Evolutionary Firefighting

Lab MA-INF 1315

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Content

Introduction

Catching the fire on a Grid

- grid graph
  - vertices $\mathbb{Z} \times \mathbb{Z}$
  - edges $\{((v, w), (x, y)) \mid |v - x| + |w - y| = 1\}$
- fire starts at $(0, 0)$ at time $t = 0$
- place f agents at non-burning vertices for protection
- fire spreads to each unprotected neighbor
- objective: enclose fire

Previous results

- fire can be enclosed for $f = 2$ optimally in 8 steps with 18 burning cells
- fire can not be enclosed for $f = 1$ (not even in quarter plane)
- fire can be enclosed for $f > 1.5$
- fire can not be enclosed for $f = 1.5$

Evolutionary Algorithms

- optimization inspired by biological evolution
- improves population P over many generations
- individual defined by set of parameters (genome)
- key mechanisms:
  - selection
  - inheritance
  - mutation
  - fitness evaluation

Introduction

Genome

- Example
  - start: $(0, -1)$
  - sequence: $((N, F), (NE, F), (SE, B), (SE, F), (E, B))$

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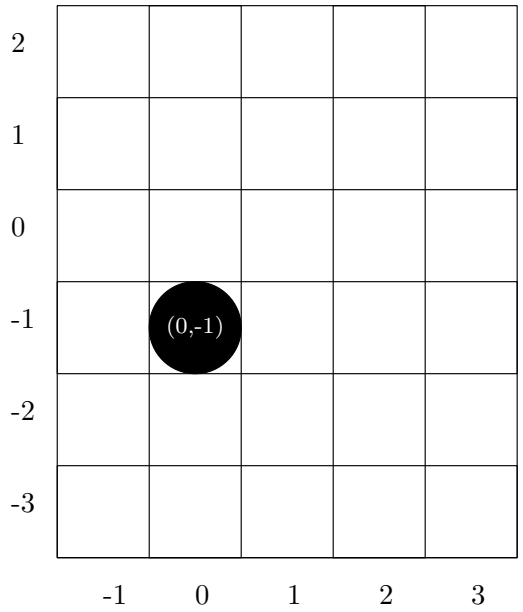

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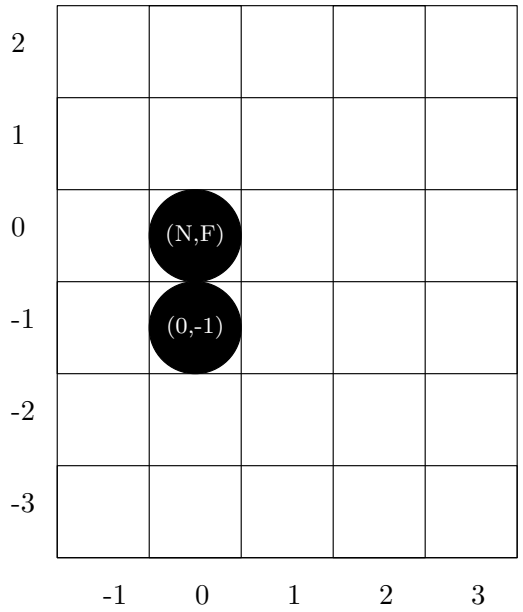

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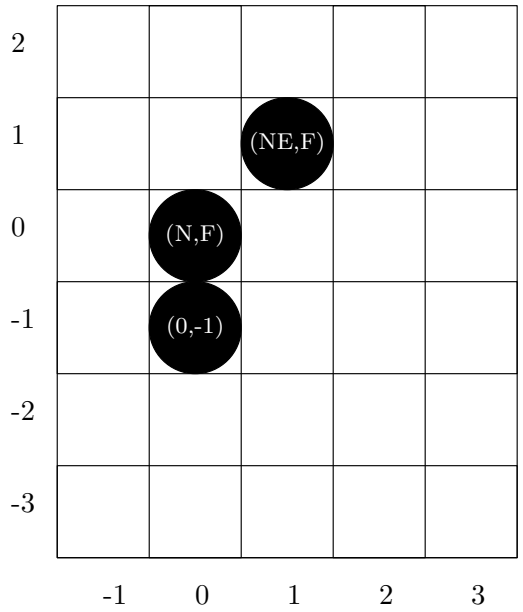

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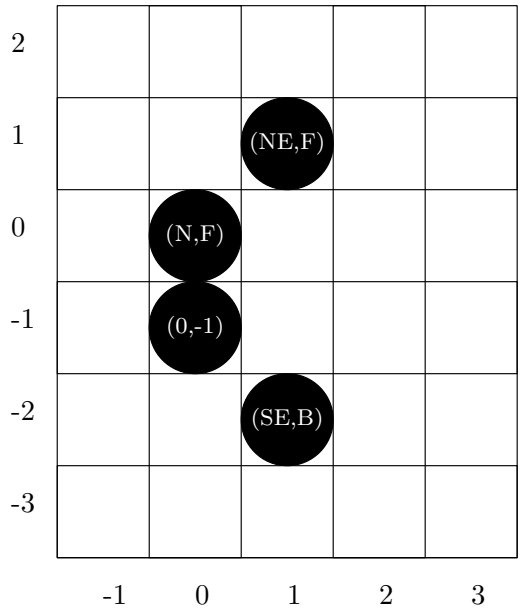

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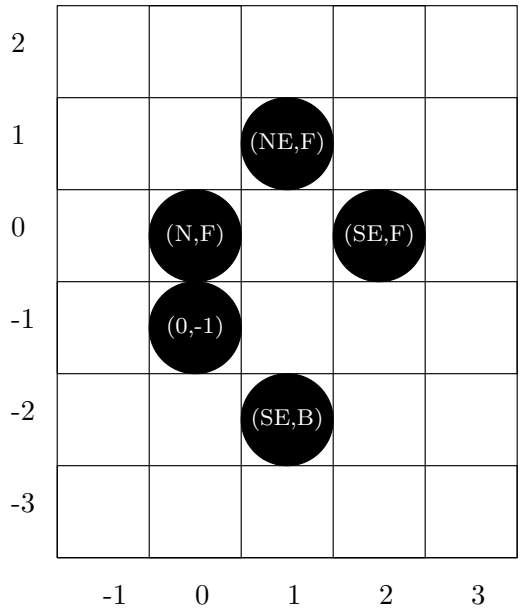

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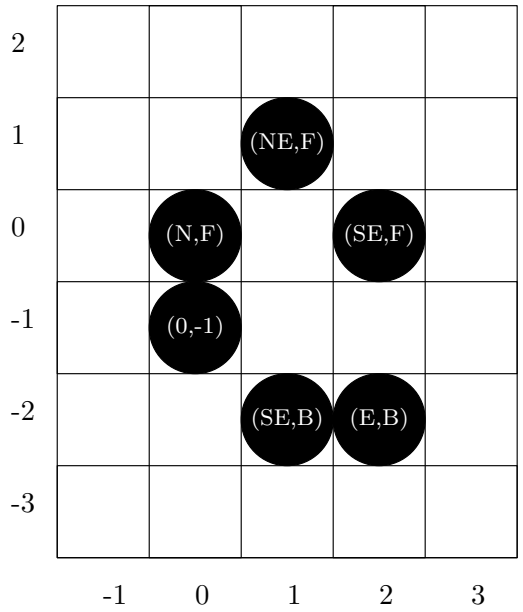
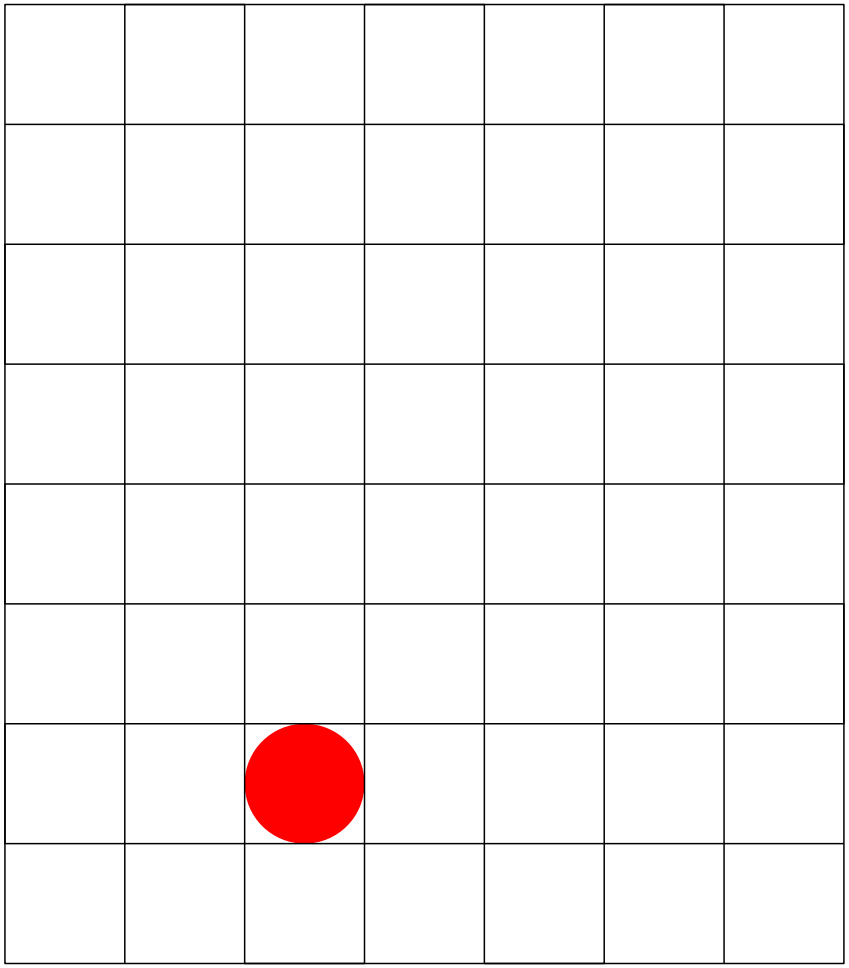


Simulation

- account idea tells when to protect next cell
  - account $> 1 \Rightarrow$ protect next cell $\Rightarrow$ decrease account by 1
  - spread fire
  - increase account by budget f
- fitness
  - number of burning cells "at the end"

Strategy found for $f = 2$



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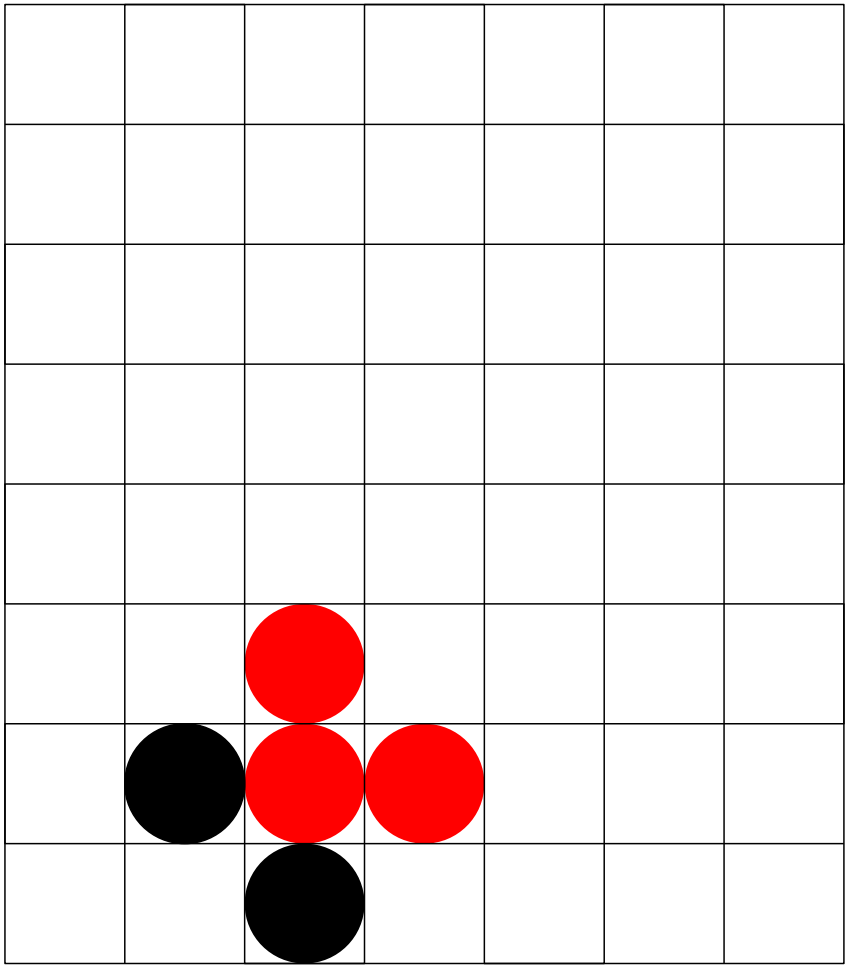

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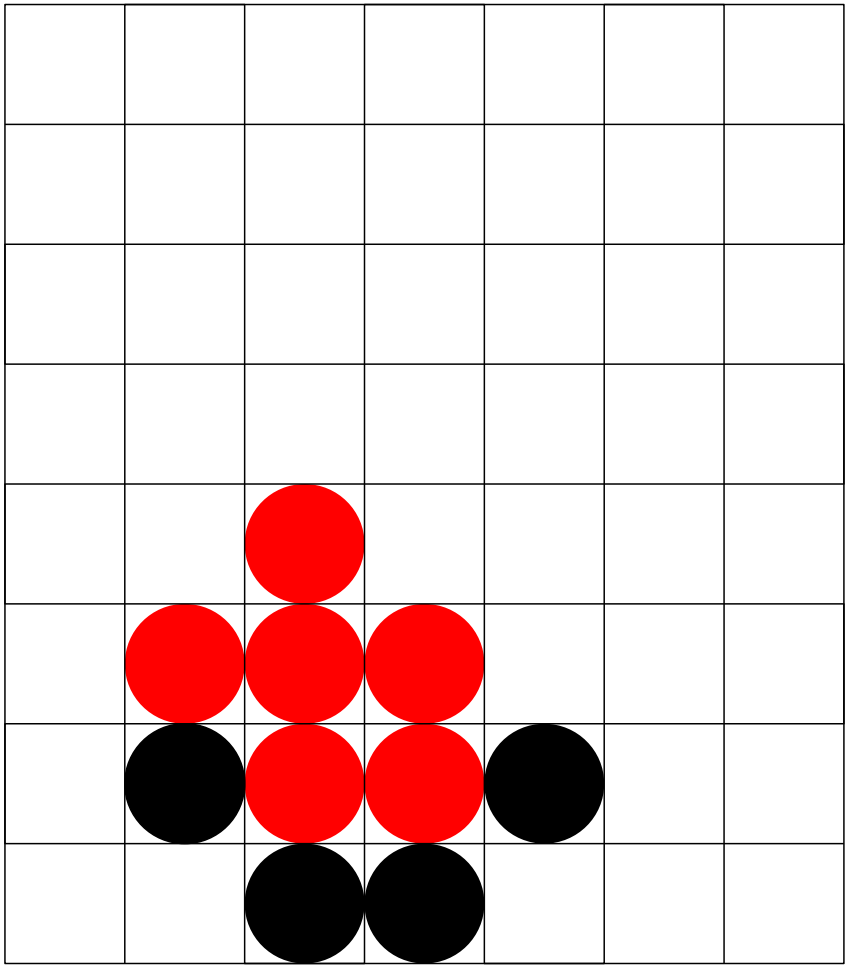

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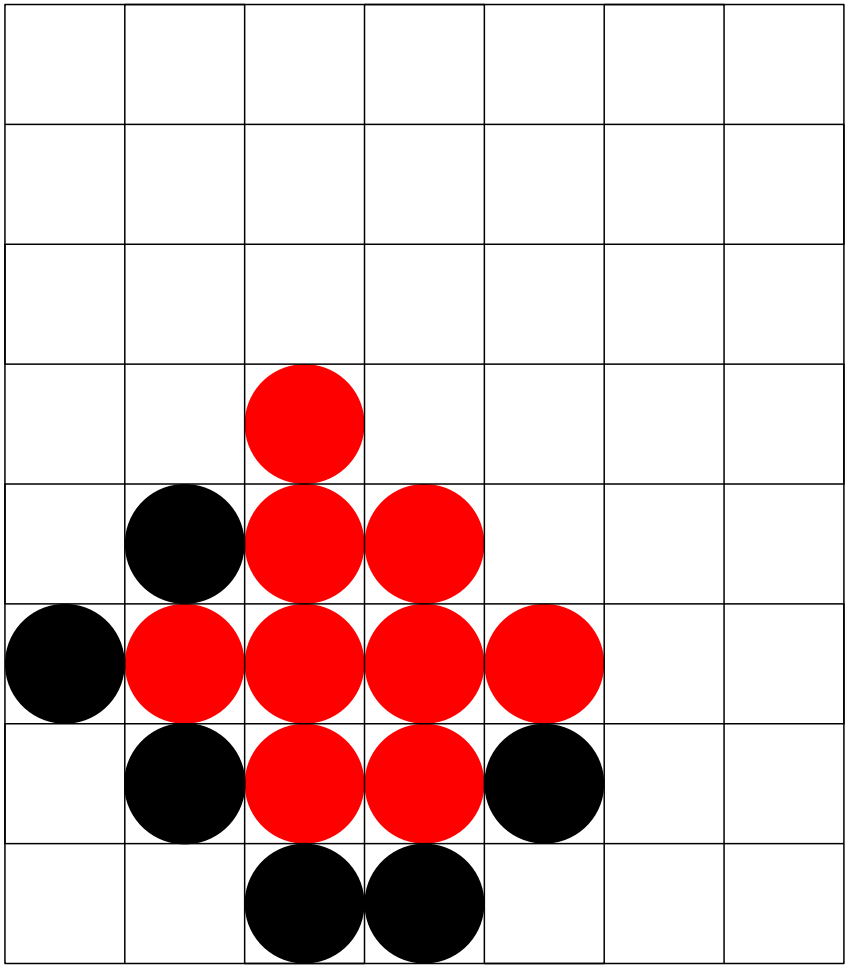

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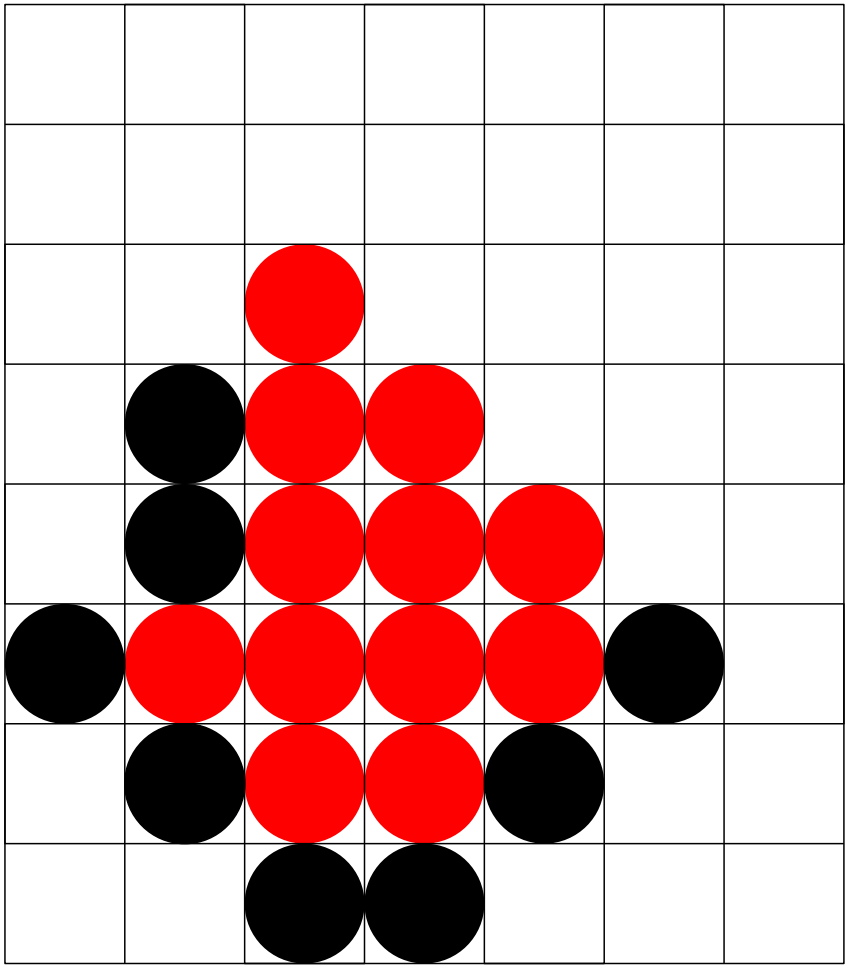

