Brazilian Journal of Cartography (2017), Nº 69/5, Special Issue GEOINFO 2017: 903-912
Brazilian Society of Cartography, Geodesy, Photgrammetry and Remote Sense
ISSN: 1808-0936

DBCELLS – AN OPEN AND GLOBAL MULTI-SCALE LINKED CELLS

DBCells – um Espaço Cellular Multi-Escala Global, Aberto e Conectado

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Received on June 19, 2017/ Accepted on July 16, 2017
Recebido em 19 de Junho, 2017/ Aceito em 16 de Julho, 2017

ABSTRACT

Land change models require large amounts of data, and are difficult to be reproduced, as well as to be reused. Some initiatives to open and link data increase the reproducibility of scientific experiments and data reuse. One pillar of the linked data concept is the use of *Uniform Resource Identifier* (*URI*). In this paper, we propose *DBCells* – an architecture for publication of a global cellular space where each cell has a URI. This new approach will allow comparison, reproduction and the reuse of models and data. However, in order to succeed, this proposal requires participation, partnerships and investments. The main purpose of this paper is to present the architecture, benefits and challenges for debating with the scientific community.

Keywords: Cellular-Space, Land-Change, Models, Open Data, Linked Data.

RESUMO

Os modelos de mudanças de uso e cobertura da terra demandam grandes quantidades de dados, tornando-os difíceis de serem reproduzidos e reutilizados. Algumas iniciativas para abrir e conectar os dados aumentam a reprodutibilidade de experimentos científicos e a reutilização dos seus dados. Um pilar do conceito de dados conectados é o uso de *Uniform Resource Identifier* (*URI*). Neste artigo, propomos *DBCells* - uma arquitetura para publicação de um espaço celular global, onde cada célula está associada a um *URI*. Esta nova abordagem permitirá a comparação, reprodução e reutilização de modelos e dados. No entanto, para ter sucesso, esta proposta requer participação, parcerias e investimentos. O objetivo principal deste artigo é abrir um debate com a comunidade científica sobre esta arquitetura, seus benefícios e desafios.

Palavras-chave: Espaço Celulares, Modelos de Uso da Terra, Dados Abertos, Dados Conectados.

1. INTRODUCTION

The reproducibility is a crucial characteristic for experimental science and requires access to data and tools (MOLLOY, 2011). Furthermore, the comparison and reuse of data and results play critical roles. The achievement of these requirements is a great challenge in experiments that demand large volumes of data, like land change models. These models demand data from environmental, social, technological, and political drivers (MORAN *et al.*, 2005; TURNER *et al.*, 2007). In general, each driver is represented as a value in a spatial unit, a pixel or a cell. A pixel is the smallest addressable element in the raster layer that represents a spatial variable, like slope or distance to roads. The cell space is an alternative representation, where each cell handles one or more types of attribute (CÂMARA *et al.*, 2008). In both cases, cells and pixels are not treated as unique and distinct entities, but as partitions of a continuous space. Then, even the smallest differences in the bounding box of the study area can generate different cell spaces. These differences make the comparison and reuse of data a great challenge. In this paper, we propose that each cell from each resolution is a unique and distinct entity that has a universal identifier, what we call *DBCells* architecture.

The *Uniform Resource Identifier* (URI) is one of the pillars of the web data architecture, which links data instead of pages. The architecture proposed by Tim Berners-Lee is referred to as linked data (BERNERS-LEE, 2006) and provides support for large datasets, such as *DBpedia* (AUER *et al.*, 2007) and GeoNames (WICK & VATANT, 2012). The *DBpedia* describes all the concepts from Wikipedia through URI, for example, the National Institute for Space Research is identifiable by:
http://dbpedia.org/data/National_Institute_for_Space_Research.rdf. This institute is located in São José dos Campos, and is identified in the GeoNames by the following url:
http://sws.geonames.org/6322578/about.rdf.

