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Towards Interactive Geodata Analysis through a Combination of Domain-Specific Languages and 3D Geo Applications in a Web Portal Environment

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1 ABSTRACT

Urban planning processes affect a wide range of stakeholders including decision makers, urban planners, business companies as well as citizens. ICT-enabled tools supporting urban planning are considered key to successful and sustainable urban management. Based on previous work in the areas of web-based participation tools for urban planning, rule-based geospatial processing as well as 3D virtual reality applications we present a tool that supports experts from municipalities in planning and decision making but also provides a way for the public to engage in urban planning processes. The main contribution of this work is in the combination of 3D visualization and interaction components with a new ontology-driven rule editor based on domain-specific languages. The 3D visualization, on the one hand, enables stakeholders to present and discuss urban plans. On the other hand, the rule editor particularly targets expert users who need to perform spatial analyses on urban data or want to configure the 3D scene according to custom rules. Compared to previous approaches we propose a portable and interactive solution. Our tool is web-based and uses HTML5 technology making it accessible by a broad audience.

2 INTRODUCTION

Involving stakeholders such as planners, architects, politicians, analysts, and citizens in urban planning is a challenging process. Today the demand from the public to influence major urban planning projects is growing. Internet-based communication facilities like social media or blogs are already popular for the discussion of urban planning projects by engaged citizens. Integrating these communication channels with a virtual reality application can help stakeholders to understand proposed actions as well as to illustrate anticipated impacts to a broader audience.

The idea to use 3D virtual reality for participation processes has been described before (Doyle et al. 1998, Al-Kodmany 2002, Zhang et al. 2007). However, broad application was not reached up to now due to the required specialized software and hardware such as costly 3D workstations and CAD expert software or CAVEs[1] for immersive virtual reality experiences, for example. 3D design and CAD software applications were mostly used to prepare printed posters or planning screenshots for special occasions. Albeit these techniques provide excellent visualization solutions they lack in portability and data interaction functionality, as it is common in GIS software.

With the availability of WebGL[2] technology it is possible to render 3D content in a web browser without the need for additional plugins. Based on this, technologies such as X3DOM (Behr et al. 2009) were developed to bring declarative 3D content to the browser and to manipulate it through a common JavaScript API. These features provide a new level of direct interaction with 3D geodata for analysis and feedback on planning proposals in a web browser.

Dambruch and Krämer (2014) report on an interactive web-based portal for public participation. Their solution can be customized with the mouse by dragging components on the screen or moving and rotating objects in the 3D visualization. Krämer and Stein (2014) describe a different approach based on a graphical rule editor allowing basic processing steps to be composed in order to automate geodata processing and in particular to customize 3D visualization. In this paper we combine these two approaches to provide a 3D web application that can be customized through a textual Domain-Specific Language (DSL). A DSL is a special textual programming language that is targeted to specific use cases or application domains. It aims at being easy to learn, understand and use for domain users. We use a DSL in a rule editor that allows users to perform spatial analyses and to customize the 3D web visualization through textual rules. The editor is

[1] CAVE: a cave automatic virtual environment, a highly immersive virtual reality 3D environment for people to step in
[2] https://www.khronos.org/webgl/

ontology-driven and links concepts used in the geospatial data and the 3D scene to the urban planning application domain.

Our tool is customizable on two levels:

- The components in the web portal can be configured to target multiple applications. They can even be moved on the screen or hidden if they are not necessary for a specific use case.
- The rule editor enables customization and interaction with geospatial data and the 3D visualization.
- Altogether this enables municipalities to provide a tool that can be used in urban planning and public participation processes in multiple ways:
- The 3D visualization can be used to present urban plans to all stakeholders including decision makers and the public. In this case, our portal can be configured to hide complex components such as the rule editor to avoid confusion. Instead we rely on the interaction elements provided by the web portal to allow users to focus on urban plans, to discuss them, and to provide feedback.
- Similarly, our portal can be configured to target expert users such as urban planners who need to perform spatial analyses and who want to prepare the presentation of the urban plans to the public. In this case, the rule editor can be used to augment geospatial data with semantic metadata and to configure the 3D visualization based on this metadata.

