Critical Forest Density

Wildfire criticality for forest with different flammability distributions
Group 8: 'Quite Some Sweat'

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Theoretical background

Two frameworks in modelling forest fires:

- Li and Magill: Cellular automata
- Zylstra: Forest fire as a complex system

Flammability:

- Bush Flammability: (1) probability of being set on fire, (2) the intensity of the fire, & (3) the duration of the fire (Zylstra, 2011)
- The heat conditions of the day (Li and Magill, 2000)

Flammability randomly drawn from uniform distribution

- Allows for diversity in forest layout (Li and Magill, 2000)

- Our approach: combining both frameworks and extending to different distributions

Research Question & hypothesis

How does the density in plant growth with different flammability distributions influence the critical point of the spread of a forest fire in a dry season?

- The critical density for a forest with maximum flammability for all vegetation starts at 0.41

For initial flammability drawn from

- a normal distribution, we expect a low amount of fires during the beginning of the model but the fire sizes will increase over time
- a uniformdistribution, we expect there to be constant outbreaks of fires over time.
- a bimodal distribution, we expect there to be big fire in the beginning of the model, but large pieces of the forest will survive the season

Our model

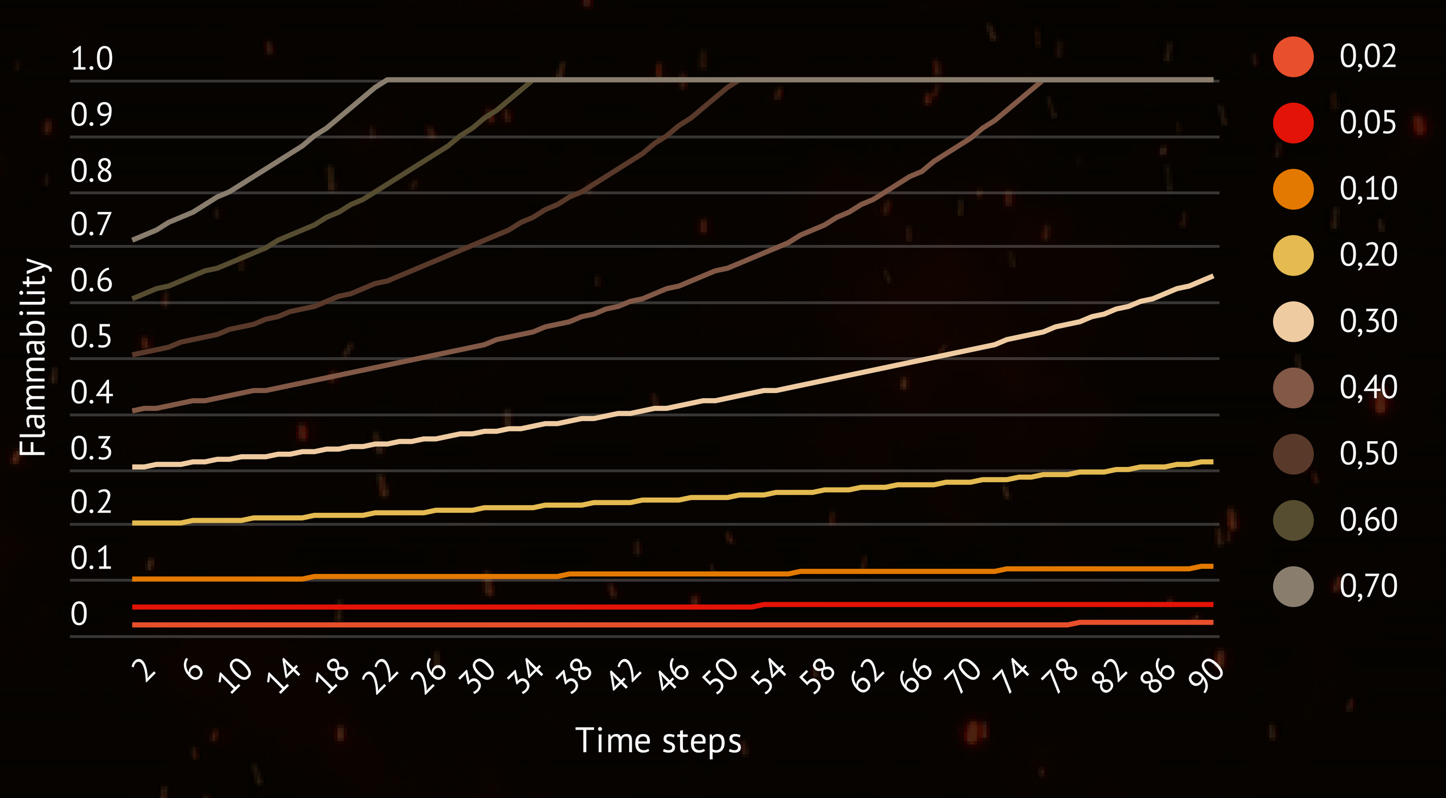
Assumptions

- Cellular Automata https://github.com/projectmesa/mesa/tree/main/examples/forest_fire
- Grid representing a forest (100 x 100)
- Cell representing a piece of forest with or without flammable vegetation

