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Voxelization: Multi-target Optimization for Biomedical Volume Rendering

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Intro

Almost all existing biomedical imaging software provide various 3D rendering modalities for volume visualization. These usually include maximum intensity projection (MIP) and direct volume rendering (DVR). Recently, probabilistic algorithms have also been considered. Depending on the algorithm, level of detail, volume size, and transfer function, rendering can be slow even on powerful hardware. We present an innovative multi-target approach to optimization that uses a *voxel grid* as a supportive structure. We show how it can be quickly built and applied to increase the performance gain of various rendering techniques.

Methods

We first construct the voxel grid and then apply this auxiliary structure to empty space skipping, optimized MIP computation, and advanced Woodcock tracking. All the techniques described are implemented in OpenGL.

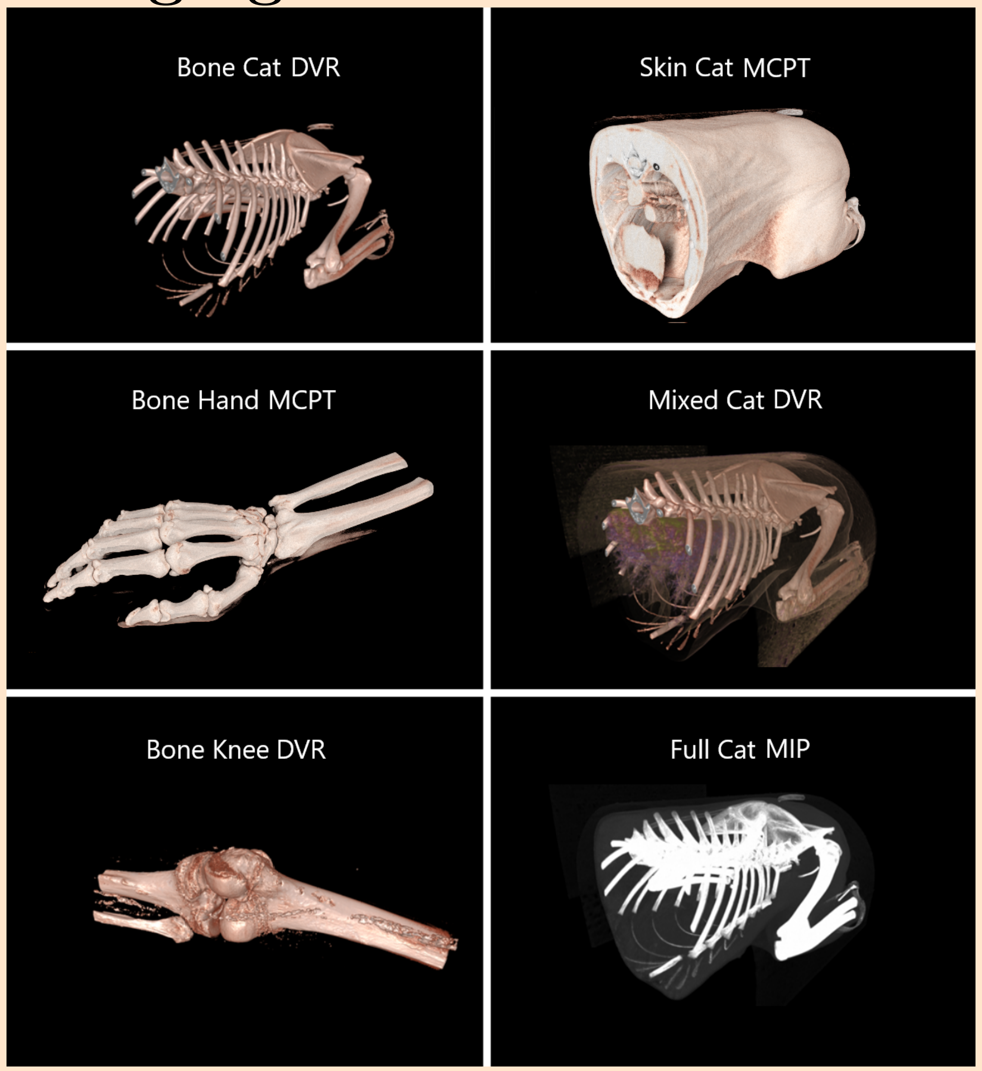
The construction of a voxel grid is called voxelization. In this process, the adjacent voxels of the original volume are combined to form a super voxel - a 3D cube of a certain size. The set of super voxels forms a voxel grid. We construct a super voxel by finding the maximum value of transparency (or density) of all voxels that fall within the super voxel.

