

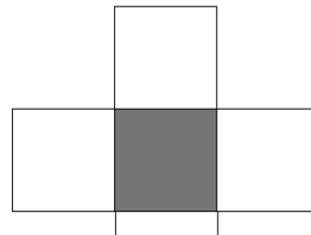
Computation in the Wild: Reconsidering Cellular Automata in Light of Irregularity

Tony Liu
Advisor: Duane Bailey

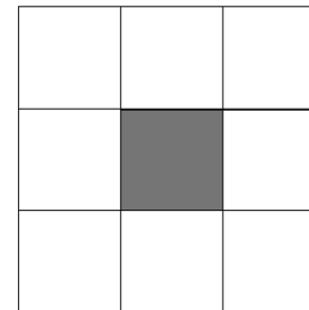
What are Cellular Automata (CA)?

Dynamic system of grid cells “evolving” over discrete time steps

Deterministic rules governing state change in local regions



(a)



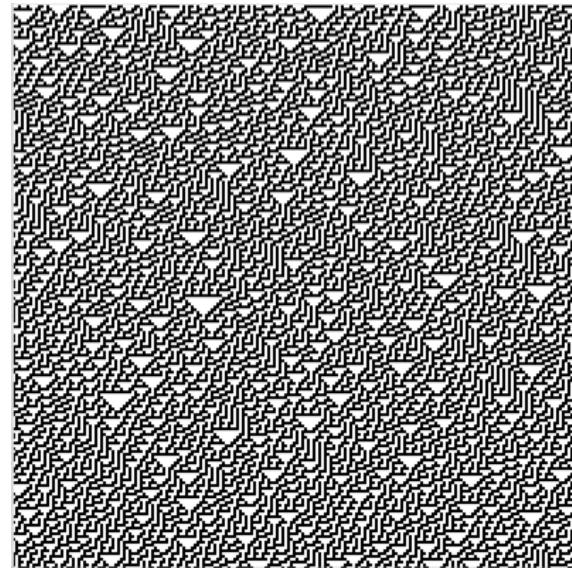
(b)

Figure 3, Mitchell et al 1996.

Cellular Automata Modeling of Natural Systems



Conus textile shell, Wikimedia CC 3.0

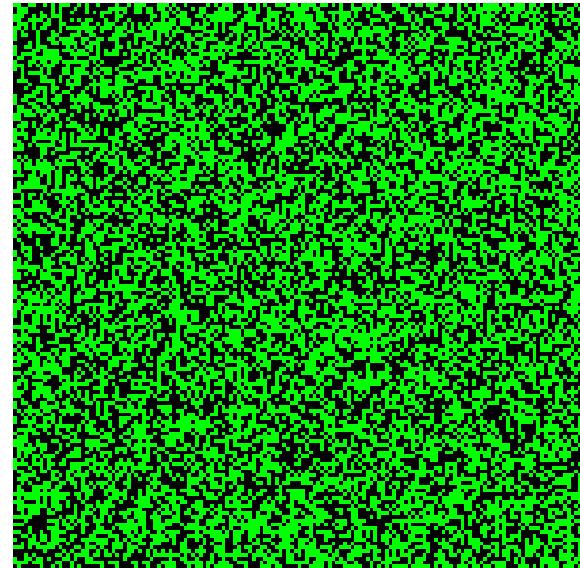


Rule 30, Wikimedia CC 3.0

Cellular Automata Modeling of Natural Systems



High Park Wildfire, Wikimedia CC 3.0



Forest Fire Model, Wikimedia CC 3.0

Threads of Research

Information transmission on Irregular Grids

Robustness of Computation in Noisy Environments

Identification of Metrics on Classifying Irregular CA

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Stomatal Coordination in Plants

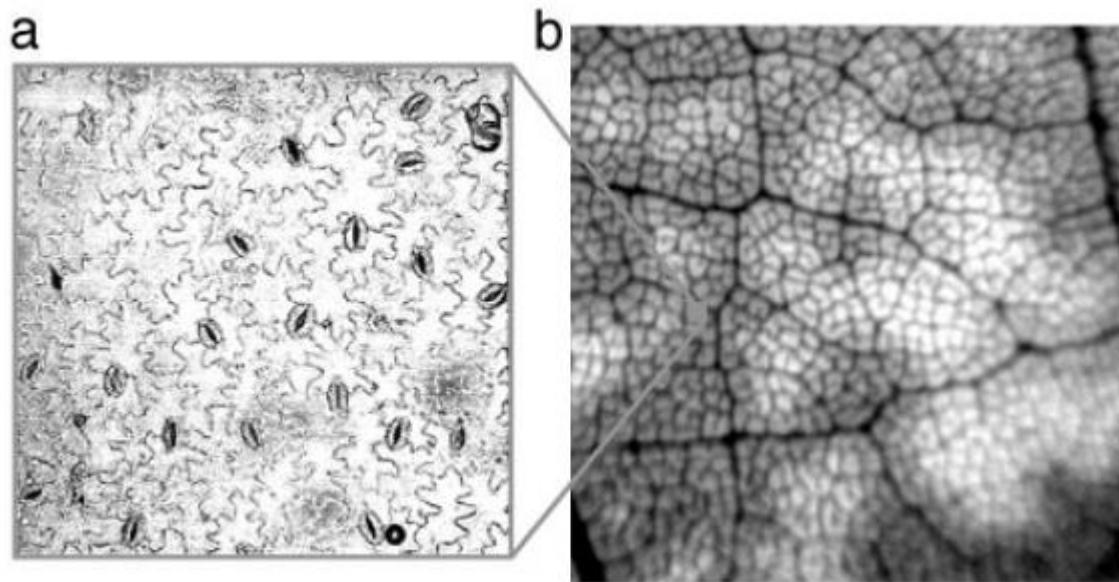


Figure 1, Peak et al 2004.

Stomatal Coordination in Plants

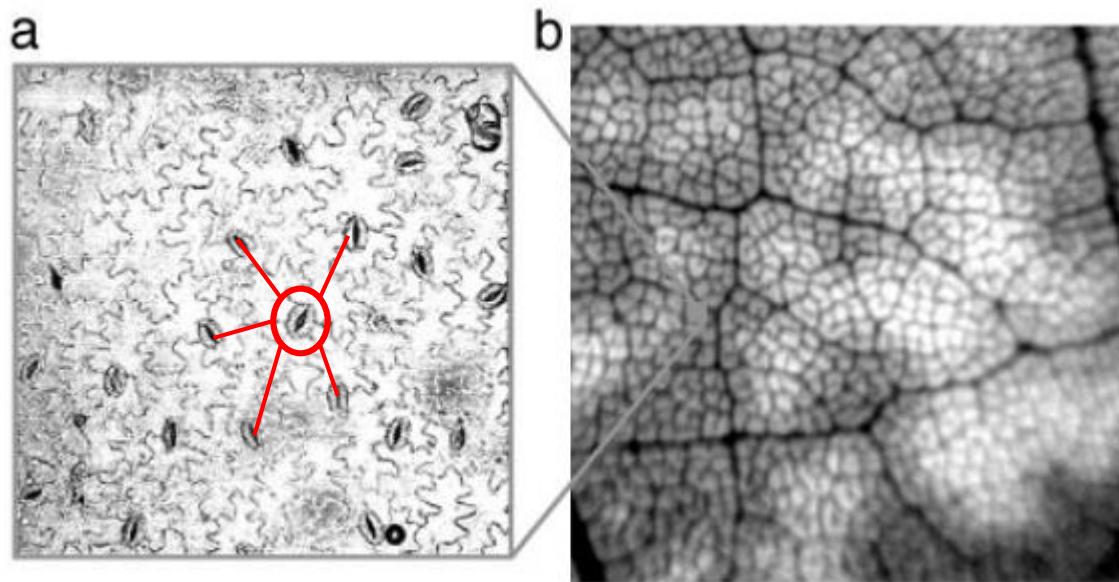


Figure 1, Peak et al 2004.

The Majority Task

45 % White

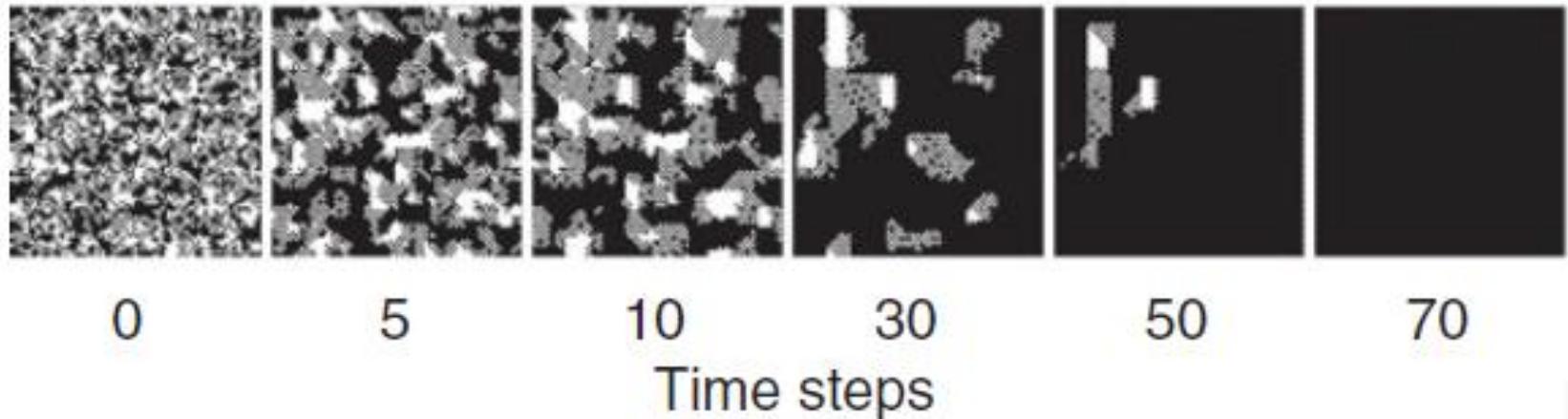


Figure 3, Mott et al 2007.

Stomatal Coordination and Majority

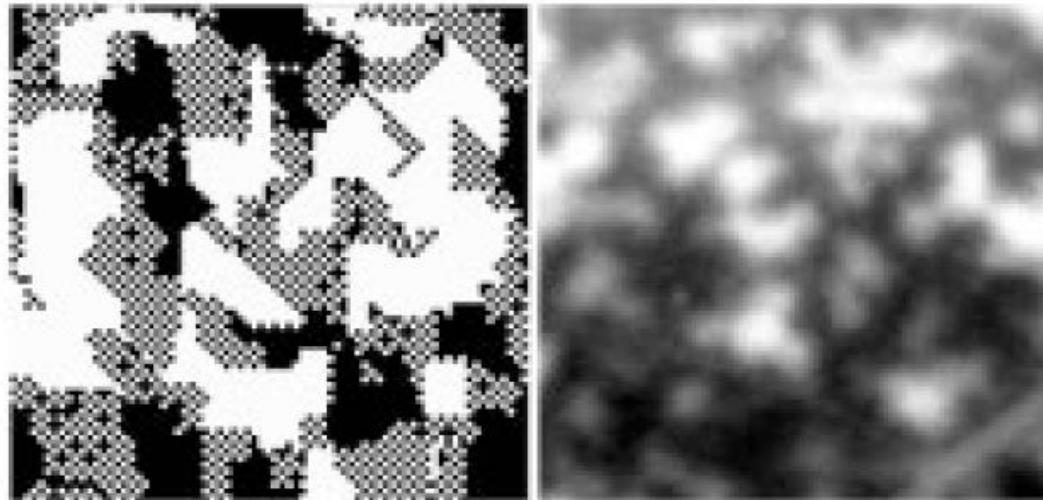


Figure 3, Messinger et al 2007.

Stomatal Coordination and Majority

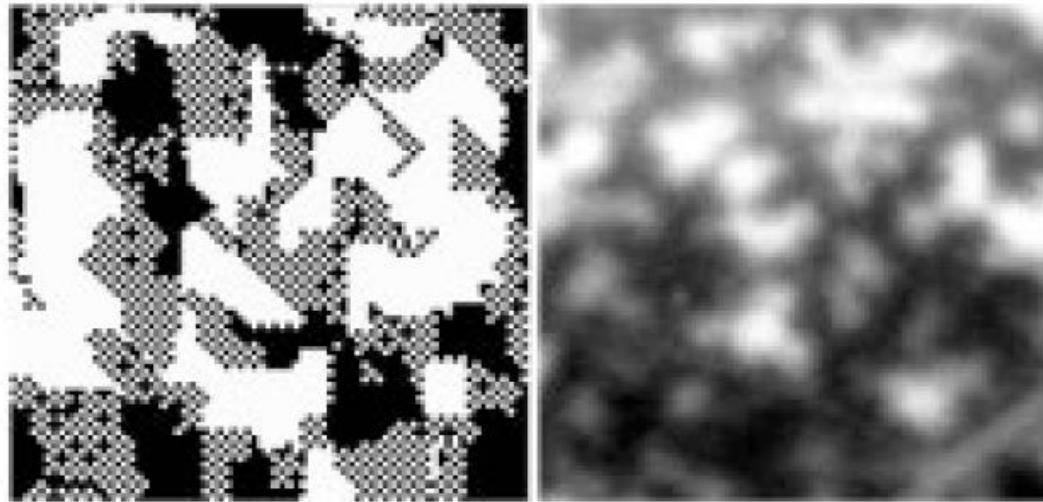
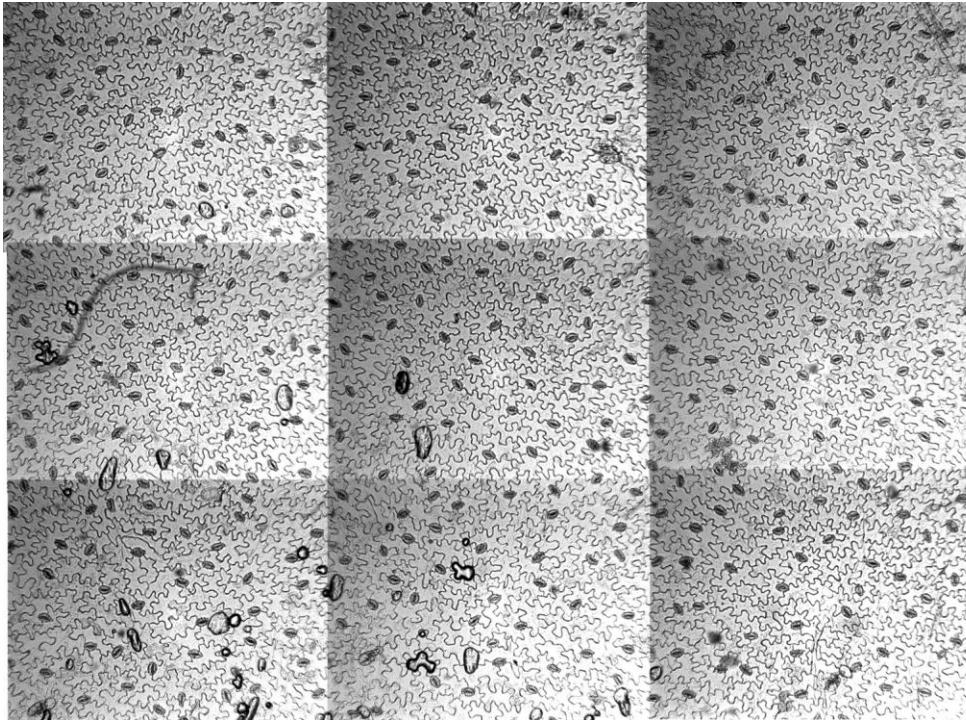


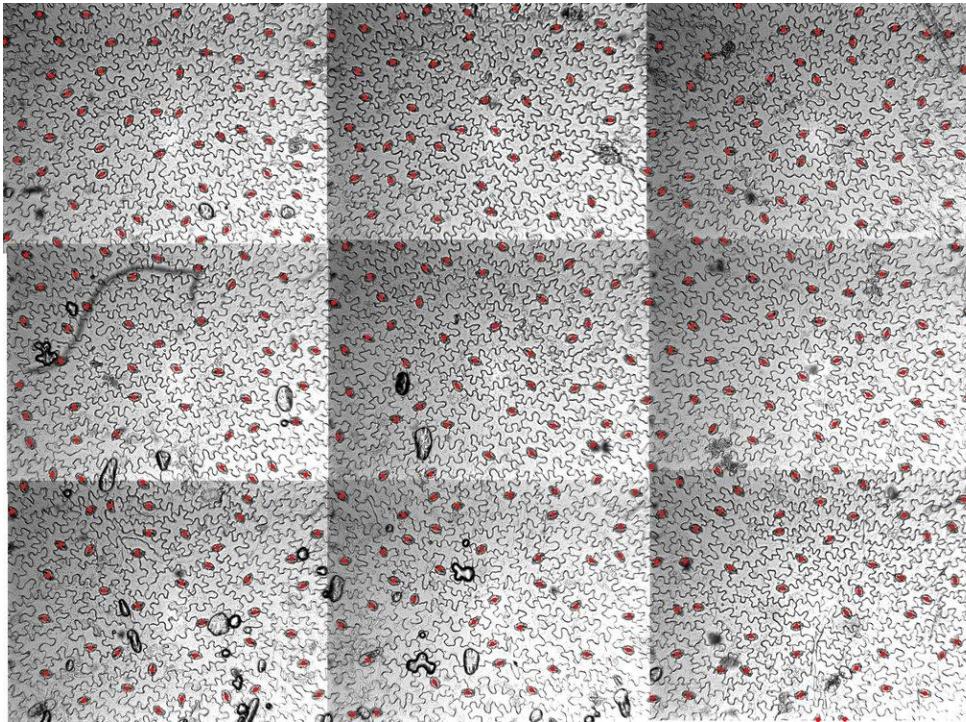
Figure 3, Messinger et al 2007.

