Extending Hypertextures to Non-Geometrically Definable Volume Data

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Abstract

Texture mapping is an extremely powerful tool for the addition of surface detail to an object. This paper aims to introduce the field of three dimensional texture mapping, in terms of *"solid textures"* and *"hypertextures"*. The second half of the paper shows how the hypertexture paradigm can be extended, with the use of *"distance transforms"*, to incorporate non-geometrically definable datasets.

1 Introduction

The increasing use of computer generated graphical representations of everyday objects, in both entertainment and industry (including such areas as medical imaging), has led to the development of powerful rendering tools such as *ray tracing*, *radiosity* and *volume rendering (see [1, 2] for a description)*. However, the images produced by such applications are somewhat bland when compared to their real life counterparts. The object's surfaces appears smooth and plastic *(Figure 1)*, not textured and natural. Therefore, increased realism in computer imagery is needed.

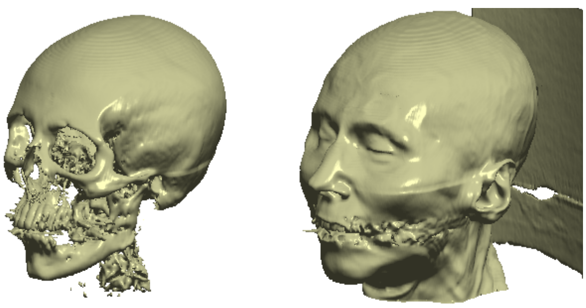


Figure 1: *Computer generated images.*

Such realism can be incorporated into a computer generated image with the application of *"surface detail"* algorithms, including:

- *Bump mapping*,
- *Environment mapping*, and
- *Texture mapping* in one, two and three dimensions.

Two dimensional texture maps are the more diverse of the *"surface detail"* algorithms as, with the use of digitised photographs, natural textures can be used. However this approach suffers from aliasing effects (caused by the warping of the texture) when applied to complex datasets, such as those obtained from computerised tomography *(CT)* scans. Three dimensional texture mapping techniques are more resistant to such aliasing effects, as the need for image warping is removed by the fact that the texture map is mathematically defined throughout $\mathbb{R}^3$, thus any point on the surface of the rendered object has a predefined texture value. Therefore, the 3D texture mapping approach is analogous to carving a statue from a block of material, *Figure 2*.

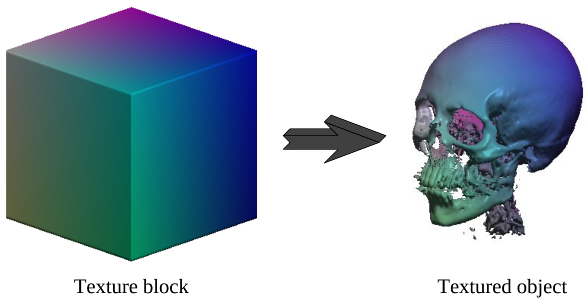


Figure 2: *Three dimensional texture mapping.*

Perlin and Hoffert [3] extended the three dimensional texture mapping paradigm to produce *"hypertextures"*, allowing a computer to model such phenomena as fur, fire and smoke. This paper shows how hypertextures can be extended to use with non-geometrical datasets. In Section 2 we introduce the area of three dimensional texture mapping through solid textures, followed by a description of hypertextures in Section 3. Finally in Section 4.1 we show how a volume dataset is modified with the use of distance transforms, thus allowing the application of the hypertexture model. Section 4.2 shows images produced with extended hypertextures, and Section 4.3 shows how the extended hypertextures produce images that are consistent, allowing the production of animations.

2 Solid Texturing

2.1 Related Work

Recent trends in research into the addition of detail to the surface of an object have turned towards the field of three dimensional texture mapping. Early work in this field, such as that by Schachter [4], used summations of long crested narrow-band noise waveforms to produce textures, that vary in two dimensions, by Fourier synthesis.