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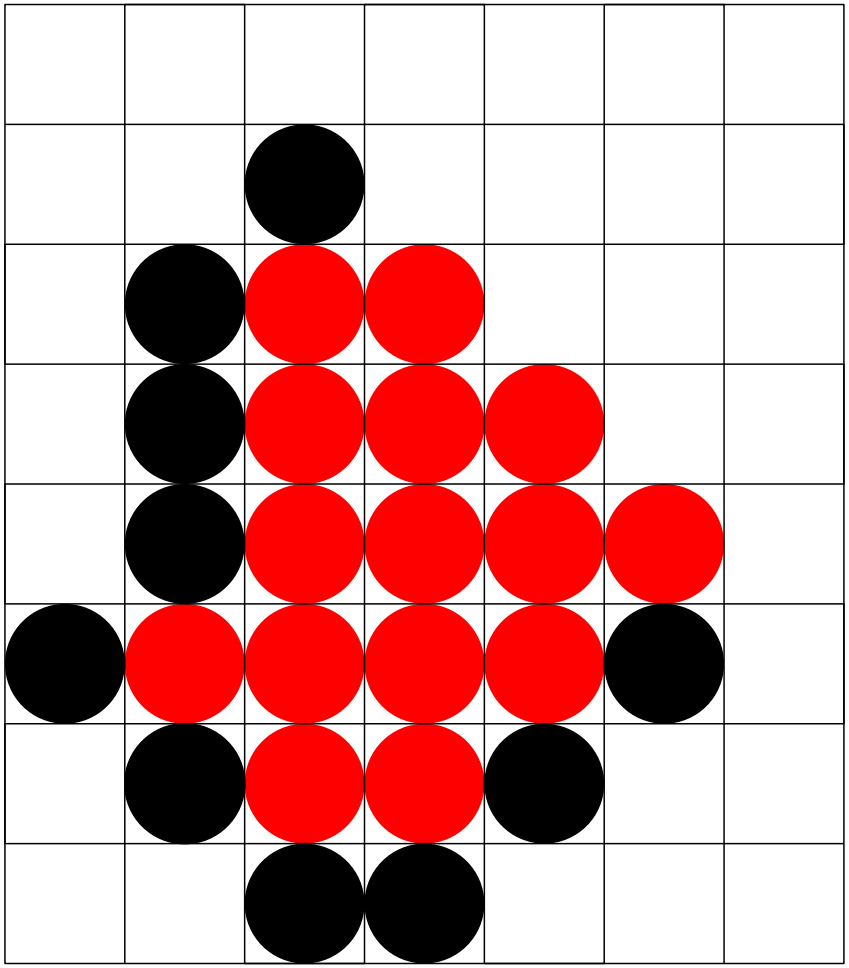

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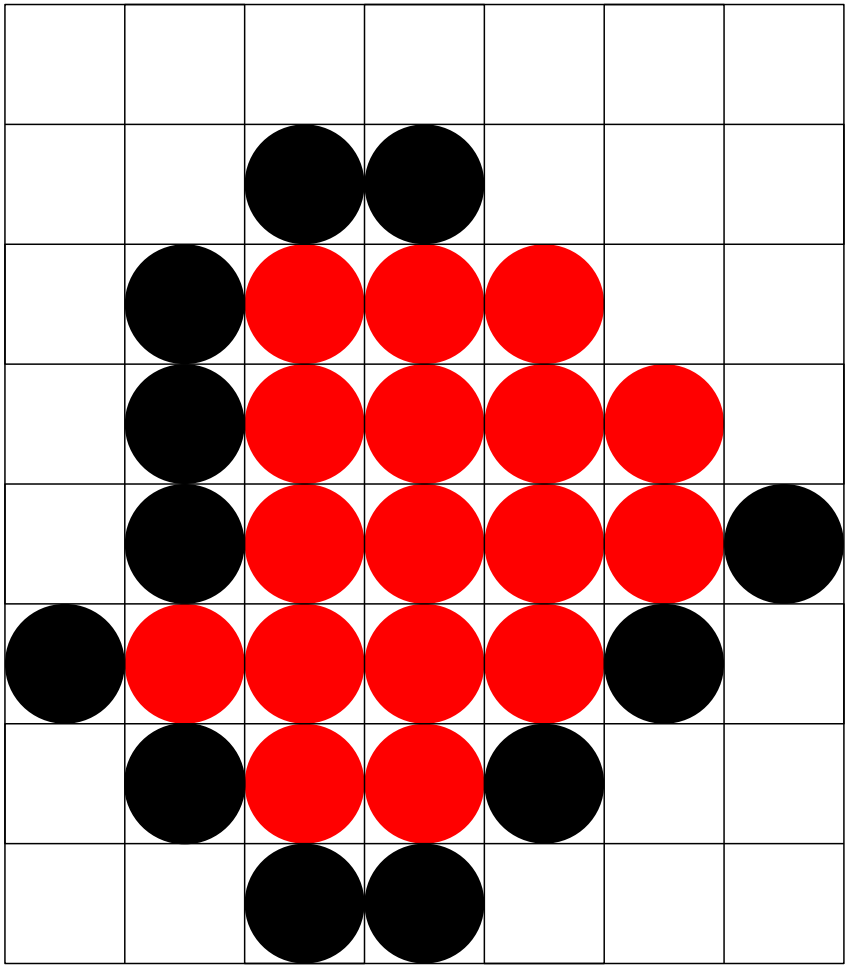

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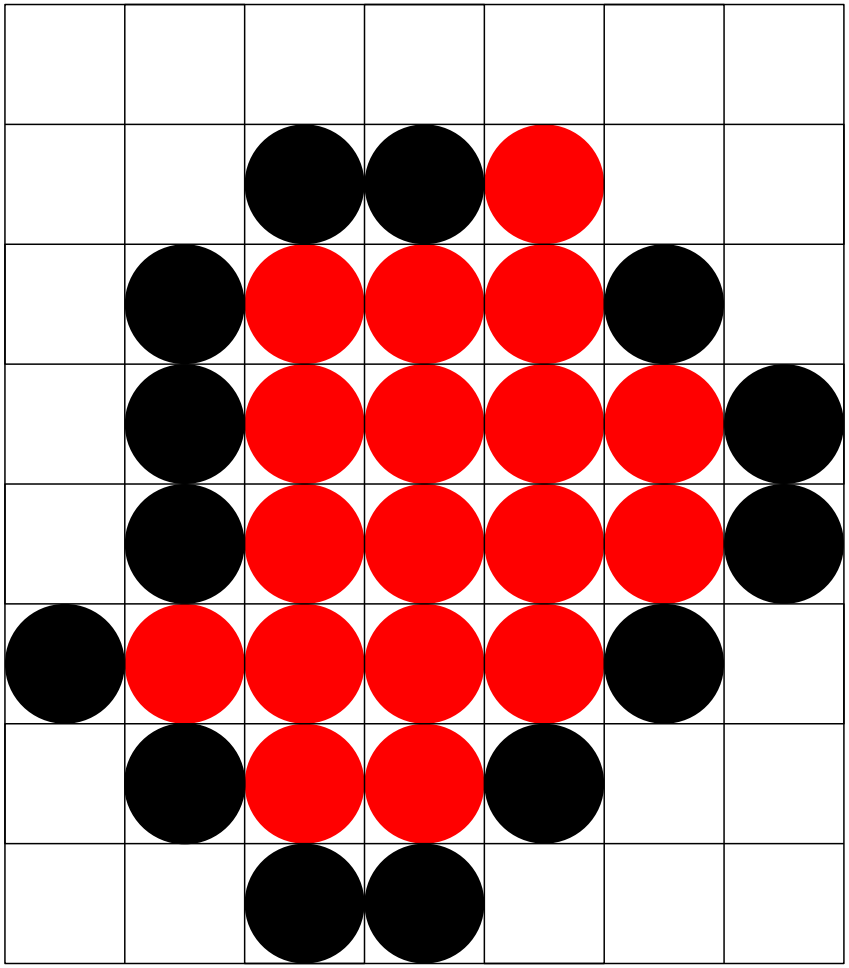

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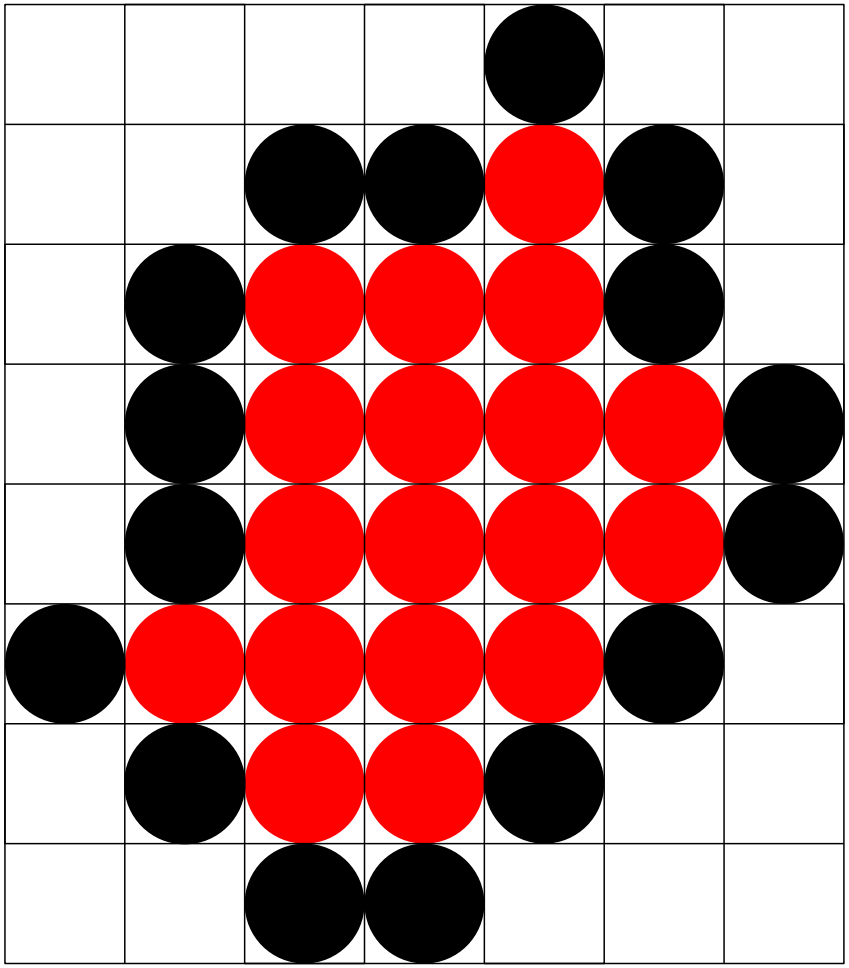
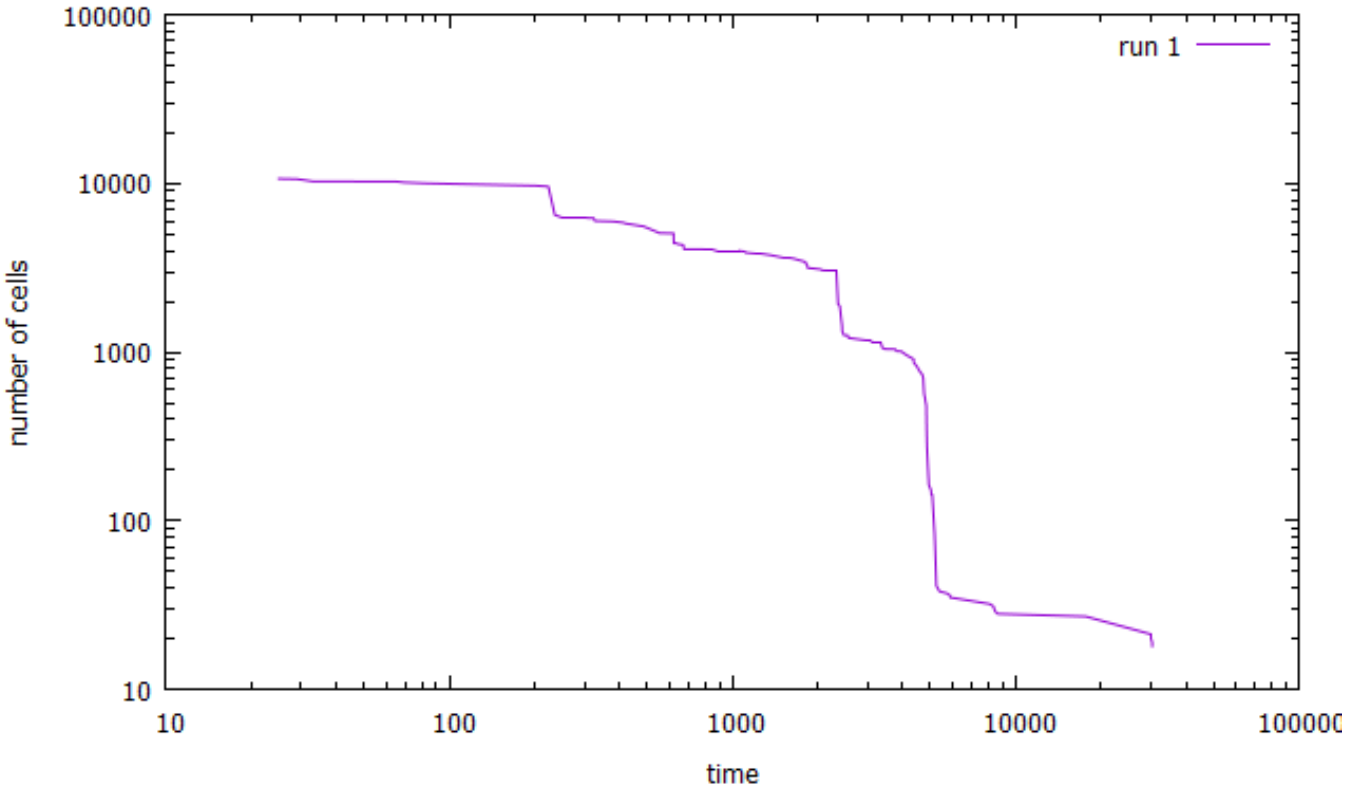
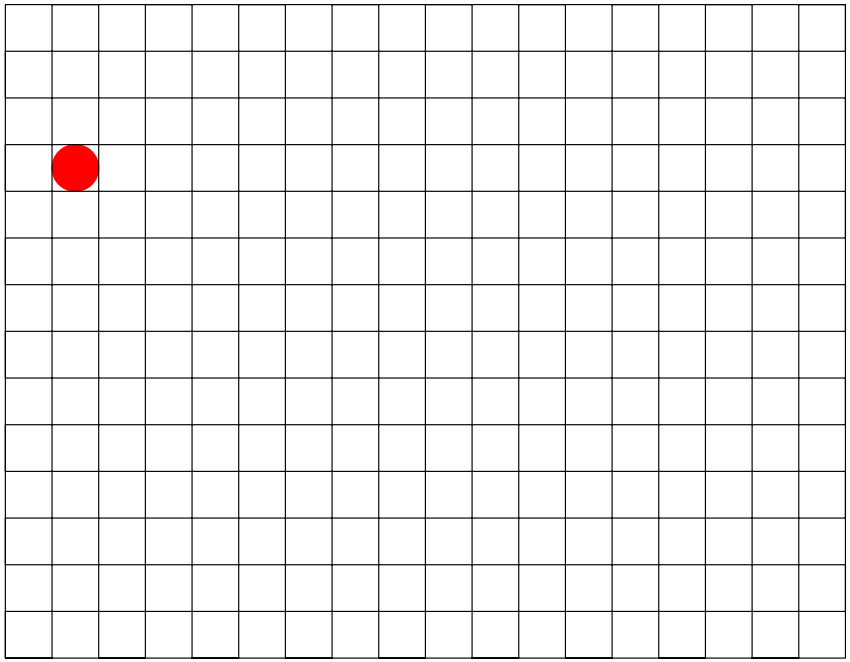


Fitness Development



Strategy for $f = 1.8$



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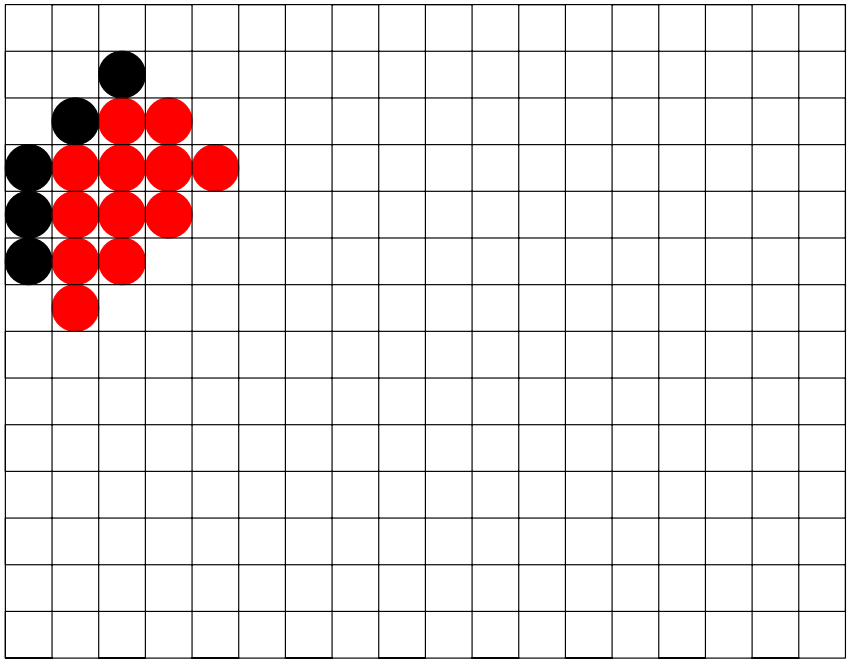

