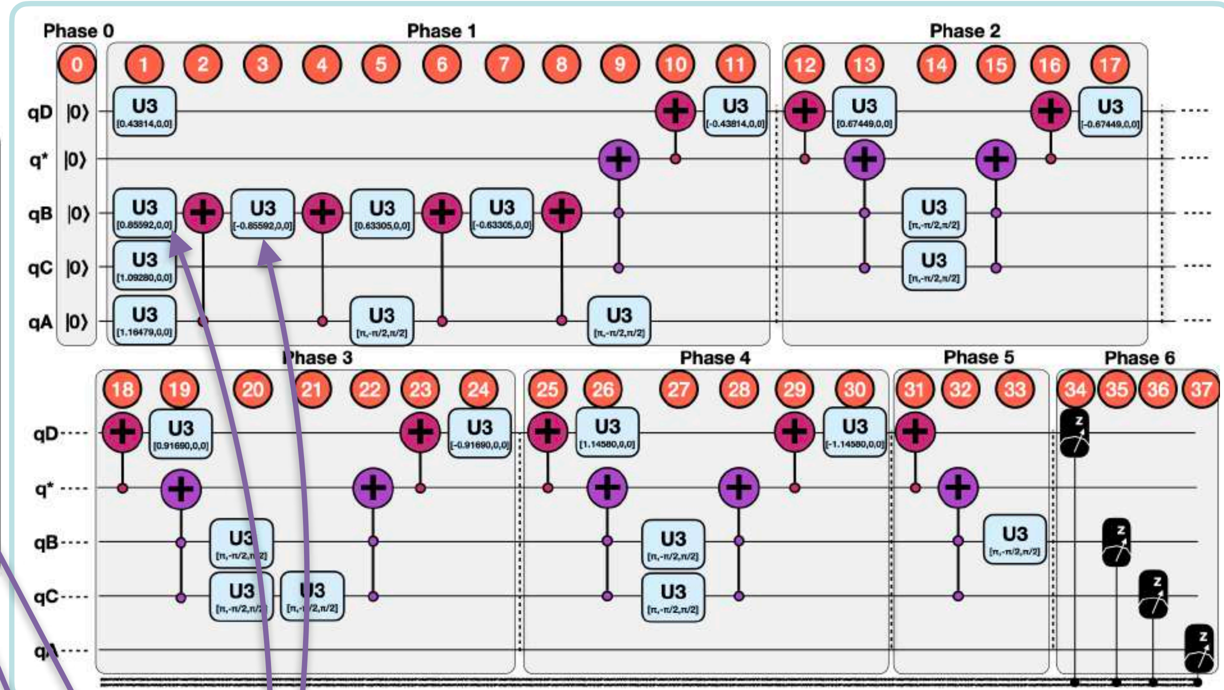
$$\theta_C = 2\arctan\sqrt{\frac{0.27}{0.73}} = 1.0928$$

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

EXAMPLE





ROOT NODE ANGLE

$$\theta_A = 2\arctan\sqrt{\frac{0.25327658}{0.74672341}} = 1.16479$$

$$\theta_C = 2\arctan\sqrt{\frac{0.27}{0.73}} = 1.0928$$

CHILD NODE ANGLE 1 PARENT

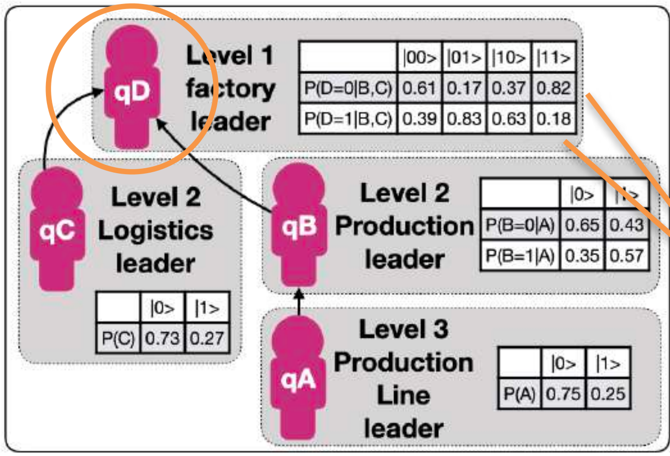
$$\theta_{B,|0>} = 2\arctan\sqrt{\frac{0.35}{0.65}} = 1.2661$$

$$\theta_{B,|1>} = 2\arctan\sqrt{\frac{0.57}{0.43}} = 1.7113$$

» QUANTUM STRATEGIC ORGANIZATIONAL DESIGN (QSOD)

» QUANTUM COMPUTING FUNDAMENTALS

EXAMPLE

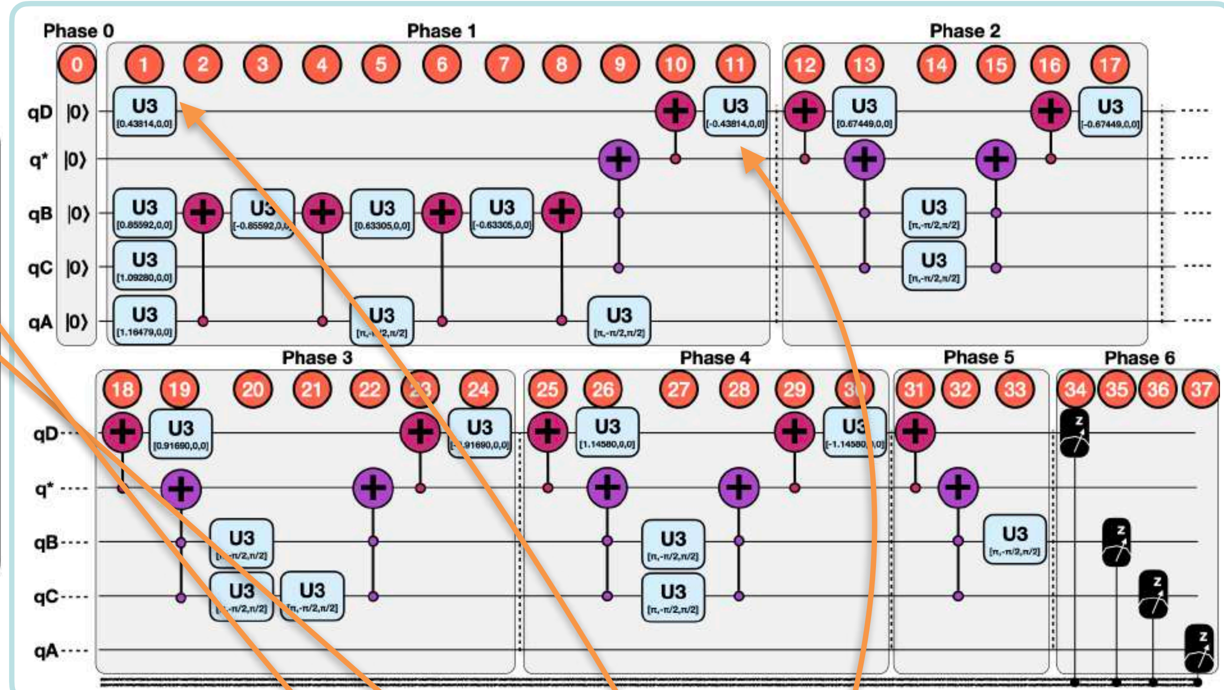


	|00>	|01>	|10>	|11>
P(D=0|B,C)	0.61	0.17	0.37	0.82
P(D=1|B,C)	0.39	0.83	0.63	0.18

	|0>	|1>
P(C)	0.73	0.27

	|0>	|1>
P(B=0|A)	0.65	0.43
P(B=1|A)	0.35	0.57

	|0>	|1>
P(A)	0.75	0.25



ROOT NODE ANGLE

$$\theta_A = 2\arctan\sqrt{\frac{0.25327658}{0.74672341}} = 1.16479$$

$$\theta_C = 2\arctan\sqrt{\frac{0.27}{0.73}} = 1.0928$$

CHILD NODE ANGLE 1 PARENT

$$\theta_{B,|0>} = 2\arctan\sqrt{\frac{0.35}{0.65}} = 1.2661$$

$$\theta_{B,|1>} = 2\arctan\sqrt{\frac{0.57}{0.43}} = 1.7113$$

CHILD NODE ANGLE 2 PARENTS

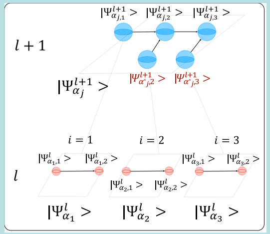
$$\theta_{D,|10>} = 2\arctan\sqrt{\frac{0.63}{0.37}} = 1.83382$$

$$\theta_{D,|11>} = 2\arctan\sqrt{\frac{0.18}{0.82}} = 0.87629$$

$$\theta_{D,|00>} = 2\arctan\sqrt{\frac{0.39}{0.61}} = 1.3489$$

$$\theta_{D,|01>} = 2\arctan\sqrt{\frac{0.83}{0.17}} = 2.29161$$

» Contents_

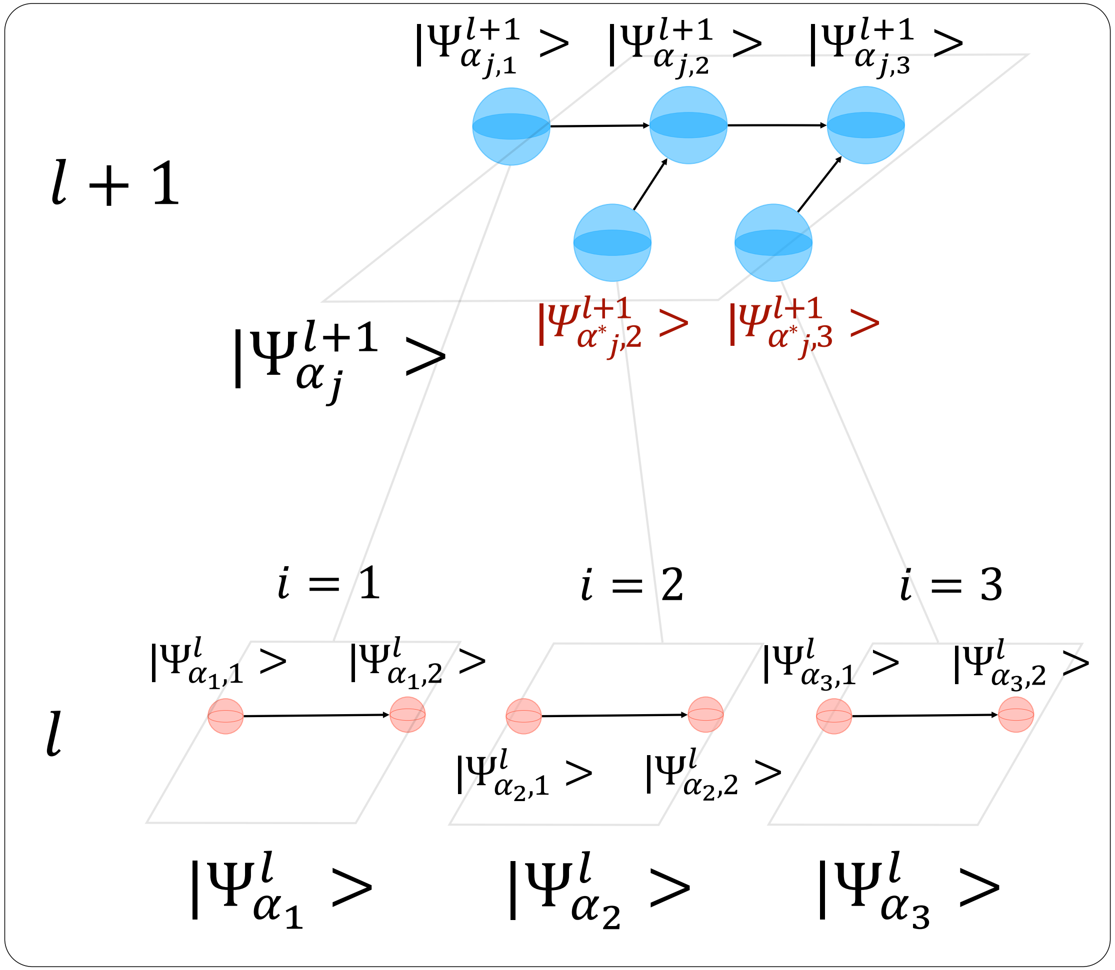


QSOD QMLN

» QSOD as QUANTUM MULTILAYERED NETWORKS

» IMPLEMENTATION OF HIERARCHICAL RELATIONSHIPS

QMLN



O1

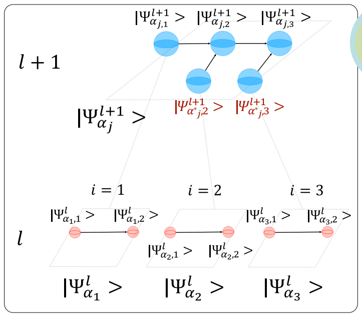
THE QMLN IS CONSTRUCTED BY FOLLOWING RULES:

1. ROOT NODES. THE INITIAL STATE OF THE UPPER LEVEL IS TRANSLATED DIRECTLY FROM THE BOTTOM LEVEL.
2. CHILD NODE. THE INITIAL STATE OF THE UPPER LEVEL NODE IS TRANSLATED WITH AID OF AN ADDITIONAL QUBIT “MARKED IN RED”.