Assumption: These phenomenon can be adequately modeled on square lattices

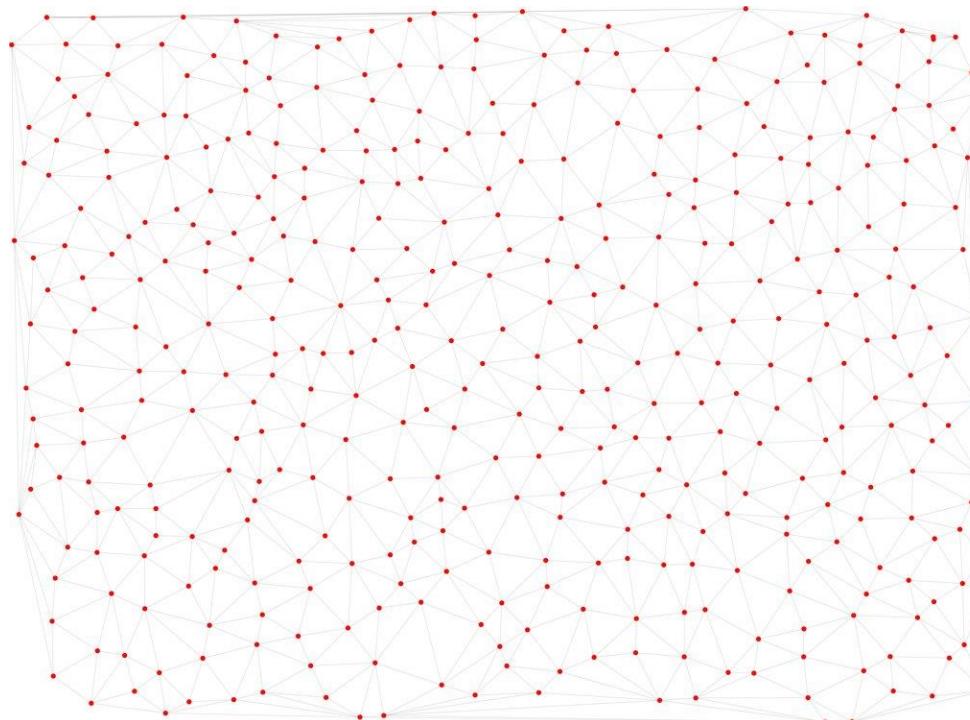
Mapping Stomata



Mapping Stomata



Mapping Stomata



Local Majority Rule

If there is a majority of black or white cells in a neighborhood, then the center cell will transition to the majority state

If there is no majority, the center cell will retain its previous state

Neighborhood	Output
000000111	0
110001101	1
000010001	0
101111000	1

•
•
•

Baseline Majority Task Performance

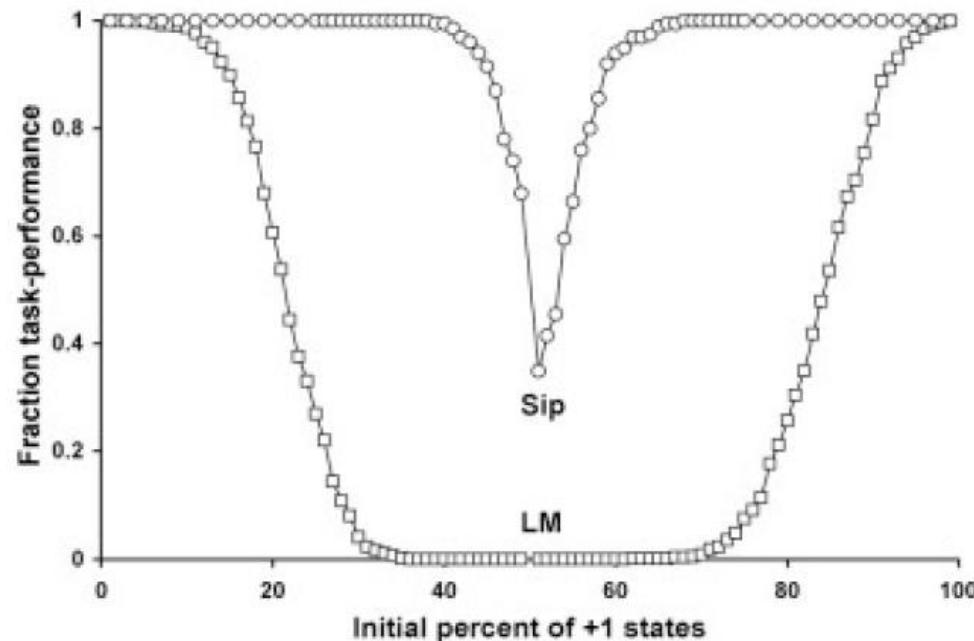
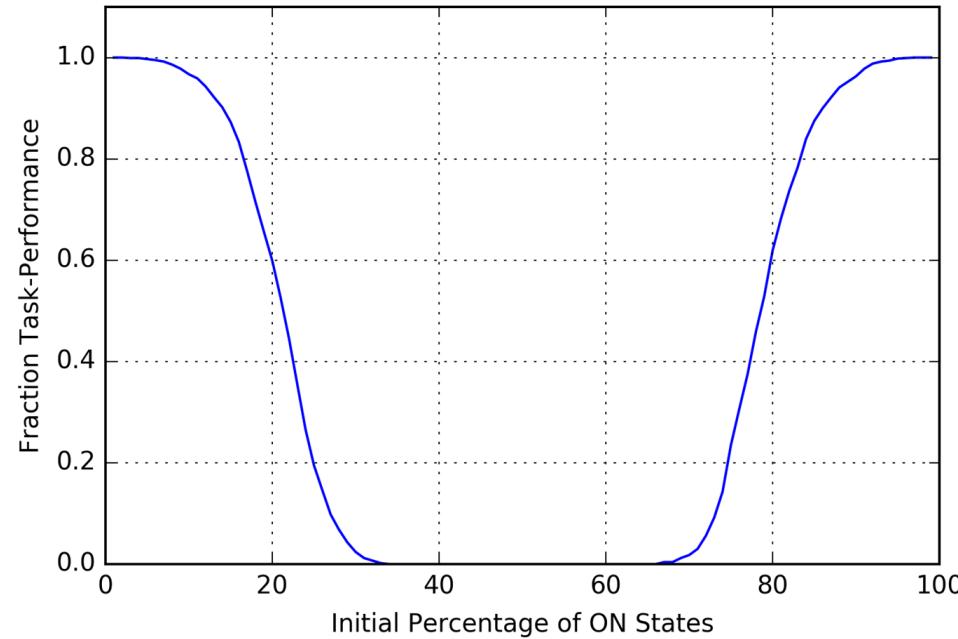


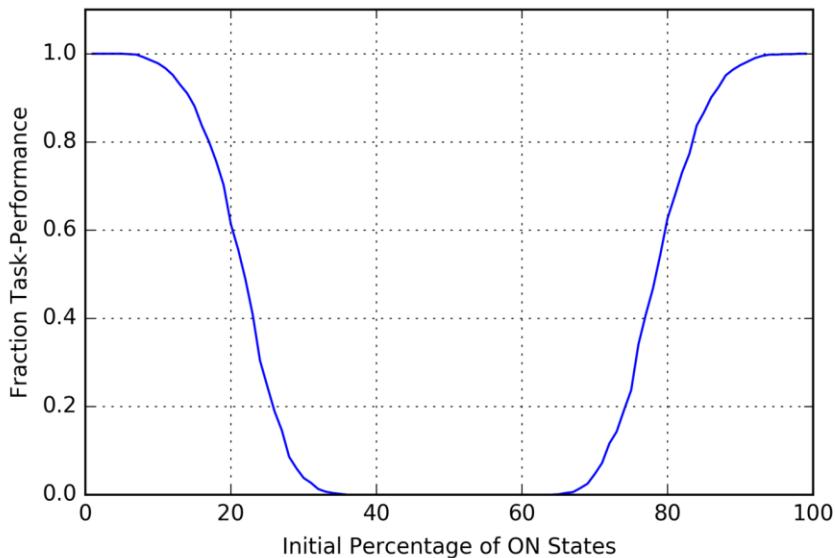
Figure 2, Messinger et al. 2007

Stoma Majority Task Performance

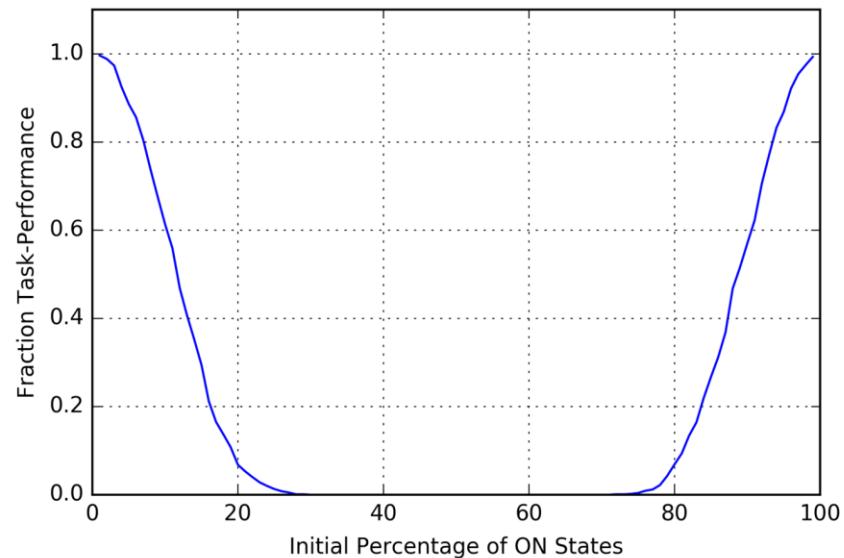


Stoma Grid, Bounded Border

Border Effects on Majority Task Performance

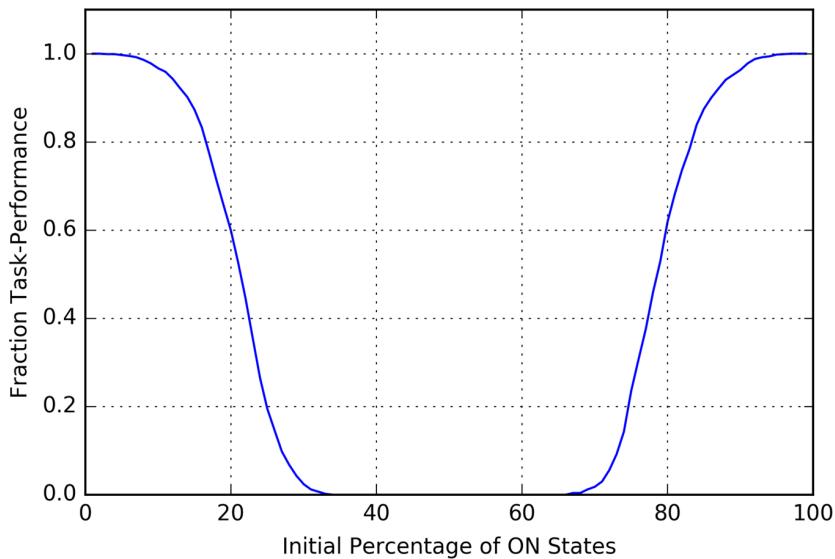


Regular Grid, Periodic Border

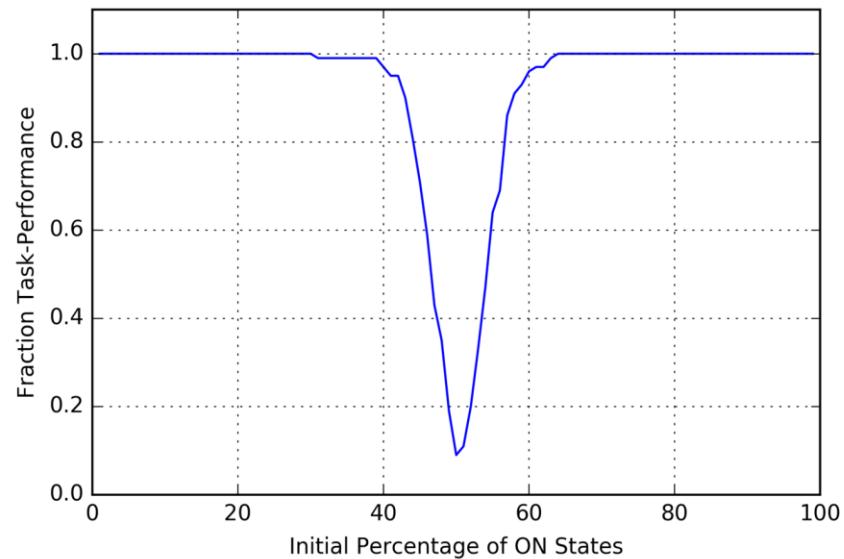


Regular Grid, Bounded Border

Temporal Noise on Majority Task Performance

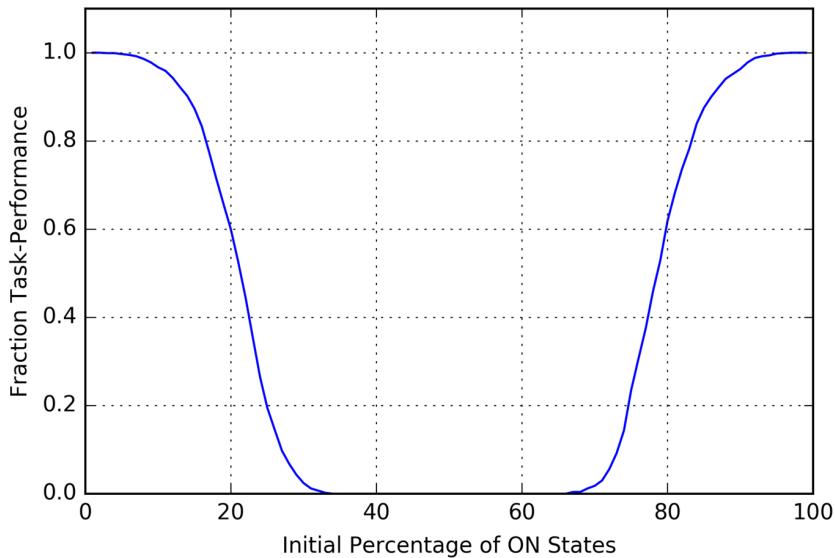


0% Noise, Stoma Grid

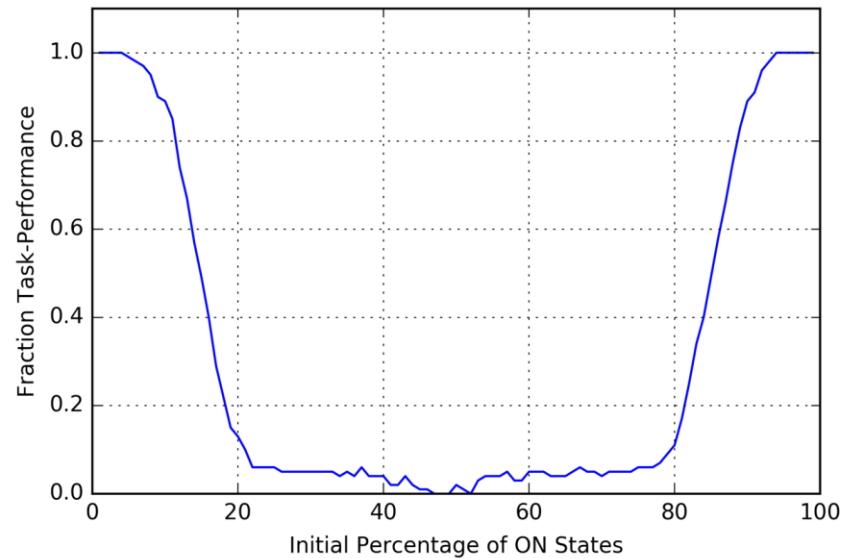


5% Noise, Stoma Grid

Temporal Noise on Majority Task Performance



0% Noise, Stoma Grid



15% Noise, Stoma Grid

Threads of Research

Information transmission on Irregular Grids

Robustness of Computation in Noisy Environments

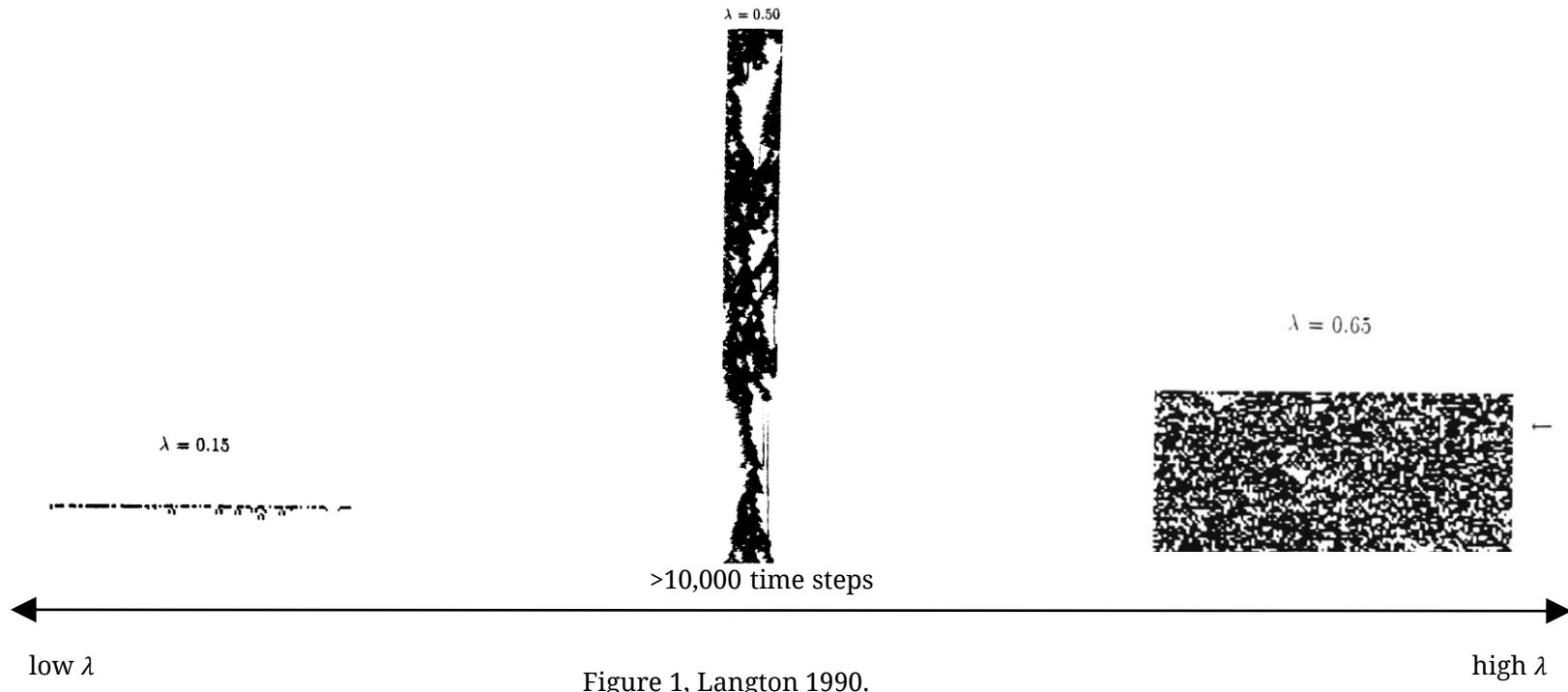
Identification of Metrics on Classifying Irregular CA