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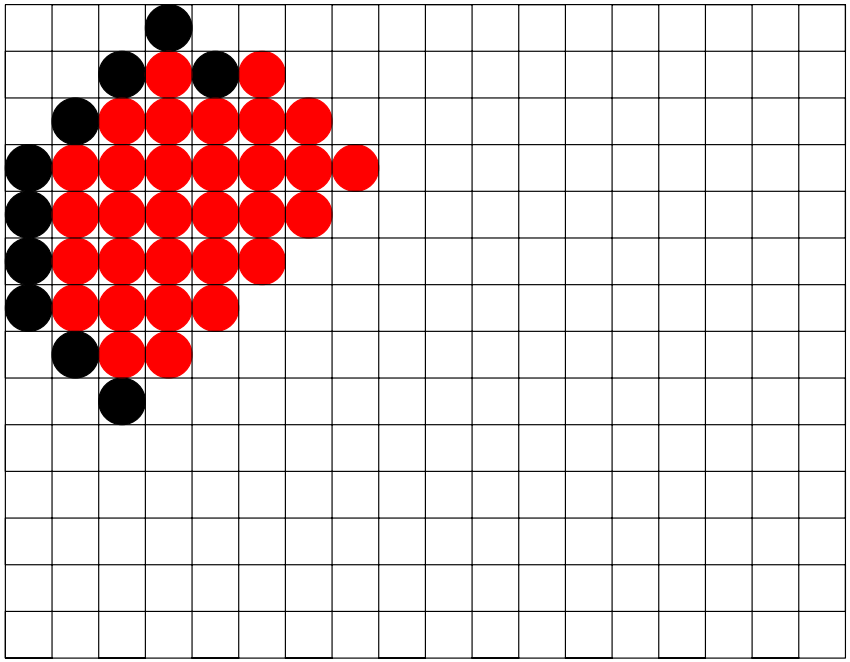

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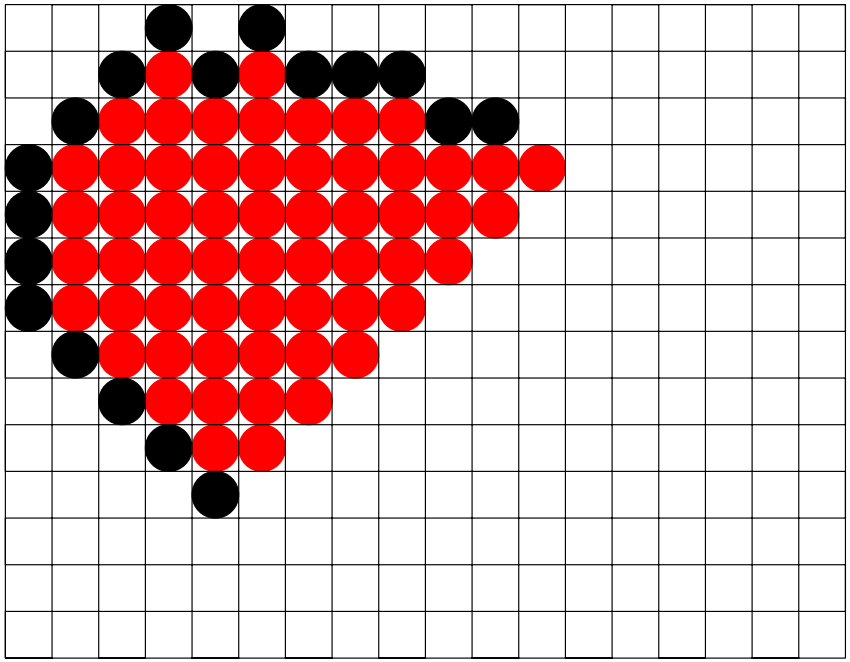

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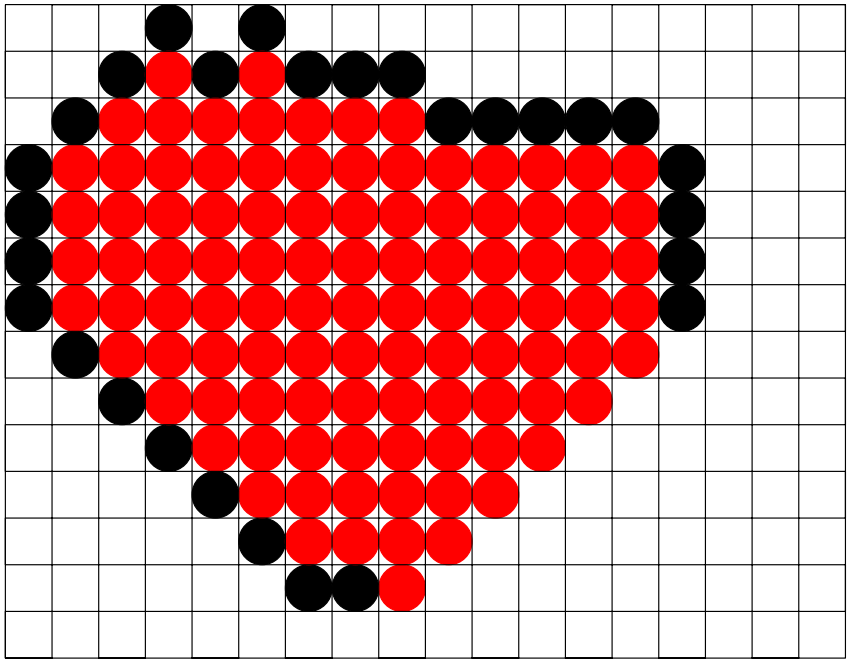

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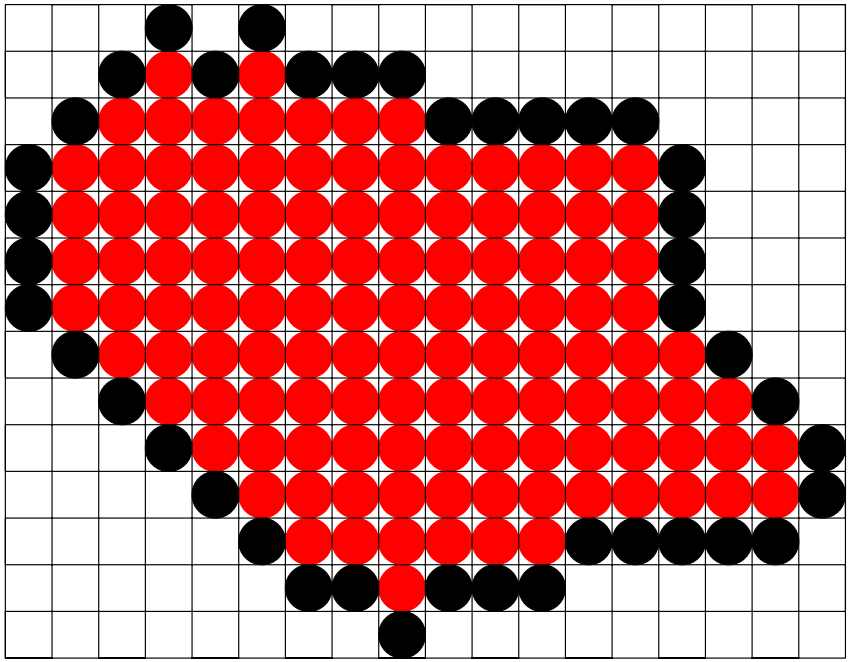

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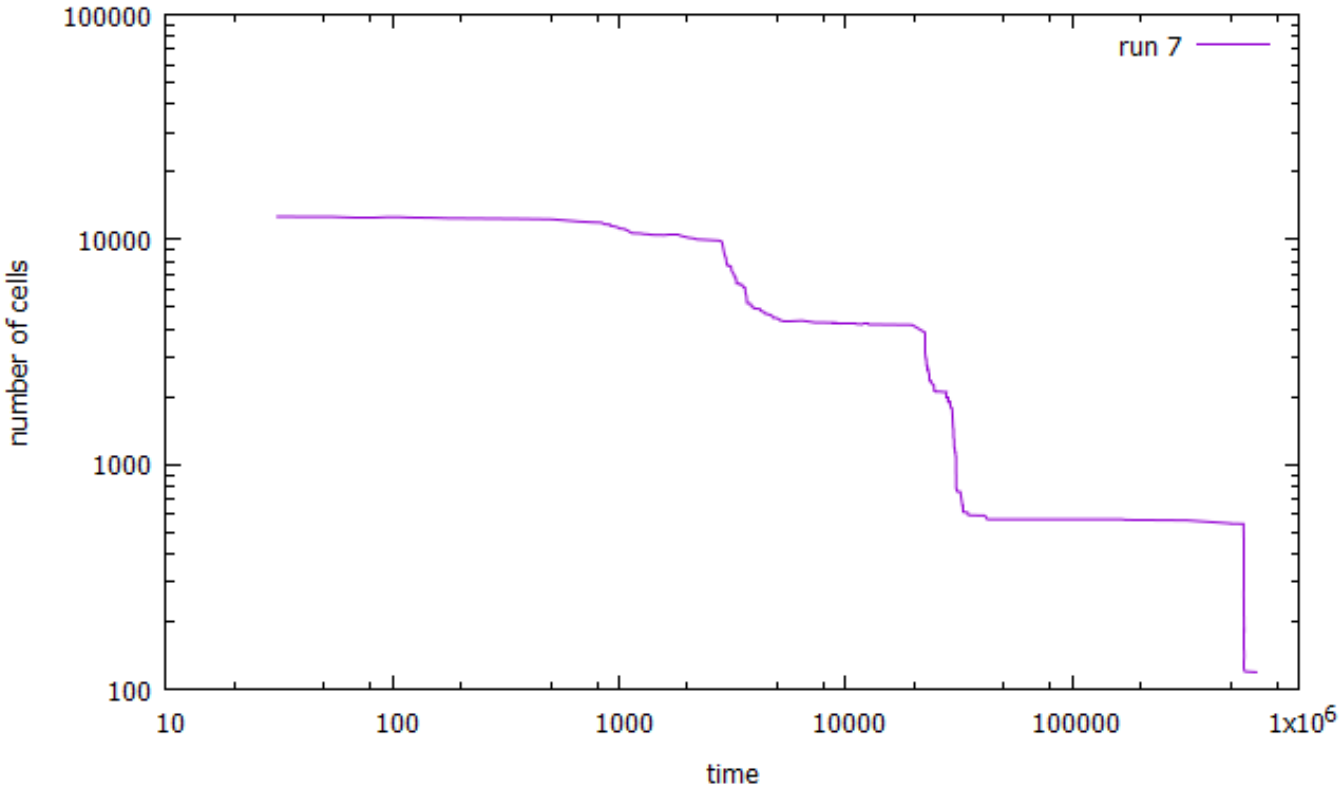
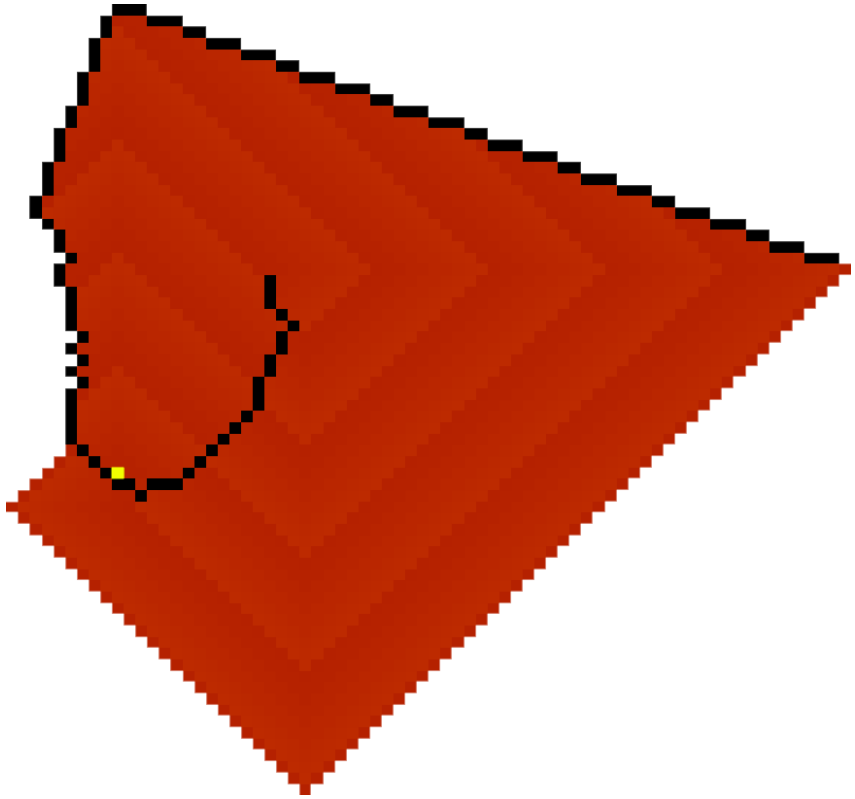


Failed Strategies $f = 1.6$



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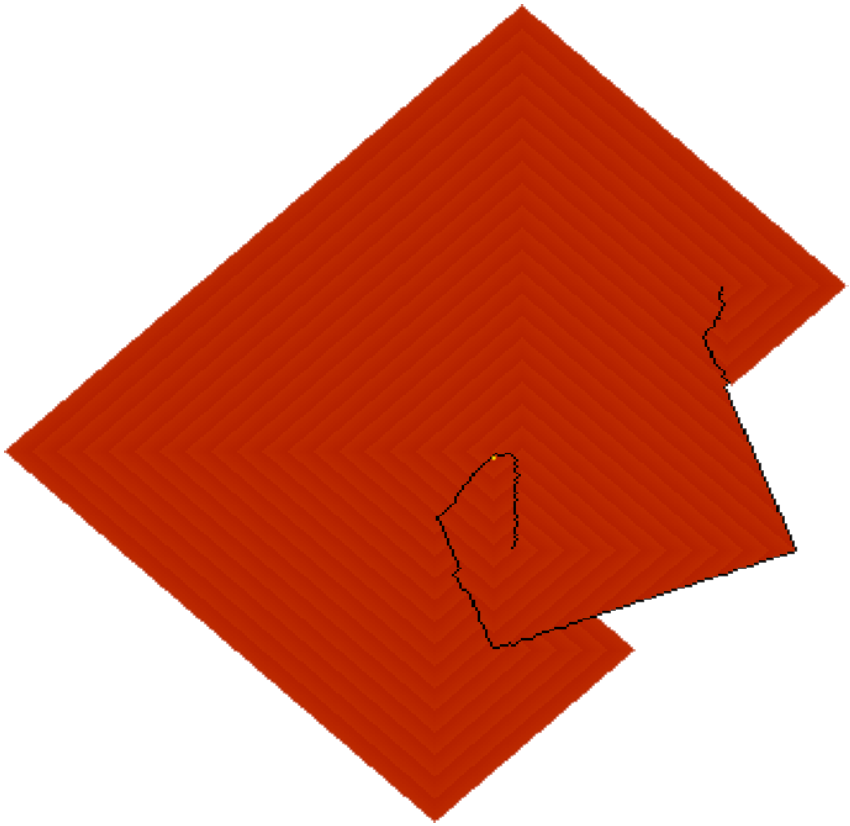
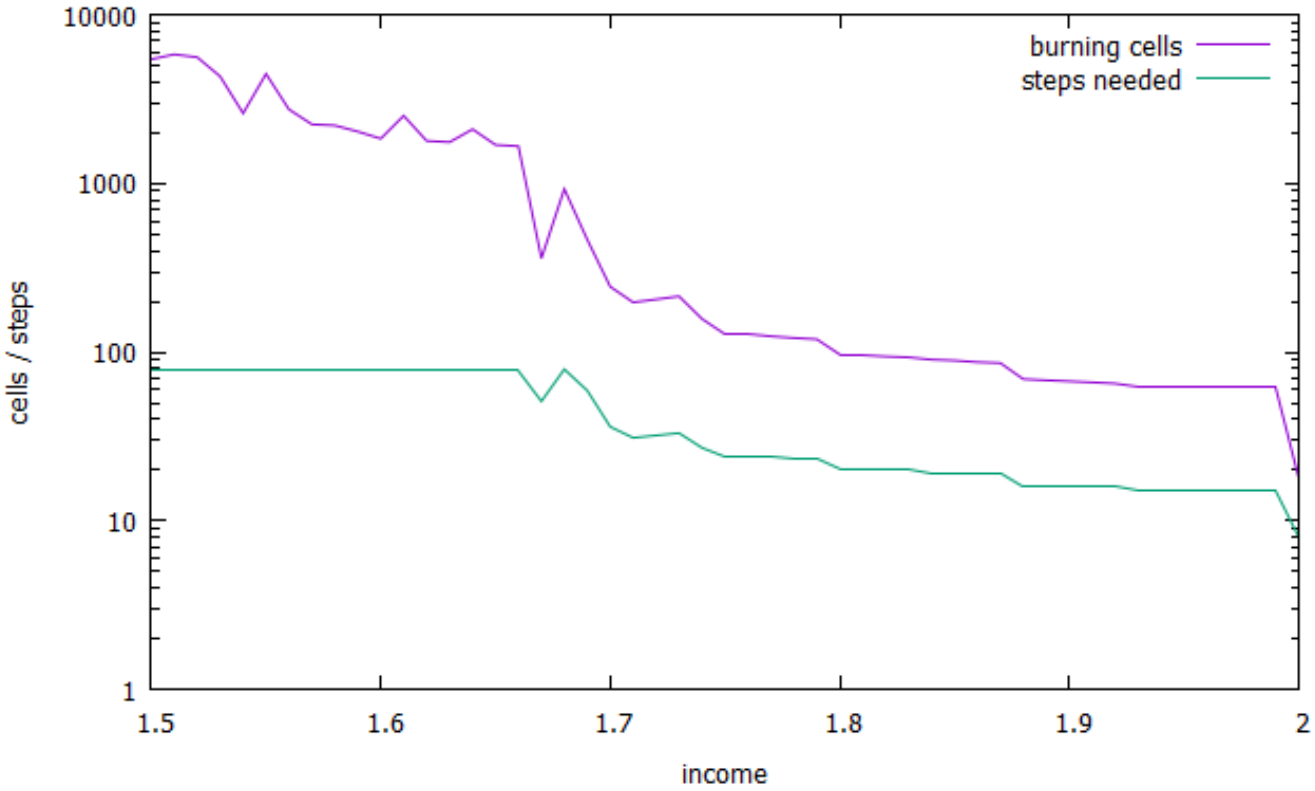


Benchmark


10000
1000
100
10
1
cells / steps
1.5
1.6
1.7
1.8
1.9
2
income
burning cells
steps needed

Highway Protection

Highway Protection

- fire starts at $(0, 0)$
- horizontal highway at distance $m \Rightarrow H = \{(i, m) \mid i \in \mathbb{Z}\}$
- objective: protect H from catching fire (as long as possible)
- good strategies unknown

