AN IMPROVEMENT OF 3D OO-SOLID MODEL

DENG Nian-dong, HOU En-ke, ZHANG Zhi-hua

Dept. of Geology and Environment Engineering, Xi'an University of Science and Technology, Yanta Road, Xi'an 710054，China - (gissearch, houek, zhzhihua99)@163.com

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ABSTRACT:

The key issue of 3D geology modeling is the 3D data model. Because of discontinuity, complexity and uncertainty of distribution of 3D geo-objects, some models only are suitable for regular, continuous and relatively simple spatial objects, and some are suitable for discontinue, complex and uncertain geo-objects, but some improvements on these models, such as, updating of model, maintenance of topological and seamless integration between models, are still to be made. The OO-Solid Model is an object-oriented 3D topologic data model based on component for geology modeling with fully considering the topological relations between geological objects and its geometric primitives. Comparatively, it accords with the actual requirements of three-dimensional geological modeling, but it has some defects, for example, the modeling sections are limited to the parallel and vertical section, still cannot adapt to nonparallel and folded sections, and don't fully consider the degradation of modeling primitives. These defects bring some negative effects on the integrality and effectiveness of organization of spatial data, spatial query, spatial analysis based on OO-Solid model. Aiming at the defects of the OO-Solid Model, OO-Solid model is modified. The component of this model is the basic element of the division of geological volumes. Primitives of OO-Solid Model are compartmentalized into node (cru-node, inner-node, isolated-node, reference-node, interpolated-node, and feature-node), arc (feature-line), polygon, component face (polygon face, component side-face, component up-down-face) and component. And conceptual model and logical model of OO-Solid model are redesigned. At last, data structure of OO-Solid model is designed. Above improvement not only benefits muti-source data compositing for modeling, upgrades auto-modeling, facilitates dynastic updating of geological model, also favors seamless integrating with other models, such as TIN.

1. INTRODUCTION

Data model is the key issue and foundation of 3D geological modeling and spatial analysis, and it's important for realization of 3DGMIS. Predecessors have conducted a lot of research, and put forward facet models, such as, Grid model, TIN model(Barry, J., 1991; Victor J D., 1993), B-Rep model, Wire-Frame model, Series Sections model, and DEMs() model etc. as the representative of the model, and component model, such as, CSG, Voxel (Dai Wu-jiao,2001), Needle, Octree, Regular Block, TEN, Pyramid, TP, Geocellular, Irregular Block, Solid, 3D Voronoi, TP(ZHANG Yu, 2001), GTP(QI An-wen, 2002; MAO Shan-jun., 2002) and OO-Solid model(HOU En-ke,2002) etc. as the representative of the model(WU Li-xin, 2003). Because of discontinuity, complexity and uncertainty of distribution of 3D geo-objects, some models only are suitable for regular, continuous and relatively simple spatial objects, and some are suitable for discontinue, complex and uncertain geo-objects, but some improvements on these models, such as, updating of model, maintenance of topological and seamless integration between models, are still to be made.

OO-Solid model, put forward by writer in 2002, is an object-oriented topological model based on sections. The OO-Solid Model is an object-oriented 3D topologic data model based on component for geology modeling with fully considering the topological relations between geological objects and its geometric primitives, Comparatively, it accords with the actual requirements of three-dimensional geological modeling, but it has some defects, for example, the modeling sections are limited to the parallel and vertical section, still cannot adapt to nonparallel and folded sections, and don't fully consider the degradation of modeling primitives. These defects bring some negative effects on the integrality and effectiveness of organization of spatial data, spatial query, spatial analysis based on OO-Solid model. Aiming at the defects of the OO-Solid Model, this model is modified; conceptual model, logical model, and data structure of OO-Solid model are redesigned.

2. MODELLING THEORY OF OO-SOLID MODEL

The component is the base modeling unit of OO-Solid model, which defined by fore-component-polygon, mid-component-polygon and post-component-polygon. Mid-component-polygon is identified by the profile of section for spatial geo-objects, and fore-component-face and post-component-face are inferred from geological staff with setting equidistant between mid-component-face. The modeling ideas are shown in document written by Hou En-ke (Hou En-ke, 2002). The primitives of component includes node, arc, feature line, component polygon and component face. OO-Solid model can consider the topology of geological objects, and can be fully taken into account the limited of geological data and the needs of interactive inference and interpretation of geological staff, and benefit constructing the complex geological model(Hou En-ke, 2006)..

