Exploring the Potential of Geospatial Agent-Based Models for Digital Earths:

• A Socio-Ecological Systems Approach

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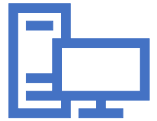
Agenda

Introduction

Background

Architecture



Applications

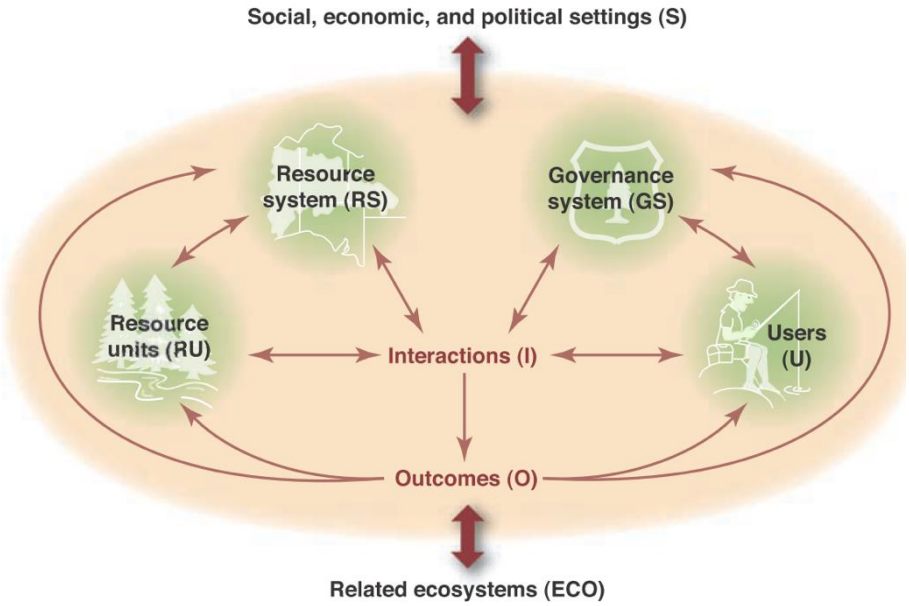
Conclusion

Part 1

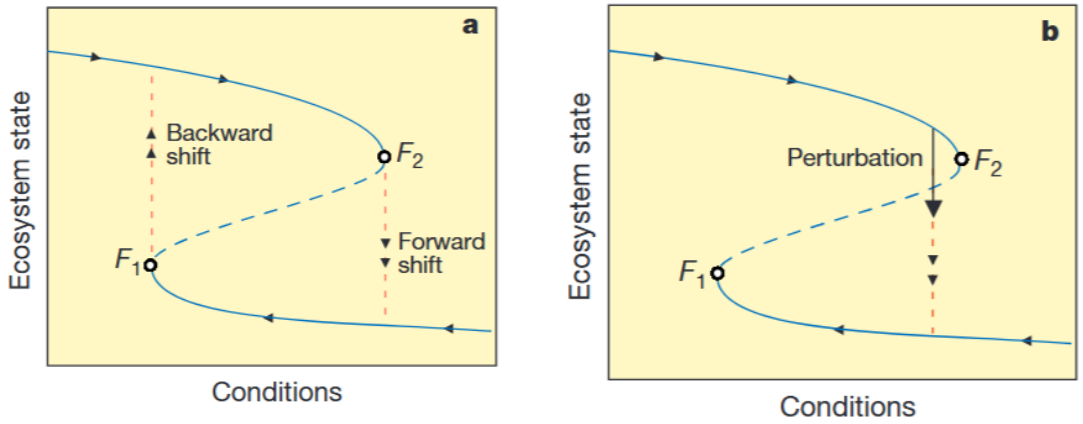
Why Geospatial Agent-Based Models?

Background

Socio-ecological systems



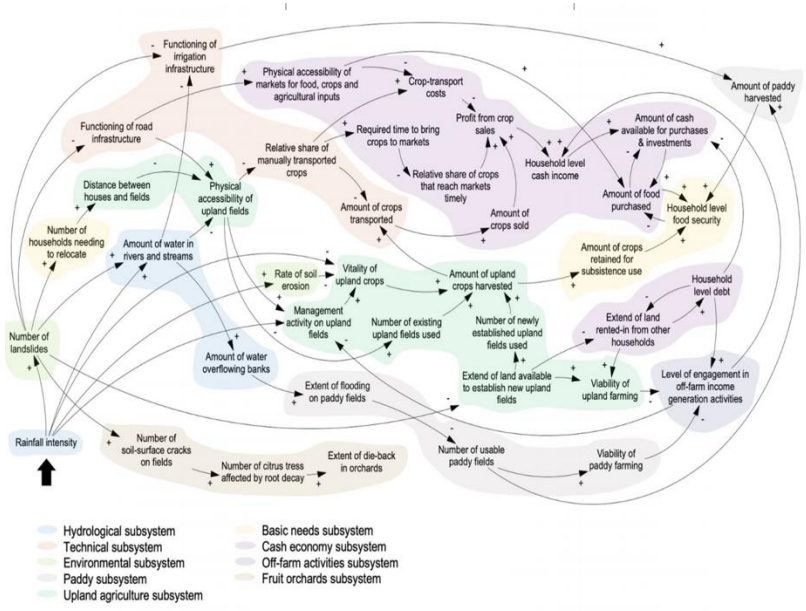
Schematic representation of a social-ecological system (from: Ostrom, 2009)



Scheffer, Marten, et al. "Catastrophic shifts in ecosystems."

- Social-ecological System (SES) refers to a coupled system with complexity, nonlinearity and multi-layer nesting formed by human interaction with the environment.
- The social-ecosystem theoretical framework provides an ideal theoretical basis for model simulation research on long-term human-environmental coordinated evolution.

