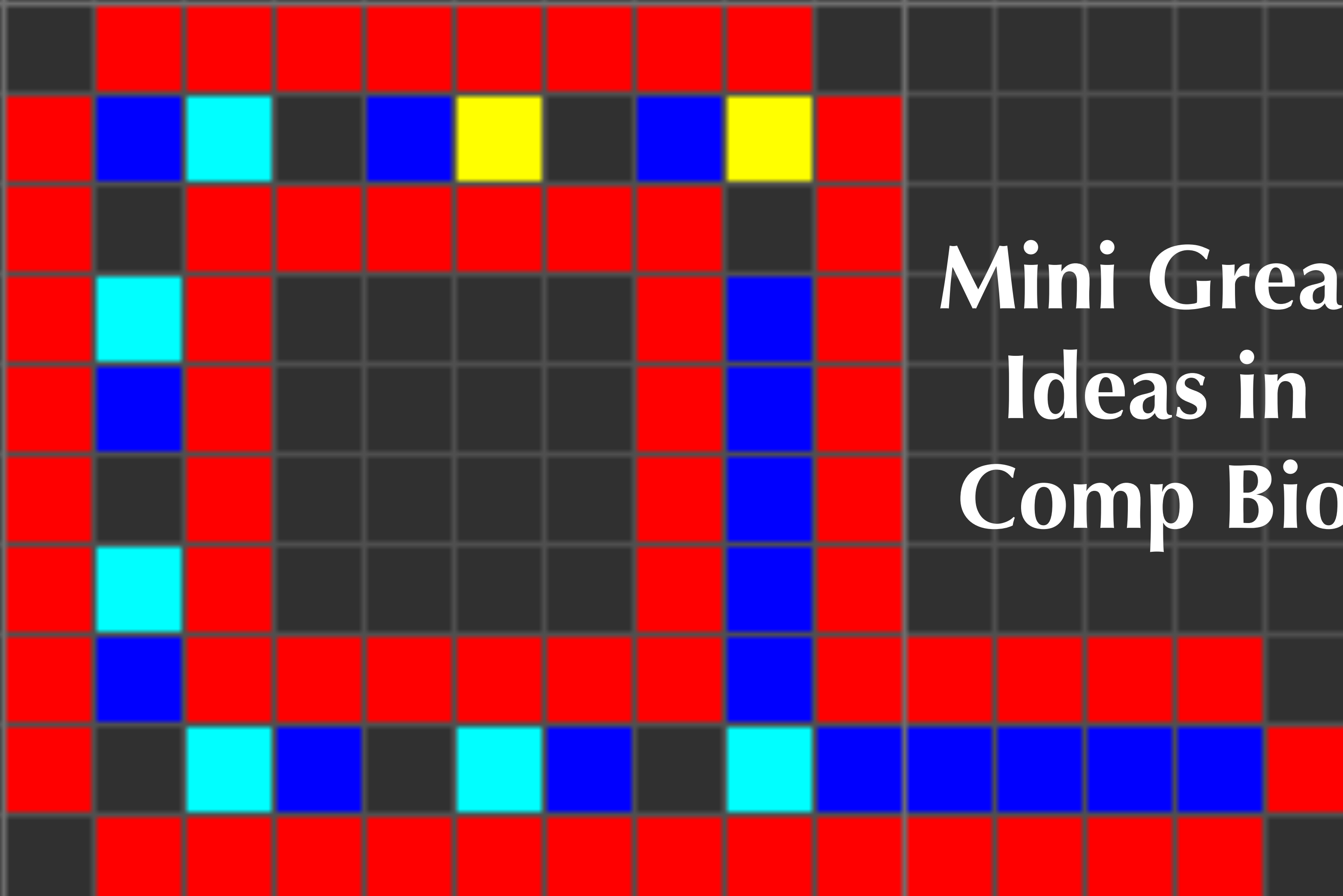
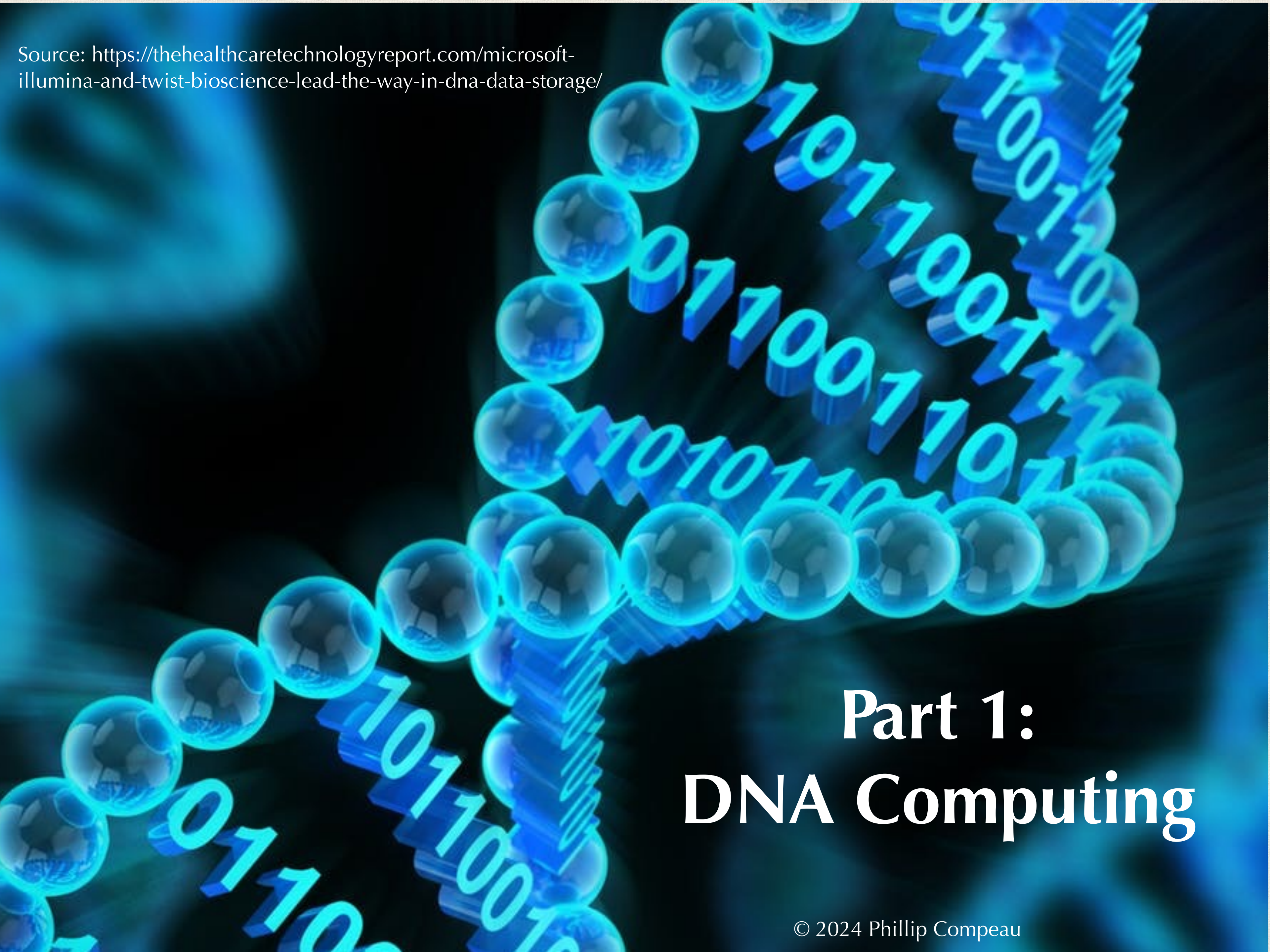


Mini Great Ideas in Comp Bio

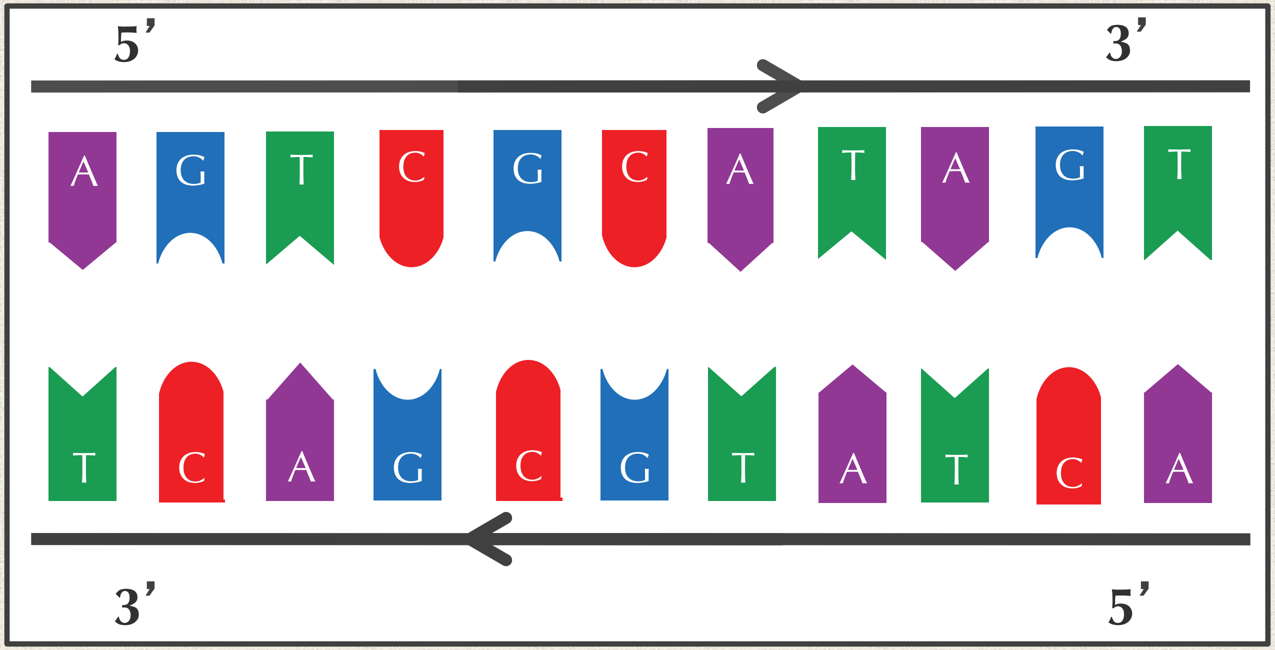


Source: https://thehealthcaretechnologyreport.com/microsoft-illumina-and-twist-bioscience-lead-the-way-in-dna-data-storage/

Part 1:
DNA Computing

What is DNA Computing?

DNA Computing: Using DNA as hardware of computer due to its molecular-scale storage capabilities.



Barriers to DNA Computing

DNA Computing: Using DNA as hardware of computer due to its molecular-scale storage capabilities.

STOP: What practical barriers do you see for using DNA as a system of storage?

Barriers to DNA Computing

DNA Computing: Using DNA as hardware of computer due to its molecular-scale storage capabilities.

STOP: What practical barriers do you see for using DNA as a system of storage?

Answer: Reading DNA is expensive, and (until recently) editing DNA has been impossible.

Some DNA Manipulations are Easy

DNA Computing: Using DNA as hardware of computer due to its molecular-scale storage capabilities.

However, there are some things that aren't hard:

- Synthesizing a strand (**oligonucleotide**) of DNA.

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- Filtering all fragments of DNA in a sample of some (approximate) length.

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However, there are some things that aren't hard:

- Synthesizing a strand (**oligonucleotide**) of DNA.
- Forcing a DNA strand to base pair given free nucleotides and DNA polymerase.
- Filtering all fragments of DNA in a sample of some (approximate) length.
- Amplifying a strand of DNA with given start/end into many copies (PCR, Nobel Prize in 1993).

Recall: Easy and Difficult Problems

Hamiltonian Cycle Problem ***NP-Complete***

Input: a directed network with *n* nodes.

Output: "Yes" if there is a cycle visiting every ***node*** in the network; "No" otherwise.

Eulerian Cycle Problem ***Polynomial***

Input: a directed network with *n* nodes.

Output: "Yes" if there is a cycle visiting every ***edge*** in the network; "No" otherwise.

Recall: Easy and Difficult Problems

Hamiltonian Cycle Problem ***NP-Complete***

Input: a directed network with n nodes.

Output: "Yes" if there is a cycle visiting every ***node*** in the network; "No" otherwise.

In particular, all *NP*-Complete problems are equivalent; if we solve the Hamiltonian Cycle Problem, then we solve them all.

Programming a DNA computer to solve the Hamiltonian cycle problem

Molecular computation of solutions to combinatorial problems
LM Adleman - Science, 1994 - science.sciencemag.org
The tools of molecular biology were used to solve an instance of the directed Hamiltonian path problem. A small graph was encoded in molecules of DNA, and the" operations" of the computation were performed with standard protocols and enzymes. This experiment demonstrates the feasibility of carrying out computations at the molecular level.
Cited by 5902 Related articles All 52 versions

Key insight: Rather than trying to use DNA as storage, why not use it to *solve* difficult problems?

Note: Adleman is also famous for public key cryptography (he is the “A” in “RSA” cryptosystem).

Programming a DNA computer to solve the Hamiltonian cycle problem

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Key insight: Rather than trying to use DNA as storage, why not use it to *solve* difficult problems?

The difficulty here is that it's not clear at all what it means to "program" a DNA computer.

Adleman's Algorithm

Algorithm for Determining if there is Hamiltonian Path in Graph *G* Connecting v_1 to v_n

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is captured.

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4. Keep only those paths that enter all the nodes of the graph at least once.

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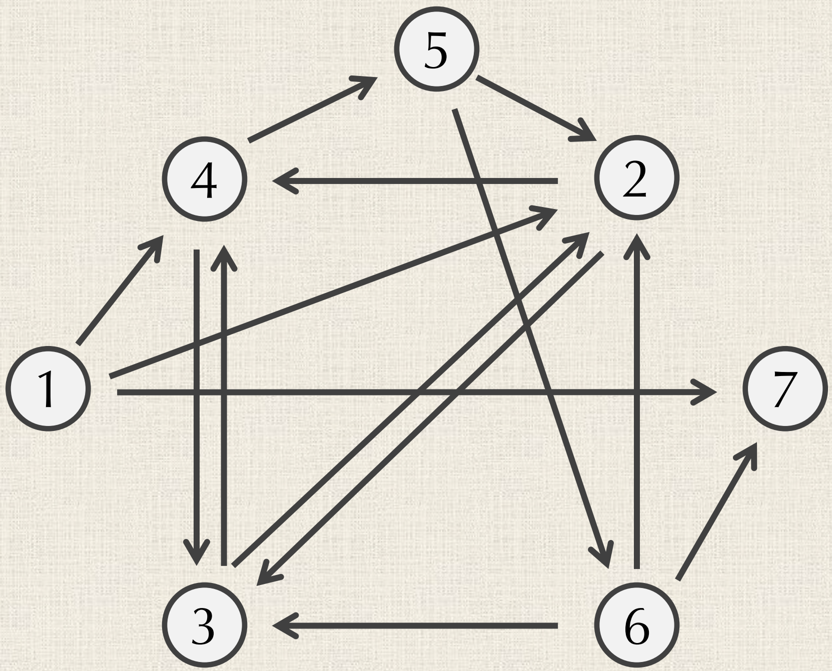
2. Keep only those paths that begin with v_1 and end with v_n .
3. Keep only those paths that have n nodes.
4. Keep only those paths that enter all the nodes of the graph at least once.
5. If any paths remain, return "Yes"; otherwise, return "No".

Converting Each Step to Experiment

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is present.



Adleman's original *G*

Converting Each Step to Experiment

1. Generate many "random paths" through G to ensure that any Hamiltonian path is present.

Associate every node i of G with a DNA k-mer denoted O_i . Call its complement O'_i .

O_i TGACGC

O'_i ACTGCG

Converting Each Step to Experiment

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is present.

Associate every edge (i, j) with a DNA k-mer $E_{i,j}$ consisting of last $k/2$ symbols of O_i followed by first $k/2$ symbols of O_j . (Preserves edge orientation.)

O_i TGACGC

O_j AAGACT

$E_{i,j}$ CGCAAG

Converting Each Step to Experiment

1. Generate many “random paths” through G to ensure that any Hamiltonian path is present.

Note: If $i = 1$, use all k symbols of O_1. If $j = n$, use all k symbols of O_n .

O_1 CATTAT

O_j AAGACT

$E_{1,j}$ CATTATAAG

Converting Each Step to Experiment

1. Generate many “random paths” through G to ensure that any Hamiltonian path is present.

Key Point: recall that generating oligonucleotides is cheap and easy.

Converting Each Step to Experiment

1. Generate many “random paths” through *G* to ensure that any Hamiltonian path is present.

Produce many oligonucleotides:

- copies of $E_{i,j}$ for every edge (i, j)
- copies of O'_i for every node other than v_1 and v_n .

Converting Each Step to Experiment

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is present.

Produce many oligonucleotides:

- copies of $E_{i,j}$ for every edge (i, j)
- copies of O'_i for every node other than v_1 and v_n .

STOP: What will happen when we combine all these DNA oligonucleotides in the lab?

Converting Each Step to Experiment

1. Generate many "random paths" through G to ensure that any Hamiltonian path is present.

Produce many oligonucleotides:

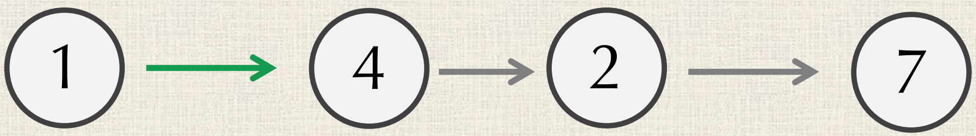
- copies of $E_{i,j}$ for every edge (i, j)
- copies of O'_i for every node other than v_1 and v_n .

Answer: edge $E_{i,j}$ will hybridize to O'_i and O'_j . Adjacent edges will therefore join into a path.

Converting Each Step to Experiment

1. Generate many "random paths" through G to ensure that any Hamiltonian path is captured.

Hypothetical path in G



O_1 CATTAT

O_2 CGTCCA

O_4 AAGACT

O_7 CTTTAG

$E_{1,4}$

CATTATAAG

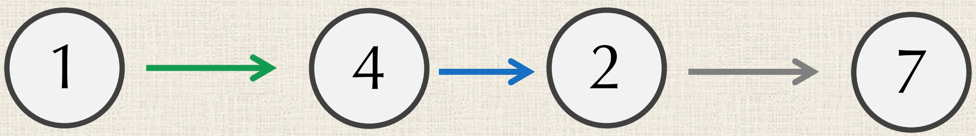
TTCTGA

O'_4

Converting Each Step to Experiment

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is captured.

Hypothetical path in *G*



$E_{1,4}$ $E_{4,2}$

CATTATAAGACTCGT

TTCTGA

O'_4

O_1 CATTAT

O_2 CGTCCA

O_4 AAGACT

O_7 CTTTAG

Converting Each Step to Experiment

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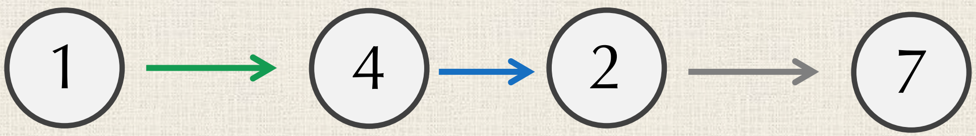

$E_{1,4}$ $E_{4,2}$

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O'_4 O'_2

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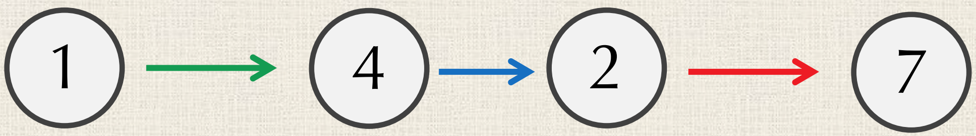
O_2	CGTCCA
O_4	AAGACT
O_7	CTTTAG

Converting Each Step to Experiment

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is captured.

Hypothetical path in *G*



$E_{1,4}$ $E_{4,2}$ $E_{2,7}$

CATTATAAGACTCGTCCACTTTAG

TTCTGAGCAGGT

O'_4 O'_2

O_1	CATTAT
O_2	CGTCCA
O_4	AAGACT
O_7	CTTTAG

Converting Each Step to Experiment

1. Generate many "random paths" through *G* to ensure that any Hamiltonian path is captured.

As a result, every path in the graph will be present as some double-stranded DNA molecule.