» QSOD as QUANTUM MULTILAYERED NETWORKS

» IMPLEMENTATION OF HIERARCHICAL RELATIONSHIPS

QMLN



O1

DIFFERENT CONFIGURATIONS ARE TESTED AND SHOWN IN THE FIGURE.

(A). ONE ELEMENT FAILING AT LEVEL “L”

(D). TWO ELEMENTS FAILING AT LEVEL “L”.

…

—

X—AXIS. ALIGNMENT PROBABILITY OF LAST NODE AT LEVEL “L”.

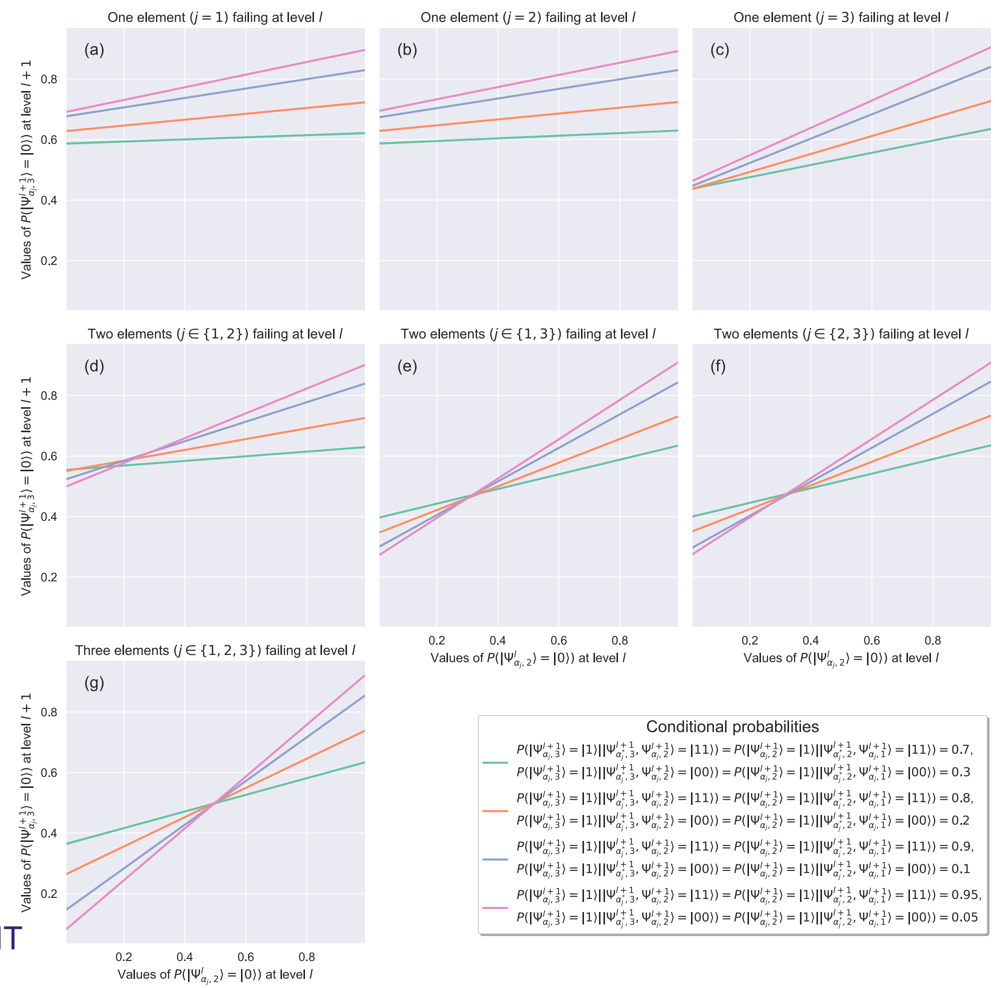
Y—AXIS. ALIGNMENT PROBABILITY OF LAST NODE AT LEVEL “L+1”

—

THE DIFFERENT LINES REPRESENT DIFFERENT PARAMETRIZATIONS OF THE CIRCUIT FOR DIFFERENT PROBABILITIES.

RESULTS

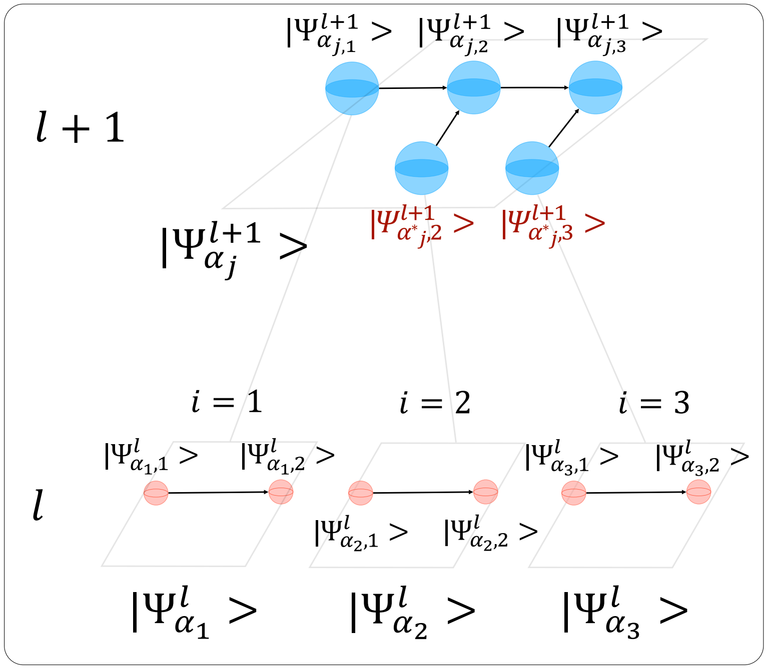
O2



» QSOD as QUANTUM MULTILAYERED NETWORKS

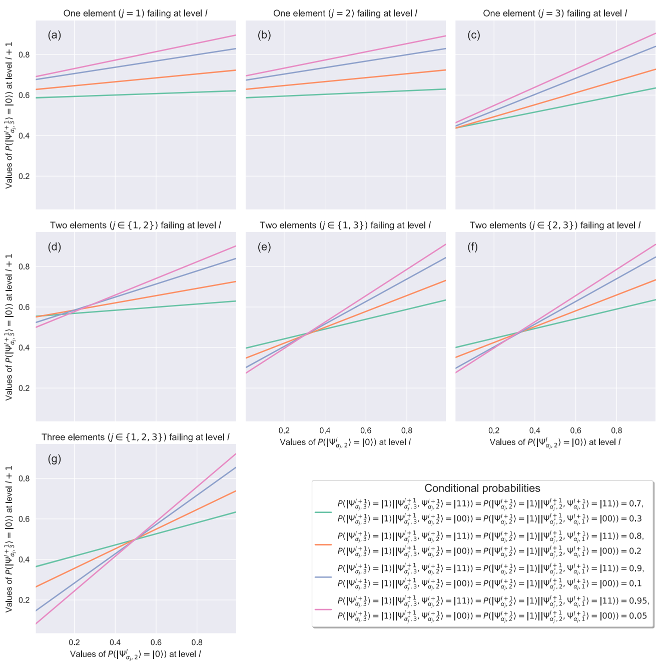
» IMPLEMENTATION OF HIERARCHICAL RELATIONSHIPS

QMLN



O1

RESULTS



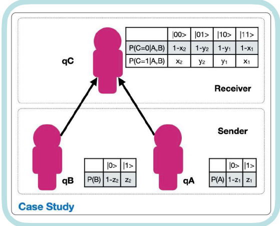
O2

CONCLUSION

THE SOLUTION PRESERVES THE NORM, IS UNITARY, AND THEREFORE IS COHERENT WITH THE REVERSIBILITY OF QUANTUM MECHANICS.

IT YIELDS THE **SAME RESULTS AS ITS EQUIVALENT BAYESIAN NETWORK** (CLASSICAL PROBLEM ALREADY SOLVED).

» Contents_

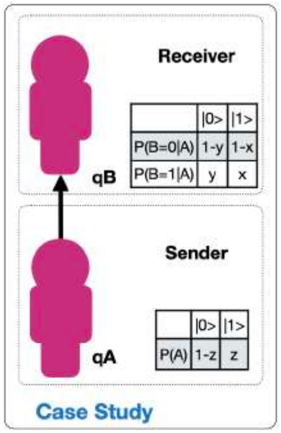


QSOD CASES

O3

» QSOD CASES

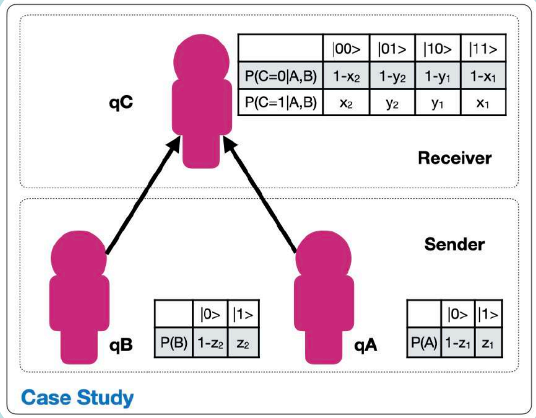
» SUMMARY



ONE SUBORDINATE REPORT TO HER BOSS

PAPER PUBLISHED

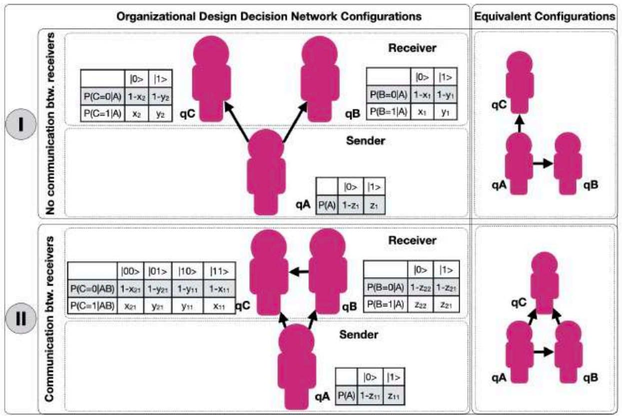
Villalba-Diez, J., Benito, R. M., & Losada, J. C. (2020). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of Two Qubits: One Reports to One. *Sensors, 20(23), 6977*. https://doi.org/10.3390/s20236977



TWO SUBORDINATES REPORT TO THEIR BOSS

PAPER PUBLISHED

Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D. (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426



