Reconstructing the World in 3D: Bringing Games with a Purpose Outdoors

[Extended Abstract] *

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ABSTRACT

We are interested in reconstructing real world locations as detailed 3D models, but to achieve this goal, we require a large quantity of photographic data. We designed a game to employ the efforts and digital cameras of everyday people to not only collect this data, but to do so in a fun and effective way. The result is PhotoCity, a game played outdoors with a camera, in which players take photos to capture flags and take over virtual models of real buildings. The game falls into the genres of both games with a purpose (GWAPs) and alternate reality games (ARGs). Each type of game comes with its own inherent challenges, but as a hybrid of both, PhotoCity presented us with a unique combination of obstacles. This paper describes the design decisions made to address these obstacles, and seeks to answer the question: Can games be used to achieve massive data-acquisition tasks when played in the real world, away from standard game consoles? We conclude with a report on player experiences and showcase some 3D reconstructions built by players during gameplay.

Categories and Subject Descriptors

K.8.0 [**Personal Computing**]: General – Games; I.4.8 [**Image Processing and Computer Vision**]: Scene Analysis – Shape

Keywords

3D reconstruction, alternate reality, ARG, computer vision, games with a purpose, GWAP, game, photography, virtual world

1. INTRODUCTION

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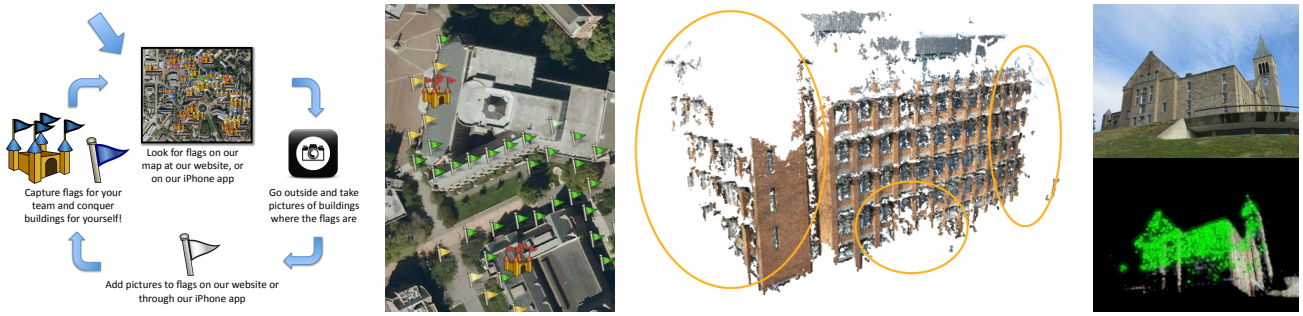
In the past few years, there has been increasing interest in building 3D models of entire cities for navigation, visualization, and planning applications. Recently, computer vision algorithms have been developed for completely automatic 3D reconstruction of buildings and landmarks from large photo collections [1], including images scraped from photo sharing sites such as Flickr. However, the resulting models are incomplete, as only "popular" viewpoints of popular landmarks are well-represented on Flickr. Reconstructing complete, high-resolution models of contiguous neighborhoods and whole cities requires many more photos, distributed more uniformly, than currently exist on such sites.

In PhotoCity, a hybrid alternate reality game with a purpose, we exploit the mobility of everyday players to collect carefully composed photographs of locations in an area of interest. Player photos include not just the standard, front-facing views of a location, but photos from a wide variety of viewpoints, allowing us to build a complete reconstruction. Bridging active collection of imagery with the human desire to playfully compete has required the design of a new gameplay form and forced the development of new computer vision technologies that can interact with players and usefully direct their effort.

We favor models reconstructed from photos because of the accuracy and realism such techniques provide. These techniques, borrowed from computer vision, are also cheaper and more automatic than hiring a 3D modeling artist.

Digital reconstructions are sensitive to the camera placement of the original images and resulting models often contain gaps and holes where additional views are needed. The data from a single pass with a vehicle-mounted camera array is often not dense enough to admit the quality of reconstructions we seek and is limited to where the vehicle can drive.

In PhotoCity, we have approached the problem of collecting useful data by actively involving players in an iterative growing and refining process. To play, players go to locations in the real world that correspond to locations under construction in the virtual world and take photos. We direct players to focus their attention on the gaps and fringes in a partial reconstruction in exchange for in-game rewards.



(a) Gameplay cycle (b) Flags on map (c) 30-photo seed (d) Player contribution (800 points)

Figure 1: PhotoCity aspects of play

Unique to PhotoCity are the combined challenges of designing an effective game with a purpose (GWAP) and an alternate reality game (ARG), using the real world as its gaming platform. This pairing requires both getting skilled players out in the world and communicating game rules and feedback to them.

