# Structsurfel: Physical Structure Parameterized Surfel for Animation

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**Abstract:** Animation methods of point based model are always lack of efficiency since using point based resampling and relaxation algorithms will have to access every animated surface point of the model. This paper presents a new method for accelerated animation of point based models by introducing new parameters to surface splatting. Differs to the classical method, surface splatting of the model are divided into soft parts and hard parts, hard parts are grouped into blocks and animated while soft parts are generated on the fly using GPU subdivision during the animation process instead of using low efficiency relaxation or resampling methods. The animation process includes two lines: assemble line which constructs the structsurfels and pseudo topology information which is needed by the soft part generation by physical parameters; animation line generates the animation of hard parts and soft parts of the structsurfel model by combining the point based methods and subdivision methods. We achieved a high performance and a same quality of animation compared to the traditional methods.

**Key words:** computer graphics; animation; point model; acceleration

## 0 Introduction

Though triangle meshes are still the most common surface representation in computer graphics applications. Point based modeling, rendering and deformation techniques have started to replace the dominant position of mesh based techniques. Point-based modeling technique existed for a long time, newly developed 3D scanner are capable of generating huge amounts of point samples with detailed surface geometry properties [1]. The quantity of the points has put heavy pressure on their processing and deformation methods.

Point based rendering has been a popular topic, the first point-based representation that is mainly targeting at rendering is proposed by Grossman and Dally [2]. A set of depth images that are orthogonally sampled from a given input geometry and each pixel is a surface sample containing geometric position information and surface color was used as rendering primitives. This method is advanced by Zwicker et al [3]. They proposed a new model based on surface splats which contains a normal vector $n_i$ and a radius $r_i$ which solved the problem of bad visual effects caused by gaps between neighboring points. A more efficient representation using the approximation and interpolation techniques has been proposed by Levin, the moving least-squares (MLS) surface, and this representation has been applied to point based method proposed by Alexa et al [4]. Advanced rendering techniques for point based rendering can be found in [5].

In light of point based rendering techniques, point based deformation and manipulation method has been proposed. Pointshop3, a point based editing tool and idea of brushes which are capable of operating all the properties of point based rendering techniques was proposed in Zwicker et al. Based on their method, they also published a method to deform point based models. Müller [6] showed a better result by using only point-based elements both for the animation control and the surface. With the help of MLS surface they create an animation model for elastic, plastic and melting objects.

But due to point based representations usually use large quantity of primitives to represent

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detailed surface geometry properties, the animation and deformation techniques for point based models which use the single point as input of the animation pipeline is low efficient. Moreover, those animation and deformation methods did not adopt the highly developed hardware which oriented in mesh base operations thus gave too much pressure to the central processing unit which are the critical computing power for the whole computer system.

In this paper, we propose a new animation method for both complex surface geometry point based objects which contain large amount of primitives and simple point based objects at interactive frame rates. Our animation method is based on additional physical information contained in point based models, though attributes of points in those models are only used in rendering process, additional attributes could be added to provide more efficient animation performance. And physical structure attributes which contain information to show the animation properties are added to the traditional point primitives in rendering. Though point oriented editing tools and watermarking tools could be used to give properties to sampled points [7] [8], a general procedure is adopted in this paper to give new properties to surface splatting.

For simplicity, we use surfel as our rendering primitives, but our method could surely be expanded to other forms of point based primitives. The process of surfel generation proposed by Zwicker is modified and two texture materials are added to geometry models and special sampling methods are introduced in order to provide physical structure information to surfels. Due to the physical structure attributes contained in them, we name this kind of surfels as structsurfels. Structsurfels which preserve the same physical attributes are grouped into structure blocks (structural blocks) and animated in the same behavior; gaps generated between the structural blocks during animation would be filled based on the attributes contained by structsurfel models. Subdivision methods is used in the gaps filling process, and due to our modeling methodology (section 3), no merging of structural blocks would occur during animation. Differs to the previously presented method, subdivision method processes data in a parallel style instead of sequential processing. This advantage goes well with the highly developed hardware structure of modern graphics processing units. We would show the advantage of using subdivision methods compared to the CPU based filling and merging process after animate point-based representation.