Agent-based model



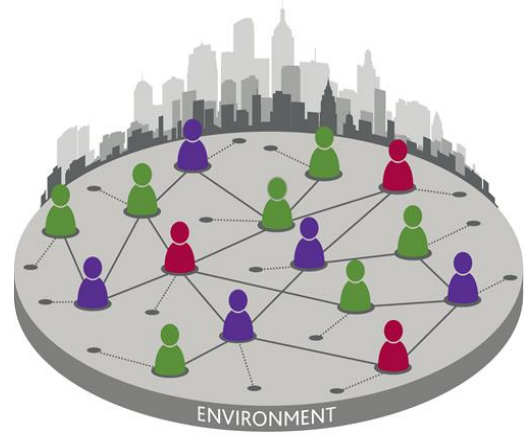
A. System dynamics model

System dynamics model

from top to bottom

Mathematical presets for theoretical models

$y = f(x)$ …



Agent based model

from bottom to top

Rule presets and code implementations

class Agent -> class Env

agent	Agent interaction	Agent-environment interactions

B. Agent based model

- **The agent-based model and the system dynamics model can simulate the human-environment interaction process and reveal the nonlinear mutation mechanism of the tipping point in its SES**
- **System dynamics tools are relatively mature, but they need to be preset by theoretical models. And agent-based model requires more sophisticated programming implementations.**

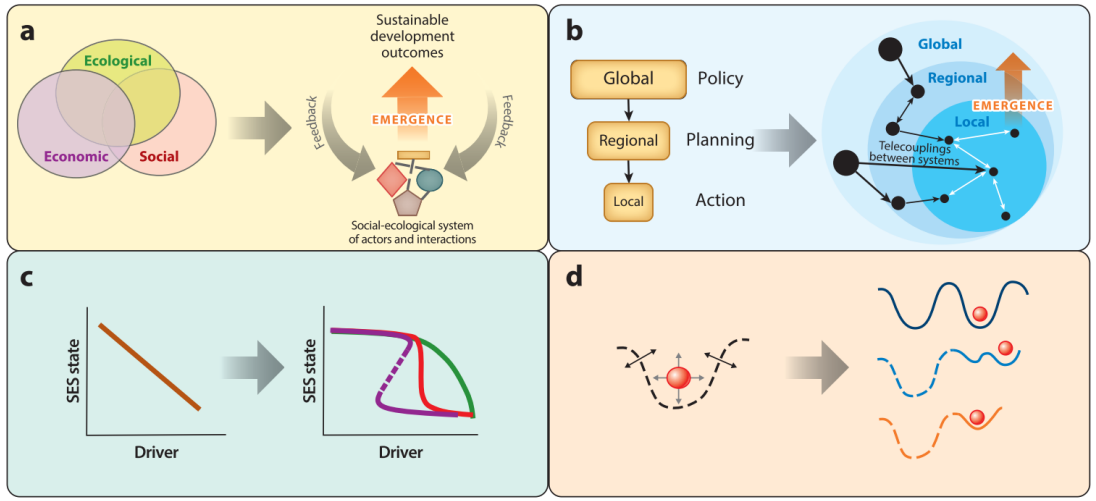
Tools for ABM

	NetLogo	Repast Simphony	AnyLogic	MASON	GAMA	**Mesa**	AgentScript
Initial Release Year	**1999**	2000	2000	2003	2009	**2015**	2018
Implementation Language	**Scala, Java**	Java	Java	Java	Java	**Python**	JavaScript
Modeling Language / Interface	**NetLogo**	ReLogo, statecharts, Groovy, Java	GUI, Java, UML-RT	Java	GAML (GAma Modeling Language)	**Python**	JavaScript
Raster Data Support	**gis-extension**	Yes	Yes	GeoMason extension	Yes	**Mesa-Geo extension**	Yes
Vector Data Support	**gis-extension**	Yes	Yes	GeoMason extension	Yes	**Mesa-Geo extension**	Yes

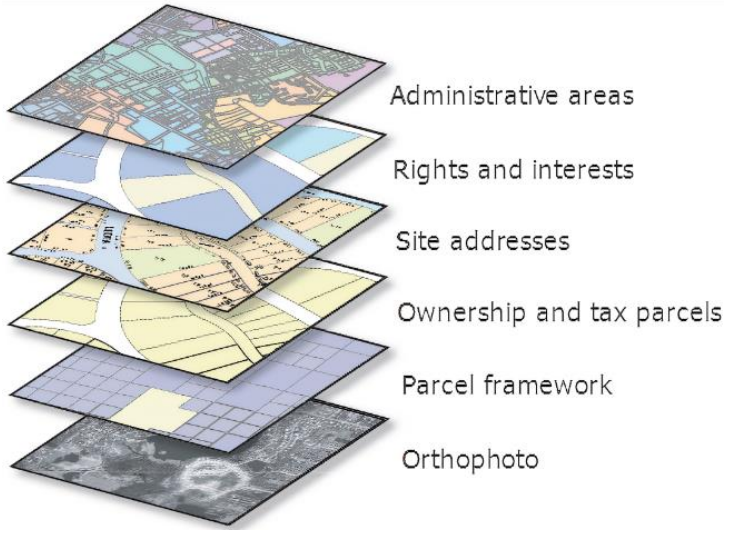
Mesa

- **Created in 2015. Source code: https://github.com/projectmesa/mesa**
- **Over the years, Mesa has been used in a wide range of application areas, from epidemiology, logistics, healthcare, to the modeling of electricity market, auction, food market, building, etc.**

The Challenge of Global Environmental Changes



Reyers 2018, Annu. Rev. Environ. Resour.



