EGU22-8122
EGU General Assembly 2022

A Genetic Algorithm Approach to Infer Jupiter's Rossby Wave Structure from JunoCam Images

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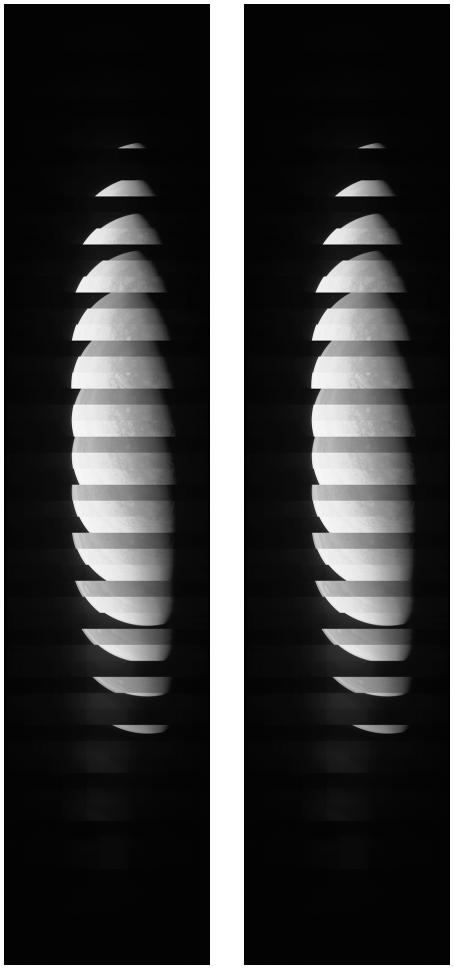
We derive a vorticity map from a pair of raw JunoCam images.

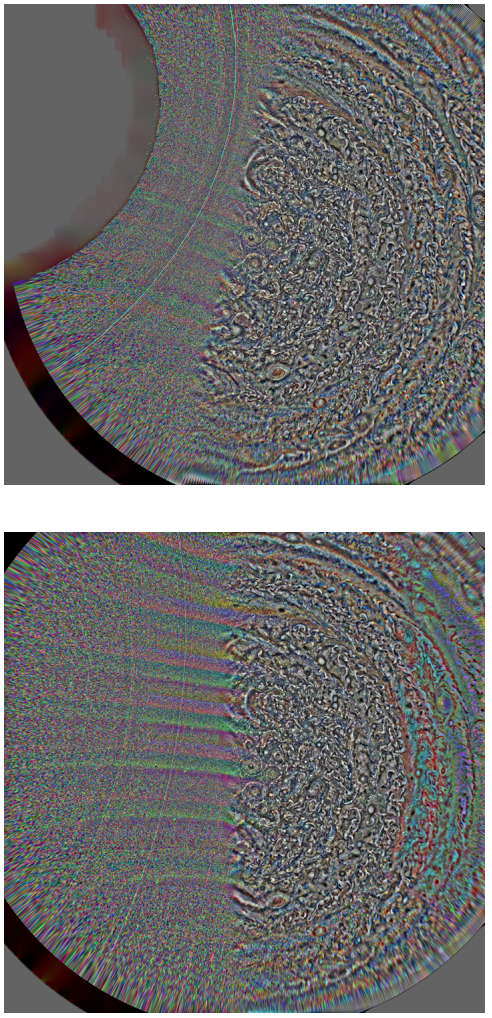
Method: Map projection followed by stereo correspondence.



raw JunoCam images
(PJ19: #09, #21)

map projection

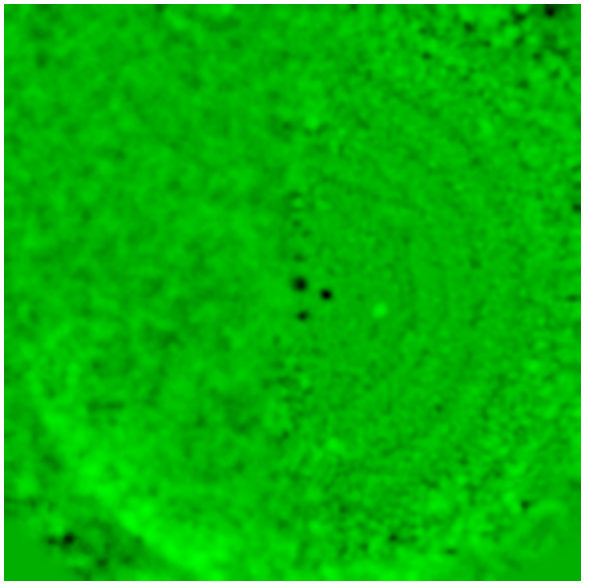
smart high-passing



polar map projections
high-passed, contrast-normalized

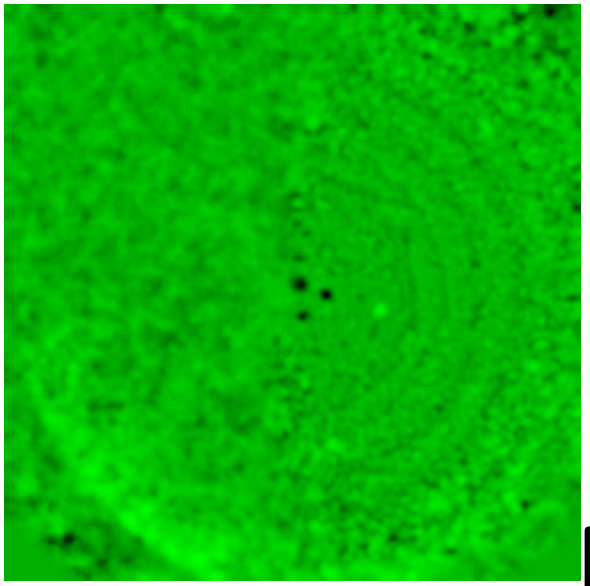
stereo correspon-dence

rotation component only

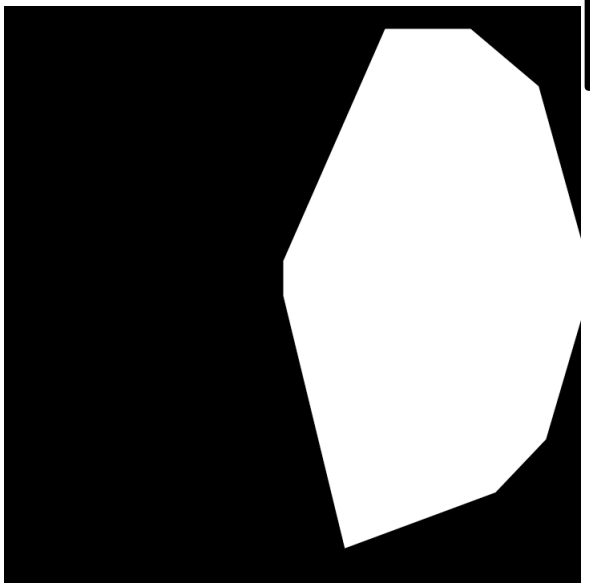


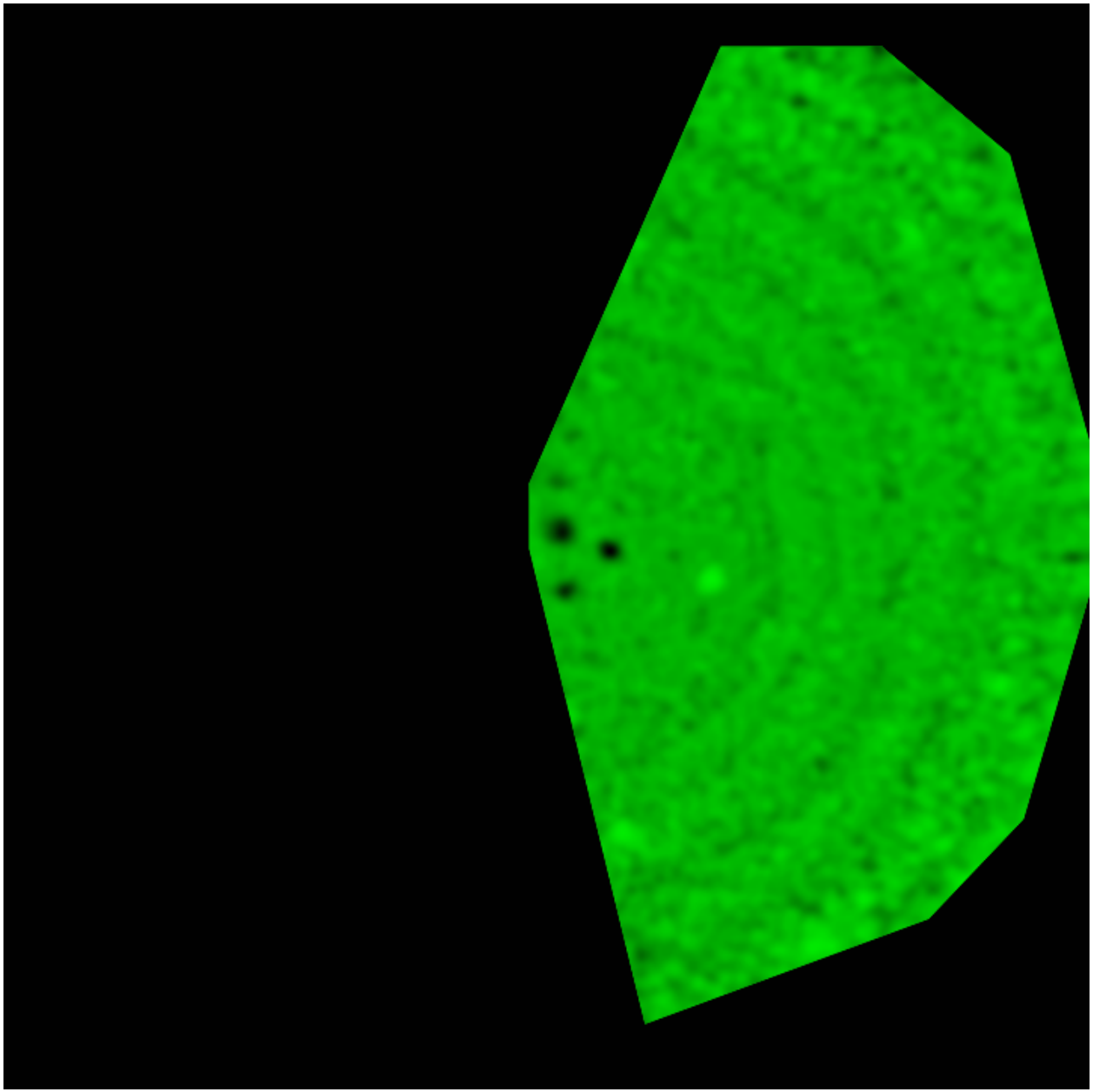
map of local rotation
~ relative vorticity

