A Methodology for Standard Cell Design for QCA

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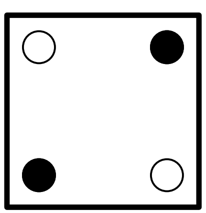
Outline

- Introduction
  - QCA
    - Clocking zones
    - Clocking schemes
- Proposed Clocking Schemes
- QCA ONE
  - Cells
  - Results
- Conclusion

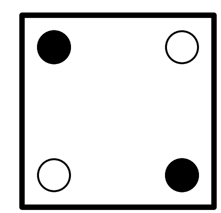
Quantum-Dot Cellular Automata - QCA

Paradigm of digital logic circuits for computing. Nanoscale; Information is transmitted without the flow of electric current **(Coulomb Interaction)**; fast; low power dissipation.



Binary 1

Polarization 1



Binary 0

Polarization -1

Quantum-Dot Cellular Automata - QCA

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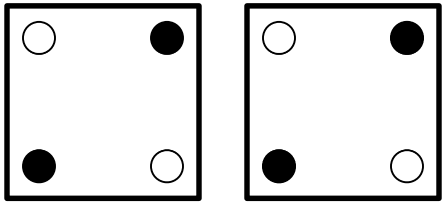

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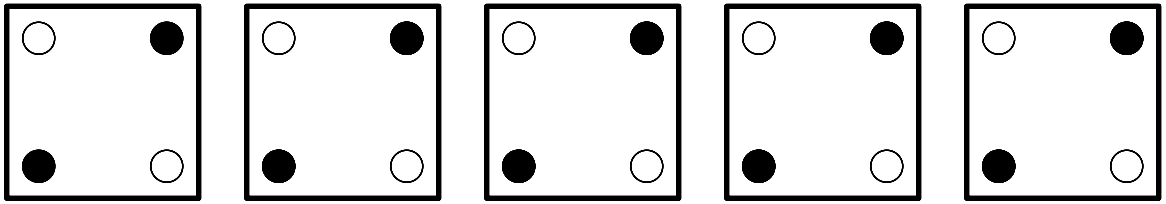

QCA Wire

Quantum-Dot Cellular Automata - QCA

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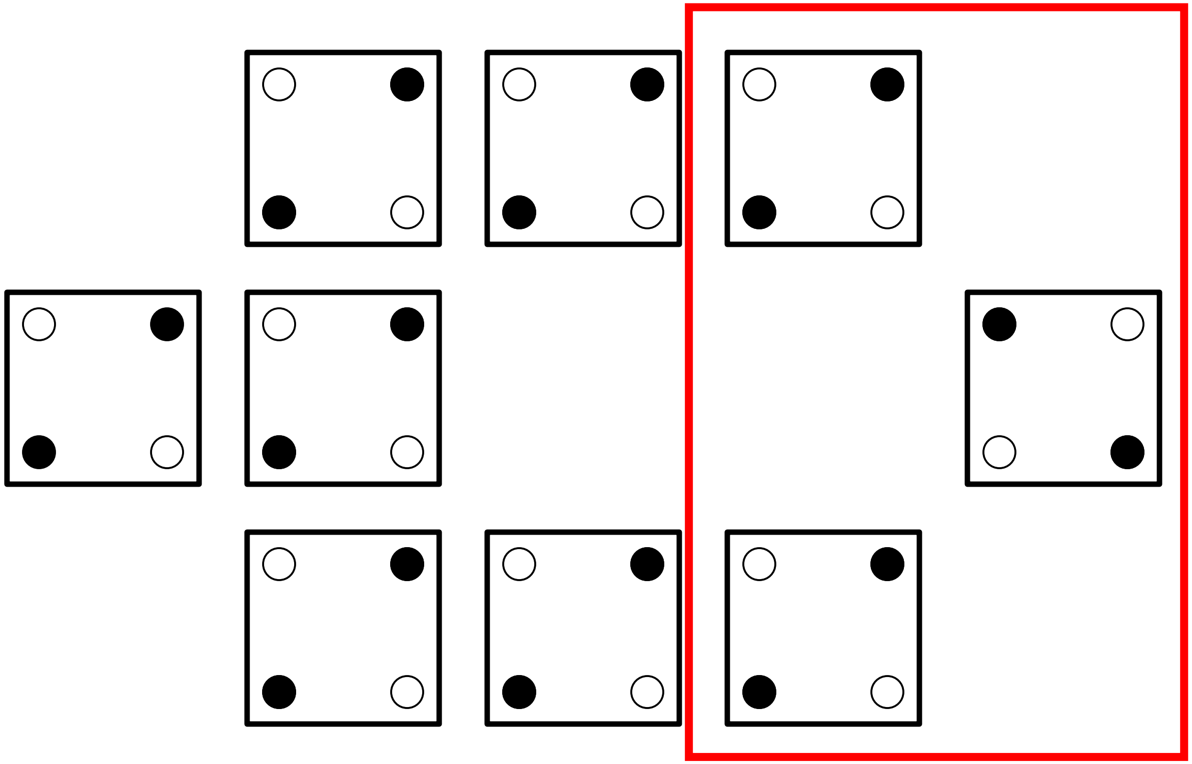
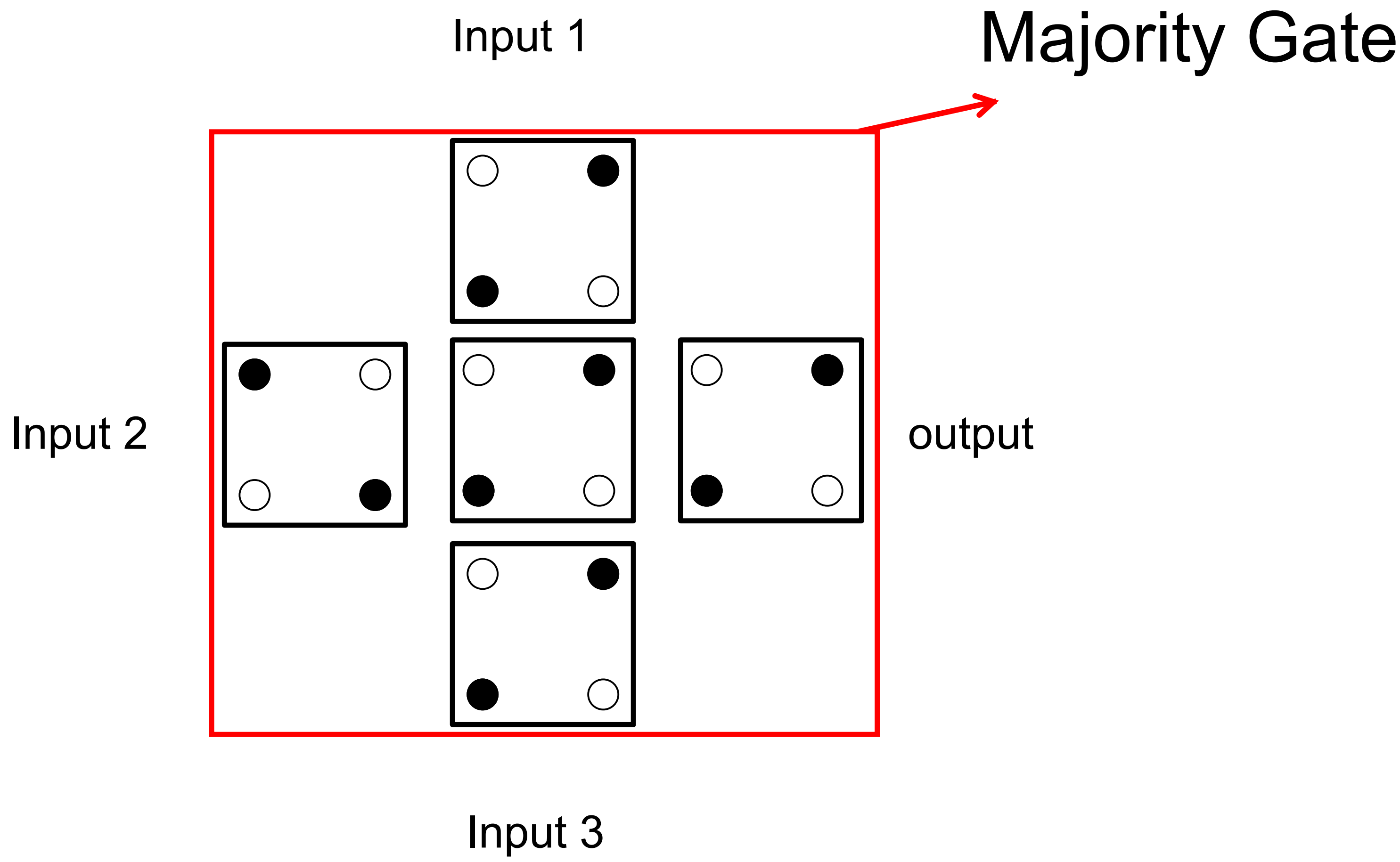


