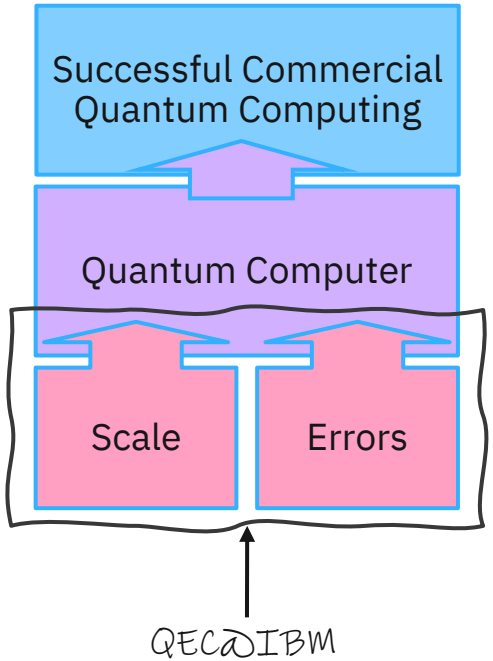
Enabling QEC@IBM Challenge – QEC Framework and GUI

Drew Vandeth, Andrew Cross
QEC@IBM

Enabling QEC Challenge



"The better the QEC, the more successful the Quantum Computing Company"

The difficulty and complexity of the QEC problem is likely too much for any one team of researchers.

How to take advantage of this state?

- Efforts towards QEC technologies will significantly increase as the number of physical qubits increases
- Competition for QEC people will increase
- Both secrecy within and cooperation amongst competing groups will be necessary in order to advance quickly