Clip vorticity data to valid area

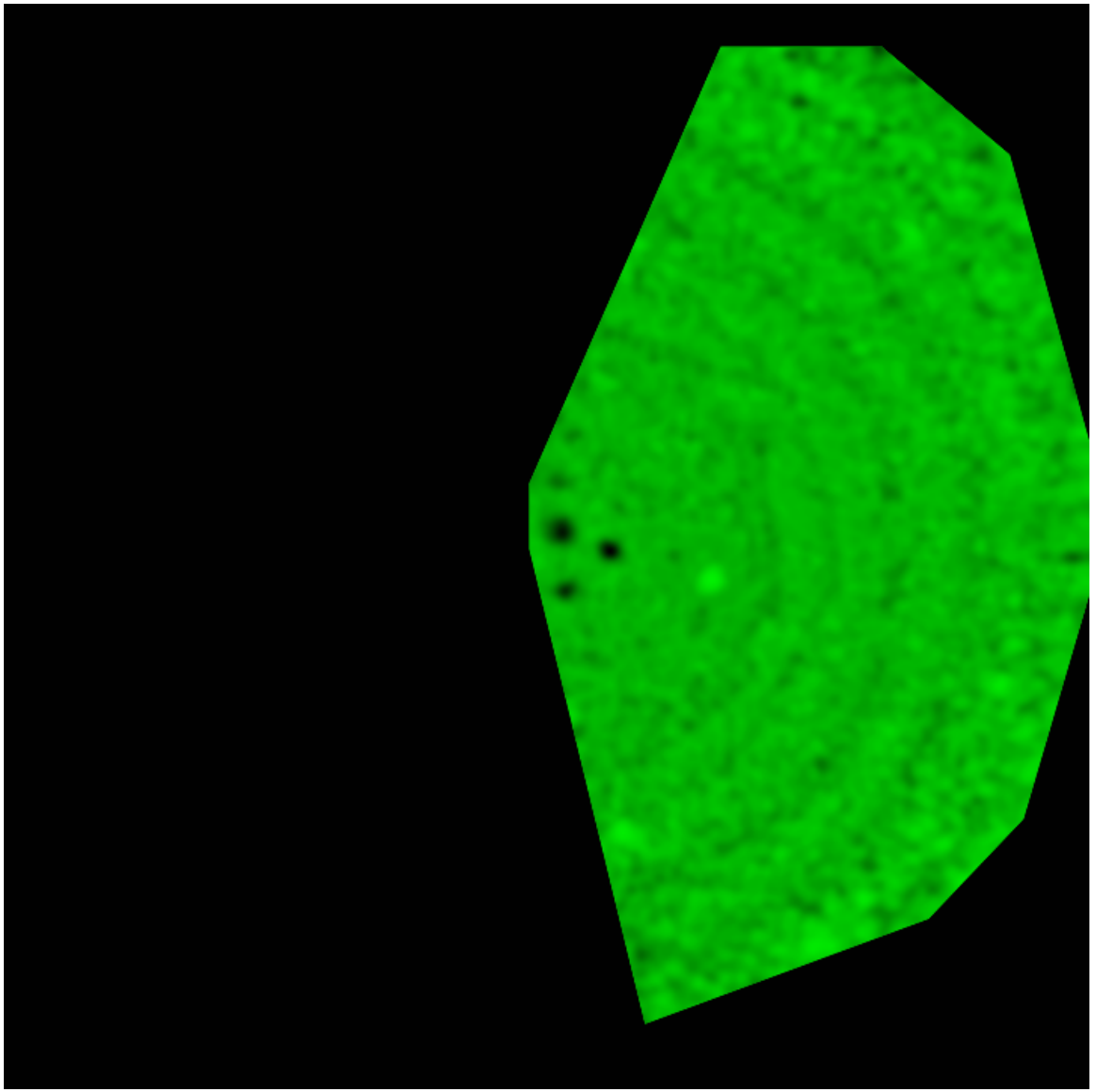


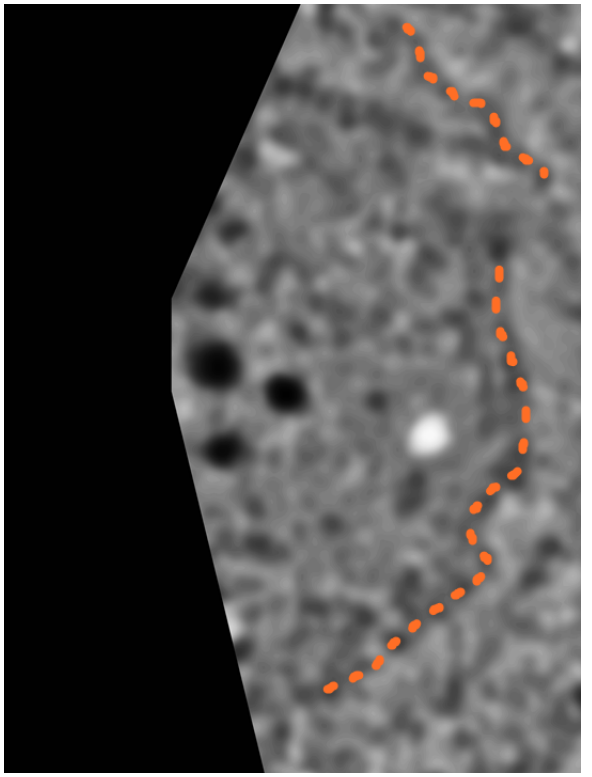
clip with mask





If I could ask a computer about Rossby waves in this vorticity map, what would be its answer?





?

If I could ask a computer about Rossby waves in this vorticity map, what would be its answer?

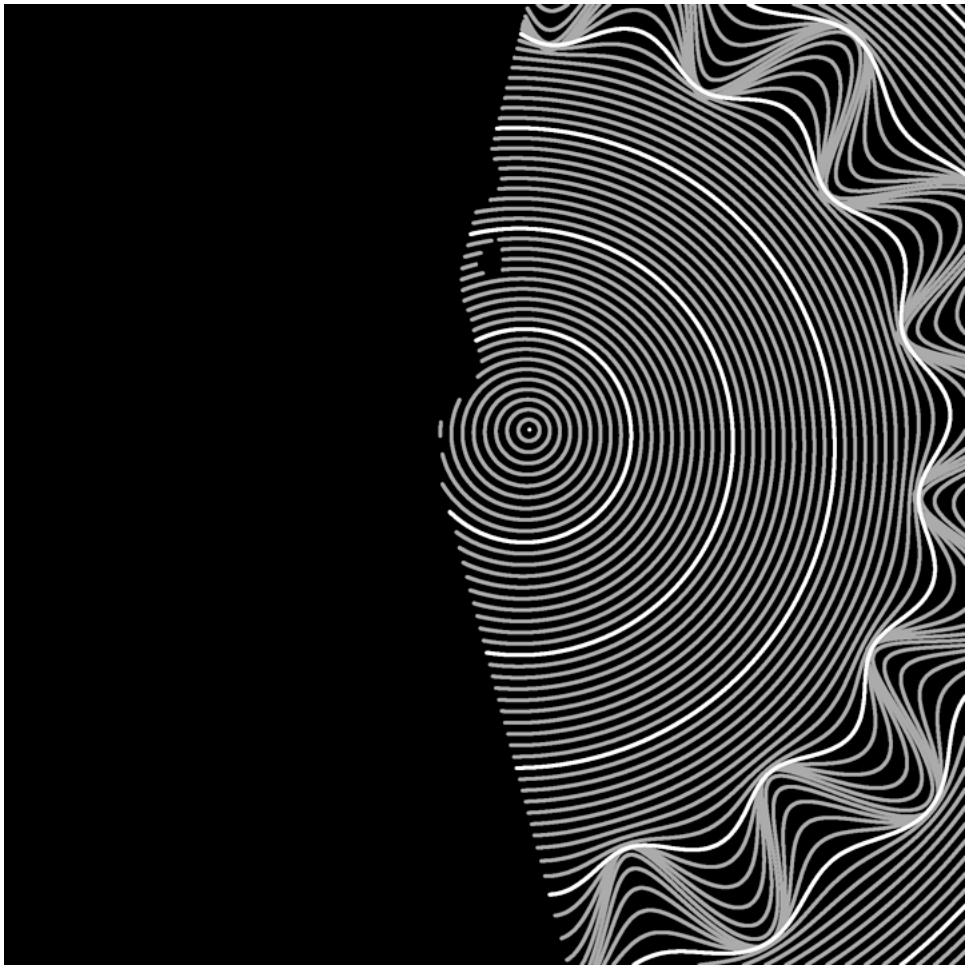
Ok, let's find it out!

If I could ask a computer about Rossby waves in this vorticity map, what would be its answer?

Approach: Genetic algorithm after pre-conditioning

A description by Fourier terms would be nice. Gauss-weighted around a given latitude.

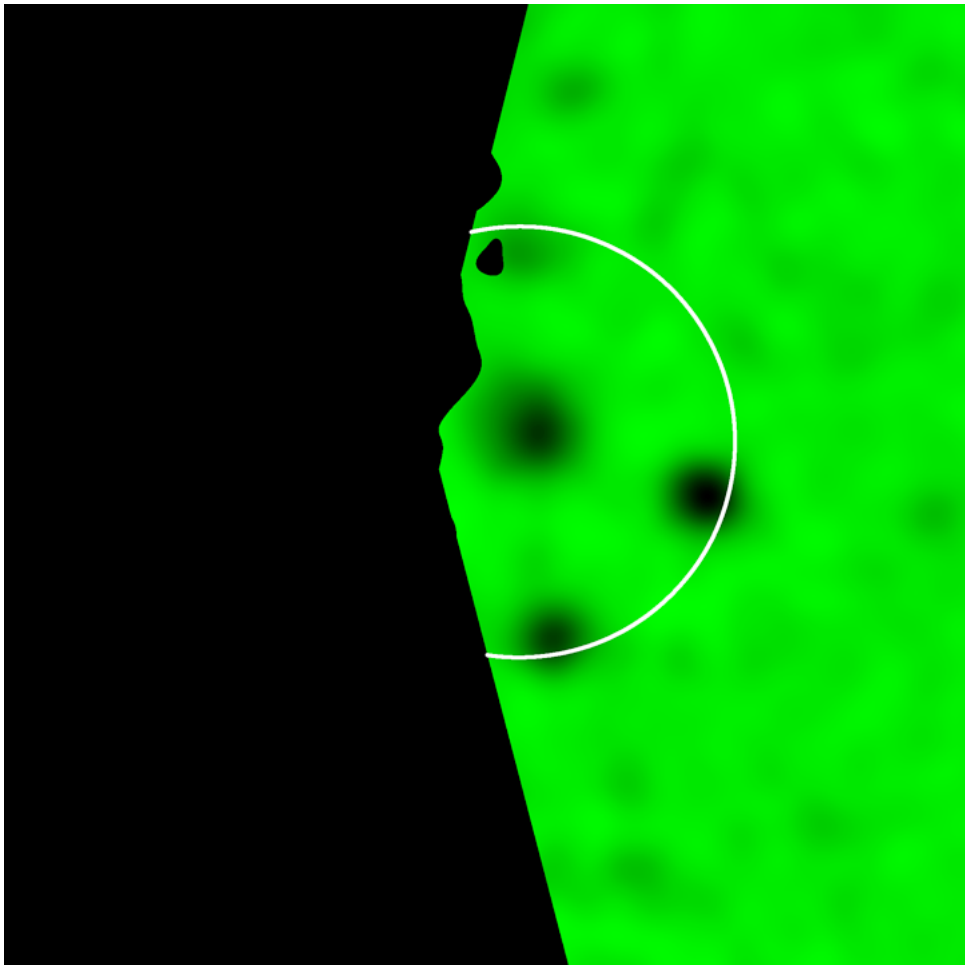
something like this one



A description by Fourier terms would be nice. Gauss-weighted around a given latitude.

