

Application of Quantum Simulators with Classical Architecture for Intelligent Control Problems

Olga V. Ivantsova, A. G. Reshetnikov, N. V. Ryabov, S.V. Ulyanov, P. V. Zrelov

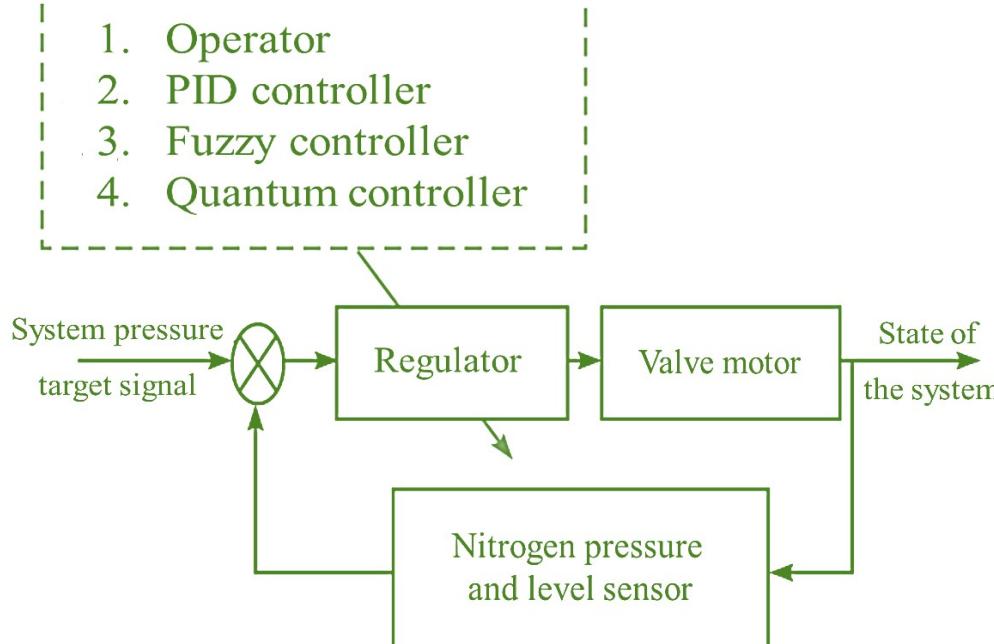
Meshcheryakov Laboratory of Information Technologies

Joint Institute for Nuclear Research



Solving intelligent control problems using soft and quantum computing

Scheme of the cooling system of a superconducting magnet



To improve reliability, it is necessary to form stable control signals with the gains of the fuzzy PID controller

QUANTUM FUZZY CONTROLLER

QUANTUM FUZZY INFERENCE

Simulation of the operation of one section of the superconducting magnet



several sections

Tools for creating and debugging quantum algorithms on classical computers

Advantages

Flexibility and scalability

Availability and low cost

Ease of debugging and testing

No dependency on physical condition

Limitations

Computational limits

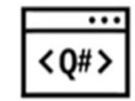
Limited accuracy and realistic modeling

Limited possibilities for modeling complex quantum effects and noise

- ✓ Multithreading.
- ✓ Distributed computing.
- ✓ Work on 2 types of classical computing architectures (CPU, GPU).
- ✓ Multiple servers or multiple GPUs on the same server.



PYQUIL



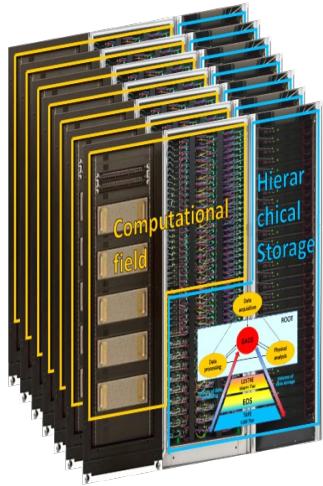
PENNYLANE



And many more...
qsim

- ⊕ Wide functionality and features.
- ⊕ Good documentation and community.
- ⊕ Integration with various frameworks and devices.
- ⊕ The possibility of hybrid classical-quantum computing.
- ⊕ ...

