

MRF Compiler

Converting Graphical Models to Quantum Circuits

Shyamal Suhana Chandra

MRF Compiler Project

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- **Problem:** Bridge classical probabilistic models and quantum computing
- **Solution:** Automated conversion from graphical models to quantum circuits
- **Support:** 8+ major quantum computing frameworks
- **Implementation:** High-performance C++ compiler
- **Status:** Open source, actively developed

Classical Side

- Probabilistic Graphical Models
- Bayesian Networks
- Markov Random Fields
- Inference challenges

Quantum Side

- Quantum algorithms
- Superposition & Entanglement
- Potential speedups
- Framework diversity

Challenge: Manual conversion is error-prone and time-consuming

What is MRF Compiler?

Definition

A comprehensive framework that automatically converts probabilistic graphical models (directed or undirected) into Markov Random Fields and subsequently into quantum circuit representations compatible with multiple quantum computing frameworks.

- **Input:** Text-based graphical model specification
- **Processing:** Automatic moralization, clique finding, Ising encoding
- **Output:** Framework-specific quantum circuit code

Key Features

- ① **Graph Support:** Both directed and undirected graphs
- ② **Automatic Conversion:** Moralization for directed graphs
- ③ **Clique Finding:** Efficient maximal clique identification
- ④ **Ising Encoding:** MRF to quantum Hamiltonian mapping
- ⑤ **Multi-Framework:** Export to 8+ quantum frameworks
- ⑥ **High Performance:** Optimized C++ implementation
- ⑦ **Easy Integration:** Simple command-line interface

Conversion Pipeline

- ① **Parse**: Read graphical model from input file
- ② **Moralize**: Convert directed to undirected (if needed)
- ③ **Clique Finding**: Identify maximal cliques
- ④ **MRF Construction**: Build MRF with clique potentials
- ⑤ **Ising Encoding**: Map MRF to Ising Hamiltonian
- ⑥ **Quantum Gates**: Translate Hamiltonian to quantum gates
- ⑦ **Export**: Generate framework-specific code

Graph Moralization

Directed Graph

- $A \rightarrow B$
- $A \rightarrow C$
- $B \rightarrow D$
- $C \rightarrow D$

After Moralization

- $A - B$ (undirected)
- $A - C$ (undirected)
- $B - C$ (added edge)
- $B - D$ (undirected)
- $C - D$ (undirected)

Key Step: Connect all parents of each node to preserve conditional independence

Maximal Cliques

A clique is a subset of nodes where every pair is connected. A maximal clique cannot be extended.

- **Algorithm:** Bron-Kerbosch with pivoting
- **Complexity:** Exponential worst-case, but efficient for sparse graphs
- **Output:** Set of all maximal cliques
- **Use:** Define potential functions in MRF

Ising Hamiltonian Encoding

Mapping MRF to Quantum

For binary variables, the Ising Hamiltonian is:

$$H = \sum_i h_i \sigma_i^z + \sum_{i < j} J_{ij} \sigma_i^z \sigma_j^z$$

- **Local Fields** h_i : From single-node potentials
- **Interactions** J_{ij} : From edge/clique potentials
- **Quantum Gates**: RY for local fields, CNOT+RZ for interactions

Quantum Circuit Construction

- ➊ **Initialization:** Hadamard gates for superposition

$$H|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

- ➋ **Single-Qubit:** RY gates for local field terms
- ➌ **Two-Qubit:** CNOT + RZ for interactions
- ➍ **Measurement:** Computational basis measurement

Result: Quantum state whose measurement probabilities match MRF distribution

Supported Frameworks

- **OpenQASM 2.0**
- **Qiskit** (IBM)
- **Cirq** (Google)
- **PennyLane** (Xanadu)
- **Q#** (Microsoft)
- **AWS Braket** (Amazon)
- **Qulacs** (Simulator)
- **TensorFlow Quantum**

Benefit: Write once, run on any framework

Usage Example

Input File (example.txt)

```
TYPE undirected
NODE 0 A 2
NODE 1 B 2
NODE 2 C 2
EDGE 0 1
EDGE 1 2
```

