Modelling the Origin of *Polis* in Anatolia. From Conceptual to Computational Approaches.

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SAGALASSOS ARCHAEOLOGICAL RESEARCH PROJECT

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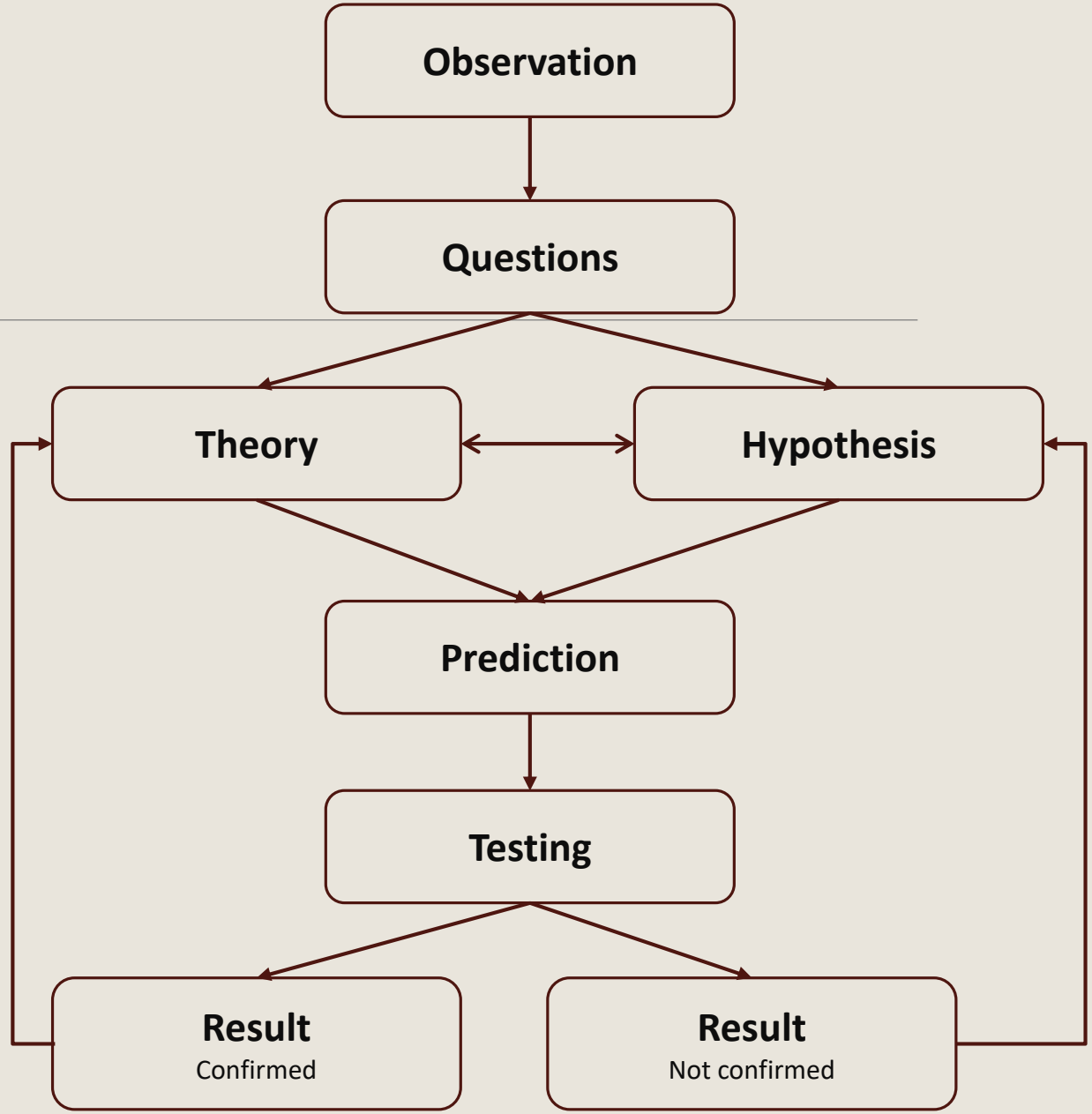
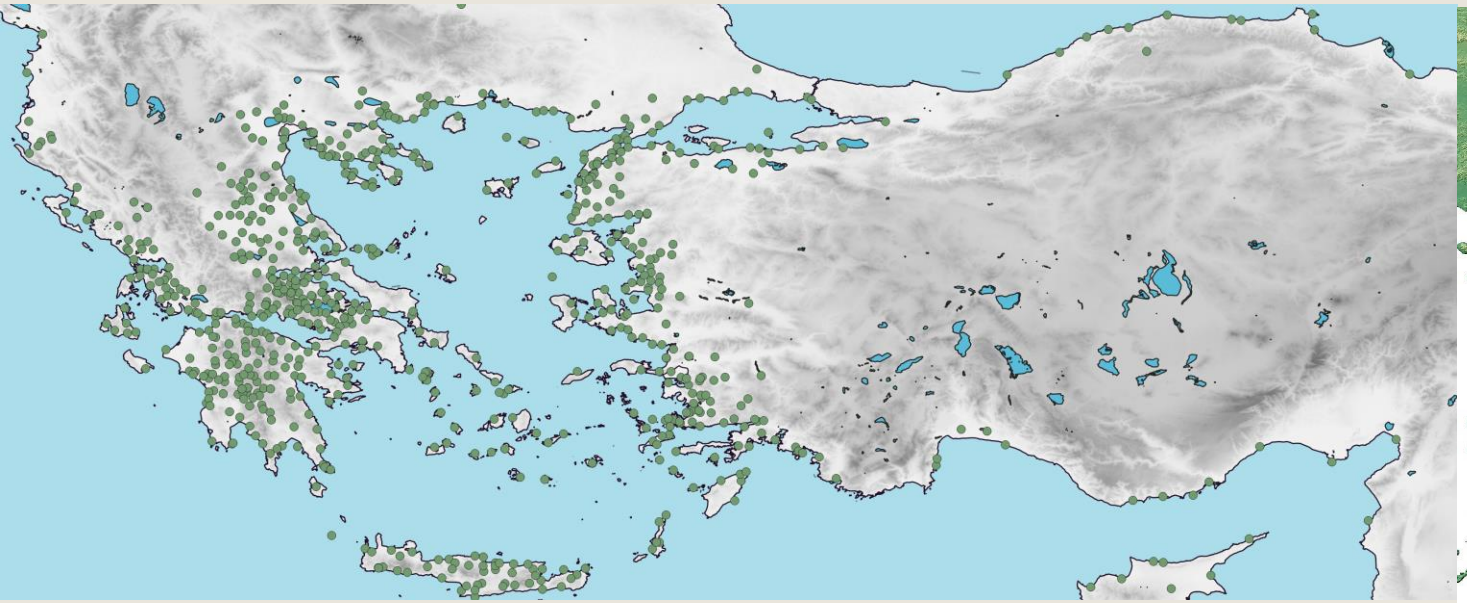
Designing Models

- Model properties:
  - Representation (what?)
  - Simplification (how?)
  - Purpose (why?)