Several authors have argued that linked data allows experiments to become more reproducible, which depends on large volumes of data (KAUPPINEN & ESPINDOLA, 2011; MOLLOY 2011). In addition, some authors argue that linked data can be explored to share large volumes of data among the scientific community (QUOCA *et al.,* 2014). In Quoca *et al.* (2014) the authors describe how NOAA dataset can be transformed and published as linked data. The data from 20.000 weather sensor stations over the world were converted to 177 billion triples. Other example of linked open data is the Linked Brazilian Amazon Rainforest Data (KAUPPINEN *et al.,* 2014). This dataset is openly available for anyone for non-commercial research use. However, in this dataset each variable (land use, demography, environmental, accessibility to markets technology) is strongly coupled to the cells. In our architecture proposal, described in Section 3, the cells are distinct entities that have an universal identifier, which can be linked from other data. In other words, each cell is a spatial unit that can link results and data from land change models. This paper is organized as follows: Section 2 presents the two major concepts – the open linked data and cellular-space; Section 3 describes *DBCells* – the architecture proposed; Section 4 summarizes the main benefits and challenges to achieve the link between the models in global scale.

This paper is based on Costa *et al.* (2015) previously presented at GEOINFO conference (www.geoinfo.info)

2. THEORETICAL FOUNDATION

This section presents two major foundations for our work: open linked data and cells. These concepts are important for a better comprehension of our architecture presented in Section 3.

2.1 Open linked data

First of all, it is necessary to distinguish data, linked data and open data, as shown in Figure 1. Data are the base of the pyramid, and are defined as symbols that represent properties of objects, events and their environment (ACKOFF, 1989). Open data are all those that can be freely used, modified, and shared by anyone for any purpose (The Open Definition, 2013). The linked data refers to a set of best practices for publishing and interlinking structured data on the Web (HEATH & BIZER 2011).

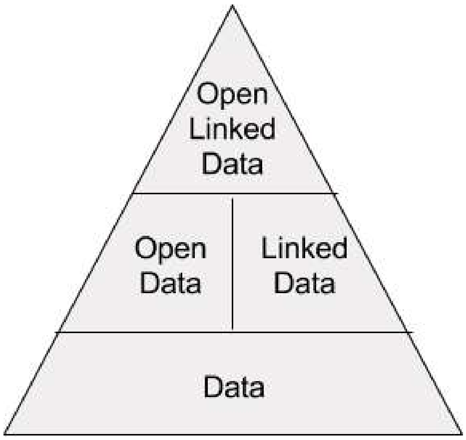

Fig.1 - From data to open linked data.

The movement of open data is inspired by open source movement and consists of three major concepts: openness, participation and collaboration (CHIGNARD, 2013). These concepts are present in the following three key features: (a) Availability and access – data must be available as a whole and in a way that does not create complicated processes for the interested party in copying it; (b) Reuse and Redistribution – data must be provided under terms that permit reuse and redistribution, including combining this data with other datasets; (c) Universal Participation – everyone must be able to use, reuse and redistribute; there should be no discrimination against fields of endeavour or against persons or groups (DIETRICH *et al.,* 2009). The open data movement can bring democratic gain, like better transparency of public action, citizen participation and response to the crisis of confidence towards politicians and institutions (CHIGNARD, 2013; Janssen *et al.,* 2012). However, authors point out some prerequisites: the availability on the web and the machine readability. In other words, they must follow the three laws proposed in Eaves (2009), which are:

1. If the data cannot be spidered or indexed, it does not exist;
2. If the data is not available in open and machine readable format, it cannot engage;
3. If a legal framework does not allow it to be repurposed, it does not empower.

Being readable for the machines is also one of the characteristics required for linked data. However, in the linked data concept, it is necessary to link and allow it to be linked by other datasets, which is summarized in the following principles (BERNERS-LEE, 2006):

1. Use URIs as names for things;
2. Use HTTP URIs, so that people can look up those names;
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL);
4. Include links to other URIs, so that they can discover more things.

In Berners-Lee (2006), the author describes the datasets in terms of five-stars.

Each rating represents a progressive transition from data to Linked Data. Every data is available on the web (at any format), but the ones with an open license have 1 star. In addition to that, if the data is available as machine-readable structured data (e.g., Microsoft Excel instead of a scanned image of a table) then it has 2 stars. To have 3 stars, the data needs to be available at a non-proprietary format (e.g., CSV instead of Excel). The next star requires data to be available according to the previous constraints, plus the use of open standards from the W3C (RDF and SPARQL), in order to identify things, so that people can link to it. Finally, to have 5 stars, data needs to be available according to all the above criteria, plus to provide context via outgoing links to other people data. It is important to emphasize that the opening is not a prerequisite for linked data. For example, a private company can link their data, but does not necessarily make to make them open. Figure 2 shows the linking open data cloud in 2014. The *DBpedia* (AUER *et al.,* 2007) and *GeoNames* (WICK & VATANT, 2012) datasets are located in the center.

