AGENT-BASED MODELING: A COMPUTATIONAL PARADIGM FOR SIMULATING SOCIAL SYSTEMS

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Multiobjective Optimization Agent Based Modeling Evolutionary Game Theory Data Science Marketing

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Top-75 & 1st Spain in CS/Eng (ARWU'19)

GRANADA

Most visited monument in Spain
110 kms. ski resort
Beaches nearby

Outline

1. What is agent-based modeling (ABM)?

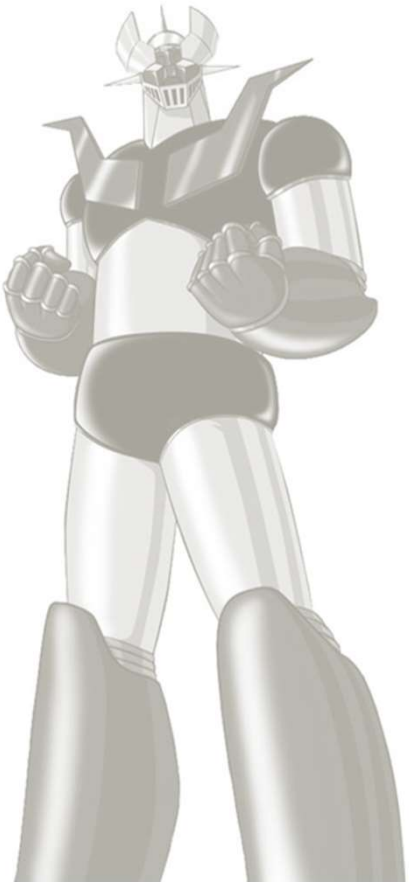
2. Information diffusion. Social networks

3. Validation of the models

4. ZIO, a commercial application for marketing

5. Another example: Migration in Vietnam

Final remarks



Part 1

What is ABM?
Social simulation

Agent-based modeling (ABM)

Discrete event simulation paradigm based on heterogeneous individuals/agents who evolve and adapt over time.

Allows the representation of individual actions and interactions between agents

(e.g., consumers, voters, citizens).

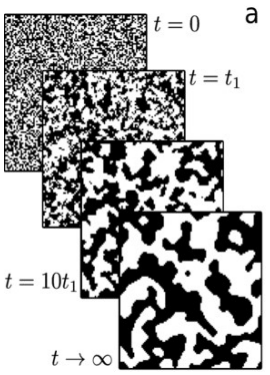
We model individual behaviors by simple agents' rules instead of the global dynamics of the system.

We normally model social or collective systems: a population.

ABMs to model emergent phenomena

ABM is a bottom-up technique and then, allows emergent phenomena to appear.

This is quite difficult when using top-down modeling approaches (e.g., system dynamics).



Schelling' segregation model [Sch69]

ABMs, because of their decentralized and bottom-up nature, are ideal for representing, modeling, and simulating those complex sytems*.

* Large number of interactions in a non-deterministic manner, able to adapt and learn. No centralized control [O'Toole 2017]

Main ABM features

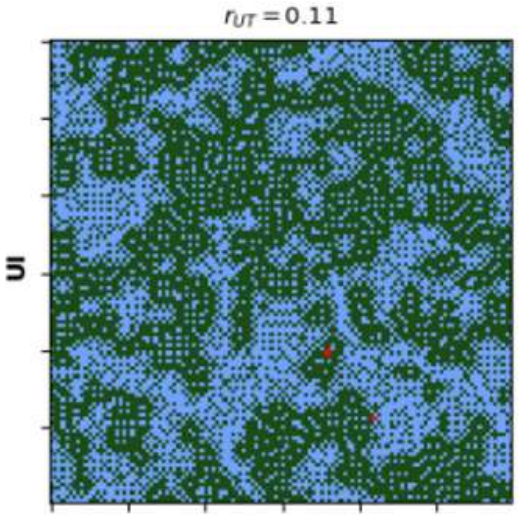
Each agent or individual is autonomous (own properties and behaviors). Also adapt to conditions. Heterogeneous behaviors.

Agents interact among them and their environment: social network / spatial environment (GIS).

We do not design the global dynamics but micro dynamics through the agents (bottom-up approach)

Pop of agents (thousands or more) to mimic reality (difference w.r.t. MAS):

if real individuals are stupid, virtual agents must be stupid as well.



[Chica et al. CNSNS 2019]

Why agent-based modeling? (I)

Micro-rules are easy to understand by stakeholders. It enhances empirical and theoretical validation.

Versatile modeling technique: from simple theoretical models to complex data-enriched decision-support systems (e.g., CRISP-DM for enhancing business use).

Journal of Simulation (2010) 4, 204–210

www.palgrave-journals.com/jos/

Discrete-event simulation is dead, long live agent-based simulation!

PO Siebers[1]*, CM Macal[2,3], J Garnett[4], D Buxton[5] and M Pidd[6]

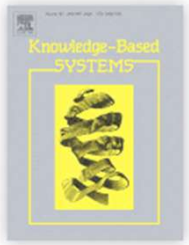
Overgoor, Chica, Rand, Weishampel. Letting the Computers Take Over: Using AI to Solve Marketing Problems. California Management Review 1-30 2019

Chica & Rand. Building agent-based decision support systems for managing word-of-mouth programs: a freemium application. J. of Mark. Res. 2017

Why agent-based modeling? (II)

It is a mature technique, used in many fields…

Moya et al. Knowledge-Based Sys. 123 200-216, 2017



-Politics (e.g., 11M attacks in Madrid, La Vanguardia)

-Evolutionary game theory (e.g., trust dilemmas, PGGs)

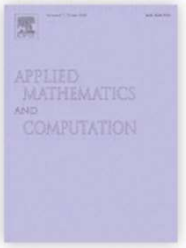
Chica et al. IEEE Tran. Ev. Comp. 2018

-Economics (The Economy Needs ABMs, Nature 2009)

SCIENTIFIC REPORTS

Chica et al. Sci.Rep. 9, 19789, 2019

-Ecology and climate change (Nature Climate Change, 2016)

