Poster

Irregular Model Synthesis via Boundary Consistency Analysis

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1. Introduction

The detailed 3D environment becomes an essential way for offering the richest user experience in the digital entertainment or virtual reality application. Model synthesis [Mer07, MM08, MM09, MM11] is one of the effective methods to create 3D complex shapes from an example. Compared with other methods, this method can realize multidirectional extending easily. Besides, it is a general-purpose modeling tool, which can accept many different example models. One problem of prior work in model synthesis is that it can only extend example models on the regular grid structure. It is inefficient when people need to create some non-parallel or curved structures, which are more popular in the real world. To solve it, we extend the previous adjacent constraint by relaxing the boundary matching constraint, and the constraint is called generalized adjacent constraint. Through a boundary consistency analysis, more adjacent relation can be found to support synthesis on the irregular structure. Then an optimization framework is introduced to refine the synthesis result by maximizing an energy function.
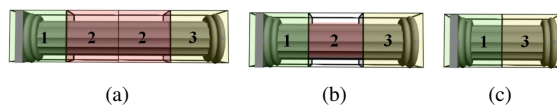

Figure 1: Model representation and constraints. (a): Model representation by a 1D array; (b): An arrangement satisfied the adjacent constraint; (c): An arrangement satisfied our generalized adjacent constraint, but unsatisfied the adjacent constraint.

2. Problem Definition

Model Representation. In our method, the input and output models are represented as multi-dimensional arrays of labels where each label corresponds to a model piece. The whole model is formed by combining the model pieces according to the arrays of labels. The model pieces are obtained by using a regular 3D lattice split the input. Fig. 1(a) shows a segmented input example, which is represented by a simple 1D array of labels. The output model is created by re-arranging the model pieces on a new subdivided grid structure. While previous model synthesis methods use a 3D orthogonal lattice to extend the structure, we use an irregular grid structure. The main difference between regular structure and ours is that the number of quadrilateral faces that are adjacent to an interior vertex is not necessarily 4.

Generalized Adjacent Constraint. Previous model synthesis methods [MM11] use the adjacent constraint to obtain the plausible synthesizing result. Fig. 1(b) gives an arrangement that satisfied the constraint. In the result, all the pieces that are adjacent to another are founded adjacent to another in the example along the same direction. However, the process may fail when some irregular vertices exist in the extending structure. To solve it, we introduce the generalized adjacent constraint, which is proposed by the following observation: any two blocks that share a similar geometric boundary can have the same adjacent relation. Fig. 1(c) shows an arrangement, which satisfied the generalized adjacent constraint. Our constraint is defined by a Boolean function T:

$$T([L_1, \theta_1, \eta_1], [L_2, \theta_2, \eta_2]) = \begin{cases} 1 & \text{if can be adjacent} \\ 0 & \text{otherwise} \end{cases}$$

Where, $[L_i, \theta_i, \eta_i]$ is a triple term with piece label L_i, rotate state θ_i and plane number η_i ($i = 1, 2$). The function shows whether η_1 plane of piece L_1 and η_2 plane of piece L_2 can be adjacent after rotation by $90 \times \theta_1$ and $90 \times \theta_2$ degrees respectively.

3. Analysis

This phase uses boundary consistency analysis to construct the generalized adjacent constraint.

Piece cutting. The goal of this step is to extract the boundary of the model piece. We use the 6 planes of the cuboid to cut the pieces, thus extract 6 boundaries for each piece.

Boundary contour clustering. The extracted boundaries

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are then classified into several categories according to shape similarity. Because the generated boundary often has multi polygons, we compare two boundaries by solving a multi contour matching problem. We only consider the comparison between the two boundaries that has the same number of polygons and set the similarity of the other pairs as 0. Given two boundaries s_1 and s_2 that has n polygons, a shape similarity matrix M is firstly computed, where $M[i, j]$ is the shape similarity between the ith and jth polygon from the boundary s_i and s_2 respectively. We use Hausdorff distance H to compare the polygons, and the shape similarity of polygon is computed by $M[i, j] = e^{-H(A_i, B_j)^2}$. We then use a greed algorithm to create the polygon correspondence f between two boundaries. And the shape similarity is the sum of the shape similarity between the corresponding polygons. If the similarity is beyond a certain threshold (the default threshold is 0.9), the corresponding boundaries are classified into the same cluster.

Generalized adjacent constraint creation. We first create the Boolean function according to the example, and the process is the same as discrete model synthesis [Mer07]. Then, we use the boundary cluster to expand the adjacent relation. If two boundaries belong to the same category, we combine their adjacent relation as an extended relation for the two boundaries. After processing all the clusters, we check whether the top or bottom boundary is rotationally invariant. We compute the shape similarity between the boundary and the rotated boundary. If the boundary and the rotated boundary are the same, the piece can be rotated by the corresponding angel. For every pair of adjacent piece, an adjacent energy is also recorded by measuring the shape similarity of the adjacent boundaries.

4. Synthesis

After constructing the generalized adjacent constraint, we can fill the segmented space by the model piece while maintaining the constraints and then deform the filling pieces according to the subspace. An optimization framework is introduced to improve the quality of the synthesis result by removing the undesirable adjacent structure iteratively.

Objective function. Suppose there are $S \times H$ subspaces in the subdivided structure space. We compute the quality of the synthesis result by measuring the similarity degree of adjacent structure between the example and synthesis result as the sum of all the adjacent energies: $E_{ss} = \frac{1}{6S \times H} \sum_{i=1}^{S \times H} \sum_{j=1}^{6} (Pro([L_i, \theta_i, \eta_j], [L_j, \theta_j, \eta_j']))$, where the binary term $[L_j, \theta_j]$ is the element of the set U_i, η_j and η_j' are the adjacent plane numbers of two pieces.

Initial solution. We use a backtracking satisfaction algorithm that outputs an initial assignment satisfying the generalized adjacent constraints, which builds on the discrete model synthesis method [Mer07]. The candidate filling set

is first iteratively updated according to the Boolean function until it is stable. Then one empty element is selected and assigned by a random candidate label. And the candidate filling sets start to update again. It stops until all the elements have been assigned by a label.

Optimization. In order to refine the initial solution, we maximum the objective function using a simulated annealing method (SA). In the SA step, we accept the new solution if $E_{new} \geq E_{ss}$; else we accept the new solution with probability of $\exp(-(E_{ss} - Enew)/t)$, where t is the temperature; else we retain the old one. During the optimization process, we reduce the temperature t and continue with the iteration. And the process stops if either the maximum number of iteration is reached, or when $E_{ss} > \upsilon$. During the process, a jump move operator is introduced to create a new solution from the old one while maintaining the constraints.

Fig. 2 shows a modeling result, and a complex city scene is created from a simple example model according to the irregular layout.
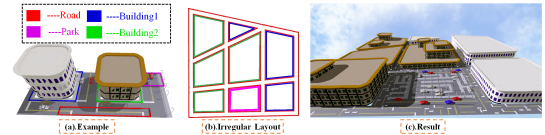

Figure 2: A representative result.

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