Genome

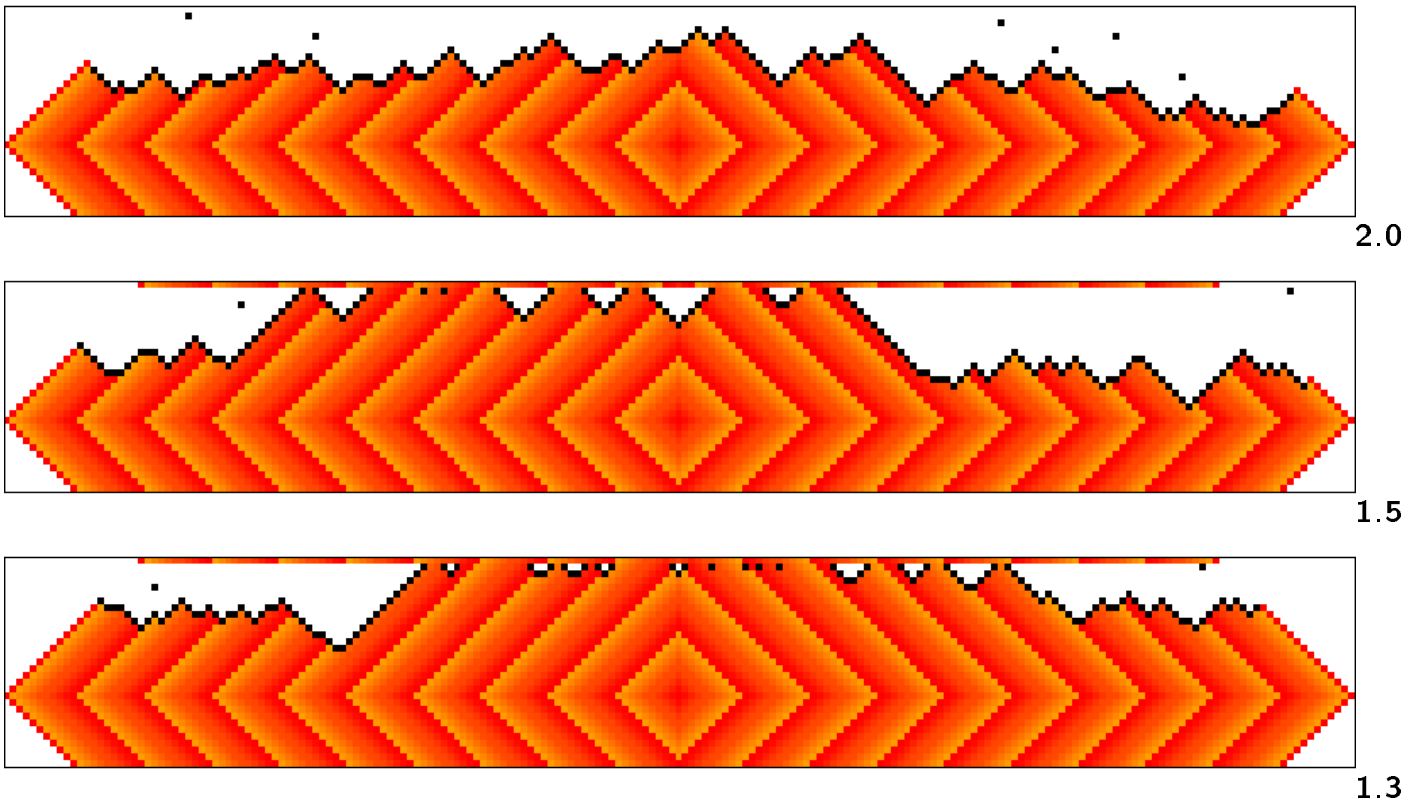
- version 1 (scattered)
  - sequence is list of exact coordinates
  - $((1,2),(5,-10),(-3,4),(4,0),\ldots)$
- version 2 (connected)
  - sequence is list of directions (as before)
  - $((N,F),(NE,F),(S,B),(SW,B),\ldots)$

Fitness evaluation

- needs to allow gradual improvements
- higher fitness when
  - fire takes longer to reach highway
  - fewer vertices are burning
  - vertices closer to highway have higher significance

Version 1

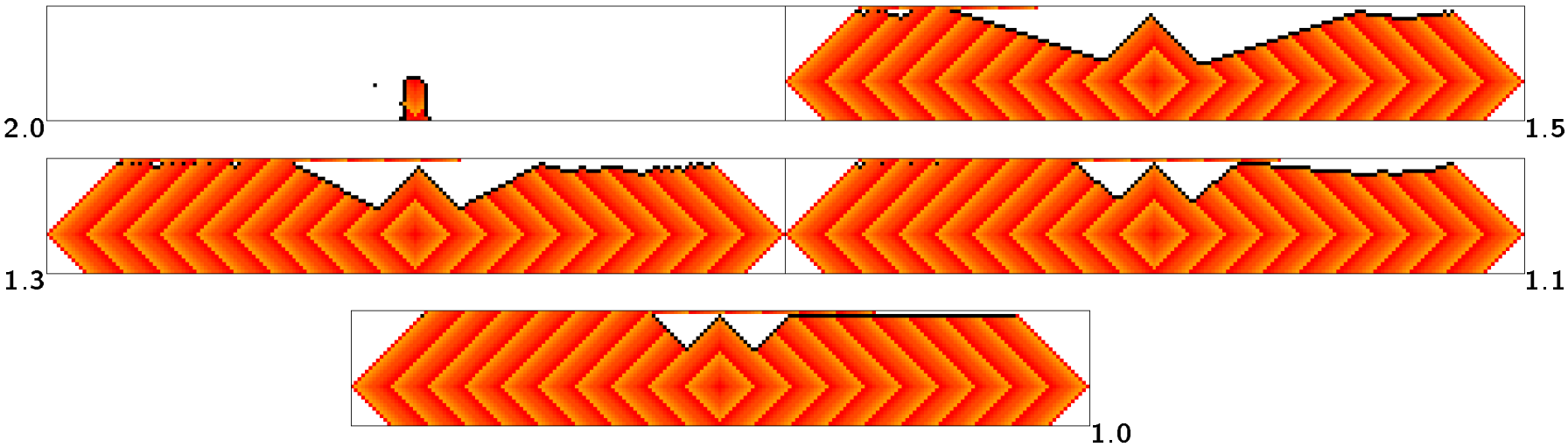
- scattered genome, random initialization



- realization: best strategy can only improve

Version 2

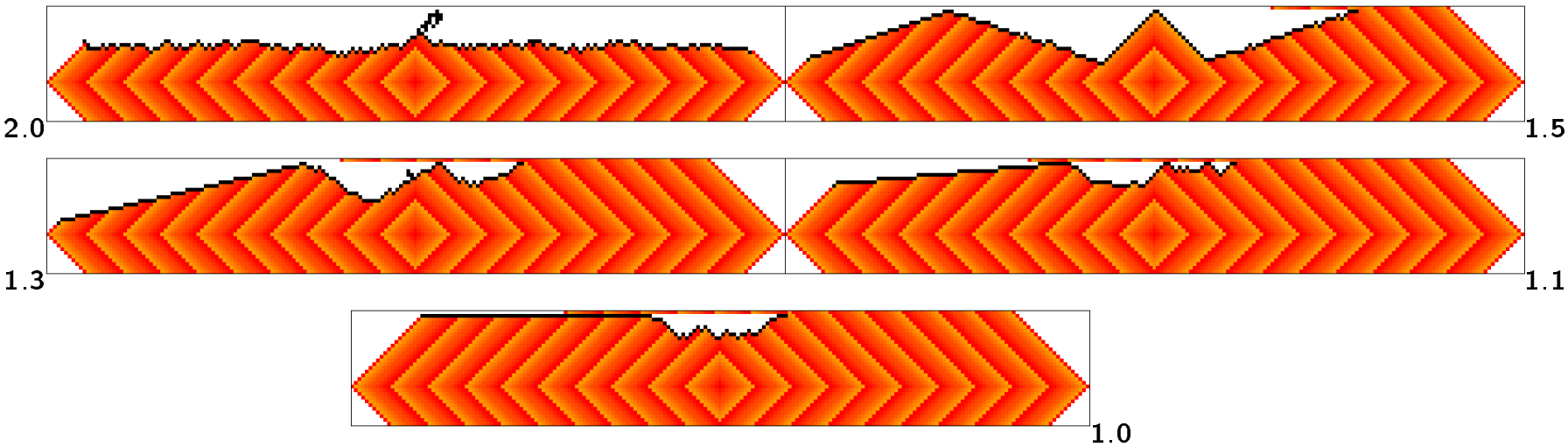
- scattered genome, manual initialization
  $(0, m), (-1, m), (1, m), (-2, m), (2, m), \ldots$



- time to reach highway never improved

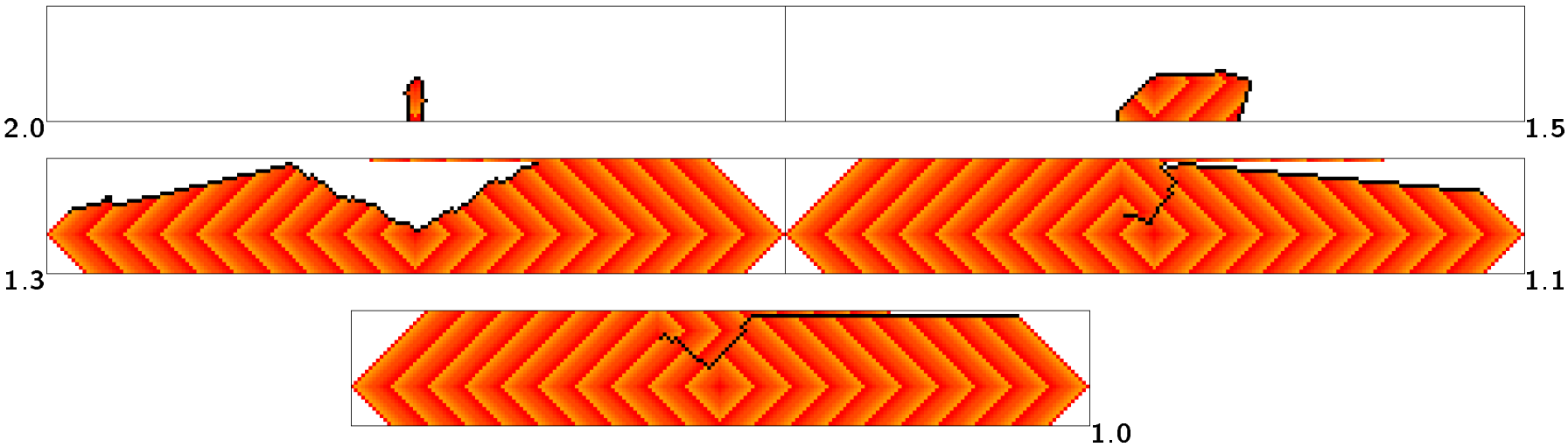
Version 3

- connected genome, random start point



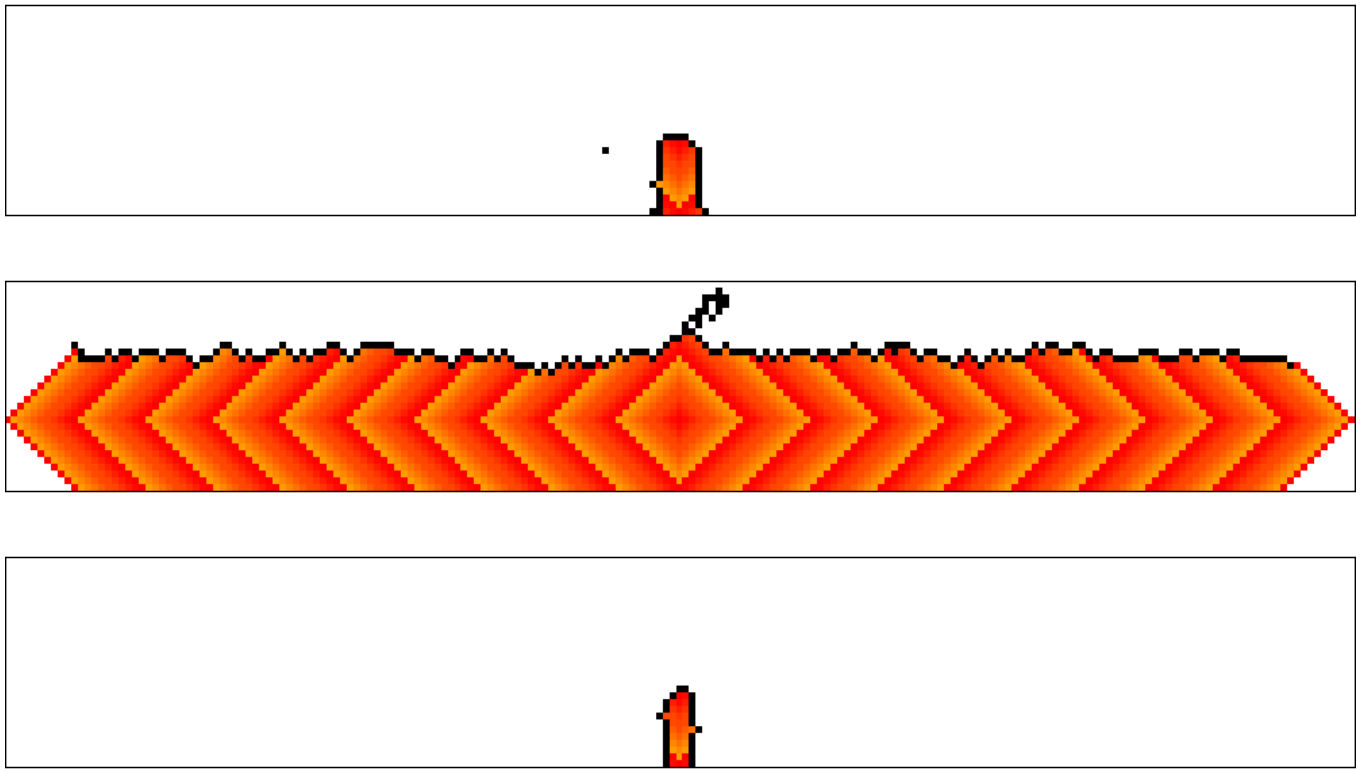
Version 4

- connected genome, start close to outbreak



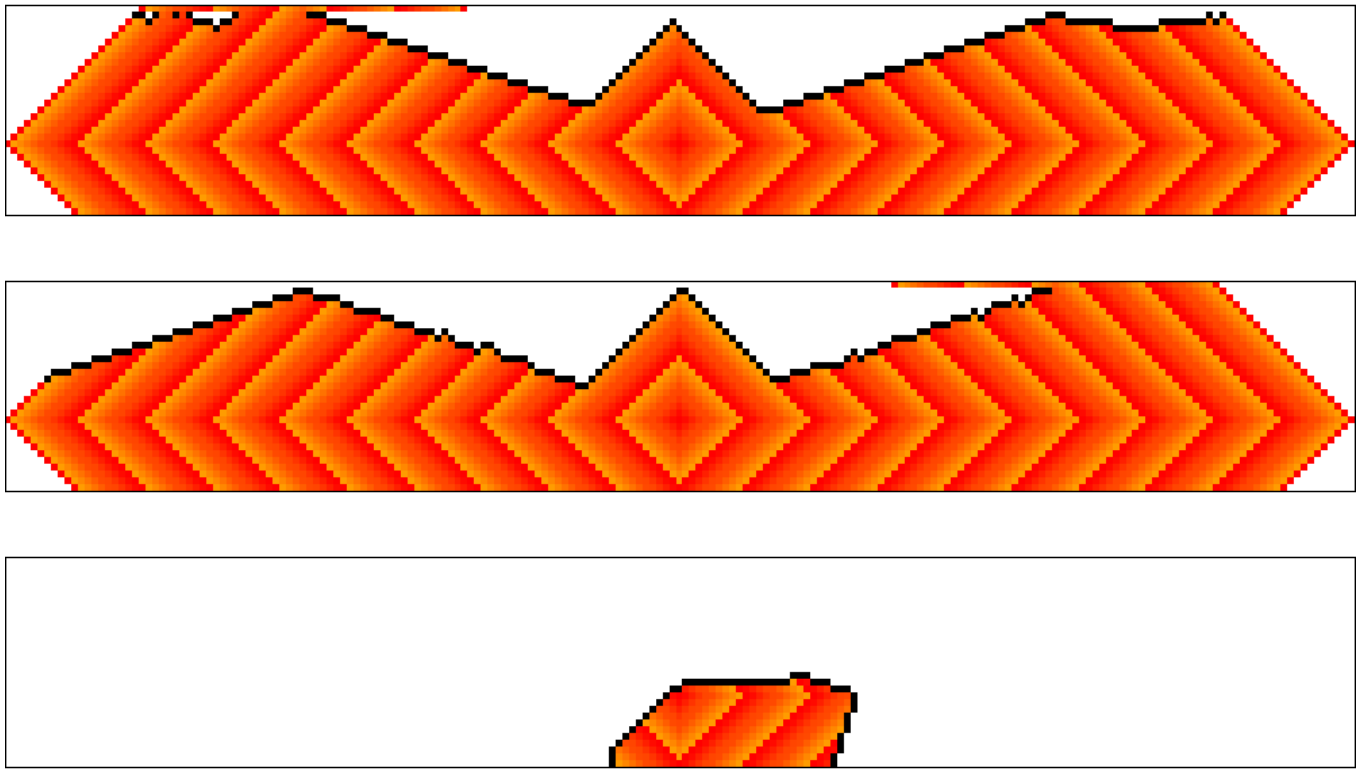
Compare $f = 2.0$

- scattered / connected (rand) / connected (close)



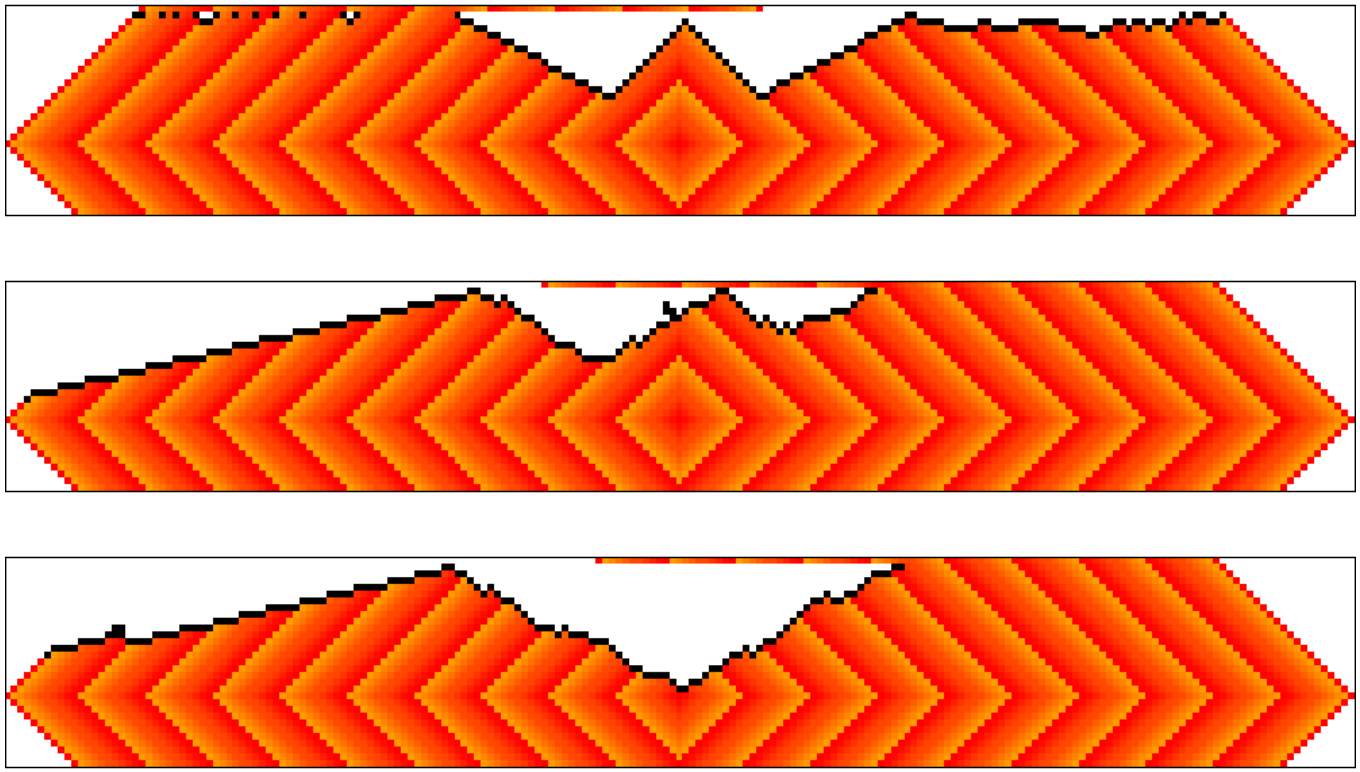
Compare $f = 1.5$

- scattered / connected (rand) / connected (close)



