Quantum-Inspired Algorithms for Covering Arrays

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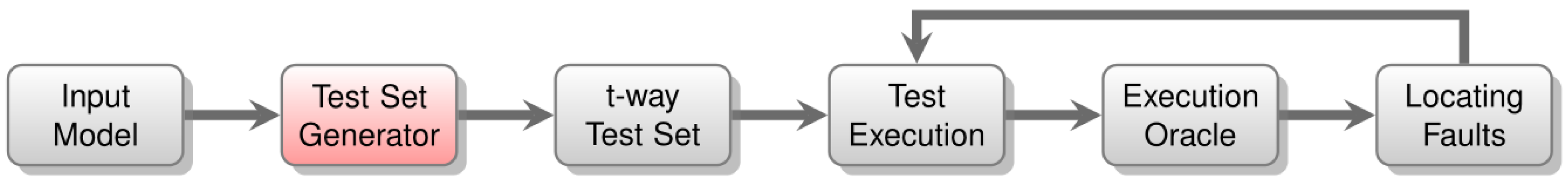
Covering Array Optimization

Covering Arrays

- Covering Arrays (CAs) are combinatorial structures used in Combinatorial Testing.
- They guarantee that every t-way combination appears in at least one row (test).
- A uniform, binary Covering Array is denoted as **CA(N;t,k)**, where N is the number of rows, t the strength and k the number of columns.
- CAs with the smallest number of rows possible are called optimal CAs.



The Covering Array Generation Problem

- Generating optimal CAs is tightly coupled to hard combinatorial optimization problems.
- Commonly used generation methods include greedy algorithms, mathematical constructions and metaheuristic approaches.
- We investigated how quantum-inspired methods can help in generating near-optimal CAs.

Quantum-Inspired Evolutionary Algorithms

- First quantum-inspired evolutionary algorithm for CA generation.
- We introduced and evaluated new Mutation and Rotation types.
- We were able to generate various optimal binary CAs for strengths $t = 2, 3, 4$.

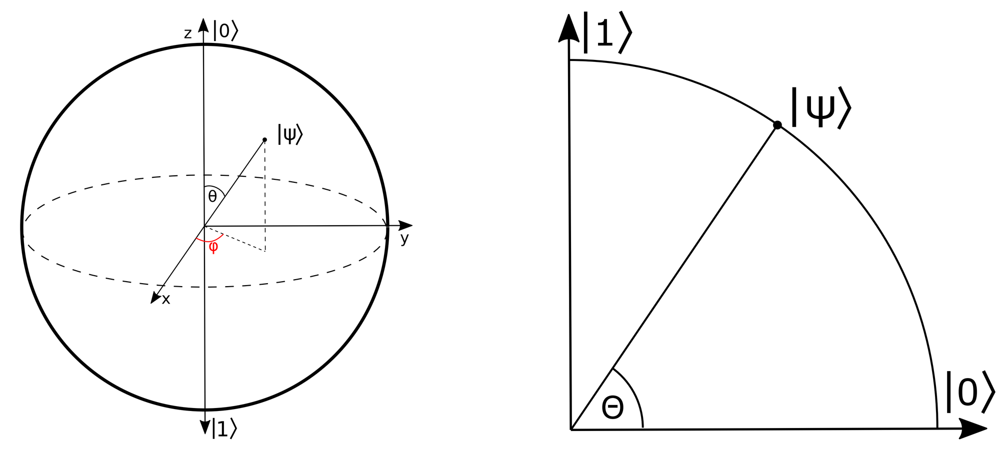


Figure 1: Qubit representation and the reduced version for real-valued amplitudes

Algorithm 1 QEAforCA(t, k, N)

```
Require: Rotation, Mutation, Termination
Create Q(n) representing the N × k array
Create candidate solution C(n) by observing Q(n)
Evaluate C(n) based on the number of covered t-way interactions
B(n) ← C(n)
while (not Termination(B(n), t) do
    n ← n + 1
    Create C(n) by observing Q(n − 1)
    if Evaluate C(n) then
        B(n) ← C(n)
    end if
    for all Qubits q_ij in Q(n) do
        α_ij ← Mutation(b_ij)        ▷ Stops individual qubits from converging prematurely.
        q_ij ← Rotation(q_ij, α_ij)  ▷ Updates the states of the Qubits to guide the search towards B(n).
    end for
end while
return B(n)
```

Covering Array Generation using IPO-Q

- Combines QEA with the In-Parameter-Order strategy:

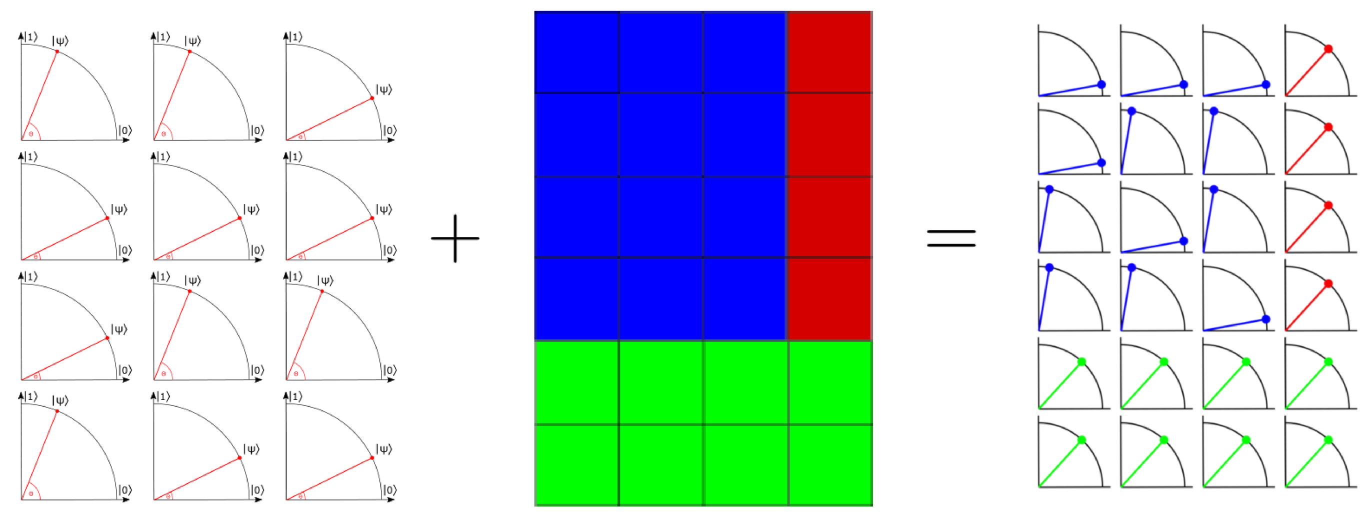


Figure 3: IPO-Q: Combining QEA with IPO

- Expands array using vertical and horizontal extension steps:
  - The blue Qubits in Figure 3 represent the CA from the previous extension step, their state biased towards their old value
  - A new column is added (red Qubits) and QEA attempts to find a CA with the newly added column
  - If QEA fails to generate a CA, additional rows are added (green Qubits)