- **SES needs to consider: system emergence, nonlinearity, elasticity and other characteristics**
- **SES's social subsystem needs to simulate decision-making: the ability of the current subsystem modeling to couple with other models is insufficient...**
- **Current ABM modeling tools lack of geographic data support**

Whether there is an integrated framework in place that supports both **socio-ecological system** research and dynamically processes **geospatial data**

Proposed Solution: Integrated ABM Framework

Target:

Develop an integrated framework that combines Mesa-Geo and ABSESpy to simulate complex spatial scenarios.

Mesa-Geo:

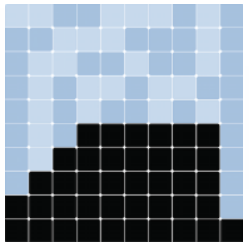
- Geospatial expansion of Mesa
- Raster data and vector data are supported
- Support for a consistent Coordinate Reference System (CRS)

ABSESpy:

- Specifically designed for socio-ecological system research
- Separate natural and human module interactions
- A unified time system supports decision-making

AB-SES-PY

Agent-Based Social-ecological systems Modelling Framework in Python



Mesa-Geo

Created in 2017

2015	2017	2023
Mesa	Mesa-geo	ABSESpy
• ABM(python)	• Geo-extension	• Ses-extension

Part 2

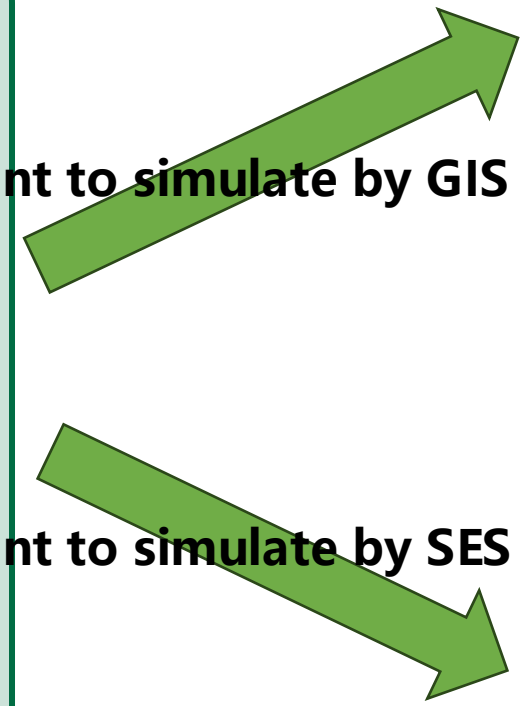
Main features

Mesa-geo & absespy

Framework Design and Capabilities

Research Objectives:

- Based on the continuous update and enhanced integration of Mesa-Geo and ABSESpy, geospatial datasets can be dynamically processed to simulate spatially explicit agent interactions.
- It supports multi-dimensional human-environment interaction simulation, and explores that agent behavior is driven by both internal decision-making logic and external environmental factors (such as water resources).



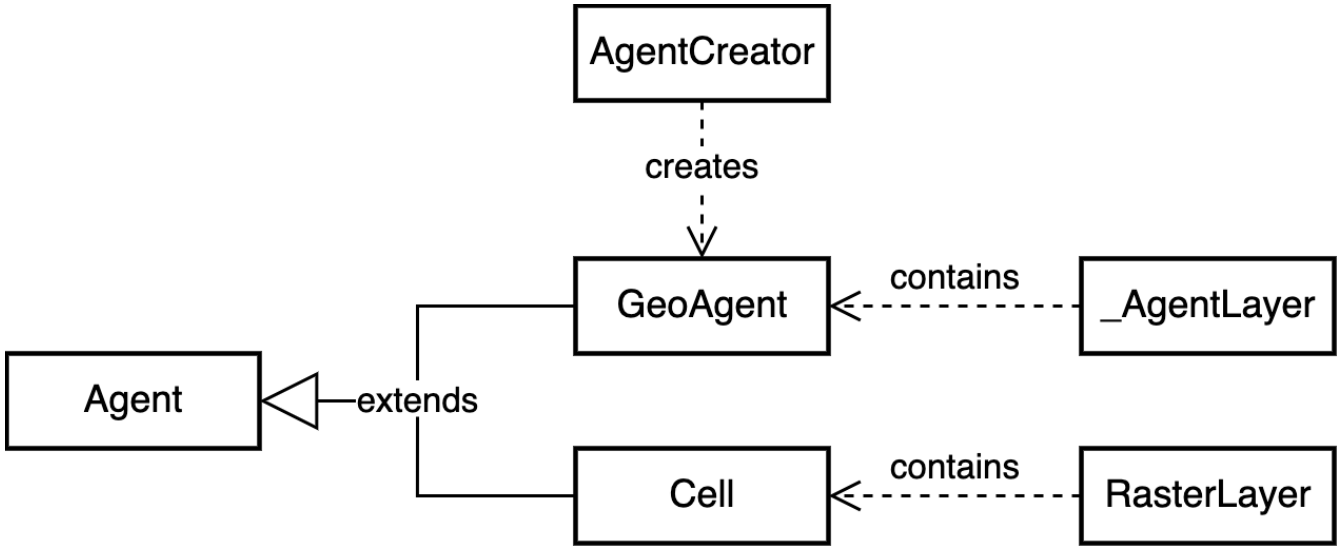
Mesa-geo

- gis visualization
- GIS data import/export
- Raster data:
- Vector data:

ABSESpy

- Social/natural module separation
- Parameters are configured in a unified manner

