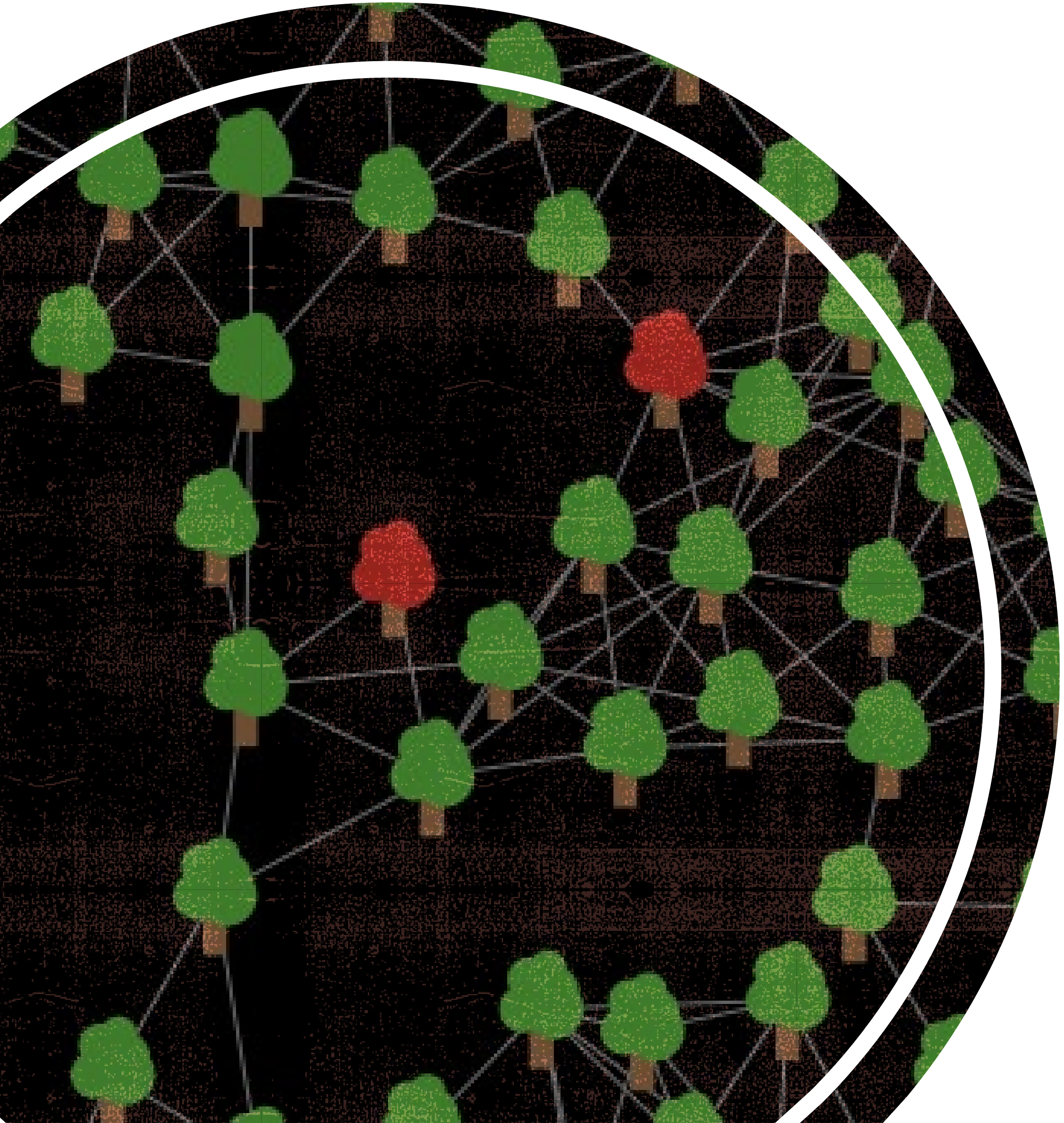
Forest-Fire and Mitigation on Network

