LLNL-POST-781437

Sand Dune Video Prediction

From Cellular Automaton to Convolutional Neural Networks (CNNs)

Divya Mohan (UC Berkeley), Jenna Horrall (James Madison University), Kelly Kochanski (University of Colorado Boulder), Barry Rountree (LLNL)

DATA SCIENCE SUMMER INSTITUTE

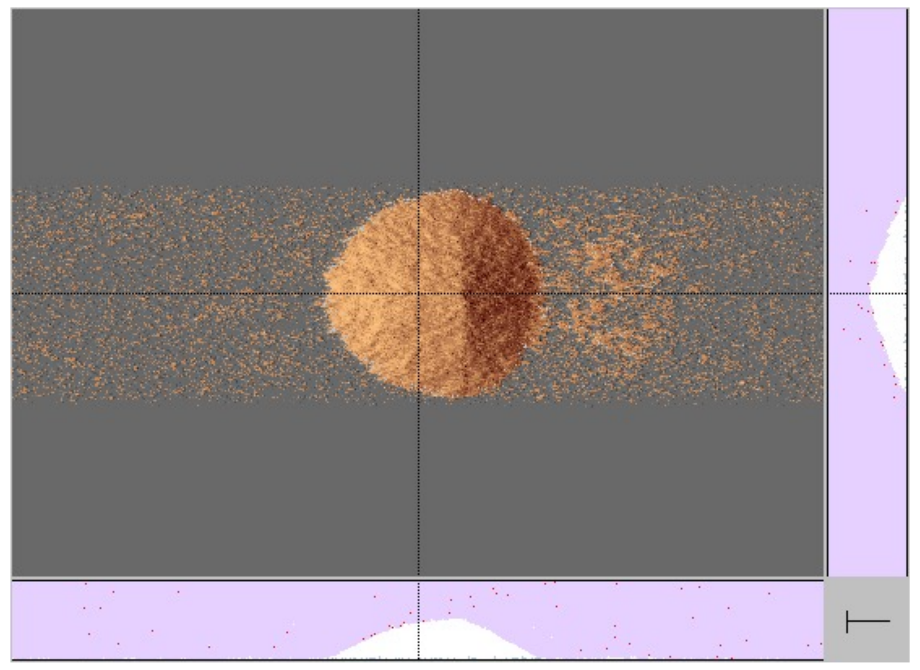
Lawrence Livermore National Laboratory

ABSTRACT

- ReSCAL (Real-Space Cellular Automaton Laboratory), a fully-developed numerical model, is a cutting-edge sand dune modeling software used widely across the geology community
- However, this simulation software is slow due to its reliance on physical calculations on a cell-by-cell basis
- Fortunately, Machine Learning algorithms have been proven to be faster due to their abilities to parallelize in training and almost instantaneous predictions
- Using real-world satellite elevation maps, a machine learning algorithm would allow us to predict sand dune movements farther into the future

