

Computer Tablets - Probably the Optimal Devices for Science Education in Virtual Reality Today ?

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Introduction

Apple iPad and Android tablets as well as smartphones with larger screens are very popular today. At the same time they are also powerful computers. There is a lot of applications for Apple IOS (iPad) and Android covering the biological themes, but few run in the virtual reality. The reason lies not only in the more demanding creation of such projects, but also in the fact that the 3D applications authoring is not so well supported for the iPad. As we have in our team more than 15 years of experience in virtual reality projects, we decided some time ago to establish a workflow for the effective creation of virtual reality applications for the mobile platforms like iPad, Android and similar. The first products showed that the tablets are wonderful devices for learning in virtual reality since one can navigate with fingers naturally and intuitively in the 3D world. This observation has given us lots of enthusiasm so that in the last year we produced several applications about the cell structure and function like metabolism and motor proteins as well as the structure and function of some sense organs like human eye, ear and proprioceptors (muscle spindle and skin receptors).

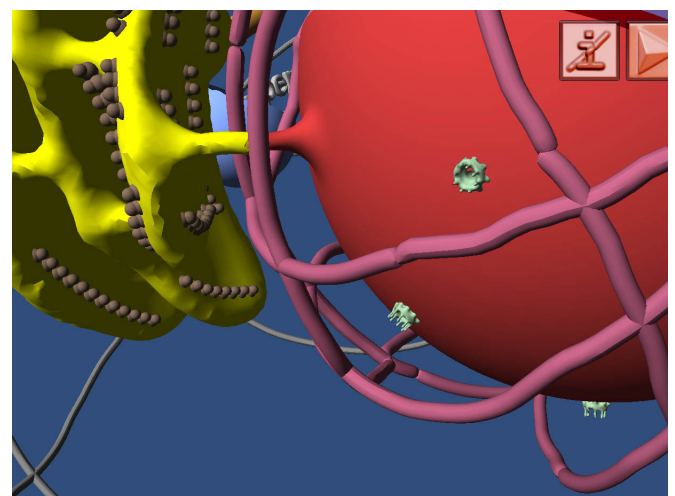
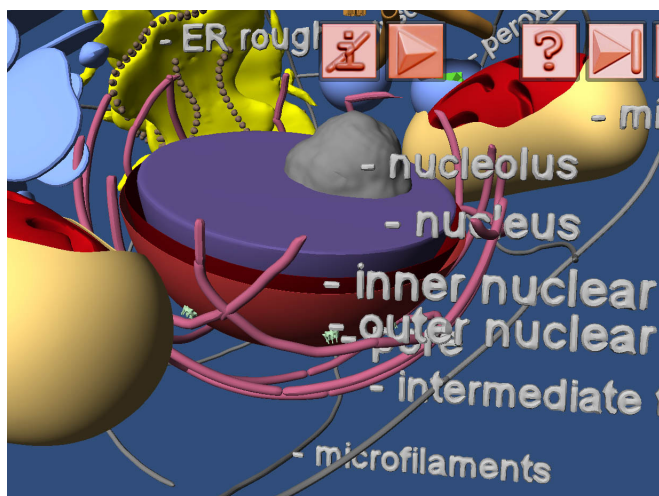
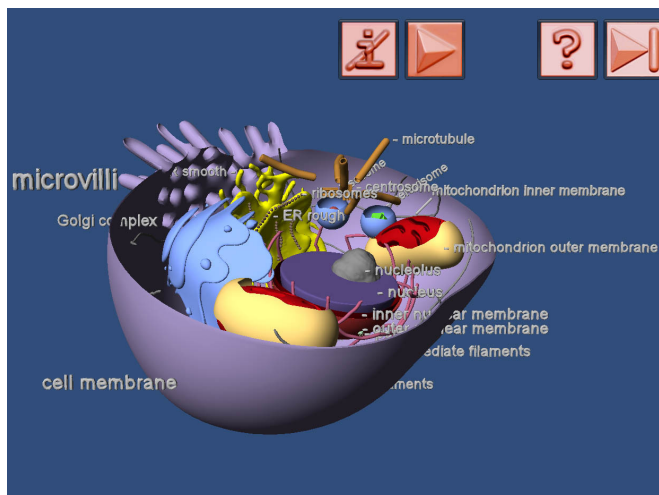
Design

Typically we start modelling in 3D modelling program called Zbrush¹ where we also paint the models in order to give them a nice textured look. Then we bring the models to the Autodesk Maya² where animations are added - especially blend shapes (morphing) and animations that are done with the help of skeletons. Finally the models are grouped together (by the help of the Maya layers) and exported as fbx files for import into the Unity3D³. Although Unity3D supports also the native Maya format, we found that the fbx files load faster in Unity3D and also the work process is more transparent this way. Unity3D is the final stage of our production because it enables the final export to all important platforms. So with a project done in Unity3D you can be sure to deploy it to Windows⁴ desktops, Windows mobile phones and tablets, Mac⁵, MacOS (=iPad and iPhone), Android⁶ and others. We have written in Unity3D (in the computer language C#) the code for user interaction (the way how touch responses are processed), for the smooth camera transitions and other code that enables an attractive learning session. Our intention was to make the learning session as simple as possible, in other words, one should spend as little time as possible with our software session - this wish is in contrary to the one shared by the game software developers. So we provided only the elementary user interface - the play button, which starts the camera transitions, the home button that brings you to the start menu, the next scene button, the buttons for showing the legends and general help and of course the exit button. We apply various schemes of the virtual reality travel, depending on the theme we explain. The first and most frequently used is just traveling from one viewpoint to the next. For example, the first viewpoint shows the whole animal cell. The centre of rotation and zoom is in the middle of the cell showing the cell membrane. When you click on the play button, the cell membrane disappears and the camera approaches to a mitochondrion. The centre of rotation and zoom becomes the centre of the mitochondrion. The second way of showing the scene is by following an animated camera. When you press the play button the camera (in other words this is what you see) moves around the scene in order to show you the processes at the

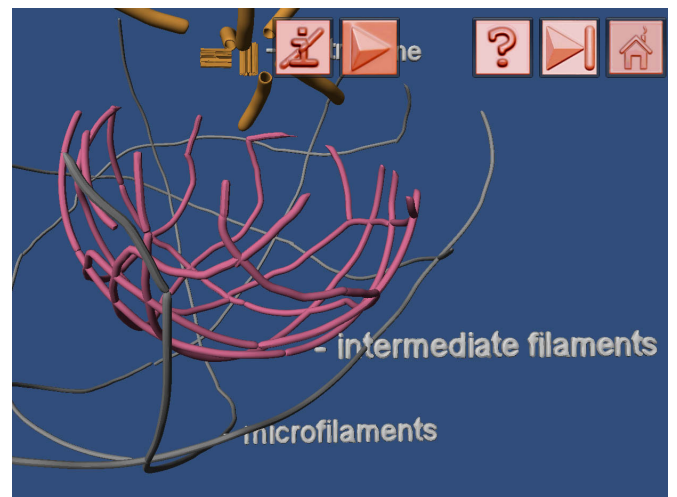
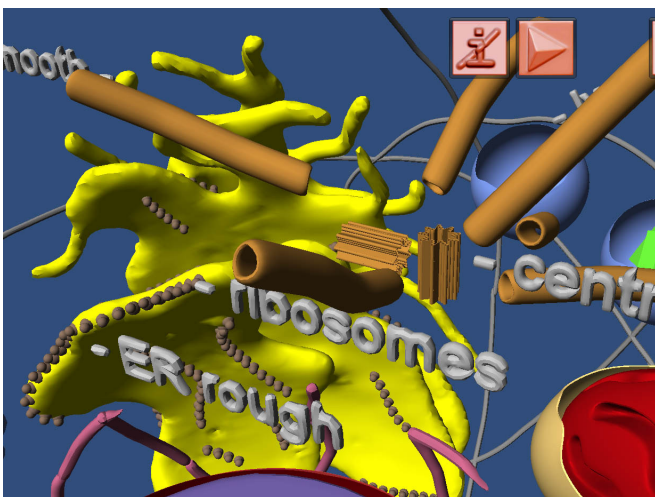
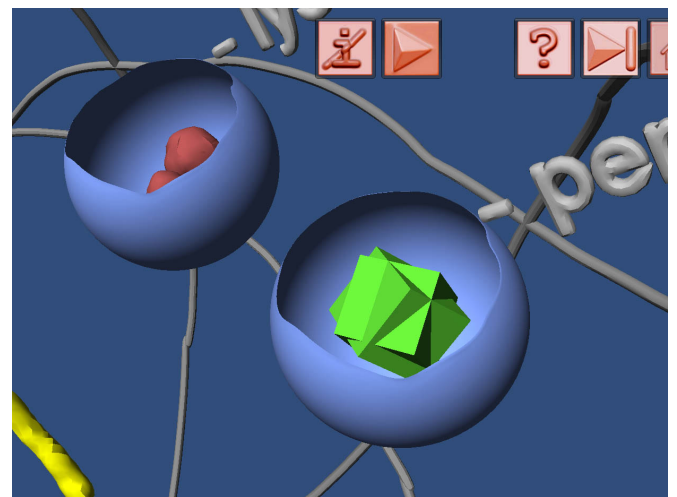
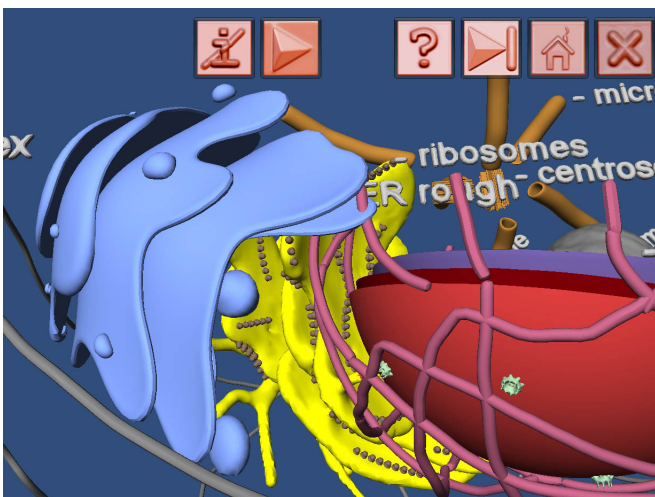
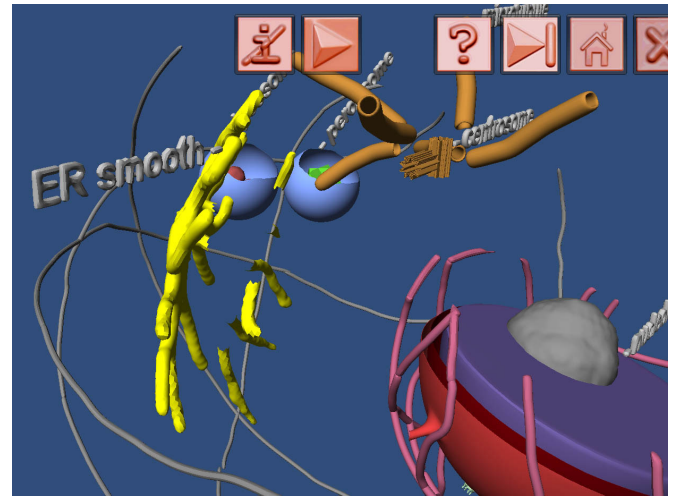
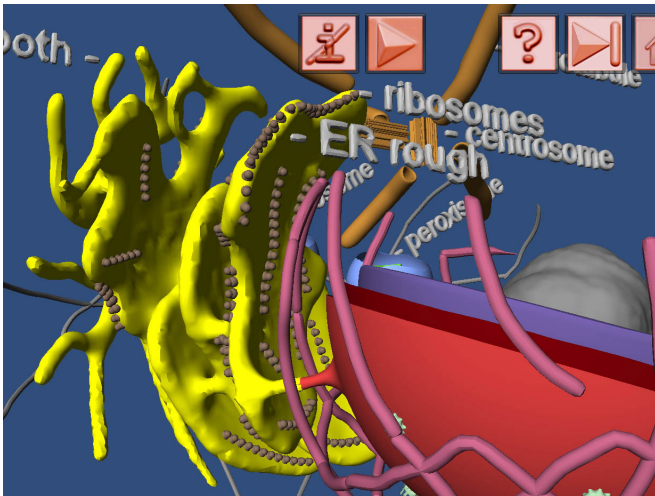
right time and at the right place. One would argue that this is the same as the traveling between viewpoints, but in the latter case one can miss the right moment to see the right sequence of an animation taking place at that very time. For example, when learning about the chlorophyll, the animated camera follows the photon as it jumps in cascade from one leaf pigment to another. Clearly this virtual reality world is not just like a video. The user can at any time press the “diver” button and so discover along with the animated camera the scene also by himself. Below there are some descriptions and screenshots from the Bioanim Complete⁸ project.