QCA inverter

Quantum-Dot Cellular Automata - QCA

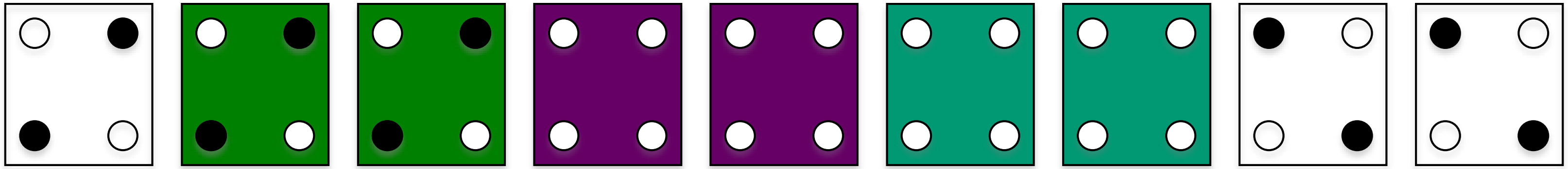


Clocking Zone, Phase and Cycle

- Allows adiabatic switching (energy efficient)
- 1 Clock cycle 4 phases

  - Phase 1 – Switch: the cells can polarize;
  - Phase 2 – Hold: the polarization of the cell can't change;
  - Phase 3 – Release: the cells depolarize;
  - Phase 4 – Relax: the cells still depolarized.

Time step 0



Clock zone 0 in switch phase	Clock zone 1 in relax phase	Clock zone 2 in release phase	Clock zone 3 in hold phase

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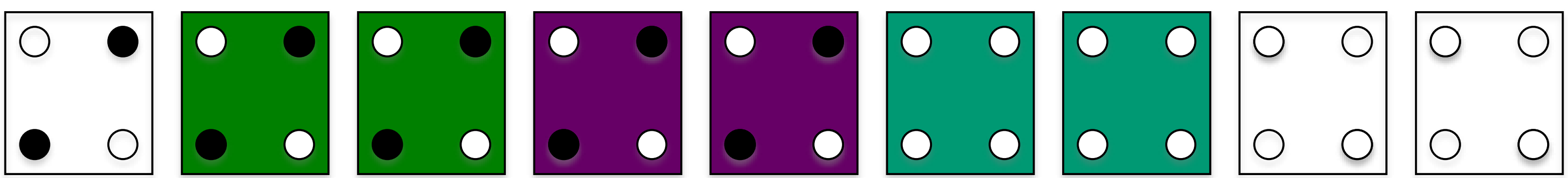
Time step 1



Clock zone 0 in hold phase	Clock zone 1 in switch phase	Clock zone 2 in relax phase	Clock zone 3 in release phase