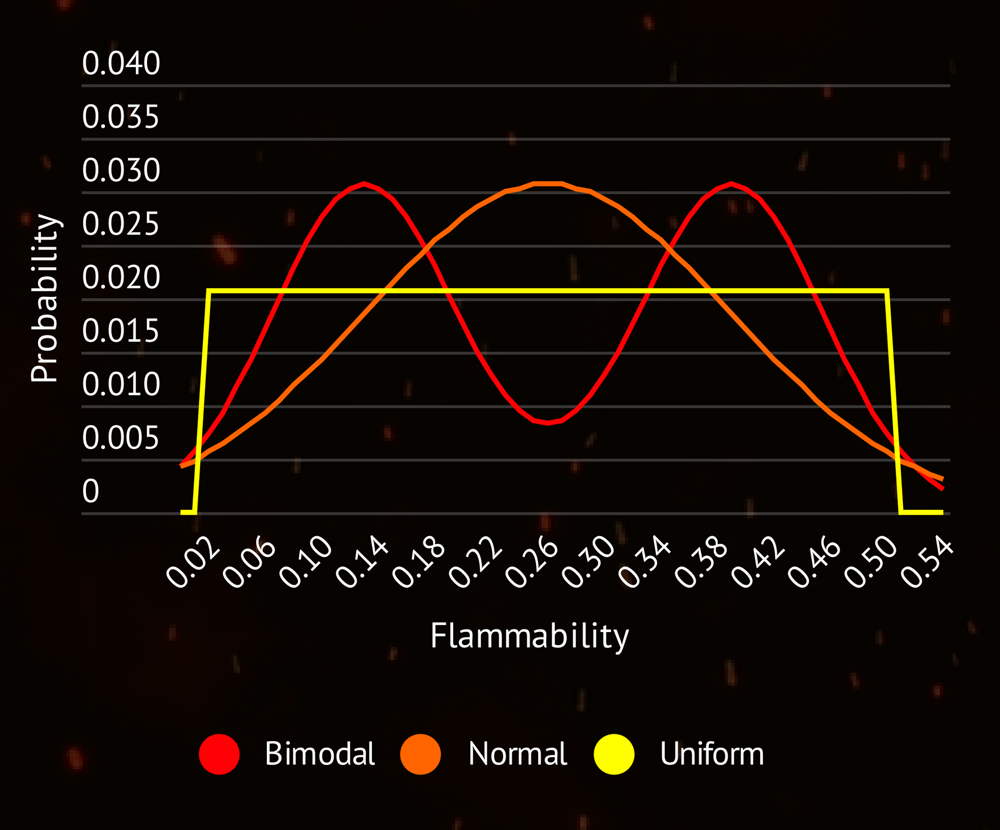
Parameters

- Forest density: percentage of places on the grid with plant growth
- Flammability: the chance of catching fire:
  1. Spontanious Combustion, i.e. the fire starting at that cell
  2. Neighbour dynamics, i.e. fire spreading from neighbouring cells
- Trees burn for the duration of one time step
- 90 time steps
- Catching fire due to neighbors: $P(f) = (1 - (1 - X_t)^{N_f})$
- Increase in flammability X over time t due to increased environmental heat