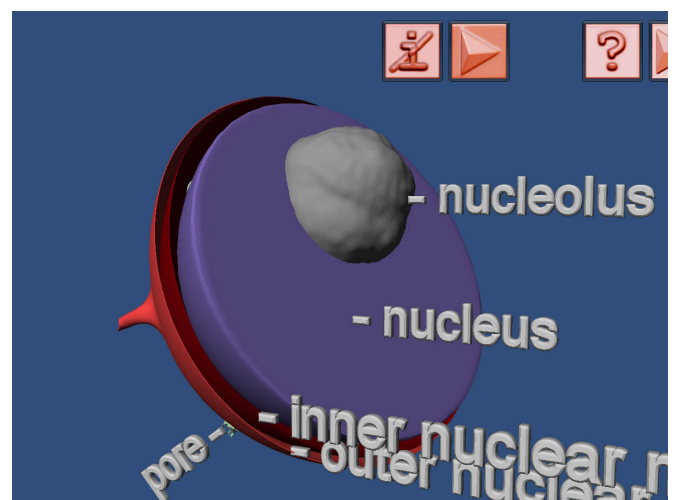
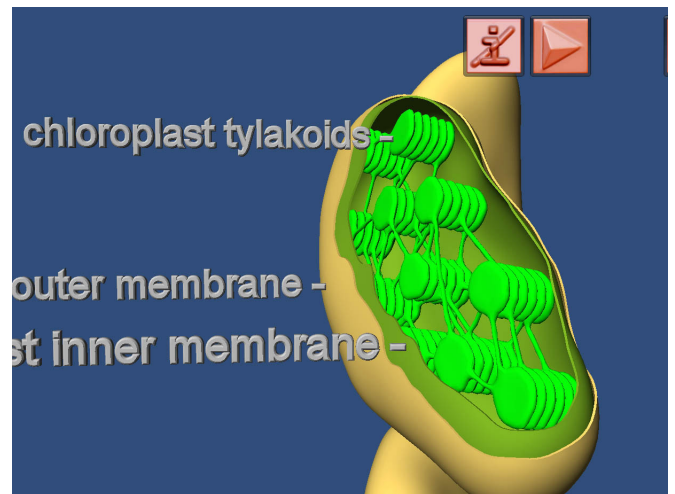
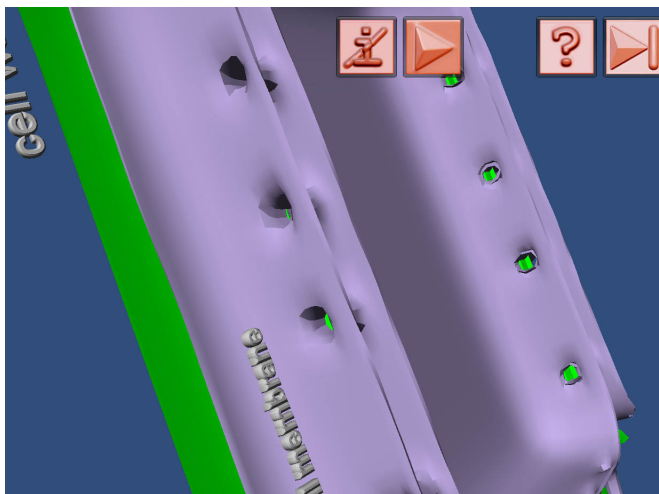
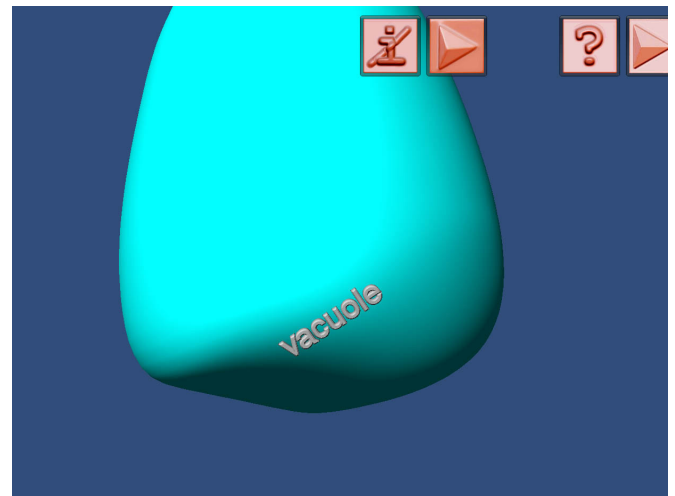
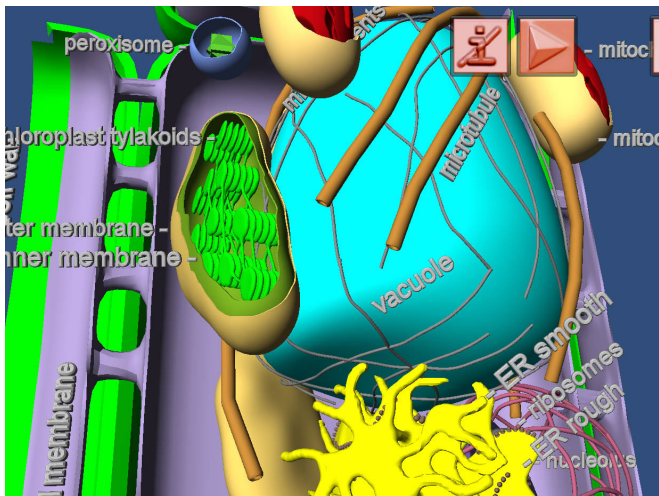
Cell tour