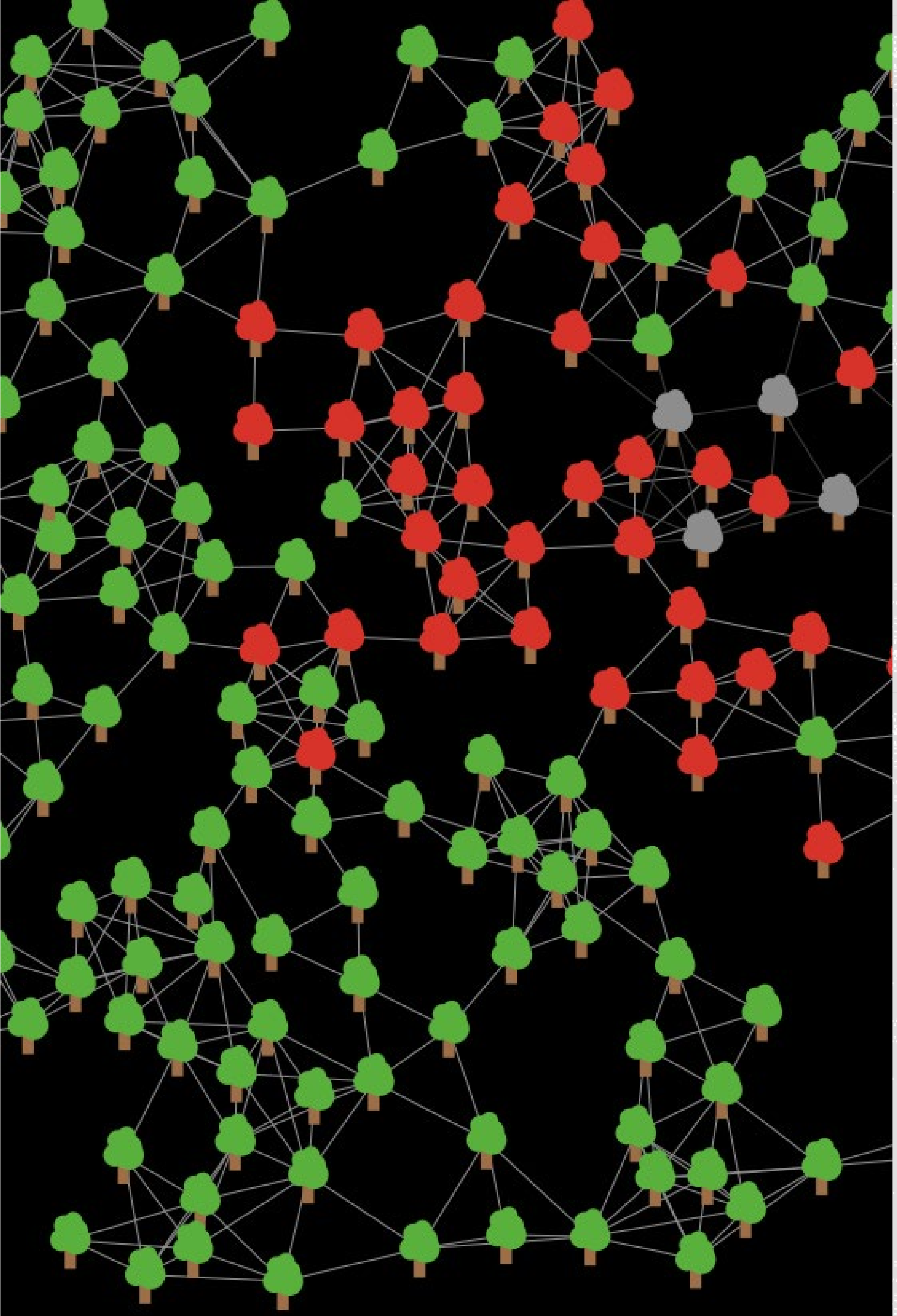
I501 Final Project

C.Y.