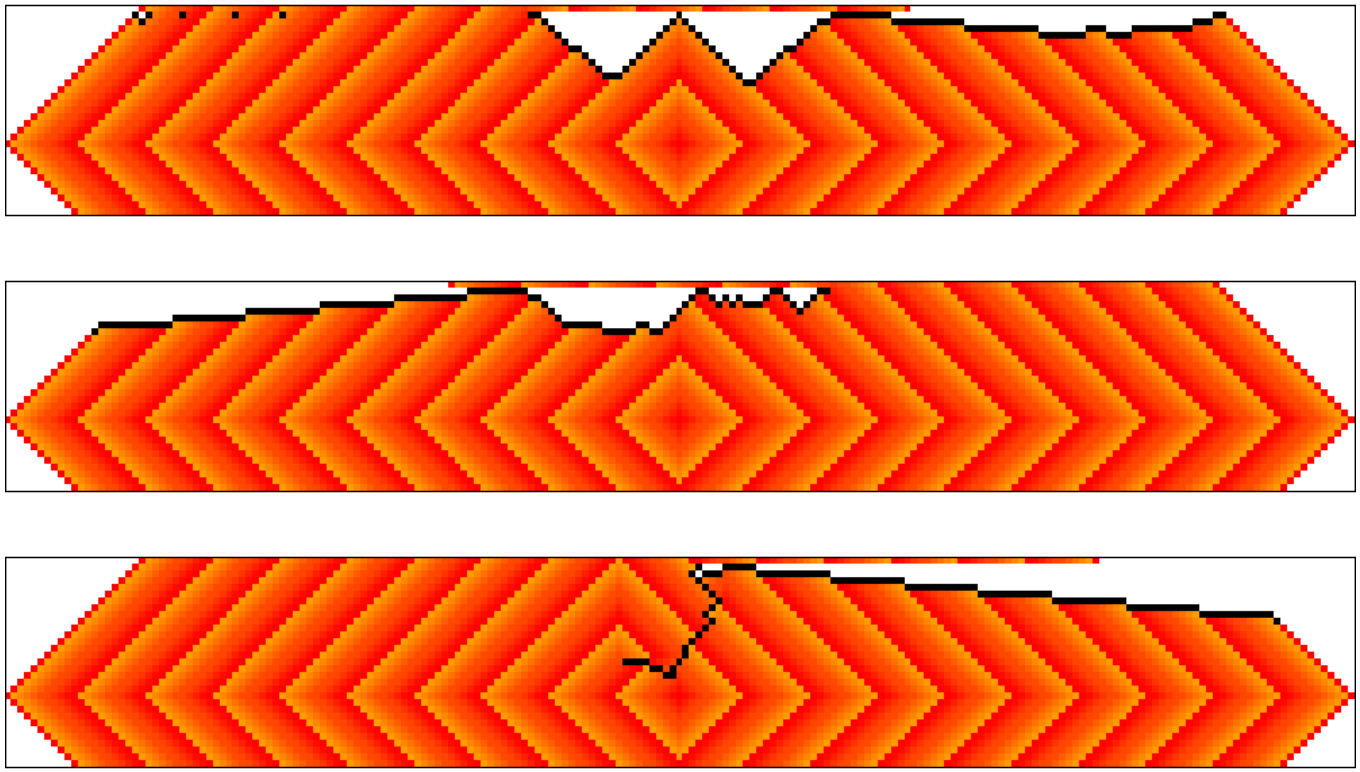
Compare $f = 1.3$

- scattered / connected (rand) / connected (close)



Compare $f = 1.1$

- scattered / connected (rand) / connected (close)



Compare $f = 1.0$

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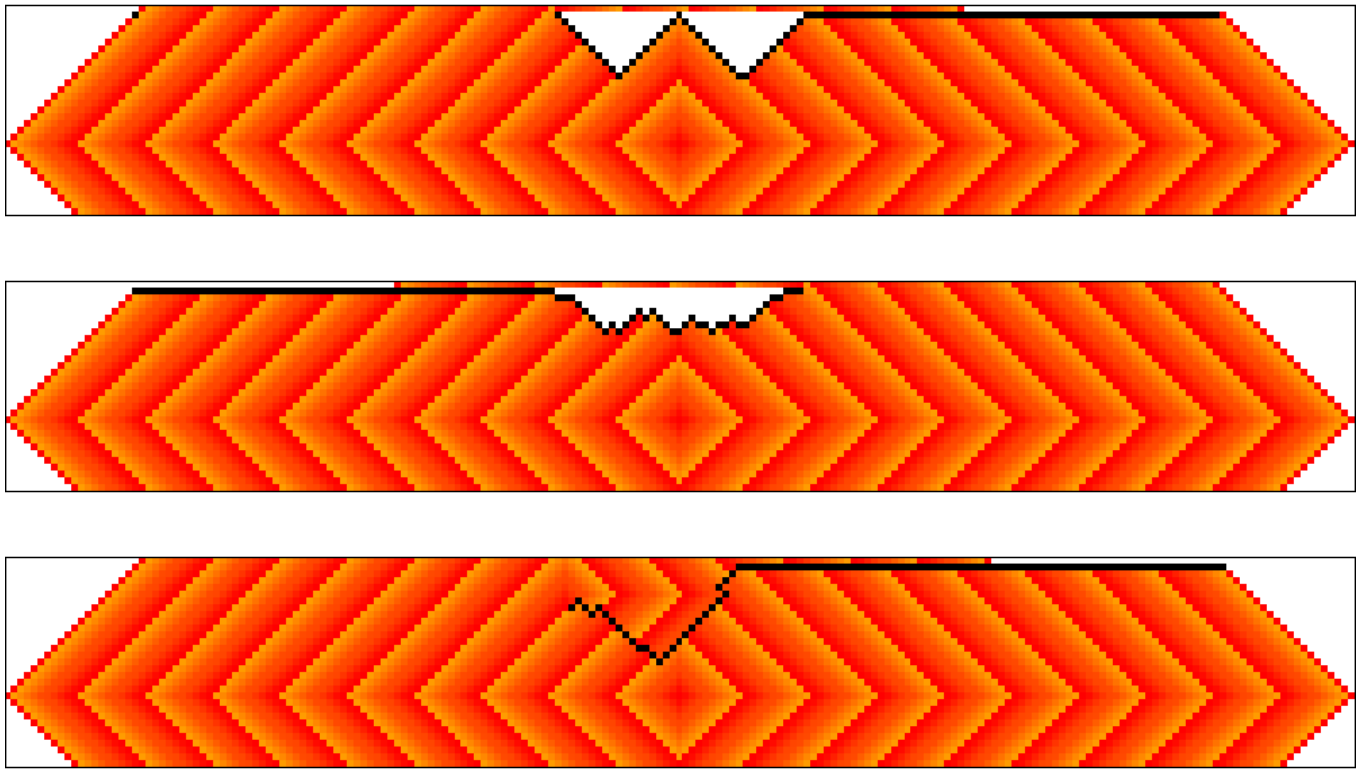


Animations

Lets see some animations

Remaining

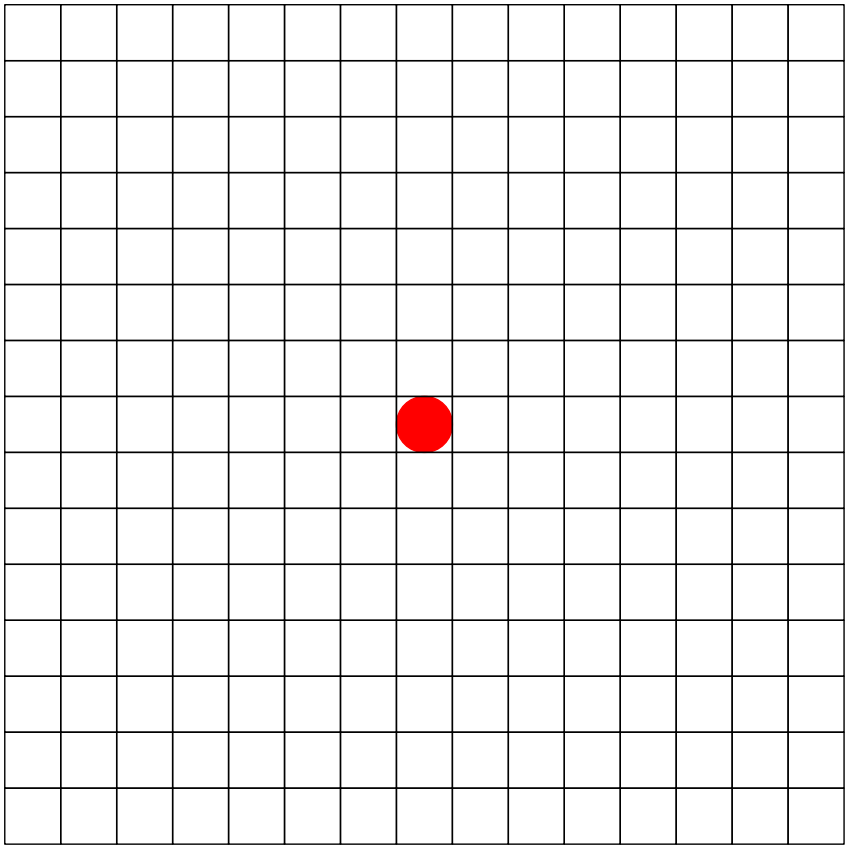
- still a lot of room for experiments
  - different genome
  - different fitness function
- theoretical results
  - possible with $f = 1.5$
  - impossible with $f = 1$, done!
  - possible with $f < 1.5$?

End

Thank you for your attention!

Beginning is critical

- $f = 1$



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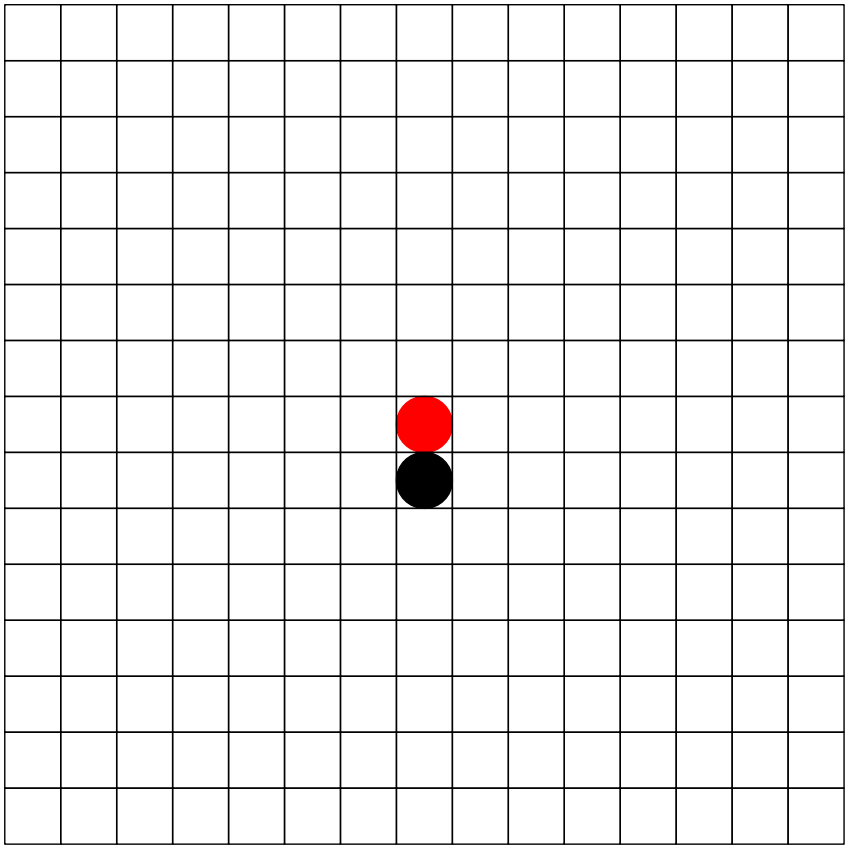

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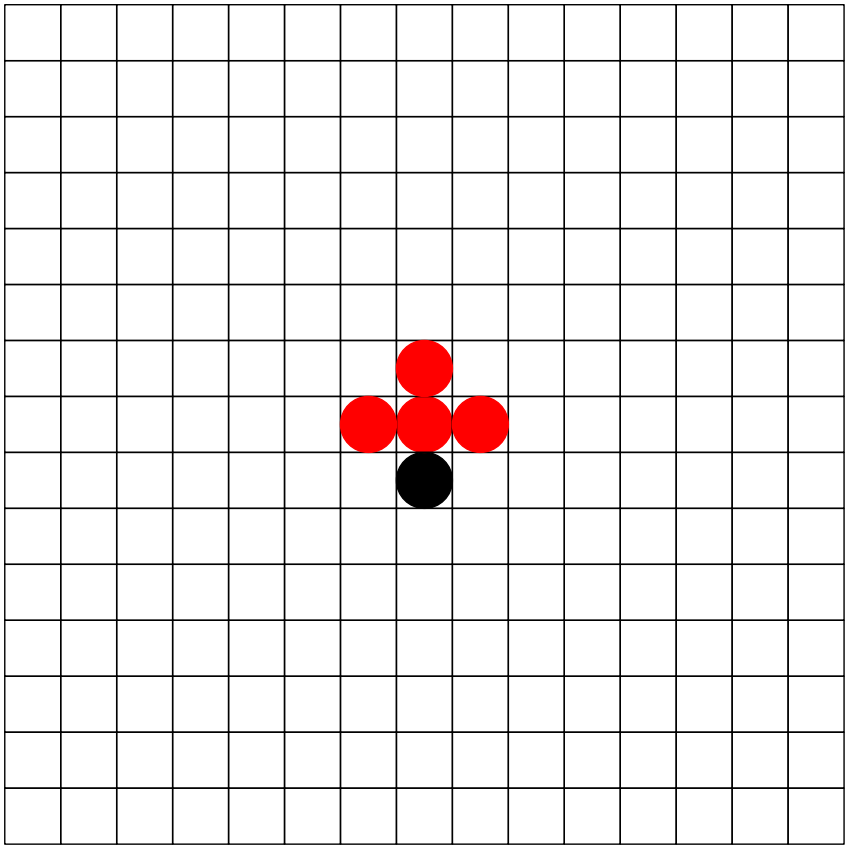

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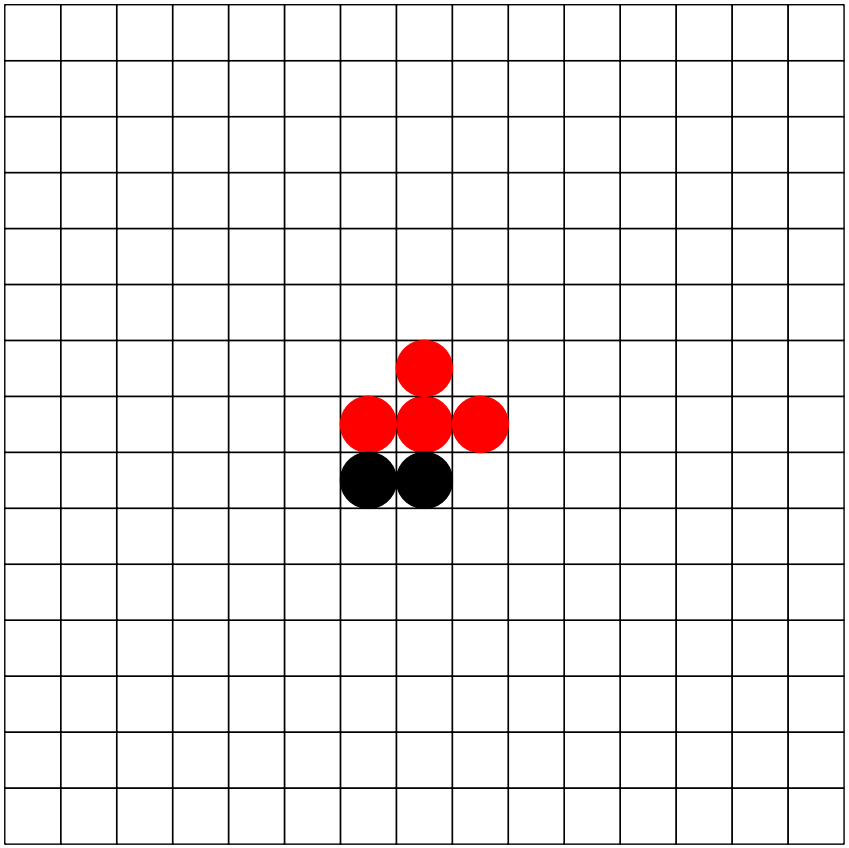

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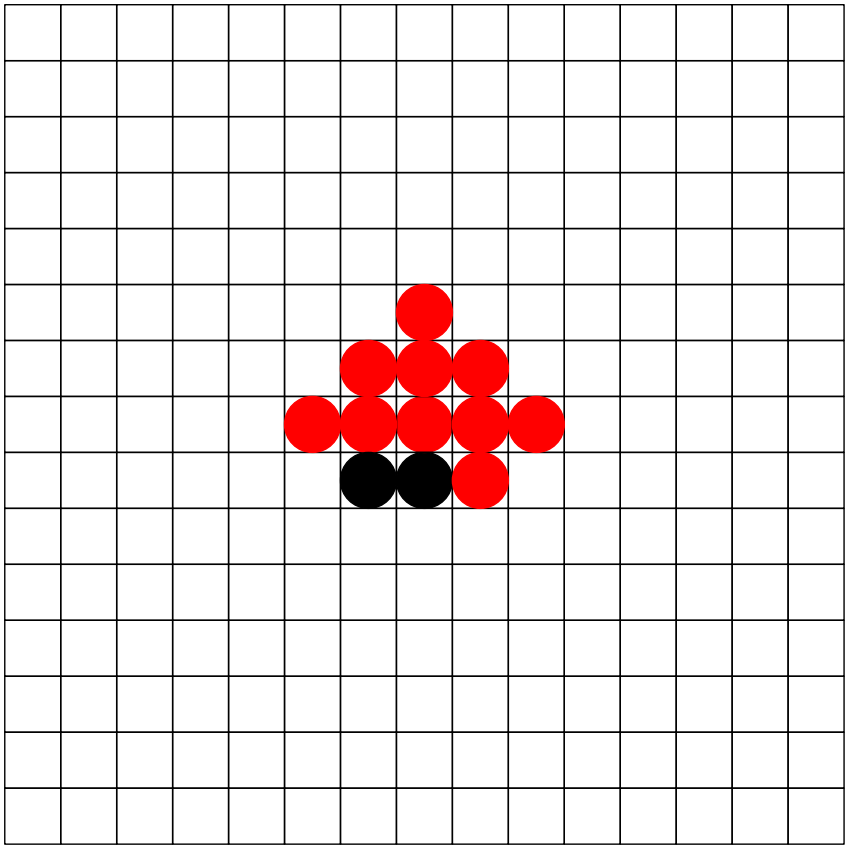

