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ANALYSIS OF THE INFLUENCE OF WEIGHTING COEFFICIENTS IN A SIGNIFICANCE METRIC FOR 3D SCENE OBJECTS IN PRELIMINARY RENDERING OPTIMIZATION SETUP

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Abstract. This paper presents an experimental analysis of the behavior of a significance metric for 3D scene objects used for preliminary rendering optimization setup in the Unity environment. The influence of three object characteristics is considered, from which the final significance metric is formed: geometric complexity (polygon count), spatial size, and the object's potential as an occluder, calculated based on visibility analysis performed using ray casting. Combining these features with adjustable weights makes it possible to obtain a unified estimate of the potential importance of an object and its impact on rendering during the configuration of optimization approaches. The results show that geometric complexity provides strong separation of objects into groups, assigning 22.6% of the objects in the experimental scene to the high-significance category. The balanced configuration and the dominance of other coefficients individually demonstrate lower differentiation, yet accurately identify the most complex objects intentionally placed in the scene, while classifying over 70% of the remaining models as low-significance. Regardless of the chosen configuration, the method correctly identifies candidates clearly suitable for further optimization.

Keywords: computer graphics, 3D scene analysis, visibility analysis, rendering optimization, Unity engine

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АНАЛИЗ ВЛИЯНИЯ КОЭФФИЦИЕНТОВ МЕТРИКИ ЗНАЧИМОСТИ ОБЪЕКТОВ 3D-СЦЕНЫ ДЛЯ ПРЕДВАРИТЕЛЬНОЙ НАСТРОЙКИ ОПТИМИЗАЦИИ РЕНДЕРИНГА

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Аннотация. В работе проведен анализ поведения метрики значимости объектов трехмерной сцены и влияния на нее коэффициентов в рамках метода для предварительной настройки оптимизации рендеринга в среде Unity. Рассматривается влияние трех характеристик объекта, из которых формируется итоговая метрика значимости: геометрическая сложность (количество полигонов), пространственный размер и потенциал объекта в качестве окклюдера, вычисляемый на основе анализа видимости, выполняемого с помощью запуска лучей. Объединение этих признаков с настраиваемыми весами позволяет получить единую оценку потенциальной важности объекта и его влияния на рендеринг при настройке оптимизационных подходов. Результаты показывают, что геометрическая сложность обеспечивает сильное разделение объектов по группам, относя 22,6% объектов на экспериментальной сцене к группе высокой значимости. Сбалансированный запуск и доминирование других коэффициентов по отдельности демонстрируют меньшую дифференциацию, но точное определение заранее встроенных в сцену самых комплексных объектов, при этом относя более 70% остальных моделей к малозначащим. Независимо от выбранной конфигурации, метод корректно выявляет кандидатов, явно подходящих для дальнейшей оптимизации.

Ключевые слова: компьютерная графика, анализ 3D-сцен, анализ видимости, оптимизация рендеринга, движок Unity

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Introduction

Nowadays, modern 3D interactive applications are developed using 3D engines such as Unity and Unreal Engine. Despite their popularity in the gaming industry, these engines are also widely used in projects related to education, industrial simulations, and the creation of digital twins [1–5]. As technology evolves, the complexity of such projects continues to grow. 3D scenes require more computations and contain increasingly detailed objects, while still demanding smooth performance and fast user feedback [6–7].

To meet these requirements, developers employ various optimization techniques. A large number of optimization tools are already integrated into modern 3D engines, but they require proper configuration to be effectively applied. The need to maintain a balance between visual quality and performance makes research on the application of optimization techniques in 3D engines both relevant and essential [8].

Among the most commonly used in-engine optimization approaches are Level of Detail (LOD) and occlusion culling systems. LOD techniques adjust the geometric complexity of objects based on

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their distance from the camera. Each object contains multiple levels of detail that are switched according to predefined thresholds. Occlusion culling, on the other hand, reduces the rendering workload by excluding objects that are not visible to the camera due to occlusion by other objects (occluders), or simply because they are outside the field of view [9–12].

