Create a Time Machine for Conway's Game of Life

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1 Problem statement

Let say we have Conway's game of life board with the size n^2 cells at timestep $t = t_0 + \Delta t$. Is it possible to retrace one of the state of the board at timestep $t = t_0$ within reasonable time? In another word, let say we have the grid G size n^2 with initial selected grids set $A_0 = \{(x_0, y_0), (x_1, y_1), \ldots, (x_k, y_k)\} \subset G$ with the following rules (at timestep t):

- *Underpopulation* Cell with less than u neighbors will be removed from A_{t+1}.
- *Overpopulation* Cell with more than o neighbors will be removed from A_{t+1}.
- *Stasis* Cell with the number of neighbors between u and o still in set A_{t+1}.
- *Reproduction* Cell with exactly $u \leq r \leq o$ neighbors will be added to set A_{t+1}.

Given a state of set $A_{t+\Delta t}$, can we retrace the possible set A_t such that after Δt timestep, will become the same set within reasonable time? For the sake of simplcity, let $u = 2, o = r = 3$.

2 Dataset

The dataset is from Kaggle (`https://www.kaggle.com/c/conways-reverse-game-of-life-2020/data`). The data refers to $n = 25$ board with start (t) and stop ($t + \Delta t$) positions represent by the binary (0 for $(x, y) \notin A$ and 1 for $(x, y) \in A$) start from row 1 column 1 to row 1 column 25 and continue to the last row (in total of 627 columns with 50000 rows each for training and testing including the board `id` and Δt). However, only one state of the game will be record, that is, if there are many starting board A_t exists, only one of them will exist on the dataset. Moreover, we can create our own dataset by simulating the Conway's game of life ourselves.

3 Optimization/Algorithm

As the problem suggested, the information is lost every increment of timestep. To recovered the lost information, we might be able to use some method similar to image upscaling or image compression problem to recreate the missing information (that is, the formation A_t from $A_{t+\Delta t}$). Or we can treat this problem as a task that we need to match $A_{t+\Delta t}$ with A_t. More algorithms might be introduced after further literature review.

3.1 Convolution Neural Network

We can look at this problem as trying to find the (set of) transformation kernels Φ such that for a given formation A_t we can transform our formation into the past formation A_{t-1}. The problem is seeming to suits CNN as we need to look at the neighbors to analyze the possibility according to the rule on problem statement which is similar to the kernel in CNN. We can use the cross entropy (for all elements inside the grid) as our loss function for simplicity and can explore more loss function later on.

3.2 Cycle-Consistent Generative Adversarial Networks (CycleGAN) [1]

We will treat this problem like style transferring problem where we need to transform $A_{t+\Delta t}$ into A_t. The whole goal of CycleGAN is to generate consistency on the input and generated output by reconstructing the input with its output. We can take the advantage of the reconstruction part. In another word, we can train the model to generate the forward iteration and reconstruct the backward iteration. In this case, we can use adversarial and cycle consistency loss like what suggested on the paper[1] and use the generator for reconstruction.

References

[1] Zhu, J.-Y., Park, T., Isola, P., and Efros, A. A. Unpaired image-to-image translation using cycle-consistent adversarial networks. In *Computer Vision (ICCV), 2017 IEEE International Conference on* (2017).