ONE SUBORDINATE REPORTS TO TWO BOSSES

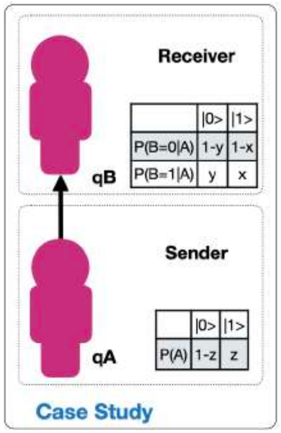
PAPER PUBLISHED

Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D. (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426

O3

» QSOD CASES

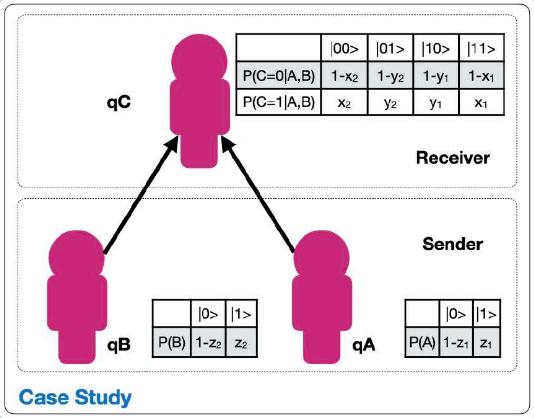
» SUMMARY



ONE SUBORDINATE REPORT TO HER BOSS

PAPER PUBLISHED

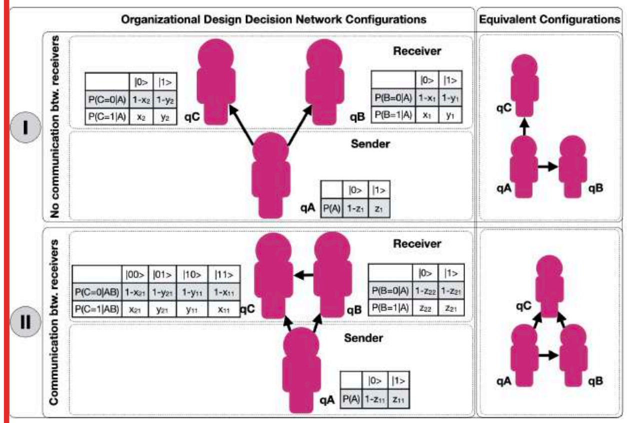
Villalba-Diez, J., Benito, R. M., & Losada, J. C. (2020). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of Two Qubits: One Reports to One. *Sensors, 20(23), 6977*. https://doi.org/10.3390/s20236977



TWO SUBORDINATES REPORT TO THEIR BOSS

PAPER PUBLISHED

Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D. (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426



ONE SUBORDINATE REPORTS TO TWO BOSSES

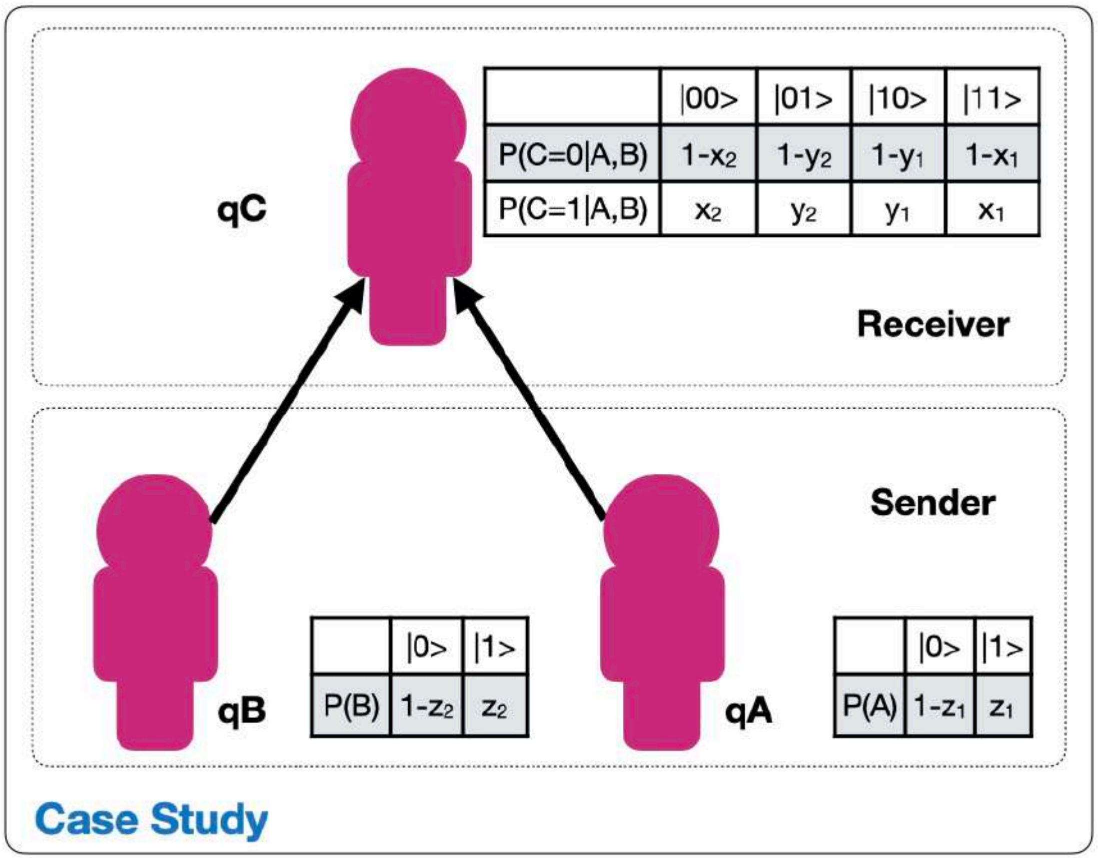
PAPER PUBLISHED

Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D. (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426

O3

» QSOD CASES

» THE CASE OF THREE QUBITS: TWO REPORTS TO ONE



OUR GOAL IS TO ESTABLISH THE ALIGNMENT PROBABILITY OF AGENT C, P(C=|0>), AS A FUNCTION OF THE ALIGNMENT PROBABILITIES OF AGENTS A AND B AND THE ALIGNMENT PROBABILITIES BETWEEN AGENT C AND AGENTS A AND B.

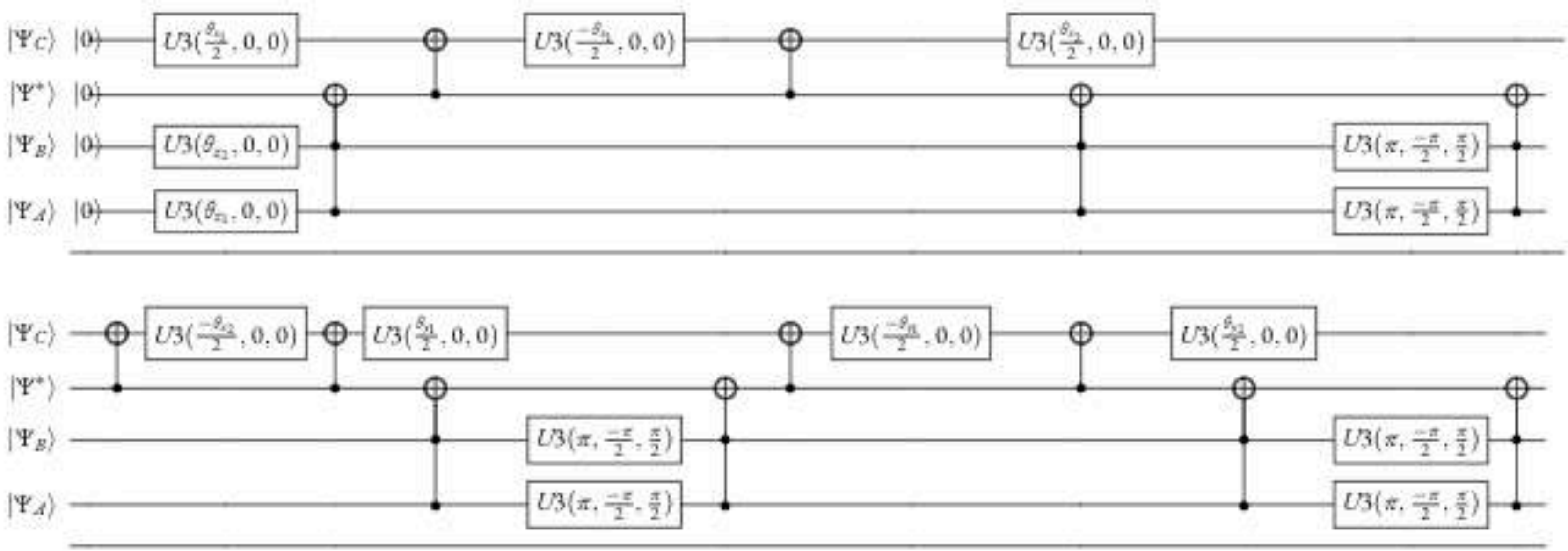
MATHEMATICALLY SPEAKING, WE INTEND TO FIND THE VALUES OF 6 PARAMETERS THAT DELIVER THE MAXIMUM ALIGNMENT OF NODE C.

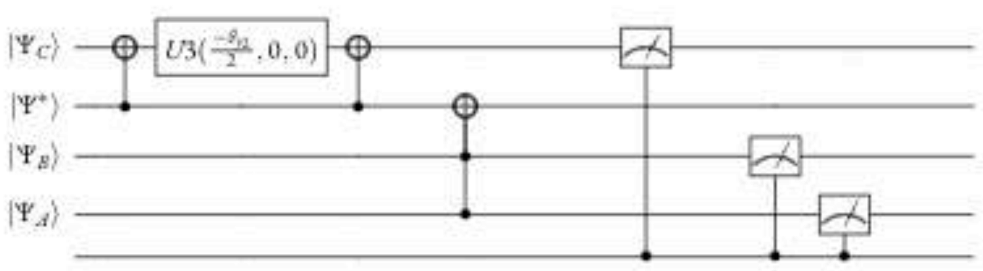
PAPER PUBLISHED

- **Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D.** (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426

» QSOD CASES

» THE CASE OF THREE QUBITS: TWO REPORTS TO ONE





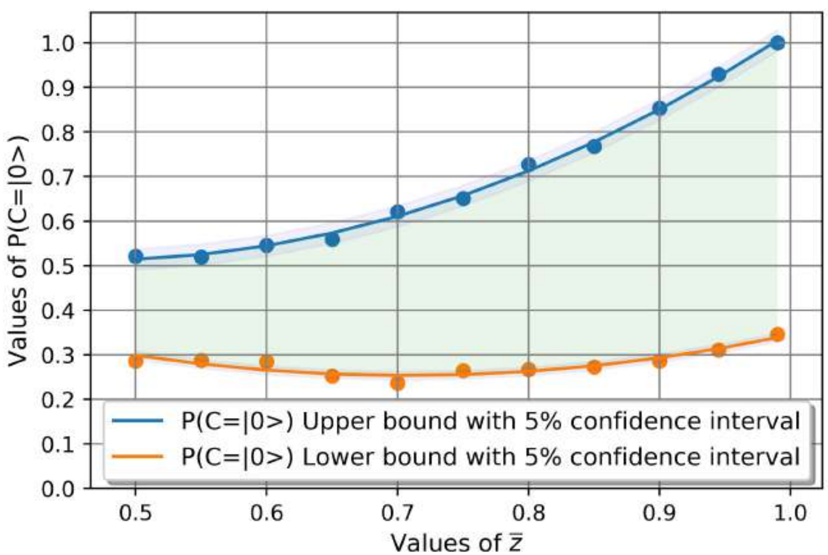
FOLLOWING THE QSOD RULES, THIS PARAMETRIZED QUANTUM CIRCUIT YIELDS THE SOLUTION.

