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Density-based evolutionary framework for crowd model calibration

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ABSTRACT

Crowd modeling and simulation is an important and active research field, with a wide range of applications such as computer games, military training and evacuation modeling. One important issue in crowd modeling is model calibration through parameter tuning, so as to produce desired crowd behaviors. Common methods such as trial-and-error are time consuming and tedious. This paper proposes an evolutionary framework to automate the crowd model calibration process. In the proposed framework, a density-based matching scheme is introduced. By using the dynamic density of the crowd over time, and a weight landscape to emphasize important spatial regions, the proposed matching scheme provides a generally applicable way to evaluate the simulated crowd behaviors. Besides, a hybrid search mechanism based on differential evolution is proposed to efficiently tune parameters of crowd models. Simulation results demonstrate that the proposed framework is effective and efficient to calibrate the crowd models in order to produce desired macroscopic crowd behaviors.

1. Introduction

Crowd modeling and simulation has become an important and active research field recently, with applications in diverse areas such as computer games [1], military training [2], and evacuation modeling [3–6]. Various modeling approaches such as the particle models [7,8], flow-based models [9,10], and agent-based models [11–15] have been proposed for crowd simulation. A thorough survey on crowd modeling and simulation technologies can be found in [16].

One important issue in crowd modeling and simulation is model calibration, which aims to tune the parameters of a model so that the output of the model can match with observed data in real world (e.g., crowd behaviors extracted from videos). Once a crowd model has been well calibrated, it can then be used for prediction and "what-if" scenario analysis. However, as the simulated crowd behavior is affected indirectly and unintuitively by the parameter settings of the crowd model, finding the correct parameter settings to reproduce desired crowd behaviors is a challenging task. Typically modelers will manually tune parameters until an acceptable simulated output is obtained. This trial-and-error method is time consuming, tedious, and requires an experienced person to manipulate the calibration process. Therefore, developing an effective approach to automate the crowd model calibration process is of urgent need. This paper aims to address this crowd model calibration problem (CMCP). That is, given a crowd simulation model and some objective behaviors, such as those extracted from videos, we aim to find the correct parameter setting of the crowd model through an automatic mechanism so that the simulated output closely matches the objective behaviors.

The CMCP problem has been addressed previously and these approaches focus mainly on using Evolutionary algorithms (EAs) [17,18] such as Genetic Algorithm (GA). EAs are metaheuristic optimization methods, which have been shown very effective to find near global solutions to complex optimization problems [19,20]. A salient feature of EAs differing from traditional optimization techniques is that they require no explicit formulation of the problem but only a fitness function to evaluate solutions. The CMCP is just such a problem for which it is hard to formulate the relationship between inputs and outputs. Besides, as EAs incorporate randomness in the search process, they are capable of avoiding stagnation in local optima. Therefore, EAs are suitable to solve the CMCP.

However, there are some drawbacks of the existing methods. Existing methods focus mainly on matching crowd behaviors at a microscopic level (e.g., trajectories of pedestrians). Nevertheless, collecting microscopic data of dense crowd is still challenging in

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practice [21]. Besides, in some cases, the individual's behaviors are highly dynamic and stochastic, matching these behaviors is usually infeasible. In addition, EAs are population-based stochastic search algorithms. They require a large number of fitness evaluations during the evolution process. For crowd model calibration, each fitness evaluation requires a few simulation runs. Therefore, using EAs to solve CMCP requires a large number of simulation runs, which can be very time consuming. It is still highly desirable to develop an efficient mechanism to reduce the computational time.

To tackle the above drawbacks, this paper proposes an effective and efficient evolutionary calibration framework. The proposed framework features a novel density-based matching scheme that is used for fitness evaluation. In the proposed density-based matching scheme, the dynamics of crowds are captured by the density distribution of the crowds over a time period. A weight vector is utilized to scale the density distribution so that more important regions, where a highly accurate match is essential (e.g., around a doorway in evacuation scenarios), can play more important roles in the similarity measurement. By calculating the distance between the scaled density distribution, the similarity between a simulated crowd behavior and an objective crowd behavior can be measured at a macroscopic level. The proposed density-based matching scheme is easy to implement and can be applied to different crowd scenarios such as the emergency evacuation scenarios. With this matching scheme, the proposed framework can automatically adjust control parameters so that certain desired collective behavior can emerge. Thus, our framework is useful for the development of crowd management strategies and can be used in conjunction with other work in the area of evacuation modeling and analysis [22–25].