Parameterizing CA: Langton's Lambda

Lambda (λ): the percentage of transition rules that map to “active” states

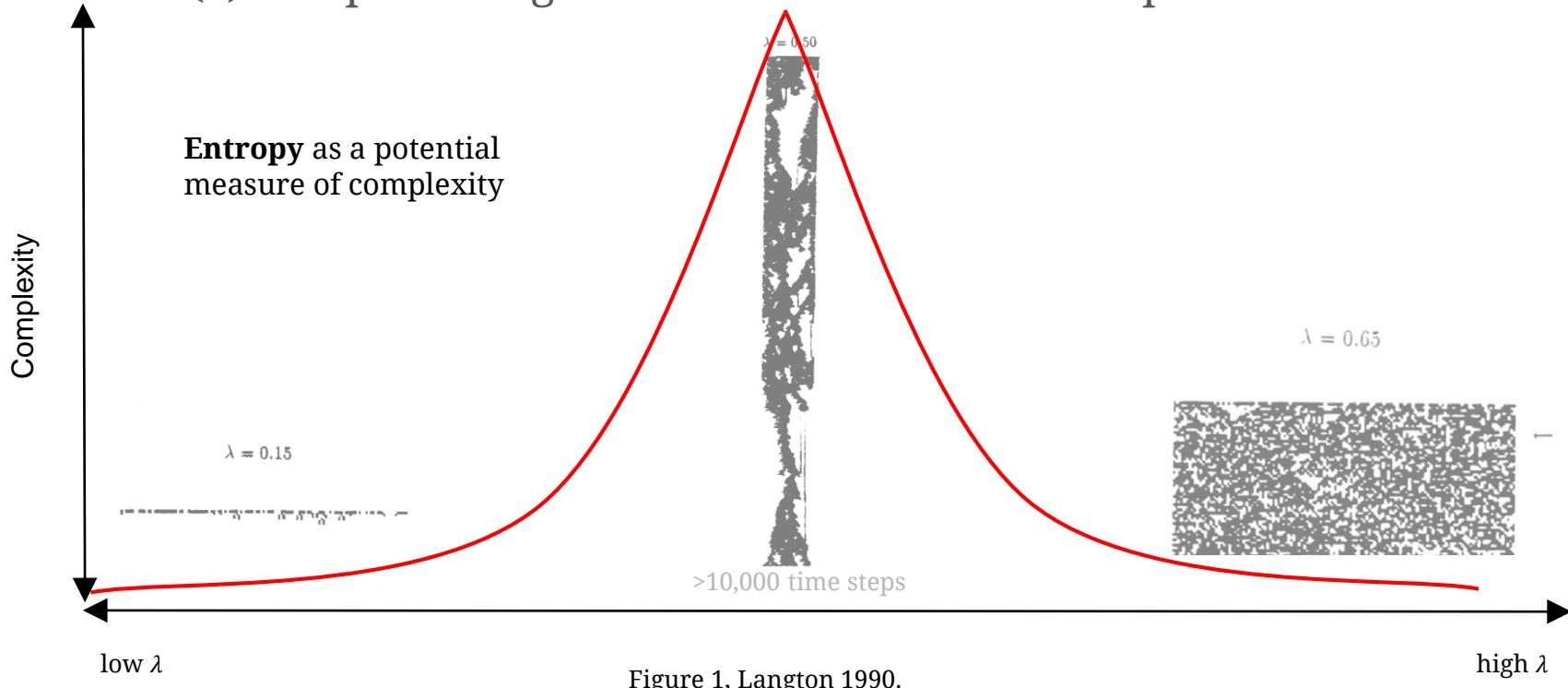
Parameterizing CA: Langton's Lambda

Lambda (λ): the percentage of transition rules that map to “active” states



Parameterizing CA: Langton's Lambda

Lambda (λ): the percentage of transition rules that map to “active” states



Measures of Complexity: Entropy

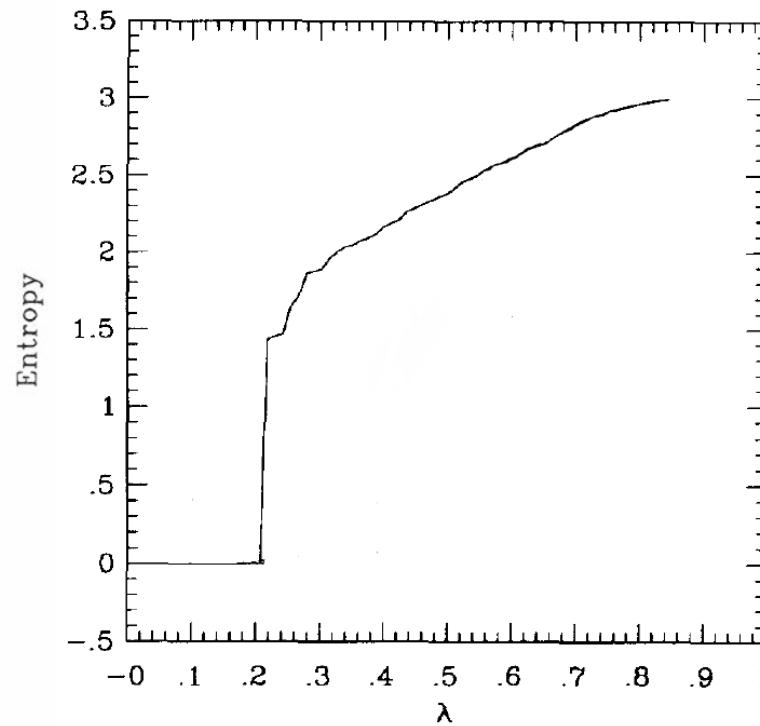


Figure 7, Langton 1990

Measures of Complexity: Entropy

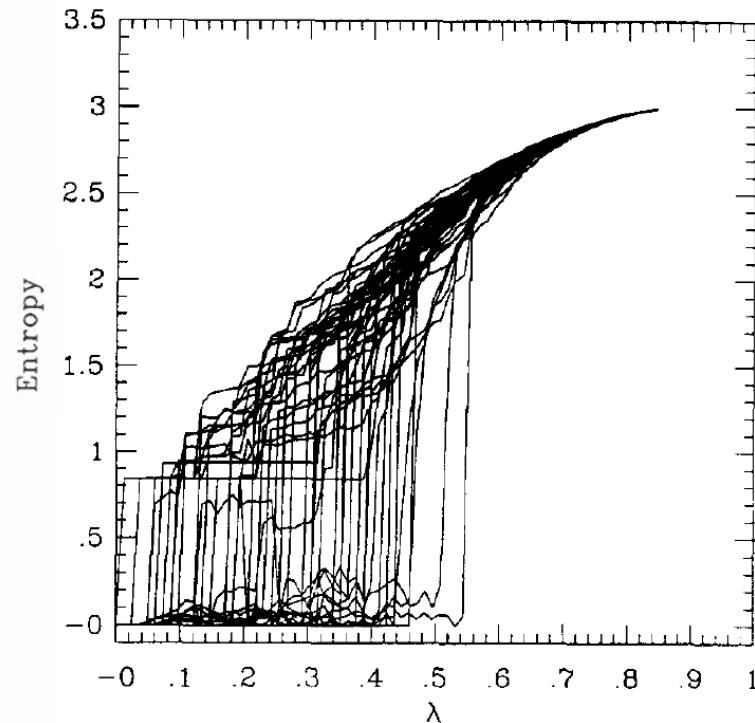


Figure 8, Langton 1990

Measures of Complexity: Entropy

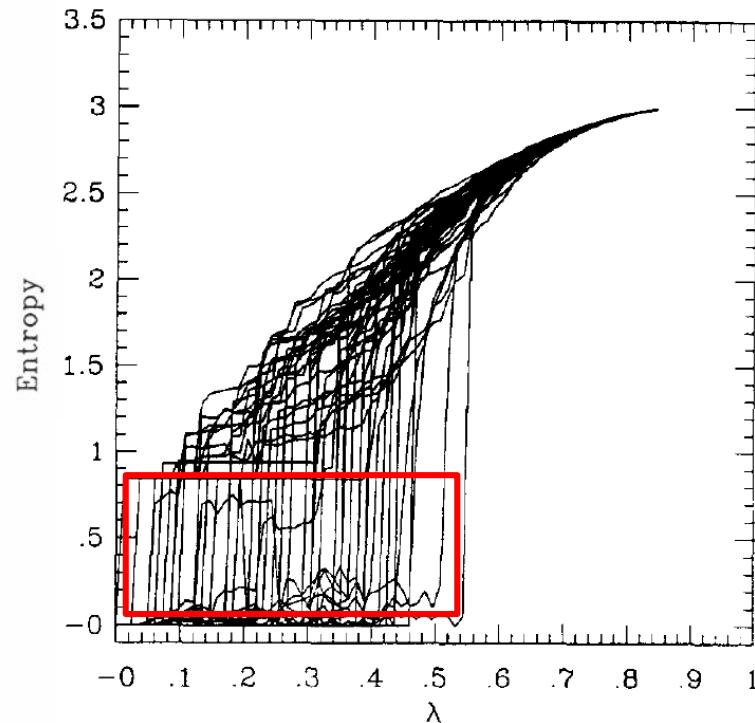


Figure 8, Langton 1990

The Langton-Wootters Profile

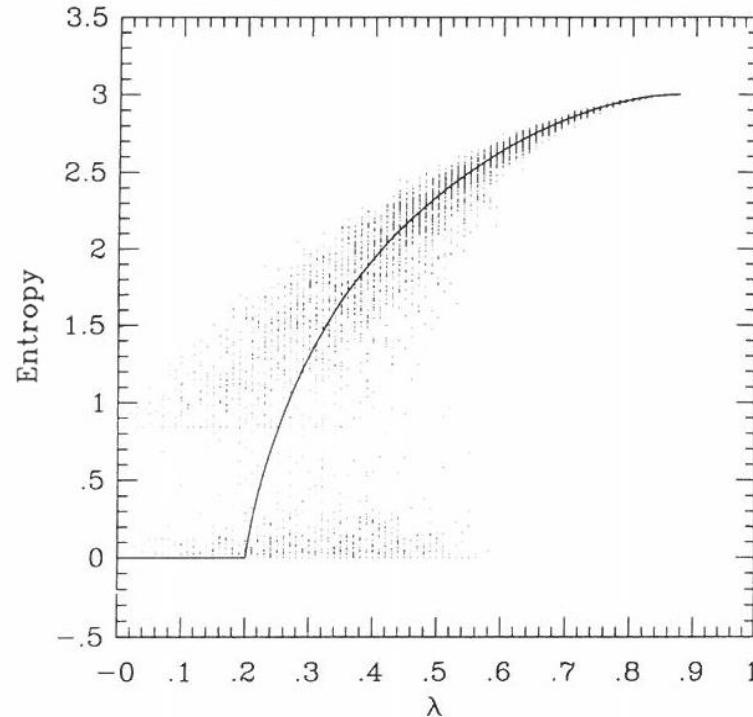
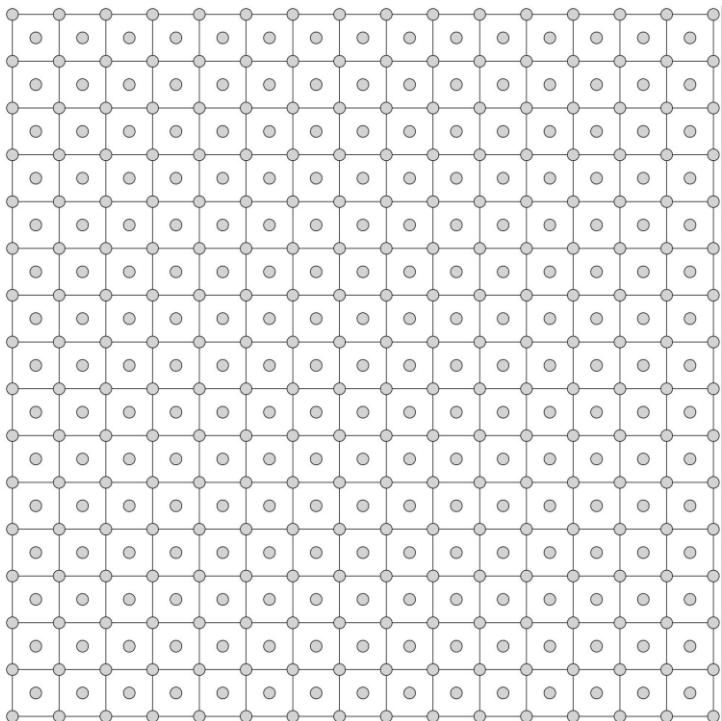
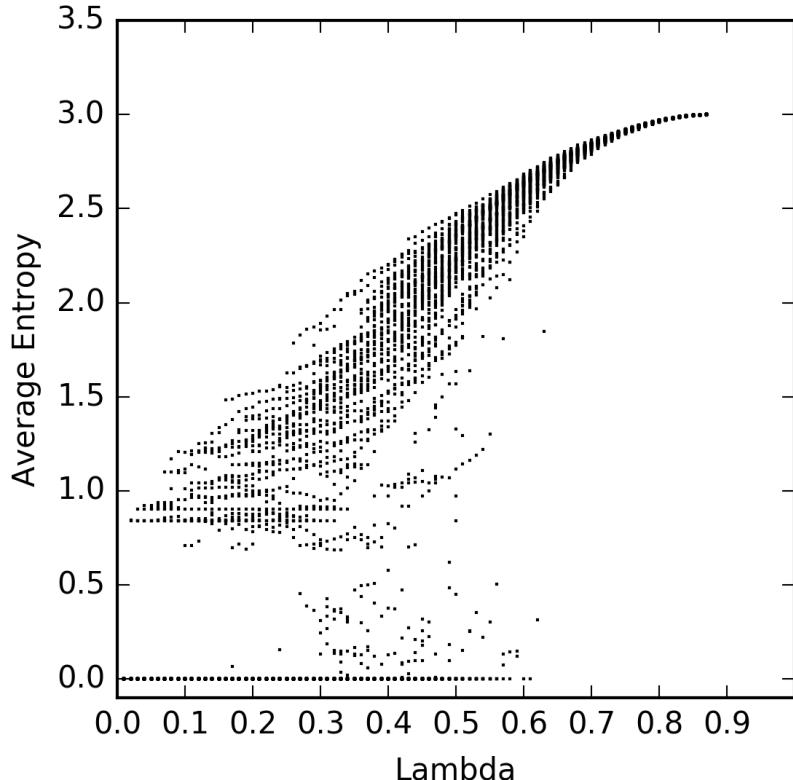


