CSE 6730 Final Project: Literature Review

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Project Description

This project employs **two-dimensional (2D) cellular automata (CA)** to simulate the **group shift (GS)** phenomenon. By leveraging the computational capabilities of CA, we aim to explore how localized interactions drive global behavioral shifts in group decision-making. Our model incorporates customized transition rules to capture the essence of GS, facilitating the analysis of emergent patterns and their dependence on initial conditions, such as personal sensitivity and average social distance, as well as neighborhood structures.

Definition of Group Shift

Group shift (GS), also referred to as group polarization, describes the phenomenon where a groups collective decision tends to become more extreme than the initial preferences of individual members. This effect arises due to social influences, including persuasive arguments, normative pressures, and the reinforcement of shared attitudes. As discussions progress, individuals align more strongly with the group, leading to either riskier or more conservative decision-making. Understanding GS is crucial for analyzing decision dynamics in fields such as political science, organizational behavior, and social psychology [1, 2].

Overview of Cellular Automata

Cellular automata (CA) are grid-based computational models in which each cell updates its state based on predefined local rules, typically influenced by neighboring states. Despite their simplicity, CAs can generate highly complex global behaviors, making them fundamental tools for studying emergent patterns in nature.

CA models provide valuable insights into various physical phenomena, including crystal growth, phase transitions, and pattern formation [3, 4]. By encoding relevant chemical and physical interactions into local rules, researchers can simulate material properties and observe the development of macroscopic features, such as grain boundaries, surface textures, and emergent symmetries. Additionally, CA models are applied to reaction-diffusion systems, where localized reactions and diffusion collectively shape large-scale structures [5].

Beyond physics, CA applications extend to computer science and machine learning, supporting tasks such as image processing, edge detection, and shape classification [6]. The strong parallelism of CA makes it well-suited for distributed computing, enabling large-scale simulations to run efficiently on specialized hardware [7].

Neural Cellular Automata (NCA)

Neural cellular automata (NCA) extend traditional CA by integrating neural networks into the state transition function of each cell [8]. Instead of manually defining transition rules, NCAs enable adaptive behaviors through data-driven training, making them suitable for applications such as image classification, pattern regeneration, and anomaly detection.

In materials science, NCA-based approaches allow researchers to model fine-scale molecular interactions, capturing how localized behaviors influence large-scale morphologies [9]. These methods have been employed in studies of crystal growth, magnetic domain formation, and metal solidification. Additionally, urban studies utilize CA principles to model city expansion under ecological and infrastructural constraints [10].

Applications of CA in Natural Sciences

CA models are widely used in numerous scientific disciplines, particularly materials science [11, 12]. CA-based simulations have been utilized to study phase separation in photovoltaic cells, recrystallization dynamics, and grain growth [13]. Hybrid models combining CA with techniques such as the Lattice Boltzmann Method (LBM) and Finite Element Method (FEM) have been developed to enhance microstructural simulations of alloys [14, 15].
Beyond materials science, CA has been applied to biochemical systems and climate modeling [16, 17]. Researchers have employed CA to analyze climate factors, including the impact of climate change on water resources [18] and carbon cycle dynamics [19], aiding in the development of policies addressing global climate challenges.

Applications of CA in Sociology

While CA applications in sociology are relatively limited compared to other domains, existing studies highlight its potential in modeling various social phenomena. CA has been used to examine self-organized proportion regulation in biological and social systems, where local agent interactions give rise to emergent global behaviors [2].
Researchers such as Xia and Liu have explored CAs capacity to simulate group decision-making dynamics, organizational behavior, and the evolution of collective actions in structured communities. Their findings emphasize the role of external influence, initial behavior distributions, and regulatory penalties in shaping the overall behavior of organized groups. Additionally, CA has been employed to simulate human responses in crisis scenarios, such as emergency evacuations and disaster management.
Beyond direct social simulations, theoretical advancements in group cellular automata (GCA) provide a mathematical foundation for analyzing properties such as injectivity, surjectivity, and equicontinuity, with implications for symbolic dynamics and information theory [1]. These studies underscore CAs versatility in capturing complex interactions and emergent behaviors within social systems.

Project Contributions

Compared with existing literature focusing on simulating GS via CA, this project builds upon well-developed CA simulation methodologies while introducing key innovations:

1. Incorporation of novel social dynamics hyperparameters and rules to refine group decision modeling, and we believe this will lead to more realistic result.
2. The consideration of social distance and individual movement dynamics and their effects on GS.
3. Integration of NCA to achieve a more granular representation of individual behaviors and therefore overall representation of GS.
4. Optimization of visualization mechanisms using parallelized divide-and-conquer algorithms or tabular dynamic programming (DP).

References

[1] Pierre Béaur and Jarkko Kari. Decidability in Group Shifts and Group Cellular Automata. *LIPIcs, Volume 170, MFCS 2020*, 170:12:1–12:13, 2020.

[2] Pierre Béaur and Jarkko Kari. Effective Projections on Group Shifts to Decide Properties of Group Cellular Automata, January 2023.

[3] Sang Won Im, Dongsu Zhang, Jeong Hyun Han, Ryeong Myeong Kim, Changwoon Choi, Young Min Kim, and Ki Tae Nam. Investigating chiral morphogenesis of gold using generative cellular automata. *Nature Materials*, 23(7):977–983, July 2024.