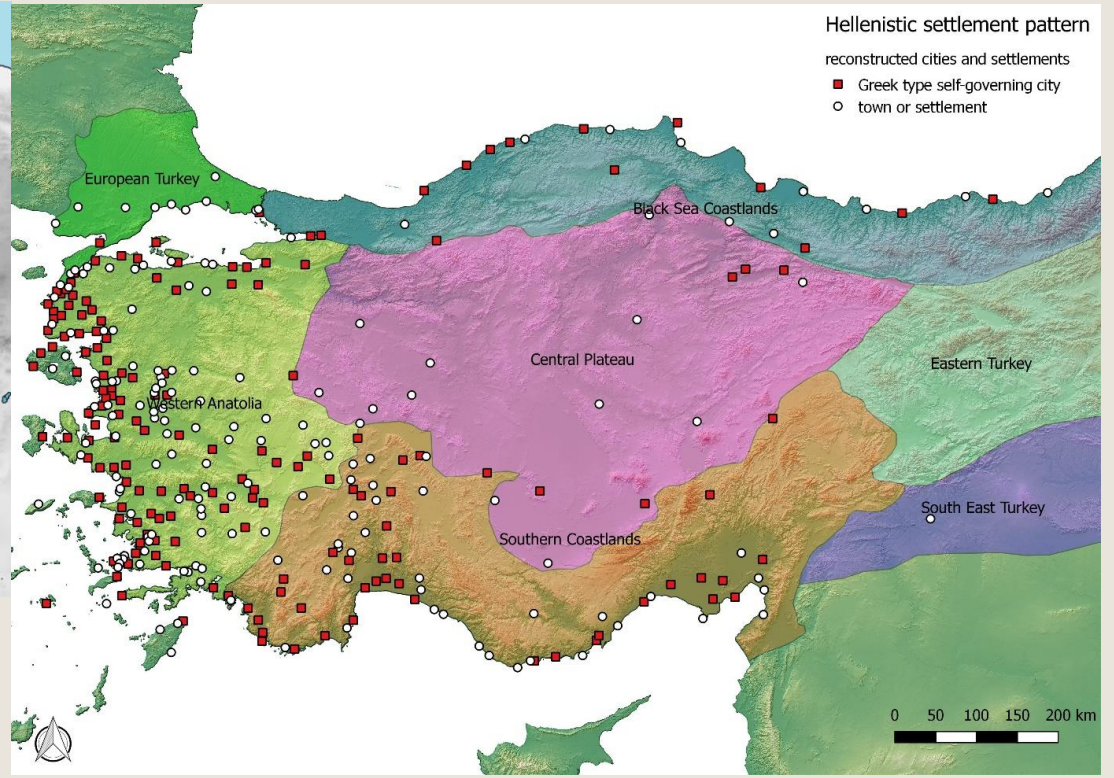
1) Explore research questions
2) Hypothesis testing
3) Theory building
4) Predictive modelling
5) Experimenting



Designing models: Origin of *Polis* in Anatolia



Made by author with dataset from POLIS website of Stanford University (http://polis.stanford.edu/); based on Hansen and Nielsen 2004.

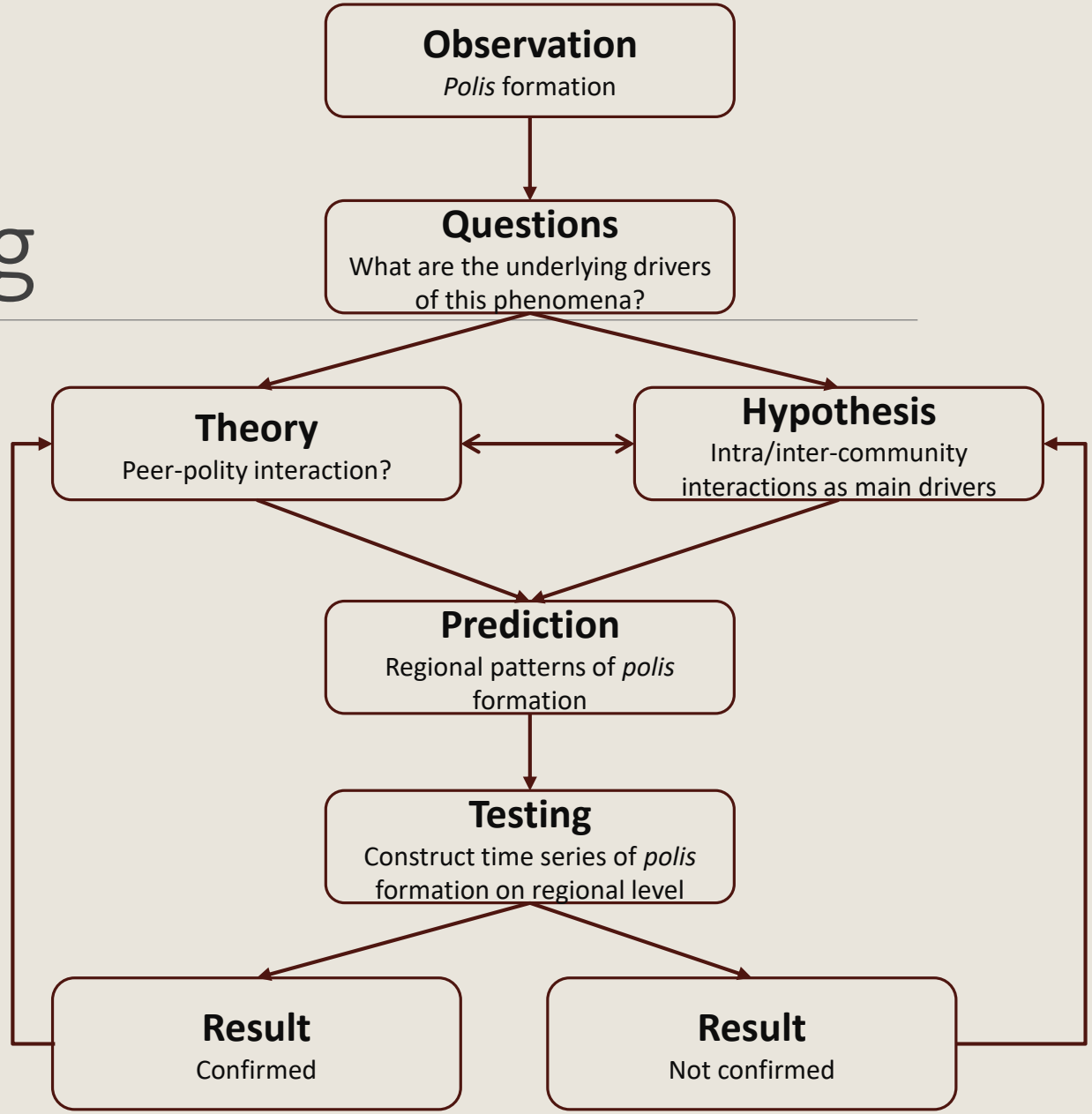


Map made by Willett (2019)

Hansen & Nielsen (2004) Inventory of Poleis
Willet 2019 The Geography of Urbanism in Roman Asia Minor

