Irregular Cellular Spaces: Suporting Realistic Spatial Dynamic Modeling over Geographical Databases

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Summary

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- Results
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  - TerraME ICS
  - Study Case
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Introduction

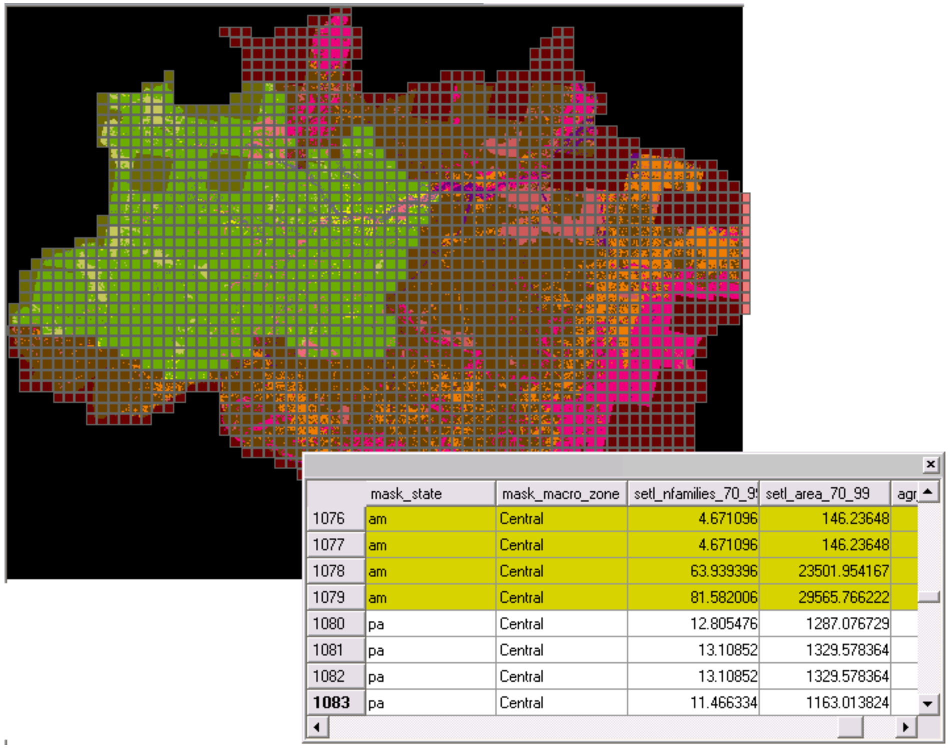
- Most modern GIS provides only static computational representations of the Geographical Space: geo-objects, geo-fields and fluxes.

- This fact had led to several proposals of integration between dynamical modeling and GIS platforms:
  - Swarm + regular cellular space [Box 2002]
  - SME + regular cellular space [Villa and Costanza 2000]
  - Repast + regular cellular space [North et al. 2006].

Introduction

Regular Cellular Space (RCS)

- a regular two-dimensional grid of multi-valued cells grouped into isotropic stationary neighborhoods
- dynamic model rules operate and possibly change cells attribute values.