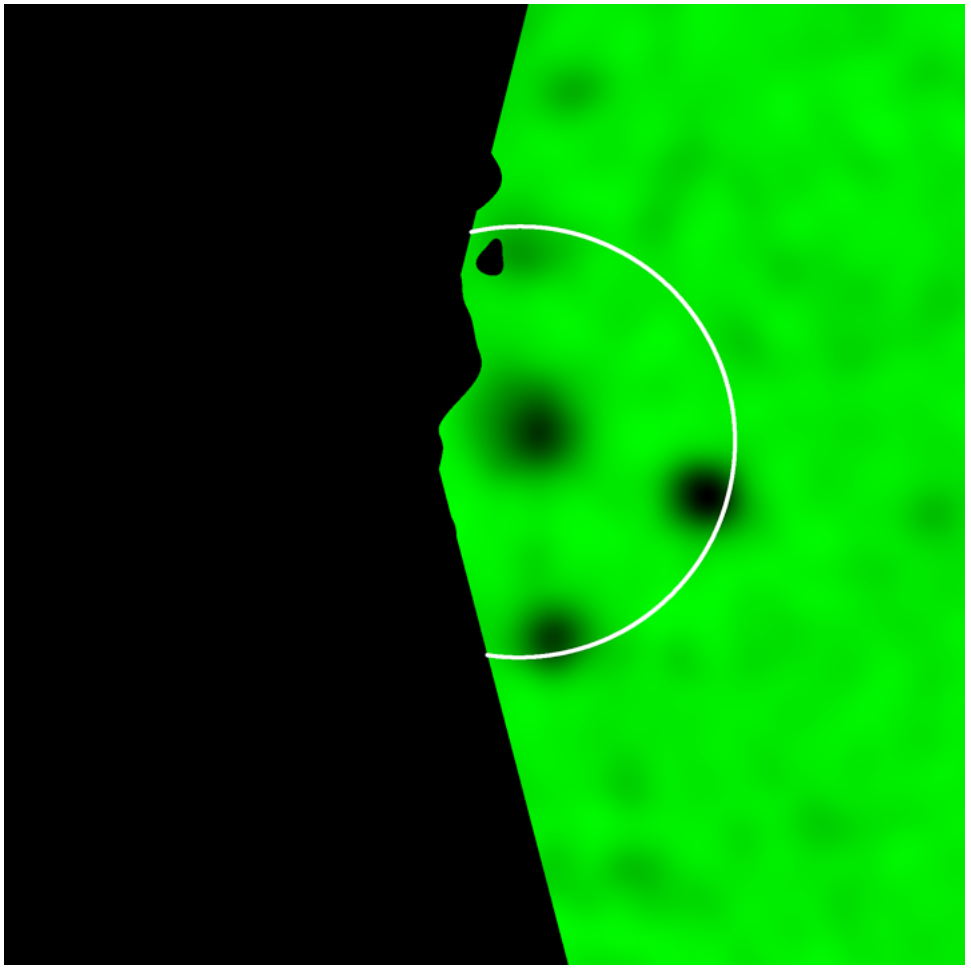
or that one

So, let's start with a single latitude

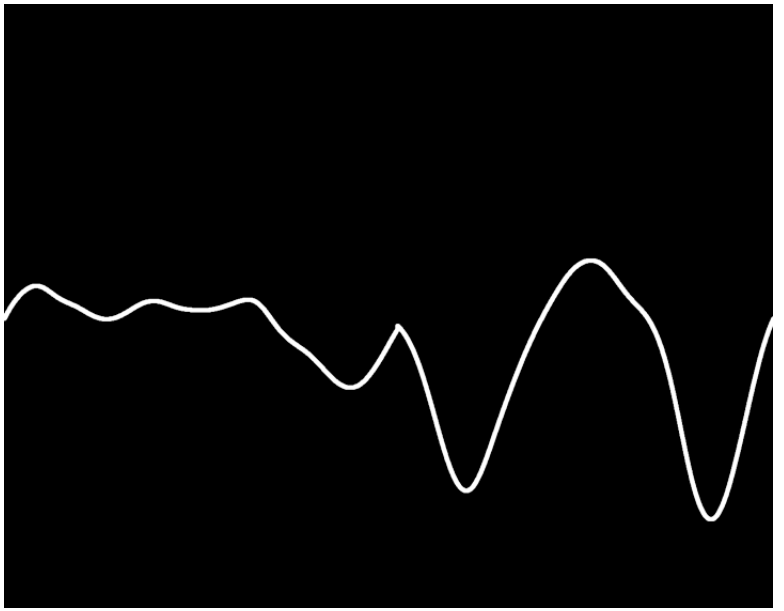


select one single fiber

The standard deviation of vorticities along our distorted circle of latitude will provide us with a fitness measure.



selected fiber

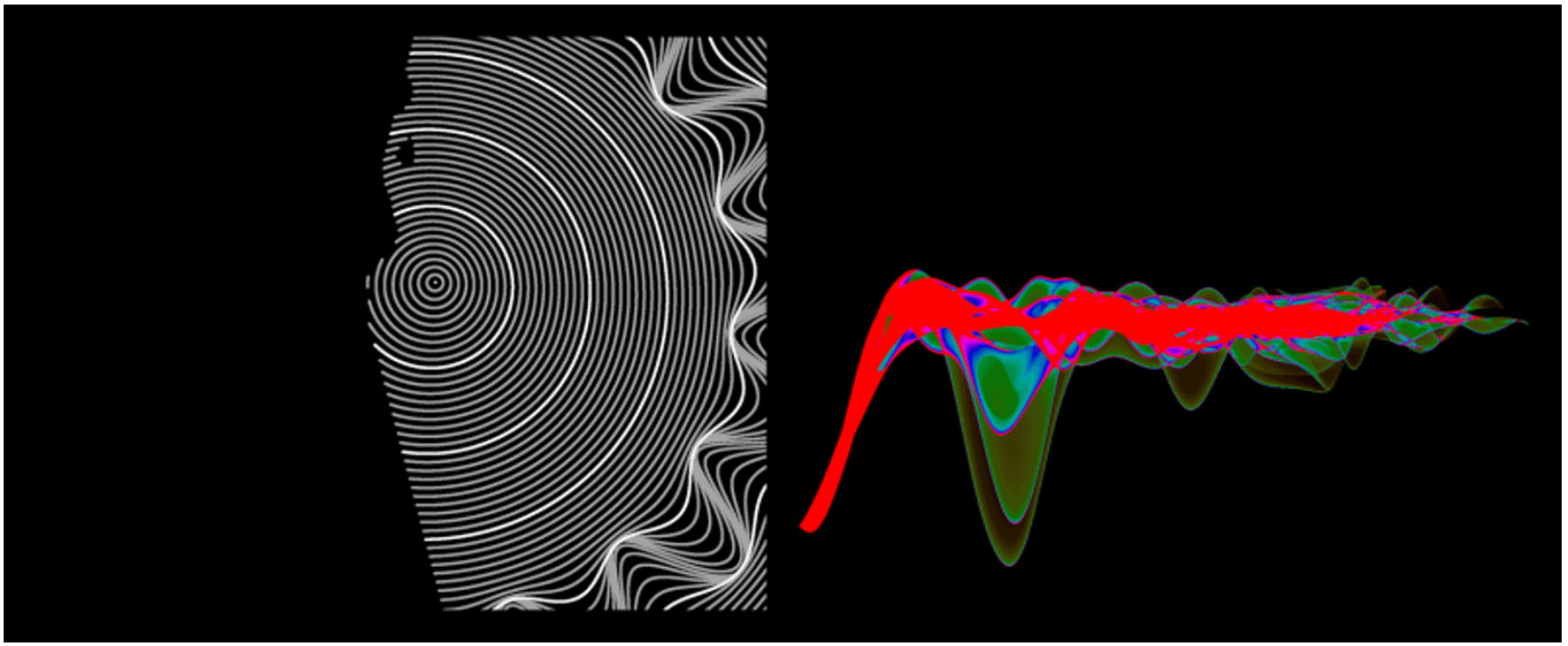


vorti-
city

length parameter of valid arc

vorticity value as
a function of arc length
along the valid portion
of the fiber

Note: Fourier terms have effect on statistics, including the standard deviation of the vorticity values sampled along a fiber (distorted circle of latitude).



vorticity

fibraton
(set of fibers,
fiber means distorted
circles of latitude)

generalized latitude parameter

heat map of vorticity
probability density function;
fiber corresponds to a column.

Back to a single given latitude:
run over
zonal wave numbers,
meridional amplitudes,
and phase shifts,
in order to find a good candidate
for that specific latitude.
A Monte-Carlo search will do the job.

Encode each Fourier term as a bit string, and call it a gene.