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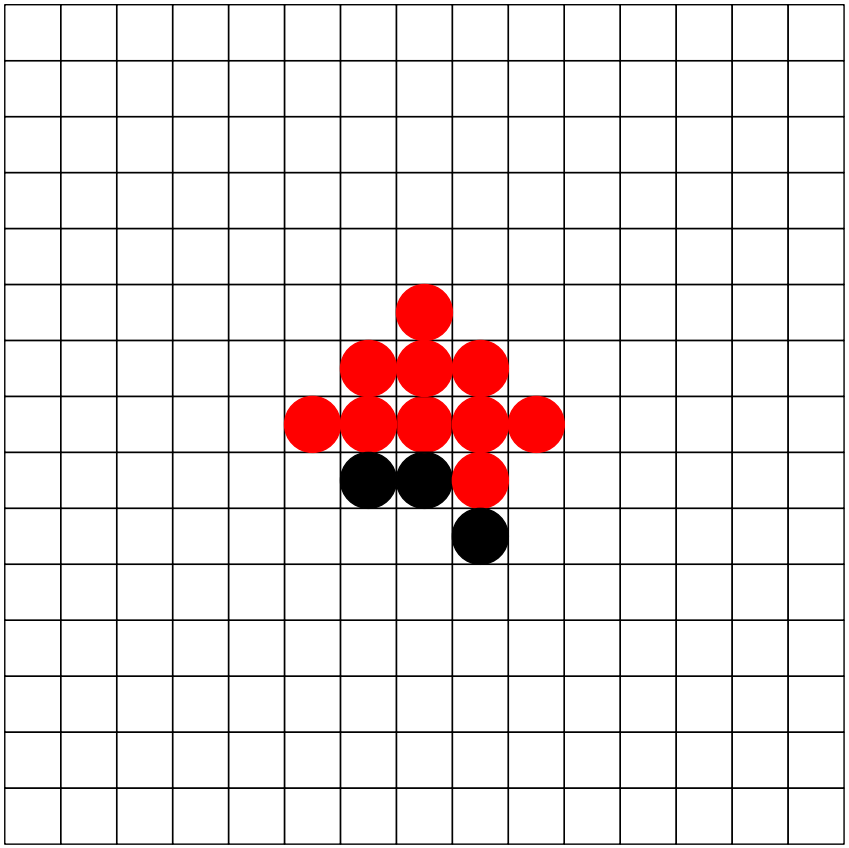

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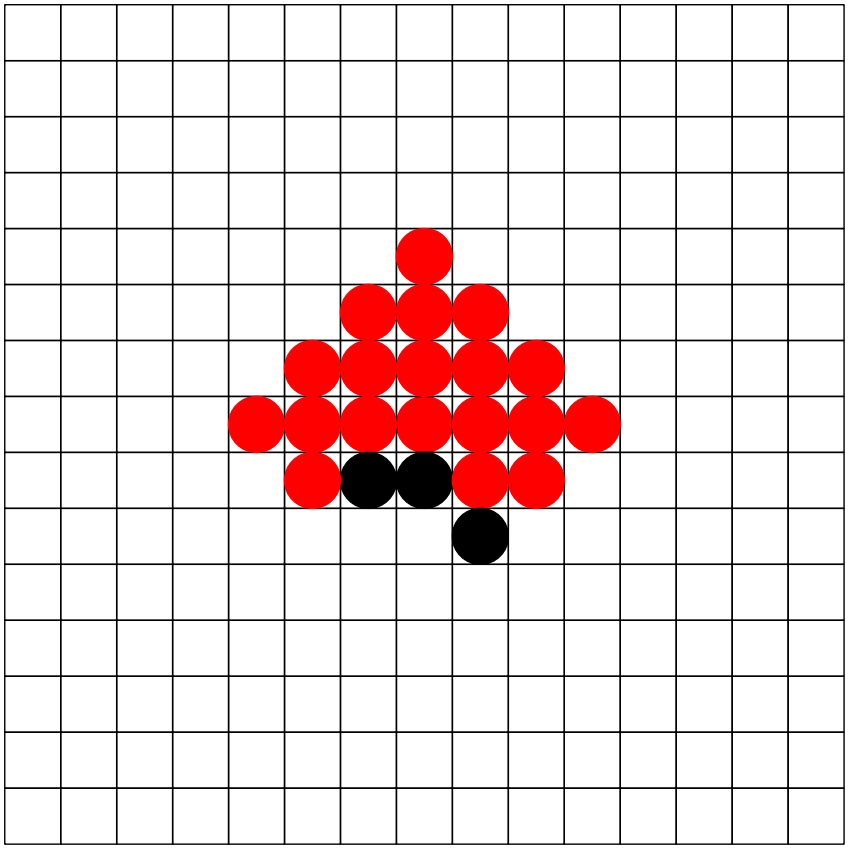

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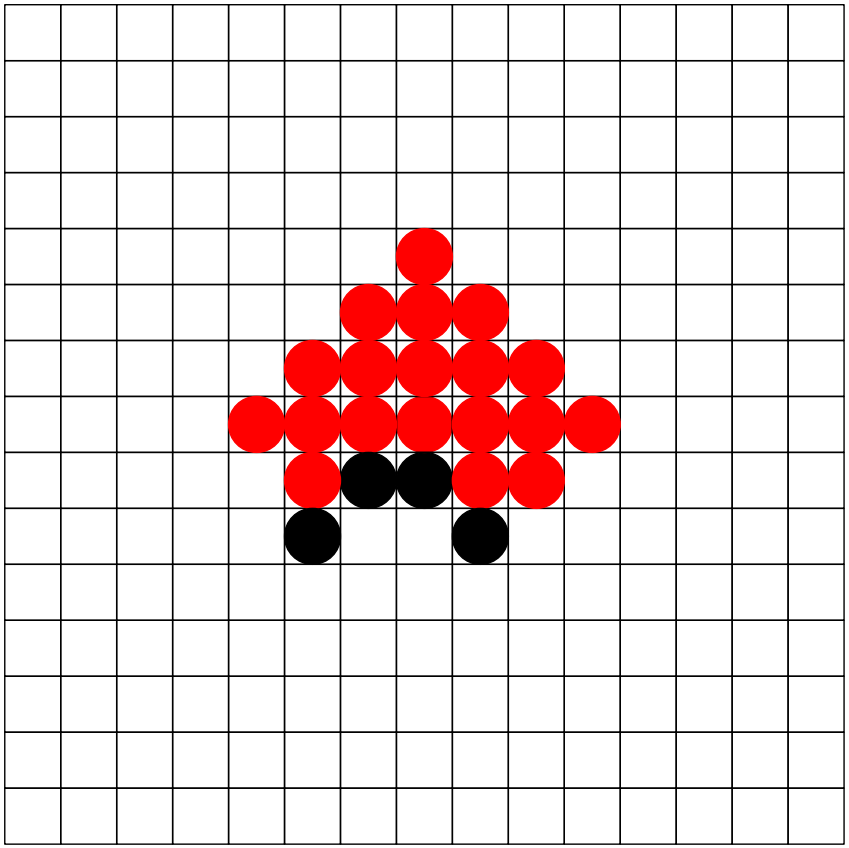

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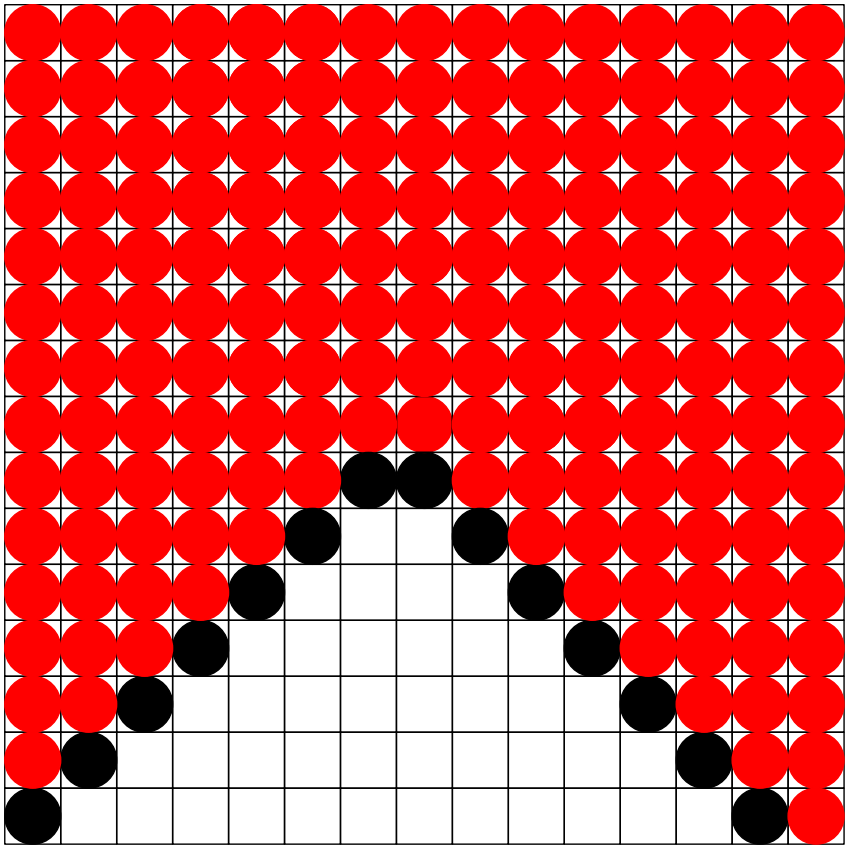
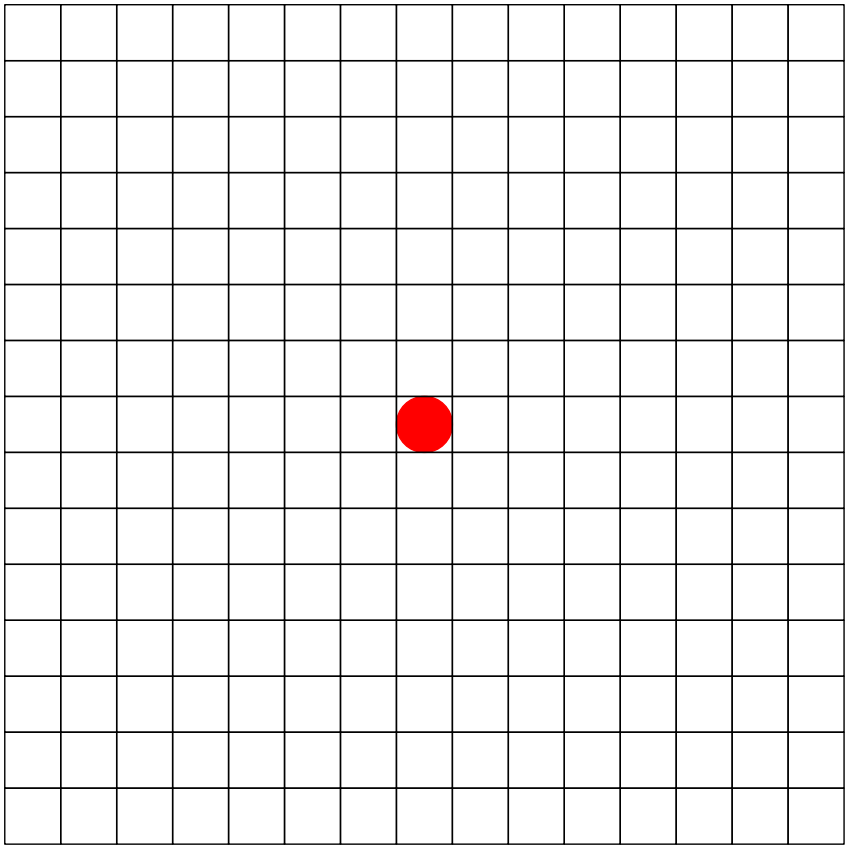


Beginning is critical

- $f = 1$ but start with 2



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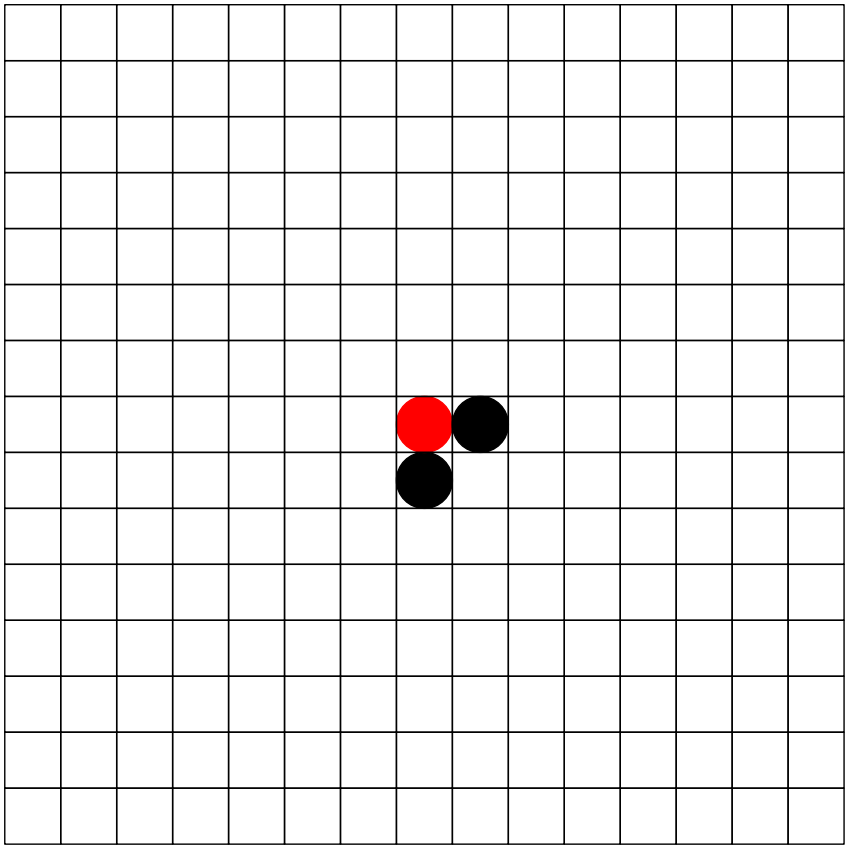

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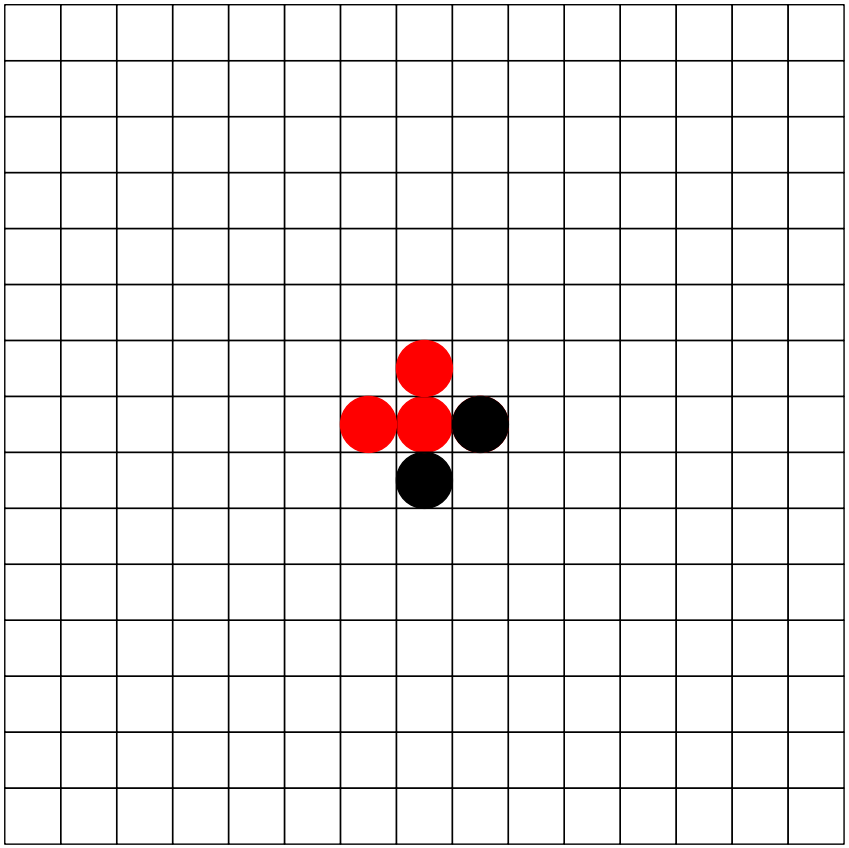
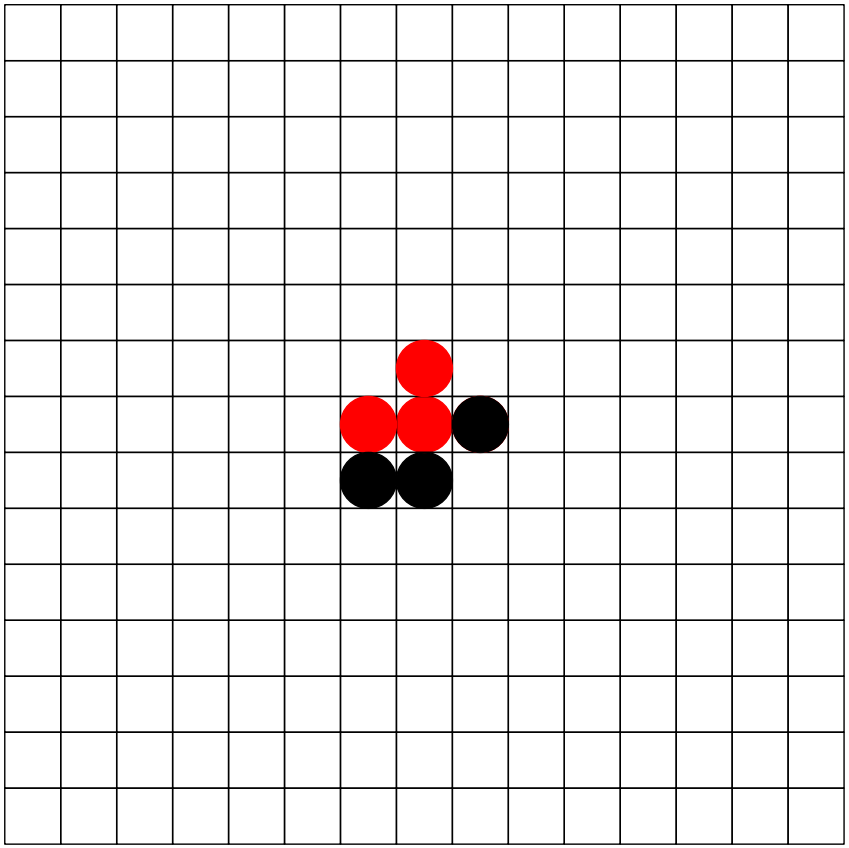