Peachey [5] shows how popular two dimensional texturing techniques, such as Fourier synthesis and stochastic texture models, can be extended to produce three dimensional textures. Combinations of these extended techniques, along with 3D projections of 2D images, make up what Peachey coined *"solid textures"*. Perlin also used the term solid textures to describe the work in [6]. Here complex three dimensional textures, such as marble, are created from primitive, non-linear, *"basis functions"*. The most fundamental of which is *"noise"*, a function that returns a random value at each point in space. In [7] Lewis reviews several existing algorithms for noise generation, resulting in two new algorithms that are more efficient, have improved control over the noise power spectrum, and have no artifacts. A further basis function, introduced by Worley in [8], creates flagstone-like textures by calculating the distance between the surface points and randomly placed *"feature points"*.

As mentioned above Peachey projects a digitised 2D image in order to create a 3D texture. A problem arises when the object is larger than the texture, resulting in the need for texture repetition, which can lead to visible artifacts between the texture tiles. Research into texture analysis aims to remove such effects by synthesising a new texture (of any size), that looks like (in terms of colour and texture properties) a given sample image.

Heeger and Bergen [9] base their analysis around the way in which the eye perceives texture, utalising the fact that it is difficult to discriminate between textures that produce similar responses in a bank of linear filters. Therefore, with the application of simple image processing operations *(histograms, convolution, etc.)*, in a pyramidal format, white noise can be modified to take on the appearance of a sample image.

Solid textures produced by Heeger and Bergen's method can be imagined as a stack of *"photocopies"*, with each layer being an exact copy of the one below. Ghazanfarpour and Dischler [10] use some of the spectral information, gained during the analysis of the sample image, to apply a selective filter to white noise. The filtered noise is next used to perturb the layers of the synthesised texture, thus removing the monotony of Heeger and Bergen's method and creating far more realistic solid textures. In a second paper [11] Ghazanfarpour and Dischler show that solid textures synthesised from a single 2D sample are only controllable in two dimensions. They continue to show that with the use of three samples, taken in the directions of the orthogonal axes, it is possible to control the texture synthesis in all three dimensions.

2.2 Perlin's Solid Textures

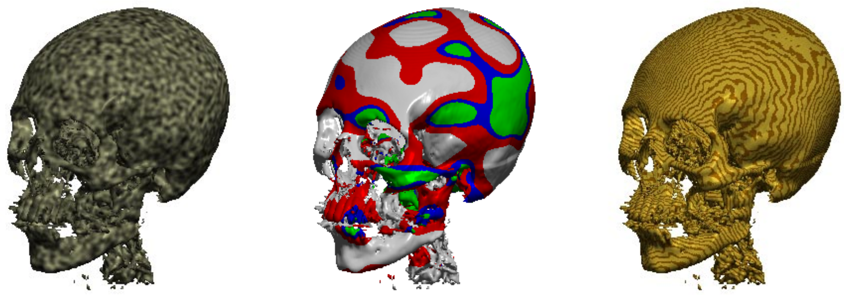
It has already been pointed out *(Section 1)* that three dimensional texture mapping is equivalent to computer sculpture, a fact that inspired Perlin to create *"solid textures"*; complex three dimensional textures constructed from primitive, non-linear, *"basis functions"*.

2.2.1 Basis Functions

Noise. The most fundamental of the basis functions is *"noise"*, which returns a pseudo-random value, in the range (-1, 1), by interpolating gradient vectors between predefined lattice points. There are numerous implementations of the noise algorithms (Lewis [7]), which all exhibit the following properties.

- Statistical invariance under rotation.
- A narrow bandpass limit in frequency.
- Statistical invariance under translation.

These properties make noise an ideal texturing tool, due to its ability to create desired stochastic effects, without affecting the execution of general graphical tools *(rotation, scaling and translation)*.