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1077	am	Central	4.671096	146.23648	
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1079	am	Central	81.582006	29565.766222	
1080	pa	Central	12.805476	1287.076729	
1081	pa	Central	13.10852	1329.578364	
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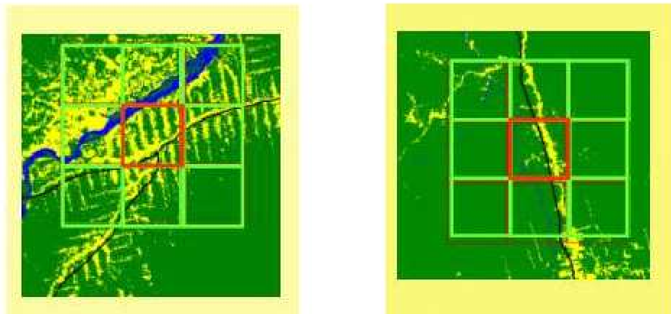
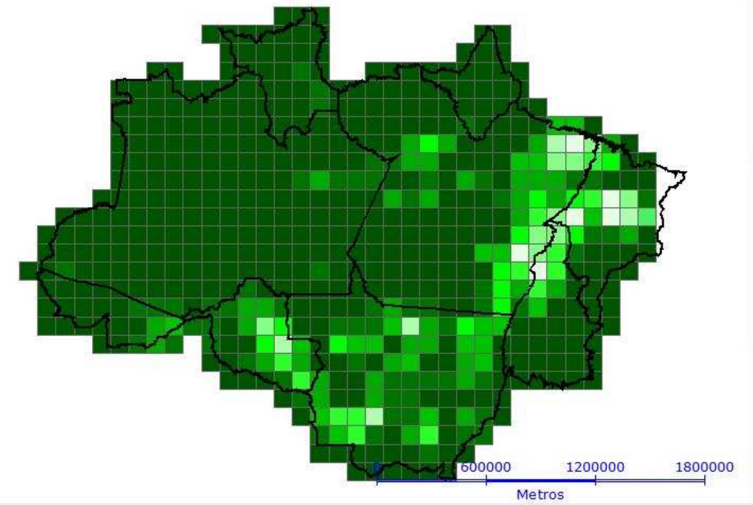
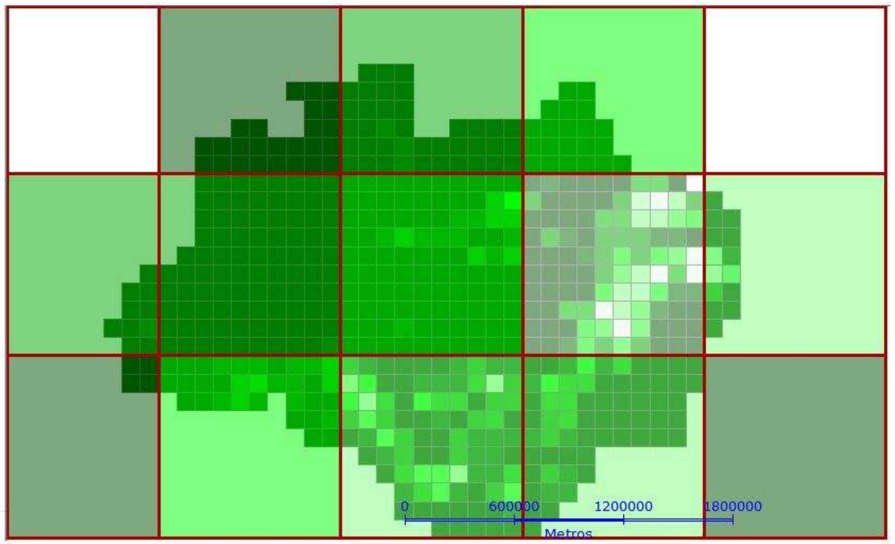


Moore or Von Neuman

Introduction

- Disadvantages of regular spatial structure
  – Border effects;
  – Aggregation of cell attributes values due a resolution
  – Lack of abstractions for representing moving objects or geographical networks





Introduction

- Cellular Spaces: a promising representation for the Space concept
  - Cellular Automata: existence of a simple and formal model of computation for complex dynamics representation
  - Easy to develop algorithms for representing process trajectories:
    - Euclidian two-dimensional grid: one may use basic analytic geometry knowledge to describe change circular or elliptical paths;
    - To go to the East just increment the X coordinate, to go to the South decrement the Y coordinate.

Goals

- **Irregular Cellular Spaces** (ICS): formally define a computational model for the Geographical Space concept to support the development of multiple scale GIS integrated spatial dynamic models.

- **TerraME ICS**: for model evaluation implement ICS as a component of the TerraME environmental modeling software platform.

Material and Methods

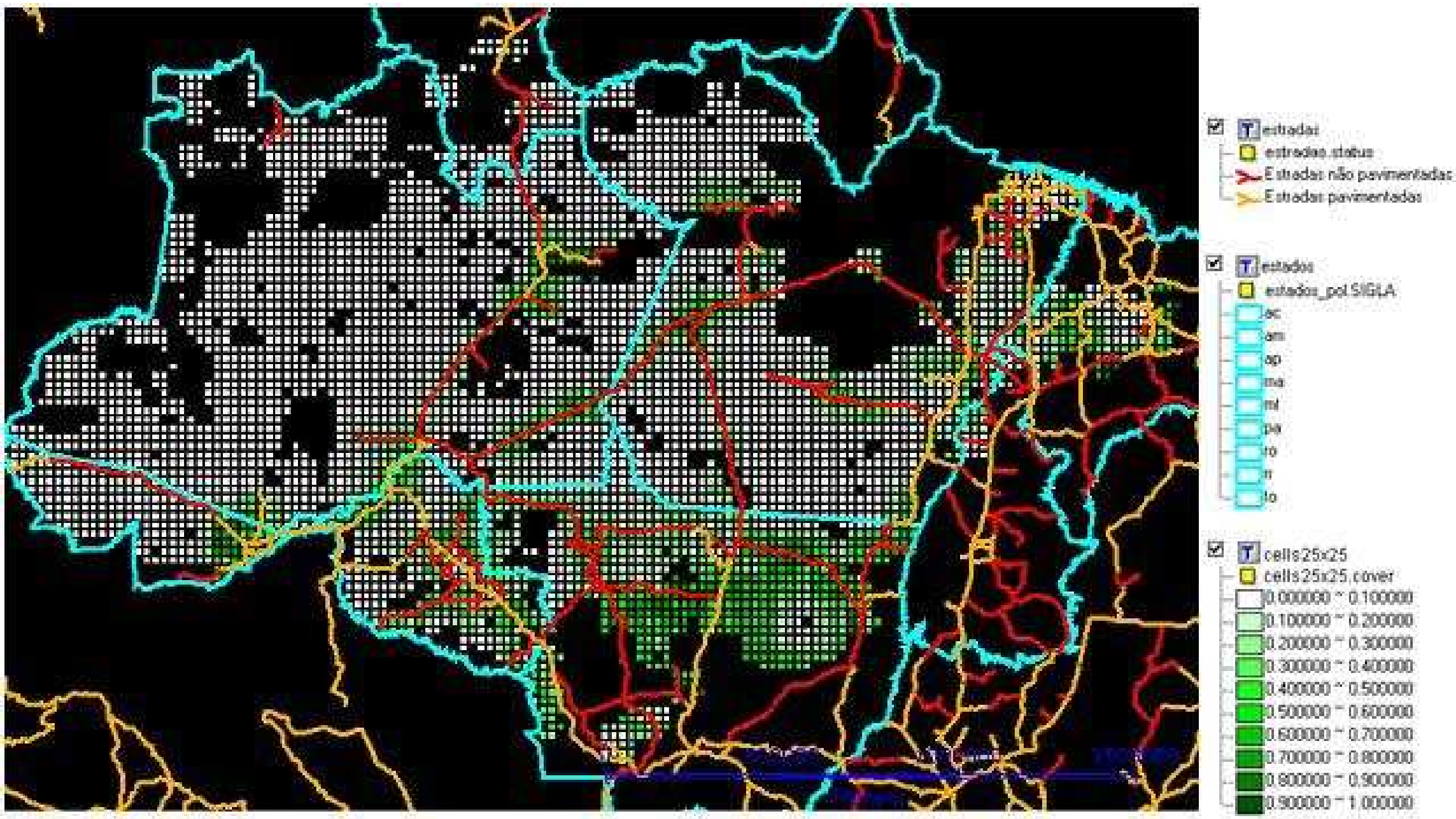
- Computer Systems:
  - TerraLib: open source GIS library
  - TerraME: open source environmental modeling platform