2. GAME MECHANICS.

With the purpose of our game being to collect the kinds of images that would yield a high-quality reconstruction, we were faced with the challenge of translating this task into an inviting gameplay experience. In our players' eyes, PhotoCity is about capturing virtual flags anchored in real-world locations and vying for nominal ownership of familiar landmarks.

The core mechanic of our game involves players inspecting the state of the game world on a map, taking photos at locations of promising in-game value, and uploading the photos, and then observing the results of their play. Through repeated cycles of this process, summarized in Figure 1(a), players introduce new geometric points in the reconstructions that correspond to points of detail in the real world.

Accumulating points lets players control flags and own models in the game's fictional world. We will briefly go through each element of the game: where the models come from, where the flags come from, how exactly a player receives points, and the requirements for capturing flags and taking ownership of models.

A model is a partial building that starts off as a seed generated from a batch of photos of the real building. A seed can be generated from about 50 photos. As a result, models in their starting state only span one face or one corner of a building and have rough edges and large holes where data for the building has yet to be captured. Figure 1(c) shows the size of a seed made from thirty photos. The seeds are added either by the game designers or the players themselves, but go through a manual approval process that rejects offensive material and low quality reconstructions.

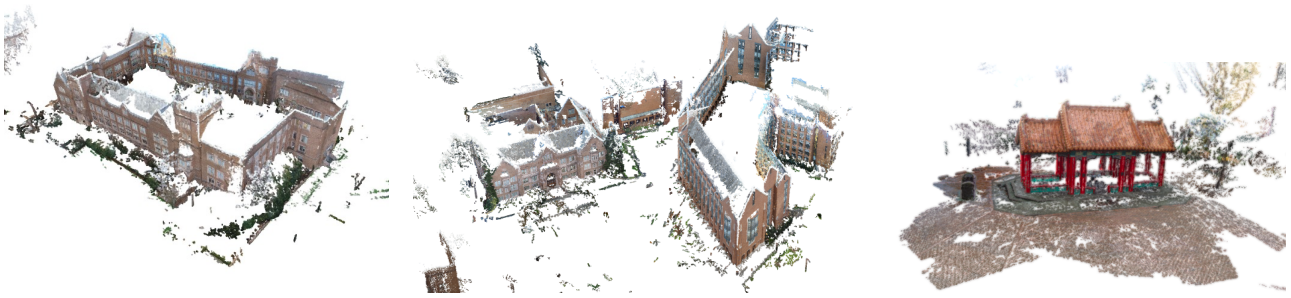
To anchor the model to the world, we manually align an overhead view of the model with a satellite map. Flags are automatically placed on the model so that each flag has a map location corresponding to a position on a wall, or sometimes a tree or cluster of non-building points. To take a photo of a flag, one must face the building the flag is on and stand far enough away get distinctive features of the building in the shot. As the models grow, new flags automatically appear at the edges of the models for players to capture. If the flags at a model's edge are already captured, a player can work to grow the model enough to spawn a new flag.

The typical player looks at the map of the game, identifies the flags she wishes to capture, and then takes photos of that portion of the building. For a photo to earn points, it must (1) overlap with enough existing points in the model and (2) overlap the empty space next to a model. The first requirement allows the photo to connect with the model and have its position within the model automatically calculated. The second requirement, that the photo look beyond the existing model, allows new points to be added to that void as soon as there are enough other photos to triangulate the 3D positions of those features. A photo can add up to several thousand new points if fills in a large patch of the model with new features.

To earn points at a flag, a player simply generates new 3D points in a column around a flag with a radius of about thirty feet. 3D points translate directly into game points. The team with the majority of points at a flag captures that flag. Flags often accumulate tens of thousands of points, so flags that one team owns but that have fewer than 2,000 points total are considered "disputed" because they are relatively easy for another team to steal.

While teams control flags, individual players control individual models. If one player has over 10,000 points at a model (roughly equivalent to making a major contribution at five different flags) and has more points than any other player, that player owns that model.

The photography must happen outdoors, in the vicinity of certain buildings, but the game can be played in two different ways. Players can bring their cameras inside and use a high-bandwidth link to upload photos to the website, or players can play using a custom iPhone application that lets them submit photos and get feedback in one seamless process. While high-end digital cameras yield better results (and more points) than cell phone cameras, anyone can play and contribute with the camera he or she already has.



(a) Circumnavigated building (b) Dense, multi-building model (c) Seed model added by a playerl

Figure 2: Reconstructions

These mechanics result in a virtual world, populated by 3D reconstructions, which grows organically through continued player interaction.

3. RESULTS

To evaluate how well we overcame these design challenges, we ran two game trials, one in May 2009 that lasted for one week, and one beginning in December 2009 that lasted for two months. Both trials took place on the University of Washington campus using the same set of building seeds, which were reset to their initial states before each trial. We report player statistics for both trials and present the reconstruction results from the second trial.