Figure 3, Wootters and Langton 1990

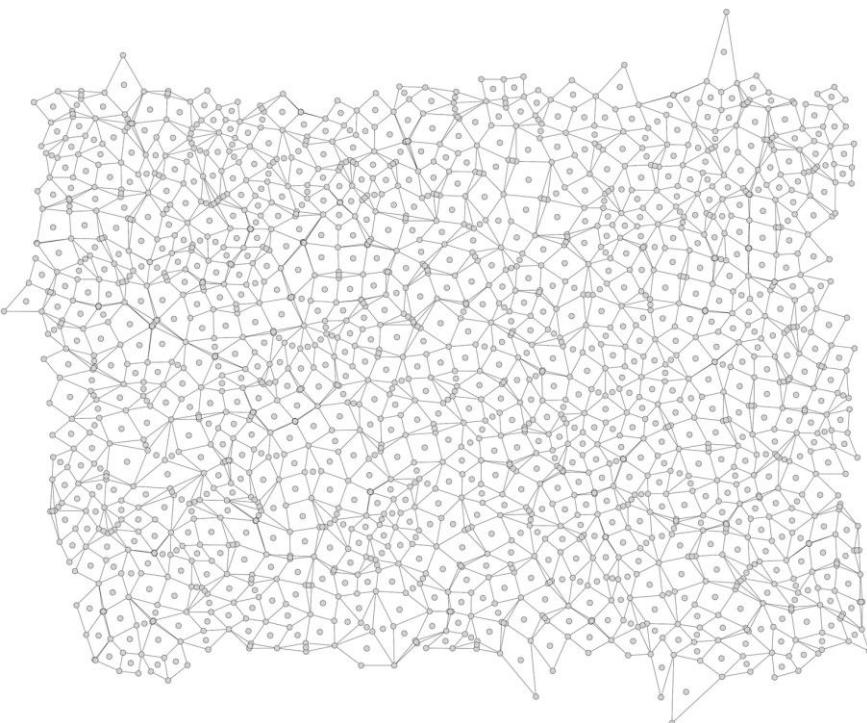
LW Profile Degradation



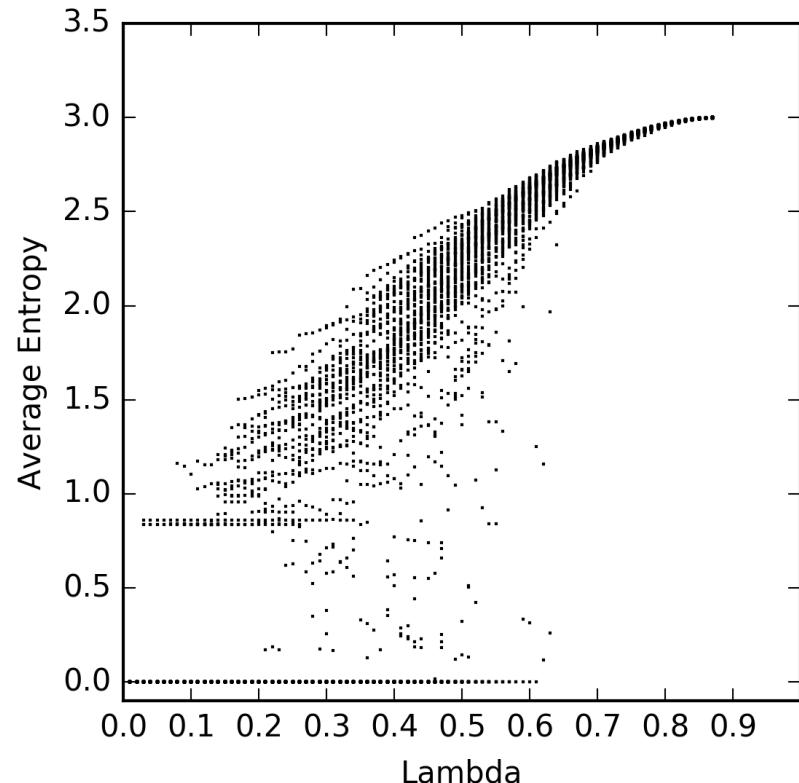
Avg Neighborhood: 4



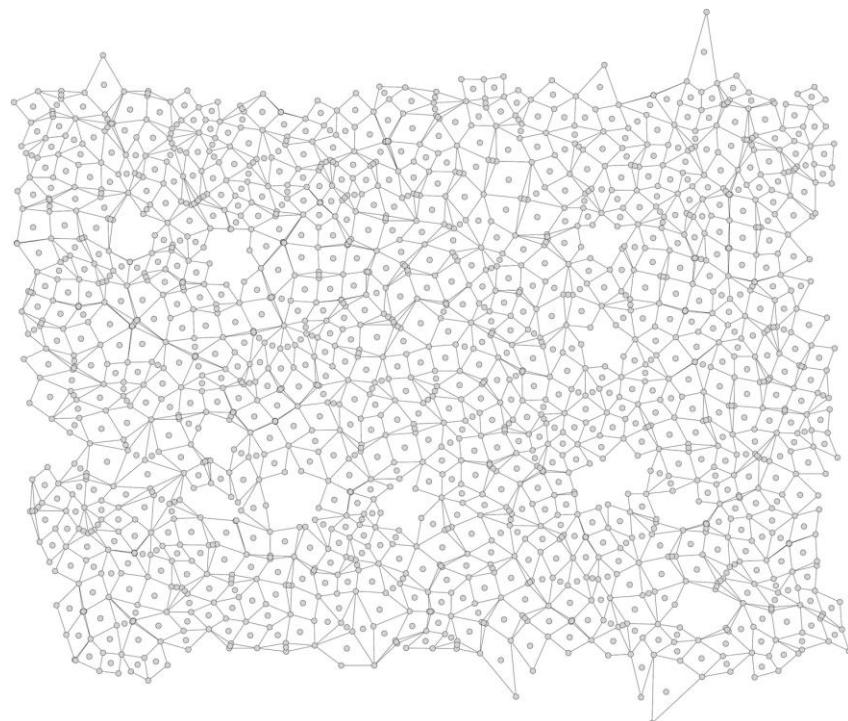
Irregular LW Profile



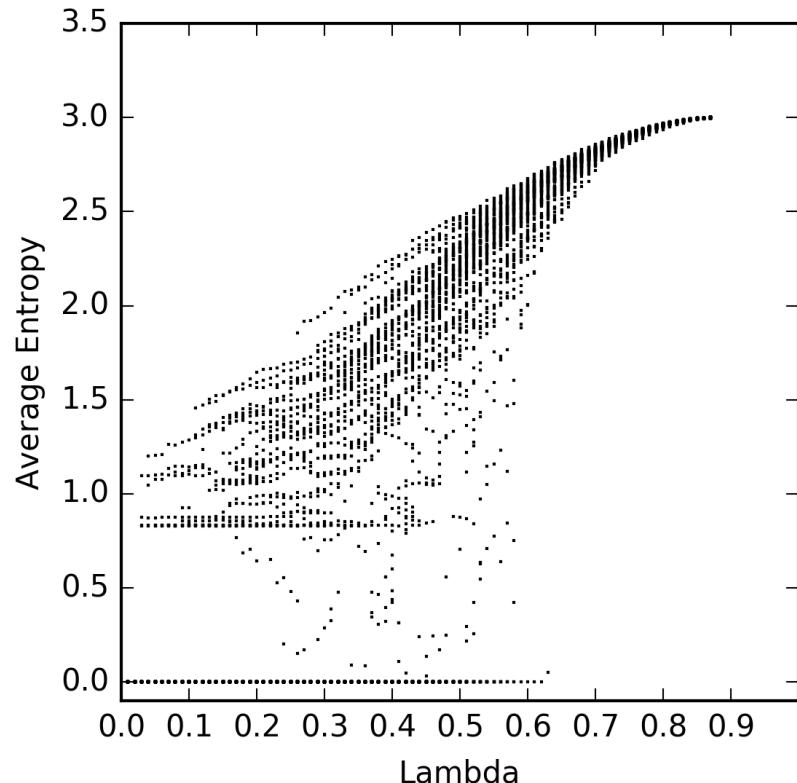
Degradation: 0%, Avg Neighborhood: 3.84



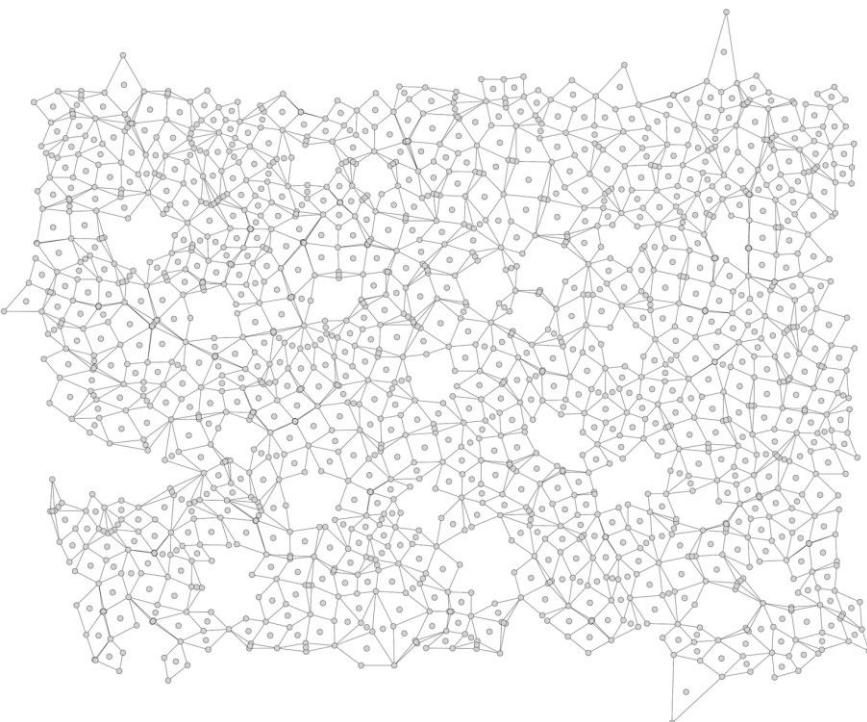
Generator Point Removal



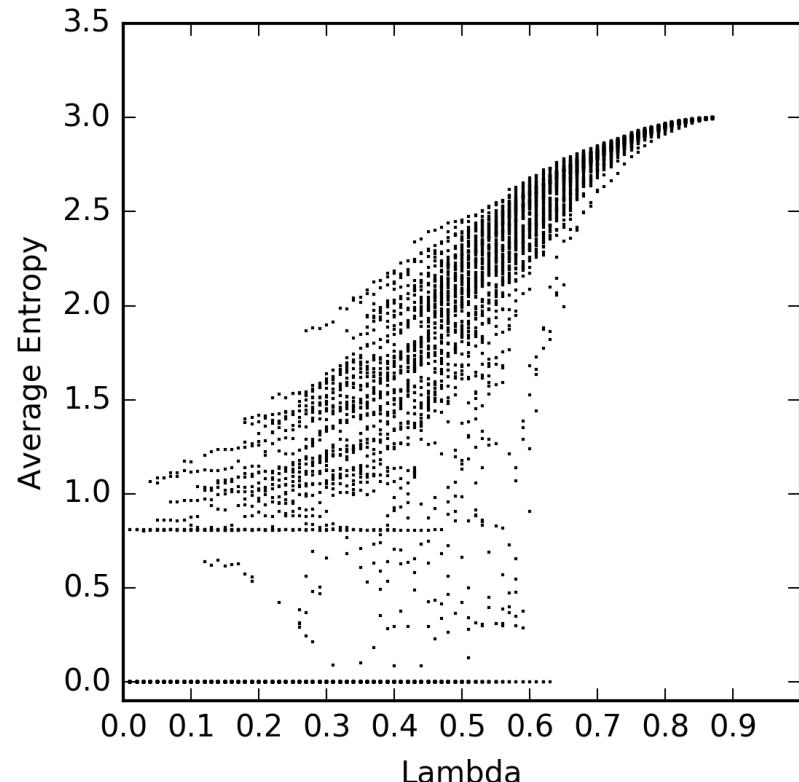
Degradation: 5%, Avg Neighborhood: 3.68



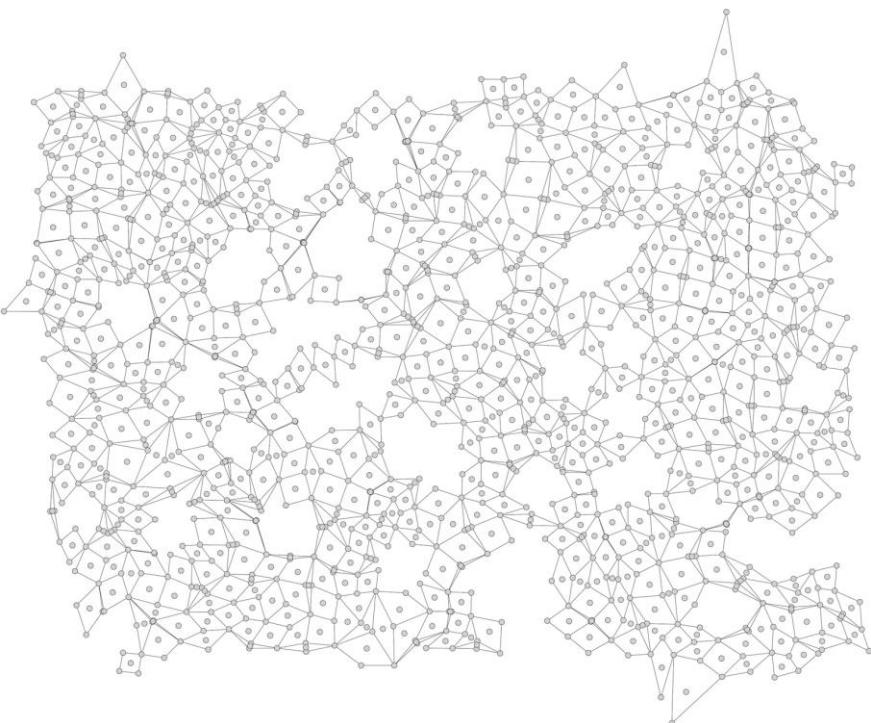
Generator Point Removal



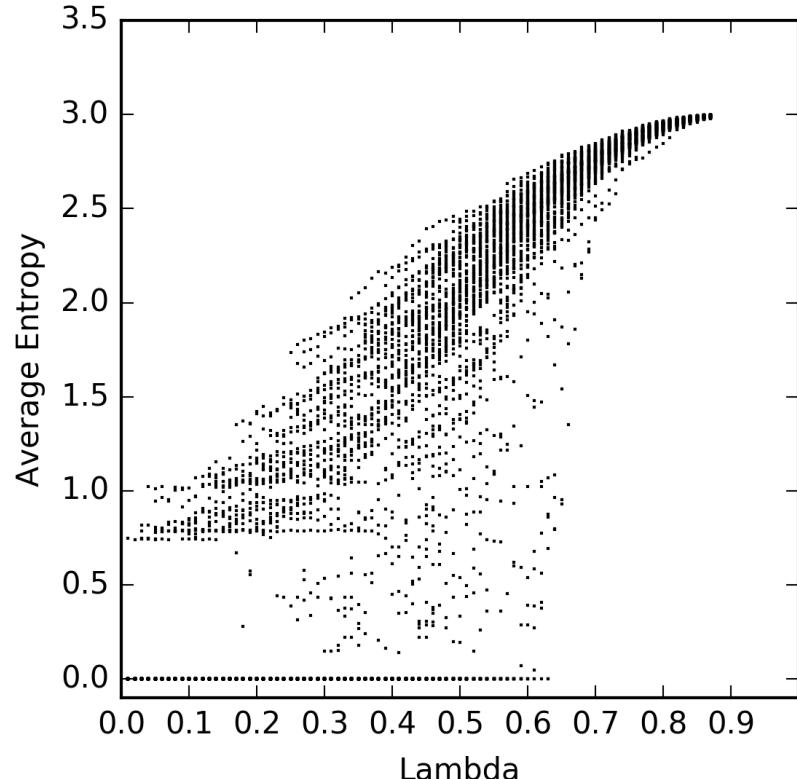
Degradation: 10%, Avg Neighborhood: 3.47



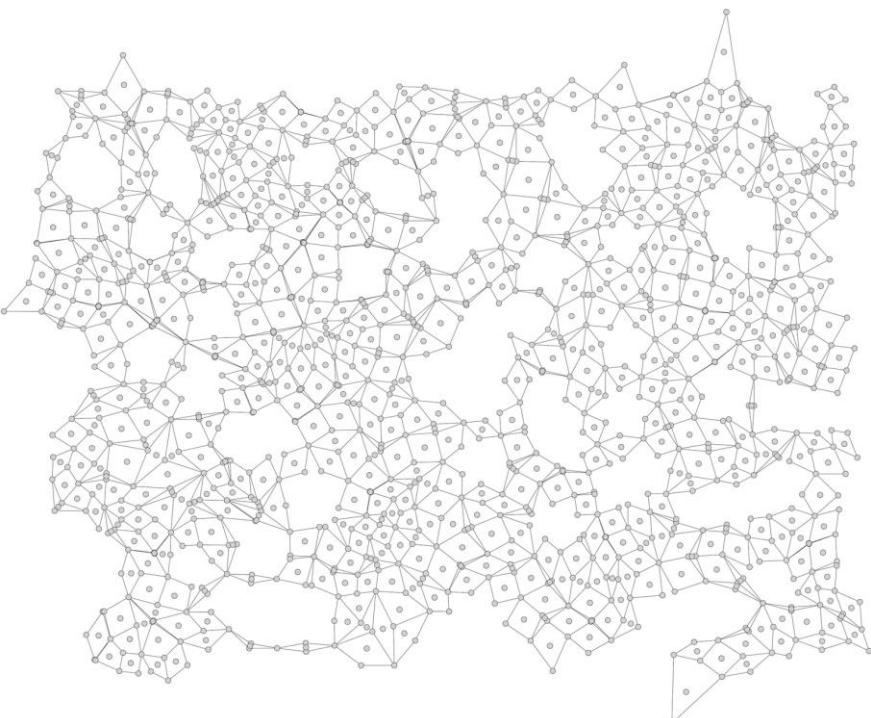
Generator Point Removal



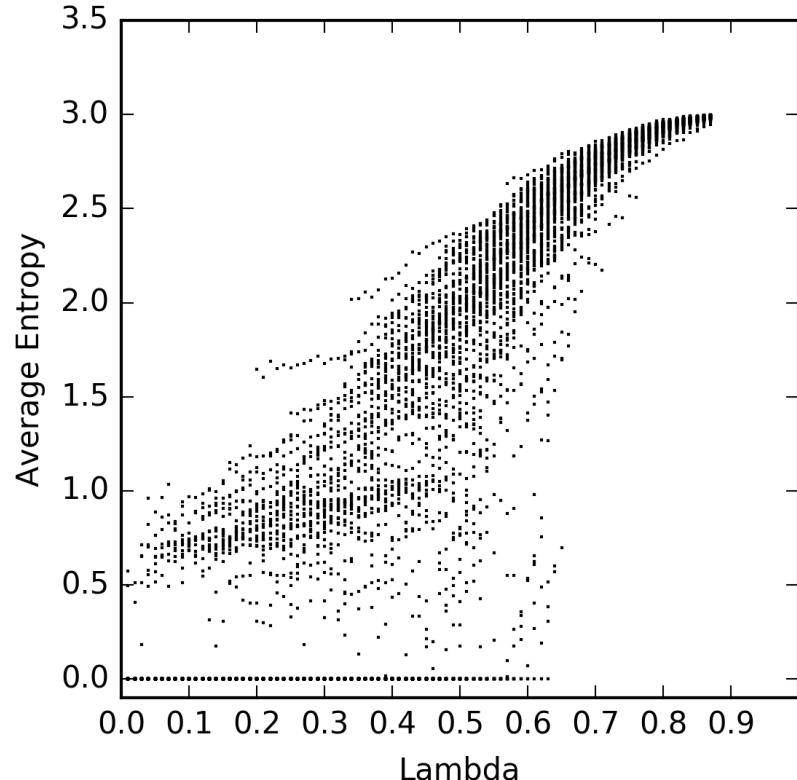
Degradation: 15%, Avg Neighborhood: 3.27