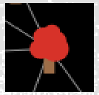
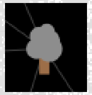


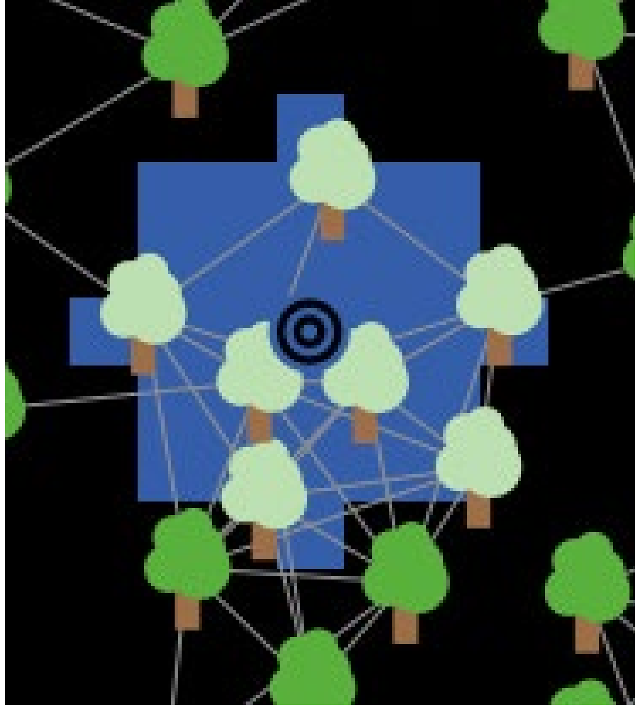
PROXIMITY OR CONNECTIVITY

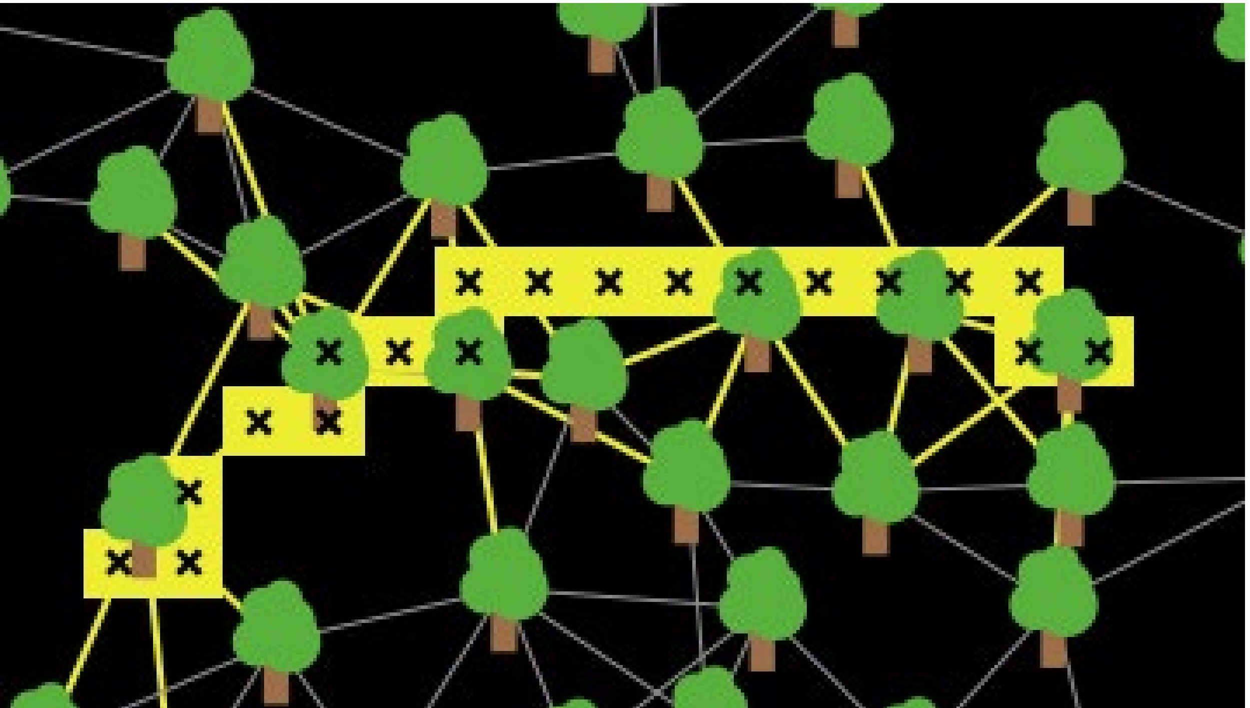
- Forest-fire spread is not governed solely by spatial proximity.
  - For example, a tall, elevated tree may ignite leaves some distance away before it ignites nearby but shorter shrubs.
- Fuels (trees, shrubs, litter) are represented as nodes in a network, and links encode the pathways along which flames, embers, or radiant heat can transmit.
  - Capture non-local transmission, allowing fire to “jump”.
  - Spread follows connectivity rather than mere proximity.



