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Improving the Mapping of Reversible Circuits to Quantum Circuits Using Multiple Target Lines

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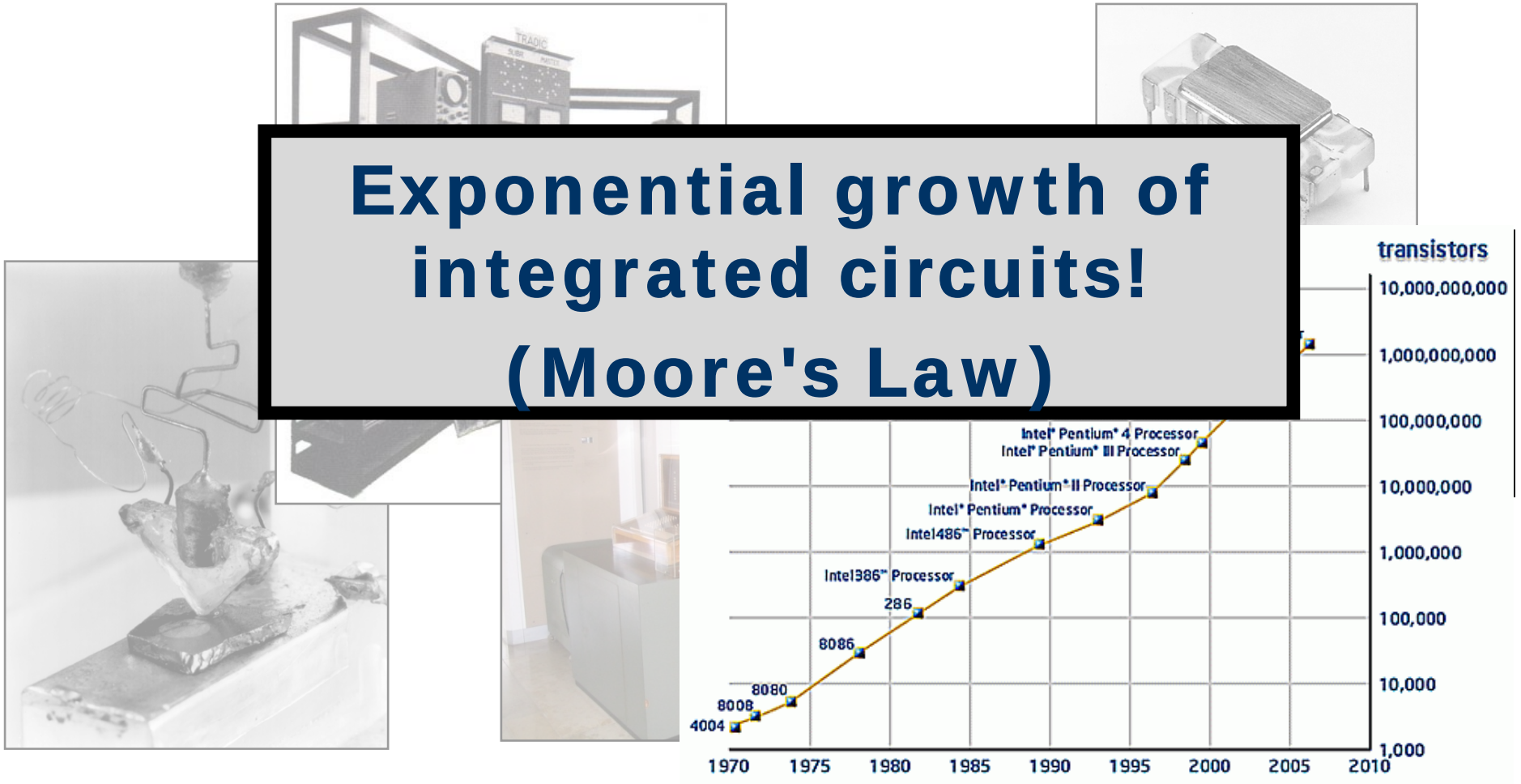
Outline