Open and linked data is an important element to open science (MURRAY-RUST, 2013; KAUPPINEN & ESPINDOLA, 2011). In (KAUPPINEN & ESPINDOLA, 2011), the authors propose the Linked Open Science aiming to be a standardized and generic recipe for executable papers. This concept was built on these four key elements: (a) Linked Data, (b) OpenSource and Web-based Environments, (c) Cloud Computing and (d) Creative Commons. An example of linked open data is the Linked Brazilian Amazon Rainforest Data (KAUPPINEN *et al.,* 2014). This dataset is openly available for anyone that will make non-commercial research use of it. The data was produced by the Institute for Geoinformatics, University of Muenster, Germany and the

National Institute for Space Research (INPE) in Brazil. However, in this dataset, each variable (land use, demography, environmental, accessibility to markets technology) is strongly coupled to the cells. In our proposal, described in the Section 3, the cells are distinct entities that have a universal identifier, which can be linked from other datasets.

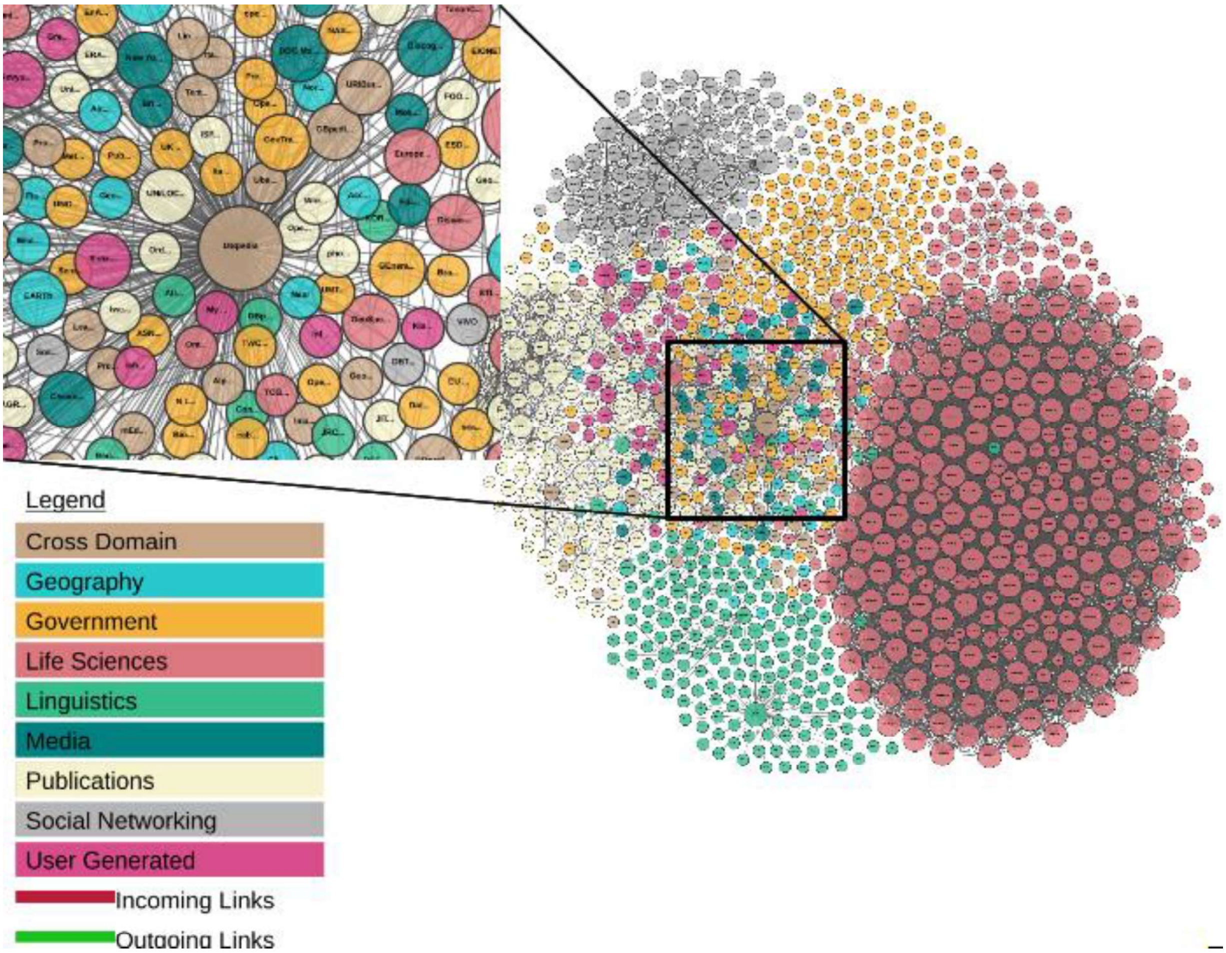

Fig. 2 - Linking open data cloud. Source: (ANDREJS ABELE, JOHN P., PAUL BUITELAAR, 2017)

2.2 From geo-fields to cellular space

Our focus is on data from land change models. In general, these models describe phenomena that vary continuously in space and time, such as deforestation in the Brazilian Amazon region. Their input and output are represented as geo-fields. Together with geo-objects, geo-fields are the two fundamental spatial representations (KUHN, 2012, CÂMARA, 2005). Geo-objects describe entities that have an identity as well as spatial, temporal, and thematic properties (KUHN, 2012). However, geo-fields have been shown to be more fundamental than geo-objects and are capable of integrating both representations (LIU *et al.,* 2008, CÂMARA *et al.,* 2014; COSTA *et al.,* 2007) As data structure, geo-fields are discretized and used two ways (KUHN, 2012):

1. through a finite number of cells, within each one the attribute is assumed to remain constant;
2. through a finite set of sample points with interpolation rules for positions among them.