BY CHANGING THE PARAMETERS AND SIMULATING DIFFERENT CONFIGURATIONS, WE CAN DESCRIBE THE SYSTEM.

O3

» QSOD CASES

» THE CASE OF THREE QUBITS: TWO REPORTS TO ONE



Upper bound

$$\overline{P}(C_{post} = |0>) = 1.7915\bar{z}^2 - 1.667\bar{z} + 0.9\bar{z} \in [0.5,1]; \overline{R^2} = 0.997$$

Lower bound

$$\underline{P}(C_{post} = |0>) = 1.061\bar{z}^2 - 1.489\bar{z} + 0.78\bar{z} \in [0.5,1]; \underline{R^2} = 0.866$$

X—AXIS. MEAN VALUE OF ALIGNMENT PROBABILITY OF SUBORDINATES

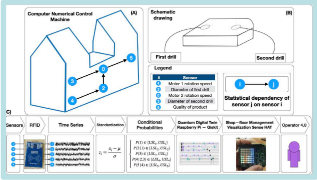
Y—AXIS. ALIGNMENT PROBABILITY OF UPPER NODE.

(1) R2.1. THE ALIGNMENT PROBABILITY OF NODE C IS NEVER GREATER THAN THE MEAN ALIGNMENT PROBABILITY OF ITS SUBORDINATE NODES. IN OTHER WORDS, THE ALIGNMENT PROBABILITY OF A BOSS CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

(2) **R2.2**. THE AMPLITUDE OF POSSIBLE ALIGNMENT STATES OF NODE **C** INCREASES WITH INCREASING VALUES OF $\bar{z}$ AND IS OBTAINED. THE GREEN SHADED AREA INDICATES THE POSSIBLE VALUES OF THIS PROBABILITY AS INDICATED. WE OBSERVE THAT INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE LOWER NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.

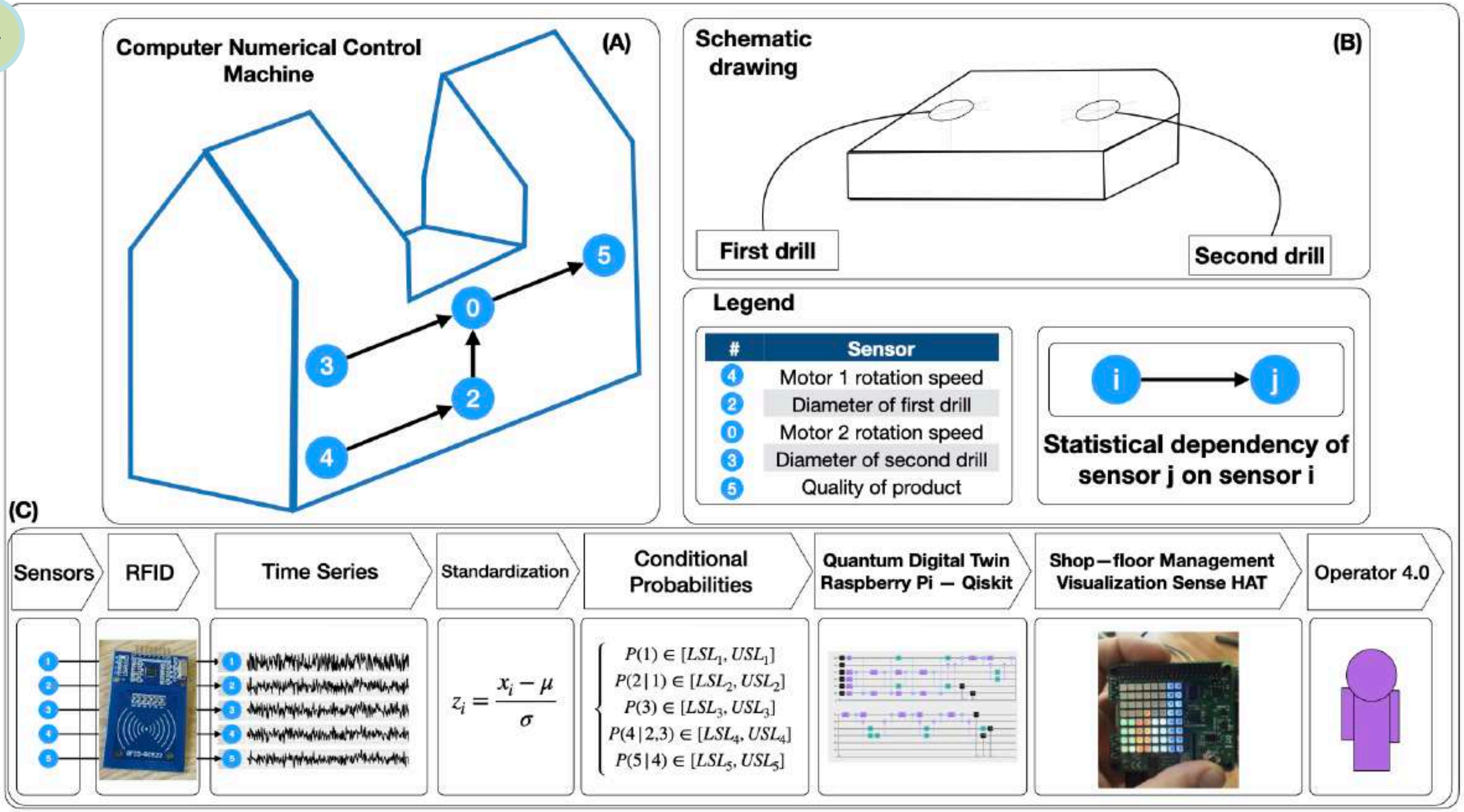
(3) **R2.3**. THE HARMONIC UNDERDAMPED OSCILLATION THAT WAS OBSERVED BETWEEN THE ALIGNMENT STATES IN THE CASE OF ONE NODE REPORTING TO ANOTHER, HAS DISAPPEARED IN THE CASE OF TWO NODES REPORTING TO A THIRD. THIS SEEMS TO INDICATE THAT THE ADDITIONAL NODE PROVIDES ADDITIONAL STABILITY TO THE ORGANIZATIONAL SYSTEM.

» Contents_



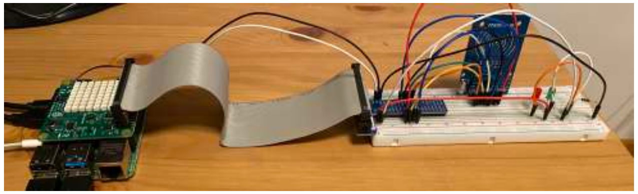
QSOD JIDOKA

O4



JIDOKA IS A JAPANESE STRATEGY THAT AIMS TO PROVIDE MACHINES WITH “HUMAN INTELLIGENCE”.

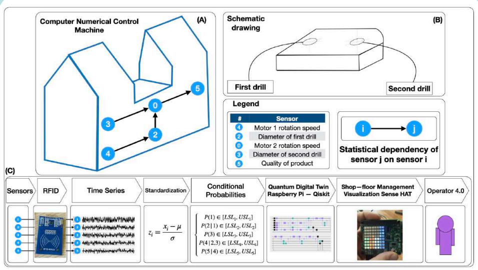
WITH HELP OF QSOD WE USE THE CNC MACHINE SENSORS TO CREATE A DEVICE THAT HELPS THE OPERATOR IDENTIFY MACHINE WRONG PRODUCTION WITH A SIMPLE TRAFFIC—LIGHT LOGIC.

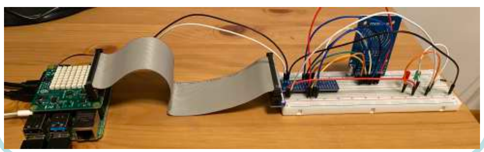


O4

» QUANTUM JIDOKA

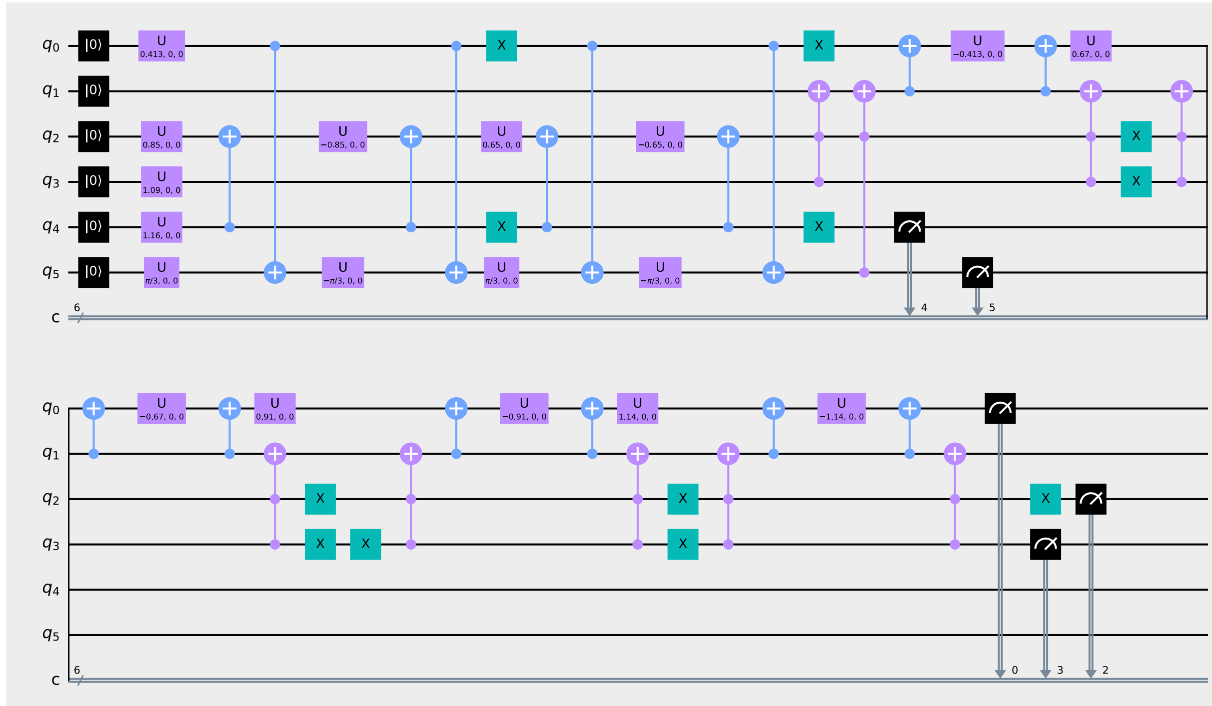
» QSOD INTEGRATION ON A CNC MACHINE

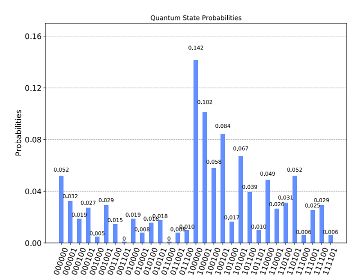


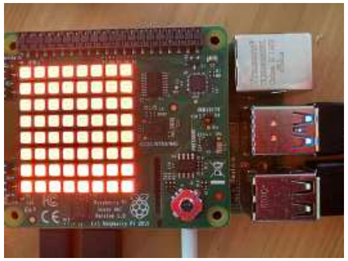


A QUANTUM CIRCUIT RESEMBLES THE SENSOR NETWORK WITHIN THE CNC MACHINE FOLLOWING THE QSOD RULES.

WE CAN CALCULATE THE ALIGNMENT PROBABILITIES OF THE FINAL NODE AND HENCE DETERMINE THE PROBABILITY OF THE PRODUCED PART TO BE IN THE PROCESS SPECIFICATIONS.