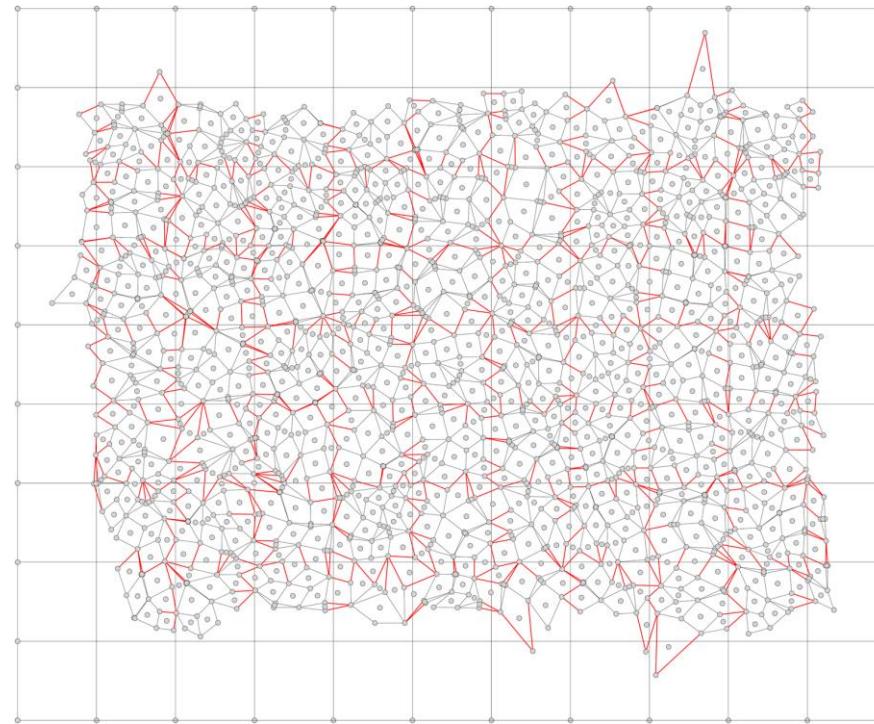
Generator Point Removal



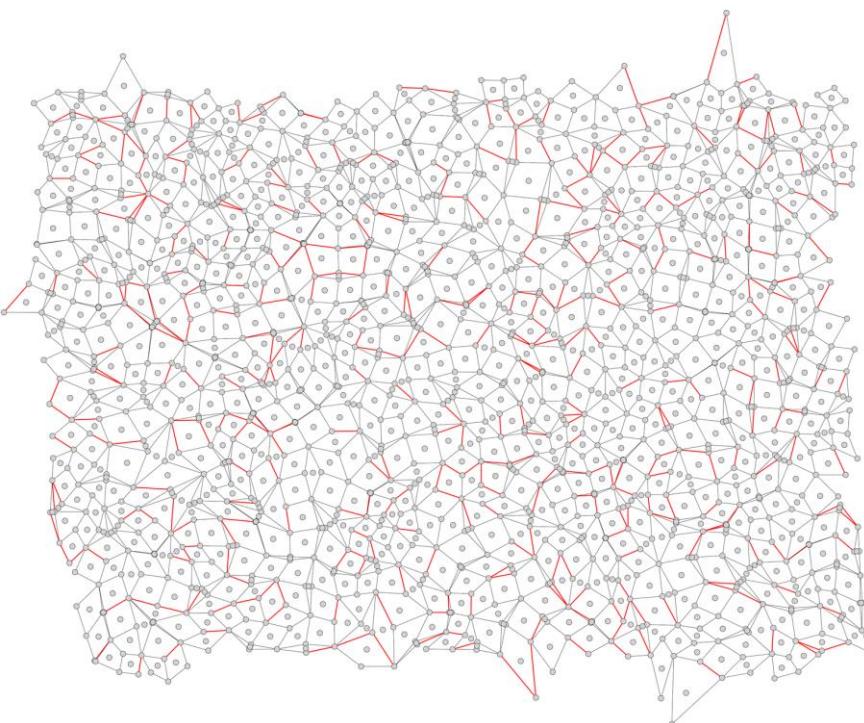
Degradation: 20%, Avg Neighborhood:
3.13



