Automates cellulaires

La palpitante vie d'un pixel en communauté

Définition

- Un système dynamique discret défini sur une grille régulière
  - On le note formellement (S, N, f) avec
    S l'ensemble des états possibles d'une cellule,
    N la structure de voisinage et
    f la fonction de transition locale

- En pratique :
  "Une grille régulière où chaque cellule a un état défini à chaque instant t selon l'état de ses voisins à l'instant t-1"

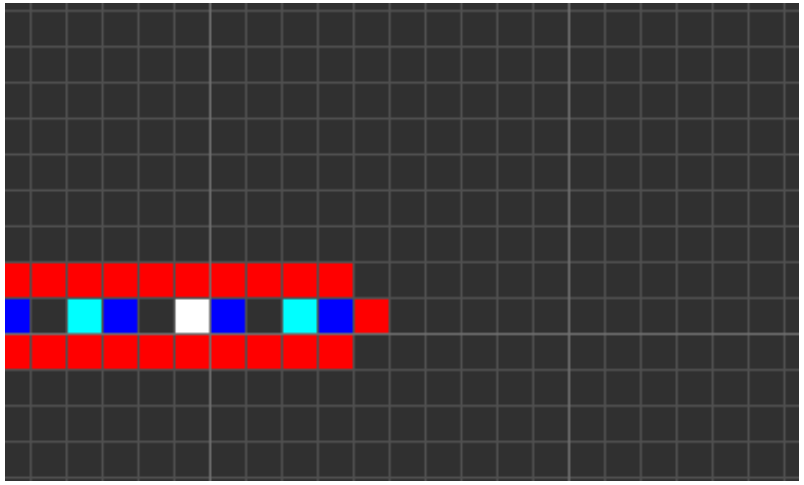
Avantages

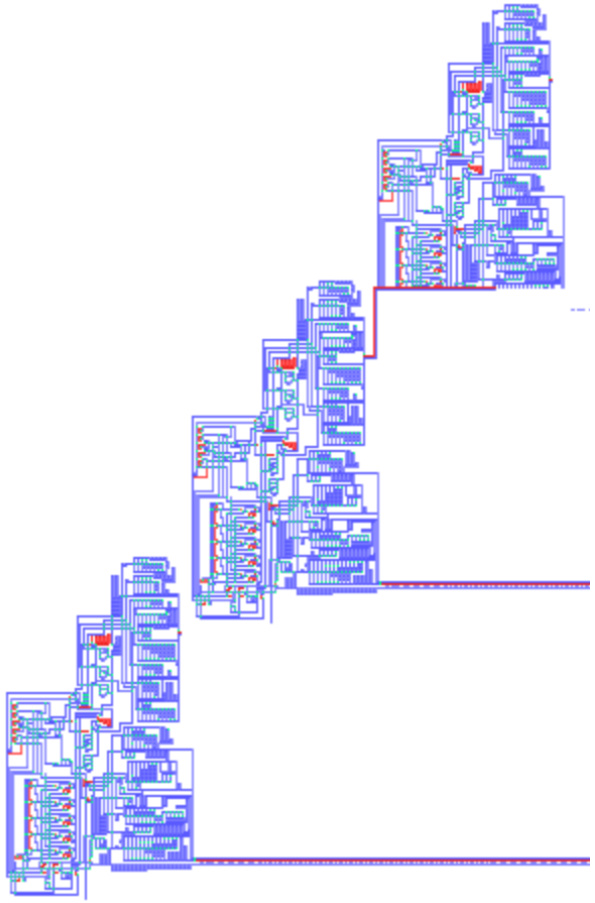
- Transitions locales
  - Adapté au parallelisme GPU
  - Utilisation de règles locales
- Emergence de comportements globaux (généralement) cahotiques
- Formalisme

Cagigas-Muñiz, D., Diaz-del-Rio, F., Sevillano-Ramos, J. L., & Guisado-Lizar, J.-L. (2022). Efficient simulation execution of cellular automata on GPU. In Simulation Modelling Practice and Theory (Vol. 118, p. 102519). Elsevier BV. https://doi.org/10.1016/j.simpat.2022.102519

Automates autoréplicants

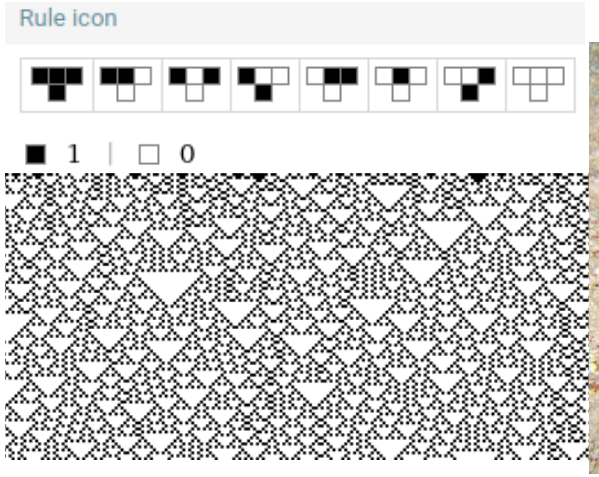
- Von Neuman (1966) : ze original, 29 états possibles
- Codd (1968) : seulement 8 états possibles
- Langton (1984) : codé en seulement 43 octets



