

Memristive oscillatory circuits for resolution of NP-complete logic puzzles: Sudoku case



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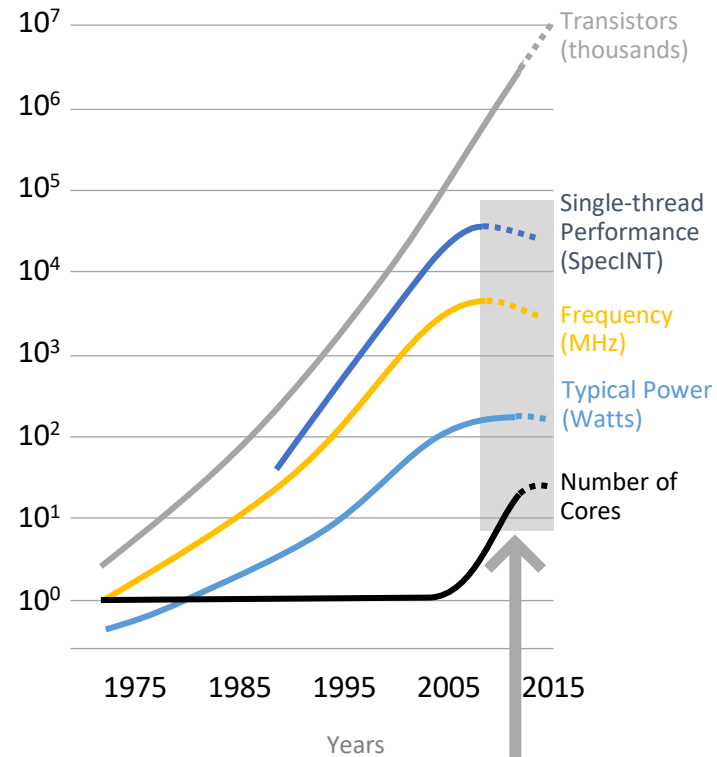
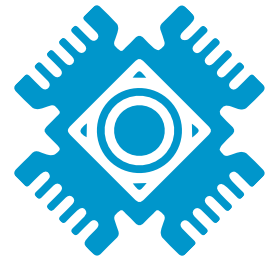
[‡] Department of Quantum and Computer Engineering, Delft University of Technology, Delft, The Netherlands

2020 IEEE International Symposium on Circuits and Systems
Virtual, October 10-21, 2020

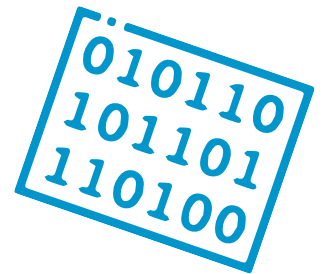
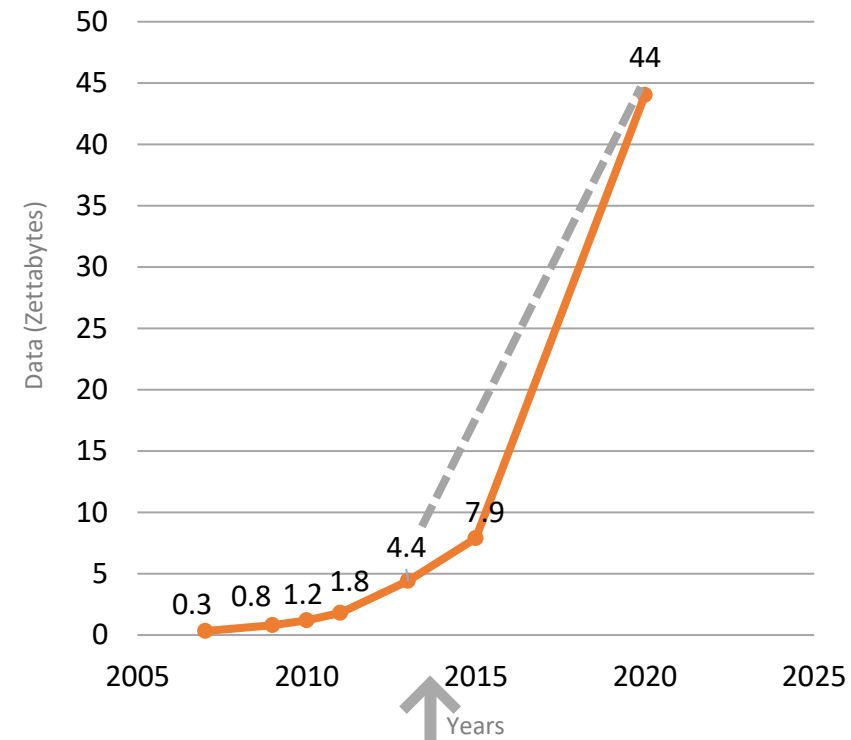


Solving NP-Complete Logic Puzzles

Conventional Technology



Data nearly doubles every 2 years (2013 - 2020)

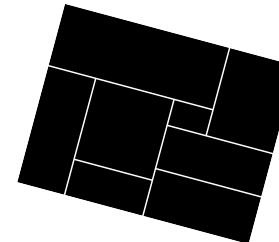
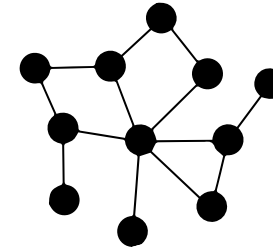
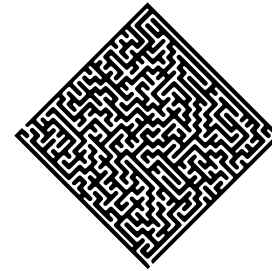
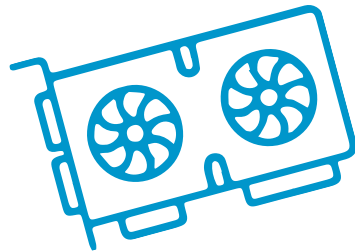
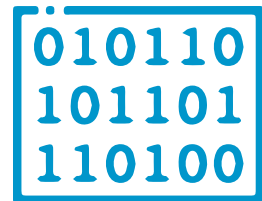
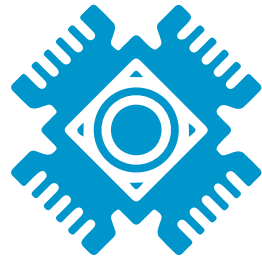


R. Stanley Williams, "A Nanotechnology-Inspired Grand Challenge for Future Computing", Hewlett Packard Labs.



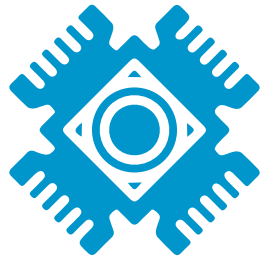
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Solving NP-Complete Logic Puzzles

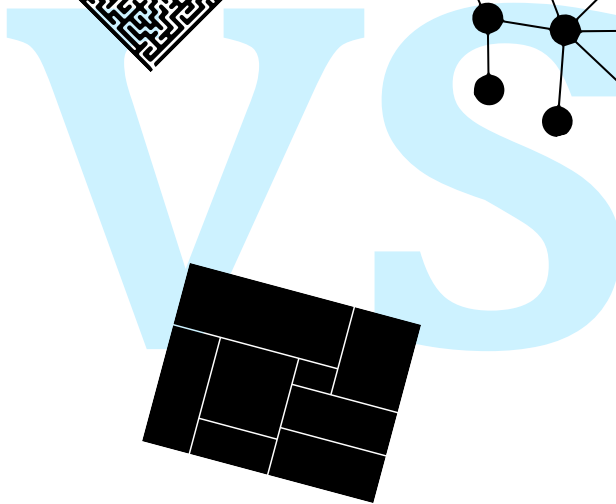
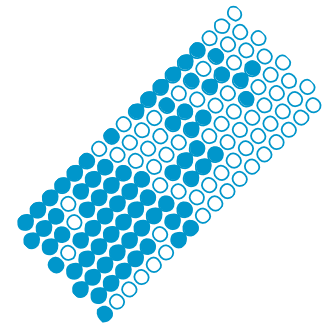
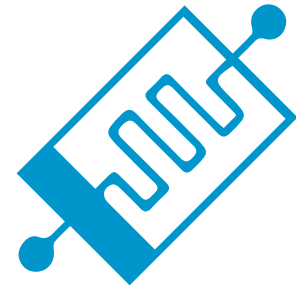
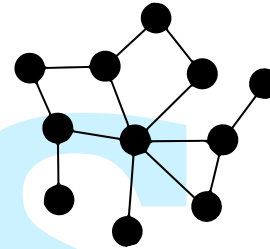
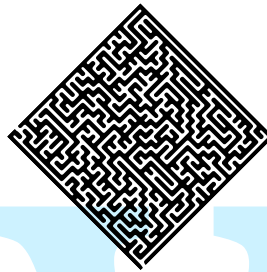
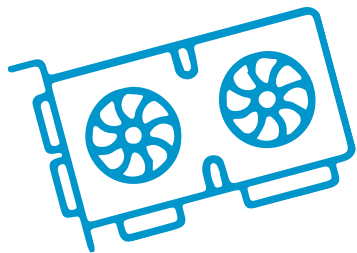


Solving NP-Complete Logic Puzzles

Unconventional Computing Circuits



010110
101101
110100



Presentation Outline

- › Proposed Memristor-RC Oscillating System
- › The Sudoku Logic Puzzle in brief
- › Representing Sudoku in a Memristor-RC Circuit
- › Conclusions



The Memristor Device

From the Prediction

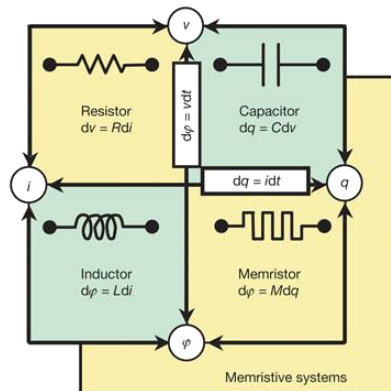
1971

IEEE TRANSACTIONS ON CIRCUIT THEORY, VOL. CT-18, NO. 5, SEPTEMBER 1971

507

Memristor—The Missing Circuit Element

LEON O. CHUA, SENIOR MEMBER, IEEE

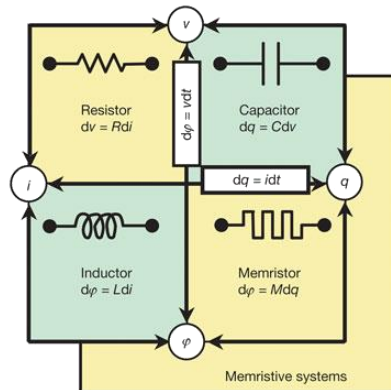


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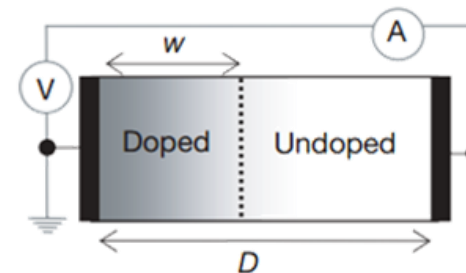
The Memristor Device

