Simulating coral growth in 2D

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TABLE OF CONTENTS

INTRODUCTION

Effect of Nutrient Diffusion and Flow on Coral Morphology

Jaap A. Kaandorp,[1] Christopher P. Lowe,[2] Daan Frenkel,[3] and Peter M. A. Sloot[1]

Use of fractal dimensions to quantify coral shape

B. Martin-Garin · B. Lathuilière · E. P. Verrecchia · J. Geister

Simulation and analysis of flow patterns around the scleractinian coral *Madracis mirabilis* (Duchassaing and Michelotti)

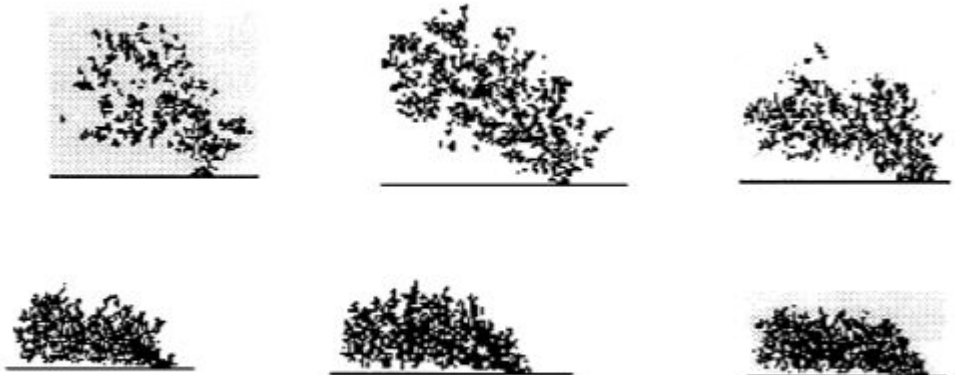
Jaap A. Kaandorp[1*], Evert A. Koopman[1], Peter M. A. Sloot[1], Rolf P. M. Bak[2], Mark J. A. Vermeij[3] and Leo E. H. Lampmann[4]

Research Question

How is the growth of coral influenced by its dependence on sunlight and nutrition?

- Sunlight
- Nutrients
- Flow
- Erosion

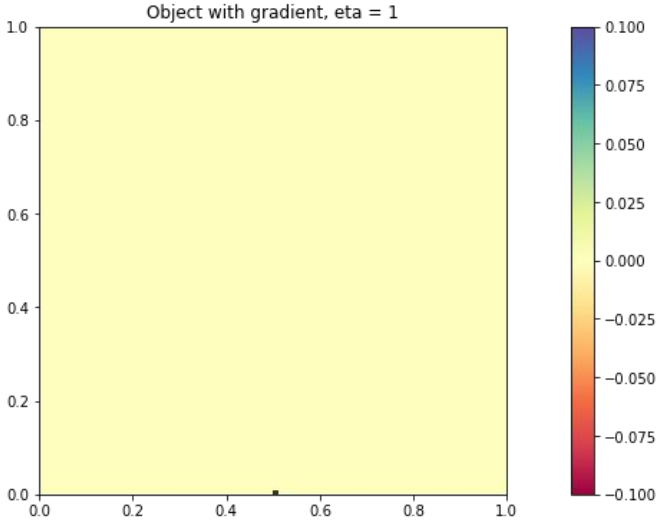
Hypothesis

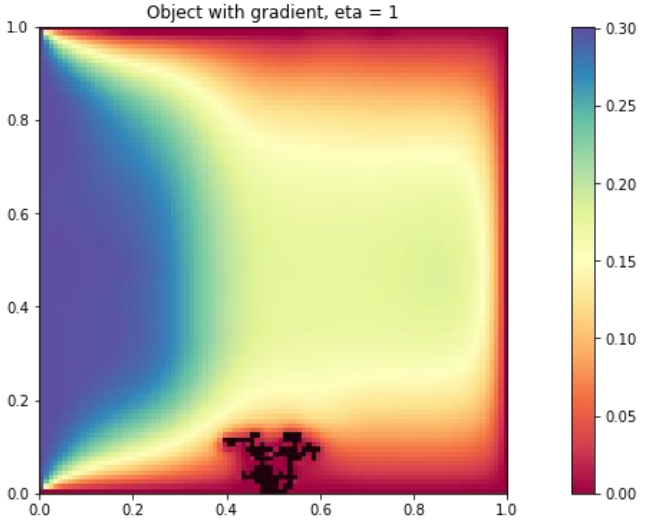


Kaandorp, J. A., Lowe, C. P., Frenkel, D., & Sloot, P. M. (1996). Effect of nutrient diffusion and flow on coral morphology. *Physical Review Letters*, *77*(11), 2328.

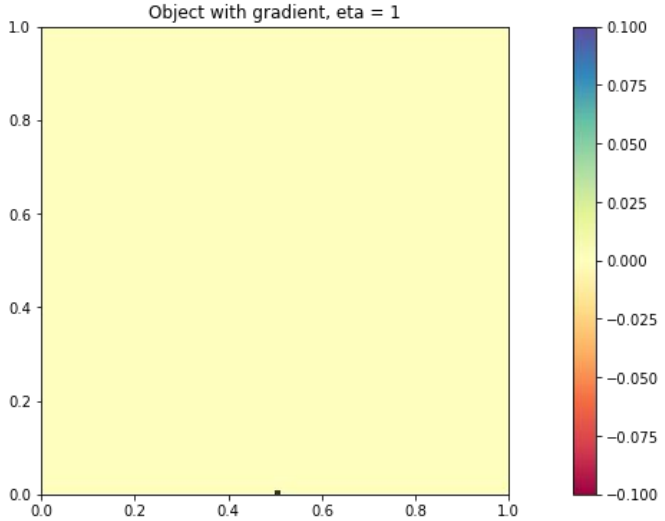
MODEL SET-UP

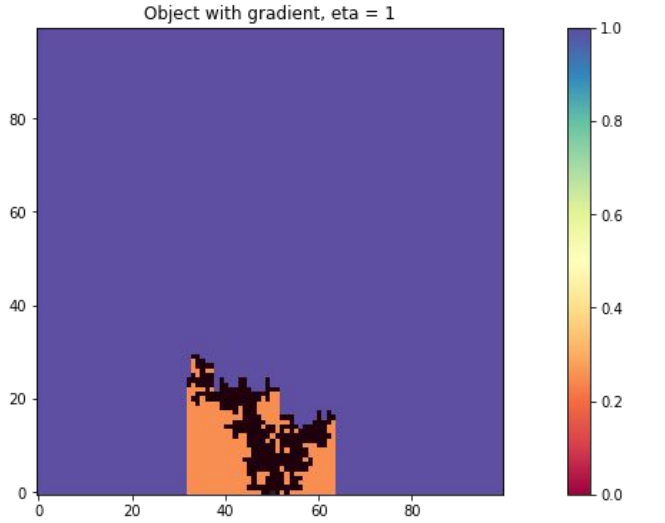
- 2D box of size 100 by 100
- Source cell at center bottom
- Environmental factors influence the chance of growth
- Each step one coral cell is added to the model
- Model stops after 100 iterations
- Flow carrying nutrients comes from left





- Homogeneous initial concentration
- Shadow
- Reflection
- Too small for sensible luminescence difference