The remainder of this paper is structured as follows. We first discuss related work and then describe our approach as well as an example use case. After this, we present technical details of our ontology-driven rule editor and domain-specific language. The paper concludes with a final discussion and gives some aspects for future work.

Since an approach for a 3D web portal for public participation has been described in detail by Dambruch and Krämer (2014) we particularly focus on the aspect of the rule editor and the DSL. We summarize their approach in section 2on related work.

3 RELATED WORK

As described above, virtual reality applications for public participation have been presented before. Al-Kodmany (2002), for example, evaluates eight visualization tools (four traditional and four computerized) for their fit for urban planning and public participation. Al-Kodmany concludes that traditional and digital tools are equally important, but the digital ones provide additional means, resources and information. Doyle et al. (1998) describe the possibilities of the World Wide Web (WWW) for visualization, modelling and analysis of urban environments. Their idea is that the WWW provides a platform for a wide range of users including planners, infrastructure managers, and citizens to access and discuss urban designs, local plans, etc. A similar approach is taken by Zhang et al. (2007) who present a Distributed Virtual Geographic Environment which is a web-based collaborative platform including a 2D and 3D visualization of geospatial data.

Although the usefulness of virtual reality and web-based visualization has been recognized, previous work has typically required special 3D hardware and software such as browser plugins or Java3D. These requirements have prevented broad application. In order to eliminate these issues Dambruch and Krämer (2014) present a web-based portal for public participation (see Figure 1). Their solution consists of a 2D map, a 3D visualization as well as other components necessary for public participation such as a forum, a feedback panel, and a questionnaire component. Their web portal is highly configurable and can be adapted to different use cases. Dambruch and Krämer specifically focus on urban planning scenarios and demonstrate how their tools can be used to present construction plans (e.g. new buildings or refurbishments) to the public, to allow stakeholders for commenting plans and to vote for different variants. Dambruch and Krämer describe each component of their portal in detail and put major focus on portability and interactivity. For example, their portal includes tools to interactively place new buildings in the 3D scene, to move and rotate them, and to create textual annotations in a 3D scene. Their solution is particularly targeted to decision makers and stakeholders from the public. However, it lacks advanced GIS functionality required by expert users such as urban planners.

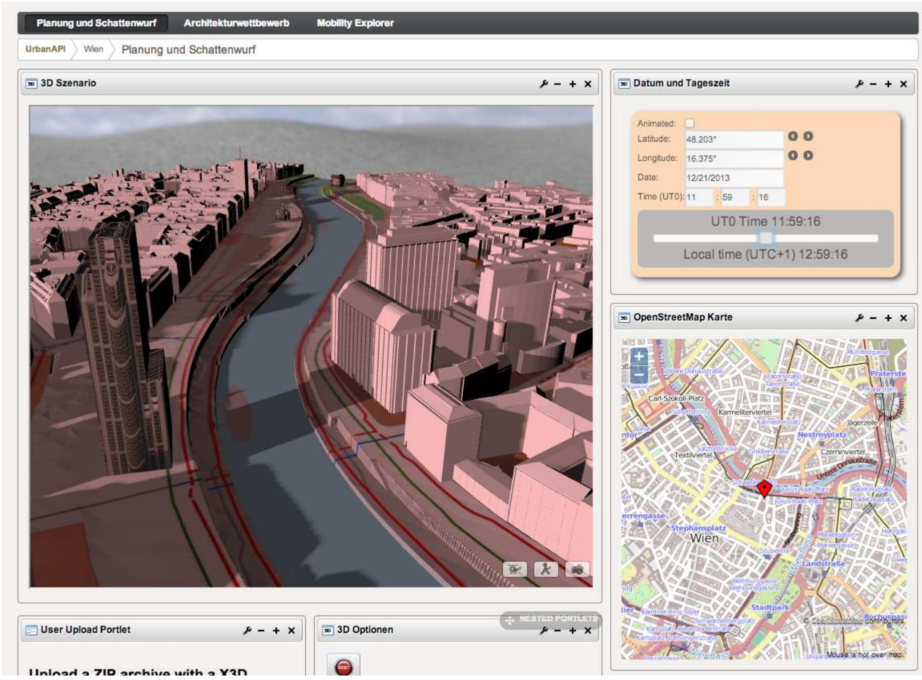

Figure 1: Screenshot of Dambruch and Krämer's web portal for public participation

Krämer and Stein (2014) target the issue from another point of view and describe a graphical rule editor that is embedded in a desktop 3D GIS application. Their editor provides basic geospatial functions that can be arranged by expert users to form complex spatial processing workflows. Krämer and Stein make use of an ontology-based domain analysis method to identify necessary functions. In doing so, they create a graphical DSL that is targeted to the 3D geospatial domain. Krämer and Stein demonstrate that they can use their DSL for the processing of spatial data (in particular 3D city models) and to customize the 3D visualization.