In this paper, we are interested in the first way, where the study area is partitioned forming a regular grid of square, triangular, hexagonal, or cubic cells as in raster based layers or a cellular space. The raster model can be compared with a bitmap image, which consists of a number of pixels organized in rows and columns. Basically, in most cases, raster data is indeed derived from satellite images, which serve as a basis for observing weather, vegetation or electromagnetic radiation. A cellular space is an alternative model to represent geo-fields. It is a spatial data type where each cell handles one or more types of attribute (CÂMARA *et al.,* 2008). In Câmara *et al.* (2008), the authors argue that cellular spaces were part of early GIS implementations, but now it is time to reconsider this decision and reintroduce it as a basic data type; they also argue that the usage of one-attribute raster data in the storage of results for dynamical models requires the storage of information in different files. By the other hand, a cellular space stores all attributes of a cell together, with significant benefits for modeling, in contrast to the more cumbersome single value raster approach. Together with the concept of Generalized Proximity Matrix (GPM), it is possible to represent hierarchical and network relations (AGUIAR *et al.,* 2003, MOREIRA *et al.,* 2008). In Moreira *et al.* (2008), the authors use these concepts to represent hierarchical and network spatial relations in multi-scale land change models, as showed in Figure 3.

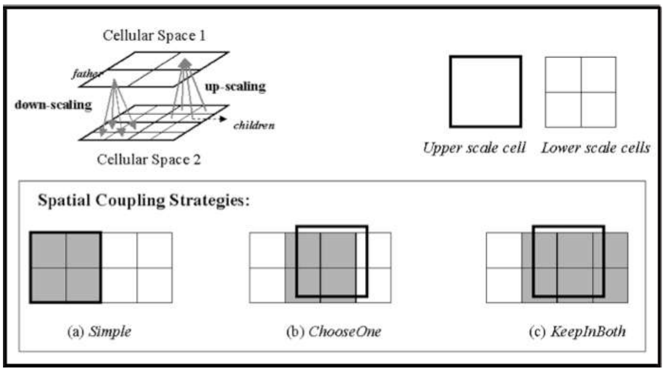

Fig. 3 - Representation of strategies for spatial coupling in the case of regular cells. Source: Moreira *et al.* (2008).

Cellular spaces have been used for simulation of urban and environmental models as part of cellular automata models (BATTY, 2000). In *TerraLib* (CÂMARA *et al.,* 2008) and *TerraME* (CARNEIRO *et al.,* 2013) the cellular space is a native building block. These concepts and tools have supported the development of models published in the literature (AGUIAR *et al.,* 2007, MOREIRA *et al.,* 2009, ESPINDOLA *et al.,* 2012, ANDRADE *et al.,* 2009).