To the Realization

1971



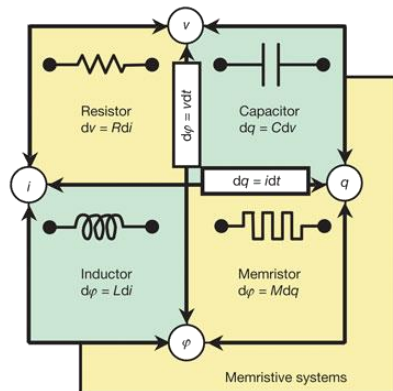
2008



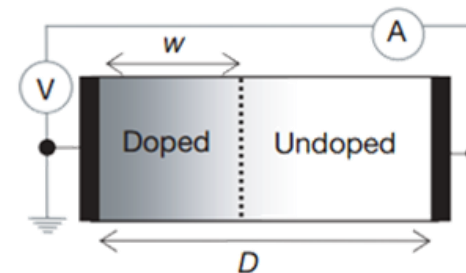
The Memristor Device

Today's Applications

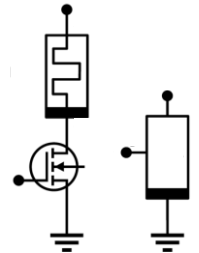
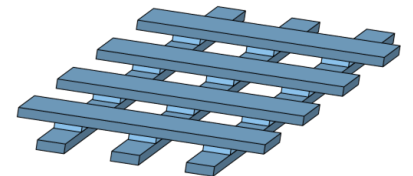
1971



2008



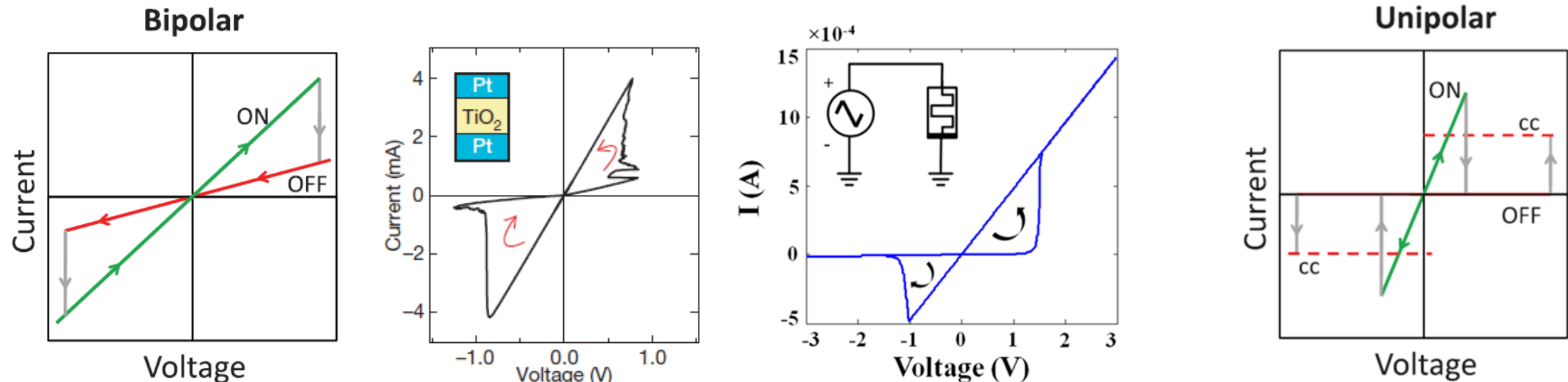
today



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Memristor Model

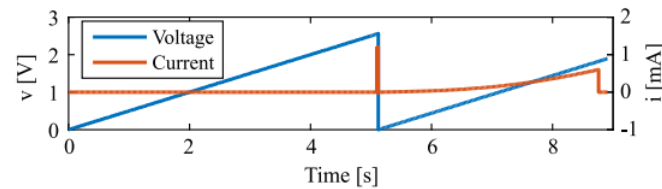
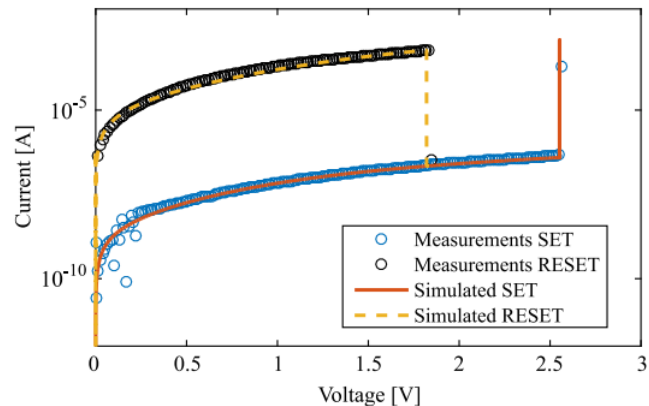
Memristor In Brief



I. Vourkas, A. Batsos, and G. Ch. Sirakoulis, "SPICE modeling of nonlinear memristive behavior", *International Journal of Circuit Theory Applications*, vol. 43, no. 5, pp. 553–565, May 2015.



Memristor Model



Unipolar device fitting: $v - i$ curves.

Voltage-current relationship together with the voltage-current transients.

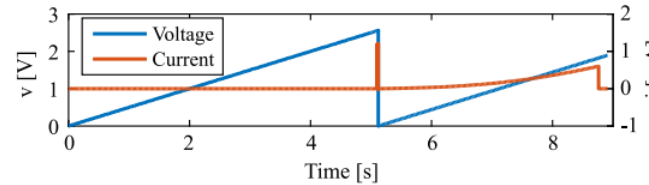
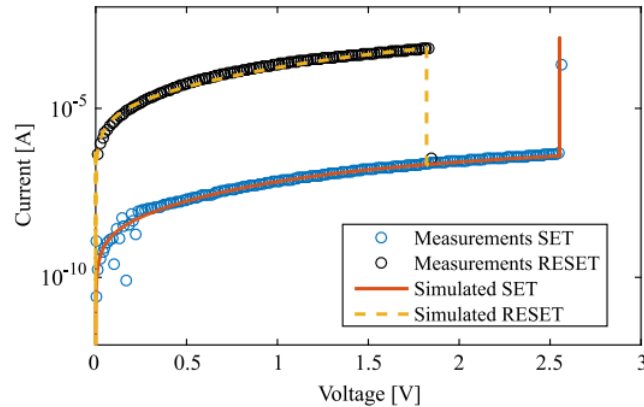
The measurement method imposes the input voltage waveform: right after the SET is accomplished the sawtooth wave is reset to perform the next switch.

F. Garcia-Redondo, R. P. Gowers, A. Crespo-Yepes, M. L'opez-Vallejo, and L. Jiang, **"SPICE compact modeling of bipolar/unipolar memristorswitching governed by electrical thresholds"**, *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 63, no. 8, pp. 1255–1264, 2016.



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Schematic for the fundamentals of the storage mechanism in unipolar RRAMs, including preliminary forming for initiating the localized filament, RESET for filament thermal rupture and SET for the structural recovery of the filament.

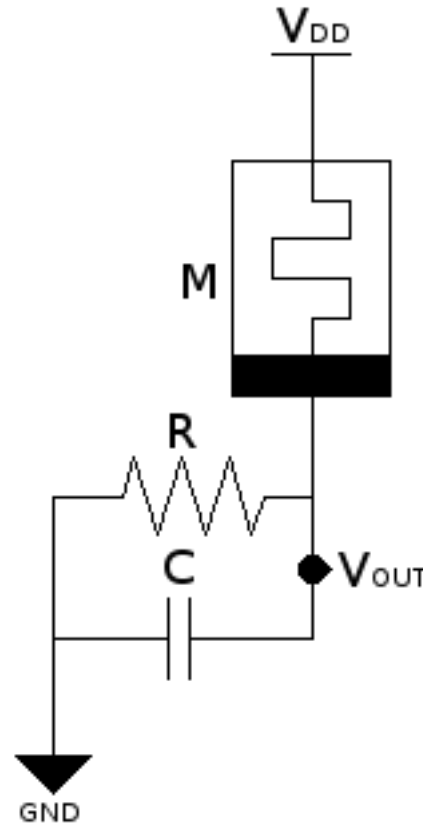
Copyright 2009, American Institute of Physics.

D. Ielmini, R. Bruchhaus, R. Waser, **"Thermochemical resistive switching: materials, mechanisms, and scaling projections"**, *Phase Transitions*, vol. 84, no. 7, pp. 570-602, July 2011.

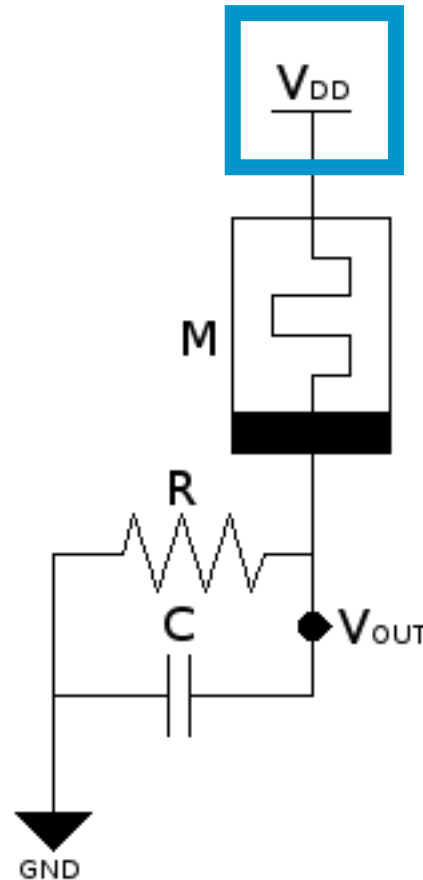


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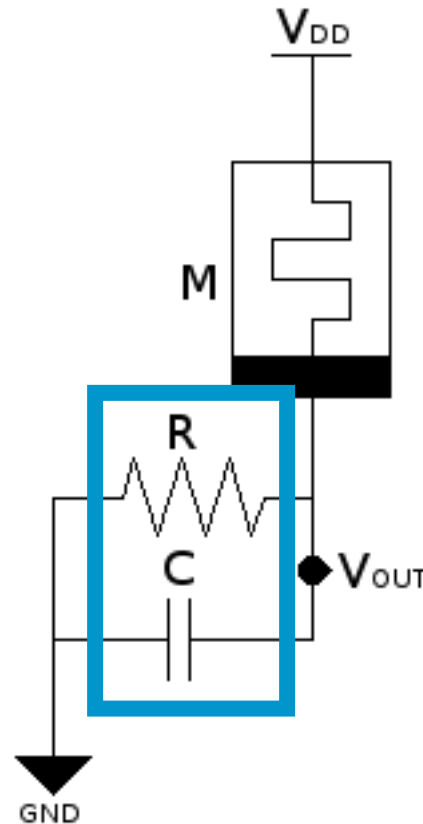
Memristor-RC Oscillating System



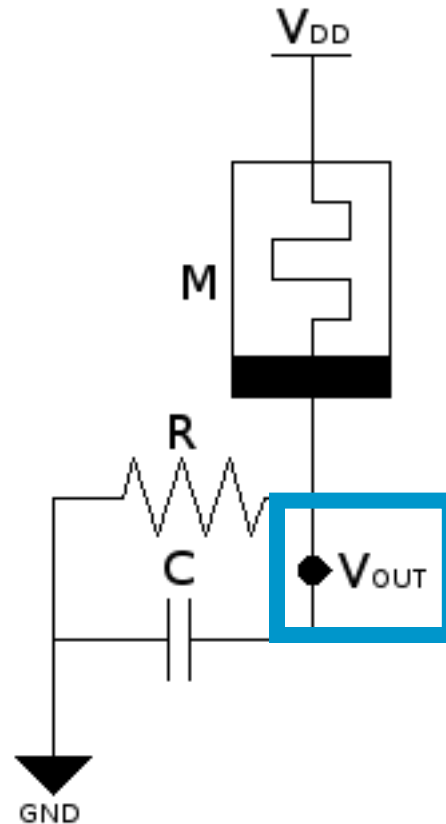
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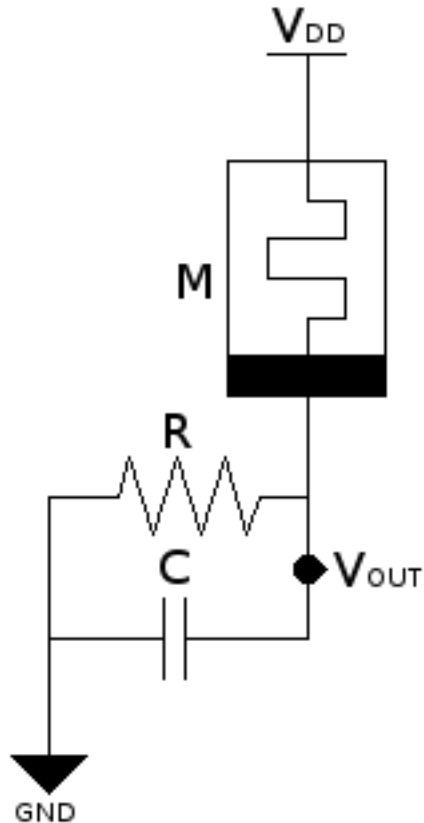
Memristor-RC Oscillating System



