USING INSTITUTIONAL ARRANGEMENTS AND HYBRID AUTOMATA FOR REGIONAL SCALE AGENT-BASED MODELING OF LAND CHANGE

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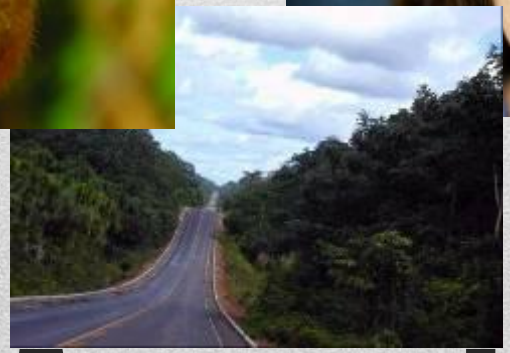
Orientadores: Dr. Gilberto Câmara
Dra. Ana Paula Dutra de Aguiar

Introduction

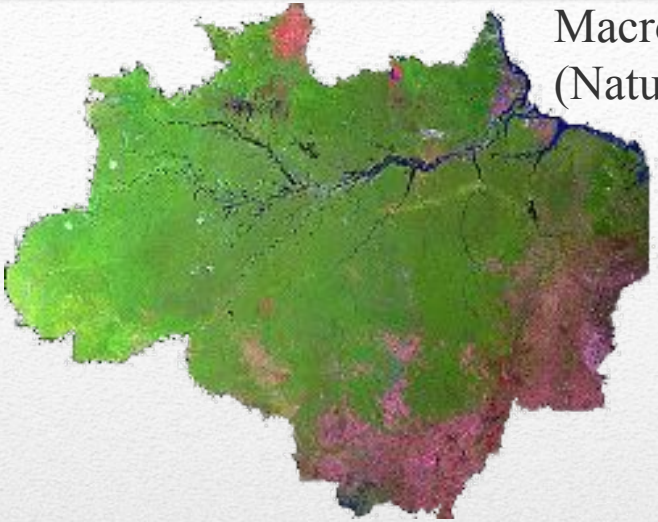
Land Change

Introduction



Land Change: Amazonia

Introduction

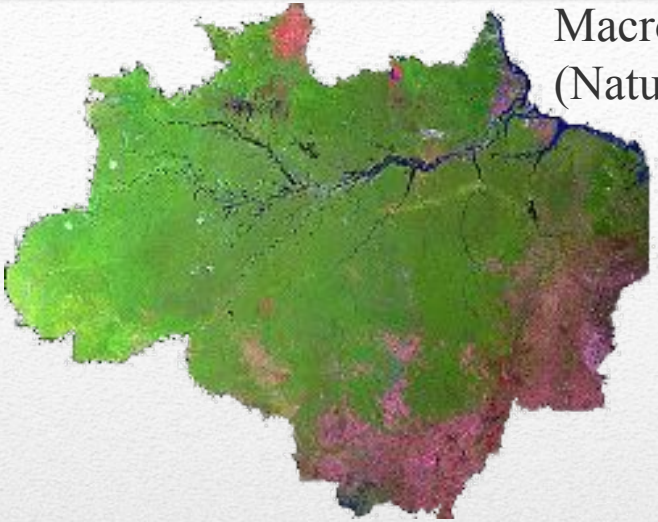


Macro
(Natural Science)

Micro
(Social Science)

Level of Analysis

Introduction



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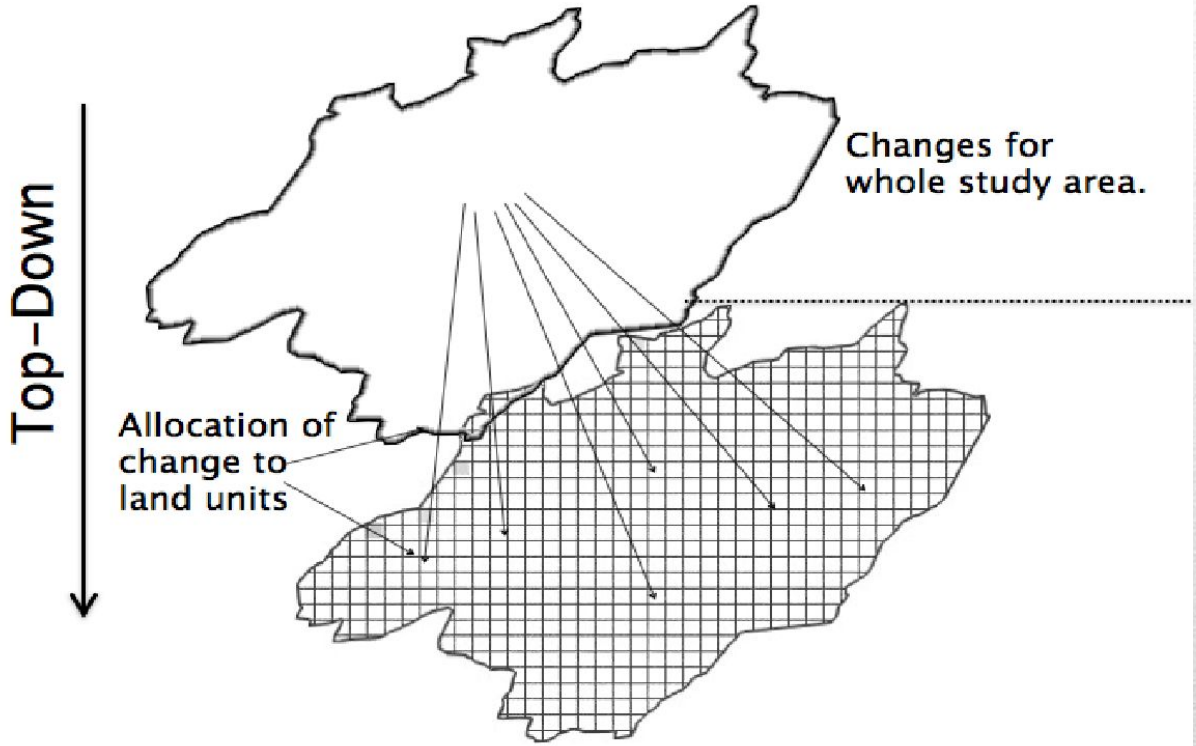
Introduction

Relation between land changes and spatial variables

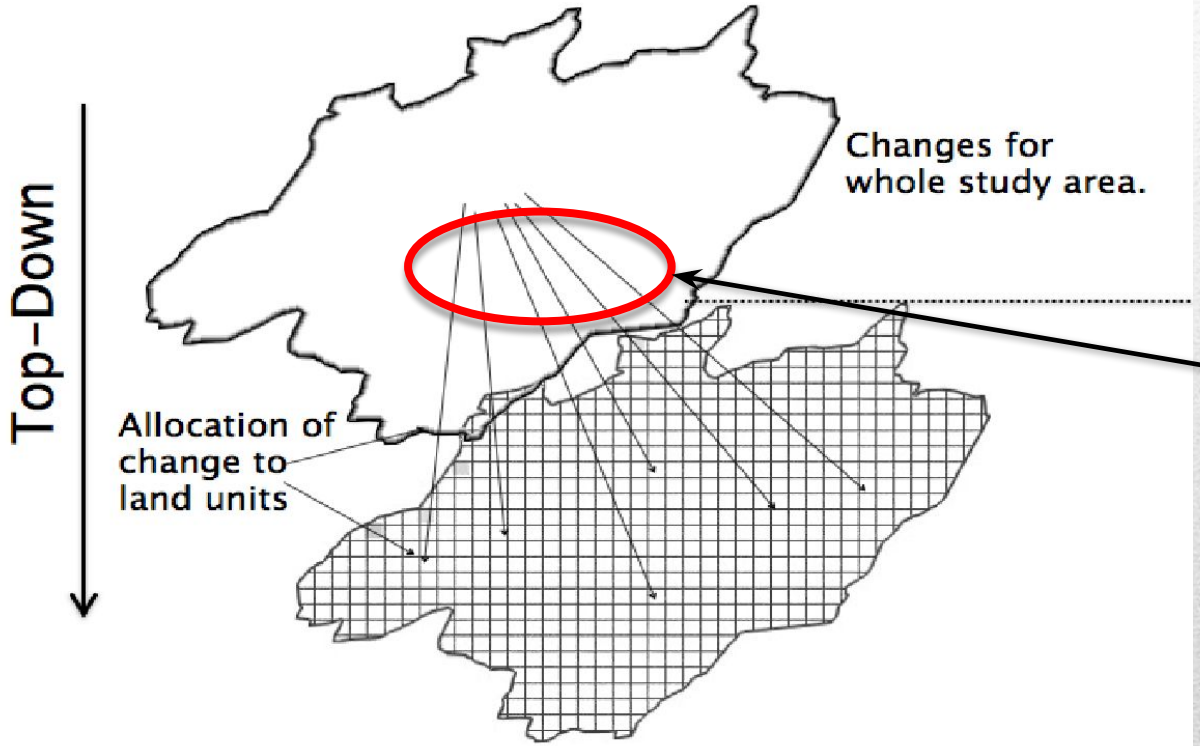


How changes in the regional (or national) scale affect the smaller units of the model, usually pixels or cells.

Pattern-based models

Introduction

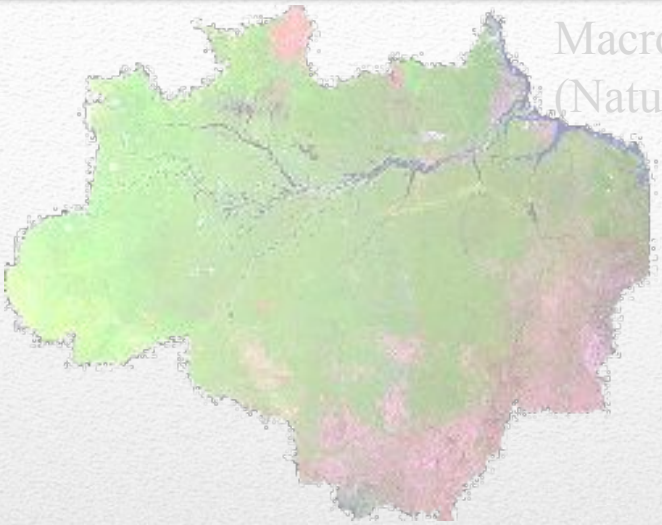
Relation between land changes and spatial variables



Analysing a deforestation hotspot

Pattern-based models

Introduction



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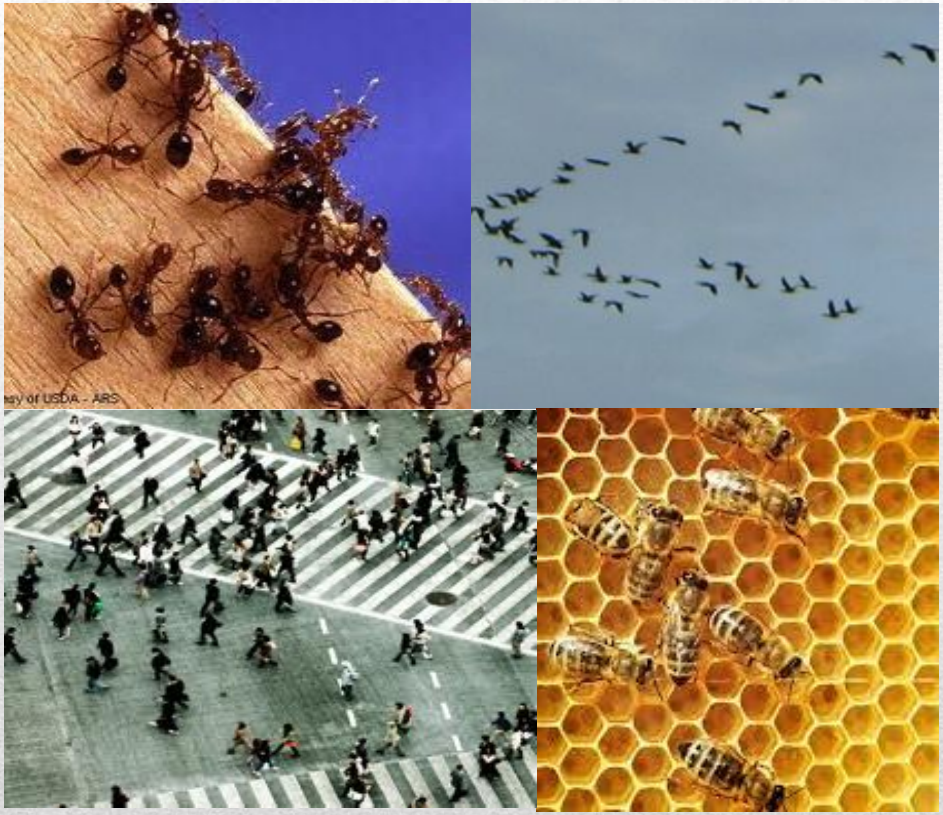
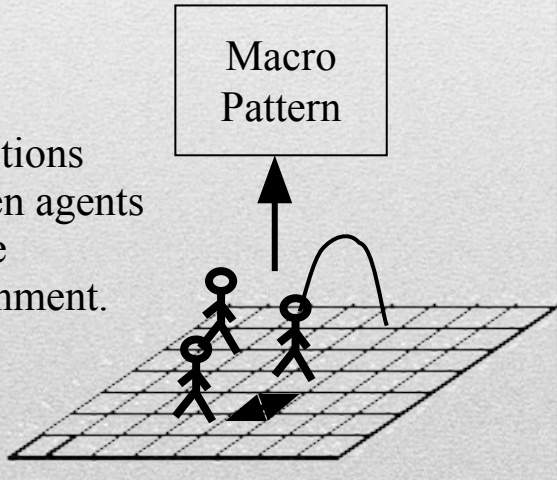


1. Agents, environmental and interactions.
2. Emergence concepts (Local actions lead to global patterns)
3. No central authority (autonomos)
4. Heterogeneity

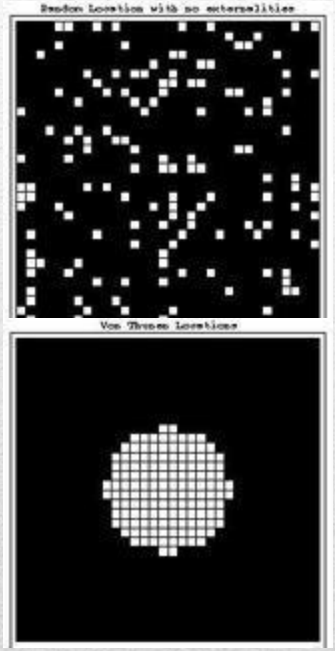


Agent-based models

Introduction

Agent-based models (ABM) range from **theoretical** to **empirical**. Theoretical models use simple generalizable ideas, whereas empirical models require more complexity and case-specific data..

Theoretical Models



Empirical models

Agent-Based Modeling of Land change

Introduction

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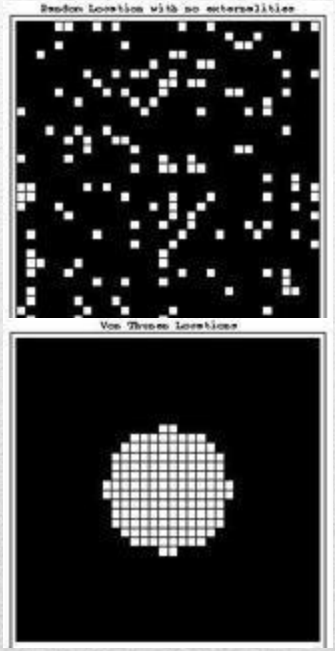
Theoretical Models



Empirical models

Agent-Based Modeling of Land change

The modellers rarely have access to individual data to represent and locate households in land change agent-based model.

Problem definition

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The lack of data is an even greater problem in large frontier area, like Brazilian Amazonia.

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Large extension of municipalities

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Large extension of municipalities

Intense land changes and land market.

Problem definition

Problem definition

Evolution of deforestation, population and agrarian structure in the study area.

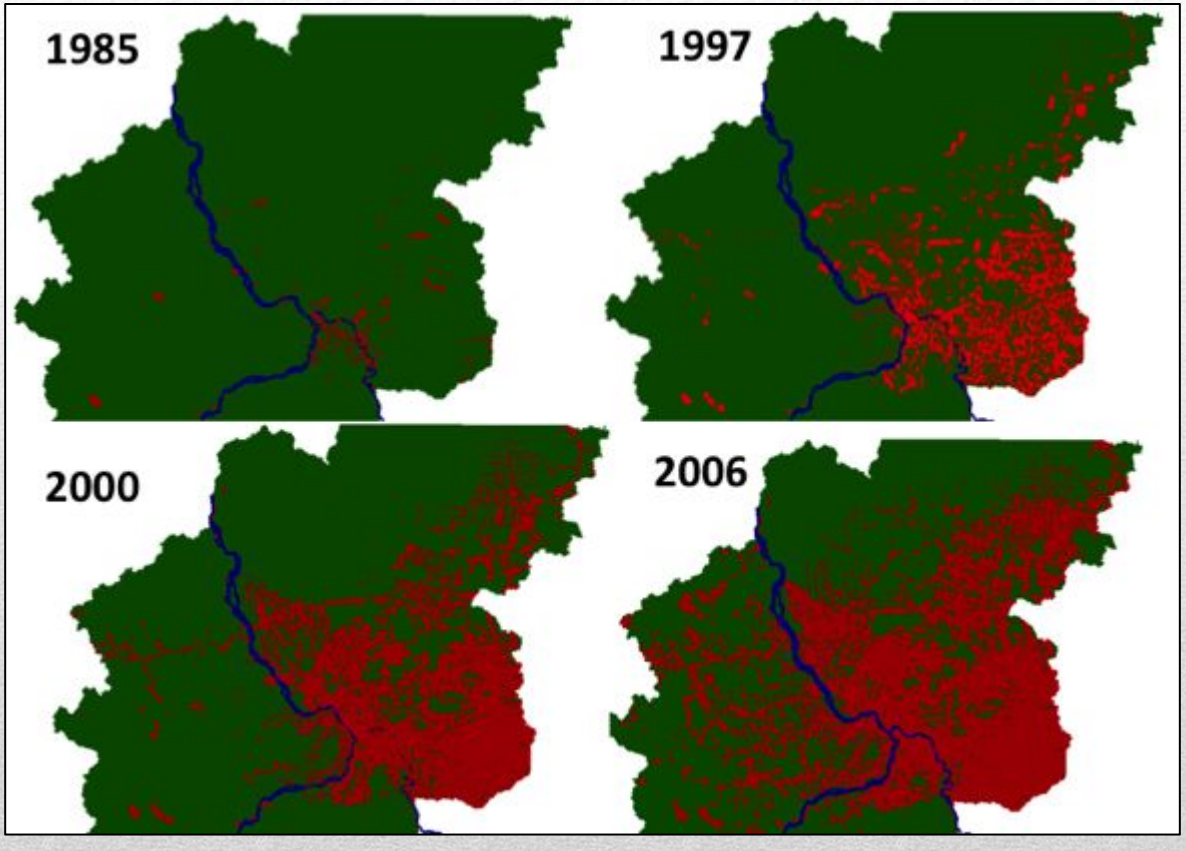
	1985	1995	2006	2010
Area of farms (km²)	2394	9601	17917	*
Number of farms	1375	5893	7148	*
Deforestation (km²)	426	4070	16762	19271
Head of cattle	24494	230875	1912033	2290538
Population	14016	69117	85751	125030

Sources: (IBGE, 2006; INPE, 2010b)

Intense changes

Problem definition

Evolution of deforestation patterns in the study area.

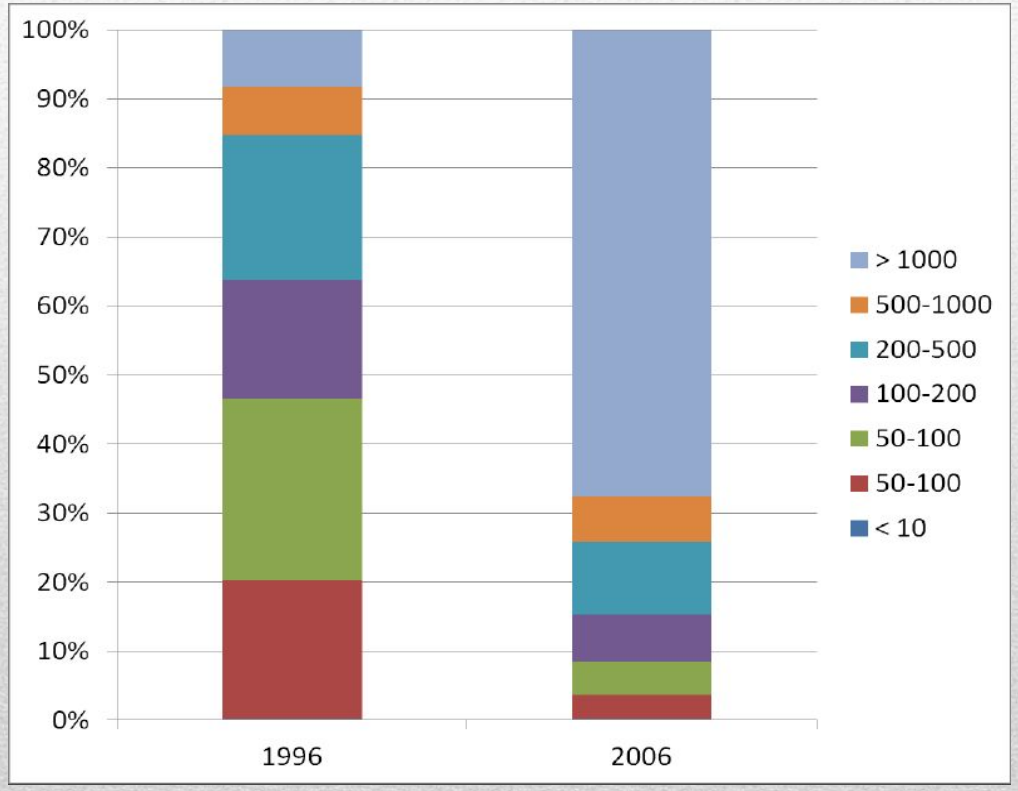


Intense changes

Introduction

In 1996, farms with individual areas greater than 1000 ha accounted for 8% of the total area of farms. In 2006, they accounted for greater than 60% of the total. In the same period, the number of farms decreased from 2518 to 1039

Concentration of land ownership in Tucumã .



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Different actors and strategies.

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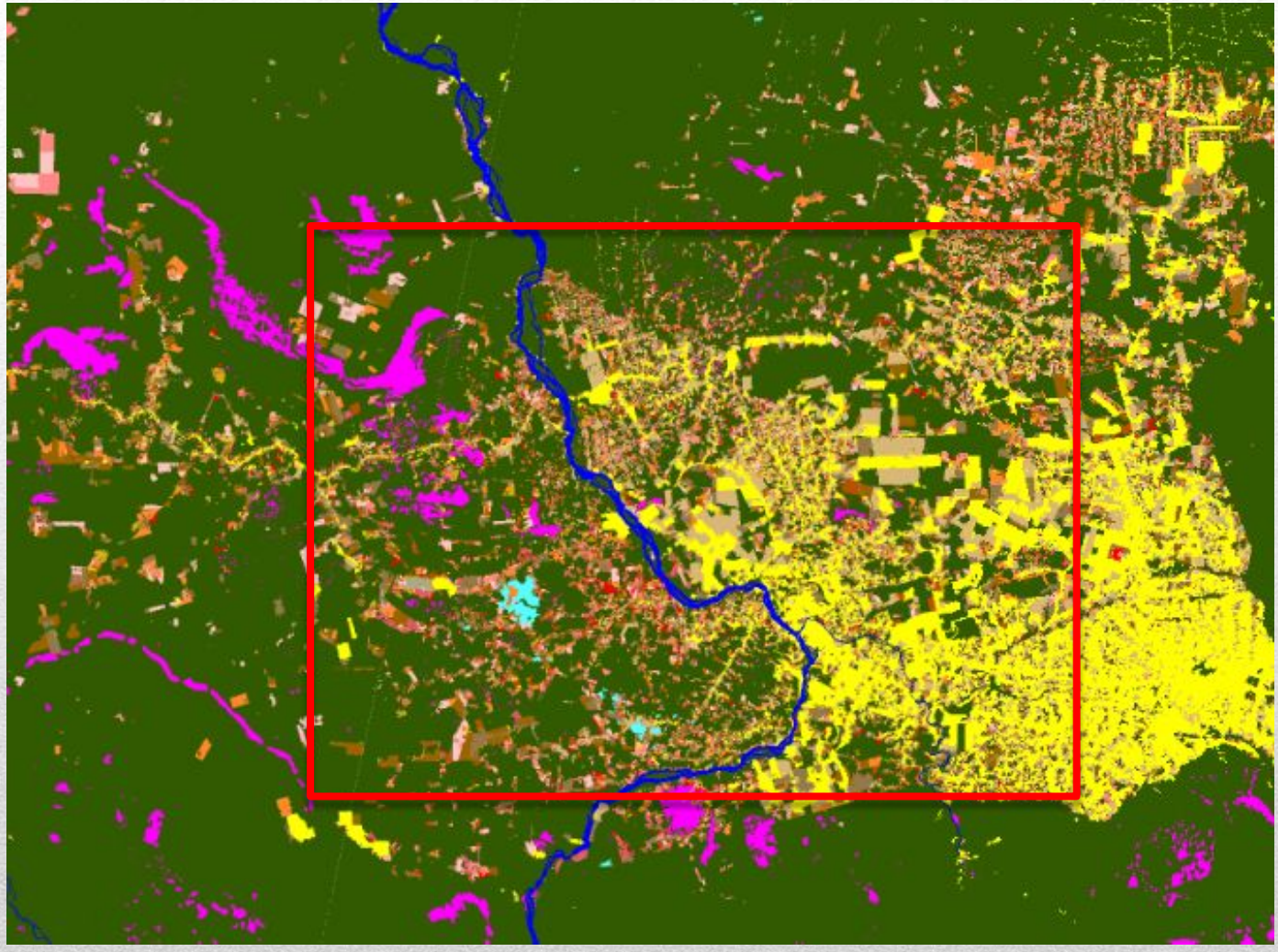
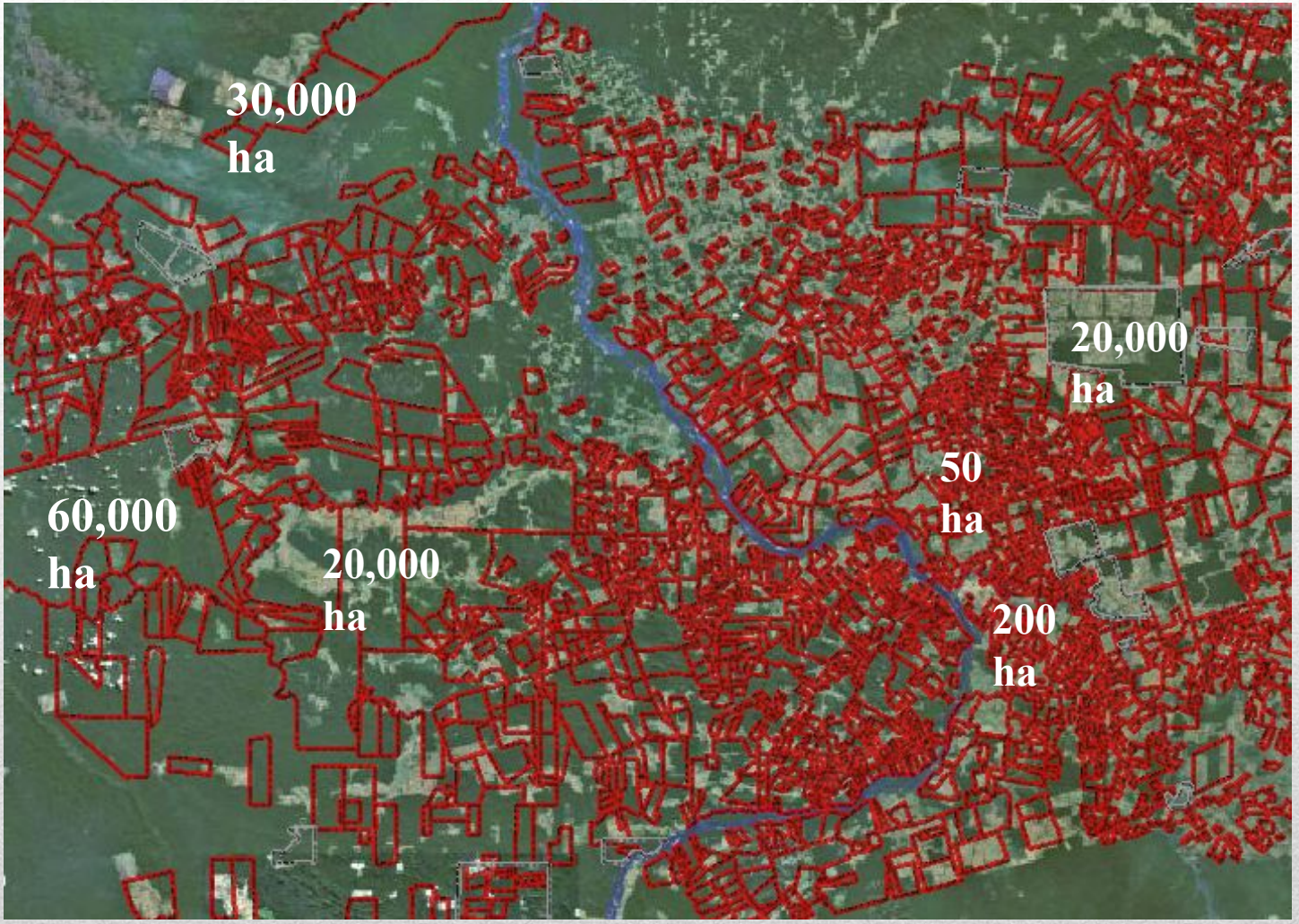


Different actors and strategies

Problem definition



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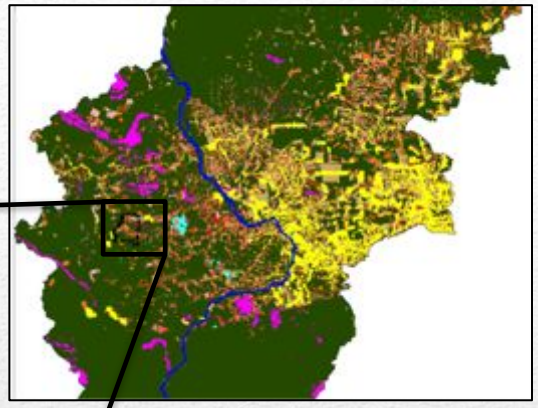
Different actor and strategies.

