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SEMANTICALLY CONTROLLED LMV TECHNIQUES FOR PLANT DESIGN REVIEW

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ABSTRACT

Inspecting large industrial plants in a virtual walkthrough environment has proven to be a valuable tool in Plant Design. Many CG techniques, such as various LOD and culling methods, have been developed to visualize complex models in VR environments. These techniques decide solely based on geometric properties how to optimize the scene. In this paper we introduce the concept of semantically controlled selection of those techniques and show how semantic considerations can enhance the CAD to VR conversion process for large model visualization (LMV) walkthroughs of Plant Design models, improving the performance and adapting the visualization to the users' needs. A taxonomy, together with semantic considerations coming from the relationship between user, model, and resources is the basis to decide which rules should be applied for a specific visualization technique. By extending a LMV walkthrough system we are able to reduce the complexity of large industrial plant models by a factor of two. On a common workplace PC the semantic preprocessing takes only 10-20 minutes for models with 10^6 to 10^7 polygons. Our approach is orthogonal to commonly known CG techniques and can be combined beneficially with those approaches.

Keywords: [Large Model Visualization, CAD/VR, Design Review, semantic conversion]

INTRODUCTION

An important part of the Plant Design process is the generation of the 3D CAD model. The model geometry is usually stored in CAD formats and is later used as a base for advanced visualization and interaction purposes, in particular in interactive walkthroughs for (i) design review of the model [GBS02], in order to find possible errors in early phases of the design, (ii) teamwork discussions about details and alternatives [ACW98, CBK04, HKC03], (iii) presentation for managers and customers, and (iv) dissemination to the general public.

Most of the CAD packages do not produce satisfactory interactive 3D walkthroughs for Plant Design, due to the complexity of the models and the limited resources available on common workplace computers. CAD to VR conversion, triangulation, data reduction, etc. has to take place to allow for interactive walkthroughs in complex scenes.

Several researchers ([BSG02],[ARB90]) have addressed the visualization of large CAD models in VR, mostly on specialized computers but sometimes even on PCs (see section 2.1 Large Model Visualization). A common characteristic in LMV is to work on the basis of the tessellated model by applying advanced CG techniques, e.g. advanced LOD and culling techniques, such as presented in GigaWalk [BSG02].

In this paper we introduce the new concept of semantics-based filtering during the CAD to VR conversion process to reduce the model size and to improve the adaptation of the visualization to the users' needs. The new idea of semantics-based filtering is orthogonal to commonly known CG techniques and can be combined beneficially with those approaches. In fact, our focus is not to implement sophisticated visualization but to control optimization techniques using semantic criteria.

Figure 1: VR view of a large chemical plant.

We present the framework and the extensions done to our LMV walkthrough system (MiroWalk) with several semantics based simplification techniques and show that it is possible to reduce the complexity of industrial plant models by a factor of two, while maintaining the quality expected by the viewer. We demonstrate that this way it is possible to interactively display these models in a VR environment with a preprocessing time of only 10-20 minutes for models with 10^6 to 10^7 polygons. To show the general nature of our work, we do testing following a 2-2-2 strategy: with two models, on two resources, for two types of user.

The remainder of this paper is organized as follows: The second section provides an overview of related work. The third section presents the relationship between LMV and semantics. Section 4 describes the semantic oriented techniques we implemented. In section 5, we present and discuss the results. Finally, in section 6 we formulate our conclusions and comment on future work.

2. Related Work

During the last years, a lot of progress has been made in real-time visualization of large engineering models. However, even with the increased performance of the newest graphic cards, the main problem remains that the amount of information exceeds the capacity of state-of-the-art hardware, and as history tells us will ever do so.

2.1 Large Model Visualization (LMV)

The acceleration of large model rendering was a very active field of research during the last years and a large number of approaches have been proposed. We are going to present a review of the most important techniques. More details can be found in [MANO00].

Levels-of-Detail methods render parts of the model that currently have a low impact on the visual appearance of the scene in a lowered quality. This is done by using a representation with fewer triangles or reduced textures. Level-of-Detail methods proved to be quite effective, especially if used with sophisticated methods of simplification ([HOP96],[GAH97]). However, visual discontinuity problems can appear while switching between different representations while the viewer is moving. Guthe and Klein [GUK04] recently presented a combination of quasi view-dependent hierarchical level of detail (HLOD) rendering with priority-based streaming that is capable of rendering highly complex models at real-time frame rates at high quality even with a low network bandwidth.