Clocking Zone, Phase and Cycle

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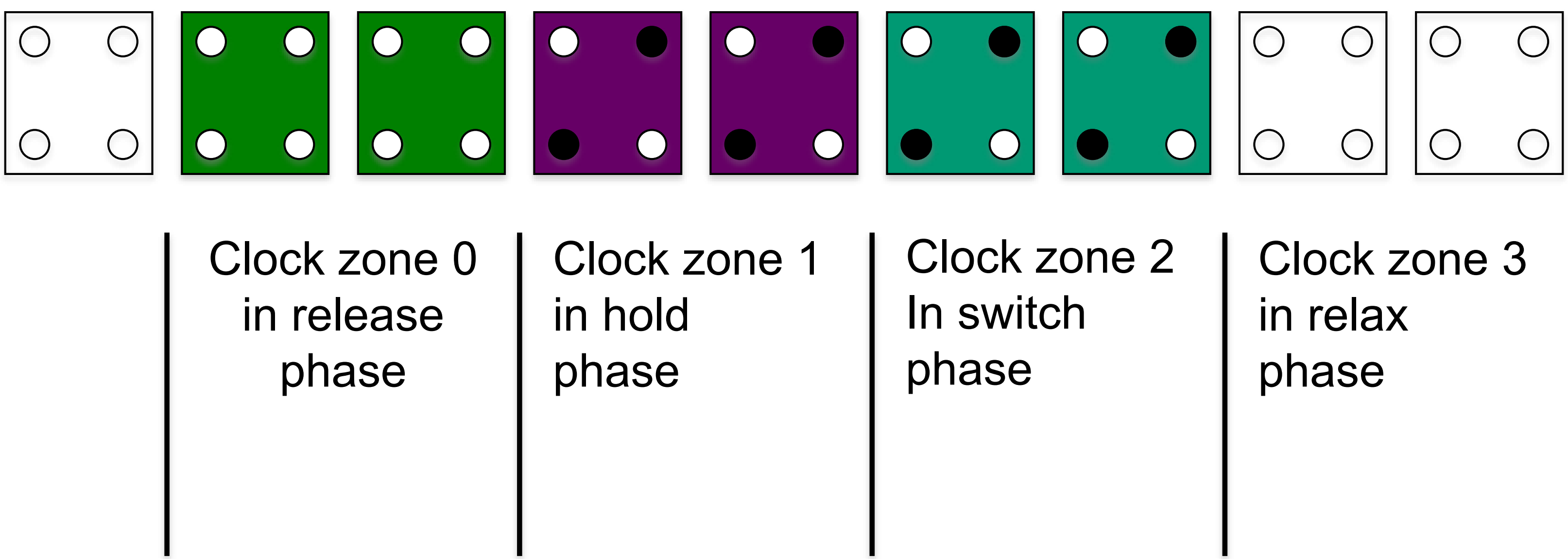
Time step 2



Clocking Zone, Phase and Cycle

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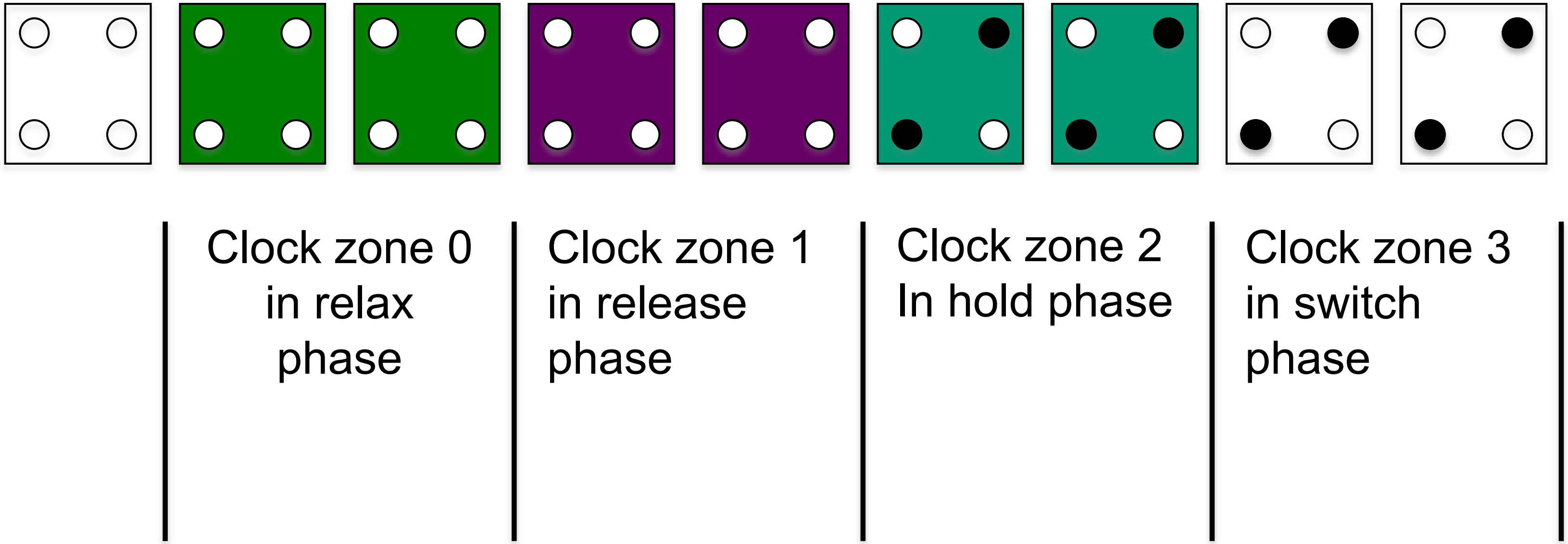
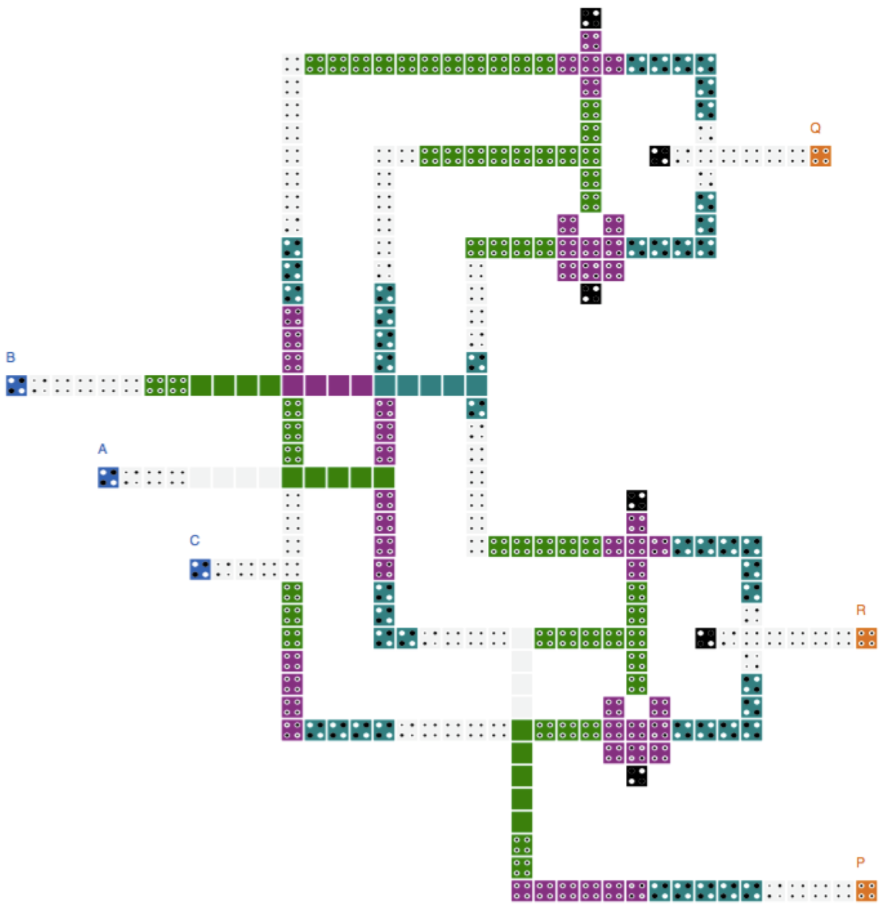
Time step 3

