STORAGE OF UNDERGROUND UTILITIES DATA IN THREE-DIMENSIONAL GEOINFORMATION SYSTEM

SHRANJEVANJE PODATKOV O PODZEMNI INFRASTRUKTURI V TRIRAZSEŽNOSTNEM GEOINFORMACIJSKEM SISTEMU

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ABSTRACT

The article presents a research on data of underground utilities like electrical power distribution grid, water, gas, heating distribution systems, sewer, and telecommunication systems storage in three-dimensional geoinformation system for municipality purposes. Besides topography, municipalities store underground and aboveground utilities data collected by surveyors. Collected geodata are treated as legal data and they are used for urban planning, designing purposes and permissions issue for constructing or reconstructing purposes. It is shown, how the existing data could be transferred to the 3rd dimension. An algorithm has been created for calculation of the heights of underground utilities. Requirements for data capture in three-dimensional geoinformation system are discussed and presented.

KEY WORDS

underground utility, 3D geoinformation system

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IZVLEČEK

V članku je predstavljena raziskava o shranjevanju podatkov podzemne infrastrukture v trirazsežnostnem geoinformacijskem sistemu, ki vključuje podatke o električnih vodih, vodovodnem, plinovodnem, toplovodnem sistemu, kanalizacijskih vodih in telekomunikacijskih sistemih. Poleg topografskih podatkov geodeti za potrebe občin zbirajo tudi podatke o podzemni in nadzemni infrastrukturi. Zbrani geopodatki so zavezujoči pri prostorskem planiranju, načrtovanju in izdaji dovoljenj za gradnjo ali obnovo. V prispevku je prikazano, kako lahko obstoječe podatke prenesemo v tretjo razsežnost. Za izračun višin podzemne infrastrukture smo razvili poseben algoritem. Obravnavane in predstavljene so tudi zahteve za zajem podatkov v trirazsežnostnem geoinformacijskem sistemu.

KLJUČNE BESEDE

podzemna infrastruktura, trirazsežnostni geoinformacijski sistem

1 INTRODUCTION

There is a constantly growing need for precise underground utilities data for design, construction or reconstruction purposes in urban areas. Utilities map data have been stored in analogous large-scale (1 : 500) plane-tables for a long time. During last few years municipalities began to collect data digitally and to store utilities data in geoinformation systems. The main data sources for geoinformation systems are vectorised old large-scale maps at a scale 1:500, stereodigitized aerial photos and new surveying data. Those methods have been applied for above ground (surface) objects, while underground data have been vectorised from old large-scale maps mainly. Utilities data have been collected and stored in 2 or 2.5 dimensions mainly, with height data points in certain places. Using modern technologies it is possible to collect position and height information for utilities quite easily. By applying the 3rd dimension it is possible to store all utilities distribution grids with heights for each vertex (with z-values). Planners and designers could benefit from more precise information while planning and designing new constructions or reconstructions. One of the advantages is the possibility to calculate real length (not projection of lines) of networks by estimating slopes in geoinformation systems.

For example, the Vilnius municipality underground utilities data have been transferred to the 3rd dimension by calculating the missing heights. An algorithm has been created for heights calculation using interpolation. For experiment purposes a module operating in ArcGIS™ 9.0 environment has been created using Visual Basic™ programming language. A three-dimensional data model for storage of underground utilities data in municipality geoinformation system has been designed and created using UML CASE tools.

2 UNDERGROUND UTILITIES DATA IN THREE-DIMENSIONAL GEOINFORMATION SYSTEM MODEL

Today, utility heights are stored in a separate data layer as points attributes mainly. Usually height points are not connected topologically with utility lines or related in another way. If every vertex of object were supplemented with the z value, object dimension would be extended to the simple 3rd dimension. During transformation to the 3D space objects could be presented by different geometrical primitives, f.ex.: if an object like pole in 2D space is represented as point, in 3D space pole would be represented as perpendicular to the ground surface line. In some cases geometrical primitives representing real objects would not change, f.ex.: top of manhole in 3D space still would be represented as a point. There is only new z parameter, which tells about location of an object not only in plane but also in vertical attitude. Line objects would be still lines, but every vertex would get its own height. In such case the height would be always associated with a utility line (Pubellier, 2003). Polygons would keep the same geometry in some cases, but in most cases it would be transformed to volumetric (body) object. Volumetric objects would consist of surfaces that limit a body. In 3D spaces objects would have one z value (a top of manhole), or a set of values in perpendicular attitude (a pole), or set of values in horizontal position (pipe lines with z values for each vertex).