Converting Each Step to Experiment

2. Keep only those paths that begin with v_1 and end with v_n .

Use PCR to amplify only those remaining fragments of DNA that begin with O_1 and end with O_n .

Converting Each Step to Experiment

3. Keep only those paths that have *n* nodes.

Filter remaining DNA fragments by length, and throw out all fragments that don't have length approximately equal to $n * k$ nucleotides.

Converting Each Step to Experiment

4. Keep only those paths that enter all the nodes of the graph at least once.

Convert all DNA to single strands, and hybridize DNA against O'_i for some *i*. Filter out strands that don't bind. Repeat for all O'_i.

CATTATAAGAAGCGTCCACTTTAG

O_1	CATTAT
O_2	CGTCCA
O_3	GACCGT

Converting Each Step to Experiment

4. Keep only those paths that enter all the nodes of the graph at least once.

Convert all DNA to single strands, and hybridize DNA against O'_i for some *i*. Filter out strands that don't bind. Repeat for all O'_i.

CATTATAAGAAGCGTCCACTTTAG	O_1	CATTAT
GTAATA	O_2	CGTCCA
O'_1	O_3	GACCGT

Converting Each Step to Experiment

4. Keep only those paths that enter all the nodes of the graph at least once.

Convert all DNA to single strands, and hybridize DNA against O'_i for some *i*. Filter out strands that don't bind. Repeat for all O'_i.

CATTATAAGAAGCGTCCACTTTAG

GCAGGT

O'_2

O_1	CATTAT
O_2	CGTCCA
O_3	GACCGT

Converting Each Step to Experiment

4. Keep only those paths that enter all the nodes of the graph at least once.

Convert all DNA to single strands, and hybridize DNA against O'_i for some *i*. Filter out strands that don't bind. Repeat for all O'_i .

`CATTATAAGAAGCGTCCACTTTAG`

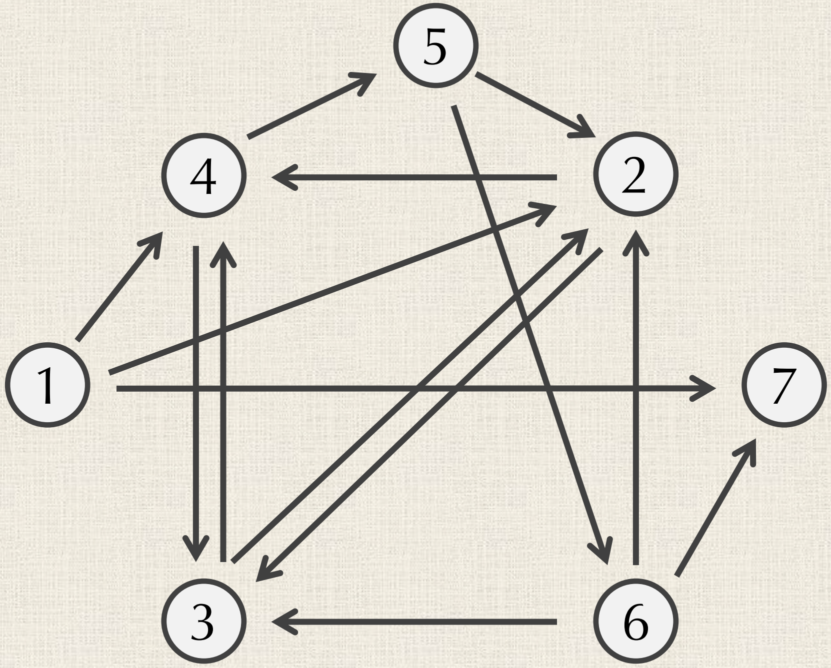
O'_3 = `CTGGCA` doesn't align!

O_1	`CATTAT`
O_2	`CGTCCA`
O_3	`GACCGT`

Converting Each Step to Experiment

5. If any paths remain, return "Yes"; otherwise, return "No".

If any DNA remains from our experiment, then we know that the answer must be "Yes"! Otherwise, it is "No".



We've Solved an *NP*-Complete Problem?!

STOP: What issues do you see with this approach?

We've Solved an *NP*-Complete Problem?!

STOP: What issues do you see with this approach?

Answer: Three immediate barriers:

1. Possibility of errors is high.
2. We still need to generate, at a minimum, $n!$ strands of DNA. So this is impossible for networks with, say, 100 nodes.
3. An enormous amount of lab work needs to be done, with hours of waiting times.

DNA is nevertheless promising as hard drive storage

DNA Fountain enables a robust and efficient storage architecture

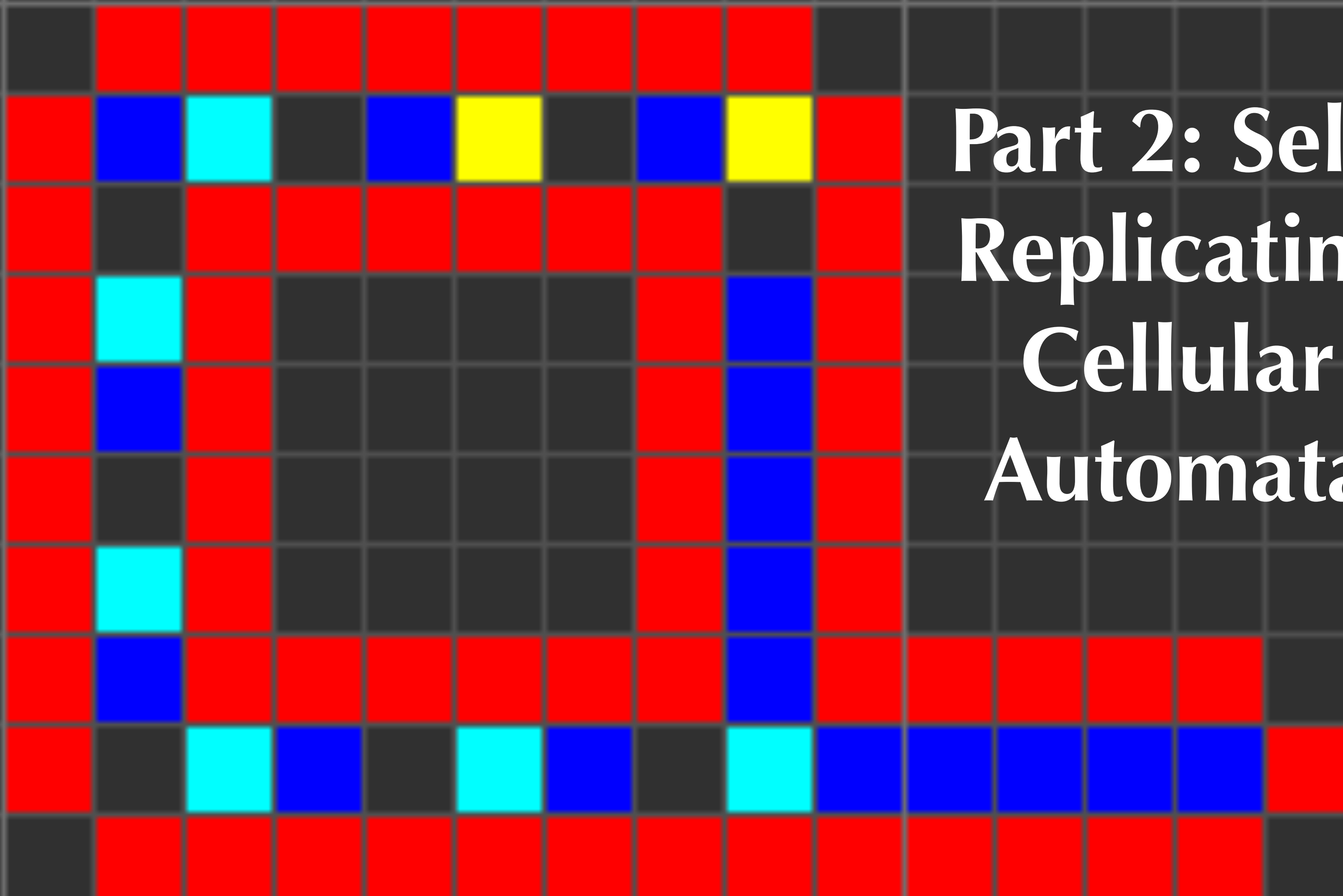
Y Erlich, D Zielinski - Science, 2017 - science.sciencemag.org

DNA is an attractive medium to store digital information. Here we report a storage strategy, called **DNA Fountain**, that is highly robust and approaches the information capacity per nucleotide. Using our approach, we stored a full computer operating system, movie, and …

☆ 99 Cited by 342 Related articles All 14 versions

November 12, 2020 03:15 PM Eastern Standard Time

SOUTH SAN FRANCISCO, Calif.--(BUSINESS WIRE)--Twist Bioscience Corporation (NASDAQ: TWST), Illumina, Inc. (NASDAQ: ILMN) and Western Digital (NASDAQ: WDC) today announced the formation of an alliance with Microsoft to advance the field of DNA data storage. These founding companies, alongside member organizations, will work together to create a comprehensive industry roadmap that will help the industry achieve interoperability between solutions and help establish the foundations for a cost-effective commercial archival storage ecosystem for the explosive growth of digital data.



Part 2: Self-Replicating Cellular Automata

Can a Machine Replicate Itself?

Cornell University. Taken from https://www.youtube.com/watch?v=gZwTcLeelAY

Why Haven't We Seen Alien Spacecraft?

Fermi paradox: No evidence of alien life has been found in the galaxy despite its likelihood.

Why Haven't We Seen Alien Spacecraft?

von Neumann Probes: a theorized space probe that can use resources it finds to self-replicate.

Von Neumann's Question

What is the simplest possible self-replicating system?

John von Neumann

Von Neumann's Question

What is the simplest possible self-replicating system?

Learn some biology, John!

Stanislaw Ulam

John von Neumann

Cells are Self-Replicators


Elon Musk
@elonmusk

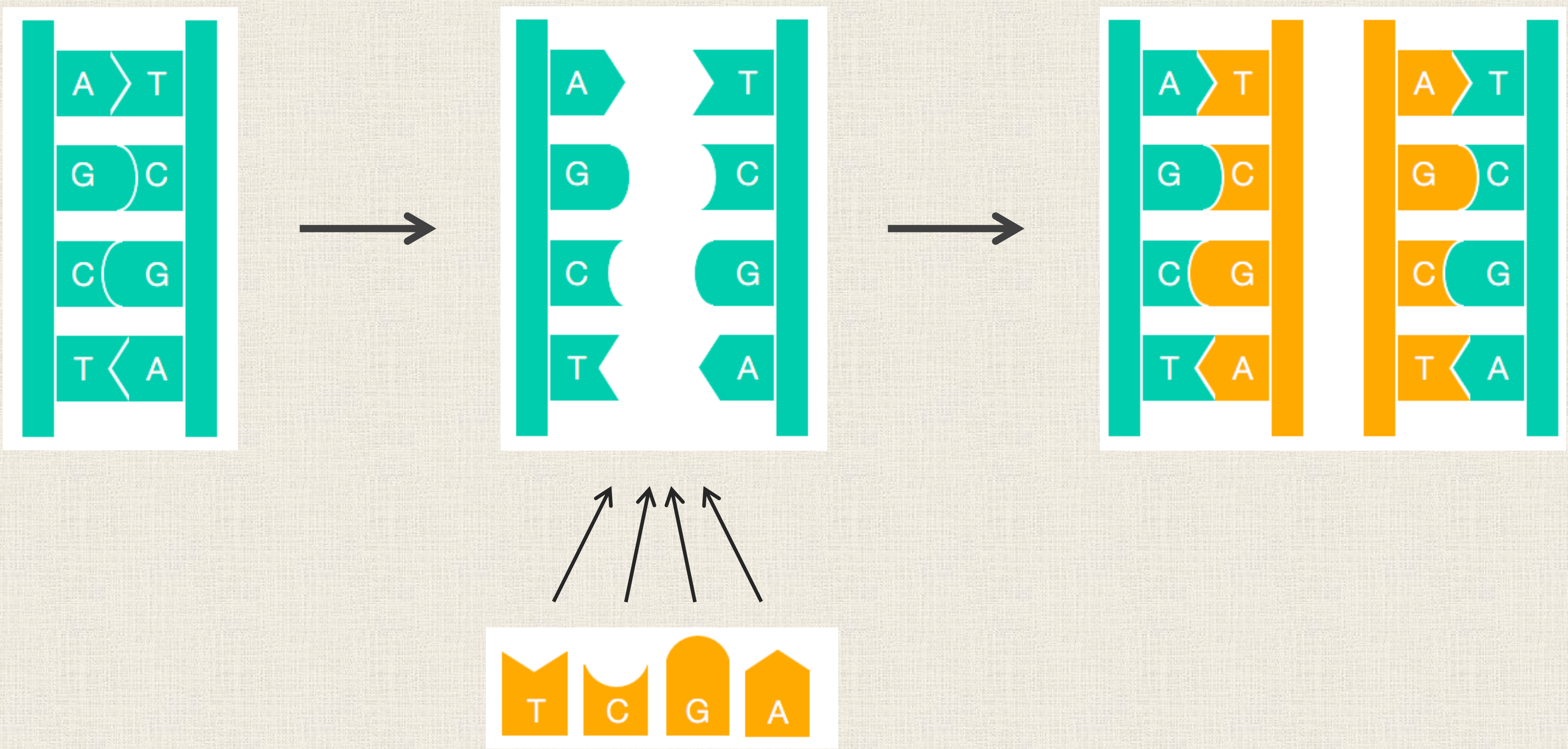
We are the Von Neumann machines

4:22 PM · Jun 20, 2019 · Twitter for iPhone

1.6K Retweets 36.8K Likes

Source: https://singularityhub.com/2017/11/10/the-dream-of-regenerative-medicine-is-alive-and-well/

Psst … There's a Simpler Self-Replicator



Cellular Automata

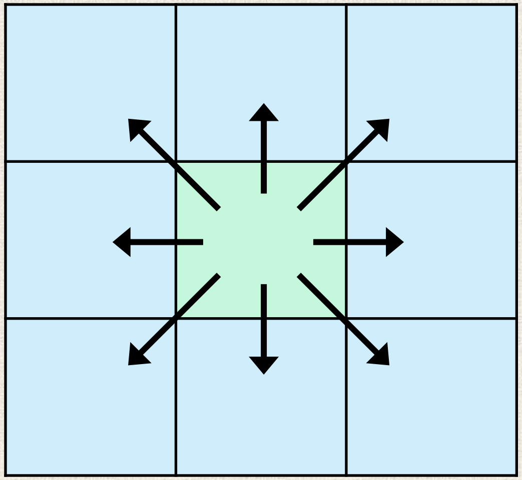
Cellular Automaton: A grid of (typically square) cells, along with a collection of simple rules that allow the cells to change from one "state" to another.

Cellular Automata

Cellular Automaton: A grid of (typically square) cells, along with a collection of simple rules that allow the cells to change from one "state" to another.

A lot of the cellular automata you could come up with are pretty boring, but then there is …

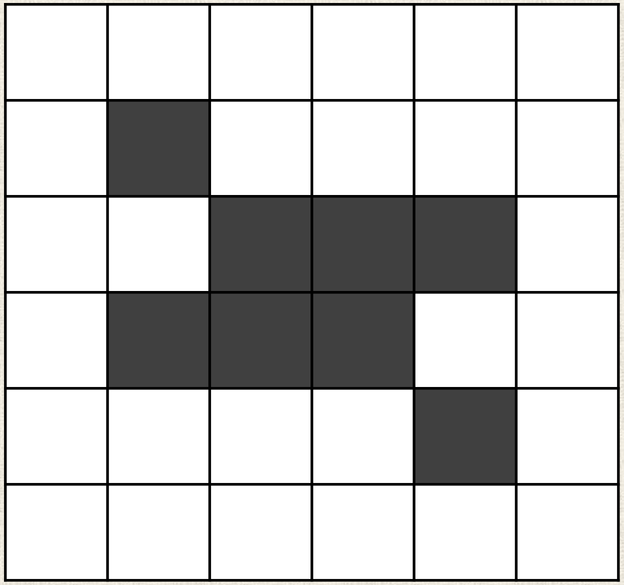
The Game of Life: Rules



Neighborhood

A: If a cell is alive and has either two or three live neighbors, then it remains alive.
B: If a cell is alive and has zero or one live neighbors, then it dies out.
C: If a cell is alive and has four or more live neighbors, then it dies out.
D: If a cell is dead and has more than or fewer than three live neighbors, then it remains dead.
E: If a cell is dead and has exactly three live neighbors, then it becomes alive.

What’s the Next Generation?



Dark = alive

A: If a cell is alive and has either two or three live neighbors, then it remains alive.
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What's the Next Generation?

D	D	D	D	D	D
D	B	E	E	D	D
D	D	C	C	A	D
D	A	C	C	D	D
D	D	E	E	B	D
D	D	D	D	D	D

A: If a cell is alive and has either two or three live neighbors, then it remains alive.
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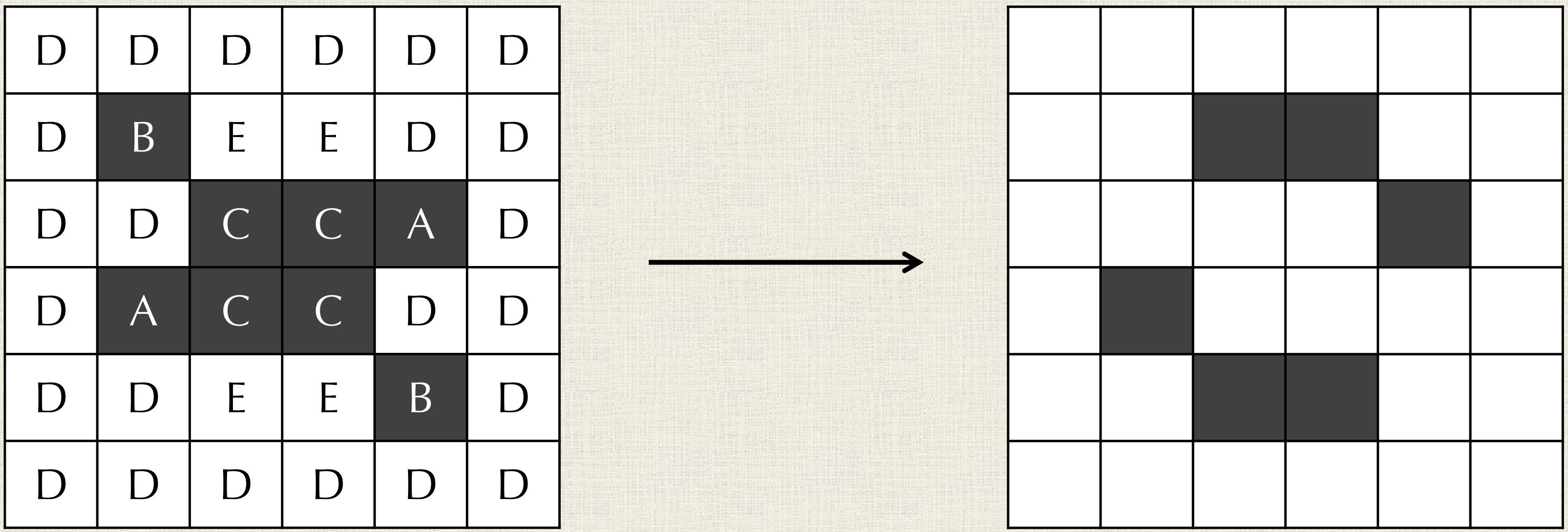

Quick Quiz

Exercise: What is the next generation?