In a typical VR scene a large part of the model's geometry is not visible. *Occlusion Culling* organizes the model into locally coherent chunks and tries to detect as early as possible in the render pipeline if a given part of a scene is not visible [MOH99]. A software based implementation often leads to an organization overhead on the CPU side, and hardware solutions are just slowly appearing on the market [VAM02].

Another solution similar to general Occlusion Culling is the pre-computation of *Potential Visibility Sets* that determine which parts of a scene are potentially visible if the viewer is in a given room. Similarly effective but pre-computationally more intense are *Image-Based Rendering* methods. Here, common views on distance geometry are pre-rendered during a pre-processing step and are copied while viewing as *Impostors* into the scene using texture mapping [BSG02]. All these methods have in common that the decisions are based solely on geometric information and the fact that the preprocessing stage needs hours or days.

In his work about compression of Large Engineering Models, Shikhare [SBM01] describes an algorithm for automatic discovery of repeating geometric features. The collected information is then used for compressing the model by removing the redundancies on its representation. The number of elements that were found was largely dependent on the model. By using this technique, compression rates between 80% and 90% are reported in the literature. This work is similar to the techniques we later use for reconstructing a parts catalog.

In addition, several commercial applications like NavisWorks[NAV03] exist. The main strategy is to hide details and textures while the viewer moves, and render the complete version once the viewer stops its movement. This approach produces discontinuity artifacts of disappearing elements, since a lot of geometry is hidden in order to maintain the frame rates. Some systems like Mantra4D [MNT03] are improving their performance based on the latest developments in graphics hardware. Bentley Autoplant Explorer [BEN04] and Intergraph SmartPlant Review [INT02] make use of internal information of their own proprietary CAD software and access their Plant Information Management (PIM) system in order to produce a better real-time visualization.

2.2 Semantics and Ontology modeling in Engineering

An ontology can be shortly described as the "*specification of a conceptualization*" [BOR97]. In several fields of engineering there is a need to define and describe the terminology and the concepts used in groups or between groups of engineers. In particular, there exists an acute need to have a semantically meaningful specification of the concepts in engineering domains. This has been the main motivation behind the recent appearance of different engineering ontologies, used mainly to facilitate knowledge sharing and knowledge management [NMG01]. A simple but in many cases effective approach in this direction is the use of taxonomies. Taxonomies are already known in various areas since a long time; they constitute a simple example for an ontology that comprises only *part-of* and *type-of* relationships. Parts catalogs can be a key component of an engineering ontology. In fact, engineering companies have been using parts catalogs since a long time [SBM01].

Our approach is to construct a simple taxonomy of a few elements present in Plant Design that have a high influence on the visualization performance and quality for walkthroughs. This taxonomy, together with semantic considerations coming from the relationship between user, model, and resources is the basis to decide which rules should be applied for a specific visualization technique when adapting a large Industrial Plant CAD model to a virtual walkthrough environment.

3. Large Model Visualization and Semantics

We hypothesize that semantic considerations added to simplification techniques of the geometrical data present in walkthroughs increase the efficiency and complement the traditional methods presented in section 2.1. Our semantic approach starts with the concept of a semantic triangle (User-Resource-Model) shown on Figure 2.

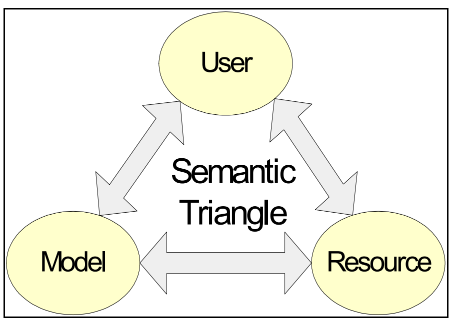

Figure 2: The Semantic Triangle.

We present a very simple structure for organizing our work with a few sample representative elements in Plant Design. Although this itself does not yet constitute an ontology, future improvements of the considered number of elements, the quality and nature of the links that join them, and the separation between the ontology (as structure representation) and the instances (as concrete objects) can be used to create a knowledge base model that extends the semantic approach of our work. In this stage, it constitutes a basic taxonomy of elements present in Plant Design. The following structure can only be considered a very simple ontology in the sense that it is a simple conceptualization of a small subset of elements expected to be found in most CAD models in the Plant Design domain. Measurements done on several Plant Design CAD models yield to the taxonomy shown on Figure 3.