Example of the QEA Cycle

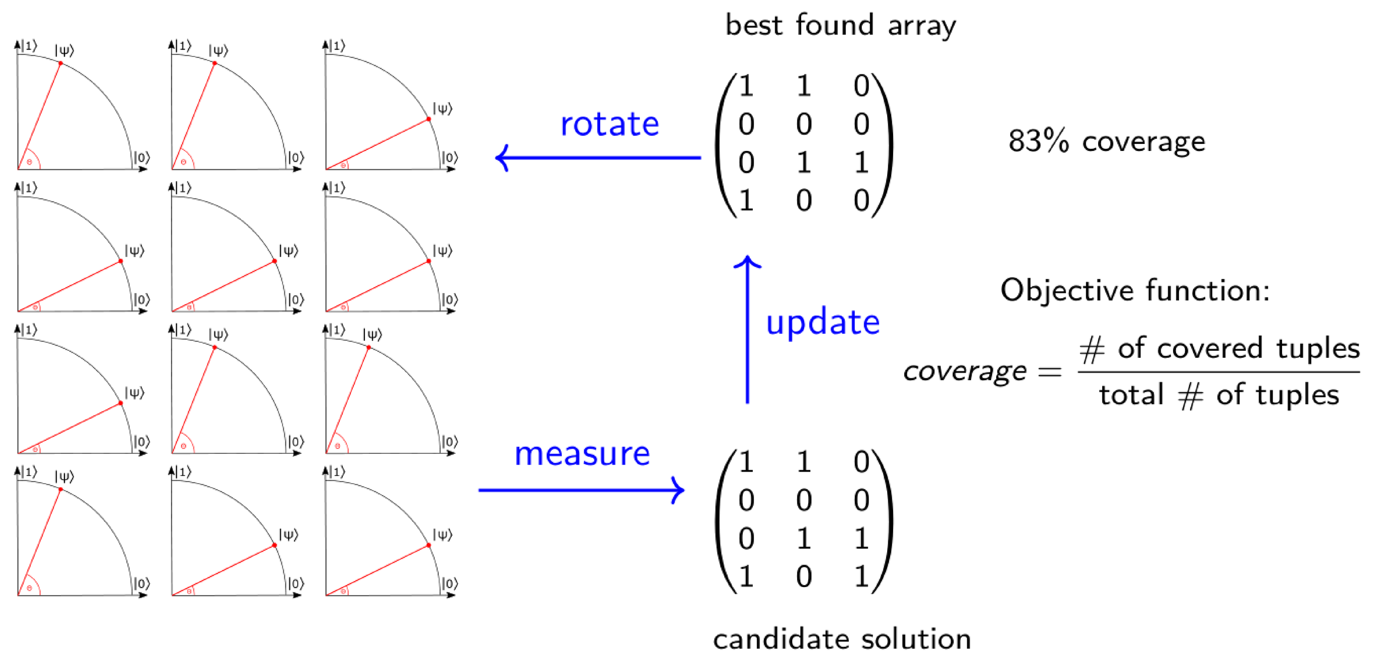


Figure 2: The workflow of the QEA cycle for the instance CA$(4; 2, 3)$.

IPO-Q Evaluation and Future Work

- Guaranteed CA upon termination
- Improved on other IPO variants by reducing the number of rows for certain binary CA instances:

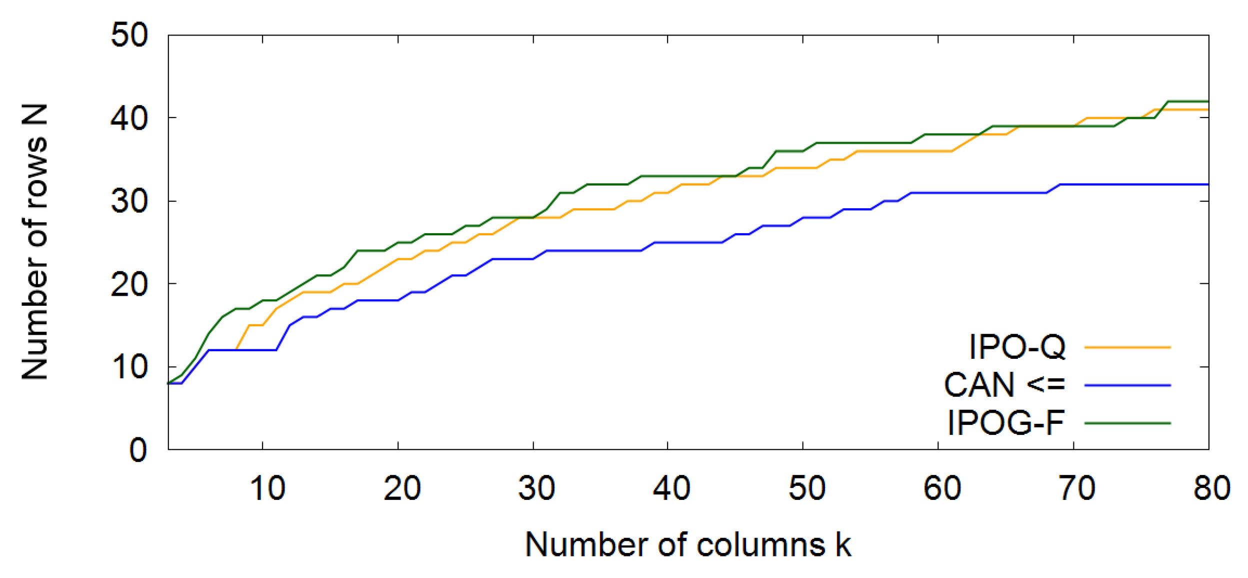


Figure 4: Comparsion between the number of rows generated by IPO-Q and IPOG-F for binary CAs of strength $t = 3$

Future Work:

- Generalize our QEA and IPO-Q for higher alphabets.
- Use Quantum Computing to solve Covering Array problems.

Michael Wagner, Ludwig Kampel, and Dimitris E. Simos. Quantum-inspired evolutionary algorithms for covering arrays of arbitrary strength. In Ilias Kotsireas, Panos Pardalos, Konstantinos E. Parsopoulos, Dimitris Souravlias, and Arsenis Tsokas, editors, *Analysis of Experimental Algorithms*, pages 300–316, Cham, 2019. Springer Publishing.
Michael Wagner, Ludwig Kampel, and Dimitris E. Simos. Ipo-q: A quantum-inspired approach to the ipo strategy used in ca generation. In Daniel Slamanig, Elias Tsigaridas, and Zafeirakis Zafeirakopoulos, editors, *Mathematical Aspects of Computer and Information Sciences*, pages 313–323, Cham, 2020. Springer International Publishing.

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