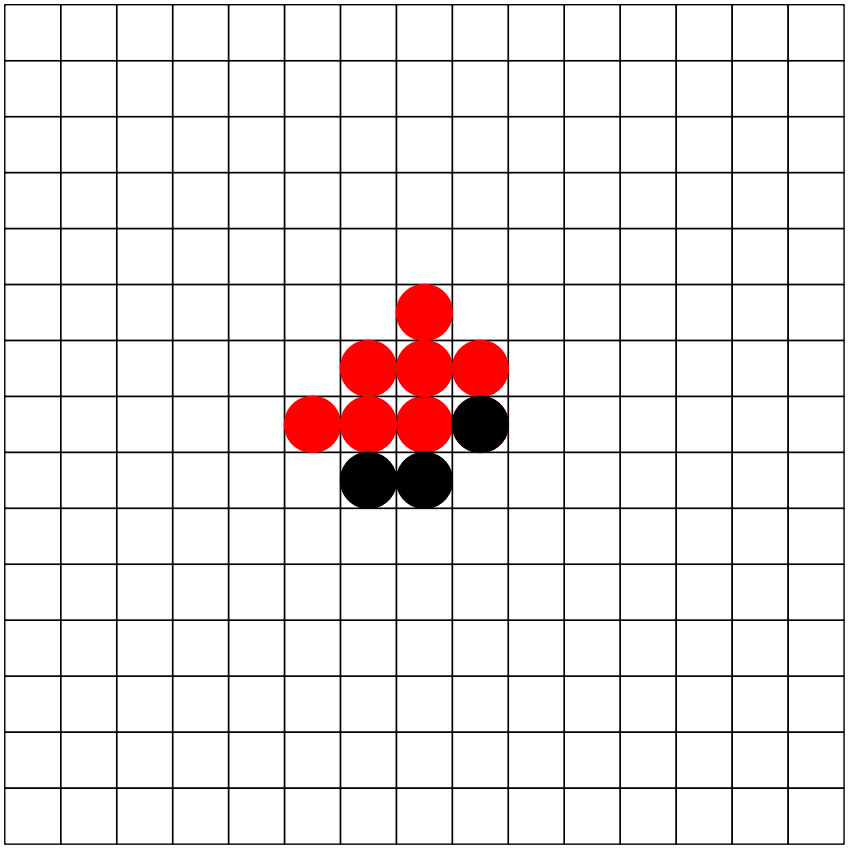
Beginning is critical

- $f = 1$ but start with 2



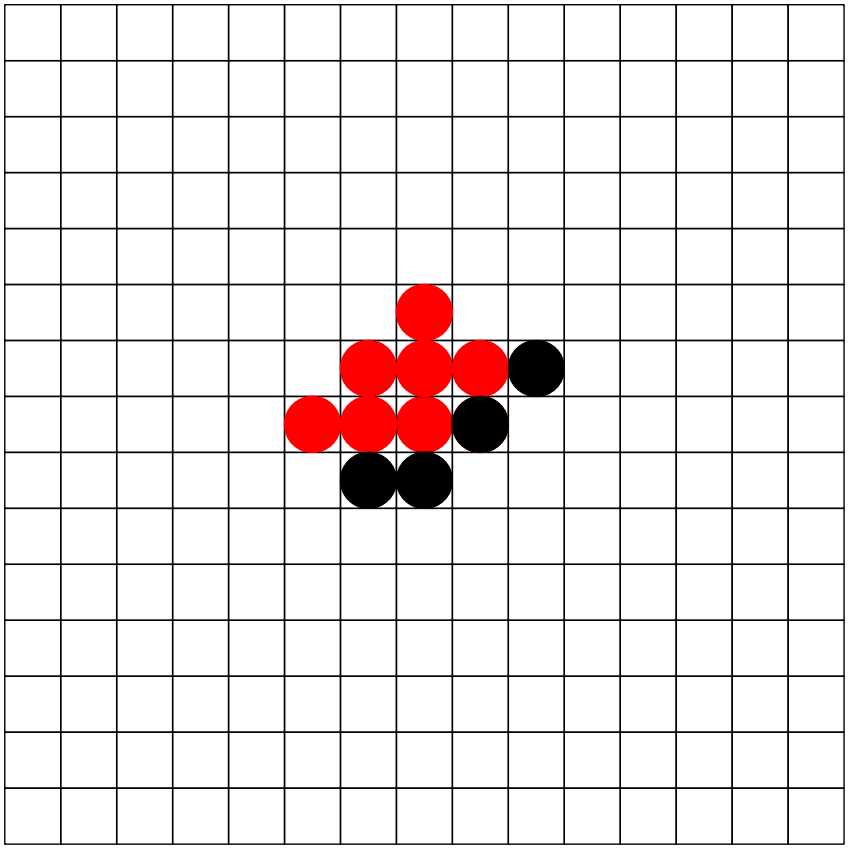
Beginning is critical

- $f = 1$ but start with 2



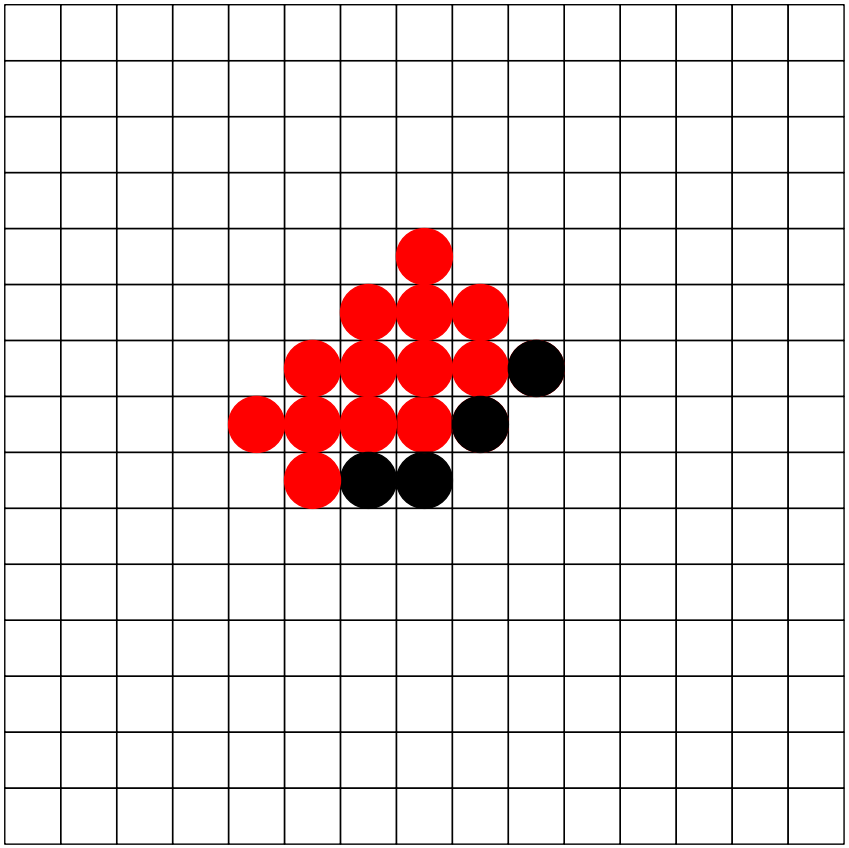
Beginning is critical

- $f = 1$ but start with 2



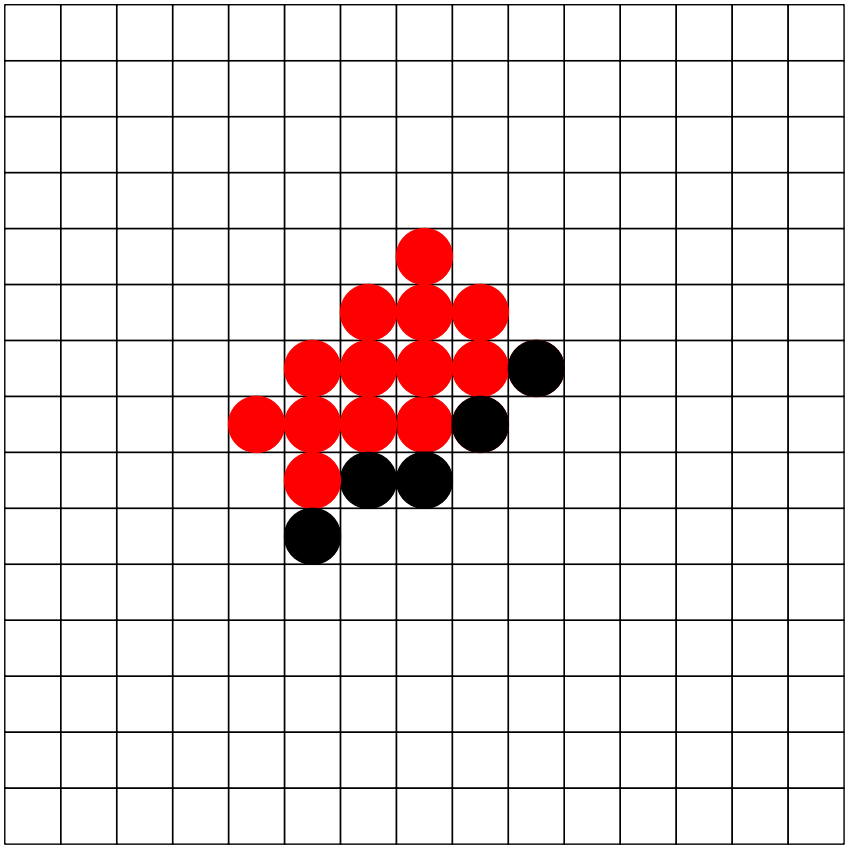
Beginning is critical

- $f = 1$ but start with 2



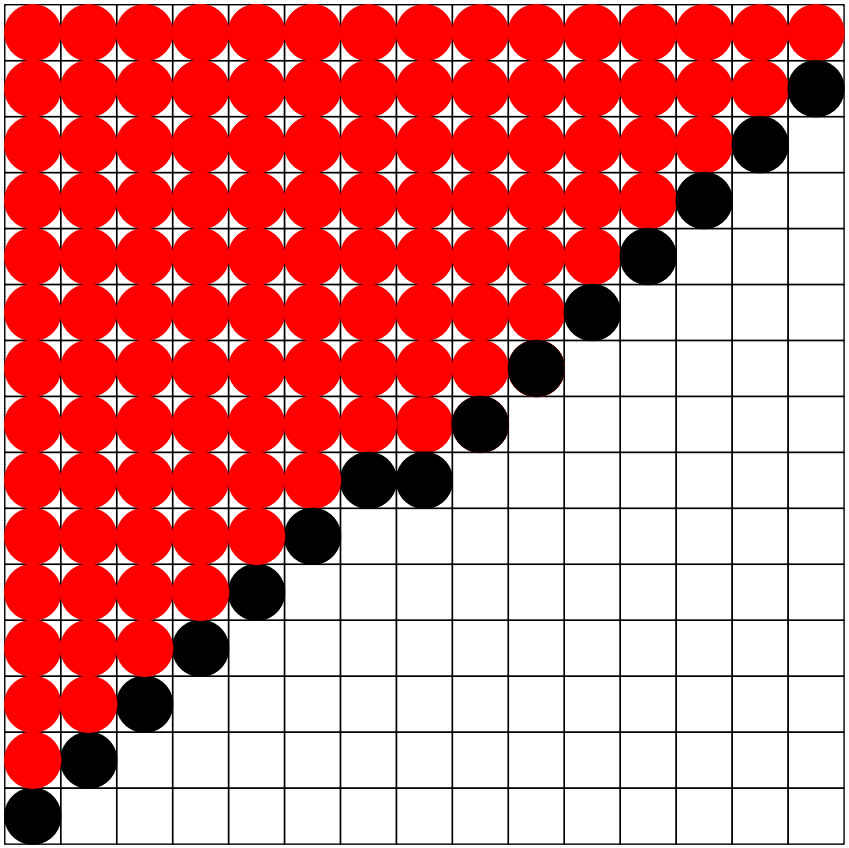
Beginning is critical

- $f = 1$ but start with 2



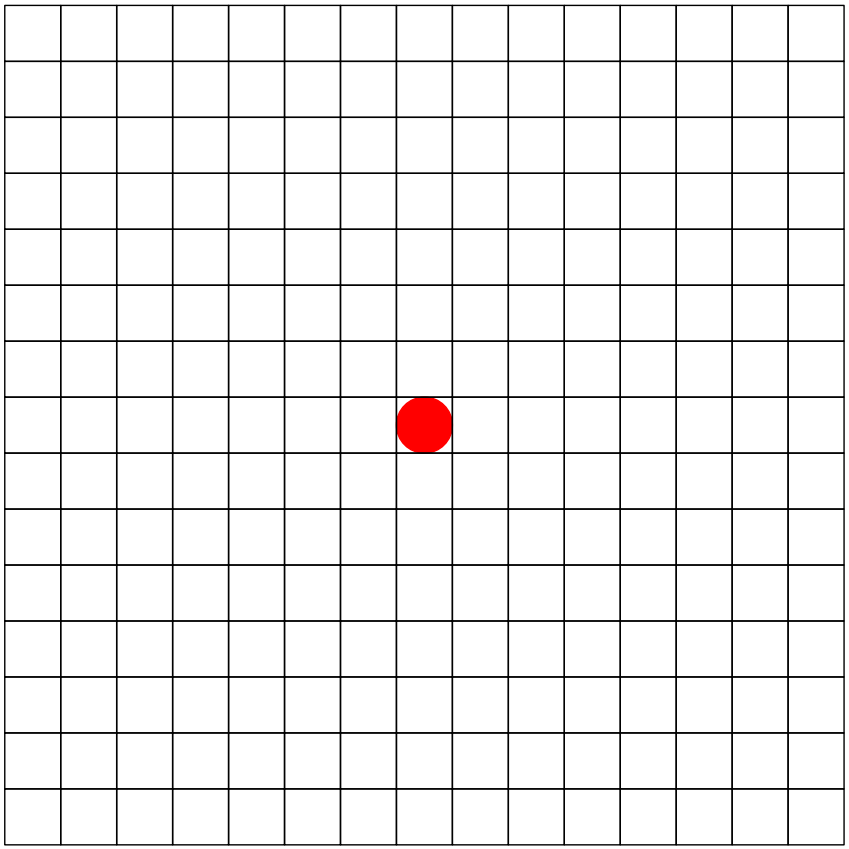
Beginning is critical

- $f = 1$ but start with 2



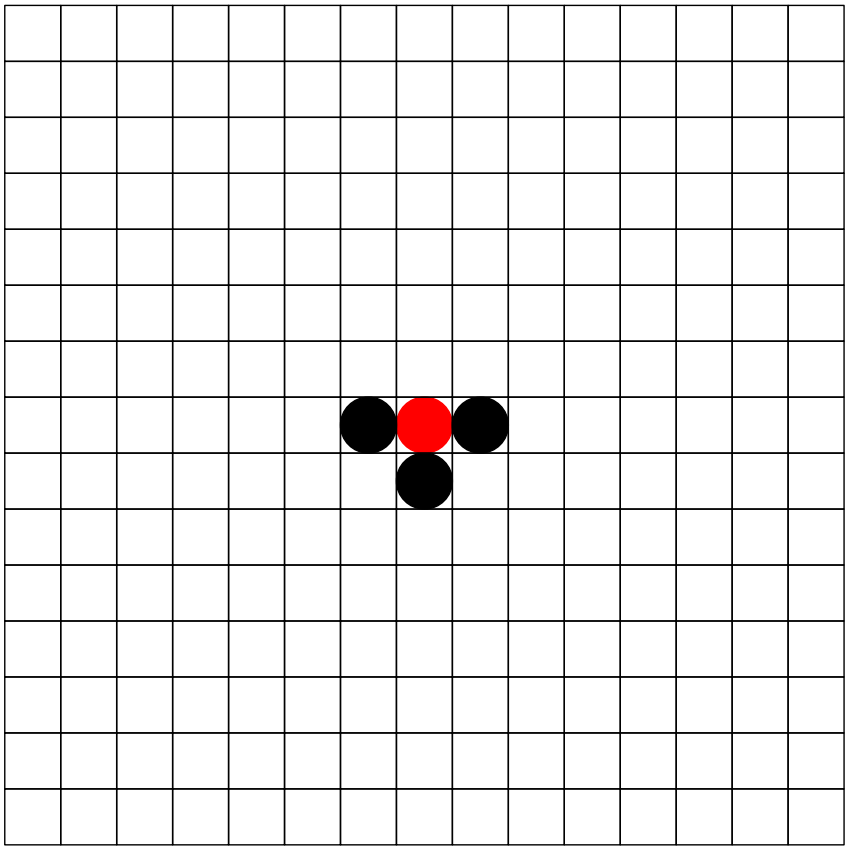
Beginning is critical

- $f = 1$ but start with 3



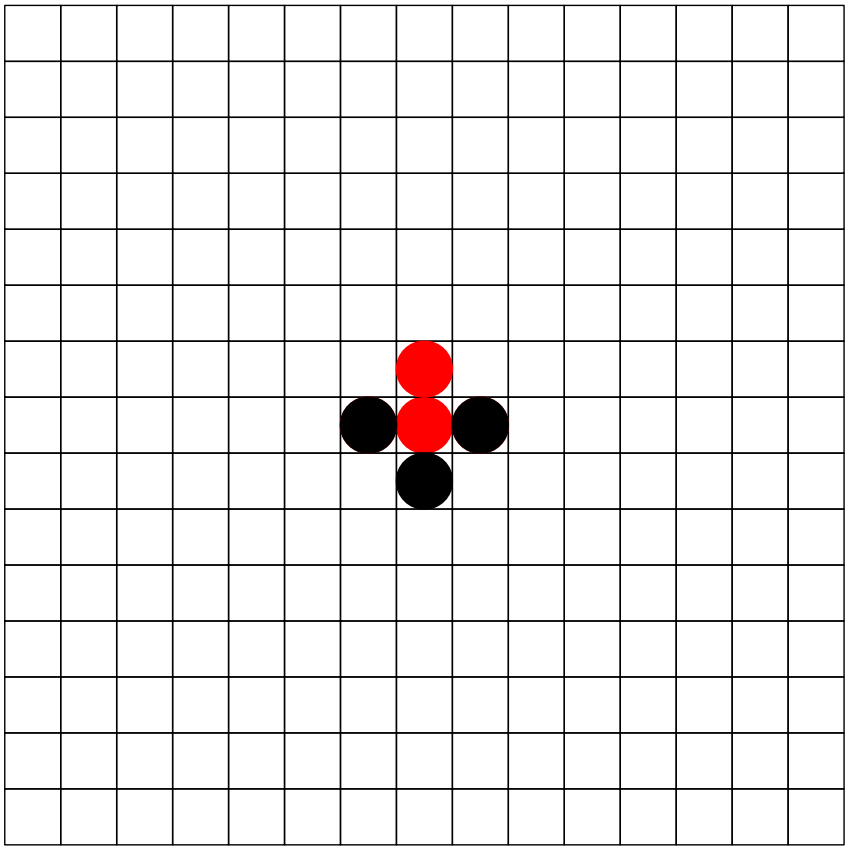
Beginning is critical

- $f = 1$ but start with 3



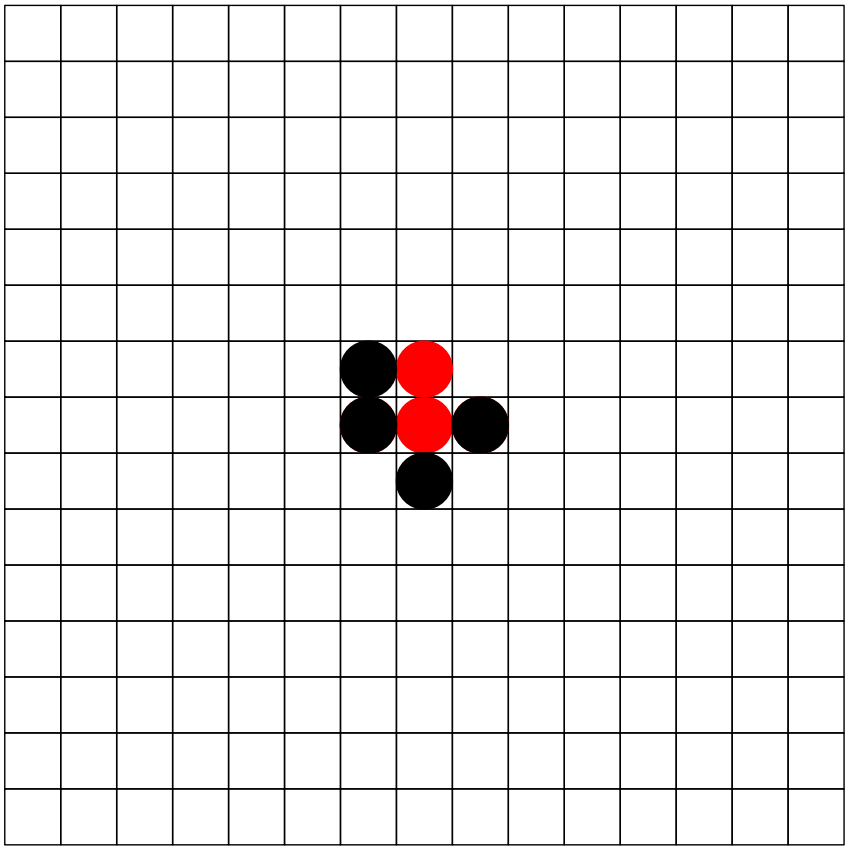
Beginning is critical

- $f = 1$ but start with 3



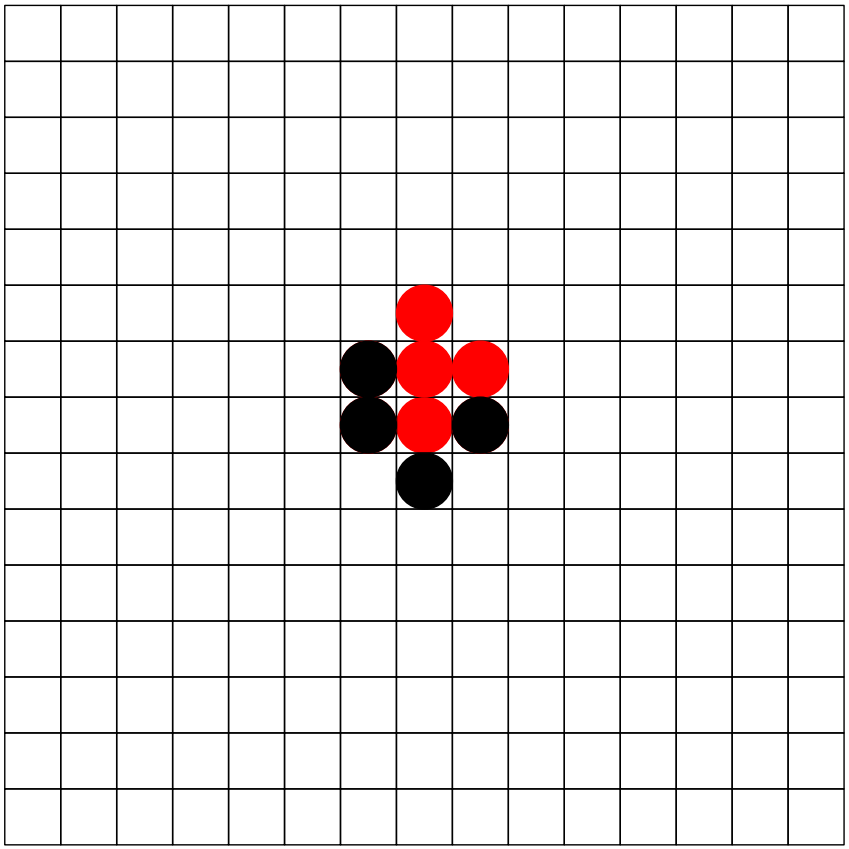