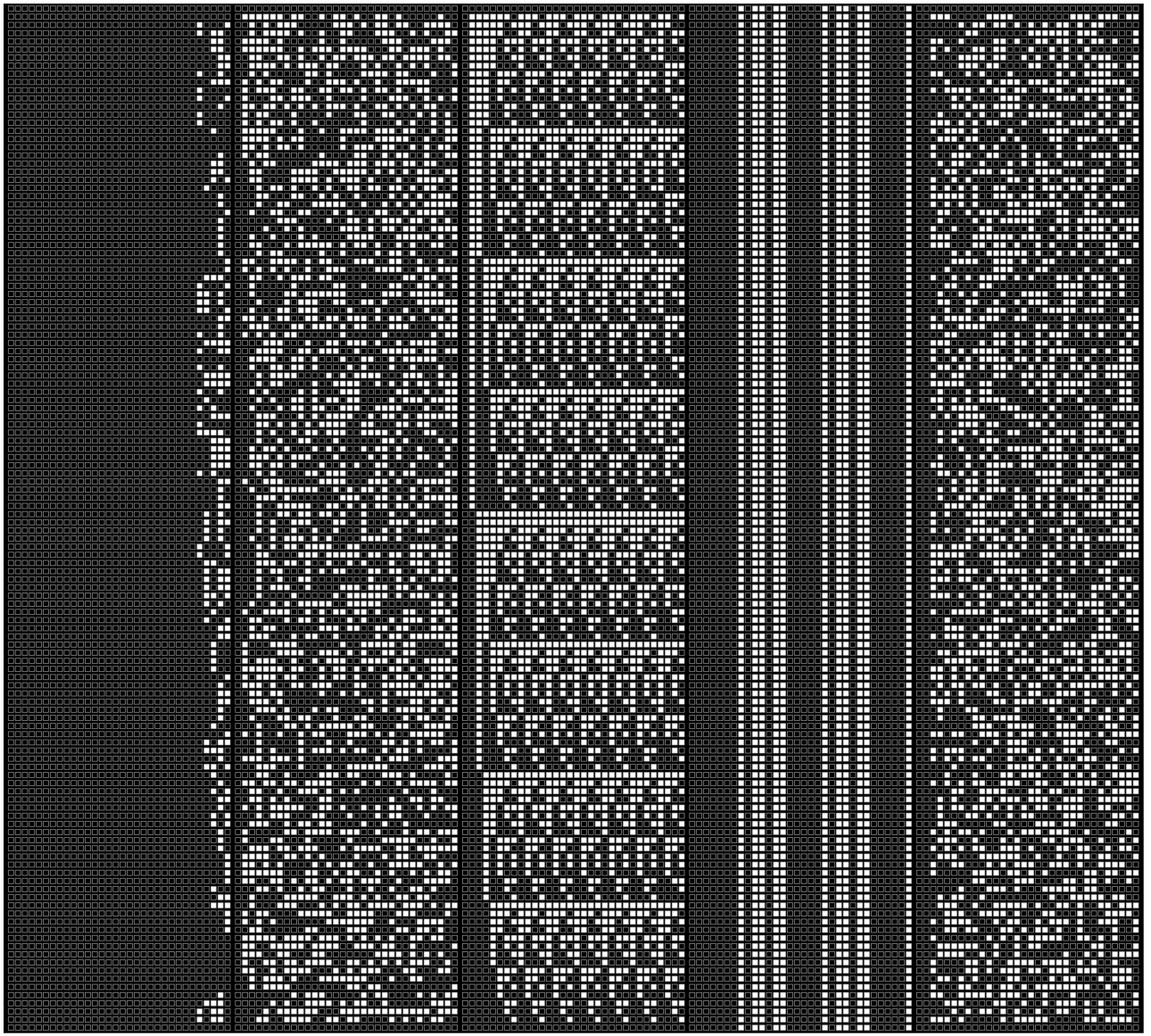
Example Fourier term parameters for colatitude 11.5°:

`00000000000000000010001000000010`	**Param 0: zonal wave number = 3**
`01000001101111011100100010010111`	**Param 1: amplitude = 2.054416939°**
`00011000100010001000100010001000`	**Param 2: colatitude mu = 11.5°**
`00000001011011000001011011000001`	**Param 3: (co)latitude sigma = 0.5°**
`00111011010001011101110010000010`	**Param 4: rotation phase = 0.308713**

graphical plot of bit string:

Repeat this task for all considered latitudes within the latitude range of interest in sufficiently small latitude steps.

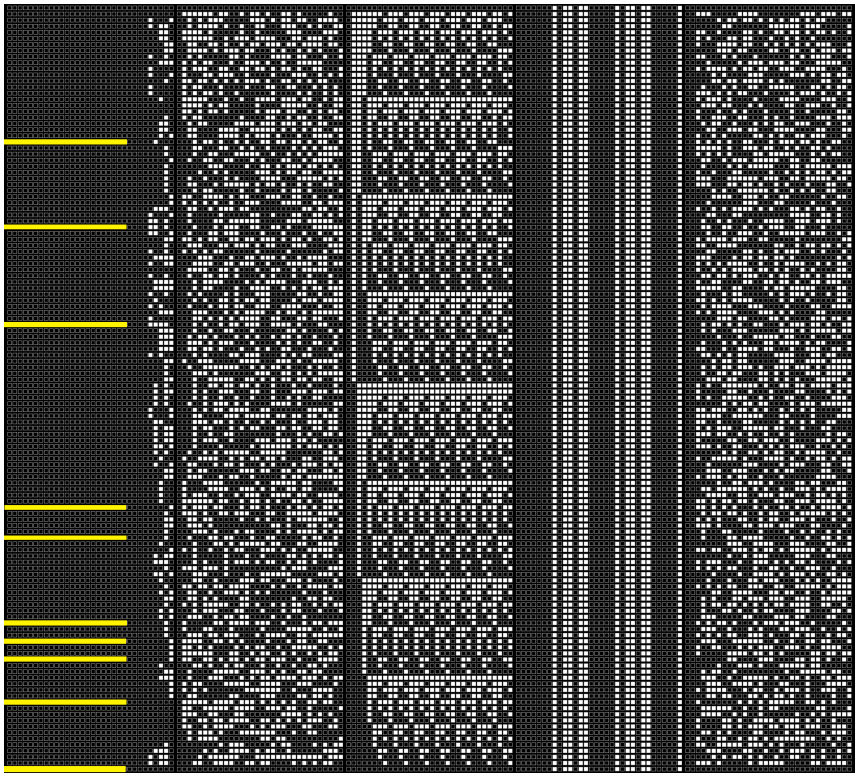
The results will provide us with a gene pool of initial values to seed the search for a global solution.



Each row encodes a gene.

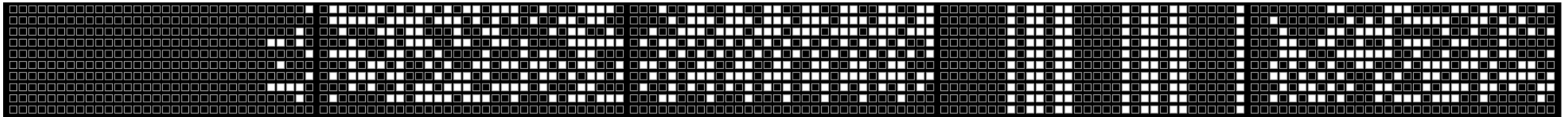
Provide each gene with the encoding of a reasonable sigma for the meridional Gauss weight, e.g. 0.5° latitude.

Call a set of genes a genome.
A genome shall be of the complexity of the global solution we aim at.
Assemble a genome by choosing genes randomly from the gene pool.



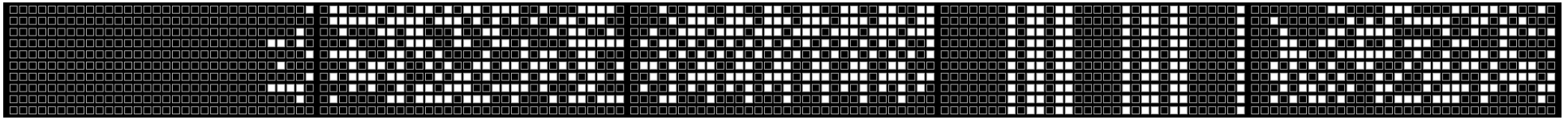
Gene pool:
Randomly selected genes are marked with yellow bars.

Genome assembled from randomly chosen genes

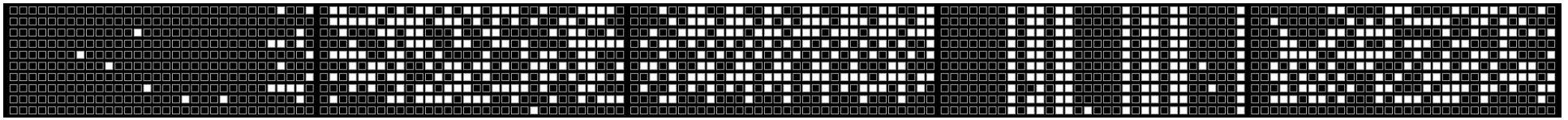


Allow for point mutations on the selected genome.