A: If a cell is alive and has either two or three live neighbors, then it remains alive.
B: If a cell is alive and has zero or one live neighbors, then it dies out.
C: If a cell is alive and has four or more live neighbors, then it dies out.
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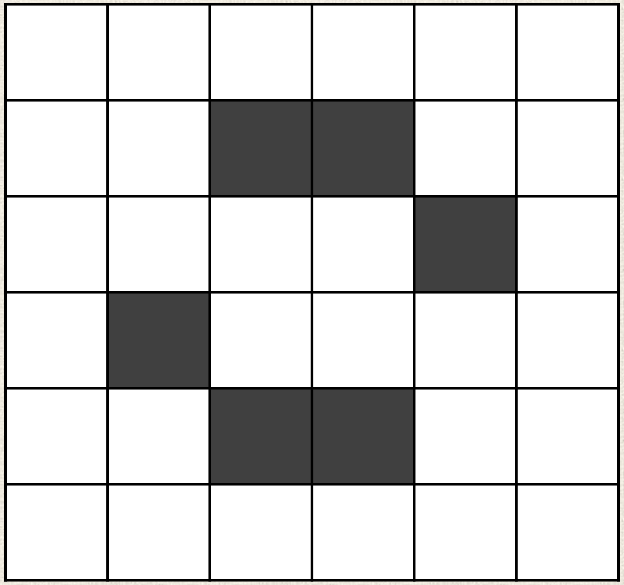
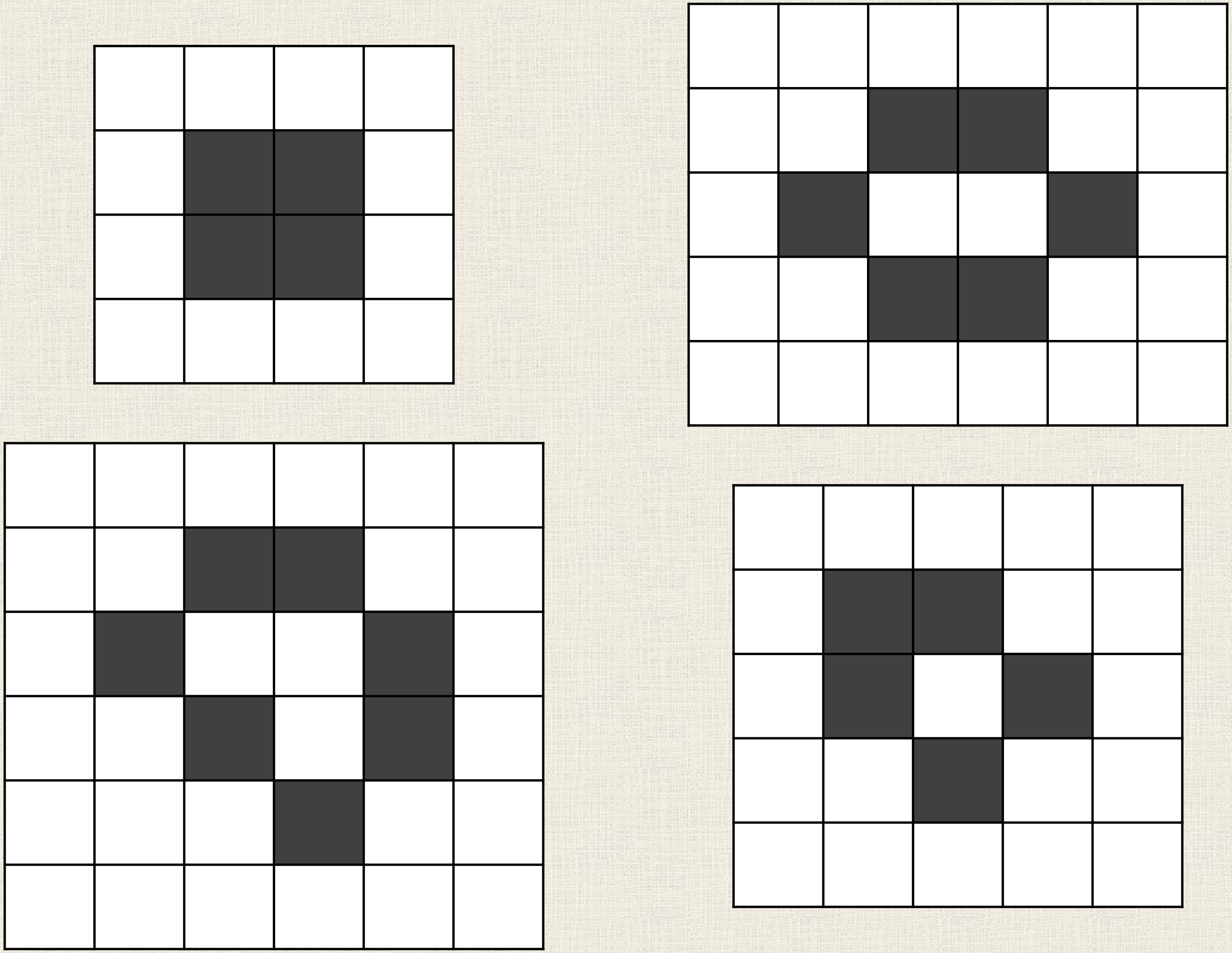
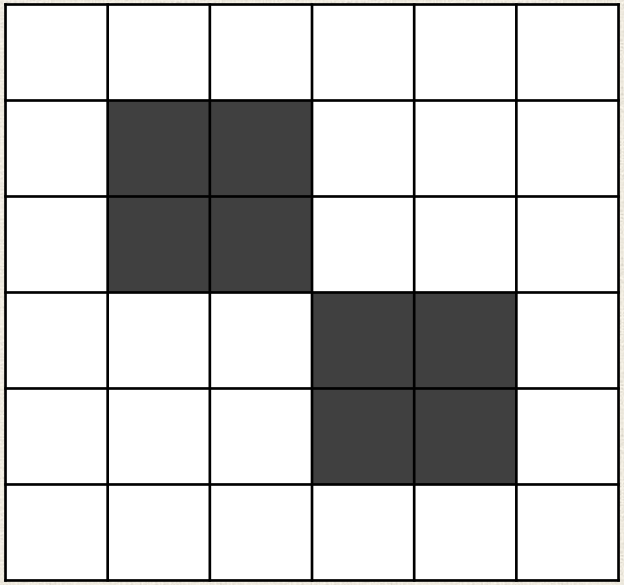


Stable Forms

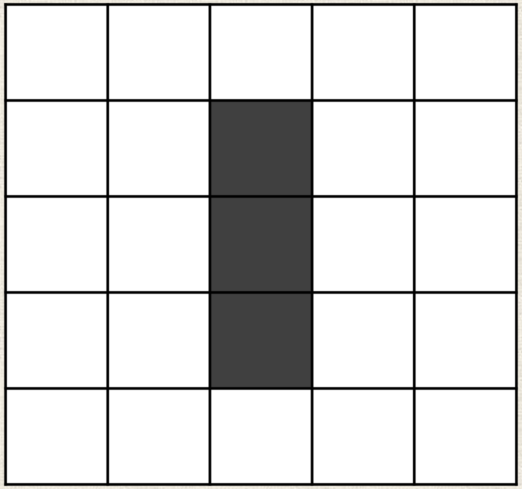


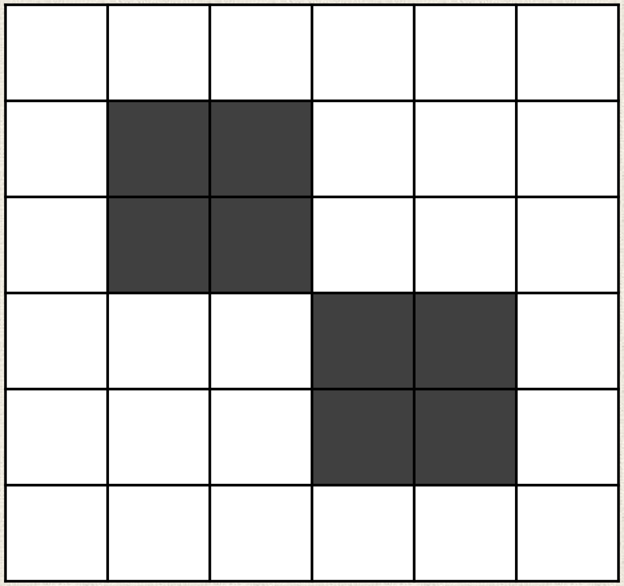
Quick Quiz

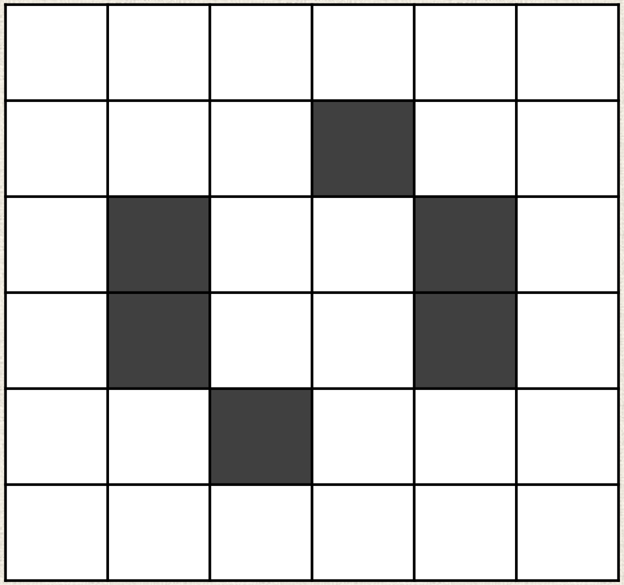
Exercise: Carry out the next few generations of this board. What happens?



Oscillators







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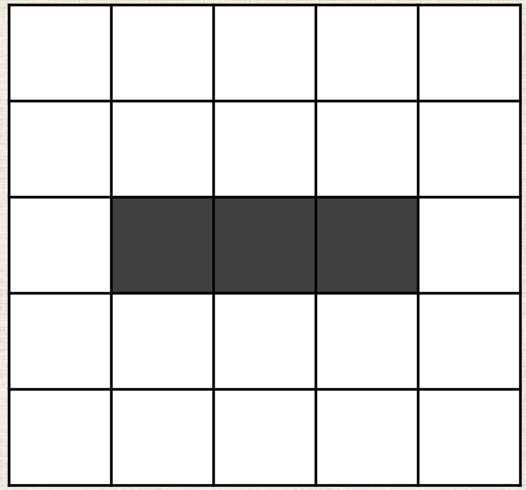

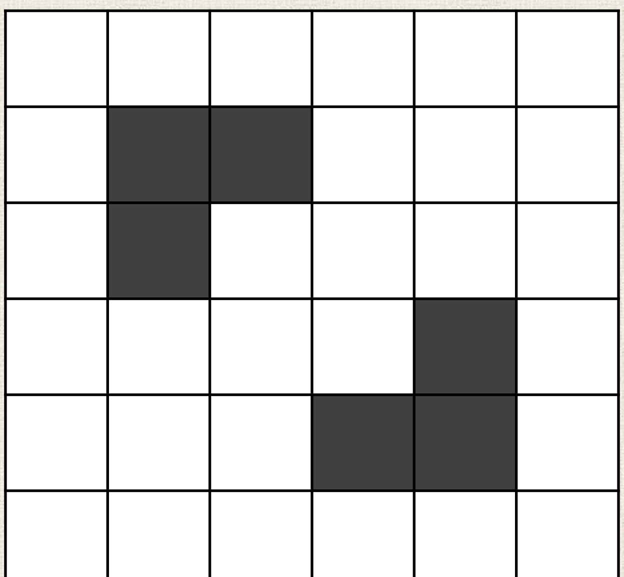

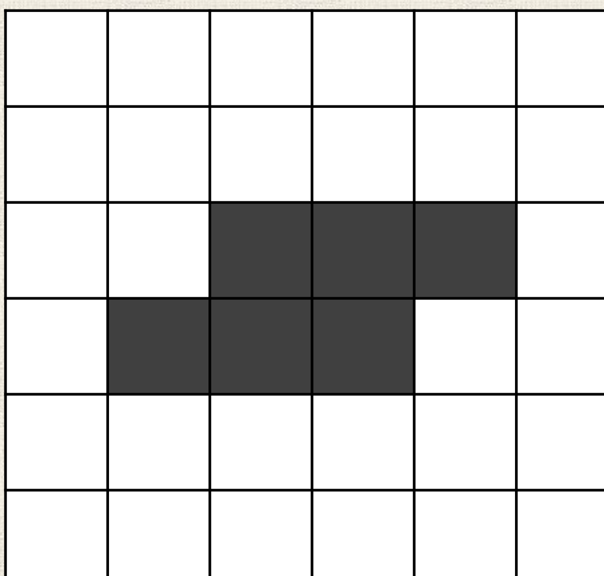

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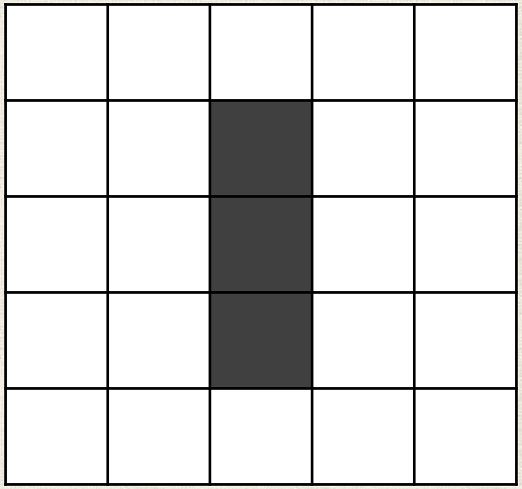

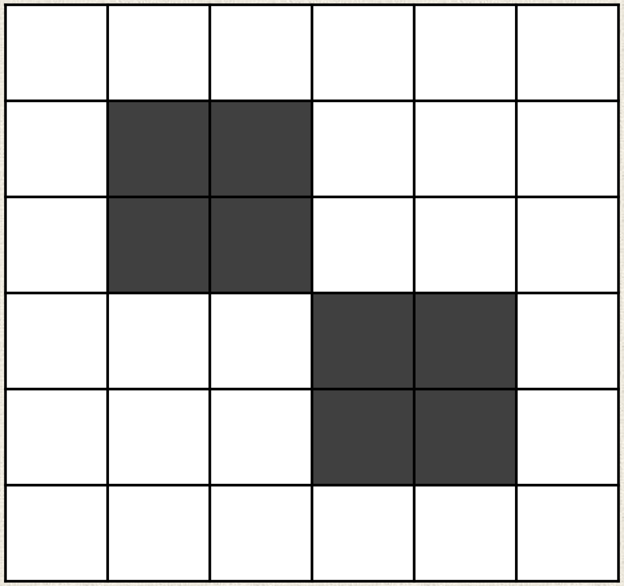

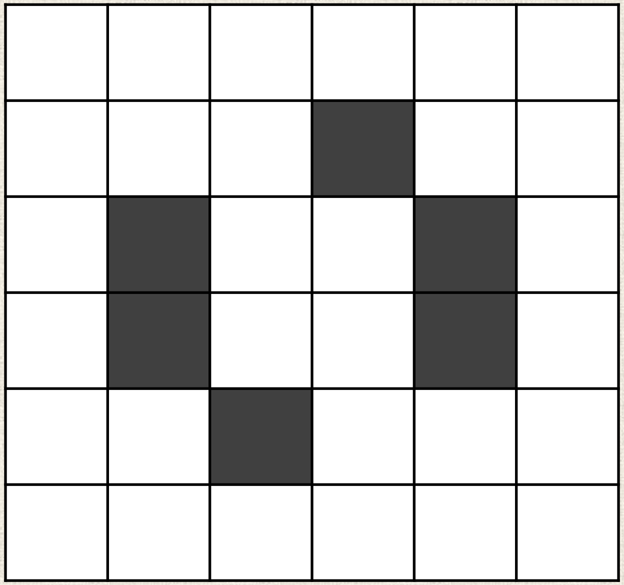

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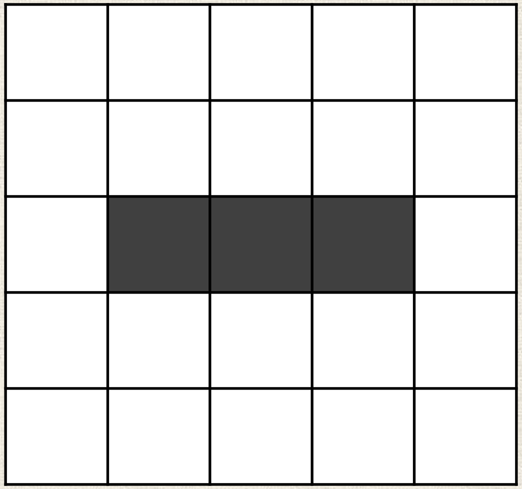