All things considered, both of these approaches, in their integrated implementations, require configuration. Such configurations heavily rely on manual decisions made by developers. To achieve efficient use of these tools, developers must determine which objects are important, which can be simplified, and which can serve as occluders for surrounding objects. In large and complex 3D scenes containing objects of varying quality, these decisions are often based on heuristic assumptions. One way to simplify this process and increase its efficiency is to introduce a formalized evaluation framework that helps analyze which objects require optimization techniques.

Existing research primarily focuses on improving real-time rendering optimization algorithms [13–15] or visibility techniques [16–17], while less attention is given to the analysis of objects targeted for optimization during the scene configuration stage. In particular, the combined effect of geometric, spatial, and visibility-related features on object importance remains insufficiently studied.

Related studies also show that the problem of identifying visually or functionally important elements of a 3D scene has already been addressed from different perspectives, including mesh saliency [18–22], viewpoint entropy [23], learning-based view selection [24], and perceptual rendering [25]. These works confirm that scene content can be differentiated by importance, visibility relevance, or perceptual contribution. However, such approaches are mainly focused on perception, view planning, or runtime rendering behavior rather than on the preliminary configuration of built-in optimization tools in 3D engines. In this context, the formalized evaluation of scene objects for editor-based optimization support remains insufficiently explored.

To address this gap, this work considers an object significance metric as a key factor in scene analysis. This unified metric is used to evaluate objects based on their features, such as geometric complexity, spatial size, and occlusion potential calculated through ray-based analysis.

This research investigates the behavior of these calculated metrics under different parameter configurations. The main objective is to analyze how different values of feature weights affect the analysis results and optimization-related decisions, such as object classification and occluder selection.

The key contributions of this paper are as follows:

- analysis of the influence of object properties on significance-based evaluation;
- experimental study of object classification and occluder selection under different coefficient settings.

The proposed approach is implemented and evaluated within the Unity engine using experimental 3D scenes containing different amounts of primitive and low-poly objects. The experimental results provide insights into the behavior of significance-based scene analysis and demonstrate the role of weighting coefficients in this approach.

Proposed approach

The developed method is based on the preliminary analysis of 3D scene objects through the formation of a unified significance metric. The objective is to provide a formalized representation of each object's importance, which can be used for subsequent automated or manual optimization decisions, such as level of detail assignment and occluder selection.

The proposed approach operates on a set of object data collected from a 3D scene and evaluates each object independently by analyzing its predefined properties. These properties reflect how an object contributes to rendering performance and the visual perception of space in a 3D scene. While the contribution of many object properties deserves further investigation, this study primarily considers three features.

1. Geometric complexity

Geometric complexity is defined as the number of polygons (triangles) that constitute the analyzed object. This value reflects the computational cost of rendering the object and is commonly used in LOD systems, since one of the most straightforward ways to reduce rendering cost is to decrease the number of processed polygons.

2. Spatial size

Spatial size represents the physical extent of an object within the scene. It is computed based on the dimensions of the object's bounding volume. By considering spatial size, it becomes possible to evaluate how much space an object occupies. Larger objects are more likely to influence visibility and, therefore, may act as occluders that block other objects. However, spatial size alone does not capture the full scene context. For instance, a large object located at the boundary of the scene may not function as an occluder, but rather as a candidate for LOD configuration.

3. Occlusion potential

Occlusion potential is calculated using a ray-based analysis. A set of rays is generated from a predefined number of source points around the analyzed object. Intersections with other objects, excluding the target itself, are recorded. If the number of intersections exceeds a specified threshold, the object can be marked as an occluder (for example, by assigning the "Occluder Static" flag in the Unity engine). Occlusion potential reflects the likelihood of an object blocking visibility by analyzing its surrounding environment, providing an approximation of its contribution to occlusion culling.

