Ontology-Based Modeling of Land Change Trajectories in the Brazilian Amazon

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Abstract.
Tropical deforestation is an example of geochange with massive impacts to the environment locally and globally. In the Brazilian Amazon deforestation has prevailed owing mostly to private investments in agricultural expansion, associated with large-scale cattle ranching, small-scale subsistence farming and soybeans expansion. Data on deforestation have been relied mostly on satellite remote sensing, mapping the extent of forest loss. Several existing data having diverse spatial and temporal resolution are maintained to analyze the whole land cover dynamics in the region. Although the extent of forest loss has been examined across the Brazilian Amazon, little is known about the transitions among land change pathways. Nevertheless, there is much information about site conditions available from different sources, such as land management and agricultural production, as well as existing settlements, land tenure and household assets. In this paper we propose the Process-oriented Land Use and Tenure Ontology (PLUTO) for semantically integrating and reasoning about data sets related to deforestation and land change trajectory in the Brazilian Amazon, and for publishing them as Linked Data.

Keywords.
Linked Data, Semantic Web, GeoChange, Ontologies, Deforestation, The Brazilian Amazon Rainforest

Introduction

Tropical deforestation causes large greenhouse gas emissions to the atmosphere every year. In the Brazilian Amazon, the rates of deforestation have averaged 17,486 km^2 per year [9], creating significant negative externalities as loss of biodiversity, erosion, floods and lowered water tables [14,6]. Although considerable research has focused on estimating rates of forest conversion in the Brazilian Amazon, less is known about the fate of land that has been converted to human use.

Data on forest loss have been relied mostly on satellite remote sensing to reveal regions where deforestation has taken place. Several existing data having diverse spatial and temporal resolution are maintained to analyze the whole land cover dynamics in the region. For example, National Institute for Space Research (INPE) in Brazil has four operating systems for monitoring deforestation in the Brazilian Amazon: PRODES, DETER, QUEIMADAS and DEGRAD. These systems are complementary and were designed to meet different goals. Nevertheless, there is much information about site conditions available from different sources, such as land management and agricultural production, as well as existing settlements, land tenure and household assets.

Regarding land management and agricultural production, agricultural census data are a rich archive of regional information on land use. Agriculture censuses constitute the most complete survey of agriculture production, including the area under different land use categories (temporary versus permanent agriculture, for example), crop production, levels of mechanization and agricultural inputs. In addition, planning dimensions, including creation of protected areas, indigenous lands and settlements, and land tenure and household assets, have been crucial in shaping the land change trajectories in the region.

However, integration of all different data about different pathways of the whole land change trajectory. is not straightforward for several reasons. First of all, there is often a lack of syntactic interoperability. But even more crucial problem is the lack of semantic interoperability [10] between data sets regarding tropical forests (see e.g. [4,11]). It is necessary to analyse causal links in order to explicate relationships between events and environmental changes [12]. Essentially, different data sets maintain information about different pathways of the whole land change trajectory. The problem hence is how to formally define these pathways, and relate them to each other. Ontologies provide mechanisms for interconnecting concepts—e.g. functions, purposes, activities, and plans [5]—in a machine-processable way, and hence together with reasoning mechanisms offer a potential solution for modeling spatiotemporal semantics of land change pathways.

In this paper we are interested in giving an ontological foundation to essential land change trajectories, and to model them with formal semantics. To achieve this we propose the Process-oriented Land Use and Tenure Ontology (PLUTO)—built as an alignment to the top-level ontology DOLCE [8]— for semantically integrating several data sets related to deforestation and land change trajectory in the Brazilian Amazon, and to publish and share these data sets as Linked Data[1].

1. Modeling Semantics of Land Change Trajectories

1.1. Background

The most compelling reason to monitor land change in the Brazilian Amazon is the strong effect of land change trajectory on the state of converted areas. Concepts of land change trajectories have been used to identify some dominant pathways leading to specific outcomes, and have been presented as typical successions of causes of tropical deforestation across the region. The potential transition

[1] http://linkeddata.org

pathway from forest to other uses depends on the state of the human occupation and site conditions, such as distance to roads [1], presence of settlements and land tenure [13], soils and environmental weather, and market conditions. Therefore, land use and tenure issues have been affecting deforestation in the Brazilian Amazon in several ways, and they are related to recent controversies about detriment impact of land law on deforestation [2]. Since the 1970s, the Brazilian federal government has set up agricultural settlement projects that constrain the ways of use of natural resources and territorial occupation. These official colonization incentive policies—and the associated agricultural and cattle expansion—remained dominant until the end of the 1980s [4].