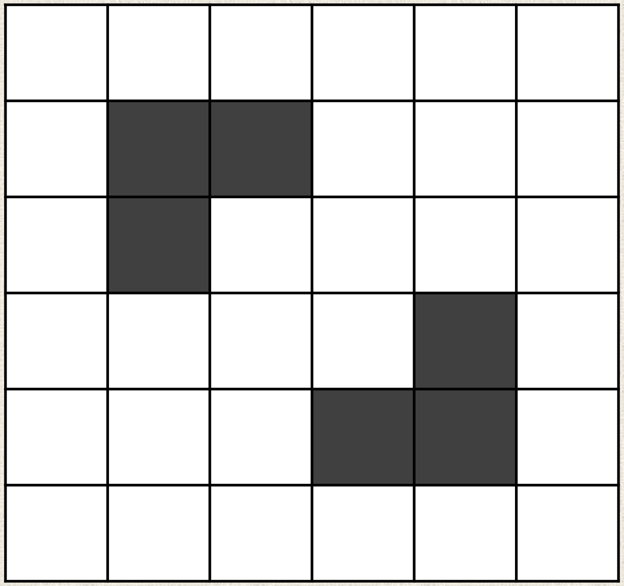

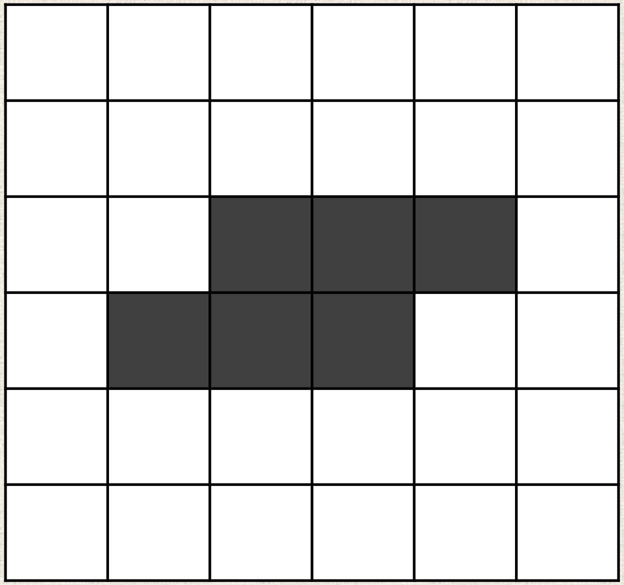

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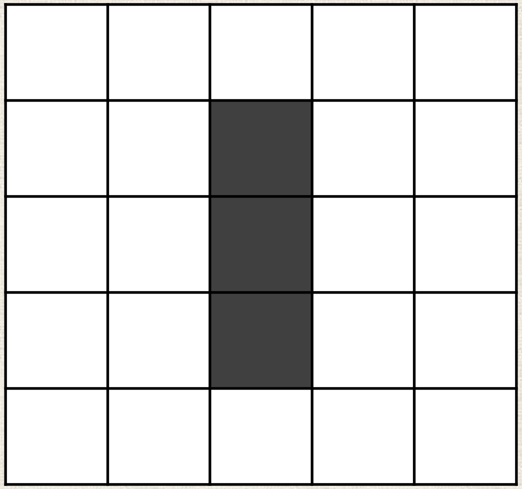
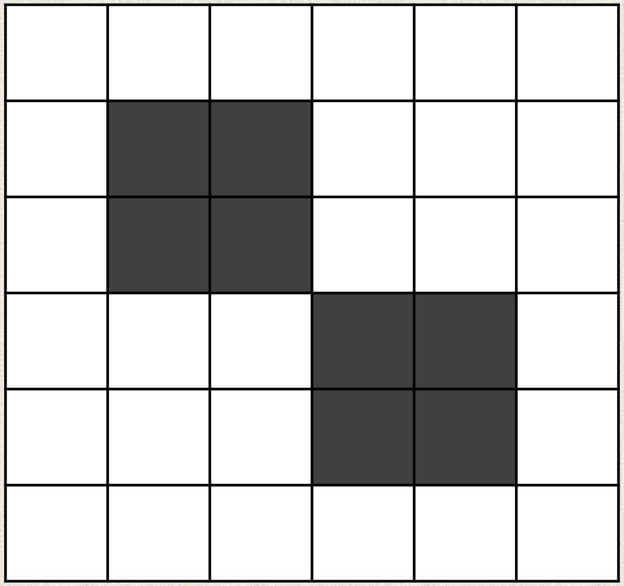
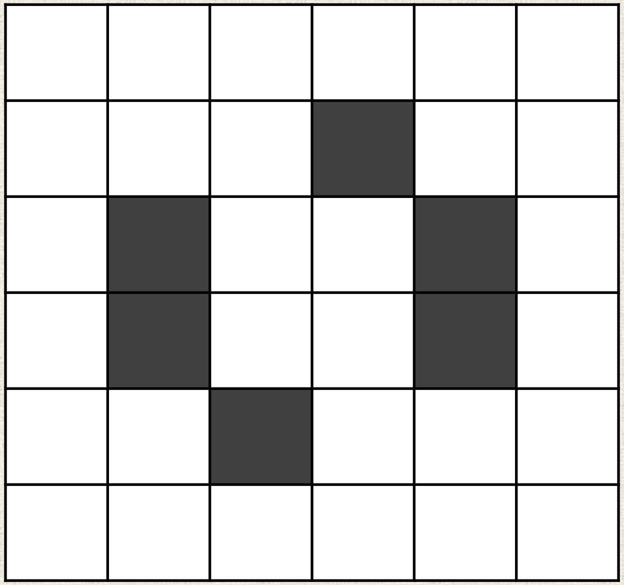
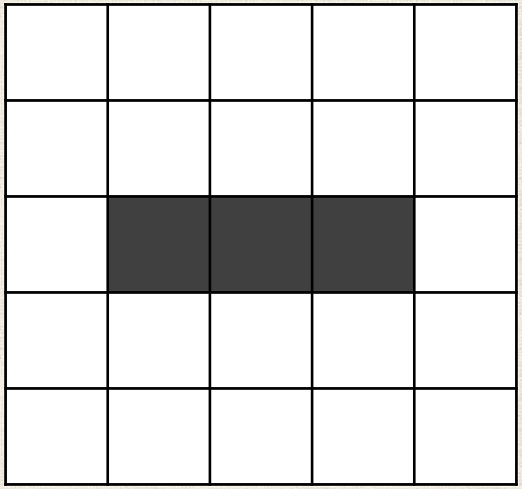
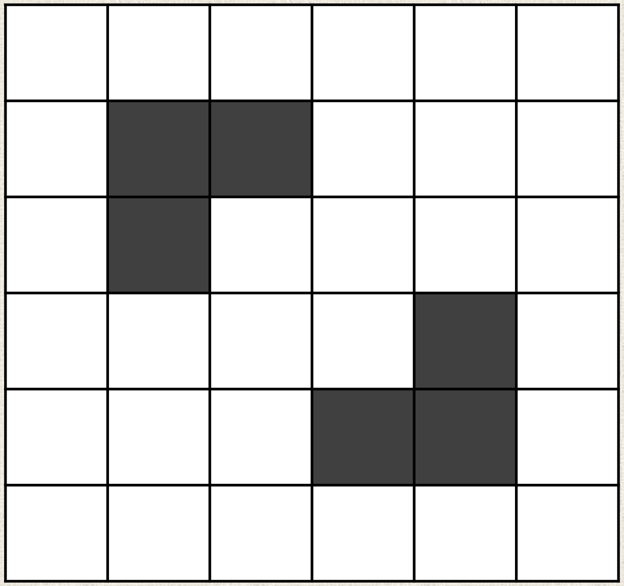


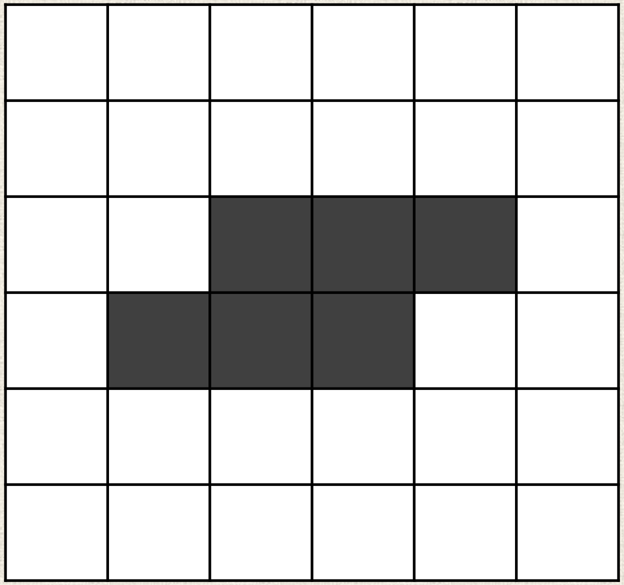




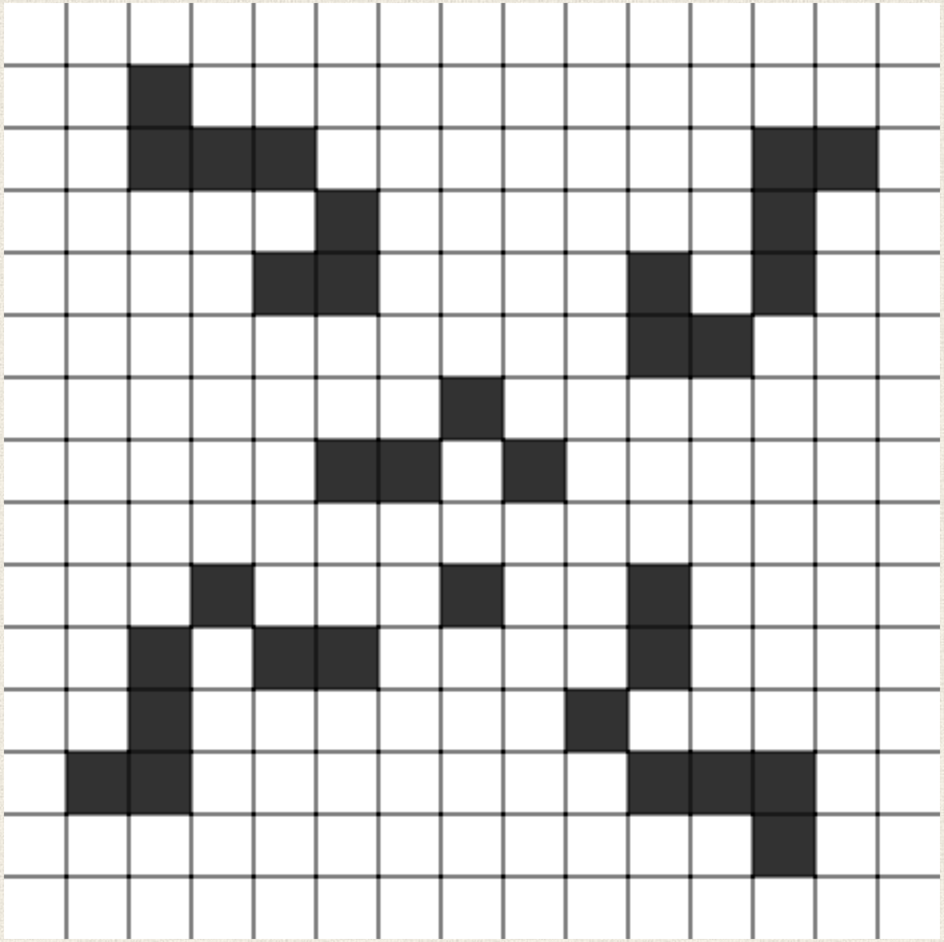
Oscillators







Getting More Complicated …



In case you were curious …

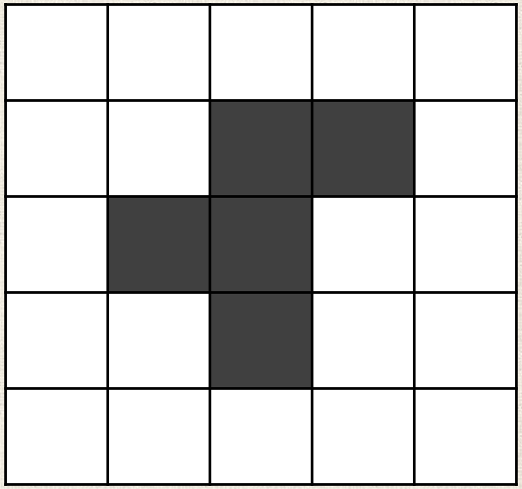
[Submitted on 5 Dec 2023]

Conway's Game of Life is Omniperiodic

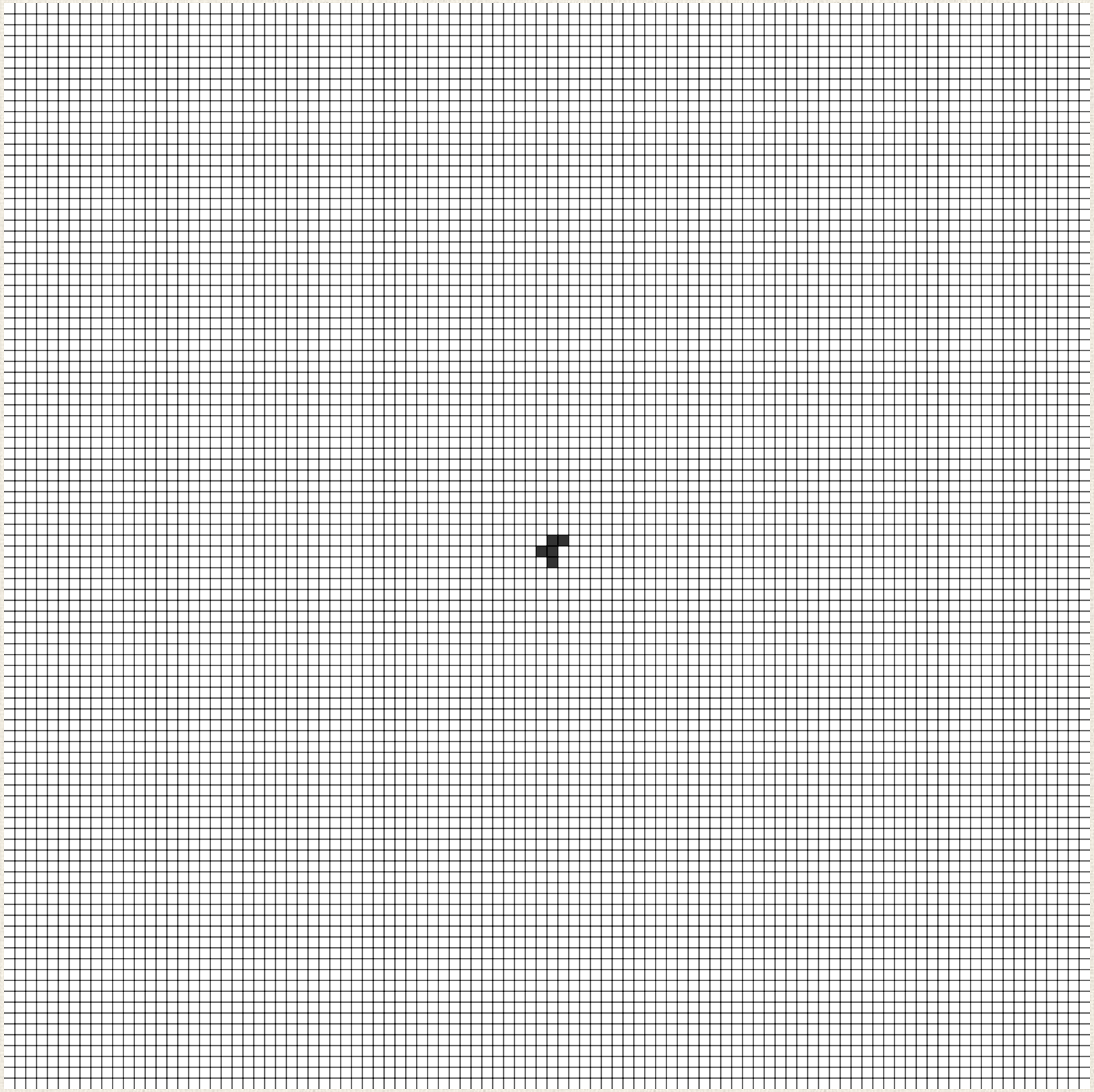
Nico Brown, Carson Cheng, Tanner Jacobi, Maia Karpovich, Matthias Merzenich, David Raucci, Mitchell Riley

In the theory of cellular automata, an oscillator is a pattern that repeats itself after a fixed number of generations; that number is called its period. A cellular automaton is called omniperiodic if there exist oscillators of all periods. At the turn of the millennium, only twelve oscillator periods remained to be found in Conway's Game of Life. The search has finally ended, with the discovery of oscillators having the final two periods, 19 and 41, proving that Life is omniperiodic. Besides filling in the missing periods, we give a detailed history of the omniperiodicity problem and the strategies used to solve it, summarising the work of a large number of people in the decades since the creation of Life.

The Curious Case of the R-Pentomino



The Curious Case of the R-Pentomino

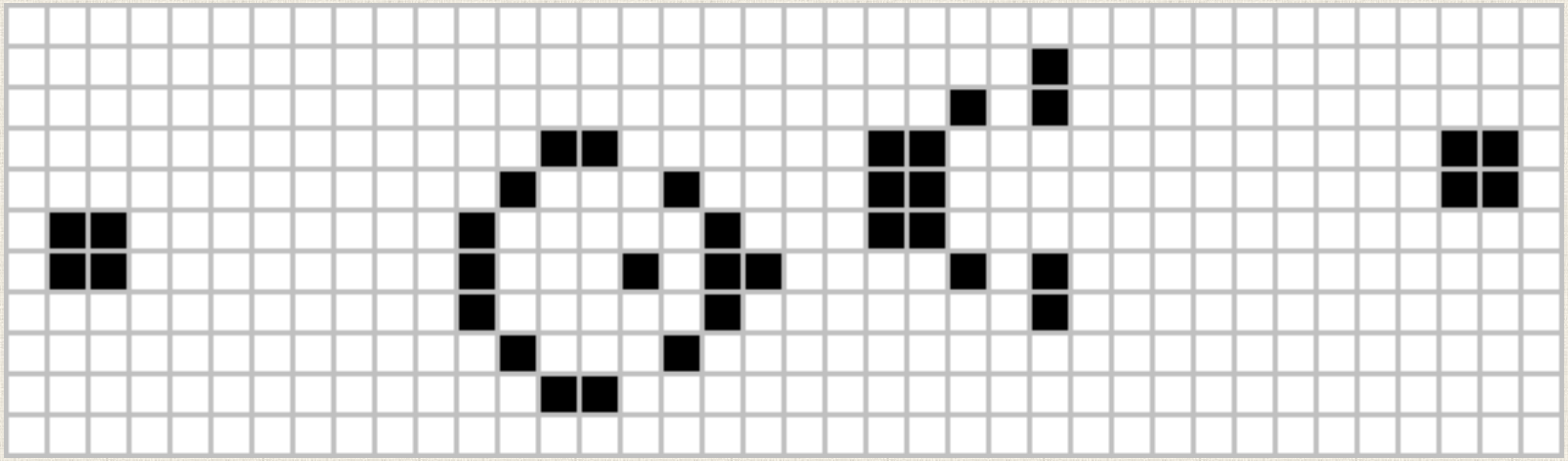


John Conway's Question

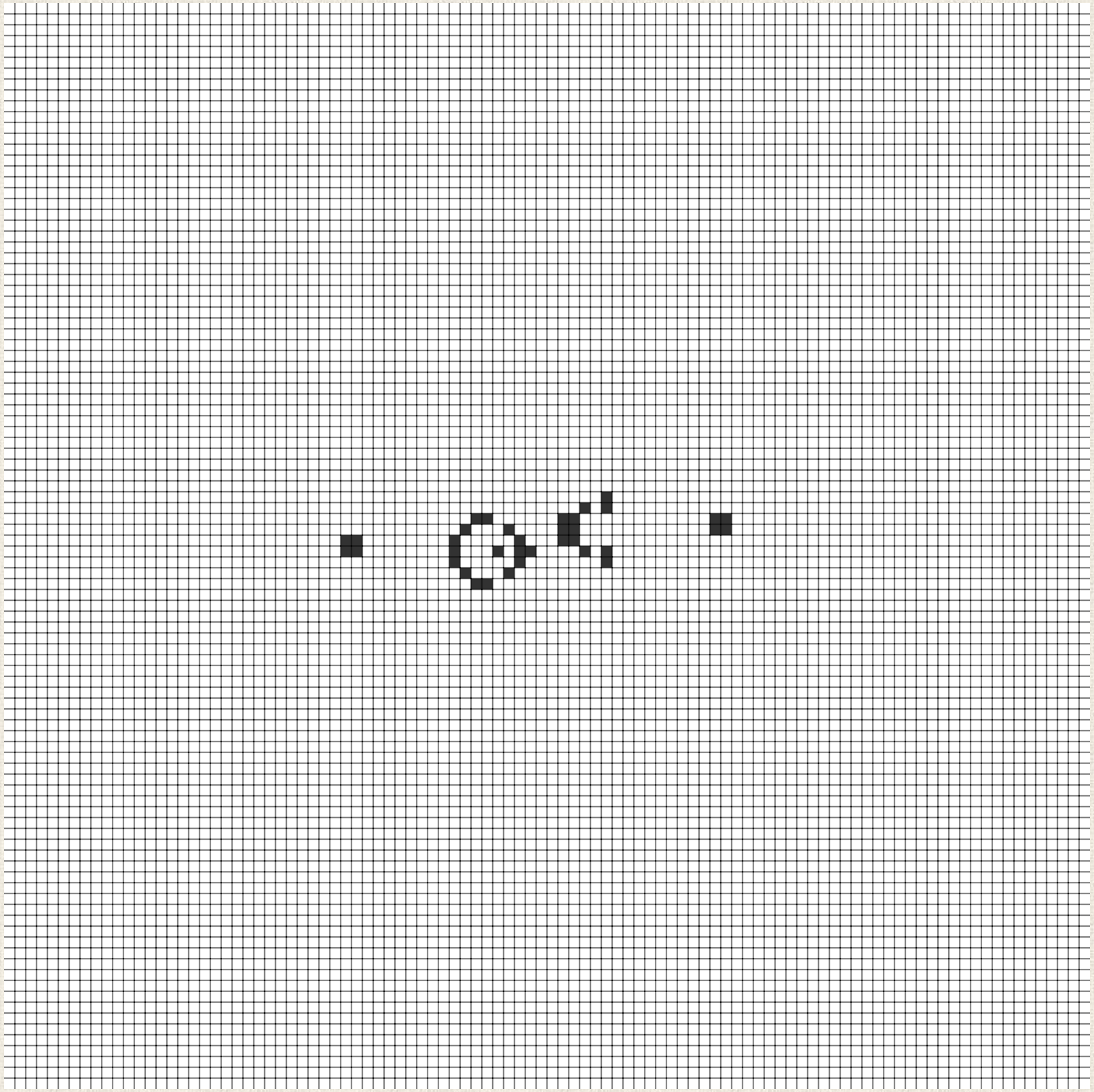
Courtesy: Thane Plambeck

Is it possible for the number of live cells to grow without bound as time goes on?