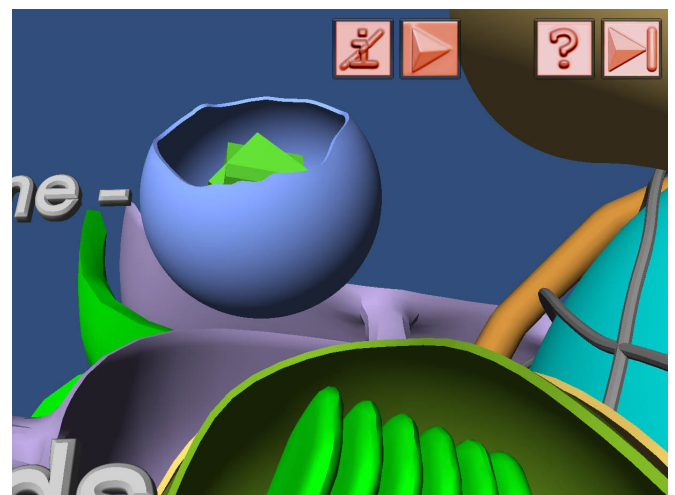
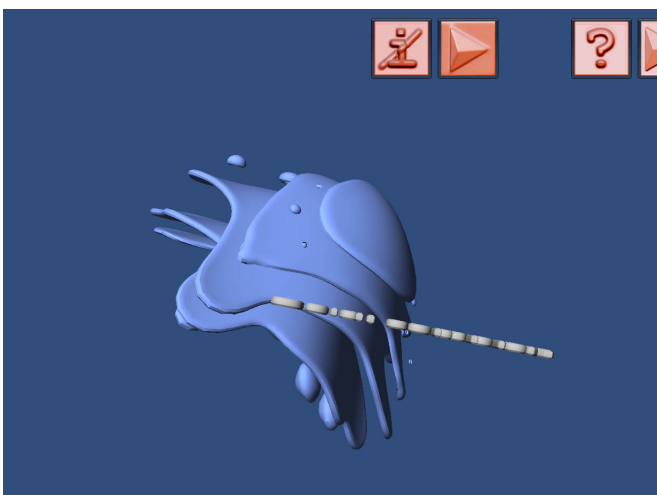
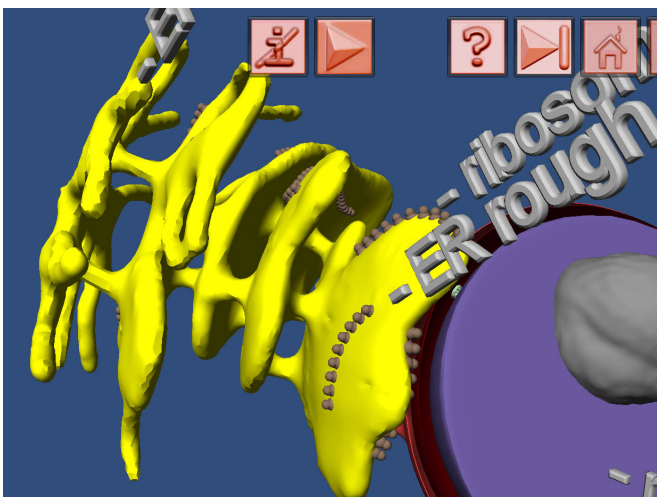
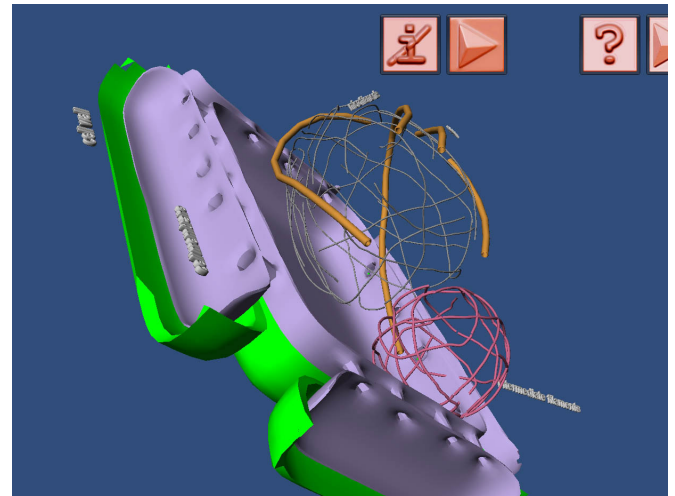
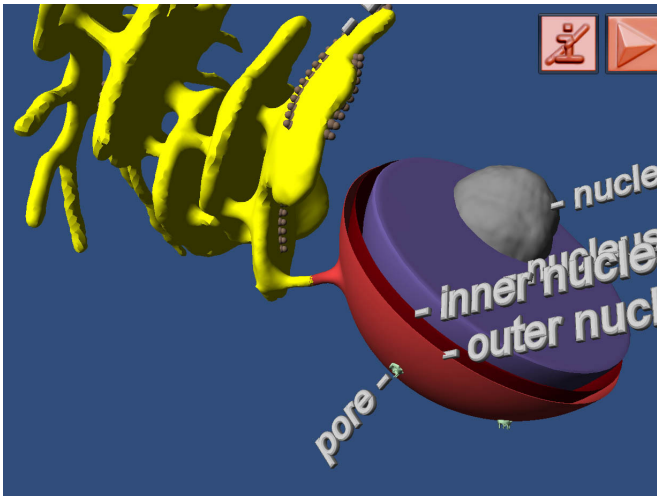
At first we provide an elementary tour of the cell in the virtual reality. You can choose between the animal, plant or prokaryotic cell. When you explore it, you enter it from outside and as you dive deeper, you explore smaller interior organelles while larger structures from the periphery become transparent.

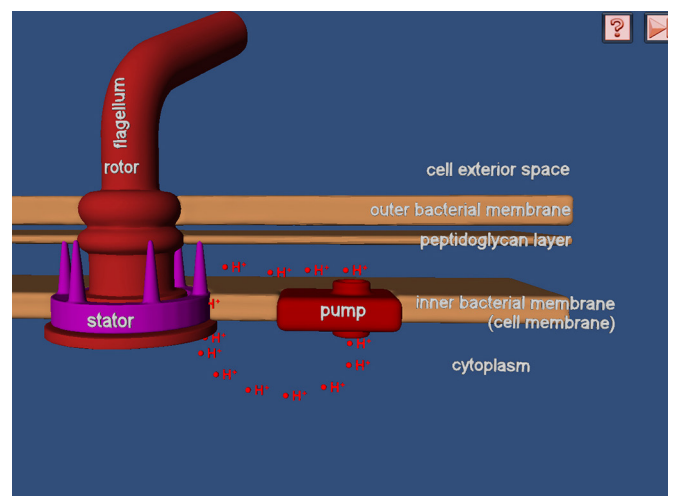
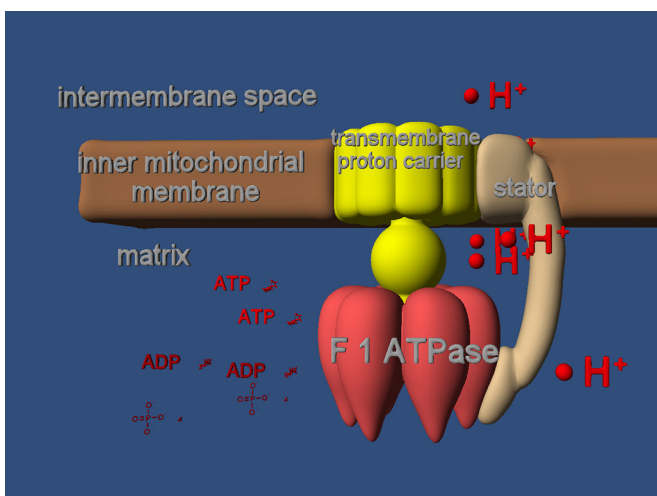
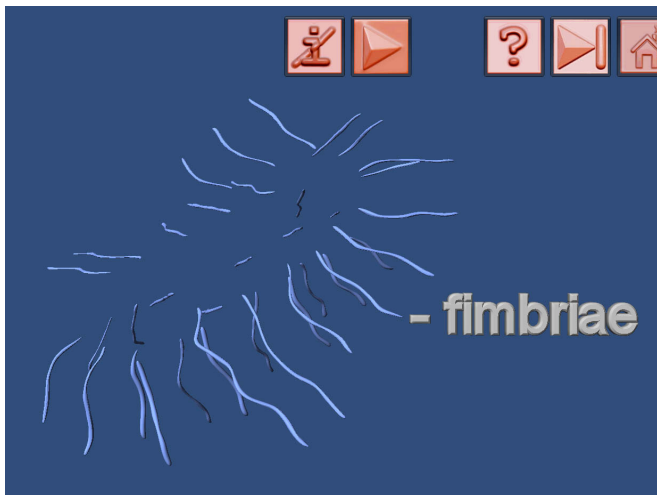
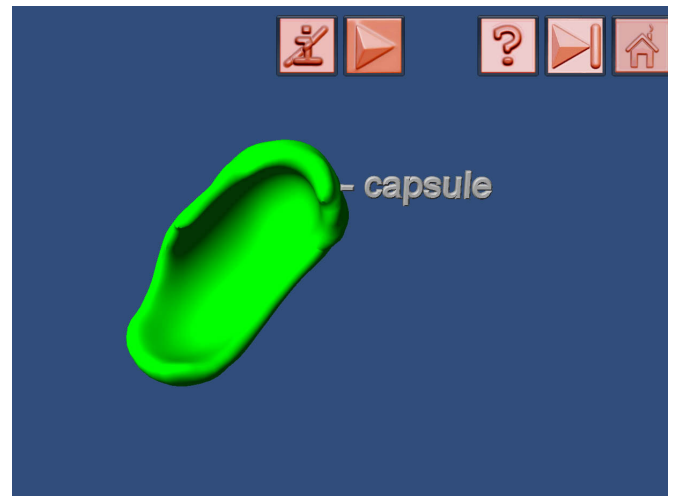
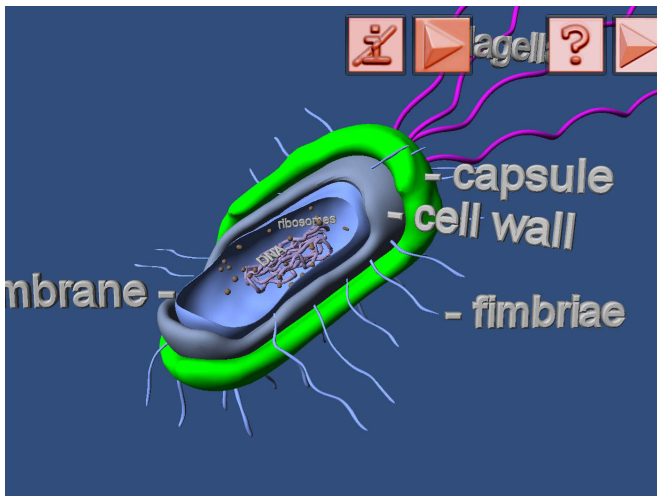


3D virtual reality Apps for iPad and Android. Learn effectively about the structure and function of the cell, tissue and human body yourself or surprise your students with this! www.bioanim.com Page 3





