Diachronical Geometry Without Polygons: The Extended HHT Ontology for Heterogeneous Geometrical Representations

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Abstract. The notion of territory plays a major role in human and social sciences. Representing this spatio-temporal object and computing their changes have been tackled in various ways. However, in a historical context, most existing approaches are irrelevant as they rely on geometric data, which is not always available. Thus we designed the HHT ontology (Hierarchical Historical Territory) to represent hierarchical historical territorial divisions, without having to know their geometry. Previous versions of the ontology were limited in this aspect by the notion of building Block. This notion was expanded to enable a more flexible representation of geometry, notably based on set operators. An algorithm to detect and qualify changes was implemented using the new geometry formalisation. Six knowledge graphs regarding the evolution of French communes and the expansion of New York City were created to evaluate the use of the ontology and the proposed algorithm.

Keywords: Territory Ontology · Geometry Representation · Change Detection Algorithm · Digital Humanities

1 Introduction

Digital Humanities are a field of studies putting forward the use of computing science to facilitate research in humanities [1]. In the particular context of history, representing territories as they once were is a keen issue, as it is mandatory to anchor facts in a contextualized geography. In History, the notion of *territory* does not merely encompass a space area, which could be boiled down to its geometry. It describes the entanglement of a geographical area and actors having an influence over it, whether this action be normalized by managing institutions or enacted by informal actors, such as individuals. One might even

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argue that the simple fact of naming a geographical area makes it a territory. The notion of territory encompasses that of *territorial unit*, which corresponds to a territorial division defined by an actor and is often involved in a hierarchy or a nomenclature.

In digital humanities, ontologies have been used due to their ability to build representation models favouring reusability and interoperability of the knowledge to be managed [5]. When it comes to representing territories, existing ontologies, such as TSN [4], focus on contemporary territories, are biased by nowadays administrative pragmatism and fail to take into account the scope of the core dynamics underlying a territory.

First of all, properly representing territories in a historical context involves the representation of both the established territorial hierarchies and the actors' claims to alter them. Furthermore, when it comes to historical territories, the geometrical representation can be challenging [14] as it can be missing or imprecise depending on the available historical data. It is to be noted that the map vision of territories, which appears to be commonsense today, was only developed across time. For instance, during the 17th century in France, the typical representation of a territory used to be a list of places [6]. Another dimension of historical territories is their layered structure within multiple, sometimes irregular, hierarchies that overlap but do not match. Finally, representing historical territories is challenging as it requires to describe asynchronously evolving entities which should be characterized by a spatial extent that is more often than not unavailable. It thus requires to provide a means to enable minimal geometrical comparisons that do not rely on an exact geometry representation.

Those challenges led to the creation of the HHT (Historical Hierarchical Territories) ontology[1]. This ontology was designed to allow to represent evolving territories, including geometrical comparisons without using any polygonal geometry, the explicit nature of the occurring changes, as well as the claims of actor who want to cause changes in the territory. Previous papers were published to present respectively an earlier version of the ontology and the territorial change computation algorithm [7] and a second paper described a modular version of HHT, which went more in depth to describe territorial claims [9]. Several limits were still observed. In particular, the diachronical geometry comparison principle proposed in [7] assumed the existence of a time-stable partition of the whole set of territories using territorial building blocks, which excluded the possibility to consider disappearing/appearing cities, if those were retained to be the building blocks. This paper comes back on the overall design of the HHT ontology and particularly focuses on the way those limitations are addressed in the lastest version. It describes a new version of the ontology, along with a new geometry formalism. An algorithm allowing to reason on this new formalism is also detailed. Finally, we provide three new datasets in addition to the three proposed in a previous paper, describing respectively the evolution of communes in France since 1790, a fine grained description of French Administration during the Third Republic, and a smaller dataset describing the expansion of New York City.

[1] https://w3id.org/HHT.

The paper is structured as follows: Sect. 2 provides a global description of the HHT ontology and its goal. Section 3 describes the improvements made to the geometry representation, which are the main contributions of this paper. Finally, Sect. 5 presents the datasets and experiments carried out to evaluate both the ontology and the algorithm.

2 Representing Evolving Territories: An Overview

2.1 Goals/Competency Questions

The overall goal of the HHT ontology is to properly describe territories, which are envisioned as geographic areas defined and impacted by actors. We further refine the needs to be met by the ontology through three main aspects, which lead to competency questions devised through recurrent interactions with historians. They are described in this section and available online[2].