$$X_{t+1} = (0,02 * X_t + 1) * X_t$$



Flammability distributions



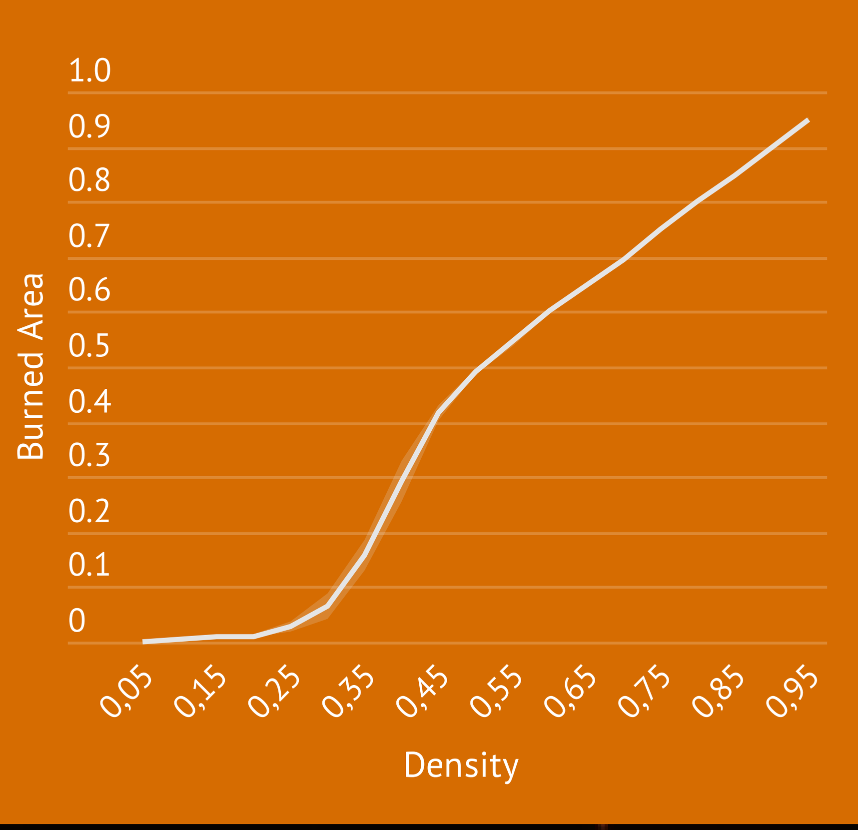
Average flammability of 0.26 for each distribution

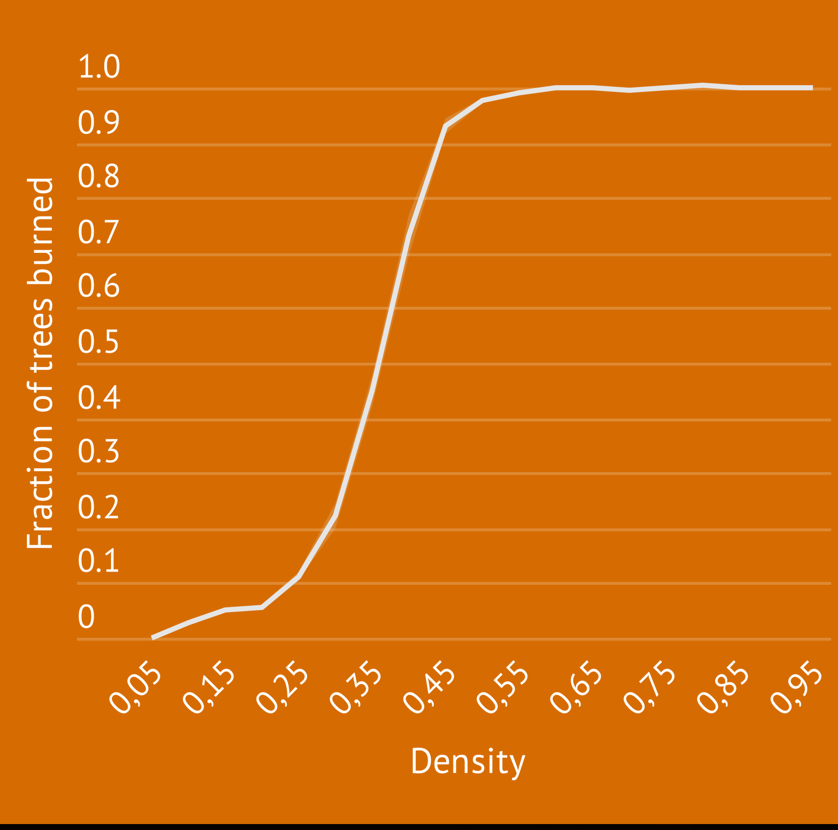
For the normal distribution there is a 5% chance of an initial flammability outside of 0.02 and 0.54. Its 1% for the bimodal distribution.