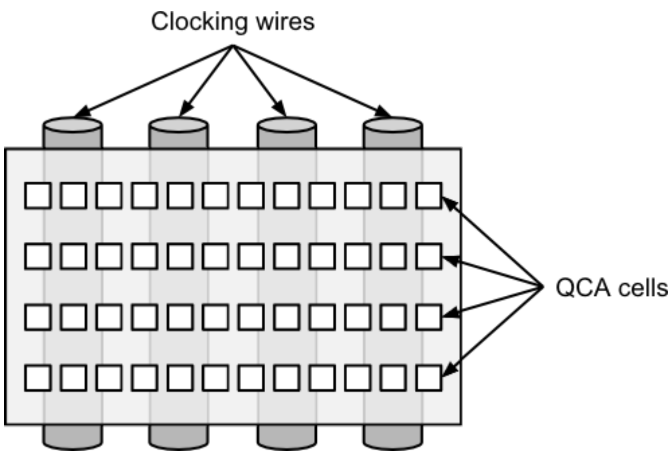


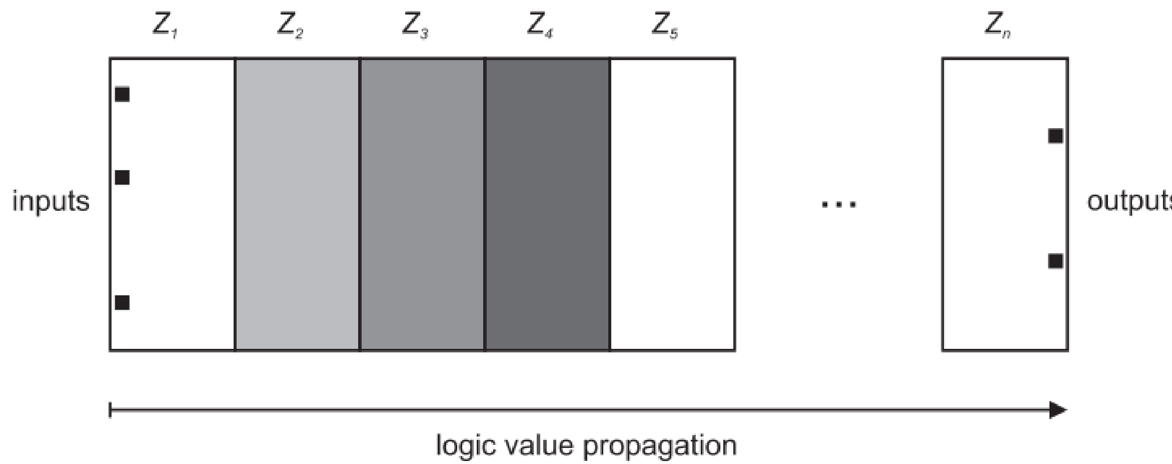
Free clocking scheme



- Colors define clocking zones;
- Designer defines the clocking zones;
- There is no clock standard;
- Does not work in **molecular or magnetic** (nanomagnet logic - NML) QCA.

Linear clocking scheme



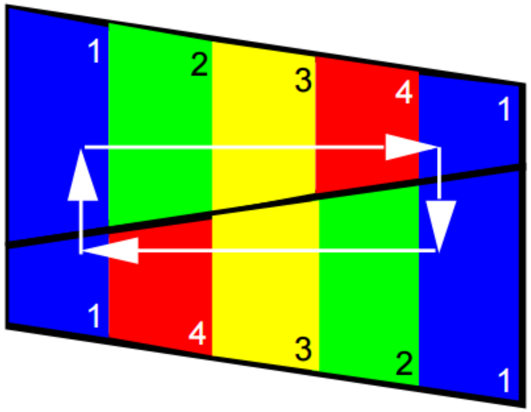


No feedback!

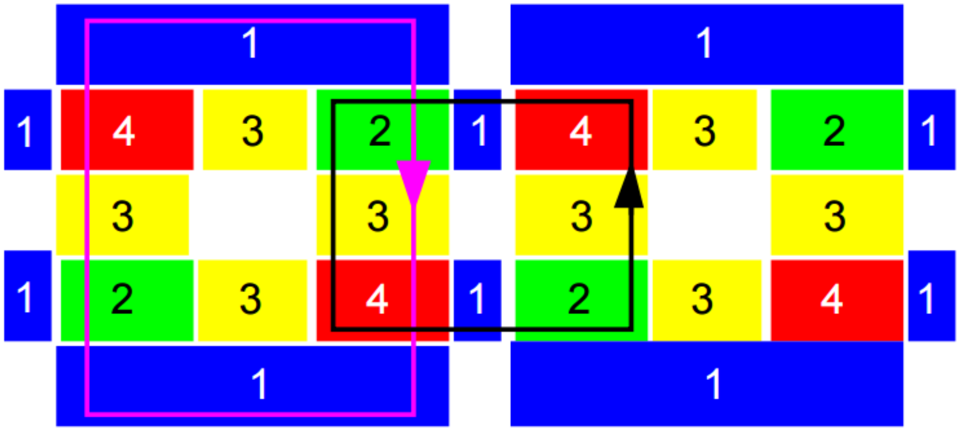
Hennessy, K. and Lent, C. S. (2001). Clocking of molecular quantum-dot cellular automata. Journal of Vacuum Science & Technology B, 19(5):1752--1755.

Janez, M., Pecar, P., and Mraz, M. (2012) Layout design of manufacturable quantum-dot cellular automata. Microelectronics Journal, 43(7):501--513.