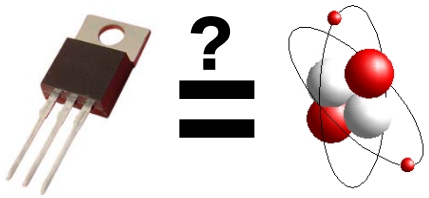
- Motivation and Background
- Quantum Circuits and their Synthesis
- Proposed Optimization Approach
- Application to ESOP-based Synthesis
- Experimental Evaluation
- Conclusions

Hardware Development



Consequences

- Transistors will reach the atomic scale



- Power dissipation becomes a crucial issue

➔ Current technologies will reach their limits!

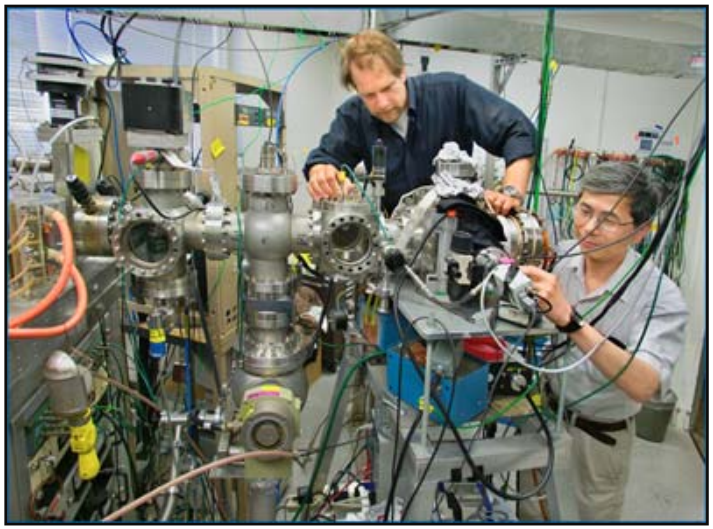
Furthermore, …

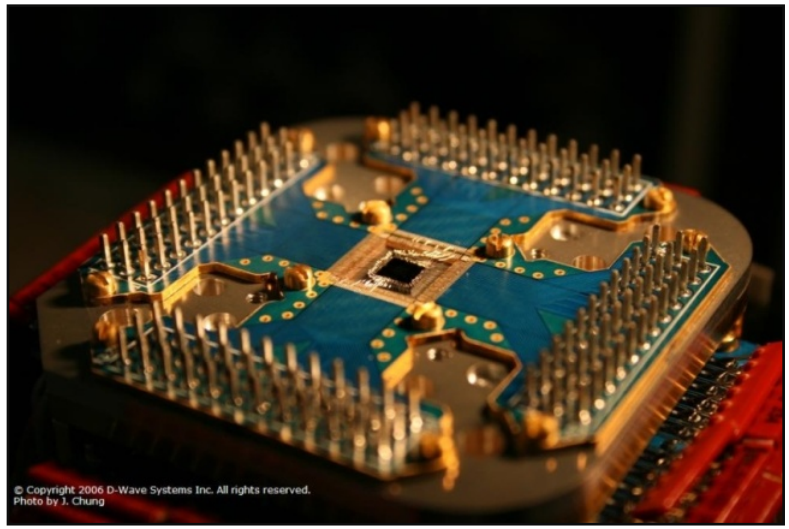
- Many problems are still too hard for nowadays computing machines

…will not become better with current technologies.