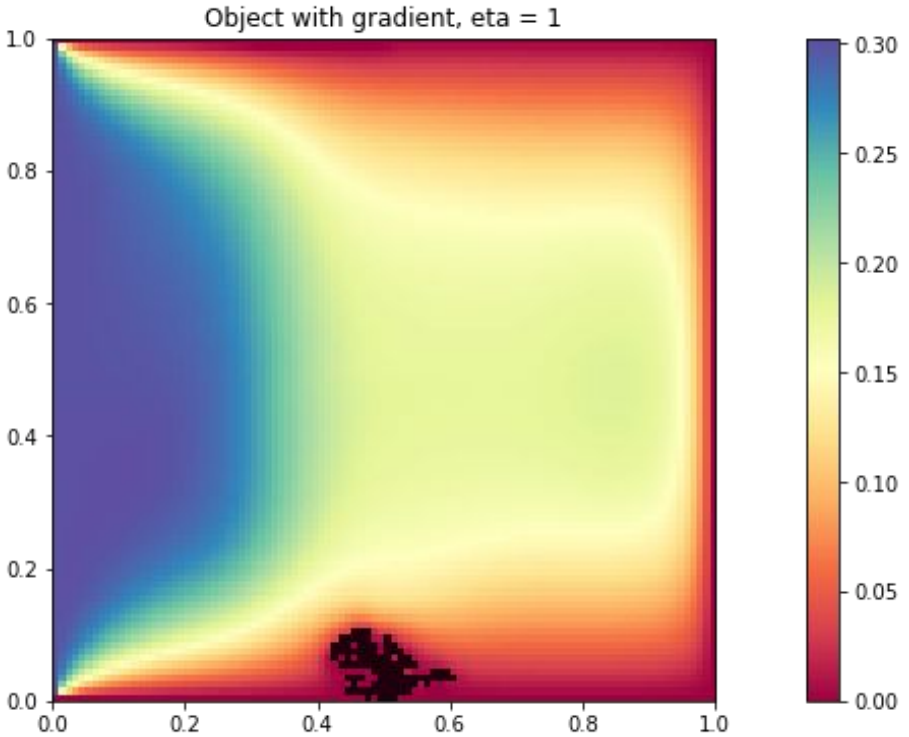




SUNLIGHT

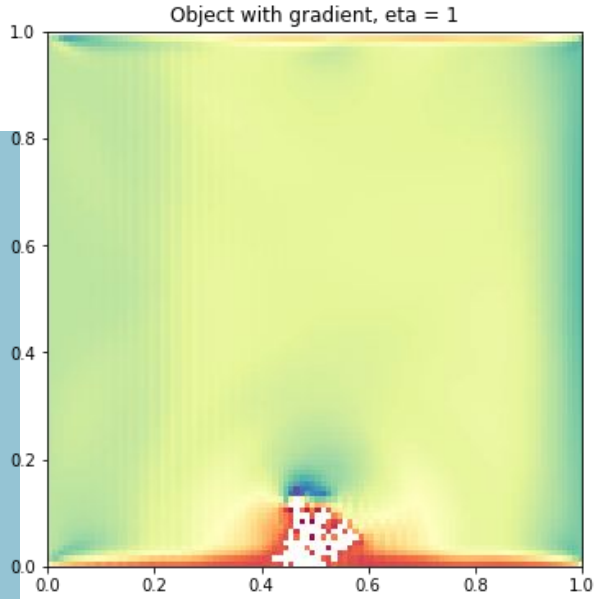
- Advection-diffusion equation
- Boundaries: sink at top, bottom, right; left-side source
- Displaced by flow + diffusion
- Finite-differencing method

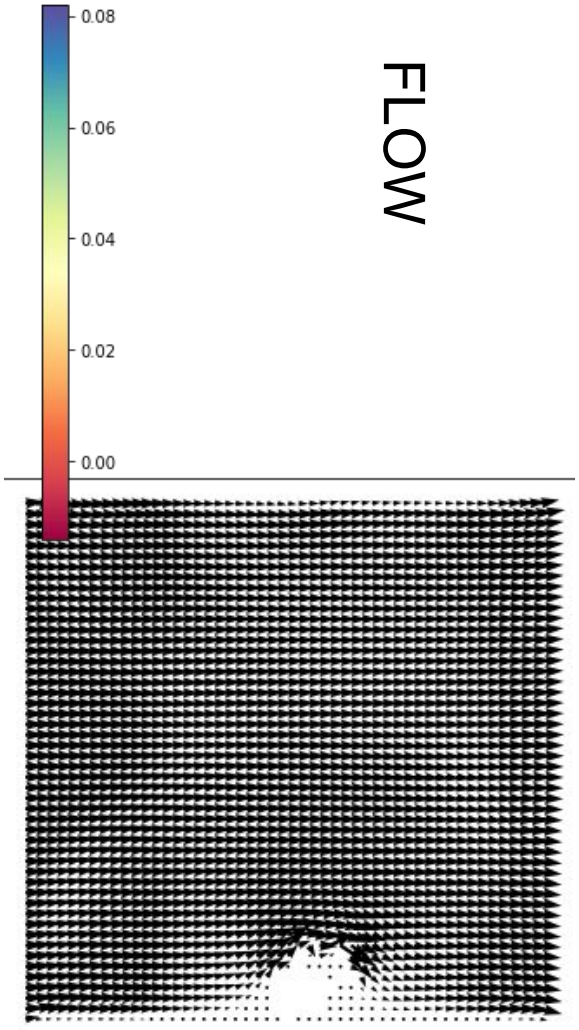
$$\frac{\partial c}{\partial t} = \nabla \cdot (D \nabla c) - \nabla \cdot (\mathbf{v} c) + R$$



NUTRIENTS

- Lattice Boltzmann Method (indirect Navier Stokes), lbmpy package
- Initial velocity field
- Inflow from left side of environment
- Boundaries: outflow, no-slip at bottom
- Flow strength is stable





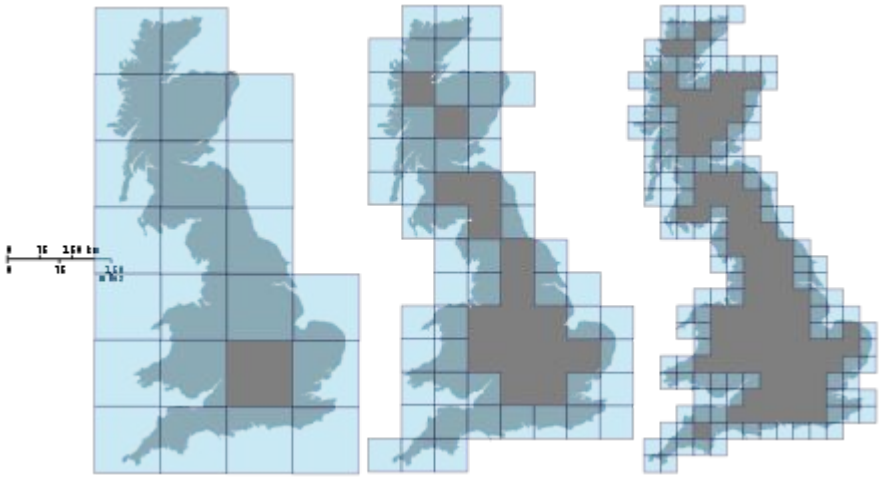
EROSION

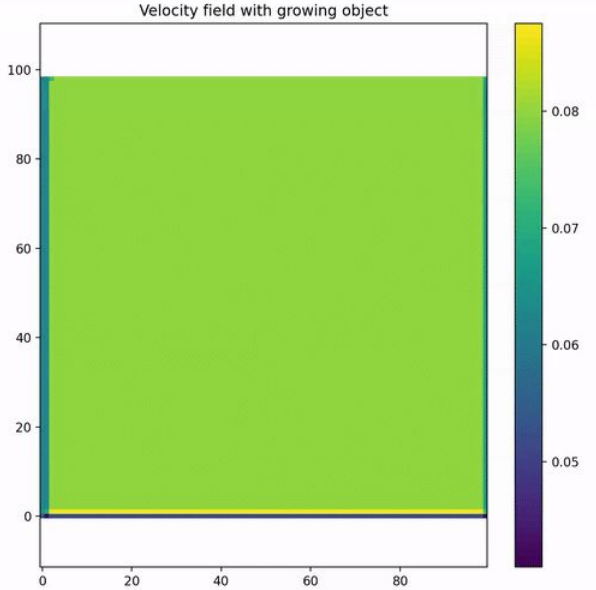
- Pressure by flow
- Coral cell dissolves
- Check which cells have connection with source cell