4. Semantics-based LMV Techniques

In this section we introduce the implemented techniques which take into account the semantic relationship of the user profile, model characteristics, and resources described in the previous section.

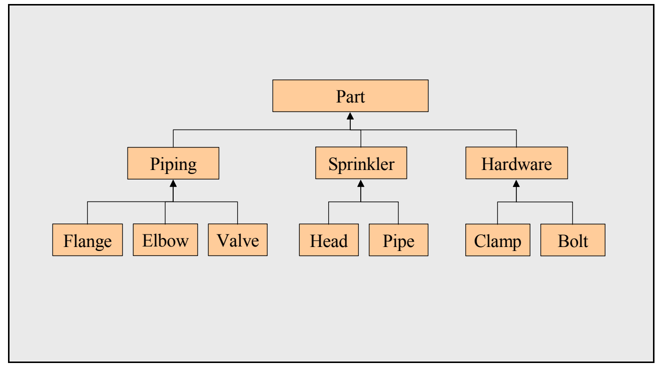

Figure 3: Part of a simple taxonomy structure used for our semantic approach.

4.1 Semiautomatic reconstruction of conceptual components/parts (Catalog Reconstruction)

The geometric objects in CAD models of Plant Design are produced mainly by specialized software that specifies how standard components/parts are located and defined in the actual model. However, the final CAD model itself does not keep this information in an explicit manner. Based on the *model characteristics*, we look for *conceptual parts/components* that occur in the application domain (in this case: Plant Design). A catalog is used to store the information about instances of elements in the model and to set up a relation between repeating elements and their possible matching concept in the ontology. An example of partial catalog can be seen on Figure 4. The catalog has to be semi-automatically filled using structural information of the CAD model and the knowledge of the user, who interacts in the process. We call this process *catalog-reconstruction.*

Figure 4: Classified parts within the reconstructed catalog.

4.2 Selective part simplification on a Per-Part Basis

Probably the most effective technique of the current implementation is the ability to define rules for applying different optimization techniques on a per-part basis. Using the information of the reconstructed catalog the export system has control over the export process on a much finer granularity; instead of applying simplifications techniques globally it can now be decided on a per-part basis which technique with which parameters to apply. The decisions are made considering information available through the semantic-triangle: information about the model, the user and its intention, and the resources. The logic for exploiting this decision is encoded in a *set of semantic rules*. Two schematic examples of rules are:

IF part = part.piping.valve.* AND user = engineer THEN REPLACE part WITH valve-symbol
IF part = part.piping.clamp.* AND user = manager THEN DROP part

4.3 Conceptual 3D Symbols

Once the catalog reconstruction is done, semantic information about parts of the model is recovered. In other words, the available implicit information has been made explicit. A technique that exploits this fact is the replacement of complex parts with conceptual 3D symbols that are much faster to render and nevertheless hold the semantic information associated by the user. The conceptual symbols are, so to speak, synonyms for parts.

Figure 5 shows a part of the class valve. The first four objects are valves rendered in their original form at different complexity levels. The rightmost object is the 3D symbol we used to replace the original valve. This symbol can be rendered with 100 triangles instead of 1000 triangles that were needed for the original representation. The high distribution of valves in our test models (Figure 6) leads to an accumulation of saved triangles.

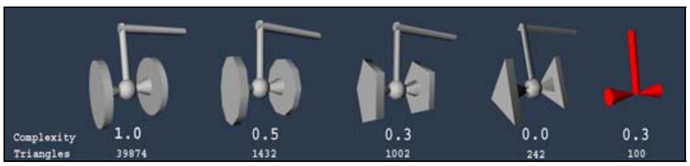

Figure 5: Valves at different complexities and a Valve-Symbol.