Alternative: Quantum Circuits

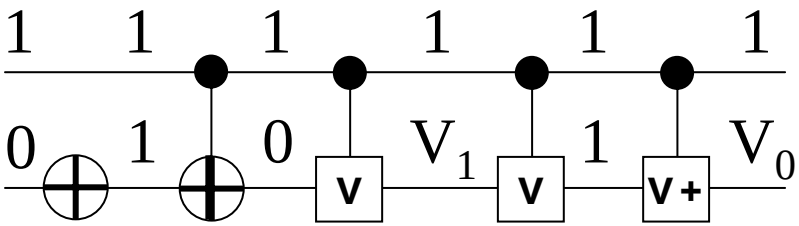
- Computation not only with 0 and 1 but also superposition of both
- Enables significant speed-ups for certain problems (e.g. factorization, database search)





Elementary Quantum Gates

- Signals represented by qubits



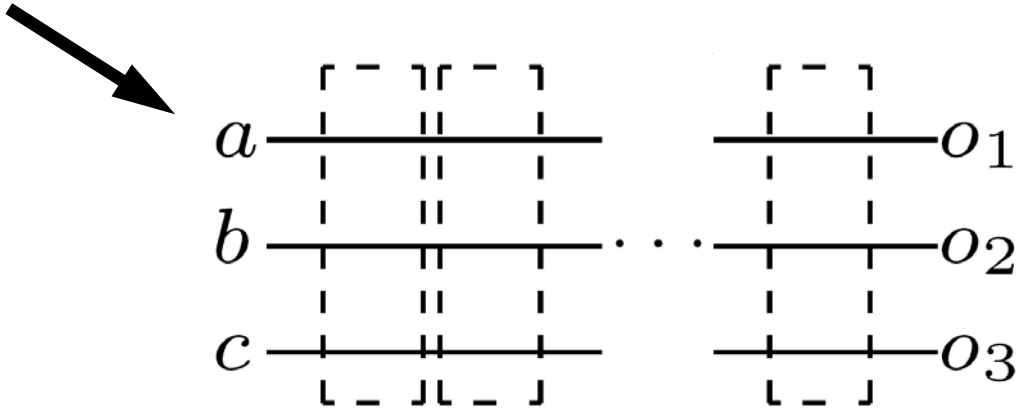
- NOT: Peforms inversion
- CNOT: controled inversion
- V: “square root”
- V+: inverse of V

- Value of each qubit is restricted to 0, 1, V_0 or, V_1
- Gates are assumed to have unit cost
- Universal (every Boolean function can be implemented with this gate library)

Synthesis Problem

- Given: Function to be synthesized

c	b	a	o_3	o_2	o_1
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	1	0	0
0	1	1	1	1	1
1	0	0	0	0	1
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	0

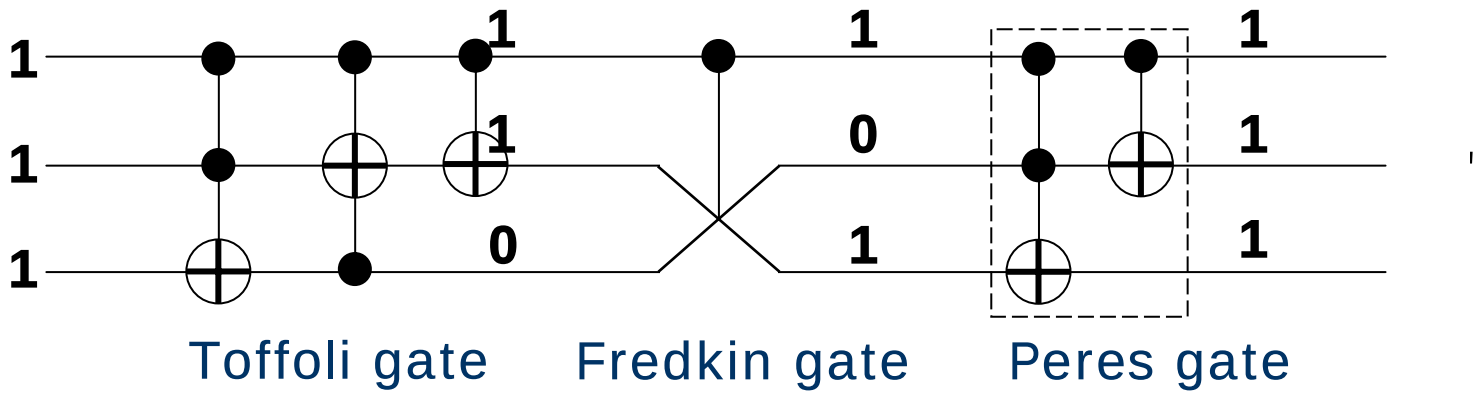


- Task: Find network (i.e. a cascade of gates)

