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A Survey of Real-Time Crowd Rendering

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Abstract

In this survey we review, classify and compare existing approaches for real-time crowd rendering. We first overview character animation techniques, as they are highly tied to crowd rendering performance, and then we analyze the state of the art in crowd rendering. We discuss different representations for level-of-detail (LoD) rendering of animated characters, including polygon-based, point-based, and image-based techniques, and review different criteria for runtime LoD selection. Besides LoD approaches, we review classic acceleration schemes, such as frustum culling and occlusion culling, and describe how they can be adapted to handle crowds of animated characters. We also discuss specific acceleration techniques for crowd rendering, such as primitive pseudo-instancing, palette skinning, and dynamic key-pose caching, which benefit from current graphics hardware. We also address other factors affecting performance and realism of crowds such as lighting, shadowing, clothing and variability. Finally we provide an exhaustive comparison of the most relevant approaches in the field.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

1. Introduction

Crowd simulations [PAB08, TM13] are becoming increasingly important in many computer graphics applications. Although the most prominent use of crowd simulations is found in video games (particularly in the sandbox genre, but also in sport and strategy games), crowd rendering is also crucial in a variety of applications including evacuation planning (like Thunderhead's *Pathfinder* software), crowd management training, phobia treatments, and psychological studies. These applications often need to render in real-time hundreds or thousands of moving agents with a certain level of visual quality and plausibility.

A close look at the video game industry reveals that each new console generation gives rise to a new predominant genre that fully exploits the hardware improvements. While in the past generation (PS3, Xbox 360) first person shooters were predominant, the current console generation (PS4, Xbox one) has lead to a substantial increase of game titles in the sandbox genre. One example is the LEGO's *Traveler's Tales* series, which has evolved from simple action-platformed games, to evolving sandbox environments e.g. in *LEGO Batman 2 DC Super Heroes* and *LEGO Marvel Super Heroes*. This is due to the trend of providing players with more alive and interactive environments with each new game. In order to allow the player to feel immersed inside game environments such as virtual stadiums, villages and cities, the scenes need to be populated with crowds of people that make the environment both alive and believable. In sandbox games this is almost a requirement, and recent games from bestselling series such as Ubisoft's *Assassin's Creed* or RockStar's *Grand Theft Auto* have pushed the limits on the amount of agents shown on screen in real-time. The recent *Assassin's Creed Unity* (Figure 1-a) claims to show up to 12,000 agents in real-time, although just 120 of them are rendered using high resolution models.

Moving to strategy games, we can find massive armies of up to 100,000 soldiers animated in real-time, as in Creative Assembly's *Total War: Rome 2* . Distant soldiers are not required to have individual appearance, animation and behavior, which makes it easier to reach such a high performance. In sport games such as Electronic Arts' *FIFA 15* (Figure 1-b), stadiums can also be filled with up to 120,000 animated virtual spectators, although they remain seated in the same place with no navigation or collision avoidance.

Real-time realistic crowds have thus a massive impact in the current game industry. Despite the substantial advances