From a modeling point of view, objects contain special physical properties in their surfaces; those properties should be directly controlled by the objects modeling processes, moreover, the inner physical properties which could also be presented by surface physical properties by some mapping methods presented by Zurich. By contrast, in tradition animation methods for point based models, properties for animation are totally controlled by the inner physical model which might damage the reality of animation.

Fast and simple subdivision methods enable us build smooth surface to fill the gaps generated during animation. Compared to the method provided by Muller et al, our methods could alleviate merging and filling computation of surfels. The structsurfel animation pipeline complements the existing graphics pipeline and fully uses the computation power of graphics processing unit compared to the traditional animation methods. Smooth surface and high performance could be achieved by tuning the structsufel model. Though this method might not be suitable for elastic models which might contain so less structural blocks of structsurfels and too large gaps are need to be filled by subdivision in real time. Structsurfels work well for most of the point based models which makes structsurfel a suitable and simple method for point based animation.

The main contribution of our work to the field of computer graphics are: physical structure parameterized surface splatting and its properties sampling methods for point based models. GPU based subdivision aided acceleration for animation of physical structure parameterized surface splatting based models.

# 1 Conceptual Overview

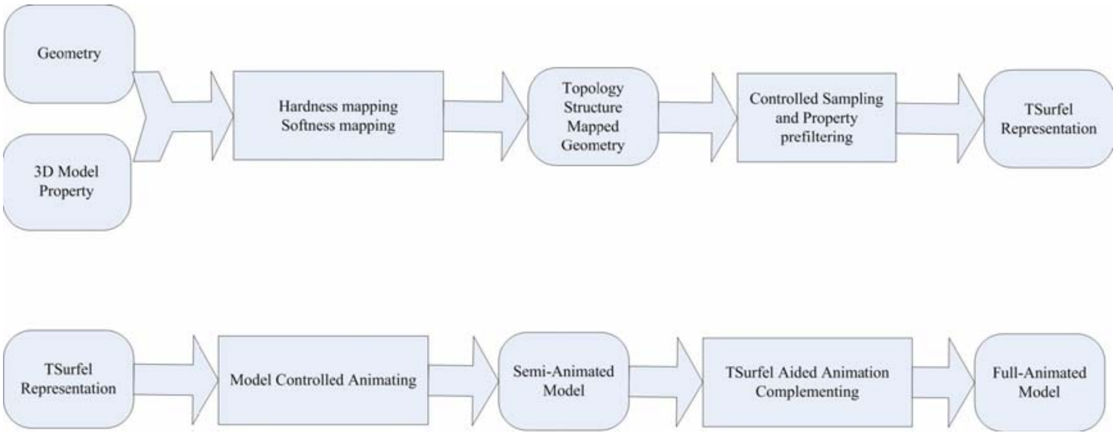


图 1　我们的点动画流水线

Fig.1 Point animation pipeline

Add new properties to surface splatting has been adopted by Botsch [9]. Our approach associate physical properties with each surface splatting. The structsurfel approach consists of two main steps: assembling and animation line, similar to the method proposed by Pfister. Assembling line is the procedure of sampling the physical structure and surface properties of the structsurfel. Animation line is the procedure of processing the physical structure attributes and the final generation of the animation. Figure 1gives out a conceptual overview of the algorithm.

The assembling process converts geometric objects, their textures, the added physical properties describing texture maps to structsurfels. Our modeling methodology divide all the object in realities into soft plastic parts and hard solid parts, these physical properties would be demonstrated in the surface of objects. Structsurfels in the hard and solid parts of surface are grouped into structure blocks and surfels in the soft and elastic part would be generated on the fly during animation. By careful divided objects and the online generation process, merging of surfels would not occur.