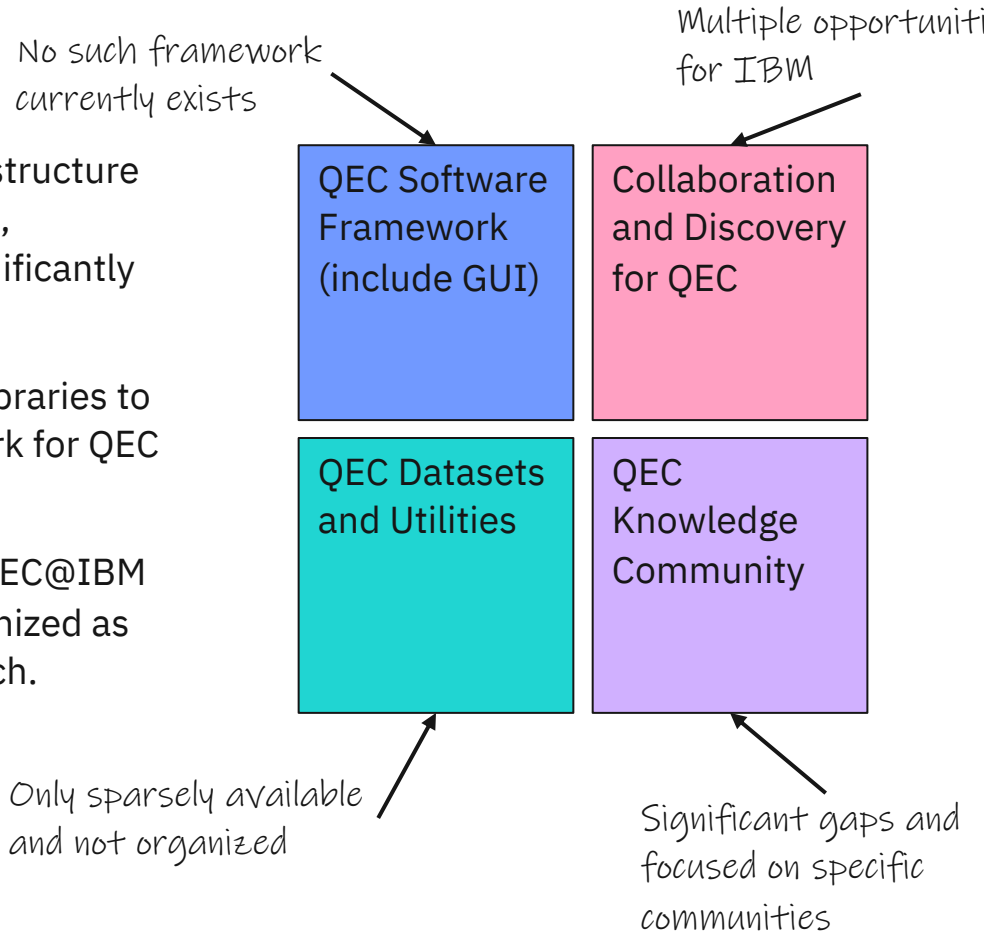
Problems to Consider

- How to attract and maintain the best QEC researchers?
- How to share with competitors to advance QEC technologies quickly enough while maintaining significant commercial lead on our competitors?
- How to obtain maximal knowledge of the QEC research community and have a significant degree of passive control?

- How to accelerate QEC research with fixed resources?
- How to accelerate the transfer of QEC research technologies into experimental and commercial environments?
- How to make Qiskit the primary tool for the QEC community?

Approach

- Provide services, capabilities, and infrastructure to enable people to learn, communicate, experiment, and research QEC with significantly less effort.
- Enable Qiskit and associated external libraries to become the de facto software framework for QEC worldwide.
- Significantly raise the global profile of QEC@IBM with the goal of having IBM being recognized as the leading organization for QEC research.