Bill Gosper's "Glider Gun"



Bill Gosper's "Glider Gun" Resembles a Factory with *Linear* Growth



Self-Replicating Automata: A History

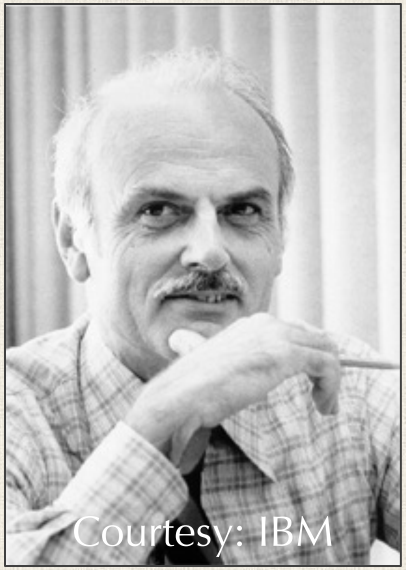
John von Neumann

Year: 1952

Number of States: 29

Size of Self Replicator: 130,622 cells

Edgar Codd

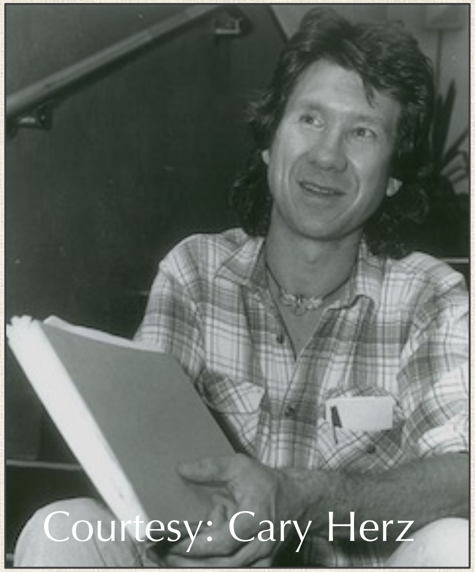


Year: 1968

Number of States: 8

Size of Self Replicator: 283,126,588 cells

Chris Langton

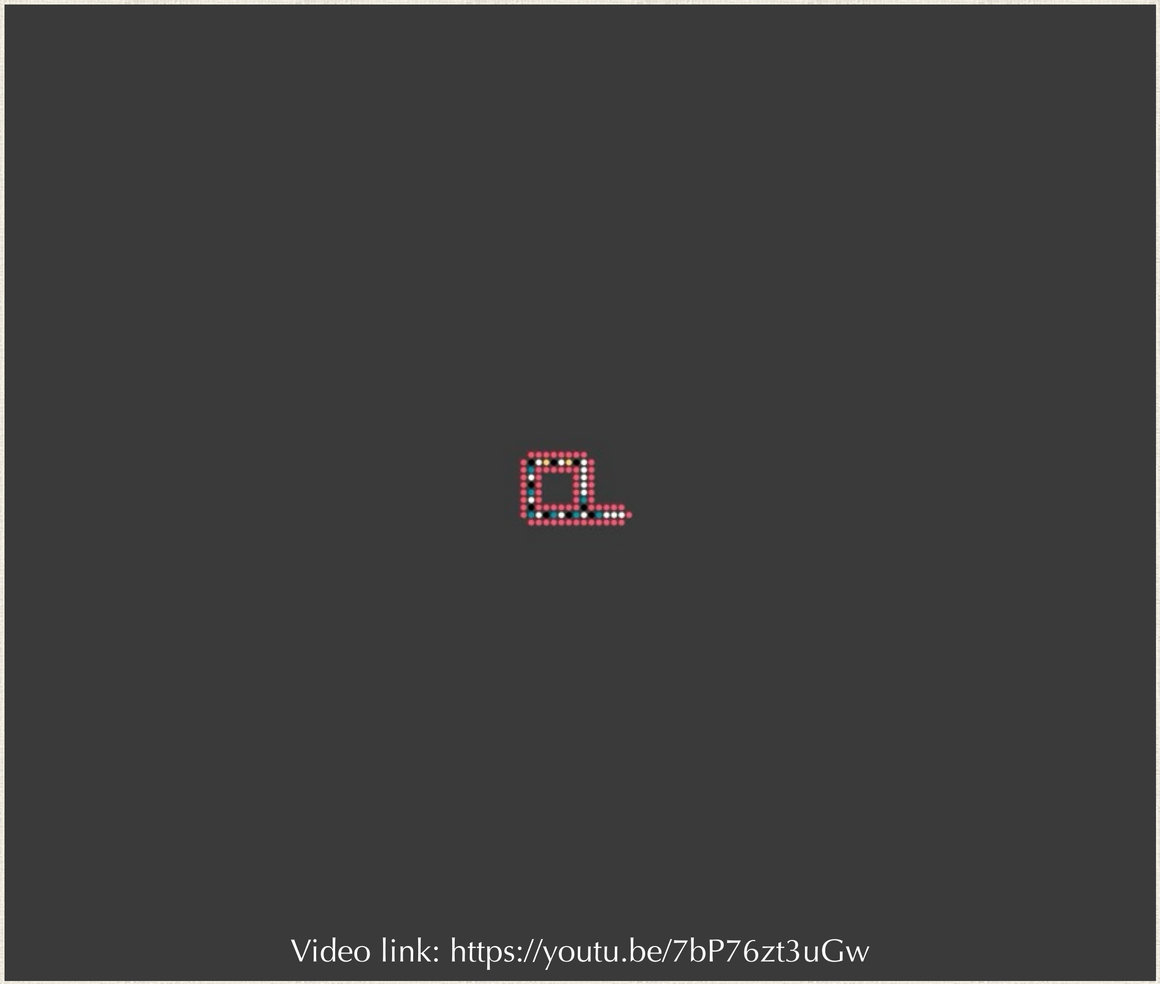


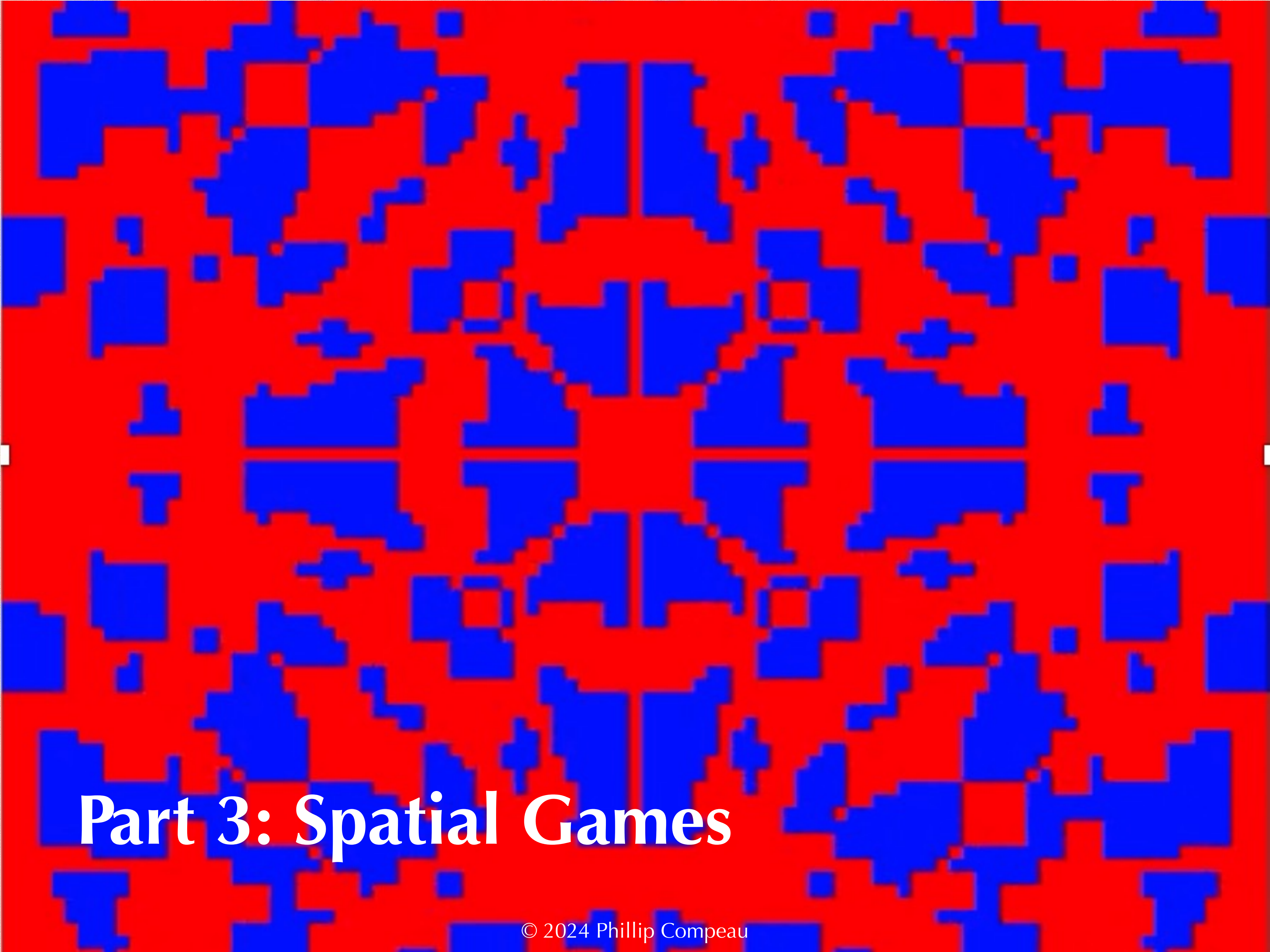
Year: 1984

Number of States: 8

Size of Self Replicator: **86 cells**

Langton Loops: A (Beautiful) Self-Replicating Cellular Automaton




Part 3: Spatial Games
© 2024 Phillip Compeau

Cooperation is Everywhere. But Why?

Courtesy: milkwood.net

"Prisoner's Dilemma"

Prisoner's Dilemma: A simple two-player game with choices between "cooperation" and "defection" against an opponent.

Your decision \ Partner's decision	Cooperate	Defect
Cooperate	1	0
Defect	$b > 1$	0

“Prisoner’s Dilemma”

Prisoner’s Dilemma: A simple two-player game with choices between “cooperation” and “defection” against an opponent.

STOP: Why would you cooperate?

Your decision \ Partner’s decision	Cooperate	Defect
Cooperate	1	0
Defect	$b > 1$	0

Axelrod's Tournament (1978): What if the game is played *multiple times*?

Group Exercise: Design a strategy.

- We are playing an (unknown) *m* number of games.
- Opponent's strategy is hidden.
- We play a variety of opponents but use same strategy.

Partner's decision

Your decision	Cooperate	Defect
Cooperate	5	1
Defect	7	3

Idea 0: “Poor-Trusting Fool”

for every integer *i* between 1 and *m*
        cooperate!

STOP: What are its strengths and weaknesses?

Idea 1: “All-Defect”

```
for every integer i between 1 and m
        defect!
```

STOP: What are its strengths and weaknesses?

Idea 2: "Grudger"

```
betrayed ← false
for every integer i between 1 and m
        if betrayed
                defect!
        else
                if opponent defected in game i - 1
                        betrayed = true
                        defect!
                else
                        cooperate!
```

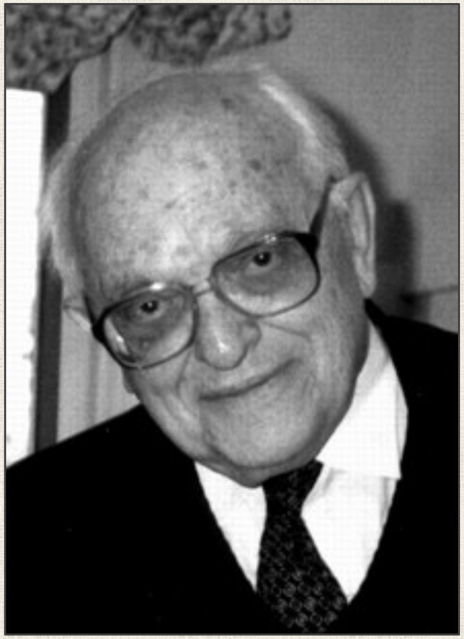
STOP: What are its strengths and weaknesses?

The Clear Winner: "Tit-for-Tat"

cooperate in game 1
for every integer *i* between 2 and *m*
    do whatever opponent did in game *i* – 1

This was the winning strategy (and the simplest!) among 15 submissions.

STOP: What properties of this strategy make it so good?



Anatol Rapoport

Words to Live By ...

More tournaments have shown that the highest-scoring strategies tend to have four qualities:

- **Niceness:** Never be the first to defect.
- **Provocability:** Get mad quickly at defectors and retaliate.
- **Forgiveness:** Do not hold a grudge once you have vented your anger.
- **Clarity:** Act in ways that are straightforward for others to understand.

http://www2.econ.iastate.edu/classes/econ308/tesfatsion/axeltmts.pdf

Spatial Game Theory: Playing Games on a 2-D Automaton

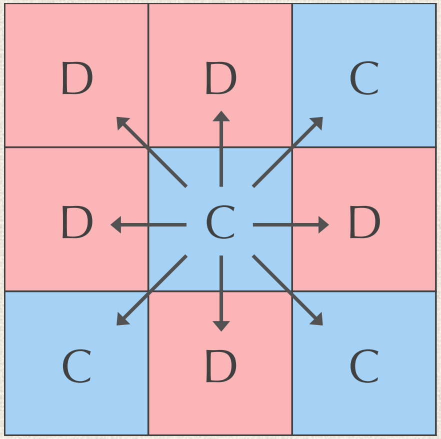
Spatial Games: Every cell in a 2-D field plays a simplified Prisoner's Dilemma with each of its neighbors.

		Partner's decision	
		Cooperate	*Defect*
Your decision	*Cooperate*	1	0
	Defect	$b > 1$	0

Spatial Game Theory: Playing Games on a 2-D Automaton

Spatial Games: Every cell in a 2-D field plays a simplified Prisoner's Dilemma with each of its neighbors.

All use same strategy: in "generation" *i*, each cell adopts the strategy of its "best-scoring" Moore neighbor (including itself) in generation $i - 1$.



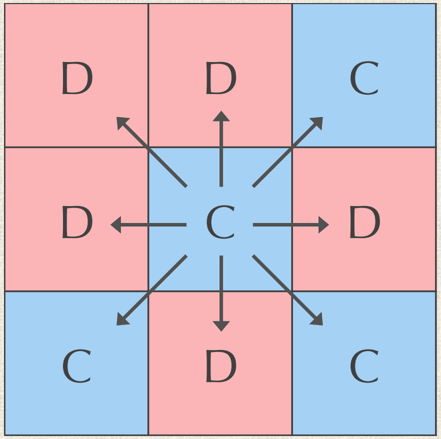
Partner's decision

Your decision

	Cooperate	*Defect*
Cooperate	1	0
Defect	$b > 1$	0

Spatial Game Theory: Playing Games on a 2-D Automaton

STOP: What is the score of the central square on the right?



Partner's decision

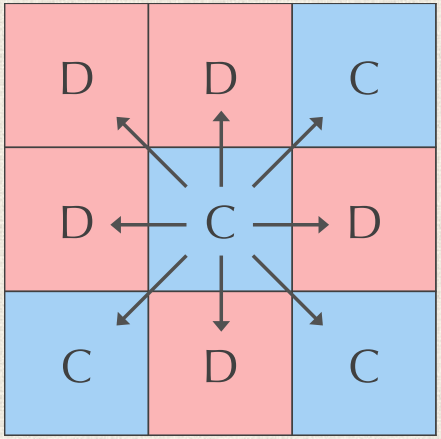
Your decision

	Cooperate	*Defect*
Cooperate	1	0
Defect	$b > 1$	0

Spatial Game Theory: Playing Games on a 2-D Automaton

STOP: What is the score of the central square on the right?

Answer: It is a cooperator, and its neighborhood has three cooperators, so its total score is 3.

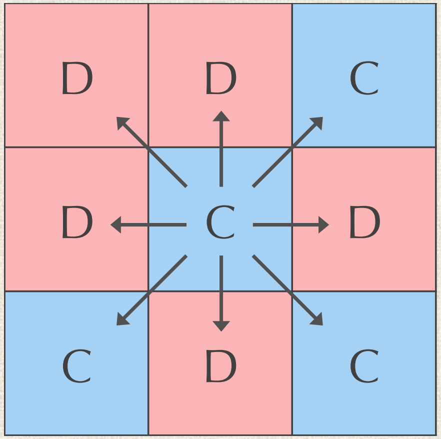


		Partner's decision	
		Cooperate	*Defect*
Your decision	*Cooperate*	1	0
	Defect	$b > 1$	0

Spatial Game Theory: Playing Games on a 2-D Automaton

After computing the score of all neighbors, we ask "Do any neighbors have higher score?"

- If "no", the cell remains a cooperator in the next generation.
- If "yes", the cell adopts the strategy of its highest-scoring neighbor (it may be cooperation or defection) in the next generation.



		Partner's decision	
		Cooperate	*Defect*
Your decision	*Cooperate*	1	0
	Defect	$b > 1$	0

Spatial Game Theory: Playing Games on a 2-D Automaton

Idea: Let's animate the spatial game board over the generations.

- Cells choosing to cooperate with their neighbors = blue
- Cells choosing to defect = red

Spatial Game Theory: Playing Games on a 2-D Automaton

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- Cells choosing to cooperate with their neighbors = blue
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Let's put one defector in the middle of our board. I wonder what we will see?

Spatial Game Theory: Playing Games on a 2-D Automaton

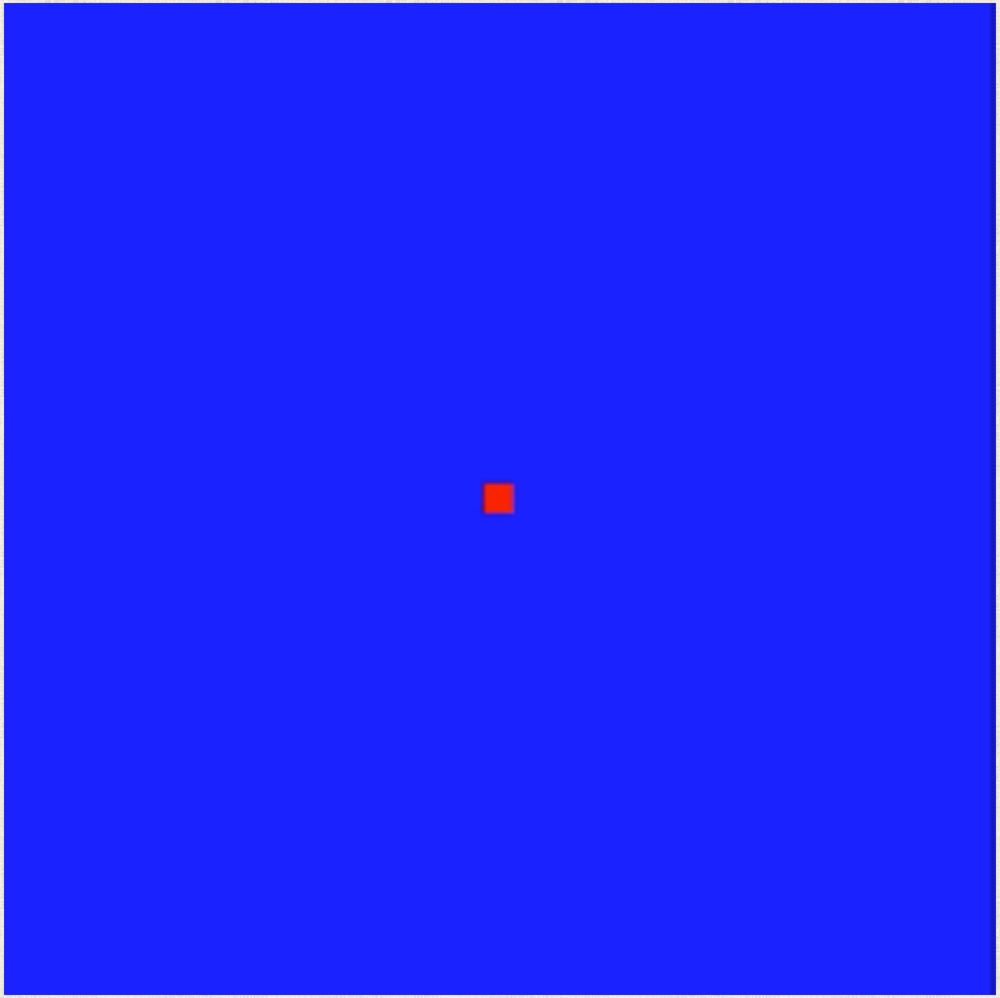
Idea: Let's animate the spatial game board over the generations.

- Cells choosing to cooperate with their neighbors = blue
- Cells choosing to defect = red

Let's put one defector in the middle of our board. I wonder what we will see?

Note: Our early reasoning would imply that the defectors would take over completely...

Spatial Games with $b = 1.65$



Citation presented without comment

www.nature.com › letters

Evolutionary games and spatial chaos | Nature

by MA Nowak - 1992 - Cited by 3747 - Related articles

Oct 29, 1992 - Evolutionary **games** and **spatial** chaos. Martin A. Nowak &; Robert M. May. **Nature** ...