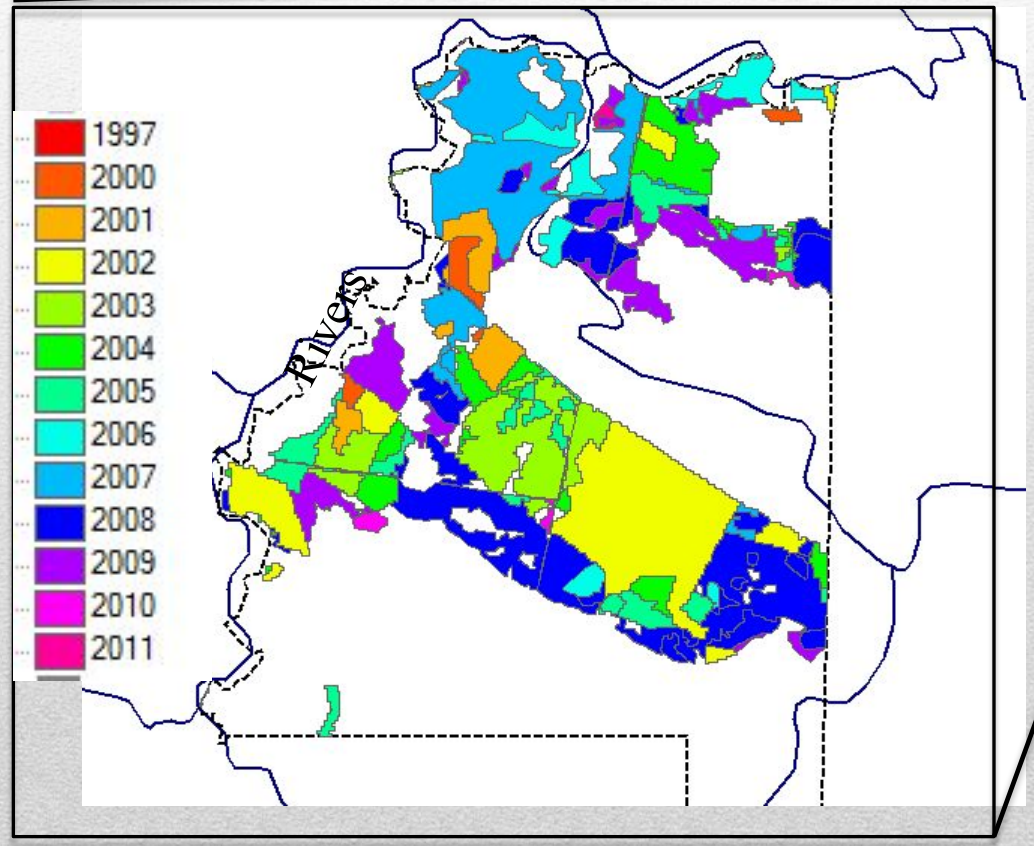
The behaviour of actors changes in response to internal and external conditions.

Problem definition

Problem definition

Lagoa do Triunfo Farm: 19962 HA

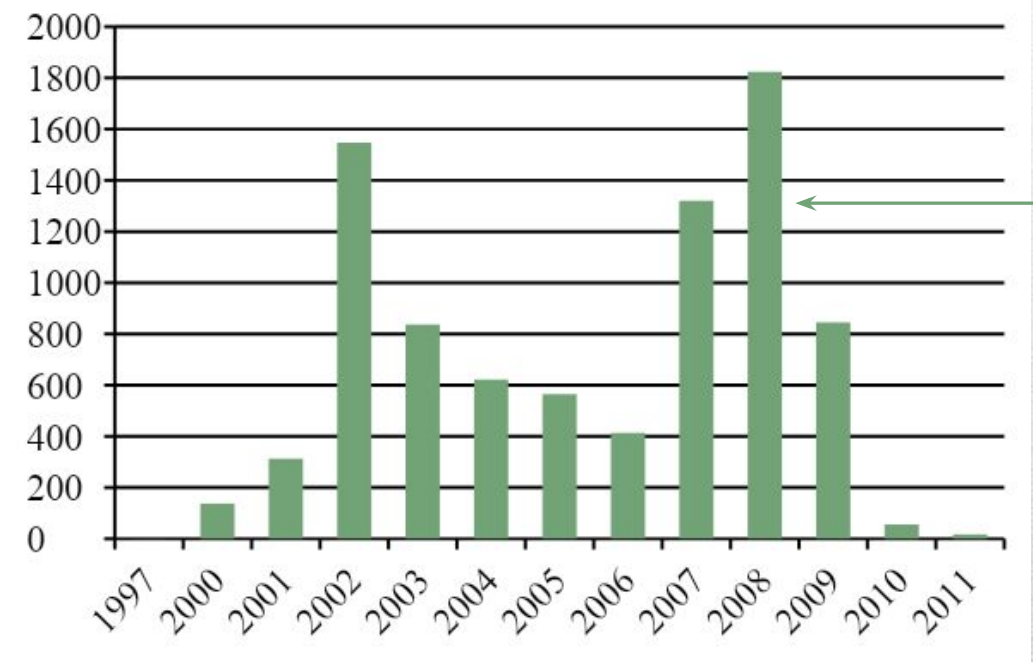




Changing of behaviour

Problem definition

Evolution of deforestation in the Lagoa do Triunfo Farm: ~653 ha/year.



APA – Triunfo do Xingu - 2007

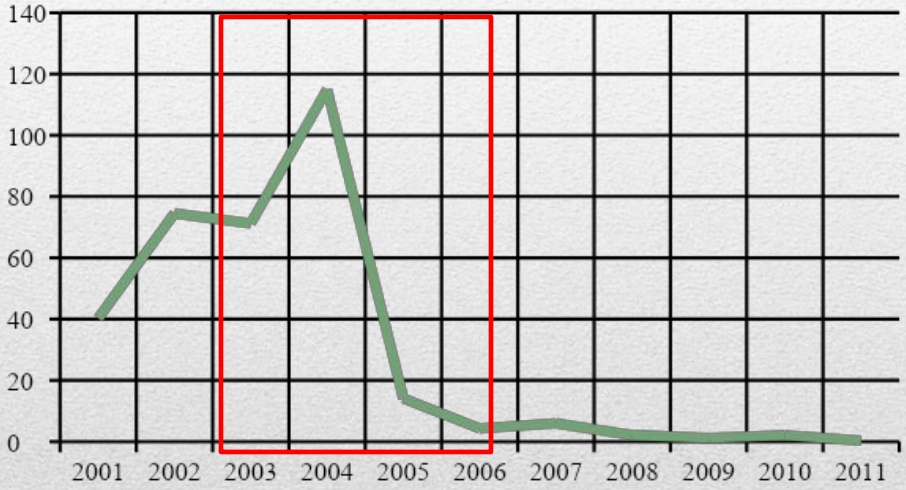
Lagoa do Triunfo Farm: 19962 HA

Changing of behaviour

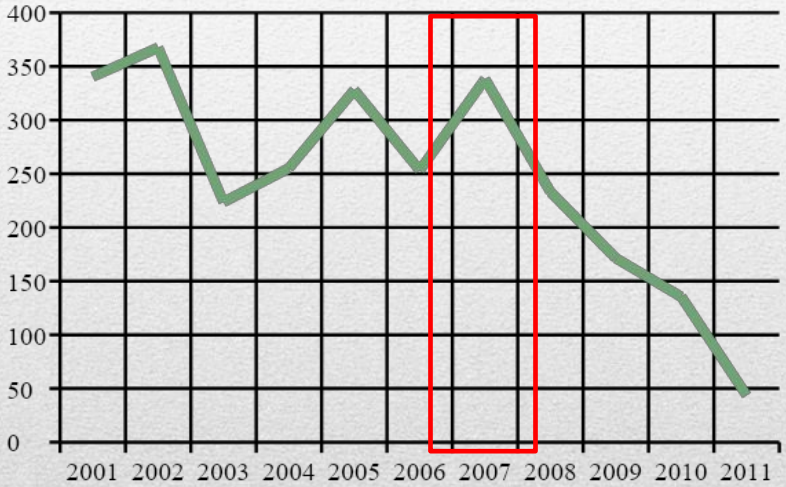
Problem definition

Evolution of deforestation in different regions:

Prot. Integral – 2005



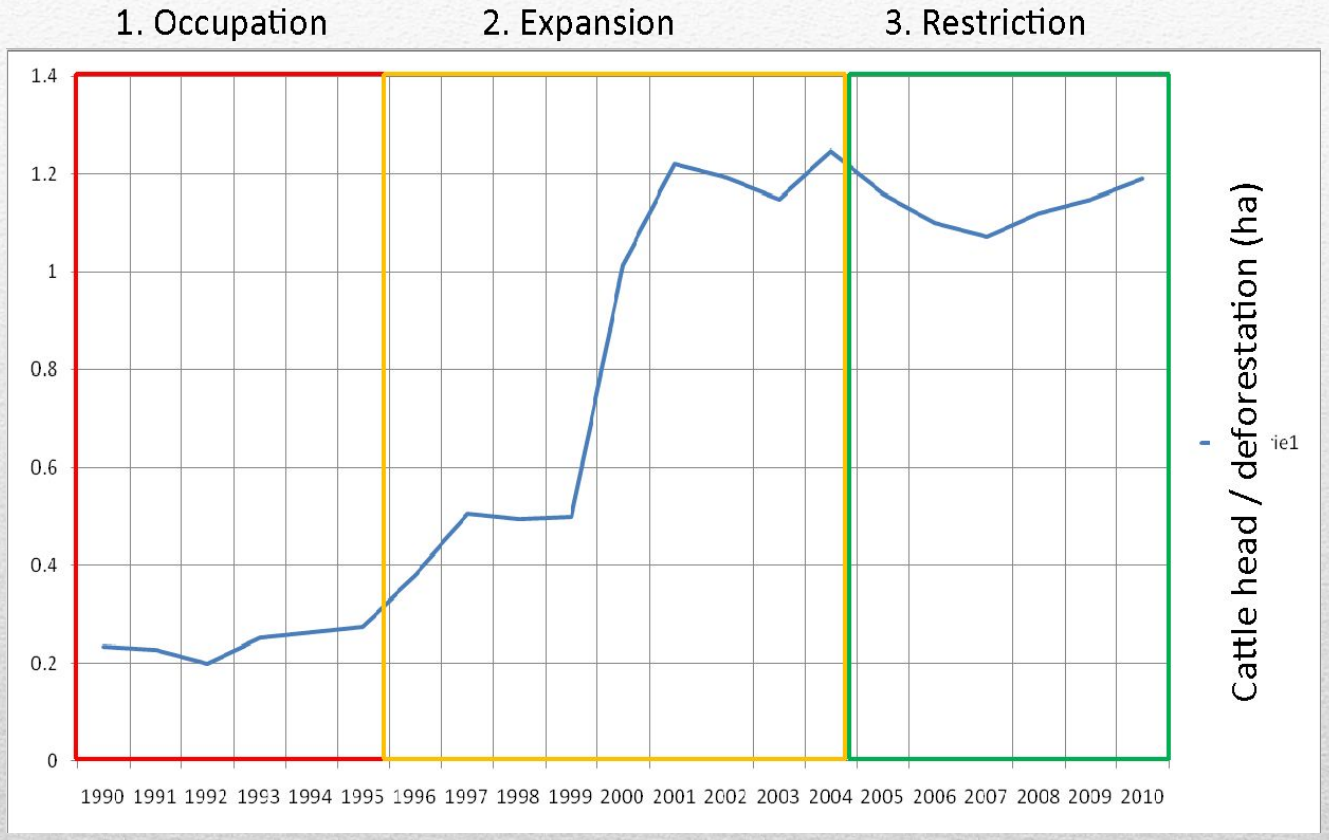
APA – Triunfo do Xingu – 2007



Changing of behaviour

Problem definition

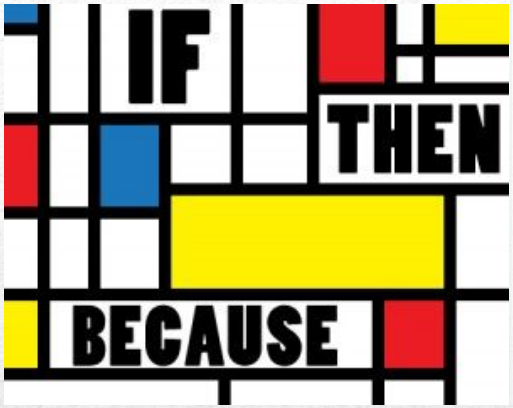
Evolution of Cattle head / deforestation in the São Félix do Xingu.



Changing of behaviour

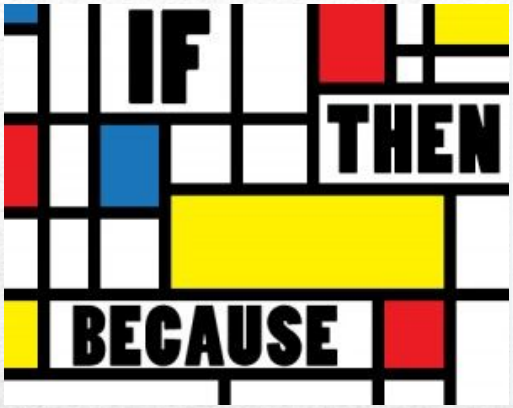
How to develop agent-based models that are expressive to account for the different strategies of land change agents in frontier areas?

Question



Our hypothesis is that the idea of strategies (supported by hybrid automata) provides a computational model that is capable of expressing complex collective behavior of land change agents.

Hypothesis



Our hypothesis is that the idea of strategies (supported by hybrid automata) provides a computational model that is capable of expressing complex collective behavior of land change agents.

Hybrid automata represent strategies that are loosely coupled to agents and may vary during the simulation in response to local and institutional variability's

Hypothesis

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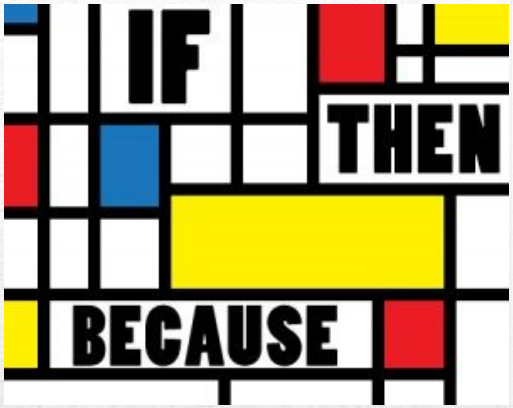


Our hypothesis is that the idea of strategies (supported by hybrid automata) provides a computational model that is capable of expressing complex collective behavior of land change agents.

Hybrid automata represent strategies that are loosely coupled to agents and may vary during the simulation in response to local and institutional variability's

To validate them, we put up a model for the area in Amazonia with the highest deforestation rate in the 1990s and 2000s. The model captures large-scale land change during the 2000s and is used to build scenarios until 2020.

Hypothesis

Grand Challenges in Computer Science Research in Brazil - 2006 – 2016 (SBC)

3. Computational modeling of complex systems: artificial, natural, socio-cultural, and human-nature interactions

> *The complexity of this kind of research grows with the increase in data volume and/or variables to be considered. Another complicating factor is the frequent need for combining several knowledge domains.*

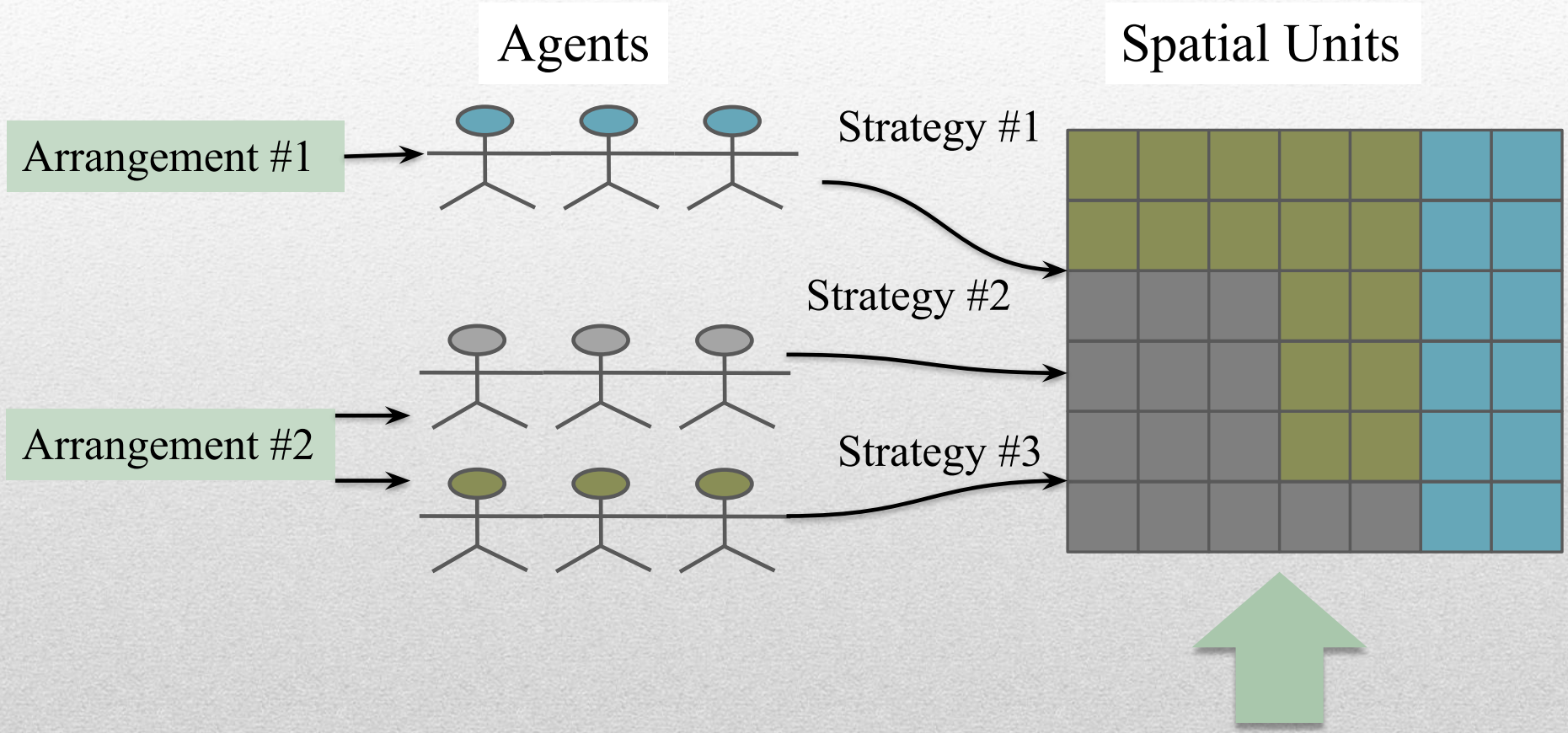
Relevance for Computer Science

1. Introduction
2. Agent-based models at regional scale
3. Implementation
4. Model description
5. Model simulation and results
6. Conclusion

Contents

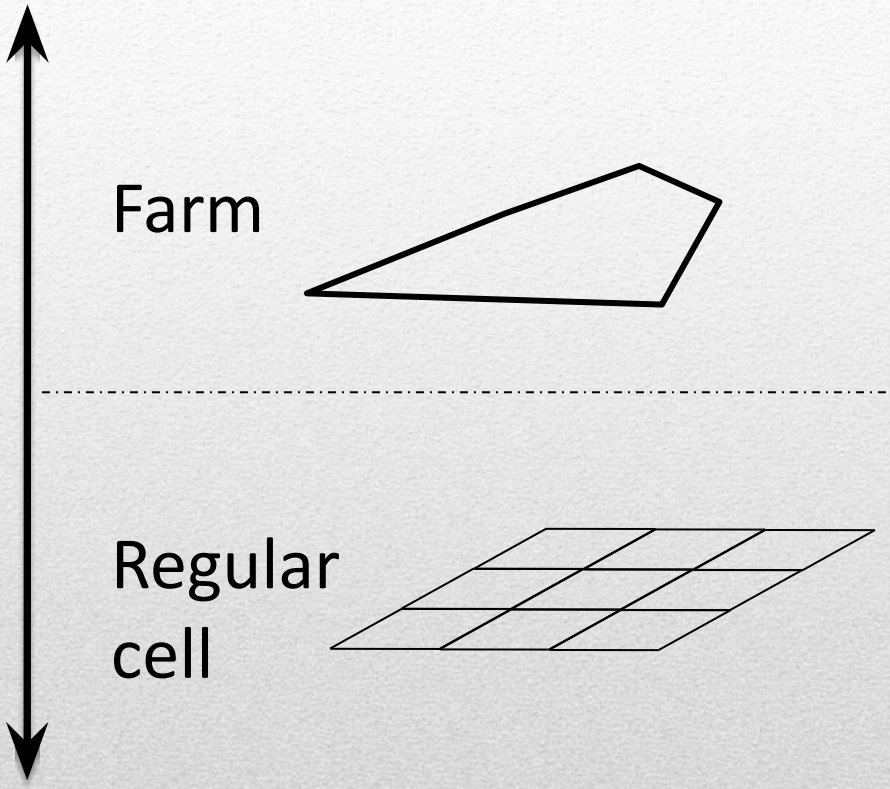
AGENT-BASED MODEL AT REGIONAL SCALE

Agent-based model at regional scale



Overview

Agent-based model at regional scale



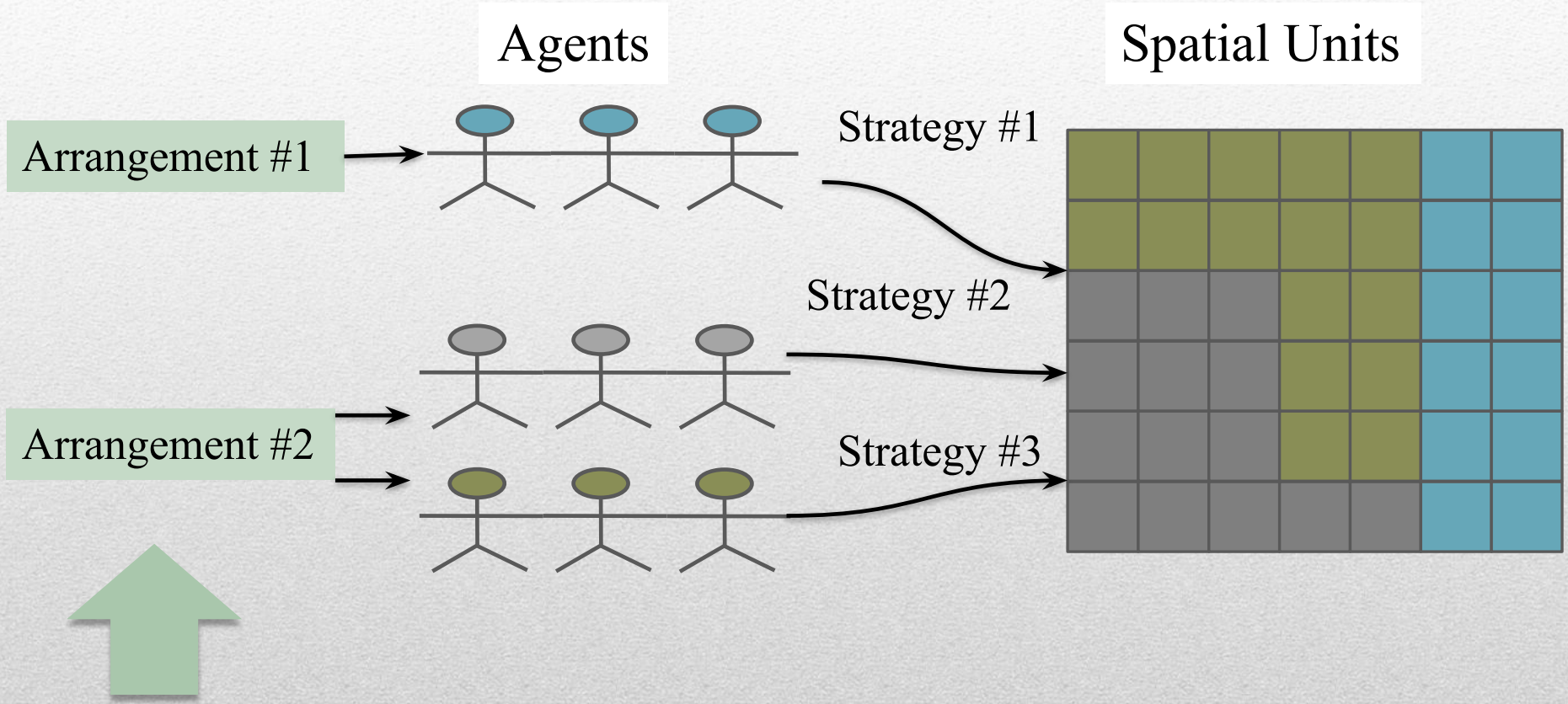
Regular cells describe the properties of space.

Each cell has information on its land cover and land use and its spatial properties, such as distance to roads.

Farms are irregular space partitions that belong to agents. A farm is linked to one of more cells.

Spatial Units

Agent-based model at regional scale



Overview

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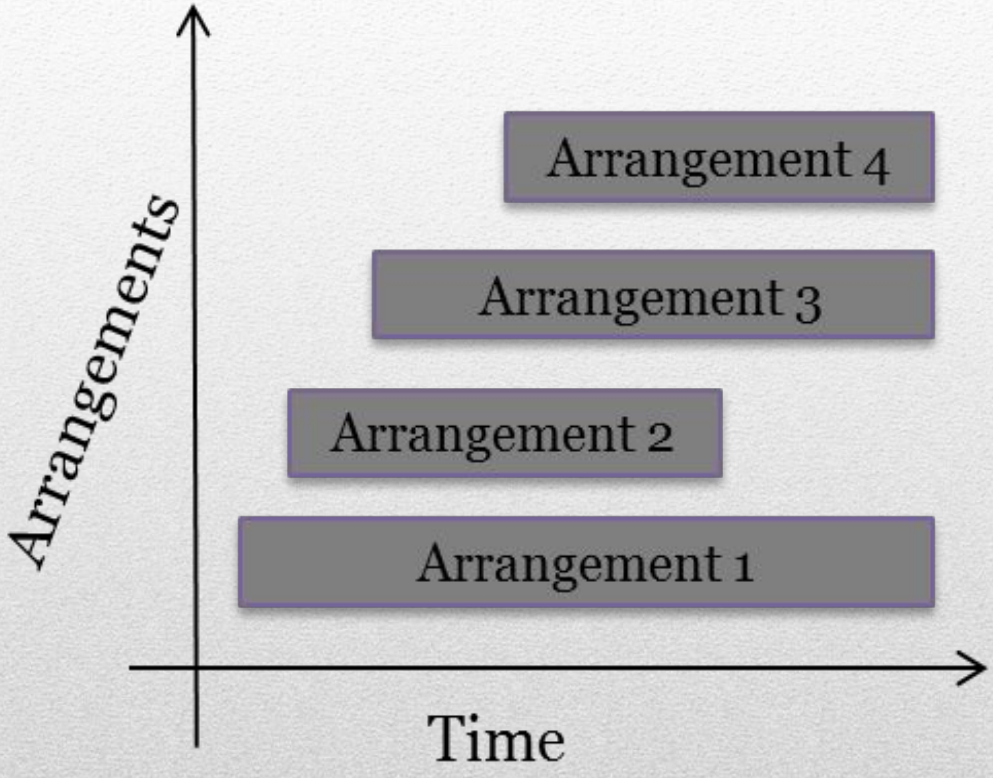


We refer to institutional arrangements as deals set up between interest groups, social movements and state agencies to respond to rules and norms that are relevant to them (DIETZ; OSTROM, 2003).