Beginning is critical

- $f = 1$ but start with 3



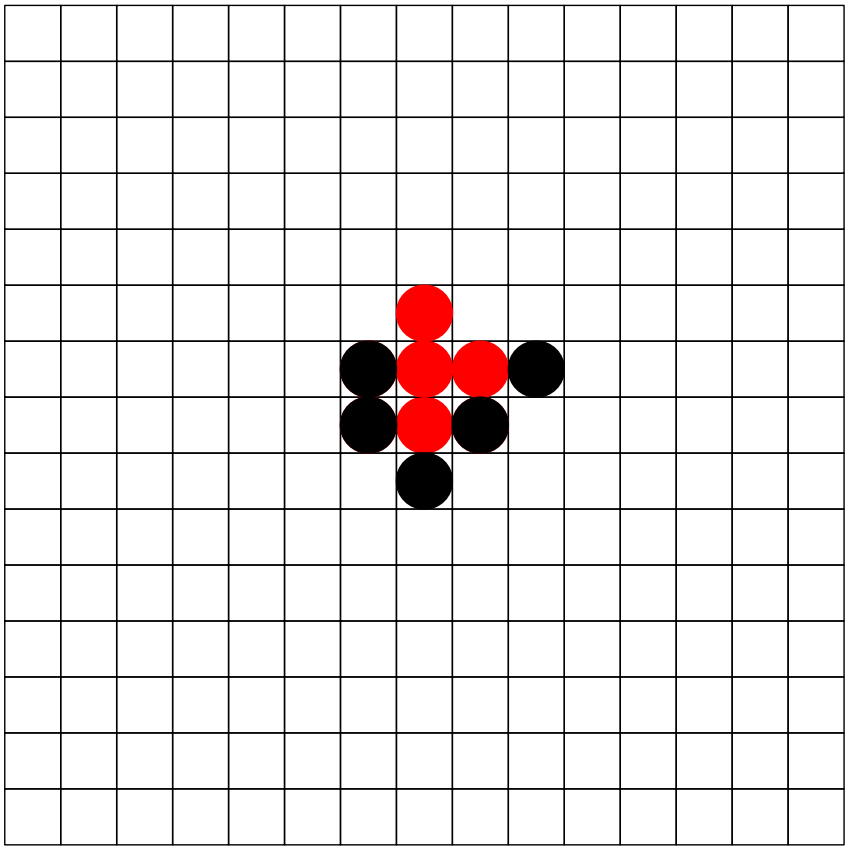
Beginning is critical

- $f = 1$ but start with 3



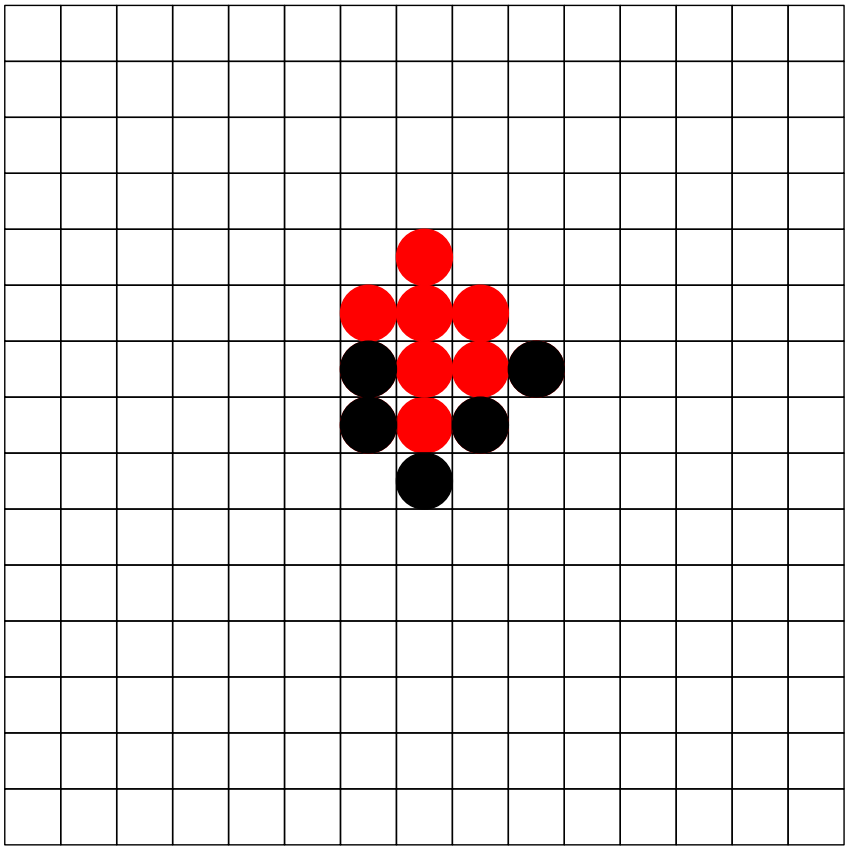
Beginning is critical

- $f = 1$ but start with 3



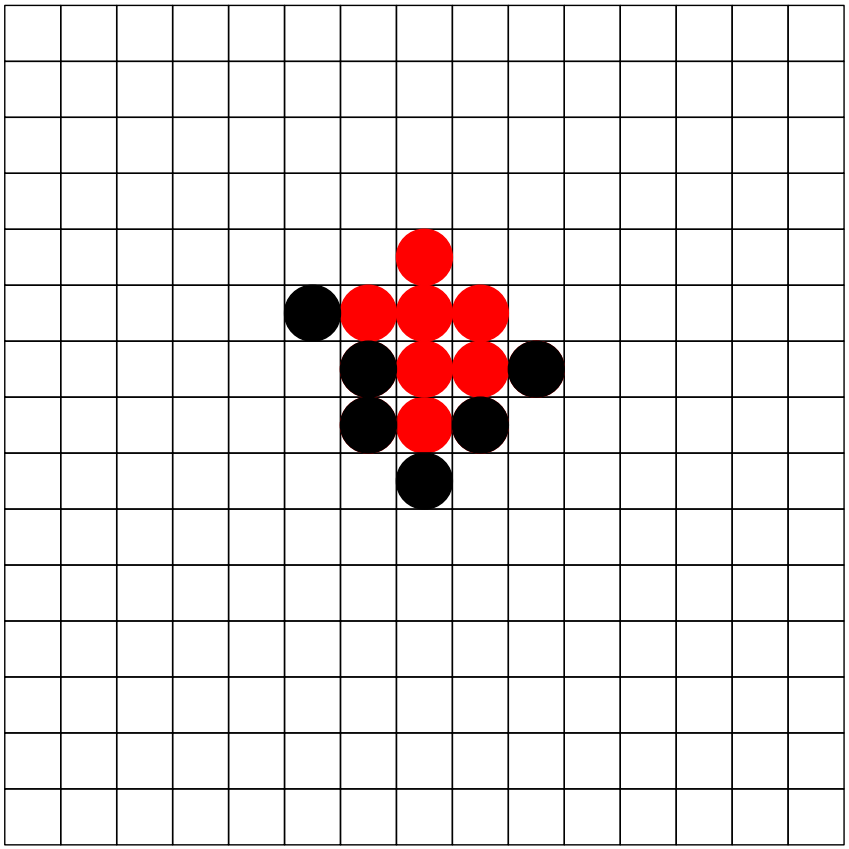
Beginning is critical

- $f = 1$ but start with 3



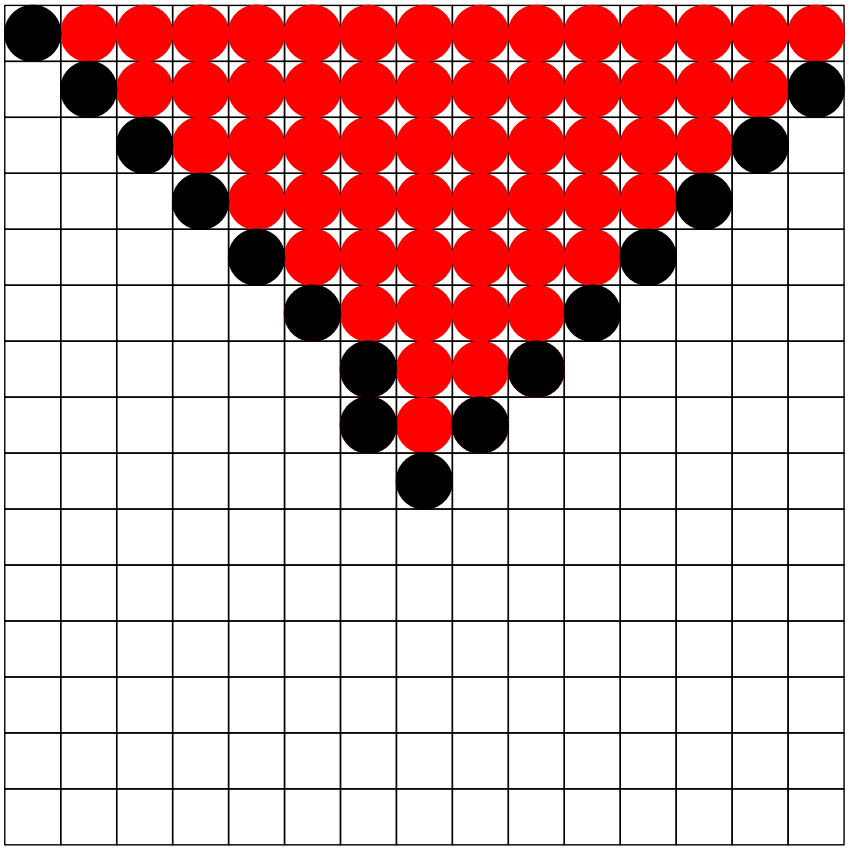
Beginning is critical

- $f = 1$ but start with 3



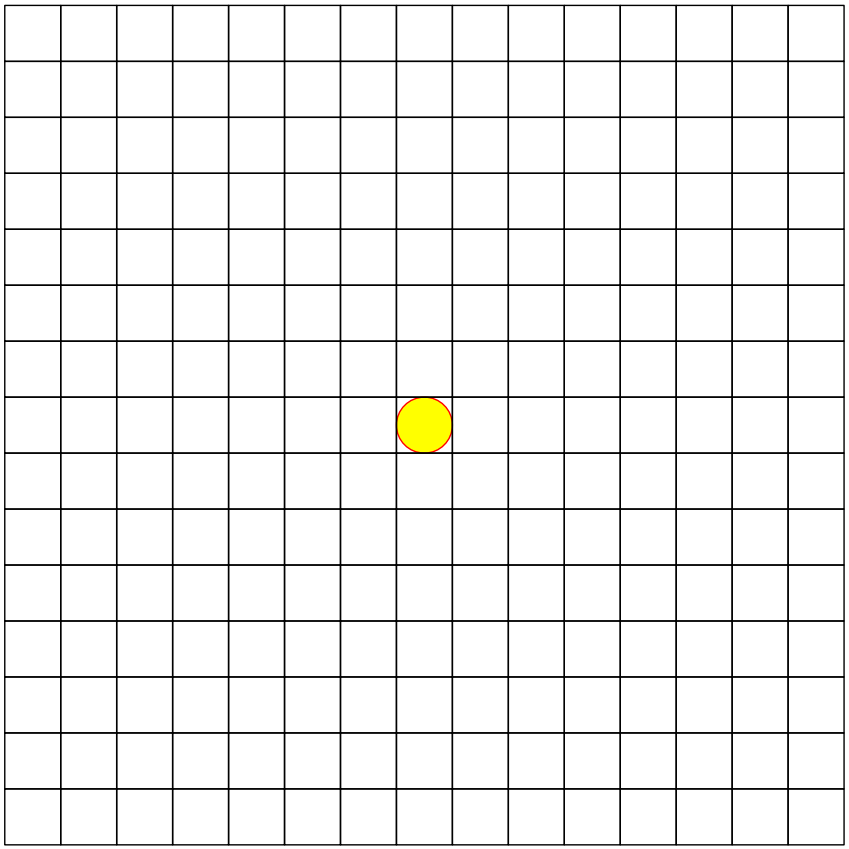
Beginning is critical

- $f = 1$ but start with 3



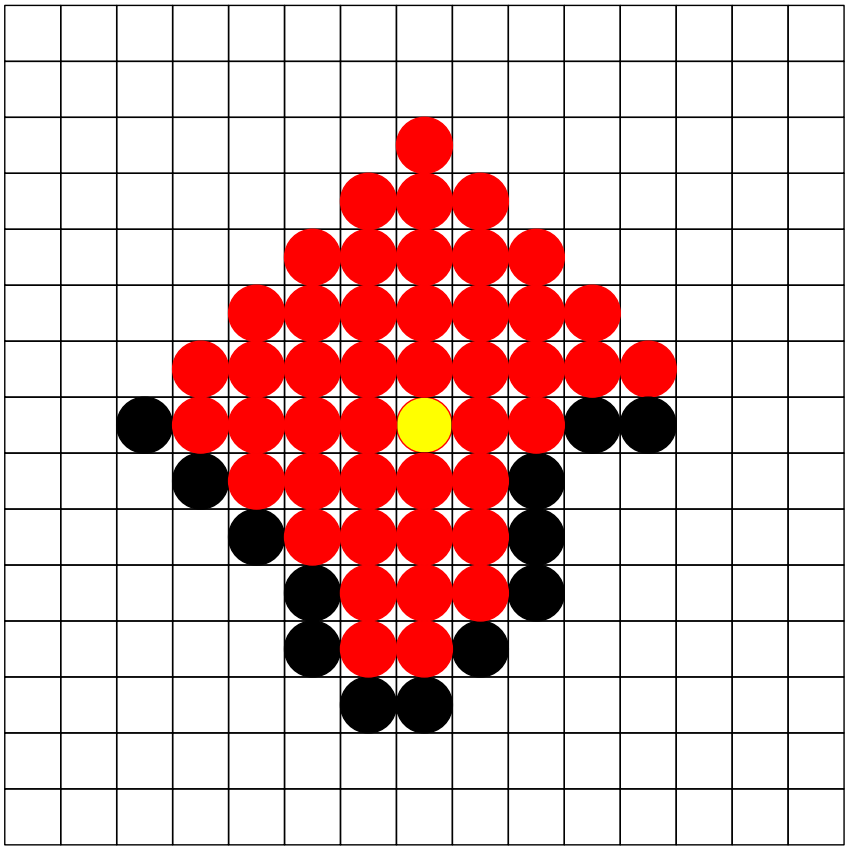
Beginning is critical

- $f = 1$ but first reach level of outbreak



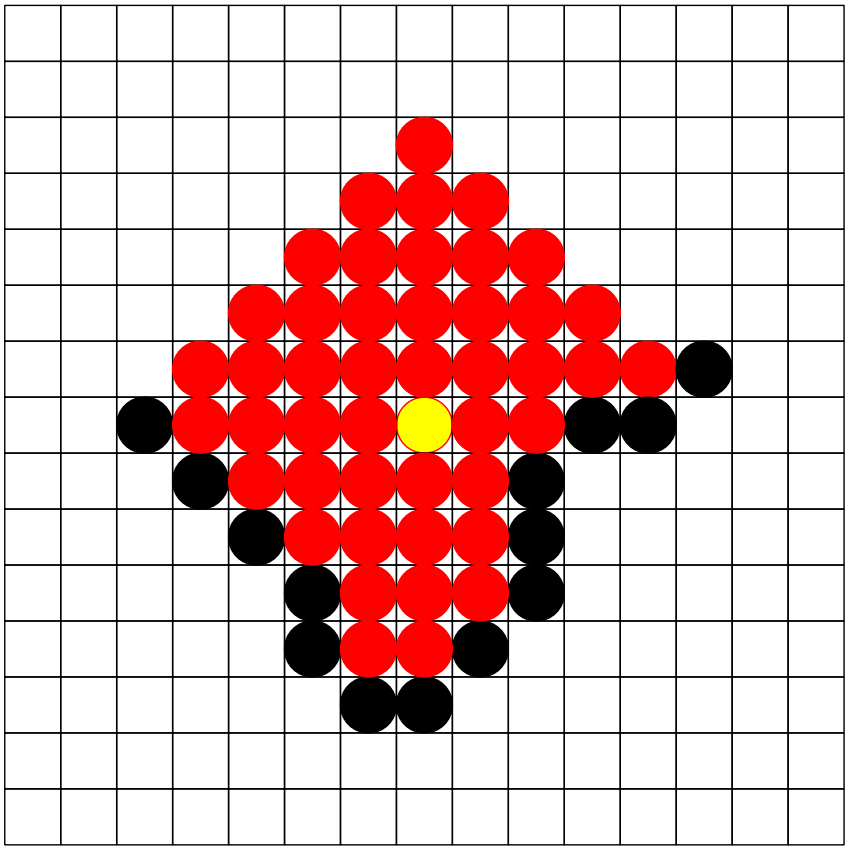
Beginning is critical

- $f = 1$ but first reach level of outbreak



Beginning is critical

- $f = 1$ but first reach level of outbreak



Beginning is critical

- $f = 1$ but first reach level of outbreak