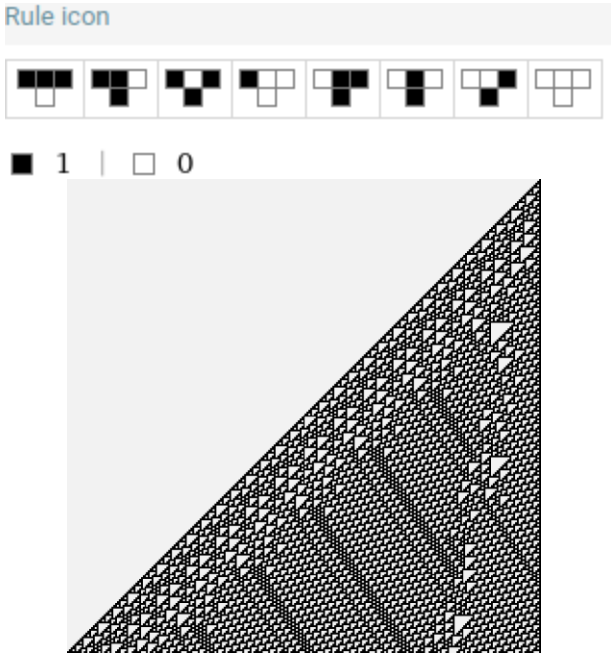


Automates élémentaires

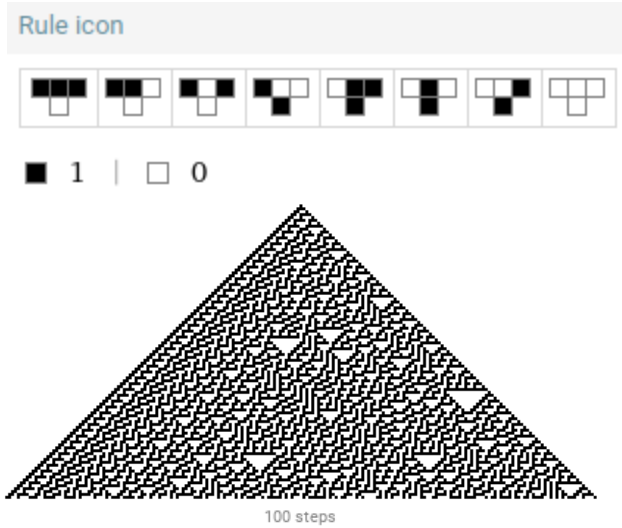
- Stephen Wolfram (~80s')



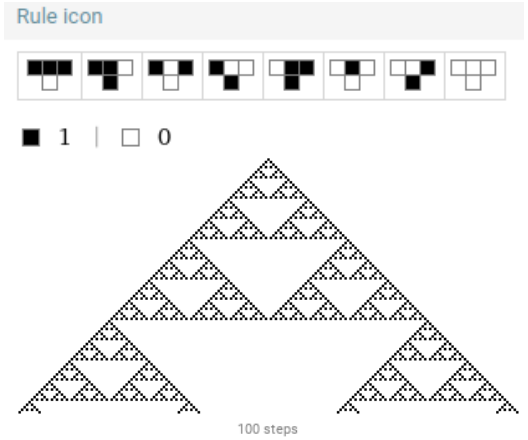
Rule 146 (random seed)



Rule 110



Rule 30



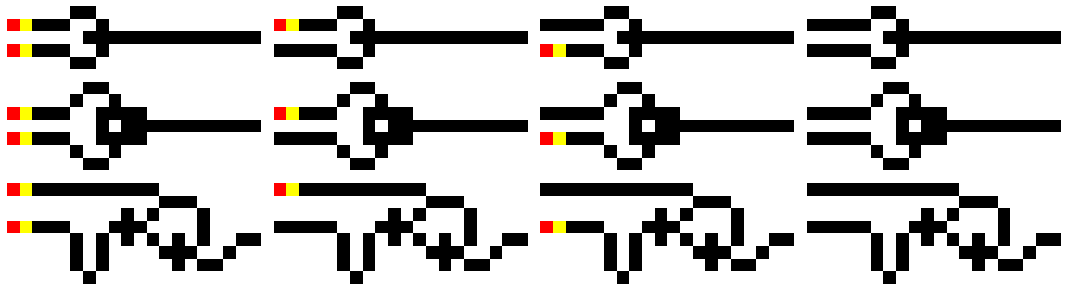
Rule 90

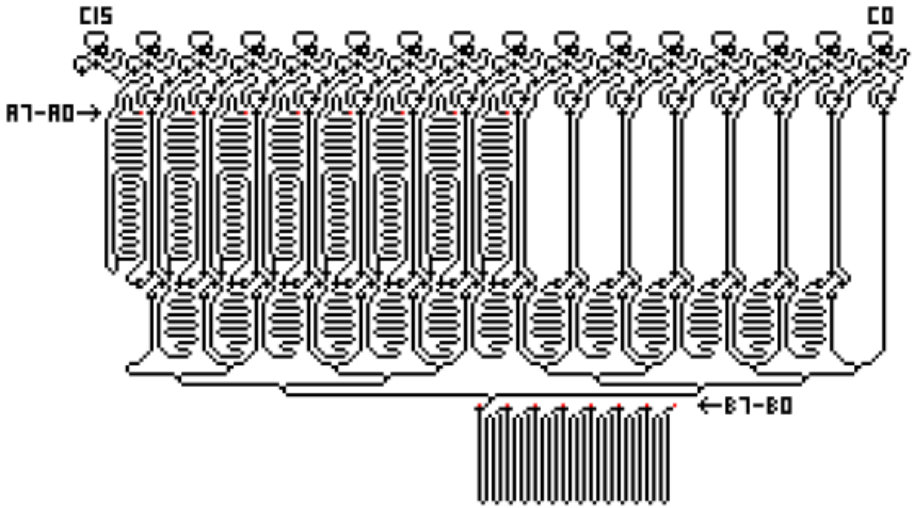
Wolfram, S. A New Kind of Science. Champaign, IL: Wolfram Media, pp. 55, 90, and 952, 2002.