Nowak, a Harvard mathematical biologist, seems to have been Epstein's favorite scientist, regularly mentioned in press releases issued by his foundations. The financier donated $6.5 million to launch Nowak's Program for Evolutionary Dynamics at Harvard in 2003 — although Epstein claimed, apparently falsely, to have given $30 million.

https://www.buzzfeednews.com/article/peteraldhous/jeffrey-epstein-science-donations-apologies-statements

Part 4: Tripping with Turing

Why Do Animals Have Stripes (or Spots)?

Alan Turing has the answer!

Turing patterns: stripe/spot patterns that occur due to specific reactions and diffusion.

Well, the stripes are easy. But what about the horse part?

The chemical basis of morphogenesis

AM Turing - Bulletin of mathematical biology, 1990 - Springer

It is suggested that a system of chemical substances, called morphogens, reacting together and diffusing through a tissue, is adequate to account for the main phenomena of morphogenesis. Such a system, although it may originally be quite homogeneous, may later develop a pattern or structure due to an instability of the homogeneous equilibrium, which is triggered off by random disturbances. Such reaction-diffusion systems are considered in some detail in the case of an isolated ring of cells, a mathematically convenient, though …

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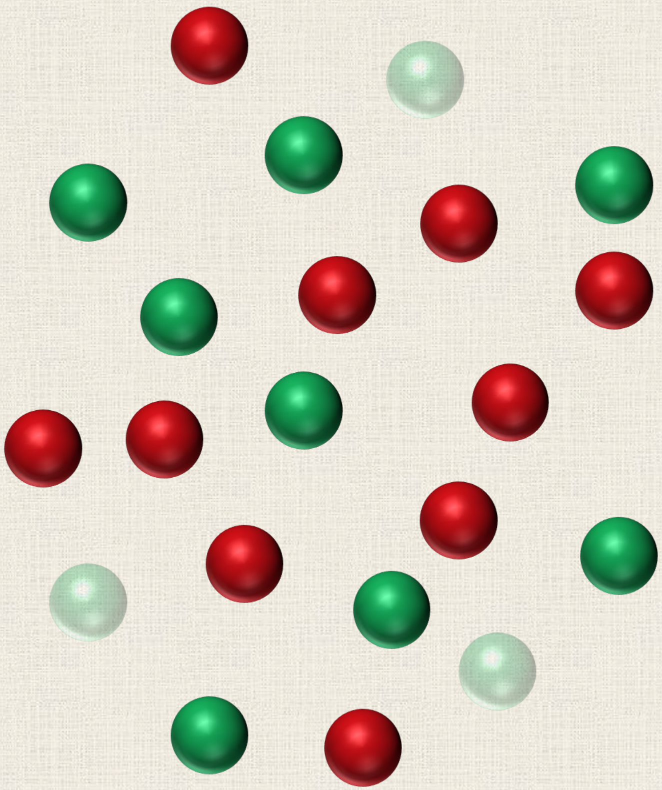
We've already seen reaction-diffusion…

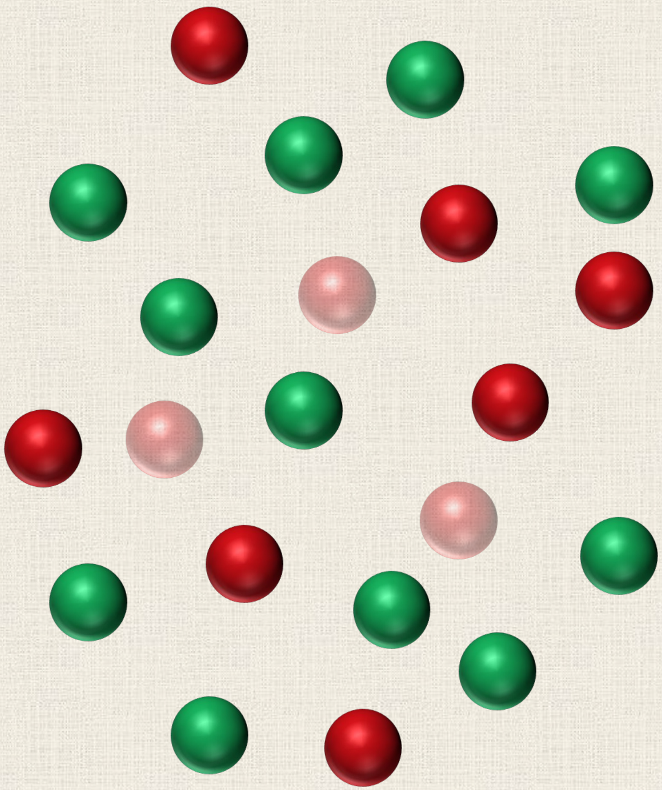
The model we will use is similar to a predator-prey simulation



"Prey" molecules enter the system at a constant **feed rate** f.

"Predator" molecules are removed at a constant **kill rate** k.

The model we will use is similar to a predator-prey simulation



"Prey" molecules enter the system at a constant **feed rate** f.

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The model we will use is similar to a predator-prey simulation

The predators can "eat" the prey and reproduce via

2 *Predator* + *Prey* → 3 *Predator*

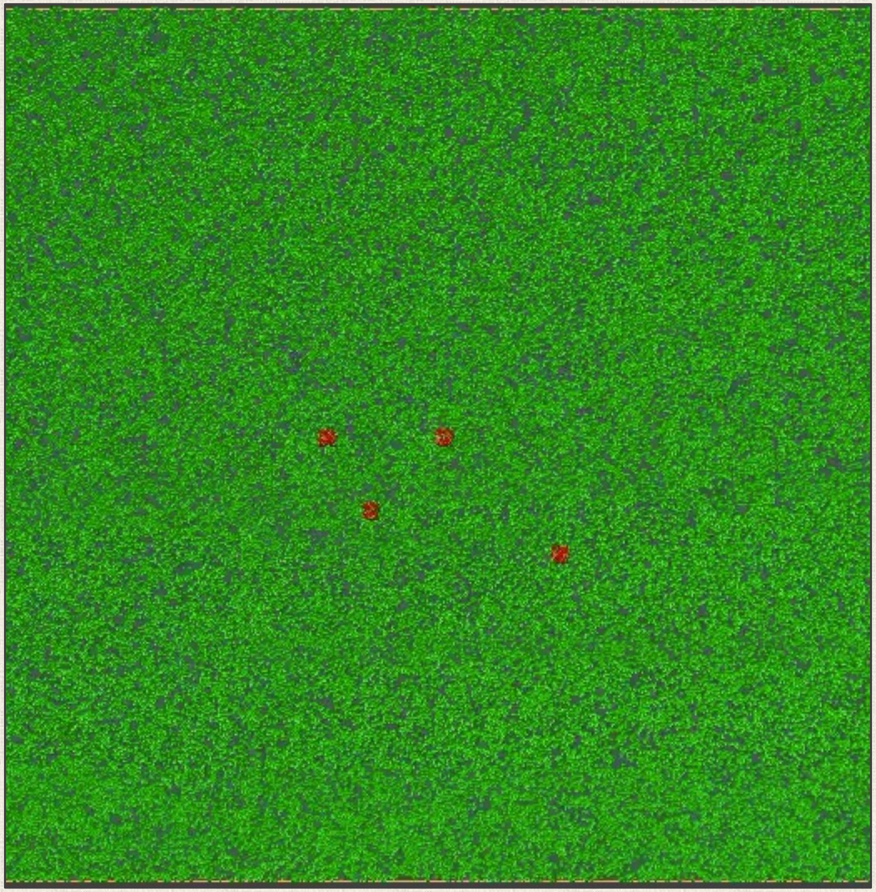
The model we will use is similar to a predator-prey simulation

The predators can "eat" the prey and reproduce via

2 Predator + Prey → *3 Predator*

But the prey are "faster swimmers", having a diffusion rate that is twice as fast.

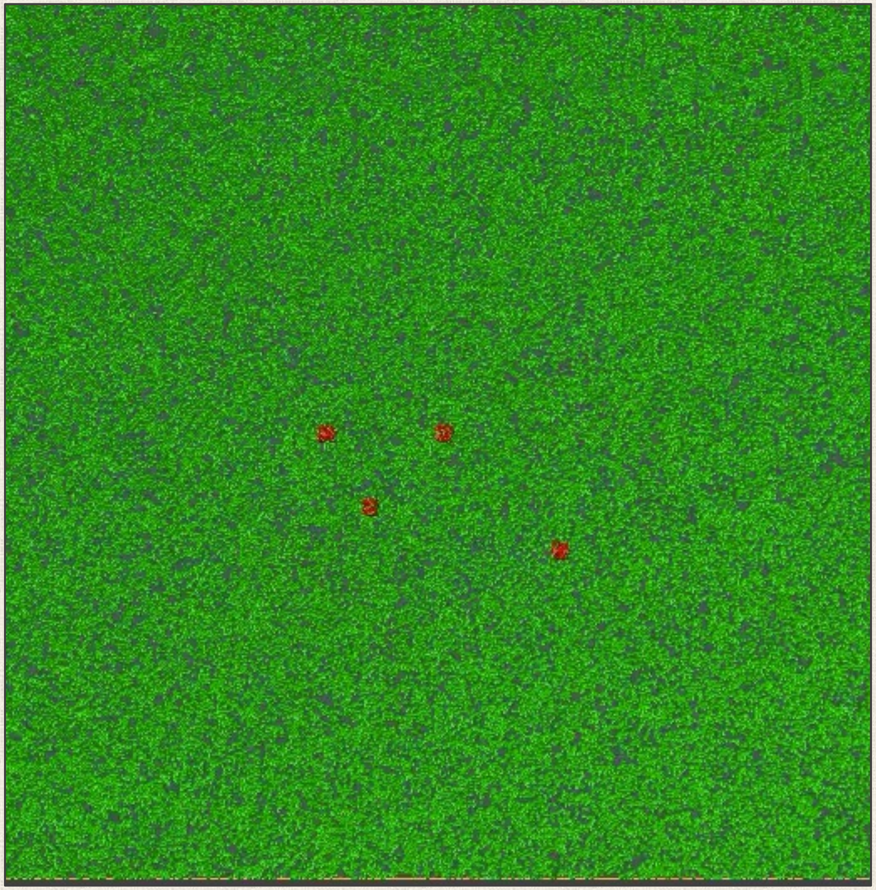
Running our simulation



f = 1,000 and k = 500,000

If the kill rate is too high, then the predators die out more quickly than they can eat the prey, and so only prey will survive.

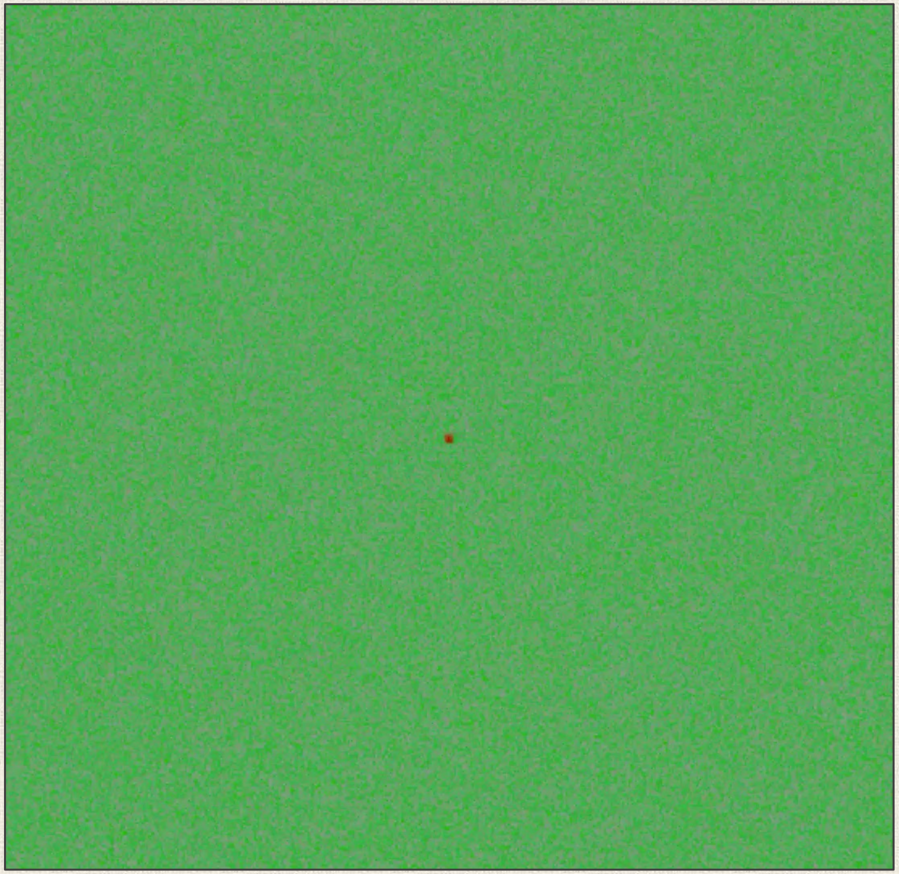
Running our simulation



f = 1,000,000 and k = 100,000

On the other hand, if f is too high, then the prey will increase, feeding the predators, and we will see an explosion in the number of predators.

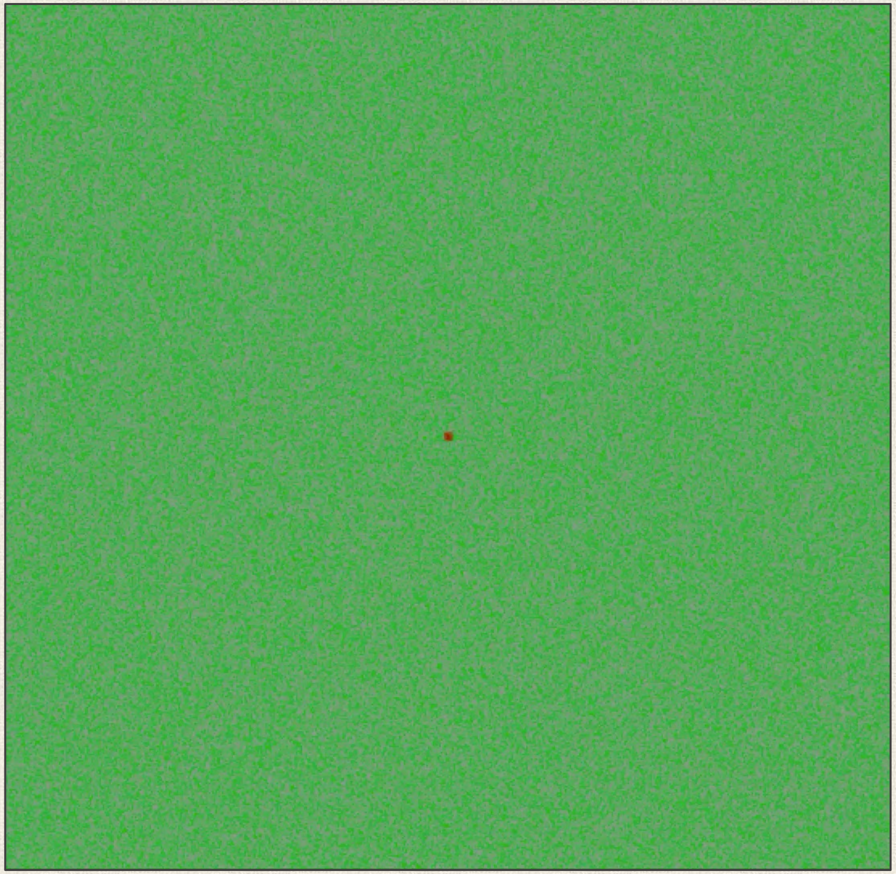
Running our simulation



f = 100,000 and k = 200,000

Finding a sweet spot set of parameters produces waves of predator “stripes” expanding outward against a background of prey.

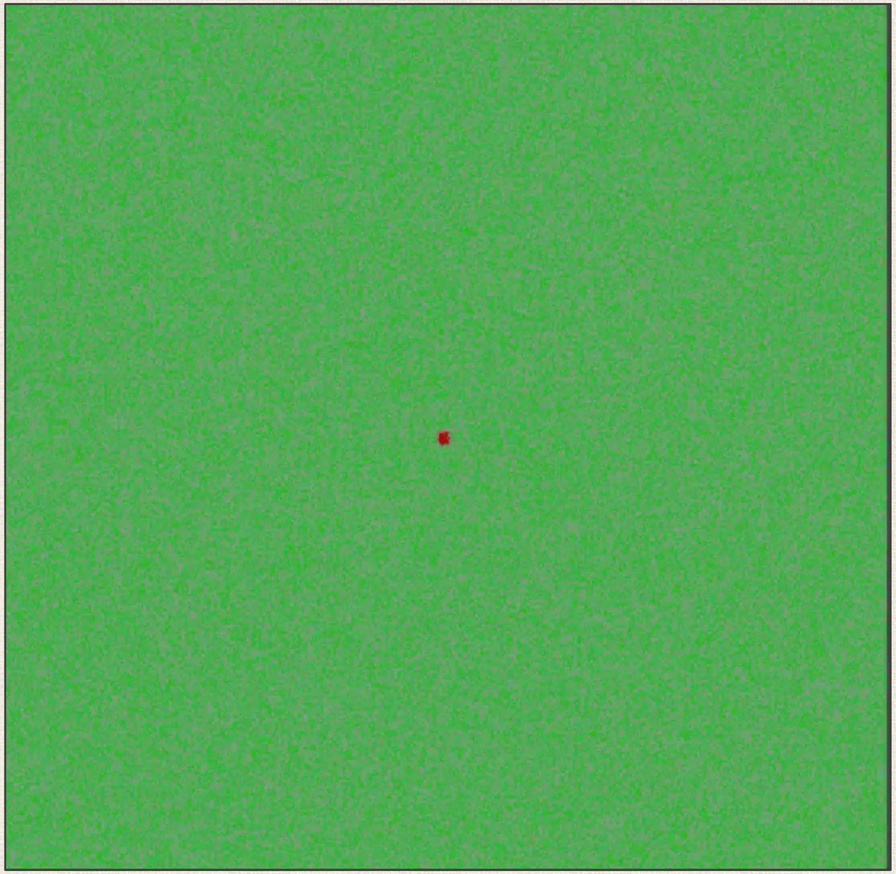
Running our simulation



f = 140,000 and k = 200,000

Holding k fixed and increasing f by a little increases the likelihood of predator-prey interactions, producing even more predator stripes.

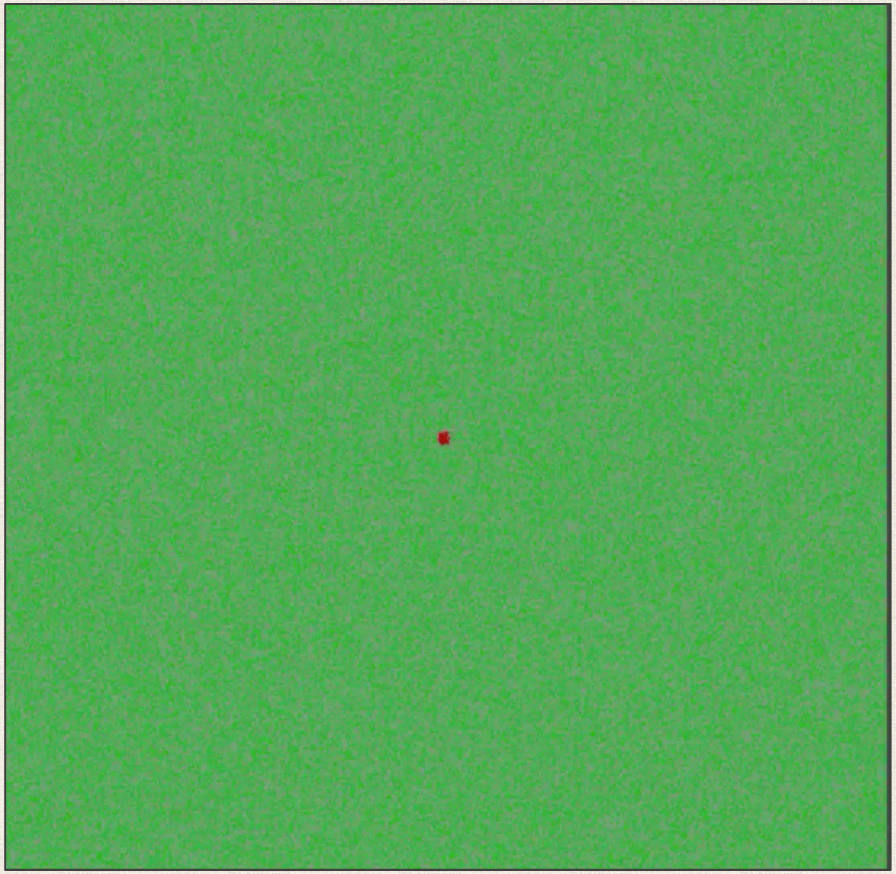
Running our simulation



f = 175,000 and *k* = 200,000

Increasing *f* further produces a chaotic stripe pattern because there are so many pockets of predators that they constantly collide and mix.

