METHODS OF DETECTION OF EQUIPOTENTIAL SURFACES IN CELL STRUCTURES

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In this paper I am concerned with some interesting possibilities of a 3-D reconstruction of cell structures based on data received from a confocal microscope. These data mathematically describe a three-dimensional scalar field with a certain scalar value (density) defined at each of its points. This scalar value may be defined in a number of different ways and the data may be subsequently visualised using diverse methods. In the case of a confocal microscope, the scalar value should be interpreted as light intensity with the data visualisation consisting then in the evaluation of a so-called lighting model.

INTRODUCTION

A complete lighting model, i.e. one that defines the manner in which the pixel colour on a screen can be determined for a given ray direction and route through the displayed volume should evaluate:

- the contributions of the light absorbed while passing through the entire volume to be displayed (absorption)
- the contributions emitted by the elementary volumes in the observer's direction (emission)
- the contributions scattered by mirror reflections and diffused in observer's the direction (scattering, diffusion)

The contribution of the emitted and reflected light are absorbed on their way to the observer in the same way as the background light when passing through the object to be displayed. In a complete model, one should also take into account the shading by individual object parts of the rays coming from the light source as well as their mutual reflections. Although using similar models to display the scalar field may lead to valuable information about the object, it is rather complicated and time consuming so that, given the present hardware performance, the methods currently used to implement complete lighting models cannot run in real time. This is not even possible in cases where, in the lighting models, we only consider the light absorption by passage through the object and the actual emitting of the object's parts.

RAY CASTING

The algorithms used to display a 3-D scalar field are more or less based on the idea published by Jim Blinn in 1982. The basic assumption is that a light ray passing through the object to be displayed does not change its direction. For each pixel of the displaying device, it is then possible to monitor and evaluate a single ray passing through the observer's eye. This ray is projected onto the object and its interactions with the surroundings are modelled. The resulting brightness value is then obtained by integrating these interactions along the ray trajectory. The particular methods based on this principle can be classified by the data with which they work and by the way in which they model the interactions:

- maximum intensity projection - along a ray, only the point with the maximum intensity is displayed
- summed intensity projection – the sum of the intensities along a ray is projected onto the point
- average intensity projection - the mean value of the intensities along a ray is projected onto the point.

In the present literature we can also encounter methods that, by throwing a ray into a scalar field, “look for a surface”. However, such methods are only meaningful if the object is uniquely defined. If we work with a scalar field, the scalar value may only take on one of the two values (zero-one) depending on whether the point in question belongs to the object. However, data from a confocal microscope are not of such a nature. Principally, it is possible to use thresholding, which means replacing the density values by zeros or ones depending on whether the density value is grater than a pre-determined threshold value. The points belonging to the object are modelled as voxels, that is, elementary cubes or blocks. In this way, we can obtain the so-called voxel model of an object, which can be seen in Fig. 1.