Automates 2D

John Conway (~70s')

- Game of life
- WireWorld

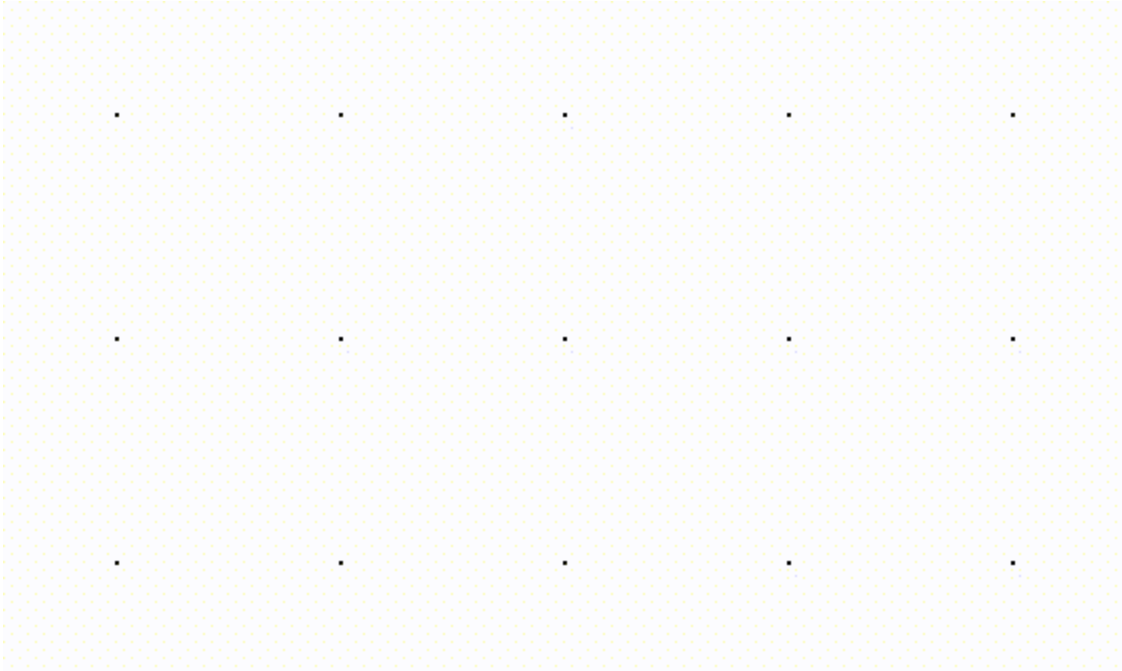




Gardner, Martin. “MATHEMATICAL GAMES.” *Scientific American*, vol. 222, no. 6, 1970, pp. 132–40
Dewdney, A. K. “COMPUTER RECREATIONS.” Scientific American, vol. 262, no. 1, 1990, pp. 146–49

CA et apprentissage profond

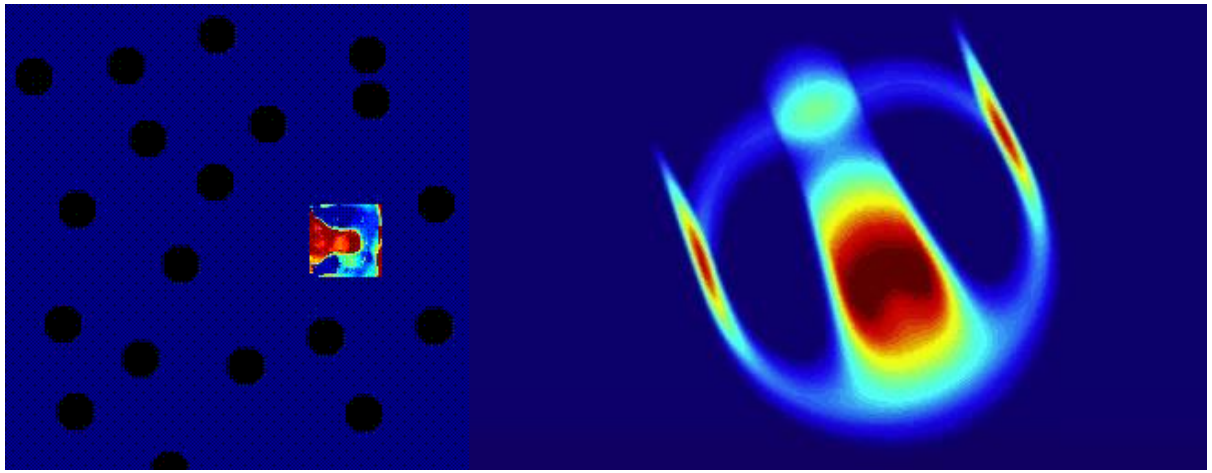
- Growing Neural Cellular Automata
- (Utilisation de ML
  pour déterminer les règles)