These pacts define how agents manage natural resources (SCOTT; MEYER, 1994).

The arrangements evolve on the time, where for each time period different arrangements are valid

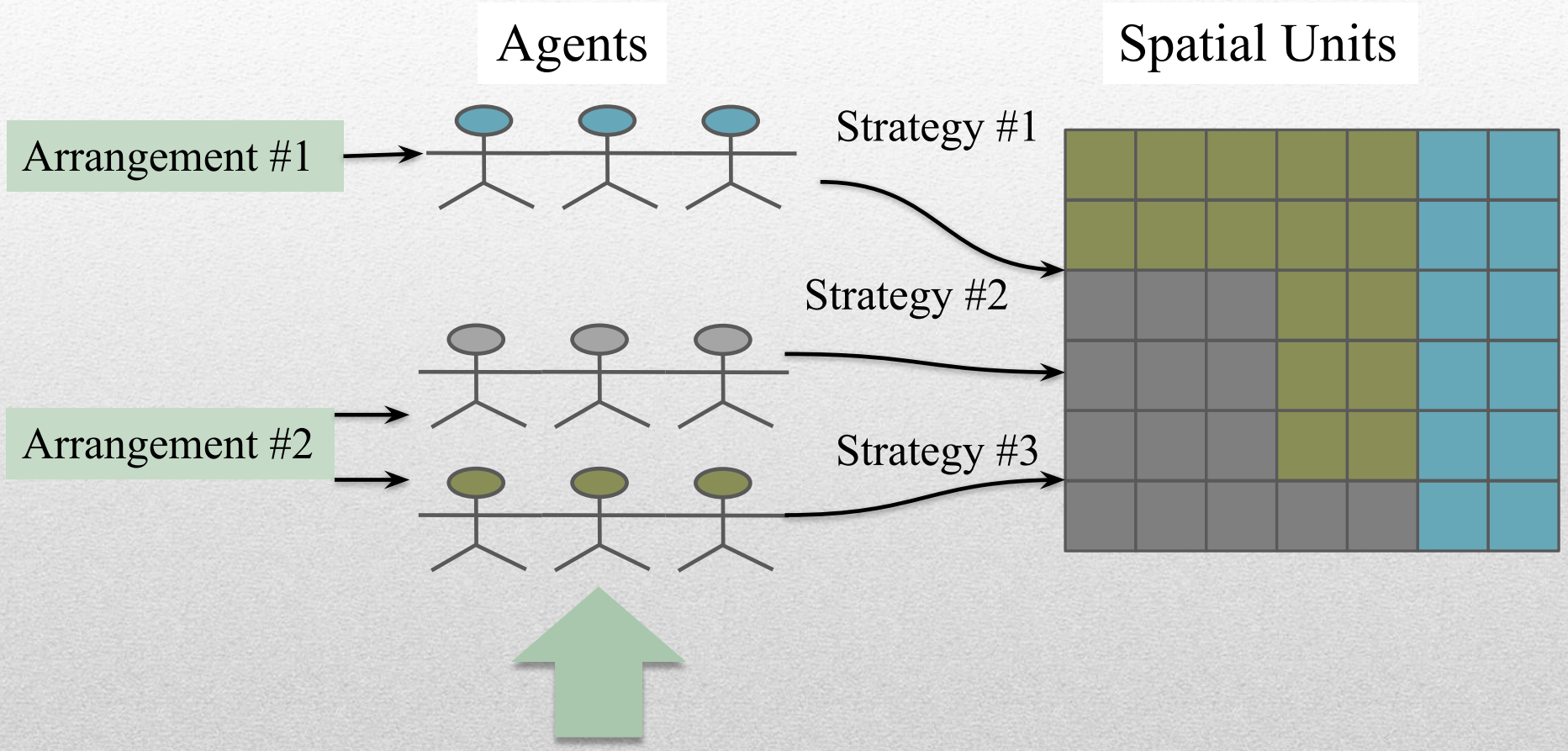
Institutional arrangements

The *Institutional Arrangements* are represented as tuples of four components:

1. *Name*, which distinguishes an arrangement from the other arrangements.
2. *Context*, inform a set of context variables to agents.
3. *Condition*, the target, which specifies the farmers that are influenced by the arrangement.
4. *Temporal*, the time period for which the arrangement applies.

Institutional arrangements

Agent-based model at regional scale

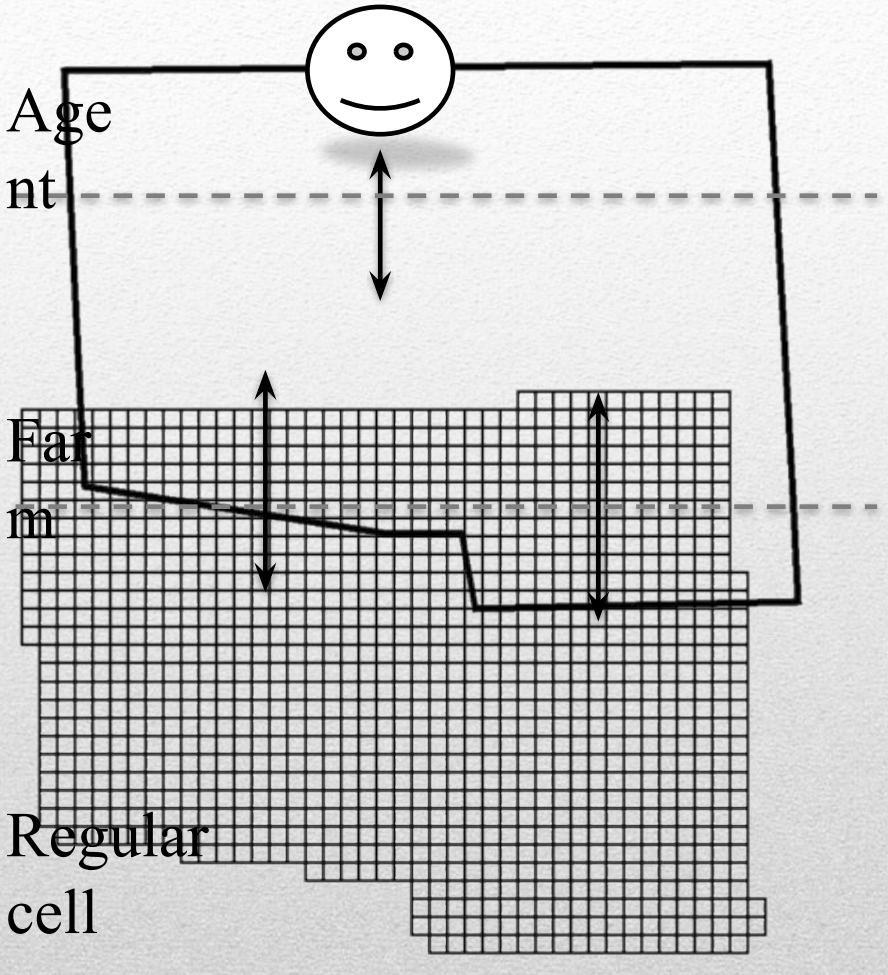


Overview

Agent-based model at regional scale

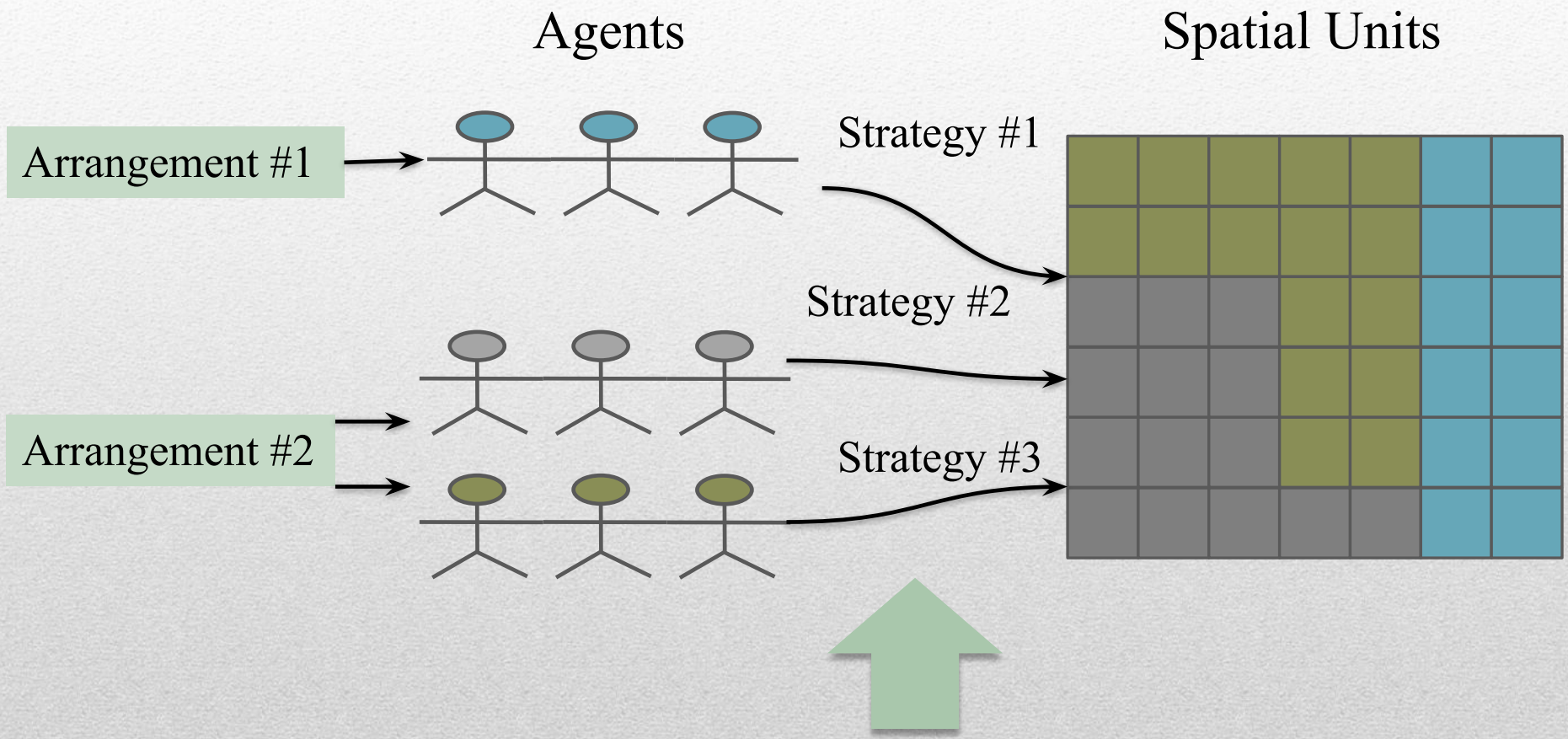
Agents are farmers that carry out land change.

Agents own farms and have attributes such as capital, technology level and expansion aims.



Agents

Agent-based model at regional scale



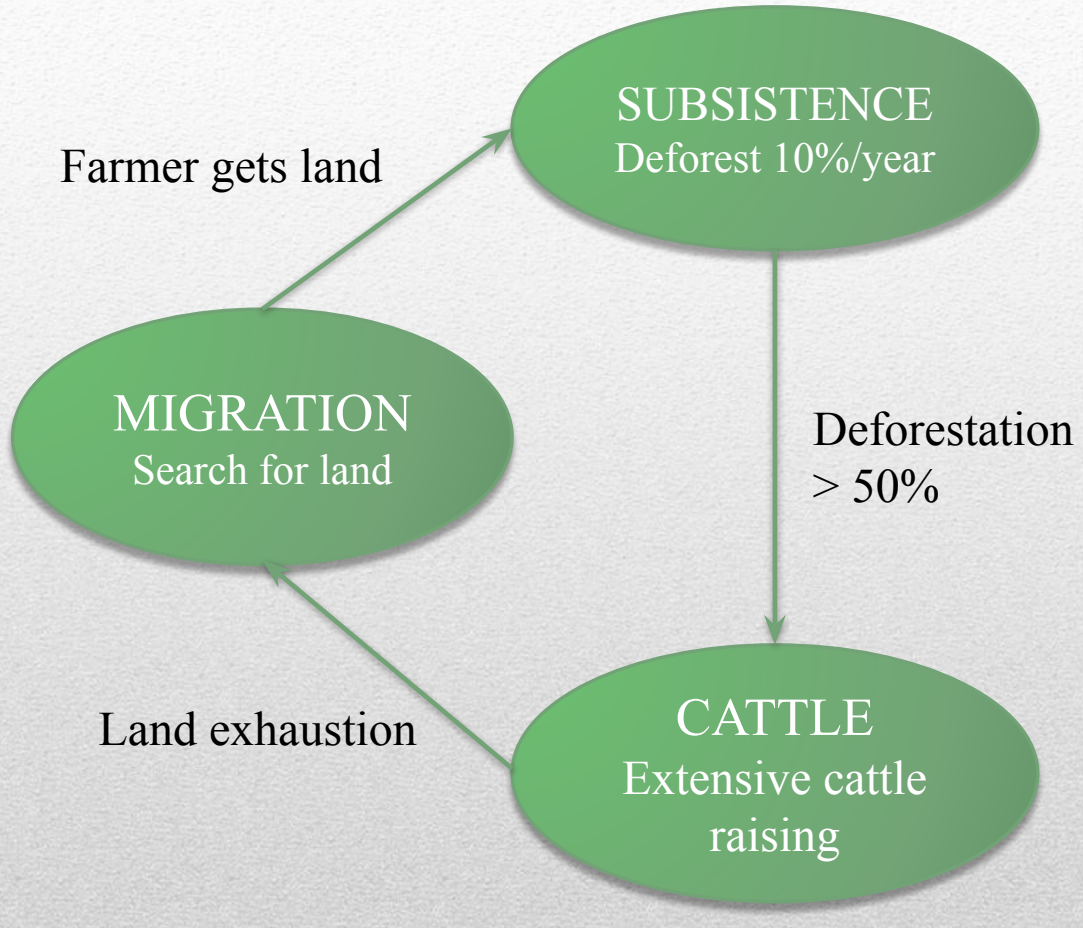
Overview

Agent-based model at regional scale

A set of consistent actions and agent decisions.

Each agent chooses one strategy at a time, which it can change later.

Examples of strategies include land speculation, intensive farming, and subsistence agriculture.

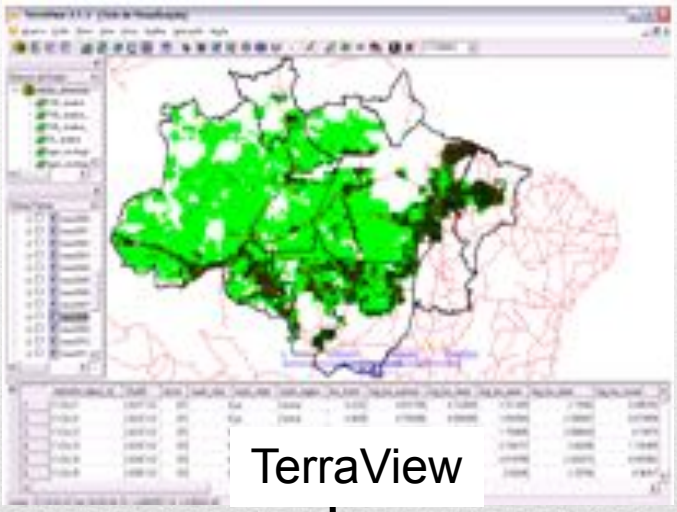


Strategies

IMPLEMENTATION

Implementation

TerraME (Carneiro, 2006)



TerraView

TerraME INTERPRETER

- model syntax semantic checking
- model execution

LUA interpreter

TerraME framework

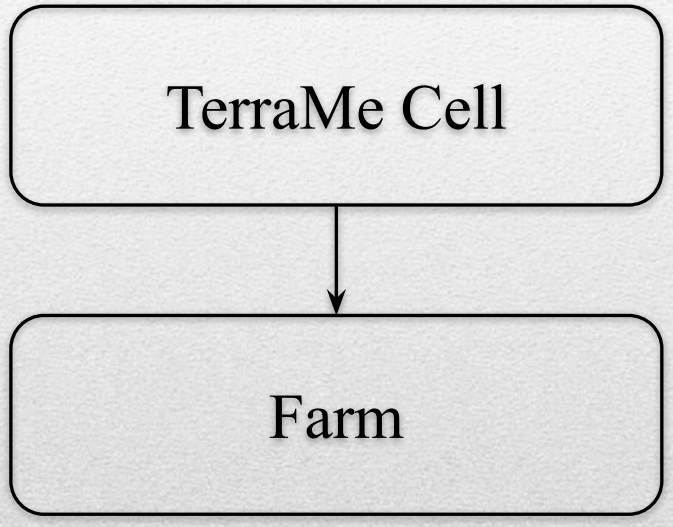
MODEL DATA

TerraLib database

Model source code

TerraME suports regular and irregular cells.

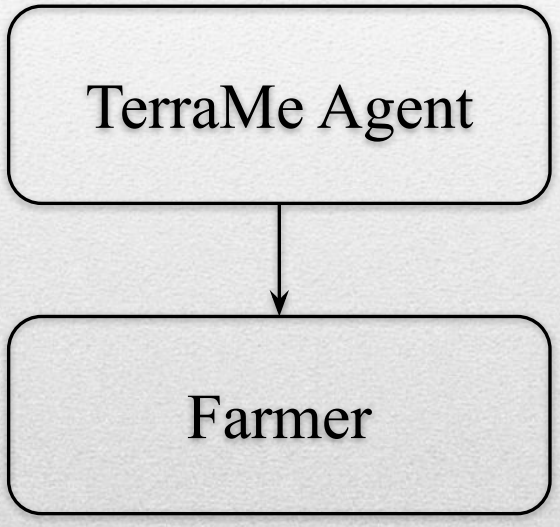
We support the *Farm data type*, which includes a set of operations for land market submodels, like farm creation, farm split and farm merge



Spatial Units

Terrame support agents and its operations.

We support the *Farmer data type* as an extension of the TerraME agent; this type includes common functions performed by and attributes of farmers.



Agents

Implementation

- To implement our proposal, we need software that expresses strategies. In computational terms, strategies make up a discrete state machine.
  - When an agent changes his strategy, he moves from one state to another. Inside a state, an agent carries out continuous actions.
- We propose the formalism of hybrid automata to capture the idea of strategies.

Strategies

Implementation

A hybrid automaton H has three parts (HENZINGER, 1996):

- A finite set of variables $X = \{x_1, x_2, \ldots x_n\}$ which is the automaton internal status.
- A finite directed graph $G = (V, E)$. The set of vertices V are *states*, and the set of edges E are *jumps*. Each edge *jump* connects a *source state* to a *target state*, following a condition. If this *jump condition* is true, the automaton discrete state will change from the *source state* to the *target state*.
- A set of *flow rules* assigned to each *state*. When a *flow rule* is evaluated it changes the automaton internal status, defined by the variables $\{x_1, x_2, \ldots x_n\}$.

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TerraME supports hybrid automaton.

Strategies

Example: A hybrid automaton model for poor migrant farmer

State	*Flow rule*	*Jump Condition*	*New state*
MIGRATION	Search for land	Farmer gets land	SUBSISTENCE
SUBSISTENCE	Farmer deforests 10% of land/year	Deforestation > 50%	EXTENSIVE CATTLE
EXTENSIVE CATTLE	Extensive cattle raising	Land exhaustion	MIGRATION

Strategies

We support the institutional arrangement as a new Lua data type. This code shows an example of an institutional arrangement.

```
arrang1 =   Arrangement (
{market = HIGH, enforcement = LOW },
 function (agent) return agent.capital> 1000  end,
 function (event) return event:getTime() > 2008 end
)
```

Institutional arrangements

Implementation

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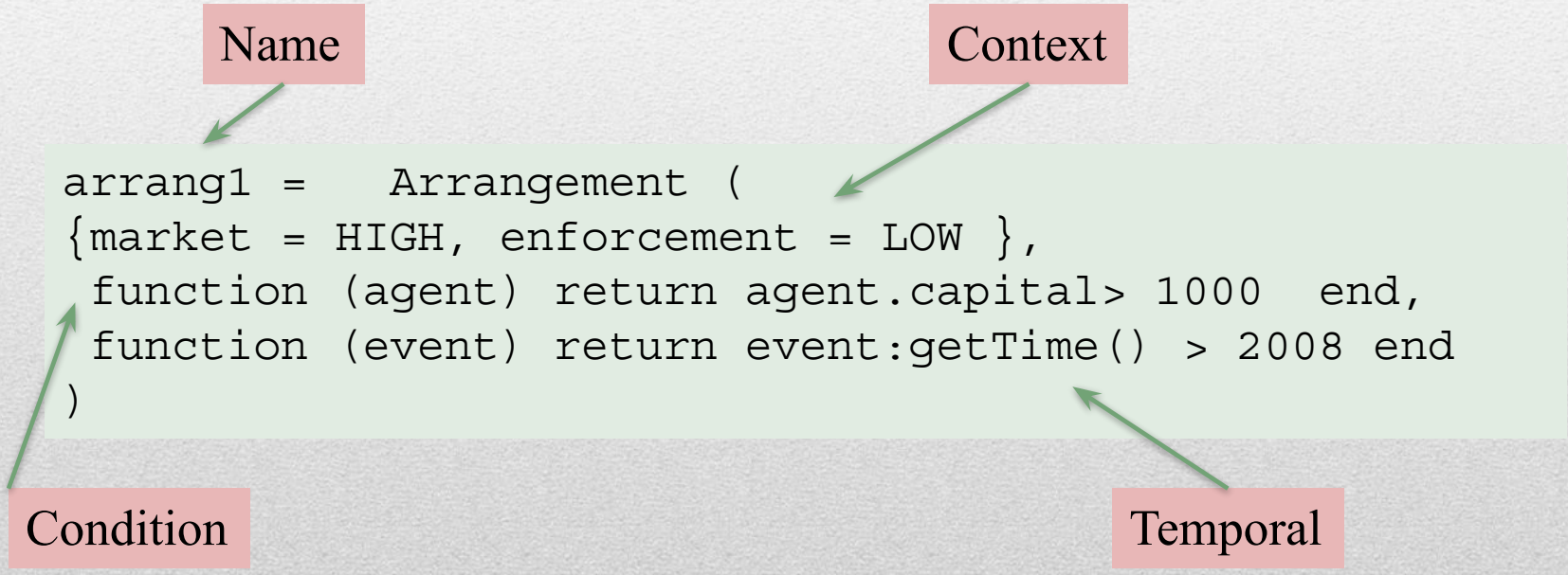

Institutional arrangements

MODEL DESCRIPTION

Model Description

The ODD (Overview, Design concepts, and Details) protocol is used to provide a standardised description of our model (GRIMM et al., 2006, 2010).

1. Purpose
2. Entities, Attributes and Scales
3. Process overview and scheduling
4. Initialisation
5. Input data
6. Submodels

Overview, Design concepts, and Details

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Overview, Design concepts, and Details

The model attempts to describe landscape dynamics and replicate the deforestation fluctuations in the time period simulated by considering changes in the **institutional context** and their **effects** on **households' strategies**.

Purpose

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Overview, Design concepts, and Details

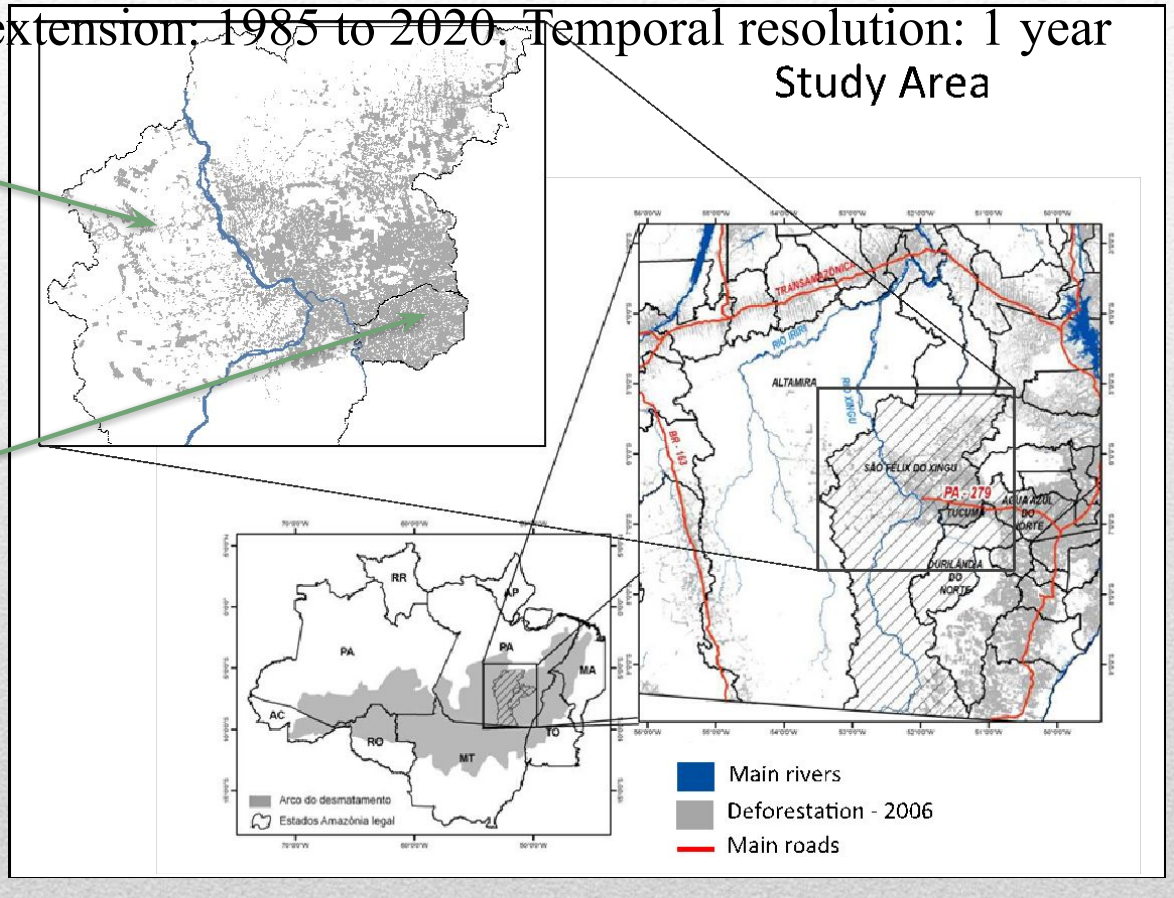
Entities, attributes and scales

The model simulates a rural region that covers 60,000 Km^2 in the south-east of Pará, Brazil. Spatial resolution 225x225 ha, 25x25 ha and 1x1 ha.