Although compared with other 3D geological model, OO-Solid model have many unique advantages, it need be perfected and rectified in some respects, such as auto-search for topological relationship and taking geological model constructing and dynamic updating into account.

3. MODIFICATION OF OO-SOLID MODEL

3.1 Modelling primitives of OO-Solid Model

Arming at these defects of OO-Solid model, the primitives are redesigned as following six primitives.:

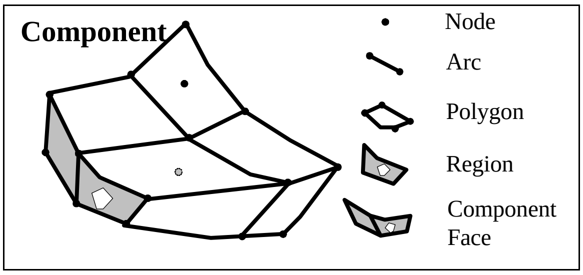

Figure 1 Primitives of OO-Solid Model Component

(1) Node.
The node is classified into six basis types, such as cru-node, inner-node, isolated-node, reference-node, interpolated-node, and feature-node.

It can be divided into three classes from geometric feature: A. u-node is the start and end node of the arc. B. Inner-node is the node except cru-node. C. Isolated node is the node not in the arc, which is on the surface or in the inner of component.

It can be divided into two classes from the data source and reliability: D. Reference-node is in the boundary arc of component and can't be arbitrarily changed. These nodes are the first-hand information obtained from exploration or mine production. E. Interpolated-node is the interpolation node in order to improve the geometric modeling or attributes modeling accuracy.

In order to increase the degree of automation modeling deliberately set the node type is feature-node, which is the common node of arcs with different attributes. 3DGMIS can automatically connect the feature-nodes of the same attributes in the three component polygons, and form feature-line.

(2) Arc
The arc, defined by cru-node(start-node and end-node) and a number of inner-nodes, is the border of polygon. Feature-line is abstracted as arc, but it have a special meaning or significance-bound meaning, and can be automatically connect by system or connect interactive by users.

(3) Polygon
It is outer border or inner borders of a region, and have direction (counterclockwise as positive, negative for the clockwise).Polygon composed by arcs.

(4) Region
The common face between component and another component or between component and surface object (such as fault plane) is abstracted as region. And it often is a part of component-face. Region, having a certain attributes, is composed by one outer-polygon, n($n \geqslant 0$) inner-polygon, and m($m \geqslant 0$) isolated-nodes. As an independent object, region can be modeled into one only regional with using modeling algorithm (such as generating a DTM with polygons and isolated-nodes using certain algorithm). This will help to reduce duplication of constructing common face, but also to avoid singular problem of common face. During dynamic updating of geological model, automatically updating of component-face, component, surface object or volume object can be realized with only updating region. Which will reduce the necessary resources of the dynamic maintenance, for example, when adding a reference-node to a component face, only the region including this node need to updating, then component face, component, surface object and volume object can be automatically updating.

(5) Component face
Component further classified into component-side-face, component-up-down-face, component-polygon-face. The sections in the OO-Solid model have generalized meaning, which isn't confined to geological section; it could be level, tilt or arbitrary surface of the two-dimensional space. Component-polygon-face can be composed of a number of polygons or can degenerate into a line or a node. The classification of component-side-face with component-up-down-face is conducive to seamlessly integrate with facet model.

(6) Component
Component can be defined by fore-component-polygon, mid-component- polygon and post-component-polygon and which surface can be represented by component faces.

3.2 Superiority for modification of primitives

The revised OO-Solid Model component in this paper is different from the model component put forth by writer (2002) in the following aspects:

(1) In dynamic modeling or updating, it is very important to define node from three different angles. Dividing the node into Cru-Node, Inner-Node, and Isolated Node from the geometric angle will help form the topological relationship of polygon automatically, and dynamically update node data change in dynamic updating in geological modeling. Dividing the node into Reference Node, Interpolated Node from the aspect of data source and reliability will be beneficial to the topological consistency analysis and dynamic updating of node data. The division of feature node is to dynamically form feature joining line, which will help distinguish region of different features and then distinguish line object, face object, body object.