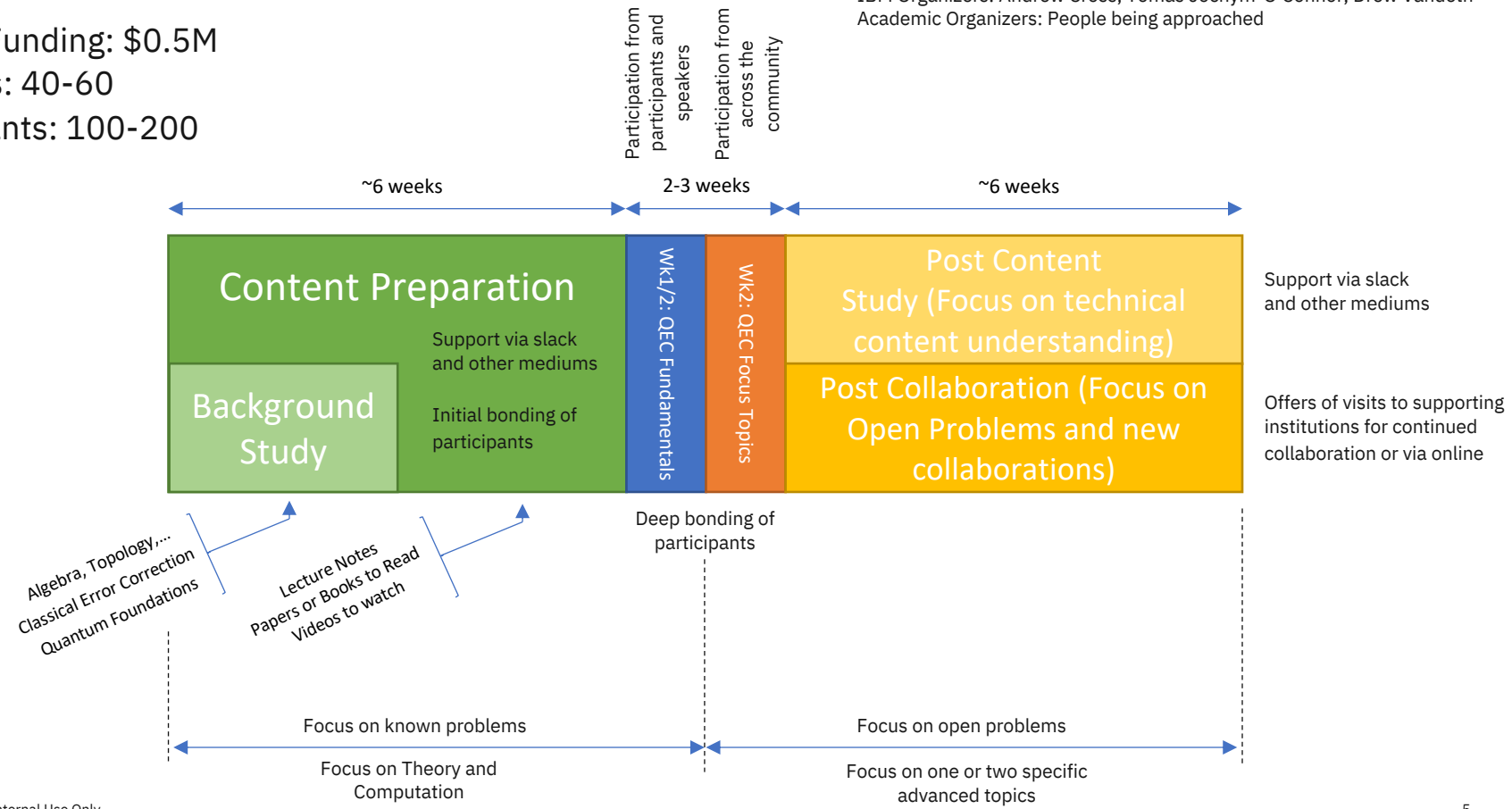


FT QEC Summer School

IBM **Quantum**

IBM Organizers: Andrew Cross, Tomas Jochym-O'Connor, Drew Vandeth
Academic Organizers: People being approached

