Gem State
INFORMATICS

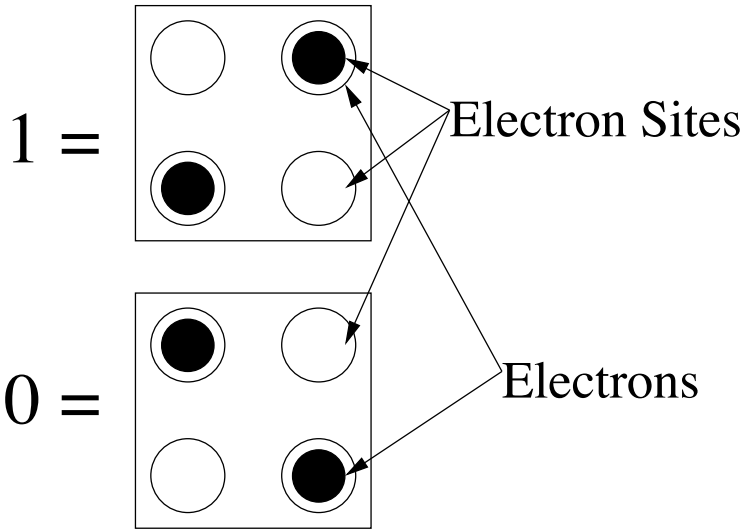
Quantum-dot Cellular Automata: A Brief Introduction

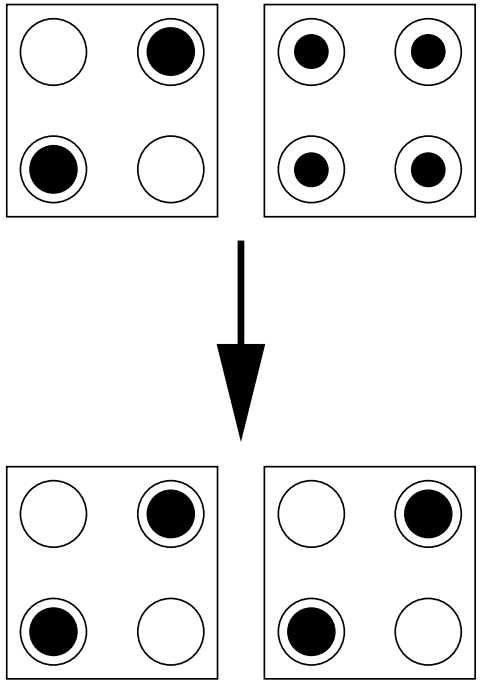
Sarah Frost-Murphy

Overview

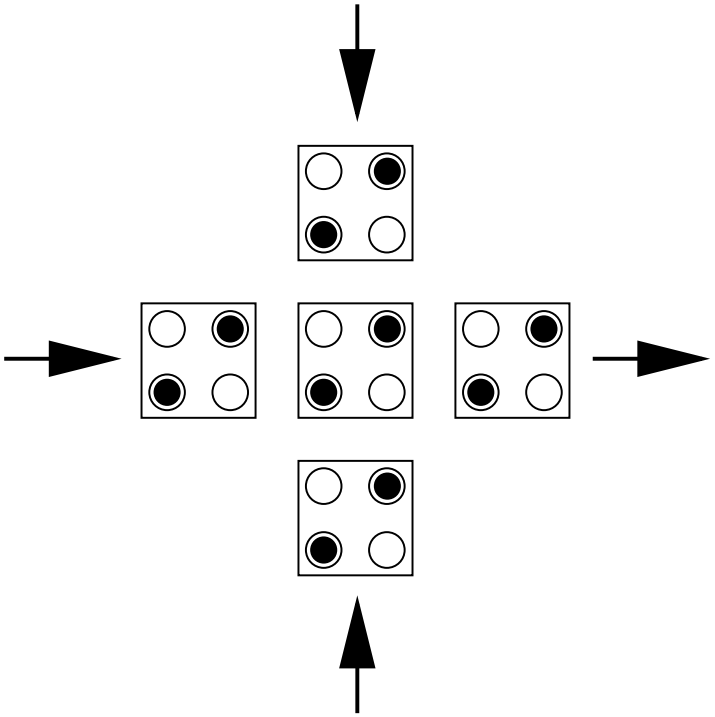
- Basic Device Operation
- Faults and Fault Tolerance
- The Clock
- Real QCA devices
- Architecture: Proof of Concept
- Floorplans
- Reversibility with QCA