[4] G. Lebreton, C. Géminard, F. Lapraz, S. Pyrpassopoulos, D. Cerezo, P. Spéder, E. M. Ostap, and S. Noselli. Molecular to organismal chirality is induced by the conserved myosin 1D. *Science*, 362(6417):949–952, November 2018.

[5] Liana Manukyan, Sophie A. Montandon, Anamarija Fofonjka, Stanislav Smirnov, and Michel C. Milinkovitch. A living mesoscopic cellular automaton made of skin scales. *Nature*, 544(7649):173–179, April 2017.

[6] Yann LeCun, Yoshua Bengio, and Geoffrey Hinton. Deep learning. *Nature*, 521(7553):436–444, May 2015.

[7] Norman P. Jouppi, Cliff Young, Nishant Patil, David Patterson, Gaurav Agrawal, Raminder Bajwa, Sarah Bates, Suresh Bhatia, Nan Boden, Al Borchers, Rick Boyle, Pierre-luc Cantin, Clifford Chao, Chris Clark, Jeremy Coriell, Mike Daley, Matt Dau, Jeffrey Dean, Ben Gelb, Tara Vazir Ghaemmaghami, Rajendra Gottipati, William Gulland, Robert Hagmann, C. Richard Ho, Doug Hogberg, John Hu, Robert Hundt, Dan Hurt, Julian Ibarz, Aaron Jaffey, Alek Jaworski, Alexander Kaplan, Harshit Khaitan, Daniel Killebrew, Andy Koch, Naveen Kumar, Steve Lacy, James Laudon, James Law, Diemthu Le, Chris Leary, Zhuyuan Liu, Kyle Lucke, Alan Lundin, Gordon MacKean, Adriana Maggiore, Maire Mahony, Kieran Miller, Rahul Nagarajan, Ravi Narayanaswami, Ray Ni, Kathy Nix, Thomas Norrie, Mark Omernick, Narayana Penukonda, Andy Phelps, Jonathan Ross, Matt Ross, Amir Salek, Emad Samadiani, Chris Severn, Gregory Sizikov, Matthew Snelham, Jed Souter, Dan Steinberg, Andy Swing, Mercedes Tan, Gregory Thorson, Bo Tian, Horia Toma, Erick Tuttle, Vijay Vasudevan, Richard Walter, Walter Wang, Eric Wilcox, and Doe Hyun Yoon. In-Datacenter Performance Analysis of a Tensor Processing Unit. In *Proceedings of the 44th Annual International Symposium on Computer Architecture*, ISCA '17, pages 1–12, New York, NY, USA, June 2017. Association for Computing Machinery.

[8] Gordon H. Y. Li, Christian R. Leefmans, James Williams, Robert M. Gray, Midya Parto, and Alireza Marandi. Deep Learning with Photonic Neural Cellular Automata, September 2023.

[9] Sorana Catrina, Mirela Catrina, Alexandra Băicoianu, and Ioana Cristina Plajer. Learning About Growing Neural Cellular Automata. *IEEE Access*, 12:45740–45751, 2024.

[10] Xiaoyan Tang, Funan Liu, and Xinling Hu. Urban growth simulation and scenario projection for the arid regions using heuristic cellular automata. *Scientific Reports*, 14(1):21106, September 2024.

[11] Ying Zhi, Yao Jiang, Diwen Ke, Xianlei Hu, and Xianghua Liu. Review on Cellular Automata for Microstructure Simulation of Metallic Materials. *Materials*, 17(6):1370, January 2024.

[12] Dierk Raabe. Cellular Automata in Materials Science with Particular Reference to Recrystallization Simulation. *Annual Review of Materials Research*, 32(Volume 32, 2002):53–76, August 2002.

[13] Peter Peumans, Soichi Uchida, and Stephen R. Forrest. Efficient bulk heterojunction photovoltaic cells using small-molecular-weight organic thin films. *Nature*, 425(6954):158–162, September 2003.

[14] Wonjoo Lee, Junho Bae, Howon Lee, Seong-hoon Kang, and Jonghun Yoon. Numerical simulation of dendritic growth and porosity evolution in solidification of Al-Cu alloy with lattice Boltzmann – Cellular automata method. *Journal of Alloys and Compounds*, 929:167233, December 2022.

[15] Guiru Meng, Yadong Gong, Jingdong Zhang, Lida Zhu, Hualong Xie, and Jibin Zhao. Multi-scale simulation of microstructure evolution during direct laser deposition of Inconel718. *International Journal of Heat and Mass Transfer*, 191:122798, August 2022.

[16] Lemont B. Kier and Tarynn M. Witten. Cellular Automata Models of Complex Biochemical Systems. In Danail Bonchev and Dennis H. Rouvray, editors, *Complexity in Chemistry, Biology, and Ecology*, pages 237–301. Springer US, Boston, MA, 2005.

[17] Éva Rácz and Miklos Bulla. Cellular Automata Models of Environmental Processes. January 2003.

[18] Hamidou Kassogué, Abdes Samed Bernoussi, Mina Amharref, and Mustapha Ouardouz. Cellular automata approach for modelling climate change impact on water resources. *International Journal of Parallel, Emergent and Distributed Systems*, 34(1):21–36, January 2019.

[19] Lichtenegger Klaus and Schappacher Wilhelm. A Carbon-Cycle Based Stochastic Cellular Automata Climate Model, March 2011.