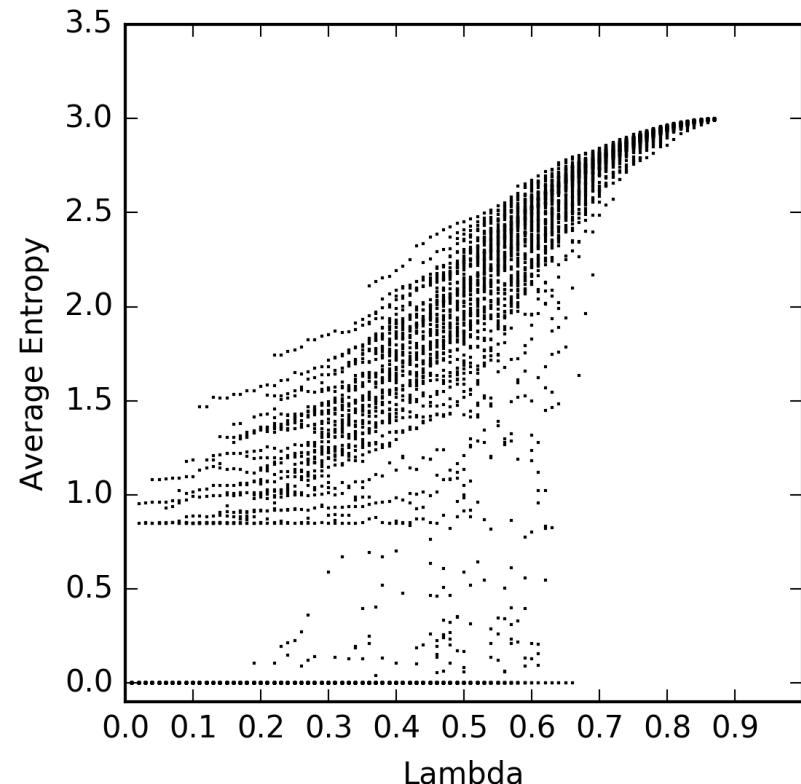
Crosshatching Degradation



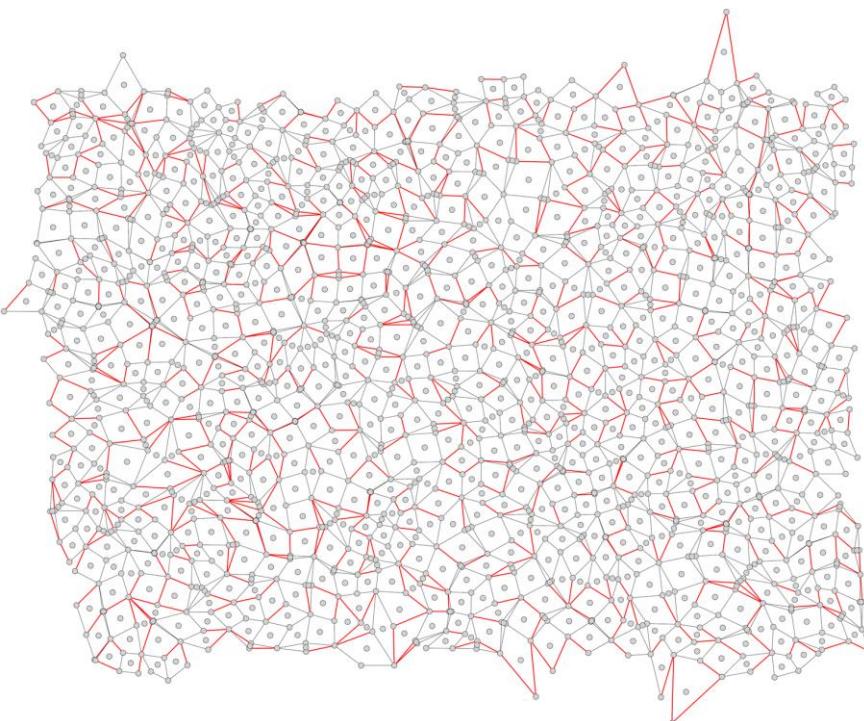
Crosshatching Degradation, $w = 10$



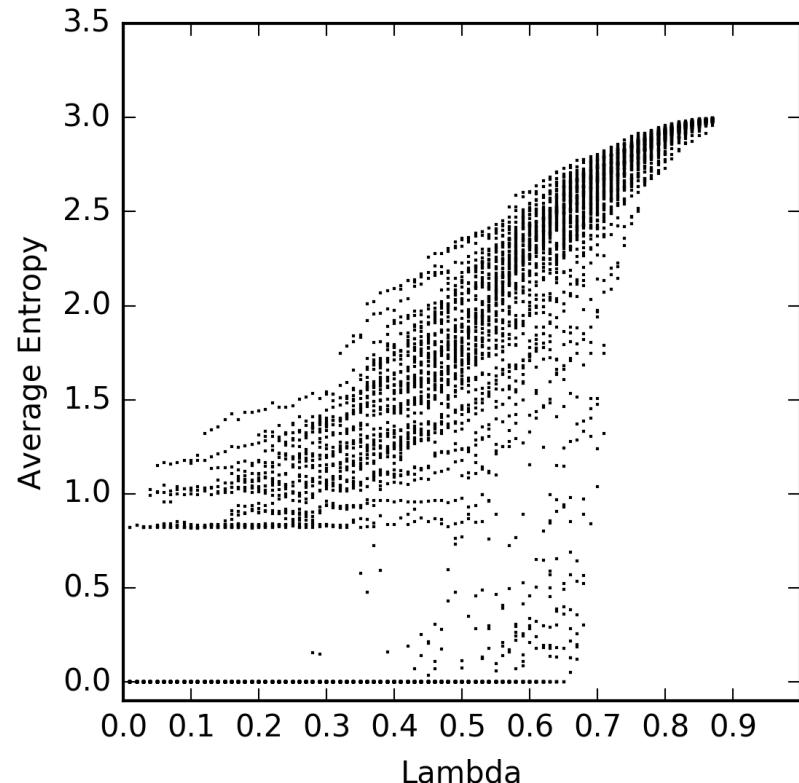
$w = 10, p = 0.25$



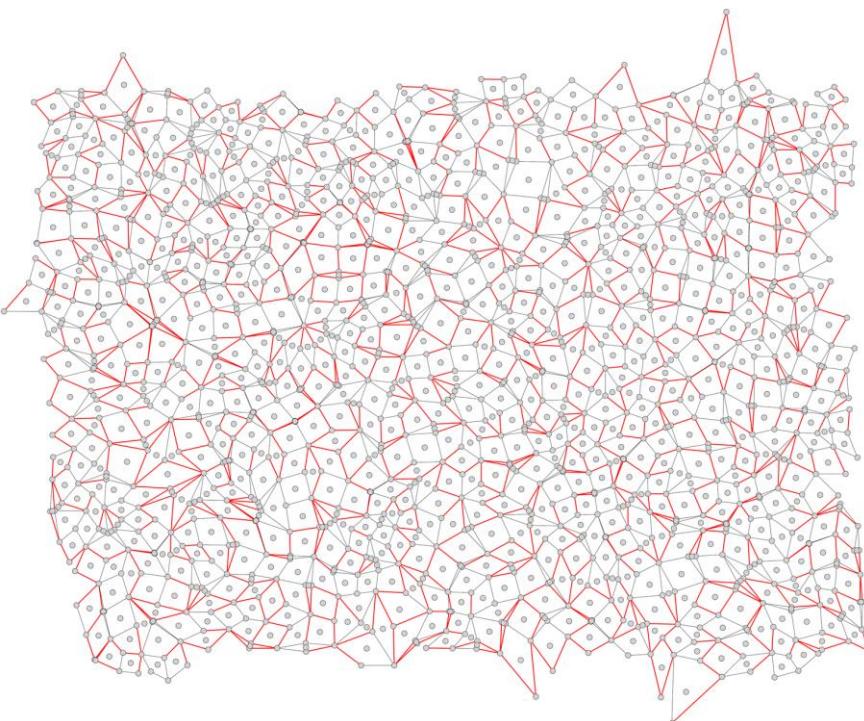
Crosshatching Degradation, $w = 10$



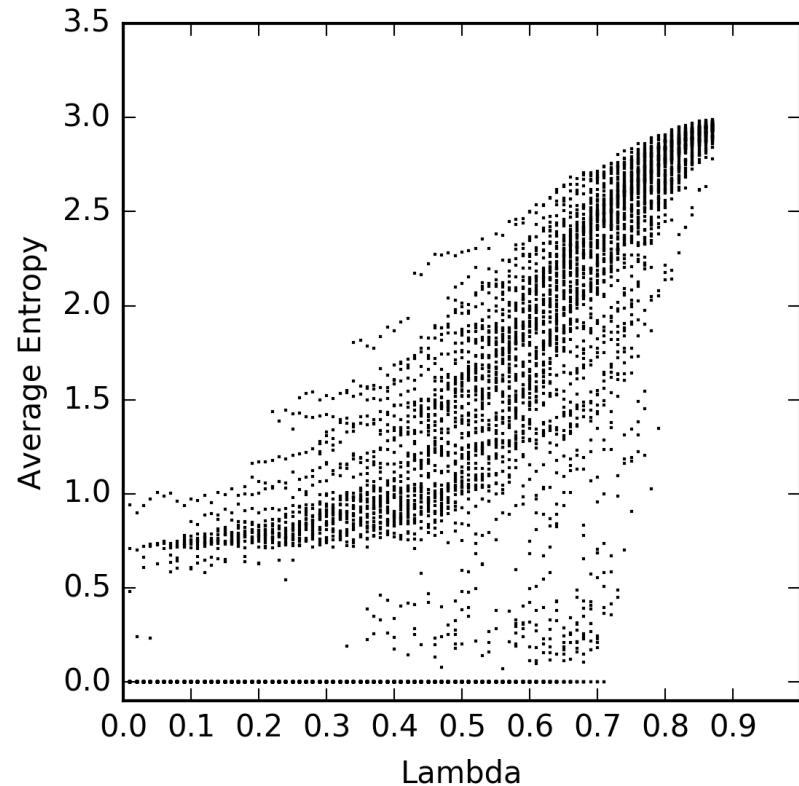
$w = 10, p = 0.50$



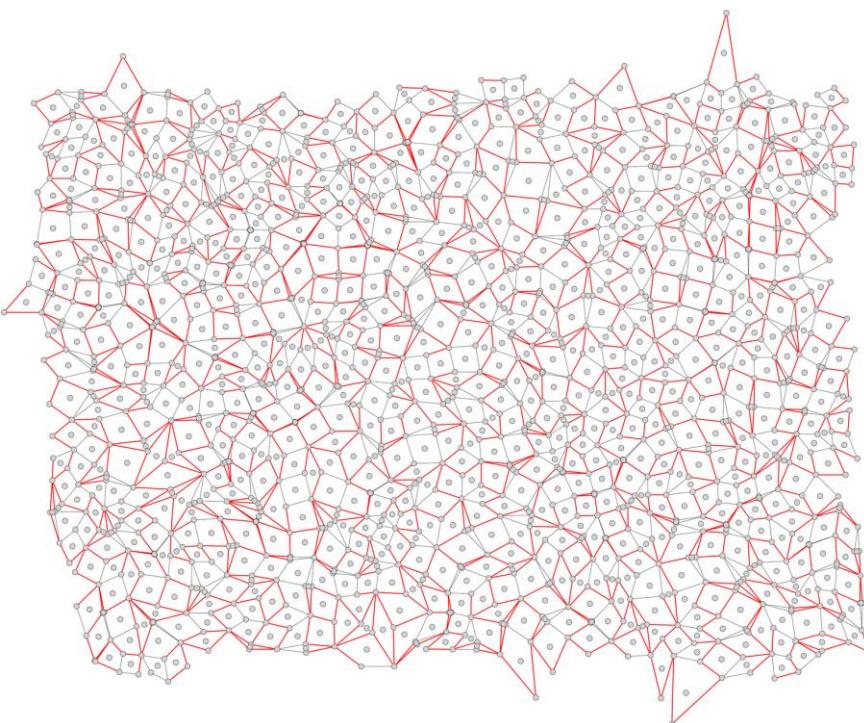
Crosshatching Degradation, $w = 10$



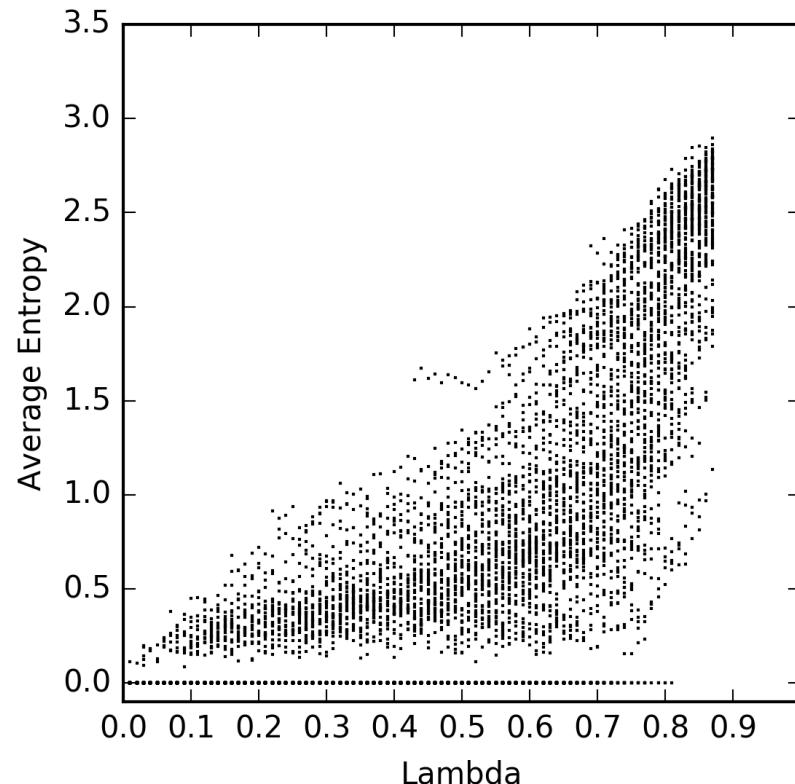
$w = 10, p = 0.75$



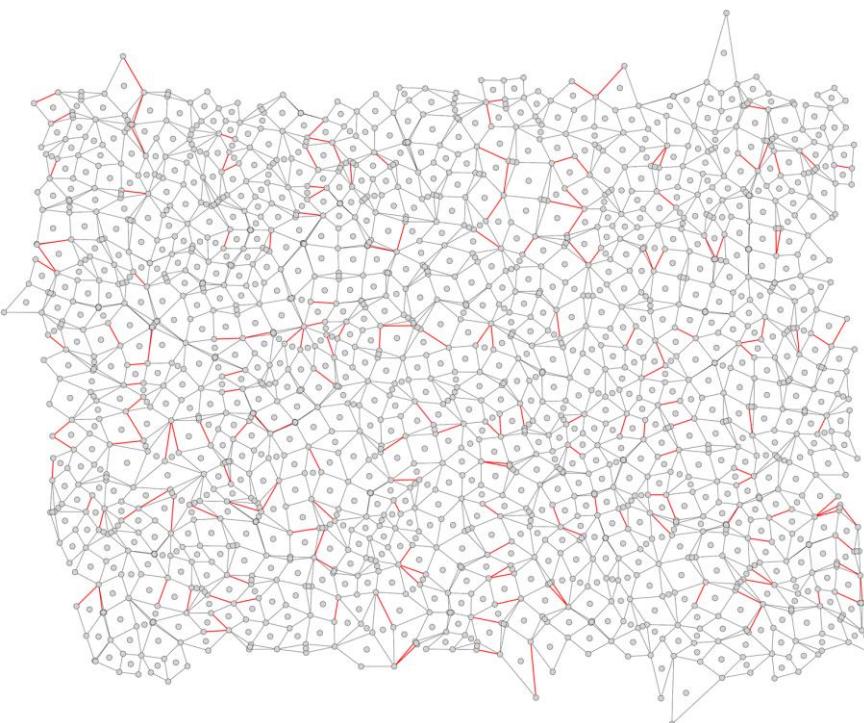
Crosshatching Degradation, $w = 10$



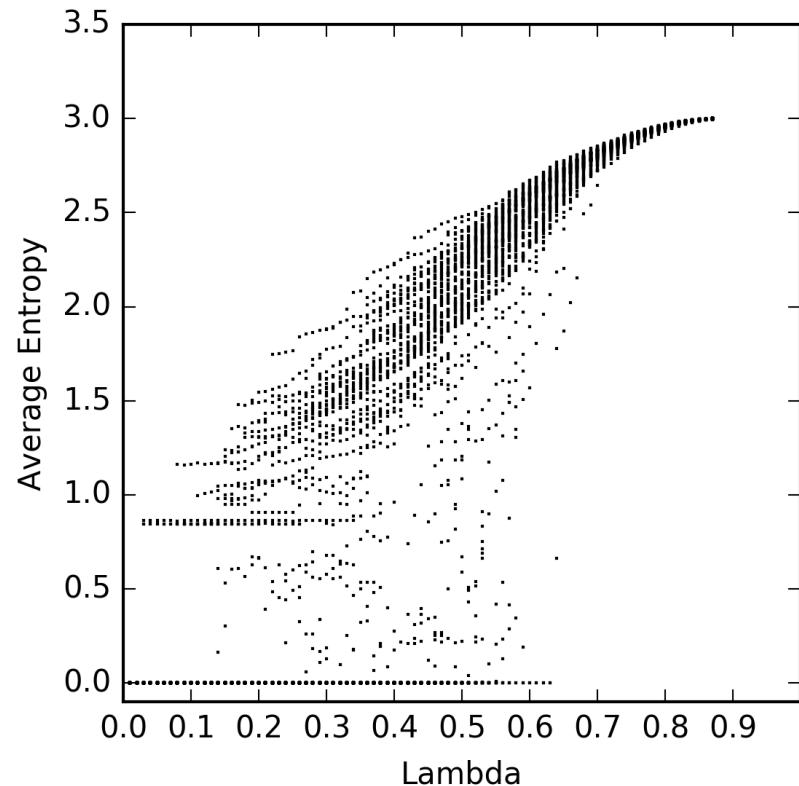
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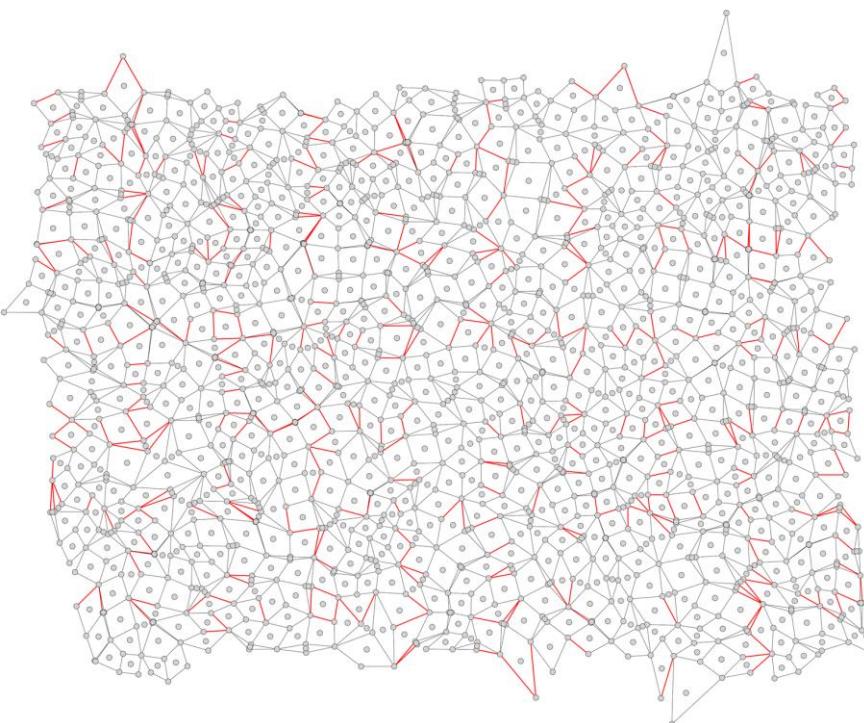
Crosshatching Degradation, $w = 20$



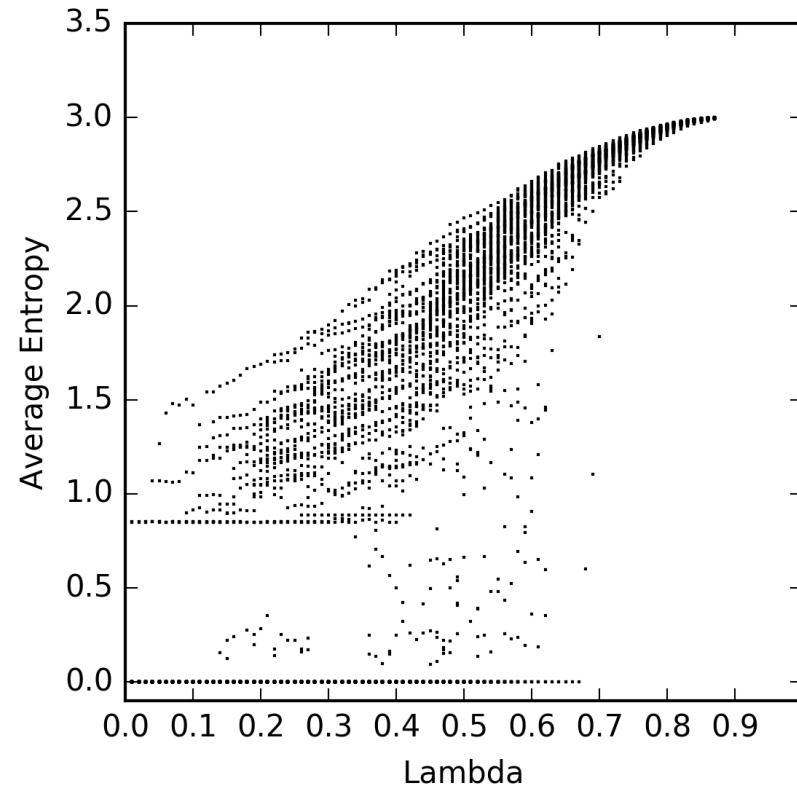
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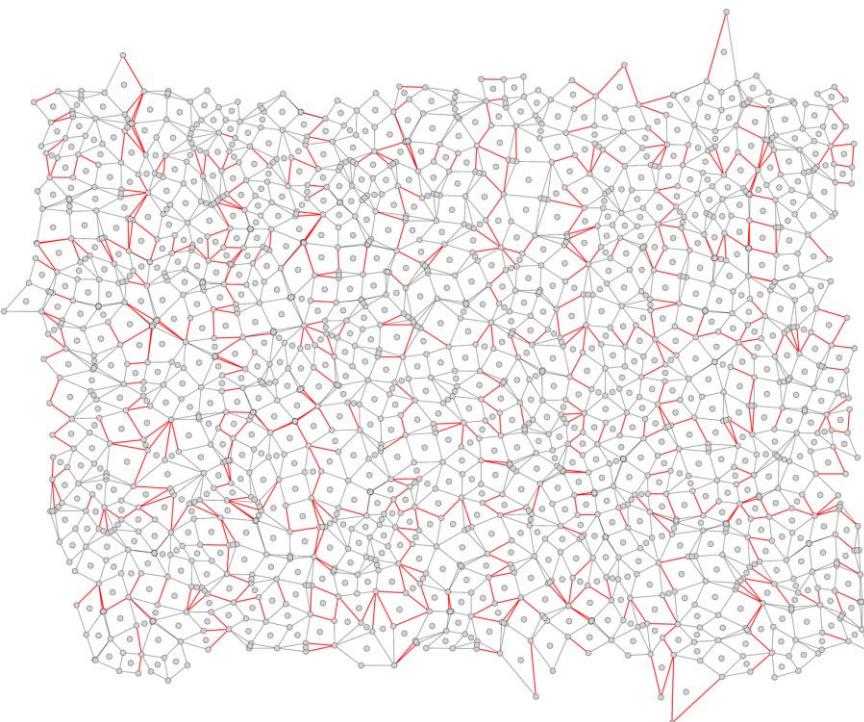
Crosshatching Degradation, $w = 20$



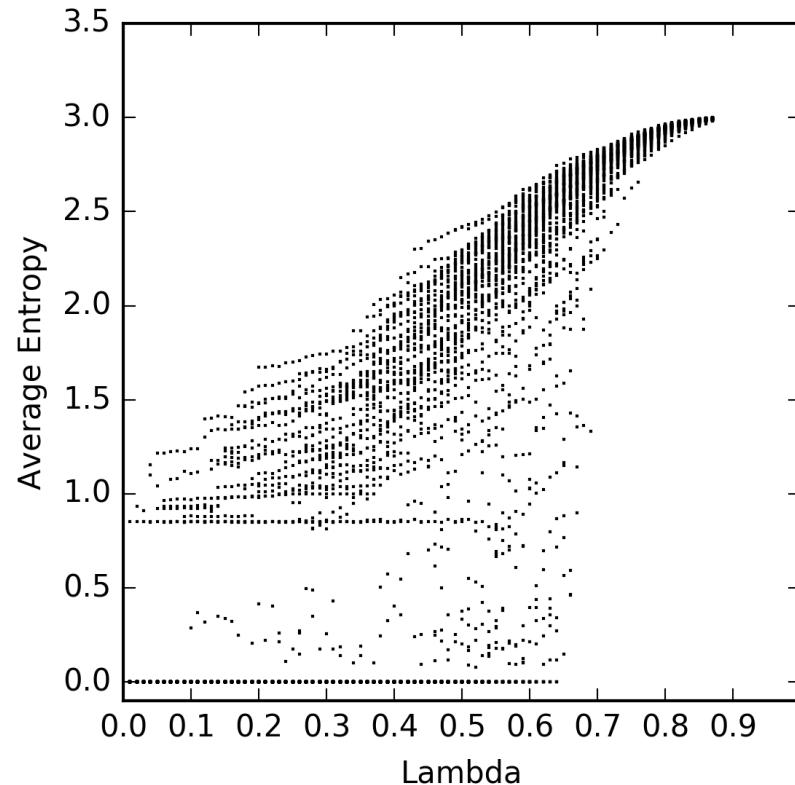
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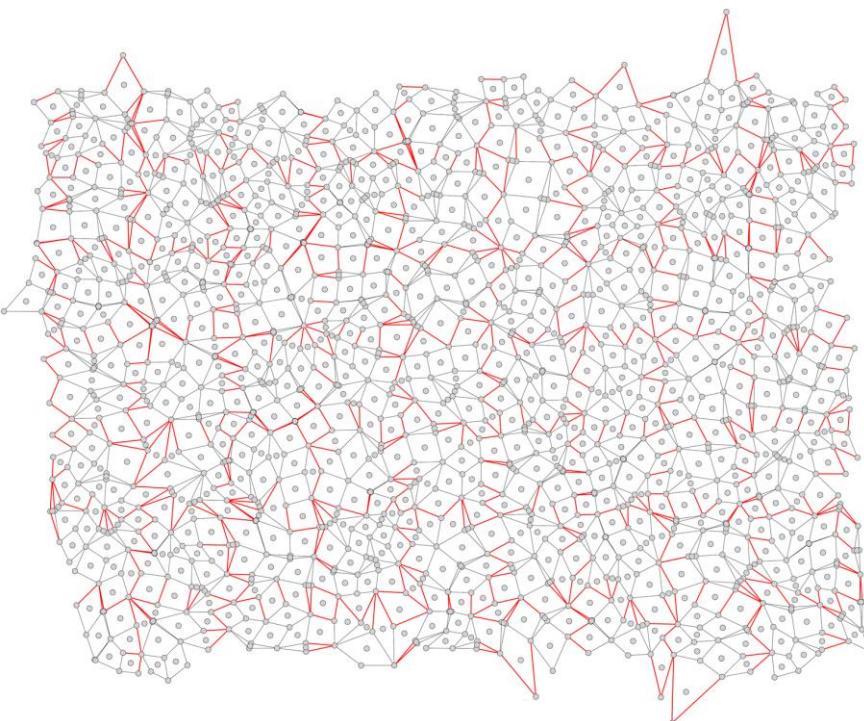
Crosshatching Degradation, $w = 20$



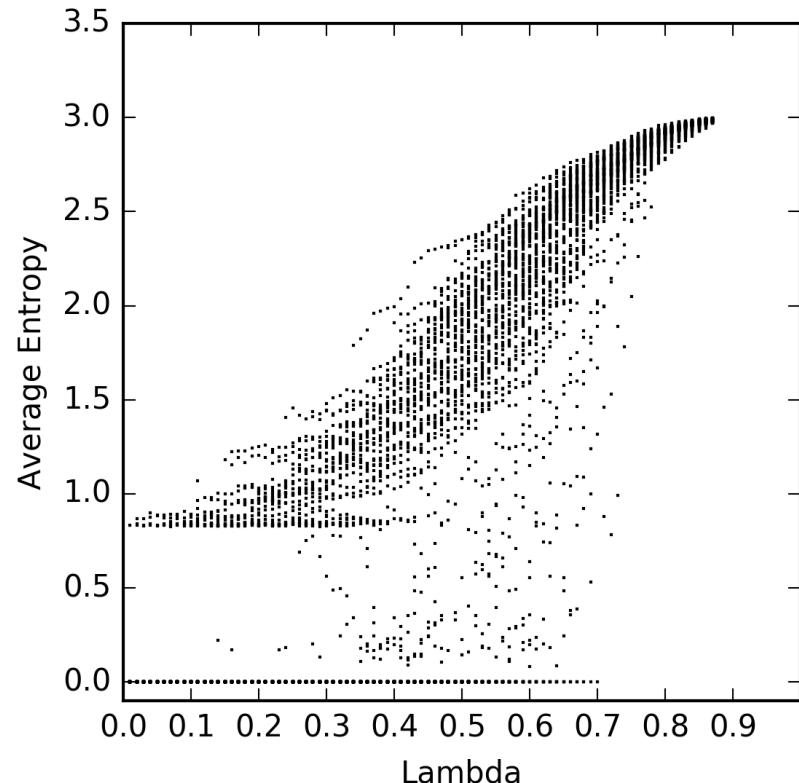
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Crosshatching Degradation, $w = 20$