STATE AND DYNAMICS

- **Node states (SIR-style)** 
  - **Normal (green):** unburned; susceptible to ignition.
  - **Burning (red):** actively burning; can ignite neighbors. 
  - **Ash (grey):** burned out; non-propagating and absorbing (no re-ignition, no further spread). 
- **Propagation rule (for each tick)**
  - A burning node may **ignite** any neighbor connected by an **active** link, with probability **spread-prob**.
  - A burning node may **self-extinguish** with probability **extinguish-prob**, reverting to normal.
  - If a node's **burning duration** exceeds its **burn limit**, **it transitions to ash.**

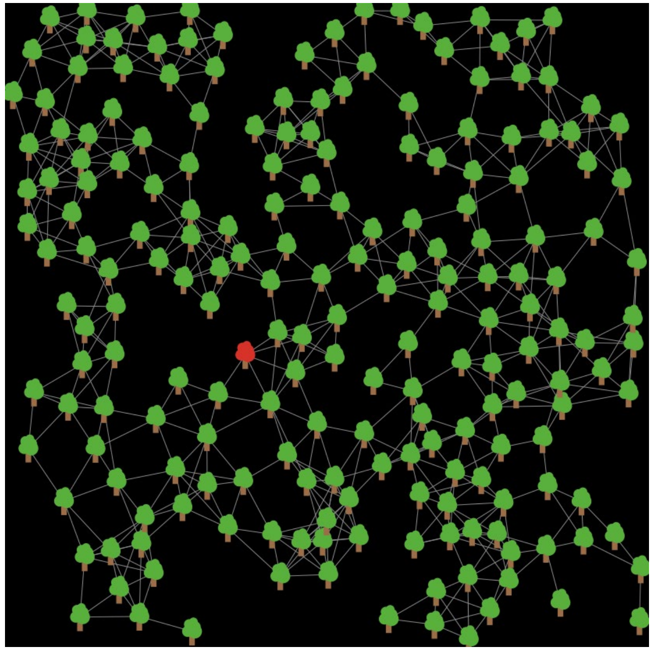


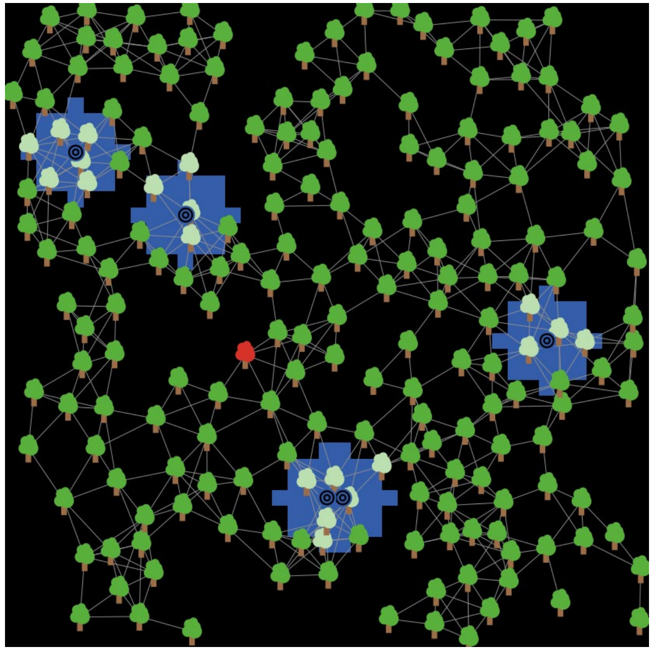


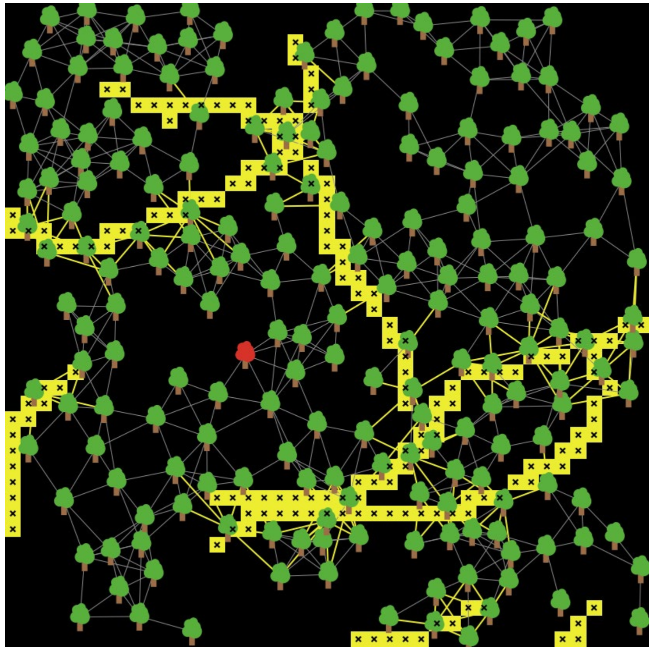
MITIGATION

- **Irrigation system (sprinklers):** Shortens each node's burning duration, reducing the time window during which a burning node can ignite its neighbors.

- **Firebreaks:** Lower the probability of transmission across selected links, creating effective barriers that hinder propagation.







SIMULATION

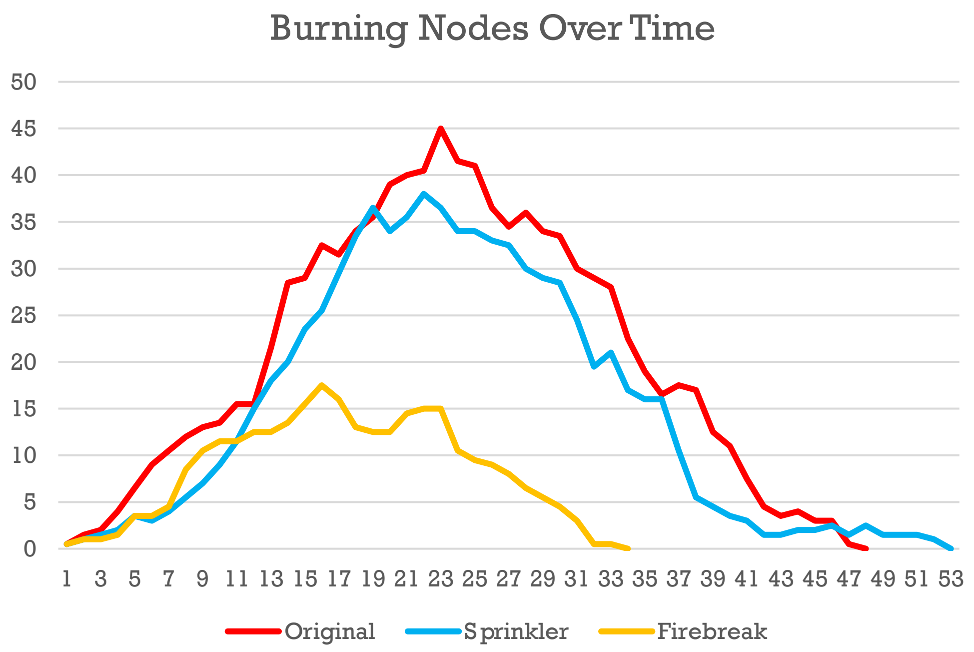
Link: Forest-Fire and Mitigation on Network

