Evaluation Report on the Doctoral Thesis

Compression of dynamic polygonal meshes with constant and variable connectivity

submitted by Jan Dvořák

Summary

The doctoral thesis of Jan Dvořák focuses on the compression of dynamic surface representations like mesh and point cloud sequences. It highlights the difficulty due to the lack of explicit temporal correspondence, leading to limitations in exploiting the coherence of such data. Current compression methods show promise but are constrained by the type of data they can handle and often compromise on preserving the original structure of frames.

The primary focus of his research revolves around introducing novel techniques to address these limitations. In particular, he proposes a unique temporal model called tracked centres, which operates on volumes rather than surface correspondences, thereby allowing representations of more diverse dynamic surfaces. Additionally, an enhanced algorithm for connectivity compression is presented that can potentially be integrated into existing compression pipelines to retain the original structure while achieving improved data rates. Moreover, he introduces a method dedicated to compressing molecular dynamics trajectories, showcasing its notable performance, particularly on large molecular systems like proteins. The significance of this work lies in its pursuit of more efficient encoding for general data and in the endeavour to maintain the structural integrity of frames within dynamic surface sequences.

The innovations introduced in this research hold promise for a wide array of applications. These advancements could potentially revolutionize fields such as computer graphics, virtual reality, and 3D modelling by enabling more efficient handling and utilization of complex dynamic surface data.

The Thesis

The thesis starts with a concise introduction of the topics investigated by Jan, as well as a summary of the contributions presented in this thesis. In Chapter 2, Jan presents the main terminology and background needed to describe the subsequent the method does not work well for highly regular meshes. While further improvements of the idea might be possible, Jan decided to redirect his research efforts towards designing temporal models for TVM compression, due to the declining interest in static and DM compression. This work was presented at the very prestigious *Symposium on Geometry Processing* (SGP) in 2018 and published in the journal *Computer Graphics Forum*, one of the leading journals in computer graphics.

Jan's second contribution, a method for compressing molecular dynamics (MD) trajectories, is described in Chapter 7. Using the newly proposed temporal "canonical molecule" model, he shows how to efficiently capture atom bond information. The key observation that led to this model is the fact that the distance between bonded atoms does not change much over time, and that the main source of atom movement is dihedral angle movement. Overall, this approach, which is specifically tailored for proteins, offers substantial enhancements compared to state-of-the-art methods, either by saving bits per coordinate or by providing significantly better precision at the same data rate. The results of this research were published in the *Journal of Molecular Graphics and Modelling*.

In Chapter 8, Jan introduces a new temporal model for dynamic surfaces and showcases potential applications in time-varying mesh compression and coherent editing. This "tracked centres" model addresses several limitations inherent in existing methods by focusing on fixed points within a volume surrounding the surface. While the initial version of this model was quite limited, Jan successfully improved it in several ways, in particular with respect to mitigating tracking irregularities. Although the model still exhibits some constraints, it shows promise in various applications, particularly in facilitating temporally coherent editing. As this work has led to three publications, including an article in the journal *Computers & Graphics*, I consider it the most important of Jan's contributions.

Chapter 9 finally introduces a priority-based method for encoding mesh connectivity. It is based on a traversal strategy that separates the mesh into processed and unprocessed parts. This approach enables the encoder to emit information necessary for the decoder to attach new triangles in a specified order. By employing a geometric priority during traversal, the algorithm achieves superior compression rates compared to existing techniques, especially on uniformly sampled surfaces. However, its effectiveness varies with the complexity of surfaces, and while it excels for real-world objects, it faces some problems for computer-generated models. The work led to another article in the journal *Computer Graphics Forum* and was presented at the top conference *Eurographics* in 2023.

The breadth of Jan's research presented in these four chapters is truly amazing, and I greatly appreciate that he released an executable or even the source code for all his projects. This is a very useful service to the community, and I know from

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Ph.D. Dissertation Review

Author of the dissertation: Ing. Jan Dvořák
Title: Compression of dynamic polygonal meshes with constant and variable connectivity
Review written by: doc. Ing. Jiří Bittner, Ph.D.

The Ph.D. thesis of Jan Dvořák deals with the problem of compressing dynamic data. The main focus of the work are polygonal meshes with both constant and variable connectivity and a specific domain of molecular data.

The dissertation consists of ten chapters. The first two chapters provide an introduction to the problem and a summary of contributions. Chapters 3 and 4 discuss the related work in mesh and point cloud compression. Chapters 6 to 9 discuss four different domains of research, in particular, the error propagation control in Laplacian mesh compression (Chapter 6), model-based molecular trajectory compression (Chapter 7), volume element tracking for time-varying meshes (Chapter 8), and priority-based connectivity coding (Chapter 9). Finally, Chapter 10 summarizes the work and discusses possible future research directions.

Efficient 3D data representation and compression is an important problem in computer graphics. For dynamic 3D data, some form of compression is inevitable for most applications. Due to the practical importance of this topic a lot of research has already been done in this area. However, open problems still exist, the author was able to cleverly spot them in his research and systematically work towards their efficient solutions. A unifying idea of most of the presented work is how to make the best use of temporal coherence even for data that exhibit unexpected topological changes in time.

All the work presented in the thesis is well grounded in the existing state-of-the-art research. The achieved results are verified systematically using a number of well-designed experimental comparisons evaluating the proposed techniques in the context of existing methods. Most of these comparisons show significant improvements achieved by the newly proposed techniques.

2. What do you think about applying the volume element tracking compression in combination with direct rendering of volumetric data, for example, using the recently popular 3D Gaussians?

3. What are the possibilities of combining the volume element tracking with the priority-based connectivity coding?

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doc. Ing. Jiří Bittner, Ph.D.