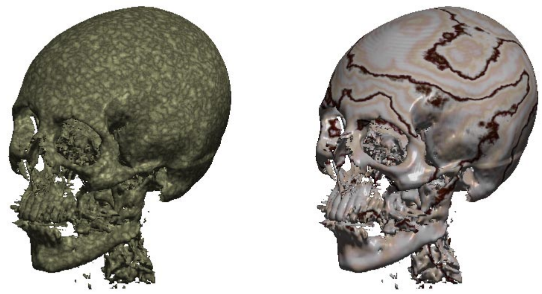


(a) *Noise* (b) *Bozo* (c) *Wood*

Figure 3: *Solid textures create using the "noise" basis function.*

Turbulence. The *"turbulence"* basis function gives the impression of Brownian motion (or turbulent flow) by summing noise values at decreasing frequencies, introducing a self-similar $\frac{1}{f}$ pattern[1]. The discontinuities of turbulent flow are introduced into the model with the use of the mathematical function *abs*, which reflects the gradient vectors used by noise.

[1]Where f is the frequency of the noise.



(a) *Turbulence* (b) *Marble*

Figure 4: *Solid textures create using the "turbulence" basis function.*

n^{th} Closest. A third basis function, introduced by Worley [8], places *"feature points"* at random locations in $\mathbb{R}^3$. The *"n^{th} closest"* basis function calculates the distance from a surface point to each of the n closest feature points. Combinations of these distances can then be used to index a colour spline, adding a flagstone style texture to the surface of the object.

3 Hypertextures

Solid texturing produces objects that have *"simple"* surface definitions. However many objects, such as fur, have surface definitions that are at best complex. Moreover, others, such as fire and smoke, have no well defined surface at all. Perlin and Hoffert [3] introduce a technique that allows for the production of such complex textures, through the manipulation of surface densities. That is, rather than just colouring an object's surface with a texture map, its surface structure is changed (during rendering) using a three dimensional texture function.

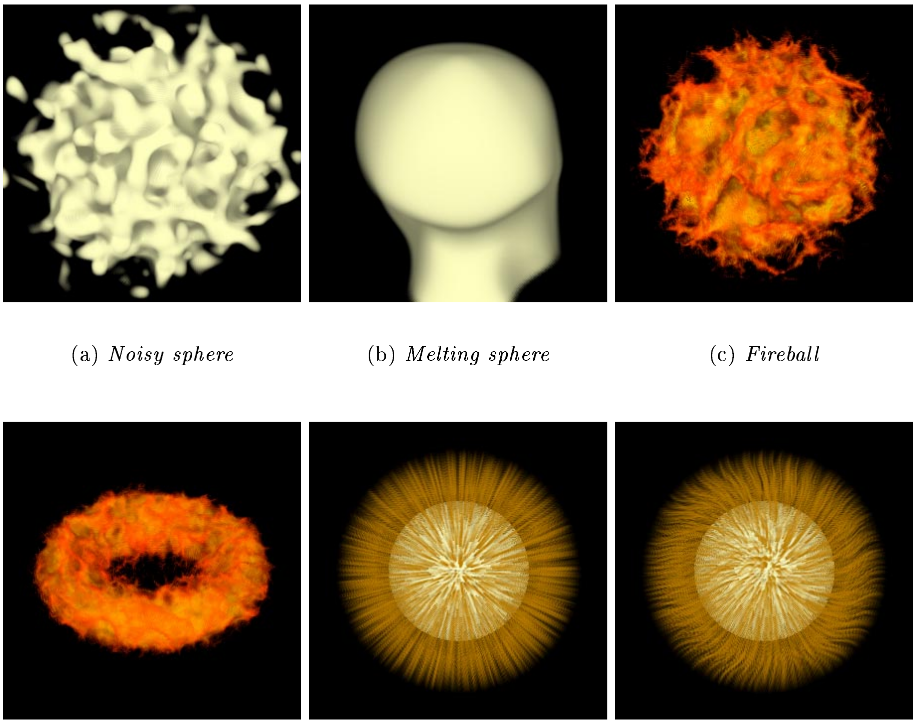
Hypertextures are implemented using a *"ray marcher"*, based on the volume rendering paradigm, to evaluate the texture at every point in space, resulting in a complexity of $O(n^3)$. Worley and Hart [12] improve the efficiency of this implementation by replacing the ray marcher with *"sphere tracing"*. Execution enhancements are also introduced by Worley and Hart, found from inspection of the basis functions

3.1 Implementation

Hypertextures introduce the idea of *"soft objects"*; objects with a large boundary region, modelled using an *"object density function"*, $D(\mathbf{x})$, thus giving three possible states to a point:

- *Inside* - the point is inside the object.
- *Outside* - the point is outside of the object.
- *Boundary* - the point is in the boundary, *"soft"*, region of the object.