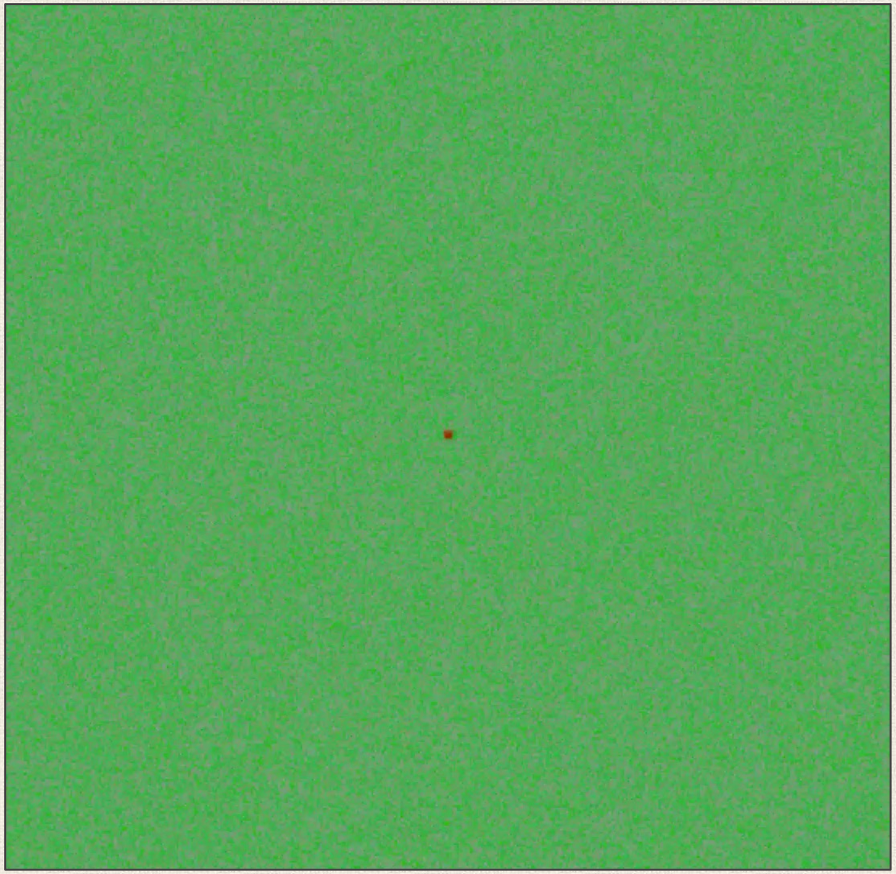
Running our simulation



f = 175,000 and k = 200,000

Increasing f further produces a chaotic stripe pattern because there are so many pockets of predators that they constantly collide and mix.

Running our simulation



f = 200,000 and k = 200,000

Once f equals k, the stripes disappear. We might expect to see a uniform mix, but instead, we see a "mottling" of red and green clusters, or spots.

Turing pattern systems have been identified in fish (but not zebras)!

These pufferfish are very similar genetically, and yet they display different patterns.

Unlike other *robust* biological systems, Turing patterns are *fine-tuned*.

An Automaton-Like Model of Reaction-Diffusion

Gray-Scott Model: a "discretized" simulation with improved runtime by partitioning space into blocks and assuming concentration of a given molecule in a block is uniform throughout the block.

Autocatalytic reactions in the isothermal, continuous stirred tank reactor: Oscillations and instabilities in the system A+ 2B→ 3B; B→ C

P Gray, **SK Scott** - Chemical Engineering Science, 1984 - Elsevier

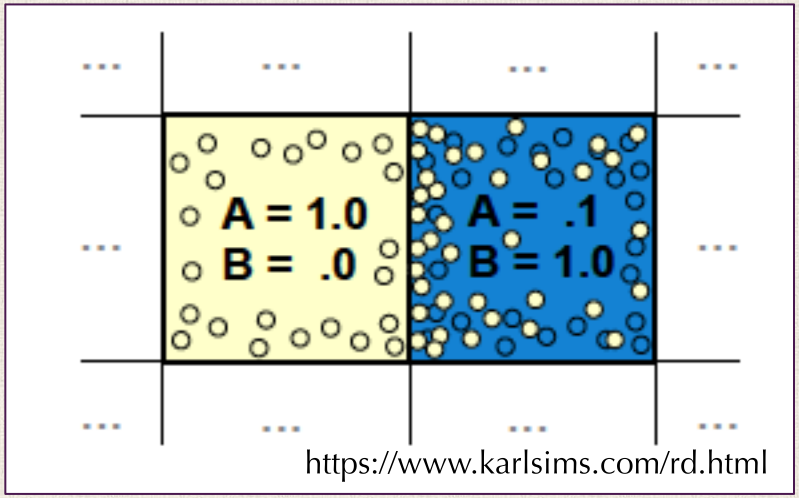
The prototype, cubic autocatalytic reaction (A+ 2B→ 3B) forms the basis for the simplest homogeneous system to display "exotic" behaviour. Even under well-stirred, isothermal, open conditions (CSTR) we may find multistability, hysteresis, extinction, ignition and …

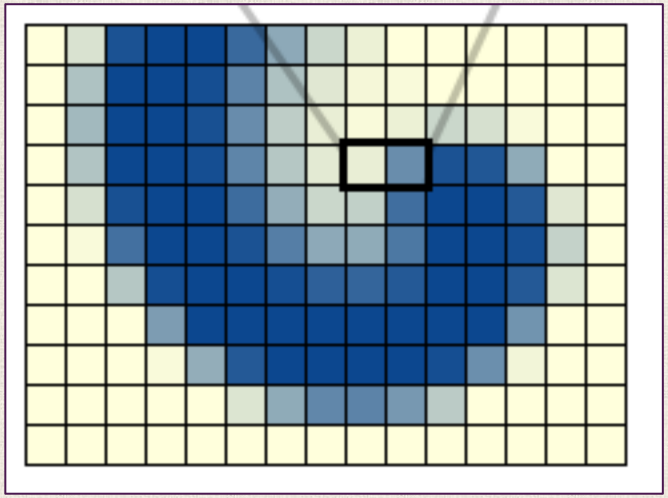
Cited by 639 Related articles All 4 versions

An Automaton-Like Model of Reaction-Diffusion

Gray-Scott Model: a "discretized" simulation with improved runtime by partitioning space into blocks and assuming concentration of a given molecule in a block is uniform throughout the block.

A = prey; *B* = predators





Implementing Reactions as Cellular Operations

Parameters d_A and d_B indicate what fraction of a cell's two particle types to diffuse into neighbors.

0, 0	0, 0	0, 0	0, 0	0, 0
0, 0	0, 0	0, 0	0, 0	0, 0
0, 0	0, 0	1,1	0, 0	0, 0
0, 0	0, 0	0, 0	0, 0	0, 0
0, 0	0, 0	0, 0	0, 0	0, 0

$d_A = 0.2$
$d_B = 0.1$
→

0, 0	0, 0	0, 0	0, 0	0, 0
0, 0	.01, .005	.04,.02	.01, .005	0, 0
0, 0	.04,.02	.8, .9	.04,.02	0, 0
0, 0	.01, .005	.04,.02	.01, .005	0, 0
0, 0	0, 0	0, 0	0, 0	0, 0

Implementing Reactions as Cellular Operations

Parameters d_A and d_B indicate what fraction of a cell's two particle types to diffuse into neighbors.

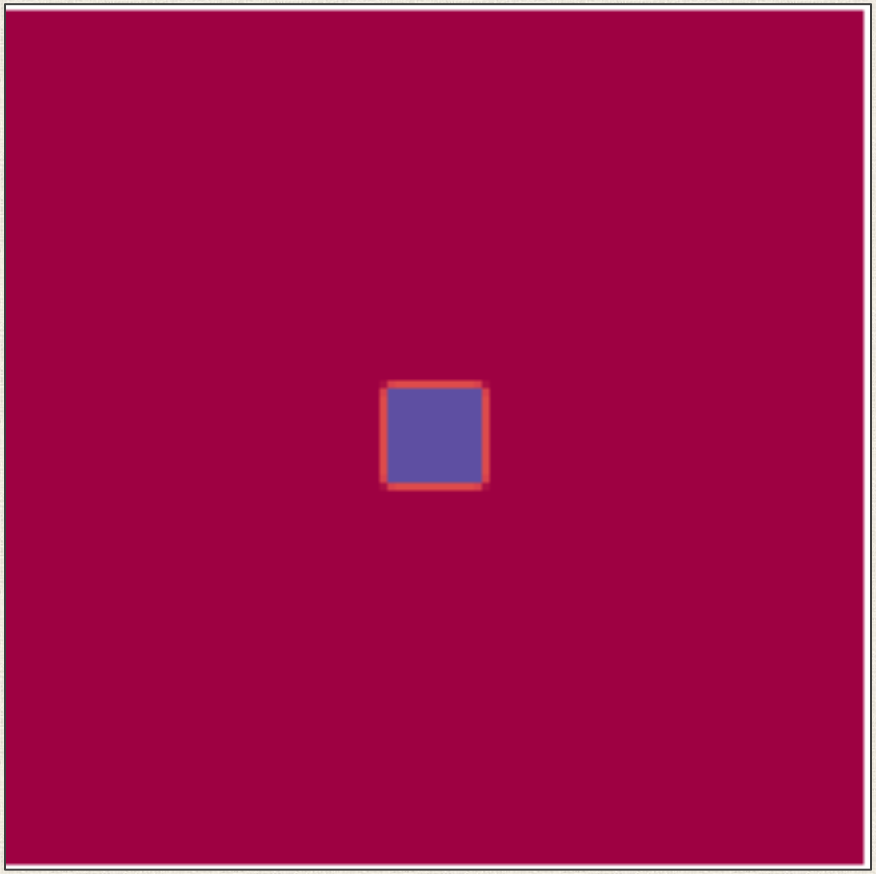
Then, we apply reactions cell by cell.

$$[A]_{\text{new}} = [A] + f(1 - [A]) - [A][B]^2$$

$$[B]_{\text{new}} = [B] - k[B] + [A][B]^2$$

Here, f is the feed rate parameter, and k is the kill rate parameter; both are between 0 and 1.

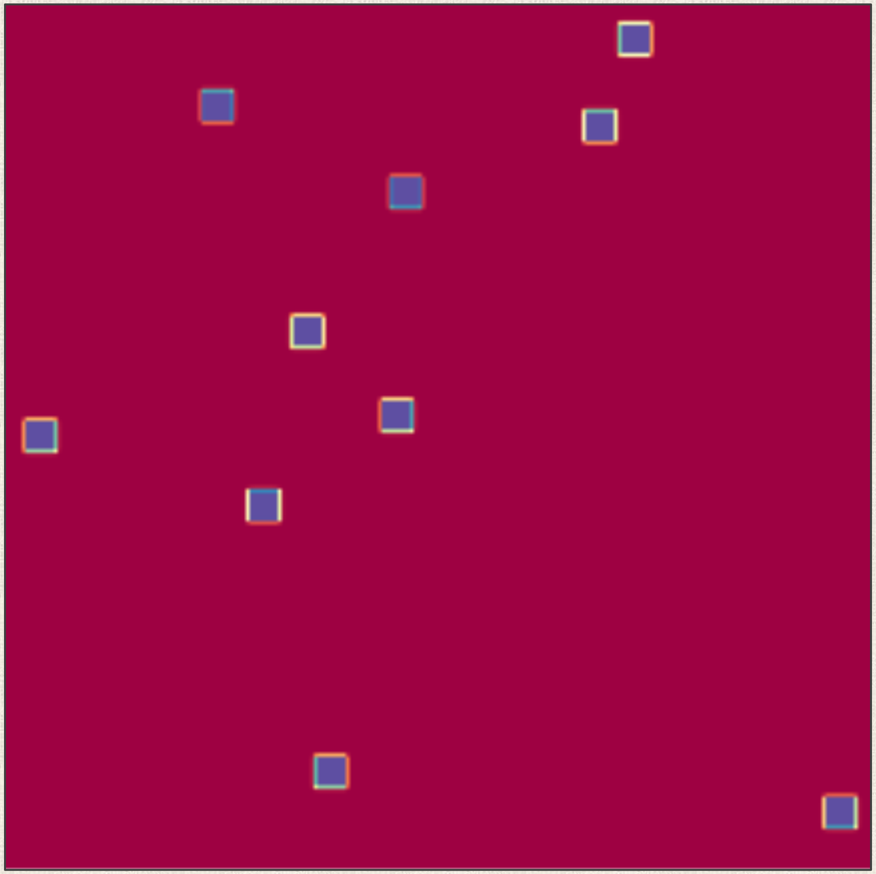
Running the Gray-Scott Model



$f = 0.034$ and $k = 0.095$

A cell's color is based on its value of $[B]/([A] + [B])$. If this value is close to zero (many prey), then it will be colored red, and if it is close to 1 (many predators), then it will be colored dark blue.

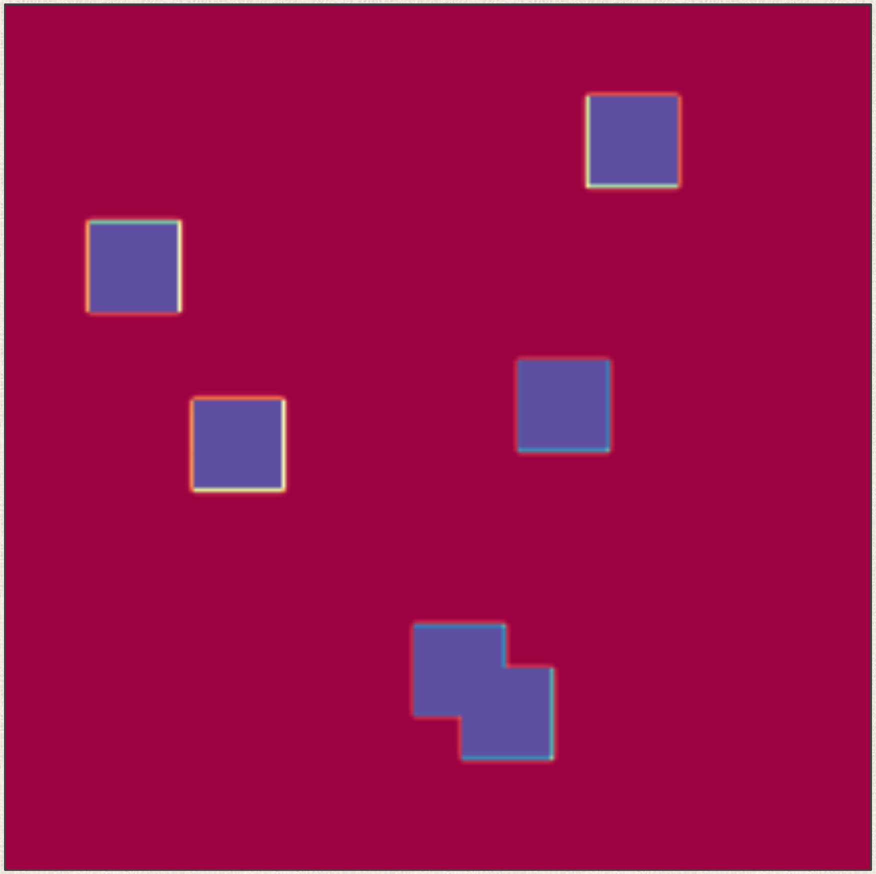
Running the Gray-Scott Model



$f = 0.034$ and $k = 0.095$

Creating multiple initial predator locations leads to more complex patterns.

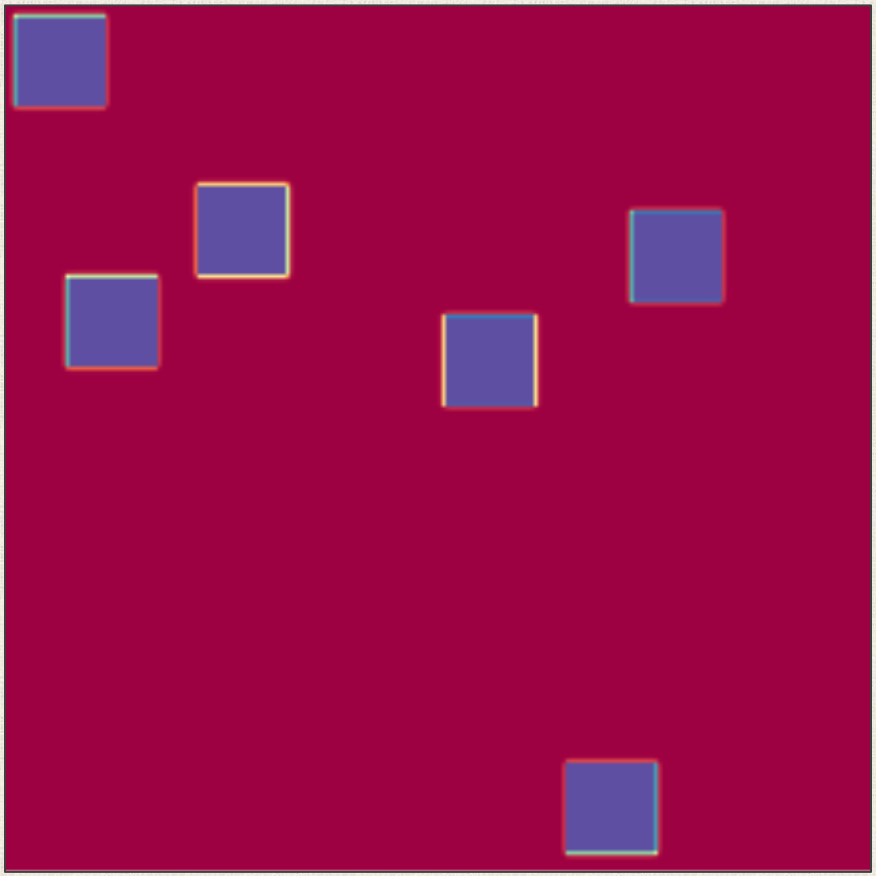
Running the Gray-Scott Model



$f = 0.034$ and $k = 0.097$

If we hold the feed rate constant and increase *k* by just 0.002, then the patterns change significantly into spots.

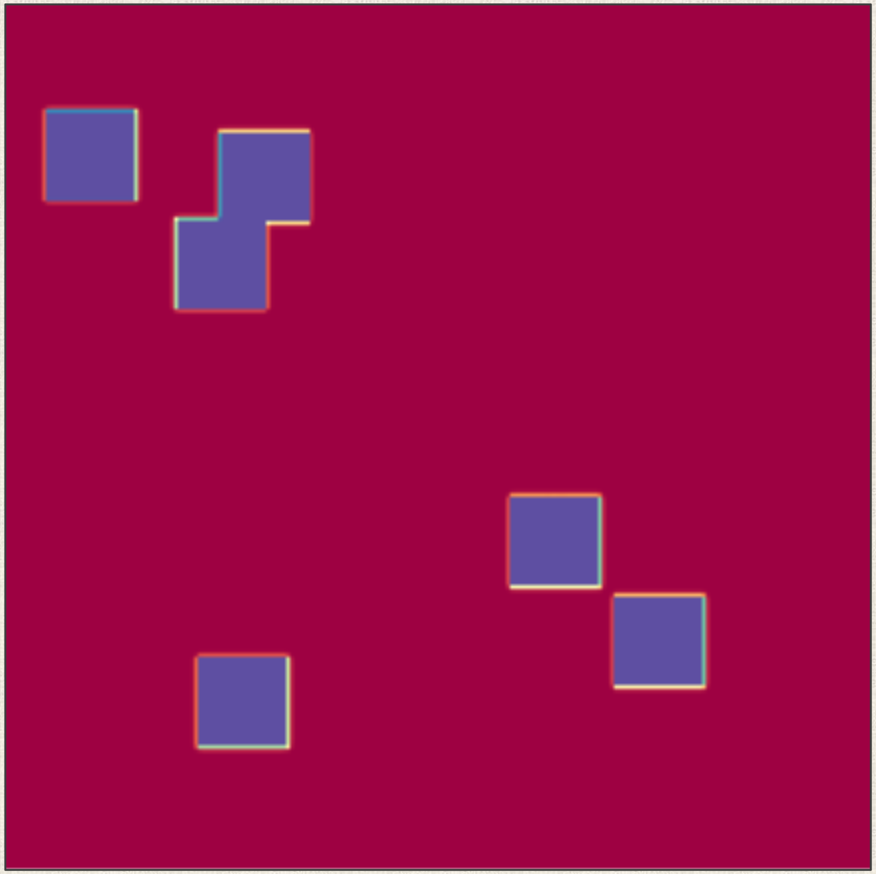
Running the Gray-Scott Model



f = 0.038 and k = 0.099

If we make the prey just a little bit happier, raising f by 0.004 and k by 0.002, then we get a striped pattern again, but a different one.

