Algebraic Topological Method for Semantic Modelling of Plant Cell Shapes

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***Abstract*—Geometric structures of objects in traditional geometric feature modelling are obtained via several numerical calculations; however, some geometric information is lost when objects are modelled in other dimensional spaces. The study proposes the method of simplicial complexes for the representation of topological structures of plant cell shapes and their 3D formalization using the Ontology Language. The proposed method provides description and representation of the topology of cell shapes according to the local and global characteristics of computer graphics and enables to obtain semantic information about their complex relations.**

Keywords—algebraic topology; simplicial complex; semantic modelling; CAD; plant cell

I. Introduction

Complex genetic mechanism and various ecological environments determine morphological diversity of plants. In plant cells, the concentration gradient of morphogens is used as their biological signals for growth and differentiation. From informatics, cell shape formation is a process of obtaining geometric characteristics of corresponding images under a stable state adapted to a set of multiple spatial and temporal scales. Individual characteristics cannot be reused, and these concepts need to be formalized, integrated and shared. In order to solve the problems mentioned above, the paper describes and constrains the semantics of plant cell models using the simplicial complex algebraic topology combined with the ontology language.

II. Related Research

In the selection of formal tools for plant cell shapes, Lindenmayer, a Hungarian biologist, developed a formal language L-System to simulate the behaviors of plant cells, and established a computer model for the relationship between local tissue and overall morphology in plant development [1]. In order to simulate the natural biological system and design a machine to propagate themselves, the cellular automaton proposed by Von Neumann can be adopted [2]. Iterated function systems based on the fractal theory are used to simulate the self-similarity of plant cell division [3]. Bezier and B-spline curves in CAD modelling are also always used in morphological modelling of plants [4]. These mathematical tools have their own advantages for different problems in this field. This paper studies the algebraic topological modelling and semantic representation of geometric shapes.

III. Materials and Methods

A. Experimental materials

Plant organs consist of different types of tissues, which are composed of cells with the same properties. Plant cell walls can be seen as the boundaries of cell shapes. As shown in Fig. 1, one side of the cell boundary $p_0\ p_1\ p_2$ is seen under an optical microscope.

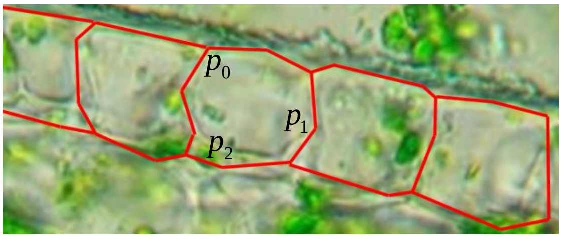

Fig.1. 2D image of plant cells

B. Modelling method

In this paper, the modelling process is divided into four layers (as seen in Fig. 2). Firstly, the bottom layer represents the measurement data of plant cell shapes. Secondly, in the information layer, algebraic topology is used to structure and symbolize data. Next, the semantization of plant cell topology is conducted using the ontology language. Finally, a user interface is established.

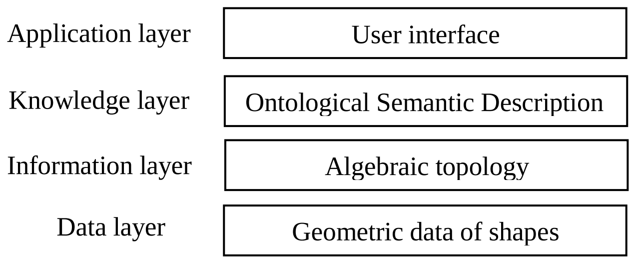

Fig. 2. Semantic modeling of plant cell shapes

An n-dimensional simplex is a convex set composed of n + 1 linear independent points, and a simplicial complex S is a finite nonempty set of simplexes [5]. It meets that: (1) all faces of the simplexes in this set belong to S; (2) any two simplexes (c_1, c_2) in the simplicial complex are disjoint, or $c_1 \cap c_2$ is a common face. As shown in Fig. 3, the faces of the simplexes are a generalized concept. In a one-dimensional face, namely n = 0, this simplex has 4 faces v_0, v_1, v_2 and v_3. When n = 1, it has 6 two-dimensional faces e_0, e_1, …, e_6 and 4 one-dimensional faces v_0, v_1, v_2 and v_3. By analogy, we can obtain the set composed of all faces and their structures of the simplex c.