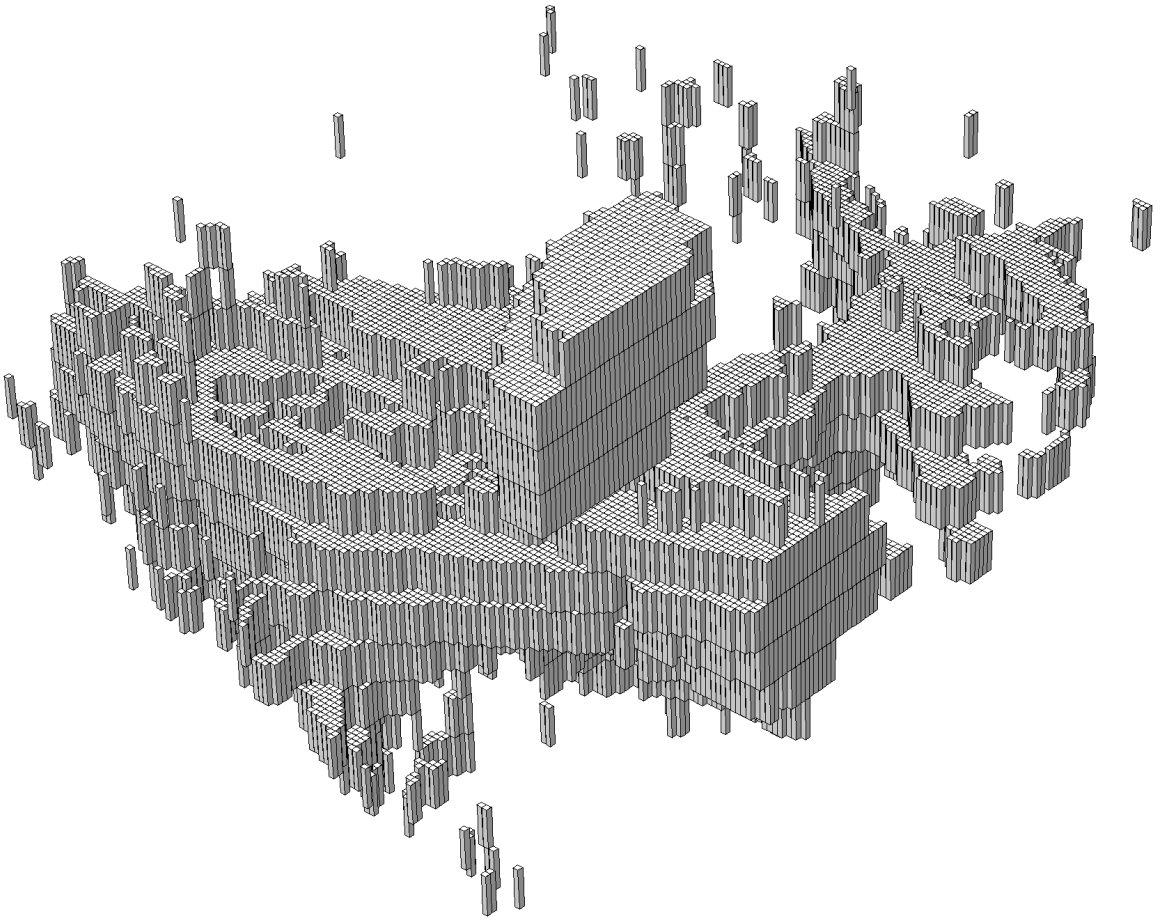

Fig. 1: Voxel reconstruction of an object

However, such data modification leads to a considerable degradation of information with the resulting object being far from the reality.

DETECTION OF EQUIPOTENTIAL SURFACES USING 3-D FILTERS

The ray casting methods described above evaluate the ray intensity on the basis of its passage through the entire volume of the object to be displayed. The calculation is considerably accelerated if the object to be displayed can be represented by a suitable surface. However, this surface will not be searched for as the "surface of an object" because this notion has no satisfactory mathematical or physical interpretation in a scalar field. The surfaces that allow a sufficiently true and fast visualisation of a scalar field are the so-called equipotential surfaces. An equipotential surface of a scalar field is the set of all the points of the scalar field at which the scalar quantity (in our case it is the light intensity or density) assumes a constant value. Such surfaces can be detected using a number of mathematical methods. In this paper, I will briefly describe their detection by 3-D filters and linear interpolations.