Temporal extension: 1985 to 2020. Temporal resolution: 1 year

São Félix do Xingu

Tucumã



Scales

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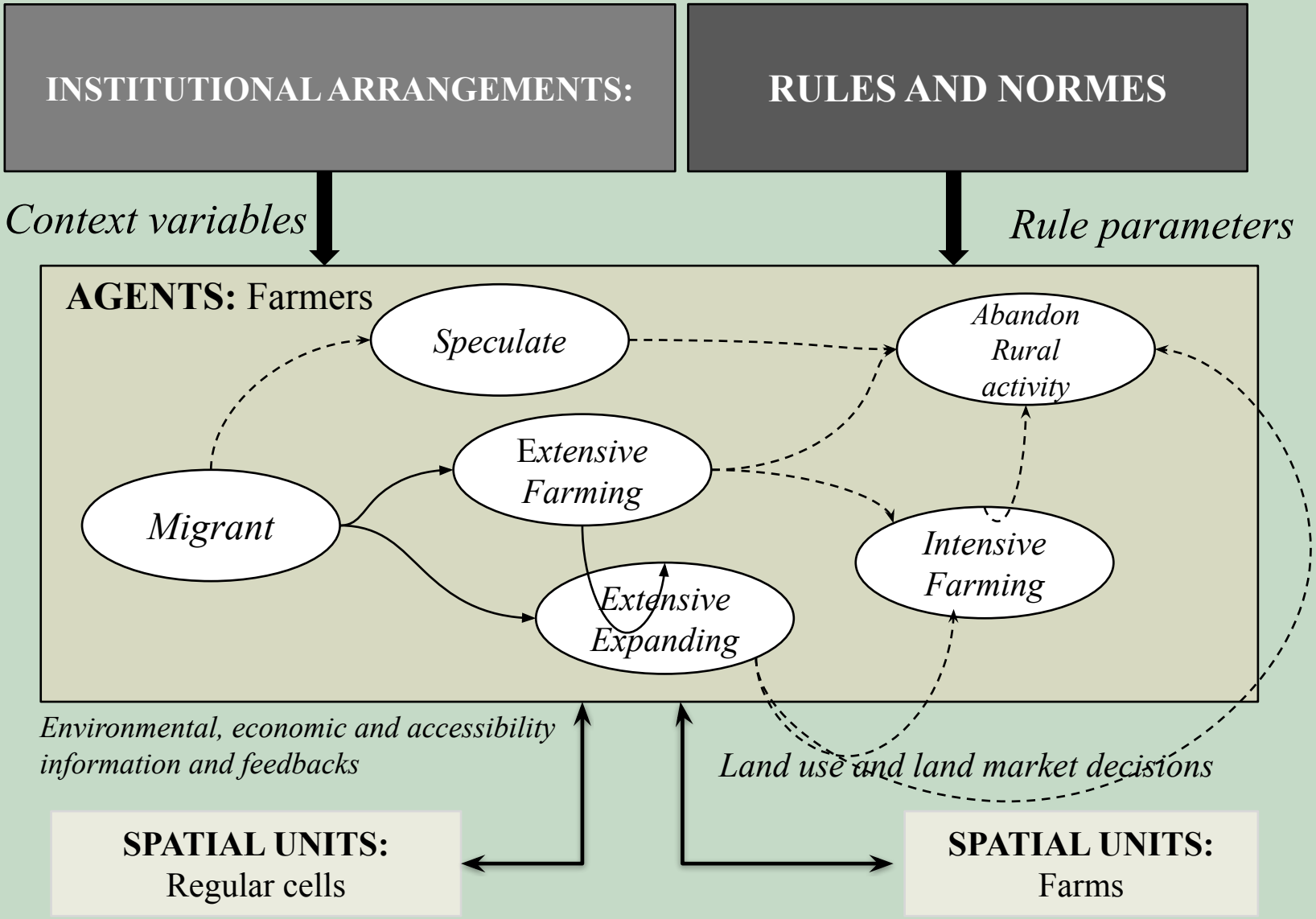
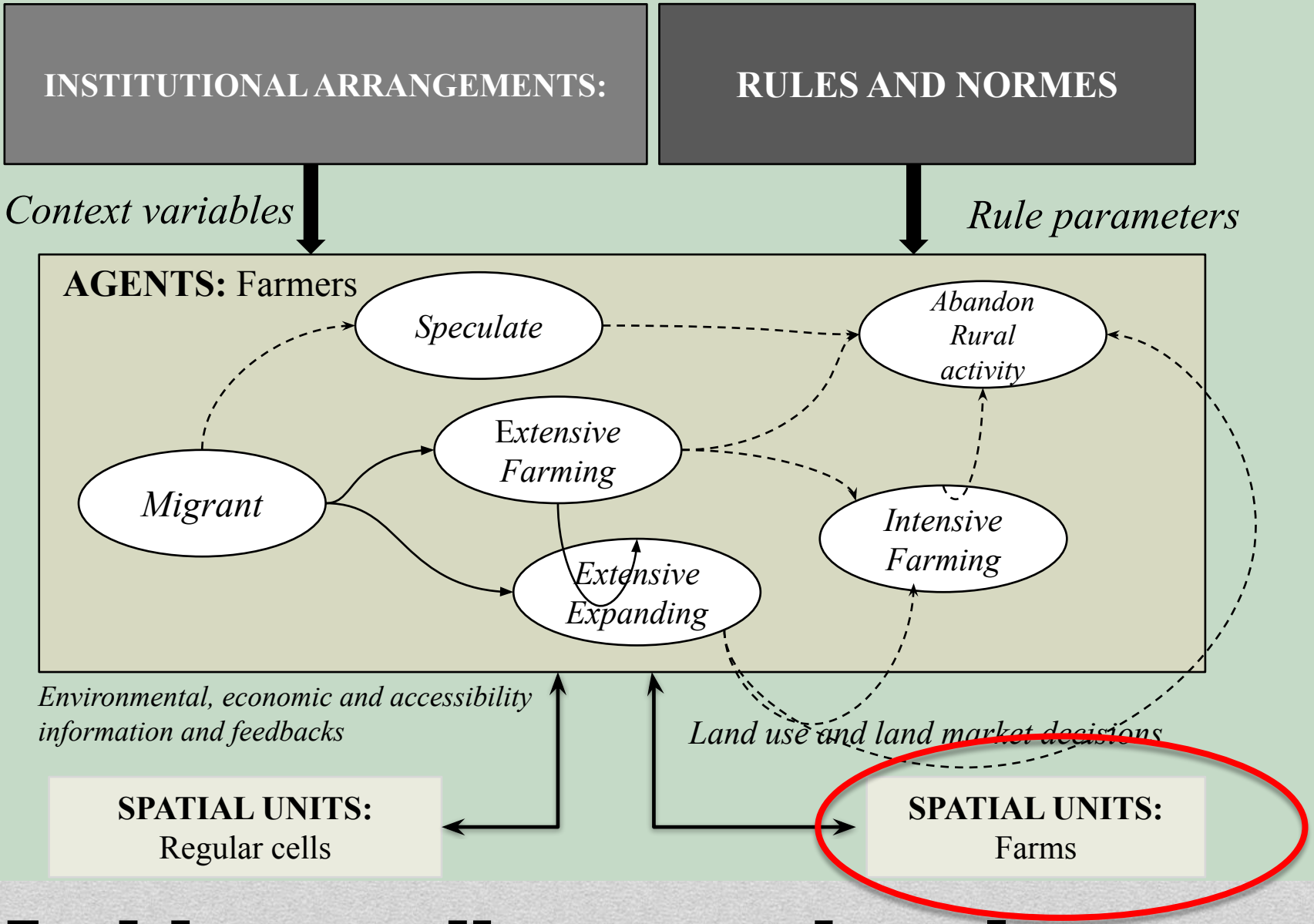
6. Submodels

Overview, Design concepts, and Details



Entities, attributes and scales



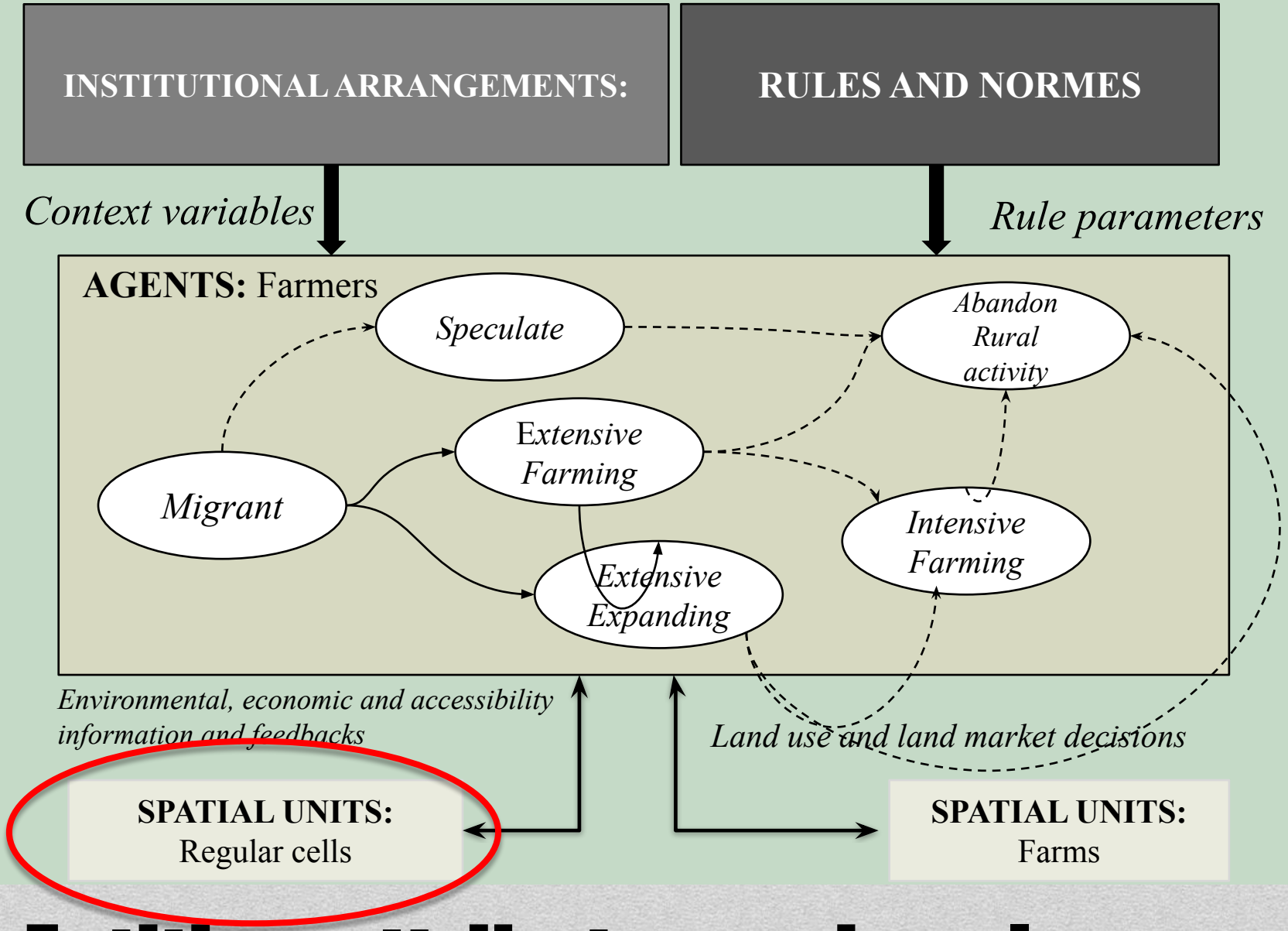
Entities, attributes and scales

Entities, attributes and scales

A *farm* is a *spatial unit* entity, and corresponds to the basic decision unit referring to *Land Market Decisions*. The *farm* attributes include

- area,
- price,
- quantity of animals,
- pasture area,
- area of degraded pasture and
- area of remaining forest.

Spatial Units: Farm



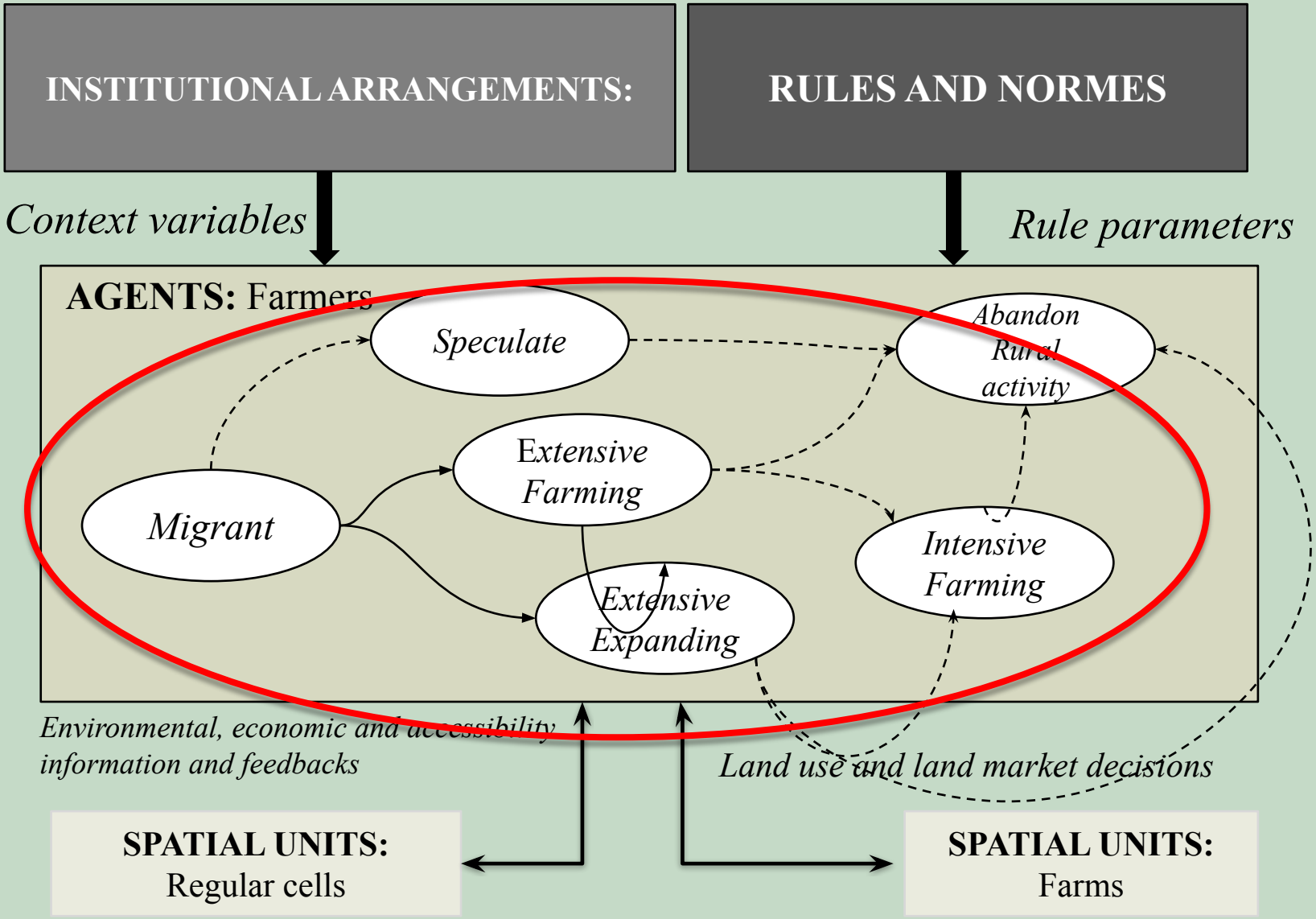
Entities, attributes and scales

Entities, attributes and scales

A *RegularCell* represents the geographic space attributes, including biophysical (e.g. slope, soil quality) and accessibility features (e.g. distance to roads and distance to river).

- Area of each cell.
- Land cover (Forest, Pasture, Secondary Forest, River, Other
- Number of animals per cell
- Minimum Euclidean distance (normalized) to roads, rivers and urban centers.
- Slope

Spatial Units: Regular cells



Entities, attributes and scales

Entities, attributes and scales

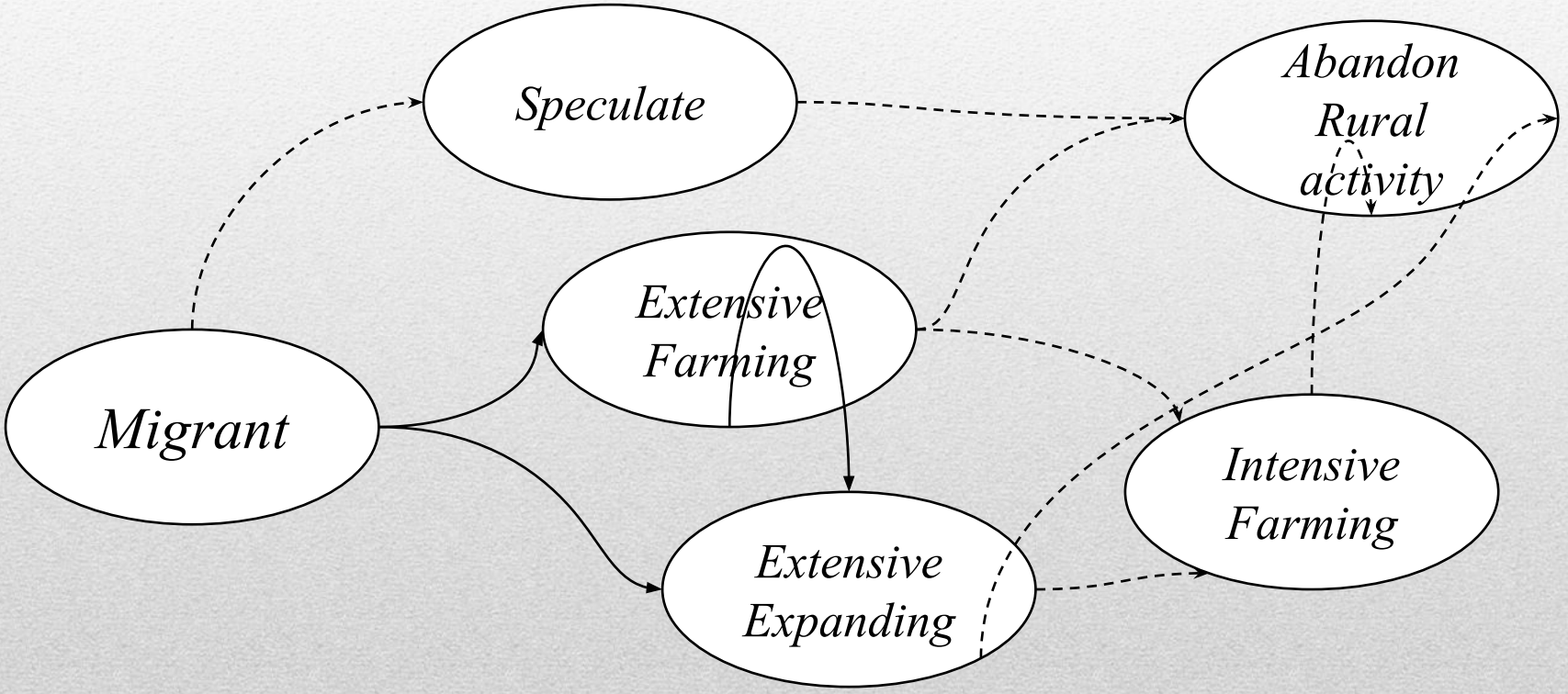
Based on fieldwork and literature review, we defined a agent to be a rural entrepreneur with the following dynamic attributes:

- Inclination to obey the law.
- Number of farms.
- Average size of the farm he wants to buy.
- Technological capability (Low, Medium, High).
- Investment capital.

Agents

Entities, attributes and scales

A *farmer* performs land use and land market decisions on these spatial units. These decisions are guided by different *strategies* that an agent can take over time. A *farmer* chooses between five *strategies*:



Agents and Strategies

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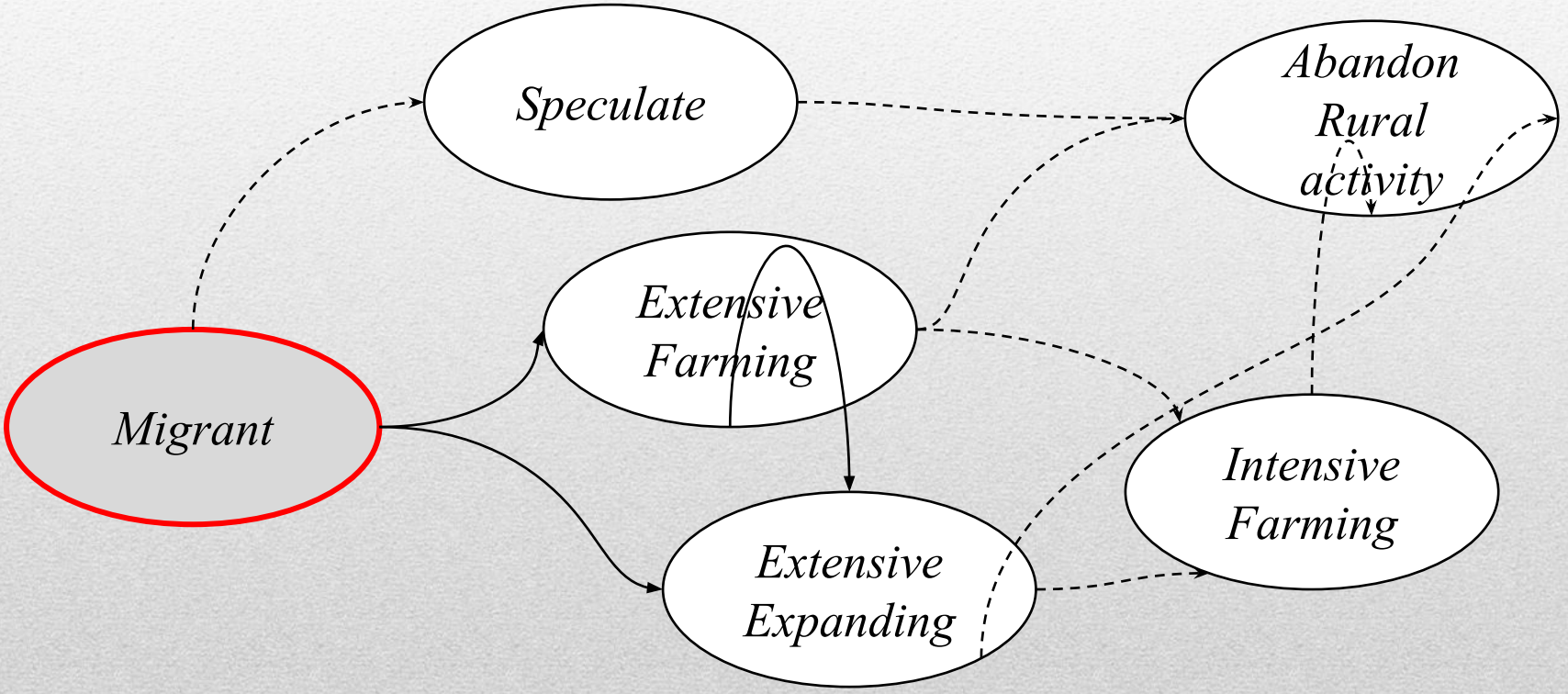

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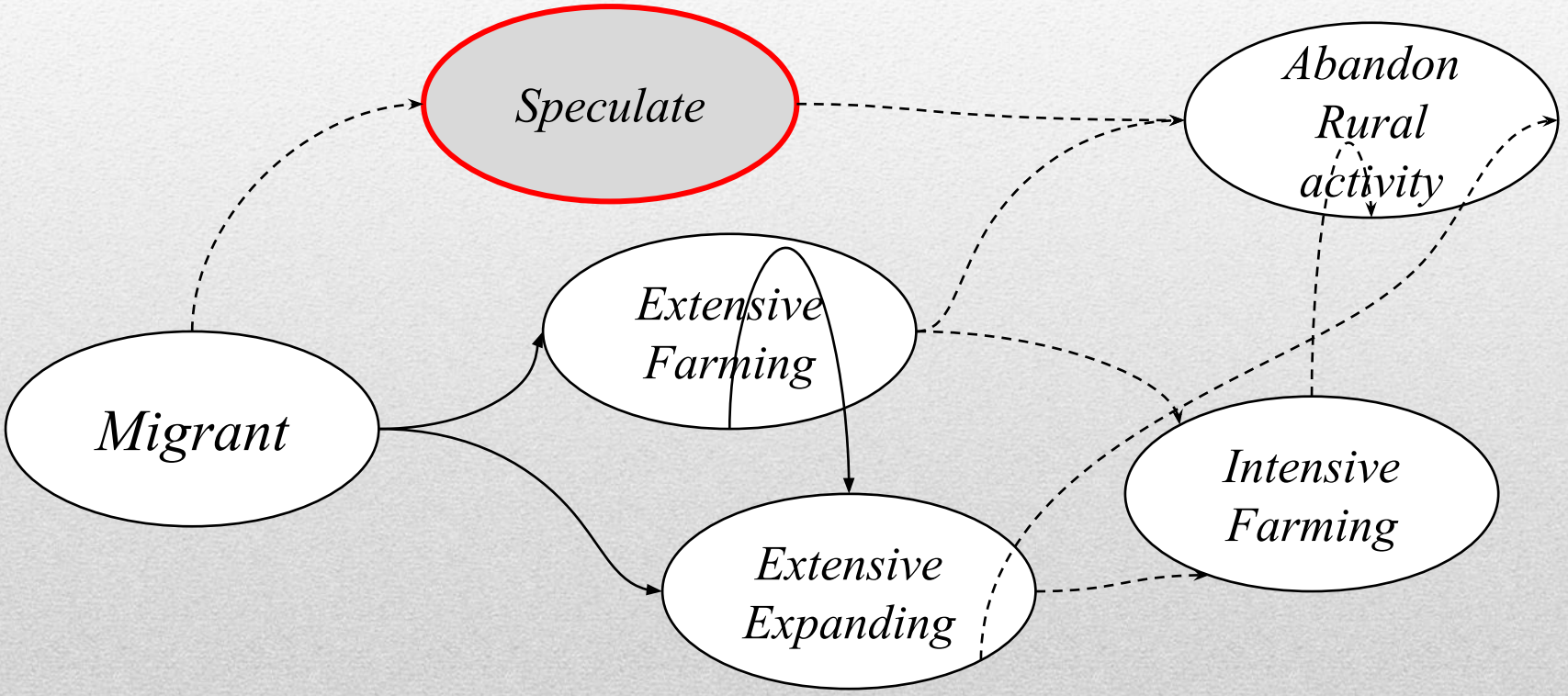

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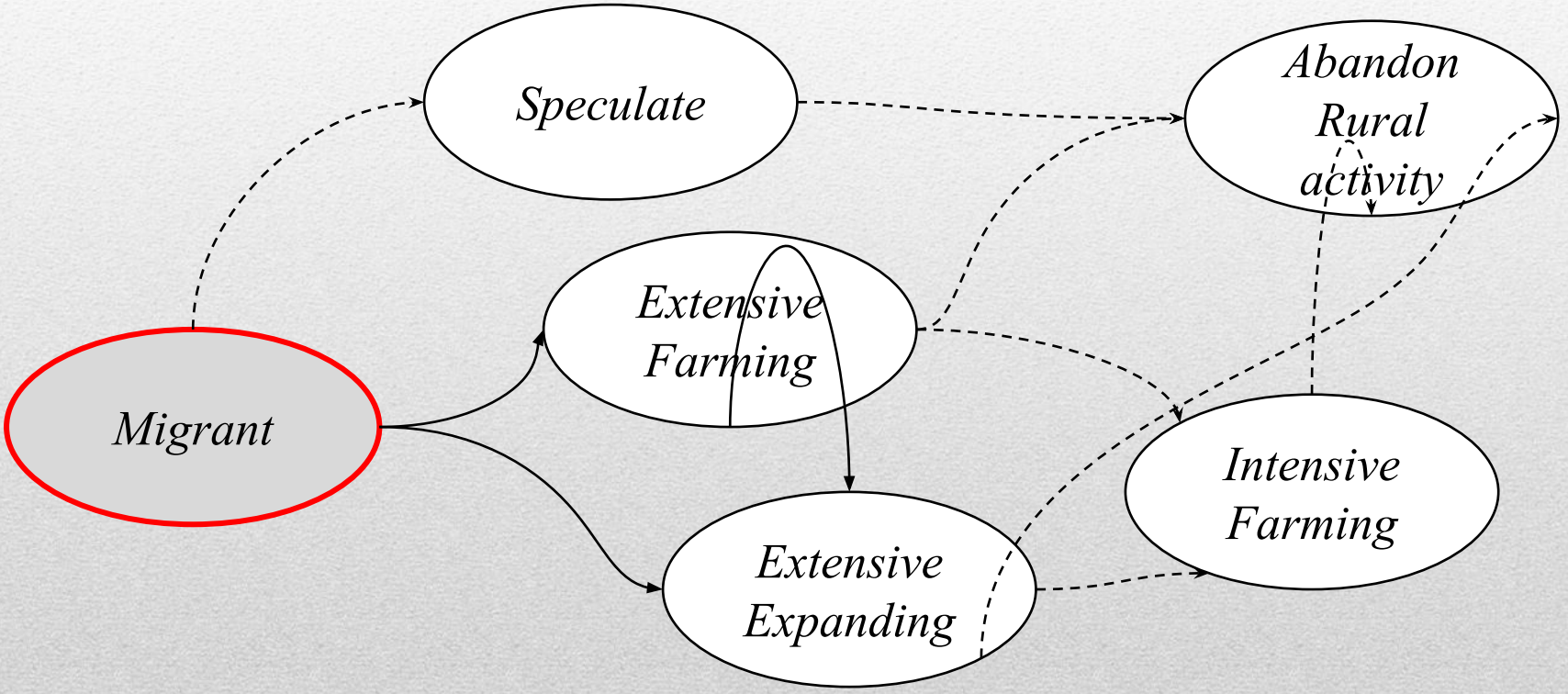