Moving to the 3rd dimension it is important to identify, how real objects would be treated in the new dimension. Each real object group would be treated differently with a unique geometrical representation (Stoter et al., 2003). Common transformation cases of underground utilities are presented in Table 1 (Cypas, 2005).

Geometric element in 2D space	Geometric element in 3D space	Explanation
Utility point (x,y)	Point (x,y,z)	Objects that could be considered without height f.ex.: manhole tops, valves
	Perpendicular line (two z's for one x,y coordinate pair: $x_1,y_1,z_1...x_1,y_1,z_2$)	Objects that could be considered with height, f.ex.: grounding bore
Utility line ($x_1,y_1...x_n,y_n$)	Line ($x_1,y_1,z_1..x_n,y_n,z_n$)	Objects that have length and could be considered with length parameter, f.ex.: cables, pipes, conduits
Utility polygon ($x_1,y_1...x_n,y_n, x_1,y_1$)	Polygon ($x_1,y_1,z_1,...x_n,y_n,z_n, x_1,y_1,z_1$)	Flat closed objects
	Simple volume (body) ($x_1,y_1,z_1,z_{1h}...x_n,y_n,z_n,z_{nh}, x_1,y_1,z_1,z_{1h}$)	Objects that have length, width, height and could be considered as volumetric object, f.ex.: underground reservoirs

Table 1. *Transformation cases for geometrical primitives of underground utilities.*

The design of three-dimensional underground utilities geoinformational data model has been performed according to large-scale geoobjects specification of geoinformational system of the Vilnius municipality, according to requirements set further and information flow analysis. Themes of underground utilities geoobjects stored in the Vilnius municipality geoinformation system are presented in Table 2 (Stankevicius, 2000).

No	Utility theme	Objects in theme
1.	Electrical power distribution grid	Transmission lines, poles, transformers, switches, fuses, substations, streetlights
2.	Water distribution grid	Water pipes, valves, hydrants, service lines
3.	Gas distribution grid	Gas pipe segments, valves, service taps, service lines, cathodic protection devices
4.	Oil network	Oil pipe segments, reservoirs, pump stations
5.	Heating distribution grid	Heating lines, reservoirs, valves
6.	Sewer system	Sewer pipe segments, manholes, valves, service taps, lateral lines
7.	Telecommunication system	Telecommunication cables, conductors, switching centers, poles, service lines

Table 2. *Utility layers in the Vilnius municipality geoinformation system.*

Data model has been designed using the UML and CASE tools and created using ArcInfo™ software. Geodatabase has been loaded to central database storage ArcSDE™ dedicated to geographical data central storage, which ensures multi-user data handling environment. ArcSDE™

lets to store geodata in popular commercial relational database management systems like ORACLE™, Microsoft SQL Server™, IBM DB2, so a data model is independent. The created data model might be transferred using XML for both data and structure. Municipality subdivision is responsible for cartographic data storage and for update of large-scale maps. According to existing regulations, the surveying company has to apply for data extraction from municipality central database for a particular territory. After the field survey, the surveying company updates the data and delivers them to the municipality cartographic subdivision. Using the designed model, the data can be easily extracted from the central database and transferred to the surveying company. Then the surveying company can use data in the delivered structure or it can export the data to their CAD software format. After surveying the data can be updated using the same data structure and delivered to municipality cartographic division. The municipality subdivision is responsible for loading new or updated data to the central database. All changed objects would be deleted and new objects would be imported to the central database within the same data model. A standardized data model would serve as infrastructure for data export, update and import procedures and would warrant data objects conformity with specification. When a required data structure is known, it is possible to check data consistency in a more automated way.

The following geometrical primitives have been used in the data model: PointZ, PolylineZ, PoligonZ, MultiPatch. These types (except MultiPatch) are standard well-known primitive types extended with additional z values. The MultiPatch data type lets to store volumetric objects, but for data load special procedures using ArcGIS™ components called ArcObjects™ should be used (Ford, 2004). An alternative for data load is to use specialized software for 3D modeling with interfaces for data load to GIS software.