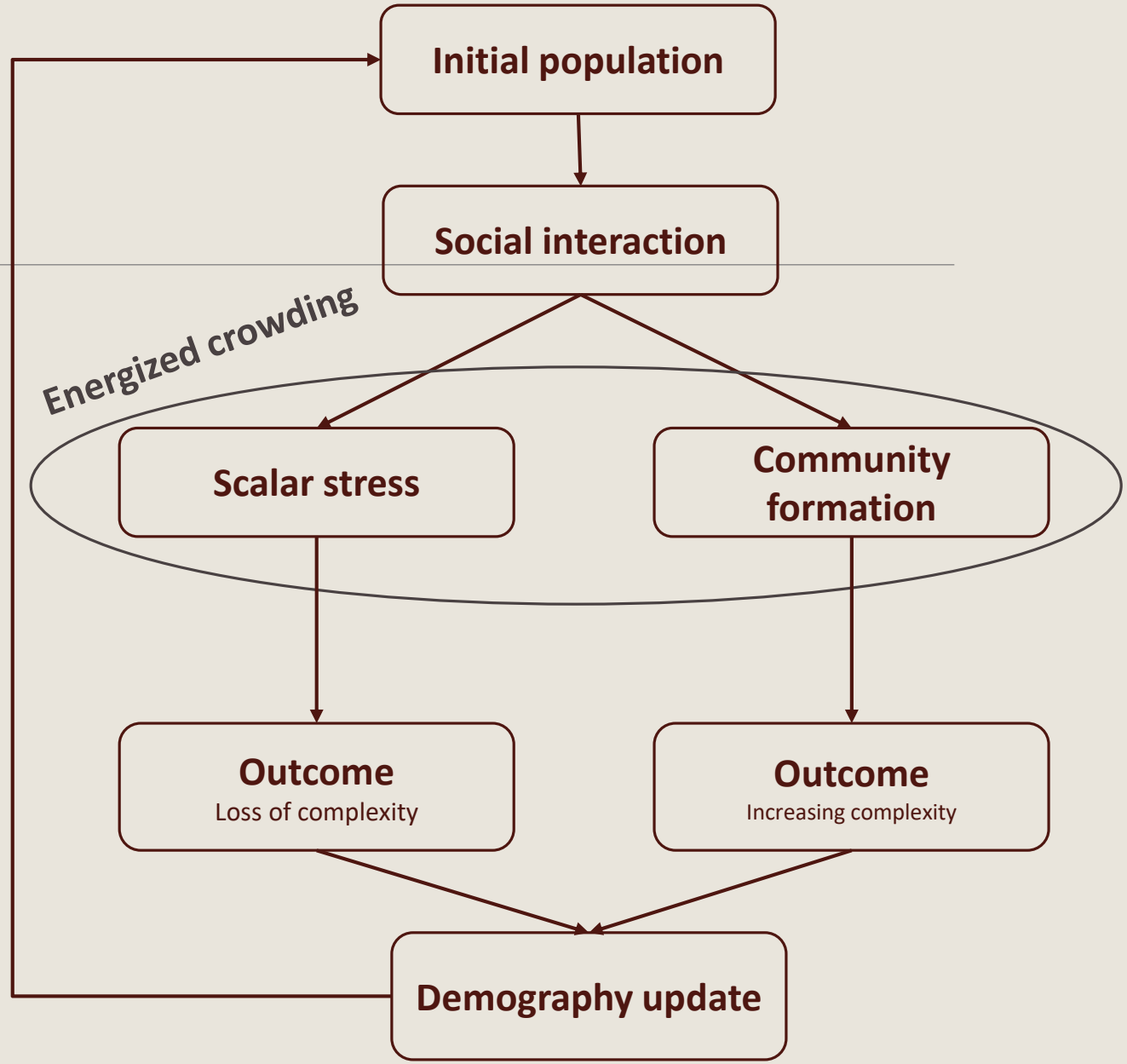
Conceptual modelling

- Model properties:
  - Representation (what?)
  - Simplification (how?)
  - Purpose (why?)
- **What?** Origin and development of *poleis* in Anatolia
- **How?** Focus on key properties:
  - Energized crowding
  - Fusion-fission cycles
  - Central place formation
- **Why?**
  - Untapped potential of computational modelling approaches in Classical Archaeology
  - Exploring possibility space



Conceptual Model: Model Structure

- **Energized crowding and settlement scaling (Bettencourt 2013; Smith 2019)**
- Fission-Fusion cycles (Bintliff et al. 2007)
- Central place formation (Knitter and Nakoinz 2018)



Bettencourt, L. 2013. The Origins of Scaling in Cities.
Bintliff et al. (2007) Emergent complexity in settlement systems and urban transformations
Knitter & Nakoinz (2018) The Relative Concentration of Interaction
Smith, M., 2019. Energized Crowding and the Generative Role of Settlement Aggregation and Urbanization.

Conceptual Model: Model Structure

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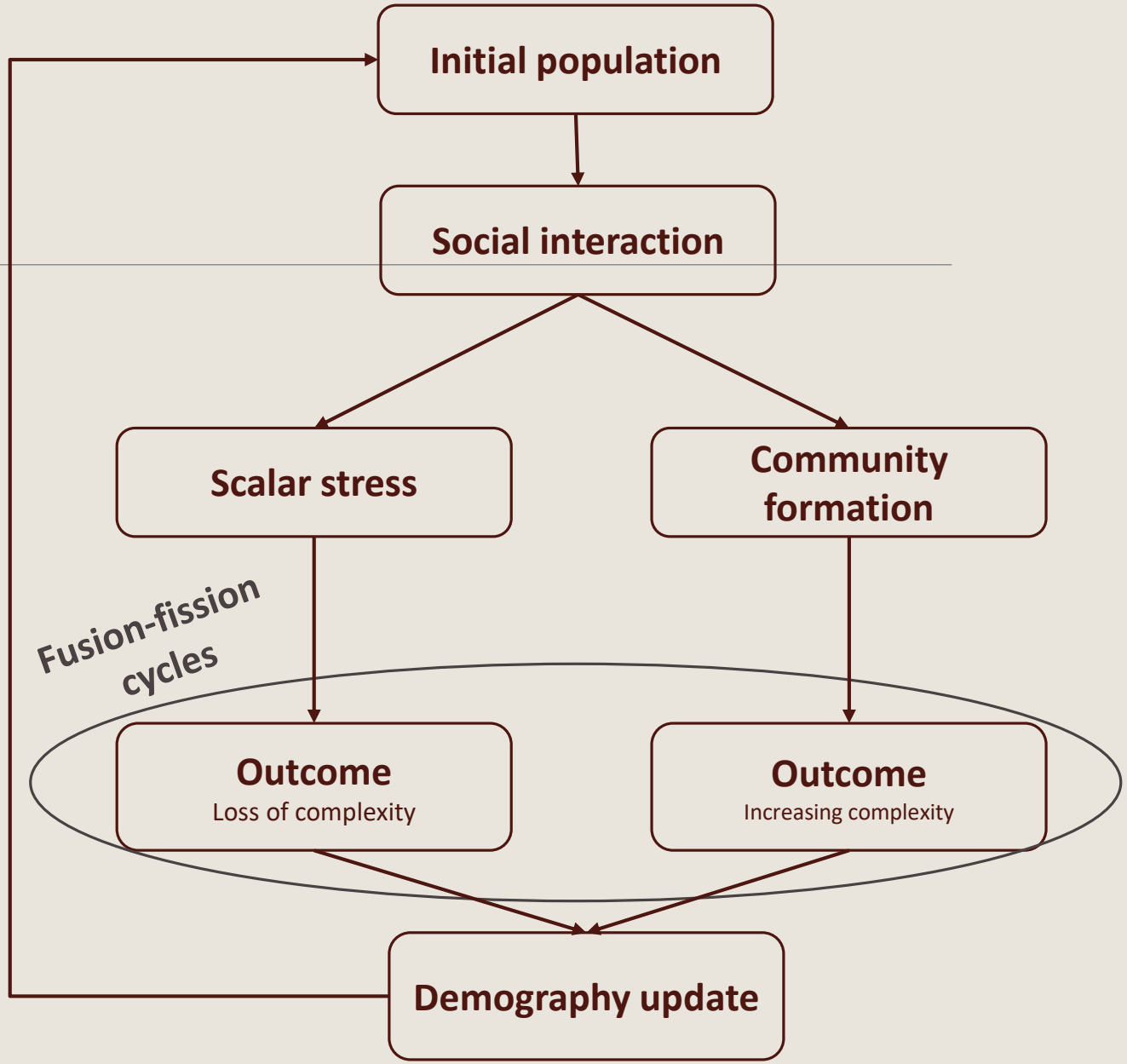