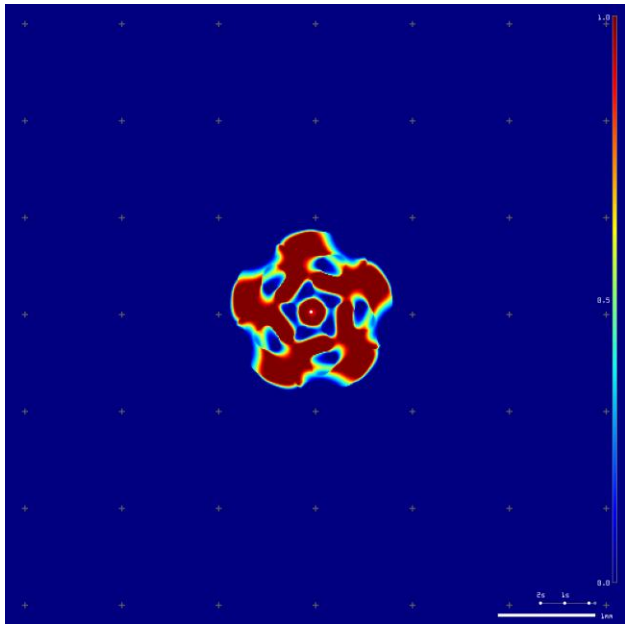


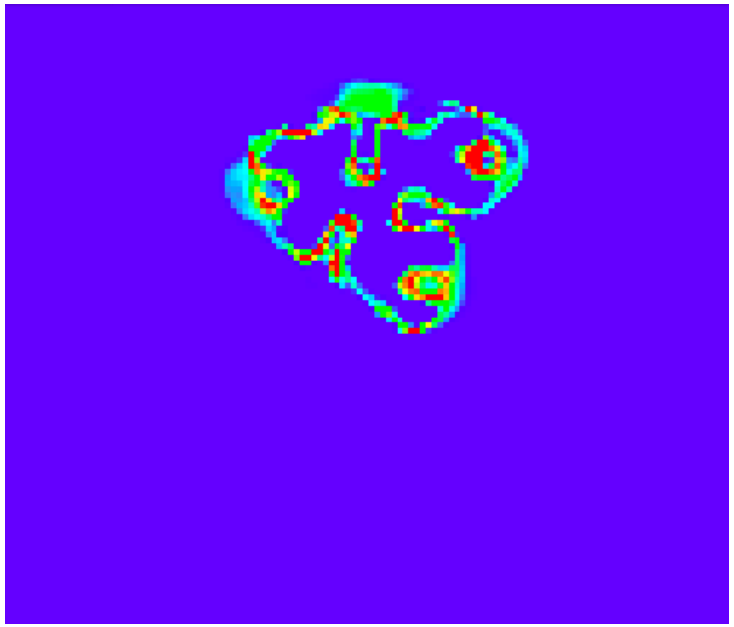
Mordvintsev, A., Randazzo, E., Niklasson, E., & Levin, M. (2020). Growing neural cellular automata. *Distill*, *5*(2), e23.

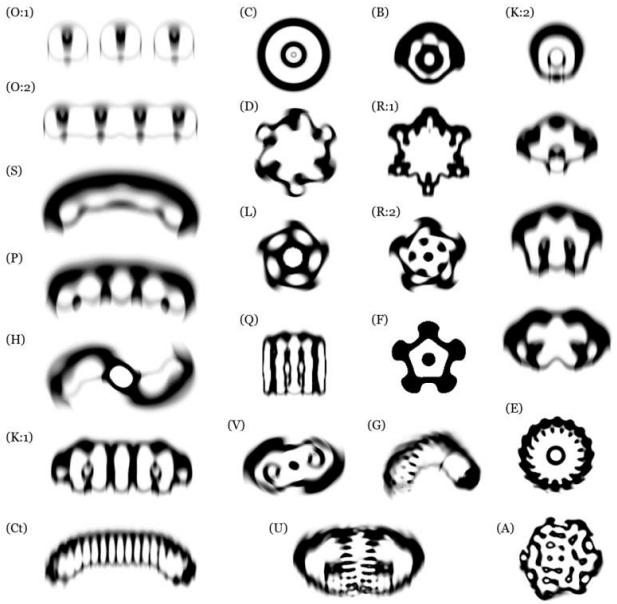
Lenia

- Continuous space and time









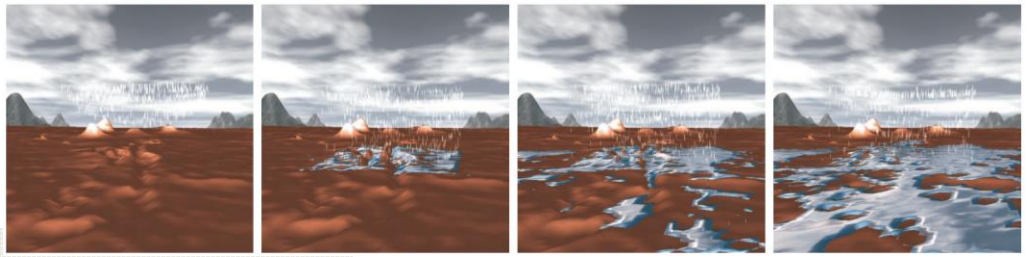
B. W.-C. Chan, “Lenia: Biology of Artificial Life,” Complex Systems, 28(3), 2019 pp. 251–286. https://doi.org/10.25088/ComplexSystems.28.3.251

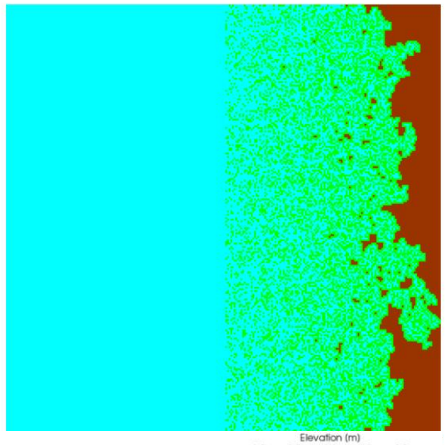
Applications réelles

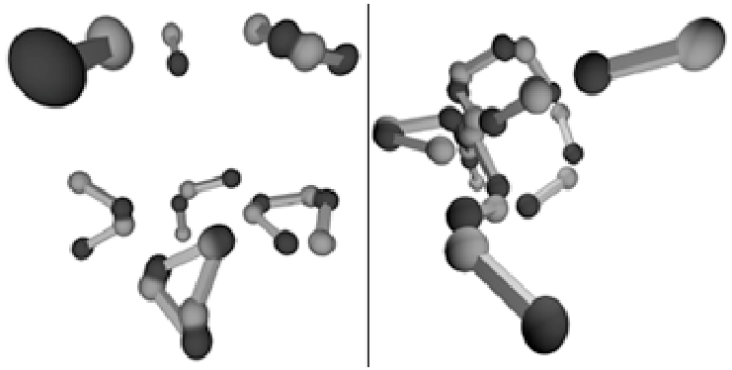
- Epidémiologie
- Anthropologie
- Sociologie
- Biologie
- Cryptographie
- Physiques