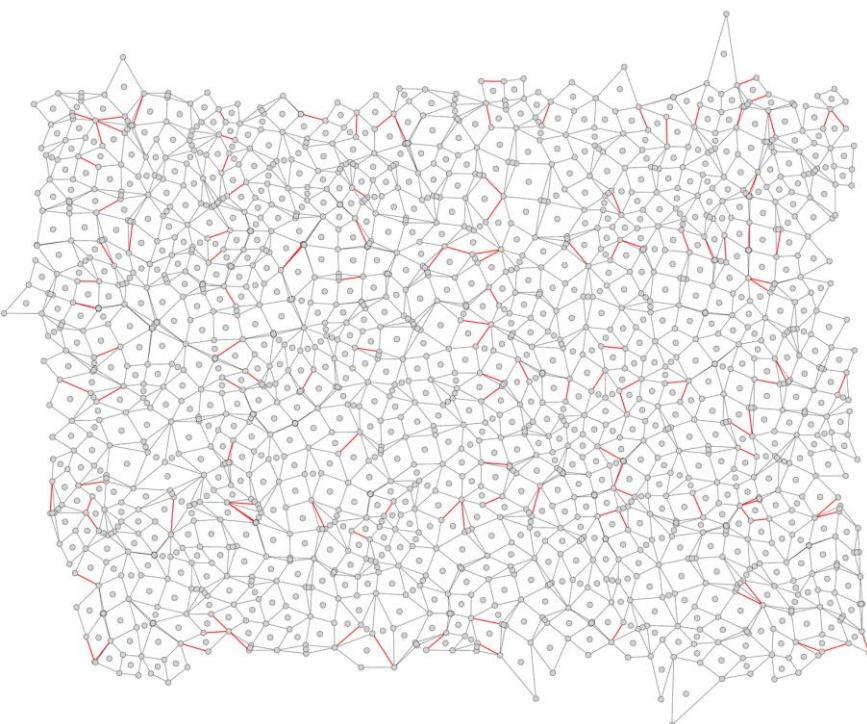


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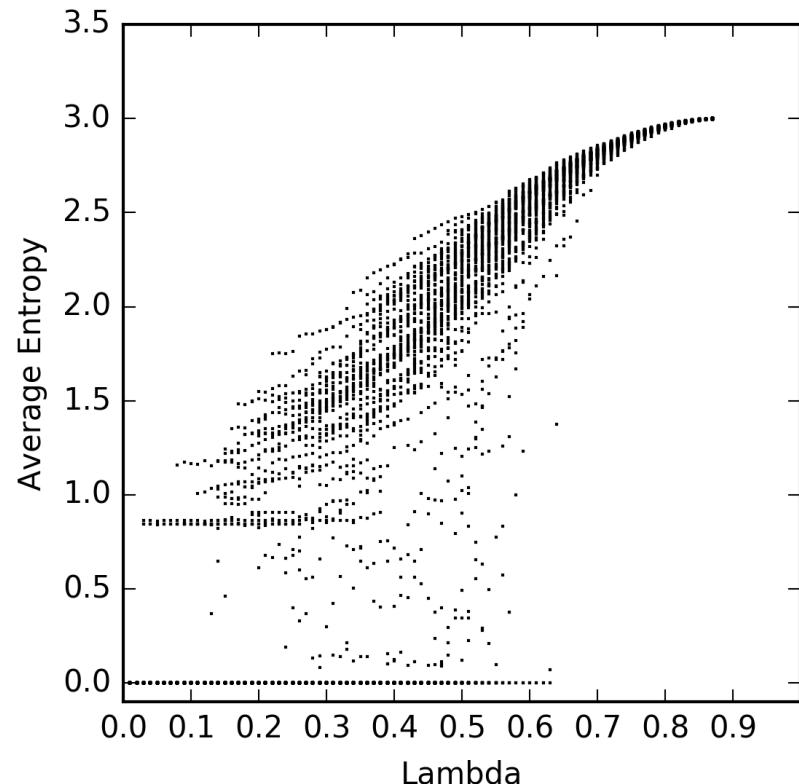


Lambda

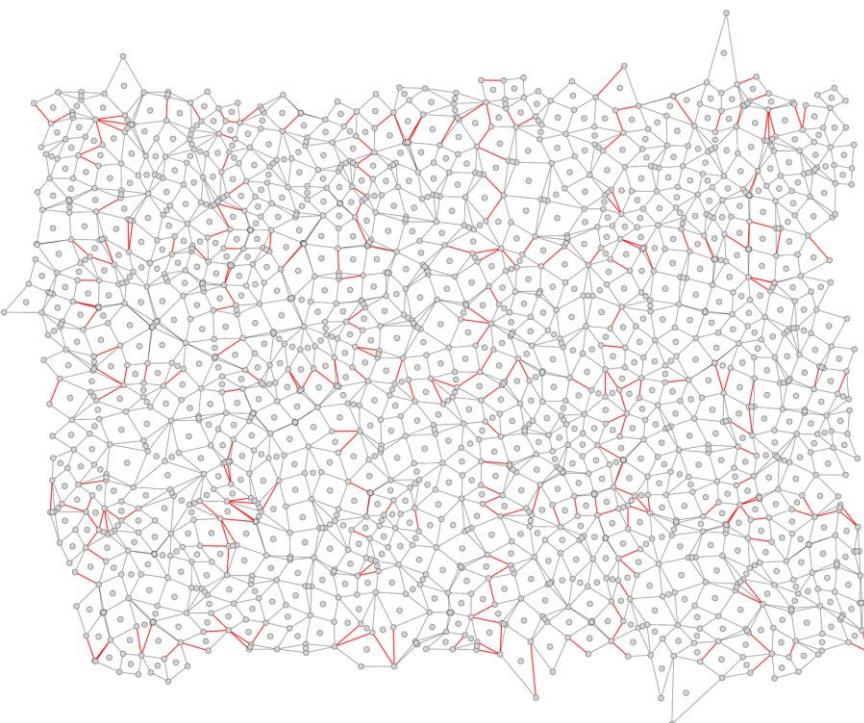
Crosshatching Degradation, $w = 30$



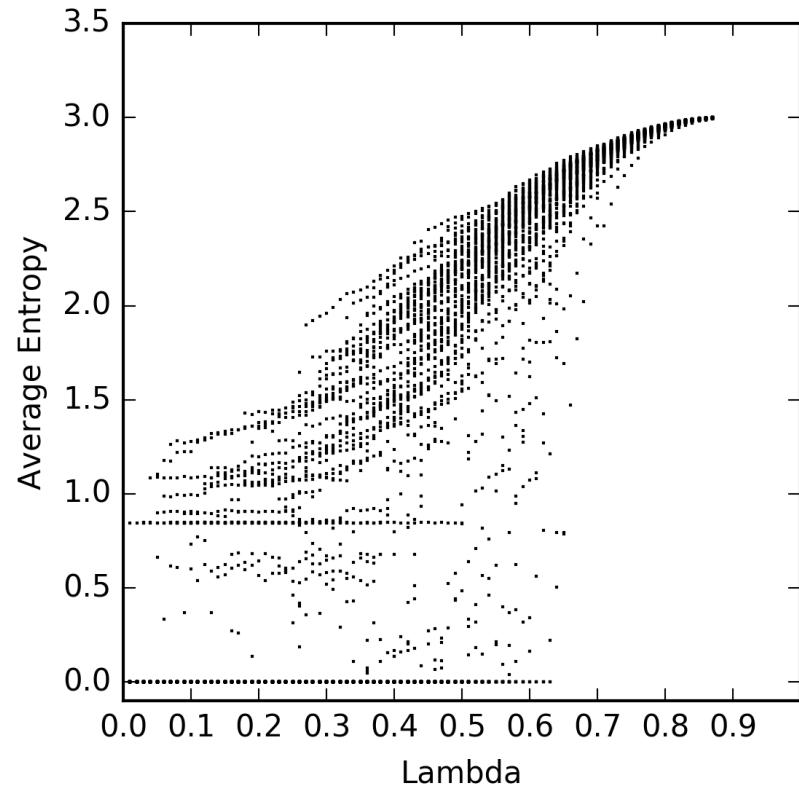
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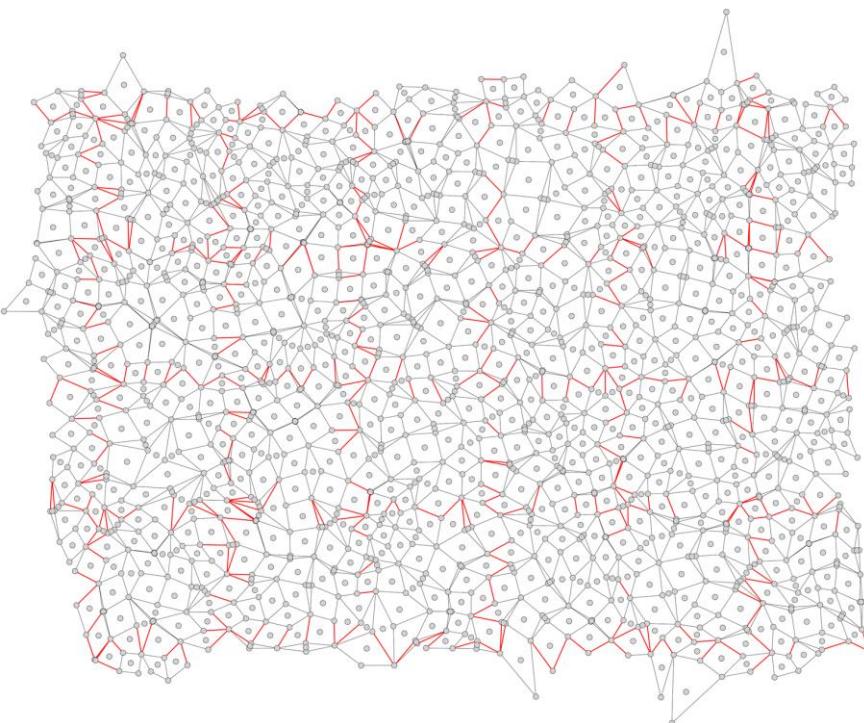
Crosshatching Degradation, $w = 30$



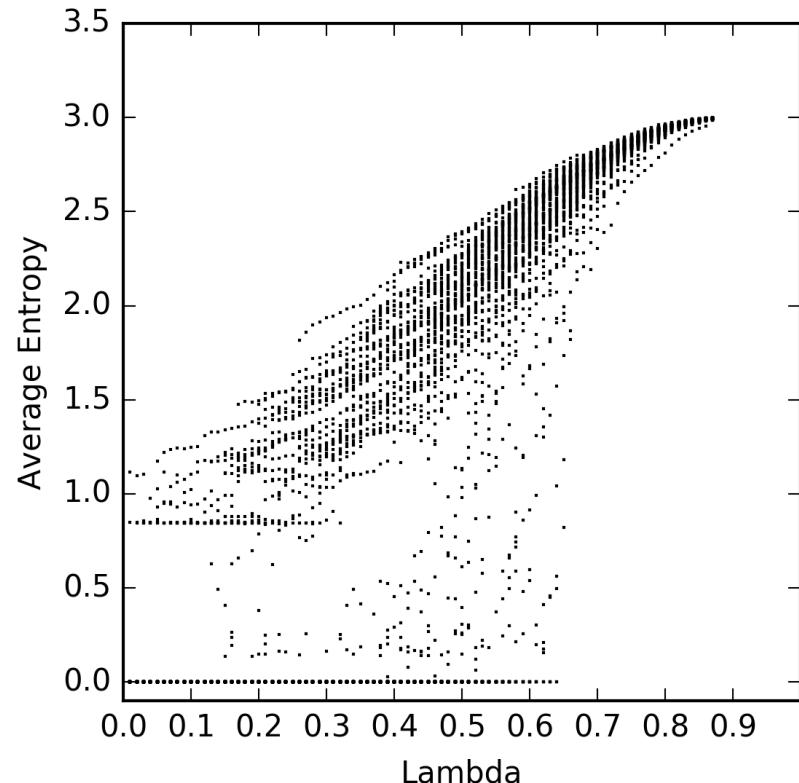
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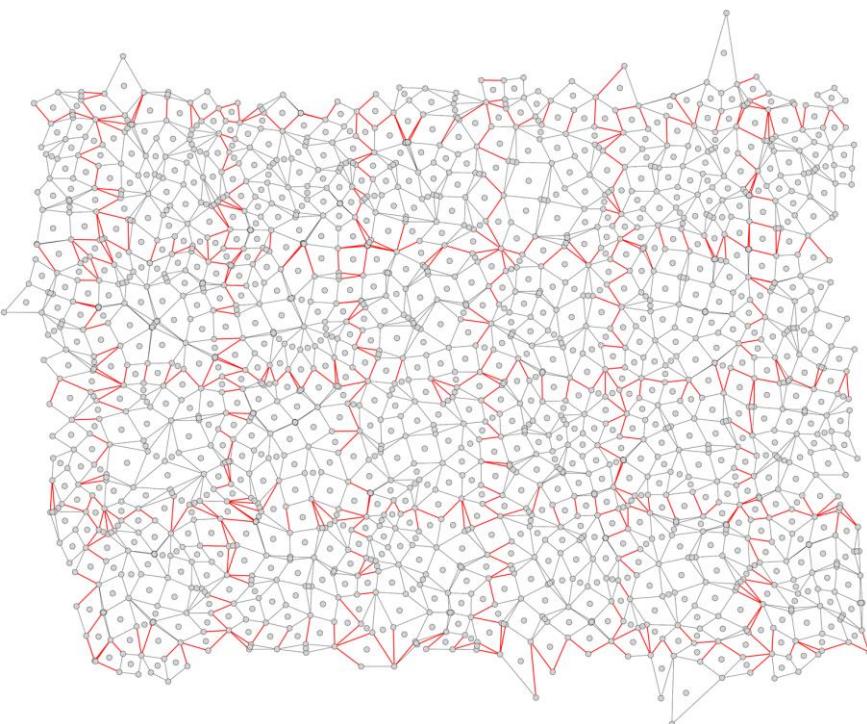
Crosshatching Degradation, $w = 30$



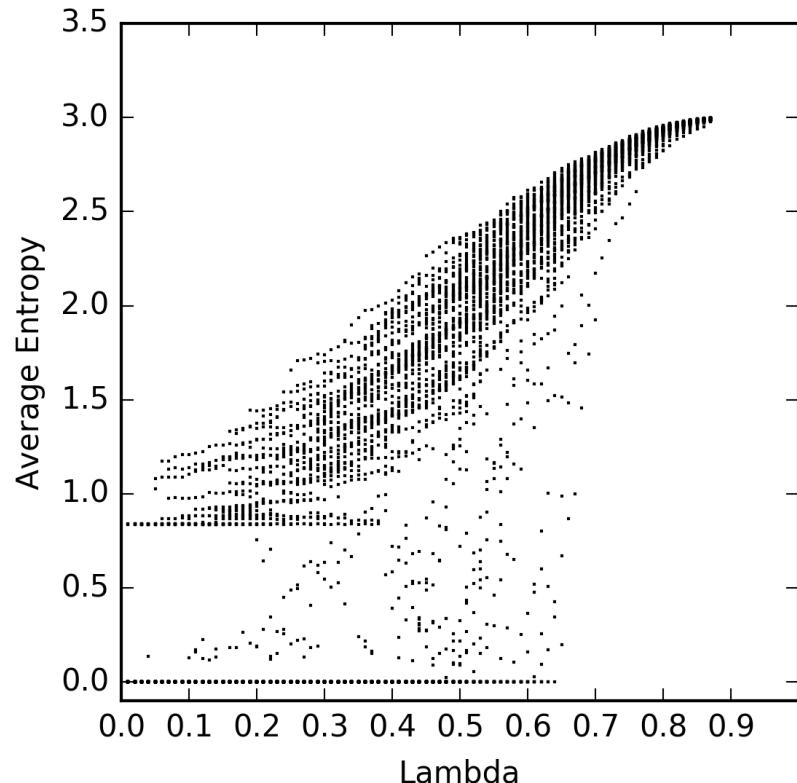
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Crosshatching Degradation, $w = 30$

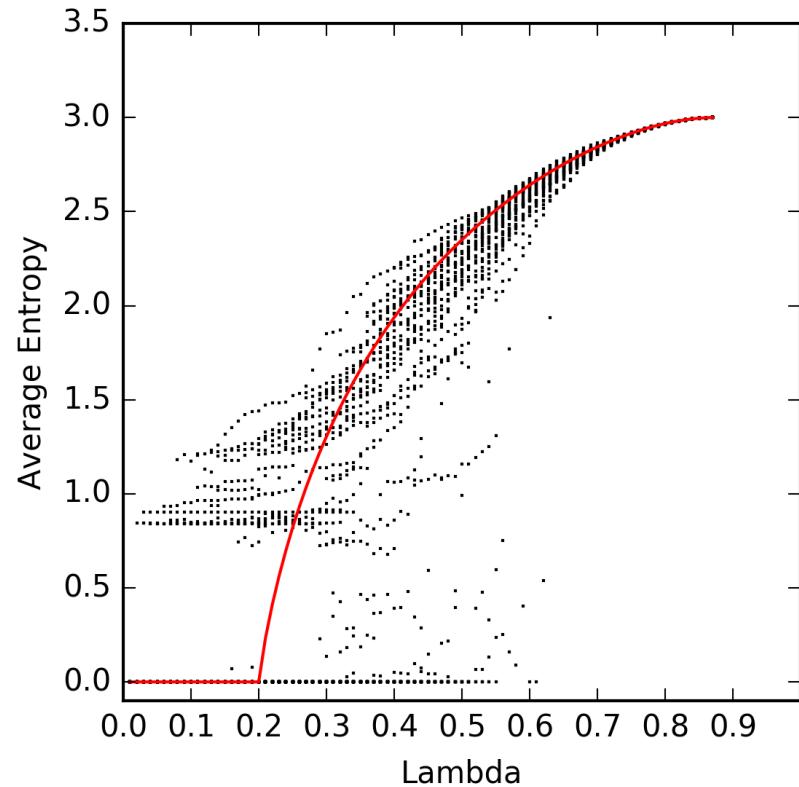


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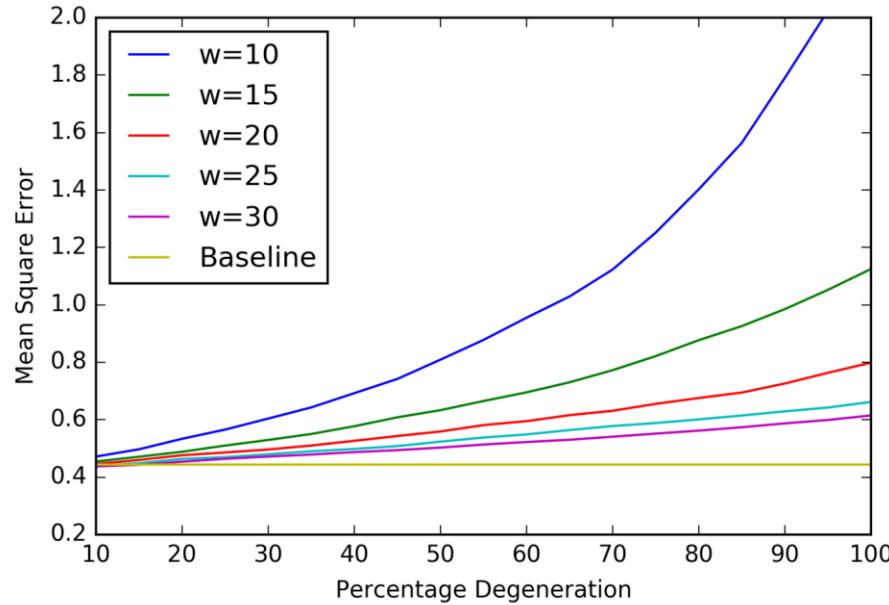