- Cyclical interactive process of Model/Software development

- Study Case: a land use and land cover change model (LUCC)

Results

The Irregular Cellular Space Concept:



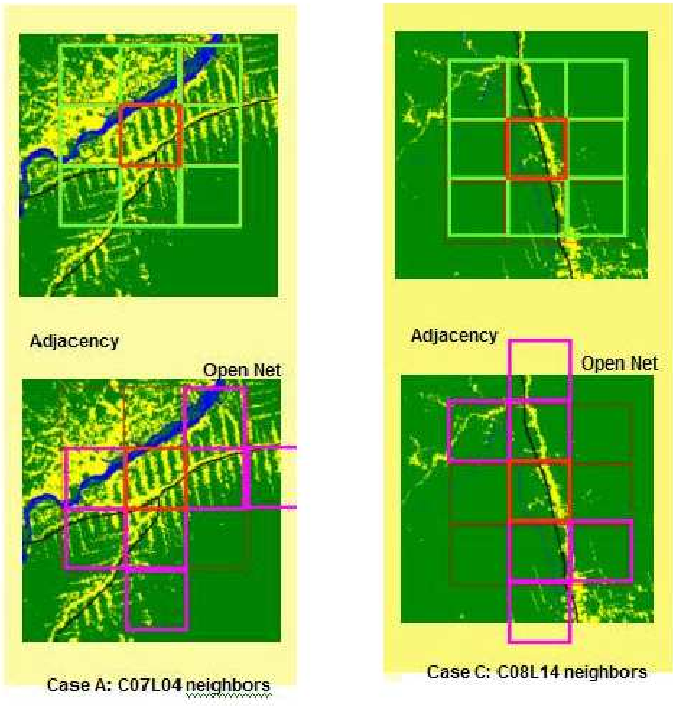
Irregular Cellular Spaces: (1) $25x25km^2$ sparse squared cells; (2) each polygon representing one Brazilian State is a cell; (3) each roads is a cell;

Results

- **The Irregular Cellular Space Concept:**
  - The cellular space is any irregular arrange of cells which geometrical representation may vary.
  - There is no rigid structure for the space representation.
  - Cells may be:
    - Grid of same size squared cells;
    - Points;
    - Polygons;
    - Lines;
    - Arch e node (Graphs);
    - Pixels;
    - Voxels.

Results

- **The Irregular Cellular Space Concept:**
  - Topological relationships are expressed in terms of **Generalized Proximity Matrixes** (GPMs) allowing the representation of non-homogenous spaces where the spatial proximity relations are non-stationary and non-isotropic [Aguiar and Câmara 2003].
    - Absolute space relations such as Euclidean distance
    - Adjacency and relative space relations such as topological connection on a network.