Supercomputer
«Govorun»



The dimension of the state vector grows exponentially with the increase in the number of qubits, therefore, due to memory limitations, the quantum circuit is limited to 38 qubits on the CPU and 31 qubits on 1 GPU and 34 qubits on 8 GPU. However, despite the CPU's ability to simulate a larger number of qubits on the existing infrastructure, the simulation speed on the GPU on all simulators is several times higher than the simulation speed on the CPU

CPU

38 qubits

GPU

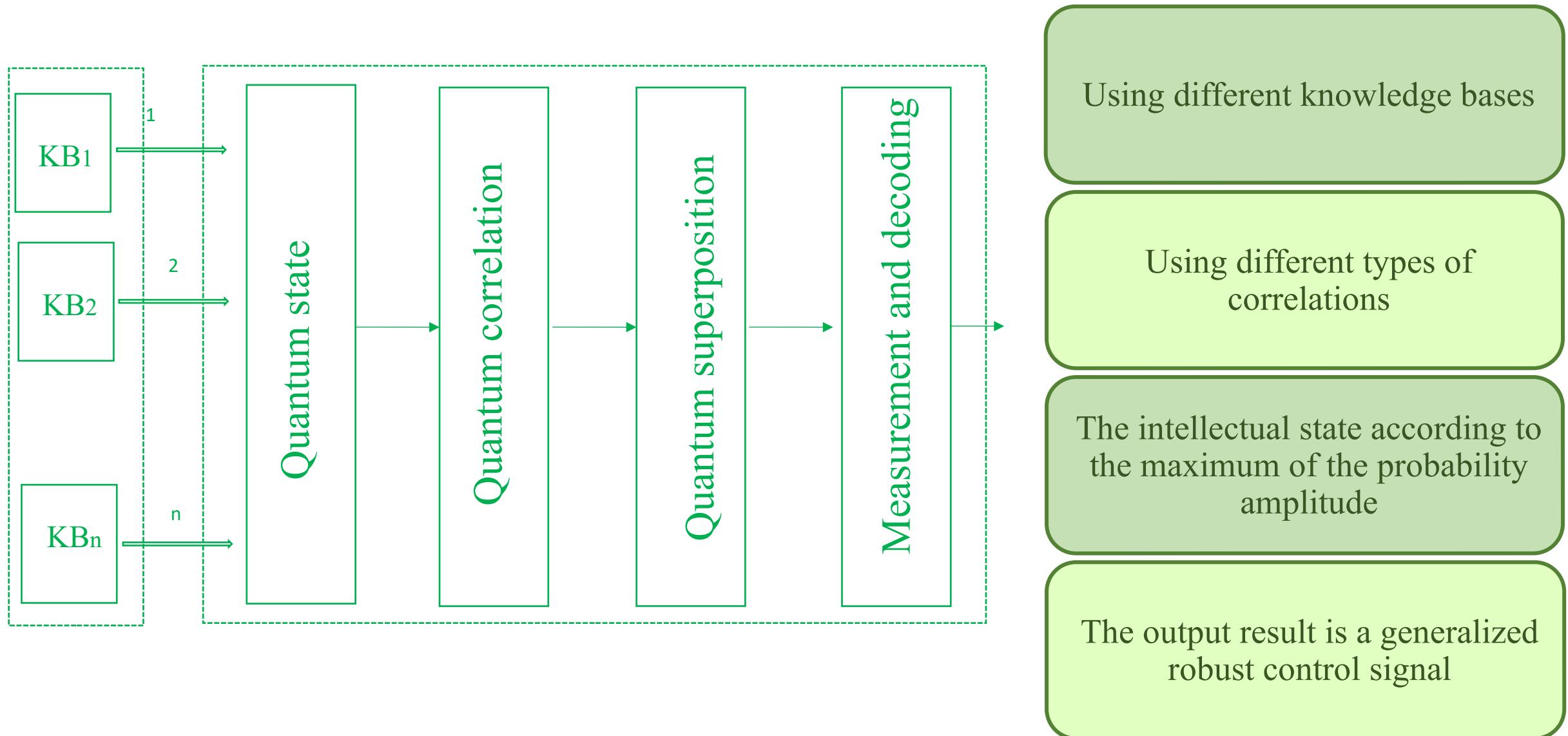
34 qubits

Multi
GPU

With an increase in the number of qubits, the speed difference becomes more noticeable with an increase in the number of GPUs (from 1.5 (1 GPU) to 3.76 times (4 GPU))

