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Technical Section

Fast cutaway visualization of sub-terrain tubular networks

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ABSTRACT

This paper proposes a context-preserving 3D visualization technique for interactive view- and distance-dependent cutaway visualization that reveals the subsurface urban infrastructure network. The infrastructure itself is displayed using the procedural billboarding technique, and its internals are revealed through a new cutaway algorithm that operates directly on the procedurally generated structures in the billboard proxy geometry. Both described cutaway techniques achieve interactive frame rates for the infrastructural network of a mid-sized city. Performance benchmarks and a domain expert evaluation support the potential usefulness of this technique in general and its particular utilization for the sewer network visualization.

1. Introduction

Illustrations are often used to convey complex internal characteristics of a three-dimensional structure. They are employed in wide-ranging domains including medicine, mechanical engineering, architecture, and art among others [1]. To understand the internal complexity of such entities, the viewer needs to look inside them [2]. However, most of the structural elements are occluded by each other and the enclosing surface. It is therefore important to reduce the mutual visual interference of the occluding elements and let the viewer focus on the element of interest.

To do so, many illustrators make the outer structures transparent in order to reveal the otherwise hidden internal details. Such strategy allows, to a certain degree, to perceive simultaneously the outer geometry and the internal details. However, when shading multiple surfaces enclosing one another, the perception of the shading might result in several interpretations of the observed geometry. As an alternative to transparency-based techniques, cutaway-based approaches enable a clear, unoccluded view of the internal structures. They utilize the outer geometry as a context, thereby supporting the depiction of the internal details without any ambiguity. Parts of the outer layers are removed from the visualization by means of a cutaway geometry.

For 3D data visualization, multiple interactive cutaway techniques have been inspired by hand-crafted illustrations, especially in the context of medical, technical, or geological data visualization. In medical visualization, cutaways reveal compact internal structures, for which algorithms have been designed. One traditional application of cutaways in medicine is for educational illustrations of human anatomy. A more recent example, as Burns et al. suggest [3], is the the display of real-time imaging data (e.g., ultrasound) embedded into dense 3D Computed Tomography scans to assist medical interventions. In the technical domain, cutaways are widely used to illustrate the internal structure of complex mechanisms [4] or processes taking place inside those mechanisms. Geological illustrations often utilize cutaway techniques for revealing important subsurface details [5]. In visualization of geological models, structures can be compact (e.g., an oil trap), or more spread out (e.g., a network of channels originating from ancient fluvial systems). The geological cutaway techniques typically do not present a complex and detailed scenery on the Earth surface itself, these only provide a sense of orientation.

In urban environments, cutaways can help to expressively communicate subsurface infrastructure of a subway line [6], as illustrated in Fig. 1. For urban subsurface infrastructure, it is essential to communicate surface characteristics such as streets, buildings, parks, and water systems as there is a very strong relationship between them and the underlying subsurface infrastructure. It is usually not desirable to compromise on the visualization of the surface features in favor of the underlying features. A cutaway should rather be limited to structures that are very important or are of the viewer's interest and to their immediate neighboring structures. Straightforward application of existing cutaway visualization algorithms tailored for other spatial data distribution would result in cutting away the entire urban surface level. Therefore,

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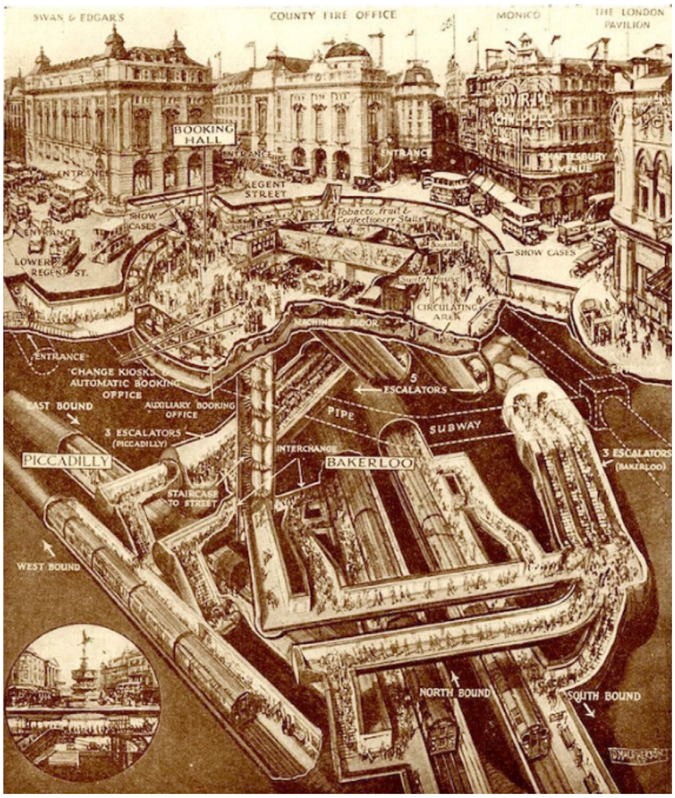

Fig. 1. Cutaway illustration of the Piccadilly Circus underground station to explain the complexity of the construction works, 1930. (c) London Transport Museum Collection.

another controlling mechanism for cutaways is needed in addition to the viewing direction. Our system incorporates a new parameter – distance to the surface – that defines whether a cutaway structure should be formed to reveal the subsurface detail or surface-level details should be conveyed instead. A novel distance-based cutaway parametrization forms the first technical contribution of this paper.