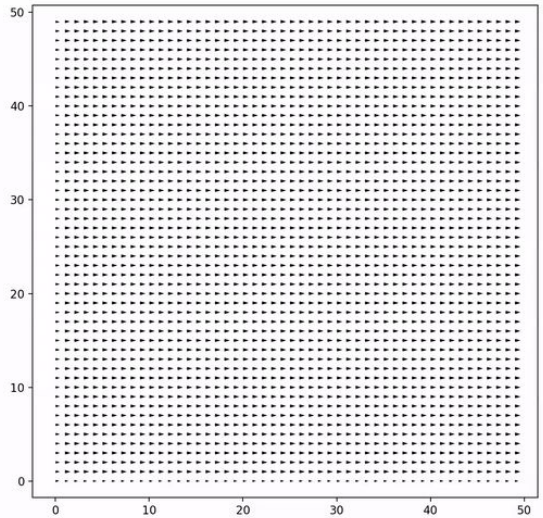
DENSITY ANALYSIS

- Fraction of cells on edge (branch fraction)
- Fractal dimensions (estimation using box-counting method)

$$D_0 = \lim_{\varepsilon \to 0} \frac{\log N(\varepsilon)}{\log \frac{1}{\varepsilon}}.$$



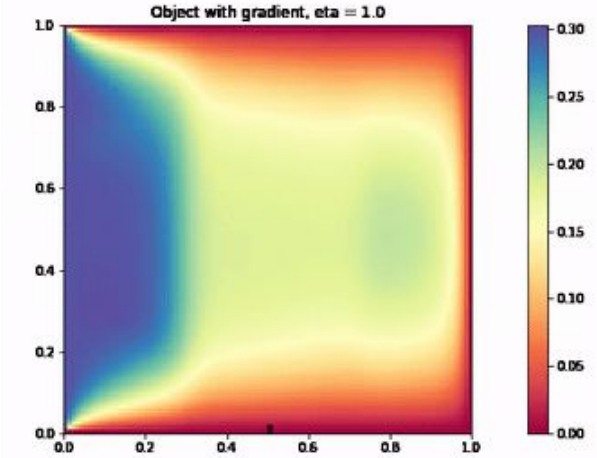

Velocity field with growing object
100
80
60
40
20
0
0
20
40
60
80
0.08
0.07
0.06
0.05


50
40
30
20
10
0
0
10
20
30
40
50

DEMO GROWTH

RESULTS
SUNLIGHT AND NUTRIENTS

Alpha = 0.0



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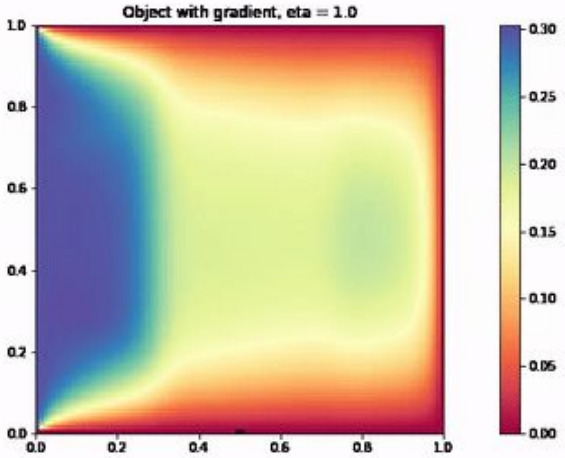

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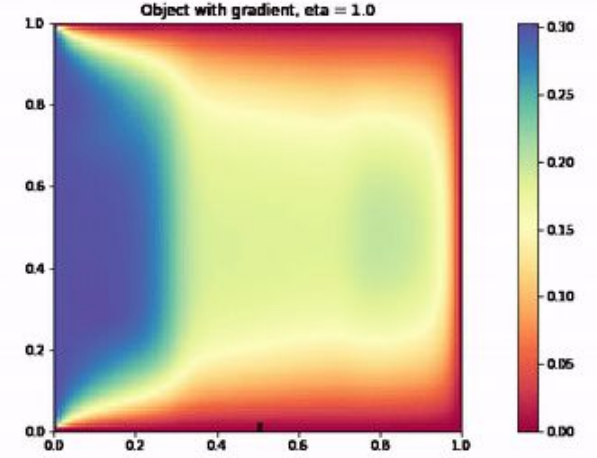

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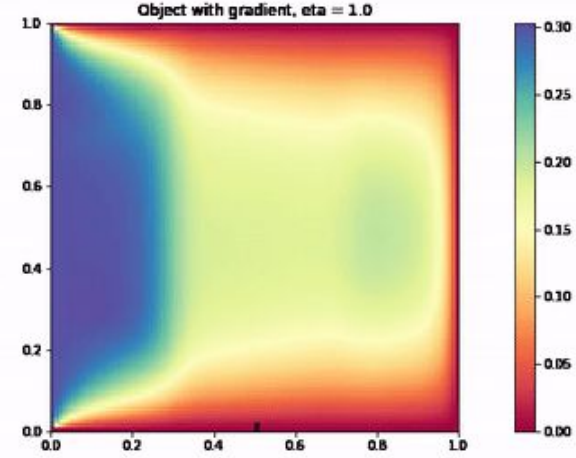
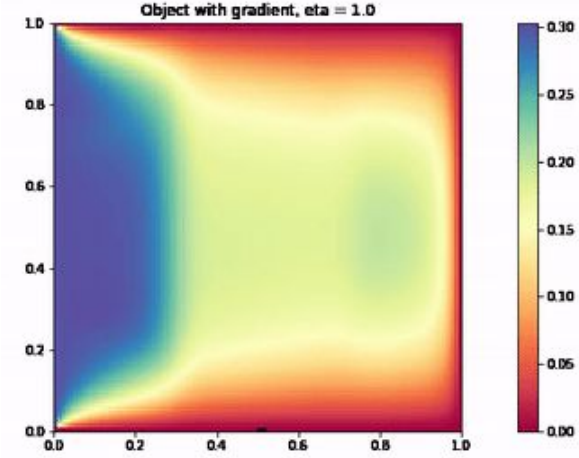
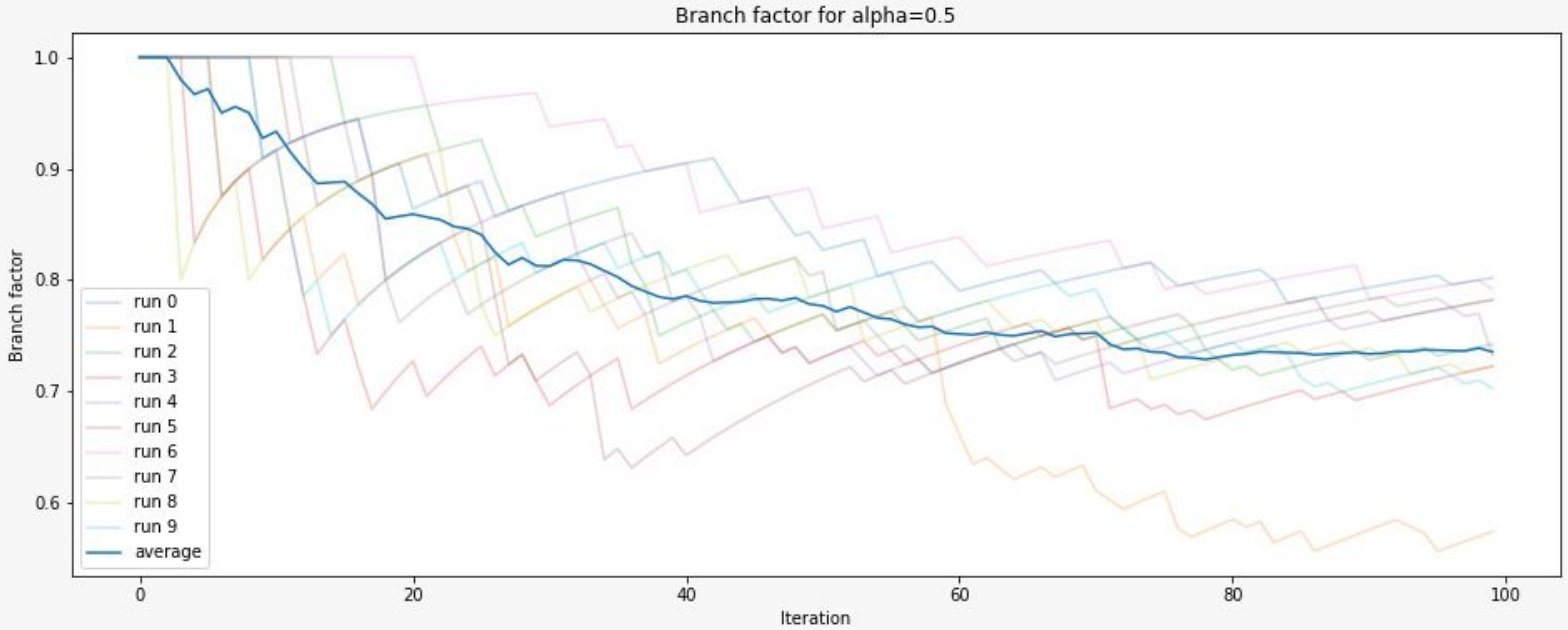