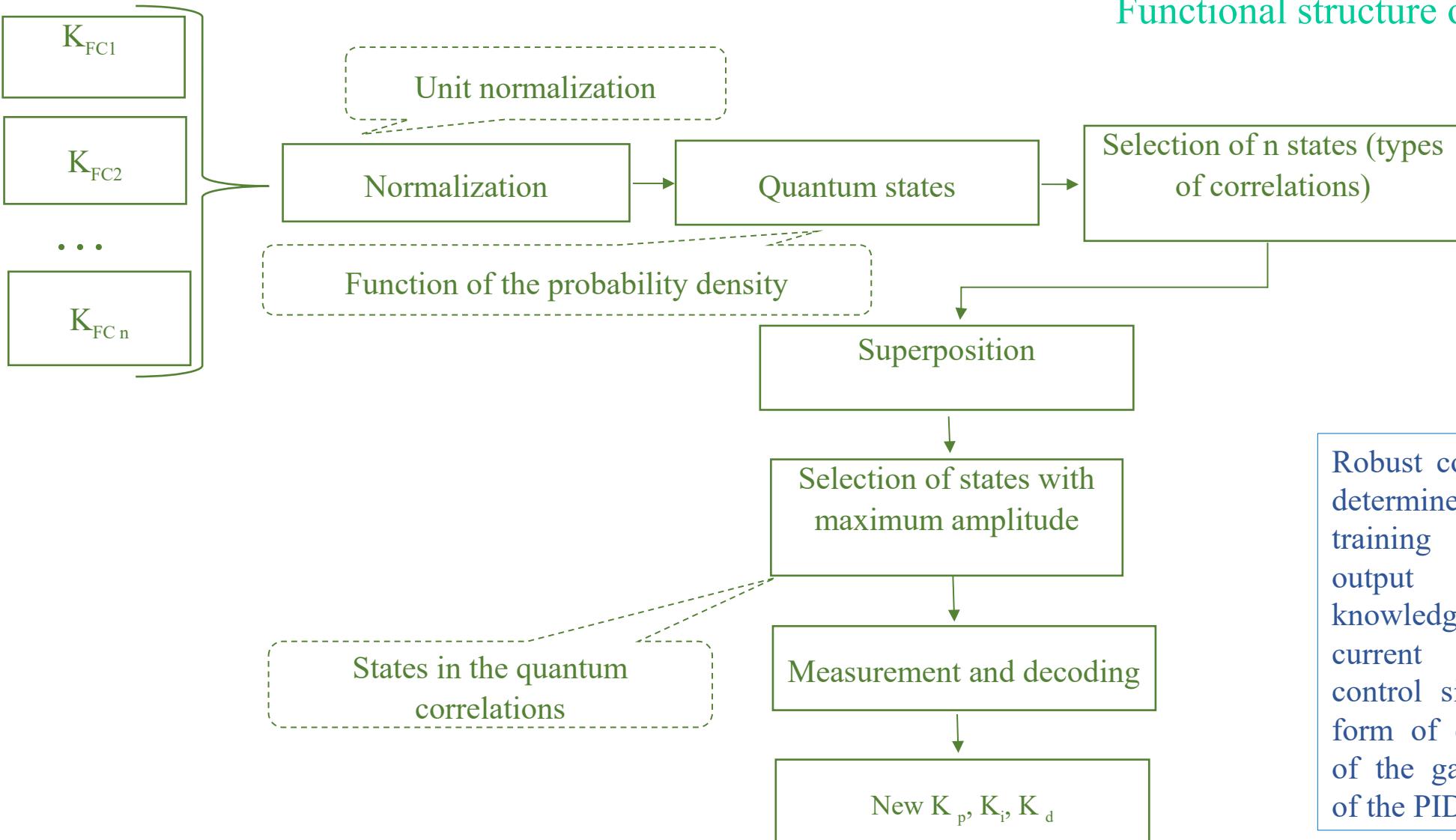
The limiting computational capabilities for the supercomputer «Govorun» are revealed by the example of modeling quantum algorithms (quantum Fourier transform, quantum phase estimation, Grover's algorithm, test synthetic algorithm, VQE) using a different class of quantum implementation schemes for the following quantum simulators: QuEST, Qiskit, CuQuantum, PennyLane.