Shape clocking scheme



Hard clock circuit implementation

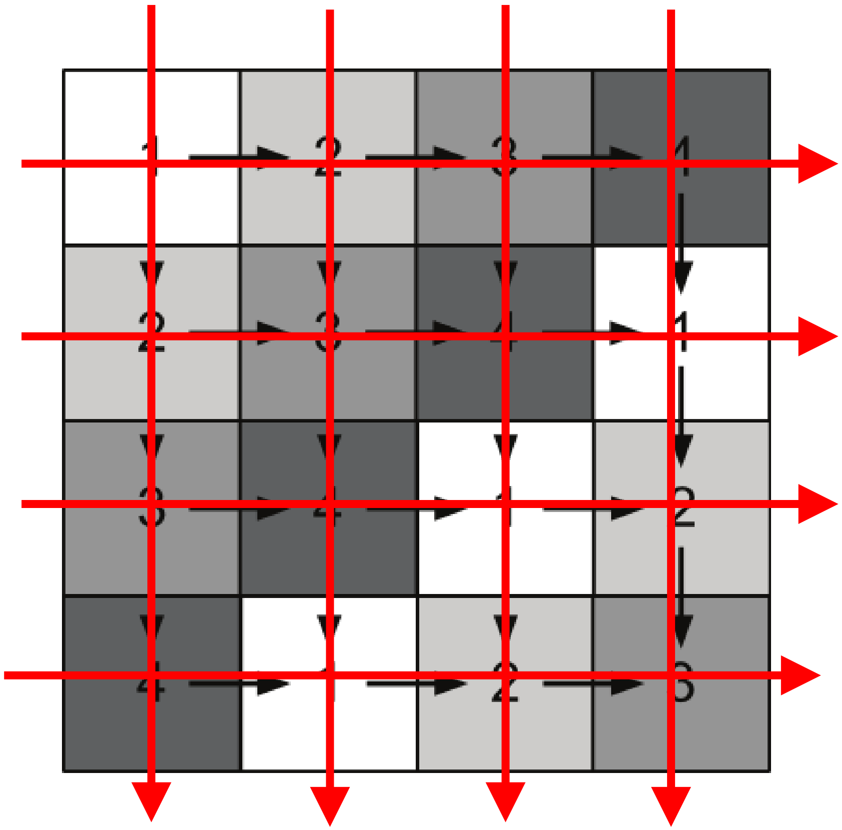


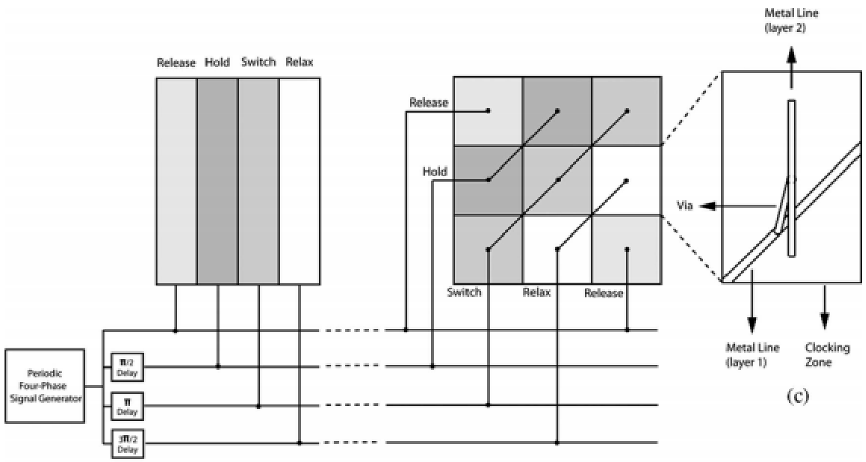
There are more zones 1 and 3 than 2 and 4!

Zones have different sizes and shapes!

Niemier, M. T. (2004). Designing digital systems in quantum cellular automata. PhD thesis, University of Notre Dame.

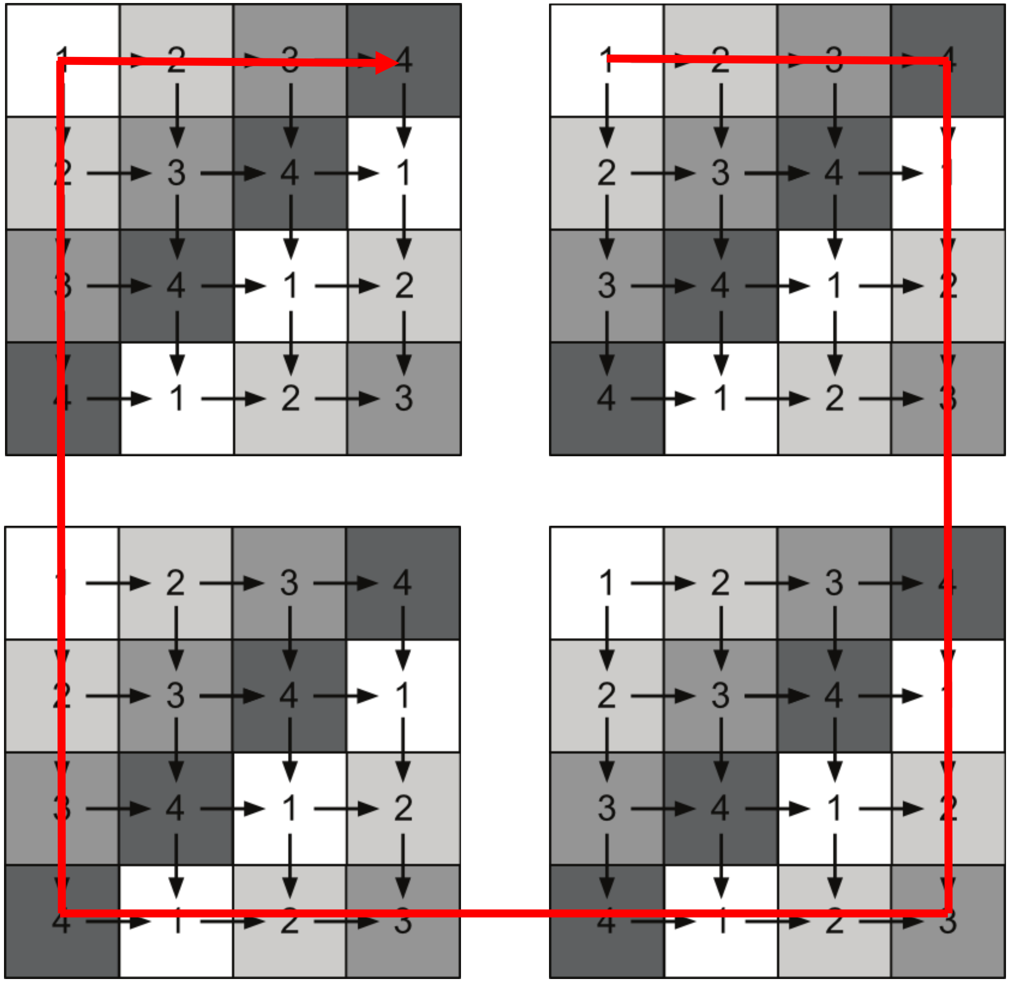
2DDWave clocking scheme





Vankamamidi, V., Ottavi, M., and Lombardi, F. (2008). Two-dimensional schemes for clocking/timing of qca circuits. Computer-Aided Design of Integrated Circuits and Systems, IEEE Transactions on, 27(1):34--44.

