Eurographics 2014 Tutorial Proposal: Simulating heterogeneous crowds with interactive behaviors

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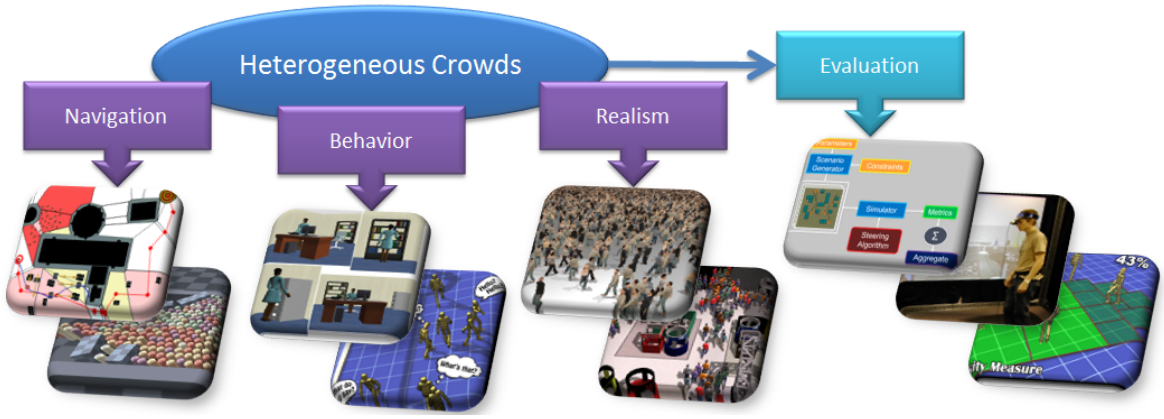

Figure 1: *Framework to achieve interactive heterogeneous crowds with accurate evaluation of the resulting simulations.*

Abstract

Over the last decade there has been a large amount of work towards trying to simulate crowds for different applications, such as movies, video games, training, and evacuations. This course focuses on heterogeneous crowd simulation for interactive applications and will describe state of the art methods to simulate large groups of agents exhibiting a variety of behaviors, appearances and animations. We will present different techniques including psychological models and data-driven approaches that attempt to imitate real humans. We also present different systems to speed up both navigation, through multi-domain planners, and rendering, using per-joint impostors on fully animated 3D characters. Finally we provide quantitative and qualitative techniques to evaluate the quality of the simulated crowds, and include an overview of future research directions in the field.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Animation, Virtual Reality; I.6.8 [Simulation and Modelling]: Types of Simulation—Animation

1. Introduction

Interactive and heterogeneous crowd simulation is a research field of increasing relevance in everyday applications. There are many elements that need to be combined in order to achieve highly realistic results. Crowd simulation requires natural looking paths in complex, dynamic virtual environments, but this alone is not sufficient to exhibit realistic behaviors. Therefore this course also covers state of the art techniques to include rich behaviors for the autonomous characters based on psychological models or data-driven approaches. Once we achieve believable crowds we also need to focus our attention on the overall realism. To enhance realism this course focuses on three relevant topics: highly detailed rendering of large crowds at interactive rates, removal of artifacts in local movement and animation, and enhancement of crowd personality.

One of the main challenges in this field is the validation of the results achieved by a crowd simulation. In this tutorial we will explain different approaches that have been proposed to compare and validate crowd simulation algorithms including: quantitative measurements, qualitative measurements through the concept of presence in virtual environments, and data-driven methods to compare real tracked crowds against simulated crowds.

This course will provide an overview of the most relevant work on crowd navigation, behavior simulation, realism, and evaluation, as well as a deeper discussion of the most recent work in each of these areas and the future research topics that are yet to be explored.

2. Tutorial Information

Our tutorial is meant to be a half day tutorial (2x90minutes)

2.1. Keywords

crowd simulation, crowd rendering, crowd evaluation, crowd animation, data-driven crowds, authoring behaviors.

2.2. Audience

Intermediate to Advanced: This tutorial is aimed at an audience interested in learning and developing techniques for simulation of heterogeneous behaviors for real-time applications, as well as learning current techniques for evaluation of crowd behavior.

2.3. Prerequisites

Ideally, participants should be familiar with basic calculus, introductory vector math (e.g., scalar and vector projection), and simple geometric processing (e.g., line-line intersections). Exposure to basic concepts of animation and graphics such as: timestep based simulation, numerical integration, and real-time rendering will also be helpful. No previous experience with crowd simulation is expected.