Command

```
./mrf_compiler -f qiskit example.txt circuit.py
```

Output

Python file with Qiskit QuantumCircuit ready to use

Generated Qiskit Code

```
from qiskit import QuantumCircuit

def create_circuit():
    qc = QuantumCircuit(3, 3)
    # Superposition
    qc.h(0)
    qc.h(1)
    qc.h(2)
    # Edge (0,1)
    qc.cx(0, 1)
    qc.rz(0.5, 1)
    qc.cx(0, 1)
    # Edge (1,2)
    qc.cx(1, 2)
    qc.rz(0.5, 2)
    qc.cx(1, 2)
    return qc
```

Export to All Frameworks

Single Command

```
./mrf_compiler -a example.txt
```

- Generates 8 output files simultaneously
- One file per framework
- Consistent circuit representation
- Easy framework comparison

Performance

Scalability

- **Small graphs** (2-10 nodes): Instantaneous
- **Medium graphs** (10-50 nodes): Seconds
- **Large graphs** (50-200 nodes): Minutes (depends on structure)

Optimizations

- Efficient adjacency list representation
- Pruned clique finding algorithm
- Template-based code generation

- ① **Research:** Explore quantum algorithms for probabilistic inference
- ② **Education:** Learn quantum computing through familiar graphical models
- ③ **Development:** Rapid prototyping of quantum-classical hybrid systems
- ④ **Comparison:** Test same model across different quantum frameworks
- ⑤ **Integration:** Bridge existing ML pipelines with quantum computing

Advantages

Automation

- No manual encoding
- Reduces errors
- Saves time

Flexibility

- Multiple frameworks
- Easy switching
- Framework-agnostic

Key Benefit

Focus on your problem, not on framework-specific details

Technical Details

Implementation

- **Language:** C++17 for performance
- **Graph Representation:** Adjacency lists
- **Clique Algorithm:** Bron-Kerbosch with pivoting
- **Code Generation:** Template-based exporters

Input Format

Simple text-based format, easy to generate programmatically

Example: Chain Graph

Graph Structure

- 3 nodes: A, B, C
- 2 edges: A-B, B-C
- Undirected graph

Result

- 2 maximal cliques
- 3 qubits
- 2 CNOT gates
- 2 RZ rotations

Quantum Circuit: Represents pairwise interactions in superposition

Example: Directed Graph

Original

- $A \rightarrow B$
- $A \rightarrow C$
- V-structure

After Moralization

- $A - B$
- $A - C$
- $B - C$ (added)
- Single clique

Key Point: Moralization preserves conditional independence

Integration Workflow

- ① **Define Model:** Create input file with graph structure
- ② **Compile:** Run MRF Compiler
- ③ **Import:** Use generated code in your project
- ④ **Execute:** Run on quantum simulator or hardware
- ⑤ **Analyze:** Process measurement results

Seamless: Works with existing quantum computing workflows

Future Directions

- **Extended Input:** Support for custom potential functions
- **Optimization:** Circuit optimization and compilation
- **More Frameworks:** Additional quantum computing platforms
- **Visualization:** Graph and circuit visualization tools
- **GUI:** Graphical user interface
- **Learning:** Automatic potential learning from data

Getting Started

Installation

```
git clone https://github.com/shyamalchandra/MRFcompiler.git  
cd MRFcompiler  
make
```

Quick Start

```
./mrf_compiler -f qiskit example.txt circuit.py
```

Documentation

- Research paper (13 pages)
- Reference manual (complete API)
- Examples and tutorials

Key Takeaways

- Automated conversion from graphical models to quantum circuits
- Support for 8+ major quantum computing frameworks
- High-performance C++ implementation
- Easy to use command-line interface
- Open source and actively developed

Impact: Enables researchers to leverage quantum computing for probabilistic inference without manual circuit design

Thank You! Resources:

- GitHub: <https://github.com/shyamalchandra/MRFcompiler>
- Documentation: Complete reference manual available
- Paper: 13-page research paper with details