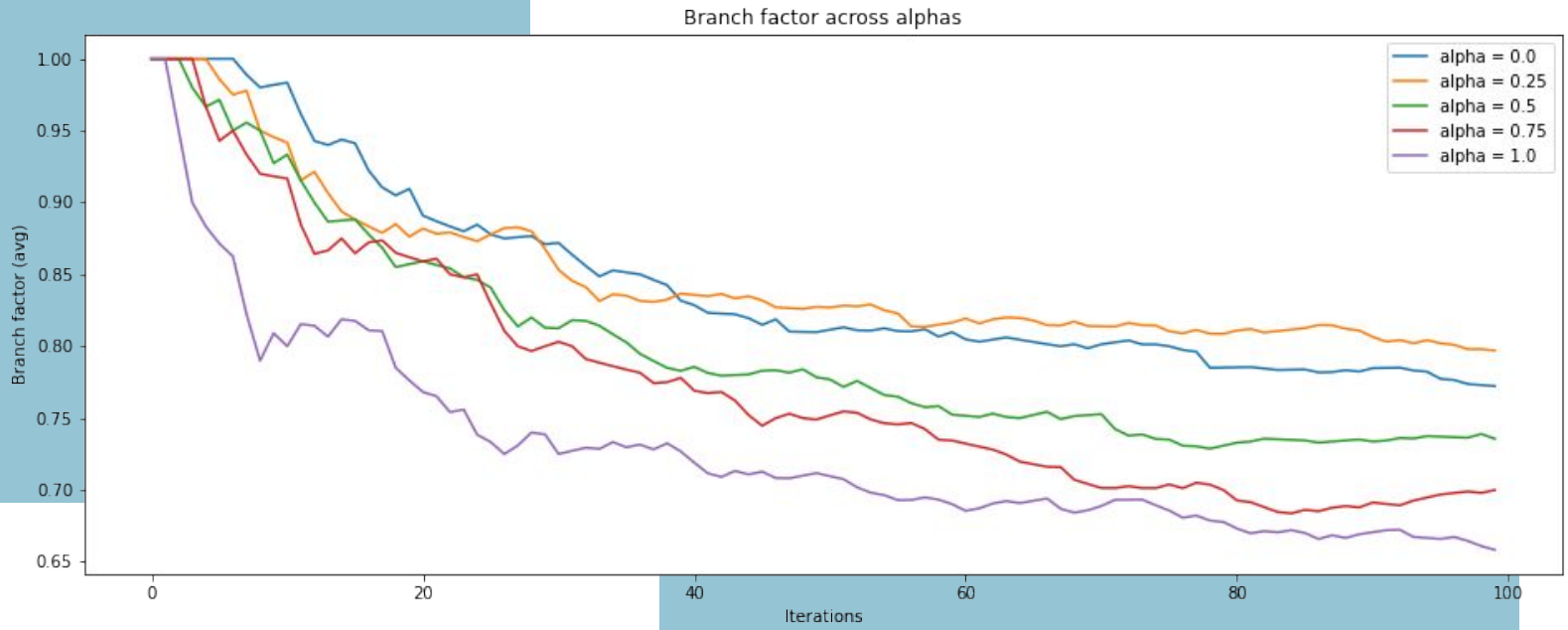
Alpha = 1



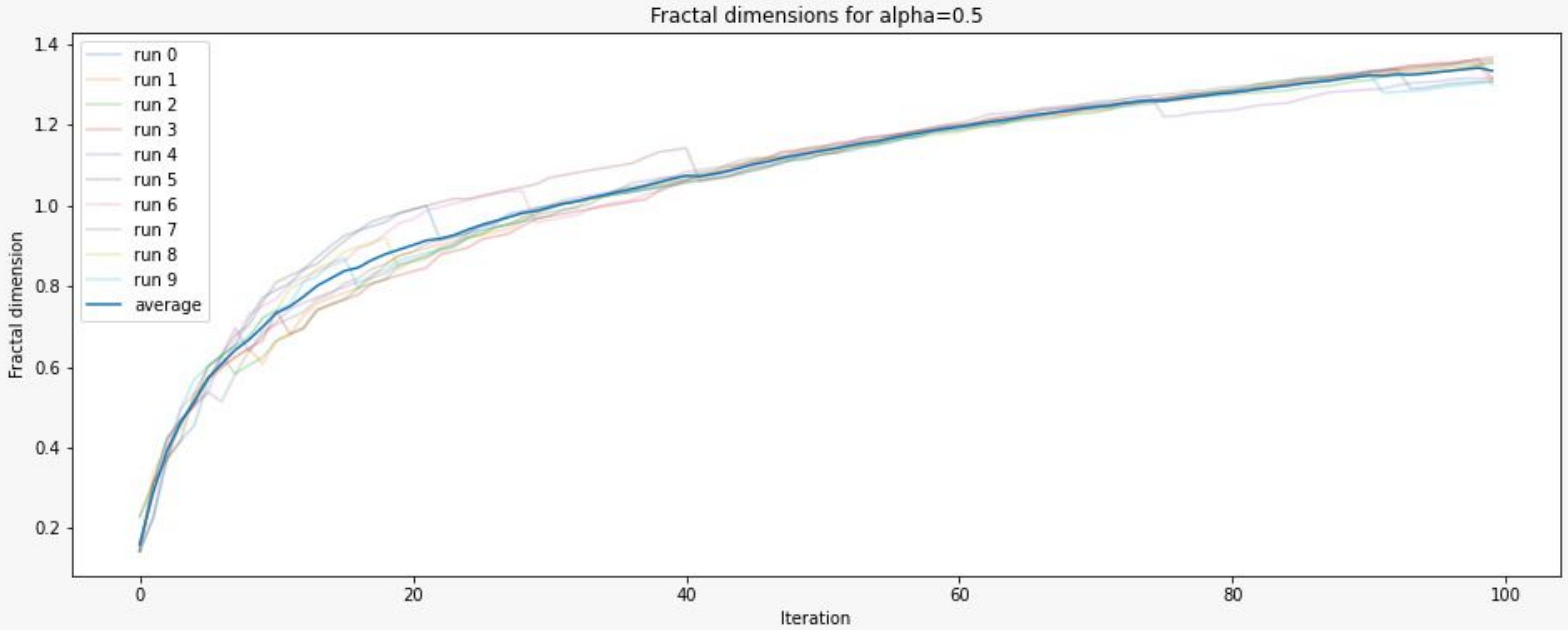
SUNLIGHT AND NUTRIENTS BRANCH FACTOR



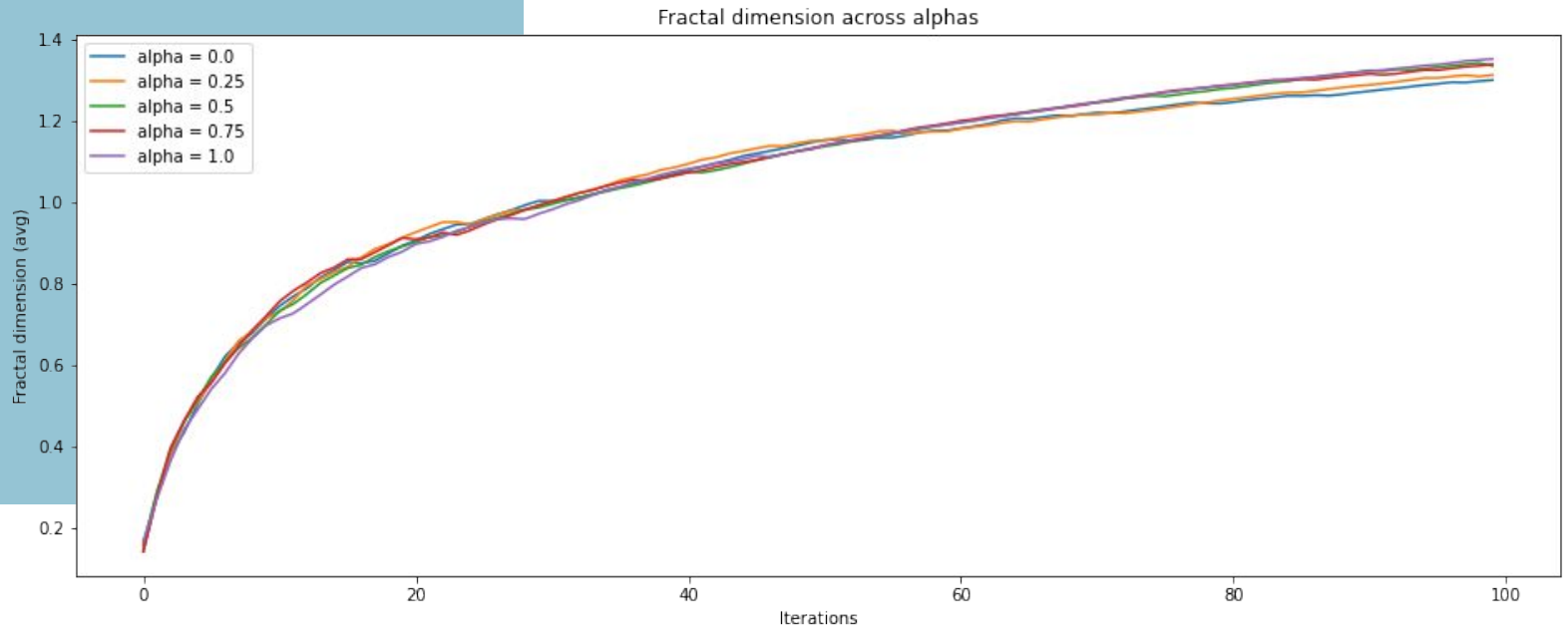
SUNLIGHT AND NUTRIENTS BRANCH FACTOR



SUNLIGHT AND NUTRIENTS FRACTAL DIMENSION

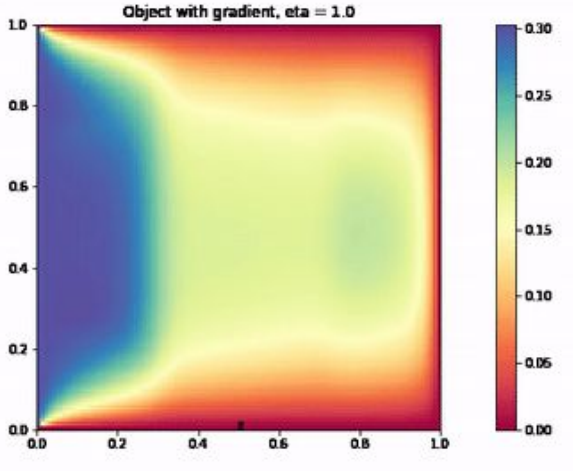


SUNLIGHT AND NUTRIENTS FRACTAL DIMENSION



RESULTS
EROSION

threshold = 0.0