3. Previous Tutorials

The last tutorial on a similar topic was presented at Siggraph Asia in 2010 (Course 0051: Simulating Believable Crowd and Group Behaviors). We believe that it is very beneficial to present our tutorial to the audience in Europe, since it presents new topics and different approaches to solve some of the common problems in crowd simulation. For instance, in the Siggraph Asia tutorial, evaluation techniques were based on perception studies, whereas we present a variety of techniques that cover both quantitative and qualitative evaluation based on presence and data-driven methods. Also, the previous Siggraph Asia tutorial had a special focus on large scale crowds and traffic, whereas we are more interested in medium size groups of agents with heterogeneous behaviors and rendering, as well as authoring tools for more interesting scenarios with distinguishable personalities.

4. Brief Resume of Presenters

4.1. Norman Badler

Norman I. Badler is the Rachleff Professor of Computer and Information Science at the University of Pennsylvania. He has been on that faculty since 1974. Active in computer graphics since 1968 with more than 200 technical papers, his research involves developing software to acquire, simulate, animate and control 3D computer graphics human body, face, gesture, locomotion, and manual task motions, both individually and for heterogeneous groups. Badler received the BA degree in Creative Studies Mathematics from the University of California at Santa Barbara in 1970, the MSc in Mathematics in 1971, and the Ph.D. in Computer Science in 1975, both from the University of Toronto. He was the Cecilia Fitler Moore Department Chair of Computer and Information Science from 1990-94. He directs the SIG Center for Computer Graphics and the Center for Human Modeling and Simulation at Penn. Among the Center's achievements is the technology transfer in 1996 of the human modeling software system Jack. Now an integrated product and marketed by Siemens, it is used worldwide for human factors and ergonomics analyses of workplace and vehicle environments. Badler is the Director of the BSE in Digital Media Design undergraduate program and the Co-Director of the Masters in Computer Graphics and Game Technology program at Penn. During 2001-2005 he was also the Associate Dean of the School of Engineering and Applied Science.
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4.2. Mubbasir Kappadia

Mubbasir Kapadia is an Associate Research Scientist at Disney Research Zurich. Previously, he was a postdoctoral researcher and Assistant Director at the Center for Human Modeling and Simulation at University of Pennsylvania, under the directorship of Prof. Norman I. Badler. He was the

project lead on the United States Army Research Laboratory (ARL) funded project Robotics Collaborative Technology Alliance (RCTA). He received his PhD in Computer Science at University of California, Los Angeles under the advisement of Professor Petros Faloutsos.

Kapadia's research aims to develop integrated solutions for full-body character animation, planning based control, behavior authoring, and statistical analysis of autonomous virtual human simulations. The far-reaching goal is to provide functional, purposeful embodied virtual humans, that act and interact in meaningful ways to simulate complex, dynamic, narrative-driven, interactive virtual worlds.
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4.3. Jan M. Allbeck

Jan Allbeck is an Assistant Professor in the Department of Computer Science at George Mason University, where she is also the faculty advisor for their undergraduate concentration in Computer Game Design and director of the Games and Intelligent Animation laboratory. She received her Ph.D. in Computer Science from the University of Pennsylvania in 2009. She has had the great opportunity to explore many aspects of computer graphics, but is most drawn to research at the crossroads of animation, artificial intelligence, and psychology in the simulation of virtual humans. Her dissertation focused on the creation and simulation of functional crowds.
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4.4. Yiorgos Chrysanthou

Yiorgos L. Chrysanthou is an Associate Professor at the Computer Science Department of the University of Cyprus, where he is heading the Graphics and Hypermedia lab. He received his PhD from Queen Mary and Westfield College (1996) and worked for several years as a research fellow and a lecturer at University College London (up to 2001). Yiorgos has published over 65 papers in journals and international conferences on Computer Graphics and Virtual Reality and is a co-author of the book "Computer Graphics and Virtual Environments: From Realism to Real-Time", (Addison-Wesley 2001 + China Machine Press 2004). He has served as Program Chair for international conferences (VAST 2004, ACM VRST 2005 and ACM VRST 2006, ECMS 2008, MIG 2010) and has been the local or overall coordinator of many research projects funded through various sources. His research interests are in the general area of 3D Computer Graphics, including real-time rendering, reconstruction of urban environments and virtual humans, with applications to serious games and cultural heritage. Most of his recent work has focused specifically on data driven simulation and evaluation of character behavior.
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4.5. Nuria Pelechano

Nuria Pelechano obtained her computer science engineering degree from the Universitat de Valencia in 2001, her MSc in Vision Imaging and Virtual Environments from the University College London in 2002, and her PhD in Computer and Information Science from the University of Pennsylvania in 2006. Currently she is an Associate Professor at the Universitat Politecnica de Catalunya, where she is a member of the Virvig-Moving group. Her research interests include animation, simulation and rendering of crowds, real-time 3D graphics, and human avatar interaction in virtual environments. She has published many papers in international conferences and journals including Symposium on Computer Animation, Computer Graphics Forum, and IEEE Computer Graphics and Applications. She is also co-author of a book entitled "Virtual Crowds: Methods, Simulation, and Control" (Morgan and Claypool) with N. Badler and J. Allbeck.
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4.6. Stephen Guy