RESULTS FROM A SINGLE SIMULATION RUN

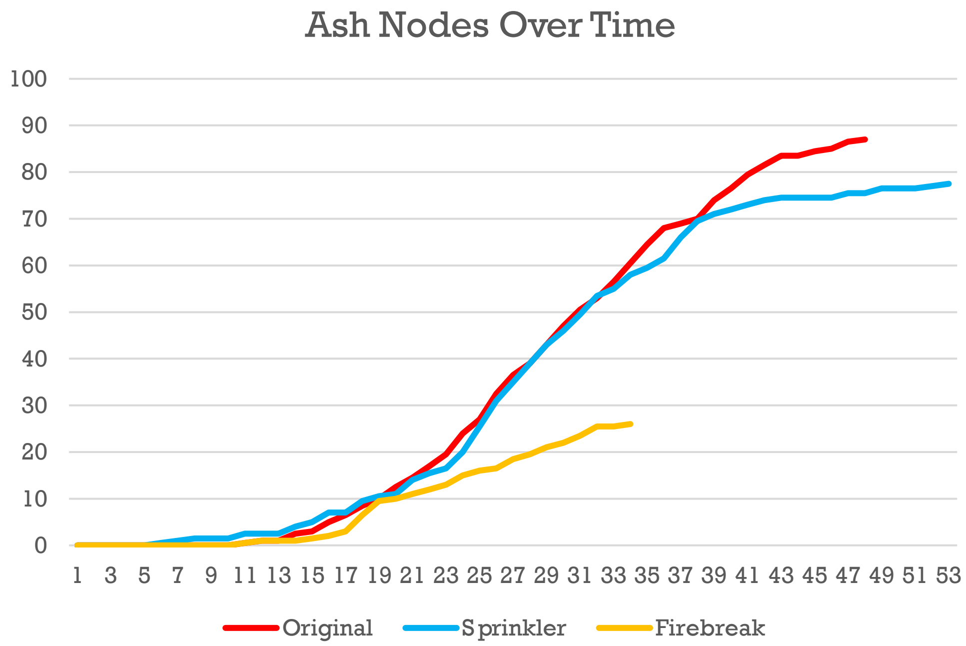
- **Burning plot**
  - **Sprinkler:** flatten with a long tail,

    burning persists but at lower intensity.
  - **Firebreak:** a much lower peak, indicating

    strongly limited spread.



- **Ash plot**
  - **Sprinkler:** tracks the baseline for most of the run, then levels off into a slightly lower plateau.
  - **Firebreak:** protects most nodes, yielding the lowest final ash.



RESULTS FROM A SINGLE SIMULATION RUN

DISCUSSION

1. How to Draw Valid Conclusions?
2. Polysemy in Agent-Based Simulation

HOW TO DRAW VALID CONCLUSIONS?