(2) The connotation of feature joining line changed from the original definition "the line segment joining the feature nodes on section border" to "the arc joining the feature nodes on section border". The revised definition has even wider meanings, including not only the inferred information given by users mutually and binding line, but the dividing arc of Component Up-Down Face and Component Side-Face, in order to express the face object in a more convenient way.

(3) The addition of two model components: polygon and region; polygon is the inner or outside border of region, and region not only decides the inner and outside border, but take Isolated Node into consideration. The definition of region ensures that section polygon can show the relationship of embodiment of polygon and even express the relationship of embodiment of geological object. Meanwhile, region is a part of component face and the modeling of region is isolated from data structure. Therefore, region is not only the member of neighboring components, but also a part of a face object, which will help the component further form body object and face object.

(4) The component face was further divided into Component Polygon Face, Component Up-Down Face, and Component Side-Face, which will help integrate the different faces of component, form model of their own and show the object of different faces separately. For example, Component Side-Face can be seen as fault surface, Up-Down Face can be seen as upper plate or bottom plate of ore body. Through the features of region and their topological relationships, the component

polygon will help form the corresponding relationship between components and form simple volume automatically.

3.3 Conceptual model of OO-Solid Model

Conceptual model is abstract concept sets of relations among entities; it is the semantic interpretation of geographical data and is the most senior abstract. It easily converts into a logical model and is independent of the specific computer achieved. Component includes six primitives: node, arc, polygon, region, component-face, and component, which constitute the basic elements of data model. In geological mining areas, nodes can describe the point geological target, such as ore sampling point, gas gathering point etc. Arcs can describe line objects such as borehole line track, folding hub, broken coal intersecting lines etc. Regions can describe surface objects, such as the formation level, fault plane etc. The simple volume can be composed by components with some of same attribute, and the complexity is composed volume by the simple volume, furthermore, the composites volume is converged by the simple volume and the complex volume. Space objects are designed into different object classes, and the superior class is generalized such as geological object class. On the basis of above model, the conceptual model of geological object of OO-Solid model is redesigned (figure 2).