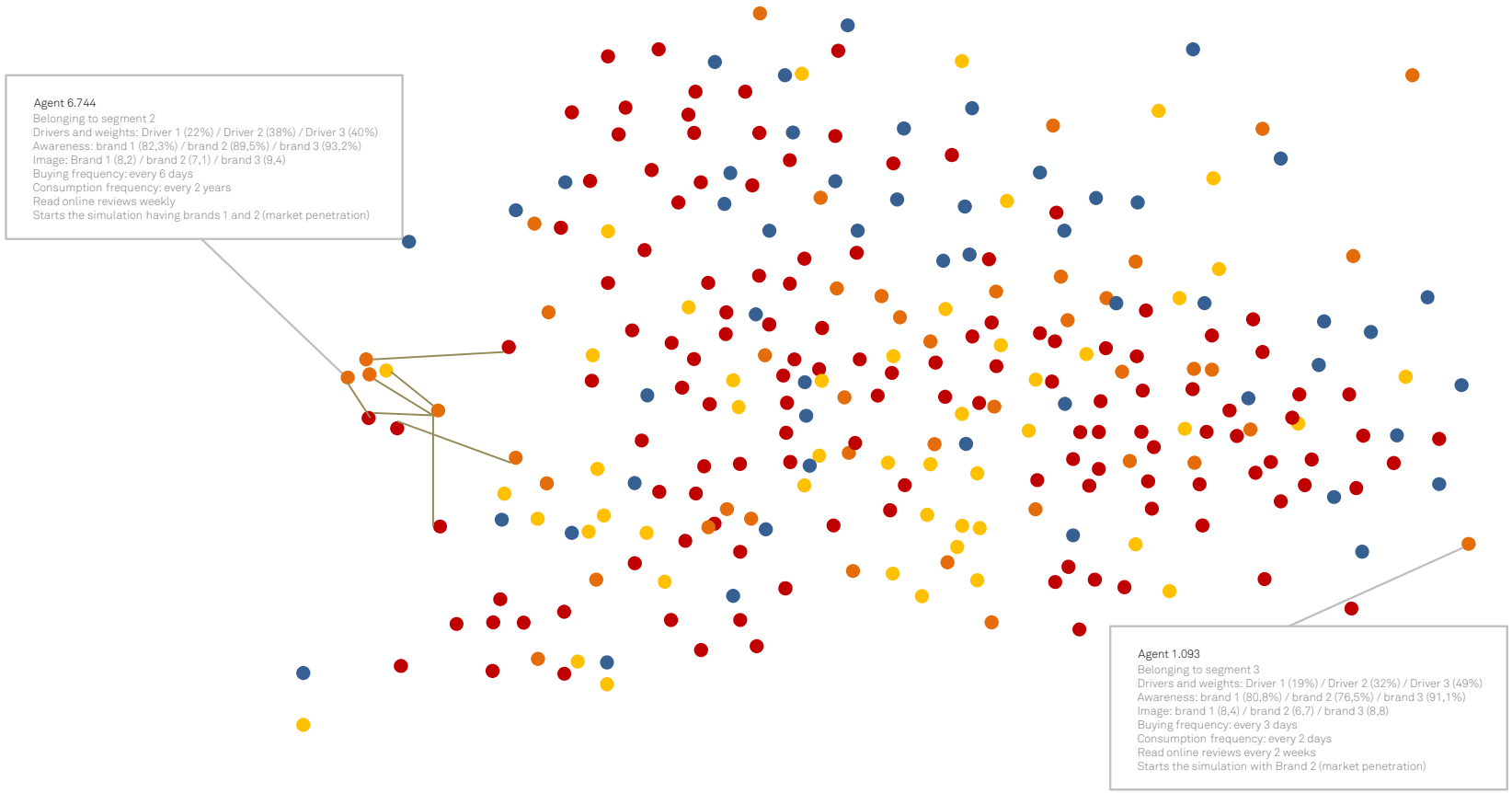


Dhakal et al. AMC 2020

Design and initialization of the ABM

Design and set parameters of the model (initialization). Two main dimensions:

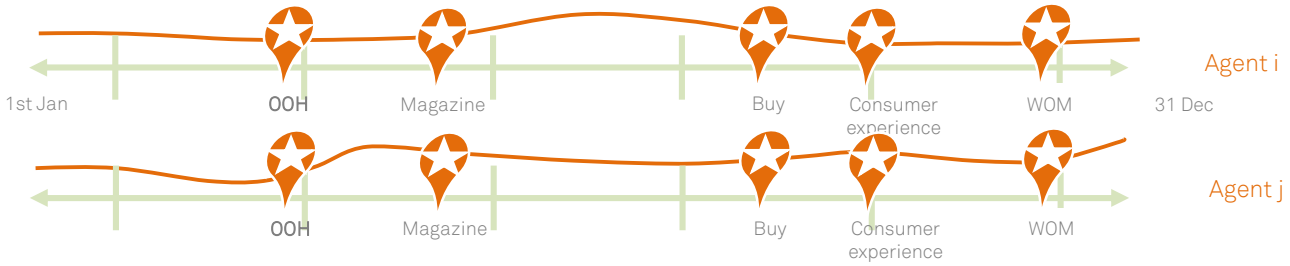
- Properties (mental state of the agents, environment)
- Behaviors (actions during the simulation, adaptation)

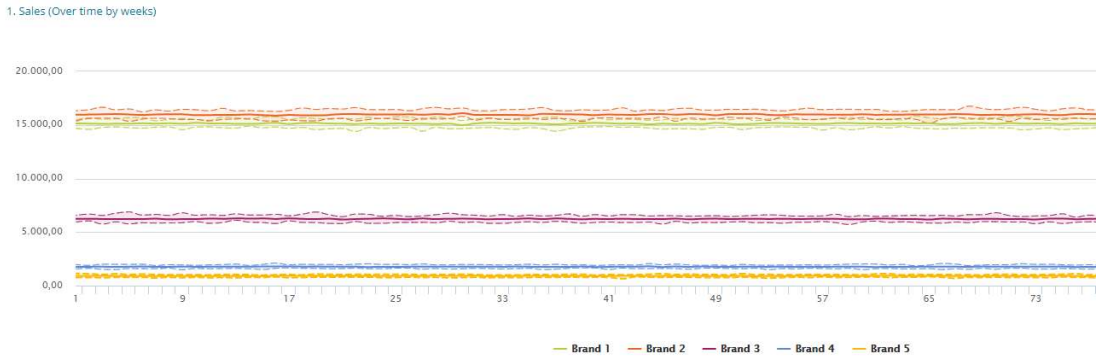


Running simulations

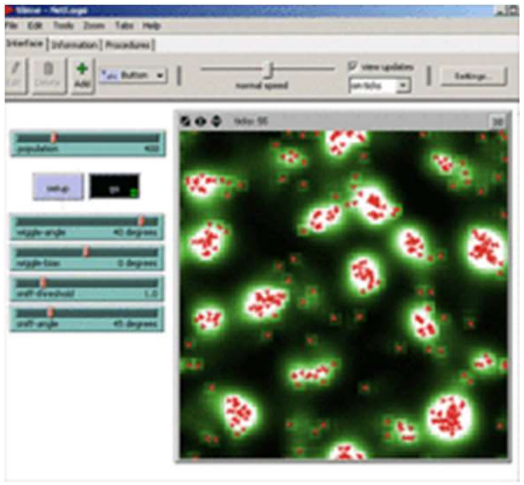
After the initialization, we can run simulations where agents apply their behavioral rules and interact with the environment (temporal evolution and adaptation).

We can focus on global outputs (e.g., market sales, migrants in a region etc.). But we can also zoom in for the individuals' journeys.