Architecture of Mesa-geo



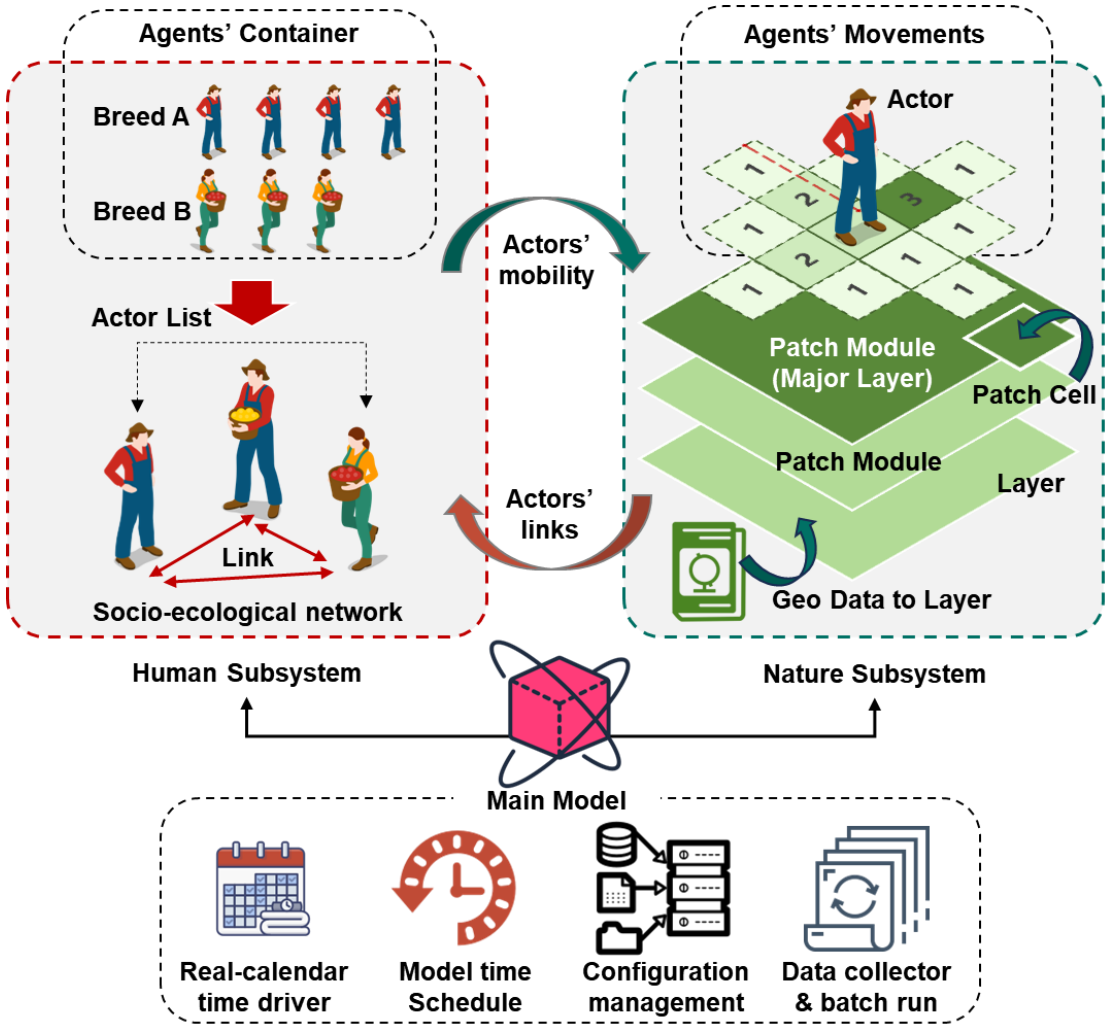
Base Modules:

- **GeoBase**
- **GeoAgent and AgentCreater**
- **Geospace:** multiple raster layers representing slope, road, land use, urban area, and so on.
- **Raster Layer**
- **Visualization**
- **Tile Layers**

- **Mesa-geo is a tool that focuses on ABM modeling of geographic data such as vector support, integrating complex GIS functions**
- **For example**
  - **Supports a consistent Coordinate Reference System (CRS) for designing agent interactions**
  - **Support raster data and vector data to be imported to create Geoagent**

Architecture of ABSESpy

- The overall architecture of ABSESpy is based on the core design concept of "**low coupling and high cohesion** " , and builds a flexible and easy-to-maintain modeling framework through hierarchical decoupling, modular packaging and standardized interfaces
- **The three main core functions are:** (1) the realism enhancement of time-space coupling; (2) modular architecture-driven maintainability; and (3) the design of deep interaction between agent behavior and environment. Meet the needs of the whole process of complex socio-ecological system modeling