Quantum fuzzy inference for a quantum fuzzy controller



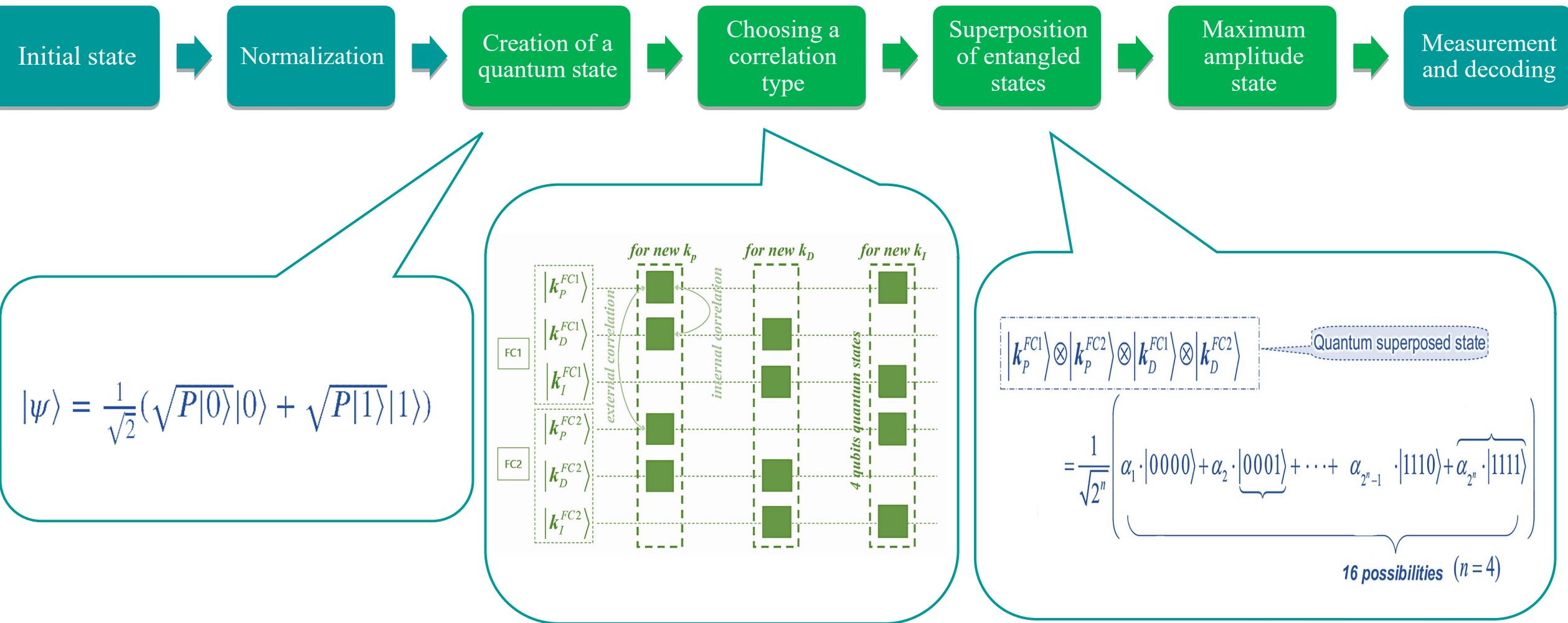
Quantum Fuzzy Inference (QFI)

Functional structure of the QFI



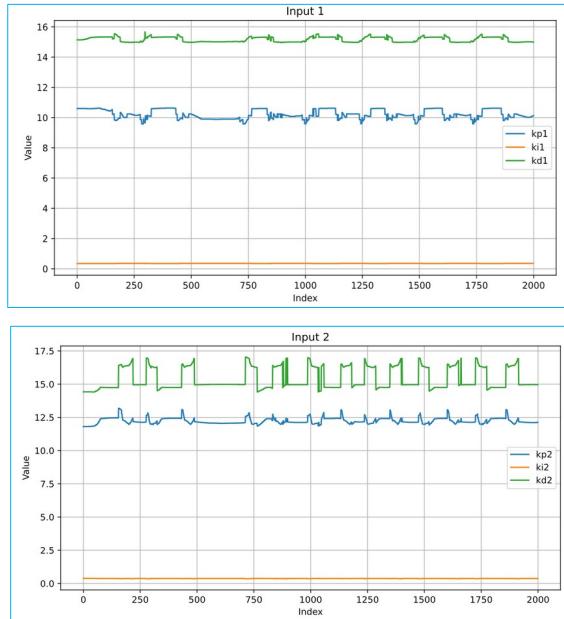
Robust control laws are determined in the training mode on the output reactions of knowledge bases to the current unforeseen control situation in the form of control signals of the gain coefficients of the PID controller.

