Computers & Graphics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

ELSEVIER

Technical Section

Using real life incidents for realistic virtual crowds with data-driven emotion contagion ☆

Q1 Ahmet Eren Başak [a], Uğur Güdükbay [a,*], Funda Durupınar [b]

[a] Department of Computer Engineering, Bilkent University, Ankara 06800, Turkey
[b] Computational Biology Program, Oregon Health & Science University, Portland, OR 97239, USA

A R T I C L E I N F O

Article history:
Received 25 October 2017
Revised 2 February 2018
Accepted 5 February 2018
Available online xxx

Keywords:
Crowd simulation
Emotion contagion
Parameter learning
Data-driven optimization

A B S T R A C T

We propose a data-driven approach for tuning, validating and optimizing crowd simulations by learning parameters from real-life videos. We discuss the common traits of incidents and their video footages suitable for the learning step. We then demonstrate the learning process in three real-life incidents: a bombing attack, a panic situation on the subway and a Black Friday rush. We reanimate the incidents using an existing emotion contagion and crowd simulation framework and optimize the parameters that characterize agent behavior with respect to the data extracted from the video footages of the incidents.

1. Introduction

Crowd psychology has attracted the attention of scholars for more than a century. In his seminal work, “The Crowd: A Study of the Popular Mind”, Le Bon [1] describes the salient aspects of crowd psychology as impulsiveness, irrationality, emotionality and mental unity. This phenomenon is also known as *collective (mis)behavior*. Social psychology literature introduces various theories to explain the reasons for collective crowd behavior, including social contagion [1,2], predisposition [3–5] and emergent-norms [6] theories. Brown [7] describes an elaborate taxonomy of crowds and classifies crowds under two general categories as *audiences* and *mobs* depending on the existence of observable unified behavior, instead of the reasons bringing crowd members together. In both categories, crowd members share a common goal unlike pedestrians on a street who happen to be coincidentally at the same place at the same time. What distinguishes mobs from audiences is their active and emotional disposition, which leads to “mob”ility. This feature makes mobs more interesting to study (and simulate) as they display more diverse and interesting behaviors than audiences. Therefore, we focus on mob simulations in this work.

One of the most influential factors that causes collective mob behavior is emotion contagion. Emotion contagion is the phenomenon of having the feelings and responses of one person influencing and manipulating the emotions of others in a group of individuals [8]. Within this continuous feedback mechanism, we generally observe that emotions and resulting behaviors converge to a single active response over time, thus converting audiences to mobs. Because of this feature, systems that model emotion contagion mostly focus on mob behaviors.

We need a universal, objective, quantitative and reusable method for validating crowd simulation models, not just in terms of the steering behaviors of individuals but the authenticity of the group behavior as a whole. We can then formally define future improvements to existing simulation systems and compare different systems under different scenario cases. Crowd simulation literature includes various techniques to evaluate the behavior of virtual agents such as learning parameters from crowd videos [9–11]; determining metrics to compare different simulations [12–14]; and referring to human expert opinions [15]. In this work, we propose a data-driven approach to mimic real crowd behaviors by learning the parameters that affect crowd behavior and to validate crowd simulation systems according to their fidelity to real life behaviors. We apply this approach to the epidemiological emotion contagion framework proposed by Durupınar et al. [16]. We explain how to learn the characteristics of emotion contagion from a real-life event video and how to improve and optimize the emotion contagion model by Durupınar et al. using the results of this analysis. To this end, we investigate the agent behavior before and after the incident and recreate the incident in a virtual environment.

☆ This article was recommended for publication by Yiorgos L. Chrysanthou.

* Corresponding author.
E-mail addresses: eren.basak@bilkent.edu.tr (A.E. Başak), gudukbay@cs.bilkent.edu.tr (U. Güdükbay), durupina@ohsu.edu (F. Durupınar).

https://doi.org/10.1016/j.cag.2018.02.004
0097-8493/

Please cite this article as: A.E. Başak et al., Using real life incidents for realistic virtual crowds with data-driven emotion contagion, Computers & Graphics (2018), https://doi.org/10.1016/j.cag.2018.02.004

The contributions of this paper are as follows:

- We propose a data-driven, quantitative and reproducible pipeline for learning parameters from real crowd videos for synthesizing virtual crowds.
- We explain how real-life incidents can be utilized for evaluation and improvement of crowd simulations.
- We clarify the properties of suitable material for this process and demonstrate how to process videos of real-life incidents for virtual environment creation.
- We analyze three contemporary incidents and apply our proposed approach to an existing emotion contagion and crowd simulation system.

A preliminary version of this research has appeared as a conference paper [17]. Different from [17], which analyzes only one scenario, this extended version includes a comprehensive set of experimental results for three different scenarios. We introduce new error metrics to evaluate the proposed approach and include new figures illustrating our approach and its experimental results, as well as new sets of graphs about the experimental results. We also re-organize and extend the related work to fully cover the state-of-the-art on the subject.

