ELECTRICITY GRID SIMULATION

Complex System Simulation - Group 3

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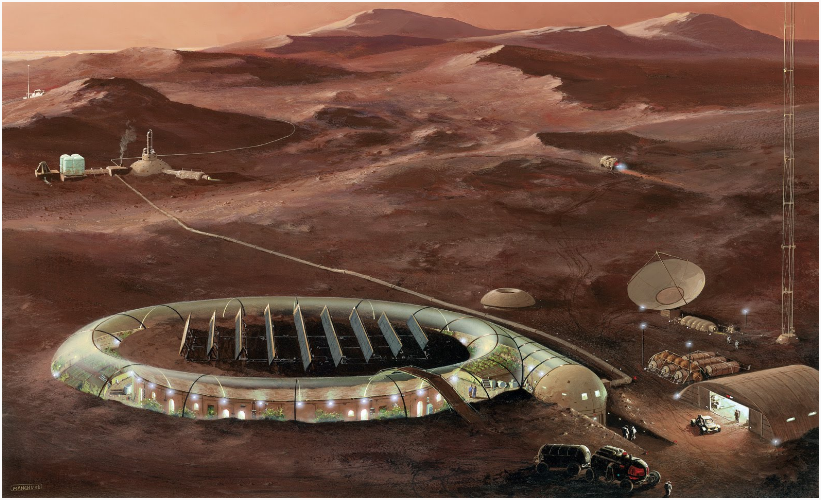
Presentation Outline

- Problem setting and research question
- Model description
- Approaches
  1. Mean-field (approximation)
  2. Network with different topologies
  3. Cellular automata
- Interactive: Jupyter Notebook and public website

Problem Setting



Problem Setting

Our future Mars society is dependent on electricity. Solar energy seems to be the most robust form of energy available; no wind, no fossil fuels. But solar panels are scarce and not evenly distributed over space.

For essential systems to function, electricity must be (re)distributed over the network or grid.

Research Question

What is the effect of energy sharing on the survival of the nodes in the solar-powered grid?

Motivation

Develop and implement a *simple* model/framework for an electricity grid solely dependent on solar power.

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Gain insight in the “power of sharing”

Clarity

What it <u>does</u>

look at the basic energy distribution tactic in a simple grid/network.

On small/medium grid topology: Pagani & Aiello. "Towards Decentralization: A Topological Investigation of the Medium and Low Voltage Grids." *Transactions on Smart Grid.* 2011

On asset (e.g. electricity) pricing: Brock & Hommes. "Heterogeneous beliefs and routes to chaos in a simple asset pricing model." *Journal of Economic Dynamics and Control.* 1998.

Clarity

What it <u>does</u>

look at the basic energy distribution tactic in a simple grid/network.

What it <u>does not</u> try to model electricity grid in detail (e.g. exact topology, financial aspects, ...)

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Model: Nodes

Introducing: The Node

A node N_i produces and consumes electricity. If nodes are linked they can share electricity.

- Consumption $C_i(t)$
- Production $P_i(t)$
- Battery capacity $E_{\text{max},i}$
- Altruism (the amount of energy you are willing to share)

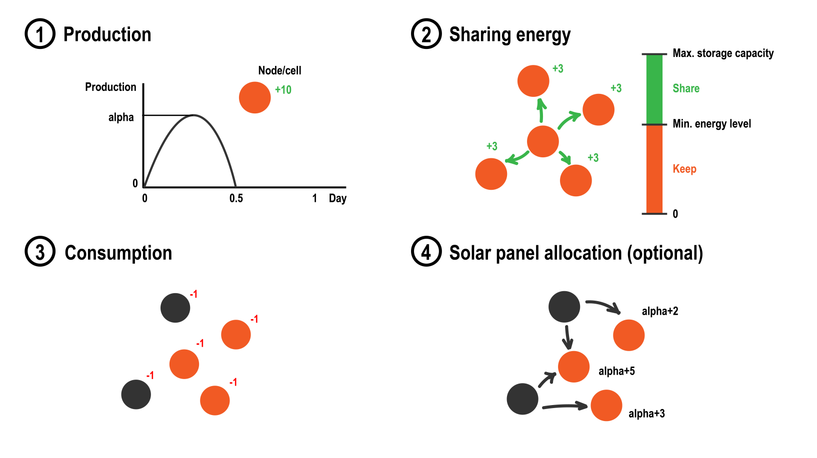
Model: Distribution

The distribution formula:

$$E_{\text{alloc,i}} = \sum_{j=1}^{N_{\text{neighbours, i}}} \frac{E_{\text{surplus, j}}}{N_{\text{neighbours, j}}} - E_{\text{surplus, i}}$$

where i is each node in the network and j is each neighbour of i

Model: Summary



Landis, Kerslake, Jenkins & Scheiman. "Mars Solar Power." *2nd International Energy Conversion Engineering Conference.* 2004.

Method

Three topologies

- Mean-field
- Network
- Cellular automata

Mean-Field Approach

Goal: Get a feel for the kind of behavior this system will show and what parameters are interesting to study.

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- Integer: each time step each node generates an integer amount of electricity $P_i(t) = \text{randint}(0, a)$, where $a \in \mathbb{N}^+$. (*See the website*)

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- Integer: each time step each node generates an integer amount of electricity $P_i(t) = \text{randint}(0, a)$, where $a \in \mathbb{N}^+$. (*See the website*)
- Sine: we simulate days and for each node $P_i(t) = A \sin(2\pi t)$ for $t < 1/2$ and 0 otherwise.

Mean-Field Approach

Consider the average amount of energy per node $\langle E \rangle$ at time t:

$$\langle E(t) \rangle = \langle E(t-1) \rangle + \frac{1}{N} \sum_{i=1}^{N} (P_i(t) - C_i(t))$$

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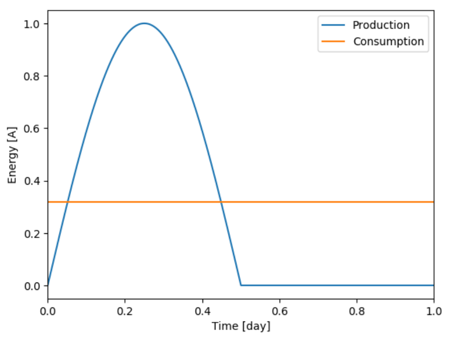
$C_i(t) = 1$ for all t and for all nodes. If $P_i(t)$ is based on probability distributions you can consider its expected value $\mathrm{E}[P_i(t)]$.

Mean-Field Approach

Each day:

Production: $P_i(t) = \alpha \sin(2\pi t)$ for $t < 1/2$ and 0 otherwise.

Consumption: $C_i(t) = \beta$



Mean-Field Approach

To reach a limit cycle for systems with period T we must have that:

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Note: As long as you use fully deterministic, smooth and continuous functions for $P(t)$ and $C(t)$ this system is not complex.

Mean-Field Approach

Show animations for limit cycle.

Mean-Field Approach

Show animations for decreasing average energy.

Mean-Field Approach

Show animations for increasing average energy

Mean-Field Approach

Now incorporate a maximum battery capacity E_{max}.

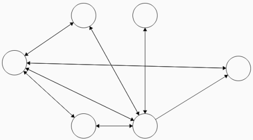
Show animation of the influence of this.

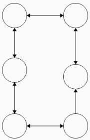
Networks: Topologies

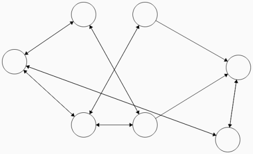
To approximate a mean-field model, we used a fully-connected network. Now let us consider other network structures such as:

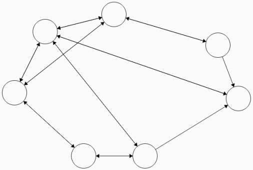
- Random Network
- Watts-Strogatz Network
- Barabási Network
- Ring Network

Networks: Topologies









Why networks?