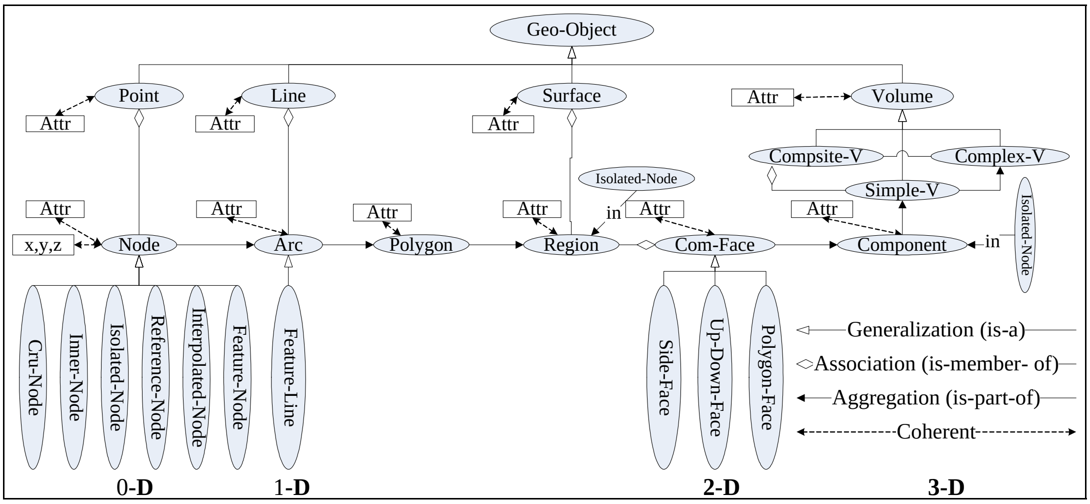

Figure 2 Conceptual model of OO-Solid Model for Geo-Objects

3.4 Logical model design of OO-Solid Model

Conceptual model clearly described the level of relations between the objects and its constituent relations. In order to facilitate the management of object data model and further meet spatial analysis, visualization, the corresponding logical model is designed. Logic model is a mathematical description of the concept of model. Logical data model is the concept of data model, data entity (or records) and the relationship between each other; it is the logical expression of geographic data, and the middle layer. The user can see the geographical space of real world. According to the concept model, the layer between the geological targets and geometric elements can be pushed: Any geological objects can be polymerized by the components. The components are polymerized by the component-face. The component-face joint from the polygon, Polygon is composed of a number of arcs. Arc is composed of many nodes. Any point in a three-dimensional space corresponds to a unique 3D spatial coordinates(x, y, z), which is located the point of spatial location. Because the primitives and conceptual model of OO-Solid model are modified through redesign, and logical model must be redesigned. According to the modified primitives and conceptual model, the logical model is redefined (Figure 3).

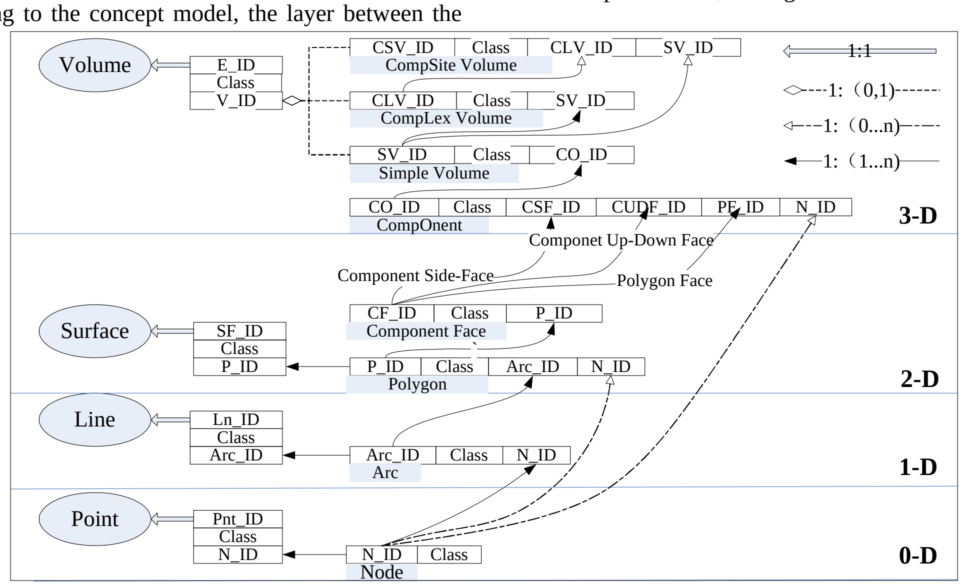

Figure 3 Logical model of OO-Solid Model

4. DATA STRUCTURE DESIGN OF OO-SOLID MODEL

4.1 Redesigning topological relationships

According to the requirement of geological modeling and updating, the topological relationships will be redesigned as following based on the improvement of the OO-Solid model. 1) node-arc-polygon; 2) polygon-region 3) node-region 4) region-component face-component; 5) nodes-point objects; 6) arcs-line object; 7) region-surface objects; 8) component-simple volume; 9) component-simple volume-complex volume; 10) simple-complex volume-composited volume .

Because the first four kinds of topological relations corresponding to the six kinds of primitives, we can directly explicit store these topological relations into the data structure, rather than separately redesign topological relations table. The next six topological relations among geological objects used object-oriented approach (association or aggregation) also can be stored in the data structure and does not require separately design topological relations table.

4.2 Redesigning data structure

Data model is the general description of a group of entities and their relationship, and is the abstract of the real world (Li R X., 1994.). Data structure is used to show data model and is the simplification of data model. The design of data structures commonly descript in relational database management system (RDBMS) in the data table or uses object-oriented methods. The following is the introduction of some data structure used in RDBMS.