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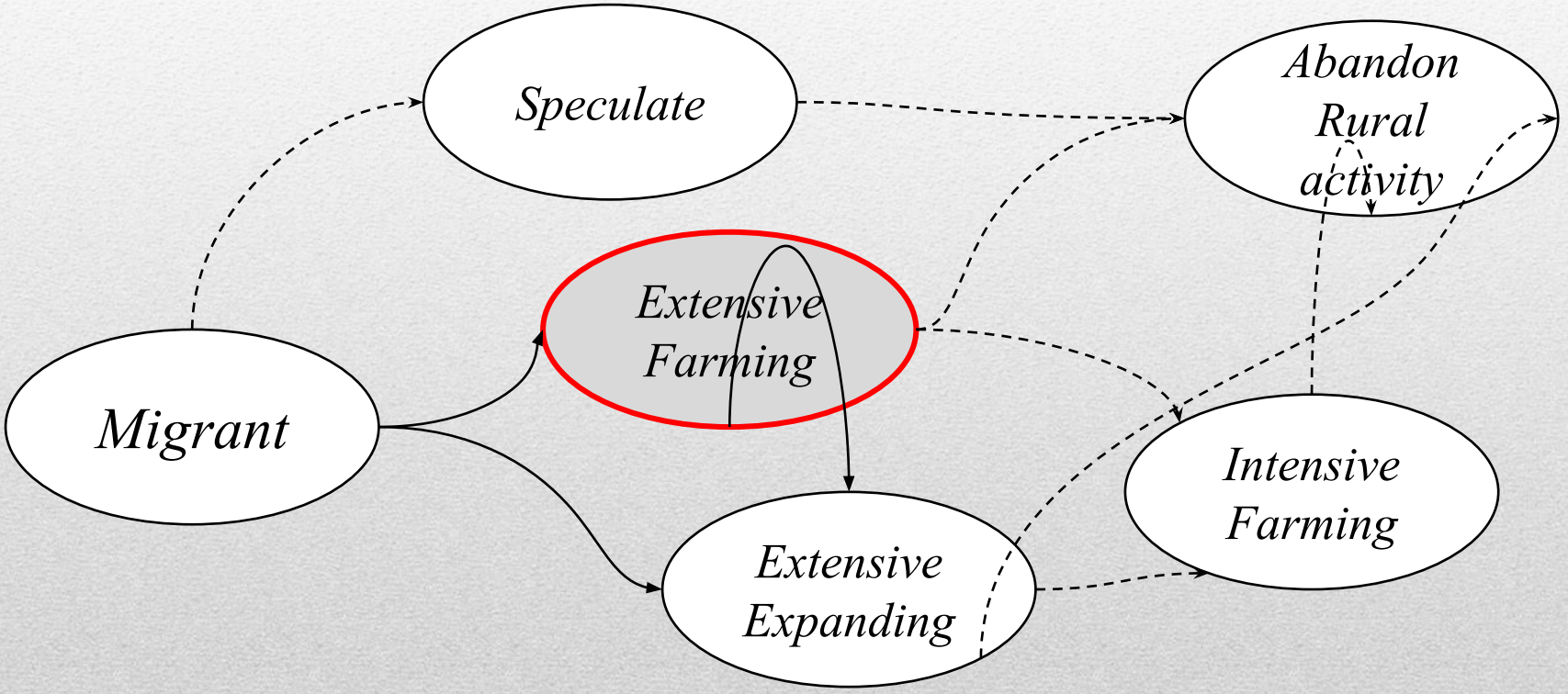

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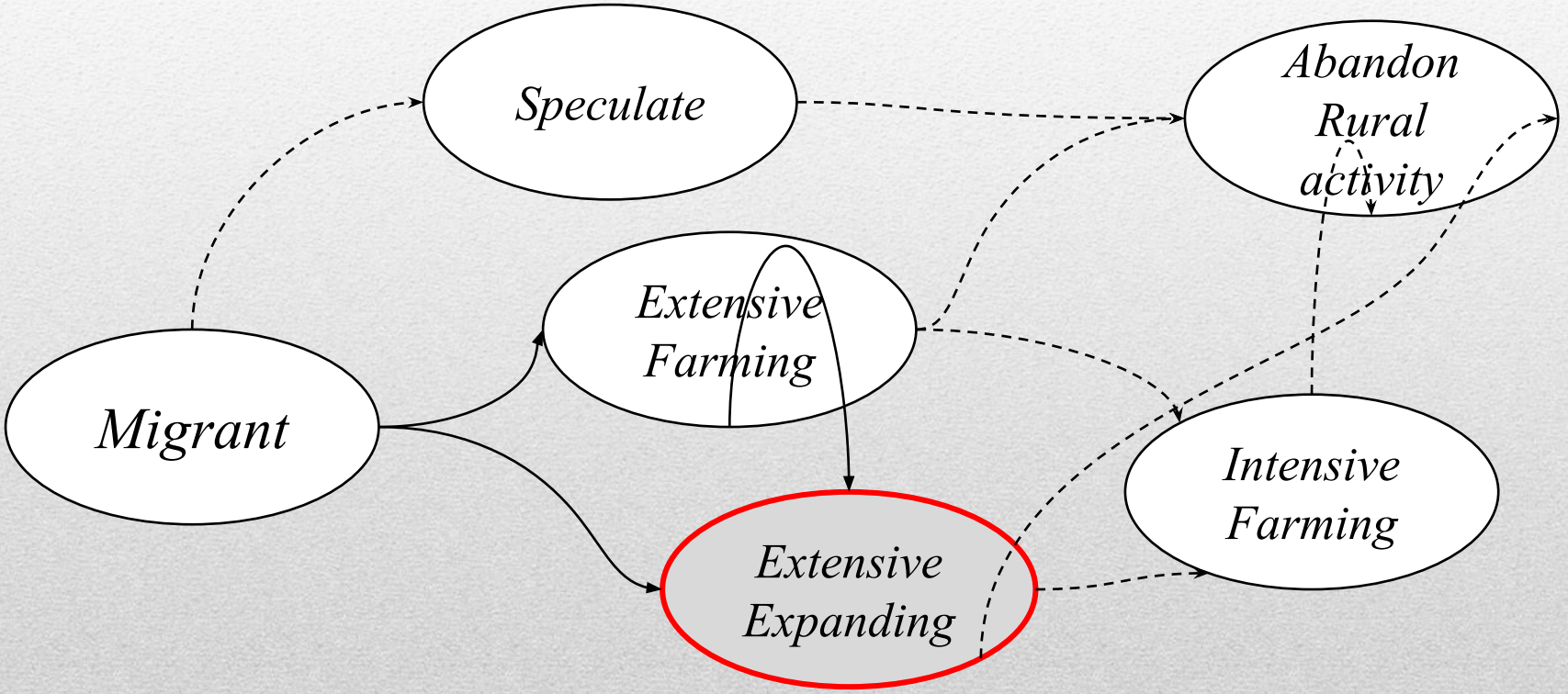

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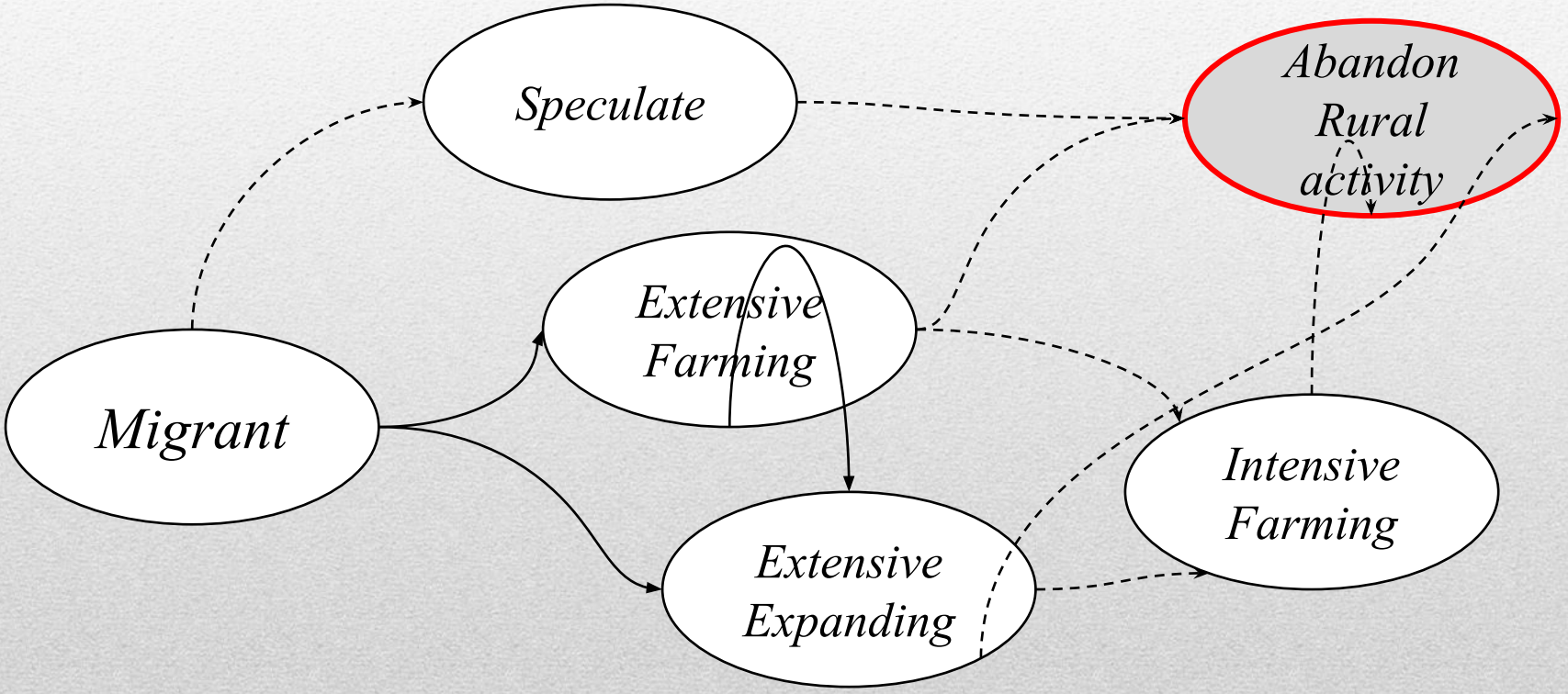

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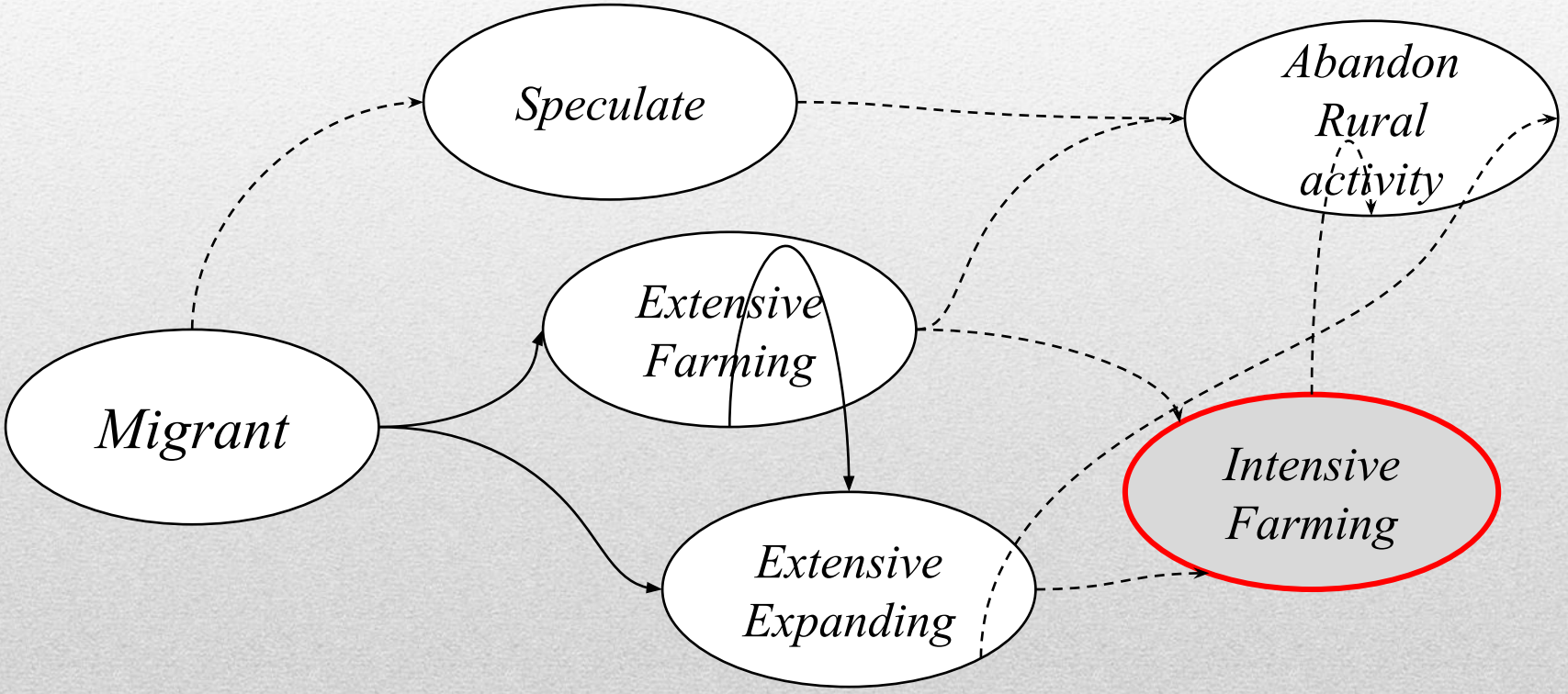
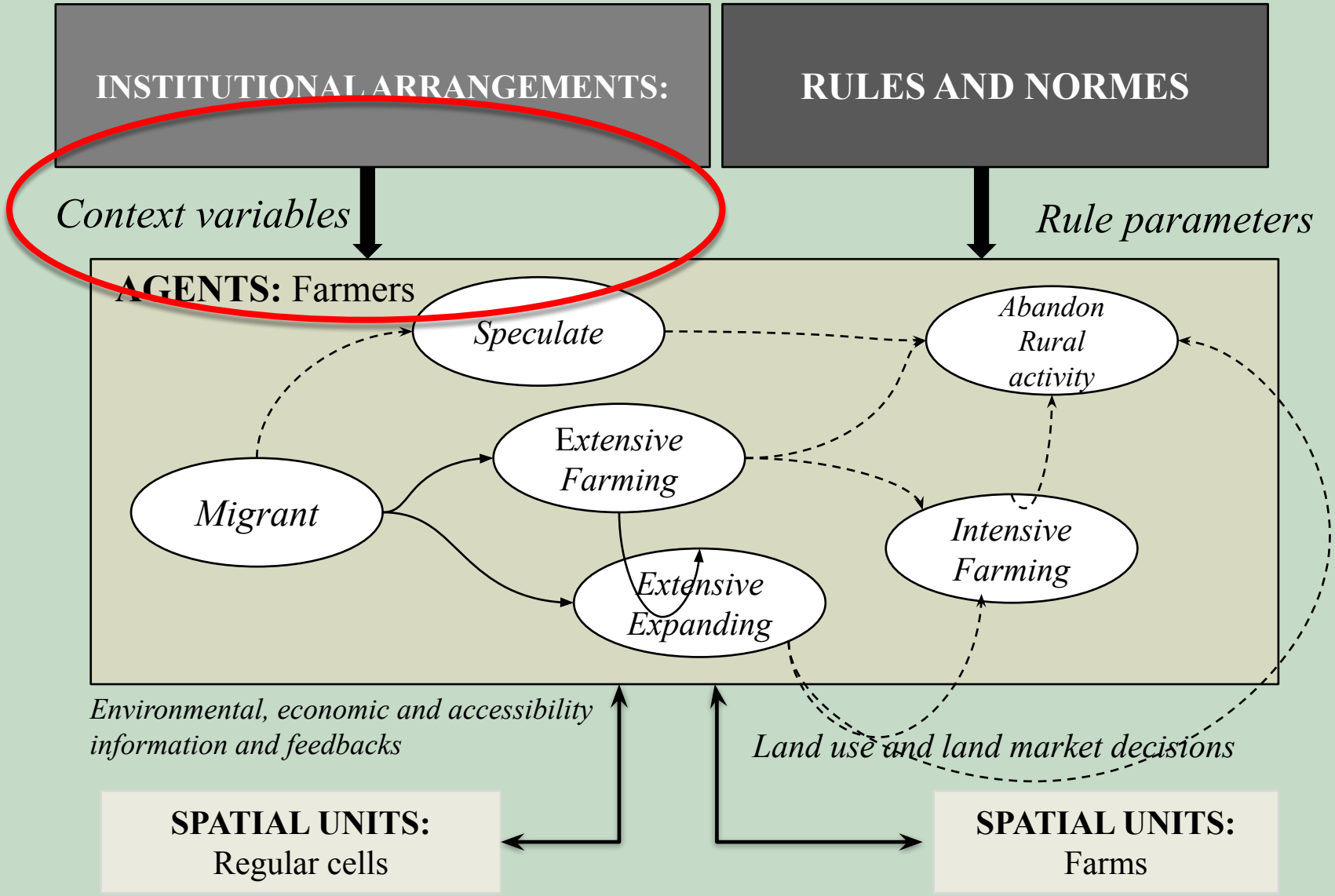


Agents and Strategies



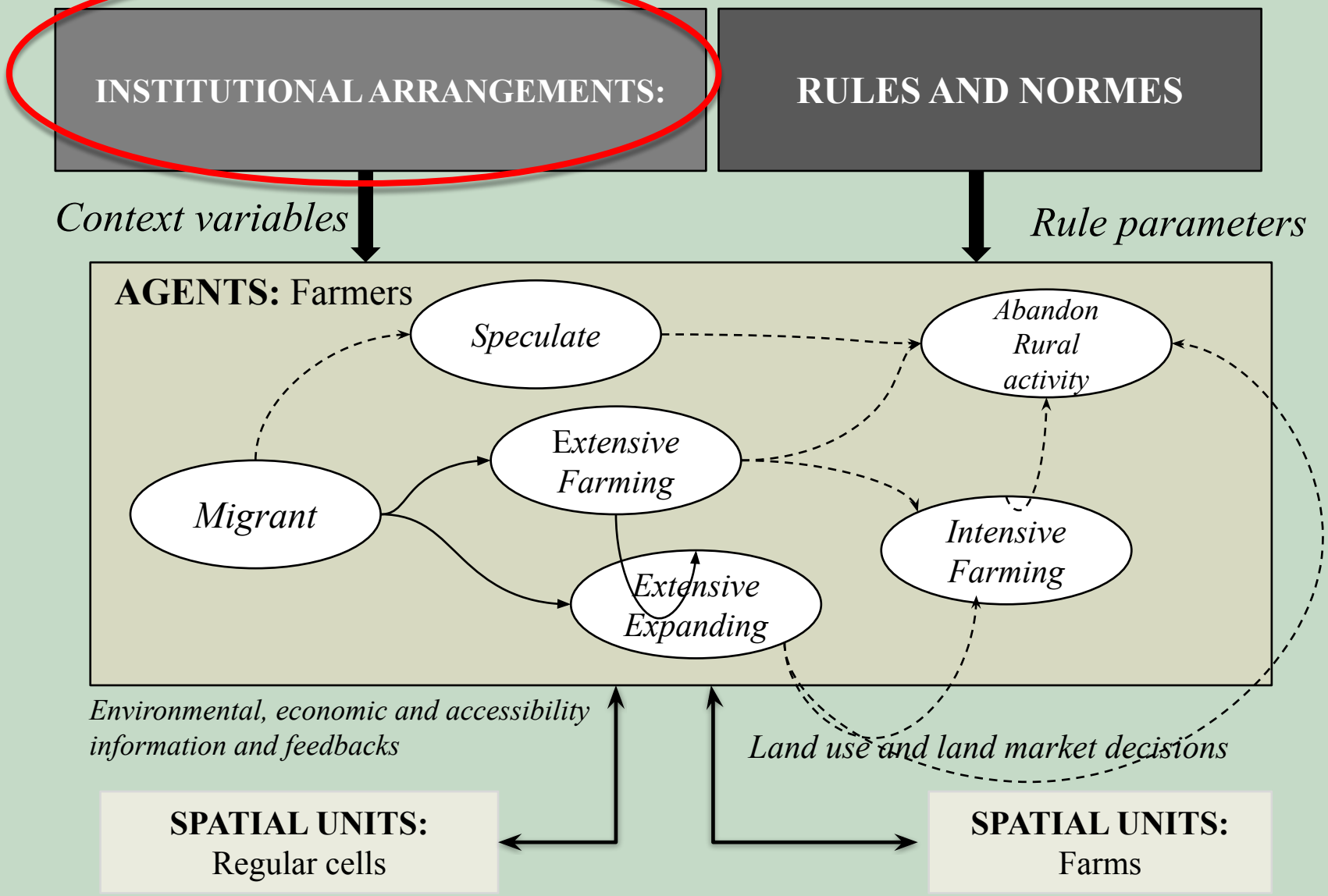
Entities, attributes and scales

Entities, attributes and scales

The agent uses six guidelines to decide on his strategy, which are:

Context variable	Description
Forest code enforcement	how is the Forest Code being followed?
Law enforcement	is there control over poaching of public lands?
Market for cattle	how strong is the beef market chain?
Credit for small farmers	how easy and cheap is the credit for small farmers?
Credit for large farmers	how easy and cheap is the credit for large farmers?
Credit for reforestation	how easy and cheap is the credit for reforestation?

Context variables



Entities, attributes and scales

Entities, attributes and scales

We defined six *institutional arrangements* in our model:

1. *Government-induced occupation*: prevalent from 1970s to mid 1990s, with the government encouraging people to occupy Amazonia.
2. *Beef market chain organization*: From the mid 1990s until today, following initial occupation with easy access to land, the beef market chain grew.
3. *Deforestation control:* From 2005 onwards, law enforcement increased and the government created new protected areas

Institutional Arrangements

Entities, attributes and scales

We defined six *institutional arrangements* in our model:

4. *Green market*: In the late 2000s, given pressure from consumers, NGOs and public attorneys, part of the private sector changed. Some farmers and part of the industry agreed to comply with sustainable practices, in exchange for market and credit access.
5. *Sustainable Development*: a possible future arrangement to bring about equilibrium between social, environmental and economic goals. This choice combines strong law enforcement with green market practices.
6. *Economic development*: a possible future arrangement based on a return to 1970s model, where economic growth prevails over environmental or social concerns.

Institutional Arrangements

Entities, attributes and scales

INSTITUTIONAL ARRANGEMENTS	FOREST CODE ENFORCE	LAND POACHING ENFORCE	CATTLE MARKET	CREDIT LARGE FARMS	CREDIT LARGE FARMS	CREDIT REFOREST
Government-induced occupation				2		
Beef market chain organization			2	2	1	
Deforestation control	1	2				
Green market	3	3	3	3	2	
Sustainable development	3	3	1	1	3	3
Economic development			2	2	1	

Relevance: 3 = strong, 2 = medium, 1 = low, no value = no relevance

Arrangements and Variables

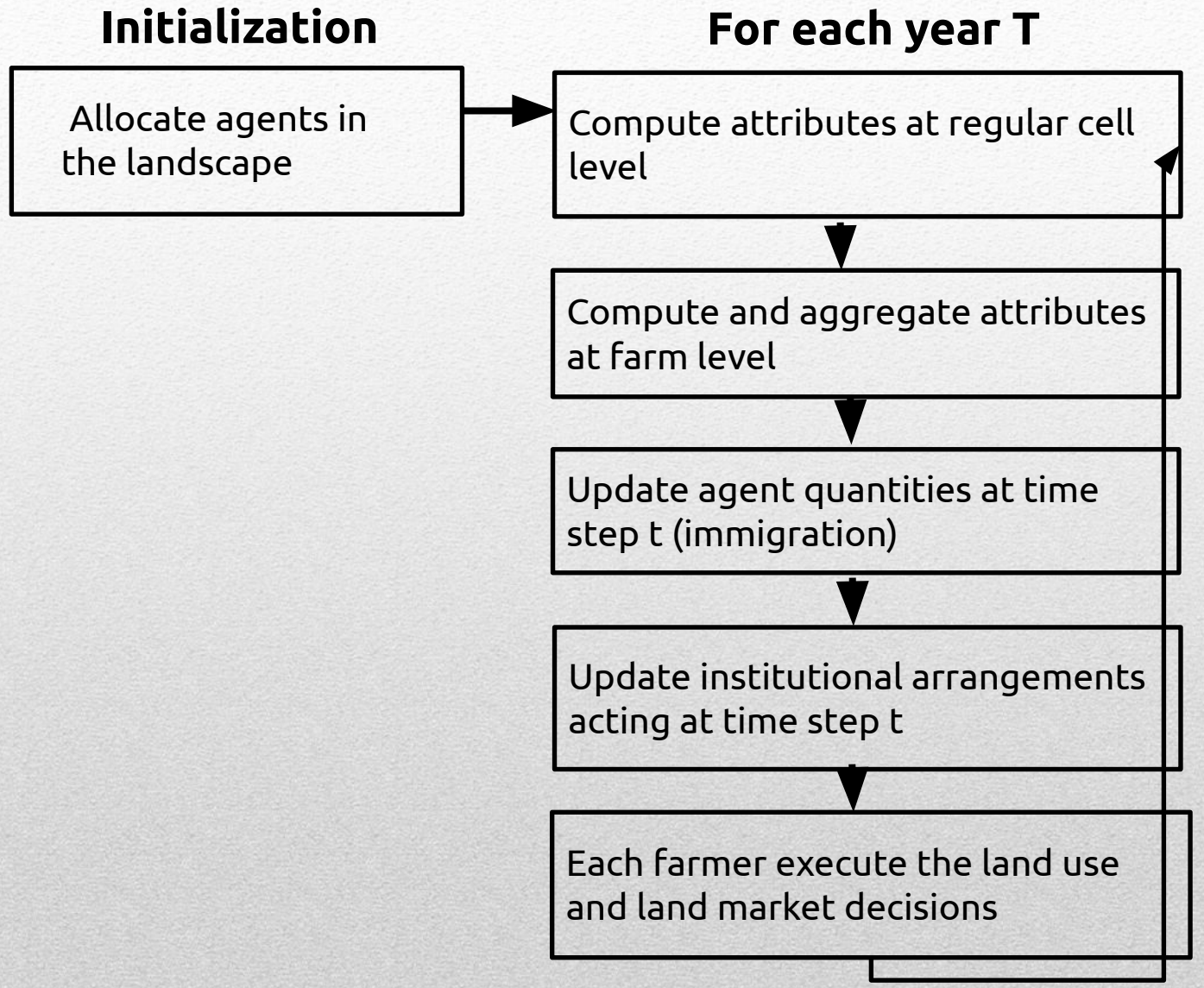
Model Description

The ODD (Overview, Design concepts, and Details) protocol is used to provide a standardised description of our model (GRIMM et al., 2006, 2010).

1. Purpose
2. Entities, Attributes and Scales
3. Process overview and scheduling
4. Initialisation
5. Input data
6. Submodels

Overview, Design concepts, and Details

Process Oververview and Schedulling



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1. Purpose
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Overview, Design concepts, and Details

- In theoretical models, the initialization may be simple random placement (EPSTEIN; AXTELL, 1996).

- Empirical models require much data, such as census and cadastral data.

Initialization

The initialization should answer the following questions at least:

- *How many farmers are in the study area?*
- *What is the size of each farm?*
- *Where are these farms located?*

Initialization

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- ***How many farmers are in the study area?***
- ***What is the size of each farm?***
- *Where are these farms located?*

Initialization

Model description

Number of farms and total area aggregated for various area ranges (IBGE, 1985).