Established Synthesis Flow (1)

- Every quantum operation inherently is reversible

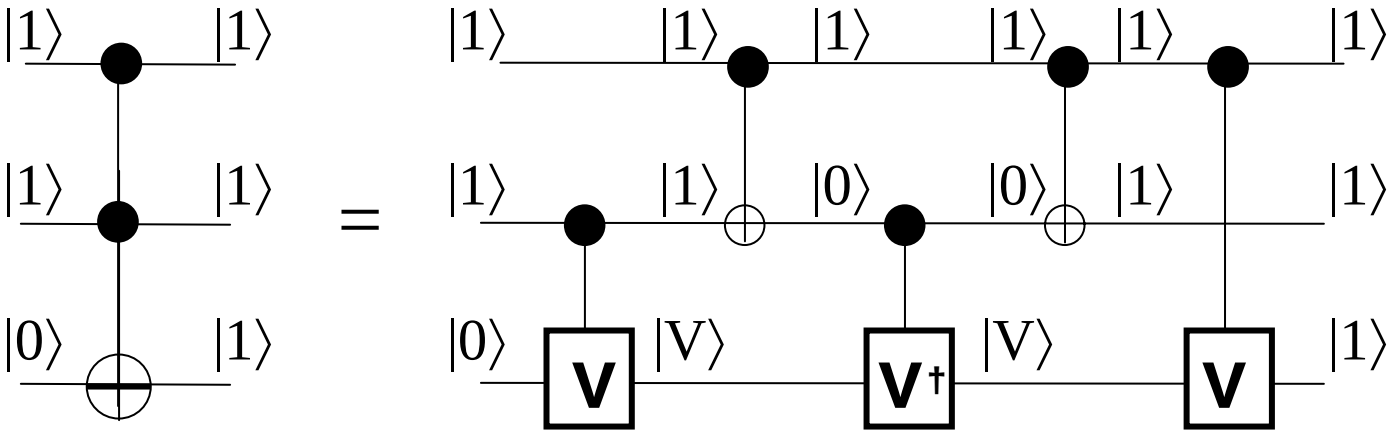
➔ Exploitation of reversible gates



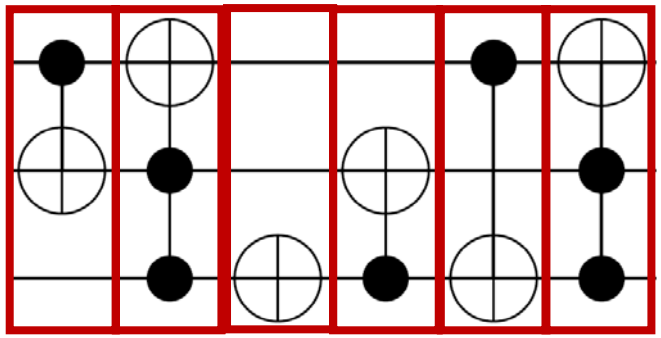
Toffoli gate Fredkin gate Peres gate

Established Synthesis Flow (2)

- Various synthesis methods for reversible circuits have been proposed in the past
- Exploited for synthesis of quantum circuits