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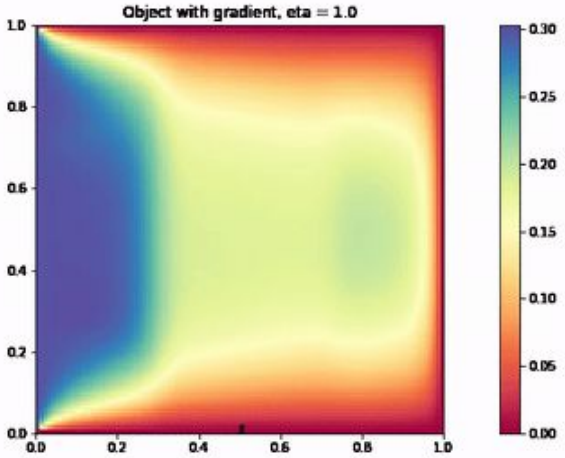
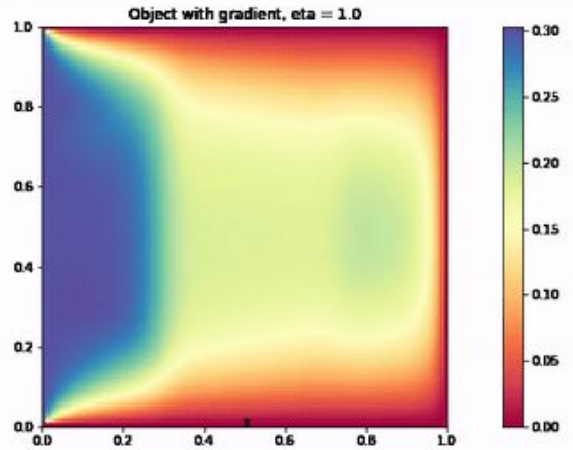


threshold = 0.0503



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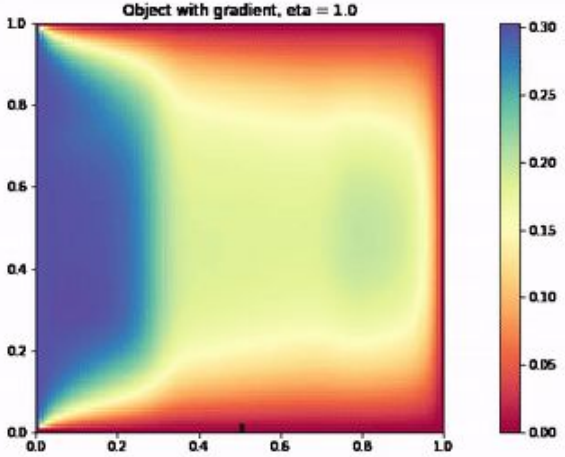

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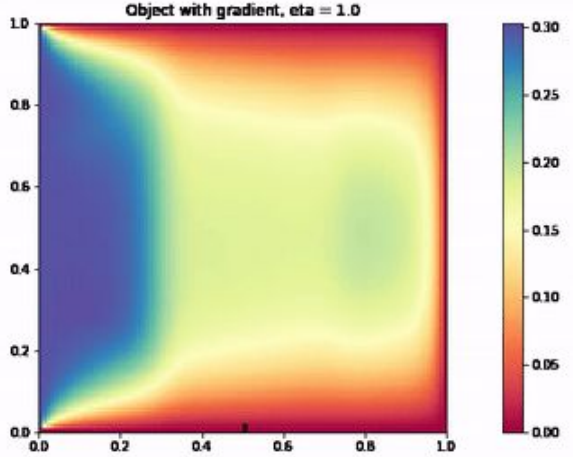
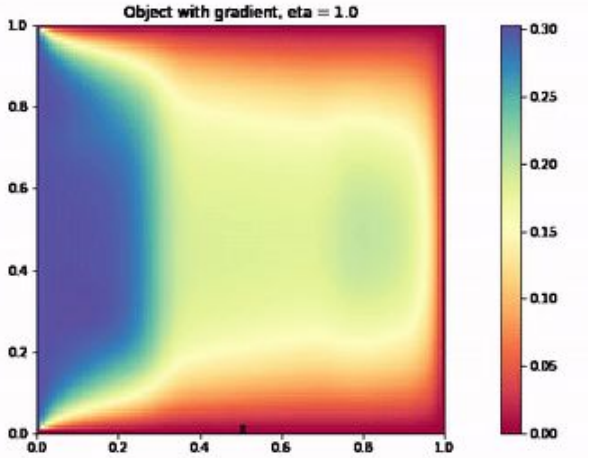