Those texture maps added to geometry model composed hardness map and softness map. Hardness map, by which the hard and solid properties of surface are modeled and sampled, demonstrate the local ascription of structsurfel, same hardness means the same behavior of structsurfels during animation. Softness map, by which we use to aid the generation of soft and elastics parts of the surface, is used to sample out the feature points of geometry model which would be used in the subdivision process. Structsurfel attributes sampled from softness map is special value that could be mapped into the pseudo topology information which would be used for subdivision process. Structsurfels that contained the softness value sampled from softness map must reside in one of the aggregate of the structsurfels sampled from hardness map. This ensures the feature point, by which we mean the structsurfels that contain softness value and used in animation, would animate along with the same hardness valued structsurfels.

By introducing the extra attributes for surfels from the assembling line for animation in the preprocessing stage, simple animation model could be used instead of using complex animation models in generation of detailed animation which would be done in subdivision. Thus less pressure of animation computation would be attained, which would be a great benefit for physical based animation models that consume computation power extensively.

We use ray tracing to create orthogonal layered depth images, which is same with the method of generation of surfels provided by Pfister, except we do not include the 3-to-1 reduction for simplicity. For the facts that ray tracing would generate filtered average surface properties due to the lost precision of the texture coordinate which would be especially significant in large geometric models, we setup a postprocess stage for correct the hardness and softness value for every sturctsurfel.

The animation pipeline animates the structsurfel model, which is also responsible for the resampling process of animated structsurfel based models after the assembling line. Animation started from the animation model, new positions and surface properties such as normal would be generated from the animation model and those changes are applied to corresponding structural blocks of stuctsurfels, this procedure is named to the Main Part Animation. After the main part animation, gaps might be generated, and the resampling process is done by the subdivision process, this procedure is named to the Sub-Part Animation. The scale of gaps between the structural blocks is estimated based on the feature point constructed in the assembling line and suitable rounds for subdivision are selected. By hard and soft division modeling and subdivision, gaps would be smoothly filled and no merge of structsurfels would take place.

# 2 Assemble Line

The assemble line is the preprocessing stage of the whole animation procedure. The main purpose is to construct the structsurfel. In light of the construction process of surfels, a procedure which is nearly the same is designed. First, hard and soft part of the geometry model is decided according to the animation and performance requirements, since more soft parts created during the modeling process (parts of the points generated on the fly during animation) means lower performance but a more elastic animation. On the contrary more hard parts means higher performance but lower reality for some elastic models. Hardness attributes which mean the surfel's grouping behavior during point-based animation is generated by sampling geometry in a controlled process to create a higher precision representation. To support the subdivision driven gaps filling method, feature points should be defined in assembling line. Softness map as another texture for geometry model during sampling structsurfels is introduced. After the sampling pseudo topology mapping would be created to help mapping the one-dimensional softness value into a two-dimensional pseudo topology map. This map would be used in the sub animation part.

## 2.1 Hardness Mapping and Sampling

Through sampling the hardness mapped geometry model, the hardness attribute of the structsurfel based model would be generated. Different to the method used by Pfister, a modified ray tracing methods are used to generate structsurfel model. Limited by current geometry modeling software, our hardness map are currently added to the model through diffusive map channel in the original geometry processing line and we would show how we migrate the sampled attributes to the structsurfel models.

### 2.1.1 Hardness Map Editing

Commercial photograph editing tool are used for generating hardness map. Different colors are given to expressed the different hardness properties, structsurfels in the same color demonstrate the same hardness attribute and info the animation line to treat those stuctsurfels as a solid group. Only group operations such as moving, normal modification are allowed to apply to the group, which make sure those stuctsurfels would preserve the hardness property during animation and prevent themselves breaking up into different parts. Figure 2 shows a 3D face model which is mapped by hardness map.