Memristor-RC Oscillating System



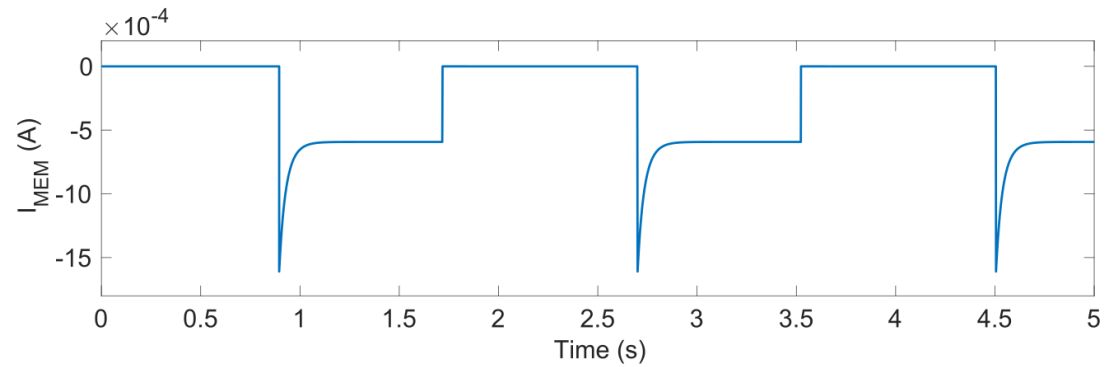
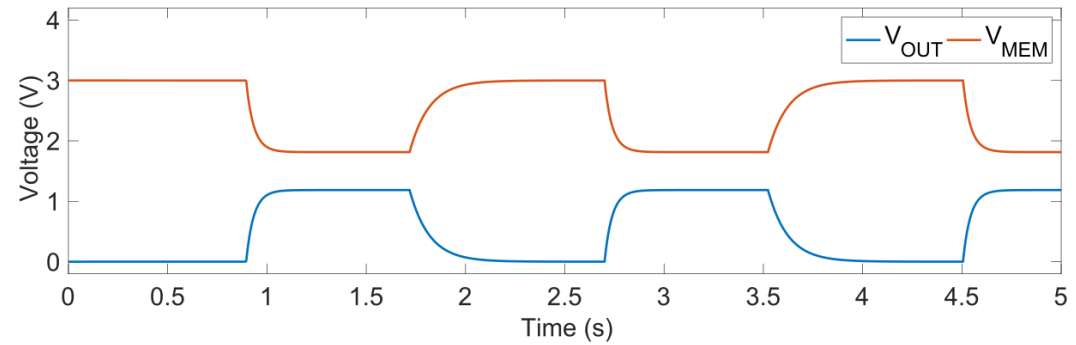
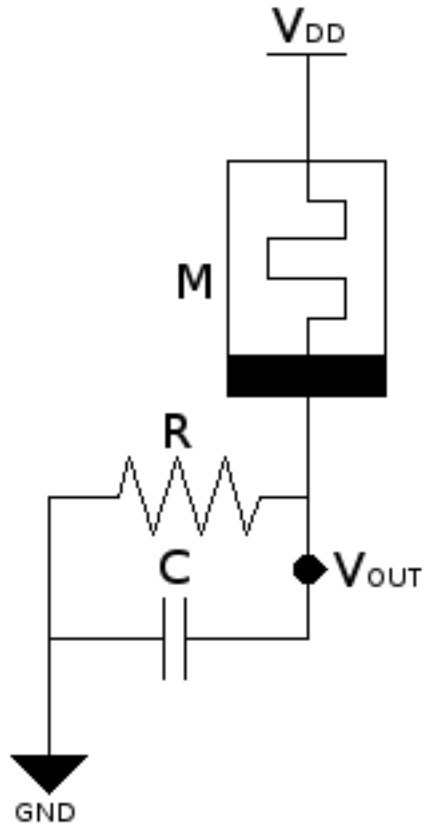
Memristor-RC Oscillating System



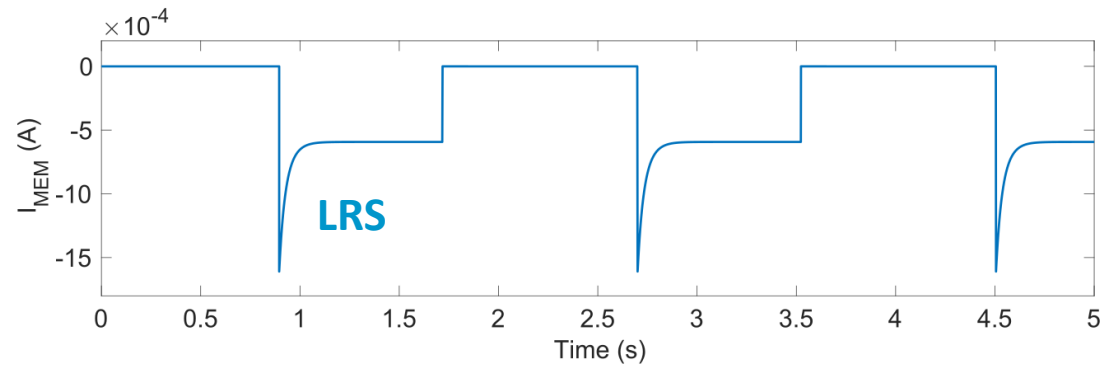
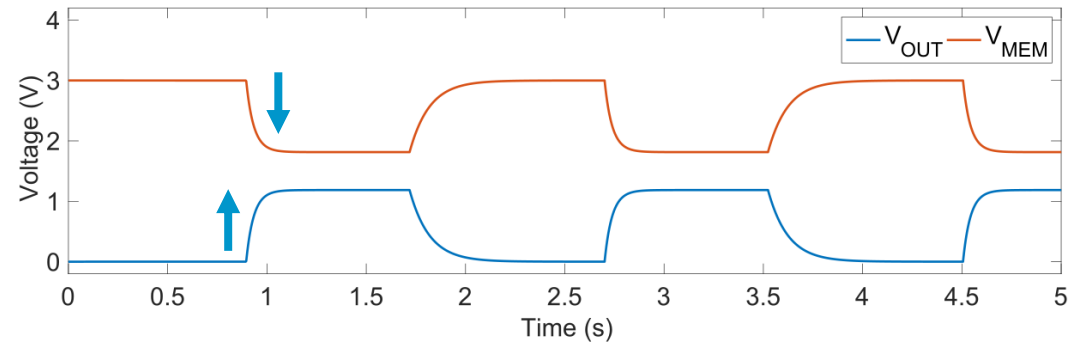
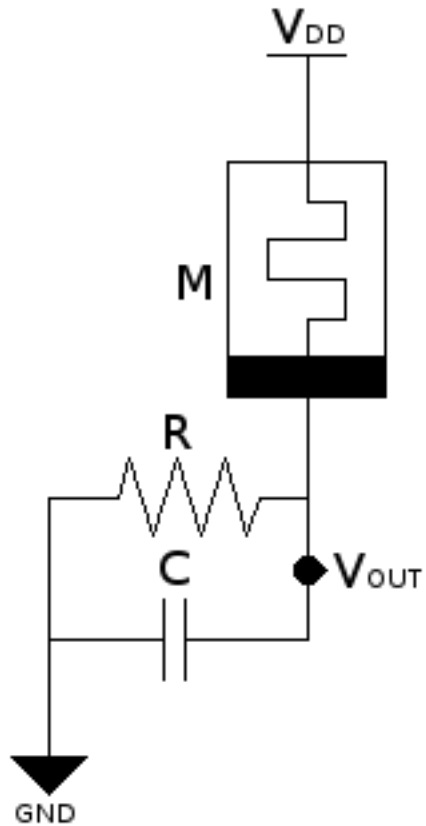
$$LRS < R \ll HRS$$



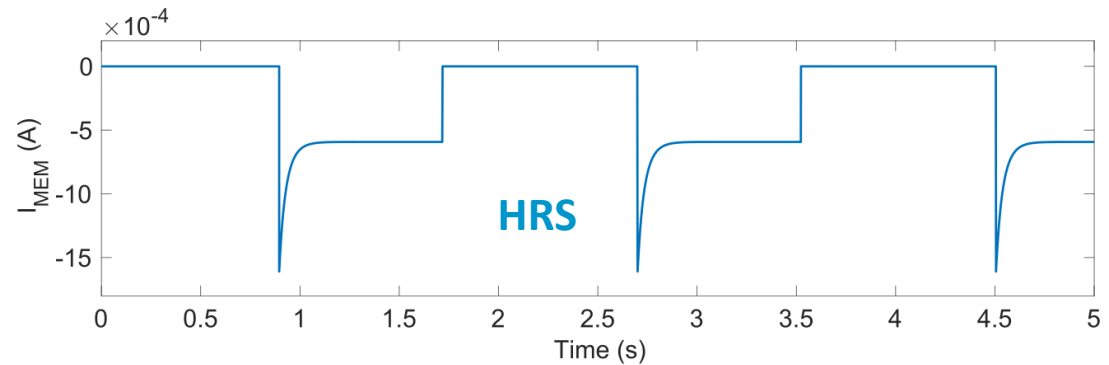
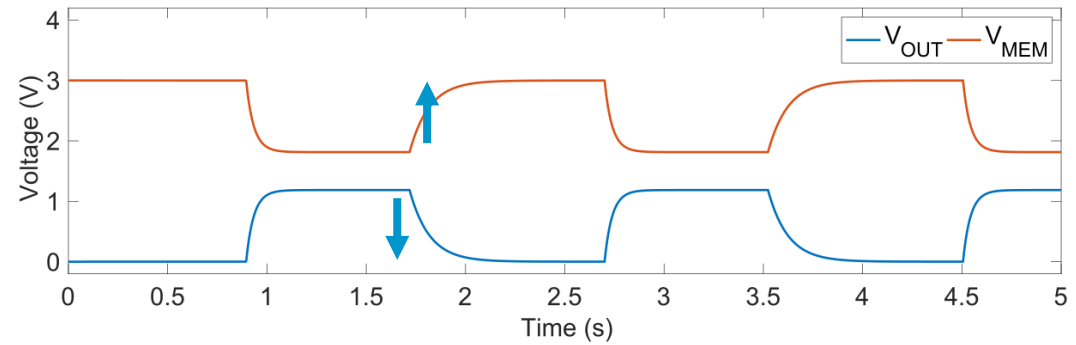
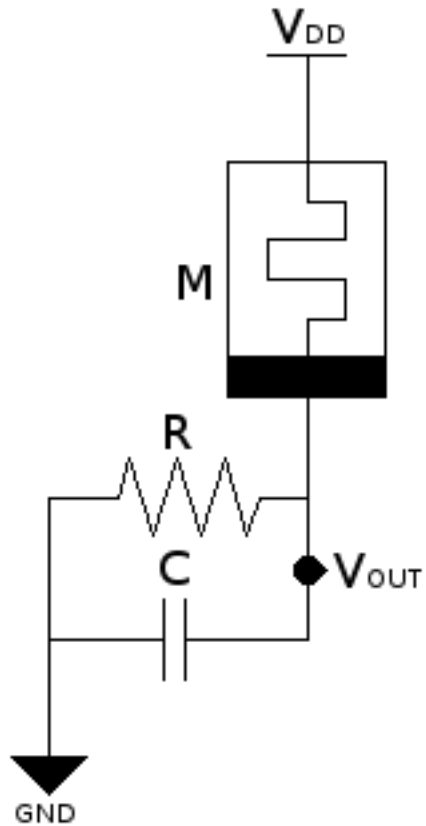
Memristor-RC Oscillating System