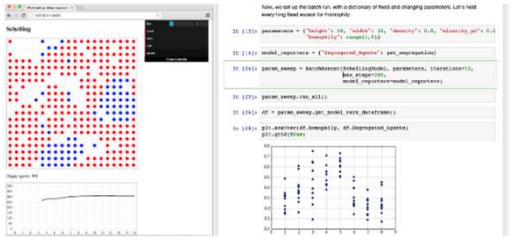
Open-source ABM software



- **Netlogo**: standard ABM language

- **MASON, Repast, Sugarscape**: normally in Java although other versions in C++/Python/.Net

- **MESA** (mesa.readthedocs.io): Python 3+, built-in tools for analysis



- **Code from other publications/projects**:

  ComSes openABM (comses.net)

  my papers @ manuchise.com

CoMSES | OpenABM NETWORK

Part 2

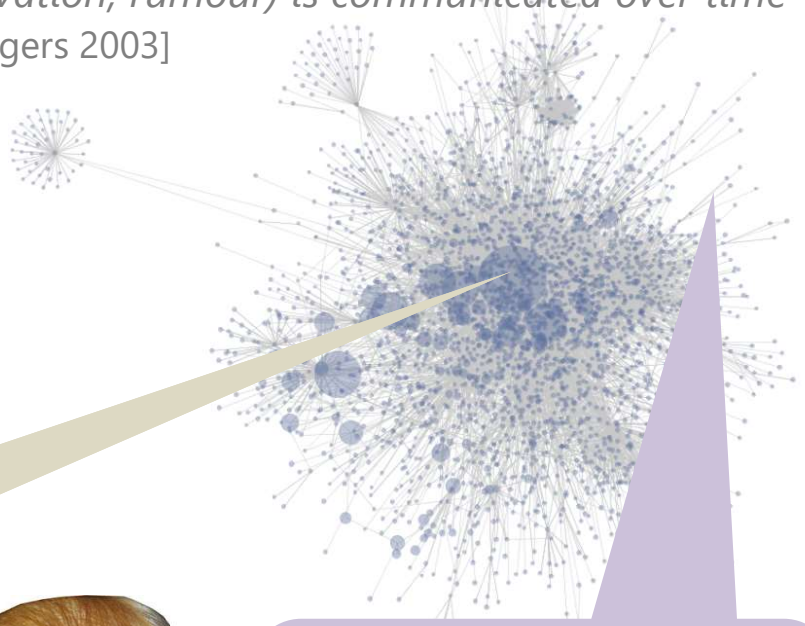
Information diffusion. Social networks

Information diffusion (word-of-mouth)

One of the most important environmental interactions modeled by ABM is information diffusion.

A process by which information (e.g., an innovation, rumour) is communicated over time among the participants in a social system [Rogers 2003]

bla,
bla,
bla!



Agent **VLADIMIR**

TALKS OCCASSIONALLY
LOTS OF FRIENDS
ONLY USE THE APP ON THE WEEKENDS

Agent **DONALD**

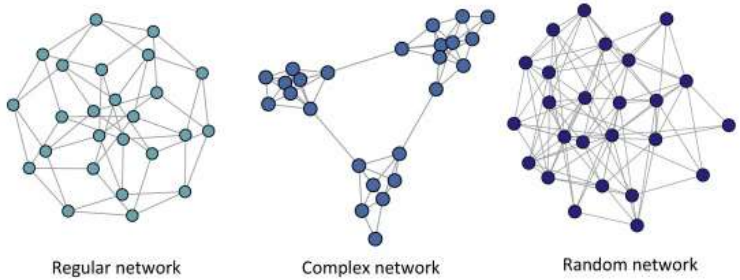
TALKS A LOT
JUST A FEW FRIENDS
DOES NOT KNOW HOW TO USE ANYTHING

Social networks (I)

The social network in ABM is the vehicle for the information diffusion and connects agents among them (their social environment): network topology (graph).

We have different types of artificial social networks topologies

Most well-known are next topologies:



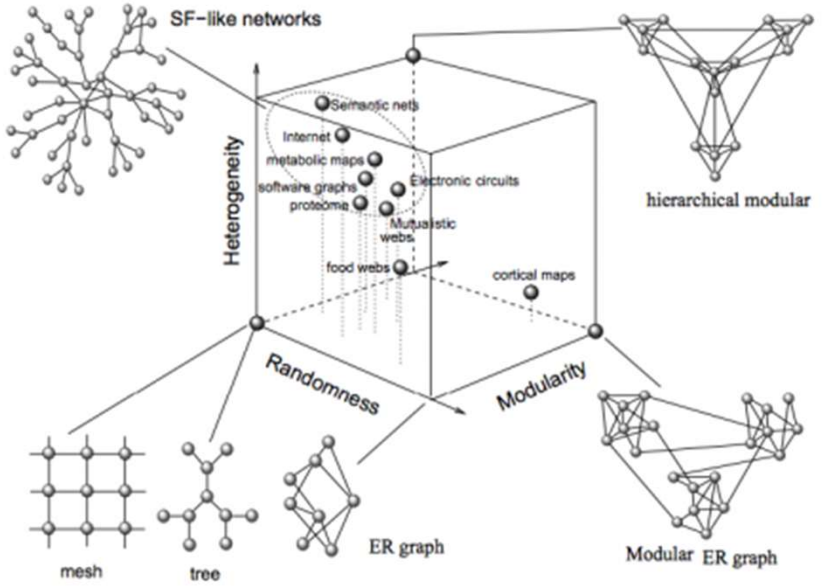


FIG. 3 A zoo of complex networks. In this qualitative space, three relevant characteristics are included: randomness, heterogeneity and modularity. The first introduces the amount of randomness involved in the process of network's building. The second measures how diverse is the link distribution and the third would measure how modular is the architecture. The position of different examples are only a visual guide. The domain of highly heterogeneous, random hierarchical networks appears much more occupied than others. Scale-free like networks belong to this domain.

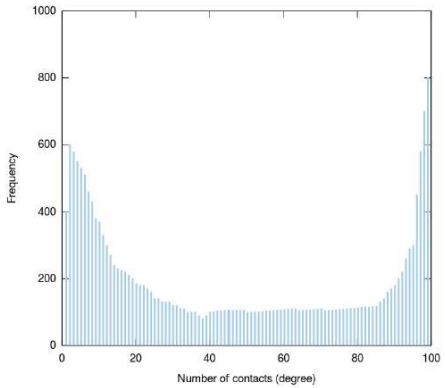
[Sole&Valverde 2004]

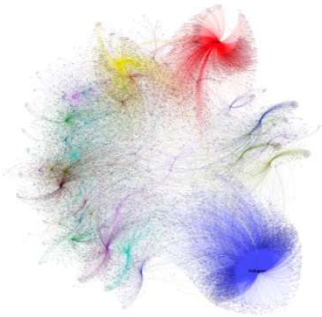
Social networks (II)

But all of them are “artificial”. If you have data about your individuals’ conversations, you can study their connections and build your own network with their features.