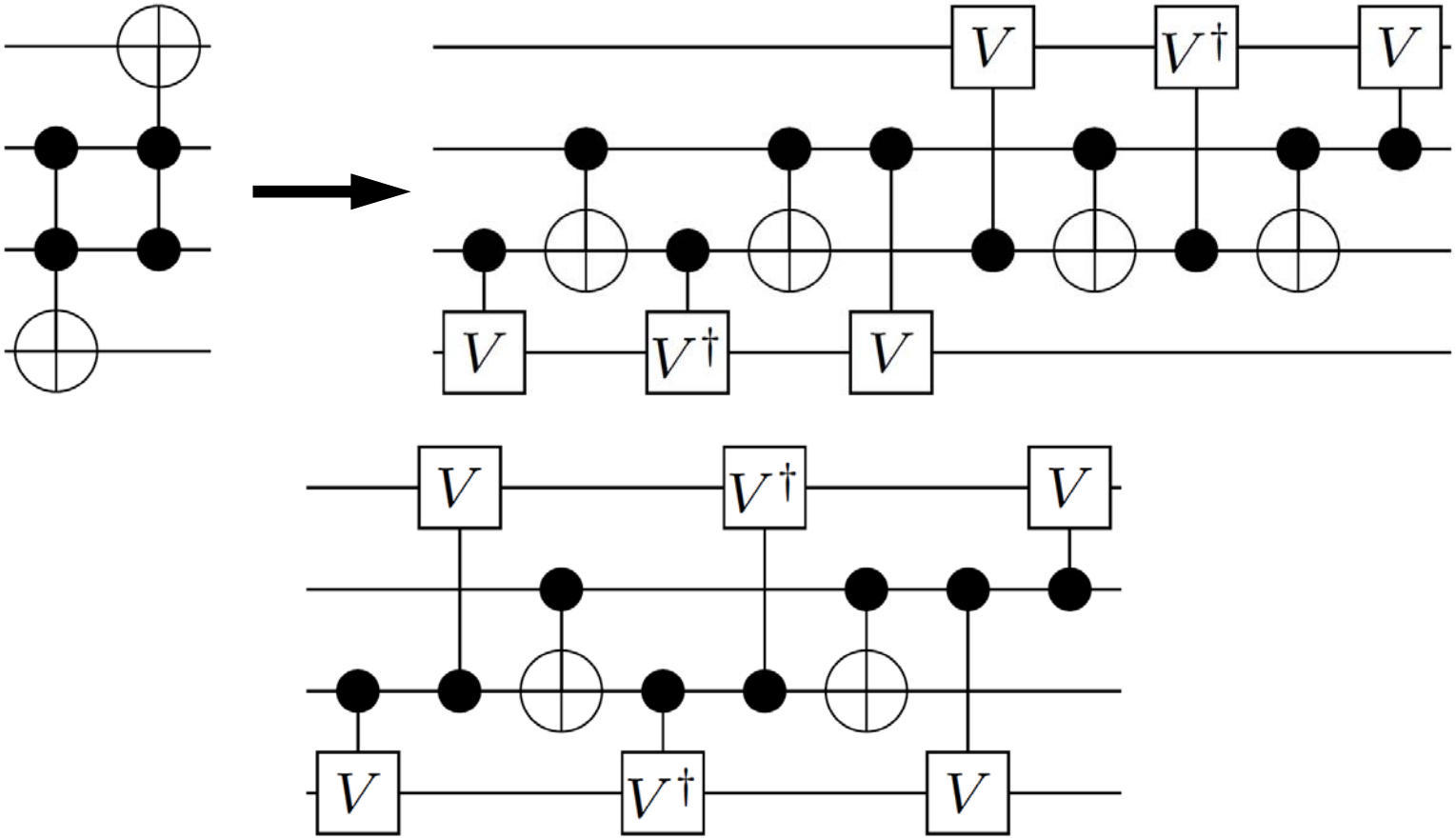


Established Synthesis Flow (3)