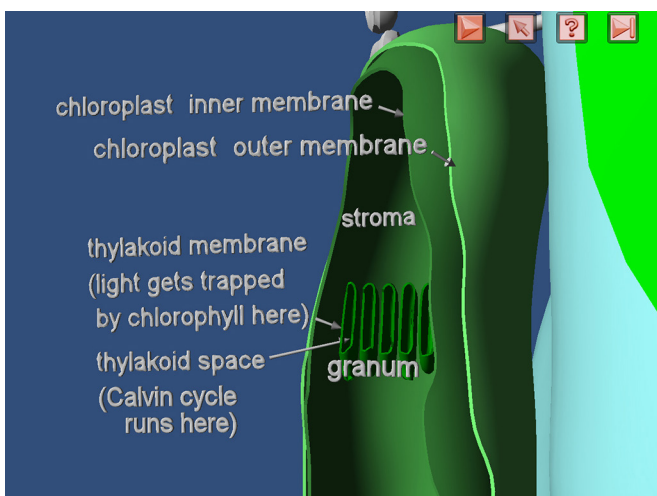
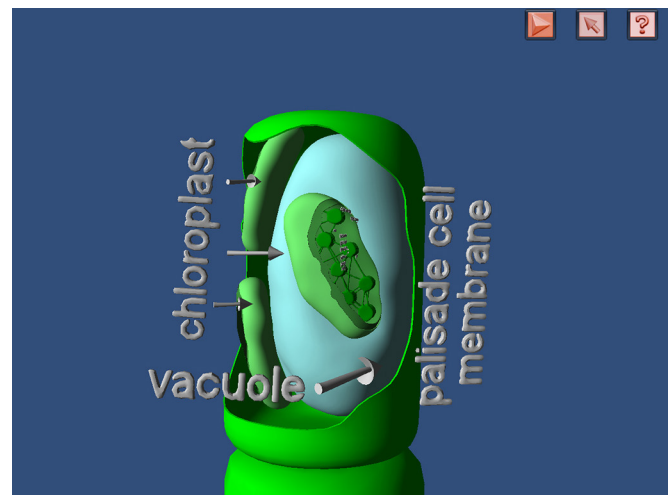
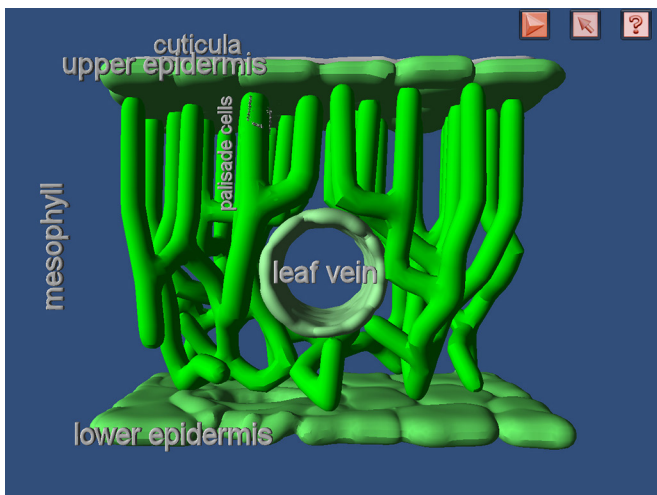




Glycolysis, the citric acid cycle and the respiratory chain are our virtual reality worlds that help you to better understand and memorize the most important features of the cell heterotrophic metabolism.

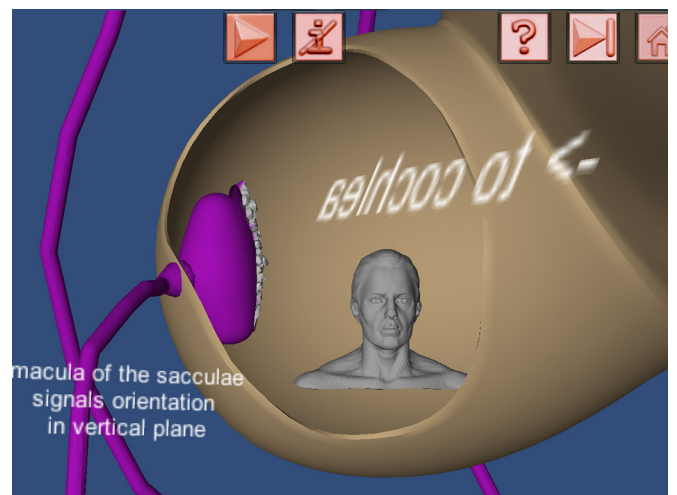
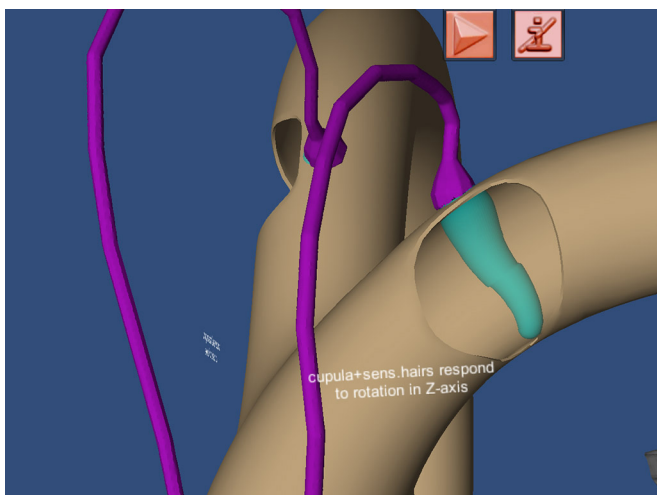
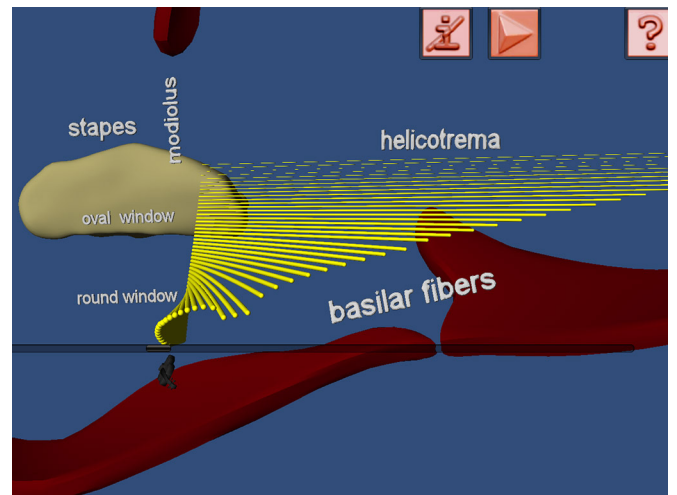
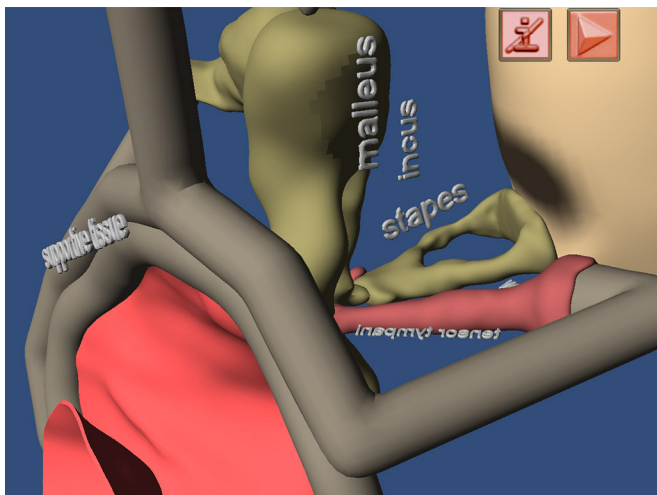
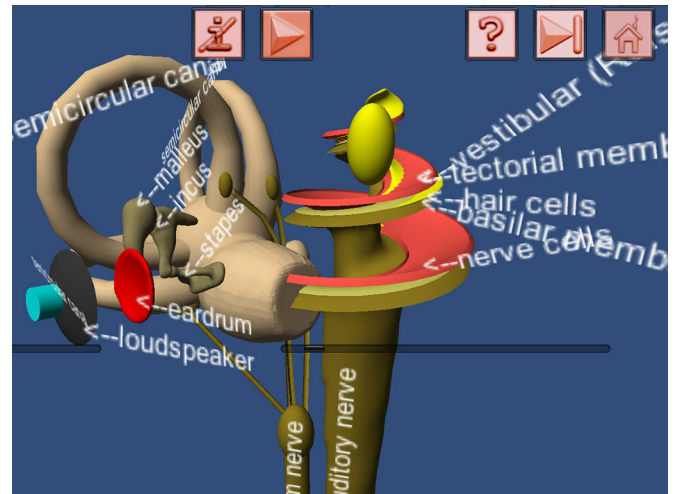
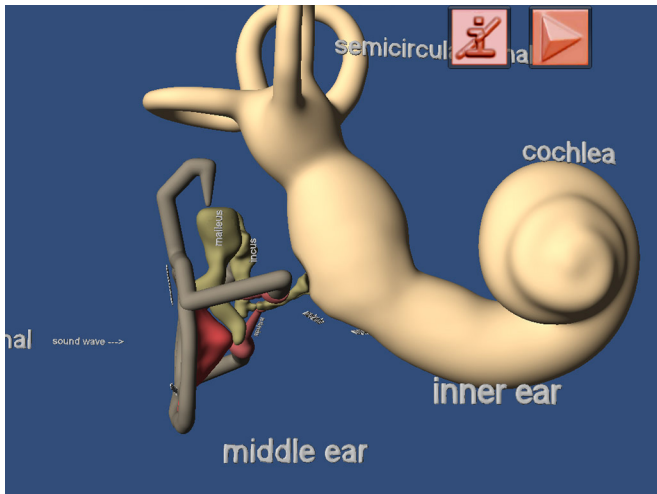
Photosynthesis

In the virtual reality worlds covering the photosynthesis you enter the plant leaf so that you see its internal structure. Then you enter a palisade cell and investigate the chloroplasts inside. In the next scene you learn about the transformation of the light energy into the chemically bound energy. You follow the photon entering into the chlorophylls seeing where and how the light energy gets stored in the cell. Finally you visit the Calvin cycle, an enzymatic pathway that works together with the above mentioned “light” phase of the photosynthesis. There are shown in the virtual reality also two important transmembrane proteins - the ATP pump and the structurally related bacterial flagellum.