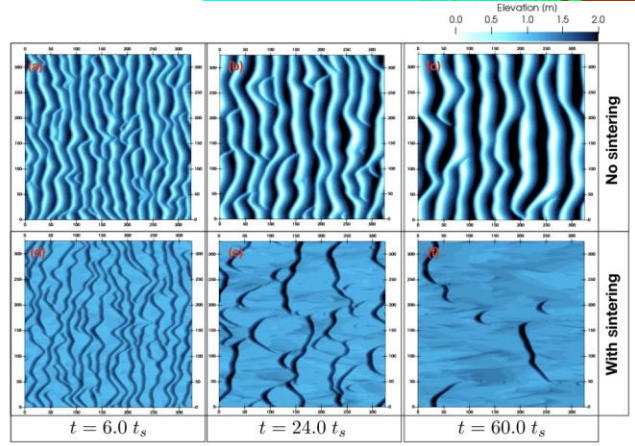
Physique ?

- Simulations physiques
- Simulation de fluides
- Modélisation géologique
- Modélisation moléculaire









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Automates et chimie

- Automates pour simulation de réactions chimiques
- Réactions chimiques pour simuler des automates
- = Peut-être une unification des 2 domaines?

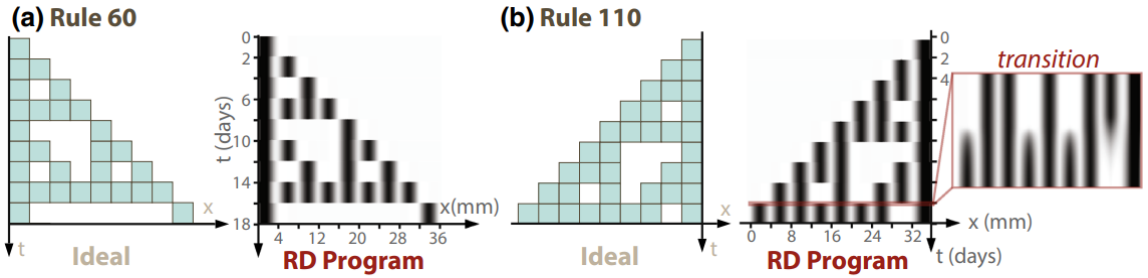
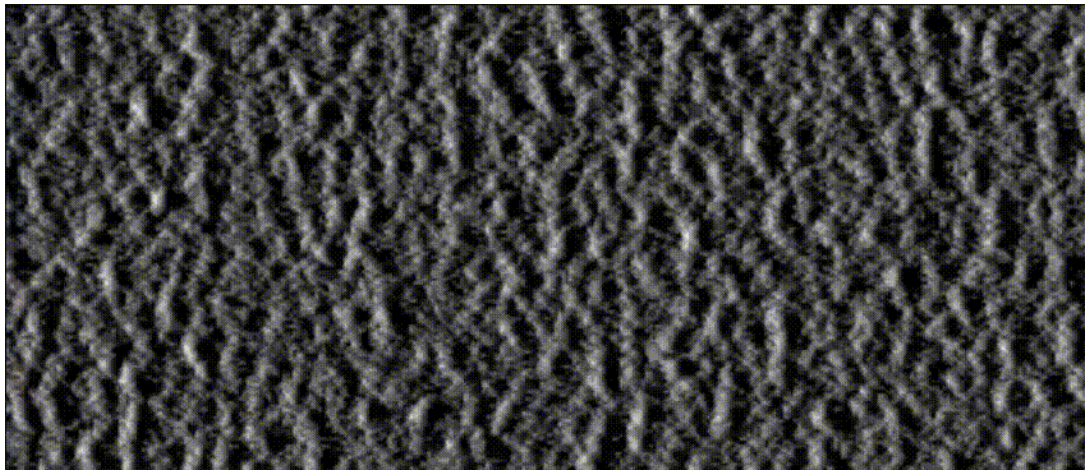


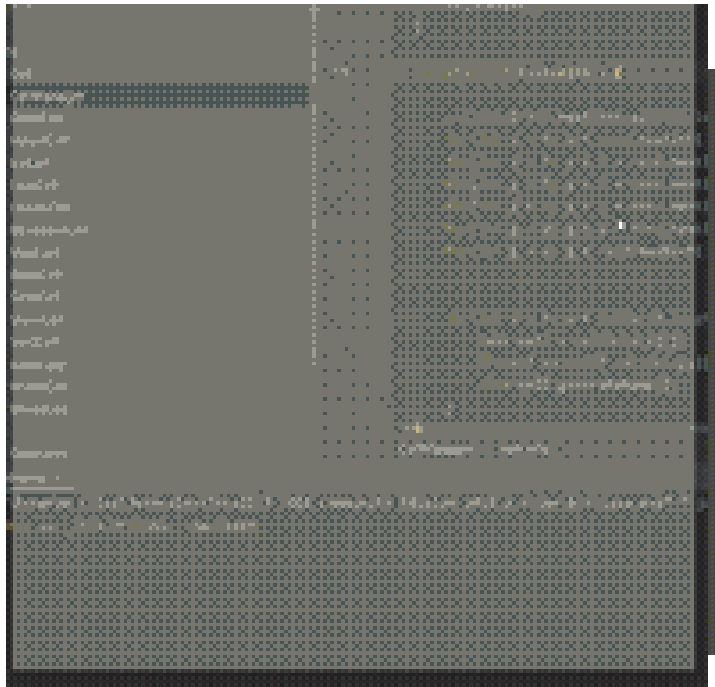
Fig. 9 *Results of chemical CA simulations* Ideal CA (*left*) compared to our simulated reaction–diffusion program (*right*). Every three-length binary input state is contained in each pattern, demonstrating correct updating for all eight possible local states. **a** Rule 60. **b** Rule 110. The dynamics shown here were computed using the set of coupled partial differential equations in Section 8. The detail of the rapid dynamics of a state transition are shown on the far right