What are the Characteristics of a Territory and How does it Interact with Other territories? The underlying notions are those of **hierarchical level** and **hierarchical criterion**. A territorial hierarchy is the result of a multi-layered division of the territory. Such a hierarchy provides each territory with a level that depends on what we call a hierarchical criterion. The criterion represents the goal behind such a hierarchy. On a single territory, several hierarchical criteria can coexist at a given time period. For example, the modern era in France sees the superposition of four hierarchies existing simultaneously, relating respectively to justice, religion, administration and taxation. Each of these hierarchies defines different levels, with some being part of several hierarchies (ex: ecclesiastical dioceses are part of both the judiciary and religious hierarchies). These issues linked to the representation are mostly tackled in Sect. 2.3.

Which Evolution Occurred in Territories? As an object resulting from the interaction with human actors from a society, every territory is bound to evolve. Thus, using our ontology, we want to be able to produce knowledge graphs representing the evolution of territories, both through their successive states and their occurring changes. These aspects are briefly addressed in Sect. 2.3.

What is the Geometry of a Territory? As stated in the introduction, geometries for historical territories are more often than not non-available. Our ontology thus must provide a geometrical representation that allows for diachronical geometry comparisons without requiring any kind of polygonal geometry. As evidenced in [7] the use of lower level territories as elementary building blocks is not sufficient whenever said territories are impacted by evolution. The representation of geometry must consequently be able to cope with evolving lower level territories and heterogeneous descriptions of territories. The matter of geometry is the core topic of Sect. 3.

[2] https://github.com/Brainchain09/HHT.

2.2 State of the Art of Territorial Ontologies

Several approaches exist to represent multi-level territorial divisions. First, several country-specific ontologies have been developed (`geofla`[3], `igeo`[4] for France, `postcode`[5], `osadm`[6] for the United Kingdom, `RAMON`[7] for the NUTS nomenclature). These ontologies are limited in their use, as the concepts they define are only sufficient to represent hierarchies of a particular country. For example, one cannot describe Spanish territorial hierarchies using `igeo` as is. Country specific ontologies can be extended to represent a different context, especially when their focus is very abstract, such as for [15]. Typically, these ontologies propose several classes representing various hierarchical levels and generic hierarchical relations which can link any kind of level. It thus can be extended by adding new classes for each new level to be taken into account. However, this implies to extend the ontology for every new context which does not favour interoperability.

In order to achieve genericity, other ontologies provide generic classes useful to represent any hierarchical territorial organization. `JUSO`[8] tries to achieve it by providing a very wide array of concepts, intending to cover every hierarchical level to be found in any context. However, the drawback of this concept collection is that the meaning of a term may vary depending on the context. The definition of a town, for example, can vary. In the United States alone, the demographic upper threshold for towns varies between 500 and 4 999 inhabitants depending on the considered state. `CIDOC-CRM` includes the notion of `E4_Period`, which can be interpreted as a territory over a cultural period. However, it does not encompass the notion of evolution of territories, or of hierarchy other than spatio-temporal inclusion.`GeoNames`[9] provides a purely abstract hierarchical structure, which is only limited in its extent by the properties defined. It is only possible to link a place to the first four upper places using the parent object property this ontology defines. `GeoSPARQL`[10] and the ontologies from the SAMPO project [13] achieve genericity by considering only spatial relations, whether they be mereological or geometrical. They do not properly describe a territorial hierarchy, as a hierarchical unit could be geometrically included into another one without being subordinated to the latest, typically in the case of multiple overlaying hierarchies. Finally TSN [3] provides a generic approach to represent territorial division nomenclatures by relying on high level classes while relegating context specificity regarding levels to named individuals. However all these approaches describe hierarchies covering a whole territory according to a single nomencla-

[3] http://data.ign.fr/def/geofla.
[4] http://rdf.insee.fr/def/geo.
[5] http://data.ordnancesurvey.co.uk/ontology/postcode/.
[6] http://data.ordnancesurvey.co.uk/ontology/admingeo/.
[7] https://rdfdata.eionet.europa.eu/ramon/ontology.rdf.
[8] http://rdfs.co/juso/.
[9] http://www.geonames.org/ontology.
[10] http://www.opengis.net/ont/geosparql.

ture, which is commonly accepted in the current country structures. They are not designed to manage several overlaying hierarchies.