The Basic Device



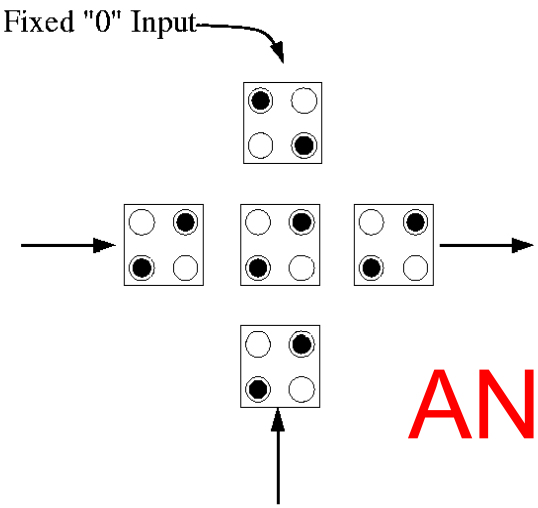


Majority Gate



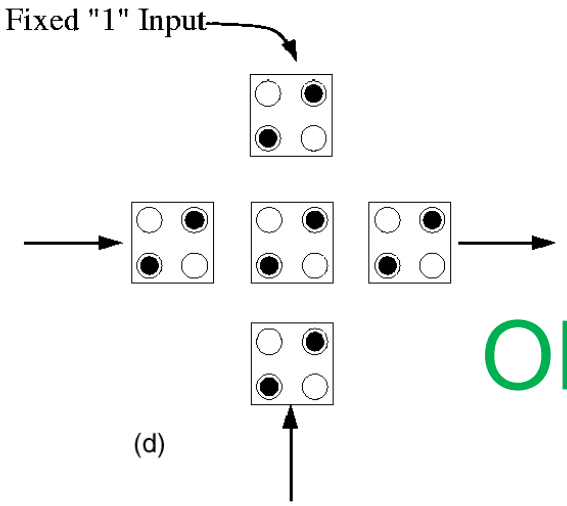
A	B	C	Out
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Majority Gate



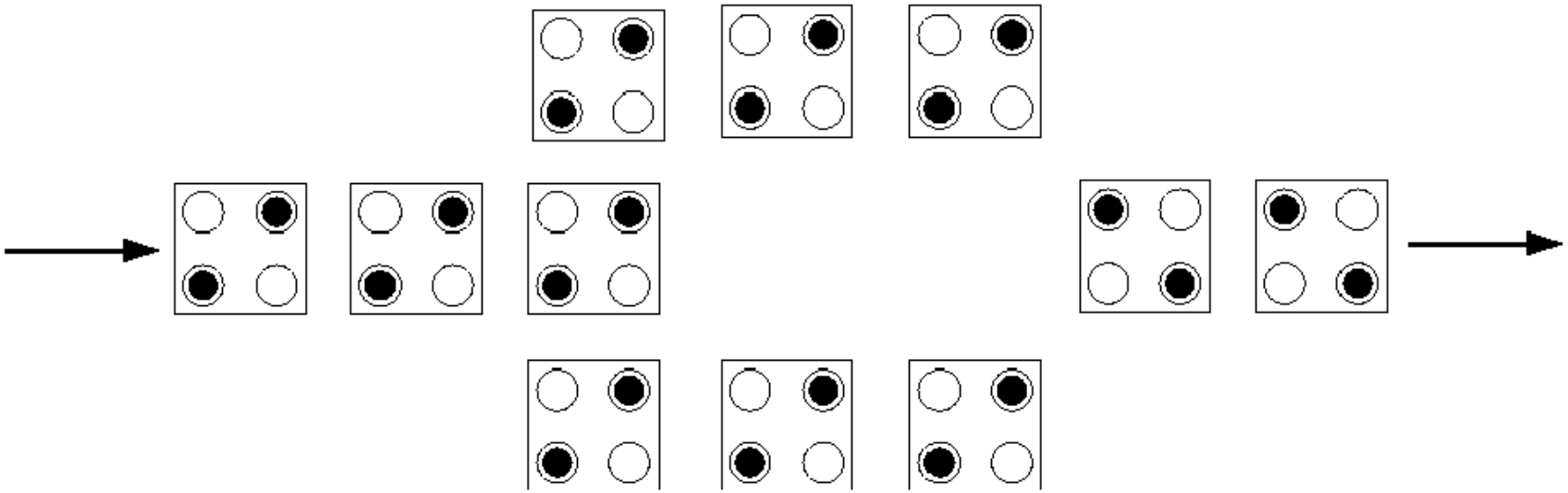
AND

A	B	C	Out
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1



OR

NOT Gate



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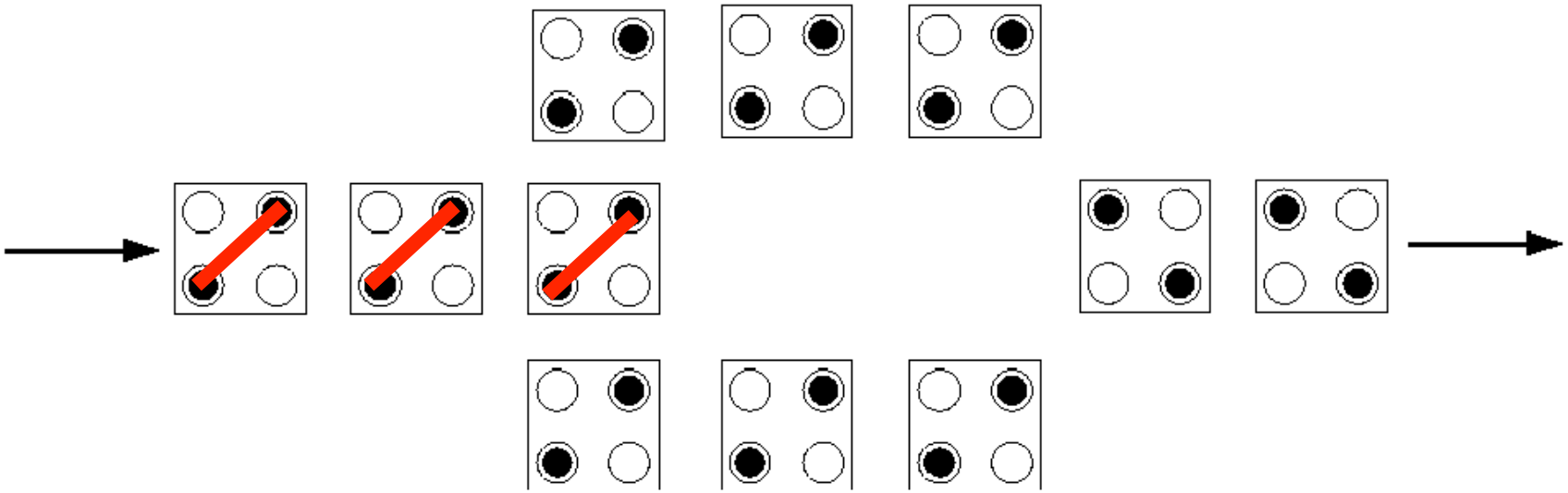