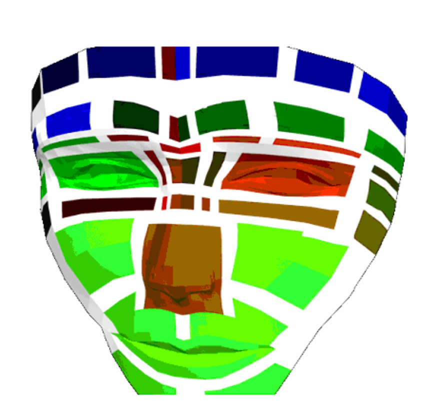

图 2. 硬组织映射至 3D 模型表面示意图

Fig. 2 Hardness mapped 3D model.

The white color part of the texture proposed that those part of the geometry model would be the soft part and should be generated in the structsurfel aided animation line. The amount of those parts was carefully chosen to balance the performance and visual effects. More soft part of the geometry model means a smoother visual effect in animation but slow performance due to large computation time spent in subdivision, less soft part of the geometry model means a coarse visual effects and even errors in animation due to corruption of two solid parts. Models should be carefully designed according to the requirement of animation and performance.

Because traditional surfel models support all the mapping method that is used in geometry based modeling, and no texture channel for hardness map exist in the current assembling line. So we generate another surfel based model for this mapping, this surfel model contains only the hardness attributes by using the channel of diffusive color and the softness attributes which would be introduced in the next section by using the specific color channel. By using same geometry model but different texture mapping we could generate two surfels based models exactly the same. These two surfel based models would be merged at the beginning of animation line to form a real structsurfel based model.

### 2.1.2 Controlled Sampling

Sampling methods for point-based model has been well discussed in Pfister's work. He proposed a LDC sampling and post process method in sampling and detailed discussed the color filtering method and the methodology of maintaining enough sampling resolution. We adopt a nearly the same method, but due to some special properties of hardness mapping, the sampling process goes in more restricted circle.

Hardness map which contains the aggregating attributes of the structured surface elements is mostly constructed by commercial photograph editors or some other editing tools. Most of those editors provided methods for anti-aliasing and blurring along the edges of two colors to provide better visual effects. But this property would impede the processing of hardness mapping. If the color which means aggregating attribute of structsurfel, would be smoothed, one structural block of structsurfels would probably become several small part of structural blocks which make the animation model failed to work correctly. So any anti-aliasing or blurring effects should be closed during editing the hardness and softness maps.

The sampling process of hardness map should also be controlled. Structsurfels sampled from geometry model by conventional ray tracing methods usually has few errors along the edges of distinctive hardness and softness colors. Though filters could be introduced to lessen the damage to visual effects for pure surface properties, hardness map require exact information to be passed from geometry models to structsurfel based models. Thus we modified the ray tracing methods and make sure the ray tracing procedure build a bounding box along the axis of 3D models and ray casting would start from the bounding box's left-low corner. This also enables the merging of two sampled surfel models (one represents the surface properties and the other represent the physical properties) into one structsurfel without errors. To stop the error introduced by filtering color during sample structsurfels, the texture pre-filter was also removed when dealing with hardness map sampling.

#### 2.1.3 Post Processing

Each sampled structsurfel would be aggregated according to its hardness attribute, if the result of generated structural blocks is not the desired amount (usually we would get more structural blocks than expected). Some smaller structural blocks would be added to a larger structural blocks according to the algorithms show in Figure 3.

The smaller structural blocks are merged to the larger structural blocks according to the k-d neighbor search structure [10]. Due to the fact that anti-aliasing in editing or other reasons which generate errors that destroy the precision of hardness attribute values could only cast effects on the edges of each structural block, and we assume that usually the structural block is much larger than the small structural blocks generated because of imprecision. The nearest structural block which is larger than certain extent, the smaller structural blocks would be added to it.