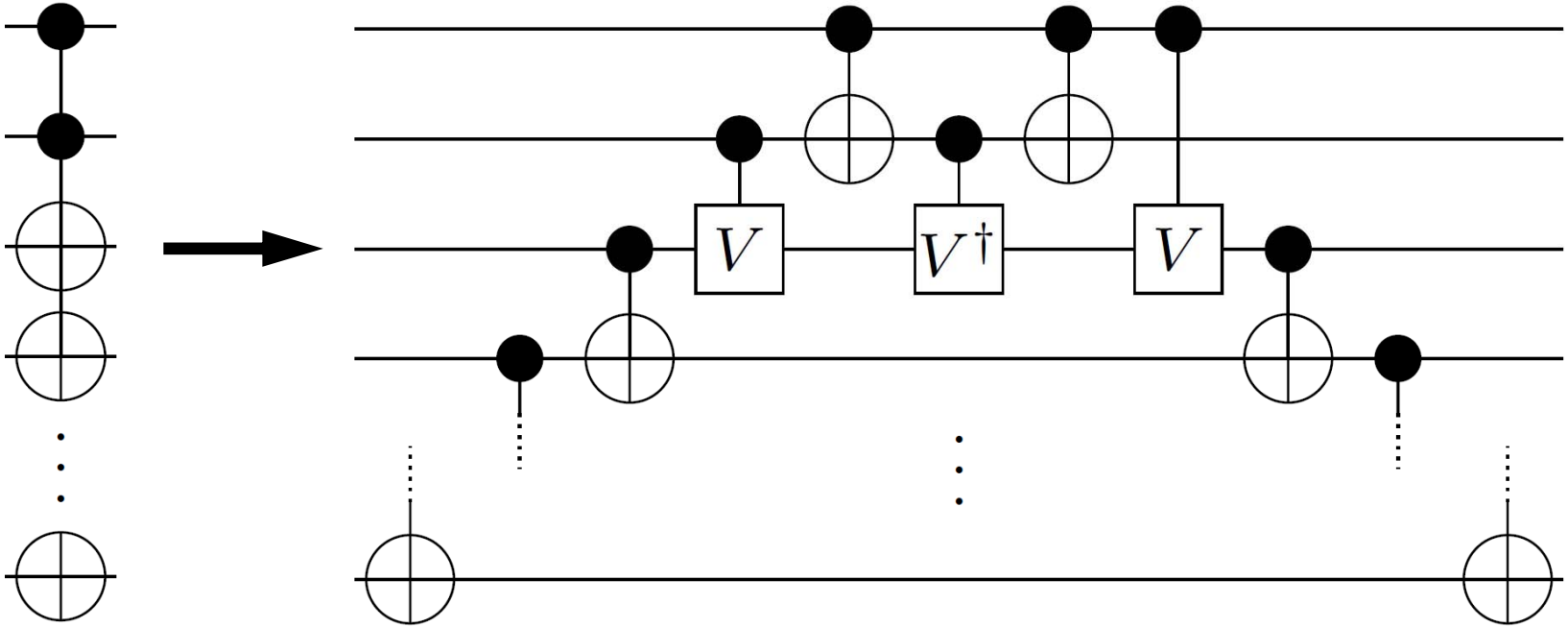


Problem

- Local consideration of the mapping



Proposed Optimization



- Applicable to other mapping schemes

Application in ESOP-based Synthesis

- Introduced in Fazel et al., PACRIM 2007
- ESOP = Exclusive Sum of Products
  (Two-level description of a Boolean function)
- Given: ESOP for function $f : \mathbb{B}^n \rightarrow \mathbb{B}^m$

General Idea:

- Generate reversible circuit with $n+m$ lines
  - First n lines work as primary inputs
  - Last m lines work as primary outputs, initialized with constant 0
- Single product of ESOP corresponds to Toffoli gate