Area range (HA)	Quantity	Sum of area by range
< 50	685	27625
50-100	574	44980
100-200	62	8877
200-500	30	9618
500-1000	9	6467
> 1000	14	141863
Total	**1374**	**239430**

Initialization

The initialization should answer the following questions at least:

- *How many farmers are in the study area?*
- *What is the size of each farm?*
- ***Where are these farms located?***

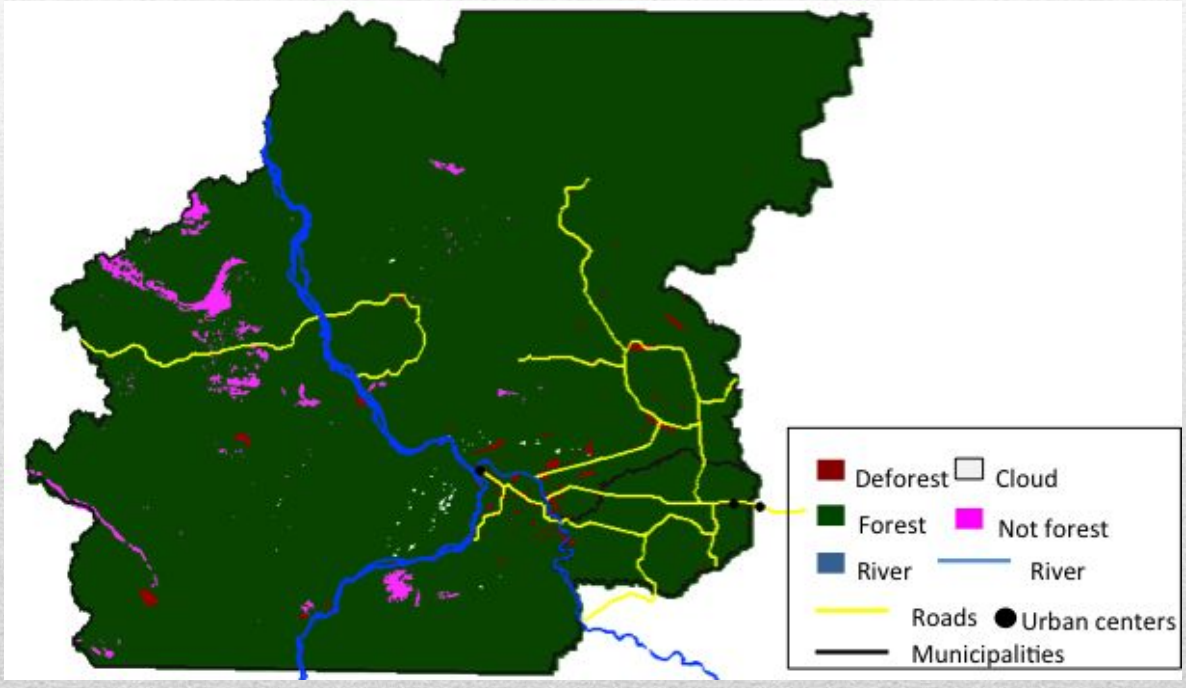
Initialization

Model description

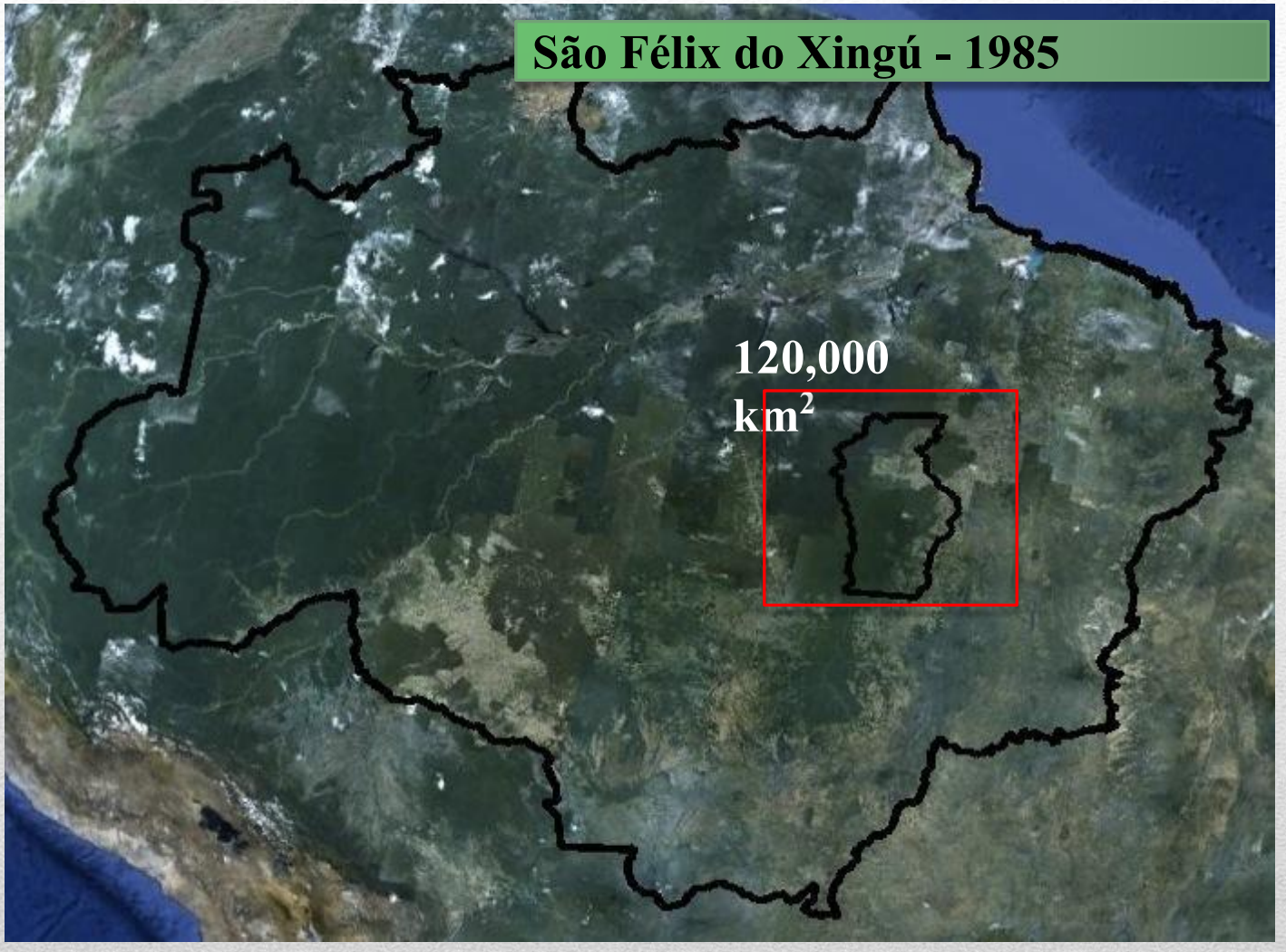
The deforestation map is derived from classification of LANDSAT TM images, which use the following classes: forest, deforestation, not-forest, cloud and river. In 1985, the deforestation class accounted for an area of 426 km^2.

Deforested Area / Area of farm

1985: 0.17
2006: 0.93



Initialization



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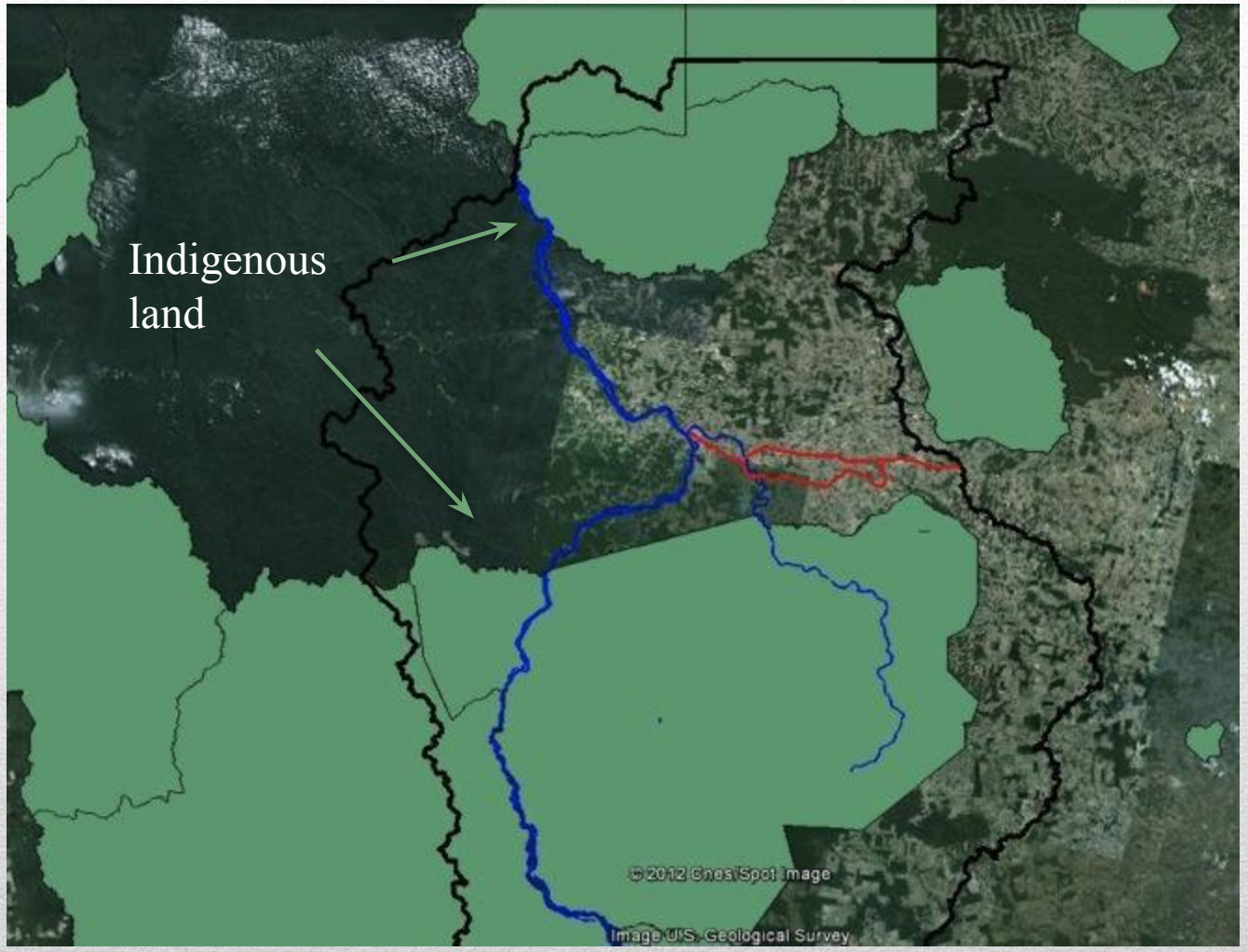
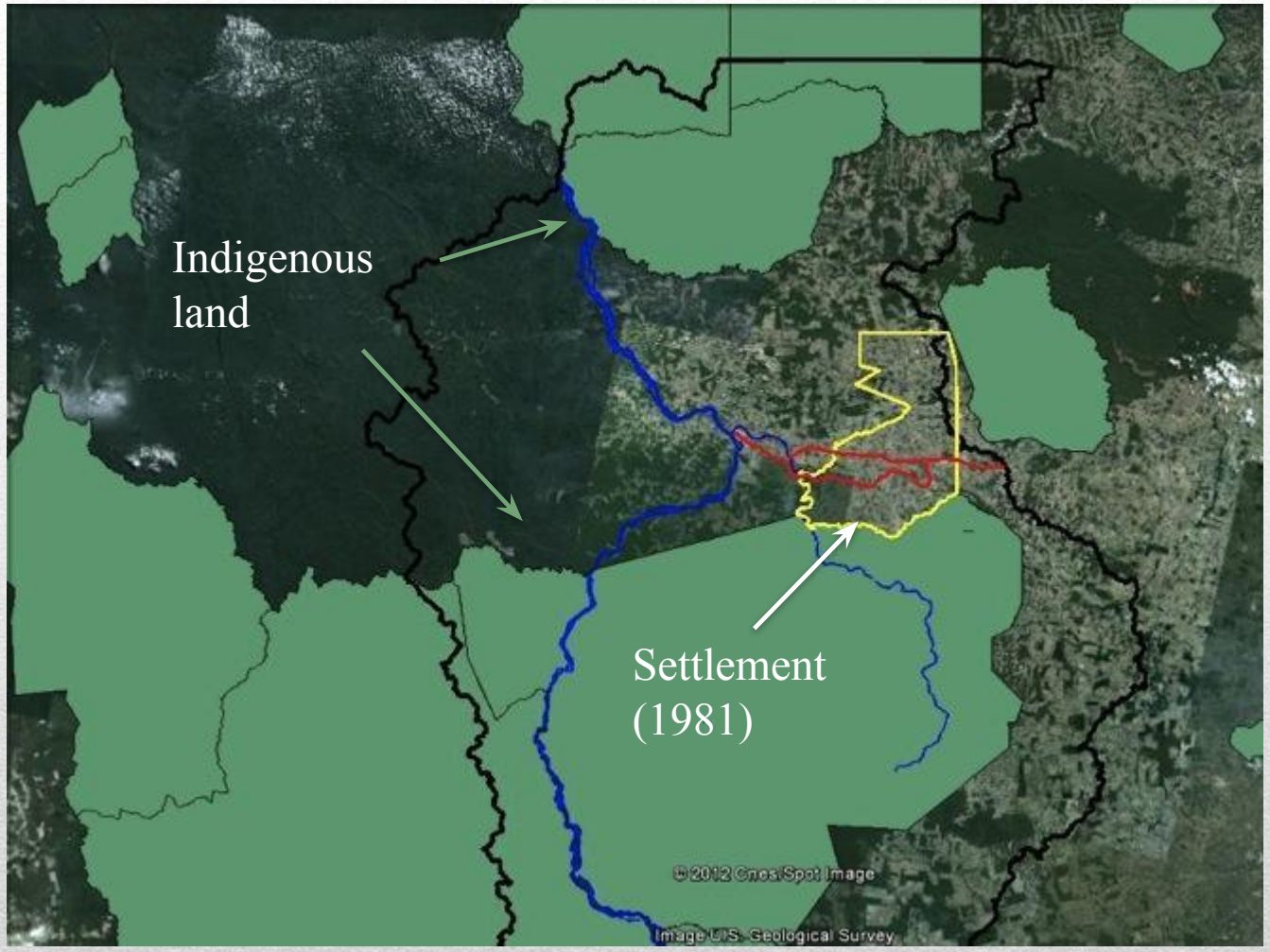


São Félix do Xingú - Contexto - 1985

Initialization

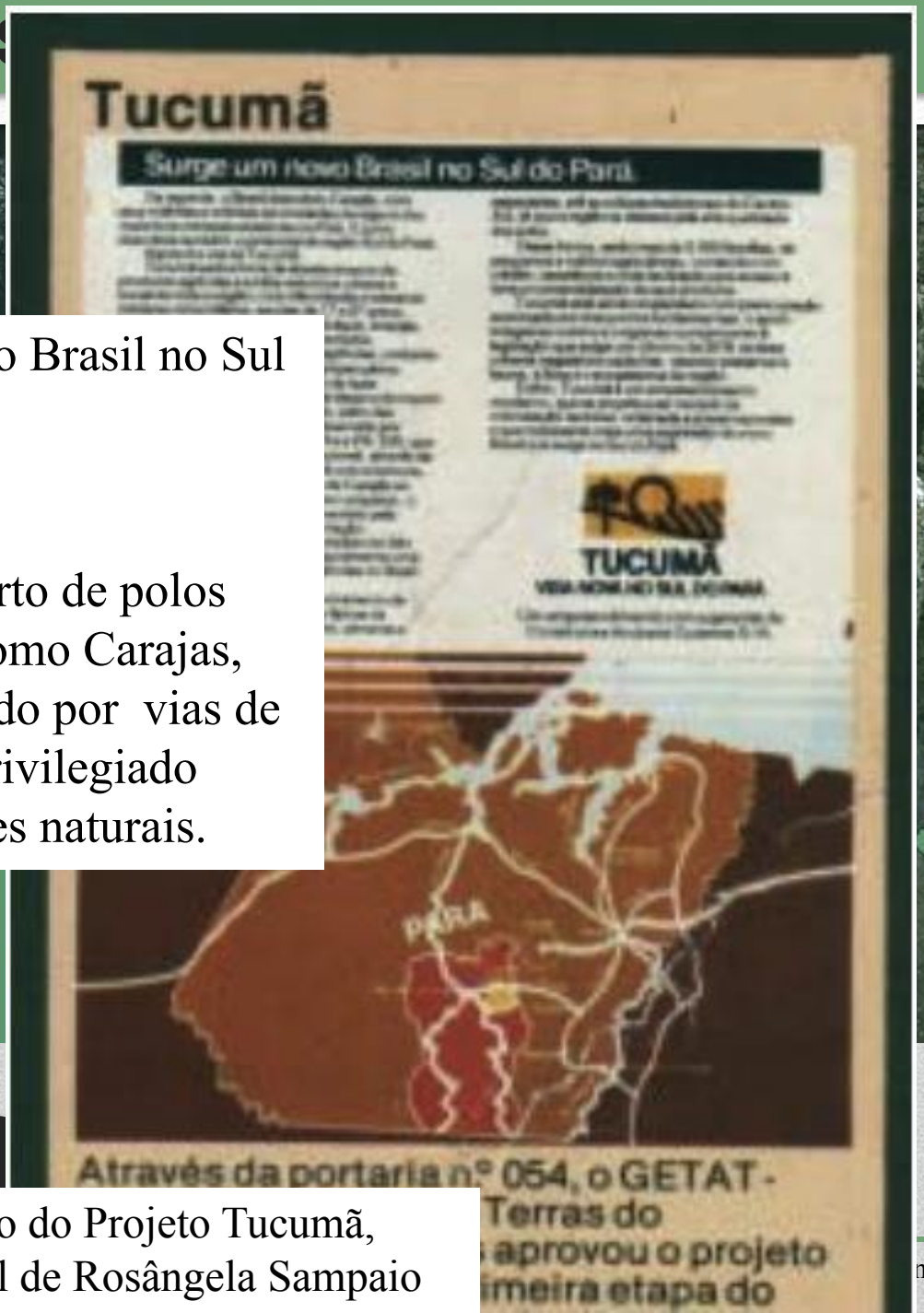
Model description



São Félix do Xingú - Contexto - 1985

Initialization

Model des



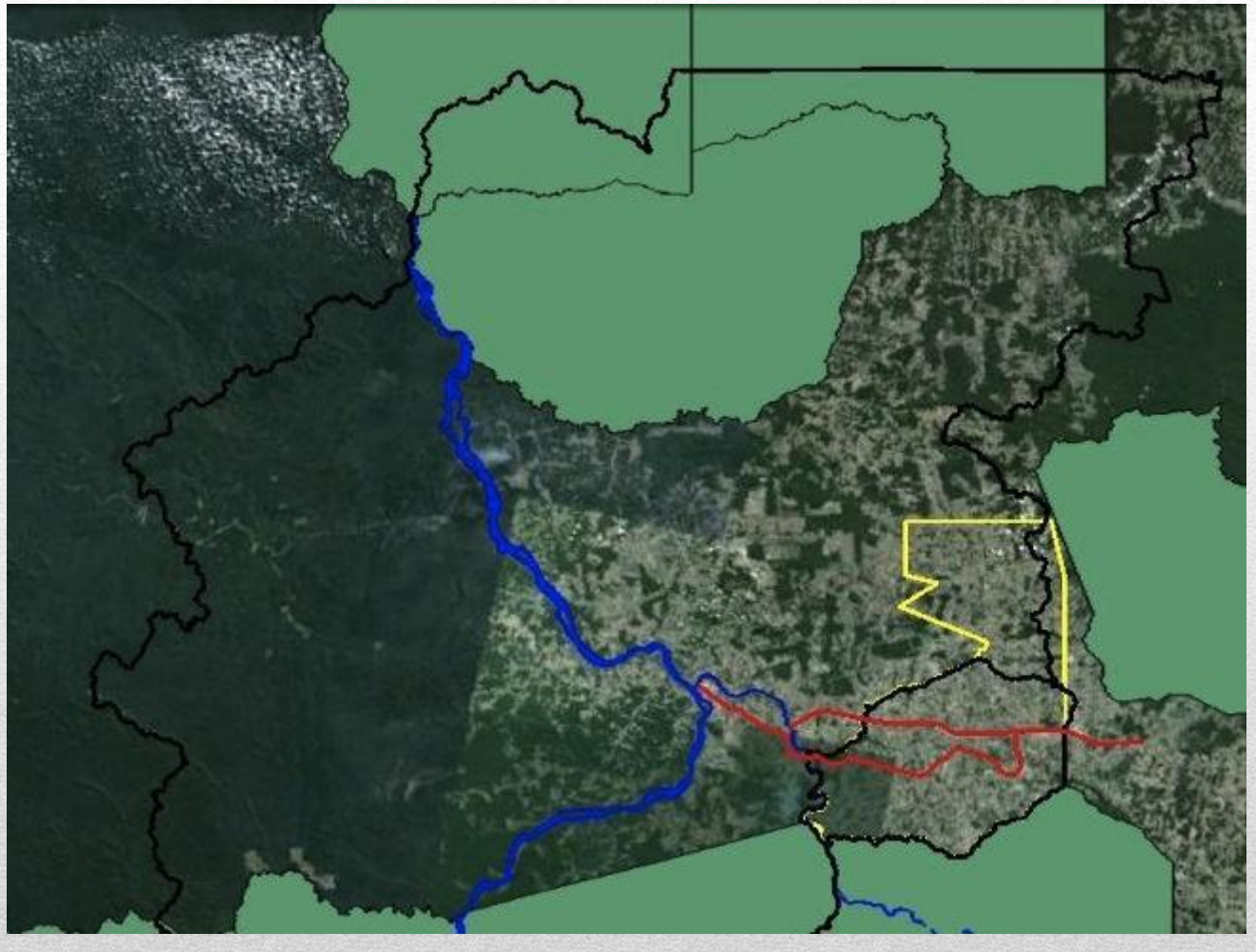
Surge um novo Brasil no Sul do Pará

...

Localizado perto de polos importantes como Carajas, Tucurui, servido por vias de transporte e privilegiado pelas condições naturais.

Initia

Panfleto de divulgação do Projeto Tucumã, 1981. Arquivo pessoal de Rosângela Sampaio



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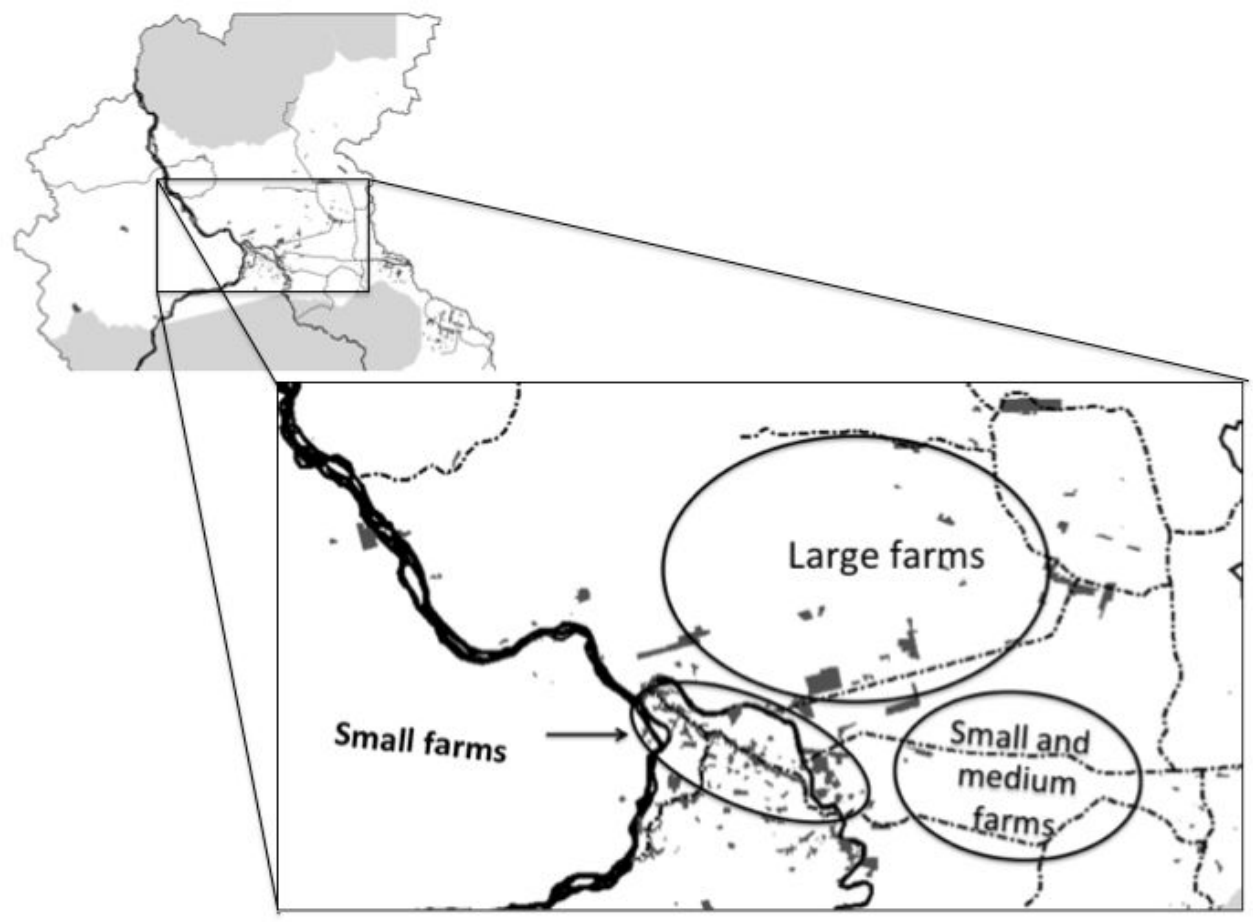

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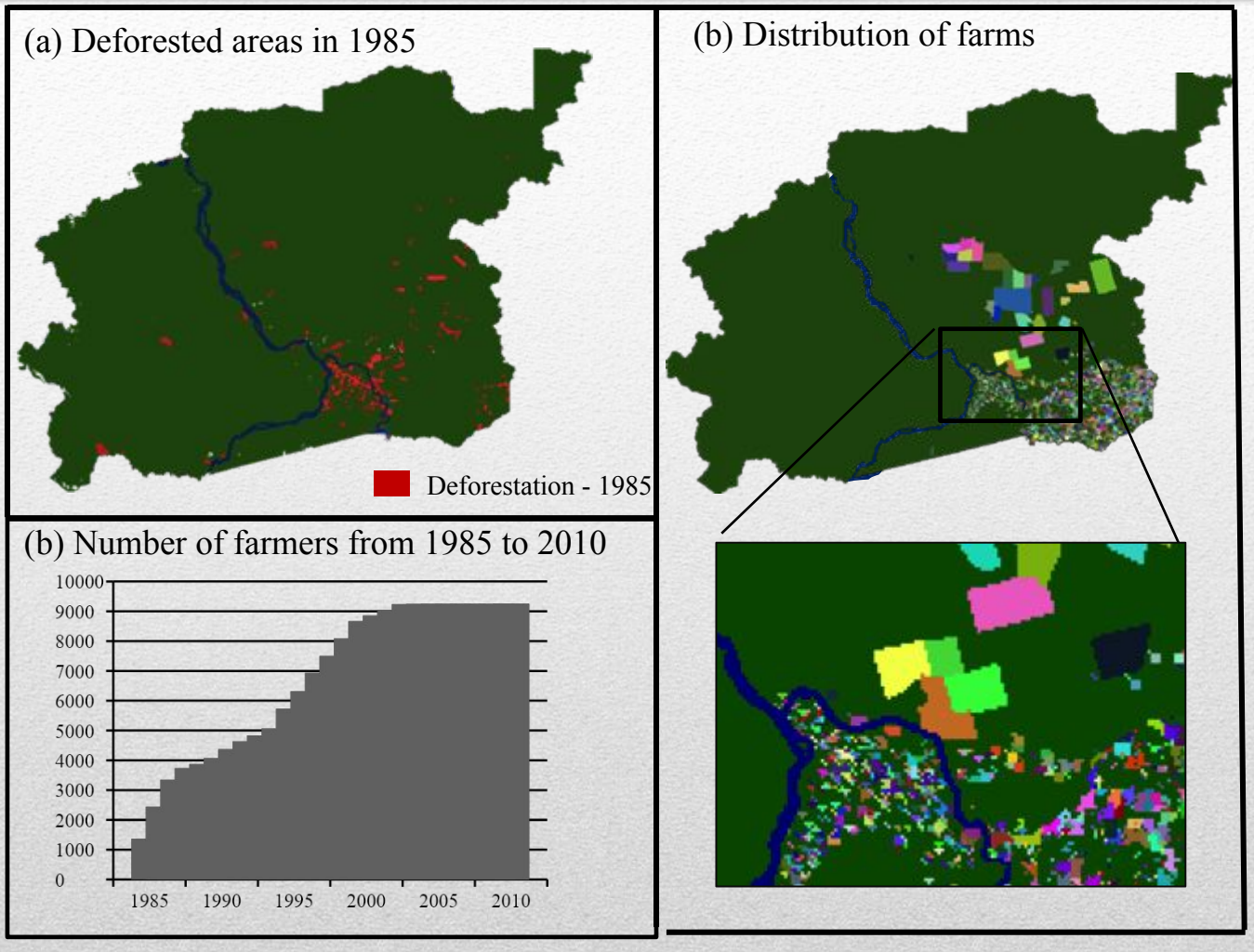
Model description



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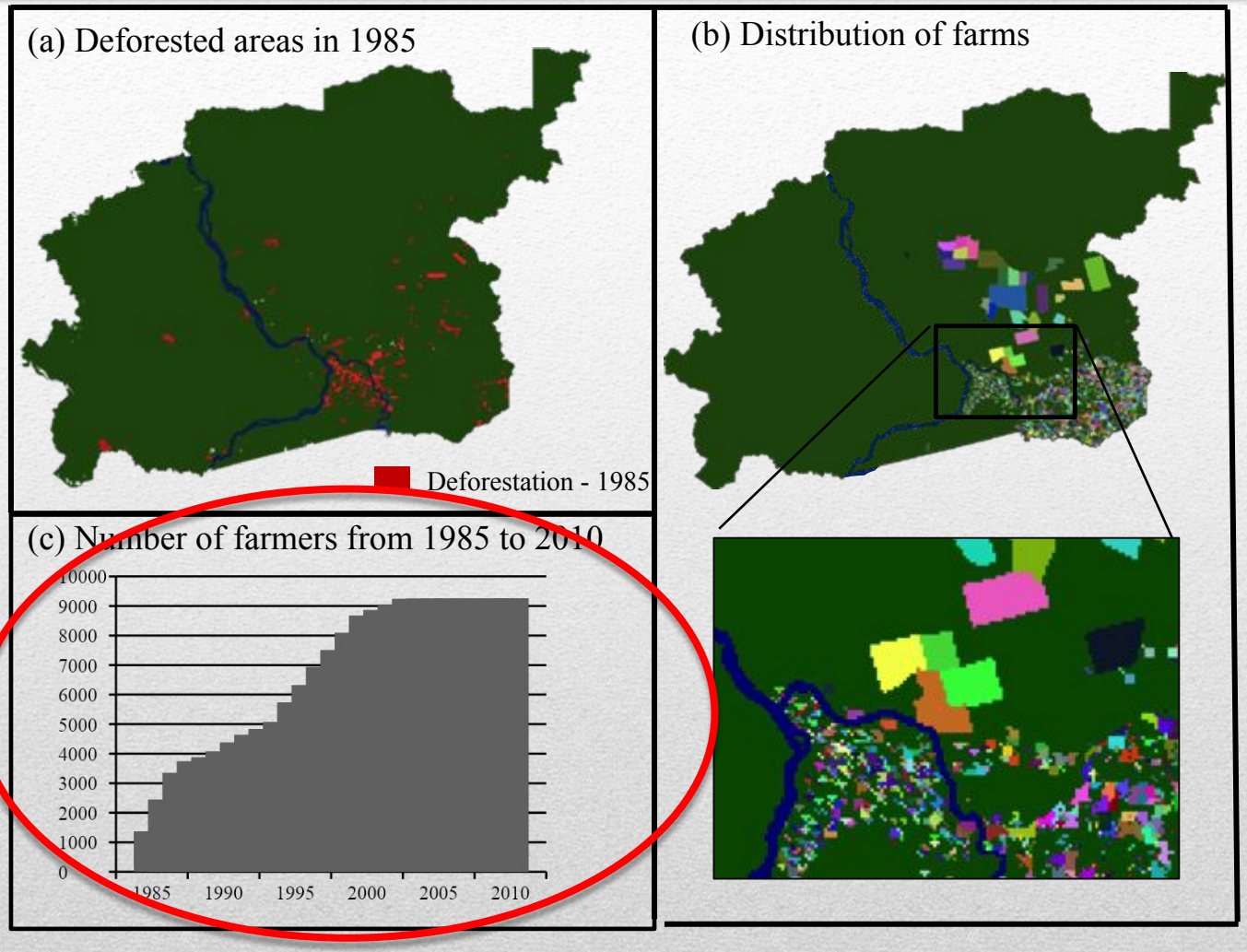

Initialization

Model description

1985					
	< 50	**50-500**	**500-2000**	**> 2000**	**total**
qt	685	666	12	11	1374
area	27625	63475	10844	137486	239430
1995					
	< 50	**50-500**	**500-2000**	**> 2000**	**total**
qt	871	1811	93	41	2816
area	42650	274944	103678	320823	742095
2005					
	< 50	**50-500**	**500-2000**	**> 2000**	**total**
qt	3895	1756	353	105	6109
area	85006	270872	363661	738062	1457601

Input data

Model description

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Input data

Model Description

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1. Purpose
2. Entities, Attributes and Scales
3. Process overview and scheduling
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5. Initialisation
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7. Submodels

Overview, Design concepts, and Details

Model description

For cattle famers, the productivity of a farm is characterised by the number of animals per ha. This variable is complex and depends on many different factors.

