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Salience Estimation for 3D Meshes

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Abstract—**In our work, we proposed an approach to estimate the part salience. Unlike previous attempts, we assume that the part salience to be a linear combination of the degree of protrusion, the boundary strength, and the relative size. In this paper we will explore the use of such estimation by visualized the distribution of the salience values. In terms of such salience estimation, feature points can be determined according to the applications requirements thereafter.**

Keywords: part salience, machine vision.

1. Introduction

Human is apt to recognize shapes. For decades, numerous researchers have devoted themselves to exploring techniques of recognizing 3D shapes by mimicing human vision. Addressed on this issue, D. Hoffman et al. [4], [9] proposed a theory of part salience. According to their theory, human usually recognized or learned an object by dissecting it into several visibely distinctable parts whose boundaries usually have negative minima of the principal curvatures [4]. Furthermore, they suggested that the *salience* of a part depends on at least three factors: namely, the *relative part size*, the *degree of protrusion*, and the *boundary strength*.

According to their work [9], a possible measurement of the *degree of protrusion* of a part can be determined by a fraction of the surface area excluding its base(s) and the area of its base(s). In a viewer-independent representation, we can take an invariant base of the part to be the minimal surface delimited by its boundary curve. In addition, the magnitude of the *relative size* of a part can be determined by a fraction of the volume enclosed between the surfaces of the part and its base(s) and the invariant volume of the whole object. Finally, the boundary strength is determined on the basis of the fact that the salience of a *crease boundary* grows as the magnitude of its *turning angle* increases; namely, the *mean turning angle* or the *maximum turning angle* over the entire boundary.

On the basis of such theory, a great number of techniques have been developed [1], [2], [10], [11], [13], [15], [17], [20], [25], [26], [27], [28], [29], [30]. Most of the works either explicitly or implicitly give their own approximation of the part salience with respect to the three factors from their own perspectives.

For example, a continuous function μ for topology matching as an integral of geodesic distances is proposed by [7] where μ of a point v on a surface S is defined by

$$\mu(v) = \int_{p \in S} g(v,p) dS, \tag{1}$$

where $g(v,p)$ is the geodesic distance between v and p on surface S.

To give an estimation of the degree of protrusion, Lin et al. suggested a discrete version of the function μ [17]. Unlike [7], Lin's integral function is constructed from the dual graph of a given mesh $M(V,F)$: namely, $\mu(v) = \sum_i g(v,b_i)area(P_i)$ where $b_0, b_1, ...$ are the dual-vertices are the center of mass of the faces $P_0, P_1, ...$ and the part salience of a dual vertex v can be estimated by a normalization of the protrusion degree as follows.

$$P(v) = \frac{(u(v) - u_{min})}{u_{max}}. \tag{2}$$

Since their approximation of the part salience requires an integral of geodesic distances, a significant amount of execution time is spent on computing All-Pairs-Shortest-Paths [11], [17], [26].

2. Our Approach to Part Salience Approximation

Instead of consider the three factors individually or simply resorting to geometrical salience features such as the curvatures, our approach approximates the part salience with respect to the three factors suggested by Hoffman et al. [9]; namely, the protrusion degree, the relative part size, and the boundary strength. Prior to the discussion of these three factors a summary of basic notations and terminologies used in this context is summarized as follows.

2.1. Notations and Terminologies

Given a vertex $v \in V$, the *1-ring* of v, denoted as $R(v)$, is the set faces adjacent to v; the *star* of v, denoted as $S(v)$, is the set edges incident on v; the *crown* of v, denoted

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as $C(v)$, is the set vertices on the boundary of the 1-ring neighbourhood of v, i.e., the set $\{v_j|\overline{vv_j} \in S(v)\}$.

In terms of Breadth-First-Search, we may extend this definition to define the $k-ring$ neighbourhood of a vertex v by $\{f|f \in F_k\}$, where F_k is the set of faces at level-k of the BFS hierarchy.

2.1.1. The Protrusion Degree. The protrusion degree of a vertex v with respect to its $k-$ring neighbourhood, $R_k(v)$, is defined as follows.

Let $c_0(v) = v$, the geometric center of the k-crown of v is given by

$$c_i(v) = \frac{1}{\|C_i(v)\|} \sum_{\forall v_j \in C_i(v)} v_j, i = 1, 2, \cdots k. \tag{3}$$

We may define the protrusion degree of v, $P(v)$, as follows.

$$P(v) = \frac{\sum_{i=0}^{k} c_i c_{i+1}}{\mathbf{max}\{\|\overline{v_i v_j}\| | v_i \texttt{ and } v_j \in \partial R_k(v)\}}. \tag{4}$$

Similar to Eq. 2, the value of protrusion degree is normalized to the range [0,1].

2.1.2. The Relative Part Size. Our measurement to the relative part size, denoted as $R(M_i)$ is by the ratio of the area of the submesh M_i to the area of the input mesh M. Hence, for a submesh M_i, the relative part size is given by

$$R(M_i) = \frac{\sum_{\forall f_j \in M_i} Area(f_j)}{\sum_{\forall f_j \in M} Area(f_j)}, \tag{5}$$

which is essentially in the range of $[0, 1]$.