The rest of the paper is organized as follows. In Section 2, we discuss the related work in emotion contagion, crowd simulation and empirical evaluation studies. In Section 3, we provide a brief overview of existing emotion contagion models and Durupınar Emotion Contagion Model that we base our studies on. In Section 4, we explain the proposed parameter learning framework and necessary steps to analyze crowd videos before using them for the optimization process. In Section 5, we explain the incidents that we studied, how we extracted data from them, how we recreated them in a virtual environment and how we simulated them using Durupınar model. In Section 6, we demonstrate and discuss the results of our parameter estimation mechanism on the studied incidents. Finally, we summarize our work in Section 7, draw conclusions and discuss future improvement ideas.

2. Related work

We provide a comprehensive review of related work on the simulation of virtual crowds including emotion contagion studies and on the comparison of virtual crowds with real crowds in our previous work [17]. The review refers to various crowd simulation studies that analyze interactions with the environment [18], the influence of architecture on crowd behavior [19], data-driven evaluation of crowds with trajectory extraction [9–11,14] and scoring metrics [12,13], emotion contagion models [16,20–23], the role of appraisal in emotion contagion [15] and how emotion contagion can be used for simulation of emergency situations [24,25]. In addition to these, there are other studies that cover the influence of the environment on the emotions and behavior of crowd members. For instance, Hoogendorn et al. study the information exchange and emotion contagion within crowds [26]. They model the change of information spread with respect to the emotional states of individuals and simulate an emergency situation to demonstrate their work. Borodin et al. [27] and Chen et al. [28] apply the concept of influence among the groups of people to social networks and show that the responses of key individuals steer the behavior of the whole group significantly.

Heterogeneity is an important aspect of realistic crowd simulation that has been studied by many groups. Pereira et al. [29] present a computational model for emotion contagion in virtual crowds, incorporating personality differences and interpersonal relationships. They take intimacy between virtual agents into account for the influence of emotions, where higher intimacy results in more homogeneous emotional behaviors in crowds. Silverman et al. [30] propose an architecture that combines an existing pathfinding and cognitive navigation system (MACES) with PMFserv, which models the changing behaviors of individuals according to stress, emotions and motivations. Helbing and Molnar demonstrate the social forces model for explaining crowd behavior [31], where the characteristics of individuals in a crowd affect the motion of surrounding pedestrians. In a later study, they model the panic behavior in crowds mixing the individualistic behavior and collective instincts [32]. This study simulates a crowd of people escaping from a smoke-filled room and proposes an optimal strategy for escaping from such disasters.

Evaluation of simulated crowds in terms of their similarity to real world is another challenge that has been extensively studied. Fridman and Kaminka [33] demonstrate a crowd simulation model based on Social Comparison Theory and argue that their model is suitable for general usage. Furthermore, they propose a method for evaluating the imitation performance by showing people video clips of random crowds and as well as simulations, then asking questions to clarify whether they perceived the video as the behavior of unrelated individuals or more like a collective response. Lin et al. [34] model the crowd behavior evacuating an office building. In their case study, using the videos taken by the security cameras, they calibrate the parameters of their model. Similarly, Tan et al. [35] use an agent-based crowd model for simulating an evacuation incident and propose a method for representing indoor space for such simulations.

3. Emotion contagion approaches

3.1. ASCRIBE

Bosse et al. [24] present ASCRIBE, a computational model of neural mechanisms of social mutual adaptation for satisfactory common group decisions. ASCRIBE incorporates a basis for modeling the interaction between the beliefs and emotions of an agent while also providing mechanisms for the influence of emotions, intentions and beliefs among agents.

In its core, ASCRIBE has a model for agents that mirror the mental states of each other, representing the contagion phenomenon. In this model the amount of influence of a mental state of one agent on another depends on the *expressiveness* of the sender agent, *openness* of the receiver agent and *channel strength* between the subjects, which depends on physical conditions such as distance and field of view. The combination of the influence of all the other agents constitutes the overall contagion strength on an agent. The updated mental state of an agent is calculated as a combination of the overall contagion and the agent's previous state. The coefficient of the contagion component determines the speed of adjustment in an agent's mental state and the convergence of the crowd behavior.

The interaction among emotions, beliefs and intentions of an agent are also incorporated into the ASCRIBE model. In this model, fear starts affecting information retrieval and amplifies the influence of the beliefs on behavior if it is above a threshold. The value given to information by an agent will be affected by the fear and personality as well, e.g., a pessimistic person with high level of fear would be significantly affected by negative information; and positive information would have less influence on the agent's behavior. Similarly, information influences the emotional state. For example, negative information has a tendency to increase fear. Finally, beliefs and emotions together affect the intentions of an agent.

Bosse et al. test ASCRIBE with two scenarios, a synthetic office evacuation scenario which demonstrates the influence of information on agents' behavior, and a reanimation of a real-life incident for demonstrating the model's mimicking potential. The May 4th incident that happened in Dam Square, Amsterdam in 2010

Please cite this article as: A.E. Başak et al., Using real life incidents for realistic virtual crowds with data-driven emotion contagion, Computers & Graphics (2018), https://doi.org/10.1016/j.cag.2018.02.004