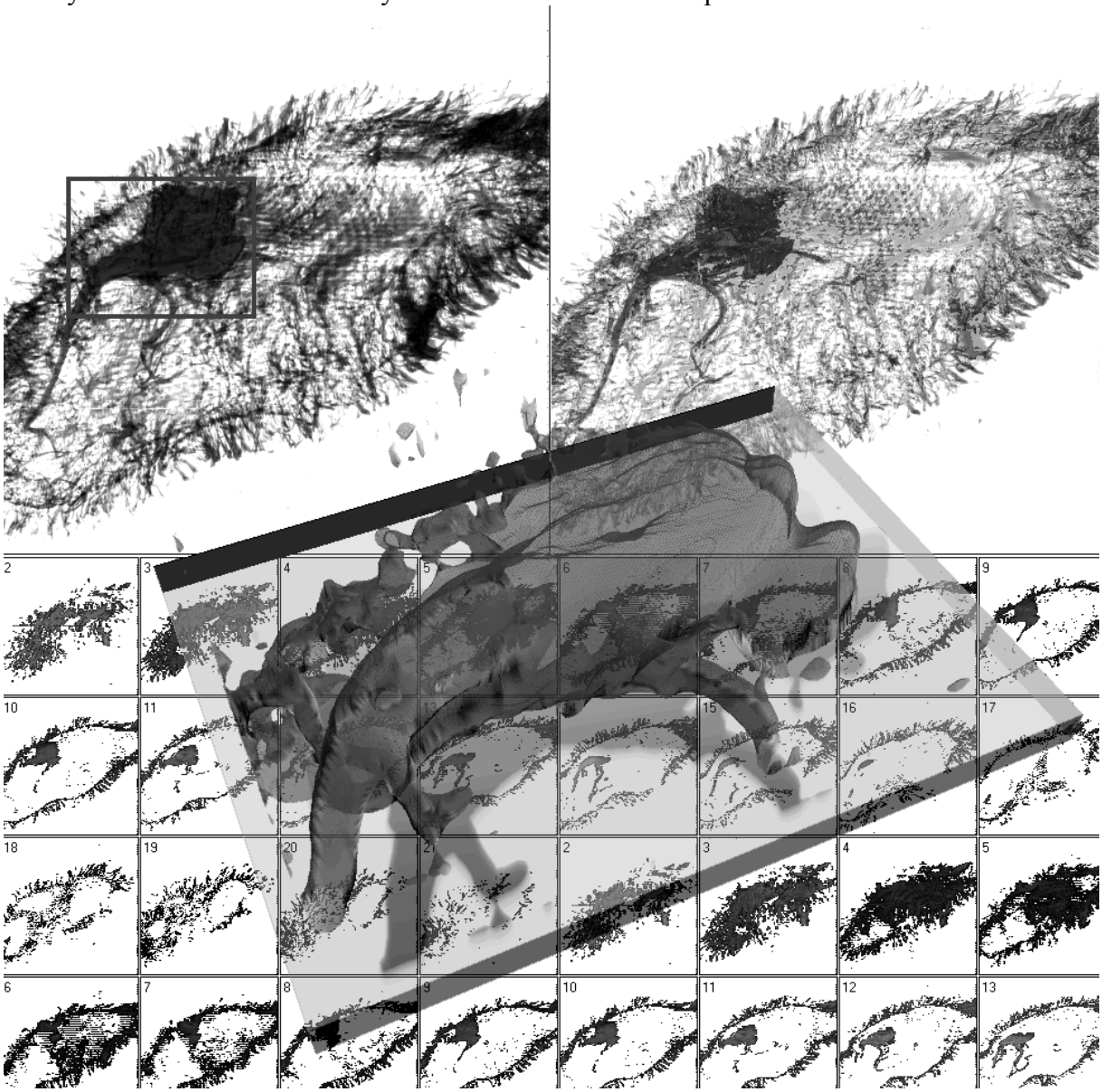

Fig. 2: Detection of an equipotential surface by a 3-D low-pass filter

1) All the voxels of the object to be displayed through which the equipotential surface passes are identified. Each such voxel is characterised by the potential at some of its vertices being less than the detected level while being higher at the remaining ones.

2) To the object selected in this way, a suitable detection method may be applied such as a 3-D low-pass filter. This filter is a 3-D generalisation of a filter with the same name used in image processing to smooth an image and subdue noise in it. The application of a 3-D filter to a 3-D object has similar effects. A 3-D object can be smoothed and, in our case, this gives an approximate method to detect an equipotential surface.