2.1.3. The Boundary Strength. Since the salience of a part boundary increases as the magnitude of its turning angle increases, we may measure the boundary strength by means of the average turning angle over the entire boundary curve.

Assuming $e_{i,j}$ is an an boundary edge of a submesh M_k whose neighbouring faces f_i and f_j and their normals are $N(f_i)$ and $N(f_j)$, respectively. Furthermore, let us denote the set of boundary edges of a submesh M_k as ∂M_k.

The boundary strength of a part defined by the submesh M_k, denoted as $B(M_k)$, is given as follows.

$$B(M_i) = \frac{\sum_{\forall e_{i,j} \in \partial M_k} \frac{1 - N(f_i) \cdot N(f_j)}{2}}{\|\partial M_k\|}, \tag{6}$$

where $\|\partial M_k\|$ is the cardinality of ∂M_k.

2.1.4. The Part Salience. Finally, we calculate the salience of a submesh M_i, or $S(M_i)$, in terms of Equations 4, 5, and 6 as follows.

$$S(M_i) = \alpha \cdot P(M_i) + \beta \cdot R(M_i) + \gamma \cdot B(M_i), \tag{7}$$

where α, β, and γ, are constant weights and $\alpha + \beta + \gamma = 1$.

3. Experimental Results

To verify our idea, we have conducted our experiments on a number of commonly used models from public domain. All the experiments were performed on a PC with Intel Core i5-4430 processor, 8GB RAM, and an NVIDIA GeForce GT 640 powered display card.

3.1. Runtime Efficiency

The runtime efficiency of our salience estimation algorithm is evaluated by program running times. A summary of our test results is summarized in Table 1.

The statistics of each test mesh along with their processing time are listed in Table 1 shown as follows.

TABLE 1. THE ATTRIBUTES AND PROCESSING TIME OF ALL THE MODELS USED IN OUR EXPERIMENTS.

Mesh	$\|V\|$	$\|F\|$	Ex. Times(secs.)
Armadillo	172974	345944	20.60
Dinopet	4500	8996	0.55
Triceratops	2832	5660	0.35
Cactus	620	1236	0.08
Octpus	4140	8276	0.46

To show how it works, some examples are rendered according to its salience as follows.

$$\begin{aligned} C(S) = (1-S)^2 \times R + 2S(1-S) \times G + S^2 \times B, \\ S = S(N_3(v_j)), \forall v_i \in V. \end{aligned} \tag{8}$$

The rendered result is shown in Fig. 1; in the figure, all the tips of protrusive parts are reddish meaning that they all have relatively higher protrusion degree than the other parts.

Such simpler yet effective part salience estimation can be used in the fields such as polygonal mesh segmentation, mesh simplification, matching, etc.

4. Concluding Remarks and Future Works

Unlike existing works, we propose a more comprehensive quantitative approach to the approximation of the part salience of a 3D mesh on the basis of the theory borrowed from cognitive science [4], [9]. Compared with traditional geometric measures such as the vertex curvatures, the novel approximation is more comprehensive and adaptive.

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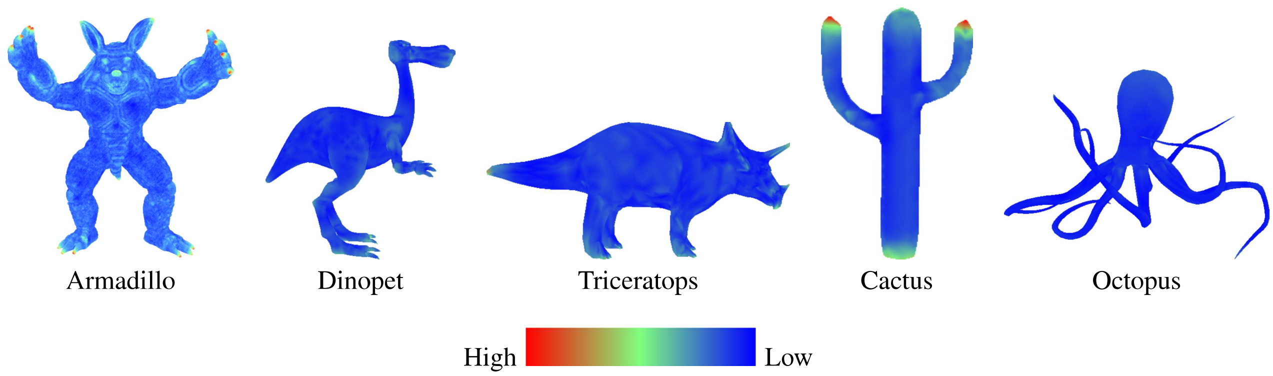

Figure 1. The distribution of the vertex salience of examples determined by our part salience approximation.

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