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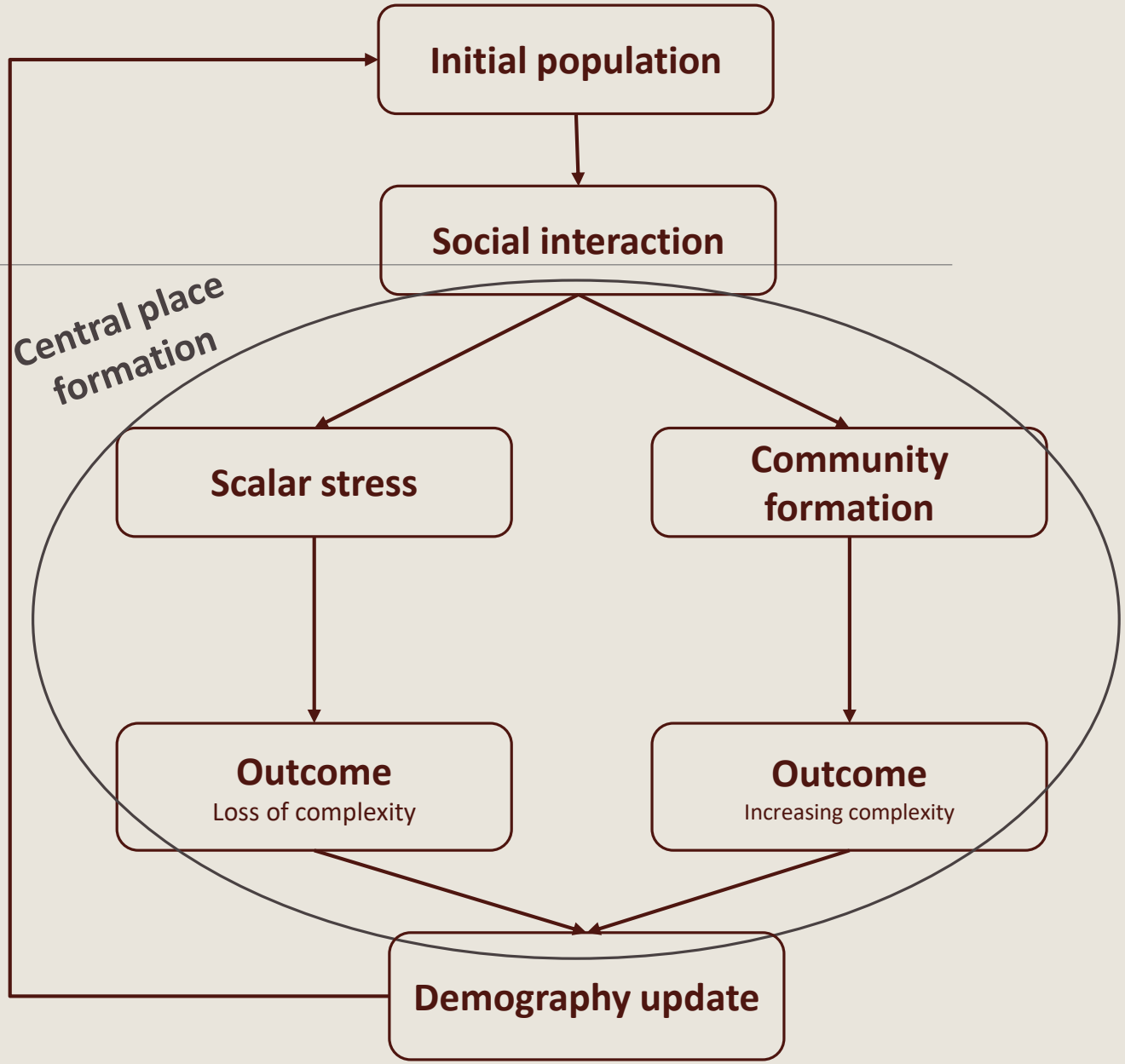

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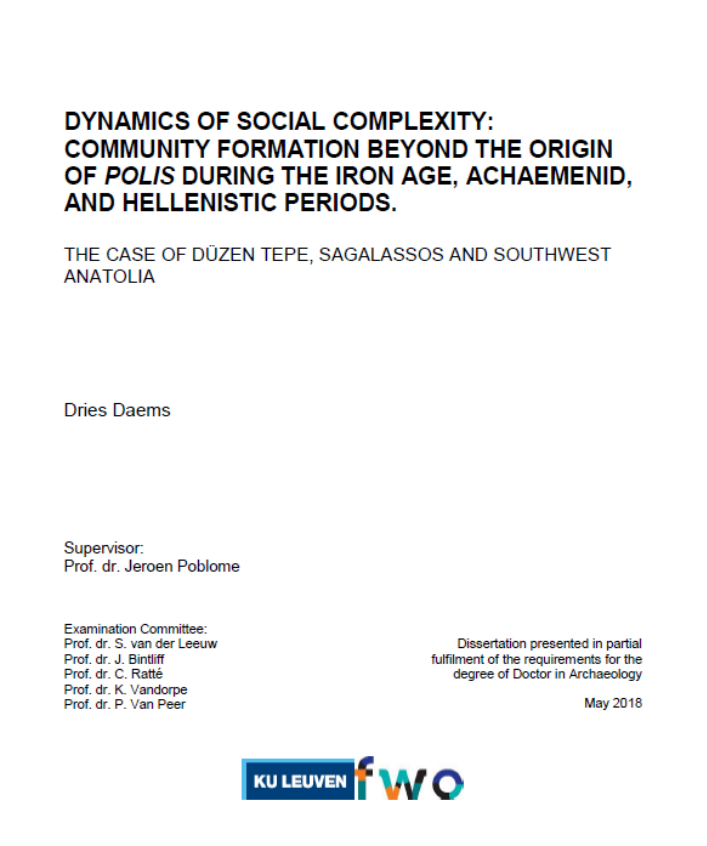
Conceptual model: Social complexity in Anatolia



DYNAMICS OF SOCIAL COMPLEXITY: COMMUNITY FORMATION BEYOND THE ORIGIN OF *POLIS* DURING THE IRON AGE, ACHAEMENID, AND HELLENISTIC PERIODS.

THE CASE OF DÜZEN TEPE, SAGALASSOS AND SOUTHWEST ANATOLIA

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Dissertation presented in partial fulfilment of the requirements for the degree of Doctor in Archaeology

May 2018

KU LEUVEN fwo

Daems, D. 2018. Dynamics of social complexity and community formation. Unpub. Ph.D. Diss. (University of Leuven).

Opinion

Adaptive Behavior

Adaptive Behavior
1–6
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On complex archaeologies: conceptualizing social complexity and its potential for archaeology

Dries Daems[1,2]

Abstract
This article surveys a number of approaches in complex systems thinking and their relevance for applications in the field of archaeology. It focuses in particular on the fundamental role of social interactions and information transmission as constituent elements for the development of organizational complexity on a community level. Given the impossibility of direct observations of these constituent interactions and practices, it is then outlined how this theoretical model can be applied on the material remains found in the archaeological record. It is discussed how material surroundings – including architectural structures and material objects – are used to shape and structure social interactions and practices in various ways. It is shown how complex organizational structures develop through underlying mechanisms of change such as diversification, connectivity and standardization, and how these can be applied in archaeological case studies. The presented framework will thus show how structures of social organization and development of social complexity can be inferred from the archaeological record.

Keywords
Social complexity, complex systems thinking, archaeological theory, material complexity, community formation

Handling Editor: Maria Coto-Sarmiento

Daems, D., 2019. On complex archaeologies: conceptualizing social complexity and its potential for archaeology. *Adaptive Behavior*.