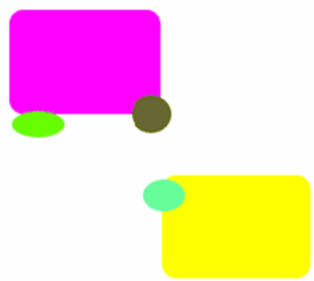

图 3. 硬组织采样后处理示意图

Fig. 3 Post processing for hardness sampling.

### 2.2 Softness Mapping and Sampling

Topology information is not contained in surfels, and subdivision requires the topology structure to be preserved in model representation. Thus softness map is used to give the pseudo topology information. The original topology could not be maintained due to the fact that surfels only contain the local attributes. As structsurfel is defined to only be a zero-dimensional n-tuple surfel, pseudo topology could only be stored in structsurfel in the form of a single value. The topology neighborhood cannot be directly stored in stuctsurfel, because of the index of structsurfel cannot be determined during modeling the softness attributes of the geometry model. Edge detection methods might be used to find pseudo topology of different part of geometry models during sampling, but it would be impossible to use ray-tracing method to sample out all of the edges due to the precision of sampling.

Instead, softness mapping use texture to give out the softness (pseudo topology) properties. As has been mentioned above, a one-to-one mapping between a four-degree point dominated topology map and a numerical value which could be represent by a color could be built. Use ray tracing methods, the numerical value could be picked out. And this value is applied the pseudo topology map transform process. The topology information that is required in sub part animation would be preserved in a single strutsurfel in this way. Figure 4 shows a softness map texture used in cloth animation.

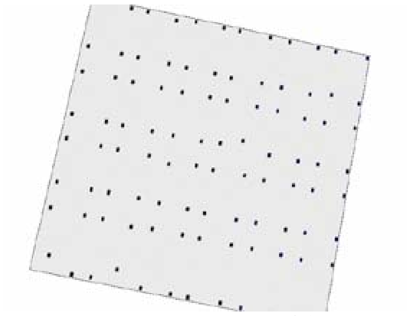

图4. 软组织映射和编辑
Figure 4: Softness Map Editing.

Sampling of softness map is partially the same with hardness mapping except in the post processing part. In order to generate only one stuctsurfel as the feature point of pseudo topology for subdivision, additional processing method is added to the softness mapping post processing stage. Topology mapping could be achieved by using only 4 degree topology point (except the edges conditions). Figure5 shows softness mapped 3D geometry and its topology properties. The front part is the softness map and the back face is the topology graph, each softness attribute which is meaningful ( in white empty) is correspond to a topology position in the topology graph.

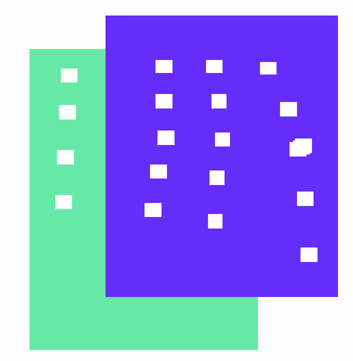

图 5. 拓扑关系映射图
Fig. 5 Topology mapping

After doing the hardness map sampling post processing, more procession are required to generate the feature point of pseudo topology. Softness mapping would put several groups of structsurfels to be the candidate feature point used in subdivision. Due to photograph editing limitations, size of the selected structsurfels by softness map would be larger than one. Figure 6 shows the method we use; we pick the gravity center of those softness mapped tsurfel groups.

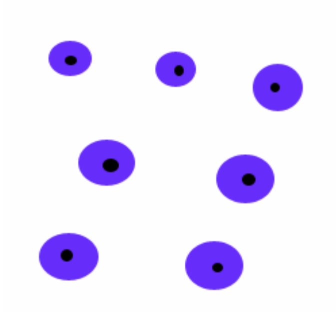

图6. 软组织后处理示意图
Fig. 6 Softness post processing.

