ODD WP2: Fusion fission dynamics and central place formation

[1] The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2006, 2010).

1. Purpose

This model will simulate the manifestation of energized crowding processes, simulated on an intra-community level in WP1, in inter-community settlement patterns through fusion-fission dynamics and central place formation. The goal is to show how energized crowding acts as underlying driver of community-building processes such as community formation, or community-breaking processes such as community fission, and can thus establish settlement networks and hierarchies as certain communities develop into central places. It will address questions such as what the critical thresholds of scalar stress are, whether this process can be linked to cross-culturally observed classes in community sizes, and what degree of social organization is required to transcend these thresholds. The basic principles of the model are derived from settlement scaling theory (Bettencourt, 2013), fission-fusion dynamics (Crema, 2014; Griffin, 2011), and central place formation (Fulminante, 2012; Knitter & Nakoinz, 2018; Vionis & Papantoniou, 2019).

2. Entities, state variables, and scales

The model includes two types of entities: people and communities. In the base model, people are assigned to a community upon initialization, and communities are given an identifier and placed in (semi-)random fashion across the (abstract) landscape. People move around and interact within their own communities, exchanging information and generating novel information that is captured on a community level. People are initialized with one 'unit' of information, which could be conceptualized as a specific idea. The number of ideas is a function of the total number of people within the community, but is not necessarily unique within that community. Following the dynamics of the model (see infra), people move between communities according to the proportionate 'weight' or pulling power of that community. Growing communities must either develop additional social organization, fission or fusion. Social organisation is set default to 1, being a face-to-face interaction. Higher levels of organisation are needed to allow population sizes to grow beyond fission thresholds.

- Temporal resolution: 1 tick = 1 year
- For now, each simulation run will end after 1000 years. This is a semi-random value: giving enough time to let significant patterns emerge, and more or less coincides with the full chronological framework of the research topic we're interested in: *polis* formation in the Eastern Mediterranean.
- Spatial resolution: Set of communities are simulated on a regional scale. Distances between communities are abstract but assumed to be easily bridgeable and no deterrent for inter-community movement.

State variables:

- People
    - Ideas (list)
    - Community association
    - Interaction history

[1] References are given in the manuscript.

- Communities
    - Location
    - Population size
    - Social organization
    - Fission threshold

3. Process overview and scheduling

Upon initialization, people are assigned to a community and communities are placed in (semi) random fashion across the landscape. People move around and interact within their own communities, exchanging information and generating novel information that is captured on a community level. People are initialized with one 'unit' of information, which could be conceptualized as a specific idea. The number of ideas is a function of the total number of people within the community, but is not necessarily unique within that community. Social interactions and information exchange generate scalar stress as well as socio-economic output following the results of the model in WP1.

Following the interaction module, fission-fusion dynamics are simulated. Communities can decide to fission based on community sizes determining levels of scalar stress, fission thresholds and availability of space. Fusion events happen when communities have no space to fission and neighboring sites have sufficiently different levels of social organization and population sizes, allowing the dominant site to incorporate the smaller one.

As sites grow and overcome thresholds, economic networks develop as sites with high socio-economic output start distributing this output to other communities. As certain sites increase this distribution, they develop as central places in the network.

Process:

- Setup
- Interaction
- Energized-crowding
- Fusion-fission
- Central-place-formation

4. Design concepts

Basic principles.
The model is based on the principles of settlement scaling studies, which constitutes a quantifiable framework that posits predictable links between community sizes and their social, economic and infrastructural properties. Dynamics of energized crowding originate in social interactions on an intra-community level, but also have emergent effects on an inter-community level resulting in changing settlement patterns. A suitable framework to study these emergent effects on an inter-community level is the fusion-fission cycle approach, in combination with central place formation.

Emergence.
Fusion-fission dynamics and central place formation on the (inter-)community level are modelled as emergent outcomes of social interactions on the individual level. They therefore constitute an emergent phenomenon driven by intra-community dynamics, but manifesting on the inter-community level

Adaptation.
Individuals do not have adaptive features. Adaptation takes place at the community level, when dealing with the interaction between community breaking and community building processes based on the level of scalar stress per community.

Objectives.
The interactions between individuals increase the total amount of information generated in a community, as well as scalar stress and socio-economic output. However, this is not an explicit objective of the interaction processes. The intention is for the community-level processes to emerge out of the interactions without being hard-coded in the model. Similarly, the objective of communities is to overcome fission thresholds to allow continued growth, but this is not an explicit objective.

Learning.
No learning dynamics are involved.

Prediction.
Agents do not predict future dynamics. Some degree of (bounded) knowledge of the environment is incorporated to facilitate interaction processes.

Sensing.
Communities sense scalar stress if their population size grows too much relative to the degree of social organization.

Interaction.
People interact directly and exchange information with other people within the community. Communities interact by comparing levels of social organization in preparation of potential fusion events, and engage in distribution of socio-economic output.

Stochasticity.
Stochasticity is involved in the balancing of scalar stress and social organization to allow group sizes to increase and community fission thresholds to be crossed. Stochasticity is also involved in every fission and fusion event and in the establishment of economic distribution patterns.

Collectives.
Individuals aggregate in collective communities. The total amount of information and pulling power of a community is an emergent outcome of the interactions between individuals.

Observation.
The data that will be collected from the ABM for further testing and analysis are population sizes and settlement patterns (in the form of rank-size distributions) that will be collected at the end of the simulation run.

5. Initialization

- A number of communities are created based on a slider between 1 and 30 with a standard value of 10.
- For each community, a number of people are created, based on a normal distribution with a mean of 100 and standard deviation of 50.
- Each community starts with a total amount of information set to 0 (updated only after first round of interactions) and an empty interaction history list
- Each community starts with:

    - scalar stress set to 0
    - fission threshold at 500 (informed by cross-cultural research) with standard deviation of 100
    - social organization level at 1 (face-to-face community)
- People are initialized with one unit of information, represented by a random value between 0 and the total number of people of that community.

6. Input data

Outcomes and simulated patterns of energized crowding dynamics produced in WP1 will be used as input data for WP2 to inform parameter values. No other input data will be used.

7. Submodels

- Setup
    - Create communities
    - Assign people to communities
- Move
    - People move randomly within the community
- Interaction
    - If people encounter each other (i.e. are in proximity), then:
    - Initiate contact
    - Exchange information
        - A virtual coin is tossed to decide whether the package of information of each participant in the interaction is transferred to the other
        - If yes: added to information list with a probability of mutation (i.e. the development of new ideas)
    - Update total information per community
        - Count of unique information values among population of a community
- Energized crowding: Based on interaction measures, energized crowding effects are created
    - Scalar stress
    - Socio-economic output
- Fusion-fission
    - Fusion-fission dynamics are initiated based on new population sizes
    - If population < fission threshold, initiate new round of interactions
    - If population > fission threshold: probabilistic fission event
        - If space available: fission halves community and creates a new community elsewhere
        - If no space available: probabilistic development of higher social organization
            - If successful: increase fission threshold
            - If unsuccessful: population size falls to a value within the initialization distribution
    - If neighboring communities with different levels of social organization: attempt to incorporate other community (fusion)
- Central-place-formation (to be developed)
    - Socio-economic output > threshold
        - Distributed to neighboring communities?
        - If distribution sufficiently large: central place development