- In the European power grid the mean degree $\langle k \rangle = 2.70$. In power grid the probability of having a node linked to k other nodes follows the exponential distribution $P(k) \approx \exp(-k/\gamma)$, in Europe $\gamma = 1.63$.
- Different network structures may be more efficient for survival and distribution

Rosas-Casals. "Power Grids as Complex Networks. Topology and Fragility." *Complexity in Engineering.* 2004.

Networks: Energy distribution

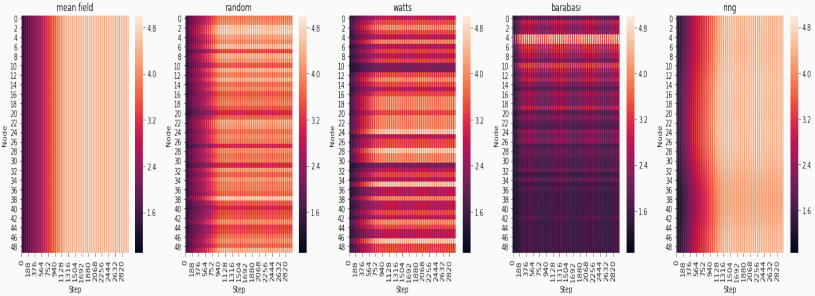
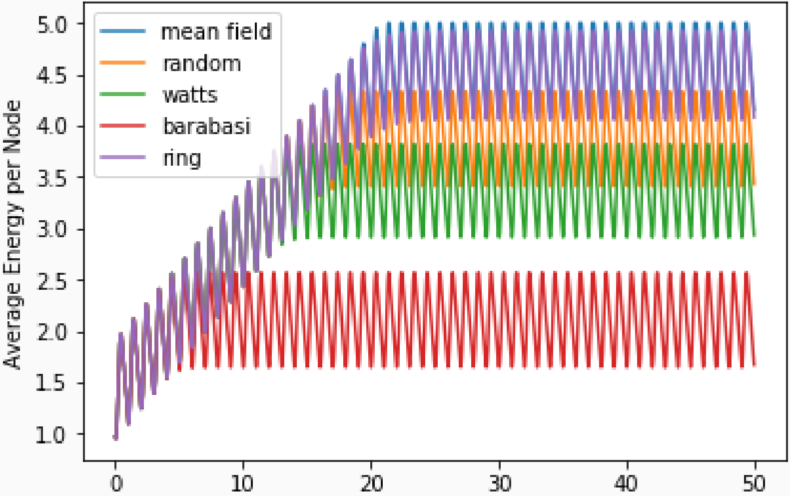


Figure: Energy distribution over time

Networks: Average energy per Node



Networks: Survival rates

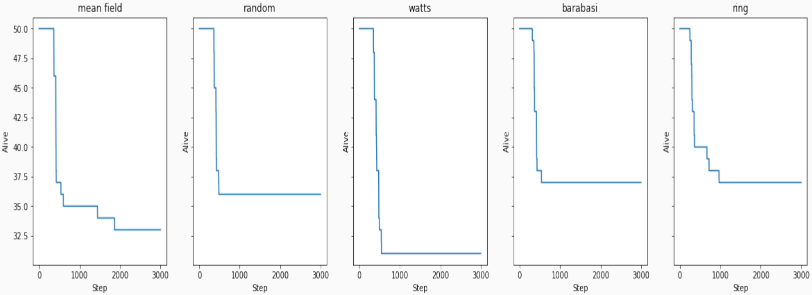
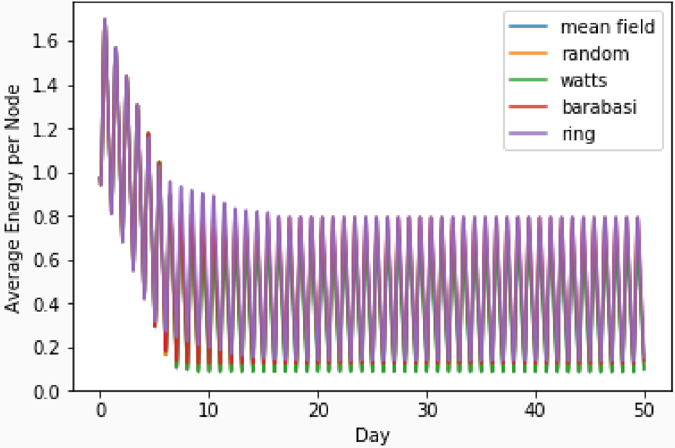