# 3 Animation Line

Our animation line provides the ability of animating structsurfels, contact handling was solved simply by the animation model, advance contact handling techniques could be found in [11]. Through the assembling line, enough information will be provided to create an animation model. In the physical (or procedural) animation model for those structural blocks, the gravity centers of the structural blocks are used as the control point of animation model. Our method has no restrictions of animation model, the only things need to be done is to build the mapping between the animation model and the structural blocks' control points, this is well studied in Zurich's paper by using coating algorithms. Structural blocks would be animated by animation models and gaps would definitely occur during animation. Careful modeling during assembling line ensures those structural blocks would not collapse or merge during animation. They would keep in a decent distance between each other and leave space for soft part of the model. To fill the gaps generated during structural blocks animation, the animation process is divided into two parts. The main part of animation is described as above.

After the main part animation, a sub part animation process is used to fill the gaps between the structural blocks. The advantage of processing the filling process in a single step, is base on the fact that parallel data processing goes well with hardware accelerating. Formal methods of point based animation were mostly based on the computation power of CPU. They process data sequen1cially and this processing would not benefit from the hardware acceleration. Our procedure based on the well-developed subdivision algorithms [12] and based on the pseudo topology structured surfels, a real time filling method for structsurfel based animation could be created.

# 4 Results and Conclusion

We implement our whole animation processing. We use two examples to show our animation methodology and its adaptivity. We adopted an explicit mass-spring model to control a cloth animation. Also a well controlled mass-spring animation model of facial animation is also designed and implemented to show our animation effects.

## 4.1 Cloth Animation

In this paper, a simple explicit animation model is used for cloth animation. Mass-spring is used to model the animation process, Hardness mapping and softness mapping is edited base on simple observation that a cloth is a uniform model, and Figure 2 and Figure 4 is given to the geometry model of cloth. From our animation pipeline, we are able to create the animation of gravity and some natural power effect. A model with 6,000 strutsurfels is used in this animation and 24 structural blocks is generated. The performance shows that the whole animation process is done in real time and with sufficient realities.

## 4.2 Facial Animation

Many facial animation systems have been developed, the muscle-based methods which are commonly employed in interactive computer graphics to generate facial expression and the feature-point-driven methods which used the feature point and subdivision process to generate facial animation are both widely used in computer graphics. Instead of the animation model presented in the previous works, a simple well controlled mass-spring model is used in the animation process.

As previous hardness mapping and softness mapping mentioned, certain parts of the face is grouped into same hardness value based on the common modeling methods in facial animation. Most of the facial expressions could be generated through our animation pipeline. Compared to the cloth animation, a point model with 30,000 structsurfels is used in this animation to create good visual effects, and this amount of structsurfel elements would not possibly animated in the classical animation methods based on merging and split single structsurfels. Compared to the works by Müller [13], the structsurfel approach provides higher performance.

We propose a new animation method for both complex surface geometry point based objects which contain large amount of primitives and simple point based objects at interactive frame rates. Our animation method has good advantages on animation of point based models.

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# Structsurfel:点动画中基于物理的具有结构化参数的 Surfel

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**摘要:** 点模型的动画往往会由于执行基于点的采样和松弛算法过程中要访问模型表面的每一点而效率低下。本文通过为表面 splatting 引入特征化参数值，提出了一种新的点模型动画的加速方法。与传统的方法不同，模型的表面 splatting 分成软组织和硬组织两部分。硬组织分组成为块并进行动画的计算，而软组织在动画过程中通过基于 GPU 的细分操作动态生成以替代传统点动画中低效的松弛和重采样方法。动画过程分成两条线: 组装线构建结构化 surfel 和软组织生成所需的伪拓扑信息; 动画线通过结合传统点动画方法和细分方法生成硬组织的动画计算和结构化 surfel 模型的软组织部分。本文方法可以得到更高性能的动画效果。

**关键词:** 计算机图形学；动画；点模型；加速

**中图分类号:** TP391