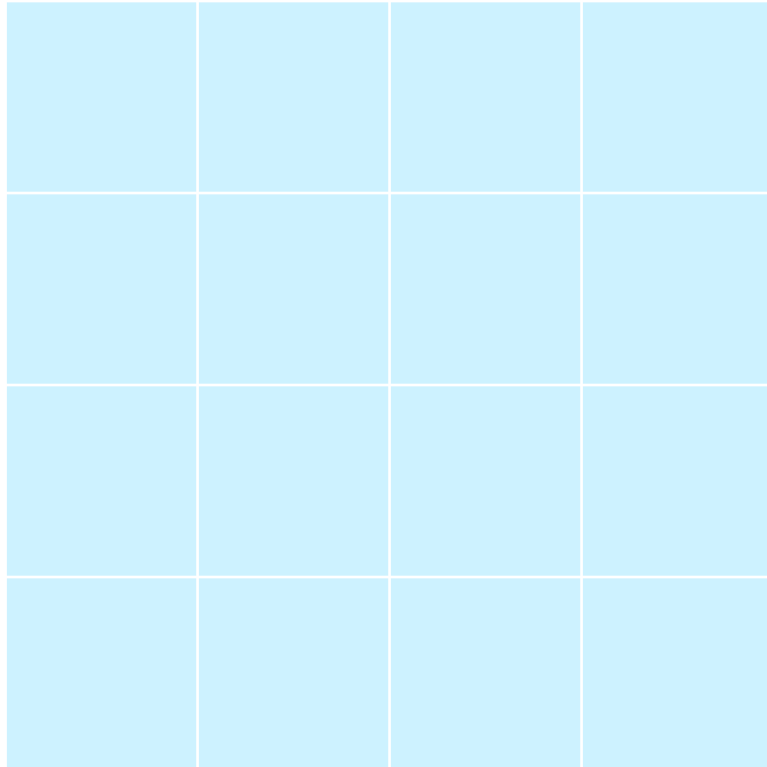
Memristor-RC Oscillating System



Memristor-RC Oscillating System



Sudoku in brief



数独



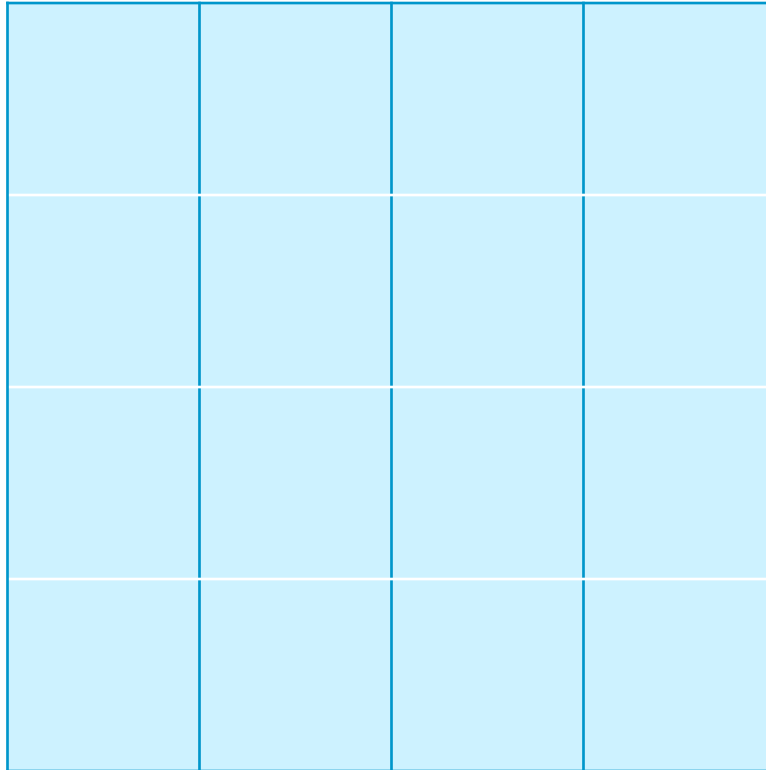
Sudoku in brief

Rows



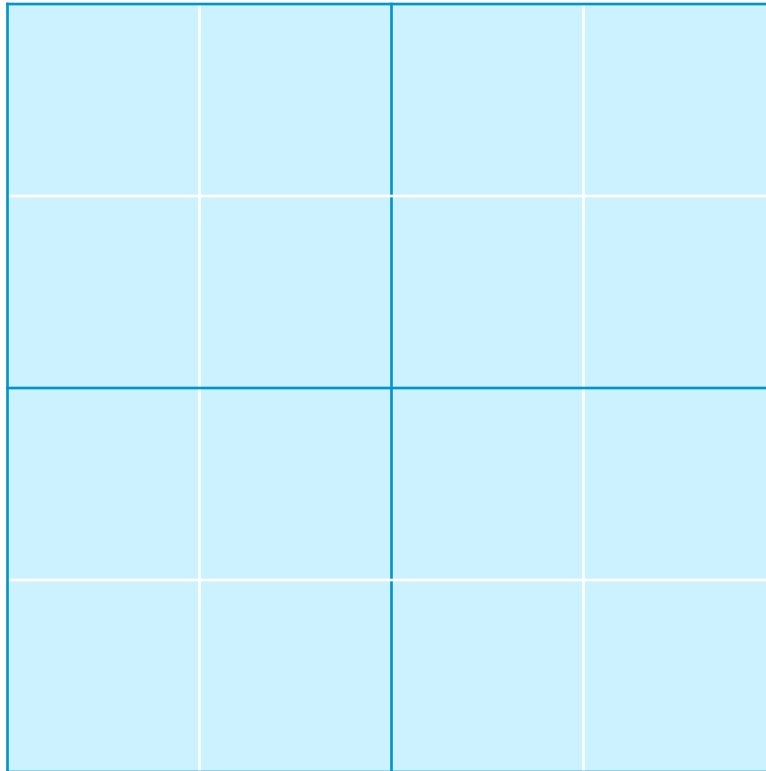
Sudoku in brief

Columns



Sudoku in brief

Groups



Sudoku in brief

