

Procedural Level Generation for Augmented Reality Games

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Abstract

Mixed reality games are those in which virtual graphical assets are overlaid on the physical world. We explore the use of procedural content generation to enhance the gameplay experience in a prototype mixed reality game. Procedural content generation is used to design levels that make use of the affordances in the player’s physical environment. Levels are tailored to gameplay difficulty and to affect how the player moves their physical body in the real world.

Introduction

Recent hardware developments in Augmented Reality (AR) and Mixed Reality (MR) headsets—such as Microsoft’s HoloLens, Magic Leap, and Google Cardboard—make it increasingly likely that commercial augmented and mixed reality games will become available in the near future. AR takes the user’s view of the real world and layers digital information on top of it. MR allows digital and physical objects to coexist seamlessly together and be interacted with in real time.

Unlike in VR, MR experiences can change significantly based on the configuration of the player’s physical environment. For example, Microsoft’s *Young Conker* game for HoloLens has the player controlling a virtual avatar on table and floor surfaces. Thus, rooms with different arrangements of furniture could result in more or less enjoyable gameplay experiences.

Augmented and mixed reality games have been developed previously, but almost universally rely on visual markers for the placement of virtual game assets (c.f., Andersen, Kristensen, Nielsen, & Grønbæk, 2004; Xu et al. 2011) or virtual characters walking on tables.

We argue that mixed reality games benefit from artificial intelligence beyond machine vision surface detection. In particular, we argue that a class of artificial intelligence algorithms called *Procedural Content Generation* (PCG) can automatically optimize players’ gameplay experience

by accounting for the specific configuration of players’ unique physical environments. Procedural content generation is the use of algorithms to automate the production of various aspects of computer games, such as terrain, levels, missions, weapons, and monsters. Artificial intelligence approaches to PCG treat the creation of game content as an optimization problem—the attempt to find a set of parameters for a specific type of content that maximizes an evaluation function.

Historically, procedural level generation has been researched in the context of fully virtual game environments (c.f., Togelius et al. 2011). Purely virtual environments are advantageous to PCG algorithms because the generator has full control over all aspects of the game level. In mixed reality, the algorithm is constrained by the configuration of real world furniture and walls. These constraints provide additional algorithmic challenges but also create opportunities for interesting interactions between virtual and real elements.

We introduce a mixed reality game, *MR Lemmings*, which uses PCG algorithms to place a set of virtual game assets that will affect the player’s interaction with the physical environment. The game was developed as a prototype for the exploration of the ways in which procedural content generation can reason about the affordances of physical environments in mixed reality games.

The Game

We developed a mixed reality platformer game loosely inspired by the popular *Lemmings* game. The game spawns a row of virtual agents, each approximate four inches tall, that simply walk in a straight line until they fall off a surface to their deaths (the floor is “lava”). The player can intervene in two ways. First, the player can place a physical box in front of the agents that redirects the agents. Second, the player can place physical coaster-like pads that launch lemmings over gaps. Different jump pads can launch the agents different distances and heights. The objective is to deliver the agents from the starting location

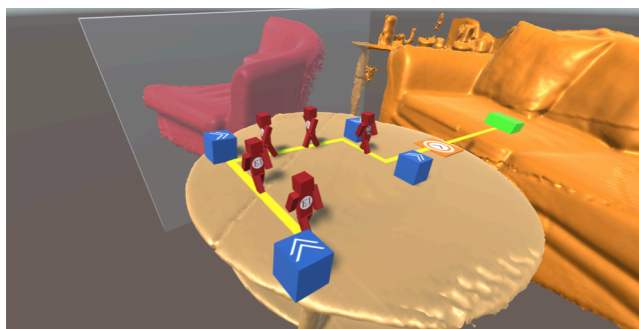


Figure 1: MR Lemmings game with virtually rendered furniture from the 3D scan of the room. The path the agents will take is shown in yellow.

safely to home base.

There may be many routes across the surfaces of a room between any two points, some of which will be easier than others. The procedural content generation algorithm has the responsibility for delivering the best gameplay experience it can to the player. The procedural content generation algorithm creates virtual walls (see Figure 1)¹ to constrain the player from certain routes. Unlike mixed reality games such as Microsoft’s *Young Conker* game that allows the player to control the avatar’s motion in three dimensions and choose the order to visit surfaces, our mixed reality level generator constrains the player to operating on a specified sequence of surfaces. By constraining the user to a single sequence that crosses physical furniture surfaces the algorithm can control for the length of the gameplay experience, create rhythms (Smith et al. 2009), or challenge progressions (Shaker, Yannakakis, and Togelius 2010; Harrison and Roberts 2013, Zook and Riedl 2015).

Our procedural content generation system first creates a 3D model of the room that the player resides in. We use a Kinect 2.0 3D camera, which is similar to the camera system that Microsoft HoloLens uses. We then identify horizontal and vertical surfaces. Each horizontal surface is represented as a node in a graph. Edges connect nodes whenever it is possible to traverse between surfaces with or without the aide of a jump pad. Edges are annotated with the distance between closest points in the point cloud that were detected for each surface.

Level generation is a process of identifying the route across surfaces that is best according to a given set of criteria (described below). Every pair of surfaces must be considered as start and goal. For every pair, we enumerate all possible routes through the graph. The solutions for all pairs of start and goal nodes are then ranked according to an evaluation function. This brute-force approach is appropriate for environments with a moderate amount of relatively sparsely arranged furniture. For larger, denser envi-

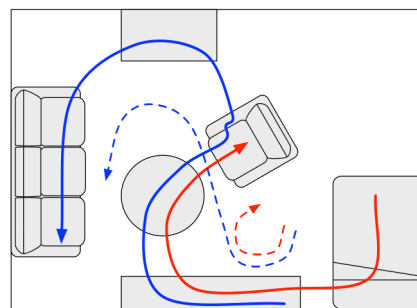


Figure 2: Two possible tracks (solid lines) and how they affect player movement profiles (dashed lines).

ronments the computational complexity may require an approximation technique such as a genetic algorithm. It is not our intention to innovate in the area of generation algorithm, but to explore the use of evaluation functions that tie virtual and physical environments together. Once the optimal route is found, the system generates virtual walls by walking the nodes of the winning route and generating a barrier between every surface that is not a predecessor or successor in the graphical representation of the space.

We describe some of the evaluation criteria that tie the selection of virtual content to the affordances of the real world environment:

- **Proportion of surfaces used.** A percentage is used since the number of surfaces cannot be known *a priori*. This can be weighted according to the size of surface.
- **Target difficulty.** Difficulty is measured as the frequency of player interventions (redirections and jump pads) required. Target difficulty can be specified as a target number or as a function (e.g., monotonically increasing).
- **Target player physical movement.** A route can require more or less movement from the player to view the agents from the best angle. The amount of movement required from the player is computed by finding the shortest route through negative space for the player to remain within a prescribed distance of the lead agent (Figure 2). Since the initial position of the player may be unknown at generation time, we randomly sample starting positions for the player and average the traversal lengths. Target player physical movement can be very important if the user has limited mobility or if physical fitness is a motivation.

Mixed reality games use the environment the player is situated in as the gameplay environment, augmented with digital assets. Most home and office environments are unlikely to be perfectly suitable game playing environments. The MR Lemmings game demonstrates how procedural content generation algorithms can constrain the gameplay to those portions of the physical world that are most conducive to gameplay. The game acts as a testbed for experimentation with different evaluation functions that reason about the affordances of the physical environment.

¹ The game can be played on HoloLens with physical blocks or with a VR headset with Leap Motion hand tracker and virtual blocks as in Figure 1.

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