From Conceptual to Computational: Simulation process

Conceptual phase

1. Identifying research questions
2. Finding most suitable method
3. General framework and resolution of simulation
4. Entities and rules of interactions

Technical phase

5. Coding and testing
6. Parameterising simulation
7. Running simulation
8. Analysis and recontextualization of results

Dissemination phase

9. Disseminate findings

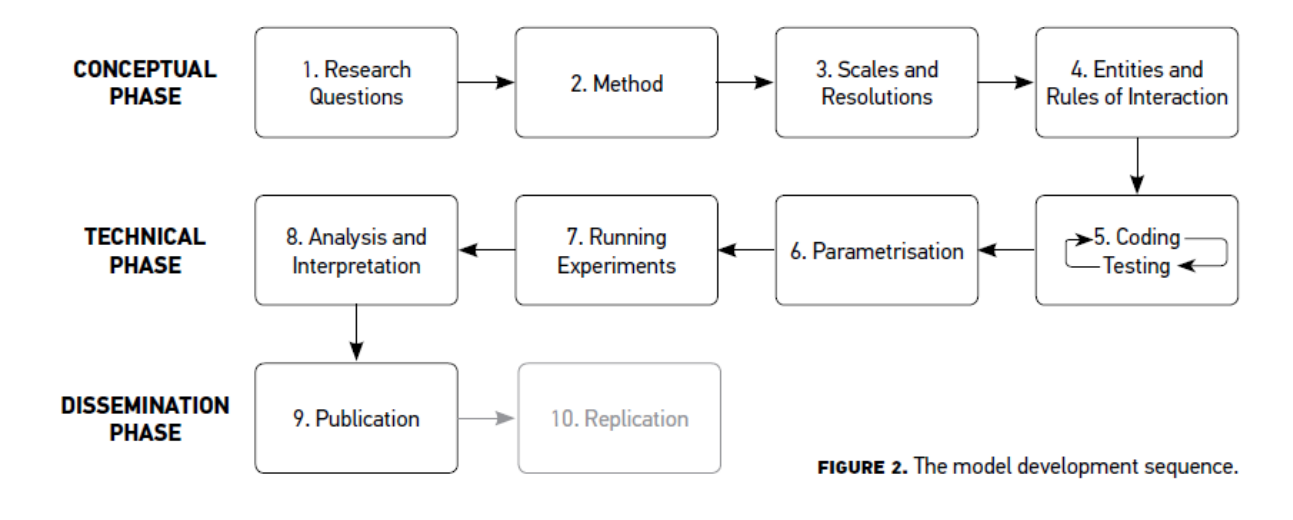


FIGURE 2. The model development sequence.

Romanowska (2015) So You Think You Can Model?

Computational Model: Documentation

ODD protocol: standardize the published descriptions of individual-based and agent-based models (Grimm et al. 2010)

Iterated process

- Structure thoughts
- Think through construction of the model

Elements of the updated ODD protocol

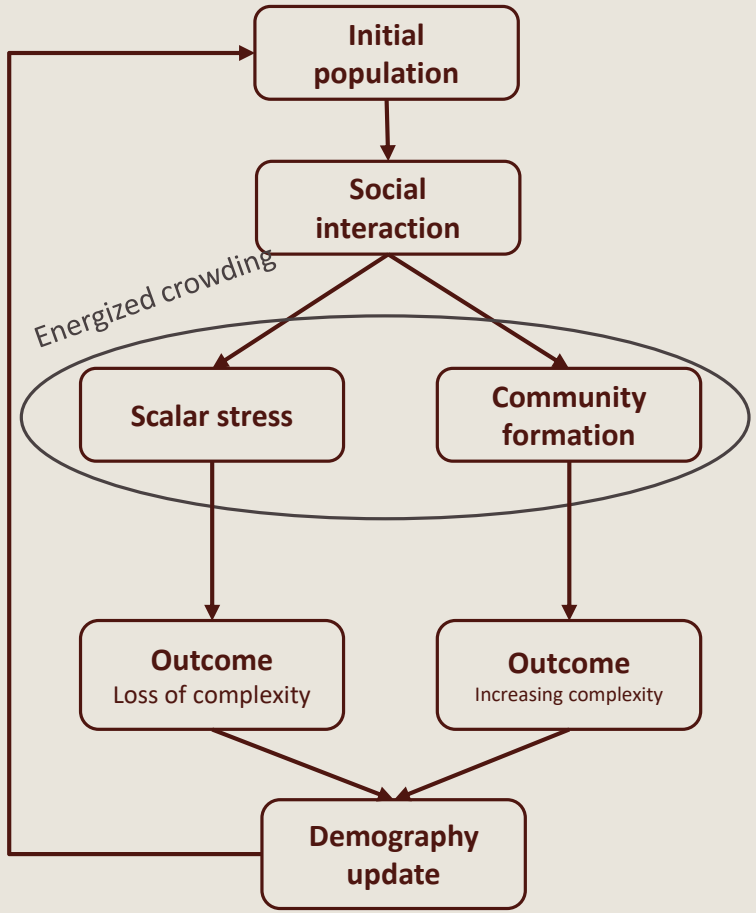
1. Purpose
2. Entities, state variables, and scales
3. Process overview and scheduling

4. Design concepts
   - Basic principles
   - Emergence
   - Adaptation
   - Objectives
   - Learning
   - Prediction
   - Sensing
   - Interaction
   - Stochasticity
   - Collectives
   - Observation

5. Initialization
6. Input data
7. Submodels

Grimm et al. (2010) The ODD protocol: A review and first update

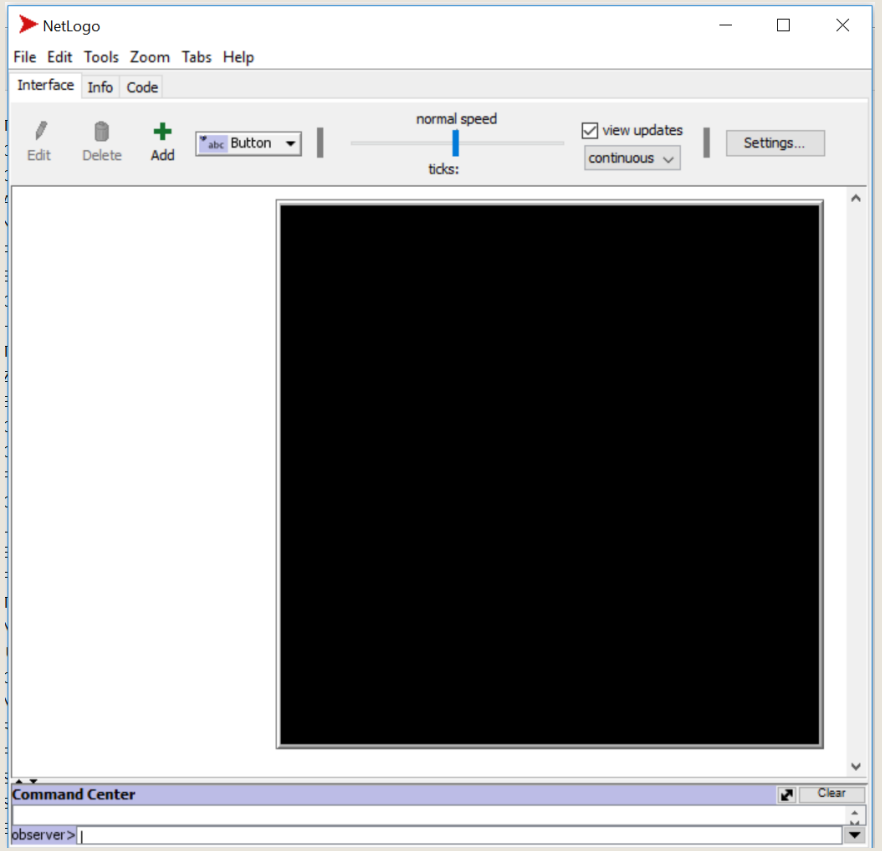
Computational Model: Pseudo-code




```
;; the model initiates people moving within an existing community
;; the initial community is a small-scale village community with small population sizes between 100 and 200 people (see Forge 1992 and Dunbar 1996)
;; in order for the community to cross certain thresholds in population sizes, social organisational structures need to be developed (Bintliff 2007; Wobst 1974)
;; the development of social organisation in larger community is an expression of increasing social complexity

Create number of agents;; population size is determined by empirical community size limits of villages: 100-200 people

agents move randomly
if encounter between agents:
        communication between agents
        Communication induces "energized crowding"

;; in order to make energized crowding concept operational: every social interaction has cognitive load and is taken into account for calculating social stress
;; but not every interaction also has positive results generating social and economic benefits

Energized crowding:
        Social interaction leads to more scalar stress
                When scalar stress reaches certain threshold --> accumulated social complexity gets reset and population numbers fall
        Social interaction results in random chance for exchanging information
                Information exchange leads to increasing returns on social and economic output
                Community formation entails development of social organizational structures
                        NEEDS TO BE OPERATIONALIZED

Population growth:
        Standard population update module: growth based on current population as long as population thresholds are not reached or scalar stress occurs
        Population thresholds determined by level of social organisation (villages - corporate communities - cities)
        population growth: dN/dt = r.N.(1-(energy needed/energy available))

Create networks
        Fission-fusion dynamics occur depending on energized crowding dynamics per community
        Composite socio-economic output metric used to calculate pulling power per settlement
        Create settlement hierarchies based on settlement pulling power

Socio-encironmental interactions (urban metabolism)
        compare available energy (within threshold?) from available land with energy needed to sustain population
        exploit certain amount of energy
        If shortage: decide on strategy: 1) expand territory; 2) Trade to cover deficit(??); 3) settlement fusion; 4) governmental structures
        If no available strategy: collapse

...
```

