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Multi-user predictive rendering on remote multi-GPU clusters

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\begin{abstract}
Many stages of the industry workflow have been benefiting from CAD software applications and real-time computer graphics for decades allowing manufacturers to perform team project reviews and assessments while decreasing the need for expensive physical mockups. However, when it comes to the perceived quality of the final product, more sophisticated physically based engines are often preferred though involving huge computation times. In this context, our work aims at reducing this gap by providing a predictive rendering solution leveraging the computing resources offered by modern multi-GPU supercomputers. To that end, we propose a simple static load balancing approach leveraging the stochastic nature of Monte Carlo rendering. Our solution efficiently exploits the available computing resources and addresses the industry collaboration needs by providing a real-time multi-user web access to the virtual mockup.

\textbf{Index Terms:} Human-centered computing—Collaborative interaction; Computer Graphics—Distributed/Network graphics; Computer Graphics—Raytracing, Predictive Rendering
\end{abstract}

1 \textbf{INTRODUCTION}

During the last two decades, virtual reality has become a promising technology widely embraced by the industry. In the automotive industry workflow, many stages including the vehicle design process, virtual prototyping and manufacturing are already benefiting from virtual reality thus resulting in a shorter time-to-market and a higher product quality \cite{1,15}. At the same time, the increasing need of mobility and synergy all along the industry pipeline has led to research efforts targeting delocalized collaboration \cite{5} thus opening the way to new perspectives such as networked virtual reality. However, real-time visualization tools including CAD software applications and virtual reality are still facing many challenges when the key concerns are focused on the aesthetic of the final product. Despite recent technological advances, real-time rendering can only be obtained at the price of numerous approximations on \textit{i}) the underlying lighting and material models and \textit{ii}) on the algorithms used to compute light-matter interactions. In practice, such visualization tools can only be used for illustrative purposes and thus, more sophisticated physically based solutions belonging to the predictive rendering field must be used when it comes to the perceived quality of the product. In contrast to the usual rendering methods, predictive rendering attempts to accurately resolve the light transport, allowing one to predict how a virtual scene would look like under the conditions defined by the virtual model \cite{14}. To achieve this expected level of accuracy, predictive-oriented approaches make an exclusive use of spectrally defined materials and light inputs to prevent well-known surface metamerism exhibited by traditional RGB/XYZ-based renderers. However, physically accurate results can only be guaranteed if the spectral and polarized natures of light are both carefully accounted for through unbiased rendering algorithms such as Monte Carlo \textit{path tracing}. As one can expect, such a simulation requires tremendous computational resources preventing any real-time use even with cutting-edge hardware, especially when targeting high definition resolutions. As a consequence, expensive physical mockups are still preferred by decision makers when assessing the perceived quality of the vehicle.

\textbf{Contribution} We propose to fill the gap between the illustrative real-time environments enabling user collaboration such as virtual reality and the computationally expensive simulations such as predictive rendering, with a predictive rendering environment taking full advantage of modern clusters to drastically reduce the rendering time. Our work mainly targets multi-GPU supercomputers frequently found in high-end industries. Additionally, the system enforces remote collaboration all along the industry pipeline by providing a remote web access enabling real-time multi-user interactions with the virtual mockup in a synchronized fashion.

This paper is structured as follows: First, a review of previous work related to remote collaborative high performance graphics is given in section 2, along with the previous work related to distributed rendering. Then, section 3 describes each logical component involved in our solution as well as their relationship. The experimental settings, the results as well as the system limitations are detailed in section 4. We conclude our paper and highlight the future research directions in section 5.

2 \textbf{RELATED WORK}

\textbf{Remote collaborative high-performance graphics} Many research efforts addressing delocalized collaboration have been carried out. Among the previous work addressing both remote collaboration and remote high-performance graphics, Renambot et al. proposed SAGE \cite{10} as a scalable framework enabling collaborative visualization, mainly focused on local collaboration through tiled display systems. The framework supports distributed rendering on remote clusters and high resolution streaming to a variable number of displays. Although remote shared visualization has been partially addressed through the Visualcasting extension \cite{8} by Jeong, important issues such as multi-user interactions at the application level were not addressed. Repplinger et al. proposed DRONE \cite{11} as a flexible framework enabling distributed physically based rendering and supporting various deployment scenarios including remote multi-user visualization and interactions. However, as the project has become outdated, the implementation does not benefit from recent advances including modern cluster interconnections such as InfiniBand and new internet standards such as HTML5 and WebRTC opening the way to ubiquitous cross-platform solutions. Commercial and free systems addressing remote visualization such as NICE DCV and VNC are also available. While these solutions
can take advantage of high-performance environments, their support for collaborative scenarios remains poorly limited in terms of mutual feeling of presence and multi-user management as all users share an unique mouse cursor and any user can preempt the remote control anytime irrespectively of the ongoing interaction flow. Other remote visualization solutions such as OTOY, OnLive and PolyStream achieve low latency streaming but do not target collaboration.