To combine the considered object characteristics into a unified value, a significance metric is introduced:

$$V(o) = k1 \cdot C(o) + k2 \cdot S(o) + k3 \cdot H(o),$$

where $V(o)$ is the significance value of object o; $C(o)$ is the normalized geometric complexity of object (number of triangles); $S(o)$ is the normalized spatial size (object's bounding box volume); $H(o)$ is the normalized occlusion potential estimated by using ray-based analysis; $k1$, $k2$, and $k3$ are weighting coefficients that define the contribution of each feature and satisfy the condition $k1 + k2 + k3 = 1$.

Prior to aggregation, all object feature values are normalized to the range [0, 1] using min-max normalization. This ensures comparability and interpretability between values of different scales.

An additive aggregation was chosen instead of multiplicative model in order to maintain balance between features, avoiding possible suppression effect caused by low-valued components. Using an additive model also simplifies sensitivity analysis, since it was important to see how different coefficient setups influence resulting metric. The application of multiplicative models is considered as a potential direction for future work.

The significance metric produces a scalar value representing the overall importance of an object within the scene. The weighting coefficients can be adjusted to emphasize different aspects of object importance, such as rendering cost (geometric complexity), spatial size, or occlusion capability.

The choice of a linear additive model for significance metric is also motivated by several practical considerations derived from 3D application development. First, linear aggregation ensures computational transparency during scene preprocessing, allowing easy and fast result interpretation. Second, the additive form provides direct traceability: the influence of each coefficient can be immediately understood and tuned. Third, the metric is supposed to be used in context of scene preprocessing, where rapid iteration and predictable behavior are in priority. It is also important that chosen model does not require high computational costs and is easy to integrate in project analysis pipeline. The model may get more complex based on discovered coefficient influence and other further research.

By incorporating the computed significance value into 3D scene analysis, more informed decisions can be made during the configuration of optimization methods. First, the metric can be applied

to occluder selection. A high significance value may indicate both strong occlusion potential and substantial spatial presence, making such objects more likely to block visibility and serve as effective occluders.

To conduct controlled experimental studies of the metric behavior, several configurable parameters are defined prior to analysis. These include the number of rays and their sources, threshold values for occluder detection and classification, as well as the weighting coefficients.

In the context of this study the selection of weighting coefficients is performed empirically to define representative configurations for analysis. Flexible coefficient tuning is supported, allowing adaptation to different 3D scene properties and optimization goals. Several configurations are considered, including balanced weighting and setups based on individual dominance of each feature. The choice of coefficients may depend on the type of the analyzed scene. For example, geometry-dominant analysis can be beneficial for scenes containing big amount of highly detailed objects. These experimental configurations are designed to investigate this idea. The derivation of optimal coefficient values for specific scene types is a prospect for future research.

The proposed framework serves as a basis for analyzing the influence of different weighting coefficient combinations on optimization decisions, which is further explored in the experimental section.

Research methods

The purpose of the research is to investigate the influence of characteristic weighting on the behavior of the proposed significance metric and its impact on optimization configuration decisions in 3D scenes. Following research methods were employed:

1. Controlled experiment. Four fixed configurations of coefficients were defined and tested on the same 3D scene to check the effect of each configuration in the same context.

2. Comparative analysis. The analysis finishes with object classification across three significance groups (low, medium and high). The results of these classifications were compared for each configuration.

3. Mean significance metric value was calculated for each configuration to check overall tendency of metric.

4. Five large-scale objects were intentionally placed in the scene to verify that any configuration will constantly identify evidently important objects.

Experimental setup

The experiments were conducted using a pre-built 3D scene created in the Unity engine editor. The test scene consists of a large number of static simple building models (up to 1000), representing an urban-like environment with varying object scales and high density. Most of the objects are not unique, as they are instances of seven base building models. These base objects differ in spatial size and geometric complexity. Such a configuration ensures diverse object combinations within the scene, making the task of identifying significant objects more challenging. Among all objects, five of them have increased size to imitate evident occluders. In addition, they differentiate in color. Fig. 1 shows model examples, while Fig. 2 demonstrates scene setup from the top-down view in Editor Mode.