PolisABM

- Software: NetLogo (Wilensky 1999)
- From conceptual to detailed design:
  - Translating the conceptualised system into a set of entities and rules of interaction
- From detailed to operational design
  - Translating pseudo-code into computer code



Wilensky (1999) NetLogo. http://ccl.northwestern.edu/netlogo/.

PolisABM: Base model Initialising Simulation

- Basis of energized crowding model
- Focus on intra-community dynamics
- Social interaction as basic constituent elements of social complexity

Entities = individuals

Initial state variables:

- Population size: 100
- Information coded as elements in a list: Every agent starts with 1 piece of information (idea)

→ random variable between 0 and pop-size

Scale

- Patch size: 10 m²
- World size: 50x50 patches

Spatially abstract

```
;; = comments
; = blocked out code

breed [persons person]
breed [communities community]
persons-own [
  information      ;; Every agent has by default one piece of information (or ide
  partner          ;; Allows for coupling of persons for interaction
  partnered?       ;; Check if person already has communication partner
  partner-history ;; A list recording past interactions with other persons ;; no
]
communities-own [complexity]

to setup
  clear-all
  ;set-community   ; determine type of community at start of simulation with cho
  create-inhabitants
  reset-ticks
end

to go
  ask turtles [
  move
  interact
  reproduce
  ]
  tick
end

to create-inhabitants
  create-persons pop-size [       ;; number of agents depend on settings of slid
    setxy random-xcor random-ycor ;; agents are created at random locations
    set size 1
    set partnered? false
    set partner nobody
    set partner-history (list)    ;; Agents are initiliased with an empty list t
    ;; Information develops through communication, so agents initialised with no
    set information (list)
    ;; One 'piece' of information (or idea) is represented as a number in a list
    ;; Agents initialised with a random number between 0 and the initial populat
    ;; There are potentially as many ideas as people at the start of the simulat
    set information fput random pop-size information
    ; set interaction-history ?
  ]
end


to move        ; random movement
    if random 9 > 0 [
    set heading random-float 360
    fd 1
  ]
end
```

PolisABM: Base model Energized crowding

Basic social interaction algorithm

- All agents interact randomly with others
- Interaction partner identified nearby
- Information is exchanged

Simulation run

- Mean number of interactions settles on linear increase
- Unique information exchange tails of as no new information can be gathered

```
to interact
  ask persons [
    set partner one-of (persons-on patches in-radius 1.5) with [not partnered?];
    if partner != nobody [  ;; if succesful in coupling, engage interaction
      set partnered? true
      ;let i random length information     ;; random idea from information list i
      set information fput (one-of [information] of partner) information      ;;
      ask partner [
        set partnered? true
        set partner myself
        set information fput (one-of [information] of myself) information     ;;
        set partnered? false
        set heading random 360
        fd 3            ;; after interactions, persons are forced to create dista
      ]
      set partnered? false
    ]
  ]
  ;communicate
  ;; to be implemented: preferential interaction based on partner-history
end
```

PolisABM: Base model Energized crowding

Basic social interaction algorithm

- All agents interact randomly with others
- Interaction partner identified nearby
- Information is exchanged

Simulation run

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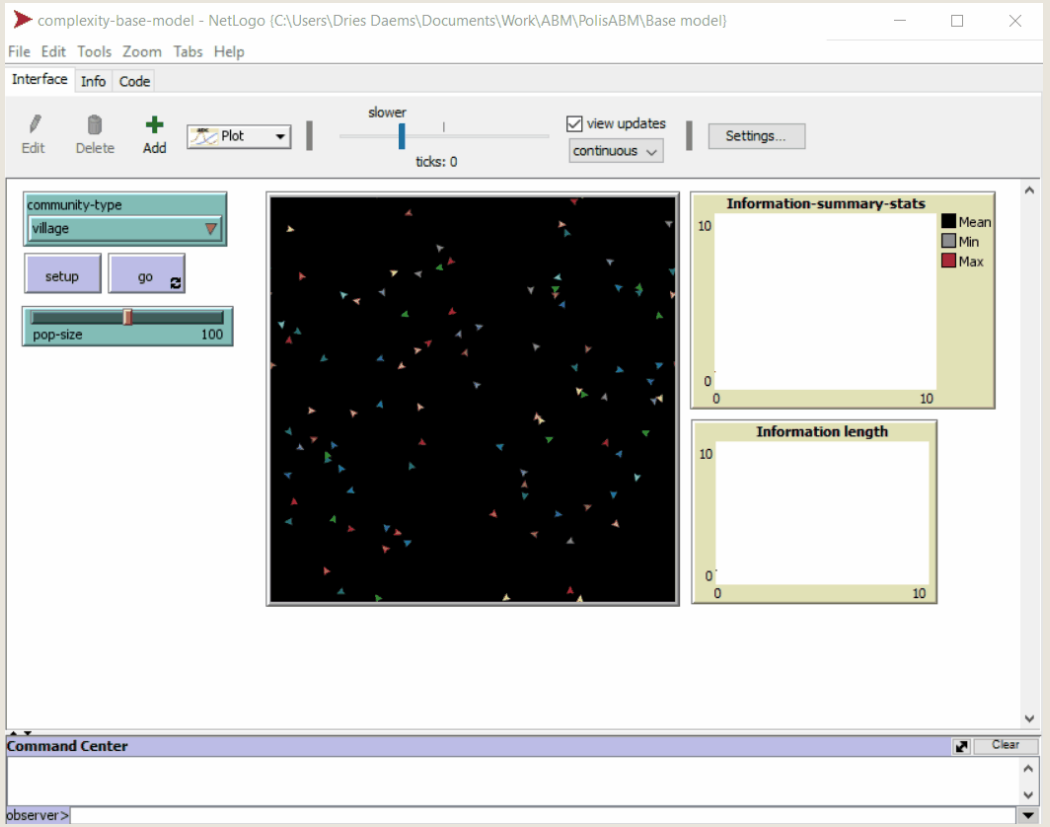