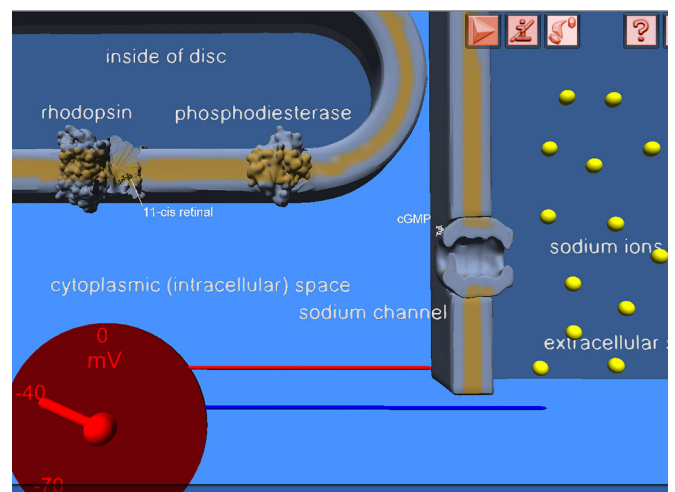
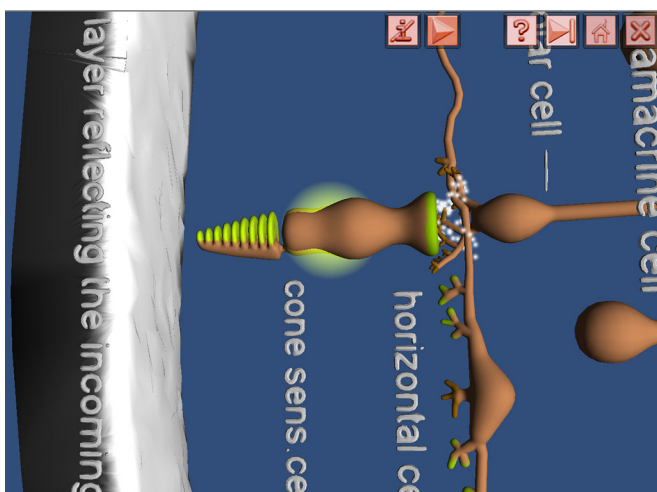
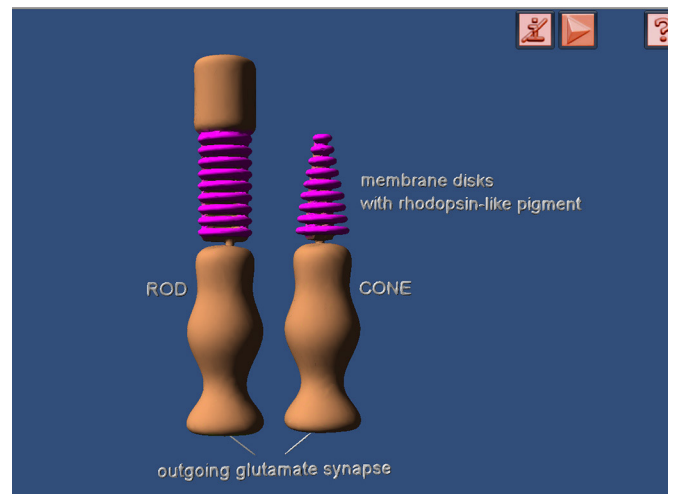
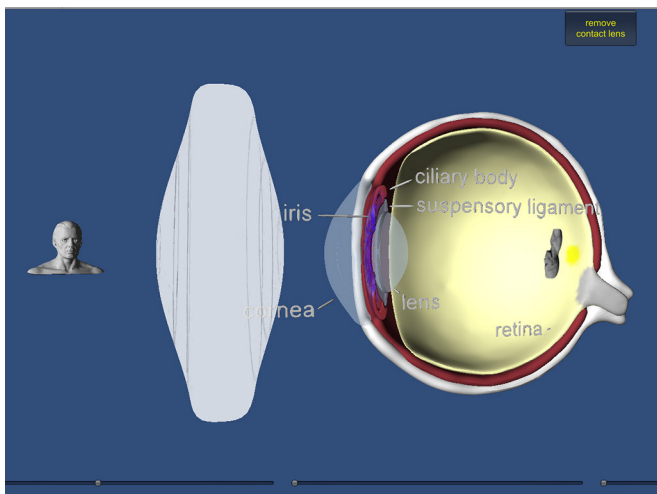
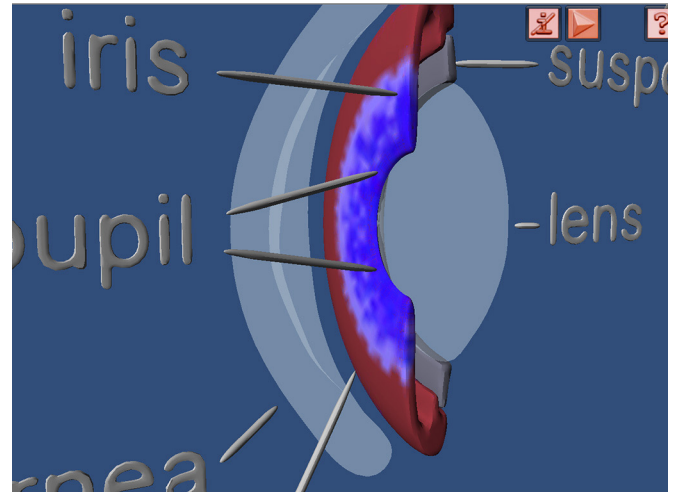
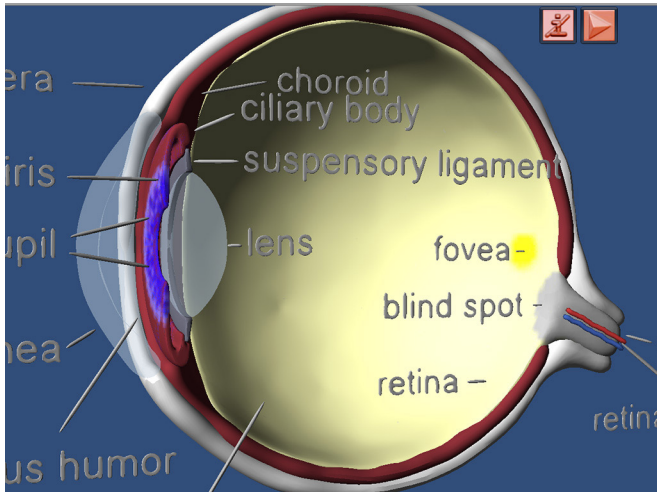
Human ear

The human ear is first visited at the level of the tympanum and the middle ear bones. Then we observe the morphology



and function of the semicircular canals - the organ of equilibrium. We enter also the inner ear where we learn how the sound frequencies are coded into the excitation of the nerve cells. You can yourself speak or sing into the device microphone and the virtual reality world simulation shows you how the inner ear codes the sound frequencies.

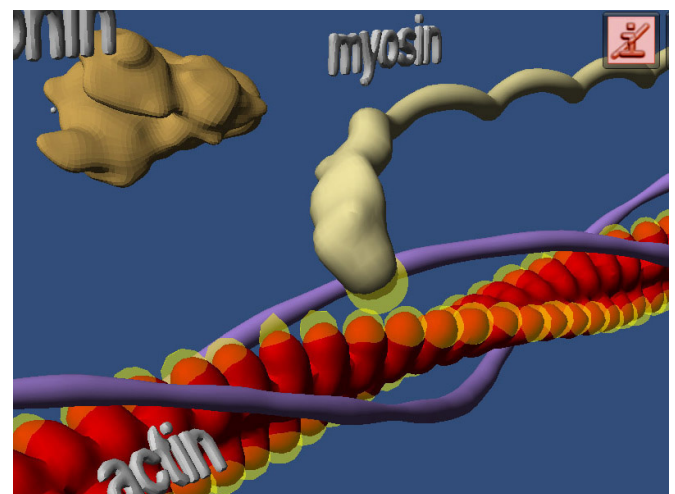
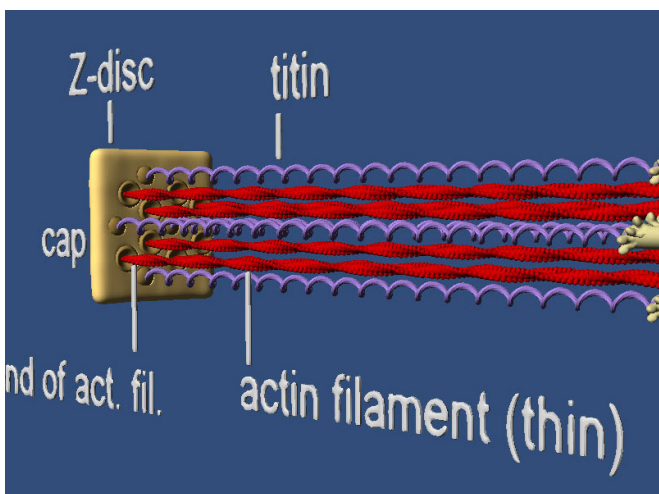
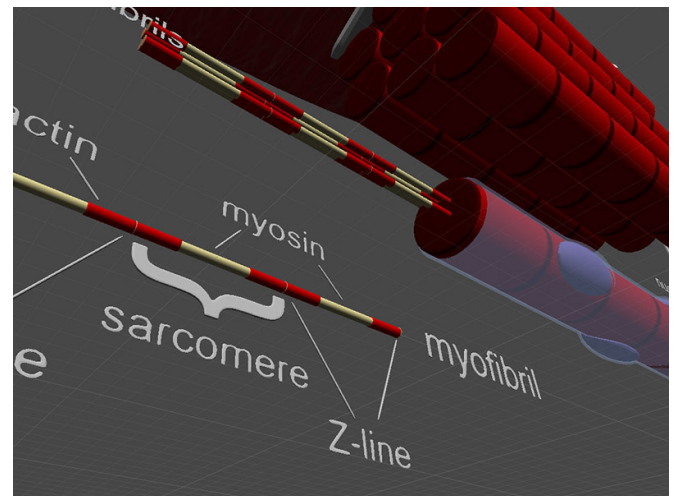
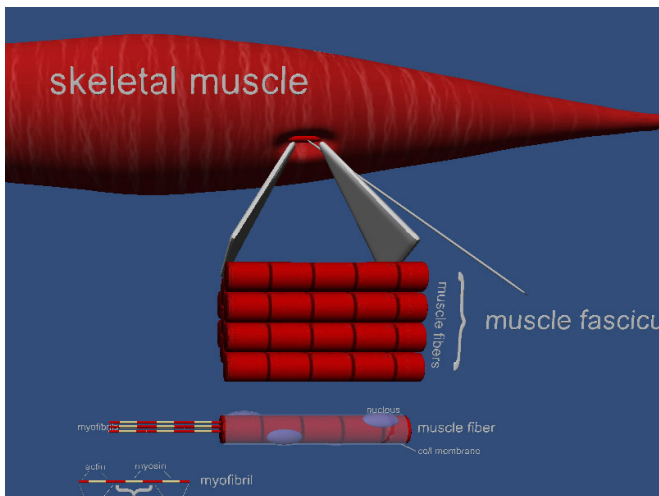
Human eye