Quantum Fuzzy Inference (Steps)

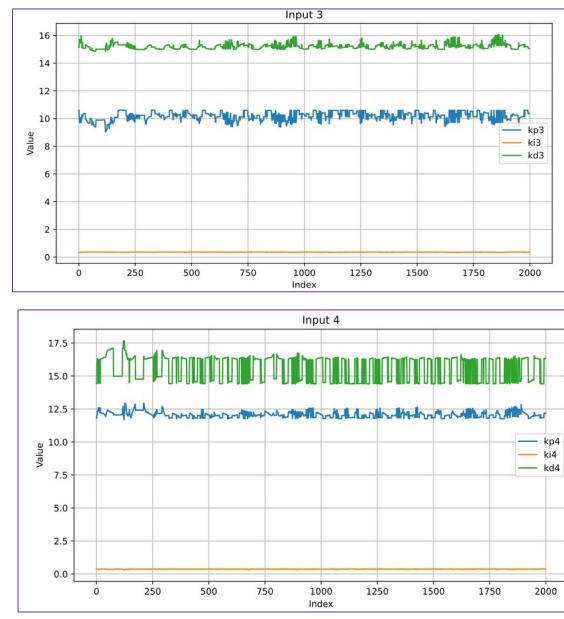


Scaling solutions

first controller



second controller



Normalization

Quantum states

Quantum correlation

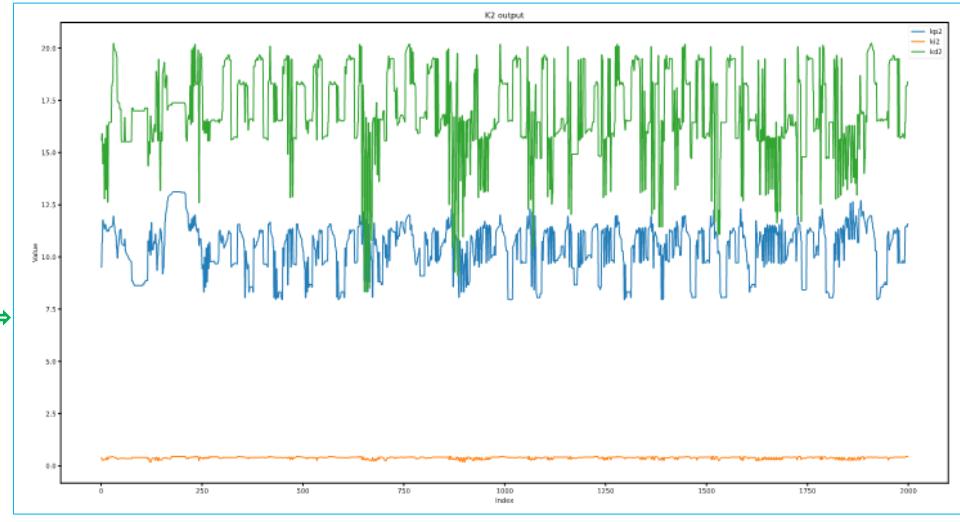
Quantum superposition

Selection of states with maximum
amplitude

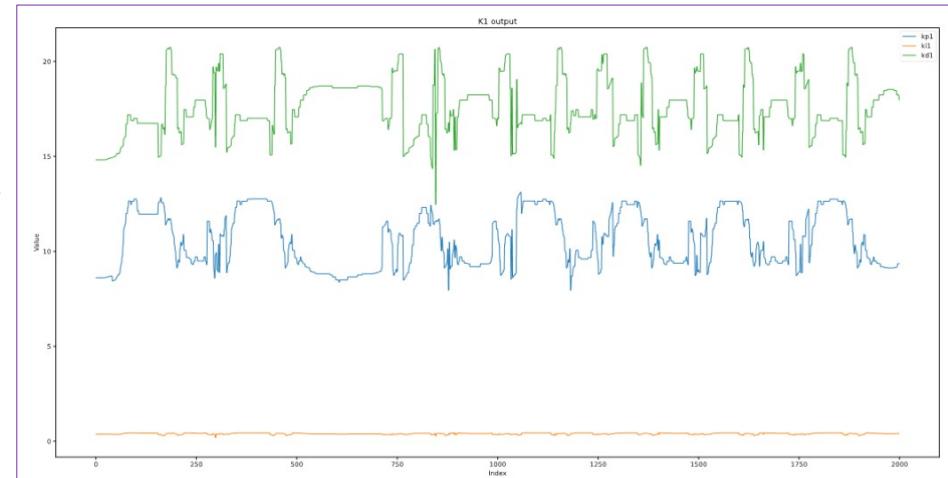
Measurement and decoding

Quantum Fuzzy Inference

Gain factors for the first controller



Gain factors for the second controller



Summary

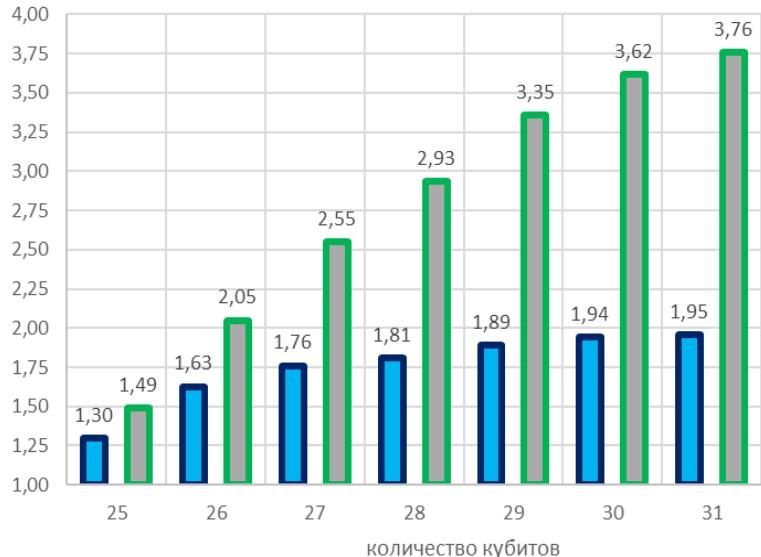
- ⊕ The capabilities of the SC «Govorun» infrastructure make it possible to simulate the operation of several sections of a superconducting magnet using quantum simulators on a classical architecture.