3 CREATION OF THREE-DIMENSIONAL GEOINFORMATIONAL SYSTEM MODEL

An experiment has been performed for transferring of utilities surveying measurements to three-dimensional geoinformational system model. The main idea of an experiment is to transfer measured height values to vertexes data of corresponding utility lines. The overall algorithm is presented in Figure 1. In the first block data layers are processed: SQL queries are applied if any. In the second block every line and every vertex of each line are analyzed and height for each vertex is being searched within 0.1 meter distance. Actually measured height point has to be on a line and a point has to be associated with a line (most common approach by using “snap”). The condition for closest distance is actually a closest allowable distance between vertexes. The closest distance between vertexes in primary data has been defined as 0.1 meter.

A search for closest height is performed in step “Find a closest height within 0.1 m from vertex”. A search for a closest height is described in separate algorithm. A result of algorithm is only one closest height of a point within 0.1 m distance from vertex. The experiment was performed for a territory in Vilnius covered by 68 km^2. The results of an experiment are presented in Table 3.

No	Utility theme	Objects in theme
1.	Electrical power distribution grid	Transmission lines, poles, transformers, switches, fuses, substations, streetlights
2.	Water distribution grid	Water pipes, valves, hydrants, service lines
3.	Gas distribution grid	Gas pipe segments, valves, service taps, service lines, cathodic protection devices
4.	Oil network	Oil pipe segments, reservoirs, pump stations
5.	Heating distribution grid	Heating lines, reservoirs, valves
6.	Sewer system	Sewer pipe segments, manholes, valves, service taps, lateral lines
7.	Telecommunication system	Telecommunication cables, conductors, switching centers, poles, service lines

Table 3. *Results of heights calculation of utilities lines vertexes.* k_{obj} *- number of objects,* k_v *– number of vertexes per all objects,* k_{Hs} *– number of assigned (transferred) heights,* k_{Hp} *– original number of heights,* i_s *– percentage of assigned heights per primary number of heights,* i_p *– percentage of assigned heights per all vertexes.*

Results after initial height transfer experiment were quite pure due to small number of measured heights of underground utilities. Only some of the measured heights were used for utility lines transformation to 3D lines.

The lowest rate of transferred heights is detected for sewer system, electricity and telecommunications. There is no any requirement for collecting heights for electricity and telecommunication cables, but sewer system have to have heights because of slopes. A low rate of transferred heights for sewer system tells about lack of requirements for storing sewer network heights. A high rate is detected for heating and water distribution systems, it tells about precise location of heights points for those systems, but still the low rate of heights per vertexes (2.2%–3.1%) tells about lack of requirements for data storing. Gas distribution system has a rate over 100%, it means that the same height was given to more than one vertex. The reason could be a wrong smallest distance in data (0.1 m). Oil network has to be excluded from results as it was too less data for an experiment.

In order to improve results interpolation procedures were developed and applied. Interpolation algorithm was supplemented to main algorithm as step "Interpolate heights of line vertexes" (Figure 2).

Interpolation was performed for each line having vertexes with z = 0 values. Interpolation algorithm has those constraints: 1) interpolation cannot be performed if there is none or only one vertex with height, 2) interpolation cannot be performed if there are two adjacent vertexes with heights. Interpolation may be performed only for vertexes that are between vertexes with known heights. Results of interpolation are presented in Table 4.