2DDWave clocking scheme



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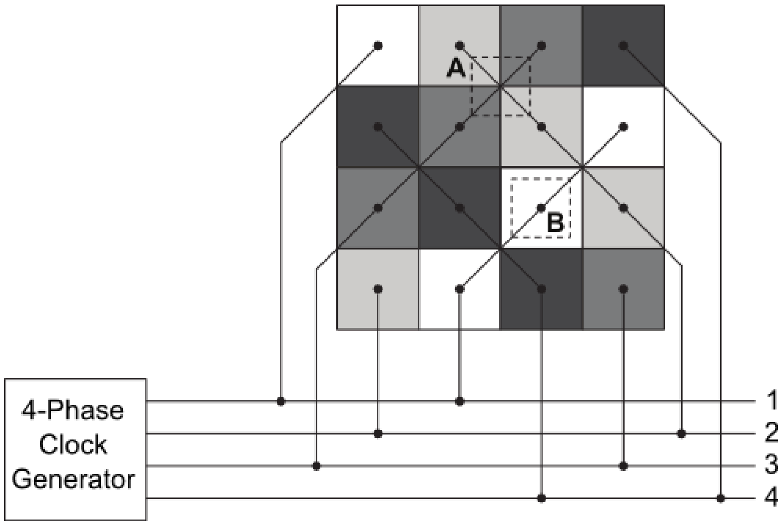
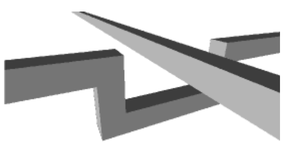
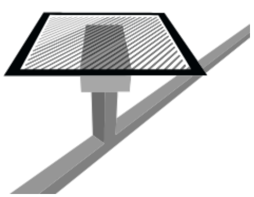
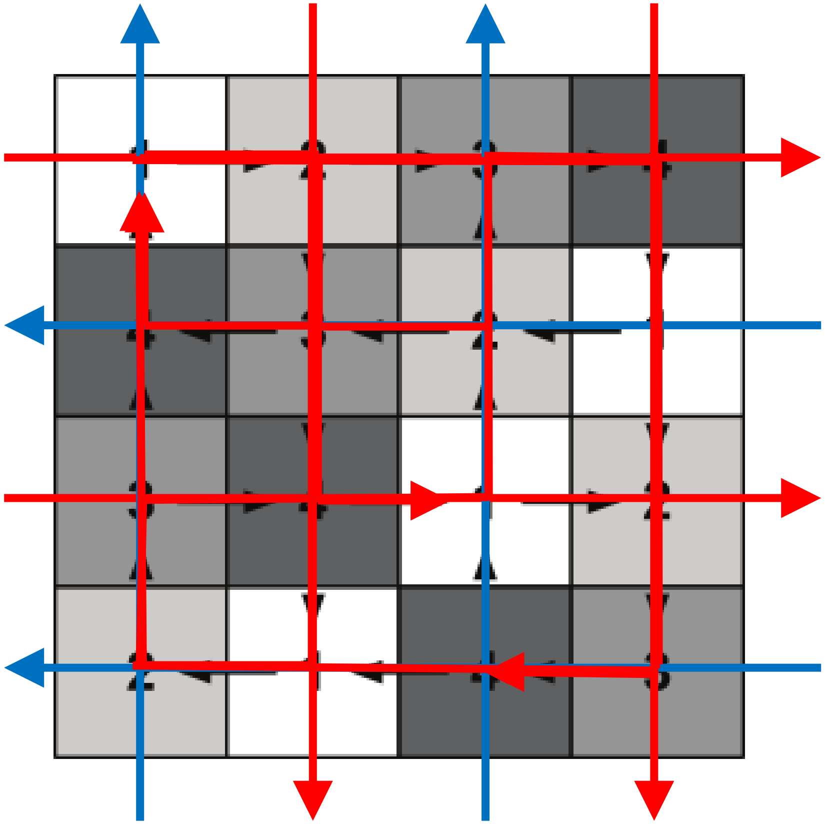
USE clocking scheme