3. THE ARCHITECTURE

We propose a layered architecture (in five layers), adapted from (HEATH & BIZER 2011), as showed in Figure 4. The publication layer includes a dataset of cellular space and multi-scale relationships. The web of data layer links the cellular space to existing datasets, like *Geonames*, *DBPedia* and SWEET Ontology. The data access and storage layer integrate local and web data, providing a transparent access and storage for modeling tools. The model layer uses and shares data provided by the lower layers. For example, coarser scales run models of climate, and finer scales run environmental and social models. The user layer runs and reproduces the experiment of a particular model. A user can publish the results and the data of an experiment in the web of data, allowing replication of experiments, an essential characteristic of science.

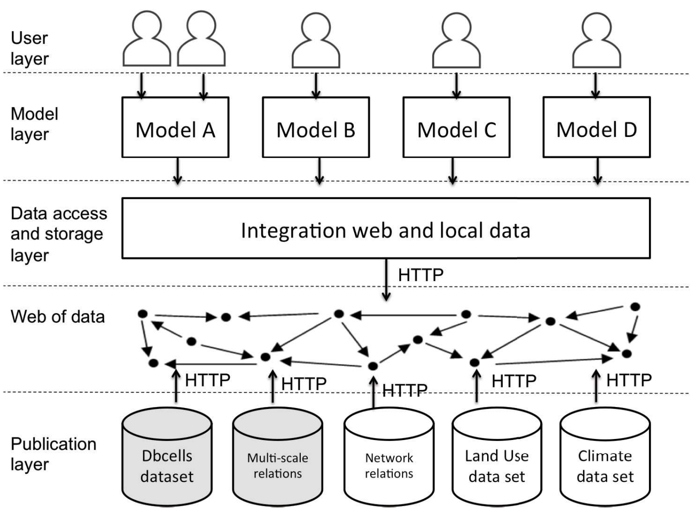

Fig. 4 - The DBCells Architecture Proposal.

In the dataset of cellular space, each cell is identified by a URI and described as a RDF graph, see Figure 5. The RDF (*Resource Description Framework*) is the data model, standardized by W3C for representing Semantic Web resources. It expresses information as graphs consisting of triples with subject, property and object (KLYNE & CARROLL, 2006).

These three graph elements are identifiable through URI. In the dataset of cellular space, each graph consists of minimal set of properties to describe a cell, such as its position and bounding box. These graphs can be stored in a graph database, like the Neo4J[1], and serialized as RDF/XML, see Code 1.

Our proposal is to describe both, the cells and their relationships, through RDF graphs. Graphs express different relations, including: (a) topological relations; (b) network connectivity, both physical (e.g., transportation infrastructure) and logical (e.g., trade fluxes); (c) vicinity in cell spaces and grids; (d) coupling between spatial scales (MOREIRA *et al.,* gdifferent datasets, allowing a model to select one or more relationships. The Figure 6 shows an example where the relationships describe a spatial coupling between cellular spaces in different resolutions. In this case, the nodes are cells and the edges represent the hierarchical relations. Similarly, these relationships can be stored in the graph database and serialized as RDF / XML.

The *DBCells* architecture is under development, and will require partnerships and investments. This article is intended to present and validate this proposal together with the scientific community, as its success will depend on the interest of this community. In the next section we present some benefits and challenges to complete this project.