Figure: Survival

Networks: Average Energy in case of deaths



Networks: Distribution with death

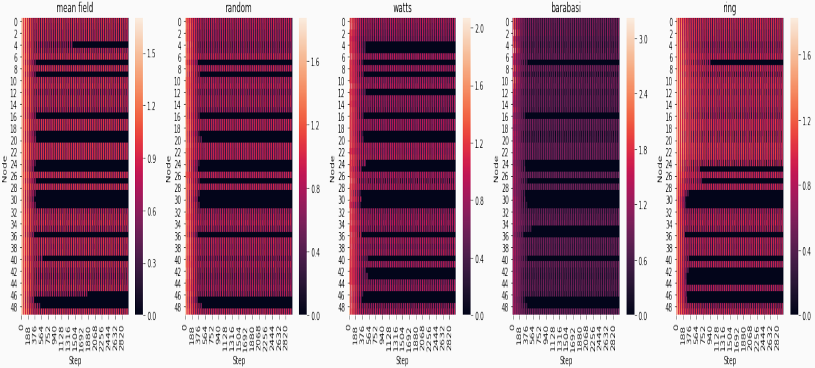


Figure: Energy distribution

Cellular Automata

▶ Optimal level of altruism at different production levels.

Settings:

- Initial energy: 0.05
- Maximum storage capacity: 10
- Days: 30, and 50 steps in a day
- 50 x 50 grid
- With/without taking panels

Related work:

Chatziagorakis et al., "Cellular Automata Model with Game Theory for Power Management of Hybrid Renewable Energy Smart Grids." LNCS volume 8751. 2014.