Stephen J. Guy is an assistant professor of Computer Science at the University of Minnesota. His research focuses on the areas of interactive computer graphics (real-time crowd simulation, path planning, intelligent virtual characters) and multi-robot coordination (collision avoidance, sensor fusion, path planning under uncertainty). Stephen's work on motion planning has been licensed for use by Relic Entertainment, EA, and other game companies; his work in crowd simulation has been recognized by best paper awards at international conferences. He received his Ph.D. in Computer Science in 2012 from the University of North Carolina at Chapel Hill with support from fellowships from Google, Intel, and the UNCF.
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5. Tutorial Outline

5.1. Introduction (10 minutes)

Our tutorial covers several topics for simulation of heterogeneous crowds with interactive behaviors. A brief description of each of the tutorial topics will be covered during this introduction, as well as a presentation of background of the other lecturers. Lecturer: Norman Badler

5.2. Navigation (40 minutes)

1. An overview of methods for local navigation between agents, focusing on a detailed coverage of selected recently proposed techniques (20 minutes). Lecturer: Stephen Guy.
   - Anticipatory vs Reactive Navigation

- Force-based techniques for collision avoidance
- Velocity-based navigation methods [GCK*09]
- Velocity-based model of physical interactions (pushing, collisions, etc.) [KGM13].

2. Revisiting representation and control for goal directed autonomous agents and multi-domain planning (20 minutes). Lecturer: Mubbasir Kapadia.

- Multi-Domain Real-time Planning in Dynamic Environments [KBG*13].
- Footstep planning [SKRF11].

5.3. Heterogeneous Behavior (40 minutes)

1. Functional crowds and psychological models (20 minutes). Lecturer: Jan Allbeck.

- Populations with purpose [LA11].
- The OCEAN personality model [DAPB08].

2. Learning heterogeneous behaviors from real world data (15 minutes). Lecturer: Yiorgos Chrysanthou.

- Crowds by example [LCL07].
- Fitting behaviors to pedestrian simulations [LFCCO09].
- Graph based acceleration of data driven crowd simulation.

3. Designing and authoring functional purposeful human characters in virtual environments, incorporating character animation, navigation and behavior (5 minutes). Lecturer: Mubbasir Kapadia.

- ADAPT: The Agent Development and Prototyping Testbed [SMKB13].
- A Behavior-Authoring Framework for Multiactor Simulation [KSRF11].

5.4. Realism (40 minutes)

1. Improving local movement and foot placement for real time crowds, followed by an overview of crowd rendering techniques to handle real time fully animated 3D characters that will enhance the overall appearance of the simulated crowds. (20 minutes). Lecturer: Nuria Pelechano.

- Local motion with exact clearance. [BAPS12].
- Efficient elimination of foot sliding in real time crowds. [PSB11].
- Overview of: LOD, impostors,polypostors, geopostors, and instancing.
- A flexible approach for output-sensitive rendering of animated characters with relief impostors [SMKB13].
- Per-joint flat impostors for an efficient rendering of thousands of animated characters in real time [BSAP11].

2. Statistical techniques to enhance and evaluate the realism of the crowd behavior (20 minutes). Lecturer: Stephen Guy.

- User-based perceptual variations [GKLM11].
- Statistical modeling of personality.
- Stress modeling and evaluation.
- Bayesian approaches to crowd trajectory comparison. [GvdBL*12].

5.5. Analysis and evaluation (40 minutes)

1. Quantitative methods to evaluate crowd simulation (15 minutes). Lecturer: Mubbasir Kappadia.

- SteerBench [SKFR09].
- Scenario Space: Characterizing Coverage, Quality, and Failure of Steering Algorithms [KWS*11].

2. Qualitative evaluation of crowds through presence experiments. (10 minutes). Lecturer: Nuria Pelechano.

- Being a part of the crowd: towards validating VR crowds using presence. [PSAB08].

3. Data-drive evaluation. (15 minutes). Lecturer: Yiorgos Chrysanthou.

- Data driven evaluation of crowds. [LCSCO09].
- Context dependent evaluation of crowds. [LCSCO10].

5.6. Wrap-up and key issues moving forward (10 minutes)

1. Overview of current key research areas, including multisense perception, and memory models to farther improve the realism of current crowd models (10 minutes). Lecturer: Jan Allbeck.