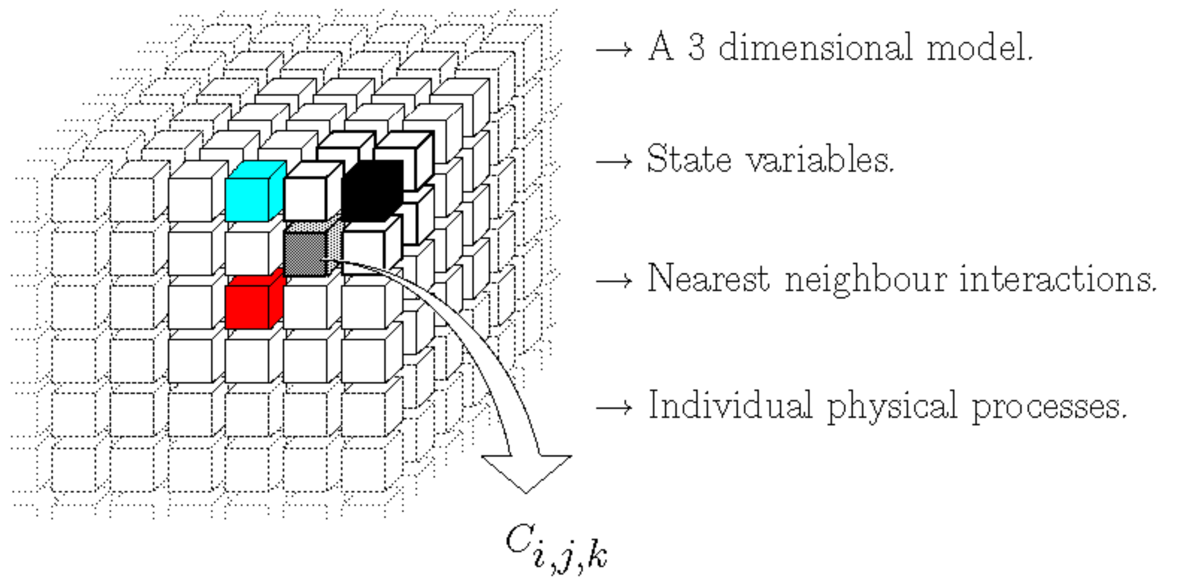
INTRODUCTION

- How ReSCAL models sand dunes: 3D multiphysics, markovian and stochastic cellular automata with continuous time



Example of a sand dune frame produced by ReSCAL

- Problem: ReSCAL is computationally expensive and difficult to parallelize for large-scale simulations →
- Objective: replace with a Machine Learning model



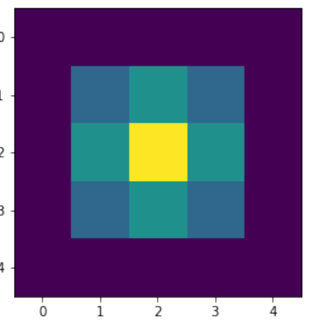
ReSCAL Cellular Automaton process (from [1])

METHOD

Data

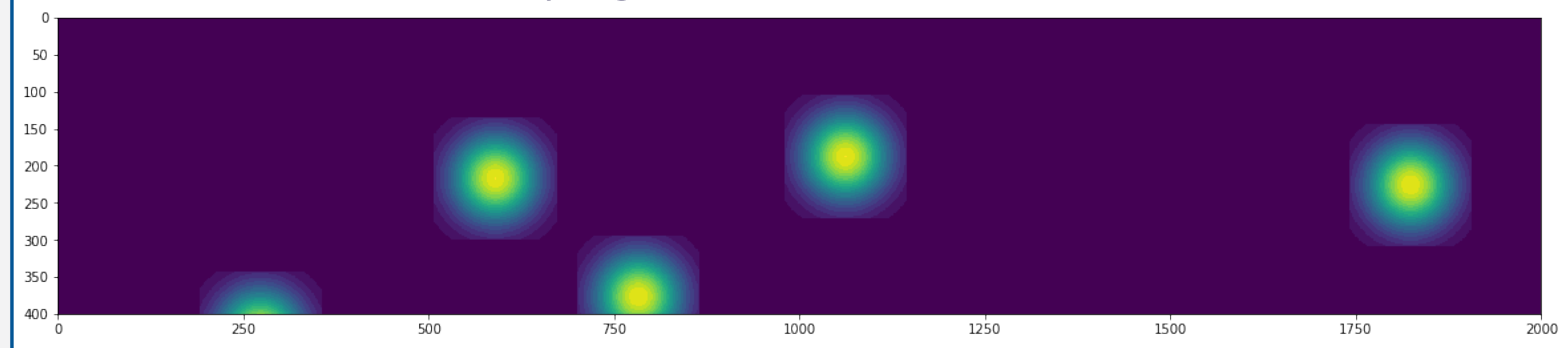
- Data Source: Run ReSCAL on Quartz LC Machine to generate frames of sand dune movements
- Data Format: 2D Elevation Maps

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 3 & 2 & 0 \\ 0 & 3 & 6 & 3 & 0 \\ 0 & 2 & 3 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



A top-down view of a small hill

- Data Collection: ReSCAL is set and calibrated with the parameters from [2]. Scenes consists of randomly placed Gaussian hills, varying the size and locations of the hills