PolisABM: Base model Energized crowding

Basic reproduction algorithm

- Fixed carrying-capacity (for now)
- New agents created every timestep
- Population growth setting
- Correction for overshoot

```
to reproduce
  if count persons < carrying-capacity [ ;and random-float 100 < pop-growth [
  create-persons (count persons / 100 * pop-growth) [
    setxy random-xcor random-ycor
    set size 1
    set partnered? false
    set partner nobody
    set partner-history (list)
    set information (list)
    set information fput random pop-size information
  ]
  ]
  if count persons > carrying-capacity [                    ;; correct for overshoot of population growth
   ask n-of (count persons - carrying-capacity) persons [die]
  ]
end
```

Simulation run

- Irregular distributions at first
- Settle in same pattern as population reaches carrying capacity limit

PolisABM: Base model Energized crowding

Basic reproduction algorithm

- Fixed carrying-capacity (for now)
- New agents created every timestep
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Simulation run

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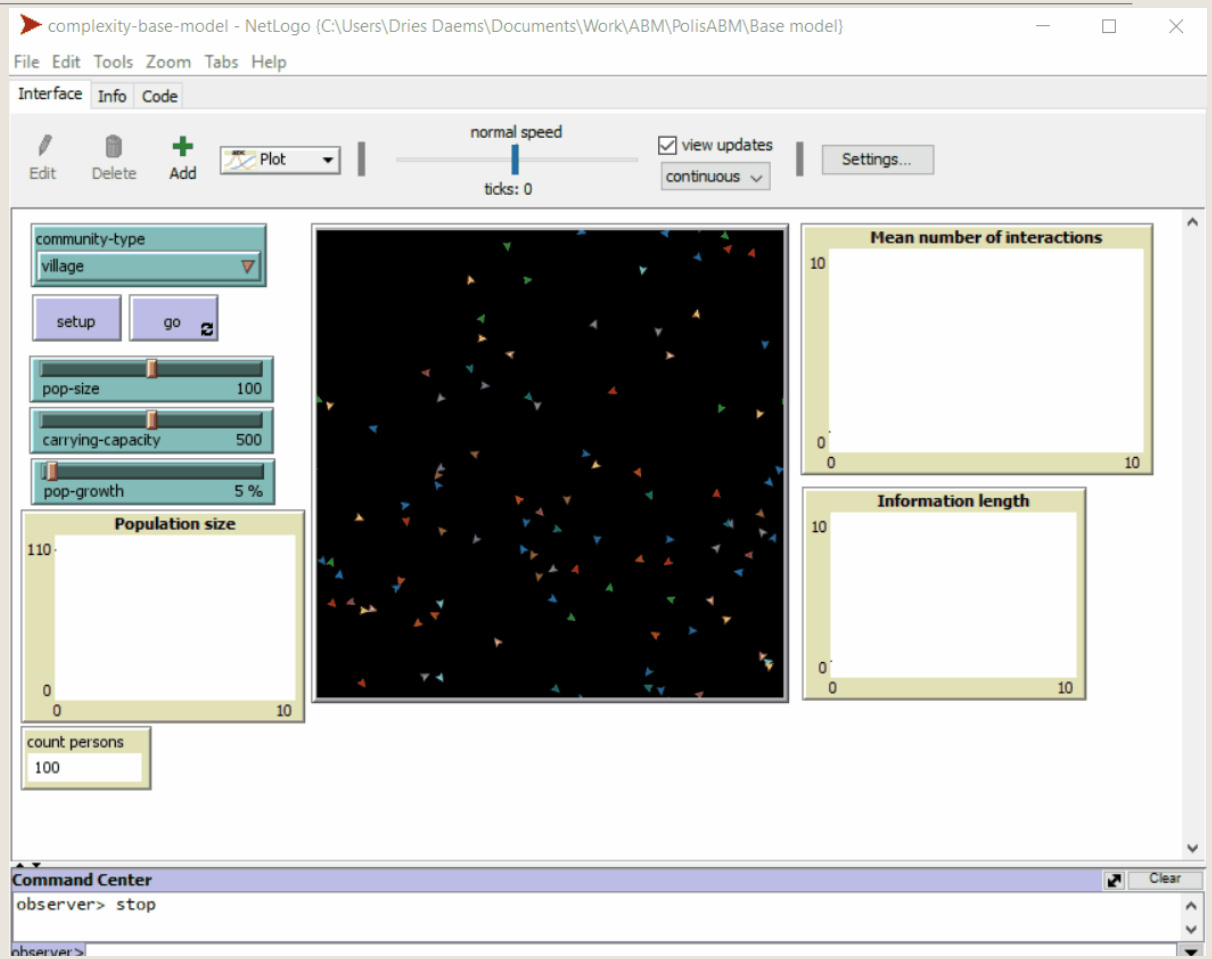

PolisABM: Base model Energized crowding

Basic information innovation algorithm

- Random innovation
- Idea selected from information list
- Random change
- Idea added to information list

```
to update-information-random
  let i random length information   ;; random idea selected from information list
  let new-idea i * random 100       ;; idea undergoes random mutation
  ask persons [
    set information fput (new-idea) information ;; agents take new idea and add it
  ]
end
```

Simulation run

- Unique idea distribution now follows same pattern as number of interactions
- Capping off population no longer has effect on number of ideas

PolisABM: Base model Energized crowding

Basic information innovation algorithm

- Random innovation
- Idea selected from information list
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Simulation run

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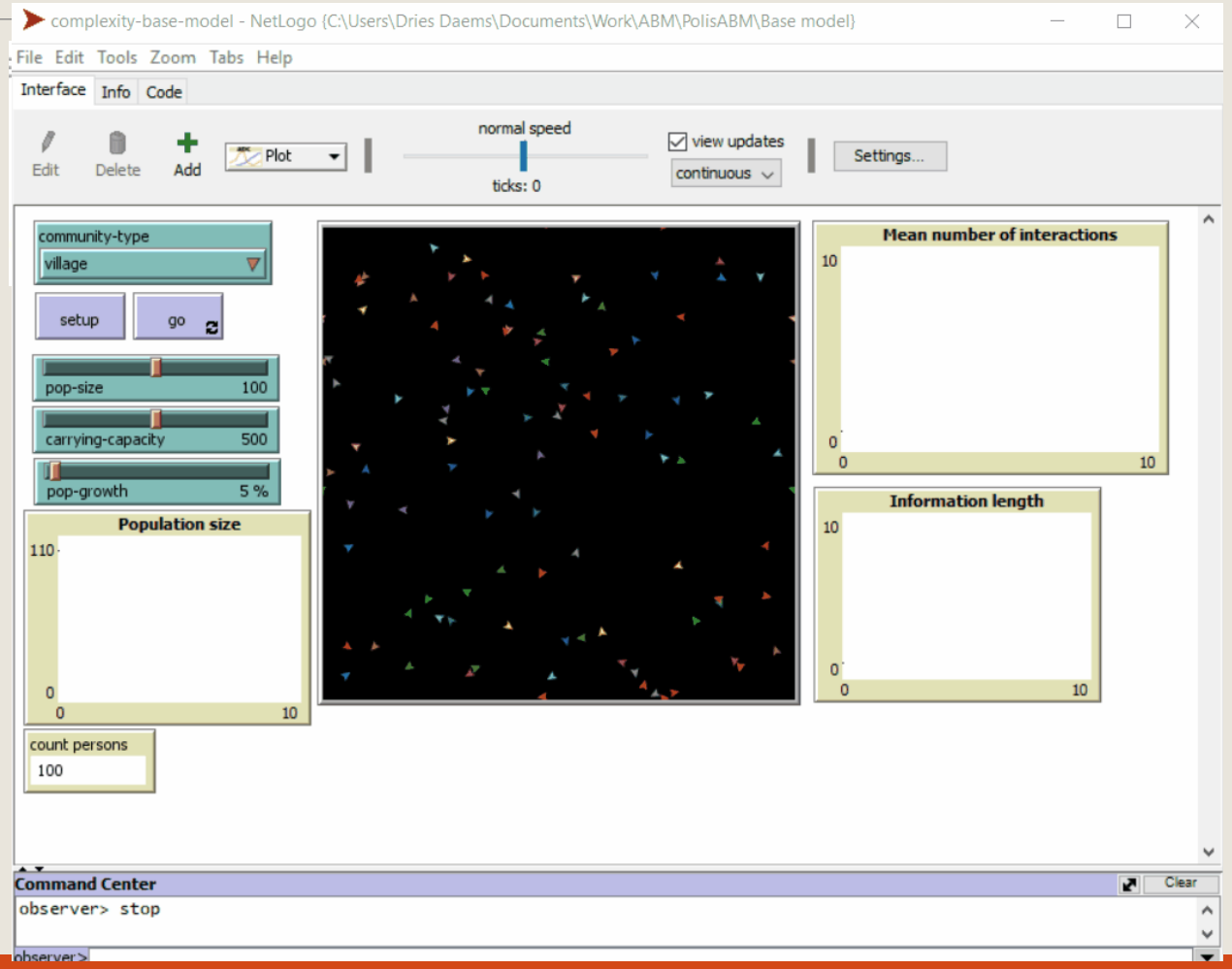


