Train Once, Generate Anywhere

Discretization Agnostic Neural Cellular Automata using SPH Method

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TL; DR We introduce **SPH-NCA**, a discretization-agnostic neural cellular automata framework that uses a differentiable SPH method for perception and a stable training scheme, allowing image and texture synthesis on *any grid, resolution, or 3D surface* while trained on a fixed-resolution 2D image.

Motivation

Neural Cellular Automata are *awesome*! They're simple, robust, self-organizing, and lightweight [1]. Inspired by their local perception mechanism, we began to search for a universal architecture that is applicable on various surfaces.

Related Works

Models	Spatial data	Perception mechanism	Robust training[1]	Robust generation[2]
NCA [1]	Regular grid	Sobel filter	✗	✗
GraphNCA [2]	Graph	Message passing	✓	✗
MeshNCA [3]	Mesh surface	Spherical harmonics	✓	✗

[1] Can the model train on diverse discretizations?
[2] Once trained, can the model generate on other types of discretization, such as from a square grid to irregular grids?

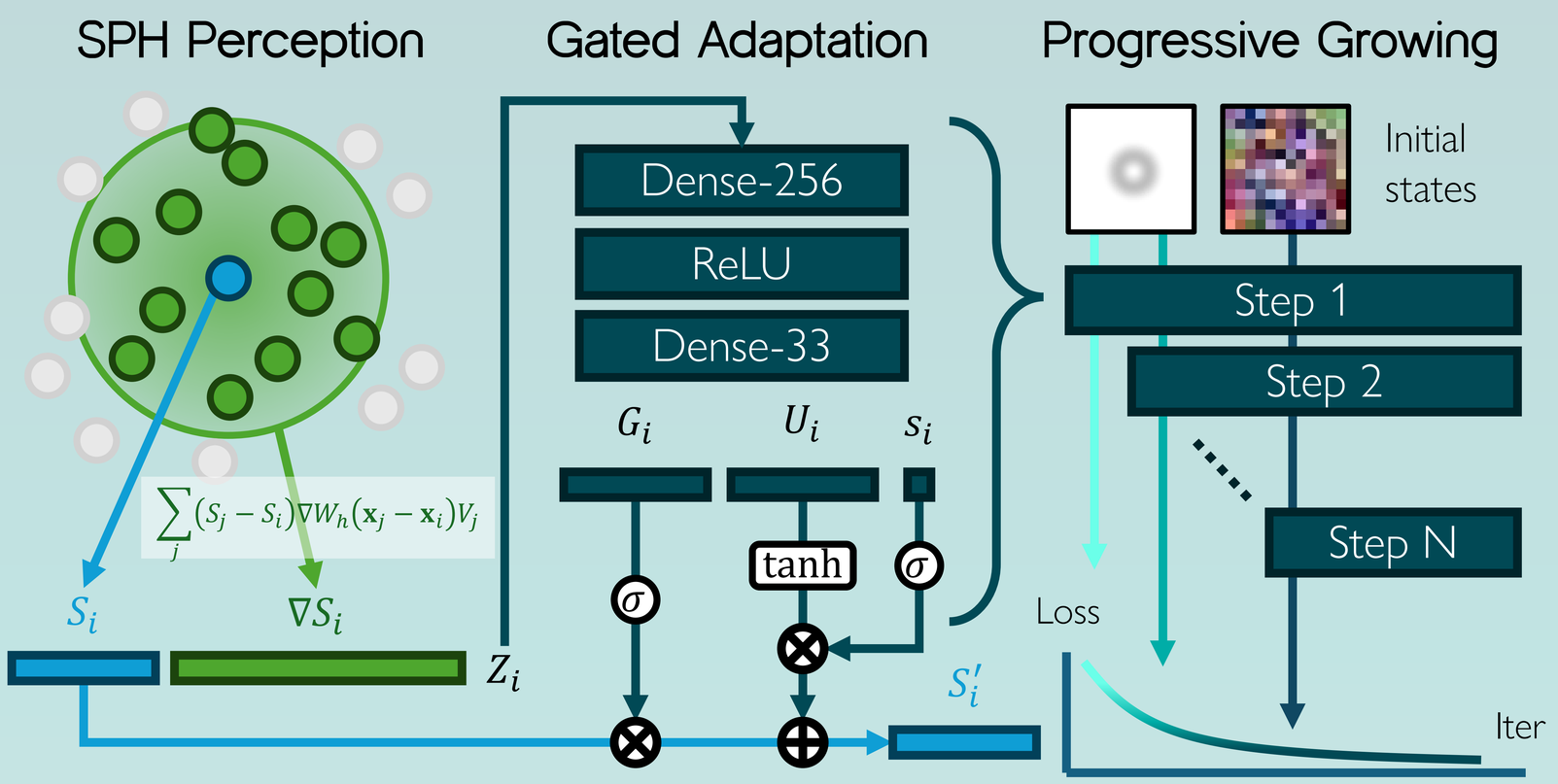
Our Approach

Perception mechanisms in previous works are prone to ***overfitting to the original topology*** of the trained domain.
We built our framework around the ***perception mechanism based on SPH method*** that can give consistent gradient for any discretization.