As with solid textures, combinations of *noise* and *turbulence (Section 2)* together with two new *density modulation functions (DMF)*, *bias*; controls the density variation across the soft region, and *gain*; controls the rate at which density changes across the midrange of the soft region, are used to manipulate $D(\mathbf{x})$ to create hypertextured objects. Figure 5 shows examples of hypertextured objects.



(a) *Noisy sphere* (b) *Melting sphere* (c) *Fireball*

(d) *Ring of fire* (e) *Straight fur* (f) *Curly fur*

Figure 5: *Examples of hypertextures.*

4 Extending Hypertextures

Figure 5 shows the pleasing effects that can be produced when the hypertexture approach is applied to geometrically definable datasets. The major set back with this approach is the inability to apply the method to irregular (or non-geometrically definable) datasets, such as CT scans.

4.1 Distance Transforms

Examination of datasets, generated by solving geometric formulae, shows that the data points give the *"distance"* to some point (or surface) within the dataset. The datasets used to create the hypertextures shown in Figure 5 were produced in this manner. Therefore, if the dataset of a non-geometric object can be converted to such a *"distance volume"*, the hypertexture paradigm will become applicable to the non-geometric object.

Such a conversion can be accomplished with the use of *distance transforms* [13–23]. A distance transform involves *"segmenting"* the dataset, to extract the surface of interest, followed by a two pass application of a *"distance matrix"*, Figure 6.

	3		3	
3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3
	$\sqrt{5}$		$\sqrt{5}$	
3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3
	3		3	

3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3
$\sqrt{6}$	$\sqrt{3}$	$\sqrt{2}$	$\sqrt{3}$	$\sqrt{6}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
$\sqrt{6}$	$\sqrt{3}$	$\sqrt{2}$	$\sqrt{3}$	$\sqrt{6}$
3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3

	$\sqrt{5}$		$\sqrt{5}$	
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
	1	0	1	
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
	$\sqrt{5}$		$\sqrt{5}$	

3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3
$\sqrt{6}$	$\sqrt{3}$	$\sqrt{2}$	$\sqrt{3}$	$\sqrt{6}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$
$\sqrt{6}$	$\sqrt{3}$	$\sqrt{2}$	$\sqrt{3}$	$\sqrt{6}$
3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3

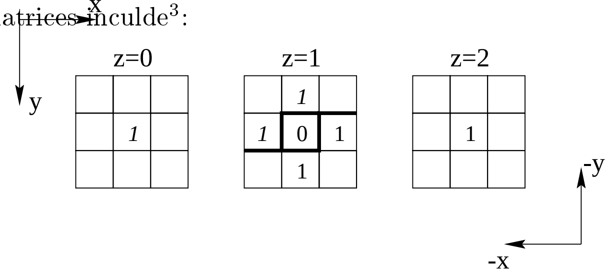
	3		3	
3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3
	$\sqrt{5}$		$\sqrt{5}$	
3	$\sqrt{6}$	$\sqrt{5}$	$\sqrt{6}$	3
	3		3	

Figure 6: *5*x*5*x*5 distance matrix.*

The two passes propagate local distance in an attempt to mimic Euclidean distance calculations. The forward pass (using the matrix above and to the left of the bold line *(italic font)*) calculates the distances moving away from the surface towards the bottom of the dataset, with the backward pass (using the matrix below and to the right of the bold line) calculating the remaining distances.

