ODD WP3: Push-pull interactions in *polis* communities

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

1. Purpose

This model will simulate the manifestation of energized crowding processes in settlement patterns through fusion-fission dynamics and central place formation, as part of a framework of push-pull interactions. The goal is to simulate push-pull interactions within and between settlements as generative mechanisms of *polis* formation in the Eastern Mediterranean from Iron Age to Hellenistic times (1000-31 BCE). *Polis* formation is often discussed in light of *polis*-centric and Eurocentric perspectives. The computational approach presented here will be part of a bottom-up study of drivers and dynamics of *polis* formation in a regional context.

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 I'm 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
- Communities
    - Location
    - Population size

[1] References are given in the manuscript.

- Pulling power
- 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. 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.

Process:

- Setup
- Move
- Interaction
- Energized-crowding
- PushPull_update
- Relocate
- Fusion-fission
- Central-place-formation

4. Design concepts

Basic principles.
The model is based on the principles of settlement scaling studies, which posit that communities can be considered as social reactors, meaning that they amplify the increasing returns of social interaction (Bettencourt, 2013; Bettencourt, Lobo, & Strumsky, 2007). The effects of these interactions can be both positive and negative, resulting in community formation and socio-economic growth (growing communities) on the one hand, and scalar stress (splitting communities) on the other (Smith, 2019). These dynamics 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 (Crema, 2014; Griffin, 2011).

This approach fits within an overall framework of push-pull interactions: Forces operating on various levels and domains, in and between social units, that provide stimuli for the creation, development and disbandment of organizational structures through the aggregation/breaking of flows of information, capital, people and resources (Altaweel 2015; Chliaoutakis and Chalkiadakis 2016; Crema 2014; Griffin 2011).

Emergence.
Fusion-fission dynamics on the community level are modeled 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.

People can relocate probabilistically based on the pulling power of settlements. Communities update their pulling power based on the amount of interactions and novel information generated.

Objectives.
The interactions between individuals increase the total amount of novel information generated in a community, 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, communities can increase their pulling power within the network of communities, improving their 'fitness', even though this is not an explicit objective of the community, but rather an emergent effect of its constituent interactions.

Learning.
People take their interaction history in account to generate preferential interaction partners (impacting the amount of novel information generated if they interact too much with the same partners).

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

Sensing.
People sense the pulling power of a community, influencing the decision to stay or move to another community. 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. Interactions consist of an 'encounter' where two individuals recognize each other as an interaction partner, and the initiation of an information transfer, where packaged of information are exchanged and stored in each agent's information list.

Stochasticity.
Stochasticity is involved in the transfer of information during interactions, and in the decisions of individuals to relocate. Stochasticity is also 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.

- This initial population determines the initial pulling power of a community.
- 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, see)
    - social organization level at 1 (face-to-face community)
    - pulling power set at 0
- 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, and fusion-fission dynamics simulated in WP2 will be used to inform parameter values. No other input data will be used.

7. Submodels

Questions: What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'? What are the model parameters, their dimensions, and reference values? How were submodels designed or chosen, and how were they parameterized and then tested?

Answer: ...

- 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
- PushPull_update
    - Update pulling power per community based on the amount of information among its population
- Relocate
    - People probabilistically decide to relocate based on the pulling power of a community

    - (operationalization of this pulling power will happen with trial and error while coding, the base model will assume a linear relationship between population size and pulling power)
- 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

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