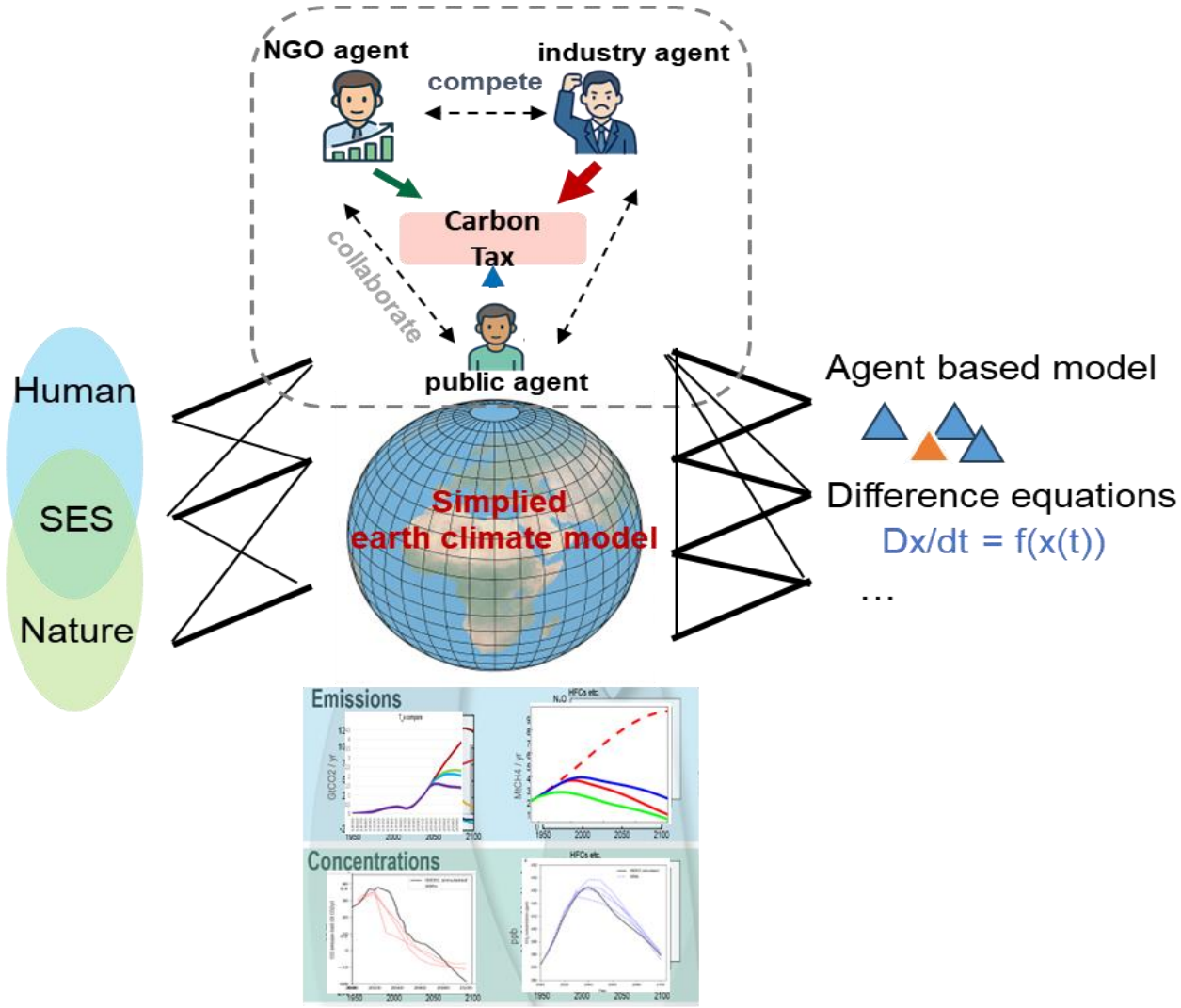
Part 3

Study Examples

ABSESpy & mesa-geo

Case of ABSESpy : multi agents gover the policy of climate system

- In the study of climate warming and sustainable development, the process of mutual feeding between the social system and the earth system is often complex and difficult to explore
- **Problems:** **How** to describe the mechanism of nature and human? **How** interactions between agents have an impact on the environment
- Here, we hope to use the ABSESpy framework to introduce ABM-based ideas, which is expected to simulate the process of policy competition, cooperation and game between multiple actors, so as to provide micro-mechanism explanation and decision support for the formulation of more effective **climate policies.**



Jonathan 2018
Ramanathan2021b

Case of ABSESpy : Framework

Initialize the environmental model (social-energy-ecological-economic)

Initialize Principal (public/industry/NGO agent)

Initialization Scenario and Corresponding Parameter Configuration (Corresponding forcing Data)

The process of Multi-agent game

Observe the current environment

Choose actions based own policy

Determine the compound action

Action strategy on the environmental impact

The environment numerical solution gets a new state

End

Storing data

(Take NGO agent as an example))

Observe Status: Get the variables you care about most in your environment

Calculating the Utility Function Score:
The score is calculated based on temperature sensitivity

$$T_{final} = \begin{cases} -15, & \text{if } T_{base} < -15 \\ T_{base}, & \text{if } -15 \le T_{base} \le 100 \\ 100, & \text{if } T_{base} > 100 \end{cases}$$

Select Independent Actions:
Actions are selected based on the score

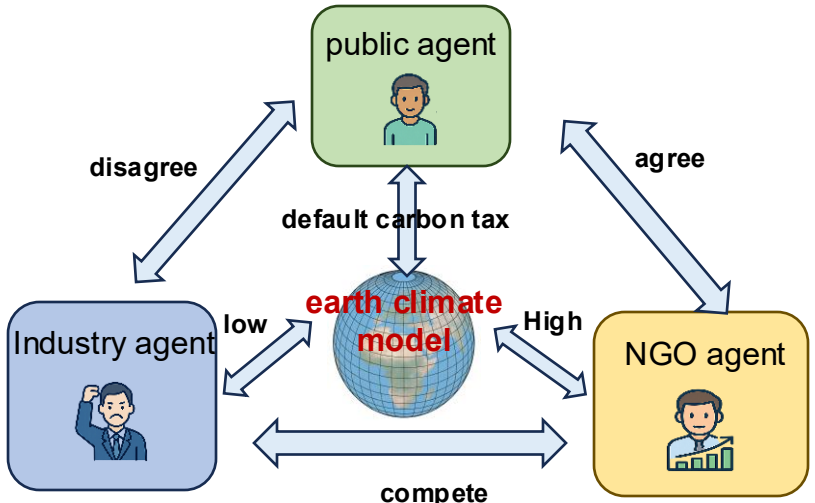
$$a_t \in [-15, 0, 20, \ldots 100]$$

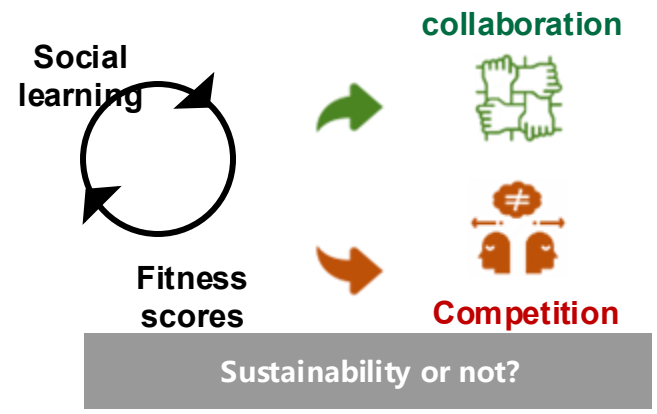
[1]World bank 2023

All agents do influence on the environment

The compound actions of multiple agents:
Compound actions to environmental change are calculated based on the policy influence of the current agent set