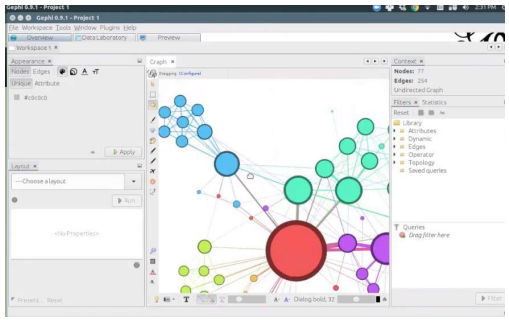
For instance, using a generator of graphs with prescribed degree sequence [Viger05] from the observed/empirical degree distribution:

[Chica & Rand 2017]



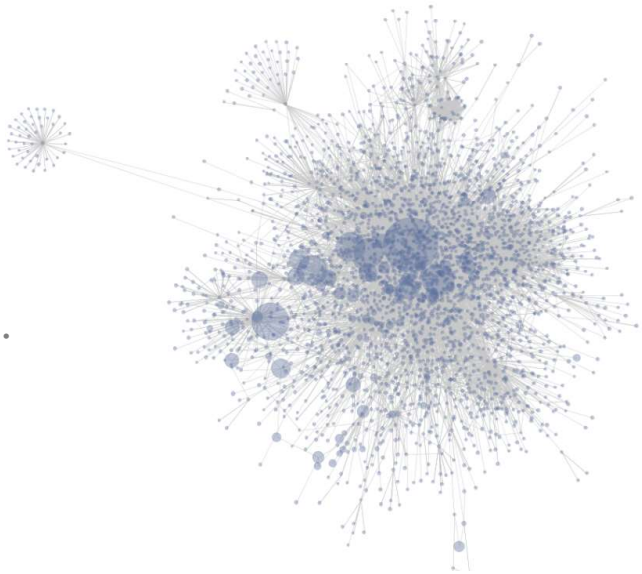


Libraries to use and analyze social networks: GraphStream (Java), NetworkX (Python), Gephi (powerful GUI).



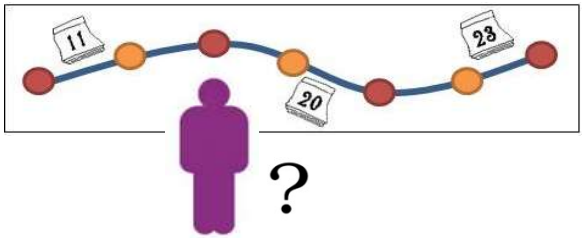
Information diffusion rules for the WOM process (I)

The diffusion of information (social imitation) can be replicated in an ABM by defining an agent's behavioral rule.



This behavioral rule will define the influence of the social network environment (direct contacts) on the properties of the agent (i.e., information it has).

Thanks to ABM capabilities, we can easily add other behaviors such as the frequency for talking or some seasonality features [Chica & Rand 2017].



Information diffusion rules for the WOM process (II)

We have different adoption models:

- Cascade models: Bass, Goldenberg et al's IC used by the IM problem.

  In the Bass model, at each step, agent's adoption depends on 2 parameters:

$$p + q(n_a/n)$$

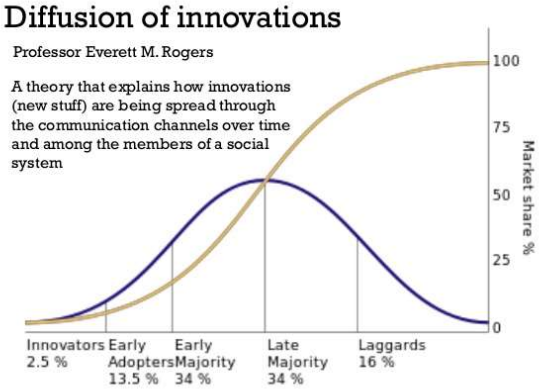
  Innovation coefficient (p) : to adopt because of external effects (ads, media).
  Imitation coefficient (q): by observing contacts. $\frac{n_a}{n}$: fraction of already adopted contacts.

- Threshold-based: traditional or other variations such as complex contagion [Centola07].
  This model takes into account the sources a_i (not the exposures).

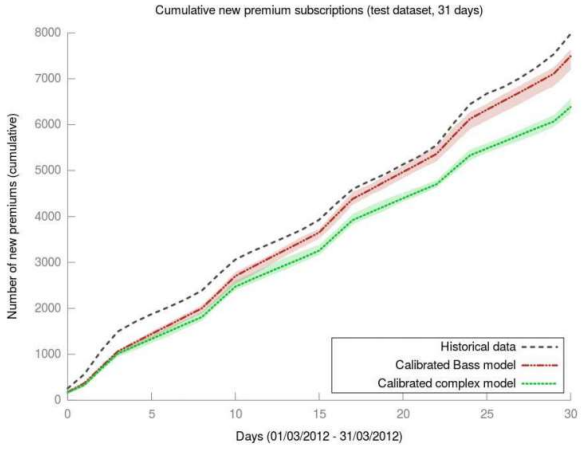
$$Pr[adopt] = \begin{cases} 1 & \text{if } a_i \geq \phi, \\ 0 & \text{if } a_i < \phi. \end{cases}$$

Information diffusion rules for the WOM process (III)

After simulating we can observe the adoption process in the social system
(e.g., NPD scenarios, viral marketing campaings).



We can check the most appropriate difussion models that match reality and explain the phenomenon.
Premium adoption in apps:

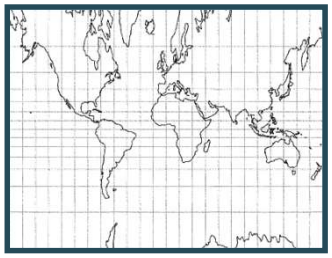


[Chica & Rand 2017]

Part 3

Validation of the models

A model is a model…



We have to remember that a model is…

- An abstract description of an object, process or event
- A model is a caricature
- A model exaggerates certain aspects at the expense of others
- A model allows you to understand micro-processes in depth

All models are wrong, some of them are useful by G. Box

ABM are for social systems, validation is crucial

Validating a social model is not as easy as industrial or physical model.

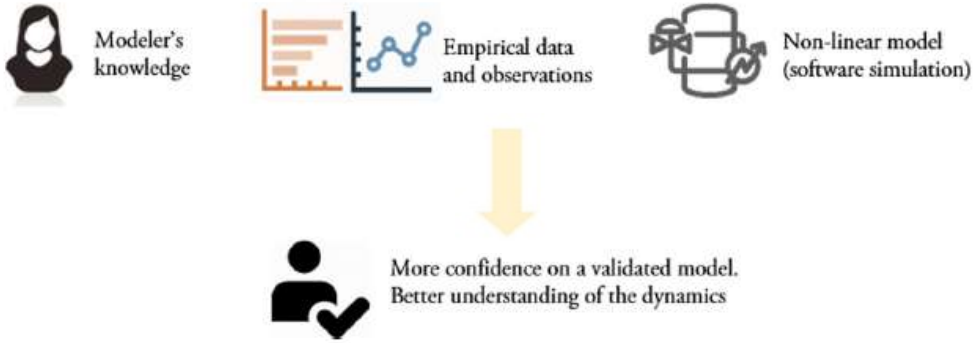
Before using it, we first need to find out if the model is correct and valid for the goals (model validation step).