Name	Type	Description
GM_ID	Int	GM's ID(PK)
GM_Name	Varchar	GM's name
GO_Num	Unsigned short	Number of GO
GO_IDSequence	Varchar	Sequence of GO-ID
GM_Attrs	Varchar	Attribute description

Table 1 Geological model data structure

Note: GM—Geological Model; GO—Geological Object; GM-Attrs can be spitted into a number of fields.

name	type	Description
GO_ID	Int	GO's ID(PK)
GO_Type	Unsigned short	GO's type (point, line, surface, volume)
GO_Attrs	Varchar	Attribute description

Table 2 Geological Object data structure

Note: GO-Attrs can be spitted into a number of fields.

name	type	description
En_ID	Int	Entity's ID
Vo_Type	Unsigned short	Volume type (simple, complex, composited)
En_Attrs	Varchar	Attribute description

Table 3 Entity Object data structure

Note: En-Attrs can be spitted into a number of fields.

name	type	description
COV_ID	Int	COV's ID(PK)
COV_Name	Varchar	COV's name
CLV_Num	Int	Number of CLVs
SLV_Num	Int	Number of SLVs
CLV_IDSequence	Varchar	Sequence of CLVs' ID(FK)
SLV_IDSequence	Varchar	Sequence of SLVs' ID(FK)
COV_Attr	Varchar	Attribute description

Table 4 Composite Volume data structure

Note: COV—Composite Volume; CLV—Complex Volume; SLV—Simple Volume

name	type	description
CLV_ID	Int	CLV's ID(PK)
CLV_Name	Varchar	CLV's name
Co_Attr	Varchar	Common attributes of the SLVs contained in this CLV
CSV_Num	Int	Number of SLVs' ID(FK)
CSV_IDSequence	Varchar	Sequence of SLVs' ID(FK)
CLV_Attr	Varchar	Attribute description

Table 5 Complex Volume data structure

Note: Complex volume can be expressed as independent geological object; also can be included in the composited volume which expressed geological object. The topological relationships can be topologically reasoned from the topological relationships among components.

name	type	description
CSV_ID	Int	SLV's ID(PK)
CSV_Name	Varchar	SLV's name
CO_Attr	Varchar	Common attributes of the components contained in this SLV
CO_Num	Int	Number of Componets'ID(FK)
CO_IDSequence	Varchar	Sequence of components'ID(FK)
CSV_Attr	Varchar	Attribute description

Table 6 Simple Volume data structure

Note: Simple volume can be expressed as independent geological object; also can be included in the composited volume or the complex volume which expressed geological object. The topological relationships can be topologically reasoned from the topological relationships among components.

name	type	description
CO_ID	Int	Component's ID(PK)
CO_Name	Varchar	Component's name
FP_ID	Varchar	ID of fore-component-polygon
MP_ID	Varchar	ID of mid-component-polygon
PP_ID	Varchar	ID of post-component-polygon
CSF_ID	Varchar	IDs' sequence of component-side-faces
CUF_ID	Varchar	IDs' sequence of component-up-faces
CDF_ID	Varchar	IDs' sequence of component-down-faces
Pn_ID_In_CO	Varchar	IDs of the isolated-nodes in the component (sequence)
CSV_Attr	Varchar	Attribute description

Table 7 Component data structure

Note:

1) The topological relationships of the components is the base of the topologically reason for complex volume, composited volume or simple volume. And his topological relationships reasons from the component-faces (regions) and nodes expressed the component.

2) Component-face (includes component-side-face, component-up-down-face, and component-polygon) can be degraded line or point.

3) The isolated-node in the component is mainly used for

interpolation of the component's attributes (such as grade, etc.);
4) Property description mainly include: volume, proportion, weight, grade of ore-bearing element, the mechanical parameters of rock strength, porosity, permeability, etc.

name	type	description
SF_ID	Int	Surface object's ID(PK)
SF_Name	Varchar	Surface object's name
SF_Type	Varchar	Surface object's type
R_IDSequence	Varchar	The IDs' sequence of regions
Attr	Varchar	Attribute description

Table 8 Surface object data structure

Note:
1) Surface object can be the real surface (such as fault plane, unconformity surface, strata surface, the top/bottom deposit surface), may be the user-defined geological surface in order to facilitate the understanding of the geological model (such as exploitation level of coal mining);
2) The field domain can be defined as follow:
FS - Fault Surface; AUS - Angular unconformity surface;
PUS – Parallel unconformity Surface; CS - Conformity Surface;
TS - Top Surface; BS - Bottom Surface; OS - Other Surface;

name	type	description
CF_ID	Int	CF's ID(PK)
CF_Type	char	CF's type(side-face, up-face, down-face)
RIDSequence	Varchar	The IDs' sequence of regions(FK)
Arc_IDSequence	varchar	The degradation line, the default is Null
N_ID	Int	The degradation point, the default is Null