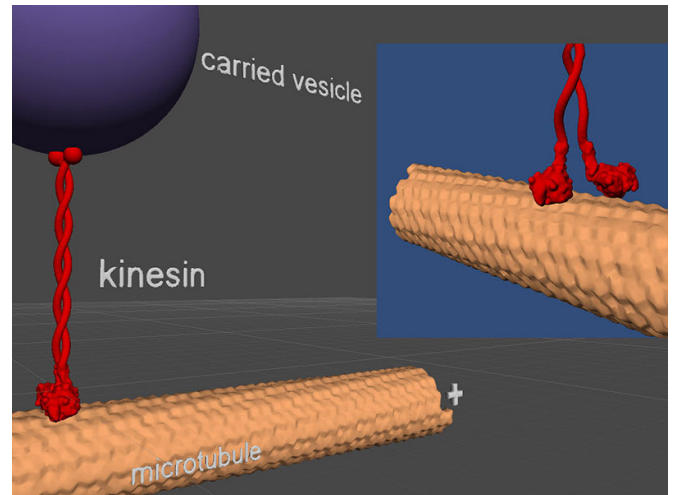
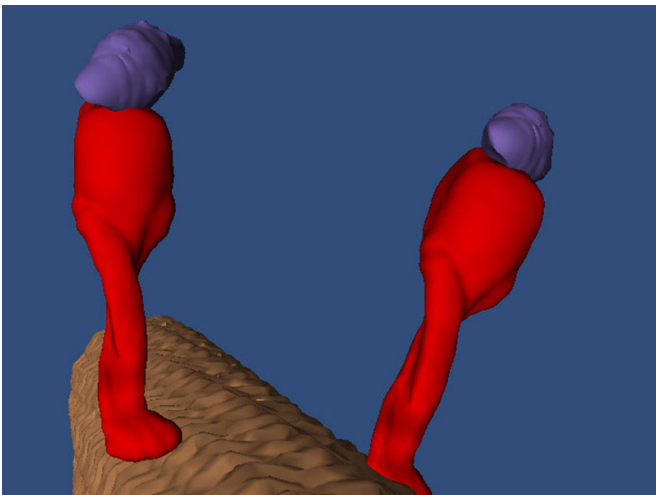
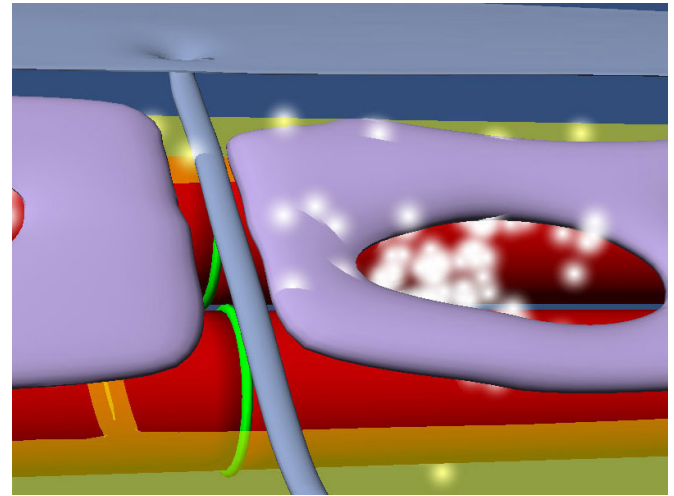
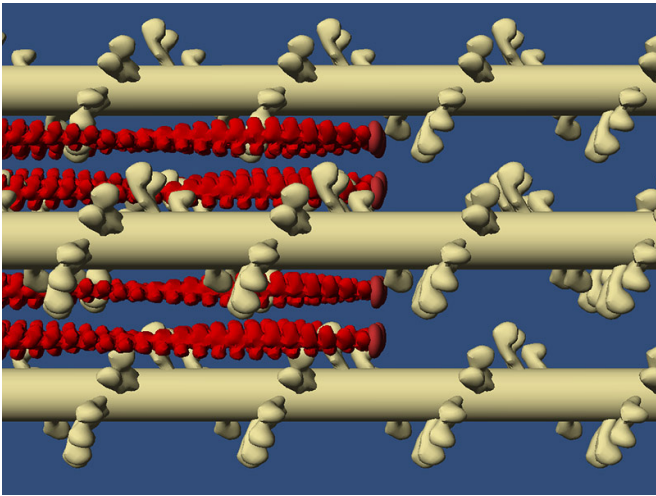


Human eye virtual reality worlds teach you about the eye structure and function. After you learn about the main eye structural elements (cornea, lens, retina etc.), you can make the eye short sighted or long sighted and then apply “spectacles” in front of the eye in order to correct the vision. There are also available virtual reality worlds about the retina and colour vision. You learn how the colours are coded in the special retinal cells - cones and how rods are used when the light intensity is low.

Muscle and motor proteins

Muscle contraction and the related “motor proteins” of the cell were traditionally a hard theme to explain to the students. With the help of the virtual reality worlds recently produced by us the students understand this difficult theme much faster. In the 3D environment you explore the whole muscle and proceed to its components - from the muscle fasciculus to the sarcomere. You learn about the sarcolemma, its system of T-tubules and the sarcoplasmic reticulum in order to understand how calcium ions invoke the muscle contraction. In another virtual reality world you closely examine the structure of the myosin molecules and how they deform after obtaining energy from the ATP. The whole sequence with actin, tropomyosin, calcium binding troponin and finally the myosin molecule walking on the actin filament is shown in another 3D scene.



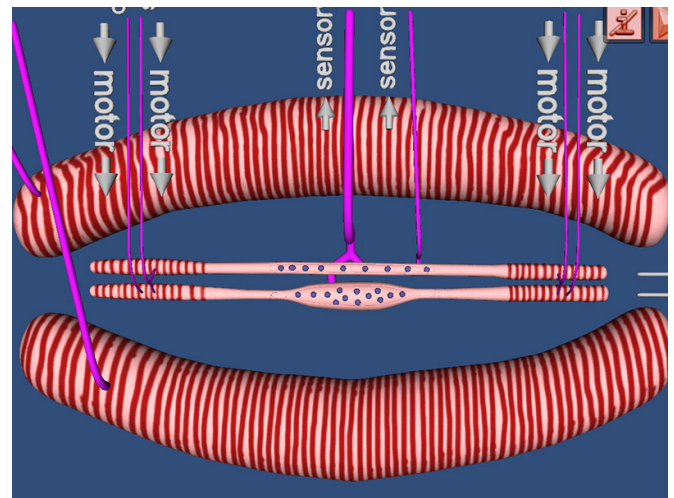
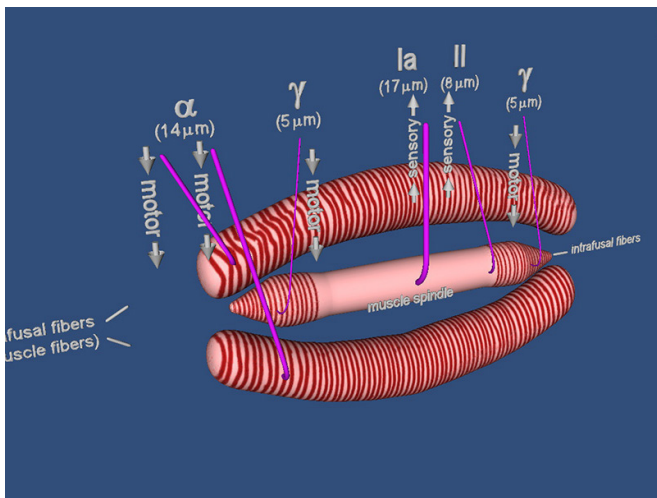


Muscle spindle

Muscle spindle is a 3-10mm long mechanoreceptor organ located inside the muscle. Its core are three to twelve miniscule intrafusal muscle fibers which are at their terminal ends firmly connected to the muscle in which they are embedded. Intrafusal muscle fibers are surrounded by the extrafusal muscle fibers. Each intrafusal fiber is a muscle fiber like the other fibers in the muscle. However, in the middle of the intrafusal muscle fiber there are few or no actin or myosin filaments. So when an intrafusal fiber contracts, only the its peripheral portions contract, while its central part gets elongated. The contracting part of the fiber is innervated by the small gamma motor neurons (=gamma efferent fibers). The "ordinary" extrafusal muscle cells are innervated by the large alpha motor fibers (type A). The sensitive part of the muscle fiber lies in its center. As suggested above, the central part of the muscle spindle stretches when the intrafusal muscle fibers get excited or when the muscle as a whole stretches (along with the interiorly located muscle spindle). There are two types of sensory neurons that innervate the central part of the muscle spindle - the primary ending and the secondary ending. The sensory nerve fiber called the primary ending is large and covers the central part of the receptive area of the intrafusal fiber. It transfers signals with the velocity 70-120 m/s, like typical nerve fibers of our body do. The secondary ending nerve fibers innervate the receptive portion of the intrafusal fiber on its sites (left or right of the primary ending). The secondary ending spreads on the intrafusal fiber like a root, but sometimes it encircles the fiber like the primary ending does. Also the intrafusal muscle fibers are divided into two groups:

the nuclear bag and the nuclear chain fibers. Nuclear bag fibers are longer and have their nuclei concentrated in the center, while nuclear chain fibers are shorter (about 50% shorter than the bag fibers) and have their nuclei arranged in a row through their receptive area. The primary ending nerve fibers are excited by both the bag and chain cells, while the secondary ending nerves get excited only by chain fibers.

