3D visualization of biomolecules: representation of surface properties

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Introduction

To communicate graphically their results, cellular and molecular biologists publish images of experimental data (from gel autorads to fluorescence microscope pictures), or synthesize them in collective forms such as graphs, plots etc.

Although a wealth of information about the shape and movement of proteins is available, the vast majority of experimental biologists still have difficulties in figuring the actual structures and movements that constitute the core of life inner workings. The aim of our project is to give an alternative vision of cellular and molecular biology, a 3D animated representation delivering in a visible way the physico-chemical properties of molecules and of the cellular environment (such as pH, electronegativity, hydrophobicity). These properties are of importance for the way biomolecules behave.

Methods

Maya-Autodesk is a powerful 3D animation and special effects software developed for cinema and entertainment industry[1]. We took advantage of this instrument and apply it to model, animate and render biomolecules.

Modelling

In Maya, as well as in other 3D programs, the creation of objects is called modelling. Using our scripts written in MEL (Maya Embedded Language) the atoms identity and positions are imported from Protein Data Bank (PDB)[2] files into virtual space of Maya as spheres or blobby particles. Blobby particles are displayed as *metaballs*, spheres that are not visible as single, defined objects, but are blended together giving the impression of a single surface that includes them.

Animation

From the point of view of animation programs, animating means inferring intermediate steps between a start and an end position. If in a PDB file at least two sets of coordinates (conformations) exist, they are imported and set at different times. Maya interpolates between them using algorithms already present in the program or according to new rules described in added scripts, obtaining the animation (movement) of the object. Protein movements can be obtained also by setting the atomic coordinates of the same protein from different PDB files solved in different conditions (active and inactive state or free and bound to a ligand or receptor).

Rendering

Rendering is the process of conferring visual surface properties to virtual objects. Biomolecules are chemical compounds with specific properties that are determined by the nature of their atoms and the way they are connected and organized in the 3D space. Molecular surfaces are characterized by a number of physico-chemical properties such as electrostatic potential, hydrophilicity or charge.

Delivering these properties in a visual way is one of the major tasks of our project. Standard chemical programs such as Swiss PDB-Viewer, RasMol, Chem3D, MolMol calculate these properties in terms of numbers and usually display them as a colour scale from red to blue, not easy to interpret without reading the legend.

Using Maya tools we are studying several possibilities to express surface properties: choice of material, transparency, incandescence, ambient colour, diffuse, bump, displacement, specular shading, reflection, lights, etc.

A *shader* (a material) is a collection of attributes that define colour, shininess, transparency and other surface characteristics. A shiny material (anisotropic) was used to render cholesterol. One of the characteristics of this material is that it does not reflect the light equally in all directions. A dulled material (lambert) was used to render ATP.

In Maya there are different ways to obtain a deformed surface. A *bump* texture makes the surface appear rough or bumpy, without altering the shape of surfaces to which is assigned while *displacement* modifies the geometry of an object in order to specify surface relief. See the difference between the renderings of cholesterol and ATP.

Incandescence is an attribute of a material that makes a surface appear to glow and *diffuse* gives it the ability to reflect light in all directions.

Combining these attributes in Maya it is possible to create realistic objects, transmitting both visual information (such as surface properties and consistence) and tactile sensations.

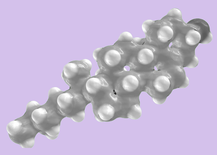
For rendering we use a plug-in, RenderMan for Maya (by Pixar)[3]. It is a high quality renderer, fast, efficient for handling complex images and it has additional features like deep shadows, special effects like motion blur, etc.

Results

Here we present the renderings for four different types of molecules.

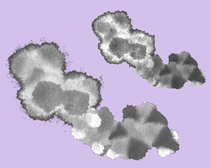
Cholesterol

Cholesterol is a small, mostly hydrophobic molecule that together with phospholipids and glycolipids is incorporated in the outer layer of eucaryotic cell membranes. To make visible the hydrophobicity of this molecule we created a shader that gives the impression of a slimy surface that does not interact with water. The shader was created adding a bump texture to an anisotropic material.



ATP

The atoms identity and positions were imported into virtual space of Maya as two different groups of particles superposed: the entire ATP is modelled as blobby particles and the three phosphate groups are modelled as overlapping clouds. To render visible the surface properties of this hydrophilic molecule with high-energy bonds between phosphates we created two different shaders.

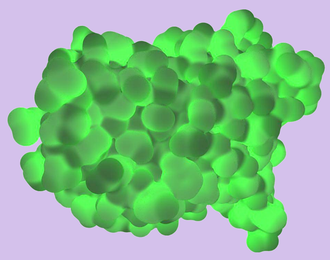


The first surface shader applied to the entire ATP is a coarse-grained surface (created with displacement) and gives the impression of a molecule that can easily interact with water.

The second surface shader created with displacement and high value of incandescence (like an emitting light source) was applied to the three phosphate groups in order to deliver in a visible way the chemical energy stored in these covalent bonds.

