Spatial SIR Simulation in Cellular Automata: A Simple Tool for Understanding Local Transmission Dynamics and Mobility Effects

Abstract

Compartmental SIR (Susceptible Infected Recovered) models are central to theoretical and applied epidemiology. However, classical homogeneous formulations (mean-field differential equations) ignore spatial heterogeneity and local neighborhood effects, which can qualitatively alter disease spread. We present a simple computational implementation of an SIR model on a 2D lattice (cellular automaton) incorporating local interaction (Moore neighborhood, 8 neighbors), stochastic or fixed-duration recovery, and individual mobility via random exchanges. We demonstrate how variations in local transmission parameters, infectious period, and mobility reshape epidemic curves and spatial spread. The lightweight, reproducible code is suited for exploratory research, teaching, and epidemiological risk communication.

Introduction

SIR models have been widely used to describe epidemics since Kermack & McKendrick's foundational work (1927). However, compartmental approaches assume homogeneous mixing a poor approximation when contacts are predominantly local (e.g., schools, neighborhoods). Explicit spatial topology and local transmission rules can reveal clustering dynamics, wave-like propagation, and critical mobility effects obscured by homogeneous models. Additionally, accessible computational tools are vital for training public health professionals and communicating policy impacts (e.g., vaccination, mobility restrictions).

Methods

We developed a 2D cellular automaton (lattice size N×M) where each cell represents an individual in one of three states: susceptible (S), infected (I), or recovered (R). Transmission is localized: a susceptible individual with **k** infected neighbors has an infection probability per time step given by

$$P(\text{infect}) = 1 - (1 - \beta)^k,$$

where β is the per-contact transmission probability. Recovery is modeled via: (i) stochastic clearance (probability γ per step) or (ii) deterministic duration (fixed infectious period τ). Mobility is introduced as random pairwise cell exchanges (fraction *m* per step), approximating population redistribution. Dynamics are iterated in discrete steps, with global fractions S(t), I(t), R(t) recorded; spatial patterns are visualized.

Results

In exemplar simulations (120×120 lattice, β=0.25, γ=0.02, initial I_0=0.2%), we observed classic epidemic curves (peak I followed by decline) and spatial clustering with wavefront expansion. Increased mobility (*m*) accelerated outbreaks and raised peak prevalence, converging toward homogeneous-model behavior at high *m*. Deterministic infectious periods (τ) reduced stochastic variability and sharpened epidemic peaks. These patterns highlight how local parameters and mobility jointly shape outbreak scale and velocity.

Discussion

The model's simplicity enables rapid policy testing: vaccination (reducing initial S), mobility restrictions (lower *m*), or transmission control (masks/isolation, lowering β) can be explored for qualitative effects. Spatial outputs further allow evaluation of targeted containment (e.g., ring vaccination or localized lockdowns). This tool complements aggregated deterministic models and serves as a pedagogical resource for concepts like local R_0, contact saturation, and spatial heterogeneity.

Practical Relevance

A 2025 measles alert underscores the need for rapid surveillance and interventions given reintroductions in populations with vaccination gaps. Spatial simulations illustrate how imported cases seed local transmission chains, justifying ring vaccination and contact tracing (see Measles_Alert_March_2025_NDAT_FINAL.pdf).

Conclusion

We present a lightweight, configurable spatial SIR model for pedagogical and scenario-based exploration. The intentionally simple code facilitates extensions (e.g., heterogeneous occupancy, directed mobility, age-stratified vaccination) and serves as a foundation for advanced investigations.

Acknowledgments

We thank public health professionals for emphasizing the need for accessible modeling tools in education and decision-making.

References

Kermack, W. O. & McKendrick, A. G. A contribution to the mathematical theory of epidemics. Proc. R. Soc. A (1927).

Health Surveillance Guide; Ministry of Health, 2024.

Epidemiological Alert: Measles cases in Brazil (NDAT/COVISA, March 2025).