3.1 Reconstructions

We started with 12 seed models at the beginning of the second trial, listed in Table 1. The 13th model was added during the game by one of the players. The first two columns show the number of photos and points in the initial seed models and the last two columns show the growth of each model.

Three very exciting things happened with the reconstructions that demonstrated the success of the game. First, as shown in Figure 2(a), players circumnavigated several buildings, despite obstacles like trees and hedges at the corners of buildings that were hard to reconstruct. Second, players learned how to expand models onto other physically disconnected buildings by taking photos of one building with the second building in the background. Players actually expanded seeds to touch and overlap nearby seeds. Figure 2(b) shows a seed that started as just the corner of the angular building expanding to include several adjacent buildings. Third, players went out and photographed buildings of persona importances and submitted them as seeds. One example of a player seed is shown in Figure 2(c).

Towards our goal of harnessing player effort to build 3D reconstructions by taking photos, the 25 players in our second trial submitted over 11,000 new photos generating over 3,000,000 new sparse-model points. Since the publication of the full paper [2], over 130,000 photos have been collected, most of which actually provide useful information for the 3D reconstructions.

3.2 Reactions to Game Elements

Did the PhotoCity players have fun? We interviewed several of them and also observed their interactions with other players.

New players who managed to score points in their first set of photos felt good about themselves, even if not all of their photos were successfully added to a model. The positive effect of a matching photo was greater than the negative effect of a failed photo.

Players who started the game when there were a large number of white (uncaptured) flags were very excited to see the flags change to their team color. However, players who came to the game when many photos had already been taken and most of the flags captured were overwhelmed and felt less able to make a difference (a common occurrence in multiplayer online games).

Despite the game being driven by the mere acquisition of points, flags, and buildings, players discovered "expert strategies" that both made them more interested in the game, and allowed them to acquire vast quantities of points. For example, when one player had built a sufficiently dense model (so dense that new photos would match but not add new points), a second player came up with a strategy to reclaim the flags by expanding nearby models into the flag-space already inhabited by the first model. This interesting emergence was a direct result of attaching abstract mechanics to locations in the physical world.

4. CONCLUSION

We have described PhotoCity, a game with a purpose that draws its players outdoors to participate in the construction of a virtual world. In creating a game at the intersection of two genres, alternate reality games and games with a purpose, we encountered challenges on a new scale. PhotoCity is both vastly more data intensive than other GWAPs and more process intensive than traditional ARGs, even requiring the development of new algorithms and deployment of them in a distributed system to maintain interactivity. Initial trials of our game have already resulted in a collection of highly-detailed 3D models, demonstrating that hybrid AR-GWAPs, played out in the real world, can be effective at collecting vast quantities of data, provided the games are interesting, fun, and equip players with the right tools and training to accomplish the task at hand.

Model	Starting Photos	Starting Points	Ending Photos	Ending Points
CSE Front Entrance	58	18,131	515	148,189
Electrical Engineering	30	13,133	1,230	380,102
James J. Hill Statue	48	51,461	406	224,783
Southeast Corner of CSE	27	9,597	935	304,030
Fountain-facing Corner of EE	68	38,439	979	321,805
Commodore Apartments	41	9,973	581	66,777
Allen Library	92	28,945	840	131,558
Engineering Library	74	8,598	584	62,095
Guggenheim	101	85,239	1,394	622,355
Mechanical Engineering	46	27,022	741	273,889
Mary Gates (West Side)	32	36,891	1,488	761,777
Suzzallo Library	41	36,566	1,526	492,871
Hing Hay Park*	73	46,965	116	54,333

*Seed added by player during trial

Table 1: Model Growth

By sharing the design of our game, we hope to stimulate further discussion on games with a purpose that extend into the real world. A great many computational problems can be solved in the presence of masses of data, so that cheaply and effectively collecting this data quickly becomes the primary issue. The reader is invited to visit the game's reconstruction gallery[1] and join our ongoing effort to reconstruct the world in 3D by submitting his or her own images.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] N. Snavely, S. M. Seitz, and R. Szeliski. Photo tourism: Exploring photo collections in 3d. In *SIGGRAPH Conference Proceedings*, pages 835–846, New York, NY, USA, 2006. ACM Press.

[2] K. Tuite, N. Snavely, D. Hsiao, A. M. Smith, and Z. Popovic. Reconstructing the world in 3d: Bringing games with a purpose outdoors. In *FDG '09: Proceedings of the 5th International Conference on Foundations of Digital Games*, New York, NY, USA, 2010. ACM Press.

[1] `http://photocitygame.com/reconstructions.php`