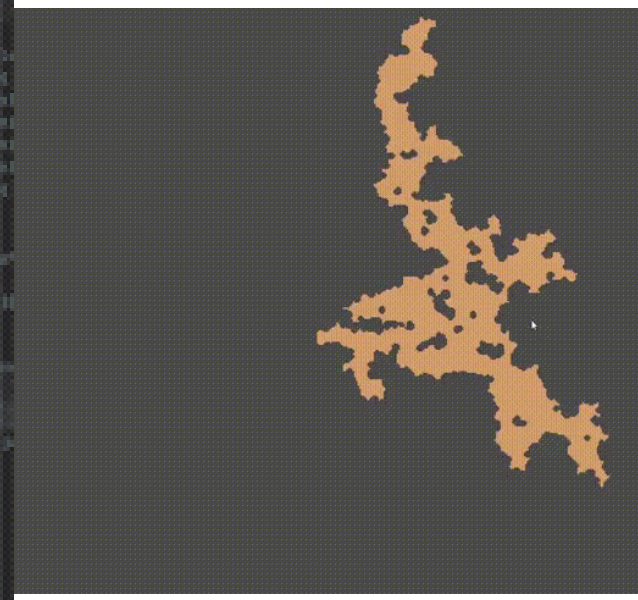
Scalise, D., & Schulman, R. (2016). Emulating cellular automata in chemical reaction–diffusion networks. Natural Computing, 15, 197-214.
Abdallah Zemirline, Pascal Ballet, Lionel Marcé, Patrick Amar, Gilles Bernot, et al.. Cellular automata, reaction-diffusion and multiagents systems for artificial cell modelling. Actes du Colloque Modélisation et simulation de processus biologiques dans le contexte de la génomique, 2002, Autrans, France. pp.257-280. ⟨hal-00827465⟩