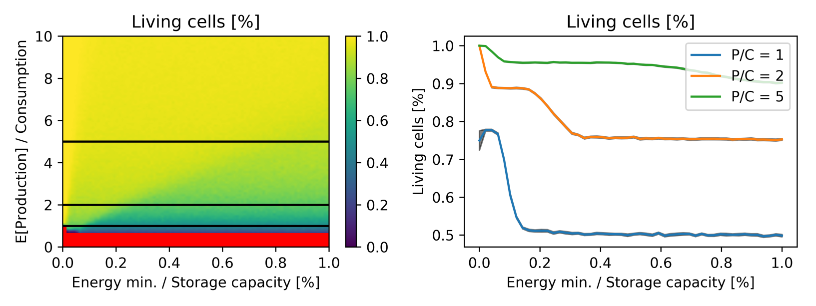
Animation - no transfer

Animation - with transfer

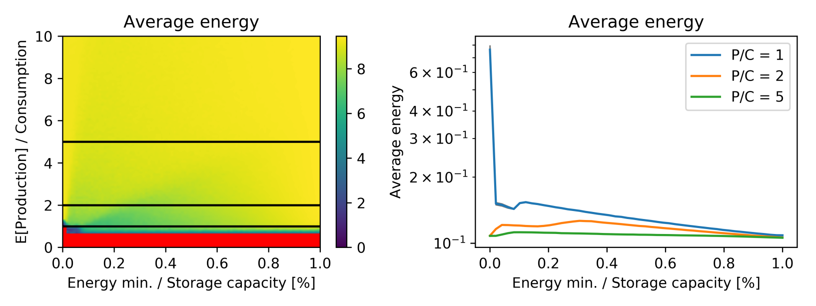
Cellular Automata

$E[P] > C$: be 100% altruistic

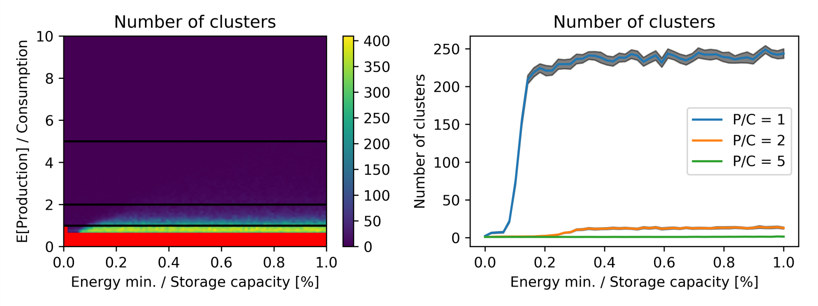
$E[P] \sim C$: be a little selfish



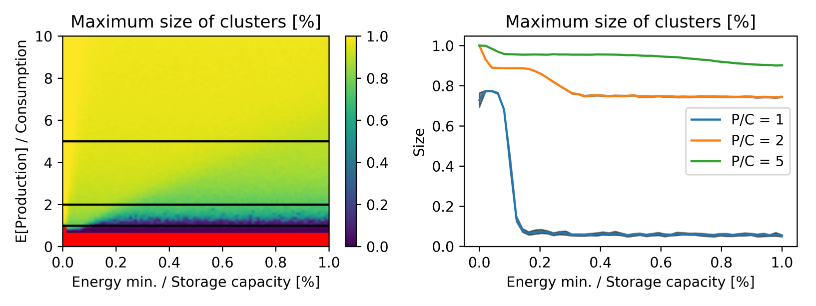
If $E[P] > C$, the average energy is lower at 100% altruism and 100% selfishness



Altruism decreases the number of clusters



Altruism increases the size of clusters



Conclusion

Mean-Field Approach

- Confirmed expected behavior for $P(t)$ in relation to $C(t)$.

Network Approach

- Both scale-free networks and ring-networks have better survival rates
- Distribution of energy in ring networks more uniform than scale-free networks.

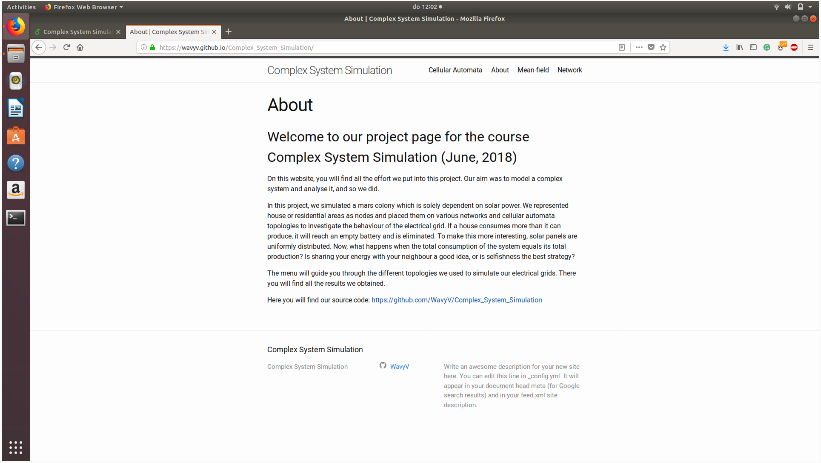
Conclusion

Cellular Automata Approach

- Being a little selfish can improve survival rate of nodes and the overall available energy in the system.
- Sharing energy allows for larger clusters to be sustained.

Website

https://wavyv.github.io/Complex_System_Simulation/



Jupyter Notebook