A growing environmentalist trend took shape during the 1990s, allied with rules enabling local populations to take part in natural resource management. Since around year 2000, the federal government has created policies about land management, including policies about the creation of settlements. In this scenario, government policies have played a significant role in the agricultural colonization frontier. Generally speaking, settler farms have in common a production system characterized by intense use of family labor and simple agricultural technologies joined to a strong drive for cattle ownership and overexploitation of land.

As a result, areas destined to settler farms move through a similar progression of land use pathways over time. The role of the land change trajectory is quite complex since it involves social and institutional arrangements that need to be better understood [3].

1.2. Process-oriented Land Use and Tenure Ontology (PLUTO)

For the purpose of this paper, we will describe a minimum process that represents the most significant pathways related to settler farms. It starts when farmers get parcels (Figure 1–Land reform) and require some initial deforestation to establish ownership and produce food crops to meet immediate food needs (Figure 1–Subsistence). Farmers then clear additional lands for more crops, and at some point they start to purchase cattle (Figure 1–Extensive cattle raising). From this point, the activities of farmers planting subsistence crops are currently small relative to the clearing for cattle raising. After an intensive use of the pasture, the land can be recuperated (Figure 1–Recuperation) or abandoned (Figure 1–Abandonment).

Considering these main descriptions we present below the main concepts of PLUTO.

Land reform Redistribution of land.

Deforestation Forest is removed from an area.

Subsistence Land stays in subsistence until the portion of the deforestation reaches a critical amount.

Extensive Cattle raising Extensive cattle raising after which pasture typically gets exhausted.

Abandonment Regrowth of the forest.

Reclaim Public repossession.

Recuperation Removal of stumps and logs, and plowing, fertilizing,

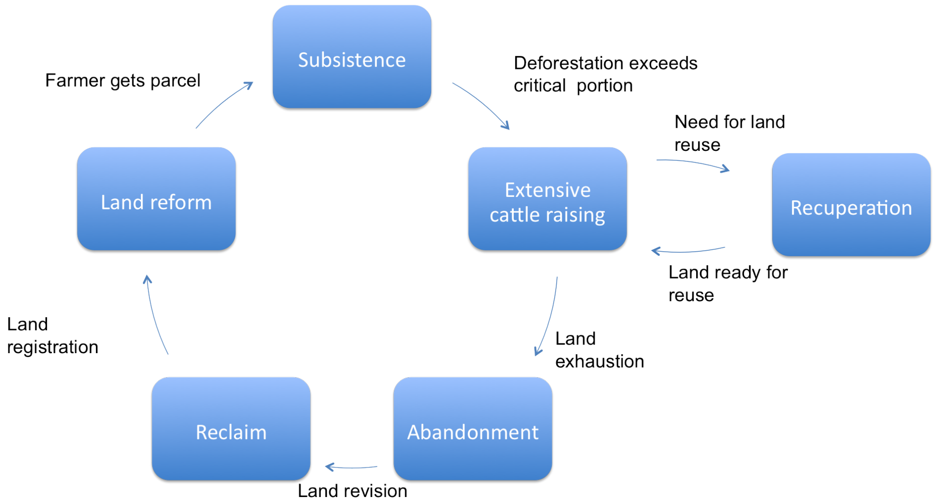

Figure 1. Land tenure model.

These concepts were defined[2] using DOLCE [8]. They are *perdurants* in the sense of DOLCE and were introduced as subclasses of *process*. In addition, in the ontology there are *endurants* that participate in *perdurants*. These include concepts such as *farmer*, *land* and *parcel*.

The intended use of PLUTO is to spatio-temporally annotate land regions in the Brazilian Amazon and model land change trajectories related to them. This allows for analysis of different regions, and of the characteristics of the land change trajectories in each land region. The hypothesis is that these characteristics may be used to find similar pathways around the Brazilian Amazon and hence to help to predict the future of regions based on similar pathways found in other regions. Combined with further data sets about regions (e.g. distance to market, distance to a river or road system, policies regarding the region) this analysis can reveal new knowledge about land change trajectories and help to create better policies for sustainability.