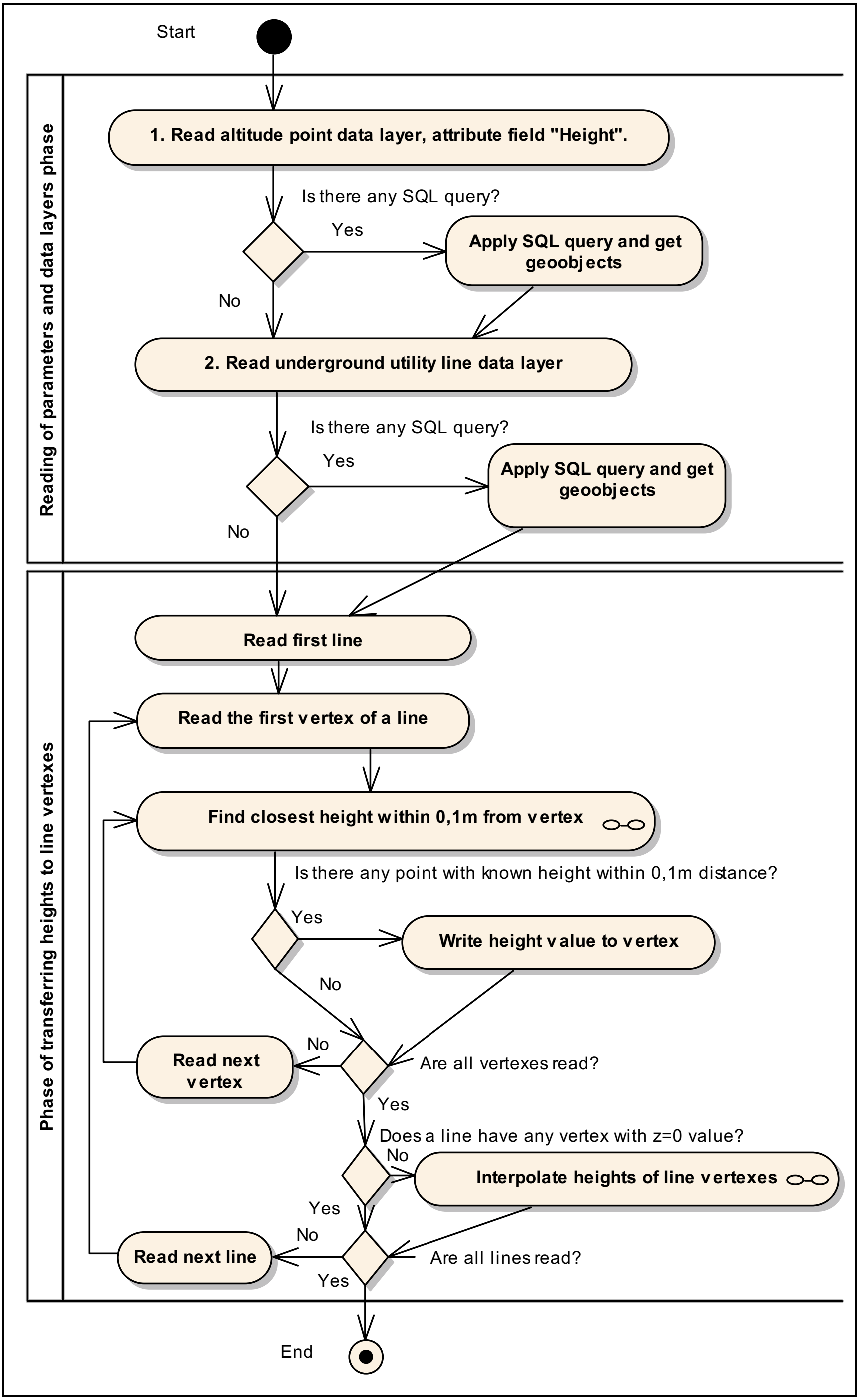

Fig 1. *Algorithm for calculation of vertexes heights.*

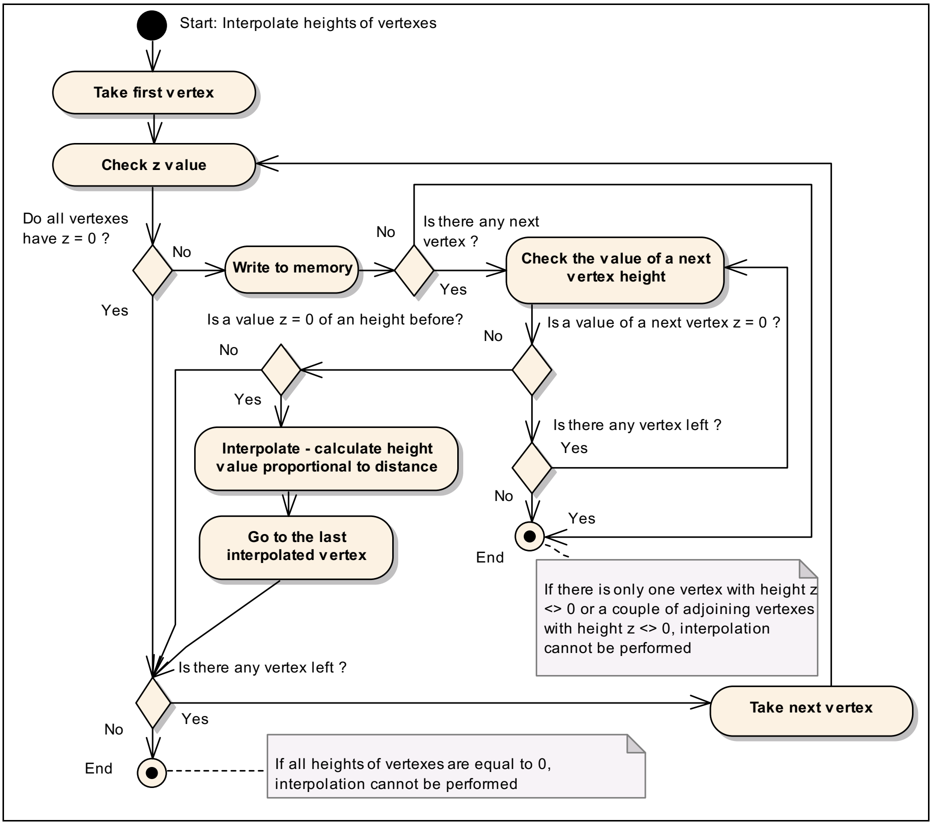

***Fig 2.** Algorithm for interpolation of vertexes heights.*

Utility theme	k_{objint}	k_{vint}	i_{pint} (difference, Δ)
Electrical power distribution grid	2 (0%)	45	0% (0%)
Water distribution grid	200 (0.5%)	1644	4.1% (+1.0%)
Gas distribution grid	1848 (6.3%)	5021	15.8% (+4.5%)
Oil network	0	0	0.5% (+0.0%)
Heating distribution grid	144 (0.6%)	1110	3.0% (+0.8%)
Sewer system	1 (0.0%)	3	0.0% (+0.0%)
Telecommunication system	2 (0.0%)	5	0.0% (+0.0%)

***Table 4**. Results of interpolation of vertexes heights. k_{objint} – number of objects with interpolated vertexes, k_{vint} – number of interpolated vertexes per objects with interpolated vertexes (k_{objint}), i_{pint} – percentage of both transferred and interpolated heights per all vertexes.*

After interpolation number of vertexes with known heights increased narrowly (up till 4.5%). The main reason is too few objects suitable for interpolation, more heights have to be stored in database. Heights have to be measured in points where slope of underground utility changes. In cases when slopes of underground utilities are known, interpolation accuracy improvement may be achieved by applying slope value. Reliable results by interpolation can be achieved between vertexes with a known slope.

4 REQUIREMENTS FOR UTILITIES DATA CAPTURE AND STORAGE IN THREE-DIMENSIONAL GEOINFORMATION SYSTEM MODEL

Nowadays underground utilities are measured using electronic total stations in most cases. Using total station it is possible to measure both horizontal and vertical positions. In those cases measured heights can be stored as z values of vertexes. When moving to three-dimensional geoinformation system it is important to set rules for capture of objects with 3rd dimension. One of issues is standardization of objects' coding as well (Stankevicius, et al., 2005). It is important to improve the underground and aboveground utilities objects coding in the three-dimensional geoinformation system.

Strict data capturing rules can benefit for surveyors while working in a field and processing data later (Koistinen et al., 1999). According to technical requirements for underground utilities surveying requirements are as follows:

1) heights of all devices tops (covers, etc.) have to be collected and stored;
2) heights of pipes and conduits have to be collected and stored (incoming to manhole and outgoing from manhole, for sewerage, drainage – heights of conduit duct, for all other conduits – height of conduit top);
3) telephone cables: heights of conduit duct have to be collected and stored, if there is a beam of conduits – heights of both a top and a bottom of conduit have to be collected and stored;
4) heights have to be collected and stored at a distance not less than each 50 meters if there is a segment with a same slope.