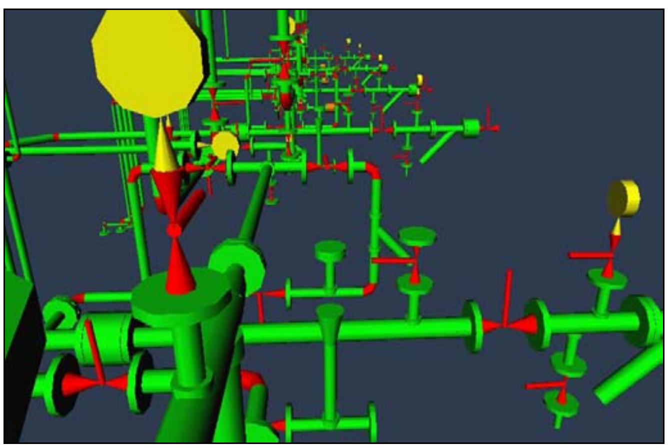

Figure 6: An outside view of the chemical plant. Valves are replaced with simpler to render 3D symbols. In this case the viewer has an engineering background and the semantic information associated by the user is maintained.

4.4 Selective Drop Culling

This technique hides selected objects that are of no or of low importance to the user (as defined in the rules and the ontology). Again, the rendering context is the key; only semantic information about the viewing user allows the system to decide if an element of a specific class is of importance for this view. In Figures 7 and 8 an example of the application of this technique is shown for the clamps that connect the pipes to the metal frames. These clamps are relatively complex to render but have a comparably small influence on the overall appearance of the model. Therefore, we implemented a semantic rule to drop all clamps for specific users, concretely for the user profile *manager*, who has a more esthetic perception of the model that is not affected by removing this detail. In contrast, for an e*ngineer* these elements may have importance and should not be removed.

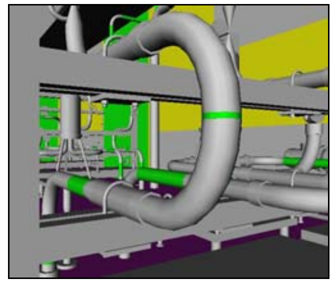

Figure 7: Rendered with clamps.

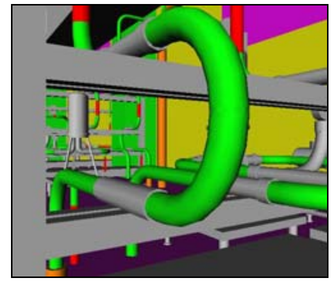

Figure 8: Rendered without clamps.

4.5 Custom Tessellation Complexity for complex surfaces

This technique allows to automatically set the tessellation complexity of complex surfaces. Again, the decision on the tessellation complexity for a specific part is based on the relevance of that part for a specific user and a specific context. Figures 9 and 10 show the technique applied to a pipe elbow.

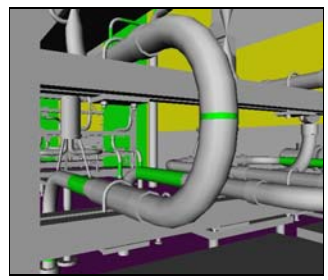

Figure 9: A smooth pipe elbow.

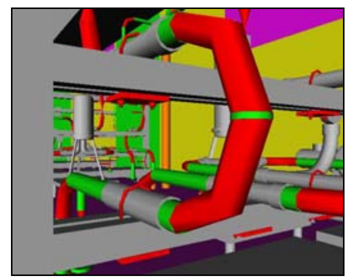

Figure 10: A coarse pipe elbow.

4.6 Custom LOD Levels

In the same fashion as we drop specific elements and set a custom tessellation complexity for specific elements, we define custom LOD levels for specific parts in the ontology. LOD levels can be set for each part class separately. It is possible to define multiple levels with several options for each level. For each level one of the following choices can be set – related to the user profiles and resources: (i) drop cull the element, (ii) display a bounding box, (iii) alter the tessellation complexity, (iv) display a symbol, (v) display without modification.

5. Results

As a proof of concept, we implemented the semantic methodology described in the previous sections for our existing system for Large Model Visualization of Plant Designs, called MiroWalk [HJR98]. The MiroWalk system is divided into three modules: a catalog reconstruction plug-in for Bentley's MicroStation, a conversion plug-in to export the CAD data to an Open Inventor format, and a viewing tool based on TGS Open Inventor.

