

Crowd Simulation

Daniel Thalmann and Soraia Raupp Musse

Crowd Simulation

With contributions from: Adriana Braun, André Tavares da Silva, Barbara Yersin, Branislav Ulicny, Cláudio Rosito Jung, Daniel Paiva, Fernando Santos Osório, Júlio Cesar Jacques Júnior, Jonathan Maïm, Julien Pettré, Leandro Motta Barros, Luiz Gonzaga da Silveira Júnior, Pablo de Heras Ciechomski, Renata Vieira, Ronan Boulic.

Daniel Thalmann
EPFL VRLab
Station 14
CH 1015 Lausanne, Switzerland
daniel.thalmann@epfl.ch

Soraia Raupp Musse
Graduate Course in Computer Science
PUCRS
6681, Av. Ipiranga, 6681 - Building 32
Porto Alegre 90619-900, Brazil
soraia.musse@pucrs.br

British Library Cataloguing in Publishing Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2007927755

ISBN 978-1-84628-824-1 e-ISBN 978-1-84628-825-8

Printed on acid-free paper.

© Springer-Verlag London Limited 2007

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

The use of registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant laws and regulations and therefore free for general use.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

9 8 7 6 5 4 3 2 1

Springer Science+Business Media
springer.com

(Daniel)
To my beloved wife Nadia and beloved daughters Melanie,
Vanessa, and Sabrina

(Soraia)
To my daughter Marina, parents Iara (in loving memory) and
Eduardo, who made me understand how simple things can be.

Preface

This book surveys algorithms and techniques of crowd simulation, and is intended for graduate students, researchers, and professionals. In particular, computer animation researchers, developers, designers, and urban planners will greatly benefit from this book.

In 1996, when the authors started researching into crowd simulation, there was very little material available on crowd simulation in the Computer Science literature. Daniel Thalmann supervised Soraia Raupp Musse PhD thesis in 1997 and since then they have jointly published more than 40 papers in the domain. There has since been significant research in this area and many techniques have been developed, with the entertainment industry in particular realising the potential of crowd animation. As a result, many other research groups have also started working in the area. As early pioneers in this research, the authors organized the first workshop on Crowd Simulation (V-Crowds) in 2005 in Lausanne. But why is this subject so fascinating?

Aggregated motion is both *beautiful* and *complex* to contemplate. *Beautiful* due to the synchronisation, homogeneity and unity described in this type of motion, and *complex* because there are many parameters to be handled in order to provide these characteristics. History shows that there has always been interest in understanding and controlling the motion and behaviour of crowds of people. Psychologists and sociologists have studied the behaviours of groups of people for several years, primarily to study the effects that occur when people with the same goal become one entity – a crowd or a mass. When this happens, people can lose their individuality and adopt the behaviour of the crowd entity, behaving in a different way than if they were alone.

Certain problems arise only when studying crowds. For instance, collision avoidance problems related to a large number of individuals in the same place require different strategies in comparison with the methods used to avoid collision between individuals. Also, motion planning used in a group that walks together requires more information than that needed to implement individual motion planning. The trajectories computed for agents who are part of the

same group and walk together with similar speeds have to be different even when they share the same environment and goals.

Moreover, a crowd is not only a large group of individuals, but can also be formed by groups which in turn are related to individuals. In addition other levels of behaviour can exist when treating crowds in this hierarchical structure. The group behaviours can be used to specify the way a group moves, behaves and acts in order to fit different group structures (flocking, following, repulsion, attraction, etc). Individual abilities can also be required in order to improve the autonomy and intelligence of crowds, for instance perception, emotional status, memory, communication, etc. However, when we consider thousands of individuals, these complex behaviours cannot be provided individually due to the hardware constraints and to computational time rates. A further problem relates to how to improve the intelligence and provide autonomy to scalable crowds, in real-time systems.

The simulation of large crowds in real time requires many instances of similar characters. We need algorithms to allow for each individual in the crowd to be unique. In this book we explain two methods: first, a simple and efficient way of attaching accessories to individuals in order to modify their look; and secondly, a new and generic technique based on segmentation maps to add detailed color variety and patterns to human meshes as well as to accessories. Both methods are scalable to suit all human levels of detail exploited in crowd simulations.

Depending on the application of crowds, other requirements may be needed. For instance real time simulations can be required in order to populate virtual environments in virtual reality systems. In order to provide a tool to simulate behavioural aspects of a crowd, social conventions of inter-relationships are needed. Yet, accurate validations should be provided to simulate safety systems.

Some crowd requirements along with strategies and techniques that can be adopted to deal with these, are described in this book. Some of the topics presented are related to population modelling, virtual human animation, computer vision techniques focusing on crowd control and crowd rendering, and some applications are analysed.

