Cinematic Rendering - A New 3D Imaging Technique for Computed Tomography

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Learning objectives

1. To give a concise overview about standard volume rendering (VR) and a new three-dimensional (3D) technique labelled cinematic rendering (CR).

2. To illustrate the image appearance and potential value of CR in comparison with conventional VR.
Current computed tomography (CT) scanners provide isotropic submillimeter resolution enabling the utilization of various 2D and 3D post-processing techniques with excellent spatial resolution. Whereas 2D techniques such as planar or curved multiplanar reformations (MPR) can be considered part of daily radiological routine [1], 3D imaging postprocessing techniques such as volume rendering (VR) are used more rarely for visualizing complex anatomical information. This holds particularly true for CT angiography examinations and for orthopedic as well as oncological imaging. 3D visualizations of CT image data can offer additional information compared with 2D axial images in both preoperative planning and post-treatment follow-up, including applications in otorhinolaryngology [2], neurosurgery [3], management of foreign body extractions [4], visualization of complex tumor [5] and vessel [6; 7] anatomy.

Nowadays, VR is used as the standard technique for the 3D visualization of CT image data. The main advantages of VR lie in a relatively simple evaluation of different body structures at the same time, which can be useful in patients with vascular malformations [8] and acute vascular syndromes [9]. Moreover, VR enables the display of CT image data in a colored fashion, which helps visualizing complex anatomy [10]. While the generation of VR images in early days was hampered by high computational demands and often was associated with long post-processing times, today's powerful computers allow for a near-real time and automatic rendering of 3D images in a fast, clinically compatible manner.

Recently, a new technique for 3D visualization of cross-sectional image data from CT has been introduced, which is entitled cinematic rendering (CR). CR works with random sampling computational algorithms and uses different light maps to generate a realistic depiction of medical data.

**VOLUME RENDERING**

VR technique represents a computer algorithm used to transform cross-sectional image datasets (from e.g. CT) into 3D images. The volume rendering technique consists of the following two steps: classification of each voxel and image projection. First, the tissue represented in each voxel of the volume dataset is determined by using predefined attenuation threshold levels and assigned to a specific color and opacity. Then, weighted sum of the percentage of each tissue type represented in the voxel is calculated to determine the overall color and transparency of each voxel. This step is performed for each voxel of the whole volume dataset.
Second, the 3D volume is displayed by using a projection technique. This is done by simulating rays of light which are projected through the 3D volume that contains the classified voxels. Each voxel which is passed by the simulated rays modulate the color of the light depending on the assigned color and transparency and contribute to the final projection and final image.

Finally, 3D perception in the projected image can be enhanced by implementing additional effects such as reflection and shadows on the surface of the rendered image.

**CINEMATIC RENDERING**

CR is currently available only as a research tool on an open research environment containing various prototype software (Frontier, version 1.0.0, syngo.Via, version VB10A) and has so far no approval for clinical use.

The CR technique introduces a new paradigm to render volumetric medical image data by using a path tracing-based technique. As opposed to conventional rendering methods such as VR that model only one light ray per pixel, path tracing integrates a huge number of light rays, each with different paths to form each pixel of the rendered image. Since the number of light paths which can be traced is in theory infinite, and tracing of light paths is computationally expensive, Monte-Carlo simulations are used to generate a randomized subset of light paths with an adequate distribution. High dynamic range (HDR) rendering light maps are used for illumination, which lead to a natural illumination of the rendered data, in contrast to synthetic light sources used in conventional rendering methods such as VR [13].

As a result, the complex physics of lighting effect can model shadows, ambient occlusion, multi-scattering, and color transmittance as well as sophisticated camera models, which include concepts such as aperture, exposure and shutter speed. This novel approach leads to a natural and physically accurate presentation of the medical data, which considerably enhances depth and shape perception.
Findings and procedure details

Both VR and CR post-processing techniques have the same general rendering concept in common, which includes the segmentation of data based on voxel attenuation and using colour look-up tables taking into account opacity and brightness. As a consequence, both VR and CR share the same problem of potentially masking findings in the dataset by inappropriate use of the rendering parameters. Albeit CR currently is only provided by a single vendor in a pre-clinical research tool with still limited display options, CR can provide the same advanced display functions such as VR including flying-through, flying-around and multiple views of the volume data with independent parameters in equal segments of the displayed window [11; 12].