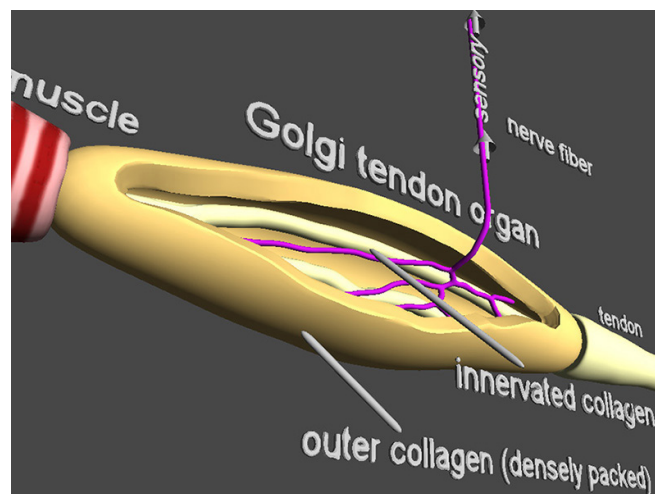
In our VR scenes we first enter a 3D muscle model showing the location of the muscle spindle. Then we pass to another scene about the anatomy and function of the quite complex way the muscle spindle responds to different ways of movement of the muscle. Therefore there are two scenes: one describing the response in case of the slow muscle movement and the other explains what happens in case of the fast extension or flexion of the muscle.



Golgi tendon organ

Golgi tendon organ is a mechanoreceptor that has its sensory fibres entangled with the muscle tendon fibres. The receptors are excited when the tendon fibres stretch. The sudden increase in the tension of the tendon fibre is reflected by an outburst of the Golgi tendon organ spike frequency. This transient response soon habituates to a constant static level activity. This activity is almost linearly dependent on the amount of the stretch of the muscle. So the Golgi tendon organ directly measures the tension of the muscle, without the sophisticated control feedback as it happens in the muscle spindle receptor.

In our project we first show in a 3D muscle model, where the muscle spindle and the Golgi tendon organ are



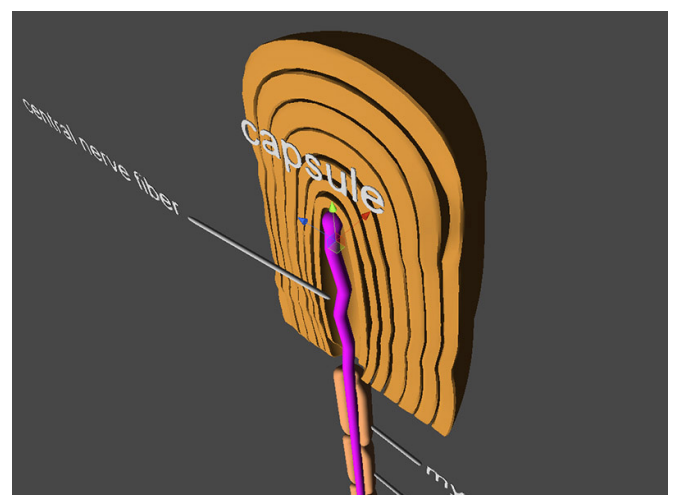
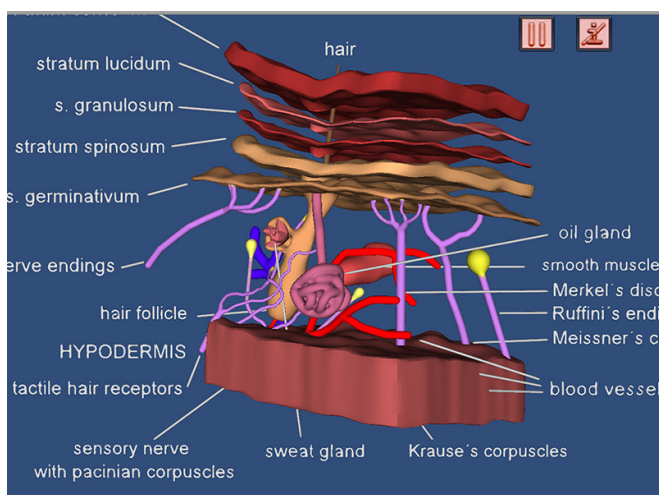
located. Then we look more closely at the Golgi tendon organ, revealing its internal structure - the outer compact collagen sheath and the inner loosely packed collagen fibres and the nerves innervating them.

Skin

Skin is a very important organ in our body. Like other epithelial tissues, epidermis has no blood supply of its own (the blood vessels terminate below it, in the mesodermal layers of the skin). The deepest cell layer of epidermis is called stratum germinativum that covers the dermis and receives from it the nutrients through diffusion. Stratum germinativum cells are constantly dividing - the new cells are pushed upwards and constitute the layer of stratum granulosum, later on they become part of stratum spinosum, which is transformed into stratum lucidum. The upward protruding cells become flattened, fill with keratin and die. This superficial layer of dead keratinized cells that repel water is called the stratum corneum. It is about 20-30 cell layers thick and accounts for 3/4 of the epidermal thickness. Dermis is a strong elastic envelope around our body. It is this layer of the skin in animals that gives rise to the leather. The upper part of the dermis is called the papillary layer. It has fingerlike protrusions on its upper side (the papillae) which tightly connect with the epidermis above. Inside the papillae are the blood vessels nourishing the skin as well as the sense organs, described in more detail where we discuss the sense organs in the skin. The reticular layer lies beneath the papillary layer. In addition to blood vessels it contains sweat and oil glands, deep pressure receptors called the Pacinian corpuscles. There is also plenty of phagocytes here that prevent the bacteria to enter deeper into our body.

We explain the skin structure in a highly animated VR scene. At first the user sees the 3D model of the skin segment in with all its layers and organs. Then the animation starts - the skin layers bend and peel off one after the other so that the complex structure becomes more easily observed and understood. This animation can be paused at any time (or even run backwards from that point) and of course - since this is a virtual reality world - the user can study the “exploded” skin segment from any angle or distance.

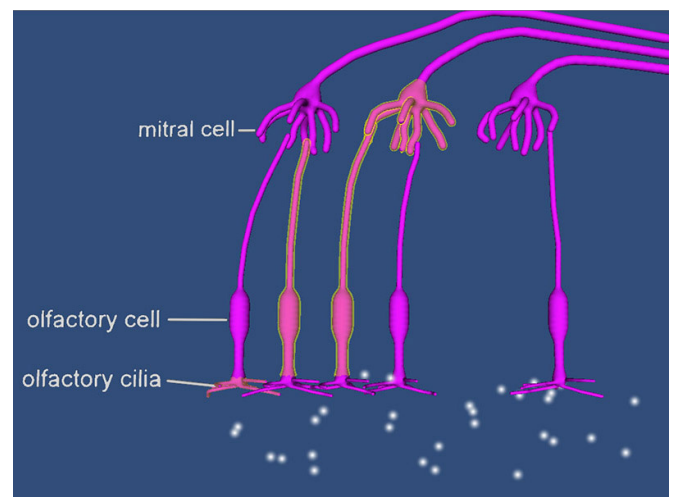
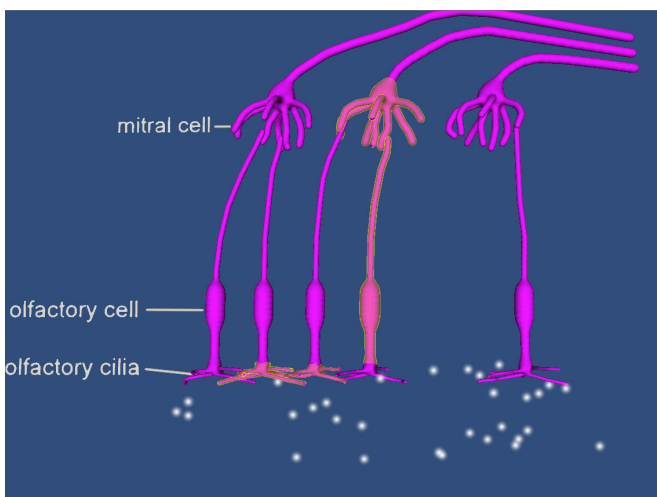
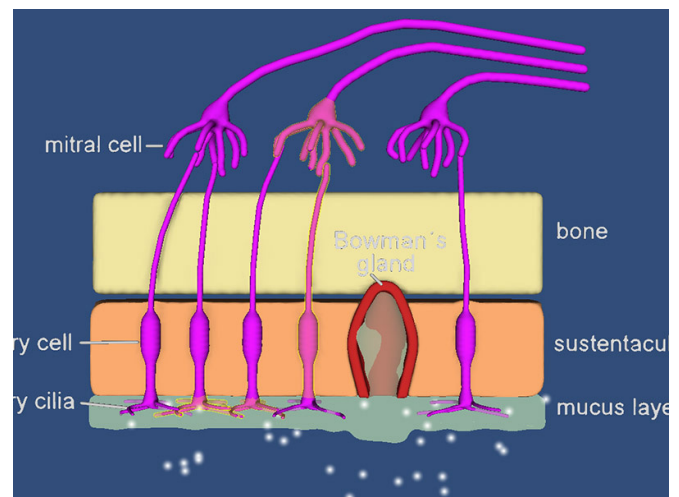
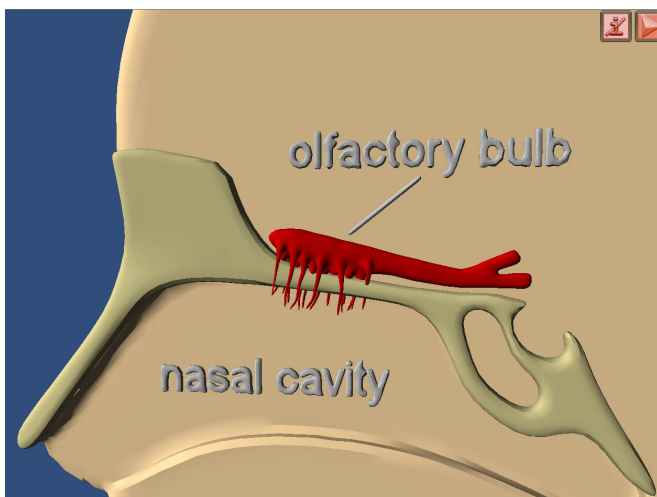
The next scene is about the Pacinian corpuscle. This is a mechanoreceptor, especially good for sensing the vibration. The first view shows the Pacinian corpuscle as a whole, with the myelinated nerve protruding downwards. Then the outer sheath disappears and we see many concentric sheaths enveloping the free nerve ending, which is the place where mechanical stimulus is translated into the nerve excitations. As the sheaths of the corpuscle get deformed during the animation, the nerve gets excited and coloured nerve impulses travel down along the sensory nerve.