- **Question:** In agent-based models with many tunable parameters, how can we tell that a result reflects a mechanism-based explanation rather than parameter overfitting?
- **ABM as Generative-Mechanism Explanation**
  - A mechanism gains credibility when it **generates data that match observed patterns**
    - But "matching" still depends on how we pick pattern facts, metrics, and tolerances.
  - **Results that stay consistent across a broad set of parameters** are unlikely to be mere parameter artifacts
    - But the "reasonable range" should come from theory
    - Common assumptions about randomness may not hold in reality
    - Aim to use as few variables as possible while explaining as much as possible.
  - A model that **challenges a well-known theory** and offers a clear alternative mechanism is valuable
    - But this does not make the alternative mechanism literally true (e.g. Schelling's segregation model)

POLYSEMY IN AGENT-BASED SIMULATION: EPIDEMICS & FOREST FIRES

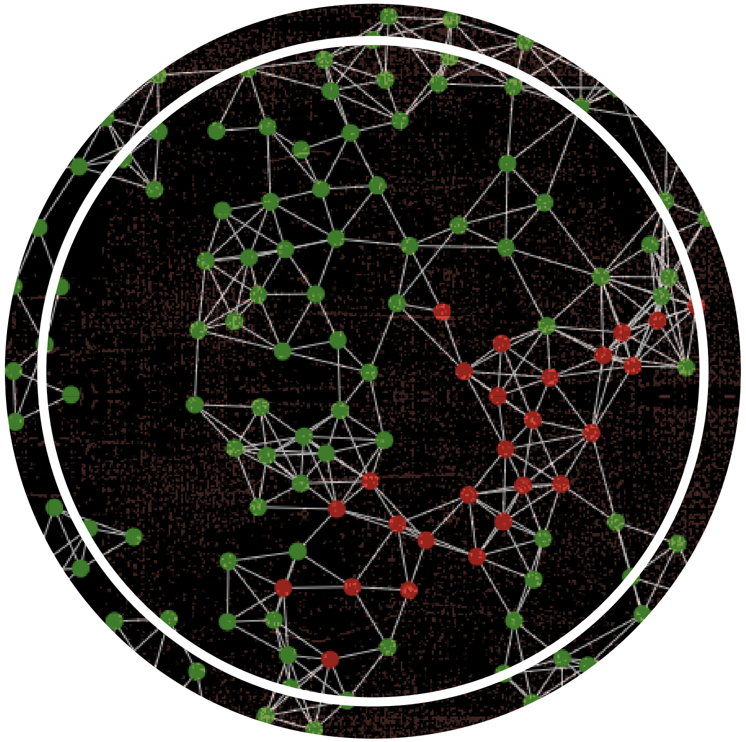
- **Shared core:** Both are propagation on networks: a state (infection/burning) moves along links at given rates and stops when susceptible individuals and fuel are depleted.
- **Mitigation 1: Speed up removal of actives**
  - Epidemics: rapid treatment increases the recovery/removal rate.
  - Fires: fast suppression increases the burnout rate.
- **Mitigation 2: Cut links to block spread**
  - Epidemics: isolation and social distancing.
  - Fires: firebreaks and containment lines.