PolisABM: Extended model Initialising Simulation

- Focus on intra-community interactions
- Network and central place formation

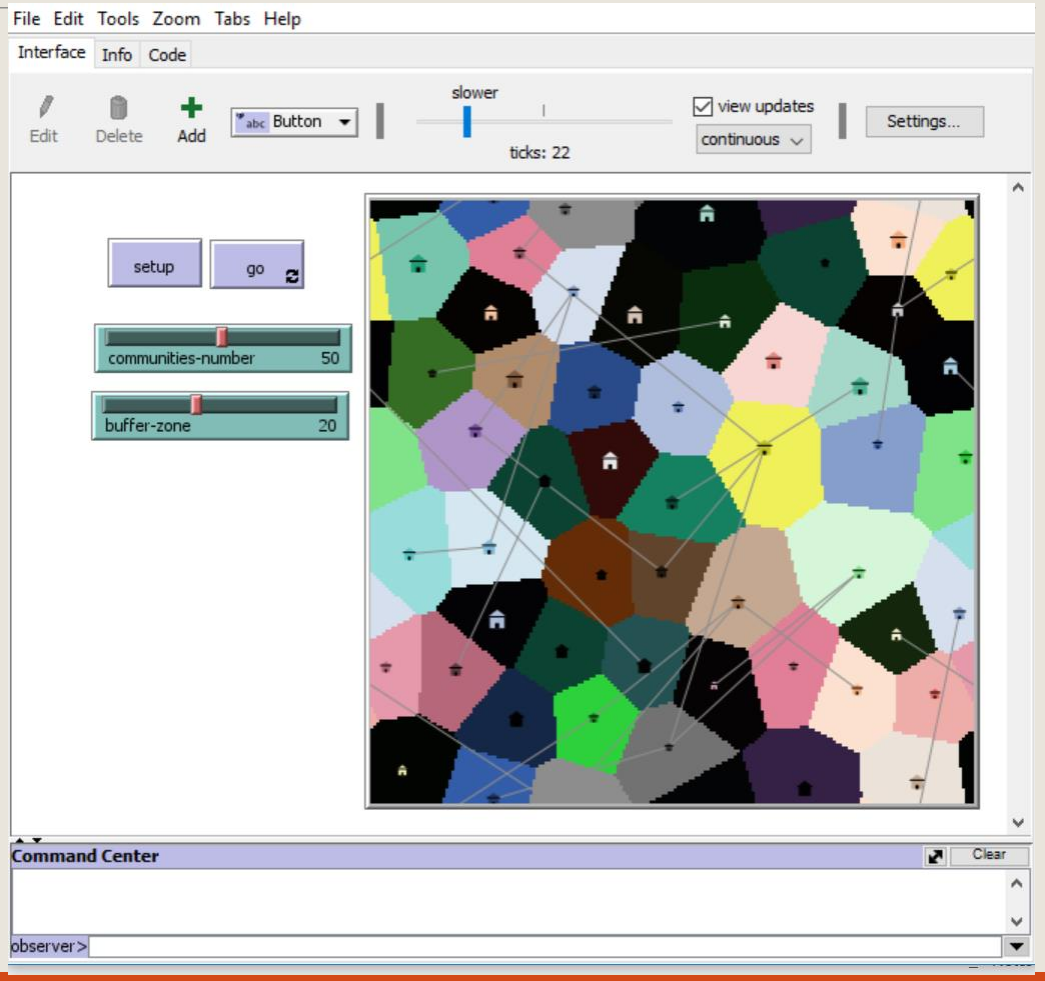
Entities = (village and corporate) communities

Initial state variables:

- Number of polities = 50
- Population size: Random in 250-750 range
- Territory: Voronoi Diagrams
- Connections = FALSE

Scale

- Patch size: 1km²
- World size: 100x100 km
- Time step: 1 year



Why model?

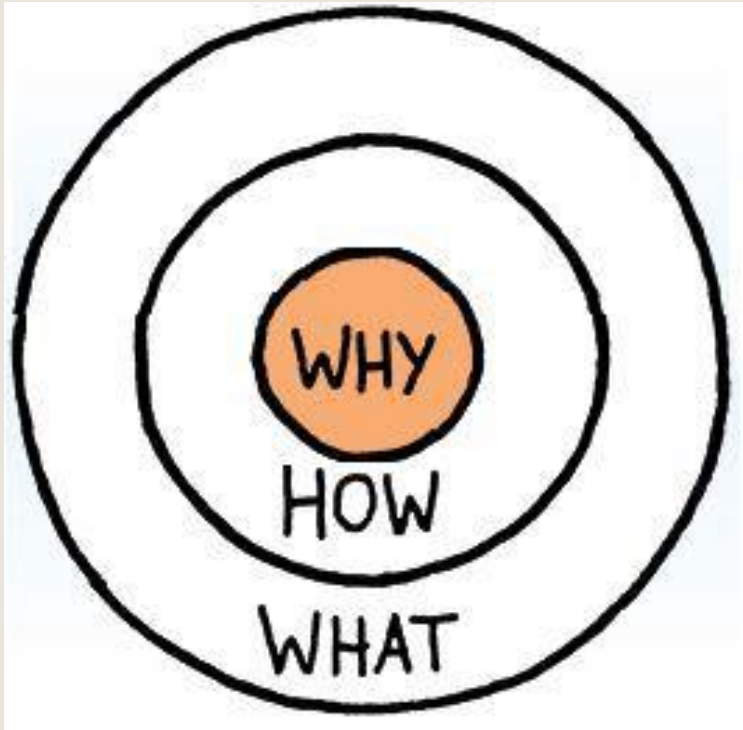
Find research questions
- What type of interaction/communication most strongly contributes to energized crowding?
- What is the importance of diversity of information? (new versus reinforced interaction)

Test new hypotheses
- Does biased information transmission accelerate energized crowding functions? (e.g. conformist behaviour)

Theory building
- Can we identify more precise parameters for economies of scale and increasing returns to scale?

Predictive modelling
- Can we use these parameters to predict other scaling processes?

Experimenting
- Parameter exploration
- Drivers of change



Future Development

- Intra-community dynamics:
  - (Composite) socio-economic output metric for community formation induced by energized crowding
  - Targeted interaction
  - Biased information transmission and innovation
- Inter-community dynamics:
  - Community networks
  - Implement fission/fusion cycles
  - Economic production and trade
  - Political hierarchies
  - Central place formation
  - Macro-level interactions
- Human-environment interactions
  - Energy capture and expenditure
  - Settlement chambers

Code and documentation will be made available:
https://github.com/driesdaems10/PolisABM

Thank you for your attention!

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