Pre-defined Cells

2			1
4		1	
3	1		2



Sudoku in brief

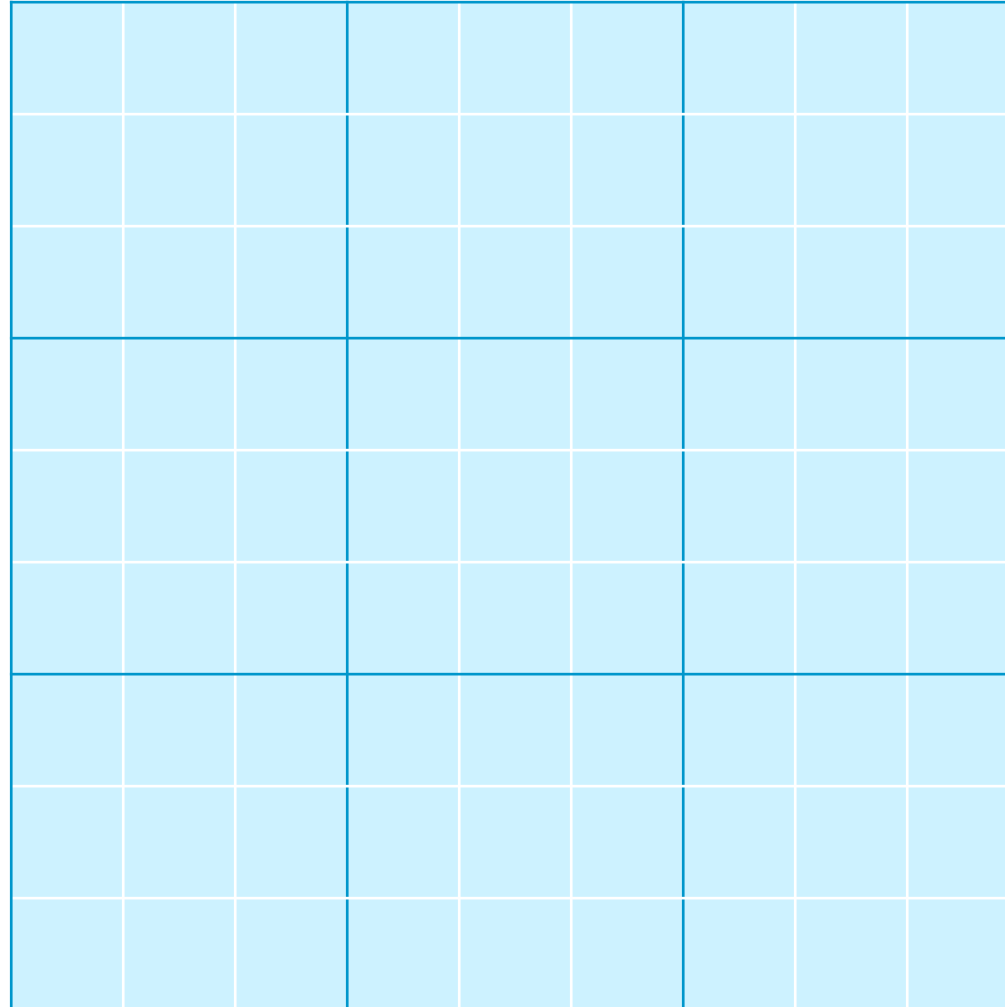
Solution

2	4	3	1
1	3	2	4
4	2	1	3
3	1	4	2



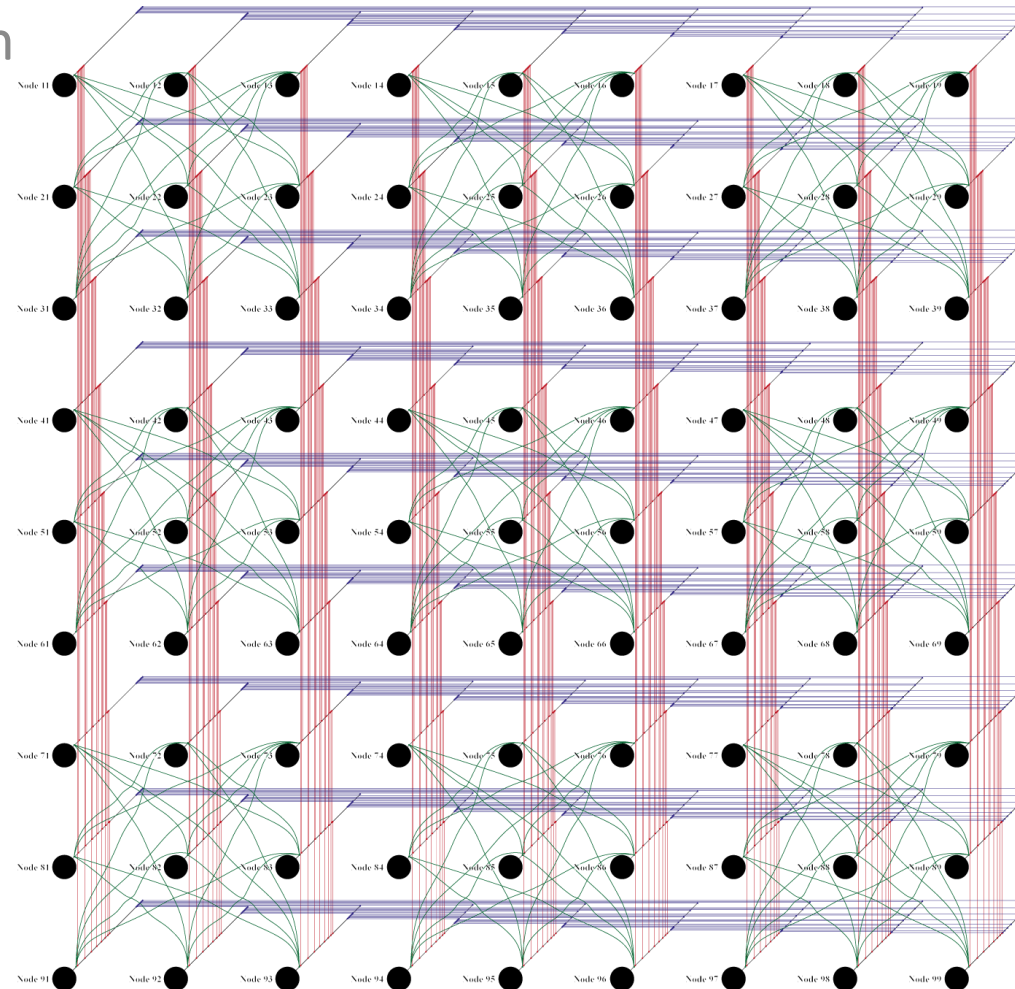
Sudoku Representation

9x9 Sudoku



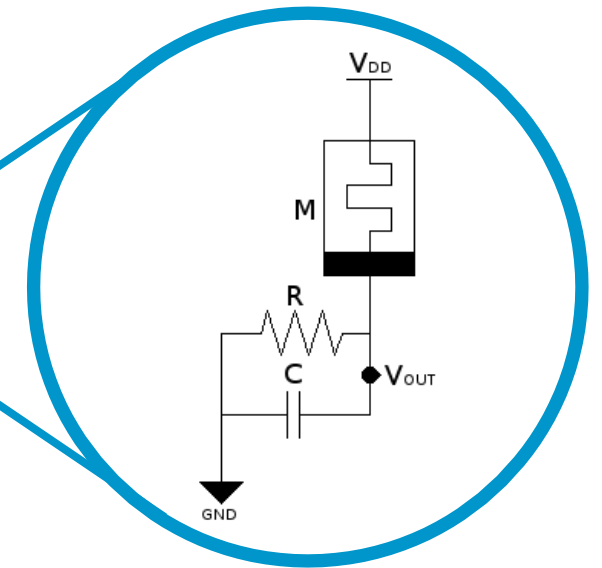
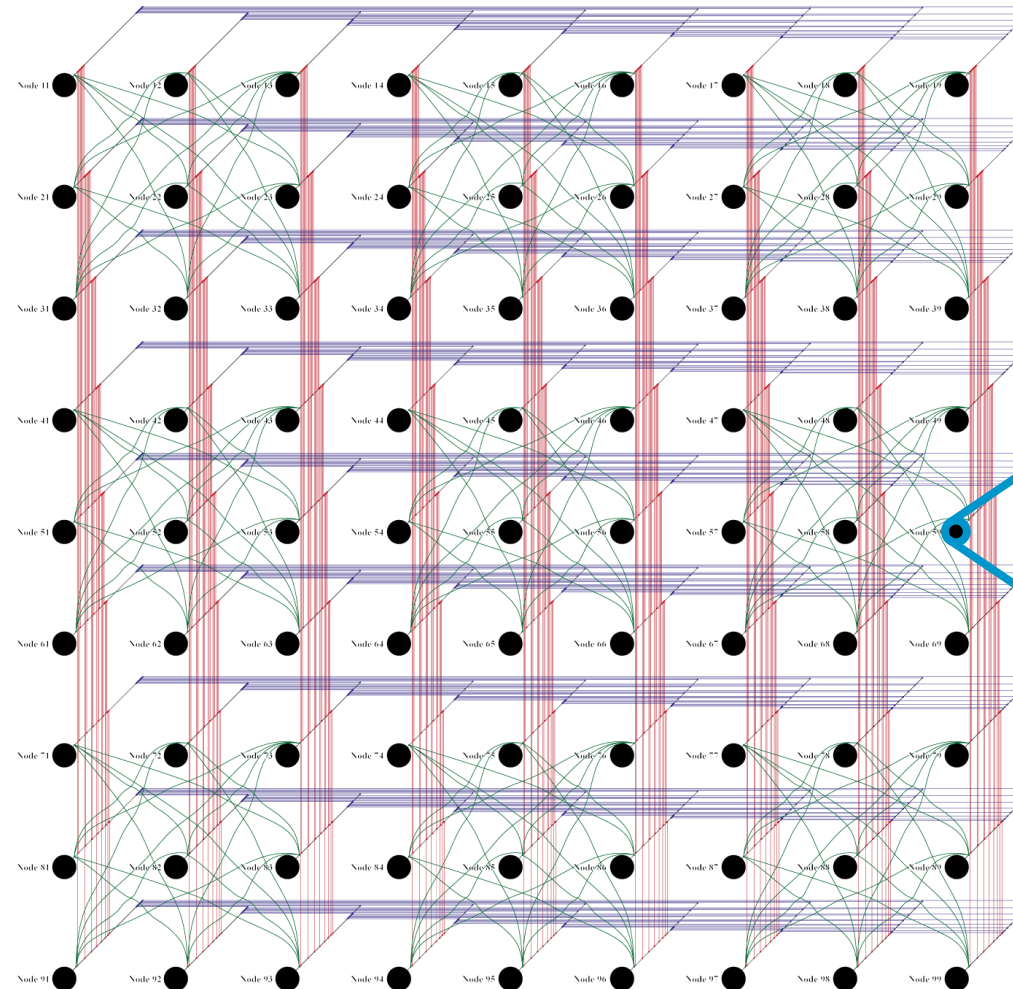
Sudoku Representation

