ODD protocol

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 agent-based model (ABM) explores the relationship between the ethnic composition of a residential area and the spatial variation in opinions on ethnically salient topics (such as immigration policies). The ABM builds on three principles:

1. There is geographical variation in the ethnic composition of a residential area. In the ABM, the ethnic composition and spatial distribution of the agent population is calibrated on twelve residential districts of Rotterdam, and specifically on the spatial distribution of non-western minorities within these districts.
2. The frequency (or likelihood) of interaction decays with distance. In other words, spatial proximity fosters interaction and thus increases the potential for opinion change. We model this by assuming that the probability that two agents interact is function of their distance in the district. The ABM explores how the strength of this distance-decay affects the system.
3. Whether one’s interaction partner belongs to the ethnic ingroup or outgroup moderates the effect of the interaction on one’s opinion change. In the ABM this principle is reflected in the choice of the social influence model that guides the opinion change of interacting agents. The social influence model is here assumed to be one of *repulsive influence*, or *RI-model* for short (Feliciani, Flache, & Tolsma, 2017; Flache, 2019). The RI-model assumes indeed that the interaction between agents from different ethnic groups is somewhat more likely to increase disagreement between them, than interactions between same-group agents.

# 2. Entities, state variables, and scales

Agents (simulated district residents) are the only entities in this ABM. Follows the list of agent attributes and global variables.

## Agents’ attributes

* *Geographic location*, expressed as WGS 84 coordinates.
* *(Ethnic) group*. This is a dichotomous variable identifying an agent’s ethnic membership. It can take values 1 (agent with a non-western background) or -1 (native or otherwise western background).
* *Opinion*: a continuous variable with range [-1,+1].

## Model parameters / global variables:

* *Time* (in discrete steps).
* *District*: each simulation run simulates the interactions in one of the main twelve administrative districts of Rotterdam.[[1]](#footnote-1) The initialization of agents’ geographic location and group membership depends on the choice of district.
* *H*: during an interaction between two agents, this parameter defines the relative importance of the difference in agents’ group membership and the difference in their opinion in in determining the weight of the interaction.
* *Initial opinion distribution*. Agent opinions are initialized in one of three ways: (1) random uniform; (2) bell-shaped beta distribution with the same average opinion for both ethnic groups; (3) bell-shaped beta distribution with different average opinions for the two ethnic groups.
* *Distance decay*. This variable defines the rate at which the distance between two agents hinders their chances of interaction. There are three available settings, distance decay = 1, 2 or 3. With “1” interaction are only local: agents only interact with their immediate neighbors, and virtually never interact with agents located at the other end of the district. When “3”, interactions are more diffuse: agents interact both with their immediate neighbors and with other agents farther away in the district, and immediate neighbors are only somewhat more likely to be chosen. Setting “2” is in the middle: agents interact mainly locally, but sometimes also interact with agents farther away.
* *Type of interaction*.  Can either be “one-way” or “two-way”. In one-way interactions, when an agent Ego interacts with another agent Alter, only Ego’s opinion is updated. With two-way interactions, both Ego and Alter update their opinions.
* *Converged?*. This is a Boolean flag indicating whether the agents have reached consensus (all agents holding the same opinion) or perfect between-groups bi-polarization (one ethnic group is in consensus over opinion +1; the other group over opinion -1).

# 3. Process overview and scheduling

The simulation is initialized by creating an agentset that mirrors the specified Rotterdam district in population size and spatial distribution of the two ethnic groups. Once the agentset is created, the ABM starts simulating interactions in discrete time steps. For each time step, agents are selected in random (uniform) to do the following: they choose an interaction partner, and then interact with them. An interaction is carried out by updating the “weight” of the interaction (see submodels), and then by calculating the resulting new opinion(s). In pseudocode:

create agentset

**set** time **to** 1

**infinite loop** ‘run‘ {

**for each** i **from** agentset (in random order) **do** {

find interaction partner j

update weight (i,j)

update opinion (i)

**if** type of interaction == two-way **then**

update opinion (j)

}

**set** time **to** time +1

}

# 4. Design concepts

## Basic principles

This model builds on an existing ABM of opinion dynamics, the RI-model, also known as “negative influence” (Flache & Macy, 2011b; Macy et al., 2003; Feliciani, Flache, & Tolsma, 2017; Flache, 2019). In essence, these models assume that interacting agents strive to minimize their opinion differences (assimilation) unless these are too wide. If the gap is too wide, agents will instead *increase* their initial opinion differences (repulsion). Crucially, agents’ ethnic membership moderates this effect: repulsion requires wider initial disagreement when the interacting agents are from the same group (e.g. both western or both non-western), than when they belong to different groups.