Génération de terrains avec des automates

- Génération de dunes
- Génération de caves
- Génération de cartes
- Faune/flore



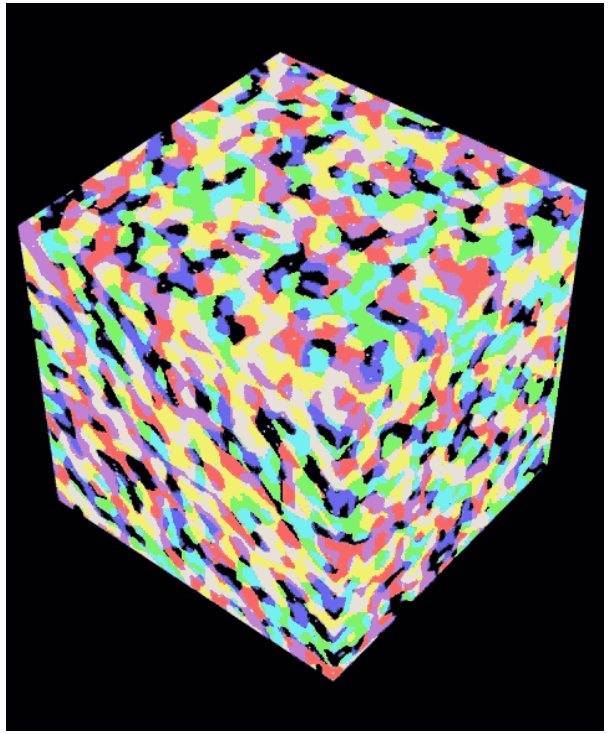


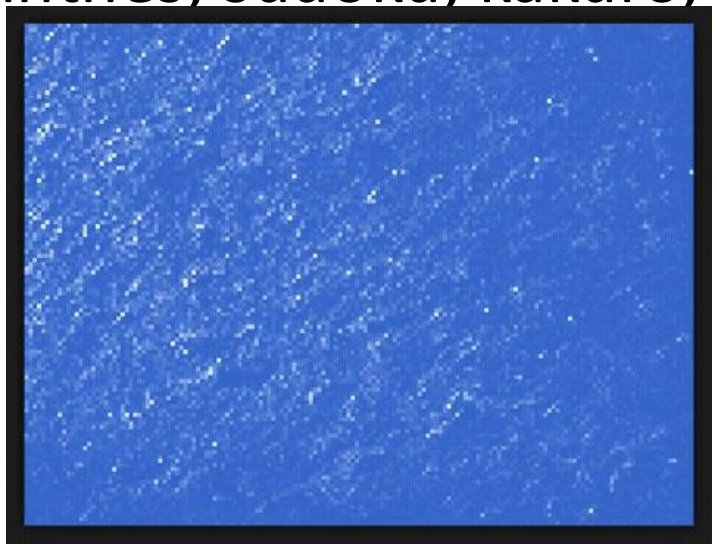


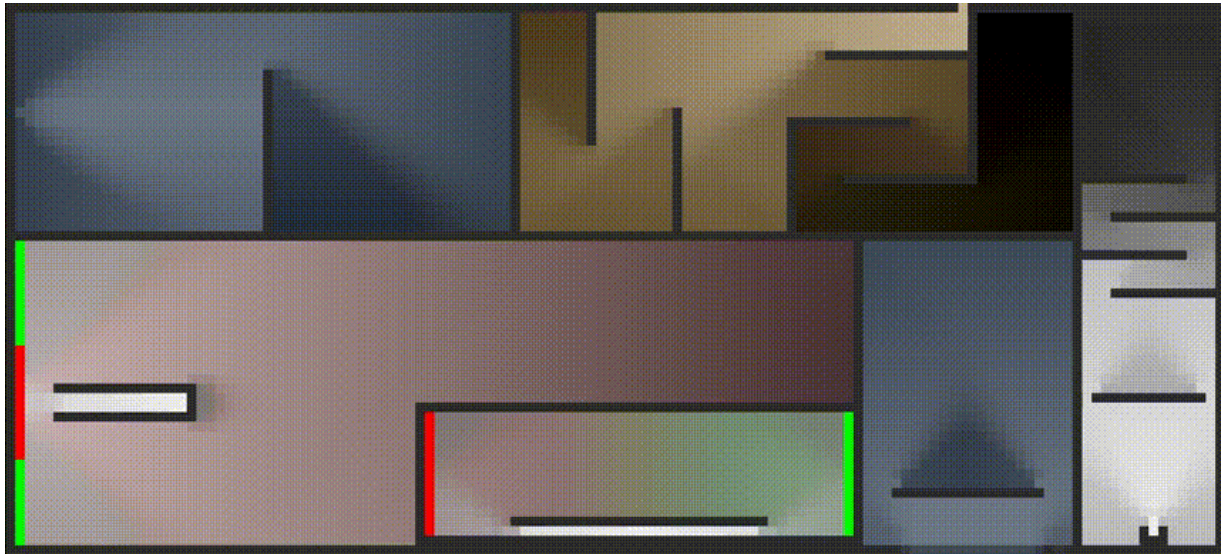
Werber, Bradley "A physical model of wind-blown sand transport." (1987).

Autres utilisations en vrac

- Global illumination
- Textures animées
- Génération et résolution de puzzles (Labyrinthes, sudoku, kakuro, tectonic)

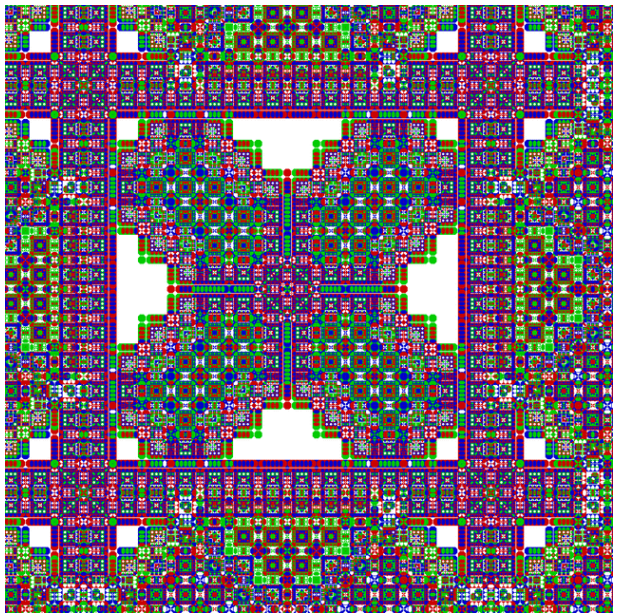






Dijk, Stefan van. “Solving Puzzles using Cellular Automata.” (2017).
Dias, Daniel et al. "A Cellular Sudoku Solver." (2009).

Procedural art



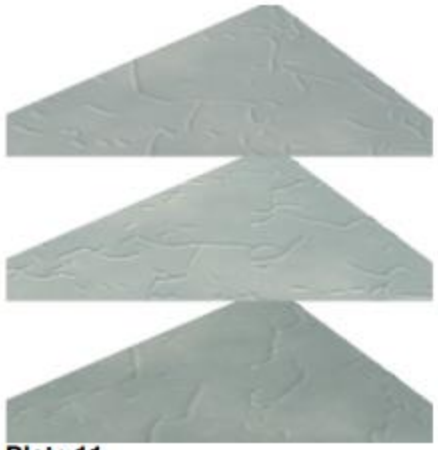
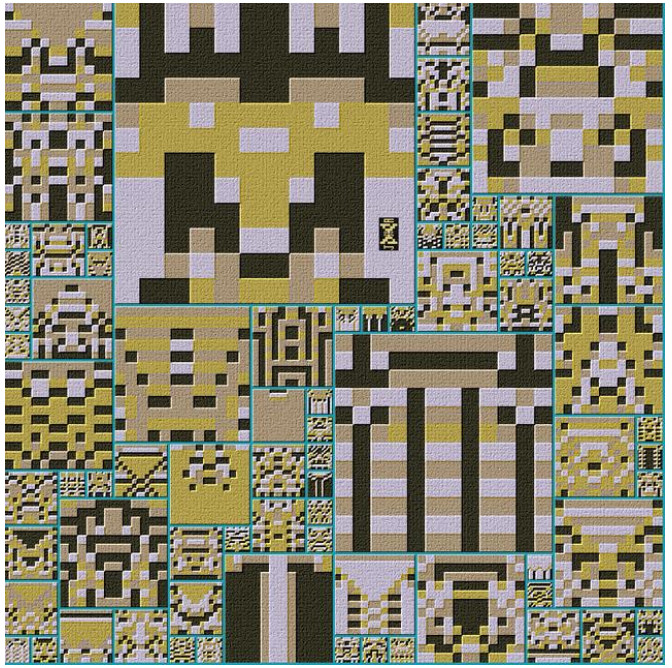
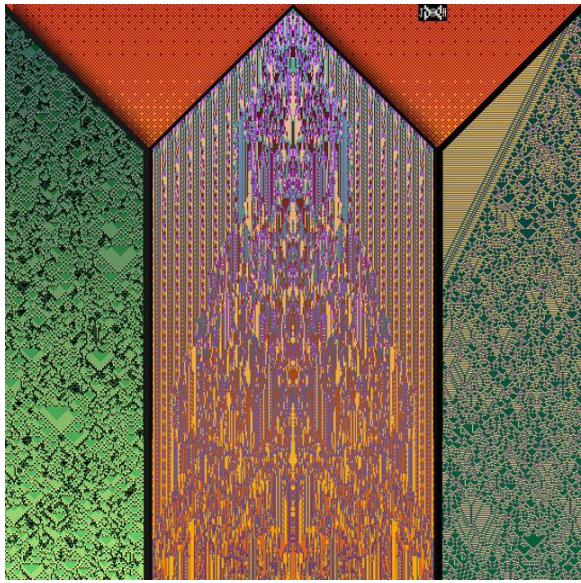