Contents

1	Introduction	1
1.1	Requirements and Constraints for Crowd Modeling	2
1.2	Crowd Simulation Areas	3
2	State-of-the-Art	5
2.1	Crowd Management Training Systems	6
2.2	Sociological Models of Crowds	7
2.3	Group Behavior in Robotics and Artificial Life	7
2.4	Crowds in Virtual Worlds	8
2.5	Behavioral Animation of Groups and Crowds	9
2.6	Environment Modeling for Crowds	11
2.7	Crowd Rendering	12
2.8	Crowds in Non-Real-Time Productions	14
2.9	Crowds in Games	15
2.10	Crowd Scenario Authoring	16
3	Modeling of Populations	19
3.1	Introduction	19
3.2	Creative Methods	20
3.3	Body Shape Capture	21
3.4	Interpolated Techniques	22
3.5	A Model for Generation of Population	24
3.5.1	Definition of the Initial Data	26
3.5.2	Choice of a Template	26
3.5.3	Definition of New Somatotypes	27
3.5.4	Calculation of Influence of Sample Somatotypes	28
3.5.5	Calculation of Mesh Variation	29
3.5.6	Body Parts' Deformation	30
3.5.7	Results and Discussion	31
3.6	Crowd Appearance Variety	35
3.6.1	Variety at Three Levels	36

3.6.2	Color Variety	38
3.6.3	Accessories	46
3.7	Final Remarks	58
4	Virtual Human Animation	59
4.1	Introduction	59
4.2	Related Work in Locomotion Modeling	60
4.2.1	Kinematic Methods	60
4.2.2	Physically Based Methods	61
4.2.3	Motion Interpolation	62
4.2.4	Statistical Models	64
4.3	Principal Component Analysis	65
4.3.1	Motion Capture Data Process	65
4.3.2	Full-Cycle Model	65
4.3.3	Motion Extrapolation	68
4.4	Walking Model	72
4.4.1	Motion Interpolation and Extrapolation	72
4.5	Motion Retargeting and Timewarping	75
4.6	Motion Generation	76
4.6.1	Speed Control	77
4.6.2	Type of Locomotion Control	78
4.6.3	Personification Control	78
4.6.4	Motion Transition	78
4.7	Results	79
4.8	Animation Variety	81
4.8.1	Accessory Movements	81
4.9	Steering	84
4.9.1	The Need for a Fast Trajectory Control	84
4.9.2	The Seek and Funneling Controllers	84
4.10	Final Remarks	87
5	Behavioral Animation of Crowds	89
5.1	Introduction	89
5.2	Related Work	89
5.3	Crowd Behavioral Models	93
5.3.1	PetroSim's Behavioral Model	94
5.3.2	A Physically Based Behavioral Model	99
5.4	Crowds Navigation	106
5.4.1	Robot Motion Planning	107
5.4.2	Crowd Motion Planning	109
5.4.3	A Decomposition Approach for Crowd Navigation	116
5.5	Final Remarks	123

6	Relating Real Crowds with Virtual Crowds	125
6.1	Introduction	125
6.2	Studying the Motion of Real Groups of People	125
6.2.1	Crowd Characteristics	125
6.2.2	Crowd Events	128
6.2.3	Parameters for Simulating Virtual Crowds Using Real Crowd Information	129
6.2.4	Simulating Real Scenes	130
6.3	Sociological Aspects	134
6.4	Computer Vision for Crowds	135
6.4.1	A Brief Overview on People Tracking	136
6.5	An Approach for Crowd Simulation Using Computer Vision	138
6.5.1	Using Computer Vision for People Tracking	138
6.5.2	Clustering of Coherent Trajectories	141
6.5.3	Generation of Extrapolated Velocity Fields	143
6.5.4	Simulation Based on Real Data	143
6.5.5	Some Examples	145
6.6	Final Remarks	147
7	Crowd Rendering	149
7.1	Introduction	149
7.2	Virtual Human Representations	150
7.2.1	Human Template	150
7.2.2	Deformable Mesh	151
7.2.3	Rigid Mesh	152
7.2.4	Impostor	152
7.3	Architecture Pipeline	155
7.3.1	Human Data Structures	157
7.3.2	Pipeline Stages	158
7.4	Motion Kits	165
7.4.1	Data Structure	165
7.4.2	Architecture	167
7.5	Database Management	169
7.6	Shadows	172
7.7	Some Results	174
7.8	Final Remarks	176
8	Populated Environments	177
8.1	Introduction	177
8.2	Terrain Modeling	178
8.2.1	Plants and Lakes	180
8.2.2	Sky and Clouds	181
8.3	Informed Environment	181
8.3.1	Data Model	184
8.3.2	Topo Mesh	186

8.4	Building Modeling	188
8.5	Landing Algorithms	189
8.6	Ontology-Based Simulation	191
8.6.1	Using Ontology for Crowd Simulation in Normal Life Situations	191
8.6.2	Applying Ontology to VR Environment	193
8.6.3	The Prototype of UEM	193
8.6.4	Simulation Results	195
8.7	Real-Time Rendering and Visualization	199
8.8	Implementation Aspects	199
8.9	Final Remarks	200
9	Applications: Case Studies	201
9.1	Introduction	201
9.2	Crowd Simulation for Virtual Heritage	201
9.2.1	Virtual Population of Worshippers Performing Morning Namaz Prayer inside a Virtual Mosque	202
9.2.2	Virtual Roman Audience in the Aphrodisias Odeon	204
9.3	Crowdbrush	209
9.3.1	Brushes	211
9.4	Safety Systems	216
9.5	Final Remarks	218
10	Book Contribution	219
	References	221
	Index	241