Different techniques are required during this process:

- Check dynamics and compare with validated dynamics in the literature.

- Sensitivity analysis to identify incorrect behavior or incorrect design (e.g., no effect or sensitive parameters).

- Stress tests for extreme scenarios to detect failures in the behavior (e.g., model with no brand awareness must not deliver brand's sales).



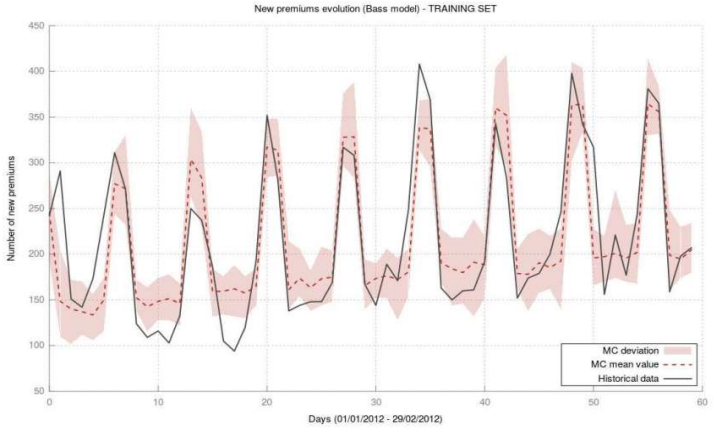
[Chica et al. 2017]

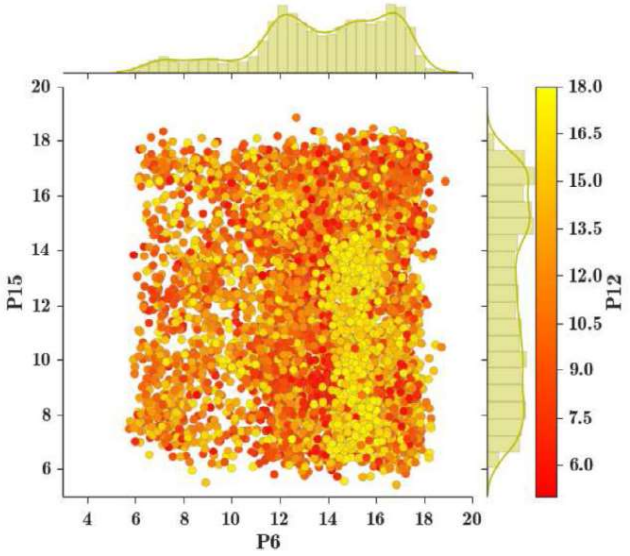
Automatic calibration can help when validating

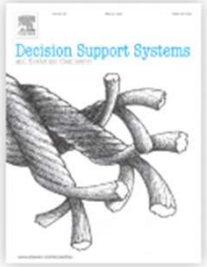
Automatic calibration is the use of optimization methods (e.g., genetic algorithms) to find the most suitable values for some model's parameters to adjust model's output with reality.

This machine learning optimization algorithms use a deviation measure and evaluate the ABM simulation until fitting historical data.

It is not straight-forward and advanced algorithms are sometimes required in addition to the modeler's knowledge.







[Moya et al. 2019]

Part 4

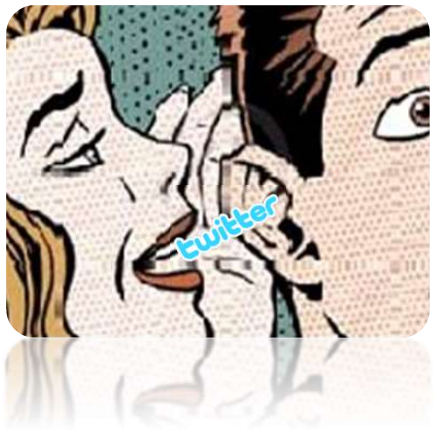
ZIO, a commercial application for marketing

Zio
virtual markets

Marketing is a complex system

Market changes in the last years have altered the way companies must deal with their marketing policies:

- more media and product channels,
- new consumers dynamics (online media, instant buying decisions, one-day logistics).



We need a new generation of more sophisticated tools and flexible such as ABM to better capture the complex nature of the basic unit decision:

THE CONSUMER

A cloud-based software for marketing

ZIO video

ZIO: agent-based DSS for marketing

Zio virtual markets

Behaviors

Seasonality
Buying frequency
Consumption frequency

Profiles

Drivers
Brand awareness
Perceptions (image)

Social networks

Connections
Segments
Influence

Touchpoints

Media campaigns
Emphasis and ads quality
Reach

Decision making

Rationale
Emotions
Social decisions

DECISION SUPPORT SYSTEM BASED ON ABM FOR MK

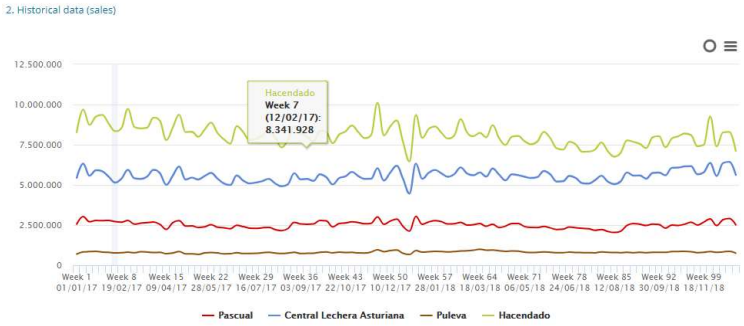
Auto-calibration and model validation

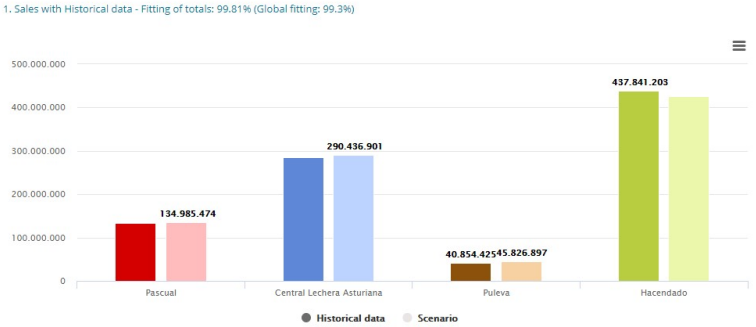
Media investment optimization algorithms