Due to the above mentioned similarities between CR and VR, there are no major differences in the visualization of CT image data when regarding the diagnostic value of the presentation. Similar to VR, we found that particularly high-contrast structures such as contrast-enhanced vessels and bones can be depicted with high quality also with CR. However, we also found a major improvement of CR in the perception of depth and soft tissue structures.

In general, lighting in 3D rendered images such as VR and CR is a function of ambient, diffuse and specular light properties. In both techniques, the brightness of each voxel is defined by the distribution of these light properties which results in different lighting of different body parts relative to the artificial light source introduced into the volume, giving rise to 3D impressions of the images. In VR, the differences in light emitted to the voxels are rather small. In contrast, CR uses a more complex lighting model taking into account the effect of lighting to other voxels and subsequent reflections as well. Also the effect of body parts blocking the trace from the artificial light source to other structures introduces shadowing into the images. As a result of the differences in lighting functions - as being illustrated in the representative image examples of this pictorial review - CR images go along with a more natural image impression as compared to conventional VR.

Despite of the potential benefits of CR compared to VR in the visualization of volume datasets, there is a higher computational power demand required for the CR technique because of the more complex lighting model. Therefore, real-time display of for instance rotating the CR image is currently interrupted by repetitive recalculation processes. In addition, there is currently no proven added clinical value of CR in terms of accuracy to neither conventional VR nor cross-sectional 2D image interpretation such as MPR [14].

Representative image examples of vascular anatomy and pathology are provided in Fig. 1 on page 7, Fig. 2 on page 7, Fig. 3 on page 8, and Fig. 4 on page 8,
representative images illustrating the quality for depiction of bones and skeletal disease are provided in Fig. 5 on page 9, Fig. 6 on page 10, and Fig. 7 on page 11, and the quality of CR for the visualization of soft tissue anatomy and tumors is shown in Fig. 8 on page 11, Fig. 9 on page 11, and Fig. 10 on page 12.
**Fig. 1:** Malignant type coronary anomaly with origin of the right coronary artery (RCA) from the left coronary sinus and interarterial course (arrows). Cinematic rendering (CR) (a) shows the RCA coursing ventrally to the aortic root to the right side. The volume rendered (VR) image (b) depicts the same anomaly from a similar perspective.

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**Fig. 2:** Basilar artery aneurysm. CR (a) and conventional VR (b) depict the base of the skull with the cerebral arteries of the circle of Willis, as well as the fusiform dilation of the basilar artery.

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**Fig. 3:** Endovascular stent graft treatment of the abdominal aorta with visceral debranching in a patient with infrarenal aortic and splenic artery aneurysm. Coronal 3D images showing the dilatation of the splenic artery with CR (a) and VR (b).

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**Fig. 4:** Arteriovenous malformation (AVM) in the upper pole of the left kidney. CR (a) and VR (b) images and close-up view (c, d) images allow for more detailed depiction of the AVM.

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Fig. 5: Cervical spine injury with luxation of C3/4. 3D rendering using CR (a) and VR (b) technique shows anterior subluxation of the cervical spine (arrows).

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Fig. 6: Polytrauma patient with multiple fractures of the axial skeleton. Back side view of the osseous structures of the spine and pelvis using CR (a) and VR (b) reveals multiple fractures of the ribs, lumbal transverse processes, sacrum, and pubic bones.
**Fig. 7:** Head shot injury. CR (a) and VR (b) showing the bullets and the extensive damage of the skull base.

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**Fig. 8:** Neuroendocrine tumor of the duodenum. CR (a) and VR (b) showing the large vascularized mass in the upper abdomen with dilated arterial feeders and draining veins (arrows).

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**Fig. 9:** Herniation of small bowel through the anterior abdominal wall caused by blunt trauma. CR (a) and VR (b) showing the soft tissue of the abdominal wall and upper thigh along with the herniating bowel loops (arrows).

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**Fig. 10**: Whole body CT in a patient with polytrauma. CR (a) and VR (b) visualize the soft tissues of the head, neck, chest and abdomen.

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Conclusion

Our aim was to give a first demonstration of a new post-processing technique for the 3D visualization of CT image data. Our first experience indicates that CR of CT images is particularly impressive when high contrast structures such as bones and vessels after the administration of contrast media are to be visualized. The main innovations as compared to conventional VR appear to be a more natural representation of the CT image data, with an enhanced depth and shape perception.