Conclusion

SPH-NCA framework can *"train once, generate anywhere"* across diverse resolutions, grid regularities, and 3D geometries.
This result highlights the potential of differentiable SPH methods for robust spatial data learning in generative models, opening new avenues for future research.

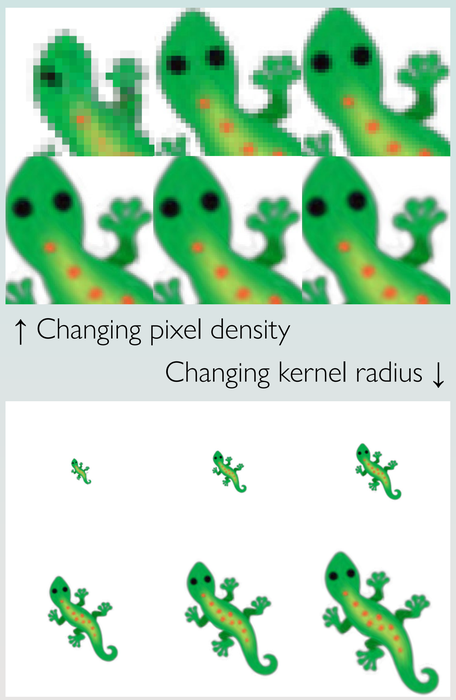
SPH-NCA Framework



Results

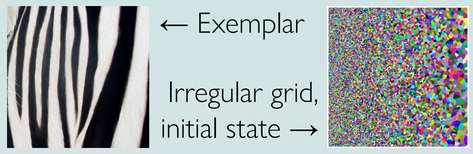
Also take a look at our supplemental video for evolving SPH-NCA in action!

RGBA Image

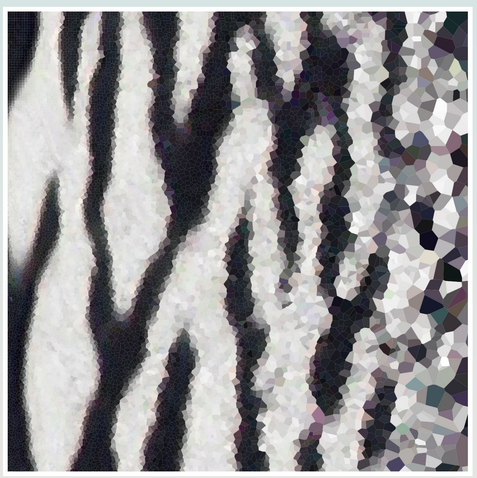


↑ Changing pixel density
Changing kernel radius ↓

Exemplar-based Texture



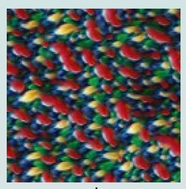
Test-time generalization on a grid of varying regularity & density ↓



Text-guided Texture

"A colorful pile of red, yellow, green, and blue jellybeans"

Trained domain →



← Test-time generalization on a 3D surface

References

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[2] Daniele Grattarola, Lorenzo Livi, and Cesare Alippi. 2021. **Learning graph cellular automata**. Advances in Neural Information Processing Systems 34 (2021), 20983–20994.
[3] Ehsan Pajouheshgar, Yitao Xu, Alexander Mordvintsev, Eyvind Niklasson, Tong Zhang, and Sabine Süsstrunk. 2024. **Mesh neural cellular automata**. ACM Transactions on Graphics (TOG) 43, 4 (2024), 1–16.

Contact me!
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