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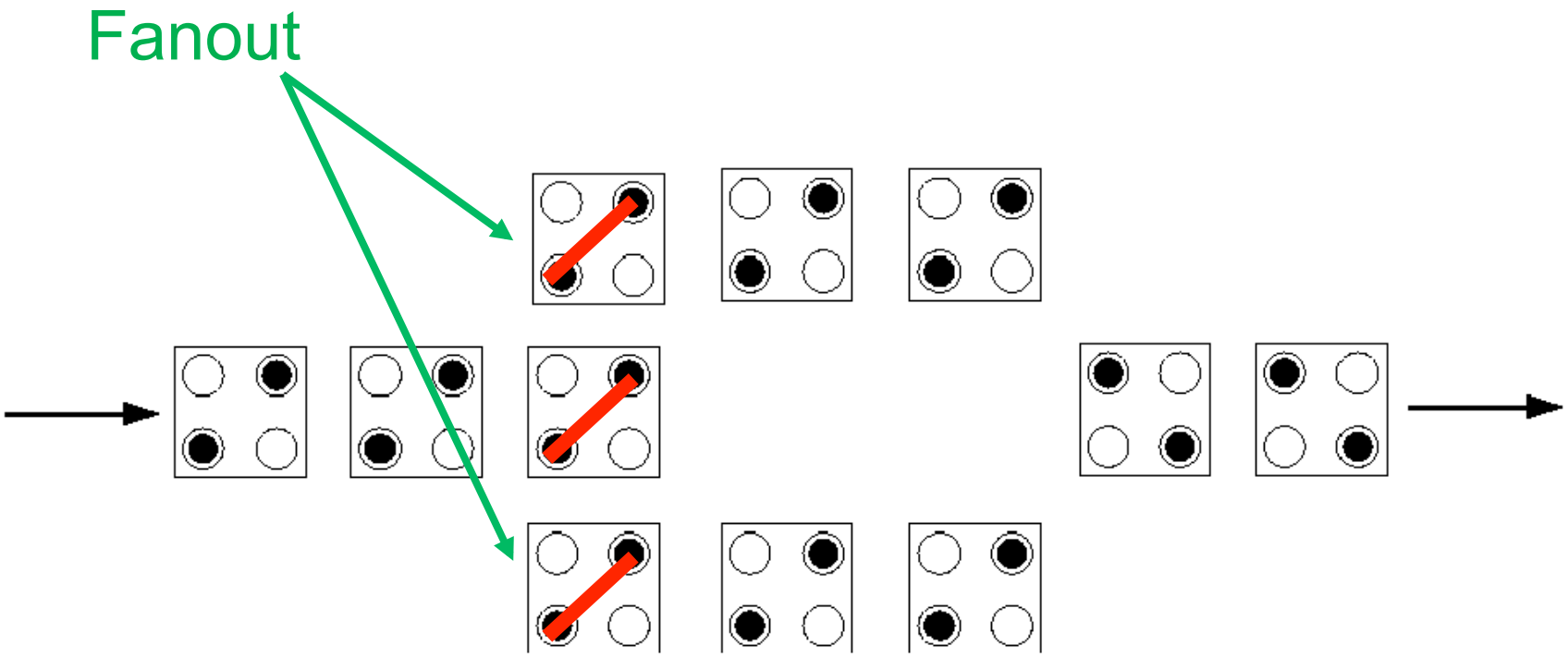