9x9 Sudoku Representation



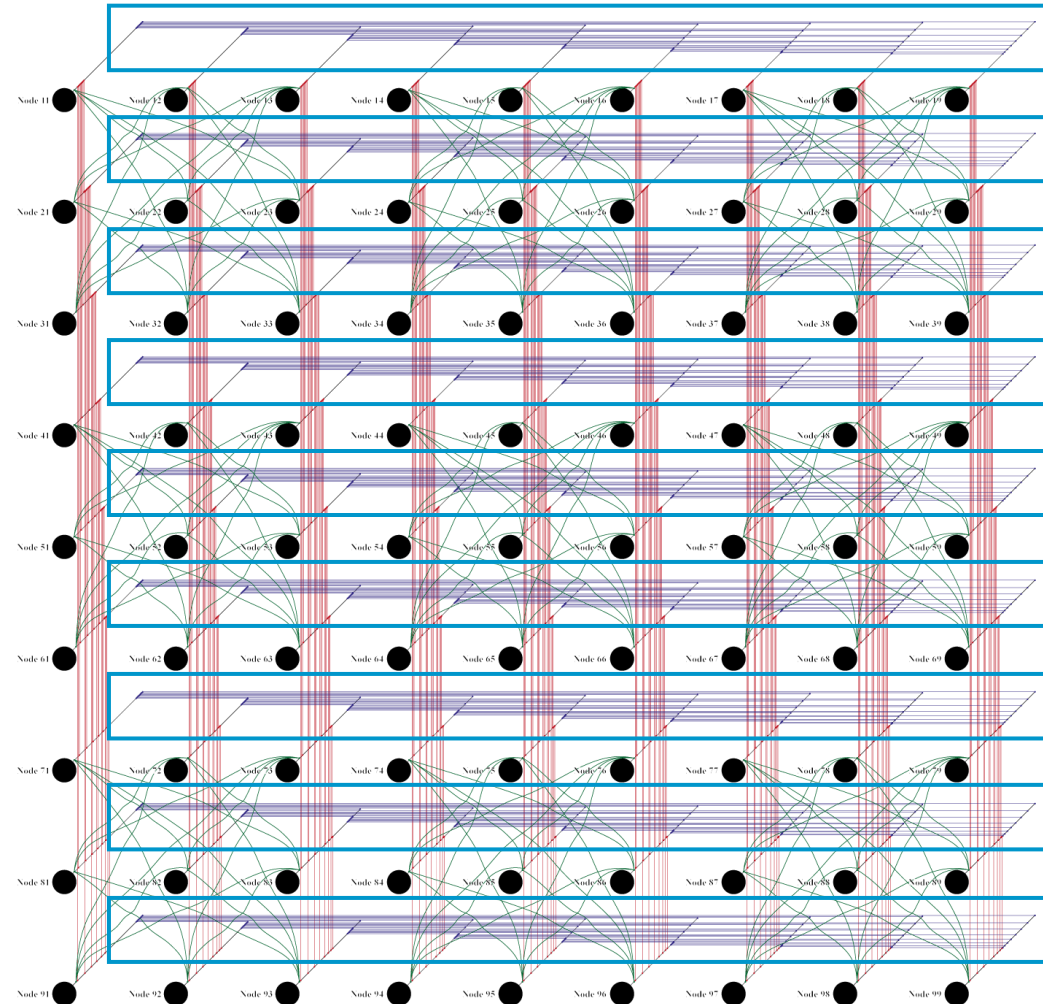
Sudoku Representation

Cells Representation



Sudoku Representation

Rows Representation

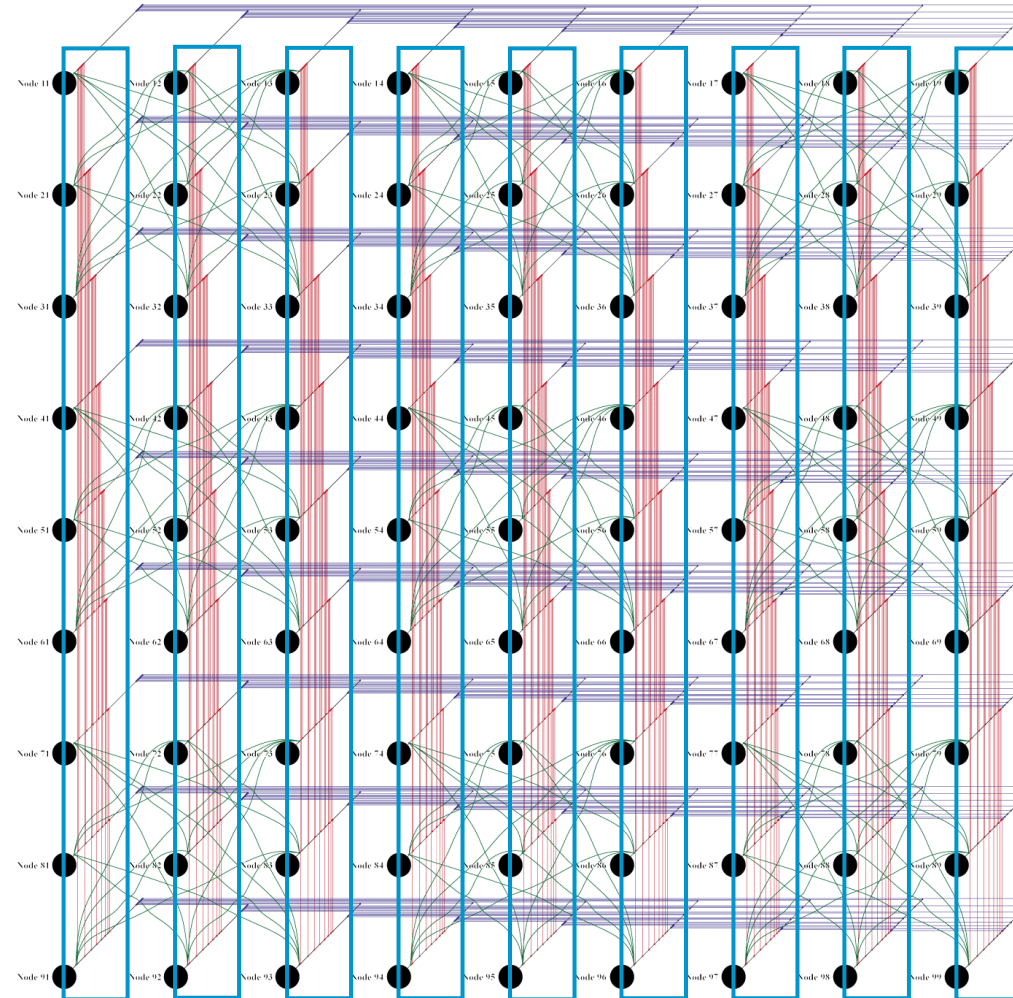


Row
Connections



Sudoku Representation

Columns Representation

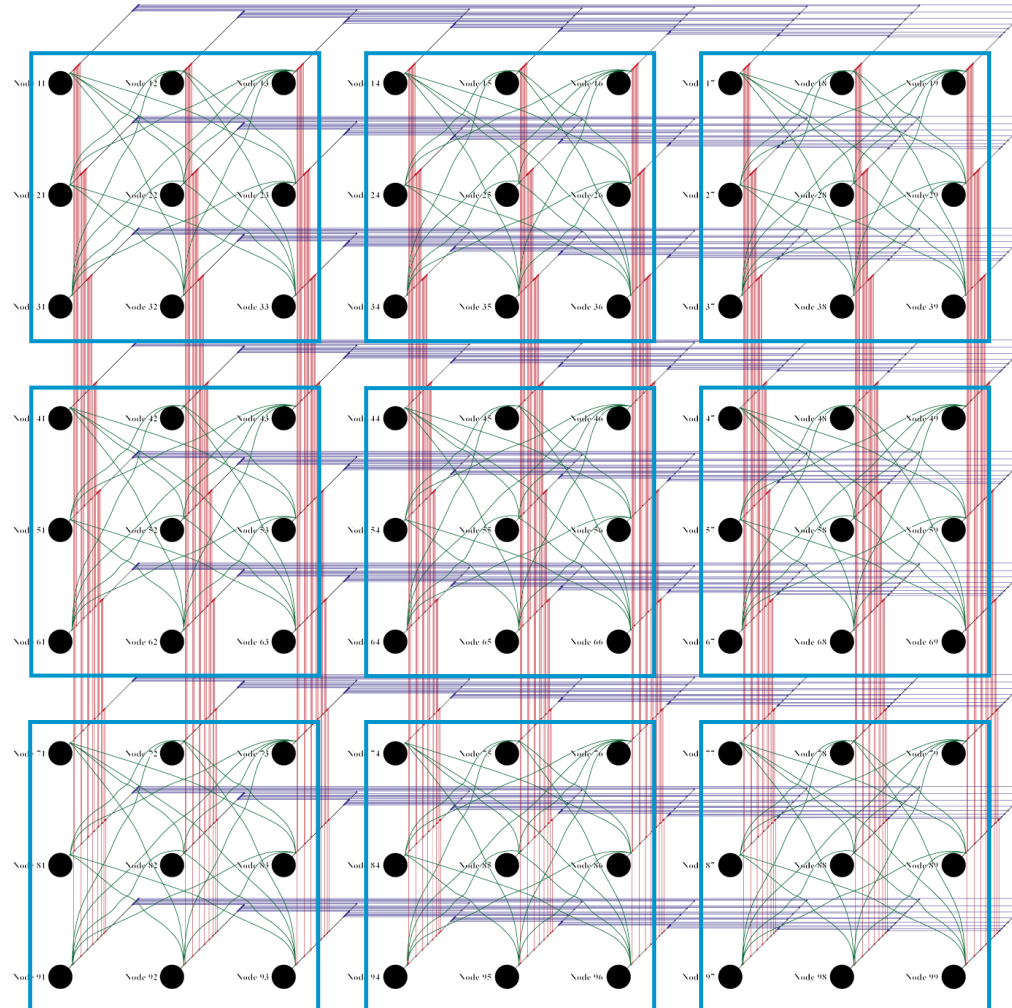


Column
Connections



Sudoku Representation

Groups Representation

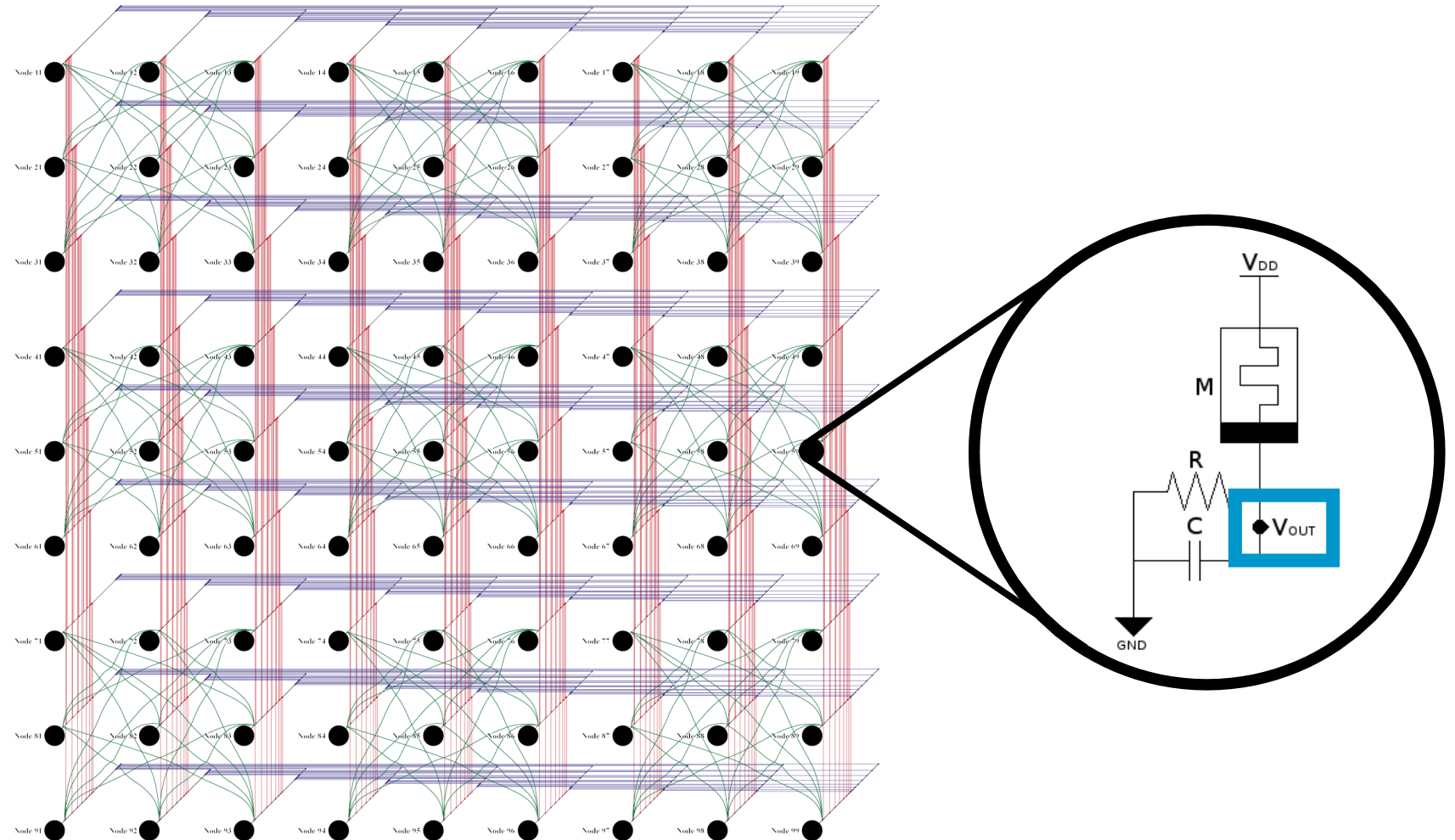


Group
Connections



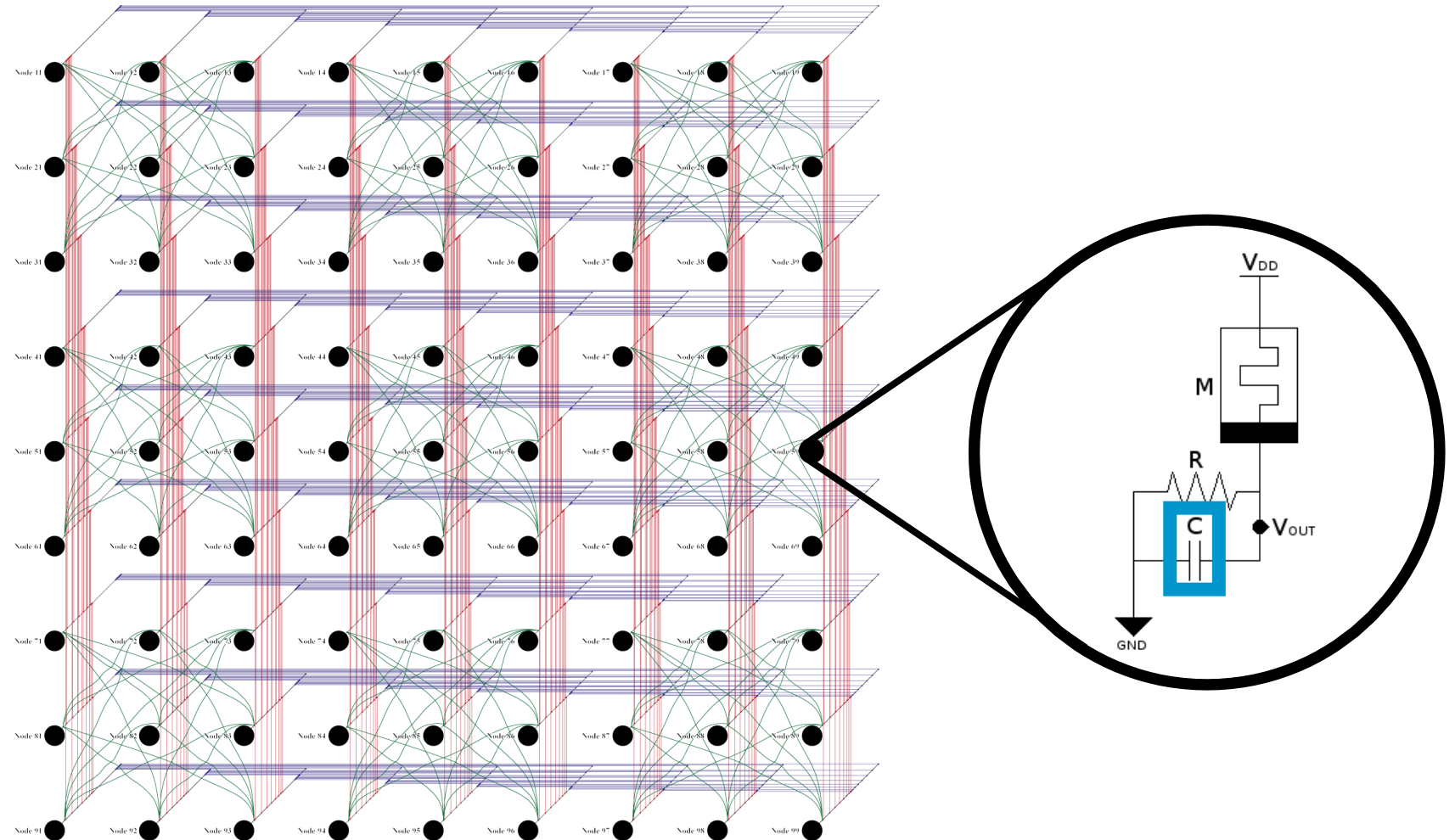
Sudoku Representation