$$a_{all} \in [\sum_{i=1}^{n} \omega_i x_i \text{ agent}_1, \sum_{i=1}^{n} \omega_i x_i \text{ agent}_2, \sum_{i=1}^{n} \omega_i x_i \text{ agent}_3, \sum_{i=1}^{n} \omega_i x_i \text{ agent}_4]$$





Case of ABSESpy : Results

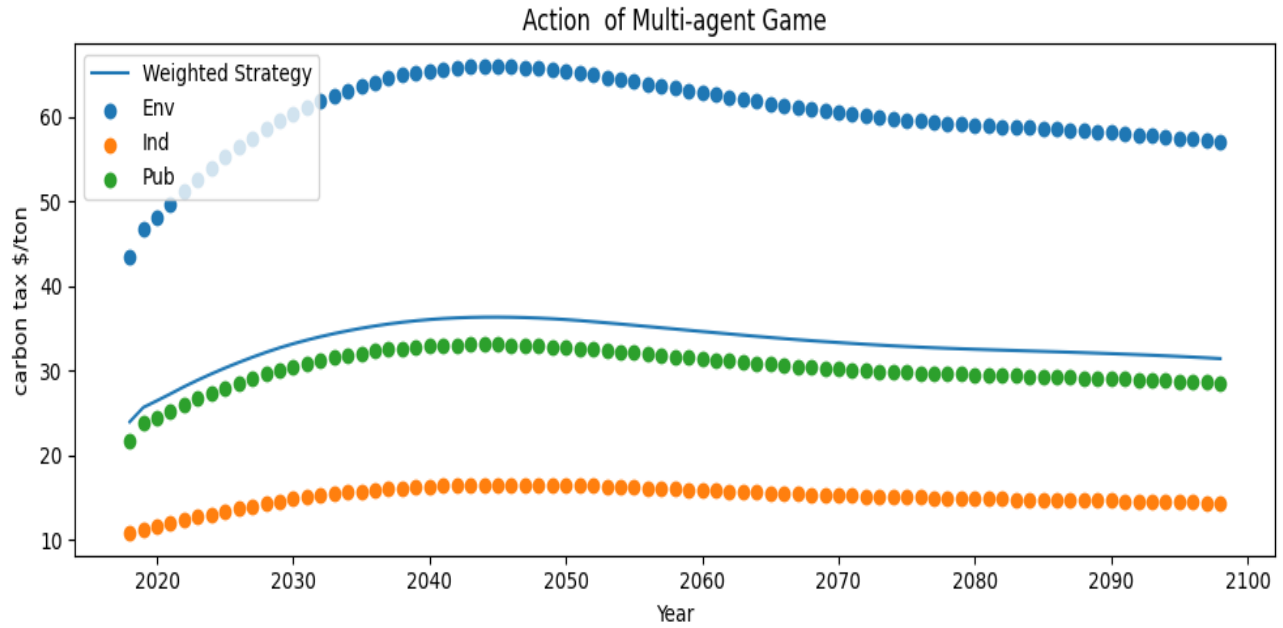


Fig.1

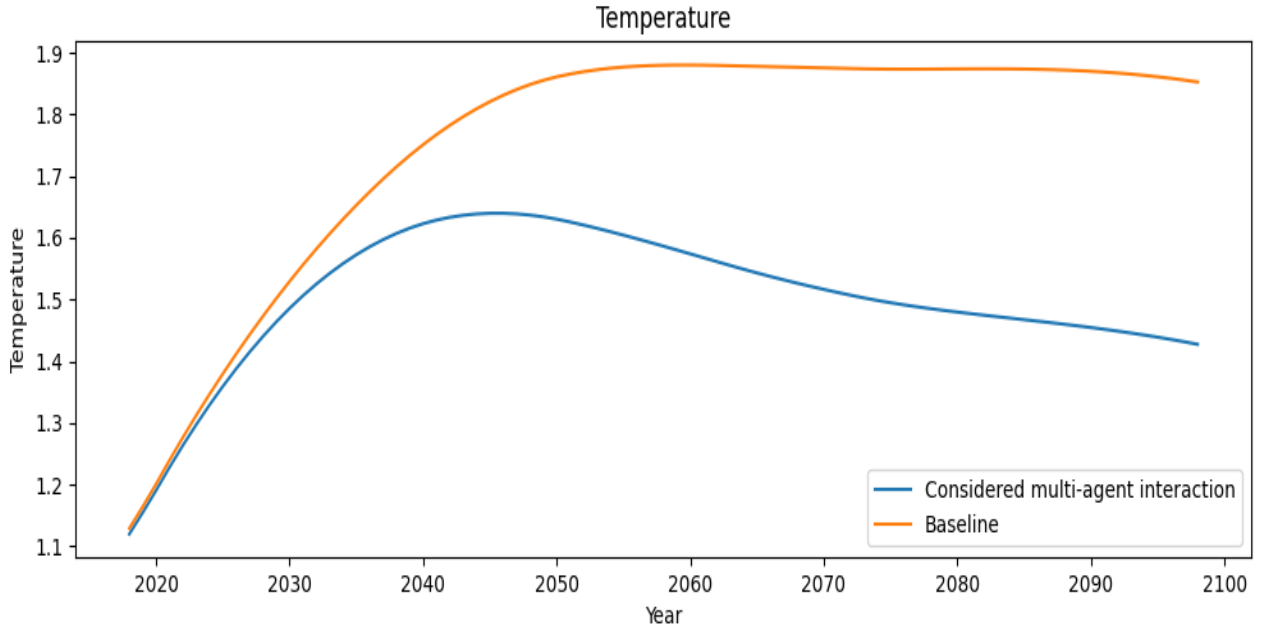
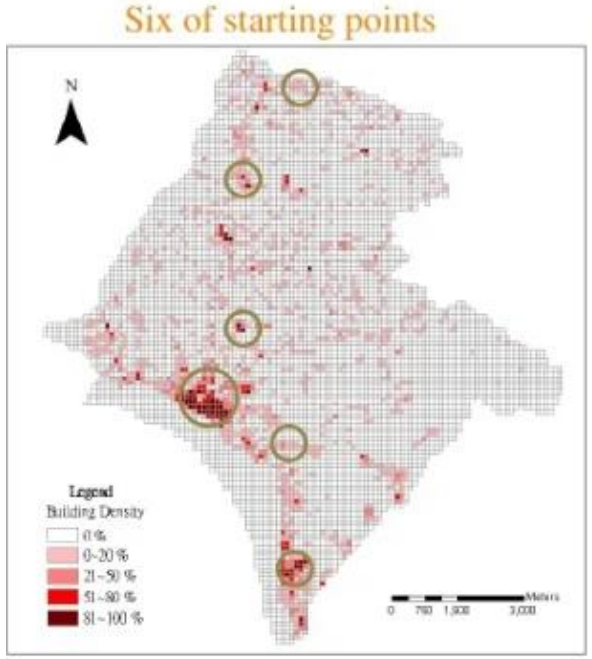