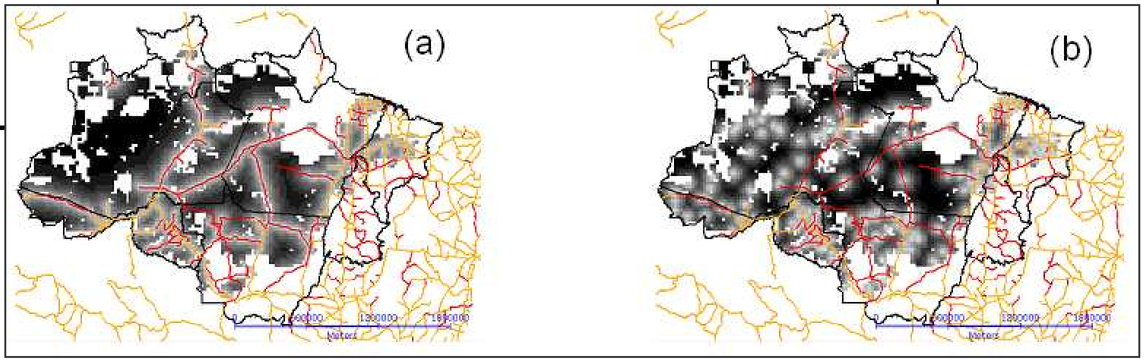


Results

- **How to model spatial trajectories of changes in an unstructured spatial model?**

- **Spatial Iterators**: are functions that maps modeler built partially ordered sets of index into cell references.

```
it = SpatialIterator{
        cs,
        function( cell ) return cell.cover == "forest"; end,
        function( c1, c2 ) return c1.distRoad > c2.distRoad; end
}
```



The Irregular Cellular Space Model

- **(definition 1)** The ICS is a set of cells defined by the structure (S, A, G, I, T), where:

  - S □ Rn is an n-dimensional Euclidian space which serves as support to the cellular space. The set S is partitioned into subsets, named cells, S = {S1, S2,..., Sm | Si∩Sj=□, □i≠ j, □Si =S}.

  - A= {(A1, ≤),(A2, ≤),...,(An, ≤)} is the set of partially ordered domains of cell attributes, and where ai is a possible value of the attribute (Ai, ≤), i.e., ai □ (Ai, ≤).

  - G = {G1, G2,...,Gn} is a set of GPMs – Generalized Proximity Matrix (Aguiar, Câmara et al. 2003) used to model different non-stationary and non-isotropic neighborhood relationships, allowing their use of conventional relationships, such as topological adjacency and Euclidian distance, but also relative space proximity relations, based, for instance, on network connection relations.

  - I = {(I1, ≤), (I2, ≤),..., (In, ≤)} is a set of domains of indexes where each (Ii, ≤) is a partially ordered set of values used to index cellular space cells.

  - T = {T1, T2,..., Tn} is a set of spatial iterators defined as functions of form

  - Tj:(Ii, ≤)→S which assigns a cell from the geometrical support S to each index from (Ii, ≤). Spatial iterators are useful to reproduce the spatial patterns of change since they permit easy definition of trajectories that can be used by the model entities to traverse the space applying their rules. For instance, the distance to urban center cell attribute can be sorted in an ascendant order to form an index set (Ii, ≤) that, when traversed, allows an urban growth model to expand the urban area from the city frontier.

The Irregular Cellular Space Model

- **(definition 2)** A spatial iterator Ti ∈ T is an function defined as Ti:(I_i, ≤)→S that maps modeler built partially ordered sets of index (I_i, ≤) ∈ I into cells s_i ∈ S.

- The following functions should be defined by the modeler in order to construct the set of indexes (Ii, ≤) and later uses it to build a spatial iterator.

  - **(definition 2.1)** filter:Sx(Ai,≤)→Boolean is a function used to filter the ICS, selecting the cells that will form the spatial iterator domain. It receives a cell s_i ∈ S and the cell attributes ai ∈ (Ai, ≤) as parameters and returns “true” if the cell si will be inserted in (Ii, ≤) and “false” if not.
  - **(definition 2.2)** ≤:(Sx(Ai,≤))x(Sx(Ai,≤))→Boolean is the function used to partially order the subset (Ii, ≤) of cells. It receives two cell values as parameters and returns “true” if the first one is greater than the second, and otherwise it returns “false”.
  - **(definition 2.3)** SpatialIterator:SxAxRxO→T is a constructor function that creates a spatial iterator value T_i ∈ T from instances of functions of the families R and O, where R are the filter functions as in definition 2.1 and O are the ≤ function as in definition 2.2. The SpatialIterator function is defined as: SpatialIterator(filter, ≤) = {(a_i, s_i) | filter(si, ai) = true, a_i ∈ (Ai, ≤) and s_i ∈ S; ai ≤ aj, i ≤ j; si = spatialIterator(filter, ≤) s_i ∈ S and a_j ∈ (A_i, ≤) where i = j}.