Alternative Metric: Mean Squared Error

$$MSE = \frac{1}{n} \sum_{i=1}^n (\hat{Y}_i - Y_i)^2$$



Crosshatching Degeneration: MSE

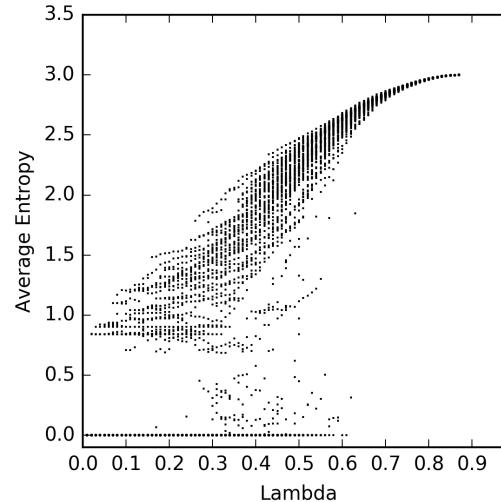
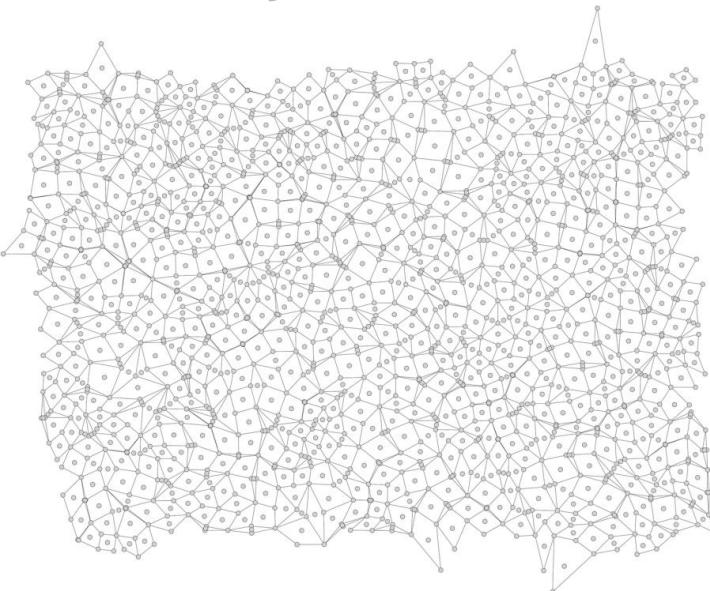


Conclusions

CA systems robust to spatial irregularity

Some regular grid features not required for complex CA behavior

Boundary conditions need to be considered

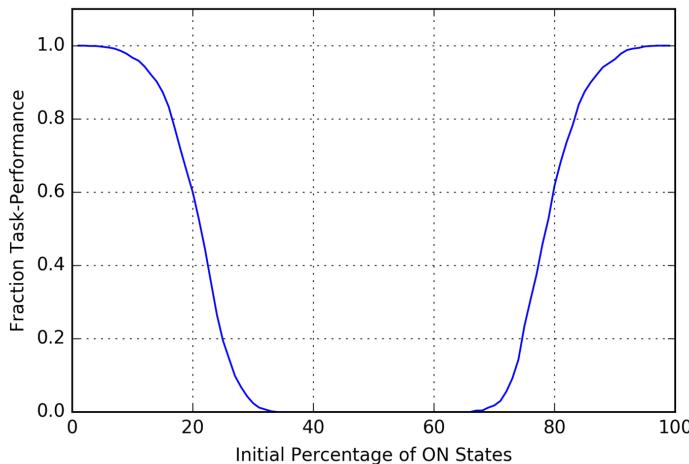


Conclusions

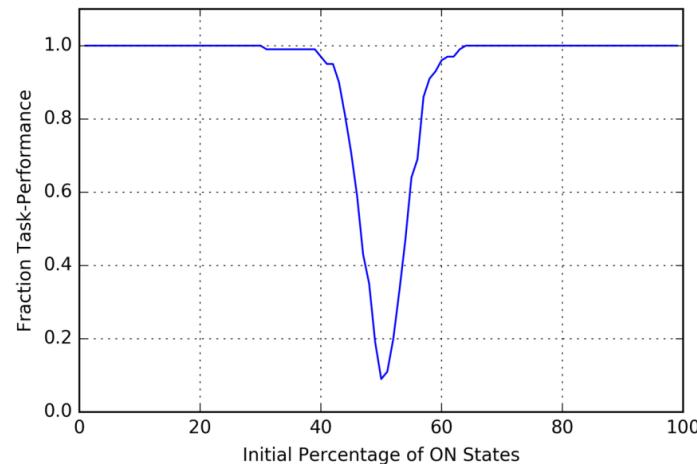
CA systems robust to spatial irregularity

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Stoma Grid, Bounded Border



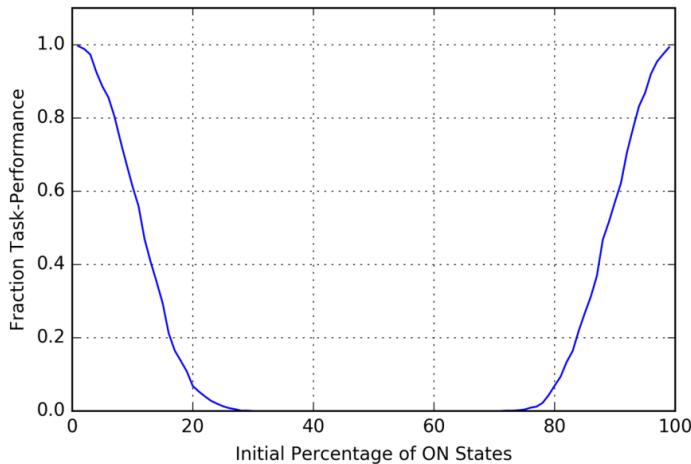
Stoma Grid, 5% Noise

Conclusions

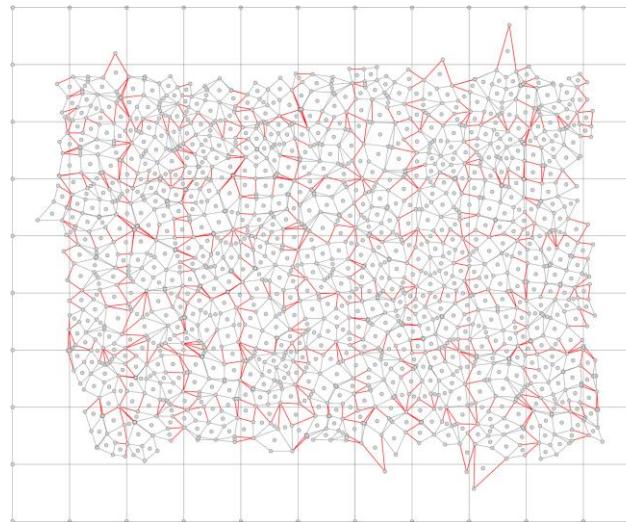
CA systems robust to spatial irregularity

Some regular grid features not required for complex CA behavior

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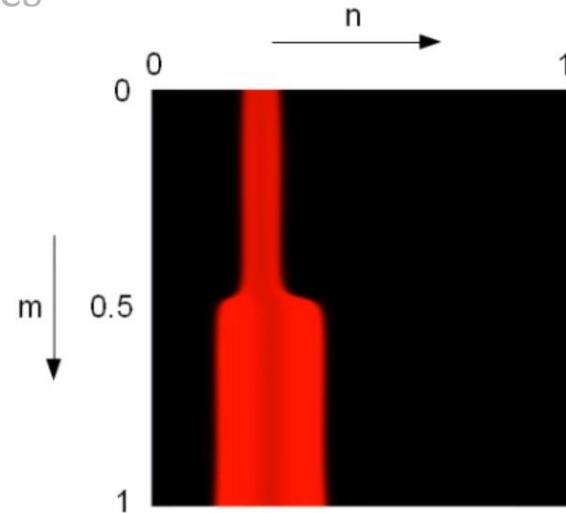
Regular Grid, Bounded Border



Future Work

Continuous CA

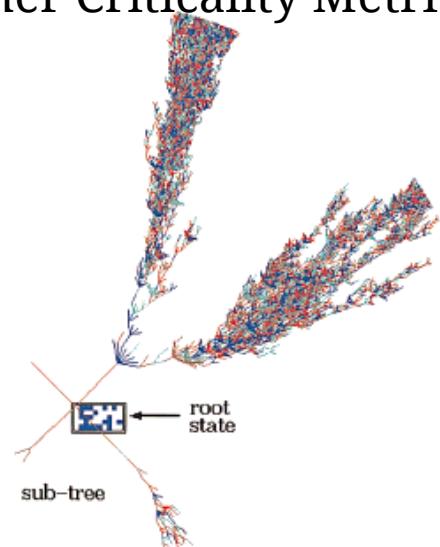
Other Criticality Metrics



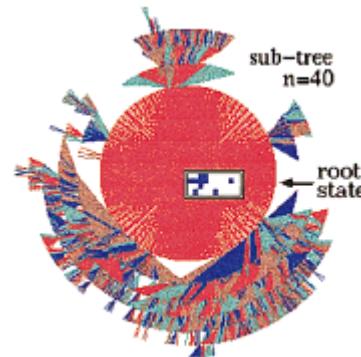
Future Work

Continuous CA

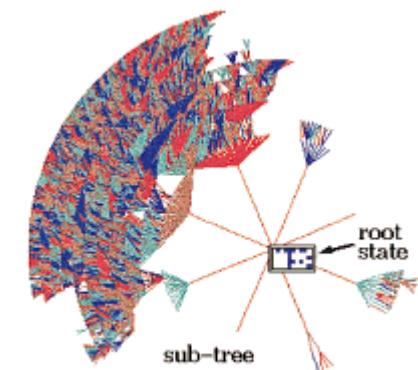
Other Criticality Metrics



Chaotic



Ordered



Complex

Figure 13, Wuensche 1998.

Acknowledgements

Thanks to:

Duane Bailey

Brent Heeringa

David Peak

Williams College CS Department

References

- Chris G Langton. Computation at the edge of chaos: phase transitions and emergent computation. *Physica D: Nonlinear Phenomena*, 42(1):12-37, 1990.
- Melanie Mitchell, Peter T Hraber, and James P Crutchfield. Revisiting the edge of chaos: Evolving cellular automata to perform computations. *Complex Systems*, 7 (Santa Fe Institute Working Paper 93-03-014):89-130, 1993.
- Susanna M Messinger, Keith A Mott, and David Peak. Task-performing dynamics in irregular, biomimetic networks. *Complexity*, 12(6):14-21, 2007.
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- David Peak, Jevin D. West, Susanna M Messinger, and Keith A Mott. Evidence for complex, collective dynamics and emergent, distributed computation in plants. *Proceedings of the National Academy of Sciences of the United States of America*, 101(4):918-922, 2004.

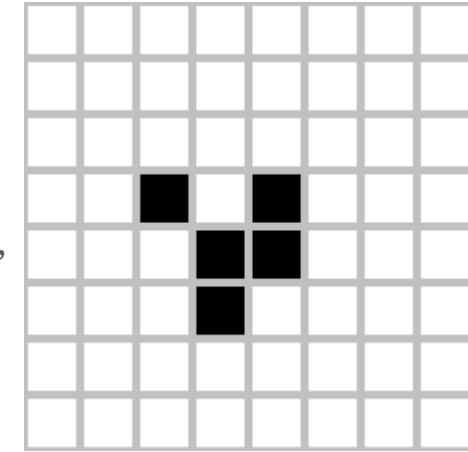
Extra Slides

Example: Game of Life

Rules

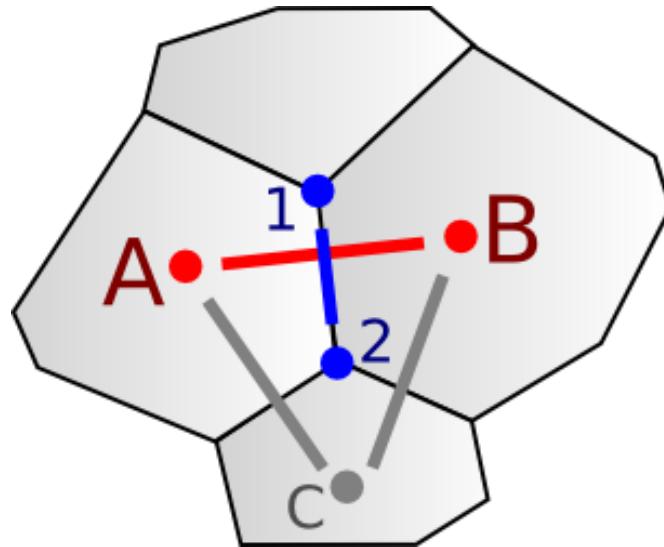
- Living cells stay alive if 2 or 3 neighbors are alive
- Living cells with >3 living neighbors die from “overcrowding”
- Living cells with <2 living neighbors die from “loneliness”
- Dead cells with 3 live neighbors are “born”

Neighborhood	Output
000000111	1
110001101	0
000010001	0
001010100	1
•	
•	
•	

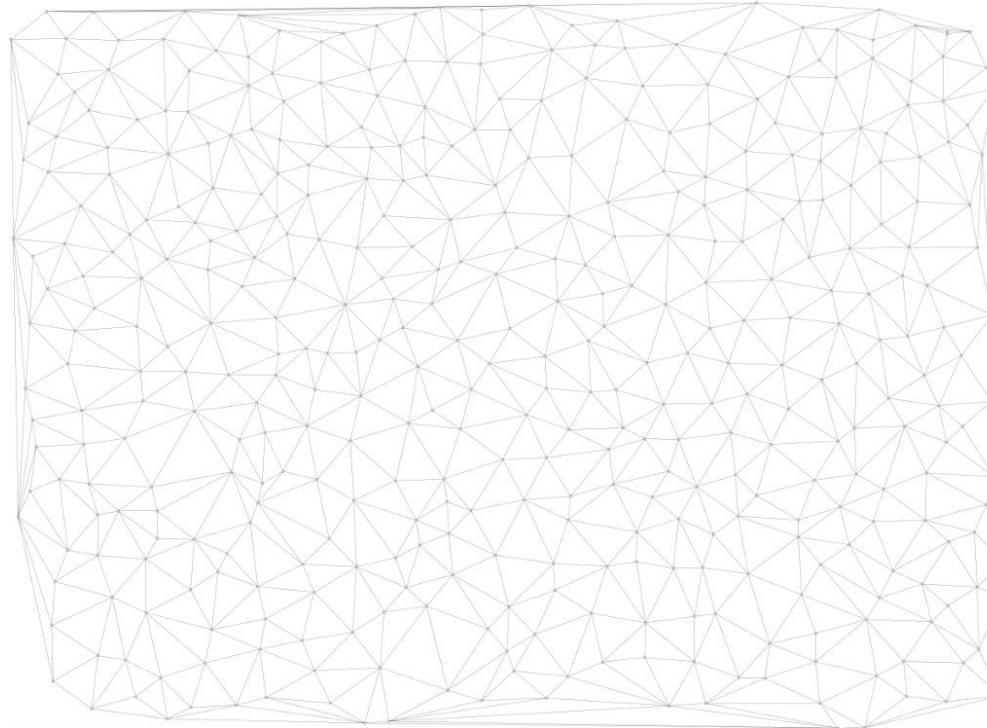


Rules of Life: Glider, Wikimedia Commons CC 3.0

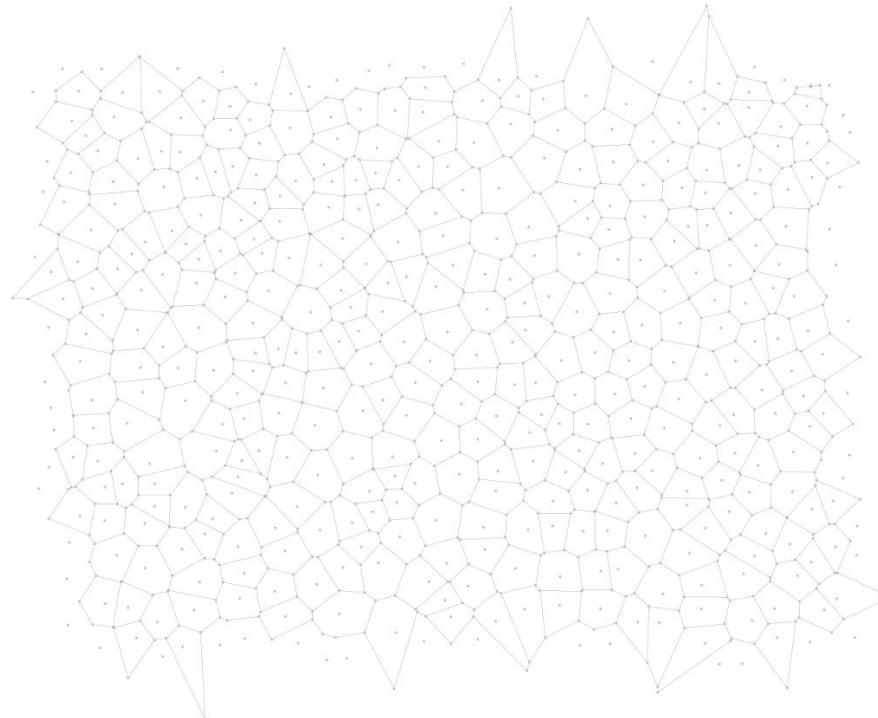
Creating “Voronoi Quads”



Creating Voronoi Quads



Creating Voronoi Quads



Creating Voronoi Quads