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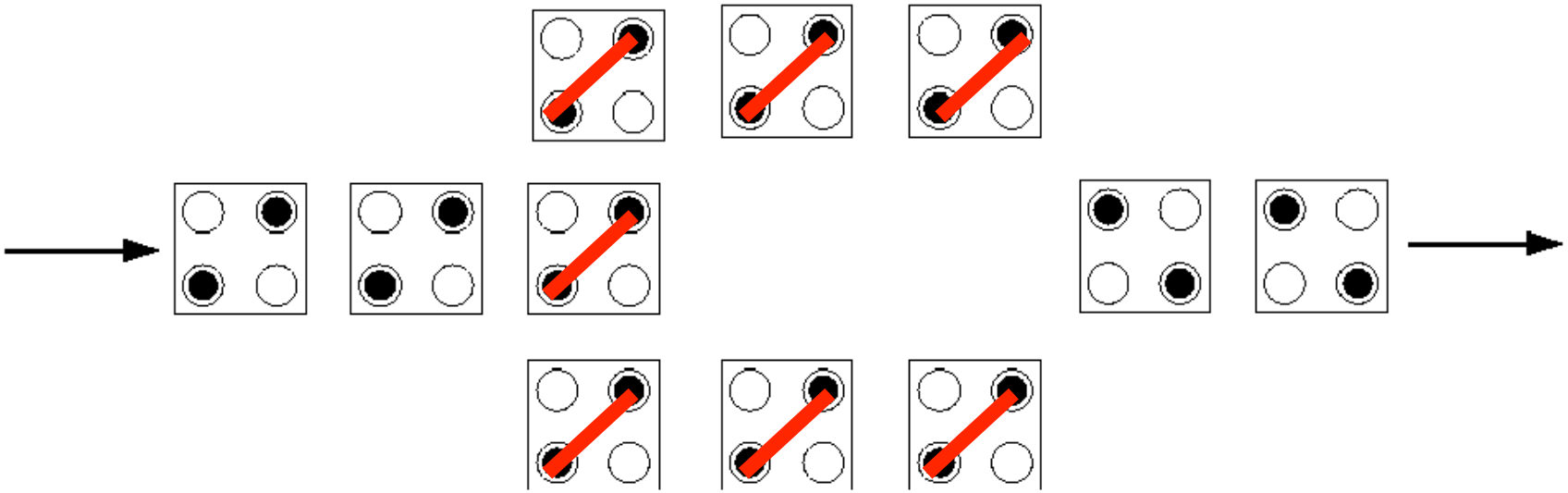
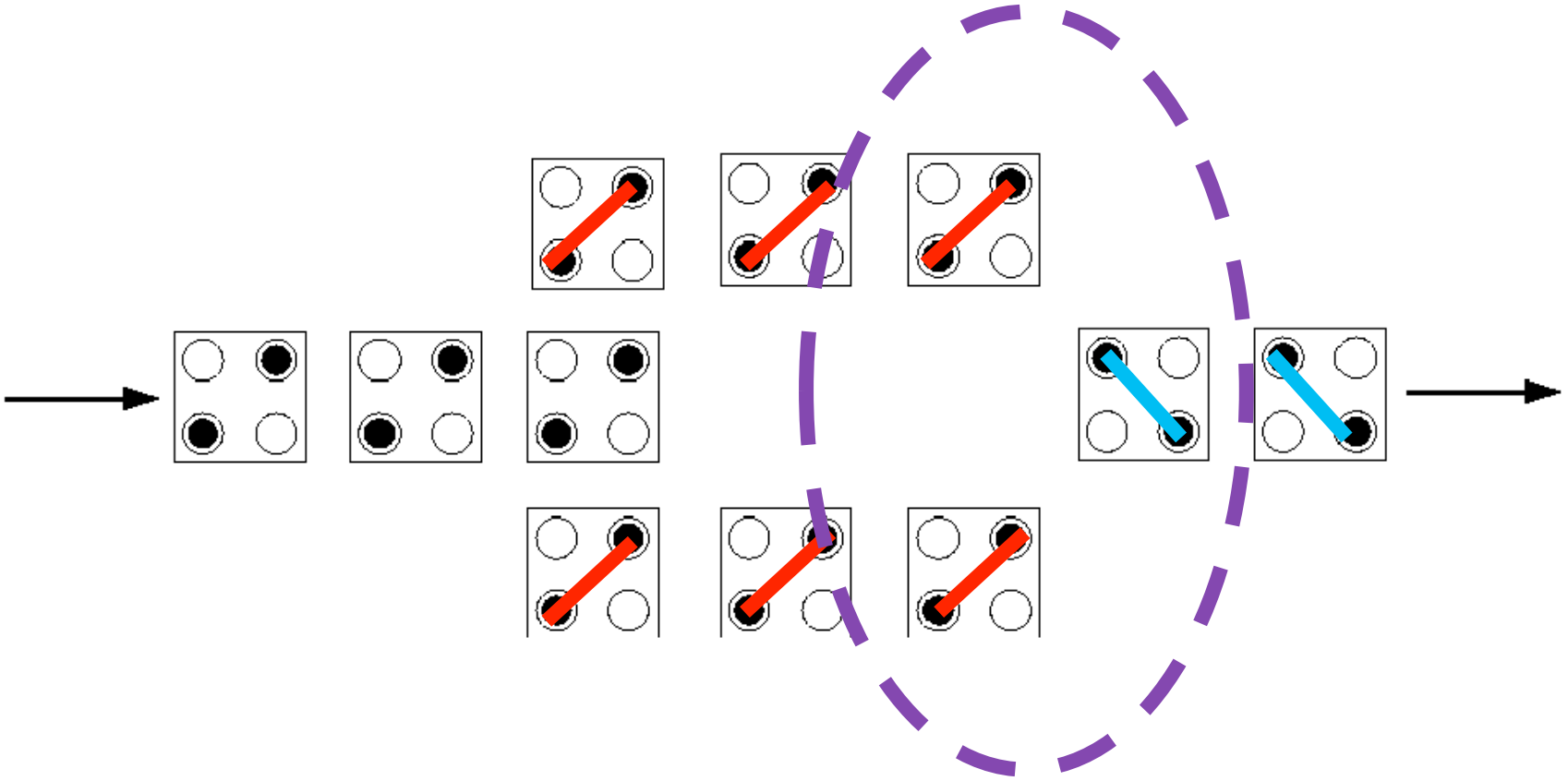
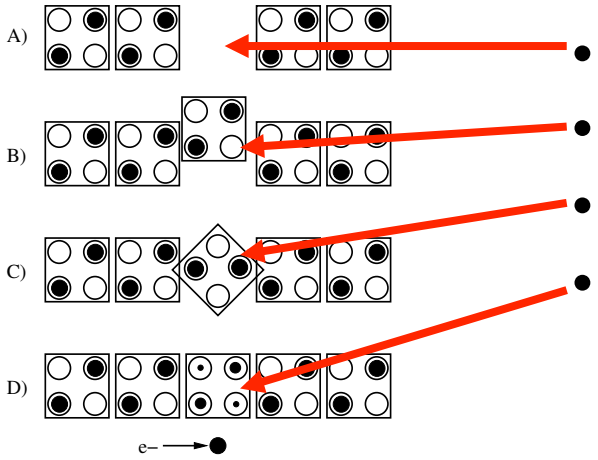