The Irregular Cellular Space Model

Dynamic Operations on ICS:

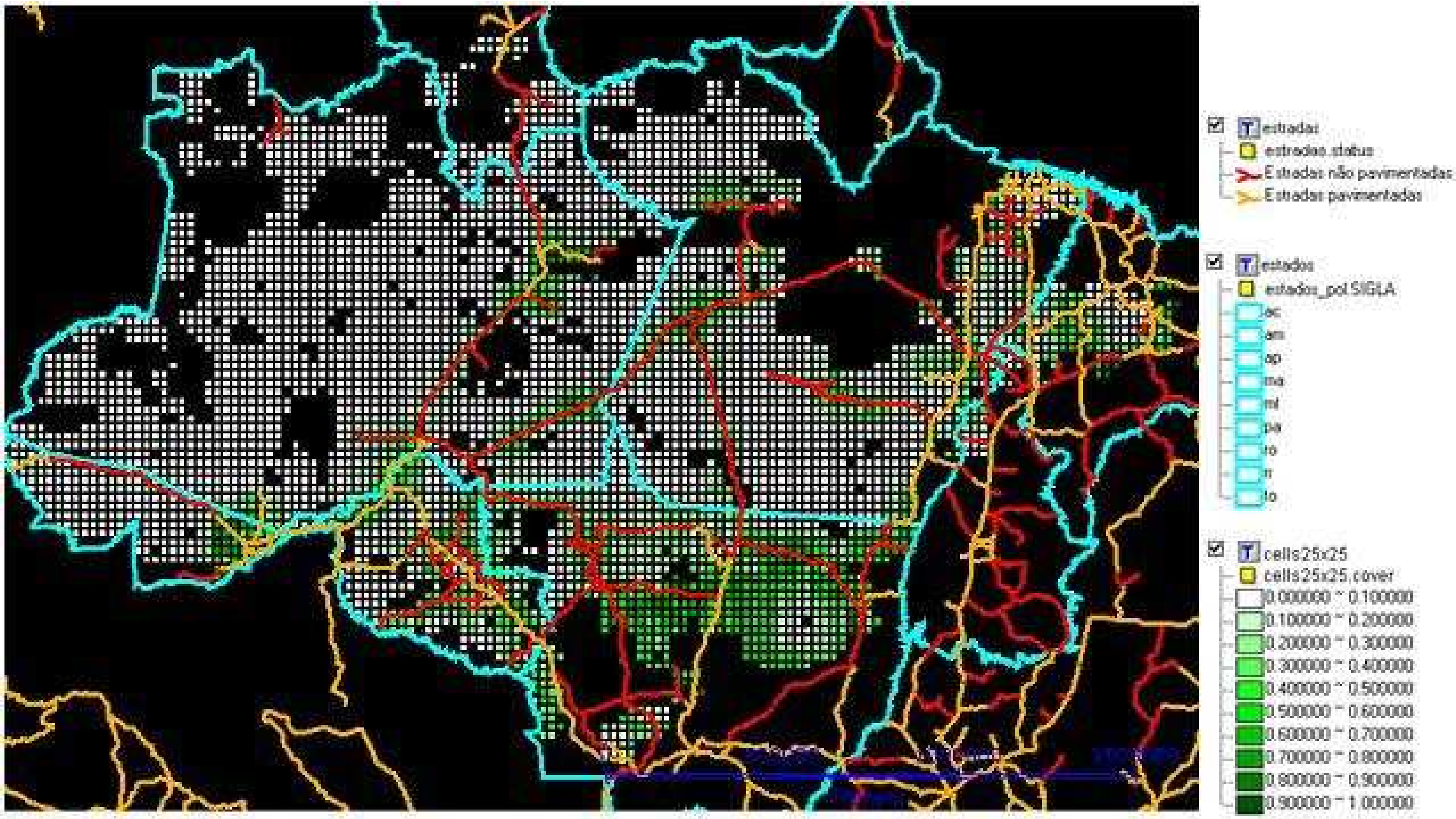
- **(definition 3) ForEachCell:TxF→A** denotes the function that uses the spatial iterator Ti ∈ T to traverse an ICS applying a modeler defined function fm ∈ F, where F is the family of functions from the form fm:SxNxA→A that calculates the new values for the attributes a_j^t ∈ Aj from the cell sj ∈ S received as parameter. These functions also receives two others parameters: n ∈ N a natural number corresponding to the relative cell position in the partially ordered set (Ii, ≤) ∈ I used to define the spatial iterator Ti, and a_j^{t-1} ∈ A the old values of the attributes a_j^t .

- **(definition 4) ForEachNeighbourhood:SxGxF→A** is a function which traverses the set of neighborhoods, G, from the cell received as parameter and applies a modeler defined function fv ∈ F to each cell neighborhood gi ∈ G, where F is the family of functions from the form fv:G → Bool. The function fv receives a neighborhood gi as parameter and returns a Boolean value: true if the ForEachNeighbourhood function should keep traversing the cell neighborhoods, or false if it should stop.

- **(definition 5) ForEachNeighbor:SxGxF→A** is a function which receives three parameters: a cell si ∈ S, a reference to one of neighborhood gi G defined for this cell, and a function fn ∈ F, where F is the family of functions from the form fm:(SxA)x(SxA)xR→Bool. The ForEachNeighbor function traverses the neighborhood gj and for each defined neighborhood relationship it applies the function fm with the parameters fm(sj, sj, wij), where sj ∈ S is the si neighbor cell and wij is a real number representing the relationship weight.