RESULTS
EROSION

threshold = 0.0



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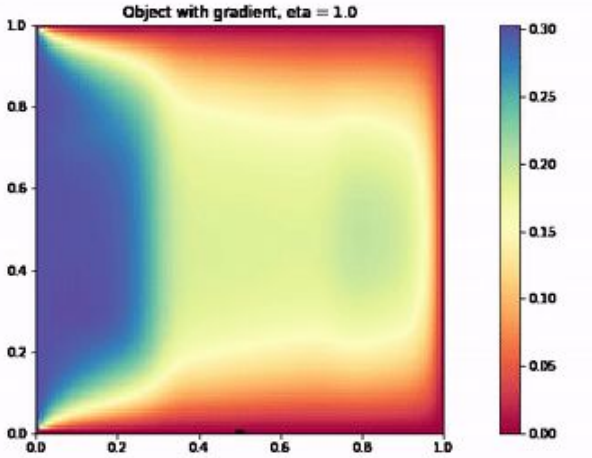

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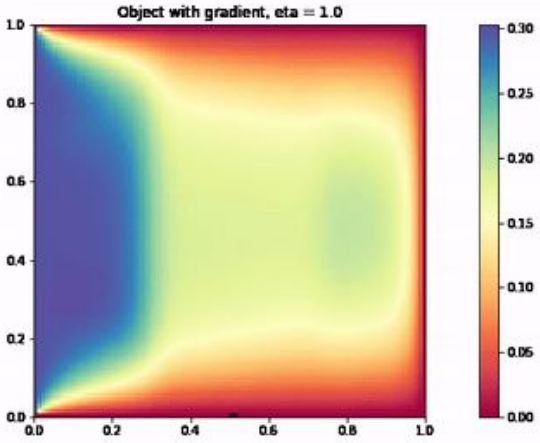

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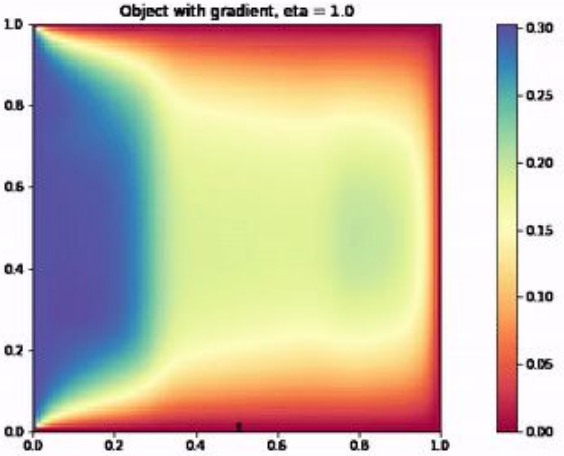

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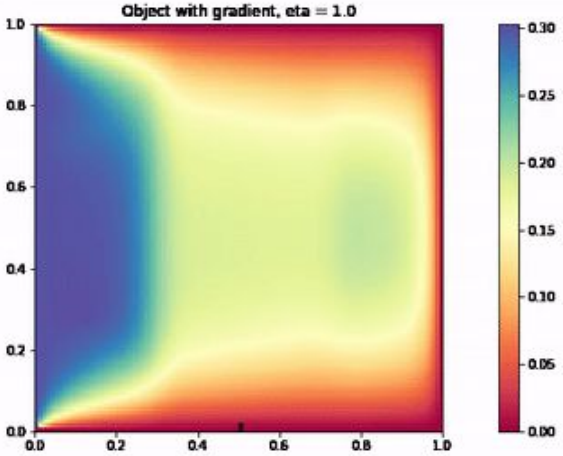
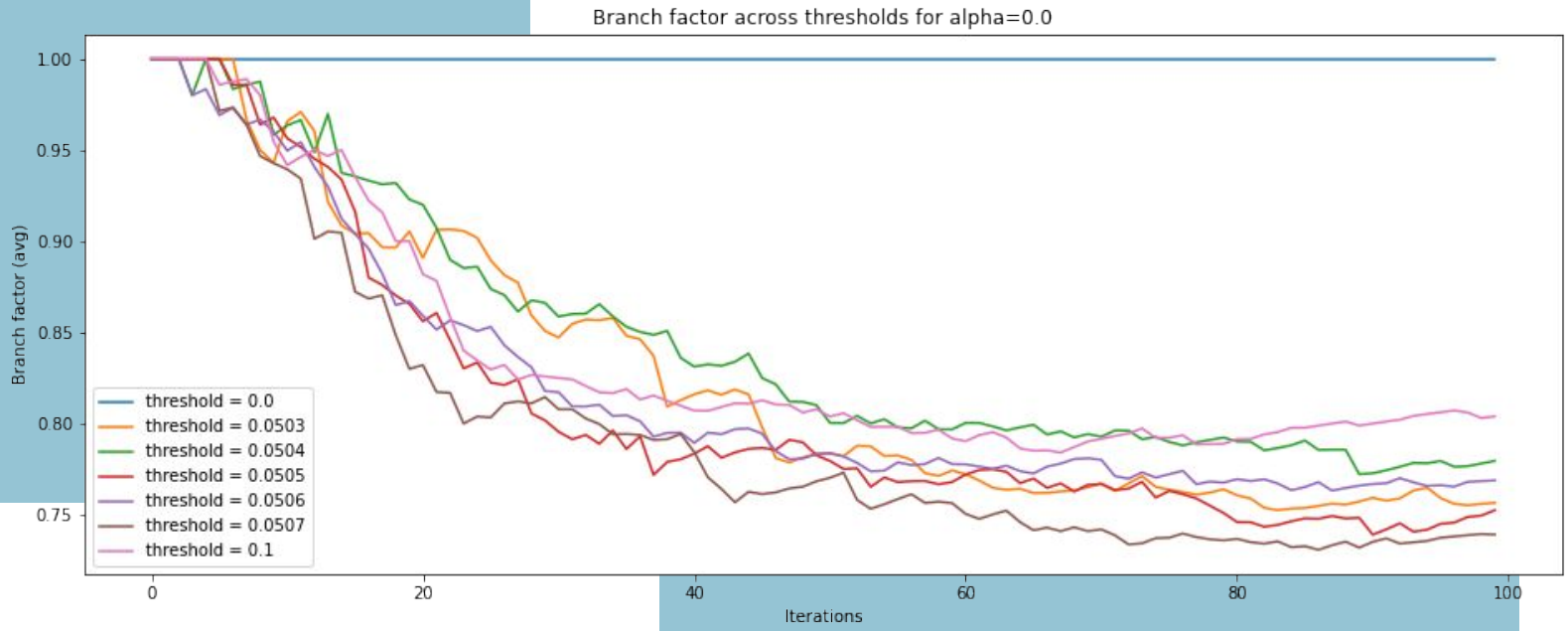
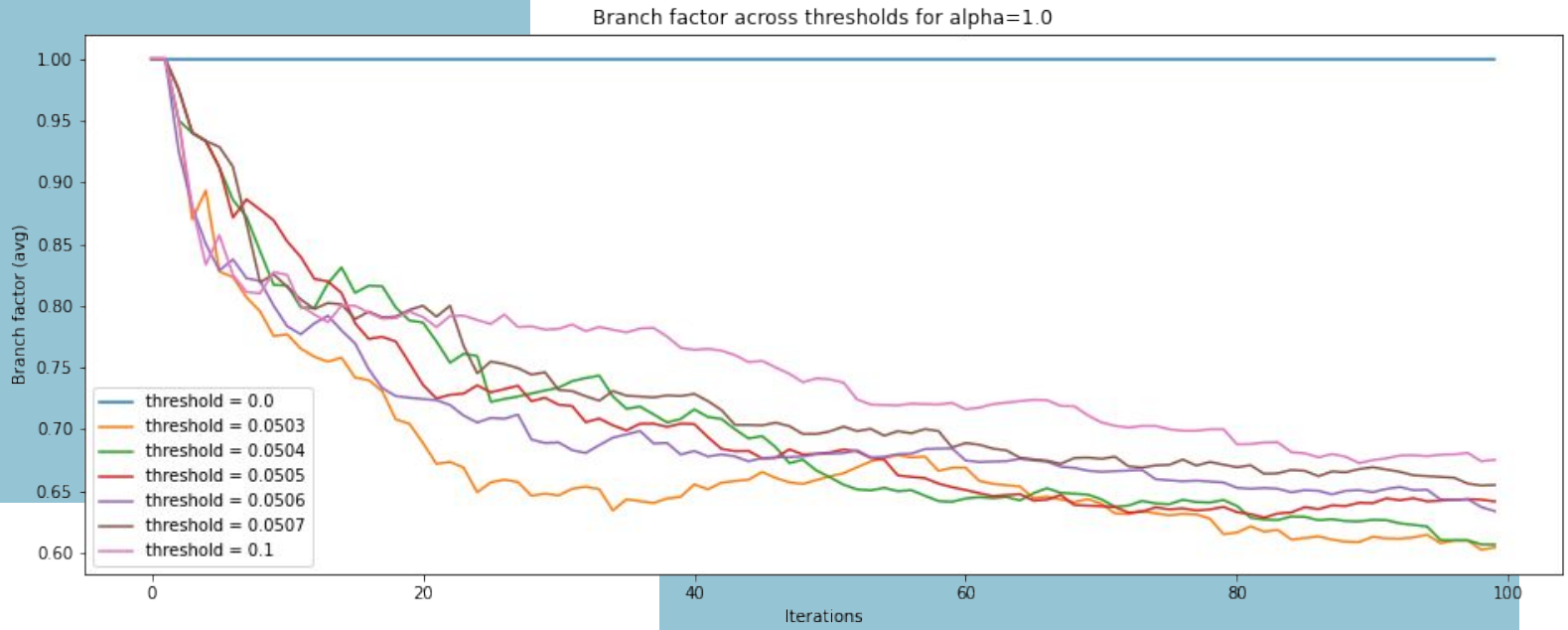