Currently Funding: $0.5M
Students: 40-60
Participants: 100-200



FT QEC Summer School

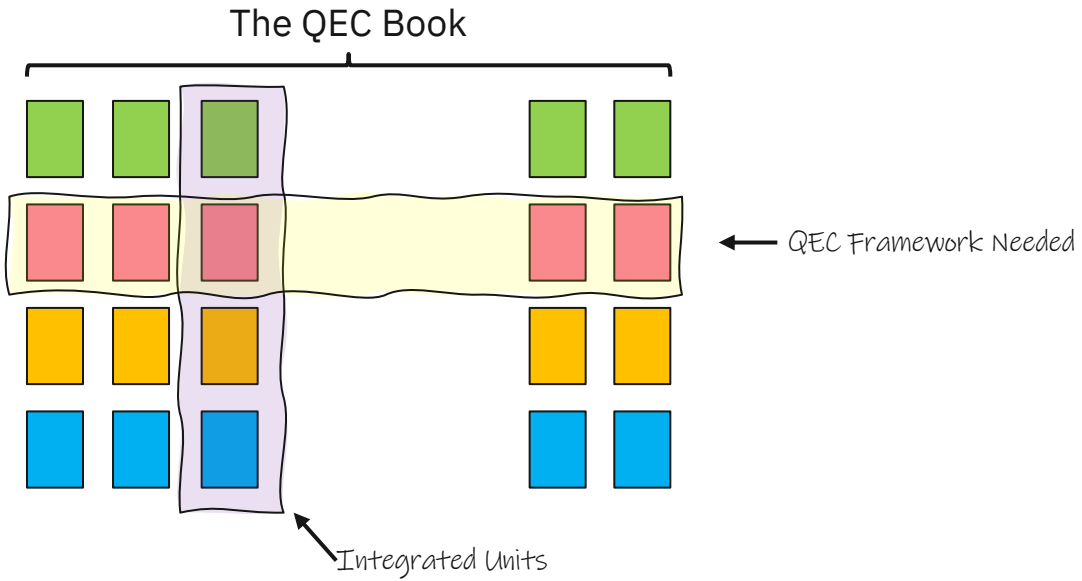
IBM **Quantum**

Lecture Chapters

Qiskit Chapters

Question Chapters

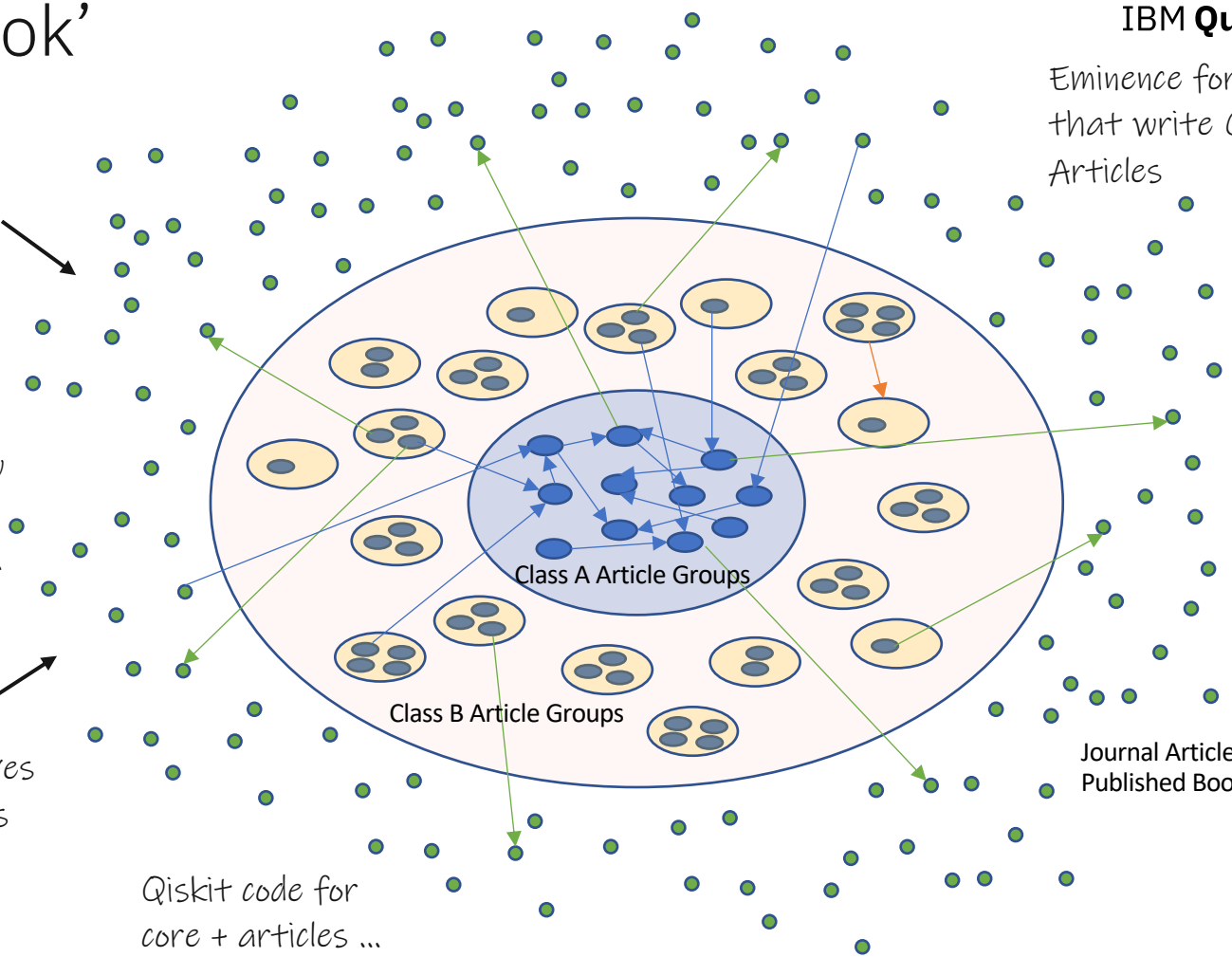
Video Chapters



‘The QEC Book’