Sense of smell (olfactory epithelium)

The sensory epithelium for smell is located on the olfactory membrane that lies in the superior part of the nostril. The receptor cells for smell are called the olfactory cells. They are bipolar nerve cells that originate from the central nervous system. On the lower (mucosal) end of the olfactory epithelium the terminal end of the olfactory cell shows a knob-like form from which protrude downwards several cilia, that are the actual sensory locus of the olfactory cell. Mucous is produced by the Bowman glands situated among the olfactory cells. Olfactory stimulus depolarizes the sensory cell. The depolarization is the result of a complex sequence of cellular processes involving G-protein and cyclic AMP. So the response to the olfactory stimulus gets very much amplified. In the final step the olfactory neuron is activated and transmits nervous impulses into the central nervous system.

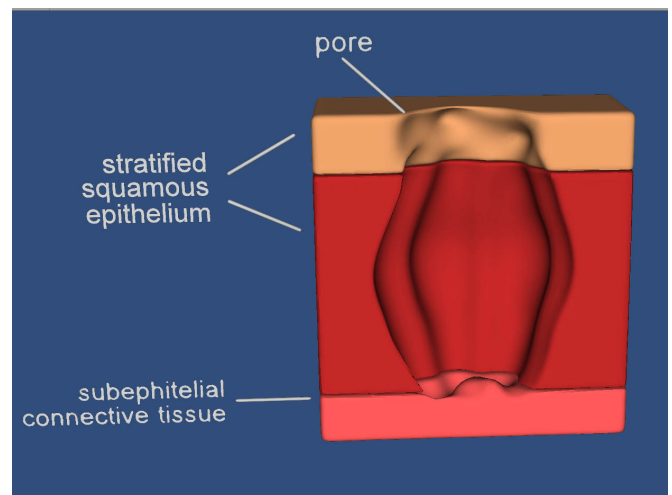
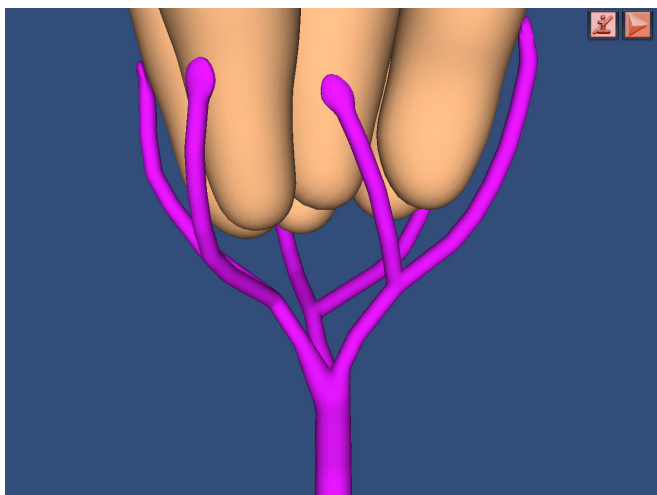
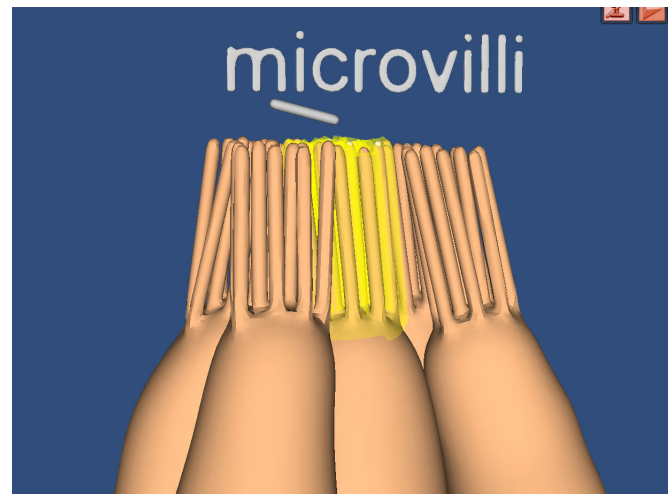
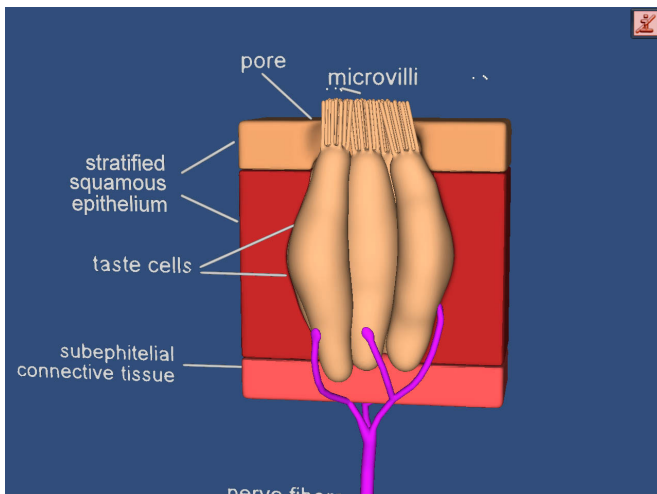
Our virtual reality scenes show first the schematic transection through the head showing the location of the olfactory epithelium. In the next scene the more detailed structure is shown. Olfactory stimuli (odour molecules) come and excite the sensory cells that are called the bipolar cells. The user can observe the mucosal site of the olfactory receptor system as well as the mitral cells that collect the olfactory information.



Sense of taste - a taste bud

There are sensory organs in our mouth called the taste buds which are the chemoreceptors informing us about the taste of the substance we eat. The sense of taste is strongly combined with the sense of smell, conveyed by the olfactory receptors in our nose. There are at least thirteen different chemical receptor types in our taste buds: Two sodium and two potassium receptors, one of chloride, adenosine and inosine receptors, two kinds of sweet and 2 bitter receptors, and finally one glutamate and one hydrogen ion (acidity) receptor.

Taste buds are found on the papillae of the tongue. The sensory taste cells are depolarized when the taste stimulus is applied to them. The degree of depolarization is in logarithmic relation to the concentration of the stimulating substance. The neurons that synaptically connect to the sensory cells are excited by the depolarization of the taste bud cells and produce action potentials that first show a transient increase in frequency, but soon (within a few seconds) adapt to a lower steady discharge rate that persists during the stimulus presence. In our virtual reality scene you see how the molecules adhere to the receptive membrane of the sensory cell on the microvilli and later on diffuse away. The microvilli of the taste sensory cells contain on their cell membrane the actual chemosensory receptors. The bodies of the sensory cells provide the metabolic machinery for the cells to stay alive and they provide also the presynaptic sites for the sensory nerve cells to connect. The sensory taste cells are depolarized when the taste stimulus is applied to them. The degree of depolarization is in logarithmic relation to the concentration of the stimulating substance. The sensory neurons that synaptically



connect to the olfactory sensory cells are excited by the depolarization of the taste bud cells and produce action potentials that first show a transient increase in frequency, but soon (within a few seconds) adapt to a lower steady discharge rate that persists during the stimulus presence.

In our scenes we show first the transection of the head and tongue, marking the area where the taste sensing epithelium is situated. The next scene shows a taste bud with the surrounding epithelium. On the top there is a pore through which the chemical stimulus reaches the sensory cells. The taste bud is inserted in the stratified squamous epithelium, underneath lies the subepithelial connective tissue.

Conclusion

The classical e-book with text and pictures can be enriched with video that is typically stored on YouTube⁷. Already these video clips can be in stereo 3D - YouTube enables this as long you have the relevant video card for stereo 3D on your computer. We produced many of our virtual reality worlds also as stereo 3D videos as you can see on my YouTube channel. We also produced interesting stereomicroscopic⁸ videos filmed with two high resolution video cameras the first mounted on the left and the second on the right optic path of the stereo microscope, respectively. However the tablets with stereo 3D graphics are practically non existent. Anyway the real virtual reality worlds provide a special and unique user experience. They attract you almost like a computer game. In addition they also provide an excellent tool for the teacher in order to enrich his or her lectures.

References

1. www.pixologic.com
2. www.autodesk.com
3. unity3d.com
4. www.microsoft.com
5. Apple.com
6. www.android.com
7. www.youtube.com
8. www.bioanim.com