Simulating Heterogeneous Crowds with Interactive Behaviors

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CRC Press
Taylor & Francis Group

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Preface

We are delighted to introduce this book *Simulating Heterogeneous Crowds with Interactive Behaviors*. This book project started after a Eurographics Tutorial, which the editors organized in 2014. The original tutorial was extended by inviting renowned researchers in the crowd simulation field to contribute their latest work to the book.

Although many of the topics covered in this book already appear in published papers, they are spread over many different journals and conferences. This volume consolidates in one place many of those fundamental topics and approaches that are important when trying to simulate crowds that demonstrate a certain level of heterogeneity.

This book is divided into four major sections: navigation and steering, editing and realism, evaluation, and applications.

The chapters on *navigation and steering* introduce a variety of methods that have been used over the past decade to move groups of virtual people toward individual goals while avoiding collisions between agents and with the environment. Some of the methods described in the first chapter include a variety of parameters that can help introduce heterogeneity in the crowd. In order to have agents navigating complex or large spaces, steering alone is not enough; the second chapter gives an overview of methods that can create abstract representations of the environments to perform higher-level tasks such as path finding. Finally, in order to enhance heterogeneity, the third chapter introduces methods for data-driven simulation that exploit heterogeneity in behaviors extracted from examples in the real world.

In the second section, *editing and realism* play a role in providing some control over the final look of the simulation. For example, we may want to observe certain formations among agent groups, or have specific densities or flows in different parts of the environment. In order to achieve heterogeneity, it is important to explore effective methods for editing and authoring in order to allow the user to orchestrate overall crowd movement. For example, crowds may have a global "personality," which is evident in their collective behavioral choices. The inclusion of models of personality and emotion to drive the simulation can also greatly enhance realism and heterogeneity. For realism and rendering speed, one chapter provides an overview of graphics display techniques, focusing on two methods that are based on graphical impostors per body part. These techniques enhance the overall realism of the crowd by adding variety in appearance.

One of the most important issues when doing research in crowd simulation is addressed in the third section on *evaluation*. Here, we cover a number of methods for performing quantitative evaluation of crowds in terms of measurable features such as densities or flows. Evaluation may also compare simulations with agent decisions based on available real data.

Finally, the fourth section of this volume documents some examples of *applications* where crowd simulation is required. The first chapter in this section provides a very entertaining view of how this field has evolved in the animation industry from a Pixar point of view. The second chapter covers a completely different industrial and societally important application in safety and evacuation dynamics.

The editors of this book have made notable contributions to and have a comprehensive history in the crowd simulation research field. Norman Badler became interested in computational modeling of humans and their movements in the mid-1970s as he was completing

his PhD dissertation at the University of Toronto. After taking an academic position at the University of Pennsylvania, he worked with a variety of geometric and animation methods for human modeling. Eventually, he and his students developed an interactive human software system for ergonomic applications: "Jack." After successfully spinning this software to a start-up, he began to look into animating groups of virtual human models. The primary drivers of these investigations were Jan Allbeck and Nuria Pelechano. Allbeck was particularly interested in agent heterogeneity, action variety, scheduling, and reactive behaviors. Pelechano examined agent communication, high-density crowds, and geometric extensions to social forces models. Their achievements were documented in the 2008 book *Virtual Crowds: Methods, Simulation, and Control*. Subsequently, Mubbasir Kapadia became a postdoctoral researcher for 2 years in Badler's Center for Human Modeling and Simulation at Penn and produced considerable new approaches to various issues in human crowd simulation ranging from steering behaviors to story-telling planning systems.

Nuria Pelechano continued her work with Allbeck and Badler during her postdoc to explore the field of presence for the evaluation of crowd simulation methods, as an alternative to the quantitative approaches presented in this book. They also investigated the inclusion of psychological models to add heterogeneity into the overall simulation. In 2007, Pelechano joined the Universitat Politècnica de Catalunya, and since then she has been working on developing rendering techniques that can handle a variety of animations for crowds in real time. Part of her recent work in collaboration with Kapadia and Badler has focused on animation techniques to accurately following footstep trajectories and simulation of groups of agents with different granularities.