NOT Gate

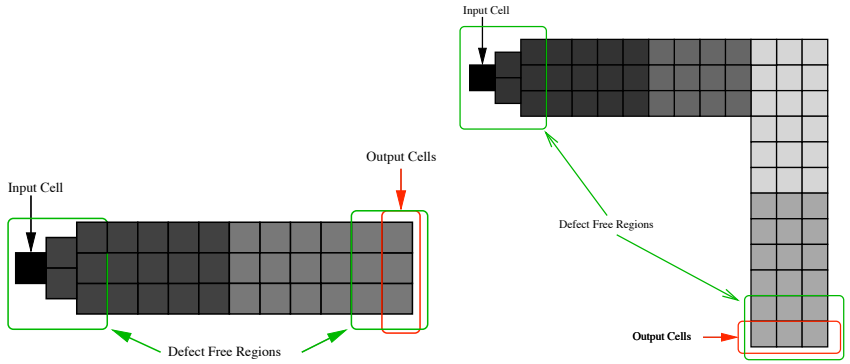


Fault Tolerance



- Missing cell defect
- Displacement defect
- Rotation defect
- Stray charge defect

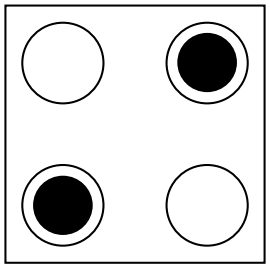
Dysart, 2009

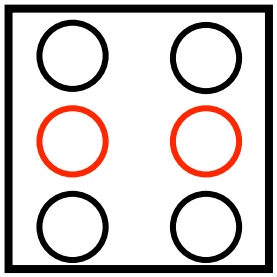


(a) A 3-wide straight wire. (b) A 3-wide bent wire.