Table 9 Component face data structure

Note:
1) CF: Component Face
2) Component face's type including:
CSF: Component Side-Face; CUF - Component-Up-Face;
CDF: Component-Down-Face; FCP - Fore-Component-Polygon;
MCP: Mid-Component-Polygon; PCP: Post-Component-Polygon
3) Component face can be depredated as line or point.

name	type	description
R_ID	Int	Region ID(PK)
Attrs	varchar	Attribute description
FatherPoly	Int	Outer polygon's ID, the default is Null(FK)
SonPoly	Int	Inner polygons' ID, the default is Null(FK)
N_IDSequence	varchar	The sequence of isolated-nodes
Front_CO_ID	Int	The positive component's ID(FK,1:1)
Negative_CO_ID	Int	The negative component's ID(FK,1:1)

Table 10 Region data structure

Note: Positive and negative decision by the Polygon, to meet the right rules for the positive and negative to the contrary.

name	type	description
P_ID	Int	Polygon's ID(PK)
Attr	varchar	Attribute description
Arc_IDSequence	varchar	The arcs' ID sequence of outer polygon, positive arc is "+", negative arc is "-"(FK,1:n)
InnerRegionID;	Int	The inner regions' IDs，the default is 0(FK,1:n)
OuterRegionID	Int	The outer region's ID, the default is 0(FK,1:1)
ClosedBox	Varchar	The Min box(defindedby (xMin，yMin，xMax，yMax)

Table 11 Polygon data structure

name	type	description
Ln_ID	Int	Line object's ID(PK)
Ln_Name	Varchar	Line object's name
Ln_Type	Varchar	Line object's type
Arc_IDSequence	Varchar	The IDs' sequence of arcs(FK,1:n)
Ln_Attr	Varchar	Attribute description

Table 12 Line Object data structure

name	type	description
FL_ID	Int	FL's ID(PK)
Ln_Type	Varchar	FL's type
Pnt_IDSequence	Varchar	The IDs' sequence of feature-node(FK,1:n)
Arc_ID	Int	The arc's ID(FK,1:1)
Ln_Attr	Varchar	Attribute description

Table 13 Feature line data structure

Note:
1) Feature line(FL) can be automatically connected or user interactively connected the feature-nodes of the arc.
2) The type of feature line is as follow:
DL: Divided Line for side-face and up/down-face
CL: Constrained Line; OL: Other Line

name	type	description
Arc_ID	Int	Arc's ID(PK)
Left_Code	Short int	Left region's ID,the default is -1
Right_Code	Short int	Right region's ID
FromNode	Int	Started cru-node's ID(FK,1:1)
ToNode	Int	Ended cru-node's ID(FK,1:1)
nPoints	Short int	Numbers of nodes contained in the arc
PointsSequence	Varchar	The IDs' sequence of nodes contained in the arc
LeftPoly	Int	Left polygon's ID(FK,1:1)
RightPoly	Int	Right polygon's ID(FK,1:1)
Attr	varchar	Attributes(format as up|mid|down or left|mid|right
nStyle	Short int	The fault's type
FaultID	Short int	The ID of fault

Table 14 Arc data structure

name	type	Description
N_ID	Int	Node's ID(PK)
N_type	Int	The node's type
x	Long	x
y	Long	y
z	Long	z
N_Attr	Varchar	Attribute description

Table 15 Node data structure

Node:
1) The value of node's type is as follow:

1: Cru-Node）; 2: Inner-Node; 3: Isolated-Node
10: Reference-Node; 20: Interpolated-Node;
100: Feature-Node.
2) The other combinations as the basic types' value added, such as, 11 for reference-cru-node, 12 for reference-inner-node and 111 for reference-feature-cru-node.

name	type	description
Pnt_ID	Int	Point object's ID(PK)
Pnt_type	char	Point object's type
Pnt_IDSequence	Varchar	The IDs' sequence of nodes(FK,1:n)
Pnt_Attr	Varchar	Attribute description

Table 16 Point Object data structure

5 CONCLUSION

Arming at these defects of OO-Solid model, the primitives, conceptual model and logical model of OO-Solid model is redesigned. At last the data structure, that includes all the topological relations for it, was designed. The key algorithms and key issues of modeling or dynamic updating based on OO-Solid model need further in-depth study.

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