In this work we build on the previous work and combine the web portal presented by Dambruch and Krämer with the means to annotate spatial data and customize the 3D visualization through a DSL based on the idea by Krämer and Stein. In the following section we describe our approach for using micro-ontologies as basis for DSLs and how this approach has been applied within the context of a research project.

4 OUR APPROACH

In the urbanAPI project[3] several ICT applications were developed addressing urban planning issues, in particular a 3D scenario creator application which makes (3D) geodata available in a web portal environment. urbanAPI was an international research project running from October 2011 to November 2014 funded by the European Commission from the 7th Framework Programme. In urbanAPI the CityServer3D[4] technology was used to prepare, fuse and maintain datasets for the use in the portal. The portal itself is based on Liferay[5], an open source JavaEE portal software and X3DOM[6] for displaying and interacting with 3D data.

The web portal is the framework to provide the set of applications. In addition to that, a development model allows for creation of several reusable components that can be configured to fit in an intended use case context. In Figure 1 an example of such a component arrangement is given: a 3D visualisation component displays a 3D city model and provides direct interaction with the model. To the lower right a 2D map display provides better orientation and is synchronised with the position in the 3D scene. Additional components can be placed on the page as needed for example to do shadow analysis on the 3D model. The direct interaction happens through mouse clicks and dragging in the scene, for example placing annotations or moving objects.

During the course of the urbanAPI project several challenges were identified, especially regarding geodata analysis for different target groups. For GIS expert users analysis tasks on geospatial data are common and

[3] http://www.urbanapi.eu
[4] http://www.cityserver3d.de
[5] http://www.liferay.com
[6] http://www.x3dom.org

straightforward but they need to deal with a lot of issues on the technical level. They are fluent with both, the technology driven vocabulary, which uses terms like Feature, TerrainGrid, Layer, etc., and the user vocabulary, which may use terms like Street, Quarter, River, etc. Decoupling the user vocabulary from the technical vocabulary allows for focussing on the use case rather than working on a technical level. Further on, analysis tasks become manageable by users with less GIS experience. In order to formulate textual rules a language specification is required. We define our language based on the concept of DSLs (Fowler 2010). DSLs have been applied successfully within the urbanAPI project for data preparation and policy modelling (Krämer, Ludlow, Khan 2013).

Figure 2 sketches the resulting prototype that builds upon the urbanAPI framework with the textual editor on the left and the 3D scene on the right. It interprets the specified rule statements and executes them on the underlying geodata. The users work with their vocabulary and do not have to take care about the technical data models. The following sections describe the application use case and detail requirements on the data and the implementation.

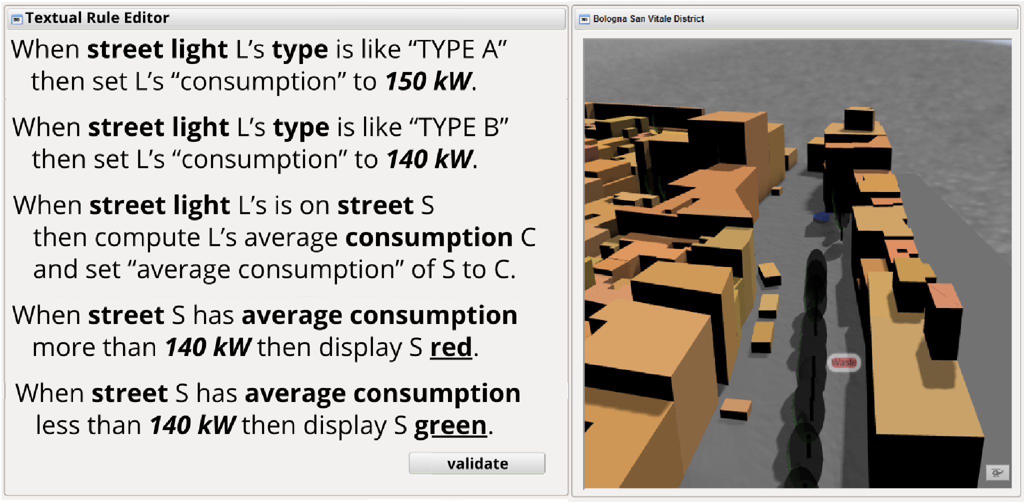

Figure 2: Combination of textual rule editor component with the 3D visualization component