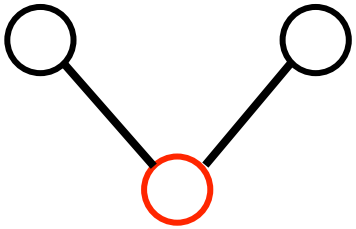
Dysart, 2005

Clocked QCA



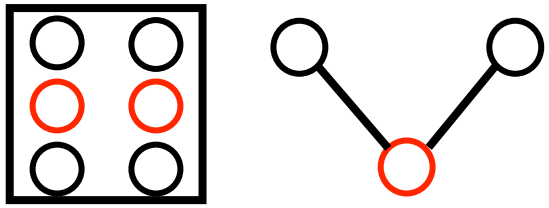


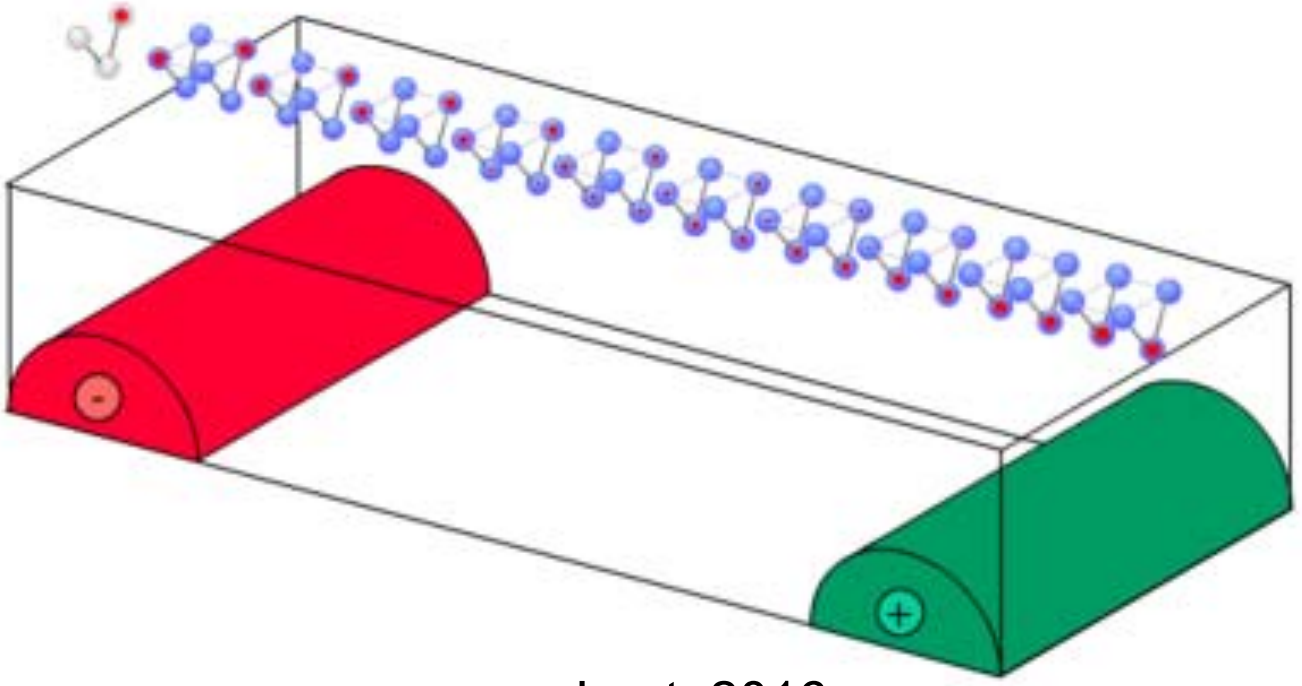
Top
View



Side
View

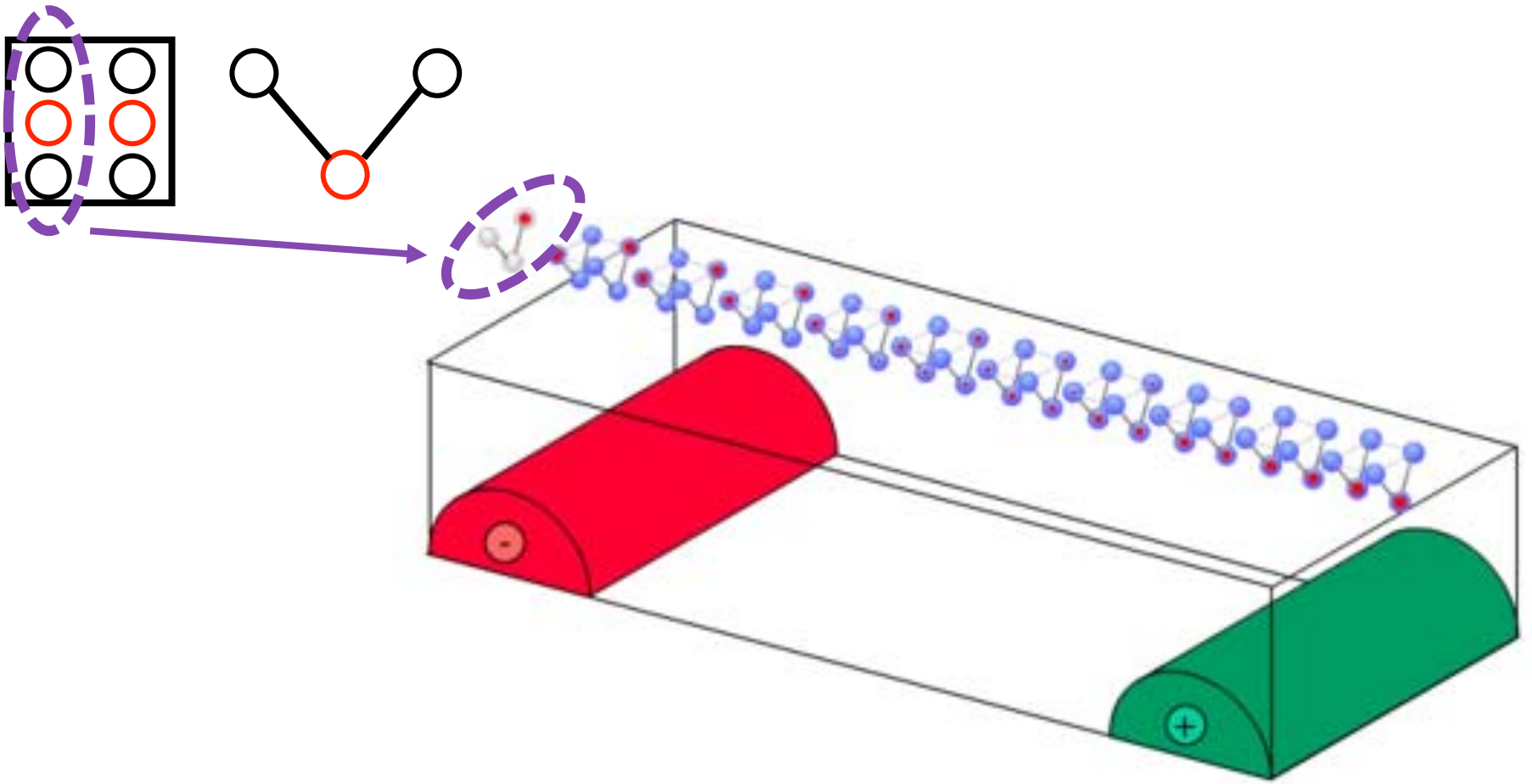
Clocked QCA





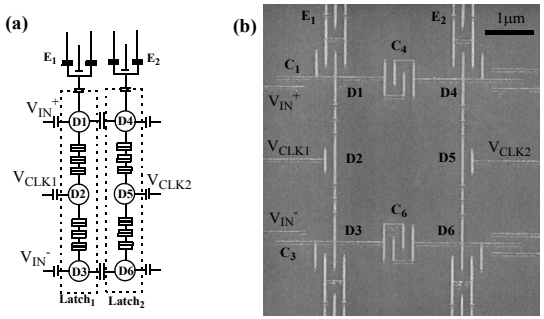
Lent, 2016.

Clocked QCA

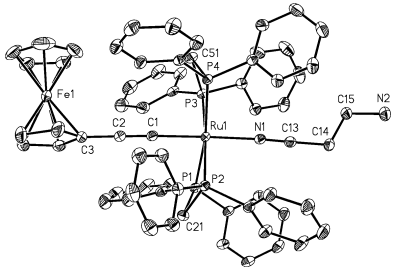


Lent, et.al, "Molecular Cellular Networks: A Non von Neumann Architecture for Molecular Electronics
2016 IEEE International Conference on Rebooting Computing (ICRC), 2016.