Running the Gray-Scott Model



$f = 0.042$ and $k = 0.101$

And if we raise f by another 0.004 and k by another 0.002, we again see a spot pattern.

Convergent patterns are very parameter dependent

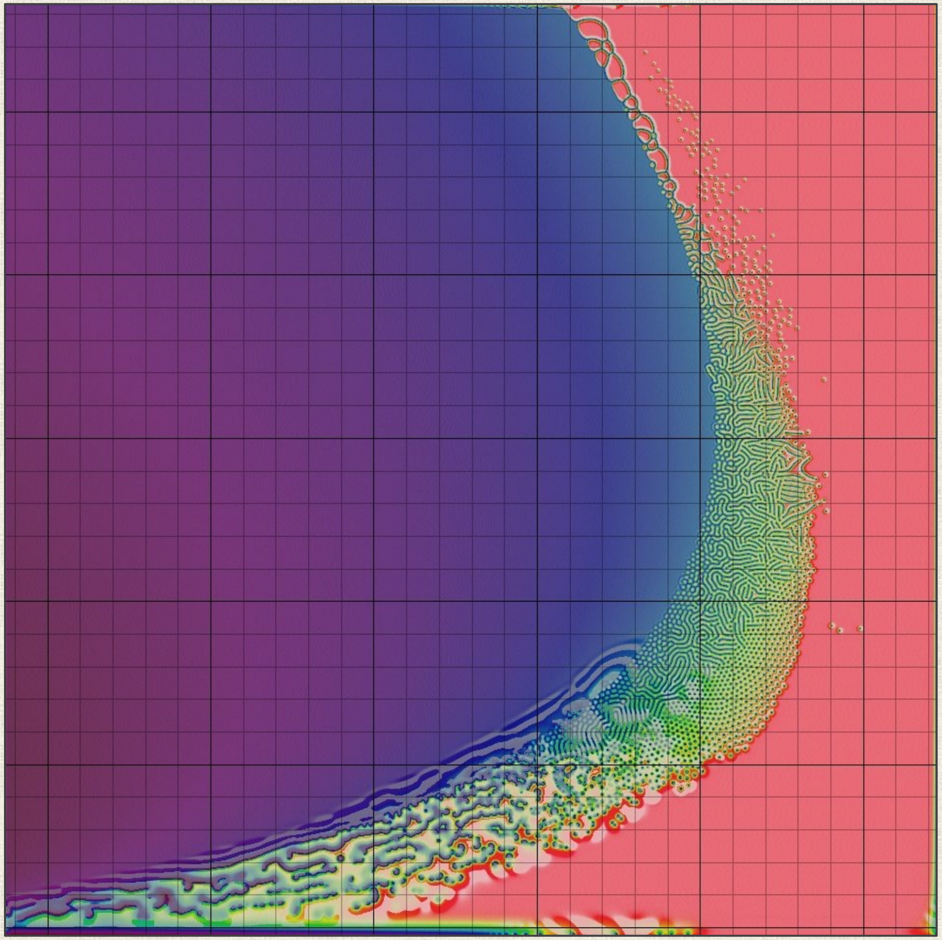


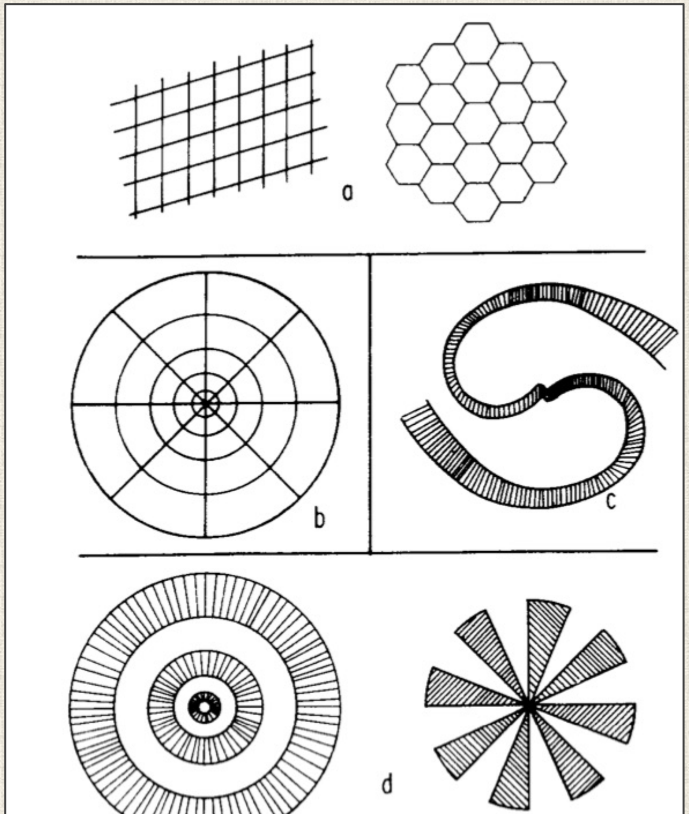
Image source: Robert Munafo

This plot shows final convergent patterns for varying values of *k* (*x*-axis) and *f* (*y*-axis).

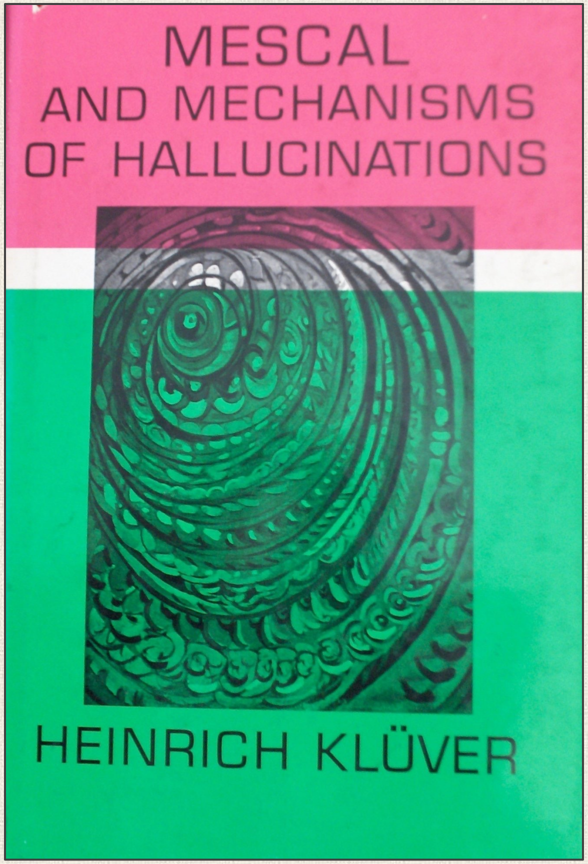
Key point: Gray-Scott is a faster model that confirms the highly fine-tuned parameters of this system.


PRETTY TRIPPY HUH

We all trip in similar ways. But why?

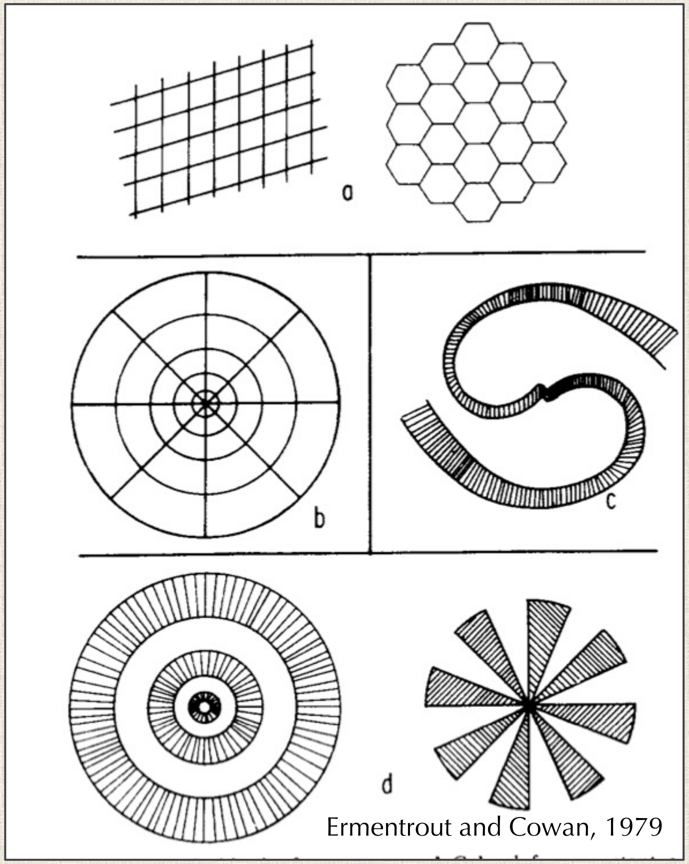


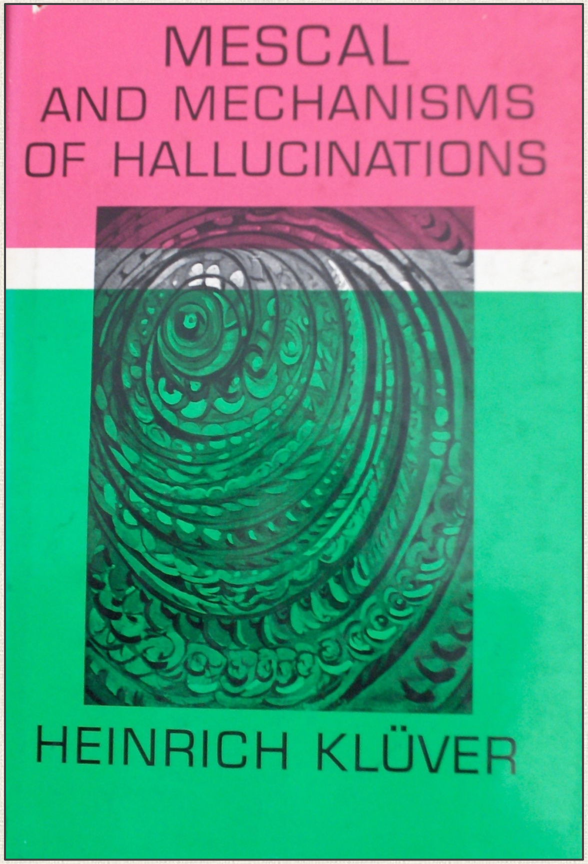
Ermentrout and Cowan, 1979



Form constant (Klüver, 1928): a commonly recurring shape in visual hallucinations.

We all trip in similar ways. But why?

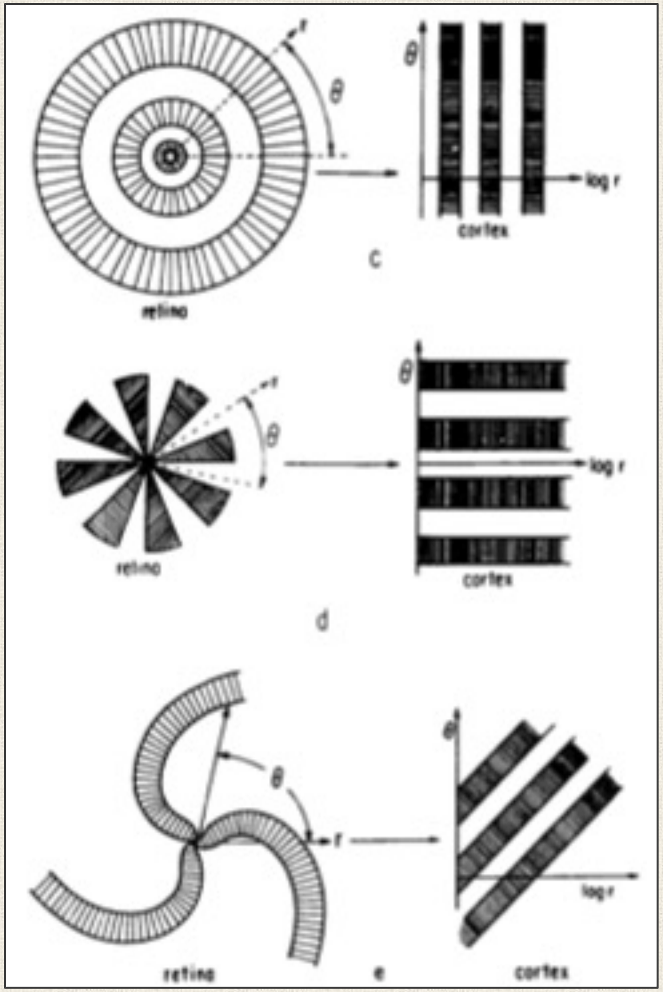




Key point: Hallucinations happen in the blind and don't move in visual field, so they originate in brain.

The brain encodes signals from retina

Cowan 1978: determined details for transformation of retinal coordinates (polar) to cortex (rectangular).



Ermentrout and Cowan, 1979

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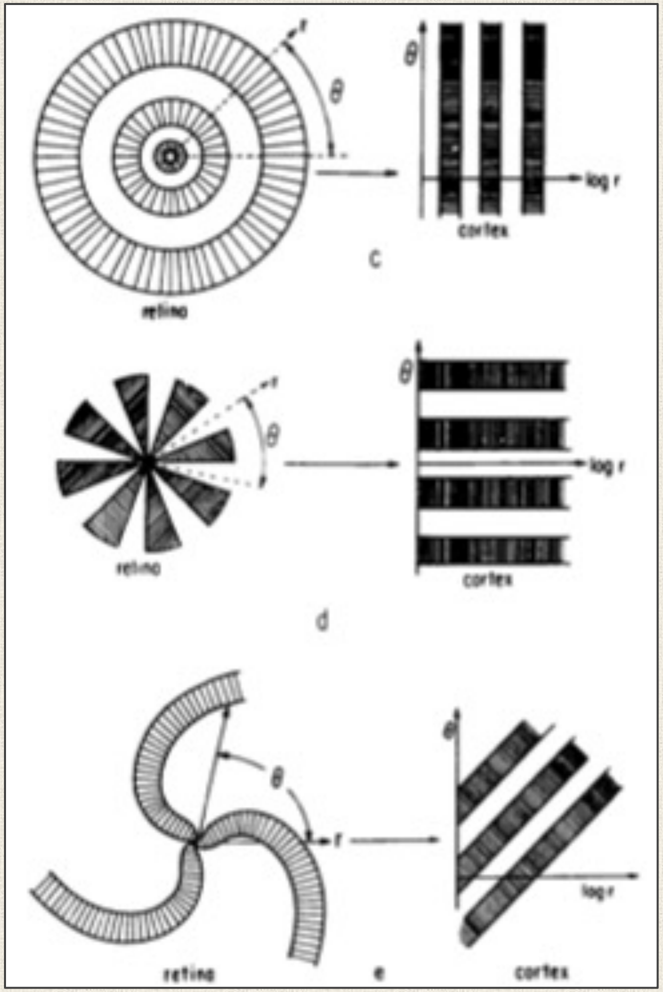
All the form constants reduce to “stripes” in the visual cortex!



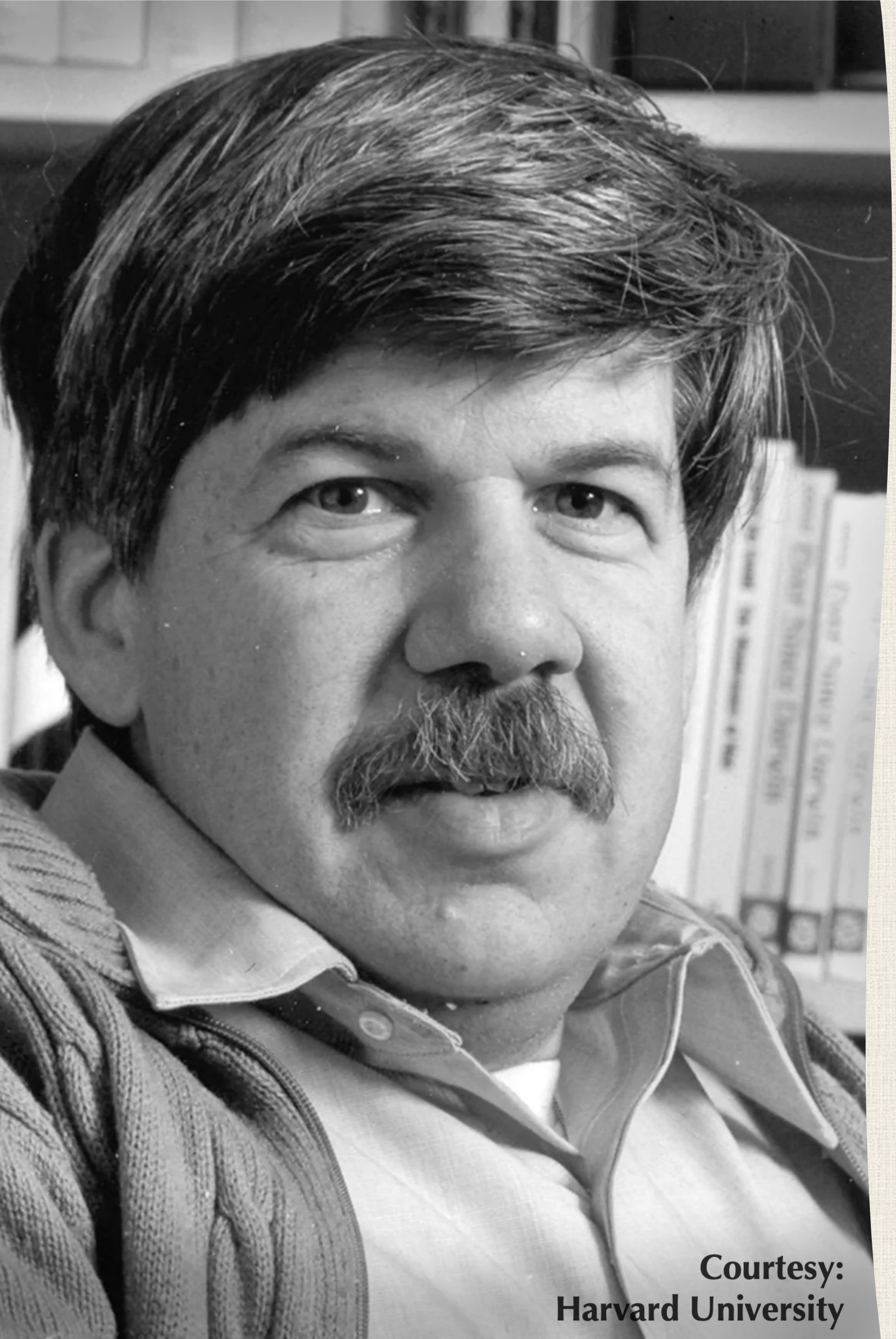
Ermentrout and Cowan, 1979

How Does This Relate to Hallucinations?

The visual cortex contains ″activator″ neurons that tend to be connected more tightly and "inhibitor″ neurons with fewer, sparser connections.

Hypothesis: activators/inhibitors are analogous to ″predator″/″prey″ molecules; some events (migraines, hallucinogens) change the underlying parameters of the system and produce Turing patterns within the visual cortex.

WHAT – IF ANYTHING – DID YOU LEARN?


Courtesy:
Harvard University

Some Parting Words

"The Lord gives us so little time for a career: forty years if we start early ... and remain in good health, fifty if fortune smiles. The Devil takes so much away - primarily in administrative burdens that fall upon all but the most resistant and singularly purposeful SOBs."

– *Stephen Jay Gould*

The End?

Time for FCEs!