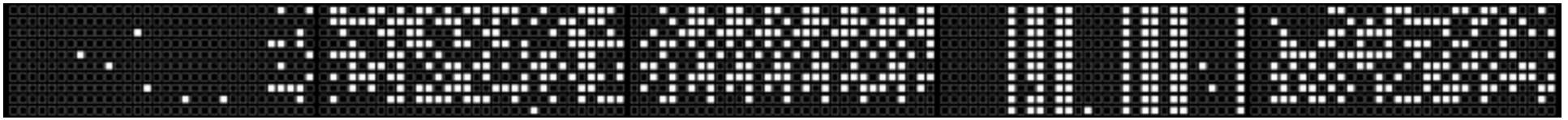
before point mutation



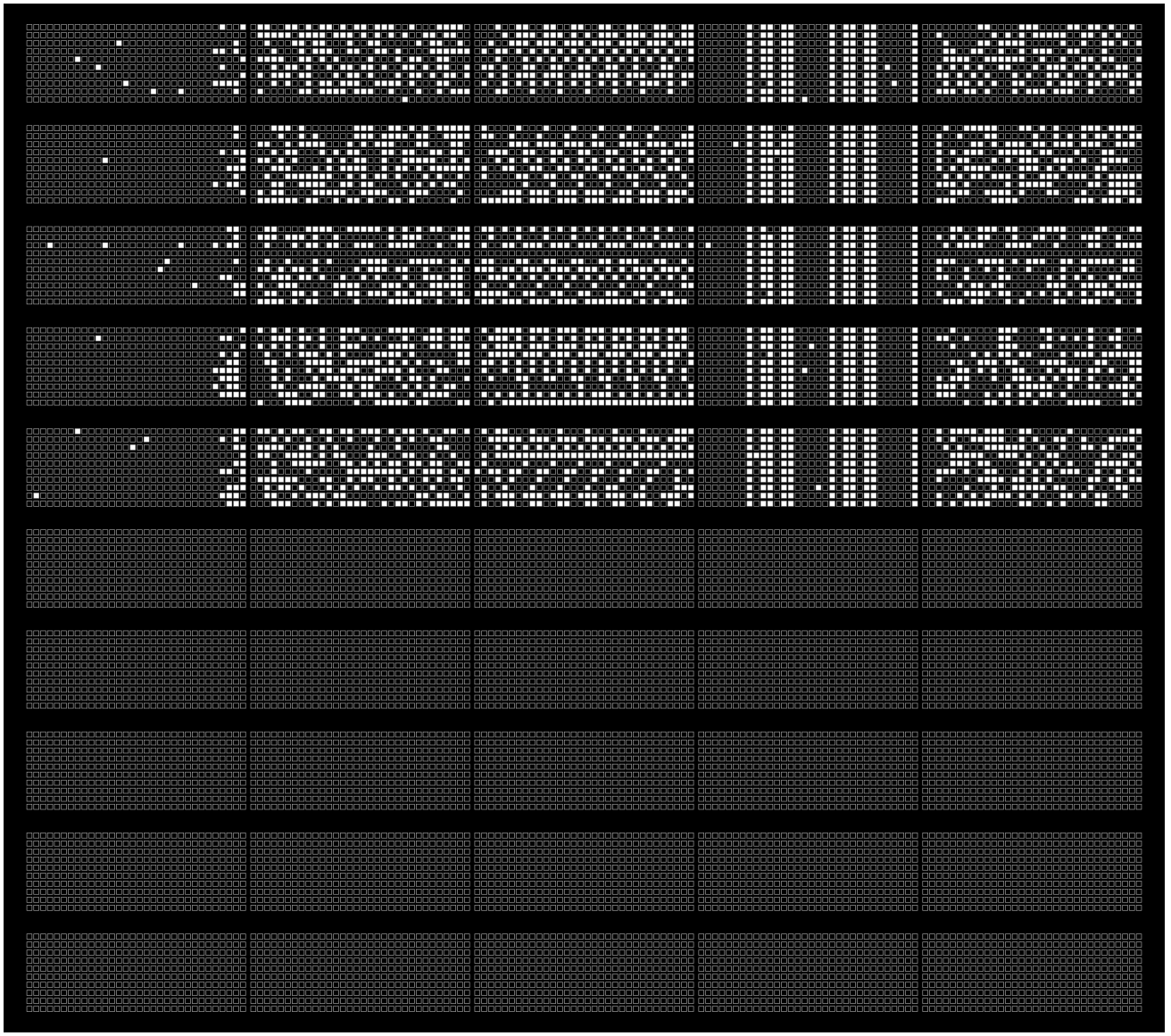
after point mutation



blink before/after point mutation

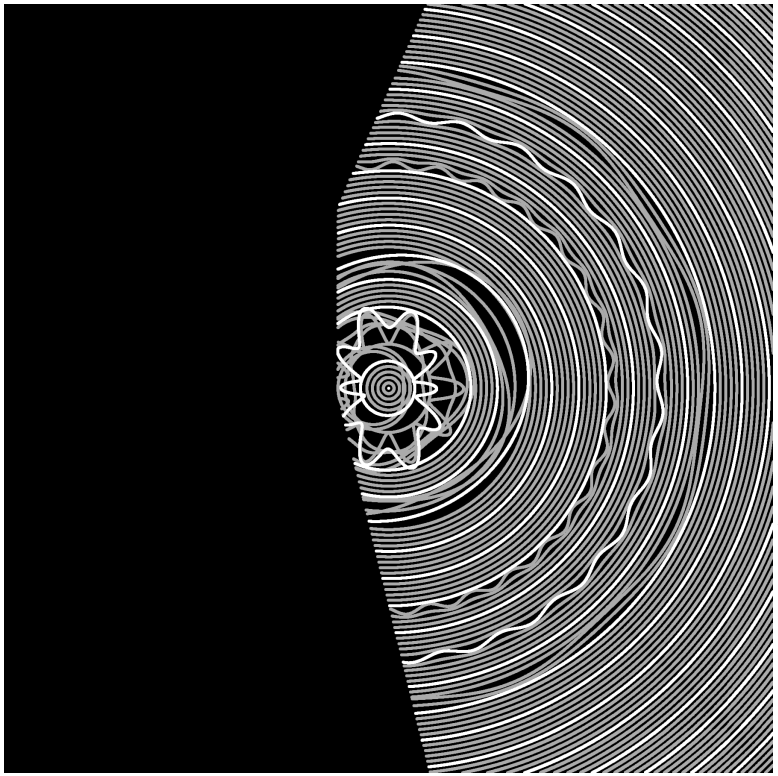


Repeat this selection process in order to seed half of a population of genomes.



population of
10 genomes,
5 genomes
valid.

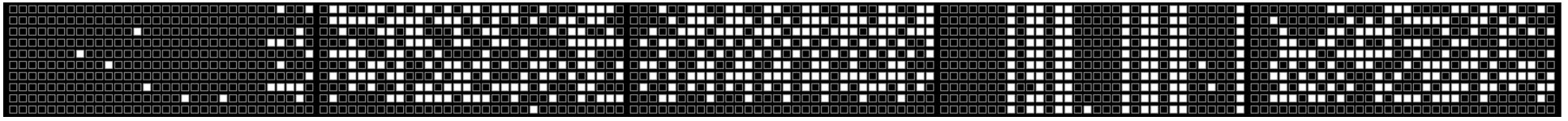
A genome is considered a genotype, while its translation into a sum of meriodally Gauss weighted Fourier terms is considerd its phenotype.



phenotype:
circles of latitude meridionally distorted by meridionally Gauss-weighted Fourier terms (fibers)

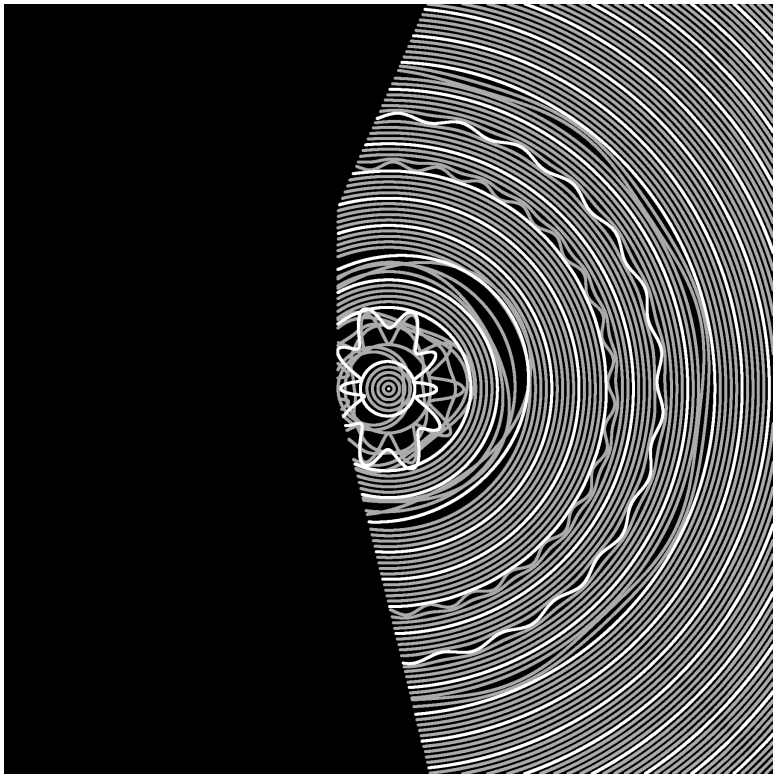
translate

genotype: string of bits

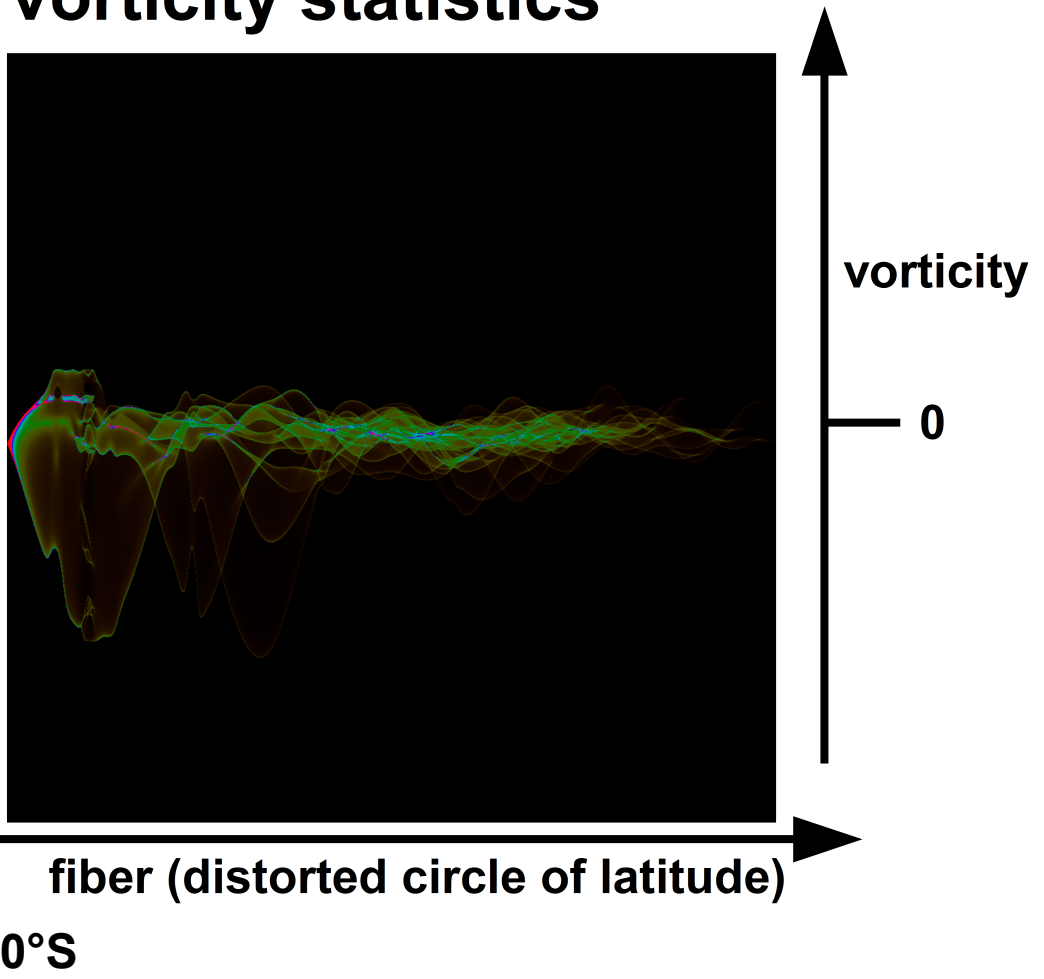


The fitness of a phenotype can be defined by the mean of all standard deviations of vorticities along respective distorted circles of latitude.