Though it is not an ontology, it is important to mention as well the work in [18]. In this approach, territorial hierarchies are presented as mereological inclusions, with several of the complexities of historical territories being addressed.

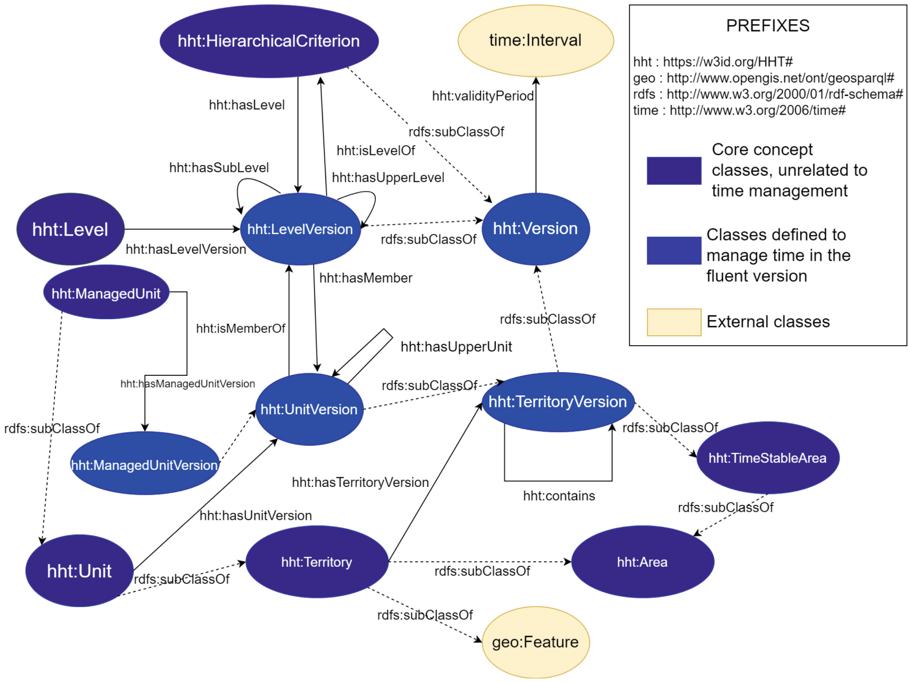

Fig. 1. HHT core classes and properties

2.3 HHT Core Concepts

Figure 1 showcases the main concepts of the core of HHT. Compared to the version presented in [9] we added the concepts of `hht:Area` and `hht:TimeStable-Area` which are used to further refine our description of geometry extent.

Area and Sub-Classes `hht:Area` represents the most generic meaning of a geographic area, meaning that it represents entities defined by their geometric extent, which can possibly evolve through time. `hht:Territory` is the core of our focus. As mentioned earlier, a territory is a `hht:Area` which is defined and shaped by actors. We further refine this definition by providing a minimal condition that is to be respected for an area to be considered a territory: the entity has to have a designation that falls under one of the following characteristics:

– A proper name, such as Paris or the Everest Mountain.
– An address, such as 417 fifth avenue, New York.
– A defined indexing designation, such as Paris third district.

Note that instances of `hht:Territory`, and furthermore its subclasses, generally are bound to know an evolution, meaning that their characteristics, including the geometry they cover, can change over time. Going further into details, `hht:Unit` encompasses all territories that are formally defined by an actor, oftentimes an Organization. `hht:ManagedUnit` are `hht:Unit` which are not only formalized by an actor but furthermore managed by one. Note that the actors defining and managing the `hht:ManagedUnit` can be different. Typically, in the current French administrative nomenclature, regions are defined by the French government and managed by a specifically elected council. All sub-types of `hht:Territory` are described using a 4D-fluents [22] approach. For each of them, a version class (e.g. `hht:TerritoryVersion`) will allow to represent the successive states of an entity. [7] describes more in depth the time-management of entities in HHT. Finally, a `hht:TimeStableArea` is an area which keeps a steady geometry across the studied period of time. This notion will be used when computing geometries in Sect. 3.2.