Since the main goal of the study is to investigate the role of weighting coefficients in the computation of the significance metric, the parameters related to occlusion potential analysis (number of rays, number of ray sources, and occluder threshold) were predefined and kept constant throughout all experiments. Four experimental cases were defined, each corresponding to a different configuration of weighting coefficients.

The specific values of the weighting coefficients used in the experiments are defined as follows:

1. Balanced configuration: $k1 = 0.33$, $k2 = 0.33$, $k3 = 0.33$;
2. Geometry-dominant configuration: $k1 = 0.6$, $k2 = 0.2$, $k3 = 0.2$;

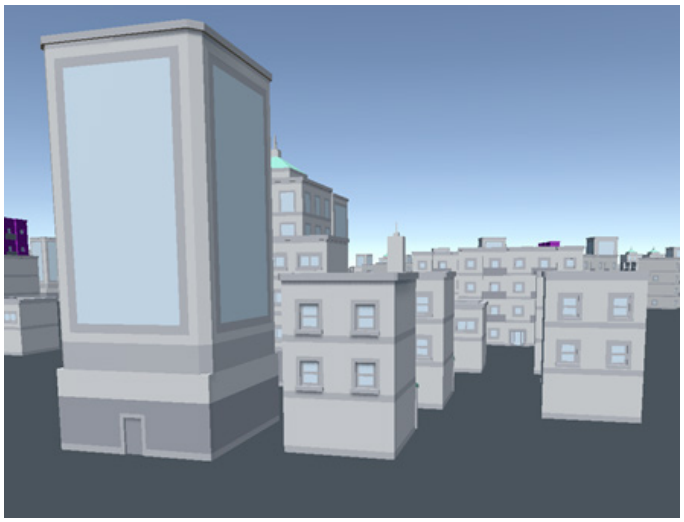


Fig. 1. Object examples

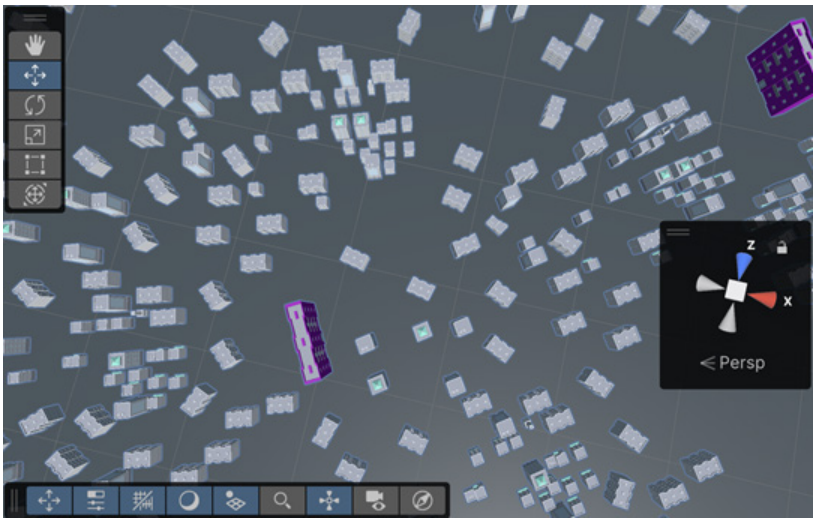


Fig. 2. Scene top-down view

3. Occlusion-dominant configuration: $k1 = 0.2$, $k2 = 0.2$, $k3 = 0.6$;
4. Size-dominant configuration: $k1 = 0.2$, $k2 = 0.6$, $k3 = 0.2$.

These configurations were selected to explicitly analyze the influence of each feature on the resulting significance metric. The first experiment is based on a balanced configuration, where all coefficients have equal importance. The second experiment uses a geometry-dominant configuration. By increasing the importance of geometric complexity, the analysis prioritizes objects with a high polygon count and, consequently, higher rendering cost. The third experiment focuses on occlusion potential, where the main objective is to analyze differences in occluder selection across the three configurations. Fourth experiment uses spatial size of the object.