We simplified this variable by making it a function of only technology level and pasture age:

$$Animal\ unit = degradation\ (technology\ level, pasture\ age)$$

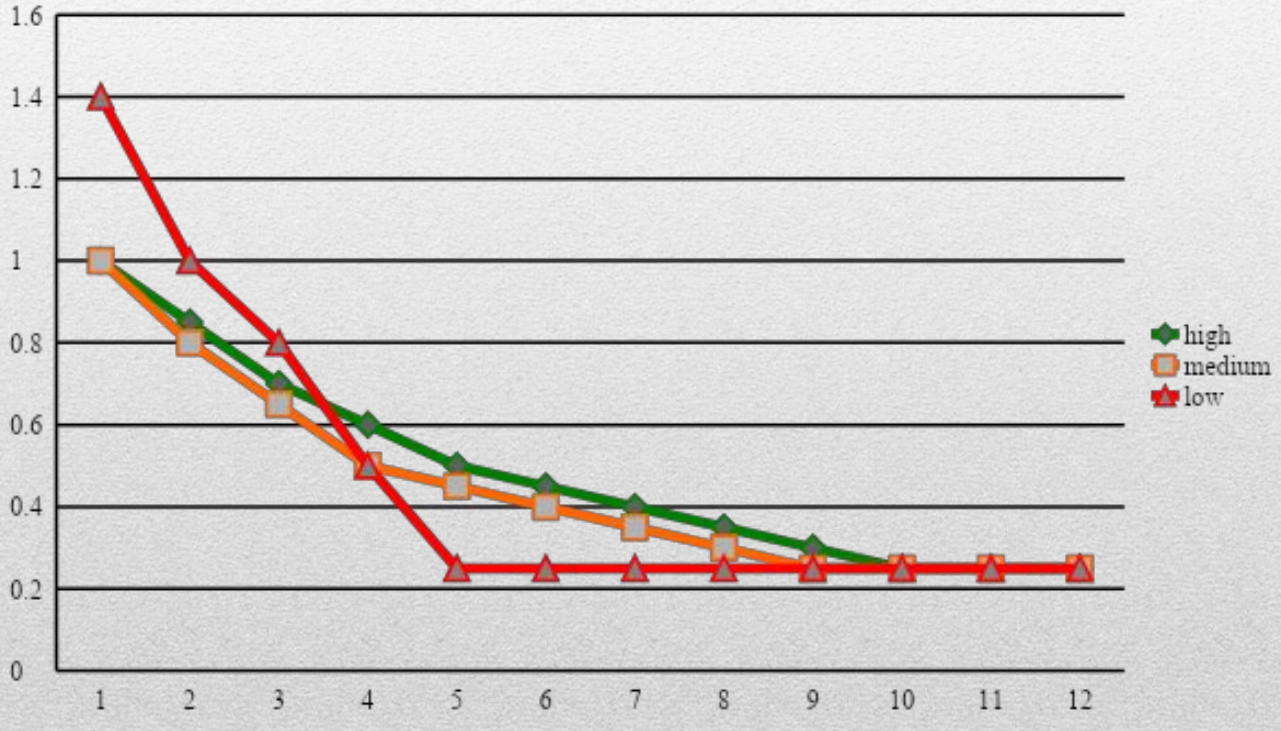
Where:

$$technology\ level = \{low, medium, high\}$$

Submodels: Pasture degradation

Model description

The degradation is a discrete function that has a single value for each technology level and pasture age. This function may be calibrated for based on the region. In our experiments, we use the discrete function represented in Figure 5-9.



Submodels: Pasture degradation

Model description

This submodel creates farms, both at initialisation and during the simulation. For each new farm in the model, it

1. first produces a sample of 500 cells.
2. it calculates the potential for each cell (x, y) using the multi-criteria evaluation (MCE).
3. chooses the cell with the greatest potential.
4. The chosen cell is marked as the location of the agent's house.
5. The *Farm Creator* operator takes the chosen cell and a specified farm area as parameters.
6. Finally, the submodel calculates and updates the spatial relations amongst farms using the *Neighbourhood operator.*

MCE $$P_{x,y} = \sum_{i=1}^{N} w_i \, z_{i,x,y}$$

Submodels: Farm locator/creator

Model description

This submodel creates farms, both at initialisation and during the simulation. For each new farm in the model, it

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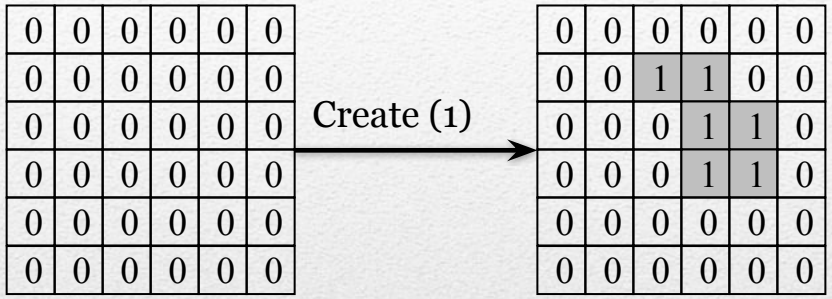
MCE $$P_{x,y} = \sum_{i=1}^{N} w_i \, z_{i,x,y}$$

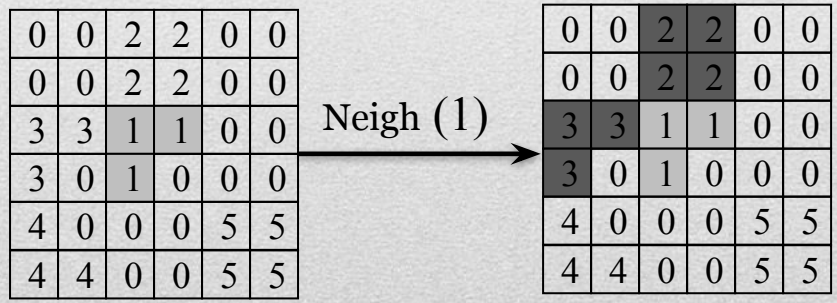
Submodels: Farm locator/creator

Model description

Farm operators used for farm locator/creator submodel:



Create operator, which instantiates a new farm given an initial settlement cell and a farm area.

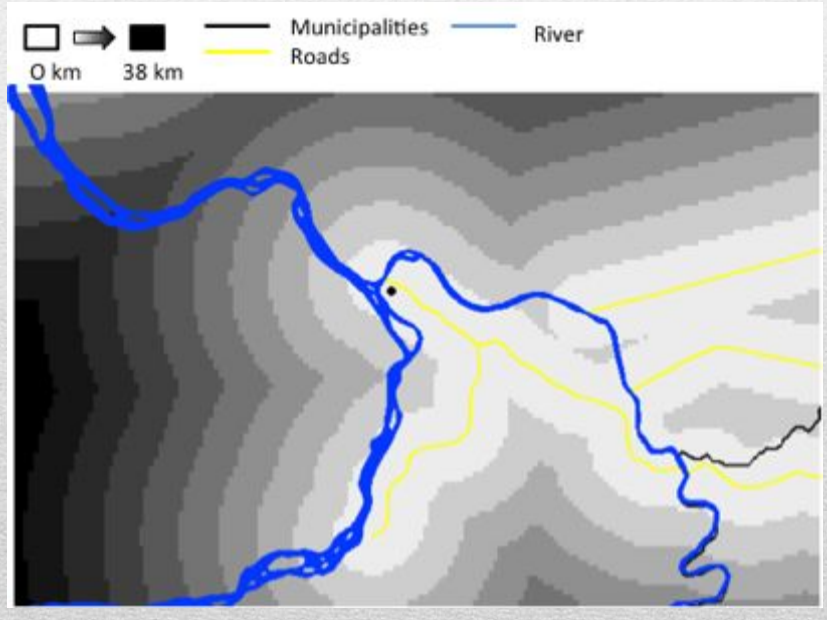


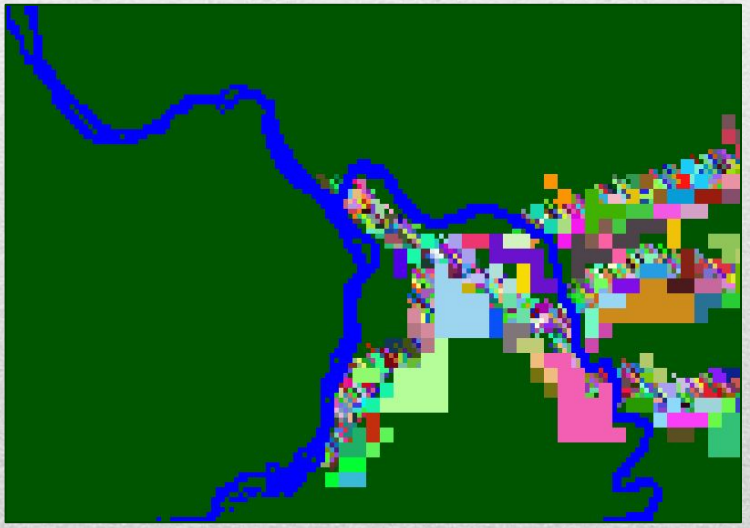
Neighbourhood operator, which identifies the spatial adjacency relations amongst the farms.

Submodels: Farm locator/creator

Model description

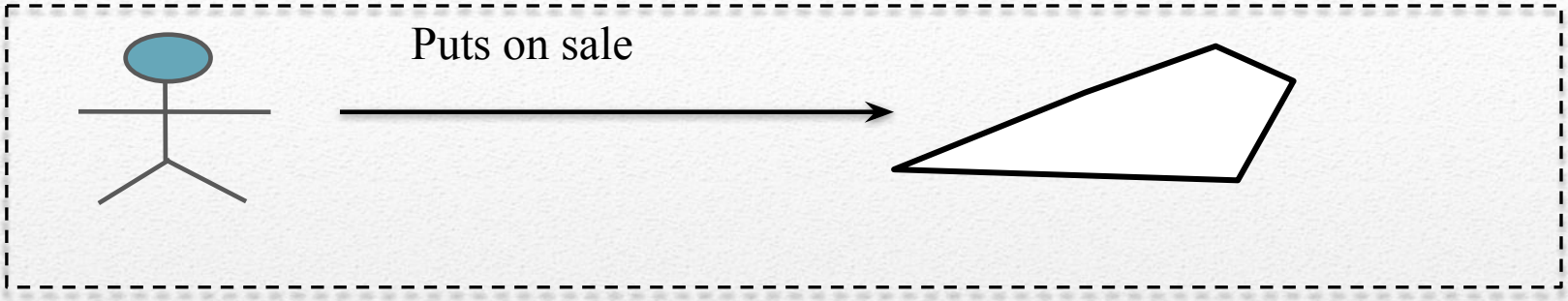
1. Receives an initial cell and farm area. The choice of initial cell may depend on factors such as the proximity of rivers or roads.
2. Adds the available neighbouring cells until a given area is attained.





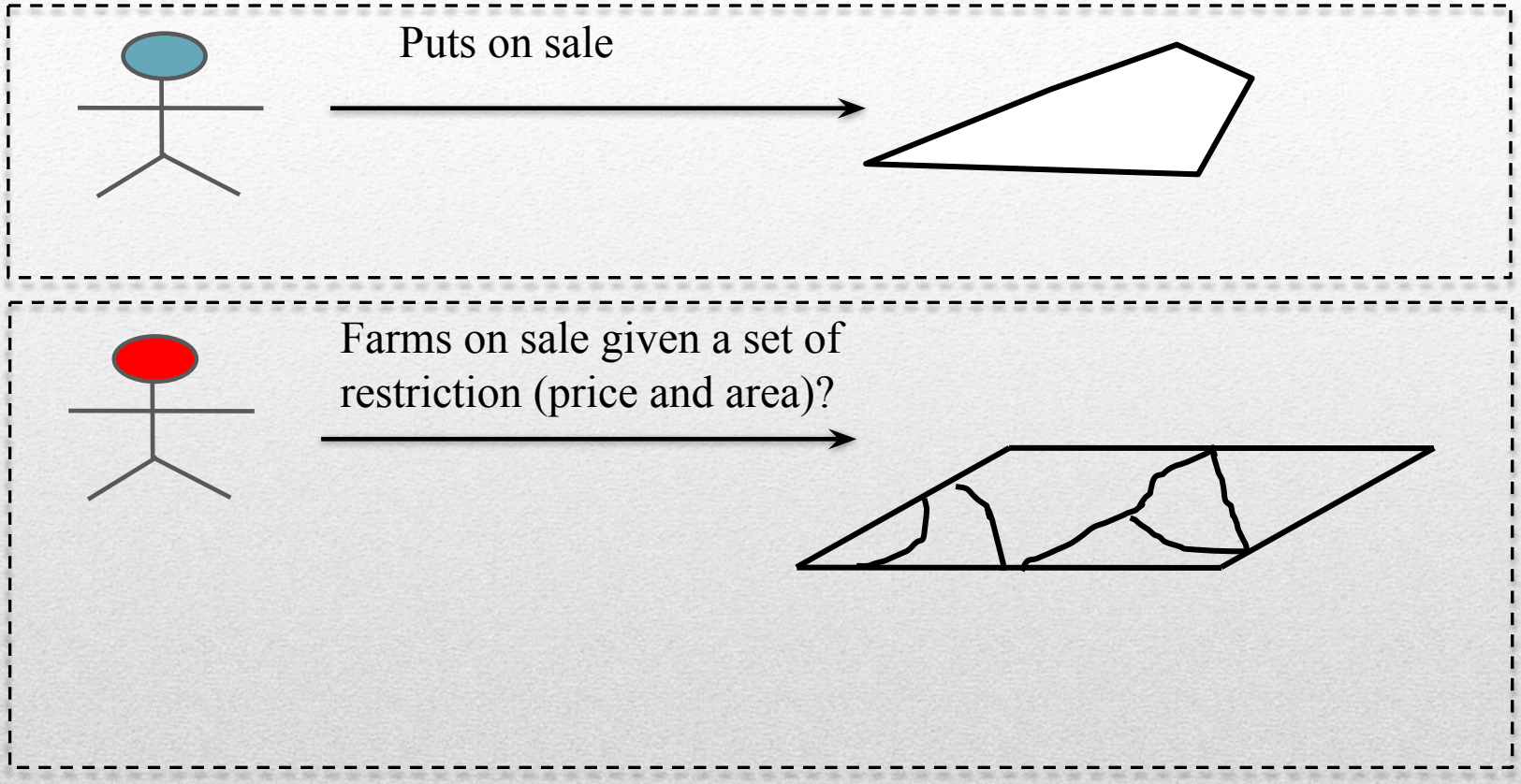
Submodels: Farm locator/creator

Model description



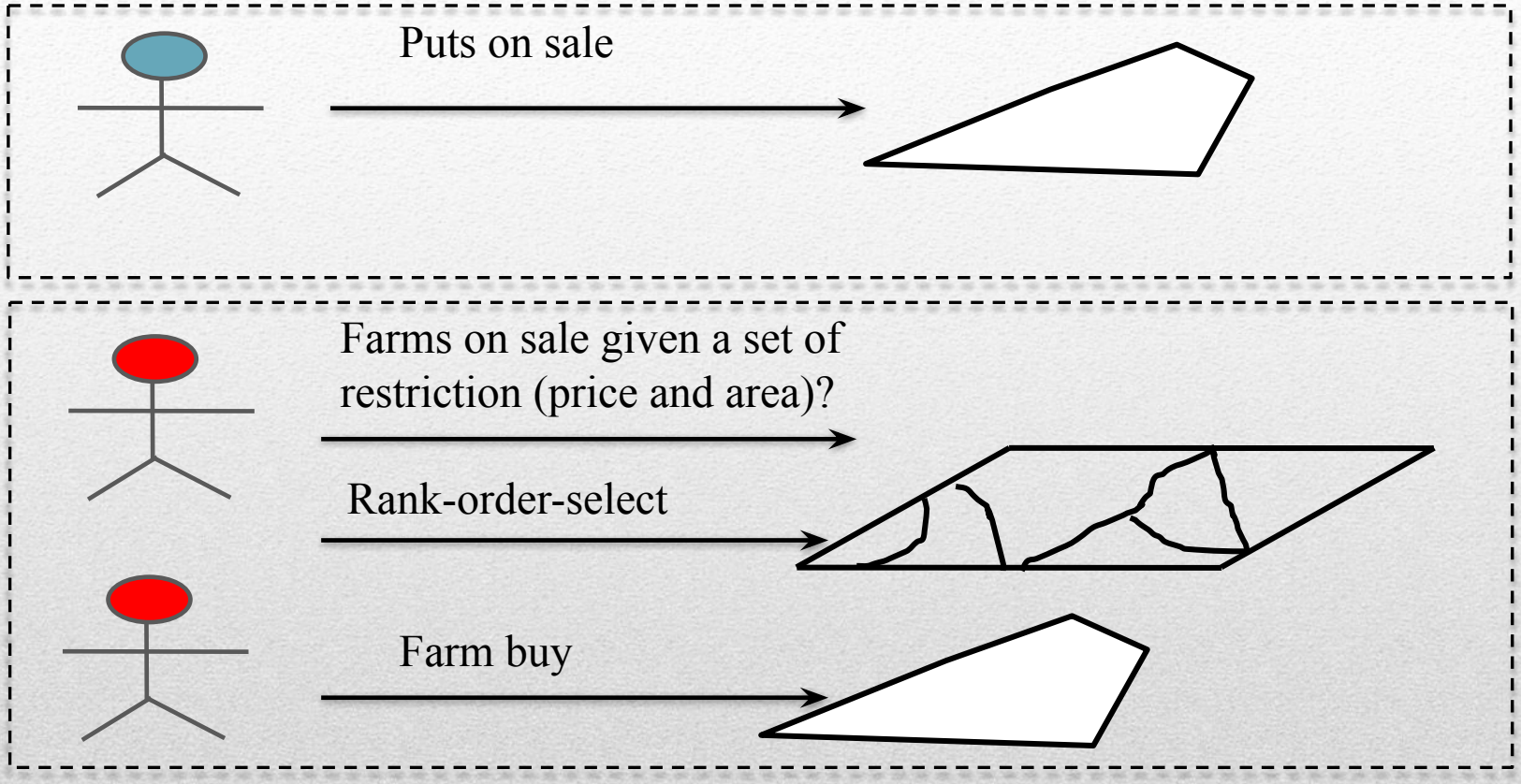
Submodels: Land-market

Model description



Submodels: Land-market

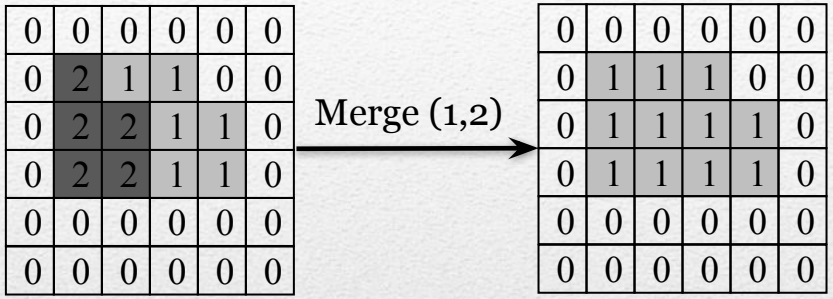
Model description



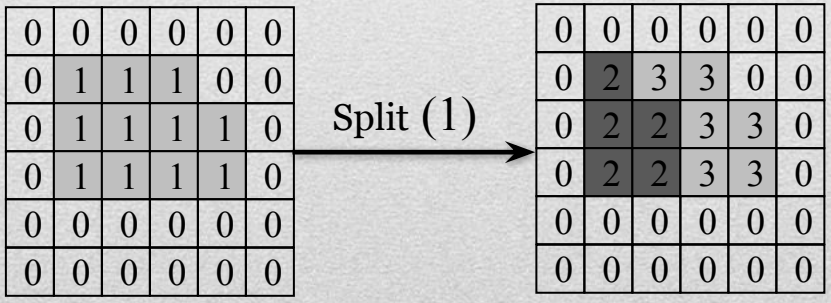
Submodels: Land-market

Model description

Farm operators used for land-market submodel .



Merge operator, which joins two farms and updates the farm boundaries.

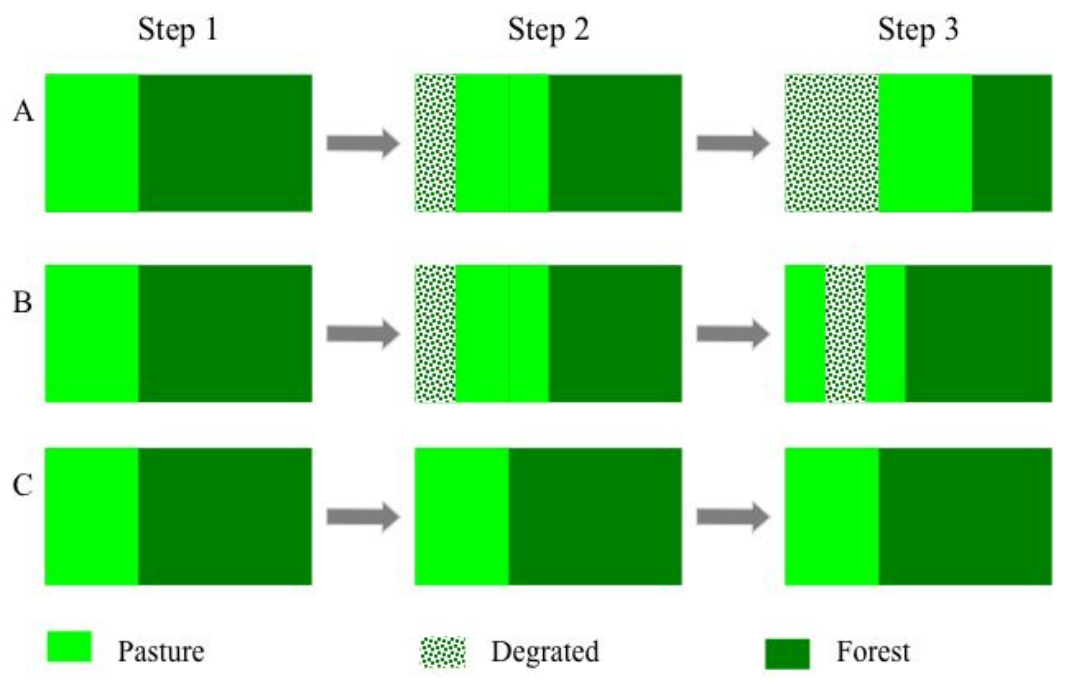


Split operator, which divides a given region into several farms of specified areas.

Submodels: Land-market

Model description

In our experiments, land-use decisions refer to deforestation and pasture creation, which depend on the technology level. Land-use decisions also include pasture reformation and reforestation. These decisions may yield to different trajectories (A, B and C),



These trajectories reflect the different strategies that farmers can employ, each strategy constrains how much, where and when the agents deforest, create pasture and manage the land.

Submodels: Land use

We propose using a land-allocation submodel (similar to pattern models) to define what cells are changed. In this model, each agent performs a land allocation, using a method such as rank-order-change or a clues-like algorithm, under the constraint that a farm can have at most 60,000 cells.

In our simulation, we use a simple allocation strategy in which we rank the cells using the MCE to calculate the potential of each cell. The factors considered include the slope and distance to the house. Then, we order the cells and finally, change the land use.