DETECTION OF EQUIPOTENTIAL SURFACES BY LINEAR INTERPOLATION

When using this method, again the voxels through which the surface passes have to be selected (see item 1 above). Although the actual detection by linear interpolation is rather time consuming, the more it is accurate.

The principle of this detection can be explained using Fig. 3. Here we can see two voxels through which the surface that we are looking for passes. On them, the points are marked with a potential higher that the potential of the surface (on the left the vertices A, B, D, A' , B', on the right the vertices C, C', D'). The surface intersections have to be looked for on the edges with only one of its two vertices marked. These edges can be identified in the following manner: each block vertex is assigned one of the values $2^0;\ 2^1;\ 2^2;...;2^7$, whenever the potential at the vertex is higher then the potential of the searched for surface. Other vertices are signed zero. In this way, the entire block can be assigned the values $0,1,...,255$. In terms of our construction, there are 256 ways in which a surface can intersect he block. The block in the figure is assigned the number $h_L = 2^0 + 2^1 + 2^3 + 2^4 + 2^5 = 59$, the block on the right the number $h_P = 2^2 + 2^6 + 2^7 = 196$. The sum of these assignments is 255 and it is clear that the construction process will be the same in both cases – the intersections have to be looked for on the edges BC, CD, DD', $A'D'$, $B'C'$ and the resulting section is then interpreted using a total of three triangles. Thus, although the number of cases to be solved is 254 (the surface does not intersect blocks assigned the values 0 and 255), "only" 127 branches are sufficient in a program. The position of the intersection on each edge is then obtained by linearly interpolating the potential values at the endpoints.

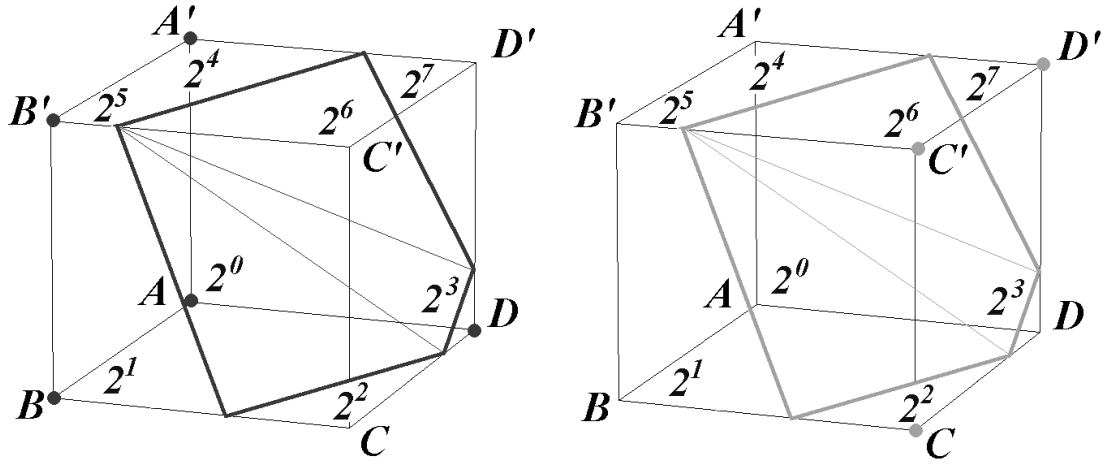

Fig. 3: Principle of the detection of an equipotential surface by linear interpolation