Subsurface network infrastructure of a mid-sized city forms a large model, and its high geometric resolution will have significant impact on the rendering performance. To ensure interactive rendering frame rates for city-scale visualization, *lightweight* geometric representations are necessary. Urban infrastructure is geometrically defined through a simple geo-referenced node-link diagram. Instead of rendering complex geometry of the subsurface infrastructure, we utilize the concept of procedural billboards, where the geometric detail is analytically computed during the rendering stage. Thanks to this approach, the overall geometric complexity of the subsurface network is represented by the essential topology, and the geometric detail is computed on-the-fly just in case it becomes potentially visible. Using this procedural billboarding (aka impostor rendering) for representing geometry, however, raises the research question on how to realize cutaway visualization on this type of data. Cutaway visualization applied to procedural billboards forms the second technical contribution of this paper.

Our prototypical visualization system has been tested and demonstrated on a city-scale sewer network infrastructure for the German city of Cologne (Fig. 2). The input data contained polygonal meshes in the .OBJ format to represent terrain, buildings, and vegetation. The sewer data was provided as a set of lines in the .SHP format (standard ESRI shape files). Additionally, water level information was attributed to each sewer pipe and sewer shaft. The use of our technique reduces the frame rate insignificantly, making the interactive visualization of the entire city scale possible on consumer graphics hardware. The visual encoding of the new cutaway techniques has been discussed with architectural visualization designers and with domain representatives who study subsurface sewer networks in the context of city flood management.

2. Related work

Seligmann and Feiner introduced the first algorithm for computer-generated cutaways [7]. Already in their work the cutaway geometry exhibited the characteristic zig-zag pattern, indicating the artificiality of the cut [8]. Diepstraten et al. [9] made an attempt to extract a set of rules from traditional cutaway techniques. These rules were further used to evaluate and compare methods of cutaway drawings. Although, according to the authors, the formalization of such rules was a hard task, five convincing rules for fully automatic cutaway drawings were provided. They are as follows: (1) *Inside and outside objects have to be distinguished from each other*, (2) *The cutout geometry is represented by the intersection of (a few) half spaces*, (3) *The cutout is located at or around the main axis of the outside object*, (4) *An optional jittering mechanism is useful to allow for rough cutouts*, and (5) *A possibility to make the wall (cut surface) visible is needed*. We make use of these rules to assess our approach. Another commonly used cutaway technique is the Stencil Test. Thereby convex exterior objects can be cut open. Our image-space technique uses the stencil test and stencil buffer to represent the cutout geometry.

In the importance-driven volume rendering technique presented by Viola et al. [10], the importance values are assigned to the data parts. An additional property encoding the visibility priority is then assigned to each voxel of the volumetric data set. In traditional volume rendering, a transfer function based on density is used to compose a final image. With additional information of importance and various composing schemes using this new dimension in the rendering pipeline, the technique of Viola et al. makes the object of interest clearly visible. In case a less important object occludes more important structures it is displayed more sparsely in the obscuring area. Bruckner and Gröller [11] present VolumeShop, an interactive system for the semi-automatic generation of illustrations. Their approach targets volumetric data and makes use of a dynamic combination of cutaway and ghosting techniques. Ropinski et al. [12] introduce interactive lenses that allow the user to define interesting regions of volumetric datasets. Different rendering techniques such as transparency or cutaways are then automatically applied to these regions. Bruckner et al. [13] propose to only suppress those regions of volumetric data that do not contain prominent features. To achieve this, the authors compute the opacity of each sample as a function of shading intensity, gradient magnitude, distance to the eye point, and the previously accumulated opacity. This approach preserves important context information such as shape cues. Krüger et al. [14] present a similar approach featuring interactive, continuous blending between different surface representations in a volume, resulting in an intuitive, depth-preserving highlighting.

Arguably, the most prominent application domain where cutaways and ghosting techniques have been demonstrated is medicine. Straka et al. used cutaways and ghosted views for blood vessel visualization [15] to provide a clear view on the vessel lumen while conveying contextual skeletal structures. Krüger et al. apply cutaways for the neck dissection planning, where lymph nodes are selectively shown using cutaways and ghosted views [16]. Another notable application is tumor surgery planning from abdominal organs, an anatomical area where many structures obstruct the view between pathological structures and the viewpoint [17]. Anatomical scans can be also used in the