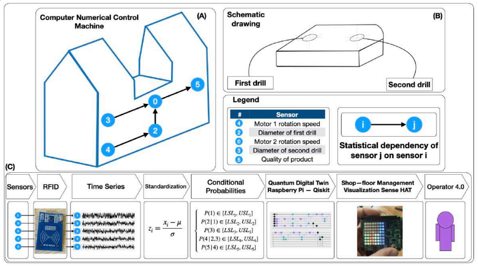


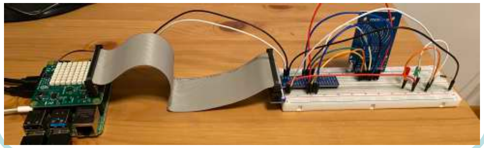


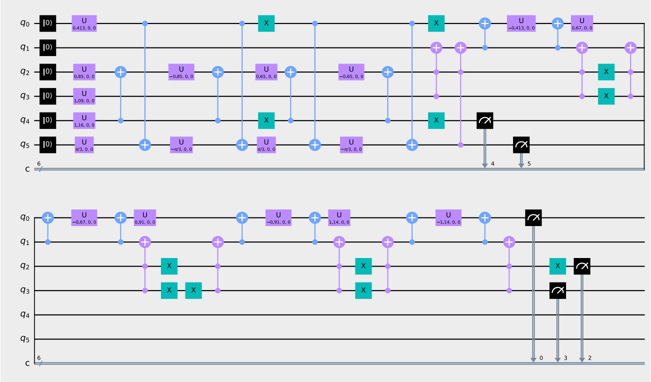
O4

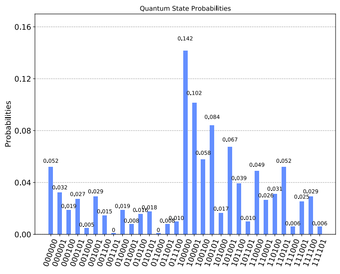
» QUANTUM JIDOKA

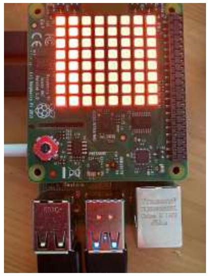
» QSOD INTEGRATION ON A CNC MACHINE









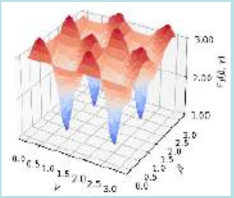


R4. WE HAVE SUCCESSFULLY TESTED THE INTEGRATION OF A DIGITAL QUANTUM TWIN BY MEANS OF QUANTUM SIMULATIONS ON A CONVENTIONAL MACHINE TO ENABLE A VISUALIZATION OF ITS SYSTEMIC STATE IN AN INDUSTRY 4.0 ENVIRONMENT.

PAPER PUBLISHED

Villalba-Diez, J., Gutierrez, M., Grijalvo Martín, M., Sterkenburgh, T., Losada, J. C., & Benito, R. M. (2021). Quantum JIDOKA. Integration of Quantum Simulation on a CNC Machine for In–Process Control Visualization. Sensors, 21(15). https://doi.org/10.3390/s21155031

» Contents_

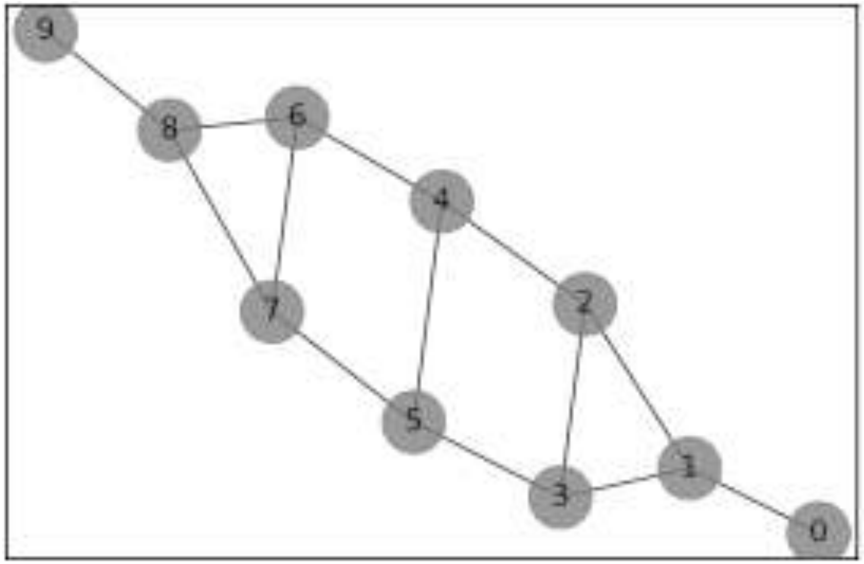


QAOA

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

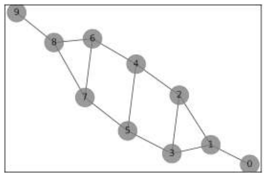
THE GOAL OF THE QAOA ALGORITHM IS TO FIND THE OPTIMAL PARTITIONING OF VALUE STREAM NETWORKS INTO TWO CLASSES SO AS TO PROMOTE A MORE EFFICIENT INDUSTRIAL RESOURCE ALLOCATION.

IN OTHER WORDS, GIVEN A VALUE STREAM NETWORK, HOW DO WE PARTITION THE GRAPH INTO TWO CLASSES FOR BEST RESOURCE ALLOCATION?



EXAMPLE GRAPH OF 10 NODES

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)



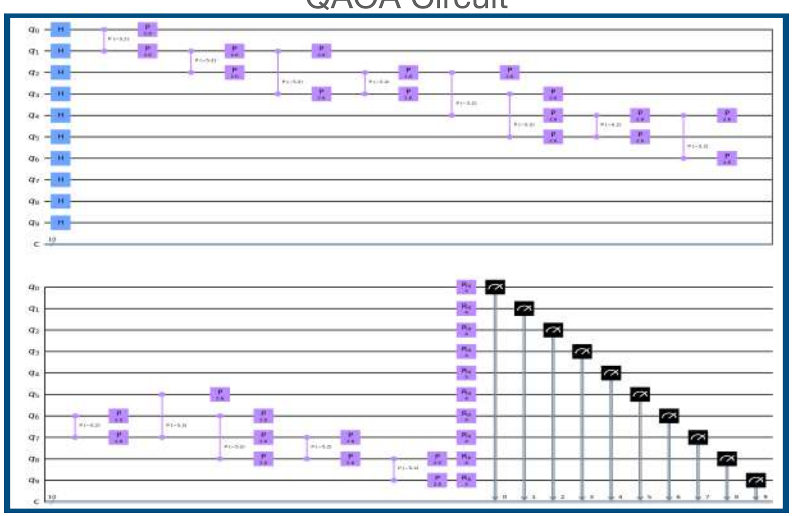
THE GOAL OF THE QAOA ALGORITHM IS TO FIND THE OPTIMAL PARTITIONING OF VALUE STREAM NETWORKS INTO TWO CLASSES SO AS TO PROMOTE A MORE EFFICIENT INDUSTRIAL RESOURCE ALLOCATION.

IN OTHER WORDS, GIVEN A VALUE STREAM NETWORK, HOW DO WE PARTITION THE GRAPH INTO TWO CLASSES FOR BEST RESOURCE ALLOCATION?

THIS OPTIMIZATION ALGORITHM IS KNOWN AS MAX—CUT AND REQUIERES THE EXECUTION OF PARAMETRIZED QUANTUM CIRCUITS THAT ARE CLASSICALLY OPTIMIZED RECURSIVELY TO FIND THE OPTIMAL PARAMETER COMBINATION.

1

QAOA Circuit

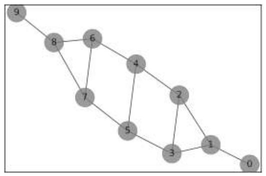


EXAMPLE CIRCUIT GAMMA=2.6 BETA=2

2

CLASSICAL OPTIMZATION

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)



THE GOAL OF THE QAOA ALGORITHM IS TO FIND THE OPTIMAL PARTITIONING OF VALUE STREAM NETWORKS INTO TWO CLASSES SO AS TO PROMOTE A MORE EFFICIENT INDUSTRIAL RESOURCE ALLOCATION.

IN OTHER WORDS, GIVEN A VALUE STREAM NETWORK, HOW DO WE PARTITION THE GRAPH INTO TWO CLASSES FOR BEST RESOURCE ALLOCATION?

THIS OPTIMIZATION ALGORITHM IS KNOWN AS MAX—CUT AND REQUIERES THE EXECUTION OF PARAMETRIZED QUANTUM CIRCUITS THAT ARE CLASSICALLY OPTIMIZED RECURSIVELY TO FIND THE OPTIMAL PARAMETER COMBINATION.

1

QAOA Circuit

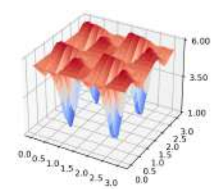
PARAMETRIZED QUANTUM CIRCUIT

2

Measure

Bitstring samples $x \in \{0,1\}^n$

Evaluate mean cut of values



Classical optimizer

Update Parameters

CLASSICAL OPTIMZATION

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

» QUANTUM CIRCUIT — CLASSICAL QAOA

THE CLASSICAL QAOA ALGORITHM USES UNITARY TRANSFORMATIONS THAT DEPEND ON TWO PARAMETERS BETA AND GAMMA AND IS ARRANGED IN ALTERNATING BLOCKS. FOR EACH NODE IN THE NETWORK WE SET UP A QUBIT.

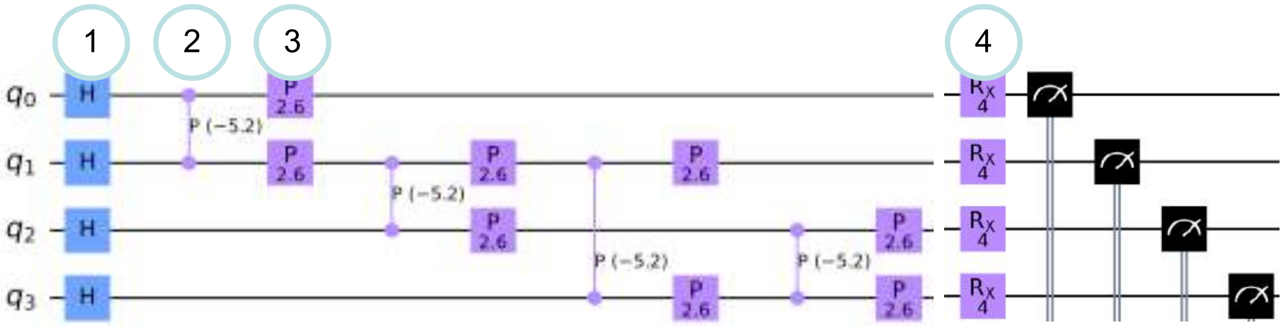
FIRST STARTS BY PREPARING THE SYSTEM IN SUPERPOSITION WITH HADAMARD GATES ALL QUBITS QUBIT.

SECOND WE IMPLEMENT CONDITIONAL ROTATIONS OF 2*GAMMA TO EACH EDGE PAIR OF EDGES IF BOTH ARE IN STATE |11>.

THIRD, A PHASE CORRECTION OF GAMMA IS APPLIED TO EACH OF THE NODES JOINED BY EACH EDGE.

FINALLY, A ROTATION OF 2*BETA AROUND THE X-AXIS IS APPLIED TO ALL NODES.

IN **SUMMARY**, IN THE CLASSICAL QAOA ALGORITHM APPLIES, AFTER A STANDARD SUPERPOSITION, A QUANTUM PHASE OF GAMMA TO EVERY NODE CONNECTED TO EACH OTHER, AS LONG AS BOTH ARE NOT IN STATE |11⟩, AND A ROTATION AROUND THE PERPENDICULAR TO THE COMPUTATIONAL AXIS OF 2*BETA TO ALL THE NODES.