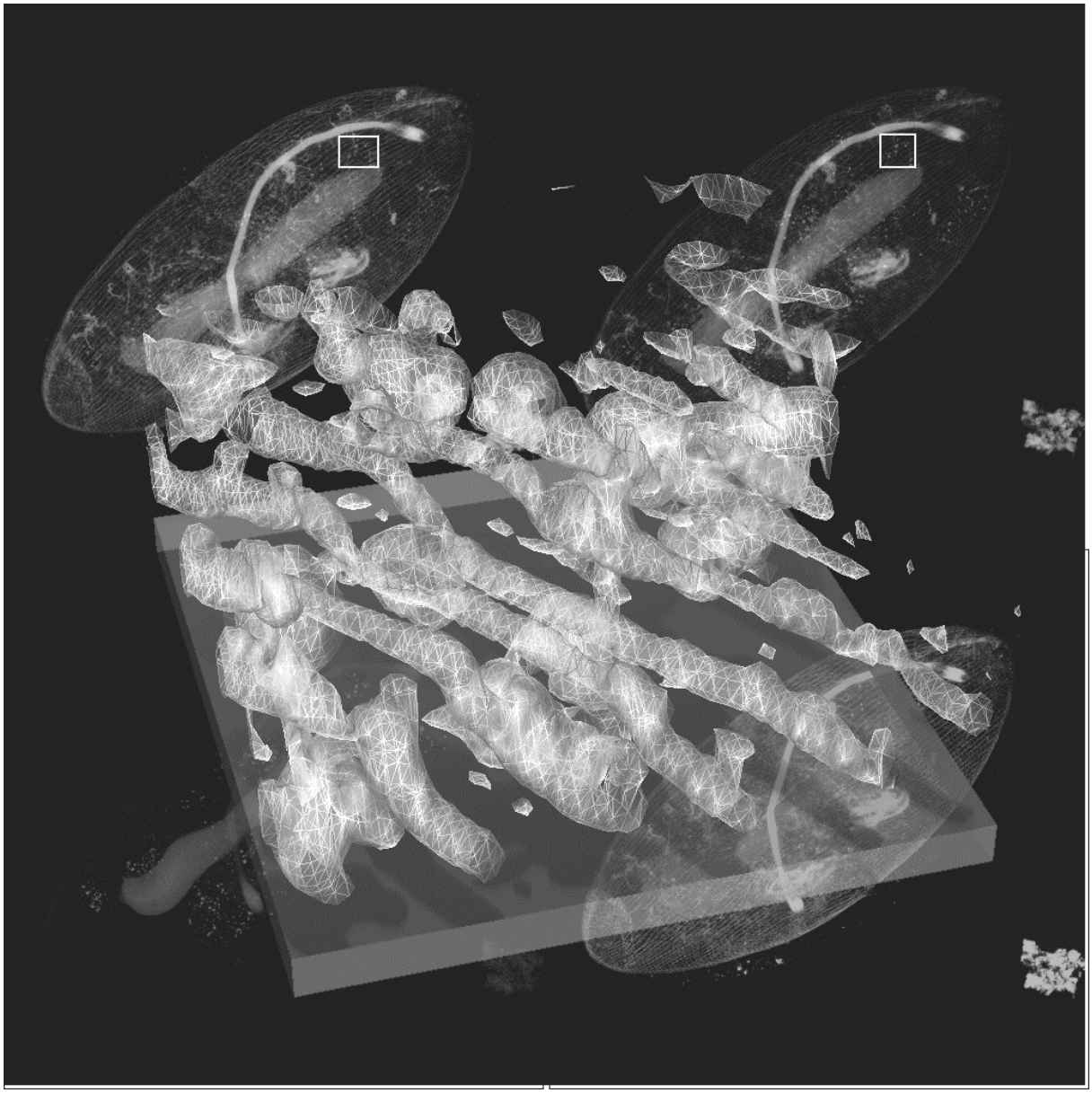

Fig. 4: Detection of an equipotential surface by the linear interpolation

RESULTS

The above methods allow real-time 3-D reconstructions of cell structures with sufficient accuracy. Fig. 2 shows a 2-D reconstruction of the picture of a protozoan of the Paramethynum species where the framed part has been reconstructed using a 3-D filter. The data has been obtained using the 1 byte/pixel colour depth. In Fig. 4, you can see a similar situation, but this time the surface detection is done using a linear interpolation. Due to their speed, these methods enable a virtual passage through the inside of a cell as shown in Fig. 5.