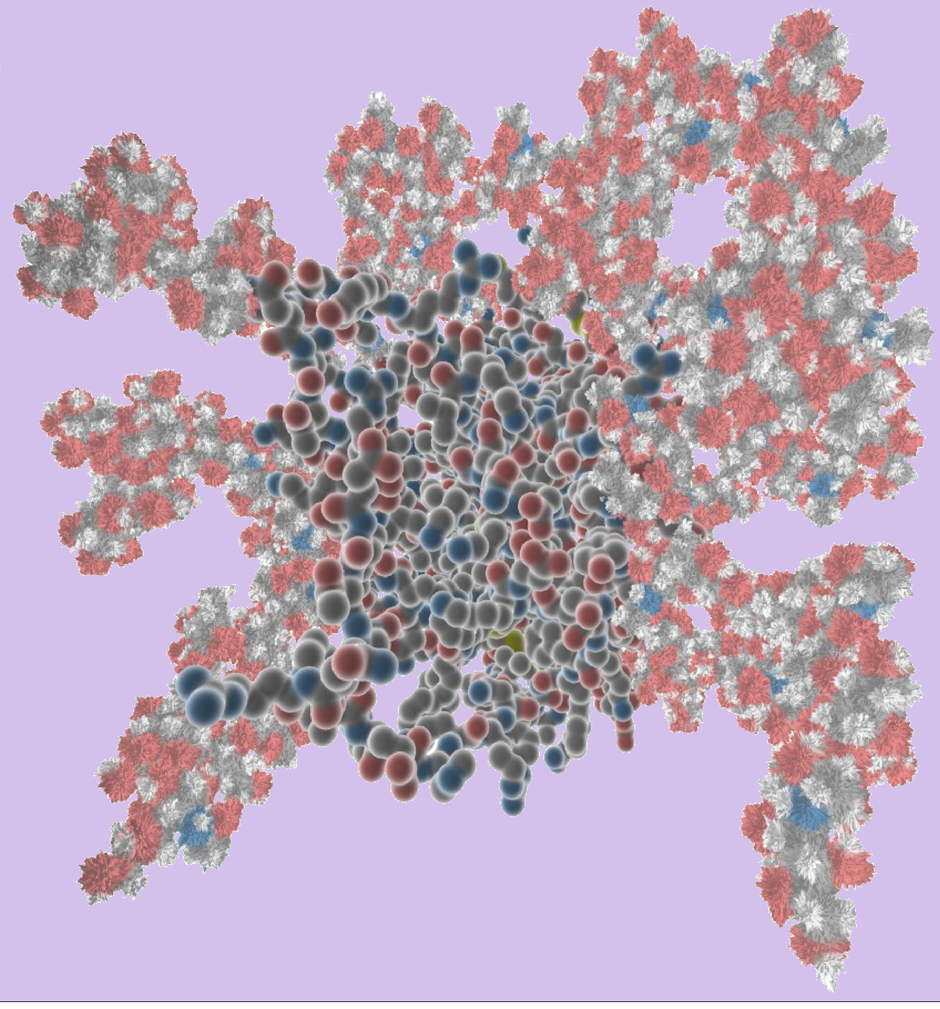
GFP (PDB 1gfl)

Another interesting molecule for our rendering studies is GFP. Its fluorescence is represented by adding a green colour to a matte material without specular highlights (lambert shader) and placing a green light emitting from the centre of the protein. This image suggests the idea that the chromophore, situated in the centre of the protein is emitting green light when irradiated with UV light.



Oligosaccharide chains

In the plasma membrane of all eucaryotic cells, most of the proteins exposed on the cell surface and some of the lipid molecules in the outer lipid monolayer have oligosaccharide chains covalently attached.



The oligosaccharide side chains of glycoproteins and glycolipids are enormously diverse in their arrangement of sugars. Although they usually contain fewer than 15 sugars, they are often branched, and the sugars can be bonded together by a variety of covalent links. The sugars that form these oligosaccharide chains are: mannose, galactose, N acetyl galactosamine, N acetyl glucosamine, fucose and a sugar that carries a negative charge (sialic acid). Sugars are polar and hydrophilic. A visual representation of these properties was realized with a displacement. This image represents N-linked carbohydrates[4] attached to gp120[5], a glycoprotein from the surface of HIV. The shader applied to the protein is a lambert material with a soft bump and a bright edge created with incandescence. In this image the colours used for rendering the atoms are the standard ones used in chemistry: red for oxygen, blue for nitrogen, white for hydrogen, grey for carbon and yellow for sulfur.

Conclusions

Representing the cell in a 3D animated vision can offer a new perspective on biology that can enable formulation of new hypothesis. Delivering information about physical-chemical properties of biomolecules in a visible way will also improve teaching because the messages are transmitted in a more direct way; it is known that humans understand things better if they see them.

Visualizing a scene with different kinds of molecules placed in a specific environment and having the possibility to “see” all their properties without the need of additional comments is important because it offers a complete “chemical feeling” of the whole image.

Here were brought only static images of those biomolecules. For a dynamic representation of them we invite you to visit our website. Seeing the molecules in movement gives a stronger and more realistic impression of their surface characteristics, introducing the viewer to a different vision of cellular and molecular biology.

References

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