Node's Output Voltage



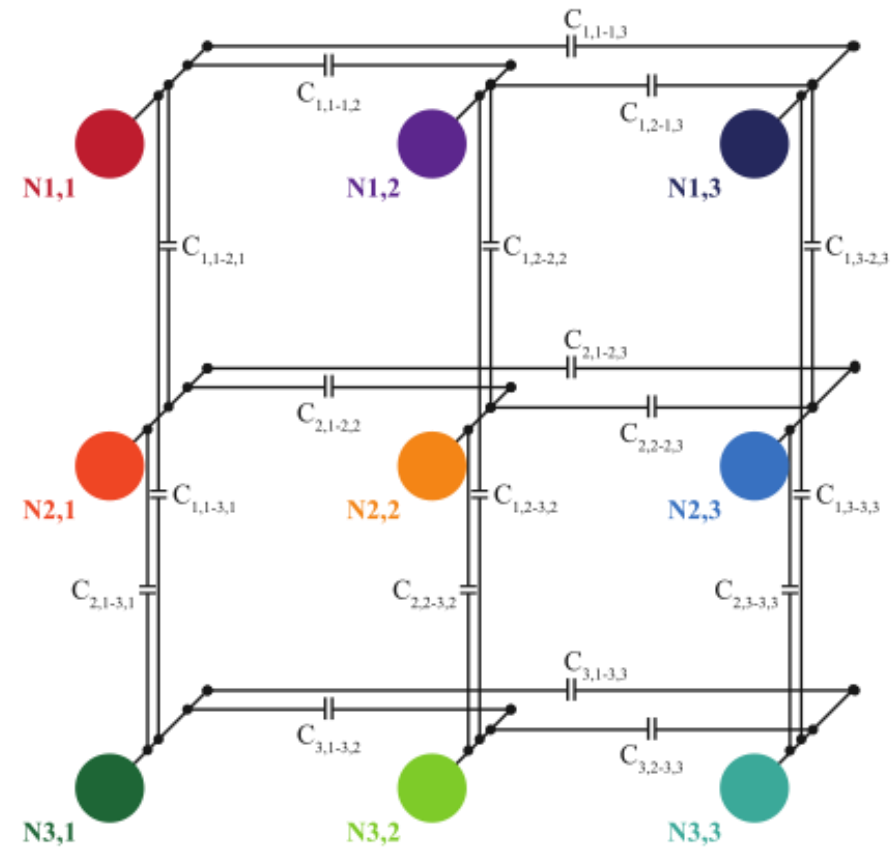
Sudoku Representation

Initial Conditions



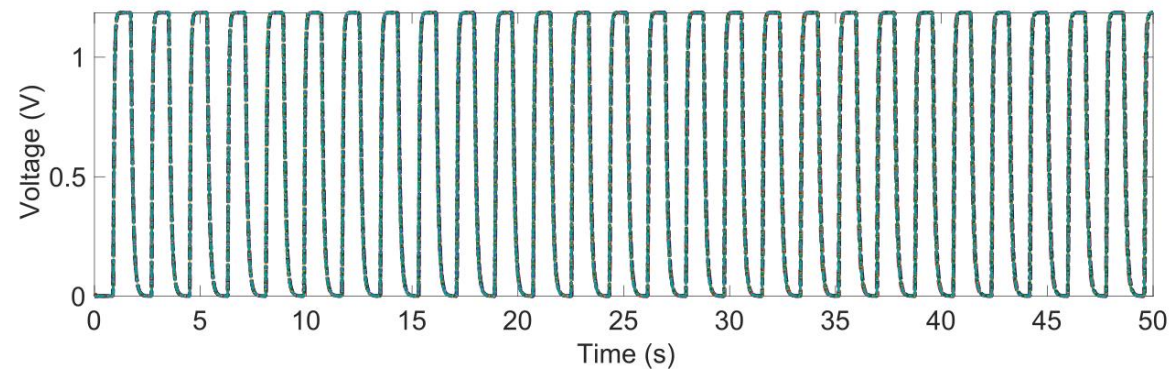
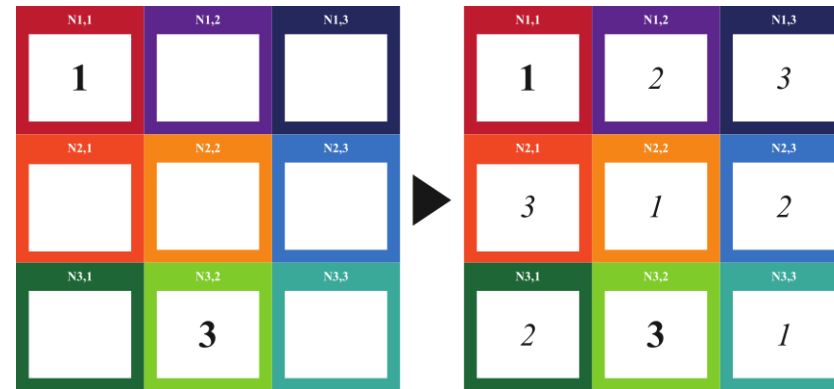
Sudoku Representation

3x3 Sudoku



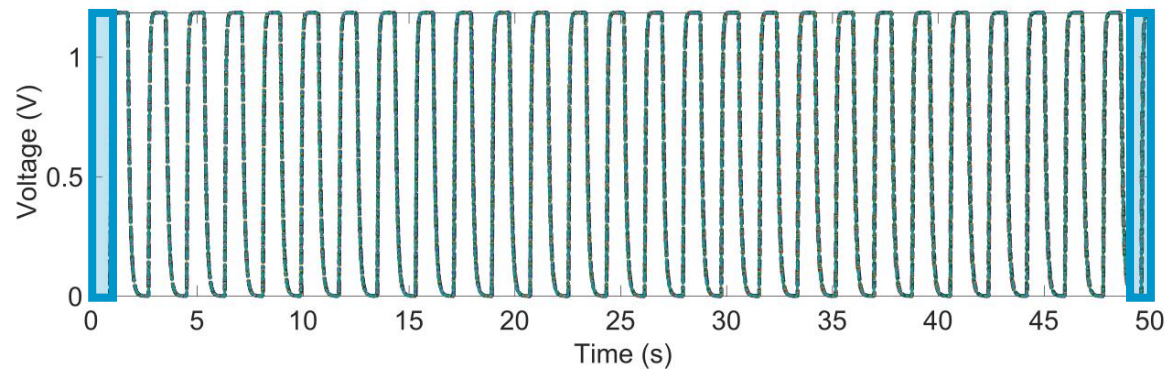
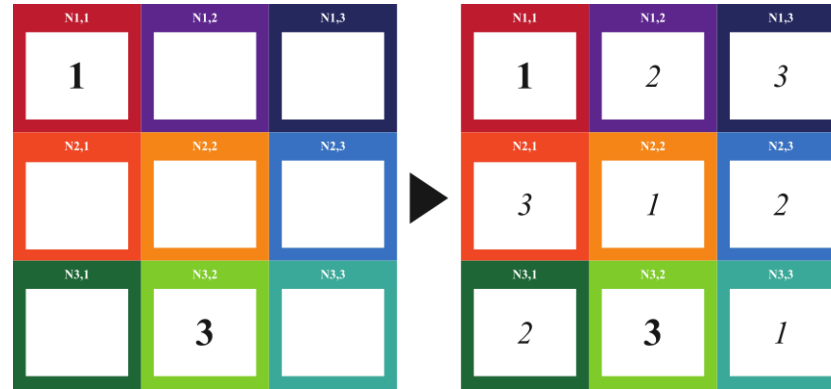
Simulation Results

Example 1



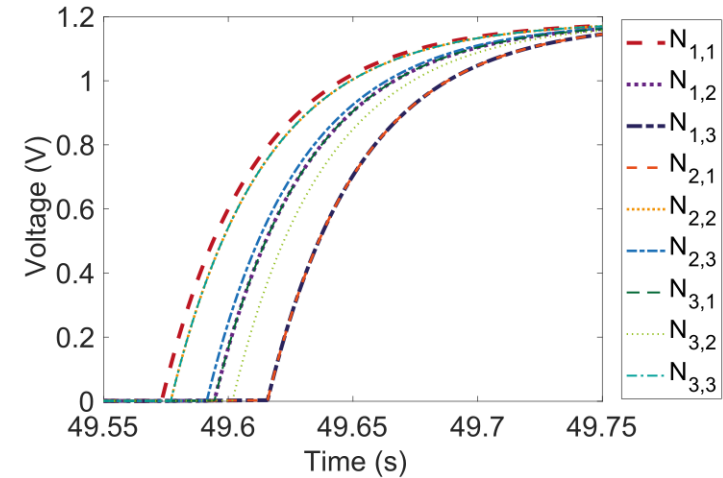
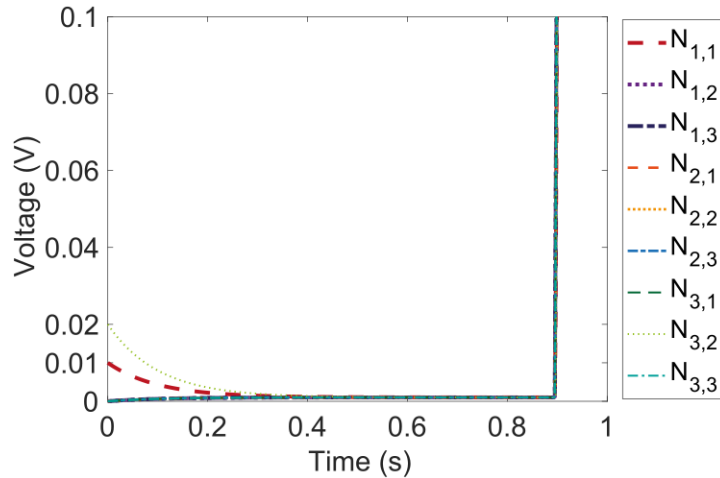
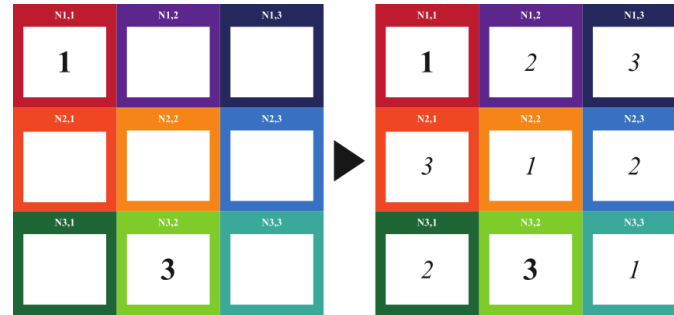
Simulation Results