Hierarchies. Hierarchies are described mostly through two classes : `hht:Level` and `hht:HierarchicalCriterion`. A level is defined following one or several `hht:HierarchicalCriterion` (attached to its versions through `hht:isLevelOf`) and represents the hierarchical level that is attributed to a unit version, through the `hht:hasMember` property. A `hht:HierarchicalCriterion`, on the other hand, is an aspect of human activity whose enactment motivates a hierarchical territorial division. Note the `hht:hasLowerUnit` property, a subproperty of `hht:contains`(and its counterpart `hht:hasUpperUnit`), which allows to express the direct hierarchical superior `hht:UnitVersion` of another unit. Another property, `hht:properContains` represents the strict geometrical inclusion of a territory into another.

3 Geometry or the Lack Thereof

The management of geometries in HHT results from an apparent issue when representing historical territories: geometrical representation often is either absent (e.g. no associated polygon) or imprecise (e.g. a polygon to be extracted from approximate maps). Thus, our ontology comes with a way to describe geometry that tries to cope with this fact. HHT is designed with a geometrical representation that allows to compare the geometries of any two territories, possibly even at different times. The used approach is what we refer to as building blocks, which are small territorial portions whose geometry does not significantly evolve across time, and are used to compose the geometry of higher level territories. Those geometries are consequently represented as sets of building blocks. In a first approach [7], we assumed that some low level territories (described as belonging to `hht:ElementaryLevel` territories), for example towns, could be used as building blocks. Formally, given u a `hht:TerritoryVersion`, we defined its geometry as the set of the lowest (elementary) level territories that compose it:

$$geometry(u) = \{b | \exists bLevel, bVersion, hht : contains(u, bVersion) \wedge \\ hht : isMemberOf(bVersion, bLevel) \wedge hht : ElementaryLevelVersion(bLevel) \wedge \\ hht : hasUnitVersion(b, bVersion)\} \quad (1)$$

However, such an approach could not cope with the creation or disappearance of new building blocks (new towns for example). We thus devised a new approach, which keeps the overall principle of territorial building blocks, but allows for a flexible granularity in their description, with enables the evolution of the geometry of building blocks or their renewal.

3.1 State of the Art

Among many issues arising when attempting to represent historical territories is their geometrical representation [14]. While it is common to use a vector geometry representation when tackling space-spanning entities, the available historical data generally has no geometric representation, which makes such approaches difficult to implement, whether it be for representation or reasoning about changes. [14] partially tackles this issue by carrying geometry comparisons during changes by relying merely on a surface values, which still requires to possess said value. However, most approaches to representing territories [3,16] rely on full geometry description, such as TSN which uses a GeoSPARQL representation. More generally, as highlighted in [19,21], when representing geospatial entities, the common solution is to use a geometry serialization, such as GeoSPARQL [2] or its CIDOC-CRM integration, CRMgeo [12].

Although these approaches are valid when representing standard geospatial entities, they do not meet our needs for a more generic geometry representation, that would enable comparisons when lacking information about the exact geometry. To achieve that, some approaches rely on mereology and mereotopology [10,11,20]. While mereology is the description of the parthood relations between entities, mereotopology includes considerations about the relative position of entities, trying to combine with the foundations of some topology principles.

3.2 Subdividable Building Blocks

In order to tackle this issue, several possible fixes were considered. The first idea was that, due to the issue being the potential evolution of building blocks, and more specifically their appearance and disappearance, representing the composite changes occurring for said building blocks would be sufficient to infer the changes occurring for upper territories. However, issues arose in the case of building blocks redistribution. More importantly, the mere representation of those changes could not provide a satisfying diachronical geometric representation. Imagine for example two territories a and b, which are merged into a new territory c. c is then split again into two new territories d and e. There is no way to compare a, b, d and e.

Thus, a new representation was selected. In this representation, the previous notion of building block is refined into both what we call elementary blocks, which correspond to the previous idea of building blocks and sub-elementary blocks, which are sub divisions of elementary blocks.