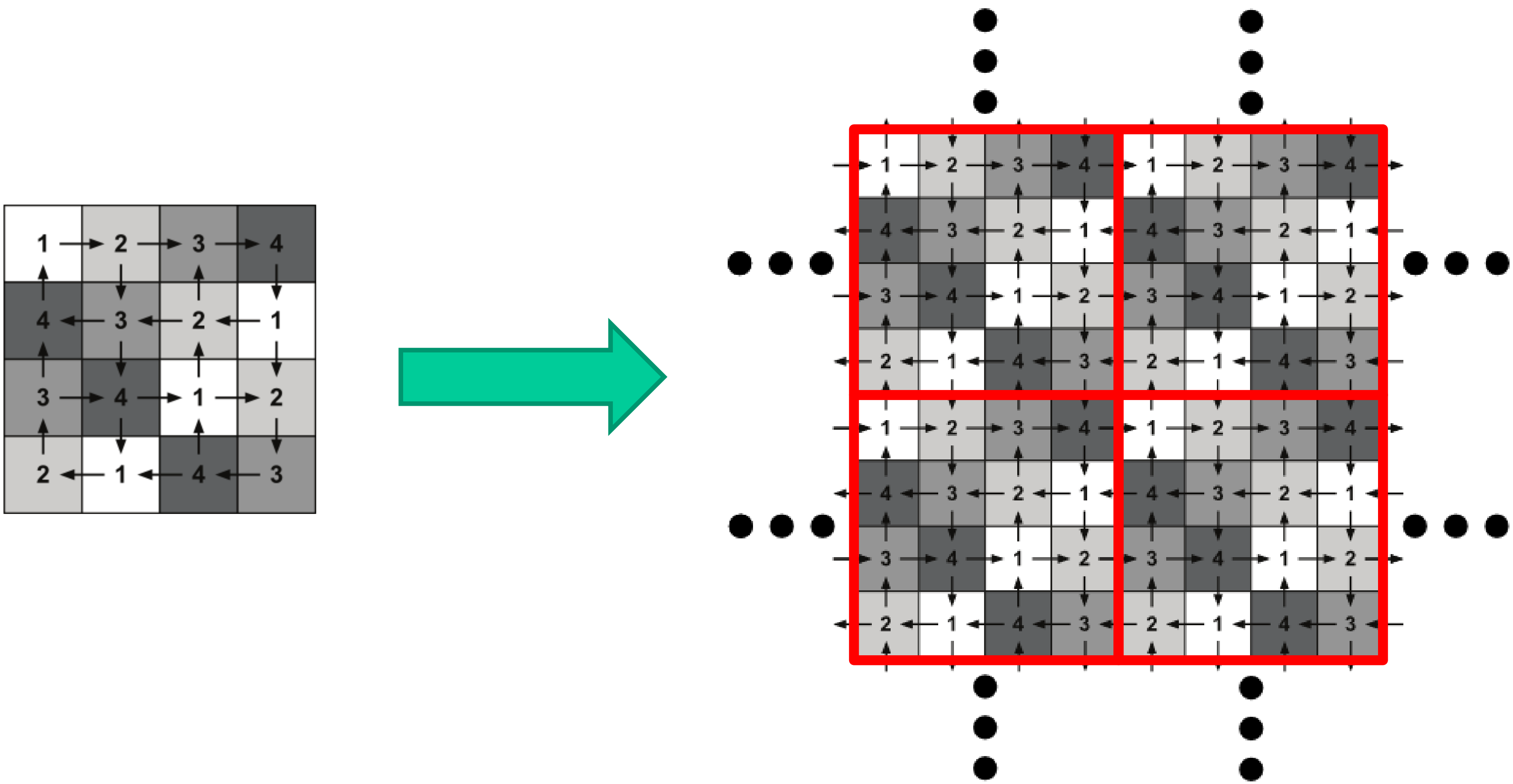






Campos, C. A. T., Marciano, A. F., Vilela Neto, O. P., Torres, F. S. (20016). USE: A Universal, Scalable, and Efficient Clocking Scheme for QCA. Computer-Aided Design of Integrated Circuits and Systems, IEEE Transactions on, 35(4): 513--517.

USE clocking scheme



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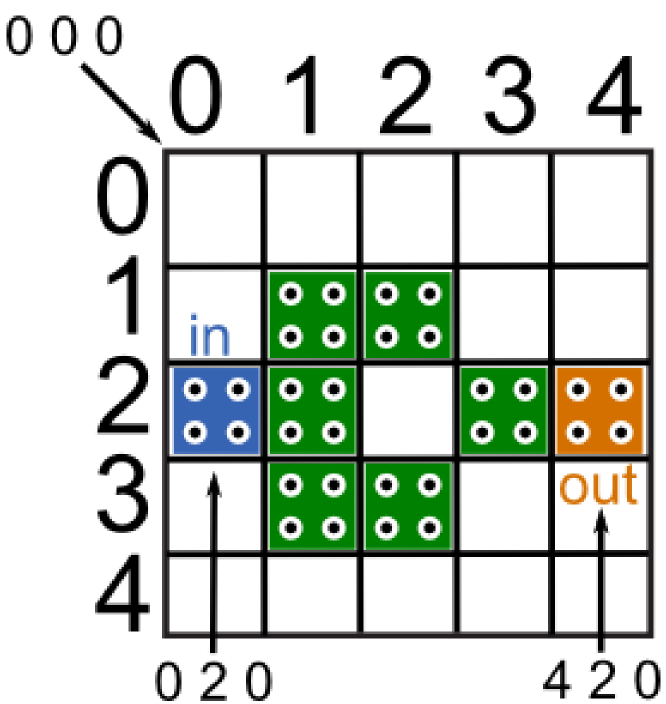
QCA ONE

- QCA Standard Cells;
- Using USE clocking scheme
    - Regular shape;
    - Enable placement & routing.