Jan Allbeck's interest since joining George Mason University has focused on developing purposeful agents. Allbeck and her students have looked at ways to increase virtual human's understanding of their environment, including attention and memory models and most recently automated generation of action and object semantics.

After his postdoctorate, Mubbasir Kapadia joined the animation group at Disney Research, Zurich. Since 2015, Kapadia is an assistant professor at Rutgers University where he conducts research in humanoid character animation, crowd simulation, and digital storytelling.

It is the editors' collective hope that this volume will continue to motivate research and applications in heterogeneous crowd simulation. Realistic spatial environments supporting real-life situations and populated by multiple individuals have been an inspiration to us. We hope you will find them just as fascinating.

Editors

Nuria Pelechano is an associate professor at the Universitat Politècnica de Catalunya. She earned a BS in computer science engineering at the Universitat de València in 2001, an MSc at the University College London in 2002, and a PhD at the University of Pennsylvania (UPenn) in 2006 as a Fulbright Scholar, under the supervision of Professor Norman I. Badler. During her postdoc, she worked at the Architecture Department at UPenn in technology transfer projects on crowd evacuation. She is a coauthor of two books on virtual crowds with Morgan & Claypool Publishers (2008 and 2015). She has over 35 publications in journals and international conferences on computer graphics and animation, and she has also been a reviewer for many conferences and journals. She has participated in projects funded by the EU, the Spanish government, and U.S. institutions. Her research interests include simulation, animation, and rendering of crowds, generation of navigation meshes, real-time 3D graphics, and human–avatar interaction in virtual environments.

Jan M. Allbeck is an associate professor in the Department of Computer Science at George Mason University, where she is also the faculty advisor for the undergraduate concentration in computer game design and director of the games and intelligent animation laboratory. She earned a PhD in computer and information science at the University of Pennsylvania in 2009. She has more than 50 publications in international journals and conference proceedings and has served as a reviewer for over 40 journals, conferences, and workshops. 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.

Mubbasir Kapadia is an assistant professor in the Computer Science Department at Rutgers University. Previously, he was an associate research scientist at Disney Research Zurich. He was a postdoctoral researcher and assistant director at the Center for Human Modeling and Simulation at the University of Pennsylvania, under the directorship of Professor Norman I. Badler. He earned a PhD in computer science at the University of California, Los Angeles under the advisement of Professor Petros Faloutsos. Kapadia's research interests include developing computational models of virtual humans with applications in crowd modeling and digital storytelling.

Norman I. Badler is Rachleff Professor of Computer and Information Science at the University of Pennsylvania. He earned a BA in creative studies mathematics at the University of California, Santa Barbara in 1970, an MSc in mathematics at the University of Toronto in 1971, and a PhD in computer science at the University of Toronto in 1975. He served as the senior coeditor for the journal *Graphical Models* for 20 years and presently serves on the editorial boards of several other journals, including *Presence*. His research involves software development to acquire, simulate, animate, and control 3D computer graphics of human body, face, gesture, locomotion, and manual task motions, both individually and for heterogeneous groups. He has supervised or cosupervised 62 PhD students, many of whom have become academics or researchers in movie visual effects and game industries. He is

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Contributors

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Funda Durupınar earned a PhD in 2010 from the Department of Computer Engineering at Bilkent University, Ankara, Turkey. She earned a BS at Middle East Technical University, Ankara, Turkey, and an MS at Bilkent University, both in computer engineering in 2002 and 2004, respectively. She conducted research as a postdoctoral fellow at the Center for Human Modeling and Simulation, the University of Pennsylvania, from 2011 to 2015. She is a research software engineer at the Oregon Health and Science University, Portland, Oregon. Her research interests include crowd simulation, intelligent and emotional virtual agents, physically based simulation, cloth modeling, and rendering.

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Eberhard Haug is one of the founding members of the ESI Group, the well-known virtual prototyping company, where he held the position of scientific director. He now acts as a consultant. He graduated from the University of Stuttgart in civil engineering and earned a PhD in structural engineering at the University of California, Berkeley, where he wrote a program for the large displacement finite element stress-controlled shape finding and analysis of lightweight structures. He was a research associate at the University of Stuttgart with Professors Frei Otto and J. Argyris. At ESI, he was the driving force behind the development of various industrial nonlinear FE analysis programs and material model

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