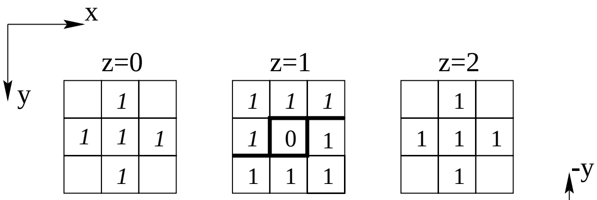
There are numerous distance matrices available for the distance transform process, each giving a different result *(Figure 7)* at the cost of execution time[2] *(Table 1)*. Such matrices inculde[3]:

- *City block.*

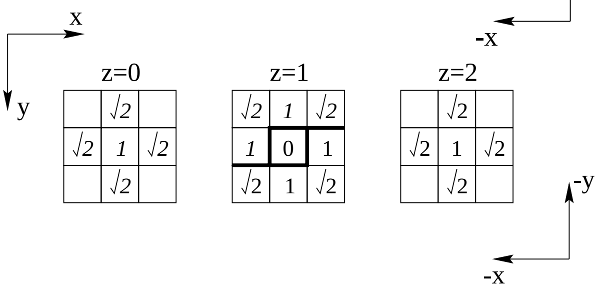


[2]Execution timings where taken on a DEC Alpha 2100 4/275.
[3]See [14] for a detailed introduction to distance transform matrices.

- *Chess board.*



- $\sqrt{2}$.



Distance matrix	*Average execution time /s*	*Average time to render a 300×300 image /s*
City Block	10.016	141.211
Chess Board	26.266	163.493
$\sqrt{2}$	28.166	161.577
5x5x5	226.408	142.244

Table 1: *Comparison of distance transform execution times.*

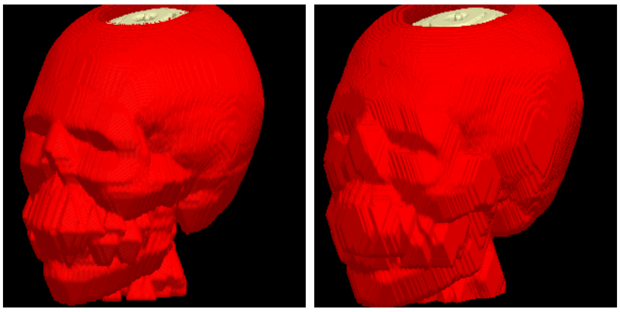
4.2 Results

Figure 8 shows the results gained from the application of the hypertextures of Figure 5 to a $256 \times 256 \times 113$ CT dataset[4], modified with the distance matrix of Figure 6.

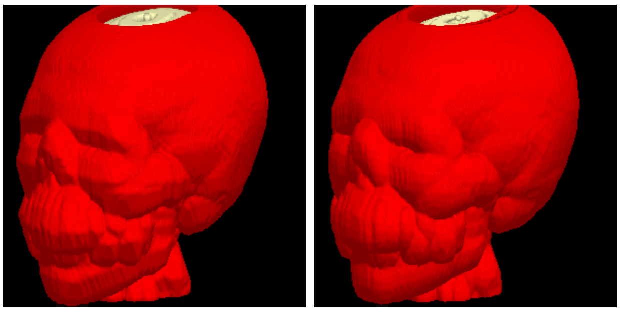
4.3 Animation

As mentioned in Section 3 a hypertexture is created by manipulating the surface densities of an object with a three dimensional texture function. The use of a three dimensional texture function allows a hypertextured object to be rendered, from different view points, without any inconsistencies in the texture. Thus introducing frame coherency for animation. Figure 9 shows a series of frames from such an animation.

[4]Obtained from the University of North Carolina, Chapel Hill.