The Devices

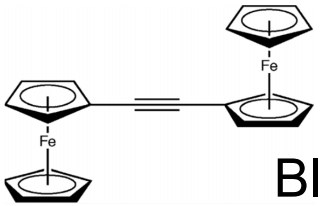


Clocked Shift Register
(Orlov, 2002)



Li, 2003

Figure 3. Structure of the cation of [*trans*-Ru(dppm)$_2$(C≡CFc)(N≡CCH$_2$-CH$_2$NH$_2$)][PF$_6$] (**3**) with 50% thermal ellipsoids (hydrogens omitted).



Blair, 2016

Diferrocenylacetylene (DFA)

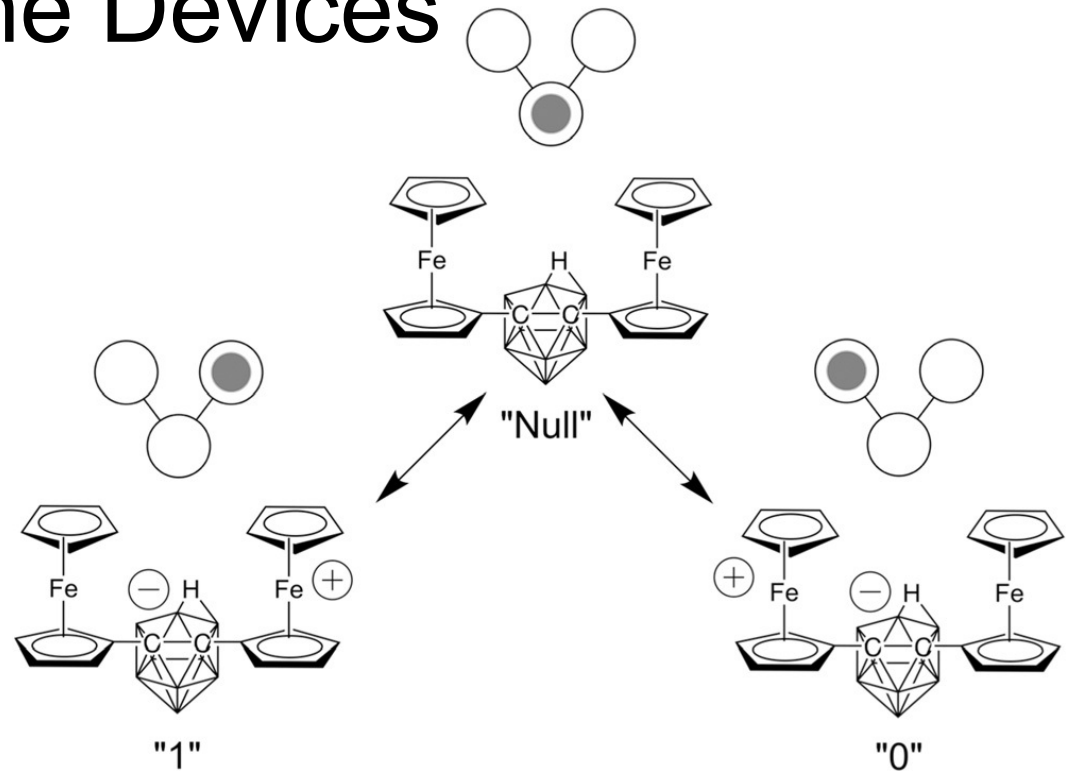
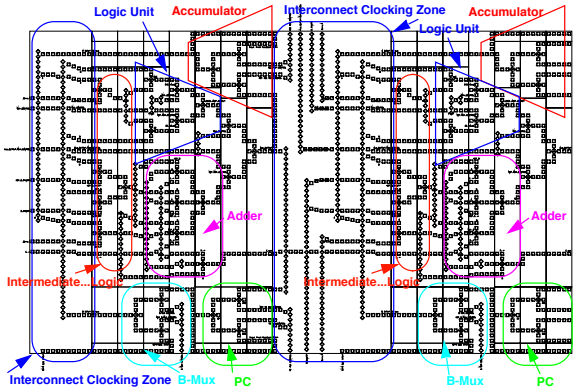


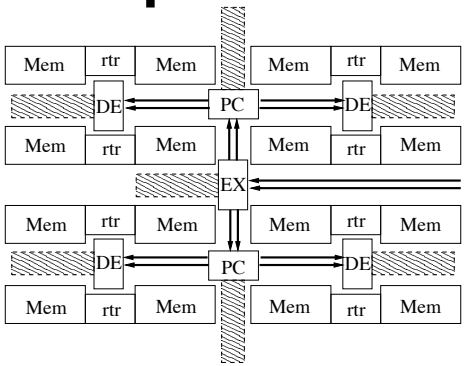
Figure 4. Bridge-mediated charge-transfer mechanism for the molecular switch $Fc^{+}FcC_2B_9^{-}$ (**3 a**), highlighting the all-neutral null state intermediate.