To improve the search efficiency, the proposed framework makes use of a hybrid search mechanism based on differential evolution (DE). DE is a popular and powerful EA which was proposed by Storn and Price [26] for global optimization. It has been shown to perform much better than several other EAs such as GA on a wide variety of problems [20]. To accelerate the search, the proposed EA framework incorporates an "Exploration Module" and an "Exploitation Module". The "Exploration Module" focuses on global search, while the "Exploitation Module" focuses on refining the best-so-far solution to accelerate the search. In addition, the proposed framework tunes the parameter setting of a given crowd model based on multiple objective behaviors (i.e., training cases). In this way, more general solutions can be generated for prediction and the overfitting problem can be avoided. The proposed framework has been evaluated through the calibration of two modified social-force models. The simulation results demonstrate the effectiveness and efficiency of the proposed framework.[1]

The rest of the paper is organized as follows. Section 2 describes the related work. Section 3 describes the proposed density-based evolutionary framework for crowd model calibration. Section 4 presents the simulation studies. At last, Section 5 draws the conclusions.

2. Related work

The commonly used methods for automatic model calibration are mainly based on the gradient-based methods [27], Nelder-Mead [28], and linear regression [29]. These deterministic search methods can provide solutions quickly, but they may get trapped into local optima easily [30].

Recently, stochastic search methods such as GA has become popular to calibrate computer models [17,31–33]. Take agent-based models (ABMs) for example, Calvez and Hutzler [34,35] proposed to consider the parameter estimation of an ABM as an optimization problem and suggested using GAs to solve the problem. Stonedahl and Wilensky [36] incorporated a GA into a software tool named "Behavior Search" to calibrate the parameters of two agent-based flocking models. Smith [37] applied a GA to calibrate the parameters of an agent-based cowbird model.

As for automatic crowd model calibration (i.e., the CMCP), the research is still at an early stage due to the difficulties in automatic evaluation of simulated crowd behaviors. The dominant methods to evaluate simulated crowd behaviors are based on "look and feel" [38]. Johansson et al. [17] proposed an EA to calibrate the parameters of a classical crowd model: the social force model. They utilized the microscopic motions of pedestrians such as the moving speed and direction to evaluate the simulated crowd behaviors. The main difference between our work and the above work is that our aim is to match crowd behaviors at a macroscopic level (in terms of density distribution), while the above work focuses on matching crowd behaviors at a microscopic level (in terms of trajectories of pedestrians). Besides, our work utilizes a specific mechanism to reduce the computational time. Wolinski et al. [18] proposed a general framework to compare different crowd models. The authors suggested using EAs to calibrate the crowd models before comparing their performances. The authors also listed some feasible metrics for evaluation such as the path length metric. However, the effectiveness of the framework is investigated mainly based on simple cases (e.g., collision avoidance behaviors), while the discussion on using EAs to calibrate complex crowd models (e.g., those contain high-level behavior rules) still remains at a conceptual level.

Some data-driven methods have been proposed to generate realistic crowd behaviors. For example, Lee et al. [21] made use of historical video data to train state-actions of agents so as to generate realistic crowd behaviors. Lerner et al. [39] proposed to control the motions of autonomous agents by searching examples in historical data that closely match the situation that they are facing. Ju et al. [40] used small examples in historical data to construct larger scale crowd behaviors. The main difference between our work and the above work is that our work focuses on developing an effective and efficient framework to calibrate a given crowd model, while the above works focus on generating realistic crowd behaviors.

3. The proposed density-based evolutionary framework for crowd model calibration

3.1. The general framework

To apply an EA to crowd model calibration, three important issues need to be addressed. The first issue is to define a general and effective fitness function to measure the distance between a simulated crowd behavior and the objective crowd behavior. The second issue is to reduce the computational time, because EAs require a large number of fitness evaluations which can be very expensive (especially for large scale scenarios). The third issue is to obtain robust solutions for avoiding the over-fitting problem. That is, the calibrated crowd model is not only able to reproduce the specific given objective behavior, but also able to correctly predict unknown behaviors that come from the same crowd. For example, when the initial positions of pedestrians in an objective behavior are changed, it is desired that the crowd model is able to predict the crowd behavior with the modified initial conditions. To solve these problems, we propose a density-based evolutionary framework as shown in Fig. 1.

Specifically, the proposed calibration framework consists of four modules. The first module is the *Preprocessing module* which aims to obtain a certain number of training and testing cases. The training

[1] Related simulation videos can be found at http://crowds.sce.ntu.edu.sg/index.php/research/dbmc.