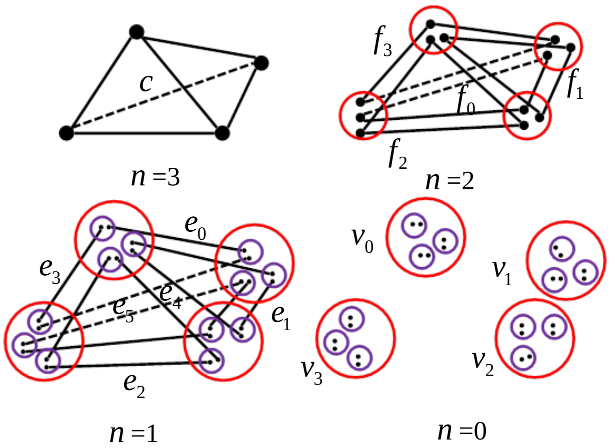

Fig.3. n-simplex

In a three-dimensional space, a 3-simplex is homologous to a plant cell shape. Therefore, the external structure of a multicellular plant tissue can be represented by a simplicial complex, starting from all its 0-dimensional faces to form a higher-dimensional face from bottom to top. The set element of faces of a simplicial complex forms a meet semi-lattice.

Definition 1: A meet semi-lattice is a special poset (S, $\leq$), any two elements of which have a least upper bound. That is, it satisfies the following axioms:

i) reflexive: if $\forall\ x \in S$, then $x \leq x$;

ii) anti-symmetric: if $\forall\ x$, $\forall\ y \in S$, $x \leq y$ and $y \leq x$, then $x = y$;

iii) transitive: if $\forall\ x$, $\forall$ y, $\forall\ z \in S$, $x \leq y$ and $y \leq z$, then $x \leq z$;

iv) supremum: if $\forall\ x$, $\forall\ y \in S$, $\exists\ u \in S$, $x \leq u$ and $y \leq u$, for $\forall\ z \in S$, $x \leq z$ and $y \leq z$, then $u \leq z$.

Based on definition 1, the relationship in S can be constructed into a tree structure, and the root node of the tree is the whole multicellular tissue.

IV. Results and Discussion

With the development of artificial intelligence and knowledge engineering, there is an urgent need for formal description of concepts and knowledge in an application field. Ontology has also been widely used in computer science [6]. In this paper, OWL language was used to describe the topological modelling of plant cell shape. As seen in Fig. 4, the visualization for the semantic modelling of plant cells was performed based on the Protégé Platform developed by Stanford University.

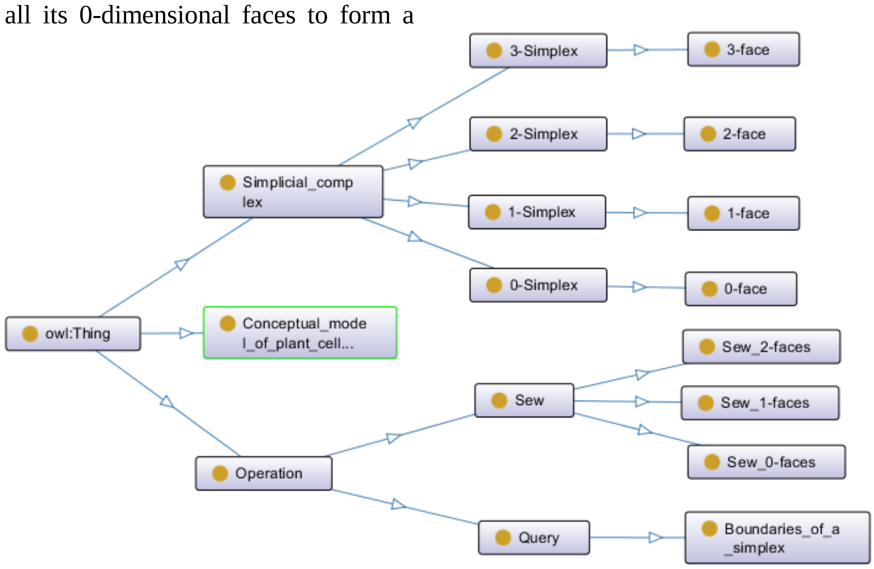

Fig. 4. Semantic modelling of plant cell shapes

The application of algebraic topology and ontology in describing of the semantic space of plant cell shapes can not only automatically verify the consistency of geometrical relationship of subjects, but enables also to analyze and to measure subjects by using the separability, compactness and connectedness of topology. The next step of the study is to map the topological model of plant cells to the three-dimensional Euclidean space to generate the 3D geometric model of cells.

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