**Distributed rendering** As the computational load may significantly vary between different image areas, one must pay a special attention to the load balancing strategy when designing a distributed rendering system. Otherwise, load imbalances can easily occur and hence penalize the system scalability. The load balancing strategies can globally be classified into three categories [12]. Static load balancers evenly divide the image space and assign each image area to a distinct compute unit. With static balancing, the assignment layout remains the same during the entire simulation. Common approaches consist in dividing the image space into homogeneous tiles or non-contiguous pixel sets spread over the image. Such strategies can be easily implemented but usually result in load imbalances in case of homogeneous tiles [6] and in poor local performances in case of non-contiguous pixel sets [13]. Semi-static load balancers split the image space into nonuniform tiles in order to balance their rendering costs [2, 12]. The layout is updated whenever a frame based on a high-definition timing map reporting the rendering time of tiny contiguous pixel sets. Unfortunately, the required high-definition timing is not suitable for GPU rendering as the operations are simultaneously performed on wide pixel batches. Dynamic load balancers follow a producer-consumers pattern [7, 13]. The image space is divided into a set of equal size tiles much larger than the compute unit count. When rendering a new frame, each compute unit is assigned one or several tiles from the pool and request new tiles to render as it becomes idle. This process repeats until the whole frame is rendered. While these approaches result in evenly balanced workloads, the central task pool can become a bottleneck as all nodes request new tasks simultaneously hence penalizing the system scalability. As an alternative, we propose an efficient static balancing scheme taking advantage of the stochastic nature of Monte Carlo rendering.

### 3 System description

As depicted in Figure 1, the whole rendering solution is hosted on the remote cluster and each cluster node is assigned a unique role among the three component classes described below. At the core of the system, the rendering process is carried out by the compute nodes. In this purpose, each compute node runs an instance of the predictive rendering engine. The renderer consists of a spectral path tracer running on the GPU. The server acts as a facade in charge of the compute nodes coordination. This component hides the underlying distributed rendering logic by exposing only a few set of functionalities to the client application which therefore remains entirely agnostic of the actual deployment setup. The server acts as a gateway between the client and the compute nodes. Scene update commands issued by the client such as camera moves are broadcasted to all the compute nodes which in turn update the concerned scene entities on the GPU. The server is also responsible for the image assemblies and post-processing before their delivery to the client application. It is important to note that in a predictive context, the rendering of a single frame may require many seconds to minutes to obtain noise-free images, even within a high-performance environment. Thus, our system follows a *progressive rendering* approach to provide the user with the current simulation progress. The client is a traditional GUI application built around a central event loop. In contrast to standalone applications, the displayed image is here requested to the server at each display refresh and any interaction with the virtual scene such as camera motions and material picking trig-

![Figure 1: Overview of the solution](image-url)
within a synchronized multi-user environment. In this environment, which is ultimately delivered and displayed on the client application (see Figure 4). The captured stream is therefore augmented with action (mouse click and/or keyboard use) as long as the system is not a user can seamlessly take the control anytime he does a specific streaming through WebRTC Data channels and processed in real-time by leveraging NVIDIA NVENC encoding. To that end, USE Together takes advantage of H.264 low latency encoding capabilities of mod-ern graphics hardware enabling remote users collaboration through the web. With this infrastructure, delocalized co-worker can remotely share a na-"
work on centralized data from any device running a web browser. This work was supported by the ROMEO Computing Center and the authors also thank OPEXMedia for their support on USE Together. The Image Center of the University of Reims Champagne-Ardenne. The shared model seems to be a promising research direction [3].

To allow the remote users to work on different views of the same model, we can easily access the computational resources of the system and multiple user input management. As a result, organization members can collaboratively leverage the computing resources of modern clusters for supporting the WebRTC protocol. We are now looking forward to extend the system to cover other useful collaboration use cases. As an example, leveraging the computing resources of modern clusters to allow the remote users to work on different views of the same shared model seems to be a promising research direction [3].

Limitations The system requires the replication of the whole scene into the GPU memory of each node which can reveal critical when dealing with large scene models. Therefore, it would be desirable to investigate on out-of-core scene management techniques to handle such cases.

5 Conclusion and future work
In this paper, we have proposed a collaborative predictive rendering environment taking full advantage of the computational power offered by modern multi-GPU clusters. To make an efficient use of the remote computational resources, we have proposed a static load balancing method leveraging the stochastic nature of Monte Carlo rendering by distributing the light path sampling process. By combining this approach to a usual image-space partitioning scheme, a good scalability can be achieved with a simple static load balancing scheme which cannot be obtained with traditional static schemes. The proposed architecture not only efficiently exploits the computational resources, but also promotes co-worker mobility and collaboration by providing a remote web access allowing real-time multi-user interactions with the virtual mockup. In comparison to the usual remote visualization tools, the system emphasizes collaboration with an enhanced feeling of presence and a transparent multiple user input management. As a result, organization members can easily access the computational resources of the system and work on centralized data from any device running a web browser supporting the WebRTC standard. We are now looking forward to extend the system to cover other useful collaboration use cases. As an example, leveraging the computing resources of modern clusters to allow the remote users to work on different views of the same shared model seems to be a promising research direction [3].

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