# Introduction to Quantum Programming and Semantics

## Revision

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# Programming, Semantics

- Layers of abstraction, intermediate representations
- **Syntax vs semantics**
- Denotational, operational
- Need model with composition, tensor, entanglement

# Circuits, OpenQASM/Qiskit

- **Circuits vs matrices**
- Universality
- **Controlled gates**
- **Oracles, Bennett's trick**
- Conditionals, loops, subroutines
- **Variables / routing**

# Graphical calculus

- **(De)constructing string diagrams**
- **Isotopy**
- States, effects, scalars

# Entanglement

- **Bending wires**
- **Map-state duality**
- **Transposition, adjoint**
- **Trace, dimension**
- Tensor networks, feedback

# Classical data

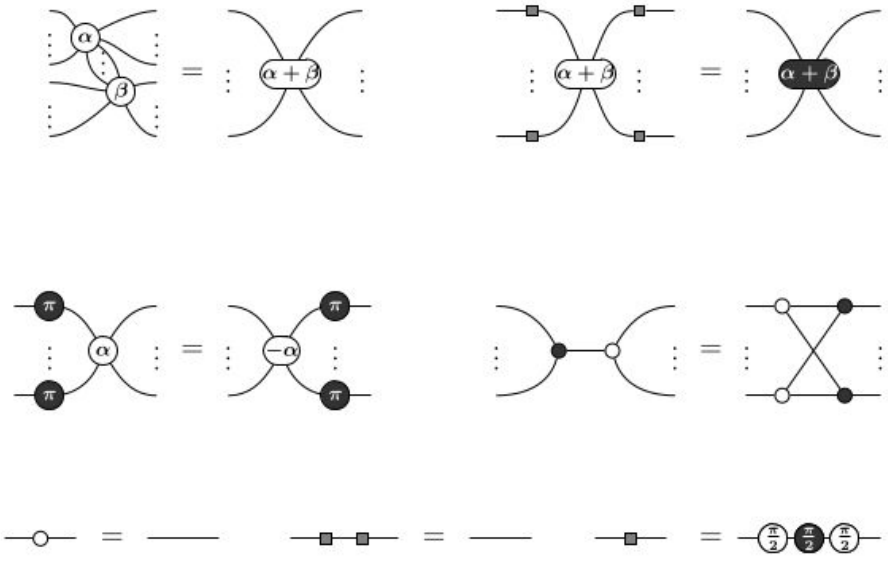
- Orthonormal bases
- Copying machines
- No-cloning, no-deleting
- **Frobenius rule, spider theorem**
- **Phase group**

# Complementarity

- Mutually unbiased bases
- Complementary classical structures
- **Strong complementarity, bialgebra rule**
- **Qubit gates**

# ZX calculus, PyZX

- **Rules cheatsheet**
- **Standard matrix semantics**
- Soundness
- Completeness
- (Approximate) universality



# Measurement, Q#

- (Mixed states, channels, measurement)
  **Thick vs thin wires, bit vs qbits**
  Preparation, measurement, discarding

- Q# functional/dot.net, mid-circuit measurement

# Phase-free ZX diagrams

- CNOT circuits
- **Dictionary circuits -> gates**
- **Parity functions, parity matrices**
- **Parity normal form**
- Circuit synthesis

# Clifford circuits

- Graph-like diagrams, Clifford diagrams
- **Graph states with local Clifford operations**
- **Local complementation**
- **Pivoting**
- Circuit synthesis

# Pauli gadgets

- **Definition**
- **Fusion**
- **Commutation with Cliffords**
- (Simulation)

# Quipper

- **Compile time, circuit generation time, circuit execution time**
  **Bools vs Bits**

- Functional

- **Higher-order / oracles**

# Uncomputation, Silq

- Dirty vs clean helper qubits
- QRAM model
- Type system, polymorphic measure:t->!t, mfree, qfree

# Exam:

- Answer two out of three questions
- One programming question
- One ZX question
- One foundational / graphical calculus modelling question
- If you can’t solve a subquestion, assume answer and move on.

**Good luck!**