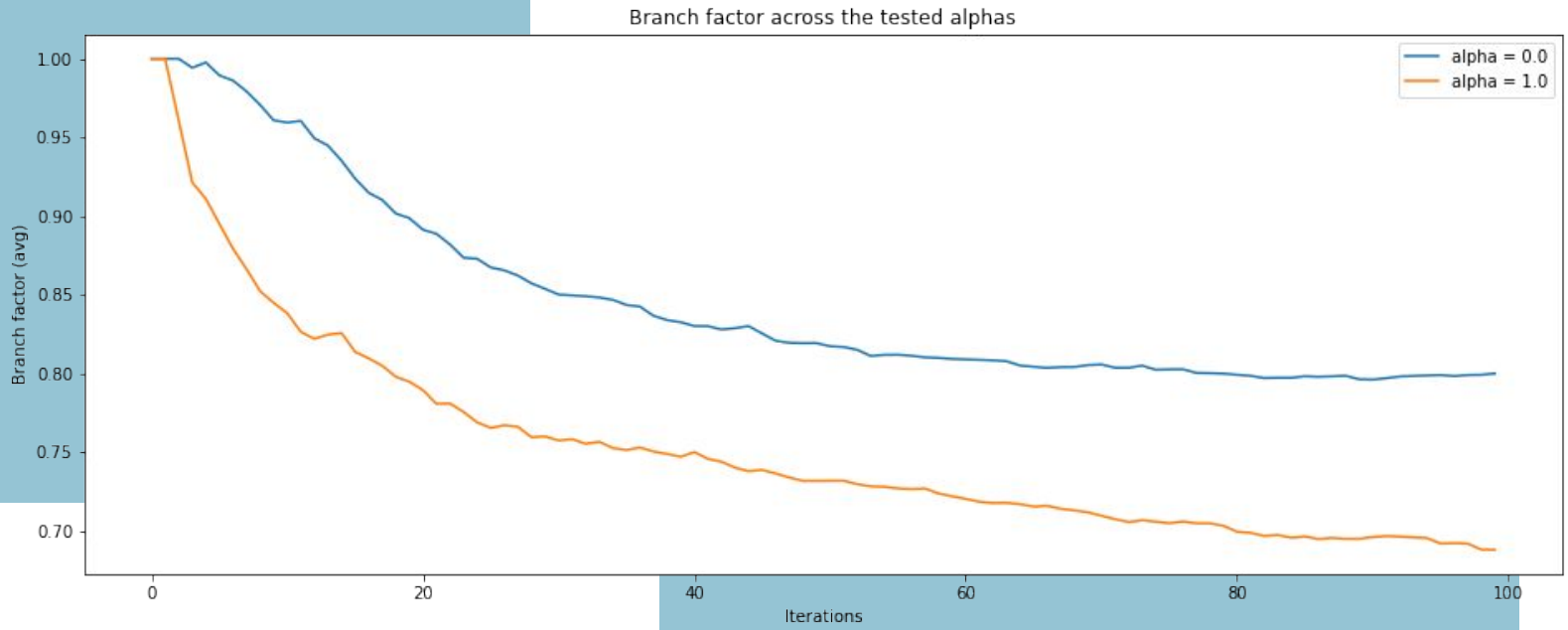
RESULTS
EROSION



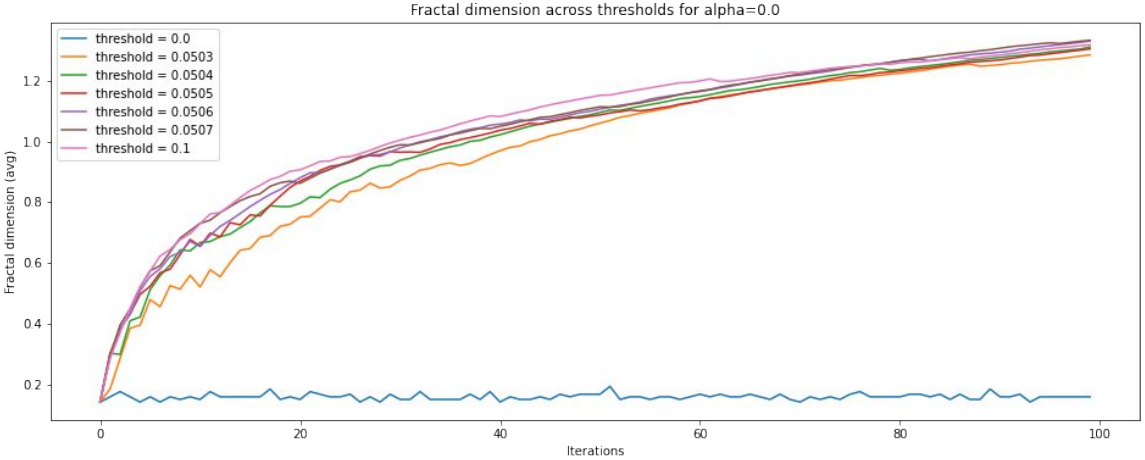
RESULTS
EROSION

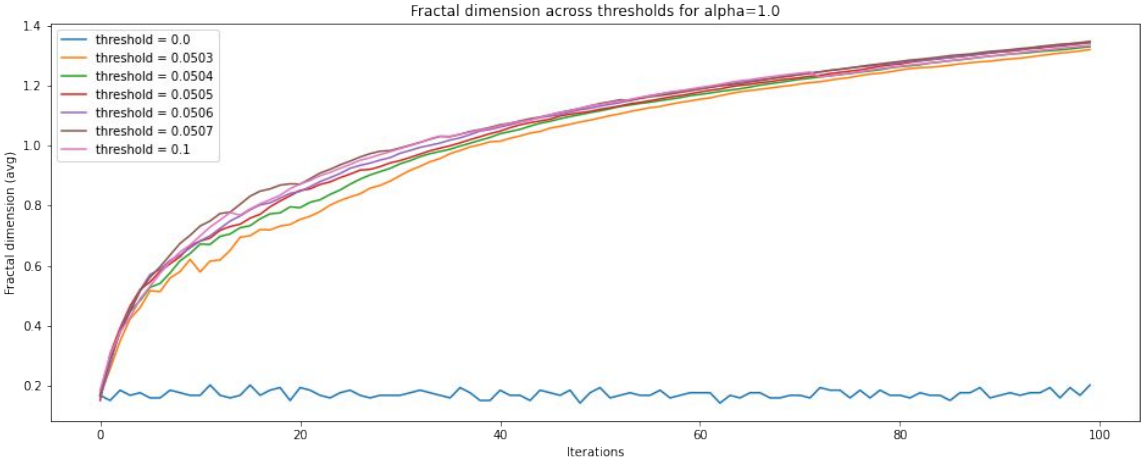


RESULTS
EROSION



RESULTS EROSION



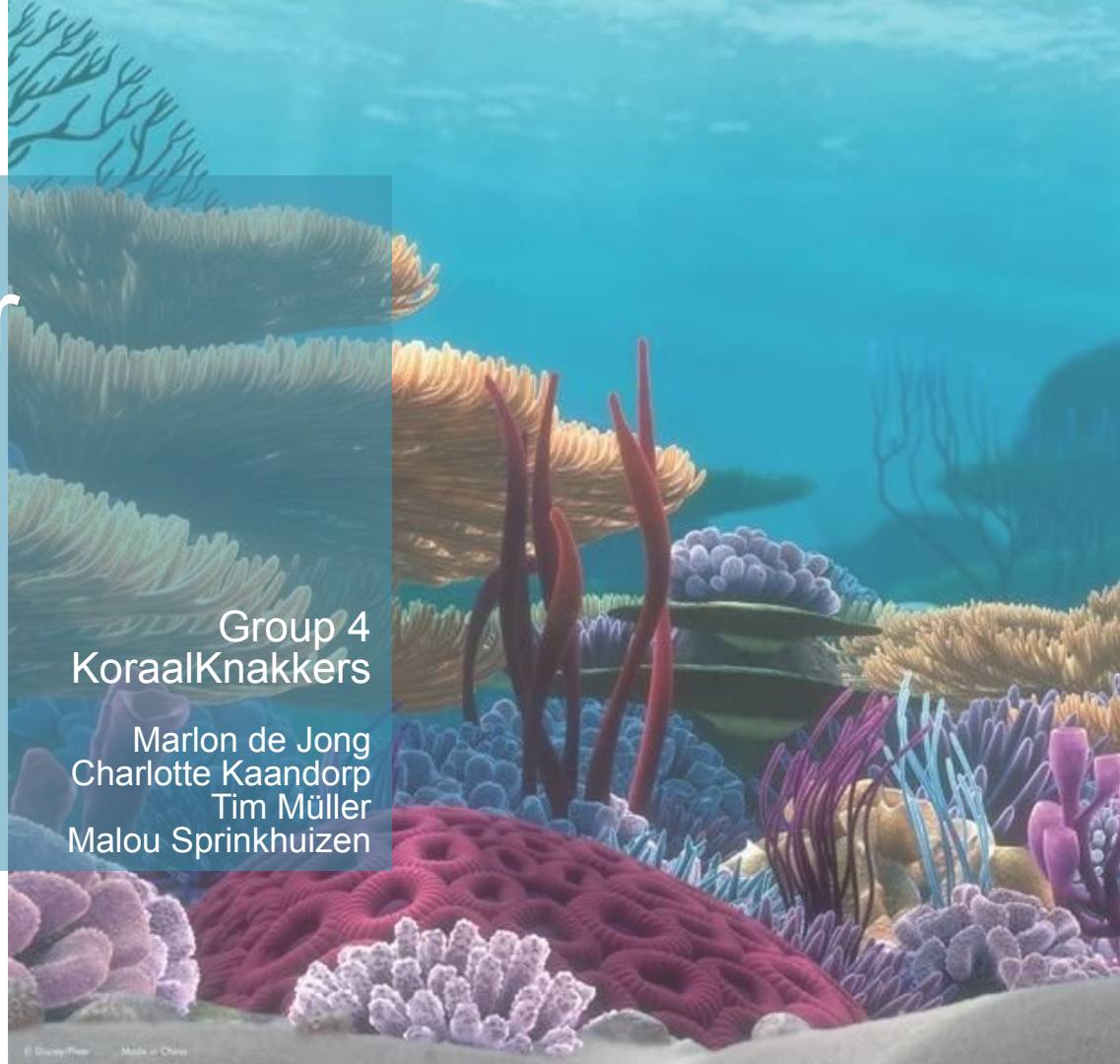


DISCUSSION

- Coral breaking would influence the environment
- Nutrient concentration has sink on all sides but left
- 2D makes a lot of assumptions
  - Nutrients cannot go around or through coral
  - Sunlight does not reflect or vary in intensity
- Flow is constant

Thank you for listening

Questions?



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APPENDIX

REFERENCES

- Martin-Garin, B., Lathuilière, B., Verrecchia, E.P. *et al.* Use of fractal dimensions to quantify coral shape. *Coral Reefs* 26, 541–550 (2007)