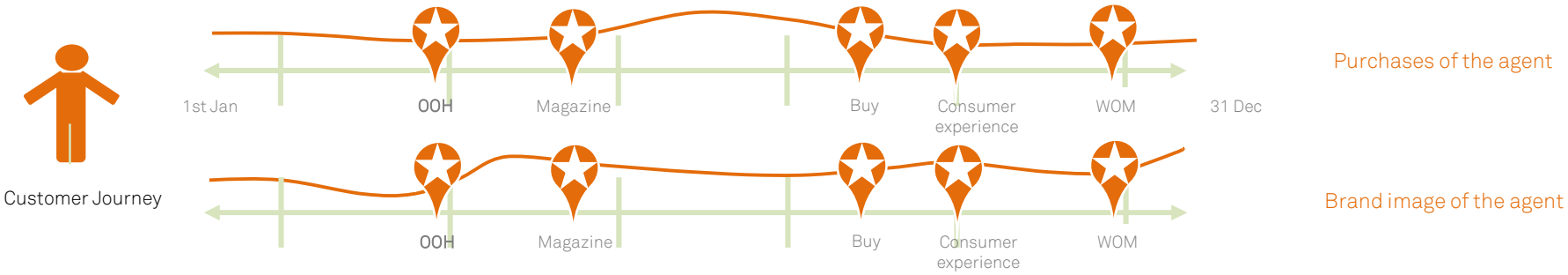
Launch of what-if scenarios from base markets

ZIO: agent-based DSS for marketing

We run simulations after calibrating and validating the model with historical data and stakeholder's agreement.

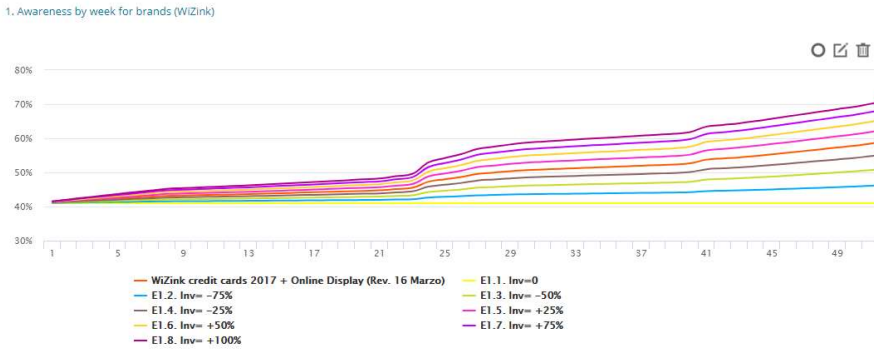


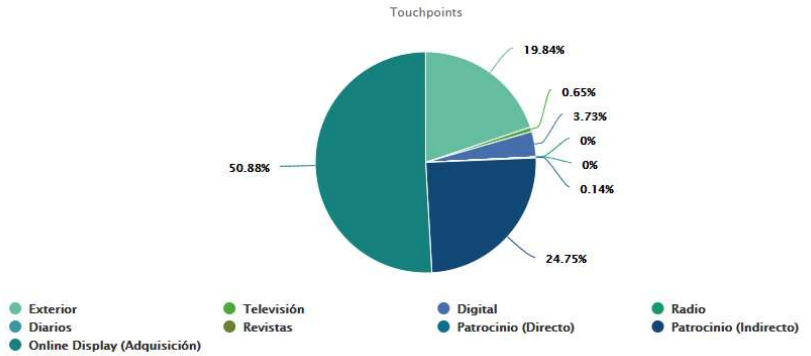




ZIO: agent-based DSS for marketing

One of the advantages of using a bottom-up approach such as ABM is the high number of indicators we can extract from the population (we have all the micro data available) and the possibility of launching tons of what-if scenarios:





Mercedes-Benz
Coca-Cola
JAGUAR
BBVA
idilia FOODS
El Corte Inglés
IBM
WiZink
pelayo
havas
Nestlé
ATKearney
Asturiana

Part 5

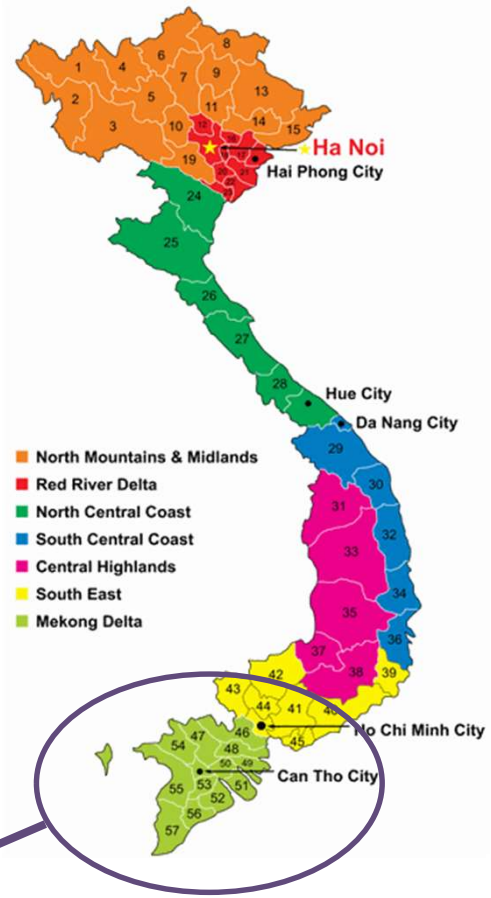
A more theoretical example: migration in Vietnam

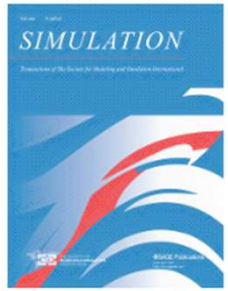
Motivation for the modeling

Migration flows from rural areas (13 provinces of Mekong Delta (MKD)) to larger cities in the South-East (SE) region of Vietnam. Important destinations are Ho Chi Minh city and Binh Duong.

We want to understand the dynamics of the migration decision process and determine the most critical factors affecting the behavior of migrants in the MKD region.

Proposal of an ABM based on the Theory of Planned Behavior (TPB) and a calibration for their main factors.





Nguyen et al. Understanding the dynamics of inter-provincial migration in the Mekong Delta, Vietnam: An agent-based modeling study. Simulation (under review)

Main ABM features

We model the system by spatial ABM (3,340 agents), considering two types of agents:

- Province Agent: population attributes (birth and death rates), socioeconomic attributes (employment, education, average income and expenditure) and environmental impacts.