Plate 11

Plate 11. Crack mirror effect: changing the light positions
Plate 12. Example of crak mirror effect on a complex object

Plate 12

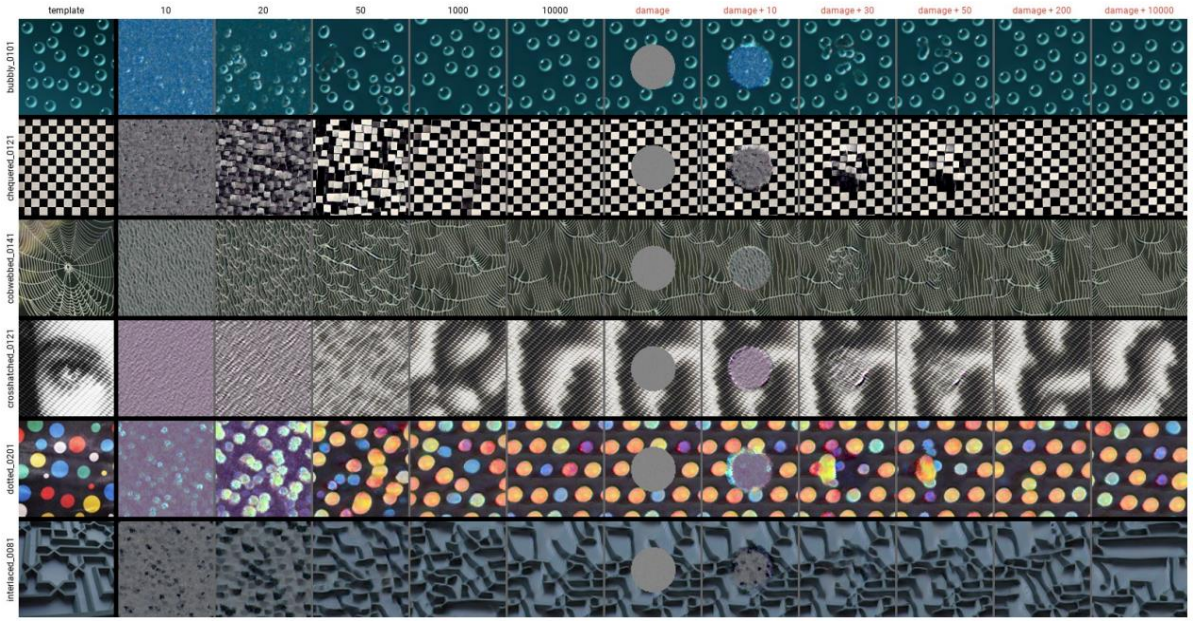




Gobron, S., & Chiba, N. (2001). Crack pattern simulation based on 3D surface cellular automata. In The Visual Computer (Vol. 17, Issue 5, pp. 287–309). Springer Science and Business Media LLC. https://doi.org/10.1007/s003710100099

Génération procédurale

- "Sandbox"
- Végétation
- Jeux videos
- Génération de textures
- …



TodePond "Sand Pond" https://github.com/TodePond/SandPond
Greene, N. (1989, July). Voxel space automata: Modeling with stochastic growth processes in voxel space. In Proceedings of the 16th annual conference on Computer graphics and interactive techniques (pp. 175-184).
Noita, Nolla Games
Mordvintsev, A., Niklasson, E., & Randazzo, E. (2021). Texture generation with neural cellular automata. arXiv preprint arXiv:2105.07299.

Conclusion

L'automate cellulaire, c'est :

- Un outil formel, mais flexible.
- Utilisant des instructions simples, pour des résultats complexes.
- Pour représenter des cellules, ou des forces physiques.
- Dans l'espace dans un espace-temps discret, ou pas.
- Utilisable pour la modélisation physique ou procédurale.
- Qui renaît aujourd'hui grace au GPU.

NB : Je n'ai pas vu l'utilisation de CA sur des grilles irrégulières ou de graphes pondérés.

D'autres sujets similaires

- Génération de textures
  - Pavage de l'espace (EinStein et le Spectre)
- Modélisation procédurale
  - Grammaires de graphes / de géométrie
  - Système de réaction-diffusion (Turing patterns)
- ...

Références

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