Bimodal is two normal distributions combined

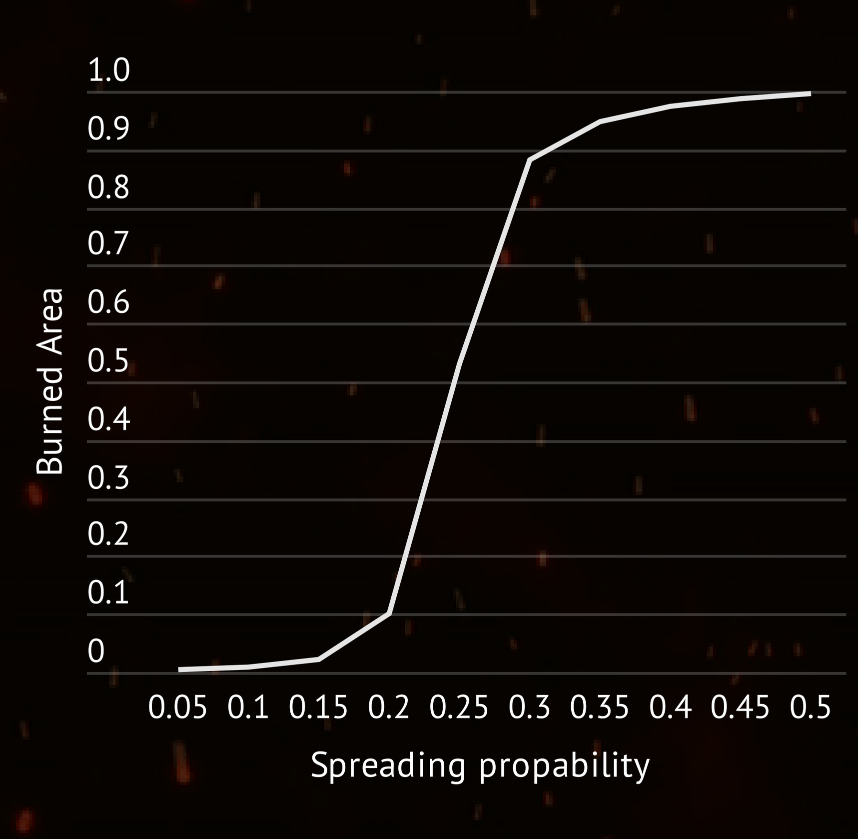
Model validation

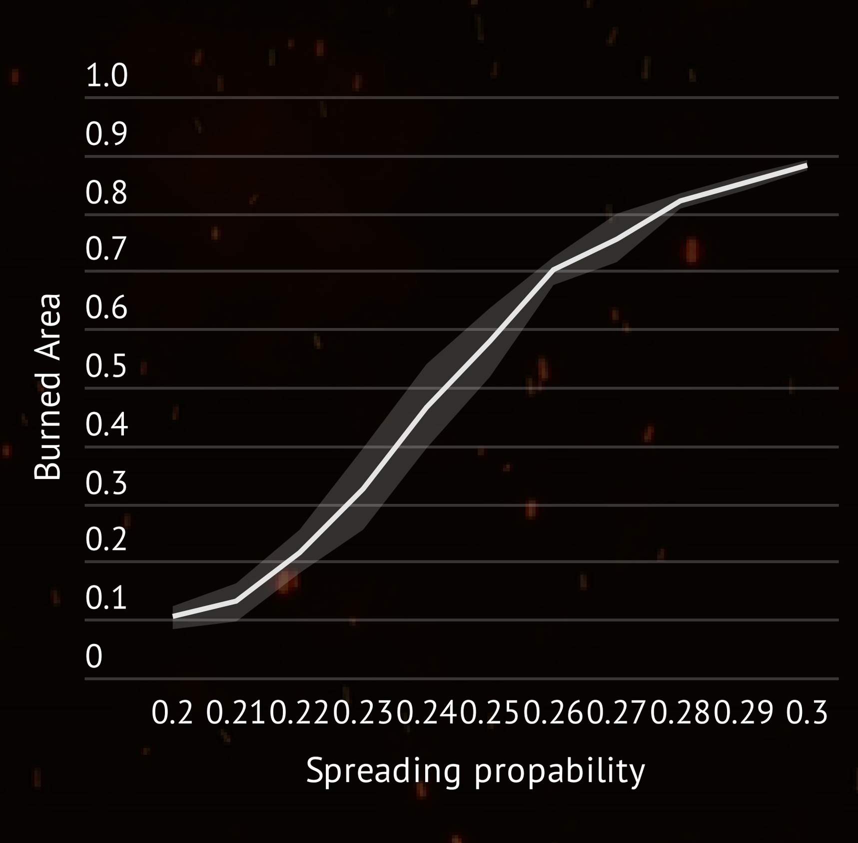
Side percolation



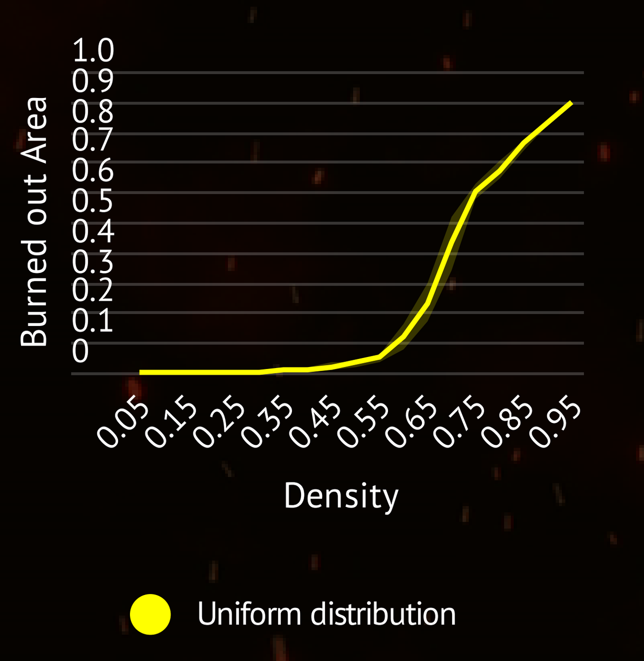


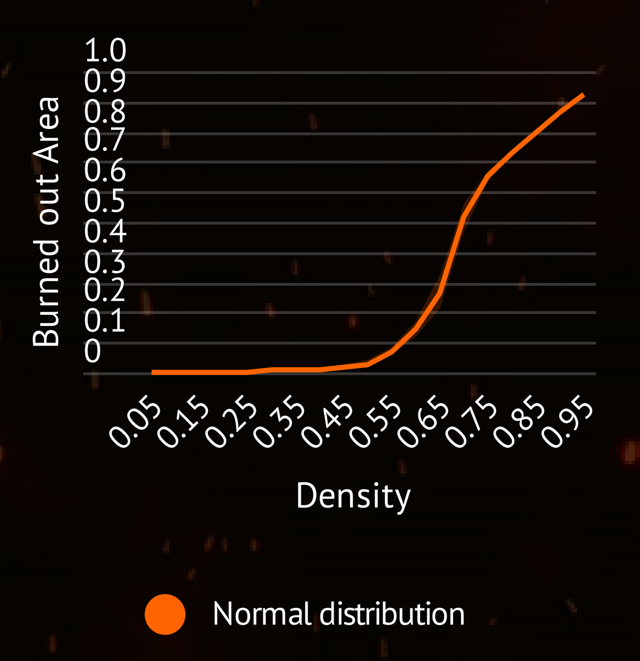
Bond percolation

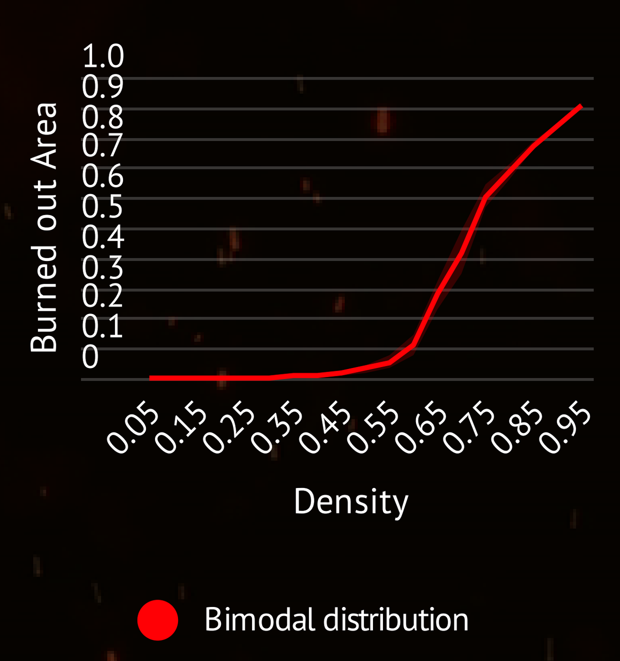




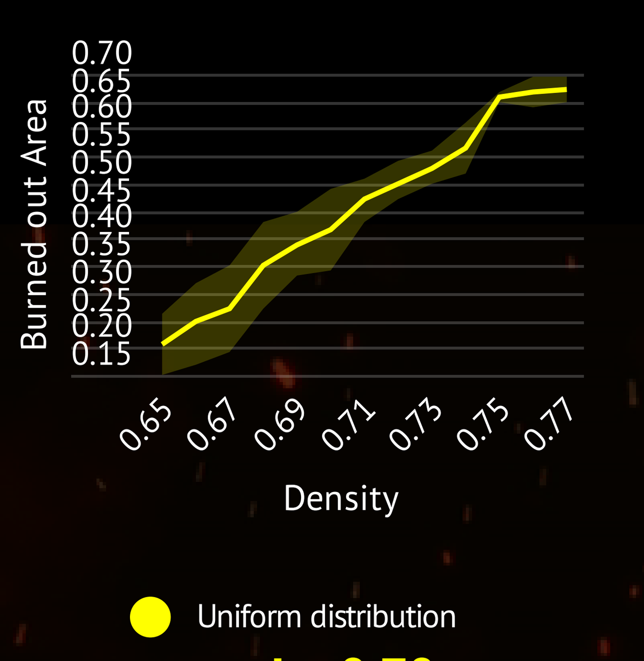
Finding the critical density



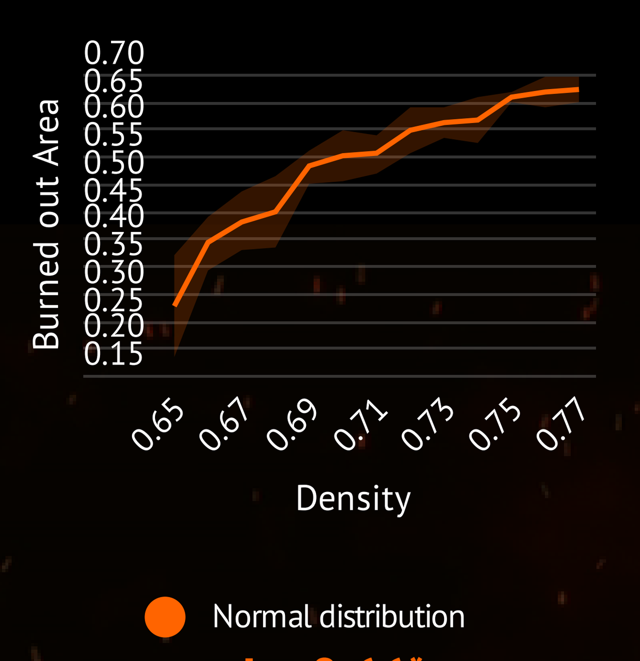