Overcoming the Hypothesis of Time-Stable Building Blocks. At any given time of the study period, we consider that elementary blocks define a partition of the whole geometry of the territory that the knowledge graph represents. Following this hypothesis, any new elementary block is created from dismembering or replacing the pre-existing ones. Likewise, the disappearance of an elementary block results in the absorption of the area it occupied by one or several other elementary blocks. The designed solution has in addition to be flexible enough to encompass the case where the information available to describe a territory varies in granularity depending on the location. As a matter of fact, though you could find some specific cases where the exact layout of a city and its evolution are described and you want to take it into account, this data is not necessarily available for other cities, which leads to an heterogeneous representation that can not be encompassed by the former geometric representation. Bearing this in mind, we devise a new representation based on the following principles:

- The notion of Elementary Level is used to describe the default level for geometry computation. When elementary blocks remain stable across the whole period, everything works the same as the previous version did.
- An instance of unit at an elementary level (an elementary block) can be further divided into sub-elementary levels (sub-elementary blocks) that will be taken into account when computing geometry.
- Geometric areas without any specific meaning can be contained by a (sub) elementary block, encompassing the case where we know that a geometric portion is ceded from one block to the other without further information on the status of said portion.

In this section, we further explicit the geometry definition that we propose on the basis of these three principles. First of all, we add to the ontology a notion of `SubElementaryLevel`, corresponding to levels that are located below the previously defined `ElementaryLevel`. If the `ElementaryLevel` was `city`, for example, `SubElementaryLevel` could include `neighbourhood` or even `building`. However, this improvement is not sufficient to describe geometries in a flexible way, as it would require a very fine-grained description of elementary blocks, for which we often lack data. The idea is thus to create geometry portions, which are instances of `hht:StableBlockArea`. The extent of these instances will not evolve in time. The data required about those portions is minimal, as they do not need to represent any actual territory. These instances are attached to the elementary territory which they take part in by means of the `hht:hasGeometry` property.

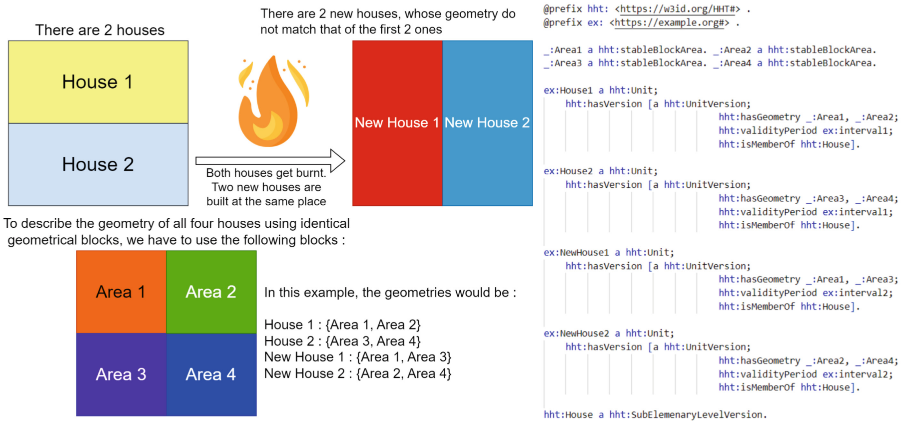

Fig. 2. The burning houses problem

The specific status of such portions is illustrated in Fig. 2. In this example, two houses, which we consider to be territories following our definition, are burnt down. Afterwards, two new houses are built on the same ground, but in a different pattern. We thus have four territories which geometrically overlap but can not be matched with one another. In order to represent the resulting geometries with our set approach, we use the geometric portion resulting from the diachronic intersection of the geometries of the houses. The resulting portions, designated as Area 1-4 in the figure, can not arguably be qualified as territories due to their having no specific meaning for a human actor except the way they are built on the basis of other territories.

With this in mind, assuming v is a `hht:TerritoryVersion` we propose the following geometry definition:

$$geometry(v) = \begin{cases} \bigcup\limits_{sub|hht:properContains(v,sub)} geometry(sub) & \text{if (2) or (3)} \\ \{b|hht : hasGeometry(v,b)\} & \text{if (4)} \\ \{b|hht : hasVersion(b,v)\} & \text{otherwise} \end{cases}$$