Submodels: Land use

MODEL SIMULATIONS AND RESULTS

Model simulation and results

Simulation	Period	Institutional Arrangements	Temporal range of arrangement
0 (Calibration)	1985-1997	Government-induced occupation	1970-1996
1 (Validation)	1985-2010	Government-induced occupation	1970-1996
2 (Validation)	1985-2010	Government-induced occupation Beef market chain organization	1970-1996 1997-2010
3 (Validation)	1985-2010	Government-induced occupation Beef market chain organization Deforestation control	1970-1996 1997-2010 2005-2010

Simulations

Model simulation and results

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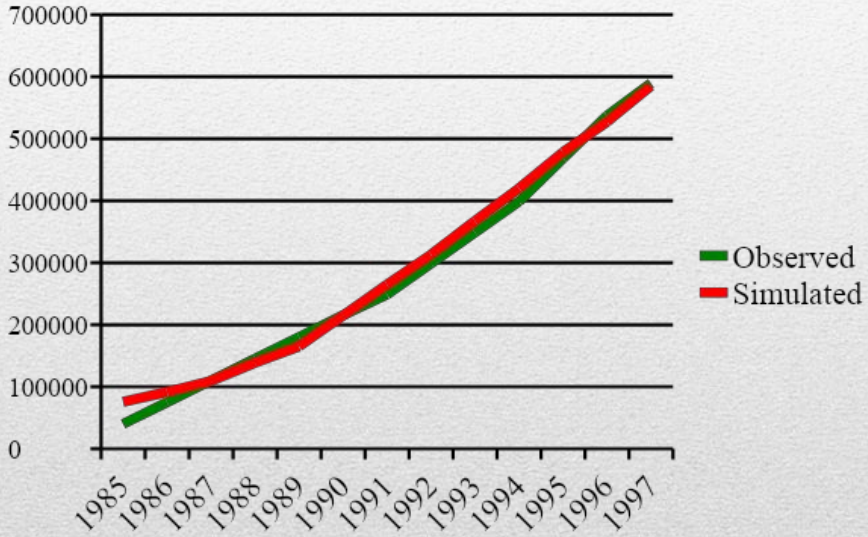
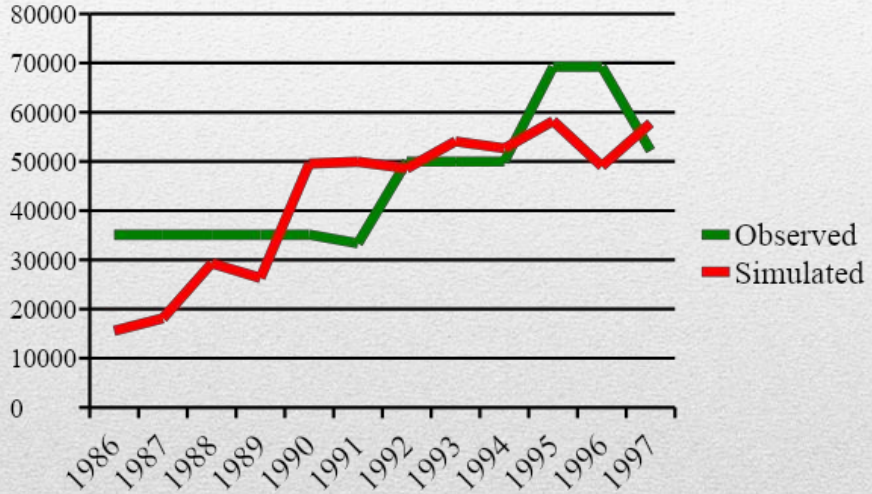
Simulations

Model simulation and results

Total deforested area



Deforestation rate



Results

Model simulation and results

Simulation	Period	Institutional Arrangements	Temporal range of arrangement
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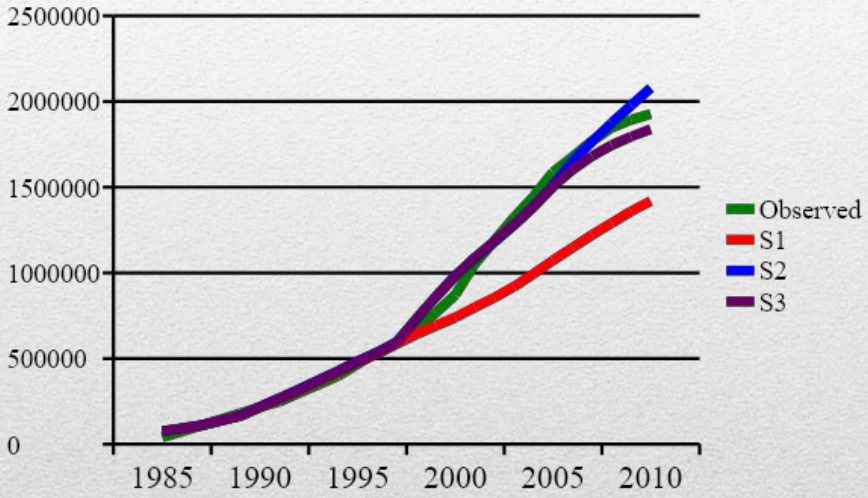
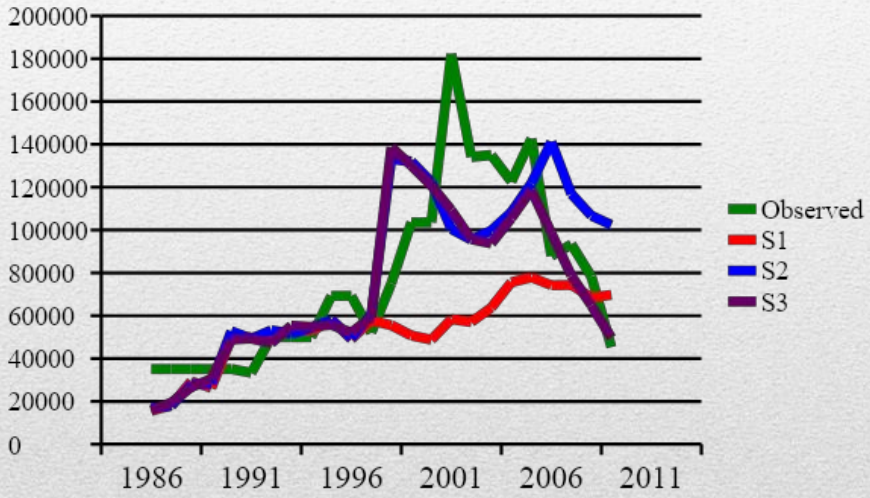
Simulations

Model simulation and results

Total deforested area



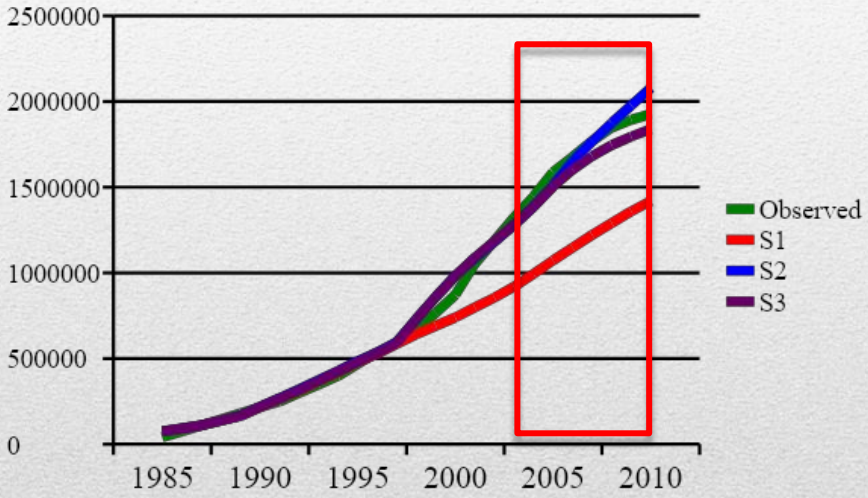
Deforestation rate



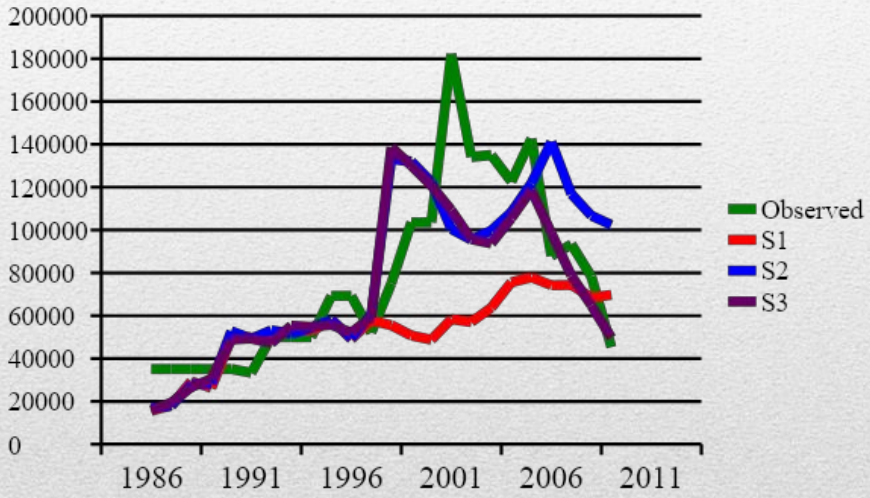
Results – S1, S2 and S3

Model simulation and results

Total deforested area

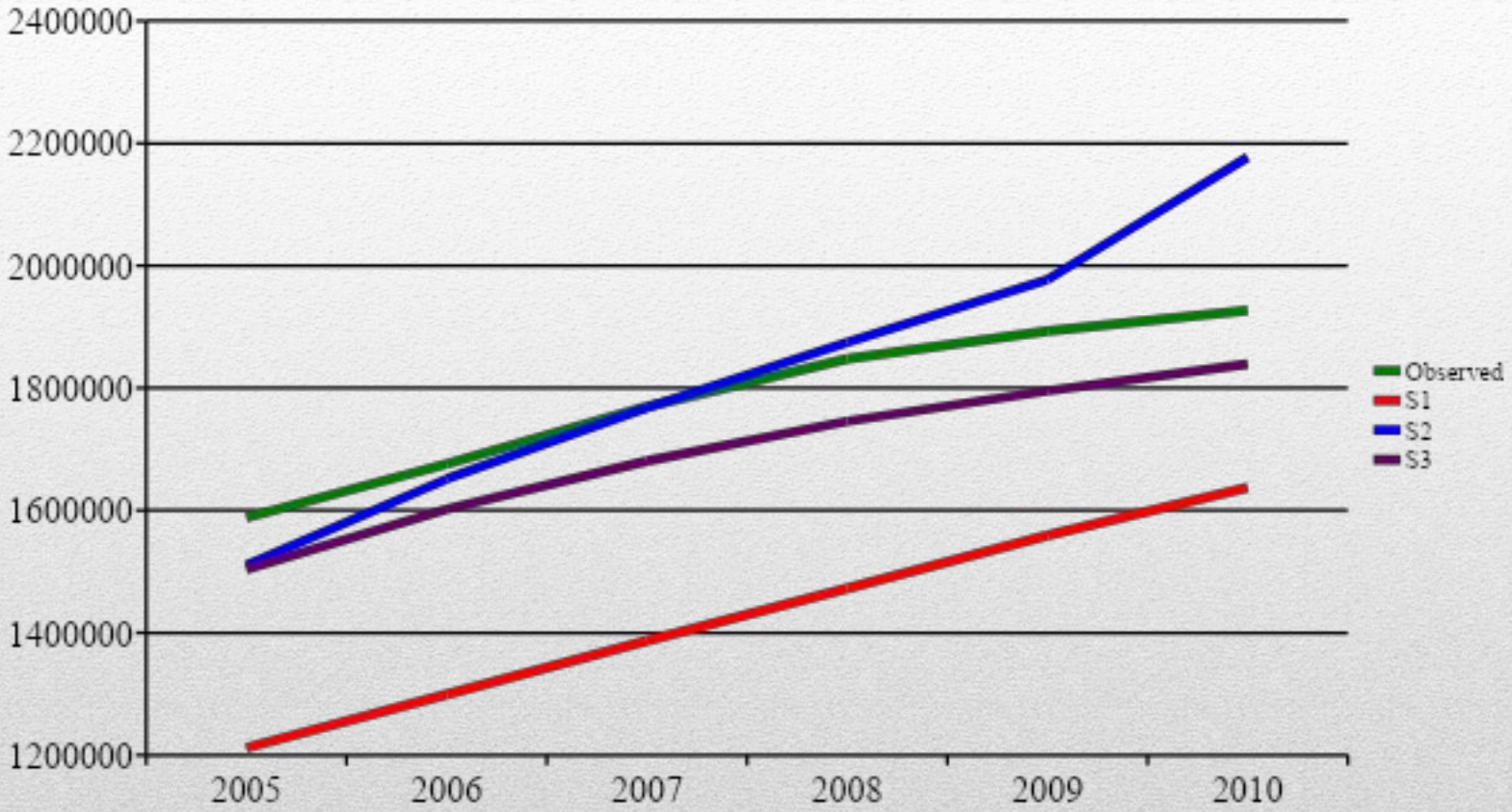


Deforestation rate



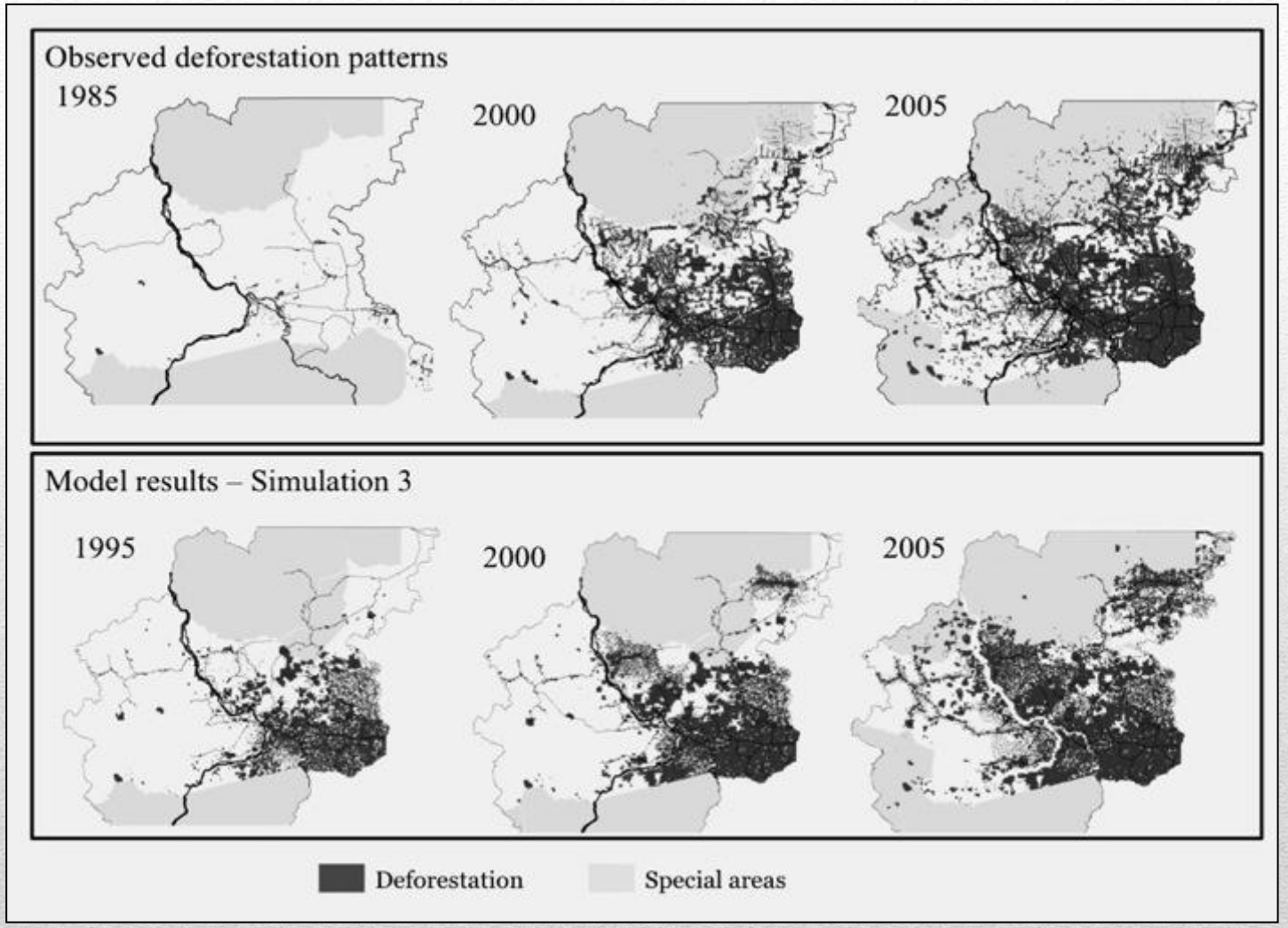
Results – S1, S2 and S3

Model simulation and results



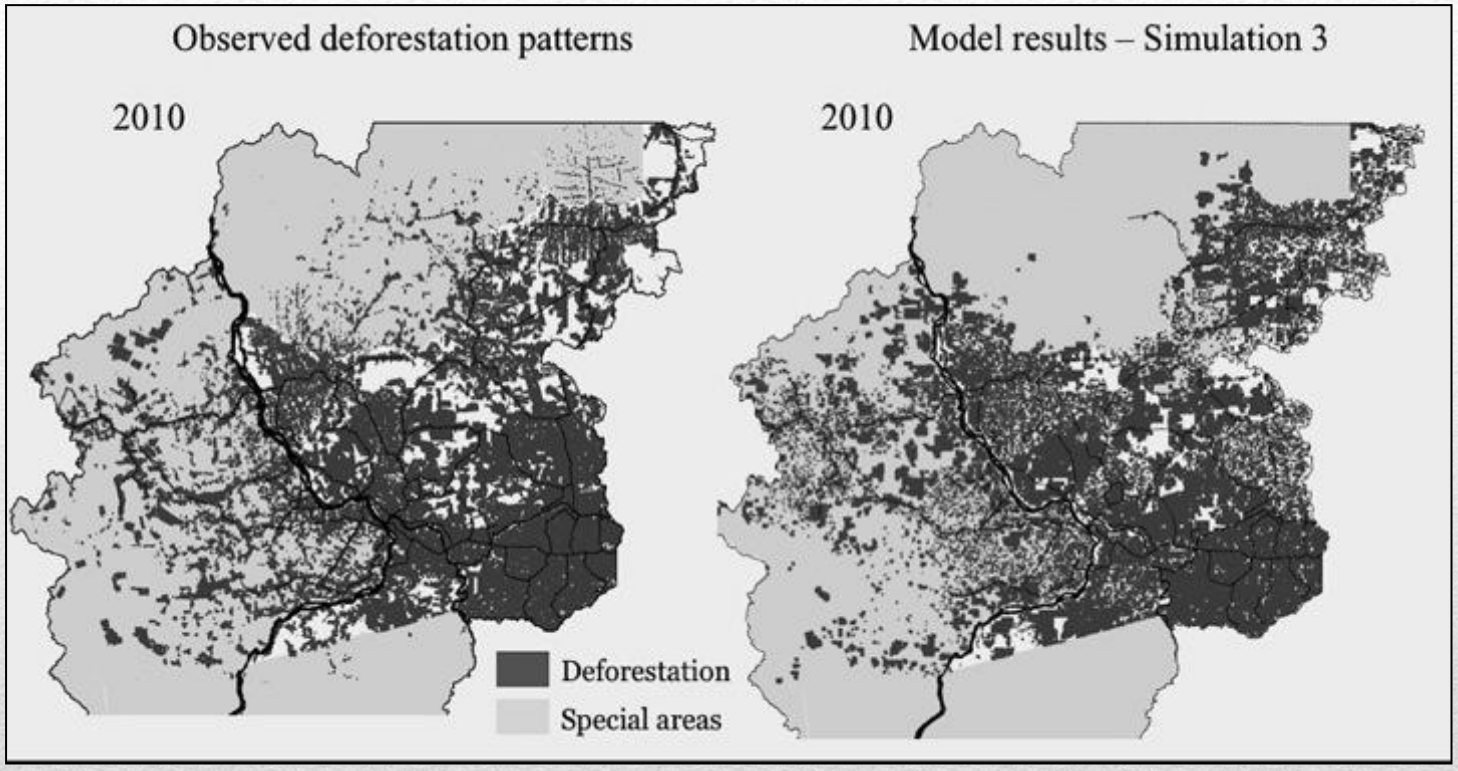
Results – S1, S2 and S3

Model simulation and results



Results – S3

Model simulation and results



Results – S3

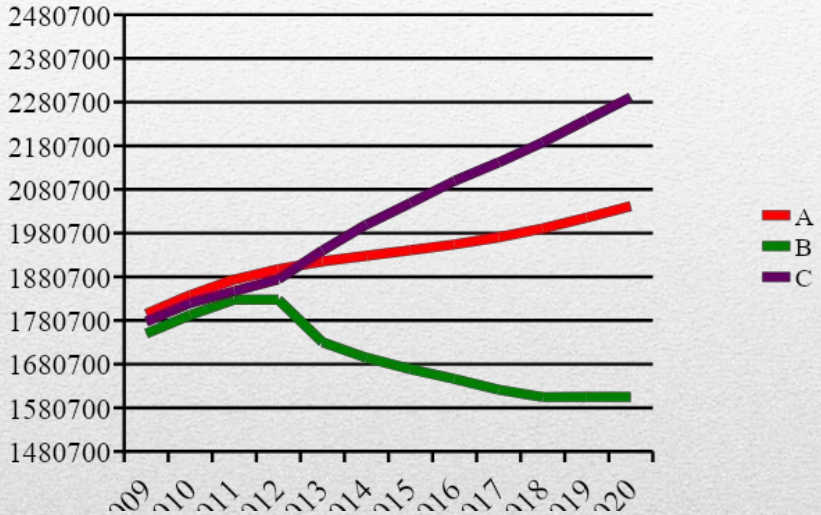
Model simulation and results

Simulation	Period	Alternative Institutional Arrangements	Temporal range of arrangement
4 (Scenario A)	1985-2020	Government-induced occupation Beef market chain organization Deforestation control Green market	1970-1996 1997-2008 2005-2020 2009-2020
5 (Scenario B)	1985-2020	Government-induced occupation Beef market chain organization Deforestation control Sustainable development Green market	1970-1996 1997-2008 2005-2012 2013-2020 2009-2020
6 (Scenario C)	1985-2020	Government-induced occupation Beef market chain organization Deforestation control Economic development Green market	1970-1996 1997-2008 2005-2012 2013-2020 2009-2020

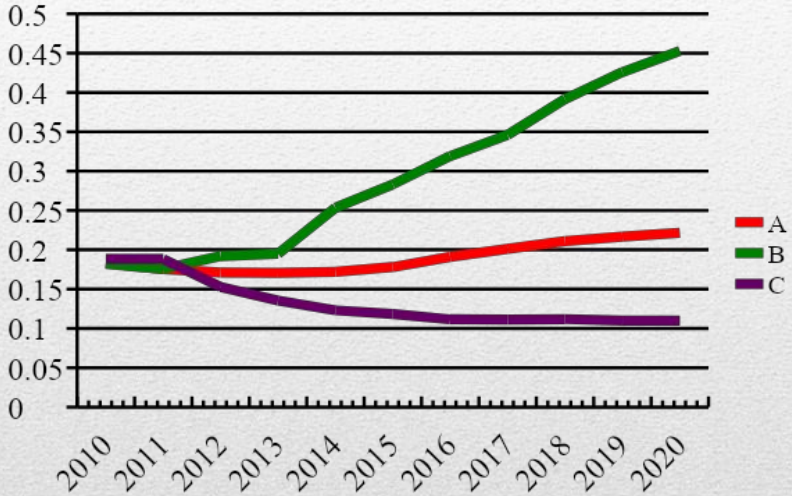
Scenarios

Model simulation and results

Pasture area (ha)

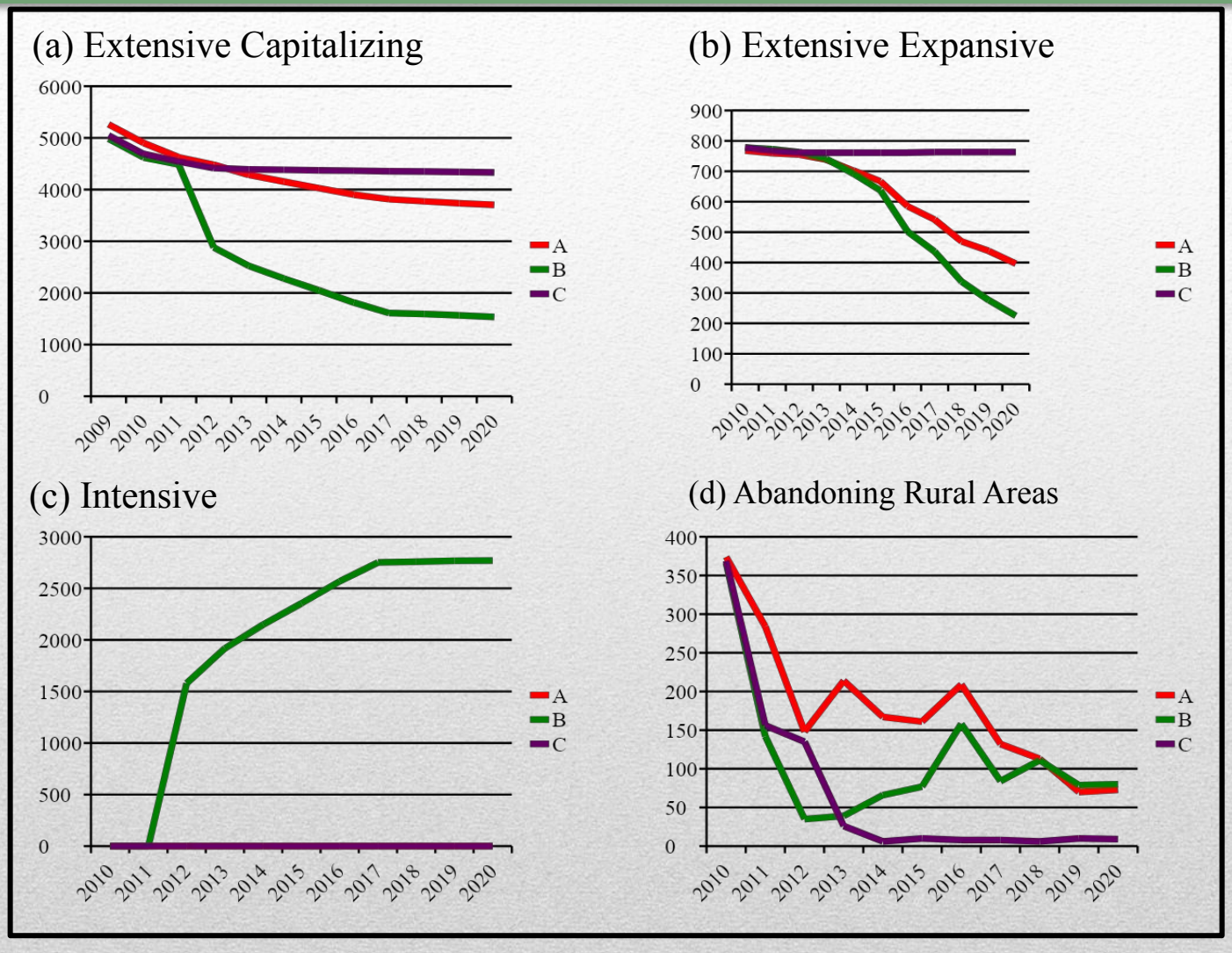


Forest area inside farms (%)



Scenarios – A, B and C

Model simulation and results



Scenarios – A, B and C

CONCLUSION

Conclusion

Using empirical ABM for socio-ecological system is a great challenge:

> *"Agent-based modelling meets an intuitive desire to explicitly represent human decision making. (...) The question is whether the benefits of that approach to spatial modelling exceed the considerable costs of the added dimensions of complexity introduced into the modelling effort."* Helen Couclelis, 2002.

We believe that the ideas of institutional arrangements and hybrid automata can help reduce the complexity of agent-based modelling of land change.

Conclusion

- The thesis shows how to express the ideas of *strategy* and *institutional arrangements* in computer simulations.
  - Strategies are loosely coupled to agents and may vary during the simulation in response to changes in local context and institutional arrangements.
  - The **hybrid automata formalism** (available in TerraME) turned out to be a good way to **express decision-making when agents change their strategies over time**.

Conclusion

- This thesis presents a method for building agent-based models of land change. Most agent-based models in the literature deal with individual decisions in small areas, based on field surveys.
- Our approach extends agent-based models to larger areas, based on collective behaviour.
- We assume that farmers have a limited set of strategies to manage land. Over time, a farmer may change his strategy depending on external conditions.

Conclusion

Conclusion

- This model was very important to validate our concepts. however, this work is an is a first step of a long journey where we may suggest the following future work
  - Calibration of pasture degradation submodel.
  - Land use submodel should consider other land use types, allowing build different scenarious.
  - Include actors, like miners and loggers.
  - Road submodel, creation of roads should be modeled as endogenous process in future version.
  - Connection to market.
  - Normative agents

Future work


Obrigado

Strategies and Jump Conditions

State	Jump Conditions
Migrate	1. When agent gets a farm and has little capital, jump *to Extensive Farming.* 2. When agent gets a farm and has much capital, jump to *Extensive Expanding.* 3. If agent is risk prone, jump to Speculate.
Extensive Farming	1. If agent gets capital, jump to *Extensive Expanding.* 2. If law enforcement is high, pasture is degraded and there is credit for small farmers, jump to *Intensive Farming.* 3. If law enforcement is high, pasture is degraded and there is no credit for small farmers, jump to *Abandon Rural Activity.*
Extensive Expanding	1. If law enforcement is high, pasture is degraded and there is credit for large farmers, jump to *Intensive Farming.* 2. If law enforcement is high, pasture is degraded and there is no credit for large farmers, jump to *Abandon Rural Activity.*
Speculate	• If law enforcement is high, jump to *Abandon Rural Activity.*
Intensive Farming	• If there is no credit for large farmers and the beef market chain is weak for more than 5 years, jump to *Abandon Rural Activity.*
Abandoning Rural Activity	(final state, no jump conditions)