4.1 Application use case

As a working example consider the following use case from the urban planning domain: in a city district street lights should be analysed by their energy consumption. In the city there are three different street light types installed. The street light type is stored to the data. Streets with a high energy consumption average should be highlighted. The following rules written in our DSL describe the analysis steps:

(1) When street light L's type is like "TYPE A" then set L's "consumption" to 150 kW.

(2) When street light L's type is like "TYPE B" then set L's "consumption" to 100 kW.

(3) When street light L's is on street S then compute L's average consumption C and "average consumption" of S to C.

(4) When street S has average consumption more than 140 kW display S red.

(5) When street S has average consumption less than 140 kW display S green.

In the first two statements the consumption of street lights of a particular type are set to their respective values. Statement 3 computes the average energy consumption of lights on a street and adds it as an attribute to the respective street. The last two statements categorise streets by their average consumption and colourize them accordingly (Figure 3).

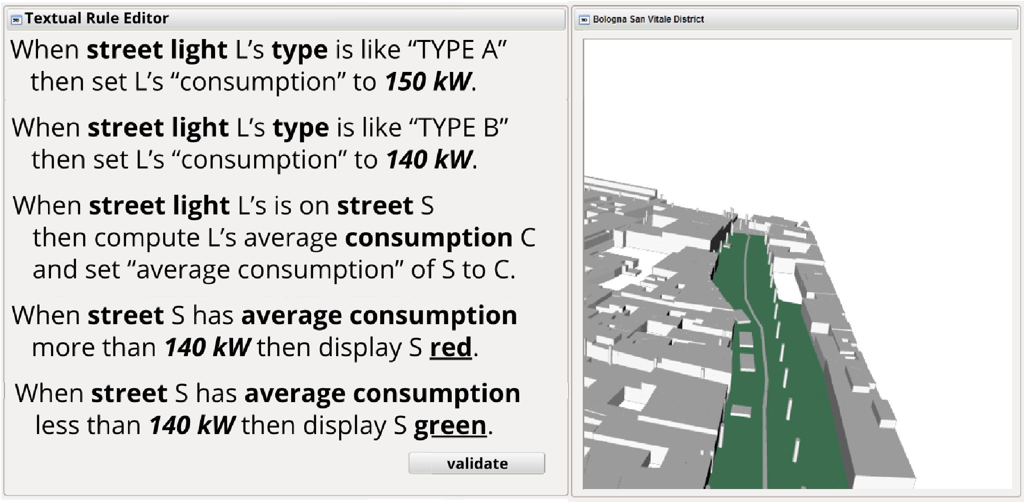

Figure 3: Result of the executed rules in the 3D scene. Buildings and background is simplified to focus on the colourised streets.

4.2 Implementation concept

This section details the process of data preparation and the rule editor's execution process. The rule editor allows for analytic interaction with the 3D scene. Therefore it combines a DSL with the rule language pattern. The DSL is injected with an extendable micro-ontology (Janowicz and Hitzler 2013) that has been specified by the domain group, responsible to work on a problem, beforehand.

The single rules are formatted in a when-statement-then-action pattern. Three steps are necessary to execute a rule:

(1) Automatic lexical interpretation and semantic annotation of rule terms.

(2) Automatic syntactic rearrangement to achieve formal rules.

(3) Injection of geofeatures and rules into a rule engine.

The first step of lexical interpretation and semantic annotation of rule terms is realized through an extension of the JavaScript parser generator PEG.JS.[7] The DSL expressions are classified to six categories:

- general rule expressions (when, then, less),
- user vocabulary expressions (street, type),
- individuals (L, S, C),
- colour expressions (red, green),
- action expressions (set, display),
- physical quantity expressions (combination of number and unit, e.g. 1 m).