- ⊕ The results of searching for one sensitivity coefficient using the quantitative fuzzy inference algorithm on PennyLane for a section match the previously obtained results on another simulation within the margin of error.
- ⊕ The scaling of the problem of searching for gain coefficients using the algorithm of quantum fuzzy inference for two sections of the SP magnet has been performed.

Thank you for attention!

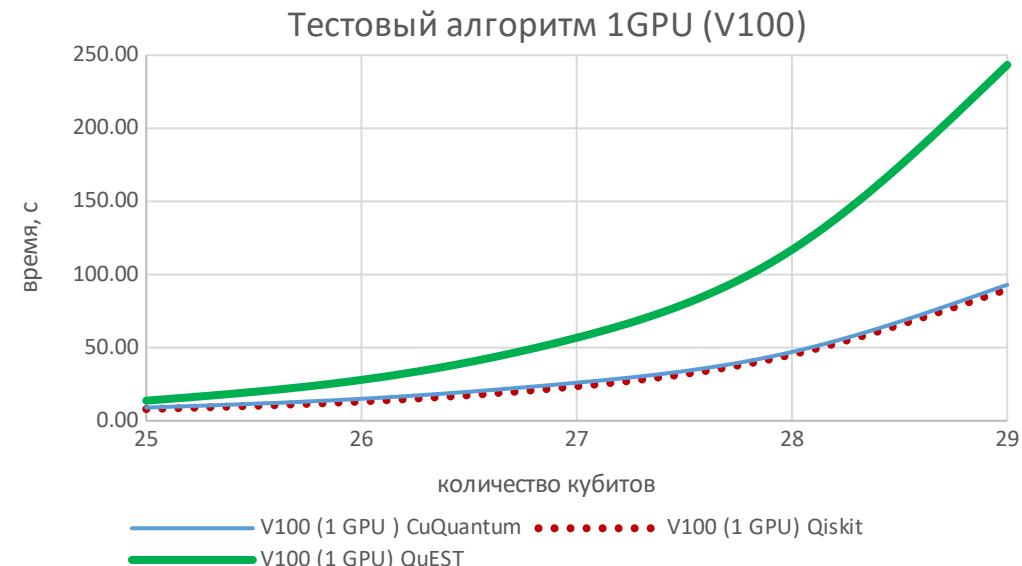


cuQuantum

Соотношение времени выполнения тестового алгоритма при разном количестве GPU (Tesla V100)



Qiskit & QuEST & cuQuantum



Кубит / симулятор	Qiskit	cuQuantum (Qsim)
29	8559 MB	4617 MB
30	16803 MB	8713 MB
31	-	16905 MB

Qiskit & cuQuantum

На одном V100 32 GB (32510) MB, для 31 кубита на Qiskit GPU нужно больше 32 GB.
cuQuantum с Qsim даёт +1 кубит.