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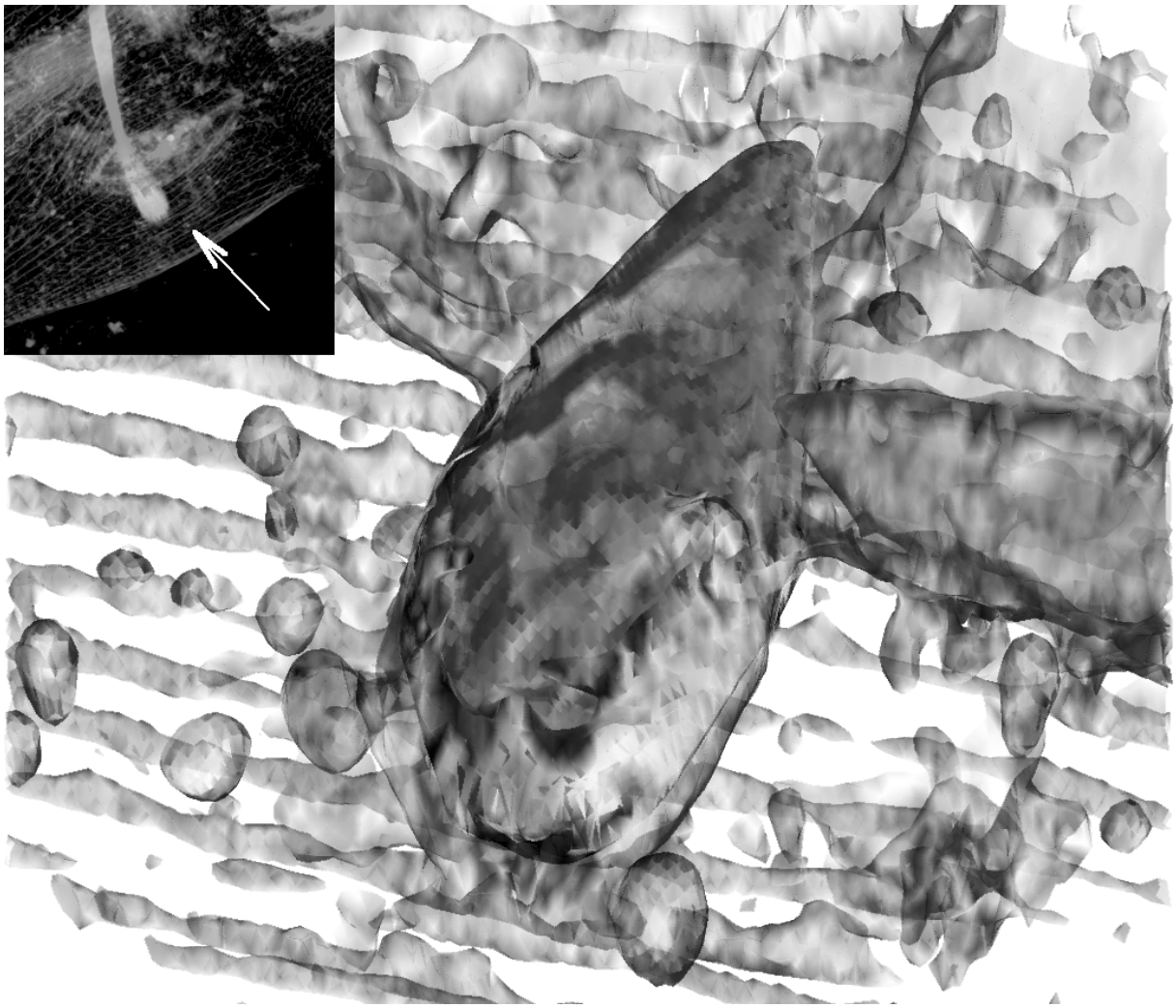

Fig. 5: The virtual passage through the inside of a cell

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