Ethnic groups tend to be unevenly distributed in residential areas - the phenomenon we call ethnic residential segregation. Because segregation affects residents’ exposure to the various ethnic groups, and because ethnicity matters for several social influence processes (such as those captured by the RI-model), we expect to find a link between ethnic residential segregation and the distribution of opinions. This is the intuition behind this ABM.

To explore this line of reasoning, this ABM makes the RI-model spatially explicit by placing the agents on a map and incorporating their relative proximity in the interaction dynamics. There is large variation between and within the districts of Rotterdam in population size, relative group size and spatial arrangement of the two groups. The combination of these features makes it so that agents from different districts (or from different parts of the same district) vary in exposure to their ingroup and outgroup. Thus, we expect that opinion patterns will vary between and within districts. The next section, “Emergence”, covers what kind of opinion patterns are considered in this ABM.

## Emergence

Emergent properties in this ABM concern the opinion distribution. First, we examine the emergence of extreme opinions (and, relatedly, the emergence of opinion bi-polarization). Second, we examine how many interactions are on average needed for agents to adopt an extreme opinion – this gives us clues as to what conditions facilitate polarizing dynamics. Third, we examine the degree to which these opinions overlap with agent’s group membership (group-opinion alignment).

## Adaptation

Agents adapt to their environment by updating their opinion according to the rules of the RI-model (see submodels). The environmental features that trigger agents’ opinion update are (1) the opinion and (2) the ethnic group of their interaction partner(s).

## Objectives

The RI-model of social influence implicitly assumes two agents’ objectives. First, to comply with the homophily principle, according to which interactions between similar individuals are more likely or more relevant than interactions between dissimilar ones. Secondly, to strive for balanced cognitions (Festinger, 1957), that is, in short, to have an opinion in line the opinion of ingroup members and opposed to the opinion of the outgroup members.

## Learning

Learning hasn’t been modeled as one of agents’ features. Agents’ adaptive trait (their opinion) varies across time solely as a function of their present opinion and of the effects that the current interaction has on that opinion.

## Prediction

This ABM does not directly aim to make predictions about the future distribution of opinion in a neighborhood. Rather, its goal is to explore the implication of three assumptions: (1) that ethnic groups are spatially segregated; (2) that interactions tend to be local; and (3) that ethnic exposure moderates interaction dynamics.

## Sensing

Agents’ sense of the environment is limited to the ethnic composition of the district (which influences interaction opportunities) and the attributes of their interaction partners (group and opinion of interaction partners influence agents’ opinion).

## Interaction

Interactions are modeled as dyadic (between pairs of neighbors). Interactions consist in a comparison between the group belonging and opinion of the two agents: if they are similar, they update their opinion in a way to average their opinion (assimilation). If they are dissimilar, they update their opinion so that they further diverge (repulsion).

A detailed explanation of how interactions are modeled out is provided in the submodel section.

## Stochasticity

This model resorts to stochasticity in two main ways:

* Definition of agents’ initial opinion;
* Agents’ choice of an interaction partner. Interaction probabilities are determined by proximity: the closer two agents are, the more likely that they’ll interact.

## Collectives

Agents are divided into two groups: group -1 (natives and western) and group +1 (non-western).

## Observation

The ABM uses various indices to measure the emergent attributes of the opinion distribution. Some measurements are taken at every time step; some other (i.e. the alignment measures) only at the end of the simulation run.