Example 1



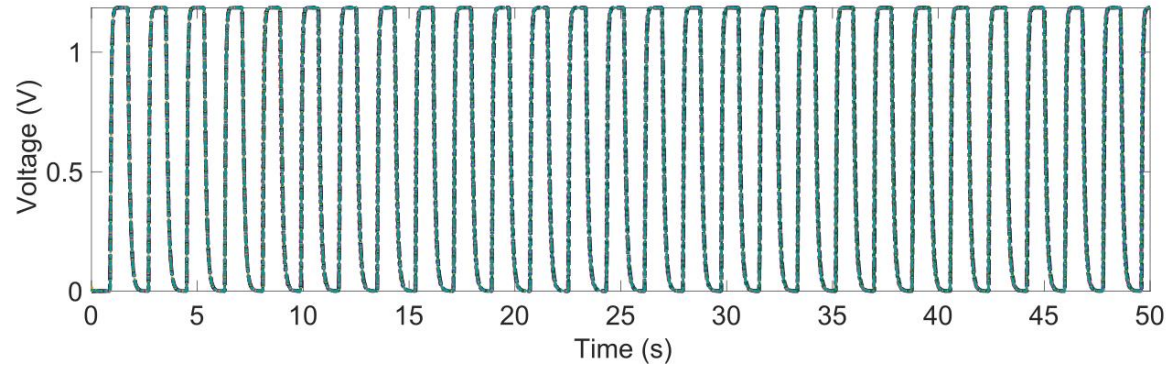
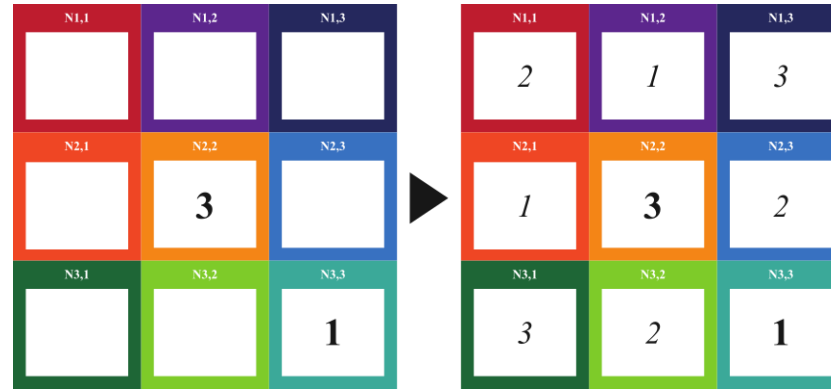
Simulation Results

Example 1



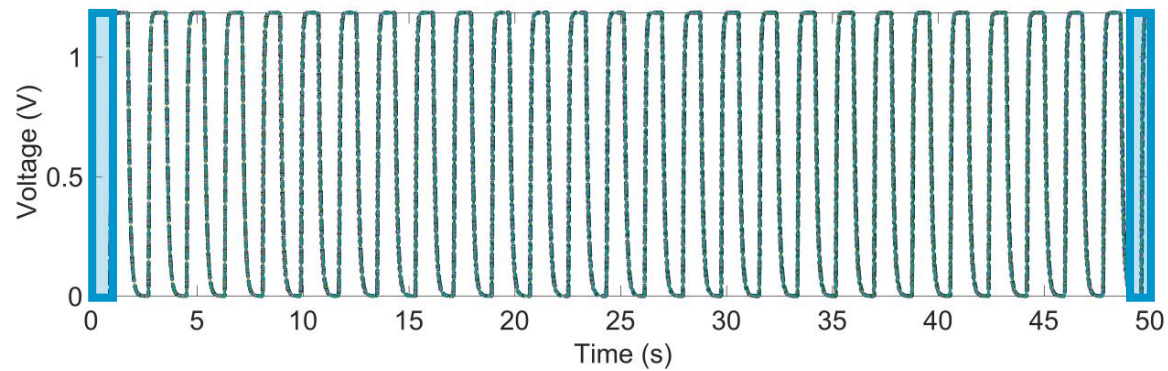
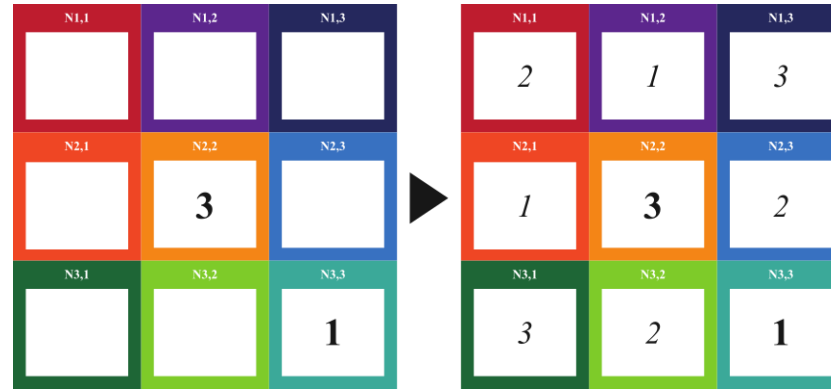
Simulation Results

Example 2



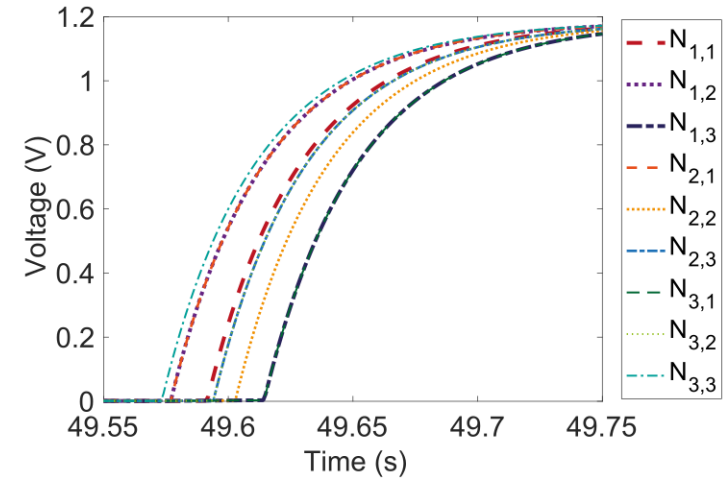
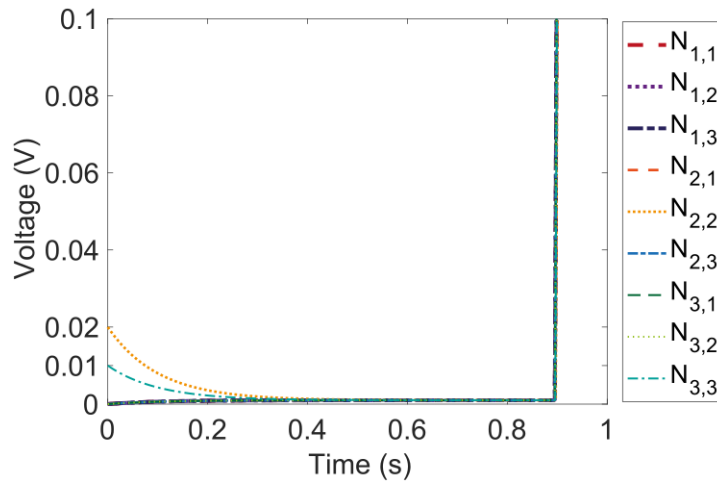
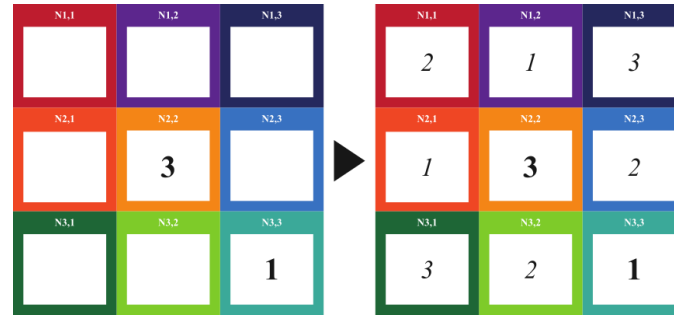
Simulation Results

Example 2



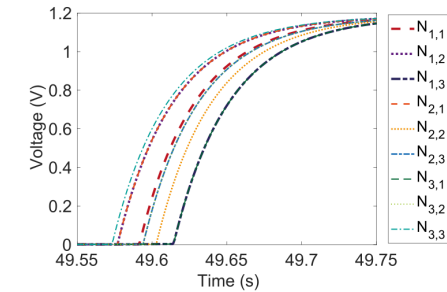
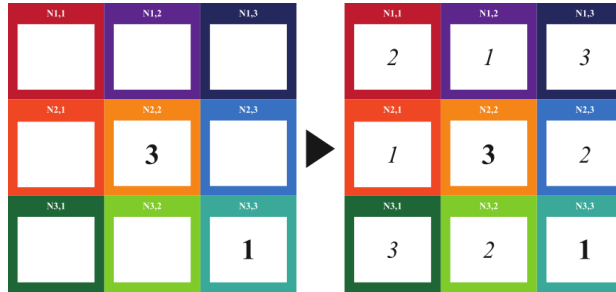
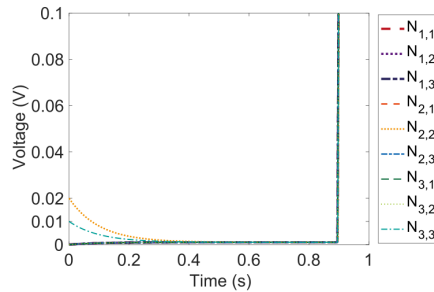
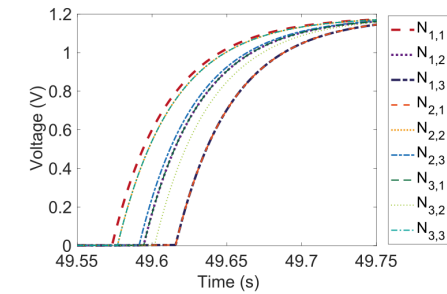
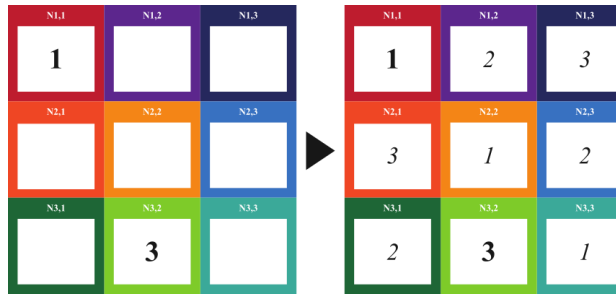
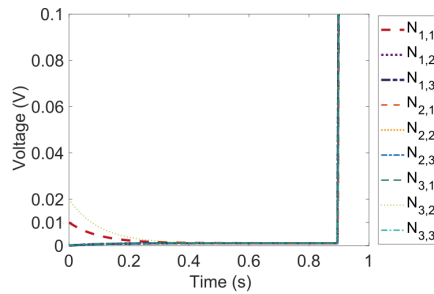
Simulation Results

Example 2



Simulation Results

Examples



Conclusions

- › A memristor-based oscillator has been utilised to address the resolution of Sudoku puzzles
- › The presented circuit is able to intrinsically come to a solution, without the use of complicated algorithmic methods
- › The designed circuit comprises only of nano-scale integration compatible electronics elements



Future Work

- › Scaling-up the proposed circuit methodology
- › Designing a re-programmable array of interconnections between nodes
- › A future generic logic puzzle problem solver
- › A further exploration of the system's behaviour in the initial conditions domain



Thank you for your attention