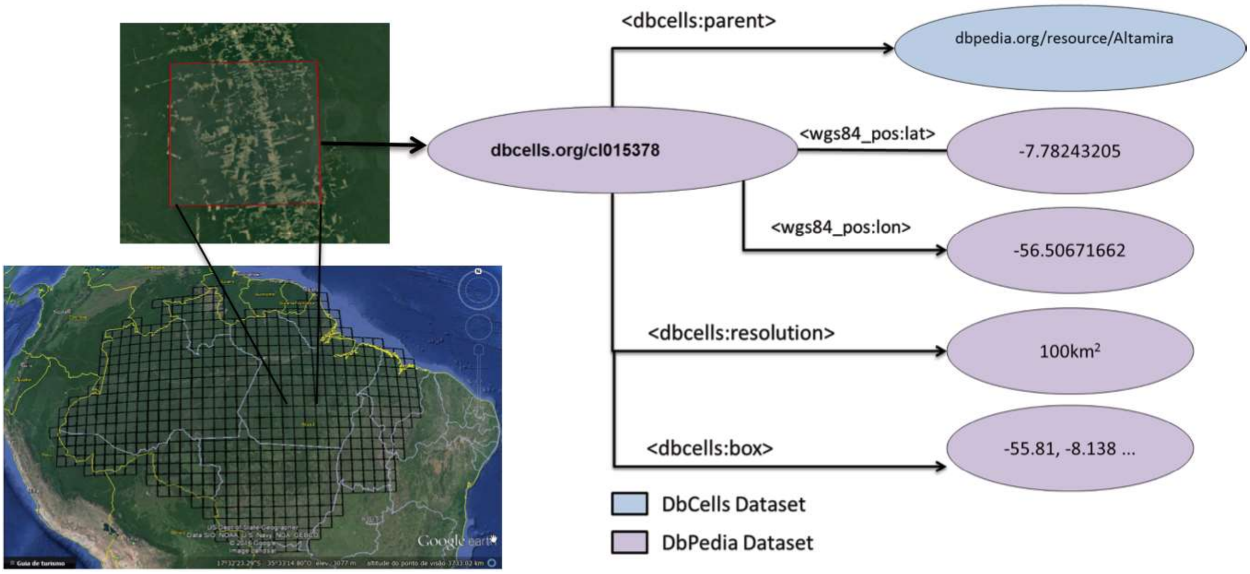

Fig. 5 - A specific cell as a RDF graph.

```
<rdf:Description rdf:about="http://dbcells.org/cl015378">
<wgs84 pos:lat rdf:datatype="http: //www.w3.org/2001/XMLSchema#double"> 7.782432055255575</wgs84
pos:lat>
<wgs84 pos:long rdf:datatype="http: //www.w3.org/2001/XMLSchema#double"> 56.5067166224542l</wgs84
pos:long
> <parent xmlns="http://dbcells.org/">
http://dbpedia.org/resource /Altamira</parent> <resolution xmlns="http://dbcells.org/">100000</
resolution>
<dbcells:box>
55.81526040160506,8.138132254243271,0 54.90595645484754,8.138133321360099,0
54.90595545105769,7.2313407607591,0 55.81525938511868,7.23133981183386,0
55.81526040160506,8.138132254243271,0
</dbcells:box>
</rdf:Description>
```

Code 1. A specific cell graph serialized as a RDF/XML.

[1]https://neo4j.com/

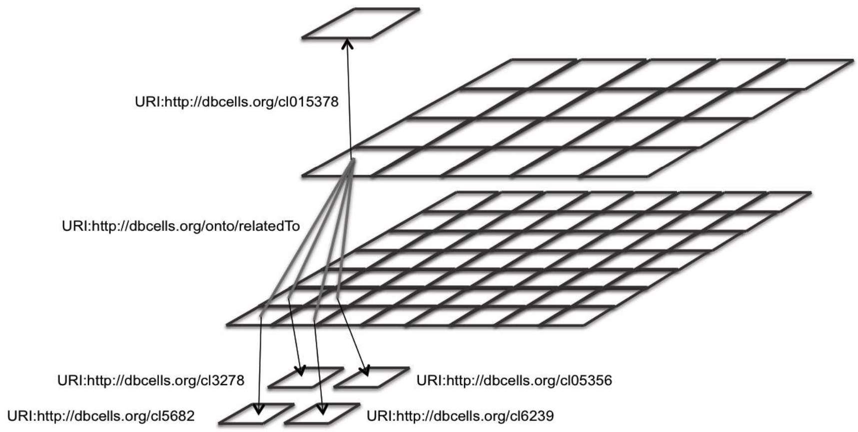

Fig. 6 - Relationships between multi-scale cellular spaces as a graph.

4. BENEFITS AND CHALLENGES

The implementation of this proposal brings several benefits and challenges. Similar to *DBPedia* and *GeoNames*, the *DBCells* may be a dataset that will link datasets from different spatial models. Since each cell has a universal identifier, the models can link their data and results to it. This will allow sharing data and results, and the reuse of datasets already published, illustrated in Figure 7.

The open data is crucial for reproducibility of data demanding experiments (MURRAY-RUST, 2013, (KAUPPINEN & ESPINDOLA 2011, MOLLOY, 2011).

According to (MOLLOY, 2011):

"The more data is made openly available in a useful manner, the greater the level of transparency and reproducibility and hence the more efficient the scientific process becomes, to the benefit of society".