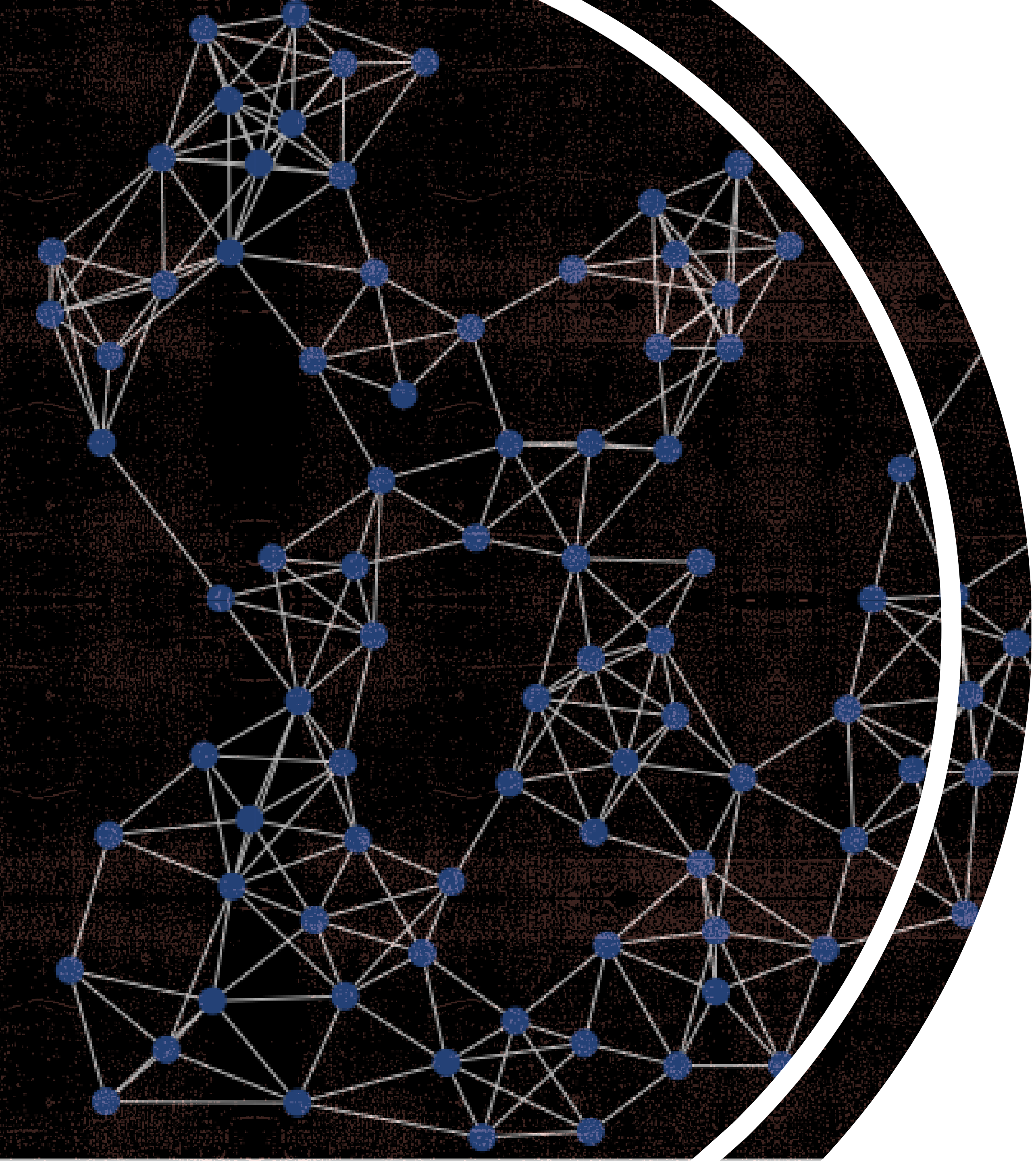
APPENDIX

Network generation reference

REFERENCE MODEL

- *Virus on a Network*: I adopted its random-network generation and layout.
- Stonedahl, F. and Wilensky, U. (2008). NetLogo Virus on a Network model. http://ccl.northwestern.edu/netlogo/models/VirusonaNetwork. Center for Connected Learning and Computer-Based Modeling, Northwestern Institute on Complex Systems, Northwestern University, Evanston, IL.





NETWORK GENERATION

- Initialize an $Erdős–Rényi$ (ER) network $G(n, p)$ with n nodes and target average degree $< k >$.
- Set the link probability to: $p = \frac{<k>}{n-1}$ to achieve the desired average degree.