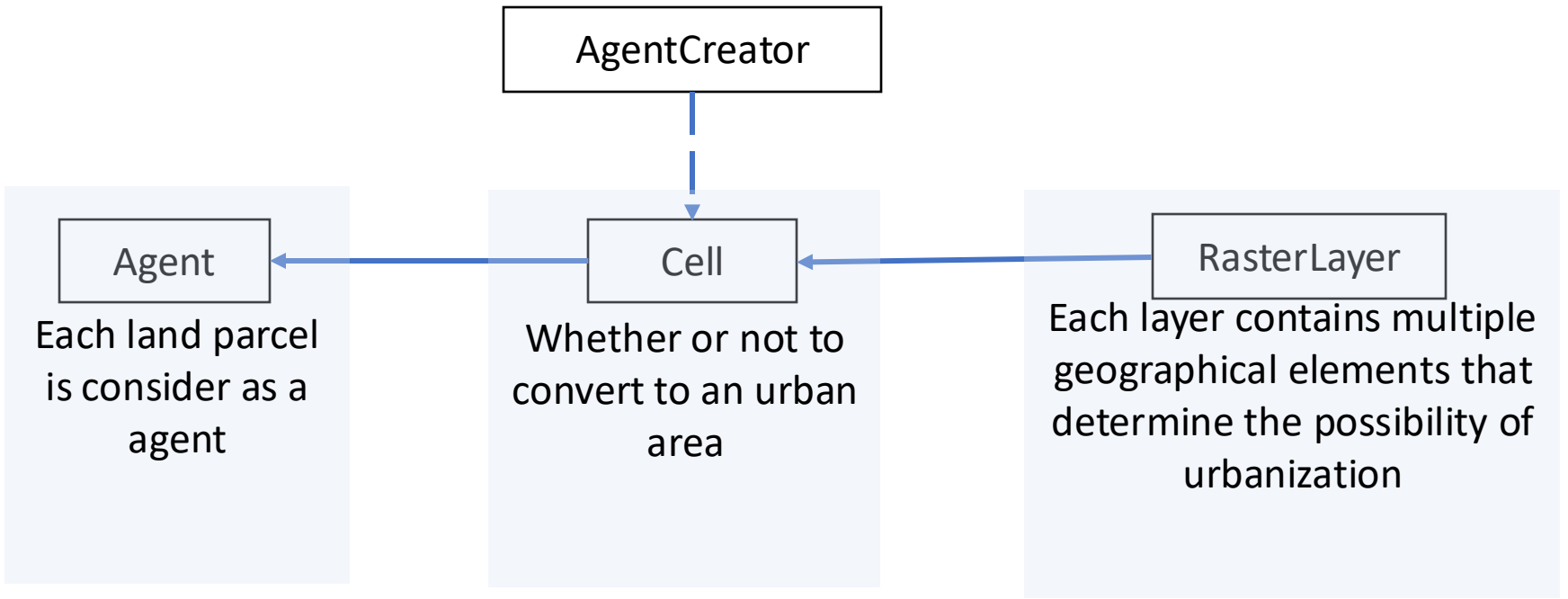
Fig.2

- Rapid ramp-up phase (2020-2024): The temperature rises rapidly, and the public agent behavior dominates
- Flat growth stage (2024-2070): The temperature rise slows down, and the temperature is significantly lower after considering multiple agents
- Slow decline (2070-2100): The high tax policies of environmentalists have brought the temperature down