The evaluation of the experiments is based on the distribution of objects across significance ranges and the number of selected occluders. Three significance levels are introduced based on the value of $V(o)$: low (≤ 0.33), medium ($0.33 < V(o) \leq 0.66$) and high (> 0.66). These thresholds correspond to an equal partitioning of the normalized value range. A simple partitioning based on three groups ensures

consistent comparison between different configurations and keeps analysis results easily interpretable. The results are compared to determine how different weighting schemes influence optimization decisions.

The experiments were performed within the Unity editor environment, inside a project containing the implementation of the proposed approach along with the required 3D assets. The analysis tool is implemented as a custom editor extension, enabling automated processing of the scene. The analysis is performed outside of runtime, as its purpose is to support configuration and optimization rather than real-time execution.

Results and discussion

The results of the experimental study are presented in Tables 1 and 2.

Table 1

Distribution of objects by classification levels

Configuration	Coefficient values	Low significance group	Medium significance group	High significance group
Balanced	$k1 = 0.33$, $k2 = 0.33$, $k3 = 0.33$	701	294	5
Geometry	$k1 = 0.6$, $k2 = 0.2$, $k3 = 0.2$	496	278	226
Occlusion	$k1 = 0.2$, $k2 = 0.2$, $k3 = 0.6$	700	295	5
Spatial size	$k1 = 0.2$, $k2 = 0.6$, $k3 = 0.2$	986	9	5

Table 1 shows the distribution of objects across significance-based classification levels for different weighting configurations of the metric. The classification is derived from normalized values of the significance metric $V(o)$, which combines geometric complexity, spatial size, and occlusion potential.

It is also important to state again that experimental scene contained five intentionally placed large-scale building models which were adjusted manually to serve as primary occluders. Across all experiment configurations these five objects consistently received the highest significance scores. These objects were always correctly classified as high significance objects, while also marked as occluders by occlusion analysis. Shown invariance to coefficient differences demonstrates that the analysis exhibits robustness in identifying most evident and important objects for optimization, regardless of the emphasis placed on different coefficients.

In the balanced configuration, where all features contribute equally, only five objects are assigned to the high-significance group, which are evident occluders. Most of the models are classified as low-significance objects. Considering the context of experimental scene, this result demonstrates that in case of non-existing domination among the coefficients, only the high-profile objects are treated as significant ones.

When geometric complexity is prioritized, the distribution shifts toward a higher number of significant objects. The share of high-significance objects increases, while the number of low-significance ones decreases compared to other configurations. This indicates that geometric complexity provides a clearer distinction between objects, as it introduces a stronger contrast between simple and complex models.

In contrast, the occlusion-dominant configuration results in a noticeably skewed distribution, similar to balanced configuration, where most objects fall into the low-significance group. This suggests that occlusion potential alone does not provide sufficient differentiation in dense scenes, as many objects demonstrate similar visibility behavior under ray-based analysis.

The most pronounced effect is observed in the size-dominant configuration. In this case, almost all objects are classified as low significance, with only a small number identified as highly significant. It should be noted that several large-scale objects were intentionally included in the scene as reference structures. These objects are correctly classified as highly significant, while the remaining objects form a nearly homogeneous group. This behavior indicates that spatial size alone is not sufficient for reliable object importance evaluation in complex environments.

Table 2 presents the average value of the significance metric for each experimental configuration. The mean value is computed by averaging the significance metric values for each previously analyzed object in the scene. The results reflect the tendency of the metric on current scene. Higher values indicate a shift towards higher significance among the objects, while lower values show that most of the scene consists of less significant 3D models.

The geometry-dominant configuration produces the highest mean value, reflecting a stronger differentiation between objects. The balanced configuration demonstrates moderate values, while the occlusion- and size-dominant configurations result in lower averages, indicating weaker separation between objects.