Hybrid between an ‘author ownership’ and ‘no author’ approach

Eminence for those that write Class A Articles



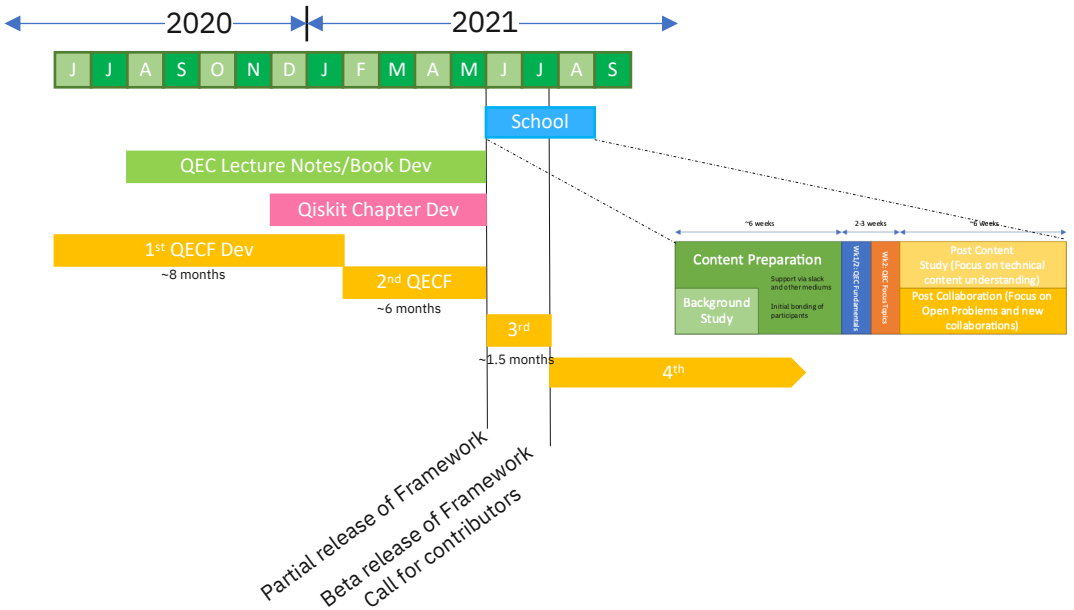
If successful could grow to the larger field of quantum computation …

Dynamic, written from multiple perspectives and multiple backgrounds

Qiskit code for core + articles …

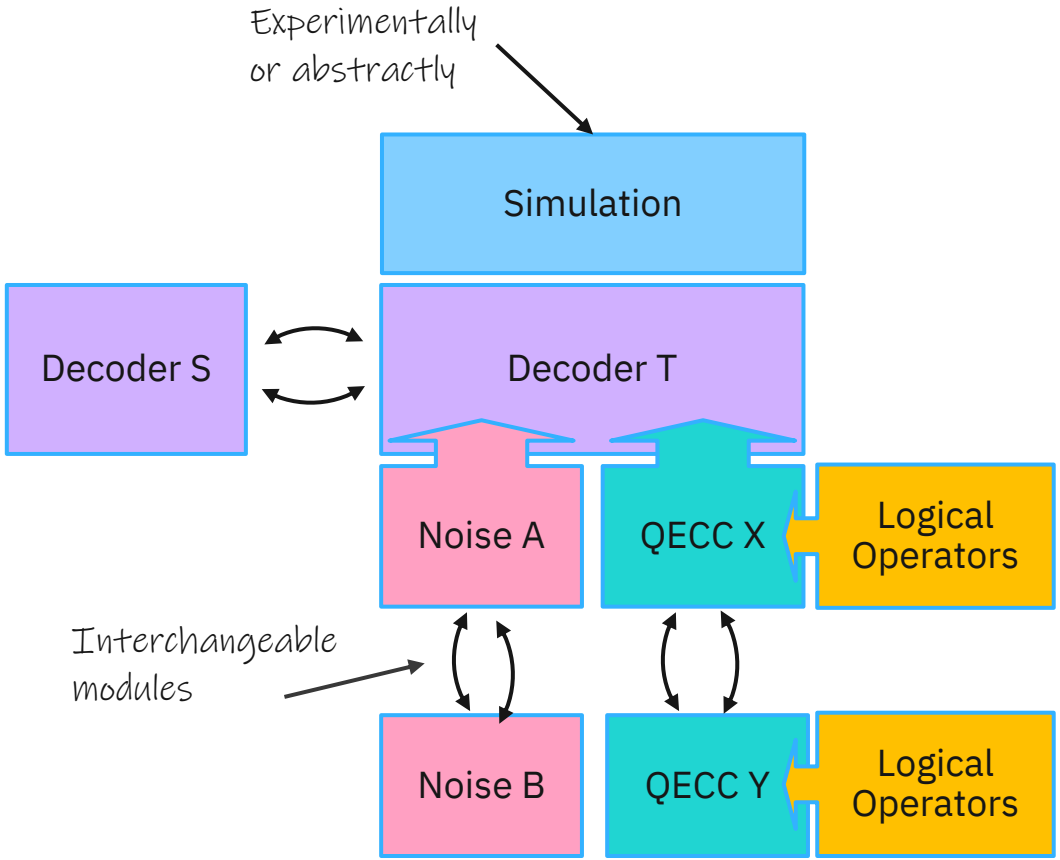
Schedule (partial):