phenotype

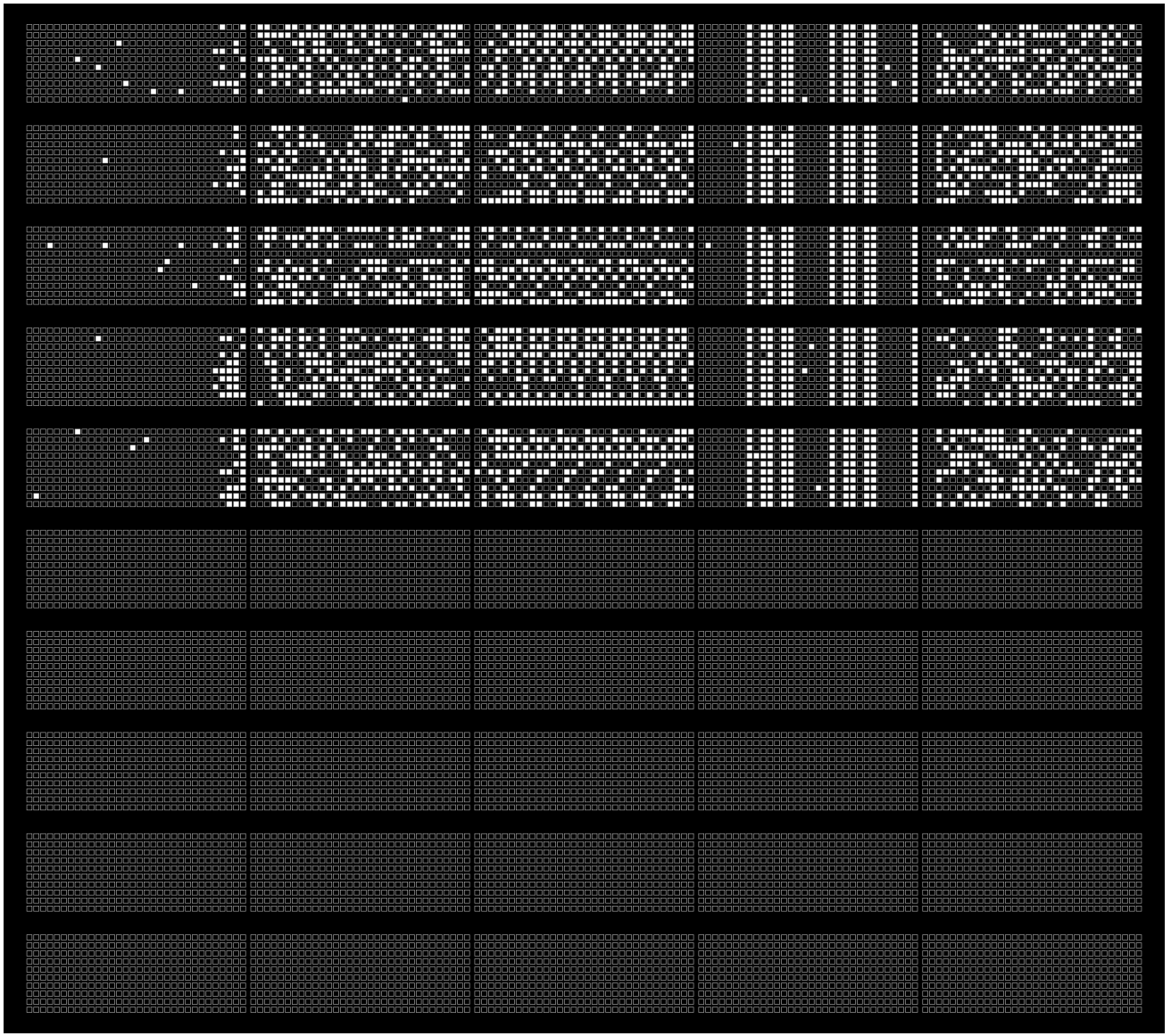


vorticity statistics



fitness := mean of standard deviation of vorticity on fiber = 0.000009703286

This way, each valid genome of our population is attributed with a measure of its fitness.



0.000009579028927

0.000009549332881

0.000009807979462

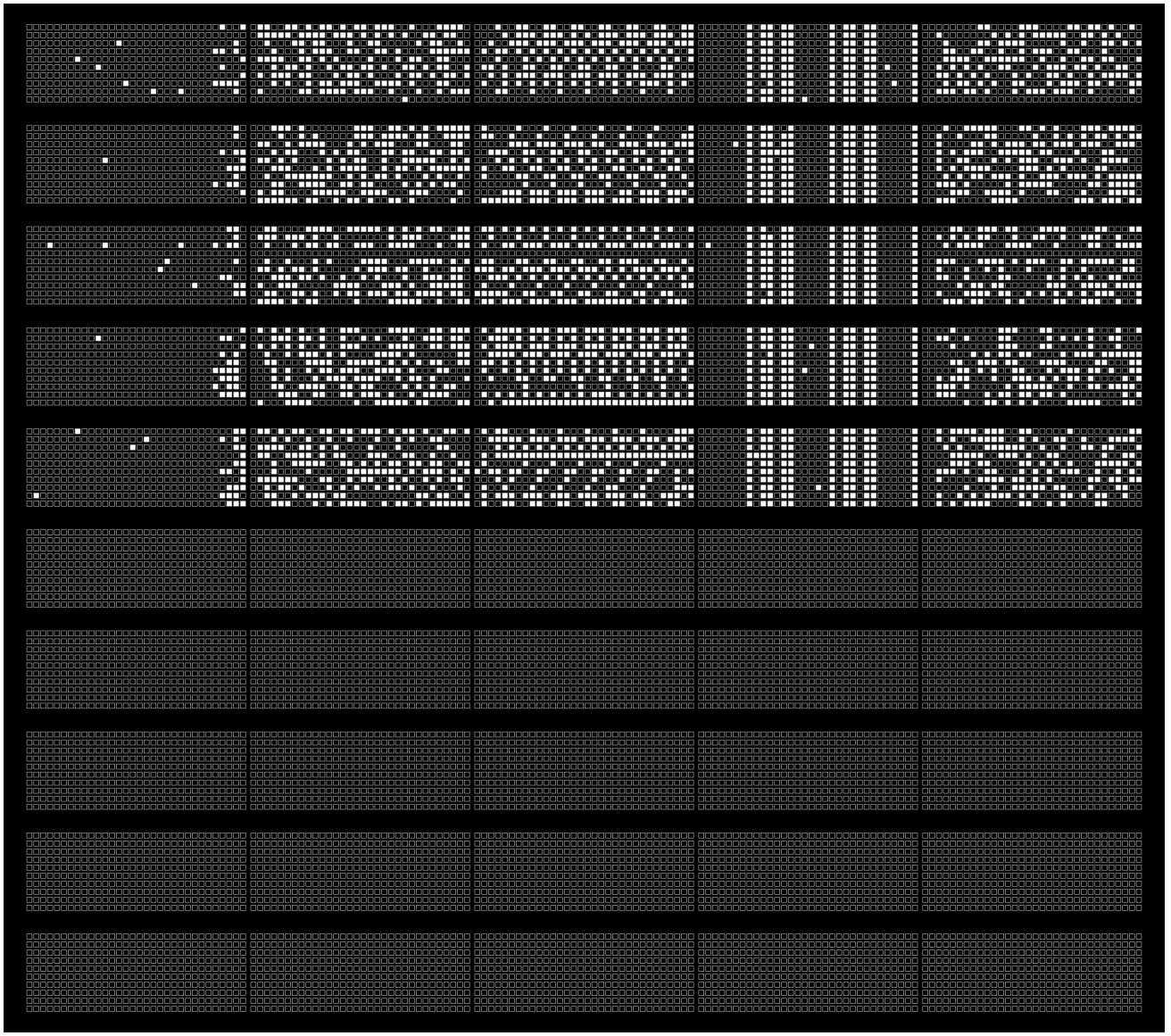
0.000009869549860

0.000009767088421

n/a

fitness value of each valid genome of the population

Evolve the population by looping over the following steps:



fitness

0.000009579028927

0.000009549332881

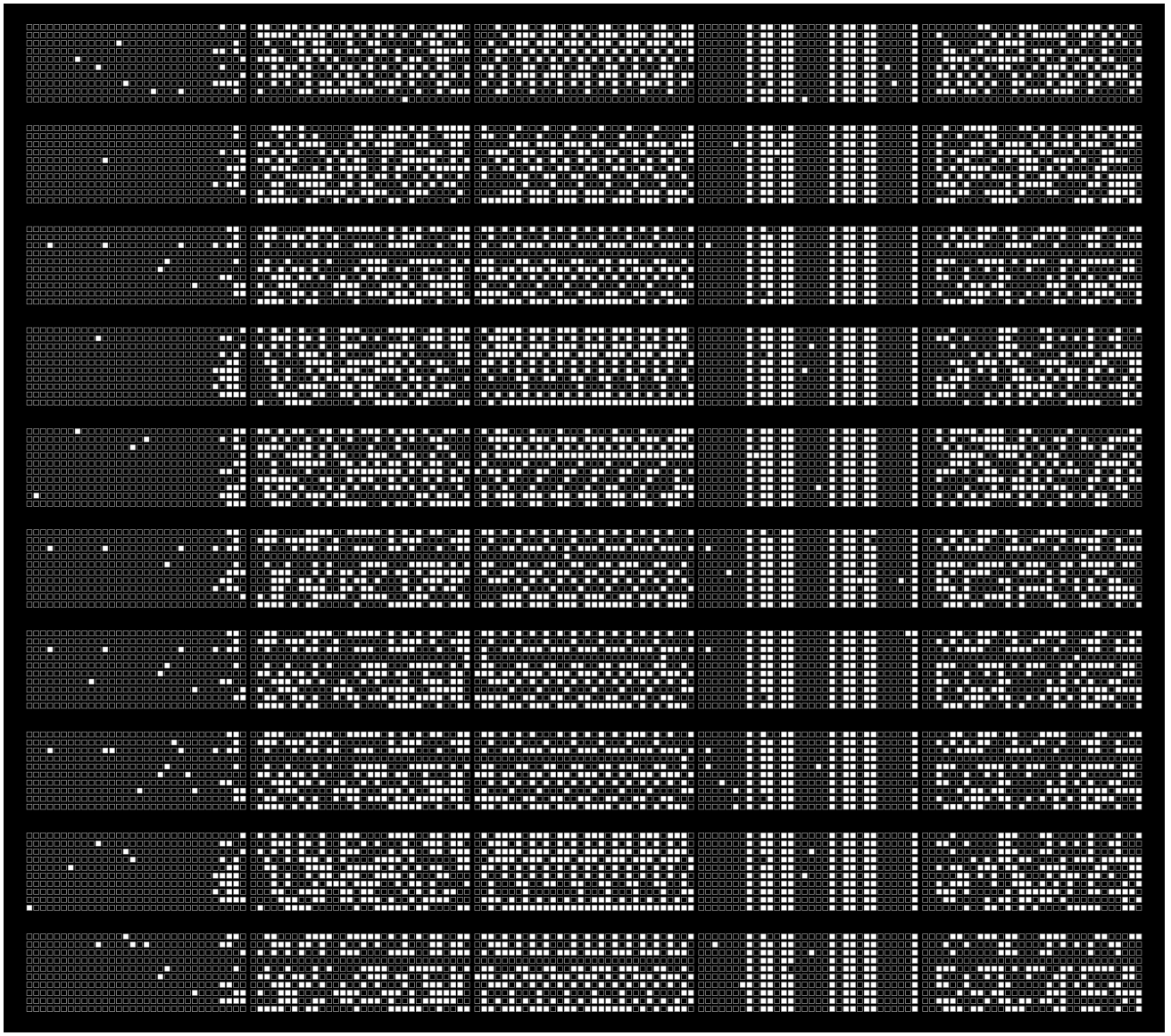
0.000009807979462

0.000009869549860

0.000009767088421

Evolve the population by looping over the following steps:

Replenish the population with new genomes.