The relationships between cellular spaces allow the reuse of models at different scales and resolutions. For example, a land use model at a finer scale can use results of a climate model in a coarser scale, which is represented in Figure 8. The proposed architecture will also contribute to a better reproducibility and comparison of the data demanding experiments. This benefit is enhanced through open source environment tools (KAUPPINEN and ESPINDOLA, 2011). This architecture presents also several challenges, for example, the participation of the scientific community. The benefits previously mentioned will depend on the community interest in making their data open and linked. Furthermore, each modeling tool will need to implement the data access and storage layer to retrieve and store data on the web. Another challenge is the conflict between vocabularies from different models. Therefore, it will be necessary to use the already established vocabularies, whenever possible. At last, an efficient and distributed computing will be necessary for storage and retrieval of data from a global cellular space at different scales. For that reason, we will conduct the initial experiments in areas of greatest interest by the scientific community like Amazon rainforest.

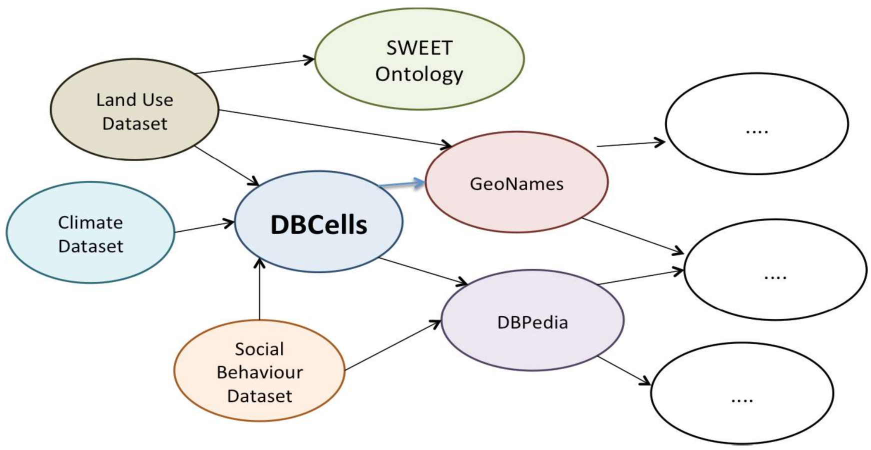

Fig. 7 - Integration between datasets.

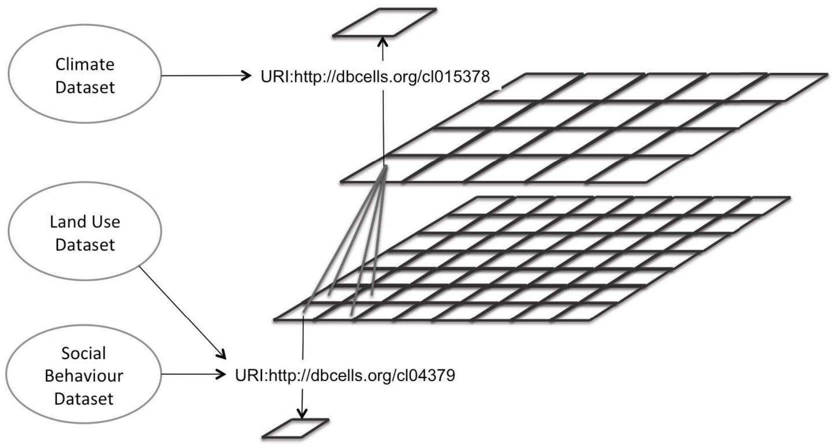

Fig. 8 - Reuse of model data and results between cellular spaces.

5. FINAL REMARKS

This paper introduced an innovative architecture – *DBCells* – that integrates two concepts: cellular spaces and linked data. The pillar of integration is to treat each cell as a unique and distinct entity that has a universal identifier. To achieve this integration, we propose four steps: 1) divide the space in regular cells, 2) associate each cell to an identifier, 3) represent each cell as an RDF graph available on the web and 4) connect data and results models to these identifiers. The main benefits of the new approach are the reuse, sharing, comparison and reproduction of land change models. The main challenges are the participation and interest of the scientific community, and an efficient architecture to store and retrieve large volume of data. Thus, the success of this proposal requires partnerships and investments. Based on that, by presenting our vision, we expect to raise an engaging debate with the scientific community.

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