An empty space skipping optimization is based on the idea of skipping the voxels whose density is below a certain threshold (usually zero). The idea of optimising maximum intensity calculation is similar to empty space skipping. The main difference is that the density of the super voxel should be compared to the current maximum intensity value, not to a constant threshold. An advanced Woodcock Tracking is an evolution of the Woodcock Tracking sampling technique, that solves the problem of large density variations within volumes. By construction, the voxel grid introduced above can be used for all of these techniques in a straightforward manner.

Results

We illustrate the results of our optimization method applied to three different CT acquisitions rendered using the following techniques: DVR, MIP, and Monte-Carlo Path Tracing (MCPT). We apply three typical transfer functions for all acquisitions and present the rendering speed measurement. The results of our research suggest the use of the proposed method especially in cases where different rendering techniques are combined. Thanks to the proposed method, real-time interaction with data obtained by computed tomography becomes feasible even for such a greedy algorithm as Monte-Carlo path tracing. The method has been successfully integrated into the **Multimodal Biomedical Imaging Platform All-in-one**.

We introduce innovative multi-target optimization (**up to 9x**) for interactive rendering within the **Multimodal Biomedical Imaging Platform All-in-one**.



Discussion & Conclusion

The proposed voxelization technique increases the performance of DVR up to 9 times. The speed-up strongly depends on the transfer function. The transfer functions that zero out a larger volume area result in a major performance gain. In the case of MCPT, the 5 times acceleration is stable and does not depend on the transfer function. Thus, the advanced Woodcock Tracking solved the problem of large density variations caused by some transfer functions. The MIP acceleration is also stable and is about 50% of the original velocity. The minor MIP speed-up can be explained by the early termination when the maximum intensity becomes larger than the threshold.

		Bone		*Skin*		*Mixed*		*Full*	
Cat	*DVR*	21.3	**7.1x**	20.4	**4.6x**	7.4	**2.6x**		
	MCPT	13.3	**4.3x**	14.3	**4.1x**	4.1	**3.4x**		
	MIP							27.0	**1.4x**
Hand	*DVR*	20.0	**9.1x**	22.2	**8.9x**	10.4	**5.0x**		
	MCPT	12.5	**5.0x**	15.2	**5.6x**	6.4	**5.3x**		
	MIP							23.8	**1.6x**
Knee	*DVR*	21.3	**8.9x**	19.6	**4.8x**	6.5	**3.1x**		
	MCPT	14.5	**5.0x**	10.6	**3.9x**	3.5	**4.4x**		
	MIP							19.6	**1.3x**

	Bone	*Skin*	*Mixed*	*Full*
Cat	303	309	322	306
Hand	539	546	548	648
Knee	534	576	600	627

The voxelization process takes between ~ 300 and 650 milliseconds depending on the volume size and structure complexity. However, voxelization occurs only when the transfer function changes and in practice does not affect interactivity.
Given the maximum volume dimension $N = max(X, Y, Z)$ and the super voxel size s, the operation complexity of the voxelization process is $O(N^3)$. The memory consumption is $O((\frac{N}{s})^3)$.
Our further research will focus on finding the optimal size of the super voxel with respect to the complexity of the volume structure.

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