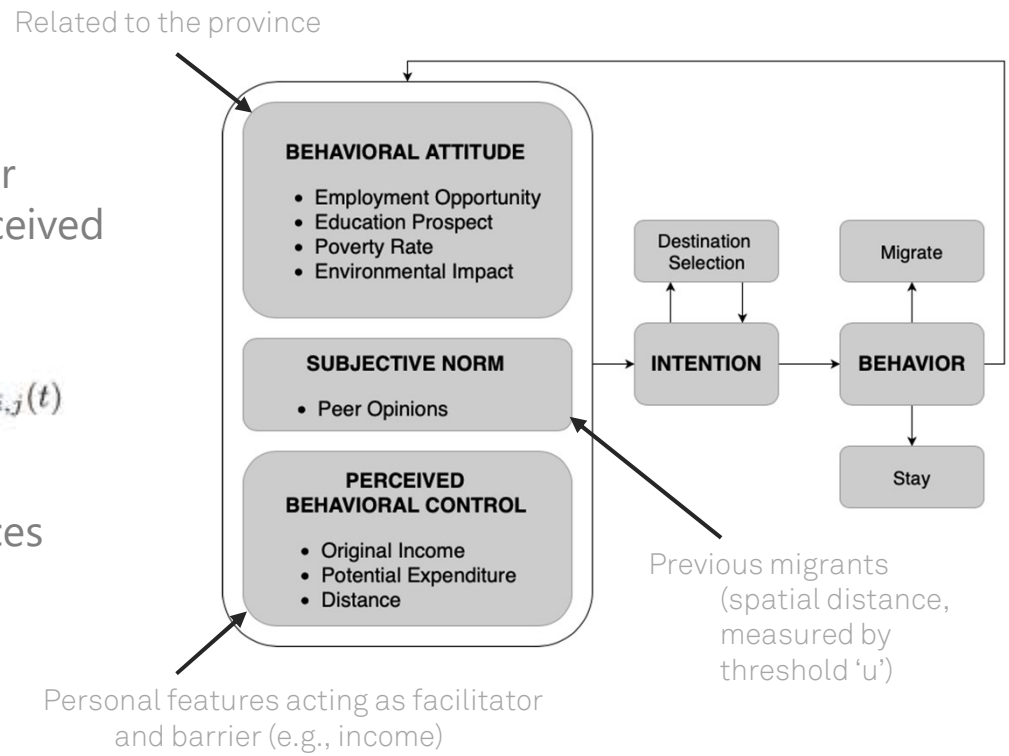
- Person agent: quintile income group and location (spatial information).

The design includes:

- a migration intention
  using the Theory of Planned Behavior
  (behavioral, social influence and perceived
  behavioral control).

$$I_{i,j}(t) = \alpha_1 \, BA_{i,j}(t) + \alpha_2 \, SN_i(t) + \alpha_3 \, PBC_{i,j}(t)$$

- stochastic behavior for those provinces
  with the highest intention values.



Calibration using a genetic algorithm

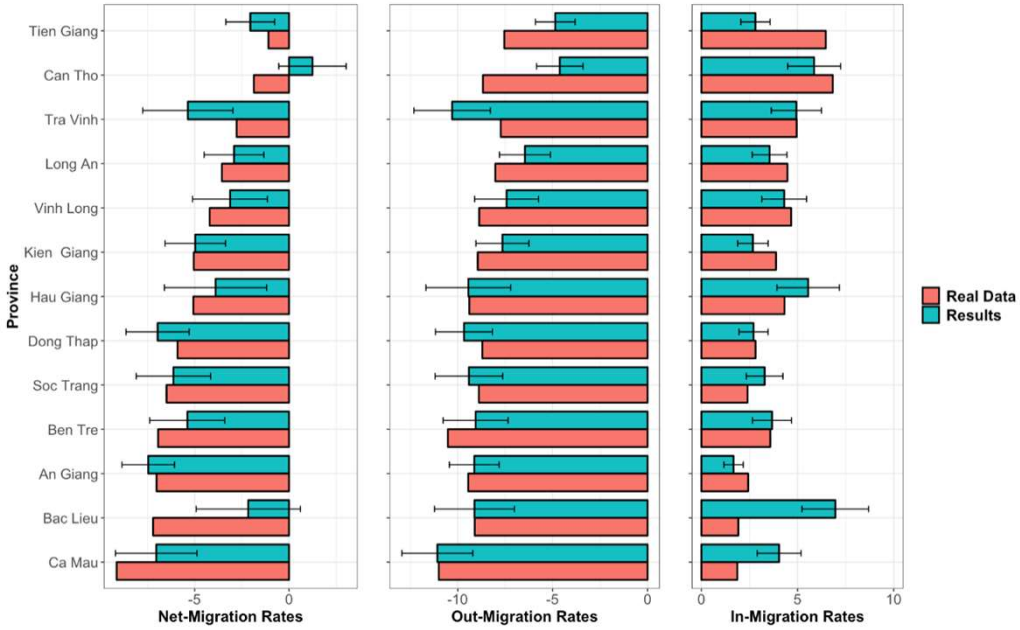
Mason and geoMason for simulating 13 years (05-17) in 17 cities (13 of MKD + 4 provinces in the south-east).

Socio-economic and environmental impact from real data and used a genetic algorithm and deviation measure for fitting out-, in- and net- migration rates (95%).

TABLE III
CALIBRATED α PARAMETERS USING THE GA

Parameters	Description	Calibrated Values
α_1	Parameter of BA	3.18e−4
α_2	Parameter of SN	9.76e−6
α_3	Parameter of PBC	0.00173
α_4	Weight of employment	0.53
α_5	Weight of high-income	0.875
α_6	Weight of migration cost	0.00528

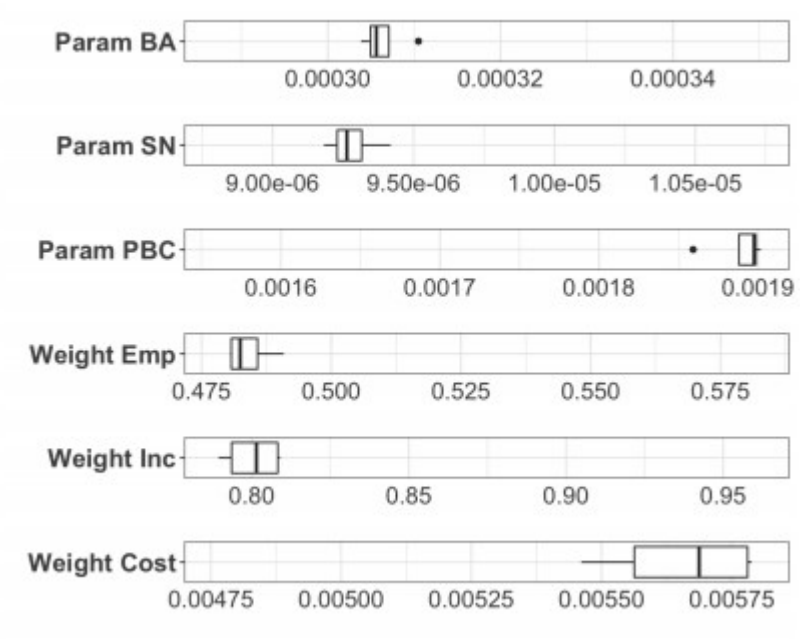
Weights for the three components and those parameters with no influence information from literature