EXAMPLE CIRCUIT GAMMA=2.6 BETA=2

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

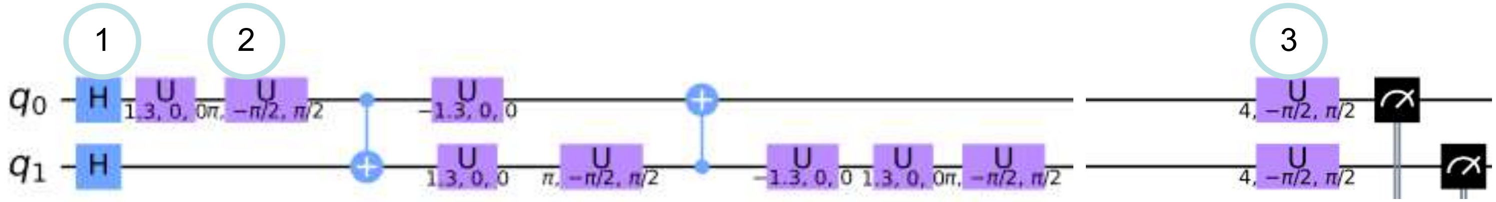
» QUANTUM CIRCUIT — NEW QAOA

WE PROPOSE A NEW QAOA QUANTUM CIRCUIT:

1. **FIRST** STARTS BY PREPARING THE SYSTEM IN SUPERPOSITION WITH HADAMARD GATES ALL QUBITS QUBIT.

2. **SECOND** WE IMPLEMENT CONDITIONAL ROTATIONS OF GAMMA TO EACH EDGE NODE CONNECTED TO ANOTHER IF THE SECOND IS IN STATE |1>. THIS IS DONE BY CONCATENATION OF TWO U3 ROTATIONS AND A CX CONDITIONAL ROTATION AS DESCRIBED IN SLIDE 28.

3. **FINALLY**, A ROTATION OF 2*BETA AROUND THE X-AXIS IS APPLIED TO ALL NODES.



EXAMPLE CIRCUIT GAMMA=2.6 BETA=2

» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

» CLASSICAL OPTIMIZATION

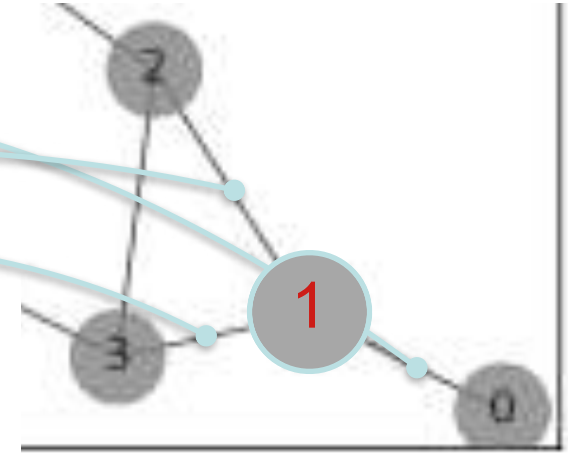
WE MAKE THE GRAPH COINCIDE WITH THE CONNECTIVITY OF OUR VALUE STREAM NETWORK, THEN THE COST FUNCTION COINCIDES WITH THE HAMILTONIAN USED TO GENERATE THE STATE.

IN OUR NETWORK WE HAVE TWO TYPES OF NODES: THOSE CONNECTED WITH AT LEAST ONE NODE WITH DEGREE ONE (A) AND THOSE CONNECTED WITH OTHER NODES WITH DEGREE THREE (B). THIS YIELDS TWO ENCODING OF THE OPTIMIZATION FUNCTION BETWEEN THE NODES.

FOR (A) EDGES, NODE (1):

$$2f_A = 1 - \langle +^1 | U_{01}(\gamma)U_{12}(\gamma)U_{13}(\gamma)X_0(\beta)X_1(\beta)Z_0Z_1X_1^\dagger(\beta)X_0^\dagger(\beta)U_{01}^\dagger(\gamma)U_{12}^\dagger(\gamma)U_{13}^\dagger(\gamma) | +^1 \rangle$$

IN WHICH $| +^n \rangle = \sum_{x\in\{0,1\}^n} \frac{1}{\sqrt{2^n}} |x\rangle$ PREPARES FOR AN EQUAL SUPERPOSITION STATED FOLLOWED BY THE PARAMETRISED UNITARY OPERATIONS.



» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

» CLASSICAL OPTIMIZATION

WE MAKE THE GRAPH COINCIDE WITH THE CONNECTIVITY OF OUR VALUE STREAM NETWORK, THEN THE COST FUNCTION COINCIDES WITH THE HAMILTONIAN USED TO GENERATE THE STATE.

IN OUR NETWORK WE HAVE TWO TYPES OF NODES: THOSE CONNECTED WITH AT LEAST ONE NODE WITH DEGREE ONE (A) AND THOSE CONNECTED WITH OTHER NODES WITH DEGREE THREE (B). THIS YIELDS TWO ENCODING OF THE OPTIMIZATION FUNCTION BETWEEN THE NODES.

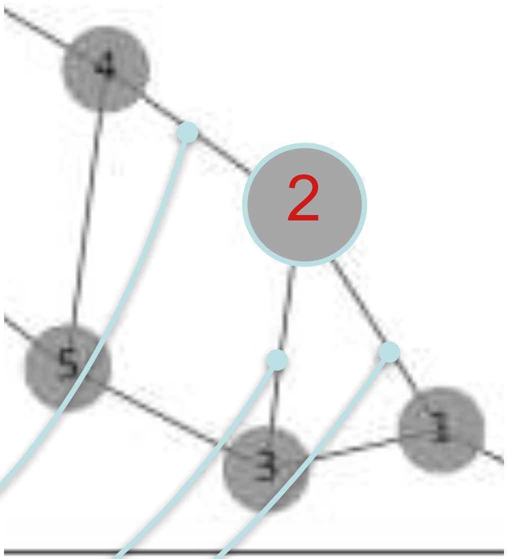
FOR (A) EDGES, NODE (1):

$$2f_A = 1 - \langle +^1 | U_{01}(\gamma)U_{12}(\gamma)U_{13}(\gamma)X_0(\beta)X_1(\beta)Z_0Z_1X_1^{\dagger}(\beta)X_0^{\dagger}(\beta)U_{01}^{\dagger}(\gamma)U_{12}^{\dagger}(\gamma)U_{13}^{\dagger}(\gamma) | +^1 \rangle$$

AND FOR (B) EDGES, NODE (2):

$$2f_B = 1 - \langle +^3 | U_{21}(\gamma)U_{24}(\gamma)U_{23}(\gamma)X_1(\beta)X_2(\beta)Z_1Z_2X_1^{\dagger}(\beta)X_2^{\dagger}(\beta)(\gamma)U_{12}^{\dagger}(\gamma)U_{23}^{\dagger}(\gamma)U_{24}^{\dagger}(\gamma) | +^3 \rangle$$

IN WHICH $| +^n \rangle = \sum_{x\in\{0,1\}^n} \frac{1}{\sqrt{2n}} |x\rangle$ PREPARES FOR AN EQUAL SUPERPOSITION STATED FOLLOWED BY THE PARAMETRISED UNITARY OPERATIONS.



» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

» CLASSICAL OPTIMIZATION

WE MAKE THE GRAPH COINCIDE WITH THE CONNECTIVITY OF OUR VALUE STREAM NETWORK, THEN THE COST FUNCTION COINCIDES WITH THE HAMILTONIAN USED TO GENERATE THE STATE.

IN OUR NETWORK WE HAVE TWO TYPES OF EDGES: THOSE CONNECTED WITH DEGREE ONE (A) AND THOSE CONNECTED WITH DEGREE THREE (B). THIS YIELDS TWO ENCODING OF THE OPTIMIZATION FUNCTION BETWEEN THE NODES.

FOR (A) EDGES, NODE (1):

$$2f_A = 1 - \langle +^1 | U_{01}(\gamma)U_{12}(\gamma)U_{13}(\gamma)X_0(\beta)X_1(\beta)Z_0Z_1X_1^\dagger(\beta)X_0^\dagger(\beta)U_{01}^\dagger(\gamma)U_{12}^\dagger(\gamma)U_{13}^\dagger(\gamma) | +^1 \rangle$$

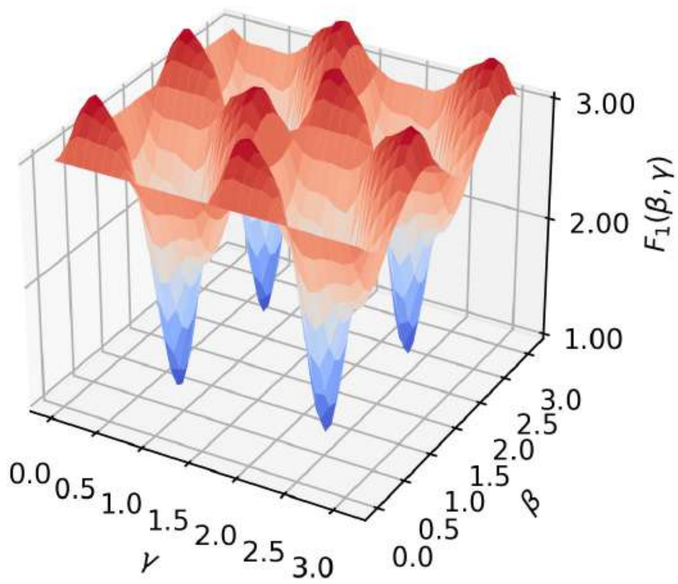
AND FOR (B) EDGES, EXAMPLE (1) AND (2):

$$2f_B = 1 - \langle +^3 | U_{21}(\gamma)U_{24}(\gamma)U_{23}(\gamma)X_1(\beta)X_2(\beta)Z_1Z_2X_1^\dagger(\beta)X_2^\dagger(\beta)(\gamma)U_{12}^\dagger(\gamma)U_{23}^\dagger(\gamma)U_{24}^\dagger(\gamma) | +^3 \rangle$$

IN WHICH $| +^n \rangle = \sum_{x\in\{0,1\}^n} \frac{1}{\sqrt{2^n}} |x\rangle$ PREPARES FOR AN EQUAL SUPERPOSITION STATED FOLLOWED BY THE PARAMETRISED UNITARY OPERATIONS.

THIS YIELDS THE ANALYTIC SOLUTION SHOWN IN THE IMAGE:

$F_1(\beta,\gamma) = 2f_A(\beta,\gamma) + 11f_B(\beta,\gamma)$ BECAUSE THERE ARE 2 EDGES TYPE (A) AND 11 TYPE (B).