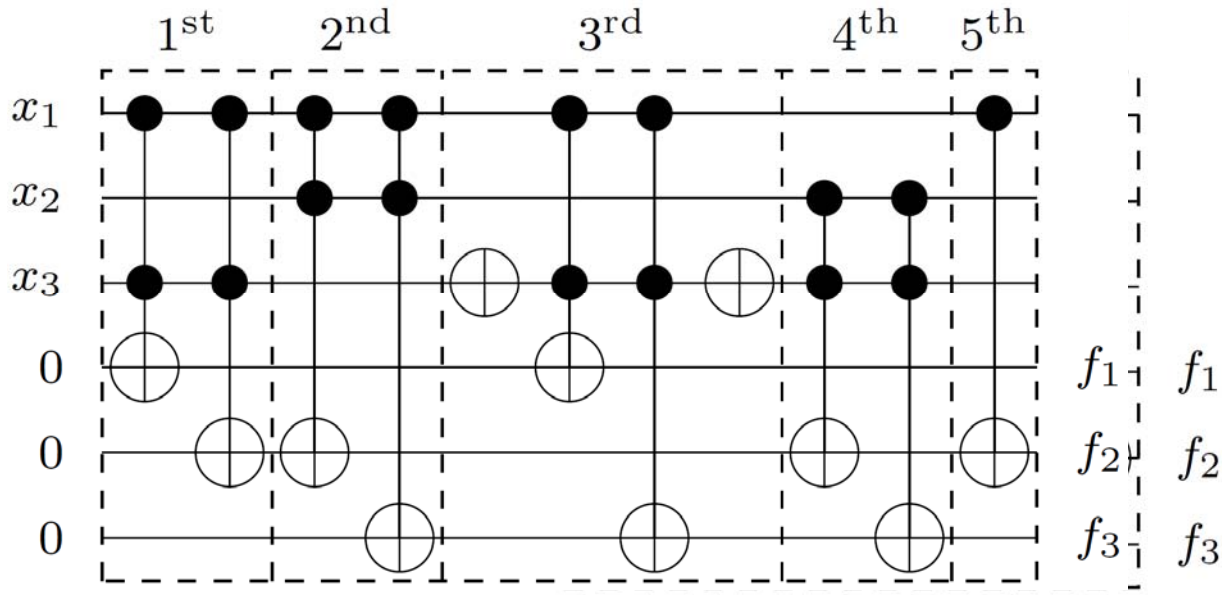
Application in ESOP-based Synthesis

ESOP

	x_1	x_2	x_3	f_1	f_2	f_3
1^{st}	1	-	1	1	1	0
2^{nd}	1	1	-	0	1	1
3^{rd}	1	-	0	1	0	1
4^{th}	-	1	1	0	1	1
5^{th}	1	-	-	0	1	0

Resulting circuit

Application in ESOP-based Synthesis



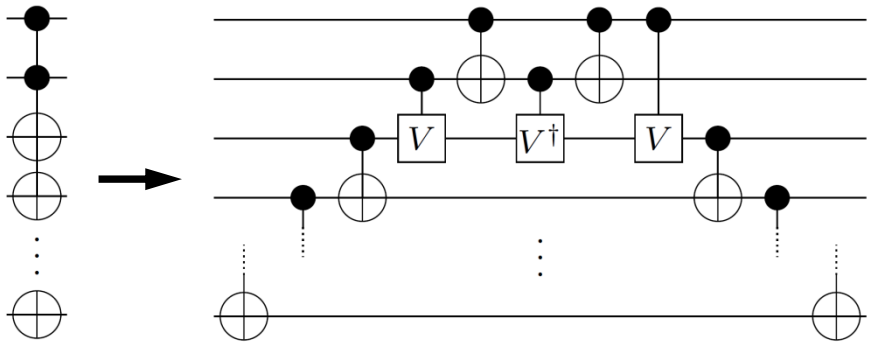
- Reduces the quantum costs from 43 to 31
- Further applications in the paper

Experimental Evaluation

- Implemented on top of RevKit (www.revkit.org)
- Benchmarks from RevLib (www.revlib.org)
- Here: Results from ESOP-based synthesis
  (further results in the paper)

Conclusion

- Proposed Optimization:



- Improvements up to 85% (28% on average) in ESOP based-applications
- Further applications in the paper
- Applicable to other mapping schemes
- Future Work:
  - Application to other gate types (e.g. Fredkin) and mapping schemes
  - Consideration directly in synthesis approaches

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