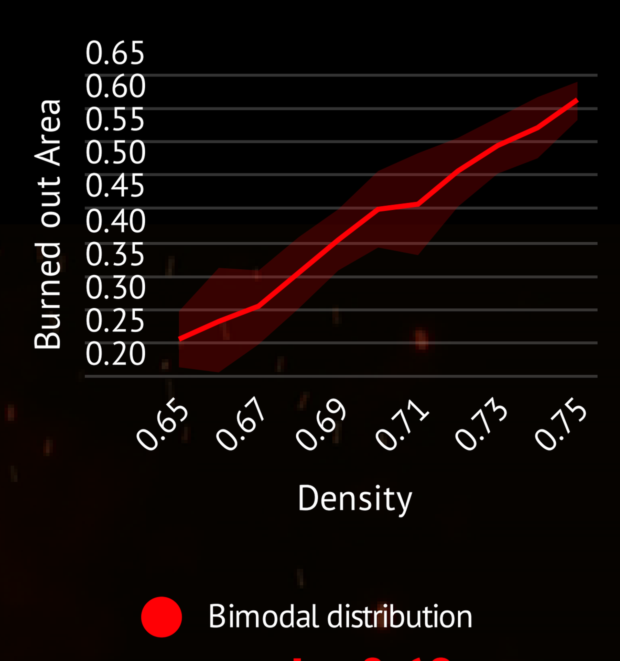
Let's zoom in



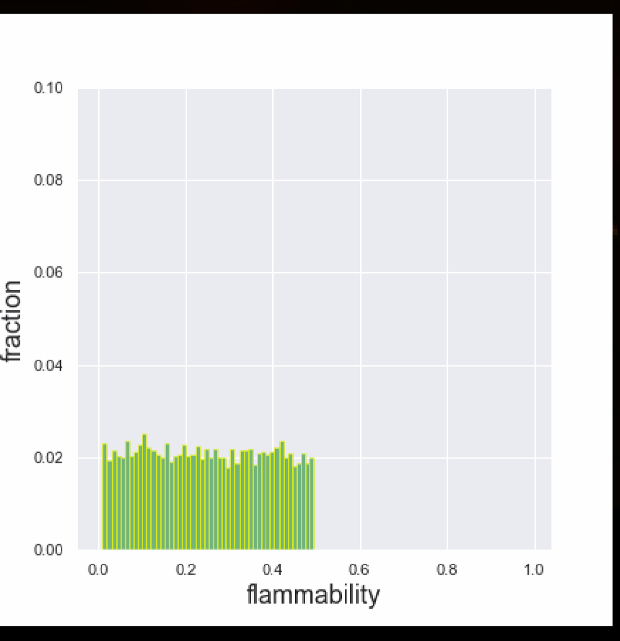
cd = 0.70

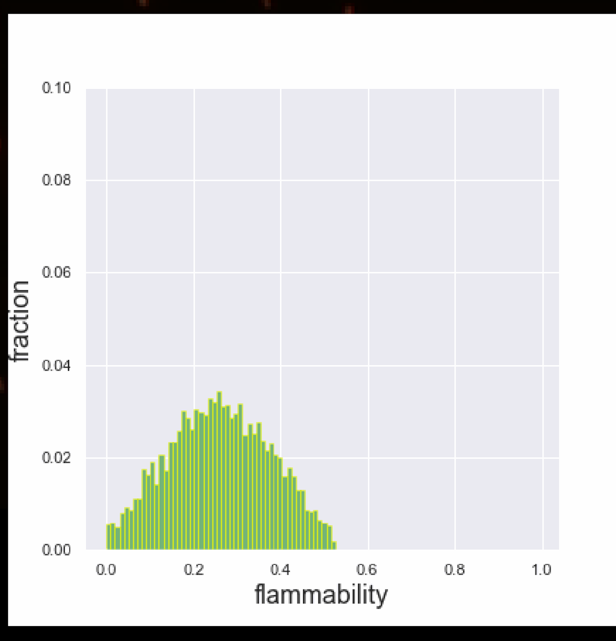


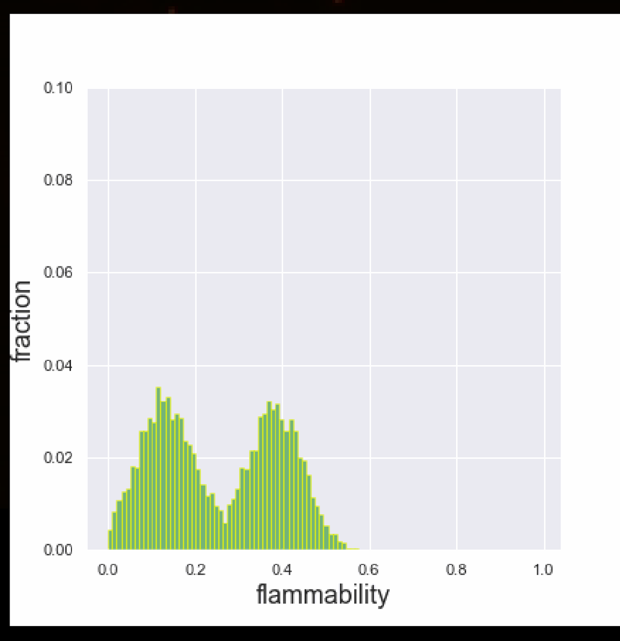
cd = 0.66*

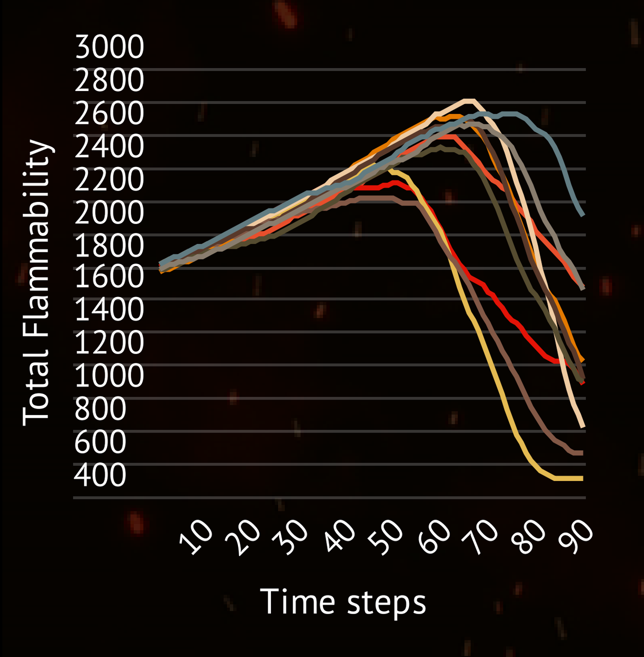


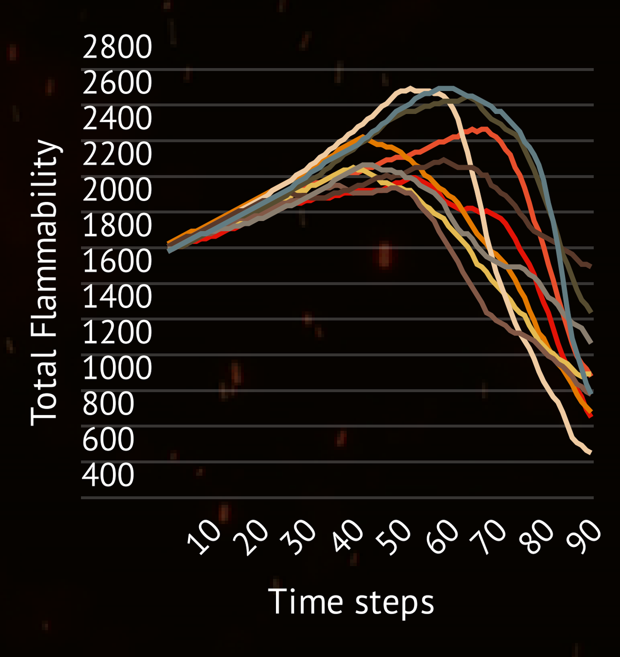
cd = 0.69







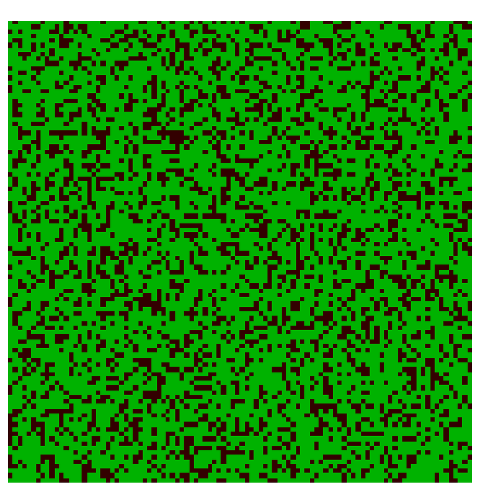


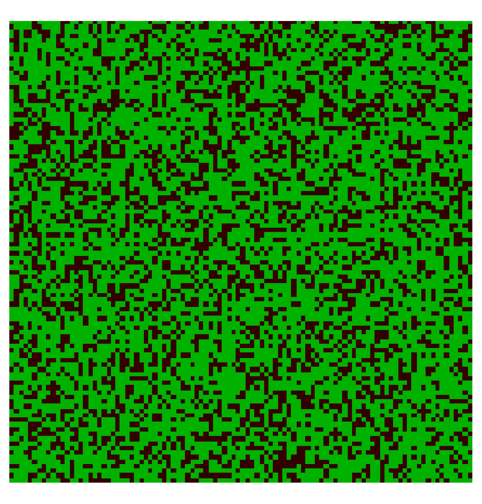


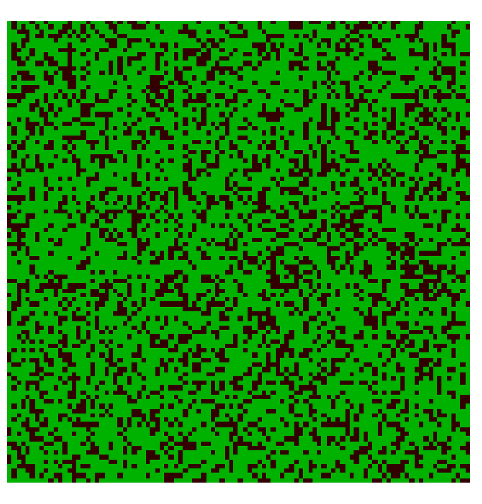
Uniform distribution

Normal distribution

Bimodal distribution







Conclusion

- Uniform and bimodal distributions similar behavior
- Normal distribution lower critical density
- Flammability increases over time up until critical point

Discussion

- Arbitrarily chosen distributions, instead of based on real-life data.
- Expanding the model with fire intensity and duration
- Possibilities for breaking the Self organized Criticality of the system

Literature

- Li, X., & Magill, W. (2001). Modeling fire spread under environmental influence using a cellular automaton approach. Complexity International, 8(1), 1-14.
- Malamud, B.D., Millington, J.D.A., & Perry, G.L.W. (2005): Characterizing wildfire regimes in the United States. PNAS, 102(13), 4694-4699.
- Palmieri, L., & Jensen, H. J. (2020). The Forest Fire Model: The Subtleties of Criticality and Scale Invariance. Frontiers in Physics, vol 8, 257.
- Zylstra, P. J. (2011). Forest flammability: modelling and managing a complex system. University of New South Wales, Australian Defence Force Academy, School of Physical, Environmental and Mathematical Sciences..

*there is at least a 90% certainty that the critical density of the normal ditribution is significantly different to the other to critical densities