(a) *City block* (b) *Chess board*

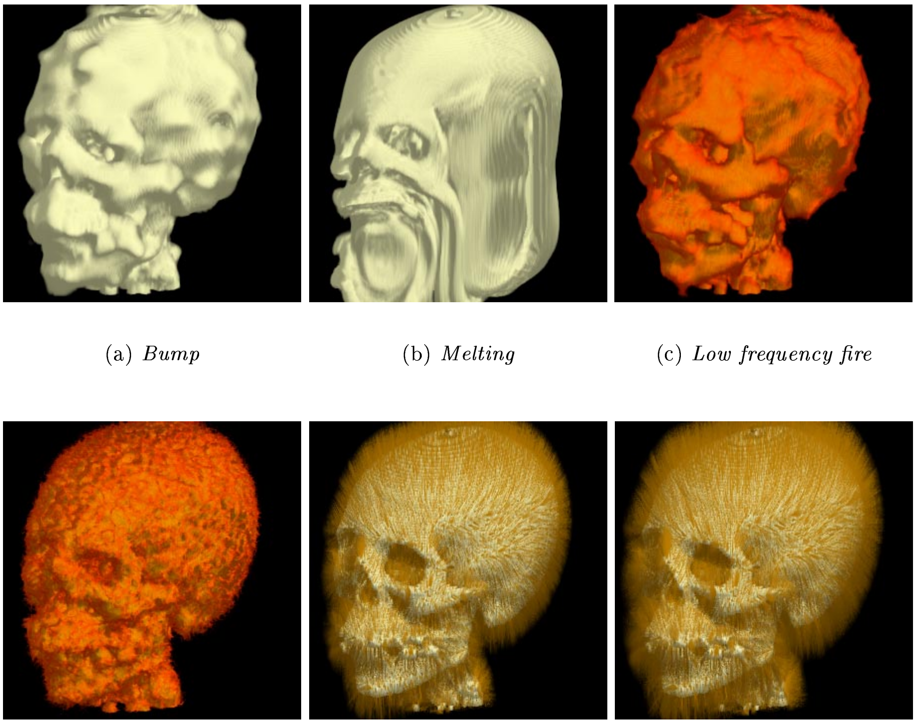


(c) $\sqrt{2}$ (d) *5x5x5*

Figure 7: *Results of distance matrix application.*

5 Conclusion

It has been shown that Perlin and Hoffert's hypertexture paradigm [3] can be easily applied to volume datasets created by invoking a geometric formula at each voxel. It has also been shown that, with the use of distance transforms, the datasets of a non-geometric object (for example CT scans) can be altered to appear geometric, allowing the application of the hypertexture functions. Figure 8 shows the application of the hypertexture functions to a CT dataset which has been altered using the distance transform approach, therefore it has been shown that the hypertexture paradigm can be applied to non-geometrically definable datasets.



(a) *Bump* (b) *Melting* (c) *Low frequency fire*

(d) *High frequency fire* (e) *Fur* (f) *Longer fur*

Figure 8: *Extended hypertextures.*

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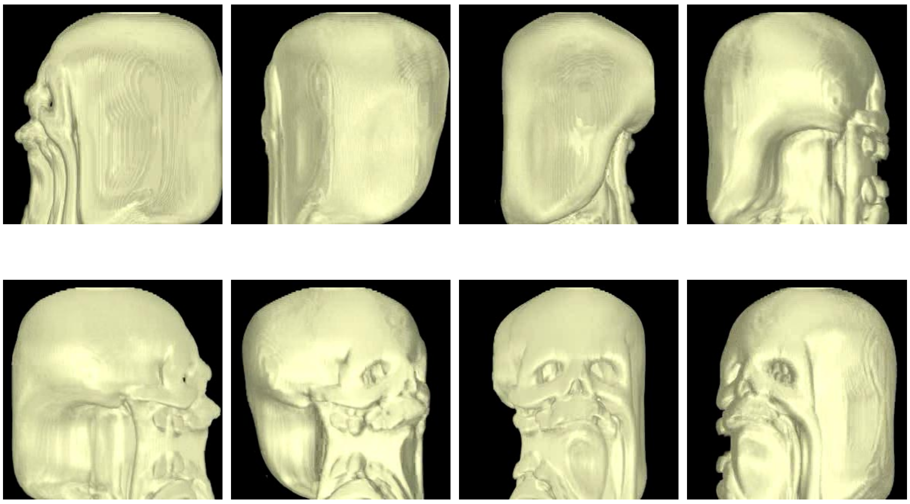

Figure 9: *Selected frames from an animation of a hypertextured (melting) skull.*

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