Existing technical requirements it is recommended to supplement with additional rules:

1) heights have to be measured for both incoming and outgoing underground cables in manhole;
2) heights have to be measured in turning points, connections for underground cables;
3) heights have to be measured at clear slope change points for underground cables;
4) heights have to be measured not less than each 50 meters in straight segments for underground cables.

Generally it is recommended to measure heights in those points where there is requirement to measure position of underground cables. In these cases height would be related to a position of typical points. According to requirements stated above following requirements have been formulated for storing underground utilities data in three-dimensional geoinformation data model:

1. Collecting line geoobjects of underground utilities:

a) line geometry has to be collected with heights of vertexes using polylineZ geometry type. An alternative could be capture of heights in a separate layer as points. Then a procedure of heights transferring to line vertexes could be performed;

b) according to regulation of technical requirements for underground utilities surveying all technical characteristics should be collected in attribute fields. Each type of underground utilities has it's own code (gcode) and is stored in different data layers. For manifolds and pipelines a diameter and material have to be indicated. In addition a flow direction is indicated for sewerage lines (a recommendation to use azimuth, then a flow direction could be placed in a map automatically). Slope could be calculated automatically, if slope calculated by using other methods it could be entered manually. For gas pipes a pressure have be indicated, for electricity cables a voltage have to be indicated. If there are protective pipes, a diameter and material for those should be indicated as well.

2. Collecting point geoobjects of underground utilities:

a) Point objects (manhole tops, valves, etc.) have to be collected with heights using pointZ geometry type. If heights of utilities have been measured separately, those are stored in separate layer for utilities heights and height is stored as attribute. Those heights will be transferred to utility lines during heights transferring to line vertexes procedure. In that case points should be on lines – have to be topologically connected with lines (using snap mode);

b) any technical characteristic of point object should be collected in attribute fields. Each type of underground point object has it's own code (gcode). Manhole data is collected using field inventory cards. Following attribute information of manhole have to be stored: city name, street name, nomenclature of large-scale map (scale 1 : 500), type, diameter and material of manifold top, ground height, material of walls and bottom, number of incoming and outgoing pipes, diameter and type of each pipe, ladder type, quantity of stairs. Each inventory card has a name and surname of a man who performed inventory and date of inventory. Reading of top or bottom of pipe, conduit and depth is stored in layer of utility heights. Height could be calculated automatically according to distance to top of manifold. Other point objects are stored with a city name, street name, nomenclature of large-scale map and type as well. It should be possible to store scanned manifold inventory card.

3. Collecting volumetric geoobjects of underground utilities:

a) volumetric geoobjects (reservoirs, etc.) have to be stored using MultiPatch geometry type. For data collecting a PolygonZ geometry data type could be used as temporary layer. In that case each vertex should have height of object bottom;

b) any technical characteristic of volumetric geoobject has to be collected in attribute fields. Each type of underground volumetric object has it's own code (gcode). As attribute a height of object could be stored as well.

All objects should have information about data collecting method, accuracy and date (metadata).

5 CONCLUSIONS

1. Additional requirements for underground utilities geodata collecting in three-dimensional geoinformation model have been set.
2. According to additional requirements 3D data model has been designed using UML and CASE tools.

3. An algorithm for height data transferring to underground utilities lines has been created. For experiment a module operating in ArcGIS™ environment has been developed. Initial data has been transformed to 3D space using an algorithm for height data transferring to underground utilities lines. The lowest rate of transferred heights is detected for sewer system, electricity and telecommunications. A low rate of transferred heights for sewer system tells about lack of requirements for storing sewer network heights. A high rate is detected for heating and water distribution systems, it tells about precise location of heights points for those systems, but still the low rate of heights per vertexes (2.2%–3.1%) tells about lack of requirements for data storing. Gas distribution system has a rate over 100%, it means that the same height was given to more than one vertex. The reason could be a wrong smallest distance in data (0.1 m). Oil network has to be excluded from results as it was too less data for an experiment.
4. In order to improve results experimental interpolation procedures were created and applied. After interpolation number of vertexes with known heights increased narrowly (up till 4.5%). The main reason is too few objects suitable for interpolation; more heights have to be stored in database. Heights have to be measured in points where slope of underground utility changes. In cases when slopes of underground utilities are known, interpolation accuracy improvement may be achieved by applying slope value. Reliable results by interpolation can be achieved between vertexes with a known slope.

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