Mesa-geo Case Studies: Urban growth model

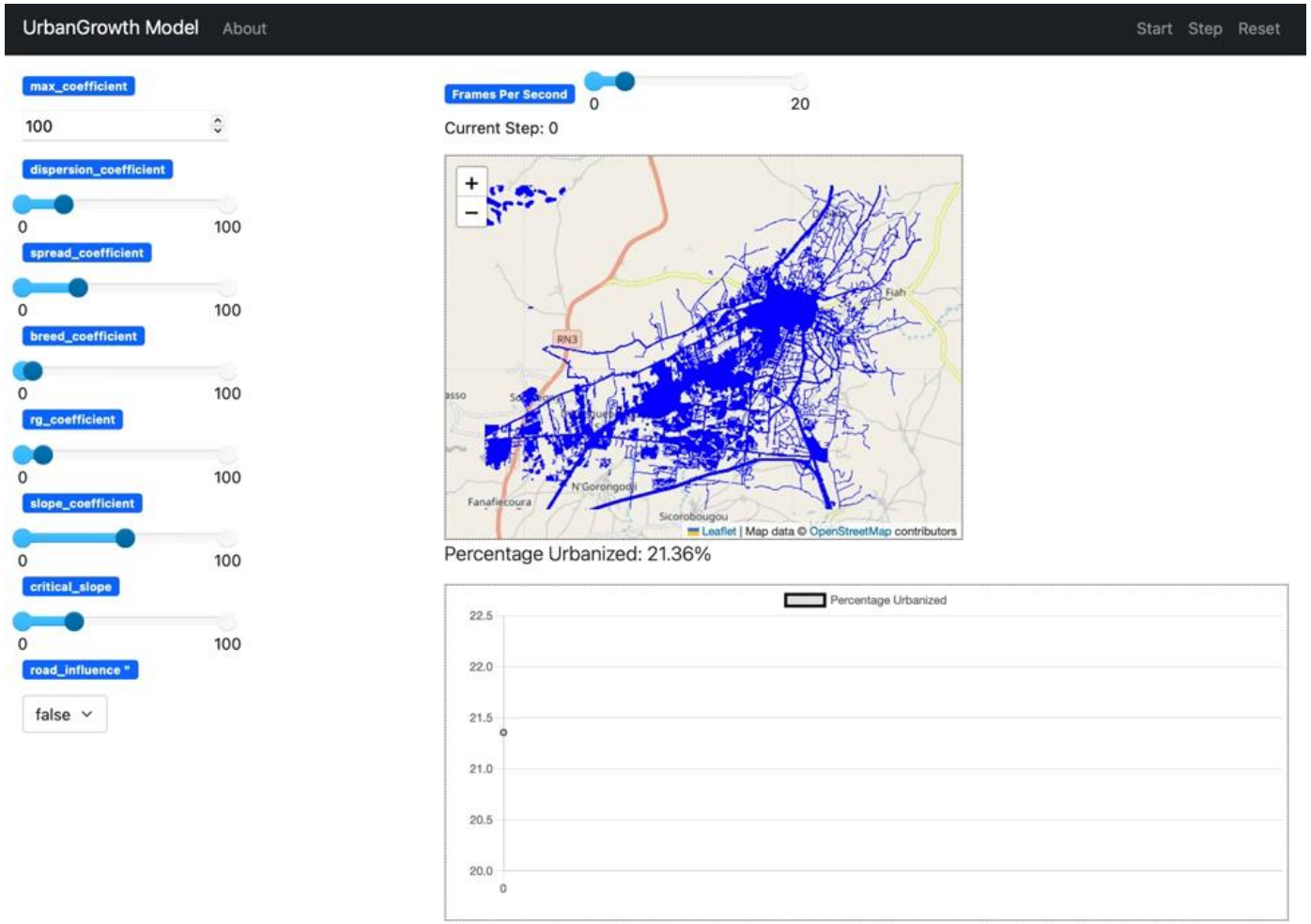
- This model is a partial reimplementation of the Urban Growth Model that was developed by Clarke et al. (1997) .
- This model explores urban growth and urbanization process.
- The **region** of study is Santa Fe, New Mexico.
- The model demonstrates how several **raster layers** can be used to initialize a Mesa-geo model.





https://github.com/abmgis/abmgis/tree/master/Chapter06-IntegratingABMandGIS/Models/UrbanGrowth

Mesa-geo Case Studies: Urban growth model



At each time step, each land parcel is decided whether it is suitable to be urbanized, based on the input raster layers as well as the user defined coefficients.

- **GeoSpace:** multiple raster layers representing slope, road, land use, urban area, and so on.
- **Cells:** land parcels.

https://github.com/abmgis/abmgis/tree/master/Chapter06-IntegratingABMandGIS/Models/UrbanGrowth

Conclusion

- **Mesa-Geo:** an open-source GIS extension for the Mesa agent-based modeling framework in Python.
- **ABSESpy**: ABSESpy is an agent-based framework that makes modeling social-ecological systems easier

- **Future Work:**
  - Extended functionality: Increase the complexity of agent behavior.
  - Improved scalability: Support for larger scale simulations.

Mesa-Geo

https://github.com/projectmesa/mesa-geo

ABSESpy

https://songshgeolab.github.io/ABSESpy/wiki/wiki/

Future Work and Community Building

- **Community Building:**
  - Build an online community, ABMind.
- **Target:**
  - Lower the barrier to learning
  - Provide learning resources
  - Promote technical exchanges
- **Future expectations**
  - 2025: Framework feature expansion.
  - 2026: ABMind community goes live.
  - 2027: Large-scale use cases.

群聊：ABMind交流学习群

ABMind: WeChat public account

2. 示例代码与项目案例

- **Mesa Core Examples:**
  https://mesa.readthedocs.io/stable/examples.html
- **Mesa Examples:**
  https://github.com/projectmesa/mesa-examples
- **Mesa-Geo Examples:**
  https://mesa-geo.readthedocs.io/stable/examples/overview.html

Detailed tutorial examples

Thanks for your attention!

Q & A

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