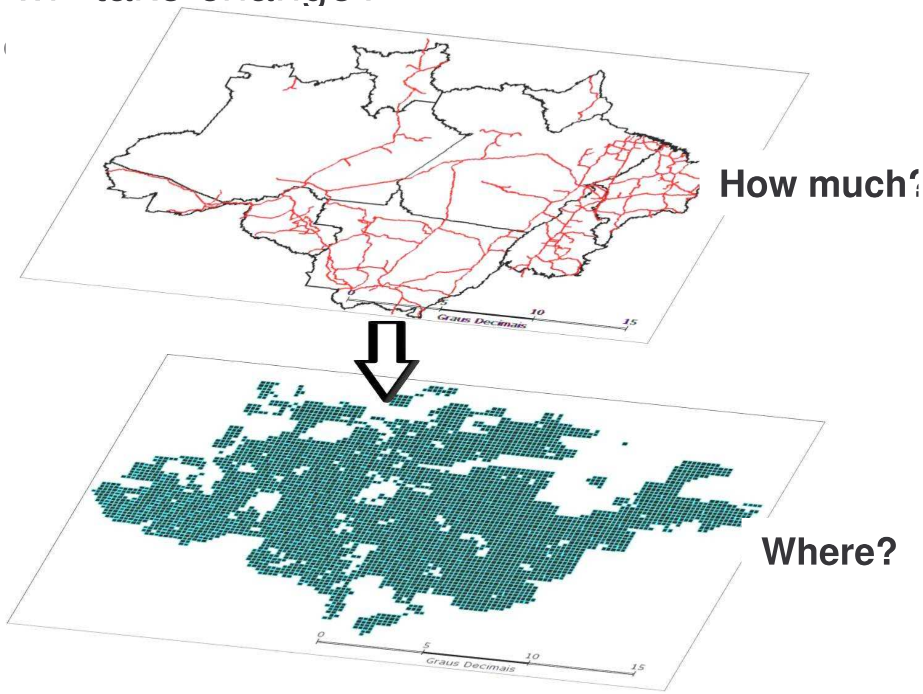
Results

- Study Case: a land use and land cover model (LUCC) for the Brazilian Amazon.



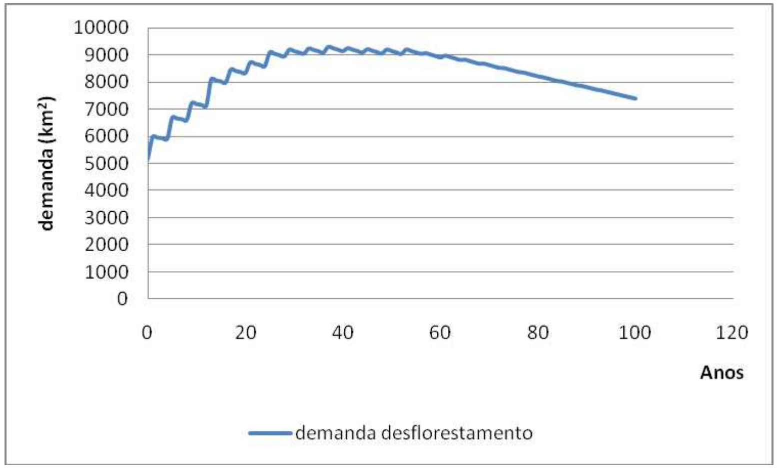
Results

- 2 Submodels (2 different scales):
  - **Demand Model:** how much change?
    - 1 Cellular Space: the Legal Amazon States
    - 1 Cellular Space: the Legal Amazon roads
  - **Allocation Model:** where the change will take change?
    - 1 Cellular Space: the sparse squared



Results

- Demand Model:
  - Each State has 2 main attributes:
    - deforestDemand
    - forestArea



  - 1 simulation step = 1 year
  - Deforestation demand:

$$state.deforestDemand = taxaReal * state.forestArea$$

  - Absolute taxes:

$$taxaAbs = \frac{\frac{state.kmEstradas}{state.area}}{\sum \frac{kmEstradas}{area}} * taxaDeforest$$

Results

- More roads → more deforestation

- Real deforestation rate per State:

$$taxaReal = taxaAbs * paved$$

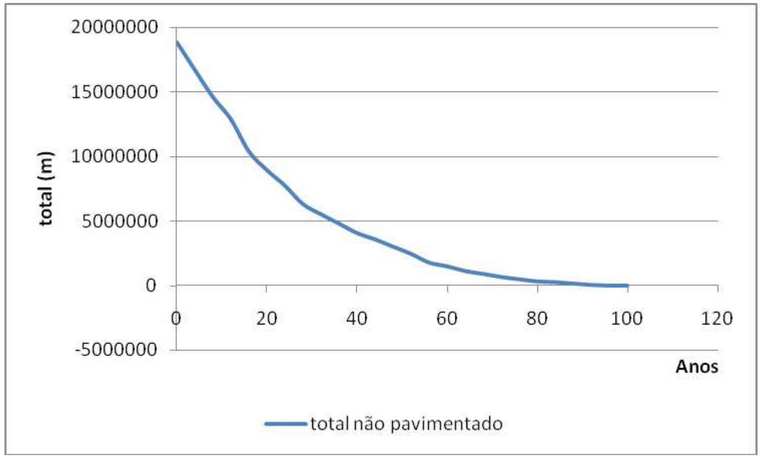
- More paved roads → more deforestation .