Table 2

Average values of the significance indicator for each experimental configuration

Configuration	Mean $V(o)$
Balanced	0.23
Geometry	0.31
Occlusion	0.23
Spatial size	0.18

Overall, the results demonstrate that the weighting coefficients of the significance metric influence object classification. Among the considered features, geometric complexity provides the most effective basis for differentiation, while spatial size and occlusion potential, when used independently, show limited capability in distinguishing object importance in dense scenes.

While direct comparison with existing methods is hard to perform due to different evaluation metrics and goals, Table 3 provides a qualitative comparison of the proposed approach with existing techniques mentioned in introduction as related work.

Additionally, in the context of comparing approach discussed in this work with other approaches, it is important to note that recent advances in machine learning, including LLM and vision-based AI systems, provide powerful tools for semantic scene understanding, object importance estimation and image analysis. Those approaches can address similar problems by learning perceptual or significance directly from provided data.

However, the proposed method differs in scope and application context. First, it is meant to be used in the preprocessing stage within 3D engine workflow, where low computational overhead and controllability are very important. Calculation of metric does not require additional training data or any integration outside of engine tools. Second, the proposed approach provides easy interpretability, since each feature can be directly controlled through weighting coefficients. It allows developers to manage and modify analysis process based on their optimization goals and current 3D scene, which can be difficult to achieve with black-box models.

Table 3

Qualitative comparison of the proposed approach with existing methods

Criterion	Mesh saliency [18]	Viewpoint selection [24]	Object-space VSD [16]	Proposed approach
Intended use	Perceptual saliency for mesh simplification and compression	View set selection for synthetic training data generation	Global visible surface determination (object space)	Preliminary in-engine optimization configuration (occluder selection)
Output type	Saliency score per vertex or per face	Set of camera poses	Binary classification (visible/invisible per triangle)	Unified significance metric per object
Requires 3D engine	No	No	No	Yes
Requires training data	Yes (RPCA-generated ground truth)	Yes (NYUDv2)	No	No
Operates on	Individual faces (patch-based)	Rendered images	Individual triangles (per ray)	Whole 3D object
Can affect scene/ objects	No	No	No	Yes (can mark potential occluders in Unity engine)

Conclusion

This paper presents an experimental study of a significance-based approach to object evaluation in 3D scenes within the Unity engine. The proposed metric combines geometric complexity, spatial size, and occlusion potential into a unified scalar value that can be used for object classification in the context of rendering optimization, particularly for occluder selection.

The experiments conducted show measurable shifts in object grouping under different configurations. In particular, the geometry-dominant configuration increases the number of high-significance objects from 5 (in balanced case) to 226, while reducing the number of low significance objects from 701 to 496. Spatial size configuration demonstrates high concentration of objects in low significance group (986 out of 1000), indicating reduced differentiation. The different distribution of objects across classification levels is also shown by mean V(o) values, calculated during experimental runs. Geometry-dominant configuration produces highest average value (0.31), while size-dominant configuration produces the smallest (0.18). The results confirm that different weighting schemes affect object classification based on their significance.

Notably, most of the time, high-significance group received only five objects, which were intentionally placed large-scale occluders. The consistency of analysis results in these cases across most of the configurations confirms the robustness of the significance metric in detecting models which definitely influence scene visibility and rendering complexity.

The proposed approach can be integrated into existing project configuration workflows as a preprocessing tool for rapid 3D scene analysis. By providing a formalized and configurable estimate of object importance, the method reduces reliance on manual judgments, which is particularly valuable for large and complex scene set ups with huge amounts of high-detail models with dense placements.

Future work may proceed in several directions. First, more complex benchmark evaluation is required to research influence on metric values in cases which are closer to real application scenarios. Second, results of rendering optimizations configured based on metric evaluation should be investigated. Finally, adaptive coefficient and analysis parameter selection is an important research prospect, since it can possibly reduce the need for manual value tuning.

The obtained results provide basis for further research in scene analysis based on object significance metric. The critical role of parameter selection and coefficient weighting in such methods is also highlighted, marking the problem of optimization technique configuration adaptation for various 3D scenes.

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