0.000009579028927

0.000009549332881

0.000009807979462

0.000009869549860

0.000009767088421

0.000009869170102

0.000009997889944

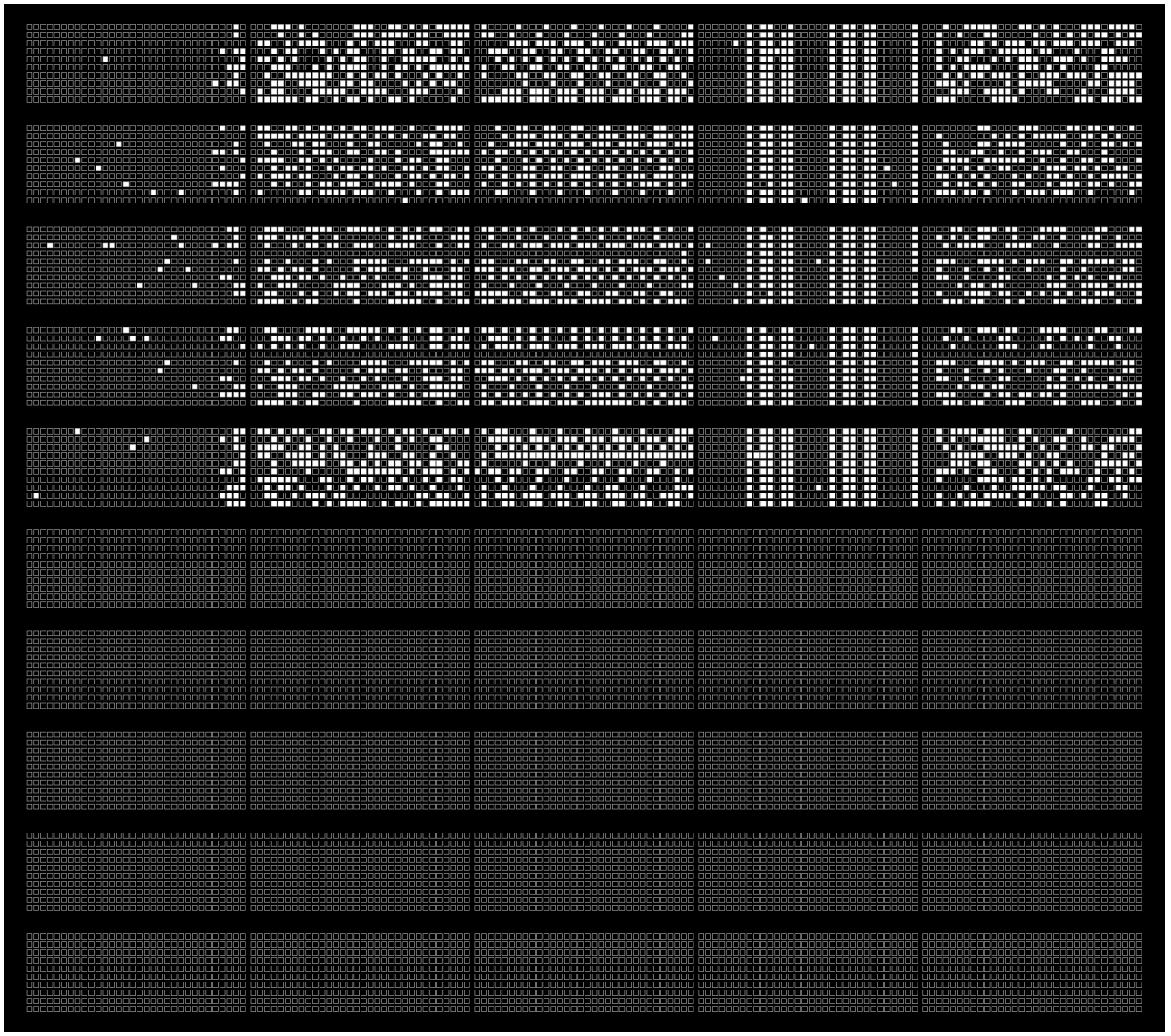
0.000009690615493

0.000009847701584

0.000009708270703

Evolve the population by looping over the following steps:

Sort the genomes of the population by their fitness,



0.000009549332881

0.000009579028927

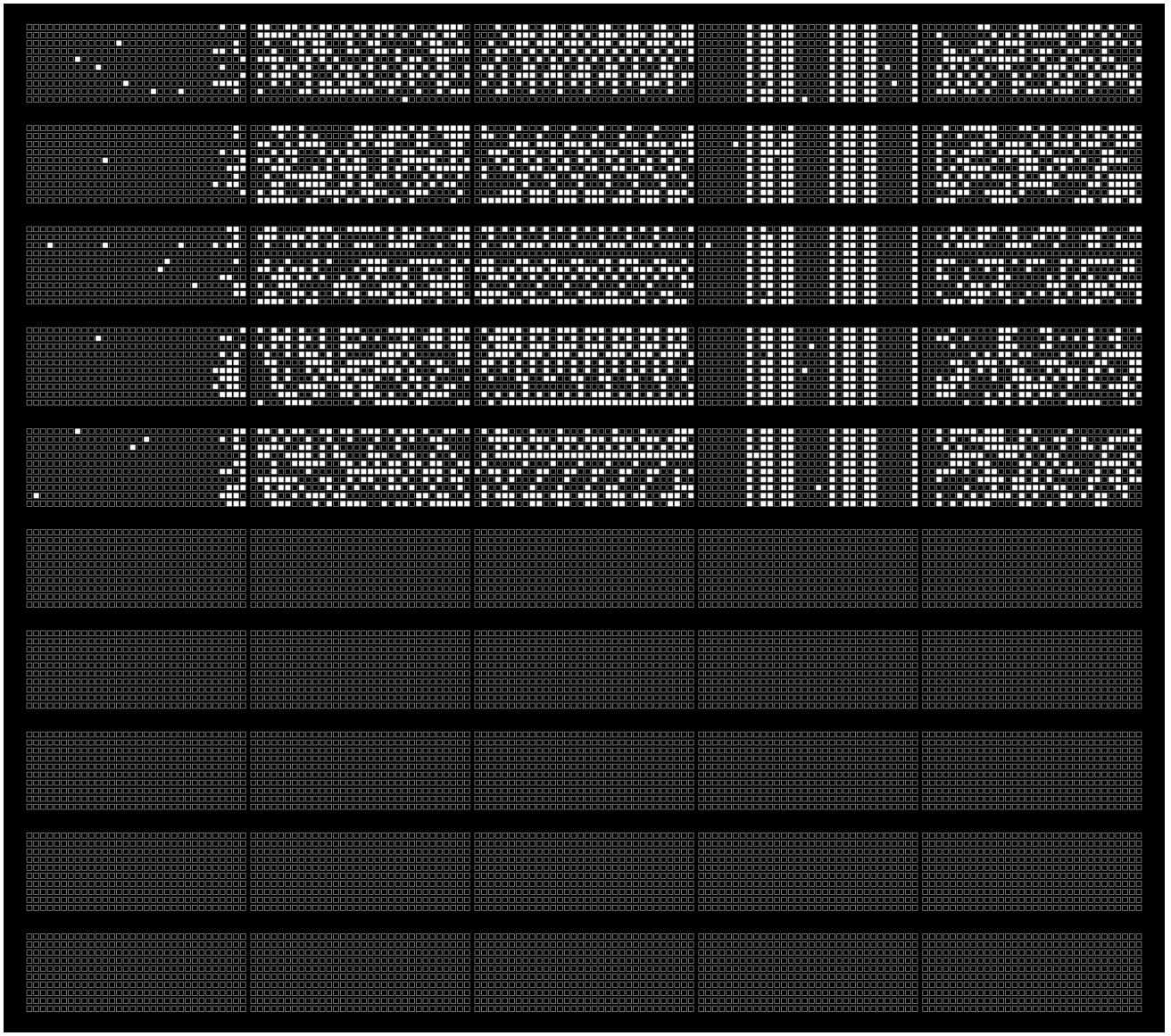
0.000009690615493

0.000009708270703

0.000009767088421

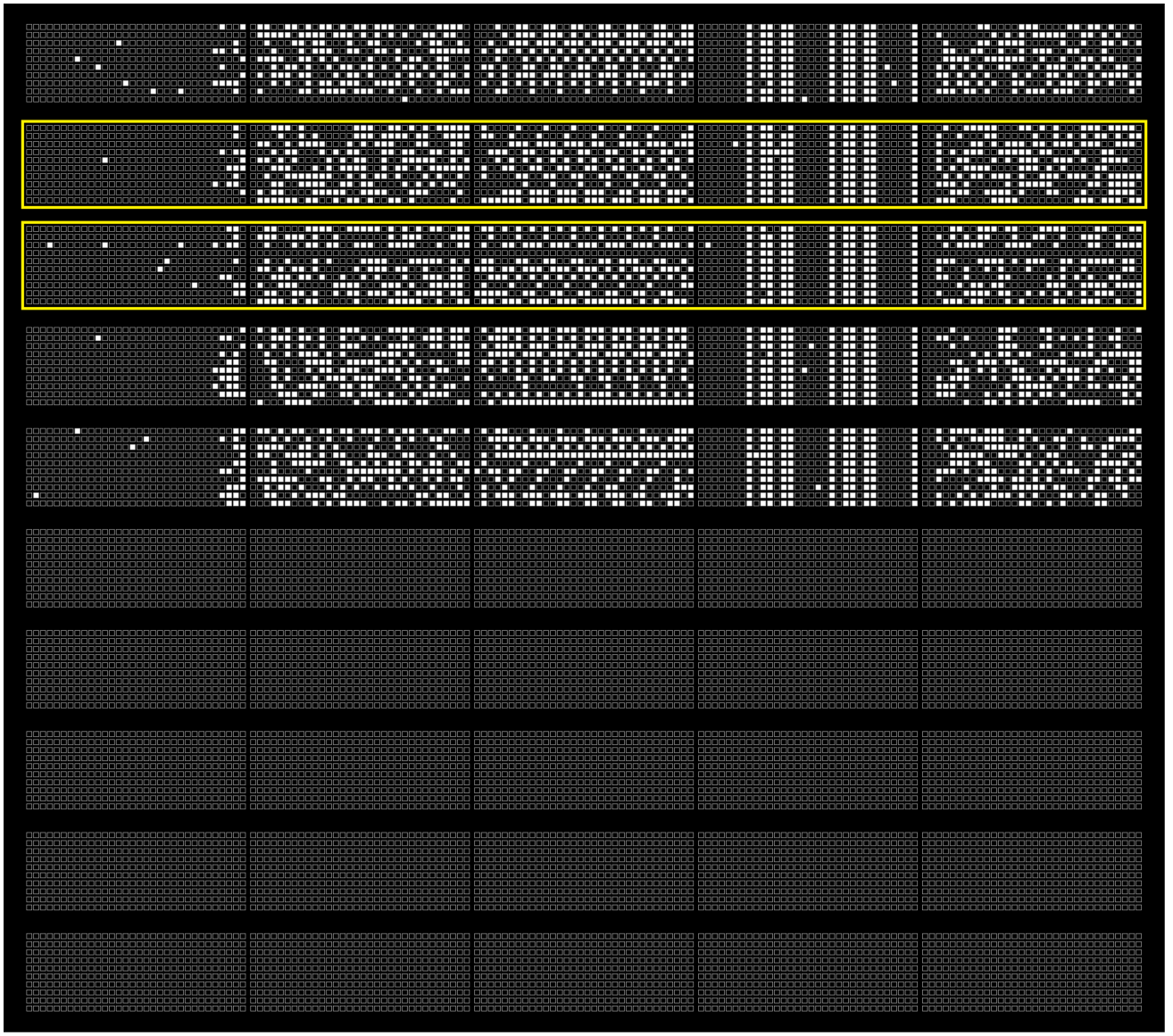
and invalidate the least fit half of the population.

A new genome is derived from the population the following way:



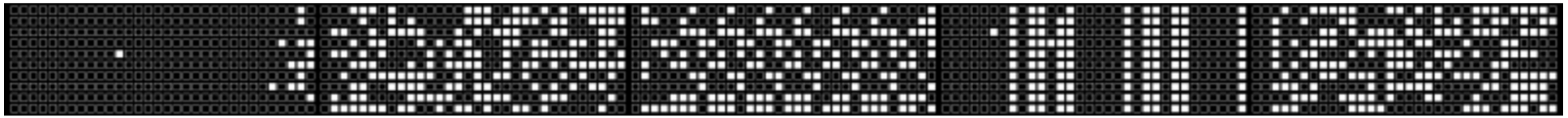
A new genome is derived from the population the following way:

Randomly choose two genomes of the population.

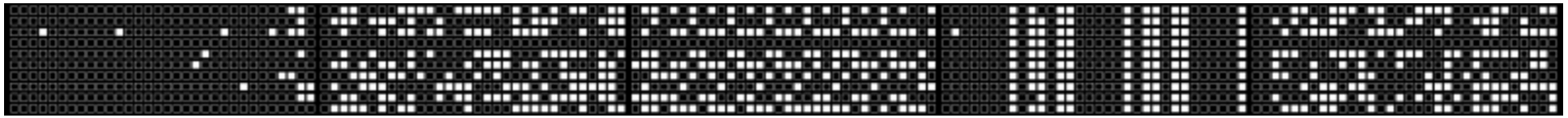


A new genome is derived from the population the following way:

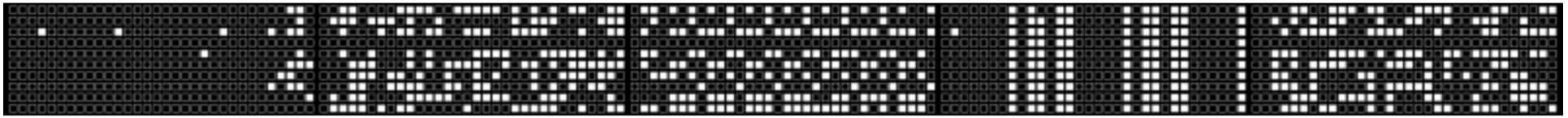
Recombine the two randomly chosen genomes by randomly choosing about half of the genes from each of the two chosen genomes.



x



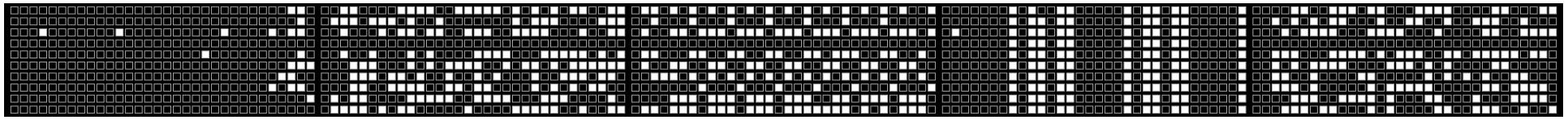
=



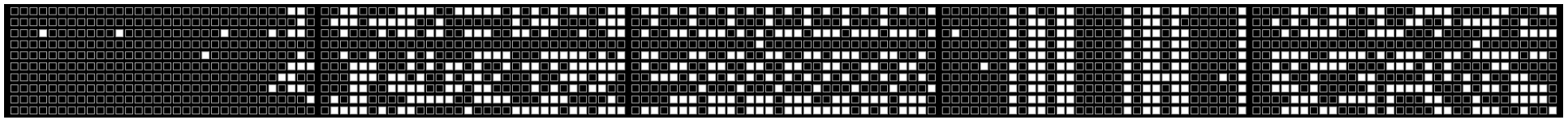
A new genome is derived from the population the following way:

Add random point mutations to the recombined genome.

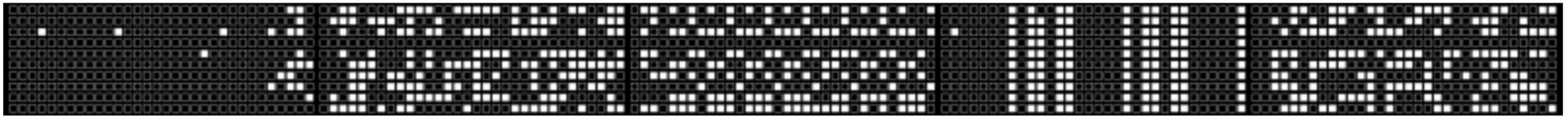
before point mutation:



after point mutation:



blink before / after point mutation:



Preliminary results

- Runs with several random populations tend to return unique results where Rossby wave structures look evident.
- They tend to return ambiguities where structures look less evident.
- Alternative solutions can be attributed with an objective measure of fitness.

Conclusion

When observing the development of Rossby wave structures over time, we should be prepared to deal with ambiguities. Those may become part of a best objective description.

This was a little too fast?

Take a look at the copy of these presentation slides in the EGU2022 abstract section.

Thank you!

Backup slides

Why is a genetic algorithm approach used?

Selected traditional approaches to fit a set of parameters:

Hill climbing or gradient methods:
Infinite-dimensional parameter space with many local stationary points expected. Method family unlikely to return a solution close to a global optimum.

Fourier analysis:
No time series available**.**

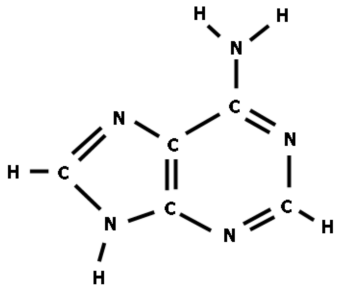
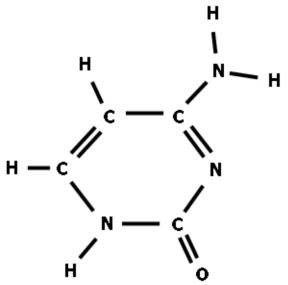
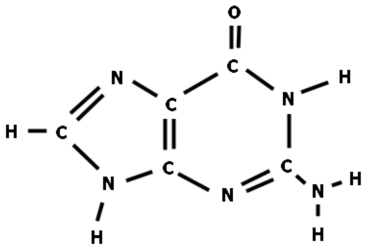
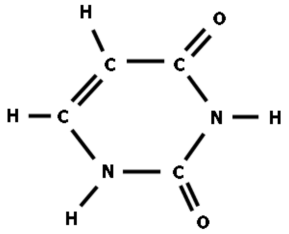
Neural networks:
No training database available.

Genetic algorithm, ingredients:
- genotype to encode phenotype,
- fitness assessment of phenotype.

Both ingredients are available!

Genotype

Inspired by biology: mRNA contains sequence of nucleobases (simplified)

	reduced to letter	reduced to digits 0 - 4	reduced to two binary digits
 **adenine**	**A**	**0**	**00**
 **cytosine**	**C**	**1**	**01**
 **guanine**	**G**	**2**	**10**
 **uracil**	**U**	**3**	**11**

Genotype encodes phenotype, phenotype maps to fitness.

Biology (much simplified)

Each sequence of 3 nucleobases (mRNA) encodes one amino acid.
sequence of amino acids = peptide.

binary representation 101011 000000 100111 101100 010111
mRNA (genotype) GGU AAA GCU CUA CCU

encodes

peptides (phenotype) Gly – Lys – Ala – Leu – Pro

determine

fitness

(of organism within a given environment)

Rossby wave encoding

Genome consists of genes.
Each gene encodes a Fourier term.
Fourier term has parameter set.
Each parameter encoded as 32 bit integer.

What's the underlying motivation to search for the Rossby wave structure?

- Retrieve a sharper and more „natural“ way to describe zonal vorticity profiles by reducing the standard deviation along fibers, here along distorted circles of latitude.
- Find a zonal dynamical pattern that can be used as a context for local fluid dynamical simulations.
- Find an objective and reprodicible way to describe Rossby waves, including ambiguities, if they cannot be resolved.