Christie, 2015

Architecture: Proofs of Concept



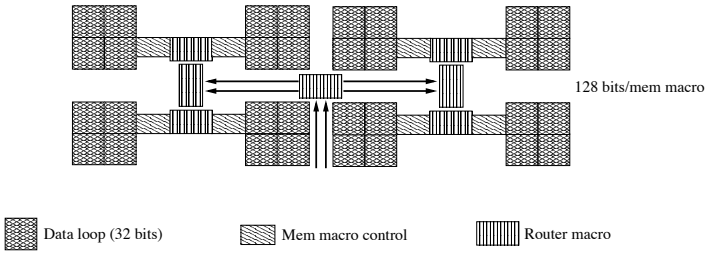
Traditional Processor
(Niemier 2004)



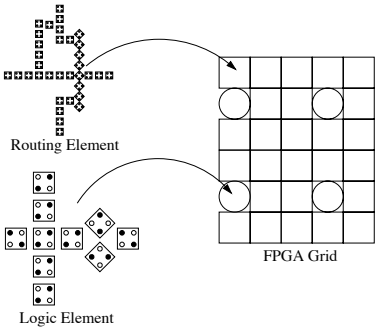
= Processing Logic

DE = Decode
PC = PC Inc
EX = Execute
rtr = Non–processing Router Macro
Mem = Memory Macro

Bouncing Threads
(Frost 2005)



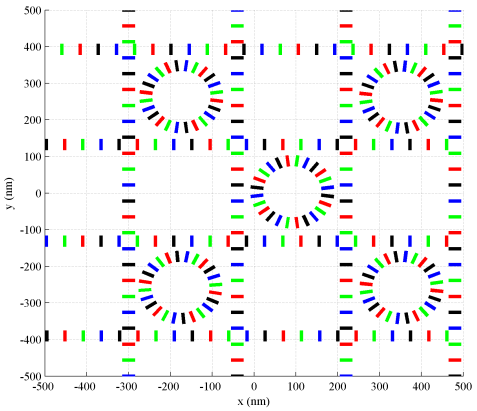
Traditional Memory
(Frost 2005)

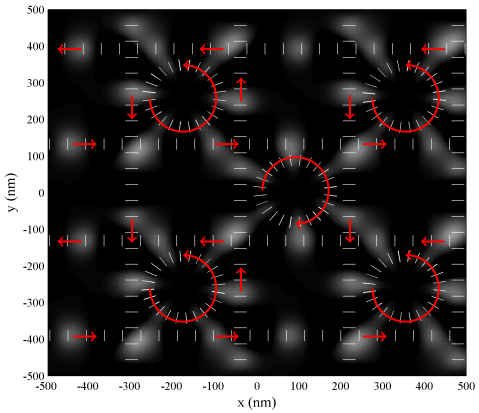


FPGA
(Niemier 2002)

Clocking Floorplans

- Fabrication Issues
  - Structural Regularity
  - Temporal Regularity
- Architecture Issues
  - Layout = Timing
  - Flexible routing
  - Feedback





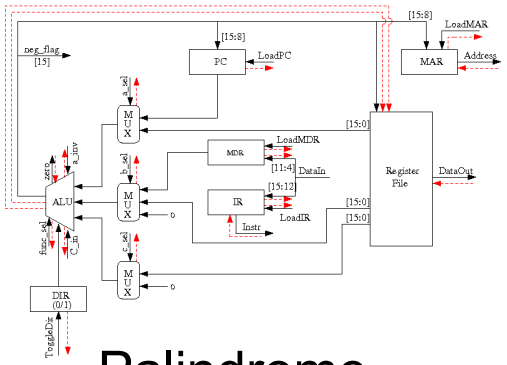
Blair, 2018

Physically Reversible Computing with QCA

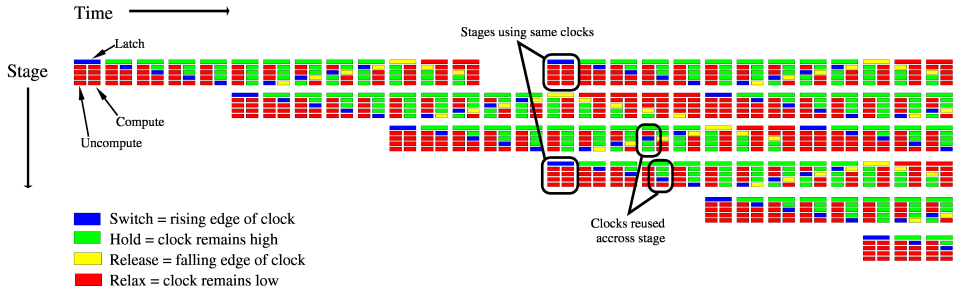
- Adiabatic: Slow compared to switching speed
  - Time for electron to hop across a molecule = very short
  - Clock speeds compared to that switching speed = very fast

- Pidaparthi and Lent: Exponential decrease in energy dissipation with adiabaticity (calculated)

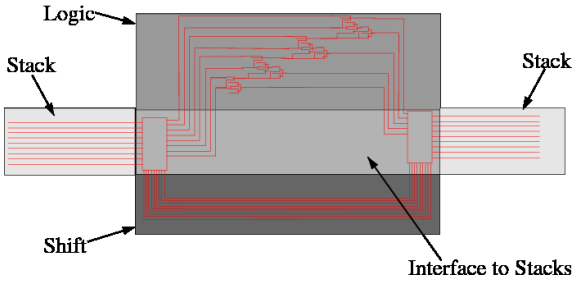
Logically Reversible Computing with QCA



Palindrome -
Reversible at datapath/ISA level
(Frost-Murphy, 2009)



Retractile Cascade in QCA
(Frost-Murphy, 2006)



Collapsed Bennett

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