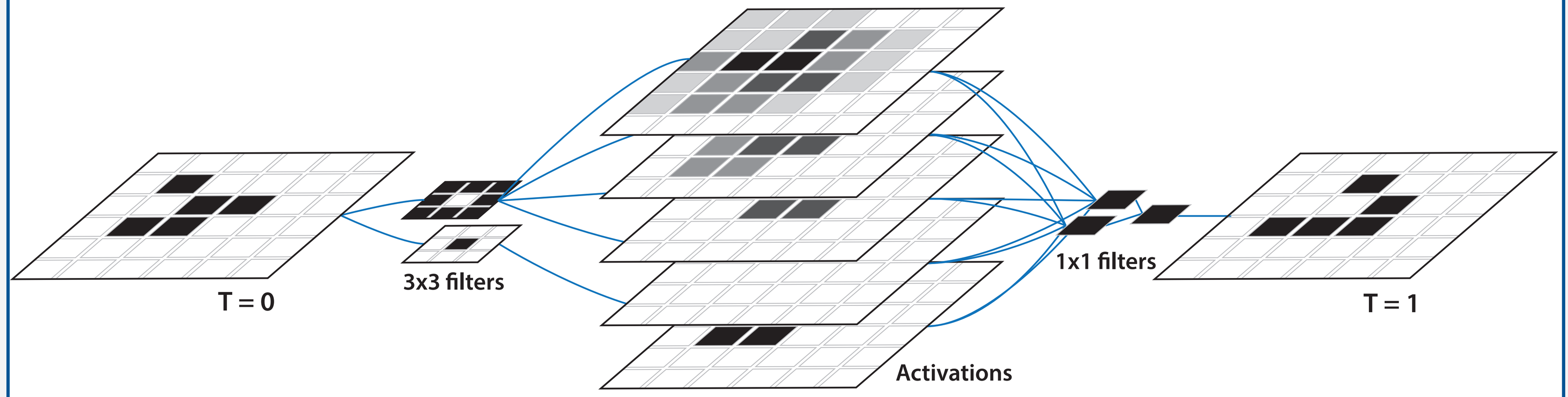


Objective

- Given n_0 frames of dimension $L \times D$, predict the frame at a later time step n_f

Model Selection

- Rather than approach this problem as a standard video prediction problem, I exploit the fact that ReSCAL uses a set of cellular automaton rules to produce each frame
- I selected a pre-implemented CNN model that trains from cellular automaton output and contains layers meant to emulate the cellular automaton process [3]



Neural network layers to represent cellular automaton (from [3])

RESULTS

Time Efficiency

- ReSCAL generates two~ $1800\times100\times200$ frames every hour
- After 24 hours of training, the CNN Model generates one $50\times100\times50$ frame in 0.01~ seconds

Mean Square Error (MSE)

Step Size*	Mean MSE	Max. MSE
1	0.9258	304.5295
3	0.1508	22.1175
5	0.2807	301.5770
7	1.2304	645.9474
10	0.1752	45.6221
15	0.7065	357.3875

*Step size refers to a model that, given $Frame_n$, predicts $Frame_{n+STEP\_SIZE}$

Example of input frame at t_n, and expected/predicted frame at t_{n+1}

DISCUSSION

- The speed efficiency of a machine learning model versus a numerical model will allow for predictions of sand dune movements farther into the future, on the scale of years.
- The ability to predict the location of sand dunes holds capitalistic promise for determining potentially hazardous locations of development

REFERENCES

- [1] Rozier, O. and Narteau, C. (2014), A real-space cellular automaton laboratory. Earth Surf. Process. Landforms, 39: 98-109. doi:10.1002/esp.3479
- [2] Narteau, C., Zhang, D., Rozier, O., and Claudin, P. (2009), Setting the length and time scales of a cellular automaton dune model from the analysis of superimposed bed forms, *J. Geophys. Res.*, 114, F03006, doi:10.1029/2008JF001127.
- [3] Gilpin, William. "Cellular automata as convolutional neural networks." *arXiv preprint arXiv:1809.02942* (2018).

- Contact: Divya Mohan <21dmohan@berkeley.edu>

Transitioning a Cellular Automaton Model to a CNN for Sand Dune Video Prediction

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.