- Kaandorp J.A., Filatov M., Chindapol N. Simulating and Quantifying the Environmental Influence on Coral Colony Growth and Form. In: Dubinsky Z., Stambler N. (eds) Coral Reefs: An Ecosystem in Transition. Springer, Dordrecht (2011)
- Kaandorp Jaap A., Koopman Evert A., Sloot Peter M. A., Bak Rolf P. M., Vermeij Mark J. A. and Lampmann Leo E. H. Simulation and analysis of flow patterns around the scleractinian coral Madracis mirabilis (Duchassaing and Michelotti)Phil. Trans. R. Soc. Lond. B3581551–1557 (2003)
- Jaap A. Kaandorp, Christopher P. Lowe, Daan Frenkel, and Peter M. A. Sloot Effect of Nutrient Diffusion and Flow on Coral Morphology (1996)

APPENDIX

FRACTAL DIMENSION

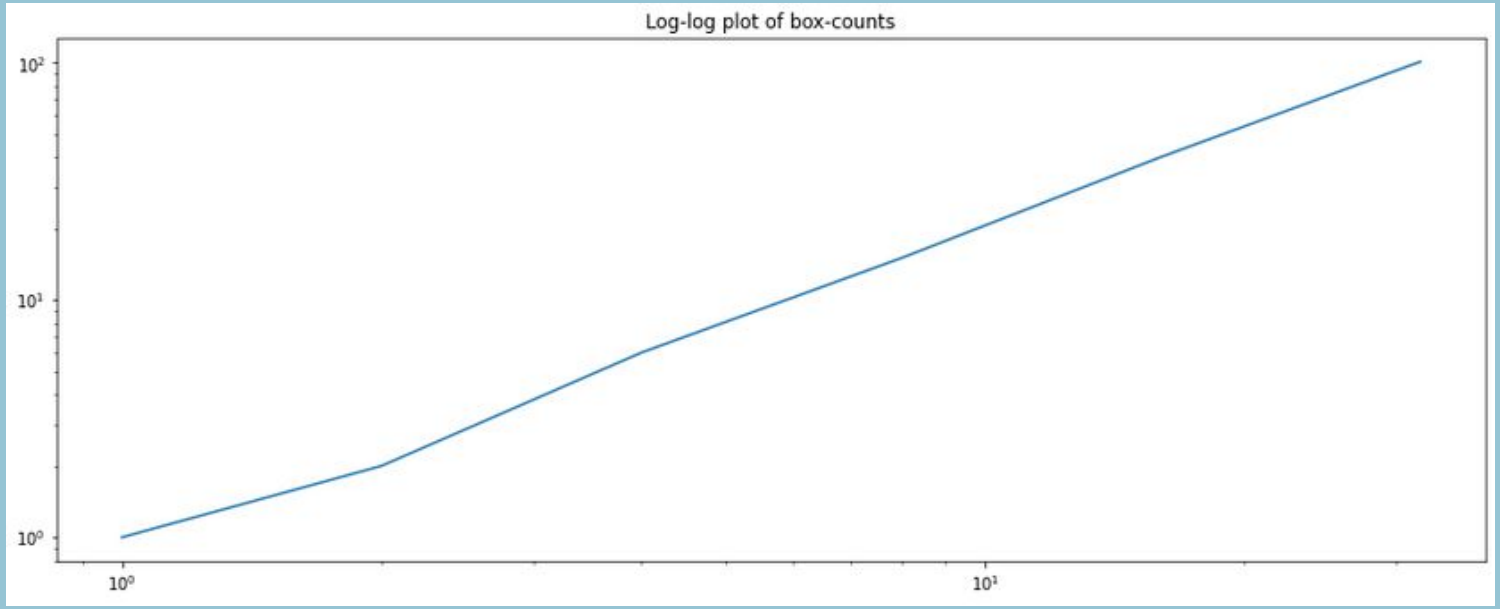

Figure 1: Plot of the fractal dimension for various alpha's. This time, it's plotted on a log-log scale to check the validity of the dimension: we should see a straight line, which we kinda see.

APPENDIX