IBM **Quantum**



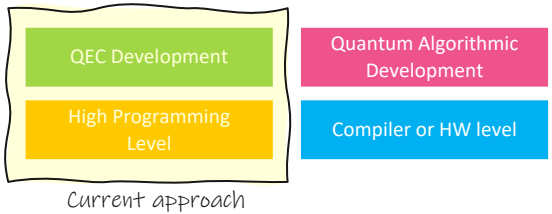
QEC Software Framework

- Our goal should be to provide a software framework for QEC which is as frictionless to the user as possible.
- The QEC framework functionally should exist beyond the Qiskit, Python and C/C++ framework.
- Three basic considerations are
  1) speed and ease of development;
  2) scale of computations; and
  3) speed of computations.
- Ability to experiment with new ideas quickly
- 'Quickly' reproduce published results
- Interacts with common systems – MatLab, GAP, …



QEC Software Framework

- Viewpoints:



- Streams:
  - Core Framework (CLI) – Python
  - Core Framework (CLI) – C++
  - GUI Framework – 2D
  - GUI Framework – 3D

- Original Approach:
  - Python for representations
  - C++ for computations
  - Initial 3 month with interns to produce a prototype framework. Then pull in larger team to build the actual framework
  - **Focus on subsystem codes**
- Issues:
  - High profile and expected success of school means that high standard for initial beta release.
  - Expected timeline shorter than originally thought
  - Workload for robust general code extensive (code +doc)

Key Areas of Discussion

- Data Representation
- Object Interfaces
- Distribution problems
- Architecture, Syntax and Qiskit integration
- (Efficient) Logical Operations
  - Lattice Surgery
  - Code Deformation
  - **Gauge Fixing**
  - (Braiding)
- Error Analysis, Propagation, …

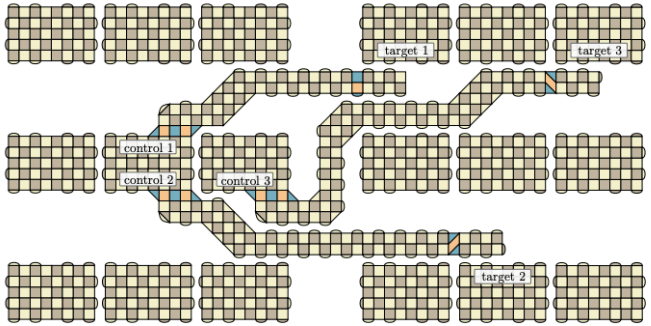


Figure 8: Example of a two-dimensional arrangement of surface code qubits, where qubits are grouped in blocks of six. The long ancilla qubits can be used for three simultaneous long-range CNOT gates.