The model computes and (optionally) outputs outcome measures once every 10 time steps, starting from time 0. These measures are:

* Opinion polarization is captured by:
  + Standard deviation of agents’ opinions;
  + Polarization index. This is the variance in the distribution of the differences in opinion between agents. In order to make the computation of this measure possible for the large agent population, this index is computed on a random sample of agents. By default, the sample size is 50 agents.
* System convergence to the relevant equilibria (opinion consensus and between-groups bi-polarization) is measured via a combination of opinion average and variance (in the entire population; and within the two groups separately).
* Alignment of group membership and opinions is measured:
  + At the agent level, using the bivariate version of LISA (Local Indicator of Spatial Association – see Anselin, 1995). Intuitively, this measures the correlation between agents’ group and the average opinion in their surroundings. This is useful to map which parts of the district produce stronger alignment.
  + At the aggregate level:
    - LISA scores can be aggregated in a summary statistic, measuring the *overall* alignment in the district.
    - The difference between the average attitude of the two groups – this is an intuitive measure of alignment at the population level that, unlike the LISA, is blind to the spatial distribution of groups and opinions.

# 5. Initialization

Agents are placed on the map and assigned a group membership in a way that reproduces the density and spatial ethnic distribution of the simulated district (see next section on “Input data”).

Depending on their position on the map and on the model parameter “distance decay”, agents are also equipped with a list of probabilities associated with all other positions on the map – these are the interaction probabilities used in the ABM to find interaction partners. See the submodel “finding an interaction partner” for details.

Agents’ opinions are then initialized by drawing from a probability distribution according to the model parameter: “initial opinion distribution”.

# 6. Input data

Agent position and group membership is based on register data for Rotterdam (reference year: 2014) published by Statistics Netherlands. Raster data on population density and ethnic membership (native, western or non-western migration background) is aggregated at the level of 100\*100 meters grids (CBS, 2021). Demographic data are not publicly available for grid cells with fewer than five inhabitants—we excluded these from the simulation, treating them as if they had no residents at all.

For lack of finer-grained information, the ABM further assumes that agents reside on the centroid of their 100\*100m cell. This assumption bears consequences for the calculation of interaction probabilities (because based on proximity) and spatial measures of alignment.

# 7. Submodels

## Finding an interaction partner

The probability that an agent *i* interacts with an agent *j* is function of their Euclidean distance *dij* (in meters):

The value for *s* defines the strength of the distance decay effect: lower *s* implies that probabilities drop very fast as distance increases; conversely, with higher *s*, probabilties remain higher over farther distances. The ABM paramter *“distance decay*” is mapped on *s* in the following way:

|  |  |
| --- | --- |
| *distance decay setting* | *s* |
| 1 (steep decay) | 10 |
| 2 | 100 |
| 3 (mild decay) | 1000 |

## Update weight

Agent *i*'s weight toward her interaction partner *j* at time *t* is defined as:

Where *oi* and *oj* are the opinions of agents *i* and *j*, and *gi* and *gj* their ethnic group membership. Parameter *H* in [0,1] captures the relative importance of group membership and opinion in determining the weight *w*.

The weight *w* ranges between -1 and +1. A higher weight signifies a stronger similarity between *i* and *j*, and vice versa. The highest similarity (*w*=1) occurs when *i* and *j* belong to the same group and have an identical opinion. Conversely, the highest dissimilarity (*w*=-1) is between two agents belonging to different groups and with opposite extreme opinions.

## Update opinion

How the interaction between agents *i* and *j* affects their opinions is inherited from the RI-model as originally formulated by Flache & Macy (2011) and Macy et al. (2003). Note that here we outline the effect of the interaction from the perspective of agent *i*; if the *type of interaction* is set to “two-way”, the interaction will affect not only the opinion of *i*, but also that of *j*. Simply swapping the indices “i” and “j” in the following text and equations allows to calculate the effect on *j*.

The effect of the repulsive influence mechanism on *i*’s opinion at time *t* is function of *i*’s and *j*’s difference in opinion, and is weighted by *w*:

Interactions end with agents updating their opinion based on their previous opinion and the raw opinion change *∆o*.

Once an agent has updated her opinion, a truncating function assures that it does not exceed range [-1; 1].

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1. The twelve districts are: Stadscentrum, Delfshaven, Overschie, Noord, Hillegersberg-Schiebroek, Kralingen-Crooswijk, Feijenoord, Ijsselmonde, Pernis, Prins Alexander, Charlois, Hoogvliet. [↑](#footnote-ref-1)