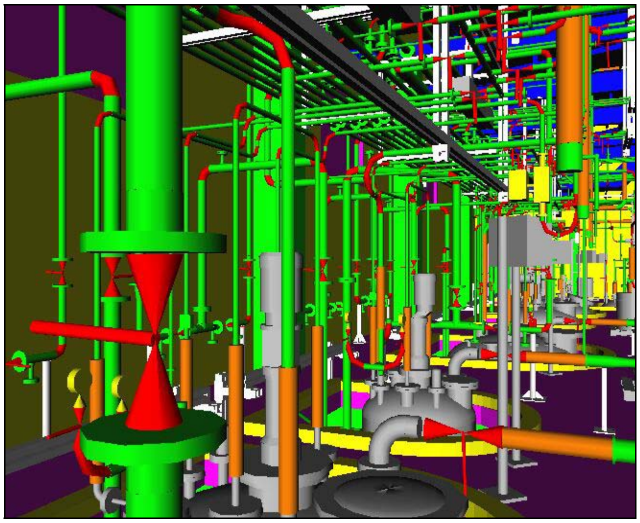

Figure 11: View inside the chemical plant. All valves are replaced with simple 3D symbols. This scene can be navigated interactively on the described workplace-class PC system.

5.1 The 2-2-2 strategy

To measure the effectiveness of the semantic concept, we did comparative statistics before and after our semantically controlled techniques were implemented. In detail, we measured:

- The performance in frames per second.
- The number of triangles.
- The final file size.
- The improvement in the categorization of elements.

We followed a 2-2-2 strategy for testing our work: with two models, for two users, on two resources. This is consistent with the semantic triangle described in section 3. As test models we used two complex CAD models from two different engineering domains: a large process plant already known from the previous work of [PLS02] and a large plant from the chemical industry[1] (Figure 6). As test users, we used two typical user profiles with different intentions and abilities – an engineer and a manager (chosen as an example for our role based representation) . The engineering profile affects the semantic techniques by forcing a detailed structural representation (all important structures and components should appear) but allowing a more schematic (conceptual) visual appearance of some elements. On the other hand, the manager has a more esthetic perception and the VR model can have a more loose structural representation (e.g. some structures such as small clamps can just be dropped) while the overall visual quality should be very realistic. As test resources, we used two computer-systems with different hardware configurations: an up-to-date workplace computer-system[2] with an advanced graphics card and a less powerful computer-system[3] with less main memory and an older graphics card.

5.2 Measurements

In Tables 1 and 2 the initial situation is presented. It shows the results obtained by MiroWalk doing a conversion with all optimization techniques turned off. User profiles were not considered during this phase.

	Triangles	Fps Computer 1[2]	Fps Computer 2[3]	File Size	Unstructured groups
Chemical Plant	3,45M	2.07	-	29.7 MB	13147
Process Plant	2,69M	2.75[4]	-	45.0 MB	9224
Chemical Plant (Subset)[5]	1M	-	1.13	-	-

Table 1: Size and performance of the initial models.

In order to see the effect of the implemented optimization techniques controlled by semantics, we applied during the conversion some of the techniques described in section 4, in particular the following:

- The semiautomatic reconstruction of some important conceptual components (catalog)
- The application of a concrete NURBS tessellation complexity on a per-part basis, based on the importance of objects for different user profiles.
- The use of simpler to render 3D symbols (semantic synonyms) that keep the full meaning expected by the user.

This subset of techniques is directly related to the small ontology introduced in section 3 and serves as a proof of concept of the impact of semantically steered techniques in our context. We have focused the measurements on these three techniques; the other methods are complementary and may lead to additional improvements. The Tables 2 and 3 show the improvement of performance comparing the initial situation and the results obtained with the addition of semantic criteria to control the techniques:

	Triangles	Fps Computer 1	Fps Computer 2	File Size	Unstructured groups
Chemical Plant					
Engineer	1.81M	4.10	-	17.4 MB	2428
Manager	1.97M	4.36	-	17.3 MB	2428
Process Plant					
Engineer	1.47M	4,95	-	34.0 MB	4879
Manager	1.52M	4.82	-	34.0 MB	4879
Chemical Plant (Subset)					
Engineer	0.58M	-	2.32	-	-
Manager	0.54M	-	2.52	-	-

Table 2: Improvement of performance after the semantic optimization.

[1] Names of producers kept confidential.