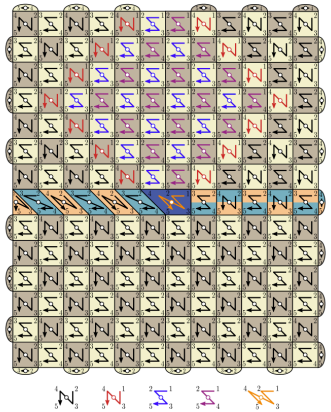


Figure 16: Possible ordering of two-qubit gates that fulfills the three conditions shown in Fig. 15. This stabilizer configuration is the most general, as it involves bulk stabilizers, a dislocation line, and a twist defect. It corresponds to a twist-based lattice surgery between a double-sided qubit and a standard rectangular qubit.

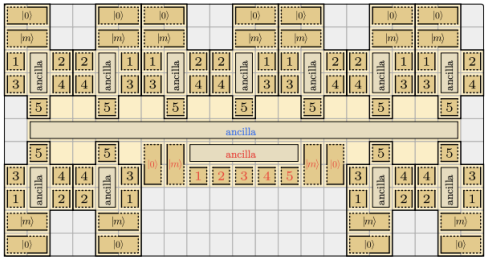
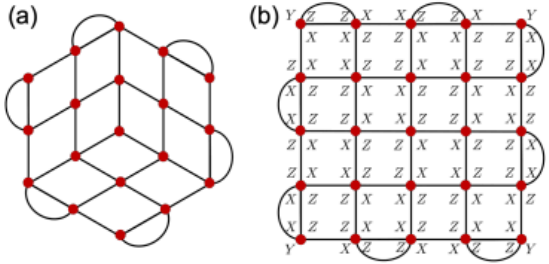


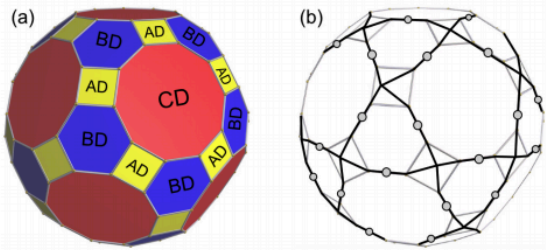
Figure 19: 176-tile block that can be used for 225-to-1 distillation. The qubits highlighted in red are used for the second level of the distillation protocol. The blue ancilla is used to move level-1 magic states into the two $|m\rangle$-$|0\rangle$ blocks of the level-2 distillation.

GUI

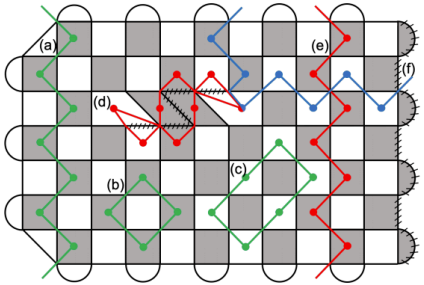
2D Codes



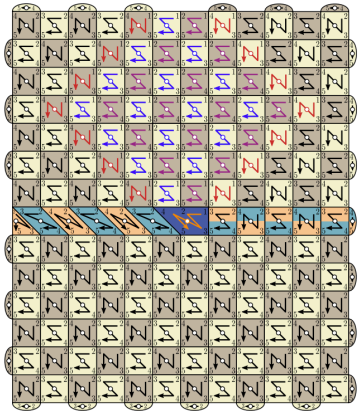
3D Codes



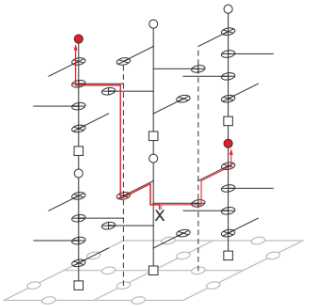
Logical Operators



Scheduling



Error Propagation



Error Analysis