(2) describes the case of a non-elementary level territory, (3) the case of an elementary level territory which is described with lower territories, and (4) the case where ane elementary level territory is described with an explicit geometry. Formally :

$$\neg\exists l | hht : isMemberOf(v, l) \wedge (hht : ElementaryLevelVersion(l) \vee hht : SubElementaryLevelVersion(l)) \quad (2)$$

$$\exists l | hht : isMemberOf(v, l) \wedge (hht : ElementaryLevelVersion(l) \vee hht : SubElementaryLevelVersion(l)) \wedge \exists sub | hht : properContains(v, sub) \quad (3)$$

$$\exists l | hht : isMemberOf(v, l) \wedge (hht : ElementaryLevelVersion(l) \vee hht : SubElementaryLevelVersion(l)) \wedge \neg\exists sub | hht : properContains(v, sub) \wedge \exists b | hht : hasGeometry(v, b) \quad (4)$$

In the burning houses example, assuming $House1Version$ is the anonymous version of `ex:House1`, $geometry(House1Version) = \{\_ : Area1, \_ : Area2\}$. Following this definition, several points are to be highlighted.

- With this definition, the geometry of a non-elementary/non-sub-elementary level territory that would not contain any territory is the empty set. The hypothesis of the studied territory being partitioned by elementary blocks, is indeed the key of this geometric representation, and thus, should a graph omit to properly describe the elementary blocks composing an upper level territory, this definition would not apply.
- This definition is recursive and uses `hht:properContains` which represents the strict geometrical inclusion of a territory into another. Assuming the knowledge graph respects the hypothesis of the building block partition, `hht:properContains` being asymmetric and transitive guarantees termination (assuming that the studied territorial division is not infinite, which is not the case in real life).

Towards a Mereological Understanding of Building Blocks. Our approach relies on assimilating geometry with a set of elementary blocks. This approach is similar to that of mereology, which revolves around the parthood relation, which is basically the inclusion relation of set theory. Following this observation, we further refine our description by including set operators of union, intersection and complementary. This proposal has two main purposes: firstly, to improve the expressiveness of our ontology to describe areas that result from operations on the geometries of various territories. Secondly, we want to be able to address open-world concerns. The definitions of geometry previously provided are fully functional only under a closed-world assumption. Imagine typically that a `hht:properContains` triple were left out of the knowledge graph, then the result of the geometry computation would be wrong and could lead to erroneous inferences, notably when it comes to deducing changes in territories. As detailed in Sect. 3.3, indeed, the computation of the nature of changes relies on comparing geometries. For instance, when comparing $V1$ to $V2$, two versions of a territory X, if a `hht:properContains` triple were missing for $V2$, a `hht:GeometryChange` could be inferred even though there is no geometry change in reality. What we are interested in is the result of such operators. We consider that an Area, that could potentially be used as part of a geometry, can be the result of the intersection or the union of several other areas, or the complementary of an area with regard to another. Thus, we introduce sub-classes of `hht:Area`: `hht:AreaUnion`, `hht:AreaIntersection` and `hht:AreaComplementary`.

To go deeper into details, an instance of `hht:AreaUnion` is the area resulting from the geometric union of $n \geq 1$ areas. More formally, given u a `hht:AreaUnion`:

$$geometry(u) = \bigcup_{sub|hht:unionOf(u,sub)} geometry(sub) \tag{5}$$

Similarly, an instance of `hht:AreaIntersection` is the area resulting from the geometric intersection of $n \geq 2$ areas. More formally, given i a `hht:Area-Interection`:

$$geometry(i) = \bigcap_{sub|hht:intersectionOf(i,sub)} geometry(sub) \tag{6}$$

To address open-world concerns, we use a datatype property that specifies the cardinality of these two operators, `hht:operatorCardinality`, which will indicate the number of territories this operatively constructed Area encompasses. Such constructs are attached to a `hht:TerritoryVersion` through the `hht:operativeContent` property, which is functional, meaning that the constructed area should describe the total extent of said `hht:TerritoryVersion`. Note that in order to fully respect the open world hypothesis, all the instances involved should be declared as distinct to be able to fully qualify the union. Regarding the complementary operator, provided our representation of territorial geometries as a set of territories, which are documented in sources in an historical context, the problem of the exhaustiveness of sources arises. Thus, one can always assume that there is a geometrical portion of the represented territory that was not listed. The complementary operator is there to address such cases. Instances of `hht:AreaComplementary` are described using two properties:`hht:complementaryTo` and `hht:complementaryWithRegardOf`. The resulting `hht:Area` is such that the geometry of the area pointed by `hht:complementaryWithRegardOf` is equal to the Union of said resulting area and that pointed by `hht:complementaryTo`. More formally, given c an instance of `hht:AreaComplementary` such as it verifies $hht : complementaryTo(c, a)$ and $hht : complementaryWithRegardOf(c, t)$ we have:

$$geometry(t) = geometry(a) \cup geometry(c) \tag{7}$$

This last operator leads to a final consideration. When we assume that a territory could have a missing portion in the sources used to instantiate the graph, we make an assumption that could be wrong. Phrased differently, the complementary we created could actually be the empty set. This leads us to add two sub-classes of `hht:Area`: `hht:VoidArea` and `hht:NonVoidArea`. The instance v and nv of those classes respectively verify $geometry(i) = \emptyset$ and $geometry(i) \neq \emptyset$. These three operators are defined as relating to either constructed areas or `hht:TerritoryVersion`. This leads to such areas being bound in time, more specifically to the intersection of the time intervals of the `hht:TerritoryVersion` they involve, except for the `hht:AreaUnion` operator, for which the temporal bounds are the union of said time intervals.

The same concern arises regarding the exhaustiveness of geometries when describing the geometry of a territory using `hht:StableBlockArea`. We thus introduce a last subclass of `hht:Area`, `hht:setGeometry`, which is similar to `hht:AreaUnion`, but focuses on representing a set of `hht:StableBlockArea` which will summarize the total extent of the geometry. In the New York dataset presented in the evaluation[11], for instance, `Kings_County` is represented using an `hht:operativeContent`, as its geometry is defined by referring to the geometries of a partition of it. On the other hand, `Yonkers` a territory about the actual content of which we have little information, can only be described using `hht:StableBlockArea`. Its definite geometry is thus documented as a `hht:BlockGeometry`.

3.3 Detecting and Qualifying Changes Without Geometry

In order to detect and qualify changes using our new geometry definition, we build on what was proposed in [7]. The proposed algorithm varies mostly from the previous one by its sticking to the geometry definition proposed in Sect. 3.2, and does not encompass the areas constructed through set operators. The overall principles remain the same. Building on HHT-Change, the HHT module to describe territorial changes[12], we aim to automatically detect and qualify the changes on territories by using HHT to describe territories. For the algorithm to work properly, the knowledge graph should meet the following criteria:

– It should describe the territorial hierarchy only for a specified time period. The Third French Republic dataset used for evaluation in Sect. 4, for example, describes the French administrative hierarchy from 1870 to 1940. Such time boundaries are essential to properly detect appearances and disappearances.
– Geometric descriptions using either `hht:StableBlockArea` or elementary level territories should be part of the knowledge graph for all territories.

Algorithm 1 presents an overview of the steps involved in detecting and qualifying changes. The steps are intentionally quite unrefined as the way some steps are actually performed depends on the chosen implementation. As mentioned in [7], change qualification is achieved using cardinality comparisons. These comparisons are still valid, although we use the current geometry definition instead

[11] Available at https://github.com/Brainchain09/HHT.
[12] https://w3id.org/HHT/Change.

Algorithm 1. Change detection and qualification algorithmic steps

```
for t|hht : Territory(t) do
    Find the time instants at which a change occurs for t
    for each change c do
        Create a new instance of feature change.
    end for
    if the timeline of t starts after the start date of the graph then
        Create a new instance of appearance.
    end if
    if the timeline of t ends before the end date of the graph then
        Create a new instance of disappearance.
    end if
end for
for each feature change created c do
    Qualify the nature of c
end for
Create composite changes aggregating the feature changes
for each composite change created c do
    Qualify the nature of c
end for
```

of the previous one. In terms of implementation, we noticed that the use of SHACL-Rules considerably constrained the way the various steps were executed. In comparison, we provide a compliant implementation with the new geometry using Python code (see Footnote 11). Although the algorithm is largely the same, some steps are affected. Feature changes are aggregated to form composite changes that are only linked to geometry. To achieve this, the approach adopted in [7], considering the possibilities of SHACLRules, relied on a two steps pre-aggregation, leading to partial composite changes, which were then aggregated to form a single `hhtC:CompositeChange`. However, in the current imperative approach, Algorithm 2 implements an alternative process. Note that in the implementation, we check the already aggregated feature changes to avoid computing the same composite change twice.