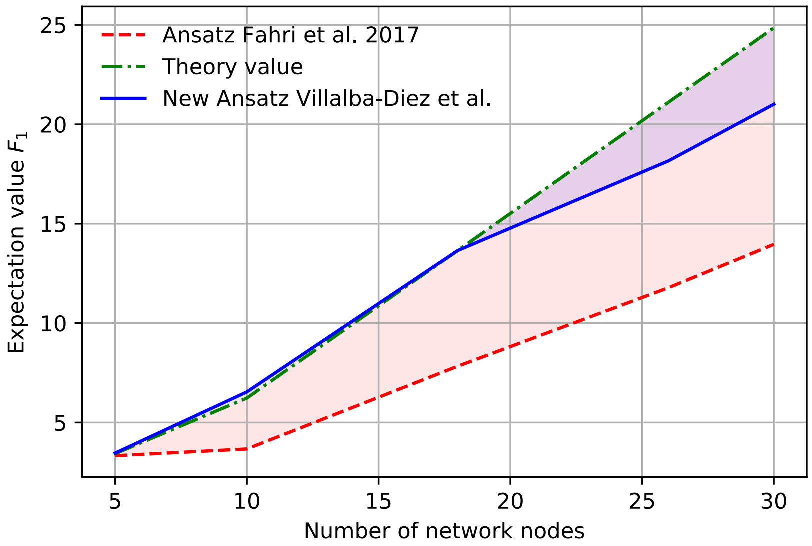
ANALYTIC SOLUTION

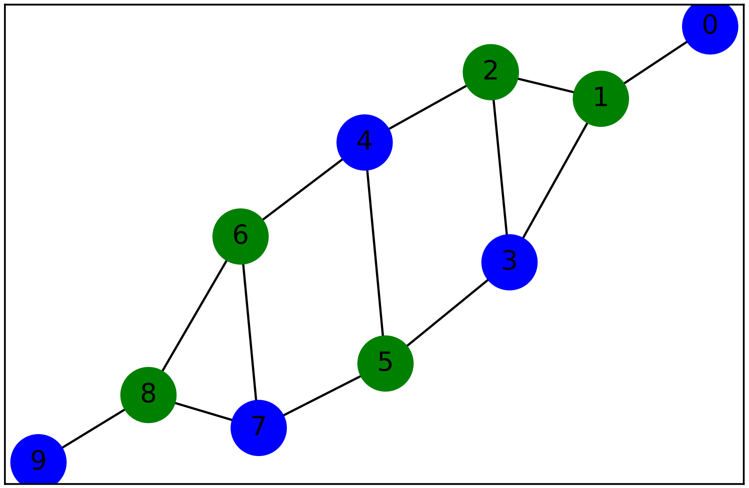
» QUANTUM APPROXIMATE OPTIMIZATION ALGORITHM (QAOA)

» RESULTS

THE RESULTS CONFIRM OUR EXPECTATIONS AND OUR PROPOSED QAOA ALGORITHM PREDICTS THE ANALYTICAL RESULTS BETTER FOR A SHALLOW QUANTUM CIRCUIT.

THE FIGURE SHOWS THE THEORETICAL VAUE (GREEN), THE VALUE GIVEN BY THE CLASSICAL SOLUTION (RED) AND THE VALUE GIVEN BY OUR SOLUTION (BLUE). OUR SOLUTIONS OUTPERFORMS STATE OF THE ART QAOA.





THE GRAPH IS SUCESSFULLY PARTITIONED IN TWO CLASSES AS INDICATED BY THE COLOR CODING IN THE FIGURE.

PAPER PUBLISHED

Villalba-Diez, J., González-Marcos, A., Ordieres-Meré, J. (2022). Improvement of Quantum Approximate Optimization Algorithm for Max–Cut Problems. Sensors, 22(1). https://doi.org/10.3390/s22010244

» Contents_

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

C3 THE ALIGNMENT PROBABILITY OF A BOSS CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

C3 THE ALIGNMENT PROBABILITY OF AN UPPER NODE CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

C4 INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE SUBORDINATE NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

C3 THE ALIGNMENT PROBABILITY OF AN UPPER NODE CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

C4 INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE SUBORDINATE NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.

C5 THE ADDITION OF A NEW NODE REPORTING TO THE SUPERIOR NODE ADDS STABILITY TO THE SET.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

C3 THE ALIGNMENT PROBABILITY OF AN UPPER NODE CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

C4 INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE SUBORDINATE NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.

C5 THE ADDITION OF A NEW NODE REPORTING TO THE SUPERIOR NODE ADDS STABILITY TO THE SET.

C6 IF UPPER NODES DO NOT COMMUNICATE WITH EACH OTHER, THE SUBORDINATES WILL NEVER BE ABLE TO SERVE THEM IN SUCH A WAY THAT BOTH ARE SIMULTANEOUSLY IN ALIGNMENT. IT DOESN'T MATTER WHAT SHE DOES.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

C3 THE ALIGNMENT PROBABILITY OF AN UPPER NODE CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

C4 INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE SUBORDINATE NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.

C5 THE ADDITION OF A NEW NODE REPORTING TO THE SUPERIOR NODE ADDS STABILITY TO THE SET.

C6 IF UPPER NODES DO NOT COMMUNICATE WITH EACH OTHER, THE SUBORDINATES WILL NEVER BE ABLE TO SERVE THEM IN SUCH A WAY THAT BOTH ARE SIMULTANEOUSLY IN ALIGNMENT. IT DOESN'T MATTER WHAT SHE DOES.

C7 IN CASE UPPER NODES DO NOT COMMUNICATE BETWEEN THEM, THEIR JOINT ALIGNMENT IS ALWAYS AROUND THE POINT OF EQUILIBRIUM, WHICH IS THE PROBABILITY GIVEN BY THE CHANCE.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

C1 THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.

C2 TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.

C3 THE ALIGNMENT PROBABILITY OF AN UPPER NODE CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.

C4 INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE SUBORDINATE NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.

C5 THE ADDITION OF A NEW NODE REPORTING TO THE SUPERIOR NODE ADDS STABILITY TO THE SET.

C6 IF UPPER NODES DO NOT COMMUNICATE WITH EACH OTHER, THE SUBORDINATES WILL NEVER BE ABLE TO SERVE THEM IN SUCH A WAY THAT BOTH ARE SIMULTANEOUSLY IN ALIGNMENT. IT DOESN'T MATTER WHAT SHE DOES.

C7 IN CASE UPPER NODES DO NOT COMMUNICATE BETWEEN THEM, THEIR JOINT ALIGNMENT IS ALWAYS AROUND THE POINT OF EQUILIBRIUM, WHICH IS THE PROBABILITY GIVEN BY THE CHANCE.

C8 ONLY A STRONG ALIGNMENT PROBABILITY AT LOWER REPORTING LEVELS ENABLES ALIGNMENT AT HIGHER LEVELS. WE HAVE SHOWN THAT THIS THRESHOLD IS SET BY 90%.

» CONCLUSIONS, FINAL REMARKS (CF)

» CONCLUSIONS

- **C1** THIS WORK HAS SHOWN THAT QUANTUM COMPUTING APPLIED TO THE STRATEGIC ORGANIZATIONAL DESIGN CAN HELP TO UNDERSTAND AND QUANTIFY COMPLEX PHENOMENA ASSOCIATED WITH DECISION MAKING IN PROBABILISTIC LOW CERTAINTY ENVIRONMENTS.
- **C2** TO ADD HIERARCHY LEVELS TO STRATEGIC DESIGN MODELS OF ORGANIZATIONS, IT IS NECESSARY TO ENSURE THE ASYMPTOTIC STABILITY OF THE LOWER AGENTS BEFORE IMPLEMENTING A STABLE AGGREGATION.
- **C3** THE ALIGNMENT PROBABILITY OF AN UPPER NODE CAN NEVER BE GREATER THAN THE AVERAGE OF THE ALIGNMENT PROBABILITY OF HIS SUBORDINATES.
- **C4** INCREASING THE AVERAGE PROBABILITY OF ALIGNMENT OF THE SUBORDINATE NODES, INCREASES THE PROBABILITY OF ALIGNMENT OF THE UPPER NODE.
- **C5** THE ADDITION OF A NEW NODE REPORTING TO THE SUPERIOR NODE ADDS STABILITY TO THE SET.
- **C6** IF UPPER NODES DO NOT COMMUNICATE WITH EACH OTHER, THE SUBORDINATES WILL NEVER BE ABLE TO SERVE THEM IN SUCH A WAY THAT BOTH ARE SIMULTANEOUSLY IN ALIGNMENT. IT DOESN'T MATTER WHAT SHE DOES.
- **C7** IN CASE UPPER NODES DO NOT COMMUNICATE BETWEEN THEM, THEIR JOINT ALIGNMENT IS ALWAYS AROUND THE POINT OF EQUILIBRIUM, WHICH IS THE PROBABILITY GIVEN BY THE CHANCE.
- **C8** ONLY A STRONG ALIGNMENT PROBABILITY AT LOWER REPORTING LEVELS ENABLES ALIGNMENT AT HIGHER LEVELS. WE HAVE SHOWN THAT THIS THRESHOLD IS SET BY 90%.
- **C9** WE HAVE SUCCESSFULLY TESTED THE INTEGRATION OF A DIGITAL QUANTUM TWIN BY MEANS OF QUANTUM SIMULATIONS ON A CONVENTIONAL MACHINE TO ENABLE A VISUALIZATION OF ITS SYSTEMIC STATE IN AN INDUSTRY 4.0 ENVIRONMENT.

» CONCLUSIONS, FINAL REMARKS (CF)

» FINAL REMARKS

DUE TO THE RESTRICTED AVAILABILITY OF REAL QUANTUM MACHINES, THIS RESEARCH HAS MADE EXTENSIVE USE OF QUANTUM CIRCUIT SIMULATIONS ON CLASSICAL COMPUTERS. IN ORDER TO MINIMIZE THE EFFECT OF THIS FACT, WE HAVE EXECUTED REPEATED SIMULATIONS OF THE CIRCUITS ON THE QISKIT SIMULATOR. WE'VE SET THE NUMBER OF REPEATS OF THE CIRCUIT TO BE 1024, WHICH IS THE DEFAULT.

THE LACK OF QUANTUM KNOWLEDGE BY THE ORGANIZATIONAL LEADERS MIGHT SET A POTENTIAL HIGH THRESHOLD ON ACCEPTANCE OF THE PRESENTED QSOD CONCEPTS.

» CONCLUSIONS, FINAL REMARKS (CF)

» FINAL REMARKS

DUE TO THE RESTRICTED AVAILABILITY OF REAL QUANTUM MACHINES, THIS RESEARCH HAS MADE EXTENSIVE USE OF QUANTUM CIRCUIT SIMULATIONS ON CLASSICAL COMPUTERS. IN ORDER TO MINIMIZE THE EFFECT OF THIS FACT, WE HAVE EXECUTED REPEATED SIMULATIONS OF THE CIRCUITS ON THE QISKIT SIMULATOR. WE'VE SET THE NUMBER OF REPEATS OF THE CIRCUIT TO BE 1024, WHICH IS THE DEFAULT.

THE LACK OF QUANTUM KNOWLEDGE BY THE ORGANIZATIONAL LEADERS MIGHT SET A POTENTIAL HIGH THRESHOLD ON ACCEPTANCE OF THE PRESENTED QSOD CONCEPTS.

» This thesis is based upon following publications_

2022

- **Villalba-Diez, J., González-Marcos, A., Ordieres-Meré, J. (2022).** Improvement of Quantum Approximate Optimization Algorithm for Max–Cut Problems. Sensors, 22(1). https://doi.org/10.3390/s22010244

2021

- **Villalba-Diez, J., Gutierrez, M., Grijalvo Martín, M., Sterkenburgh, T., Losada, J. C., & Benito, R. M. (2021).** Quantum JIDOKA. Integration of Quantum Simulation on a CNC Machine for In–Process Control Visualization. Sensors, 21(15). https://doi.org/10.3390/s21155031
- **Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D.** (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426
- **Villalba-Diez, J., Losada, J. C., Benito, R. M., & González-Marcos, A.** (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: One Reports to Two. Entropy, 23(3). https://doi.org/10.3390/e23030374

2020

- **Villalba-Diez, J., Benito, R. M., & Losada, J. C.** (2020). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of Two Qubits: One Reports to One. *Sensors, 20(23), 6977*. https://doi.org/10.3390/s20236977
- **Villalba-Diez, J., & Zheng, X. (2020).** Quantum Strategic Organizational Design: Alignment in Industry 4.0 Complex-Networked Cyber-Physical Lean Management Systems. *Sensors, 20(20), 5856*. https://doi.org/10.3390/s20205856

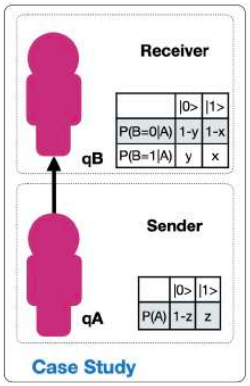
» Additional slides_

O3

» QSOD CASES

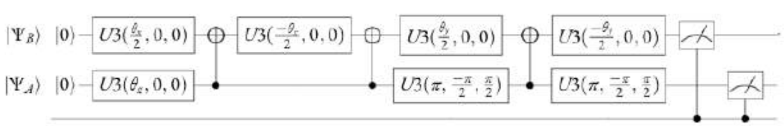
» THE CASE OF TWO QUBITS: ONE REPORTS TO ONE

1

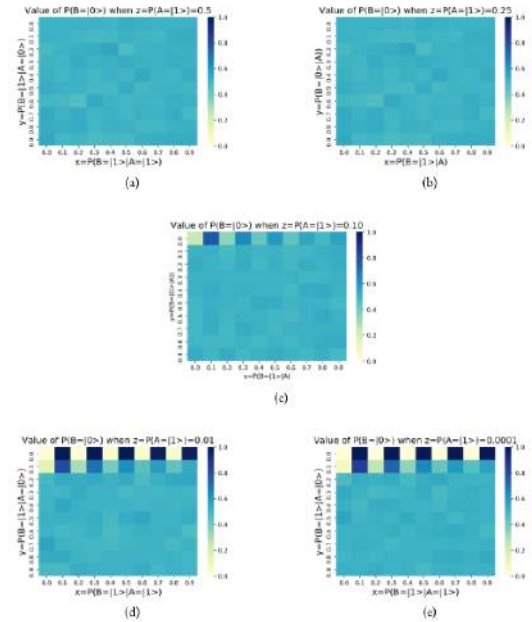


Our goal is to determine the probability of alignment of agent **B**, P(B=|0>), as a function of the alignment probability of agent **A**, given by P(A=|0>=z, and the conditional alignment probabilities between agents **A** and **B**, given by x=P(B=|1>|A=|0>) in [0,1] and y=P(B=|1>|A=|1>) in [0,1].