1.3. Rules for Reasoning about PLUTO

In this section we define rules for reasoning about PLUTO ontology. Essentially, these rules are used for asserting new facts concerning endurants and perdurants. The syntax of the rules is as follows. The rules consist of lefthandside (before "$\longrightarrow$") and righthandside (after "$\longrightarrow$"). The idea is that if the lefthandside of the rule matches to some individuals in the knowledge base then the facts in the righthandside are asserted to the knowledge base. The notion parcel(x) means that x is an individual of parcel, i.e. isA-relationship holds between x and the category parcel. Slots (properties) for each class are defined inside brackets. For example, deforestation(d)$\{$participant $x\}$ means that there is an individual d of the class deforestation, which has a participant x. The rules are as follows:

[2]PLUTO is downloadable at `http://observedchange.com/`

$$\begin{aligned} &\text{parcel}(x) \wedge \text{land-reform}(a)\{\text{participant}\, x\} \\ &\longrightarrow \text{farmer-gets-parcel}(g)\{\text{participant}\, x\}, \end{aligned} \tag{1}$$

where if a parcel x is a participant in a land-reform a then the parcel x participates in an event farmer-gets-parcel g.

$$\text{parcel}(x)\{\text{deforestedPortion} > 0\} \longrightarrow \text{deforestation}(d)\{\text{participant}\, x\}, \tag{2}$$

meaning that if at least some portion of parcel x is deforested then x is a participant in deforestation process d.

$$\begin{aligned} &\text{parcel}(x)\{\text{deforestedPortion} < p_1\} \wedge \text{deforestation}(d)\{\text{participant}\, x\} \\ &\longrightarrow \text{subsistence}(s)\{\text{participant}\, x\}, \end{aligned} \tag{3}$$

where p_1 is a typical maximum portion of deforestation of a parcel x such that the x is still a participant in subsistence process s, i.e. the parcel is not (yet) used for extensive cattle raising.

$$\begin{aligned} &\text{parcel}(x)\{\text{deforestedPortion} \geq p_2\} \\ &\longrightarrow \text{extensive-cattle-raising}(e)\{\text{participant}\, x\}, \end{aligned} \tag{4}$$

where p_2 is a typical minimum portion of deforestation of a parcel x such that if it is exceeded then the parcel x will be a participant in extensive-cattle-raising e.

$$\begin{aligned} &\text{parcel}(x) \wedge \text{extensive-cattle-raising}(e)\{\text{participant}\, x\}\{\text{duration} \geq t_1\} \\ &\longrightarrow \text{land-exhaustion}(e)\{\text{participant}\, x\}, \end{aligned} \tag{5}$$

where t_1 = a typical time period of extensive-cattle-raising e after which pasture land normally gets exhausted (degraded) i.e. the parcel x is then a participant in land-exhaustion e. For example, according to [7] "pasture degrades after about ten years", i.e. according to it $t_1 = 10$ years.

$$\begin{aligned} &\text{parcel}(x) \wedge \text{land-exhaustion}(e)\{\text{participant}\, x\} \\ &\wedge \neg\, \text{recuperation}(c)\{\text{participant}\, x\} \\ &\longrightarrow \text{abandonment}(a)\{\text{participant}\, x\}, \end{aligned} \tag{6}$$

where a parcel x participates in land-exhaustion e and not in recuperation c then the parcel x will participate in abandonment a.

2. Conclusions

A tremendous quantity of information related to land change—deforestation, creation of settlements, types of land use—that should be interoperable, linked and shared is still not effectively done. In this paper we addressed the need for information interoperability in the domain of deforestation research. The idea was to support the linking of information resources with the help of an exhaustive and rigorous ontology. We propose use of PLUTO for semantic information integration within the domain of deforestation research. PLUTO enables interconnection between disparate sources for the purpose of 1) processing them automatically, 2) reasoning about it in a way only possible when information has been integrated, and finally 3) sharing and publishing information about deforestation as Linked Data for different organizations to use.

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