- Each 4 years 10% of the roads are paved.

- Initially, we have 100% of forest.

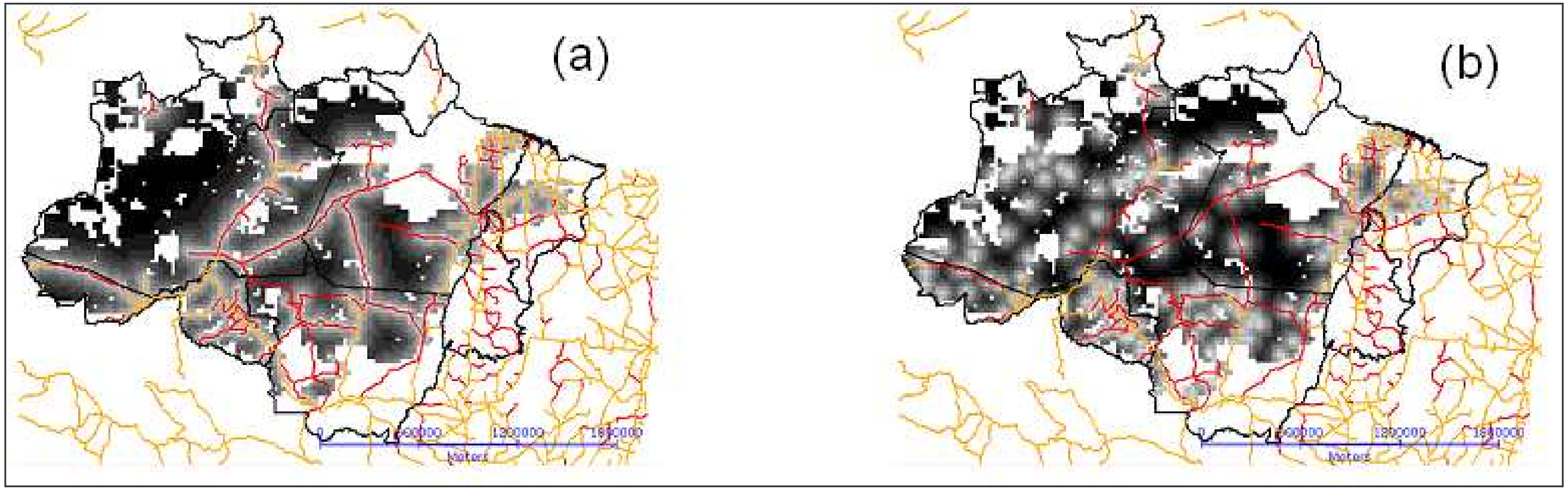
- The forest total area is:

$$state.forestArea = state.forestArea - state.deforestDemand$$

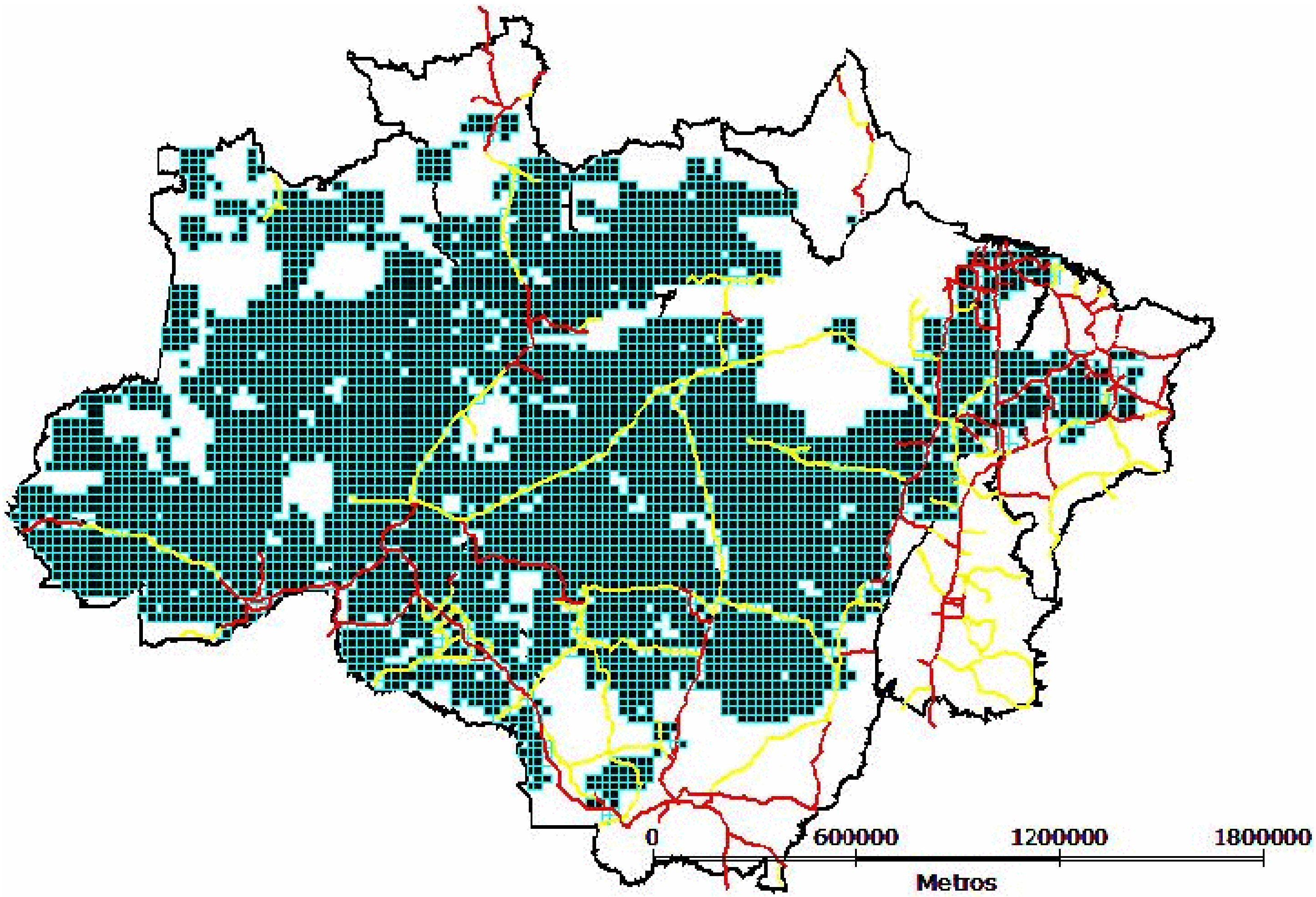


Results

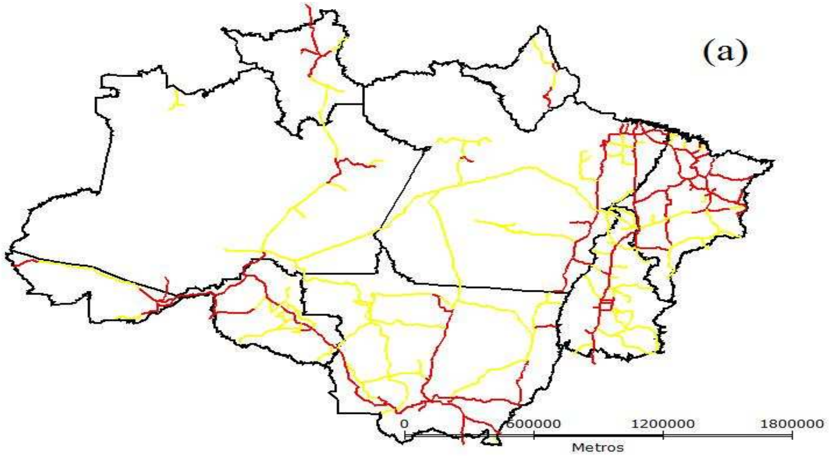
- Allocation Model:



Results



Results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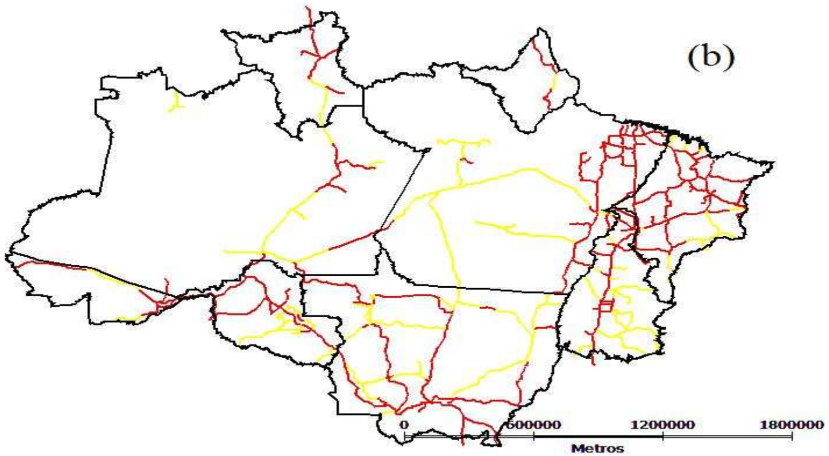
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The End

Thank You!

Questions?