After annotation of the terms, an intermediate reasoning step identifies whether the user vocabulary expressions have to be interpreted as geofeatures or attributes and whether their relations have to be interpreted as topological relations or as common attribute patterns.

We used the JavaScript rule engine library NOOLS.JS[8] for rule interpretation and execution. Therefore, the rule phrases must be reformatted in the second step to match the NOOLS.JS rule description pattern. PEG.JS detects triple patterns and rearranges such patterns to fit into the rule description language of NOOLS.JS. Four triple patterns are known to the system:

- possession with apostroph and s ('s): street lamp's type
- possession with has: street has average consumption
- topological relation: street lamp is on street
- possession with of: average consumption of street

[7] http://pegjs.org/
[8] http://c2fo.github.io/nools/

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Listing 1 shows the resulting NOOLS.JS rule. Lines 2 and 3 filter all available geofeatures by their type. Lines 4 and 5 compare the attribute average_consumption to a physical quantity, namely 140 kilowatts. Line 8 calls a function that interacts with the 3D scene framework.

```
1  when {
2     A : GeoFeature
3     A.type == http://www.sig3d.org/codelists/standard/.../LandUse_function.xml#2010'
4            && A.compareProperty('average_consumption', '>', 140,
5                 http://purl.oclc.org/NET/ssnx/qu/unit#kiloWatts");
6  }
7  then {
8     ruleExecutor.display (A, 'red');
9  }
```

Listing 1: rule as interpreted by the NOOLS.JS rule engine

During the third step the specified rules are added in their order of occurrence to the rule engine. Consequently the available geofeatures with their corresponding attributes but without geometrical information are injected into the rule engine at runtime. The interactive functions are added to the rules and therefore executed from the rule engine when implemented.

4.3 Data preparation

Figure 4 illustrates the micro-ontology for the use case. It defines ten concepts and connects them through another ten relations. The concepts contain a set of attributes along with a native language label. Three vocabularies are used additionally and form the knowledge base of the system: the QUDT[9] – Quantities, Units, Dimensions and Data Types Ontologies, the colour knowledge base of dbPedia[10] and GeoSparql[11] as reference ontology for geofeatures and topological relations.

The double lined concepts in Figure 4 are geofeatures and connected with a spatial representation. Interrelations among geofeatures that are either prepositions or has are interpreted as topological relations from the region connection calculus (Renz 2002). As an example Street is in District is interpreted as Street isContainedIn District.

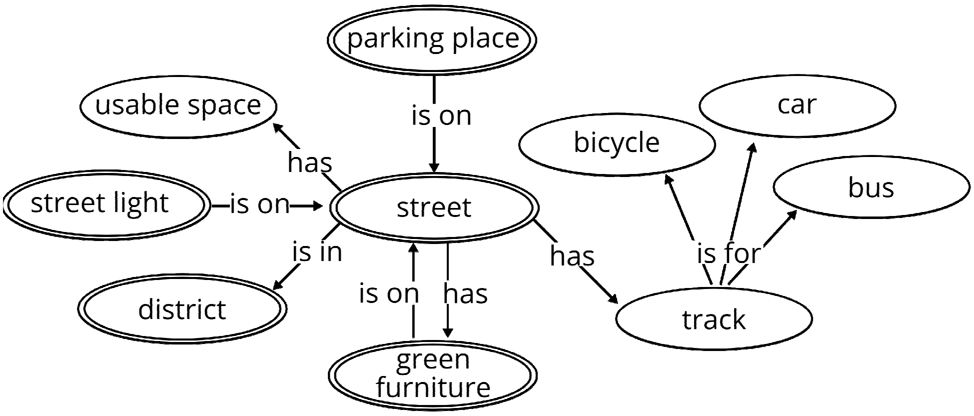

Figure 4: Micro-ontology modelling core parts in a city district

The geodata to be analysed is injected with semantic annotations during pre-processed step. Semantic annotations are unified resource identifiers that link to a source on the web, where the meaning and connection to further related resources is described. For example, in CityGML the expression road is accessible through a URI.[12] This URI is ensured to be added to the geodata descriptions as shown in Listing 2 line 2.