[2] Computer 1: Intel Pentium 4 CPU 2.4 GHz, 512MB RAM, NVIDIA GeForce 4 Ti 4200

[3] Computer 2: Intel Pentium 4 CPU 1.4 GHz, 256MB RAM, NVIDIA Riva TNT2

[4] Automatic measurement software crashed for unkown reasons, estimated fps.

[5] Neither of the two models could be visualued as a whole on PC2. We used a subset of the chemical plant for measurements on PC2.

	Reduction In Triangles To	Increase Fps Computer 1	Increase Fps Computer 2	Reduction File Size To	Reduction Unstructured groups To
Chemical Plant					
Engineer	52.4%	198.0%	-	58.6 %	18.5 %
Manager	57.1%	210.6%	-	58.2 %	18.5 %
Process Plant					
Engineer	54.6%	180.0%	-	75.5 %	52.9 %
Manager	56.5%	175.2%	-	75.5%	52.9%
Chemical Plant (Subset)					
Engineer	58.0%	-	205.3%	-	-
Manager	54.0%	-	223.0%	-	-

Table 3: Percentage improvement rates.

In Table 4, the results for the structuring and internal classification of the objects into concepts of the ontology are presented, an important basis for the improvement in performance.

	Chemical Plant		Process Plant	
Initial Unstructured Groups	13147	100%	9224	100%
Valves	867	7%	157	2%
Elbows	2064	16%	1248	14%
Flanges	3663	28%	0	0%
Pipe Section	3509	27%	31	0%
T-Adaptors	425	3%	878	10%
Sprinkler Heads	0	0%	1982	21%
Clamps	191	1%	0	0%
Groups that were not identified	2428	18%	4879	53%

Table 4: Classified groups in both models.

5.3 Analysis of the Results

The tables show the influence of the semantically steered techniques on the performance of the walkthroughs. We remind that instead of comparing the performance of our system to other systems, we focus on showing the potential increase of performance of most traditional LMV systems by introducing similar techniques as the ones presented here.

With respect to the influence of the user profile, we see that the overall performance increases for both profiles (engineer/manager) in all the measured aspects. The number of triangles is reduced for both models to about 50% - 60%. The frames per second are in both cases reduced close to twice the original fps, as it could be expected, even considering the small overhead in the structuring. On the other hand, the file size (an important factor for storage and collaborative work) decreased to about 50% in the chemical plant, and to 75% in the process plant. The reduction is due to the non-redundant storage of structured groups.

Finally, the Table 4 shows how the majority of unstructured groups of geometric primitives in both models could be tackled in a high proportion with the use of the simple ontology described in section 3. In the chemical plant, 81.5% of all the unidentified groups could be classified (and therefore, adapted to the semantically steered techniques), whereas in the process plant, 52.9 % of the groups were identified. The difference is due to the fact that the chemical plant is composed of many parts/components that are part of the ontology, while the process plant has several elements that are not yet included.

In comparison to the previous version of MiroWalk, the conversion times increased from about 1-2 minutes to about 10-15 minutes. However, export times of around ten minutes are still acceptable for near real-time conversion and are especially low compared to preprocessing times of other visualization systems that reach several hours or days [BSG02] .

Based on the above results, we can say that the identification of a small subset of concepts related to physical components often used in Plant Design, and the use of techniques that take advantage of the explicit definition of rules for user profiles, available resources and model types, can bring important improvements in the performance of walkthroughs for Plant Design. This is specially applicable to common workplace PCs and near-real-time conversion times.

In general, our work significantly improves the performance of interactive walkthroughs in our example models. We can now visualize both models at interactive frame rates (4-5 fps) showing an adequate visual quality (Figure 7&8).

6. Conclusions and Future Work

In this work we showed that considering semantics and user knowledge can substantially improve LMV of engineering models in visual quality and performance. Whereas previous work focus on developing new graphics-based optimization techniques, we introduced semantics into LMV by applying semantic criteria to traditional optimization techniques. Our results show that this new approach leads to an improvement in quality and performance of most current techniques in LMV.

Currently, an effort is being made in adapting other existing LMV techniques to our semantic approach. In addition, we plan to develop a full-grown ontology for use in the Plant Design domain. Moreover some traditional techniques like detail hiding while the user is moving can be semantically optimized.

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