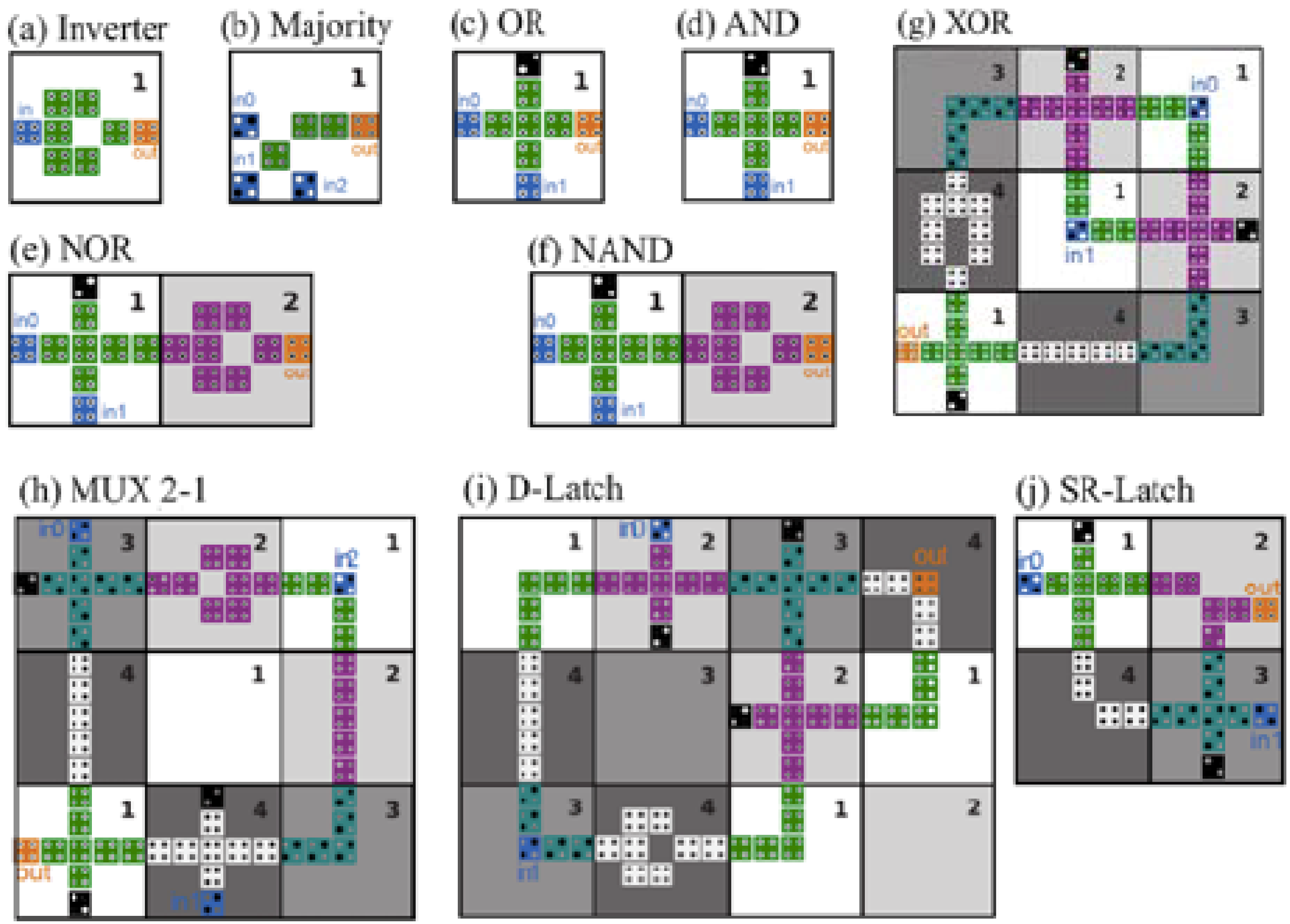
QCA ONE

Inverter

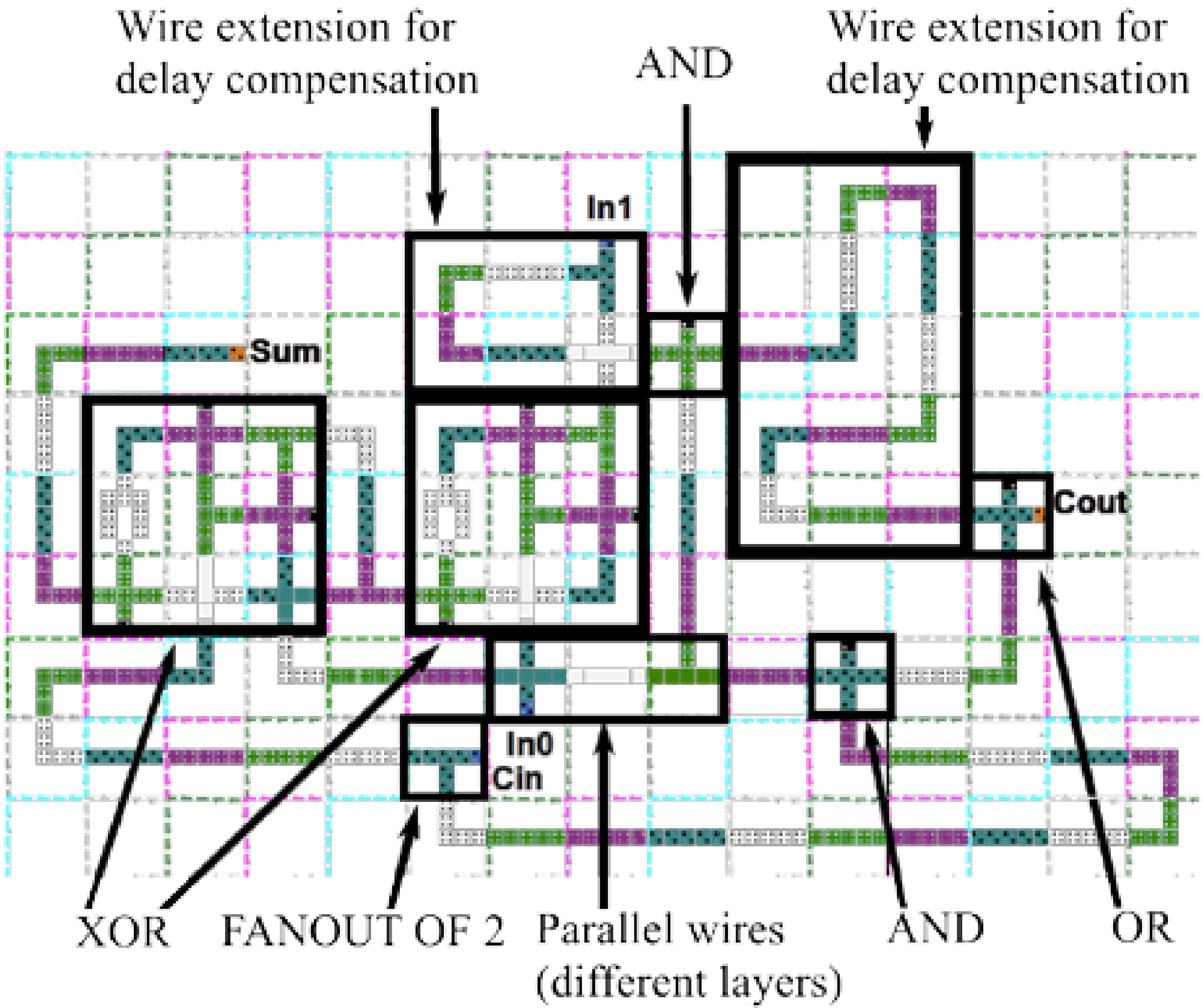



```
name: inv # cell name

n_input: 1 # number of inputs
n_output: 1 # number of outputs
input: in # list of inputs
output: out # list of outputs

expression: # expression corresponding to the function performed
out = -in

zone_dimension: 5 # dimension of USE zone in terms of QCA cells

width: 5 # width in number of QCA cells
height: 5 # height in number of QCA cells
layers: 1 # number of layers used
l_reference_zone: 1 # left reference zone
r_reference_zone: 2 # right reference zone

delay_table: # table of delays between each pair input/output
/   in
out 0

port_location: # coordinates for input and output ports
in  0 2 0
out 4 2 0

free:
```

QCA ONE


(a) Inverter
(b) Majority
(c) OR
(d) AND
(g) XOR
(e) NOR
(f) NAND
(h) MUX 2-1
(i) D-Latch
(j) SR-Latch

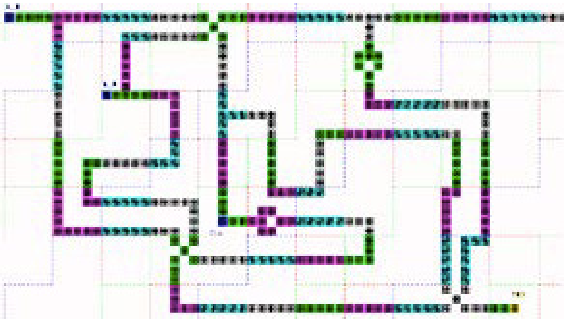
QCA ONE - Results



One bit full adder

QCA ONE - Results

8 bits
Ripple
Carry Adder



Conclusion & Future Works

- We proposed and implemented a QCA standard cell library;
- We presented some no optimized circuits implemented with the cells;

- **Placement and routing** must be developed;
- **More cells** are being created;
- A **QCADesigner** with **USE** and **QCA ONE** will released;
- **Clocking schemes and standard cells** library will be implemented to **NML**.