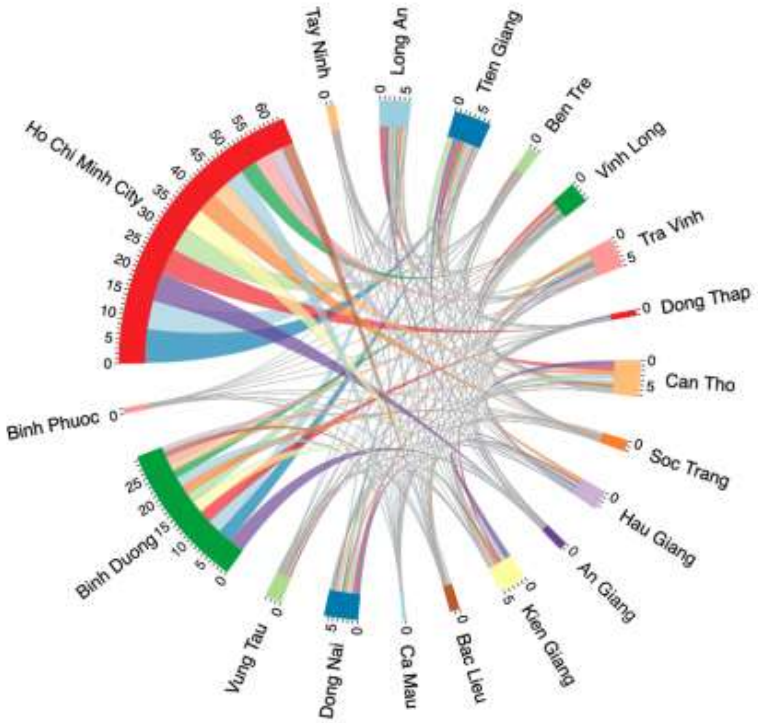


Insights from the study

We explore the values of the calibrated parameters to see main factors affecting migration flows:
- Employment related factor is the most important variable for moving.
- Migration costs among provinces are not very important for choosing the destination.

Model is ready to get global migration outputs among provinces and test what-if scenarios and policies of interest.





Final remarks

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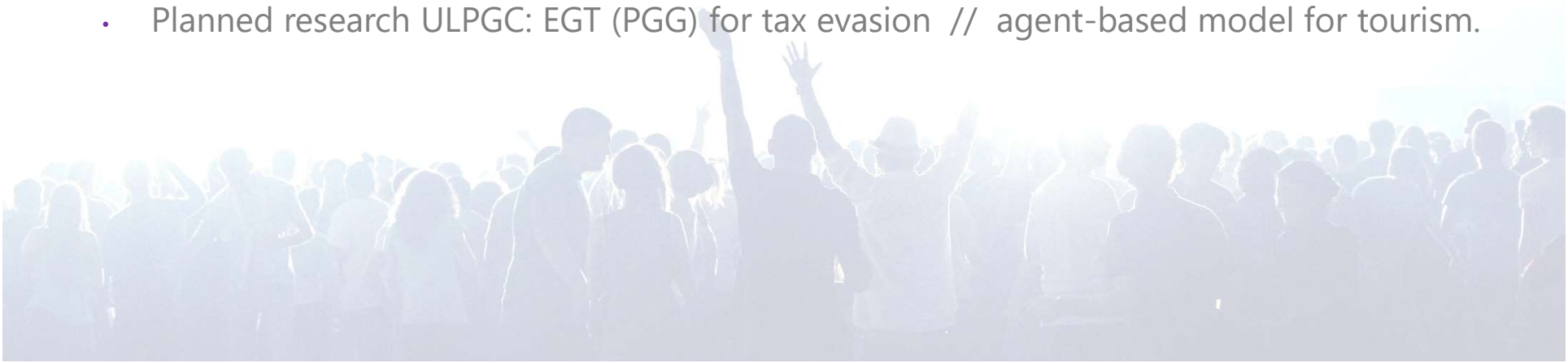
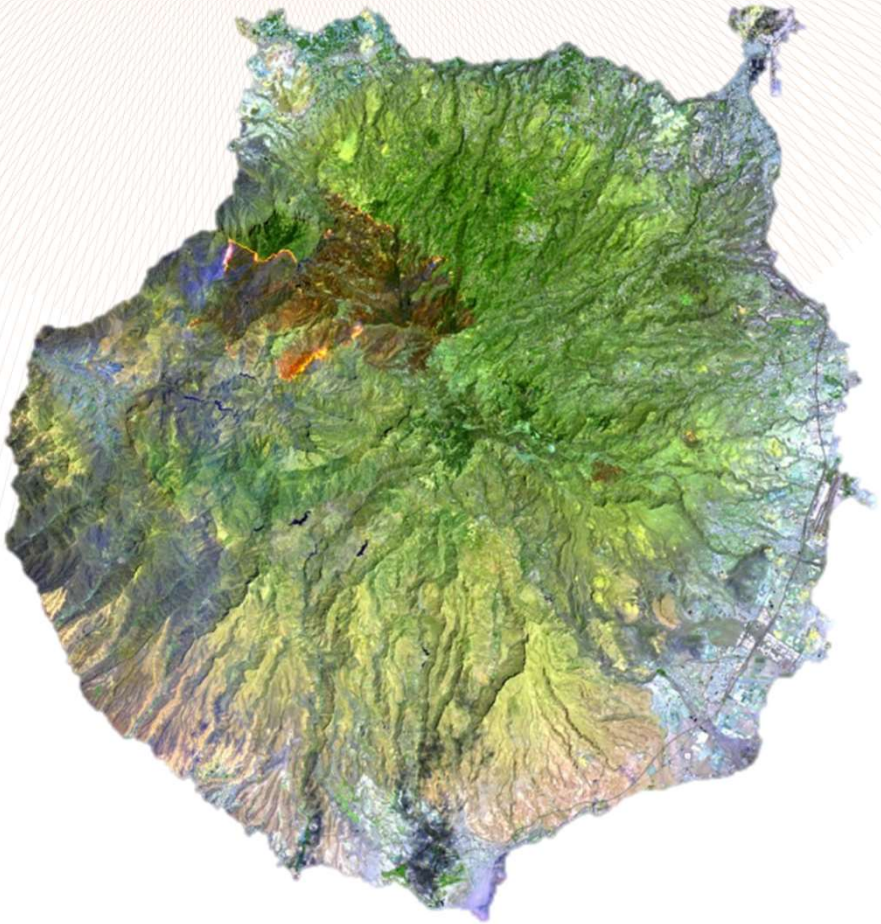
- Agent-based modeling is a prominent simulation paradigm for complex systems and population-based problems.
- Bottom-up approach where we define properties and rules of the agents. Global behavior emerges from agents' actions, interactions, and adaptation.
- Model validation should be rigorous not to use incorrect models and provide with wrong answers.
- ABM is being used in many fields (marketing, ecology, politics or social dilemmas). We showed both a commercial DSS and a theoretical migration model.
- Planned research ULPGC: EGT (PGG) for tax evasion // agent-based model for tourism.





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