4 Evaluation and Produced Resources

The evaluation focuses on two aspects: firstly, testing the expressiveness of the produced ontology and assessing the practical writing of the competency questions, and secondly evaluating the algorithm on produced resources. Six datasets are used for this evaluation. First of all, we reemploy the datasets that were proposed in [7]. In addition, we propose two additional datasets about the evolution of communes in France since the French Revolution. The first one only focuses on representing the evolution of French communes from 1789 until 1940 and was built by scrapping the Wikipedia pages detailing the evolution of communes by department[13]. The result of the scrapping was complemented with manual data

[13] e.g. https://fr.wikipedia.org/wiki/Liste_des_anciennes_communes_de_l%27Ain.

Algorithm 2. Aggregate feature changes around a change c

```
composite ← {}
toCheck ← {c}
while length(toCheck) > 0 do
    total ← {}
    for j ∈ toCheck do
        Add the feature changes geometrically linked to j to total
    end for
    toCheck ← {}
    for r ∈ total do
        if r ∉ composite then
            composite ← composite ∪ {r}
            toCheck ← composite ∪ {r}
        end if
    end for
end while
```

corrections, as some changes detailed in these pages turned out to be non-existent or erroneous. The code written to build this dataset is available on Github. The second dataset results from the alignment of this commune dataset with the one about the French Third Republic which uses current communes as building blocks. The resulting dataset provides a more detailed representation of the evolution of territories using the `stableBlockArea` class. Finally we manually constructed a dataset concerning the expansion of New York city based on the data available in [17]. This dataset uses the full expressiveness of the various geometric operators to describe the successive states of the involved territories.

Ontology Expressiveness. The New York dataset illustrates how the expressiveness of the extended geometry definition can be used to its full extent. Notably, it contains cases where we do not describe an entire territory due to lack of information. For example, we do not detail the whole layout of New York state, focusing only on the counties that were fully or partly merged with New York City. Thus, the geometry is partly documented using a complementary operator. The HHT ontology allows to answer all the competency questions detailed on the git resource, which provides SPARQL queries that implement each of these questions.

Algorithm Evaluation. The algorithm was first tested with the datasets produced in [7] to assess the retro-compatibility of the new geometry formalism. The results obtained for these datasets were consistent with those obtained with the previous algorithm. The changes observed in the results compared to [7] are mainly due to the way composite changes are aggregated. The SHACL-Rules approach led to a single composite change being counted several times. Additionally, occurrences of disappearances followed by reappearances have been left out of the count in [7], which explains a difference in the accounting of feature changes, notably in Third Republic dataset. It should be noted, however, that the Python implementation of the algorithm is much faster than the SHACL-Rules implementation. On the old Third Republic dataset, typically, the average computation time was divided by 15. Tested on the newly produced Third Republic dataset, which includes the evolution of communes, the algorithm led to results which encompassed those obtained with the (old) less detailed dataset, supplemented by new changes resulting from the evolution of communes.

5 Conclusion

Currently, the HHT approach enables to represent historical territories, by taking into account multiple overlaying hierarchies, by providing a geometry definition that does not rely on knowledge of any vector geometry or surface figure. The definition of geometry has been extended to allow for more flexibility. It now makes it possible to compare territorial geometries without assuming the existence of a non-evolving territorial elementary partition. Improvements will address the possible use of approaches relying on time stamping properties (instead of creating new objects) by using RDF-star, the further qualification of actors' interaction with territories, as well as the explicit representation of the sources used to build a knowledge graph, and more generally how these sources were used to build the graph. The adoption of HHT by a larger community is also tackled as collaboration with established digital humanities communities is being discussed. This version of HHT also comes with an algorithm relying on our definition of geometry. The provided implementation is restrained to the use of `hht:StableBlockArea` and does not encompass the newly added geometric operator. Further work will need to tackle this aspect, and notably consider how to combine datasets that do or do not specify constructed areas, given that, depending on whether these constructions are represented or not, we need to reason either under a closed-world or an open-world assumption.

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Resource Availability Statement. Source code for the algorithm, the datasets as well as the ontology are available on Github [8] and on Zenodo (**DOI: 10.5281/zenodo.10952532**) All resources are licensed under **Creative Commons Attribution 4.0 International**. The HHT ontology and its documentation are also available at https://w3id.org/HHT.

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