In the case study we proceed to simulate a total of 500 configurations of the circuit show. We intend to find the values of parameters (x, y, z) in [0,1] that maximize the probability of alignment of the agent **B**, P(B=|0>). To do this, the parameters (x, y) in [0,1] are varied in 10% incremental intervals in order to make a uniform mapping and create a proper display of the results. However, not all z in [0,1] values are relevant. We are interested in values of z>0.5, since they indicate that the alignment probability of the agent **A**, P(A=|1>), is greater than 50%.

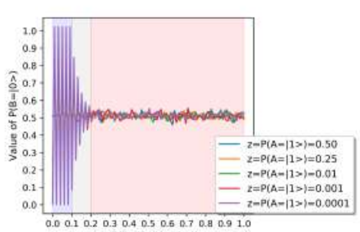


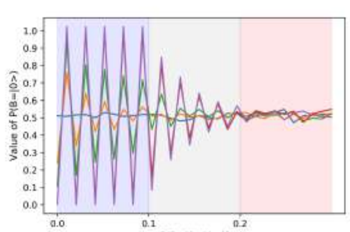
2



Results obtained for P(B=|0>) for different values of the no--alignment probability of agent **A**, z=P(A=|1>). (a) P(A=|1>)=0.50 (b) P(A=|1>)=0.25 (c) P(A=|1>)=0.1 (d) P(A=|1>)=0.01 (e) P(A=|1>)=0.0001

3





4

R1.1. In general we can say that the probability of alignment of agent **B** oscillates consistently around the value 0.5 as a harmonic underdamped oscillator for different values of z=P(A=|1>) which is the equilibrium state of the system.

R1.2. At the scale represented of in Figure 4 we observe that the angular frequency of this oscillator changes for different values of y and therefore we can separate the behavior of the function in three different regions, marked.

R1.6. The behavior of this system is fractal. Fractality in this QSOD context allows for a quantification of the organizational complex dynamics and its pervasive effect offers robustness and resilience to the two qubit interaction.

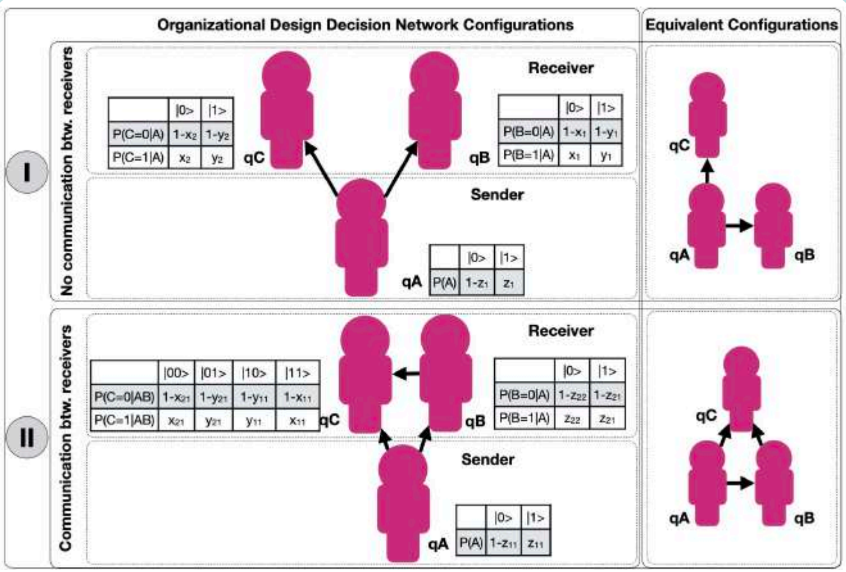
PAPER PUBLISHED

- **Villalba-Diez, J., Benito, R. M., & Losada, J. C.** (2020). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of Two Qubits: One Reports to One. *Sensors, 20(23), 6977*. https://doi.org/10.3390/s20236977

O3

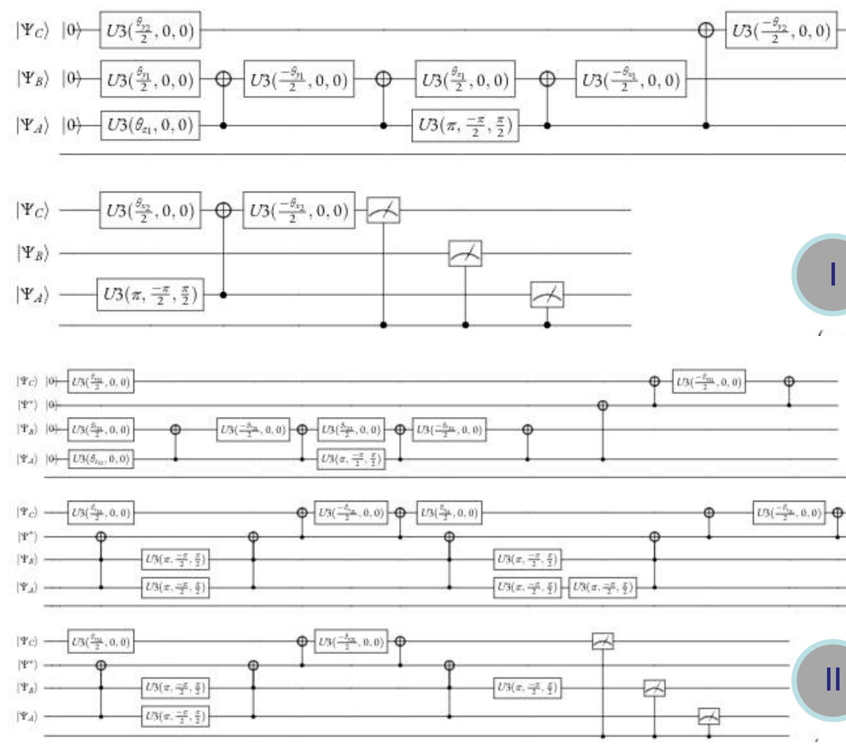
» QSOD CASES

» THE CASE OF THREE QUBITS: ONE REPORTS TO TWO



1

Our objective is to establish the alignment probability of agents **B** and **C**, P(B=|0>) and P(C=|0>) respectively, in dependence of the alignment probability of agent \(A\) and the conditional alignment probabilities between agents **A**, **B** and **C**.



I

II

PAPER PUBLISHED

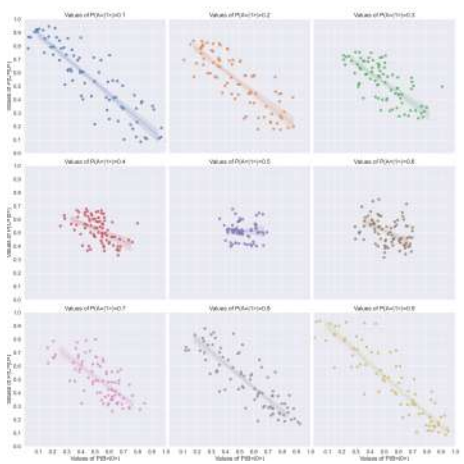
- **Villalba-Diez, J., Losada, J. C., Benito, R. M., & Schmidt, D.** (2021). Industry 4.0 Quantum Strategic Organizational Design Configurations. The Case of 3 Qubits: Two Report to One. Entropy, 23(4). https://doi.org/10.3390/e23040426

03

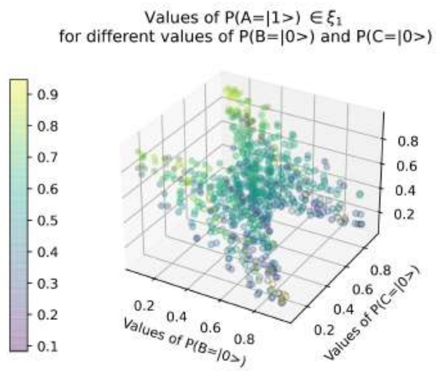
» QSOD CASES

» THE CASE OF THREE QUBITS: ONE REPORTS TO TWO

2



Correlation between P(B=|0>) and P(C=|0>) for different values of P(A=|1>) for the case of no communication between **B** and **C**.



I

Correlation between P(B=|0>) and P(C=|0>).

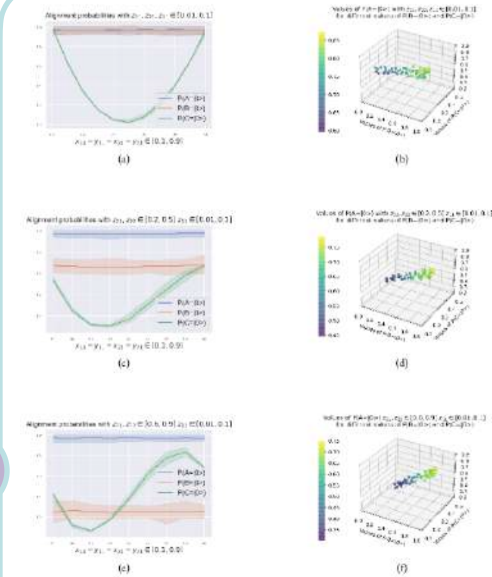
3

R3.1. Agents **B** and **C** have an antagonistic alignment probability}. The two never have a high probability of alignment simultaneously. The management conclusion derived from \textbf{R3.1} for subordinate agent \(A\) is staggering and somehow tragic: if the two bosses do not communicate with each other, \(A\) will never be able to serve them in such a way that both are simultaneously in alignment. It doesn't matter what \(A\) does.

R3.2. Agents **B** and **C** only agree by chance. In case the two superior agents do not communicate between them, their joint alignment is always around the point of equilibrium, which is the probability given by the chance. As long as the subordinate node has a higher or lower probability of alignment, their positions will be more or less differentiated.

R3.3. Quantum phase transition with 90% alignment probability of node **A.** Only a strong alignment probability at lower reporting levels enables alignment at higher levels. We have shown that this threshold is set by 90\%.

4



II

Alignment Probabilities of P(A=|0>), P(B=|0>) and P(C=|0>).

5

R3.4. When **B** and **C** are entangled, they work as one. High levels of alignment in both reporting agents **A** and **B** do not imply a high level of alignment of node **C**.

R3.5. Agents **B** and **C** interact. The interaction between the superior agents **B** and **C** becomes manifest when the alignment probability of **A** is fixed at values higher than 90%.