9 QUDT ontologies are accessible at http://www.qudt.org/. An alternative ontology is NASA's SWEET ontology (Raskin & Pan, 2005)

10 http://dbpedia.org/

11 http://www.opengeospatial.org/standards/geosparql

12 http://www.sig3d.org/codelists/standard/landuse/2.0/LandUse_function.xml#2010

```
<MetadataSet containerField='value' name='Feature_1382'>
  <MetadataString containerField='value' name='type'
value='"http://www.sig3d.org/codelists/standard/landuse/2.0/LandUse_function.xml#2010
"'/>
</MetadataSet>
```

Listing 2: Semantic Annotation in X3D. The type attribute's value of Feature_1382 is specified through a URI.

In order to link the user vocabulary (target vocabulary) with the data source (source vocabulary) a mapping table is created. Therefore either a concept of the target vocabulary is linked (I) one to one with a semantic annotation type or (II) triple patterns are linked one directional to a concept of the source vocabulary's semantic annotation as shown in the following.

(I) ex:Street –> cml_lu:2010

(II) ex:Track ex:isFor ex:Bicycle. –> cml_ta:3

The suffix ex: represents the ontology from Figure 3; the suffix cml_lu: represents the land use function schema of CityGML; the suffix cgm_ta: represents the traffic area schema[13] of CityGML. We have chosen the straightforward form of a mapping table and avoid terms from the Semantic Web (e.g. owl:sameAs) that have been discussed as semantically error-prone (Halpin et al. 2010). We argue that an objective mapping level among two concepts as introduced in the SKOS ontology is not possible. The level of mapping between two concepts is only possible per use case.

Given the prerequisites of semantically annotated geodata sources and a mapping table the user is now able to analyse the scene with their very own fit-for-purpose vocabulary by scripting rules in a near natural language speaking mode into the editor field as depicted in Figure 3.

5 CONCLUSION

In this paper we have shown the combination the web portal for public participation in the urban planning process with a DSL based rule editor. This combination has two major advantages. On the one hand it enables users to work in their language level without the need to have strong geodata and technology domain knowledge. It eases the analysis process for those users that are not experienced in GIS but require spatial data for solving their issues. On the other hand a DSL rule editor in combination with a visualization component offers a base, based on which GIS experts can communicate their analysis process and results to non-experts.

The urbanAPI evaluation sessions revealed a lot of potential for the application of declarative rules. A prominent example from the urban planning domain is a pliancy indicator for placing objects in the 3D scene. At the moment there are no constraints where users can place objects, so trees can be put in the middle of the road or houses in a river. A rule which forbids to place trees directly on streets and communicates this fact to the user, for example through colourize conflicting objects in red would be very helpful. These types of rules will be investigated further in the future. Also the possibility to combine various rules to achieve different goals leads to more flexible ways of analysis. Especially if several steps are involved a lot of work can be saved compared to a graphic user interface that offers no scripting.

However the major prerequisite to apply the approach given is semantically annotated data. Klien (2006) defines the goal of semantic annotation as making the meaning of data explicit. This means that the data structures given (for example entries in GIS file formats) are associated to already known concepts given by ontologies or likewise, which enables to use the data in the particular context. As an example the objects in the 3D scene representing streets, bicycle lanes or street lights were annotated as such along with other properties such as the energy consumption, as discussed in the sections above. For the use with our prototype and within the project this was done mostly manually, which is a laborious work and not reasonable for the intended target audience. Herein we have to elaborate, how automatic mapping algorithms or schema mapping tools, such as HALE (Reitz and Templer 2012) can help. In the daily workflow the amounts of new data are growing and it is clear that an additional step involving intense manual intervention for semantic annotation is not appropriate. There are already several approaches for automated annotation. Lutz and Klien

[13] http://www.sig3d.org/codelists/standard/transportation/2.0/TrafficArea_function.xml#3

(2005) show how the spatial relations in data sets can be used to create semantic annotations automatically. Upcoming prototypes need to address this issue to be usable on a wider scale.

In summary we think that an interaction with geodata through a DSL with interchangeable core vocabulary is a powerful approach to break the complexity of GIS analysis down to casual users. It gives an enormous amount of flexibility and allows for verbal interaction tailored for both, differing target audiences and use cases.

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