References

[BAPS12] BEACCO A., ANDUJAR C., PELECHANO N., SPANLANG B.: Efficient rendering of animated characters through optimized per-joint impostors. *Comput. Animat. Virtual Worlds 23*, 1 (Feb. 2012), 33–47. 4

[BSAP11] BEACCO A., SPANLANG B., ANDUJAR C., PELECHANO N.: A flexible approach for output-sensitive rendering of animated characters. *Computer Graphics Forum 30*, 8 (2011), 2328–2340. 4

[DAPB08] DURUPINAR F., ALLBECK J., PELECHANO N., BADLER N.: Creating crowd variation with the ocean personality model. In *Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems - Volume 3* (Richland, SC, 2008), AAMAS '08, International Foundation for Autonomous Agents and Multiagent Systems, pp. 1217–1220. 4

[GCK*09] GUY S. J., CHHUGANI J., KIM C., SATISH N., LIN M. C., MANOCHA D., DUBEY P.: Clearpath: Highly parallel collision avoidance for multi-agent simulation. In *ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (2009), ACM, pp. 177–187. 4

[GKLM11] GUY S. J., KIM S., LIN M. C., MANOCHA D.: Simulating heterogeneous crowd behaviors using personality trait theory. In *Proceedings of the 2011 ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (New York, NY, USA, 2011), SCA '11, ACM, pp. 43–52. 4

[GvdBL*12] GUY S. J., VAN DEN BERG J., LIU W., LAU R., LIN M. C., MANOCHA D.: A statistical similarity measure for aggregate crowd dynamics. *ACM Trans. Graph. 31*, 6 (Nov. 2012), 190:1–190:11. 4

[KBG*13] KAPADIA M., BEACCO A., GARCIA F., REDDY V., PELECHANO N., BADLER N. I.: Multi-domain real-time planning in dynamic environments. In *Proceedings of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (New York, NY, USA, 2013), SCA '13, ACM, pp. 115–124. 4

[KGM13] KIM S., GUY S. J., MANOCHA D.: Velocity-based modeling of physical interactions in multi-agent simulations. In *Proceedings of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (New York, NY, USA, 2013), SCA '13, ACM, pp. 125–133. 4

[KSRF11] KAPADIA M., SINGH S., REINMAN G., FALOUTSOS P.: A behavior-authoring framework for multiactor simulations. *Computer Graphics and Applications, IEEE 31*, 6 (nov.-dec. 2011), 45 –55. 4

[KWS*11] KAPADIA M., WANG M., SINGH S., REINMAN G., FALOUTSOS P.: Scenario space: characterizing coverage, quality, and failure of steering algorithms. In *Proceedings of the 2011 ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (New York, NY, USA, 2011), SCA '11, ACM, pp. 53–62. 4

[LA11] LI W., ALLBECK J.: Populations with purpose. In *Motion in Games*, Allbeck J., Faloutsos P., (Eds.), vol. 7060 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2011, pp. 132–143. 4

[LCL07] LERNER A., CHRYSANTHOU Y., LISCHINSKI D.: Crowds by example. *Computer Graphics Forum 26*, 3 (2007), 655–664. 4

[LCSCO09] LERNER A., CHRYSANTHOU Y., SHAMIR A., COHEN-OR D.: Data driven evaluation of crowds. In *Proceedings of the 2nd International Workshop on Motion in Games* (Berlin, Heidelberg, 2009), MIG '09, Springer-Verlag, pp. 75–83. 4

[LCSCO10] LERNER A., CHRYSANTHOU Y., SHAMIR A., COHEN-OR D.: Context-dependent crowd evaluation. *Computer Graphics Forum 29*, 7 (2010), 2197–2206. 4

[LFCCO09] LERNER A., FITUSI E., CHRYSANTHOU Y., COHEN-OR D.: Fitting behaviors to pedestrian simulations. In *Proceedings of the 2009 ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (New York, NY, USA, 2009), SCA '09, ACM, pp. 199–208. 4

[PSAB08] PELECHANO N., STOCKER C., ALLBECK J., BADLER N.: Being a part of the crowd: towards validating vr crowds using presence. In *Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems - Volume 1* (Richland, SC, 2008), AAMAS '08, International Foundation for Autonomous Agents and Multiagent Systems, pp. 136–142. 4

[PSB11] PELECHANO N., SPANLANG B., BEACCO A.: Avatar locomotion in crowd simulation. *The International Journal of Virtual Reality 10*, 1 (2011), 13–19. 4

[SKFR09] SINGH S., KAPADIA M., FALOUTSOS P., REINMAN G.: SteerBench: a benchmark suite for evaluating steering behaviors. *Computer Animation and Virtual Worlds 9999*, 9999 (2009), n/a+. 4

[SKRF11] SINGH S., KAPADIA M., REINMAN G., FALOUTSOS P.: Footstep navigation for dynamic crowds. *Computer Animation and Virtual Worlds 22*, 2-3 (2011), 151–158. 4

[SMKB13] SHOULSON A., MARSHAK N., KAPADIA M., BADLER N. I.: Adapt: the agent development and prototyping testbed. In *Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games* (New York, NY, USA, 2013), I3D '13, ACM, pp. 9–18. 4