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Guide them through: An automatic crowd control framework using multi-objective genetic programming

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ABSTRACT

We propose an automatic crowd control framework based on multi-objective optimisation of strategy space using genetic programming. In particular, based on the sensed local crowd densities at different segments, our framework is capable of generating control strategies that guide the individuals on *when* and *where* to slow down for optimal overall crowd flow in realtime, quantitatively measured by multiple objectives such as shorter travel time and less congestion along the path. The resulting Pareto-front allows selection of resilient and efficient crowd control strategies in different situations. We first chose a benchmark scenario as used in [1] to test the proposed method. Results show that our method is capable of finding control strategies that are not only quantitatively measured better, but also well aligned with domain experts' recommendations on effective crowd control such as "slower is faster" and "asymmetric control". We further applied the proposed framework in actual event planning with approximately 400 participants navigating through a multi-story building. In comparison with the baseline crowd models that do no employ control strategies or just use some hard-coded rules, the proposed framework achieves a shorter travel time and a significantly lower (20%) congestion along critical segments of the path.
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1. Introduction

Crowd modelling and simulation has gained increasing attention from industry, academia and government due to its wide applications [2] to understand, replicate and predict crowd dynamics in various situations. As a natural extension to and an application of crowd modelling and simulation, crowd control aims to intervene [3] the movement of crowds in a desired manner so that certain objectives are met, for instance, to prevent turbulence or stampede in events involving massive crowds, to avoid bottlenecks of crowd flow, or to minimize overall travelling time, etc.

To apply appropriate crowd control strategies to intervene the crowd in a desired manner, one needs to first understand the implicit (unintervened) crowd dynamics under specific scenarios, which can be studied through crowd modeling and simulation. One promising approach is agent-based modelling (ABM), which treats individuals as agents that can perceive, decide and act independently based on some rules [4]. From the ABM perspective, crowd dynamics emerge from the motions of individuals, and the motions can be generated through a simplified two-layer movement model [5]. At the *path planning* layer (the higher layer), an agent plans/finds a path to navigate through the environment. The path segments are usually formed as a list of waypoints representing important landmarks and accessable areas. While at the *collision avoidance* layer (the lower layer), it avoids collisions with others while moving along the planned path. From the modeling perspective, there are some established methods to specify the rules for agents at both layers. For path planning, both shortest path algorithms (such as A^*) [6] and accumulative segment-based algorithms that take account of vision range [7] have been well established to guide an agent to move through a set of static obstacles in an environment. For collision-avoidance, algorithms such as reciprocal velocity obstacle (RVO) and its variants [8], and social force model (SFM) [9] are proven efficient and widely adopted. With the two layers of movement behaviours, ABM can generate various crowd dynamics given the initial configurations of the agents (e.g., preferred speed, personal space factor etc.) and the environment (e.g., waypoints of paths, obstacles etc.).

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Due to the complex interactions among the agents, the stochastic nature of the crowd model and the large number of parameters involved, finding a "good" crowd control strategy that explicitly intervenes movements of crowds in order to produce the "desired" crowd movements often requires a large number of simulations, which is time-consuming if performed manually. It is therefore important to automate the search process for optimal crowd control strategies. Evolutionary algorithms (EAs) are population-based non-deterministic search algorithms, which can be used to adaptively evolve a simulation model through automating the calibration of model parameters as well as model structures (such as behavioural rules of agents) [10,11]. Although there are scattered existing works on using EAs for automatic crowd control, they mainly focus on the optimization of parameters, which may limit the search space by the fixed number of parameters. In this paper, we apply Genetic programming (GP) to enable both parameter and structure evolving for automatic crowd control, which will be depicted in Section 4.

The need for multi-objective optimization [12] is also essential for crowd control, as a good control strategy often needs to achieve different aspects of crowd dynamics simultaneously. For example, increasing the speed of an escalator may improve the flow rate of one segment of a path, while it may cause congestion at other (e.g., the subsequent) segments if there are spatial bottlenecks. Thus, the overall flow rate and the congestion conditions along the path need to be considered simultaneously in searching for a good crowd control strategy in this case. In this paper, our proposed GP-based framework can automatically search for the optimized parameters and rules used in an agent-based crowd model for crowd control purposes, specifically to optimize multiple objectives from the crowd dynamics perspective.

The rest of the paper is organized as follows: Section 2 describes the existing efforts in applying EAs to calibrate crowd simulation models, and traditional crowd control approaches. The problem of automatic crowd control through optimization of an agent-based model is formally defined in Section 3. As the proposed solution to address the problem, the GP-based crowd control framework is discussed in Section 4. In Section 5, we test the framework with two scenarios, a well studied evacuation scenario in [1] and a real life event planning scenario, where approximately 400 delegates are directed to leave a multi-story building with escalators transporting between stories. Section 6 concludes the paper and gives recommendations for future work.

2. Related work

2.1. Application of evolutionary algorithms in crowd simulation models

Modeling and simulation has become a promising approach to study crowd dynamics in recent years. Various models [4,5,13,14] have been proposed with different focuses on particular aspects of a crowd according to the requirements of an application. One common and critical objective of these models is to generate *realistic* crowd behaviors through model calibration and validation [10,11,15], and variations of EAs have been applied to achieve this goal.

The most common idea is to use EAs to tune parameters of a crowd model so that the *microscopic* individual behaviors (e.g., moving trajectories) can match those retrieved from image or video data. For example, Johansson et al. [16], applied an EA to calibrate the parameters of the social force model (SFM). They tried to match the microscopic motions of pedestrians such as the moving speed and direction. Similarly, Li et al. [17] used a Genetic Algorithm (GA) to find an optimal set of weighting parameters for composing virtual forces in a crowd model. On the other hand, efforts have also been made to tune crowd model to match *macroscopic* crowd features such as dominant moving directions and paths of the crowd in a specific scenario. For example, Zhong et al. [11] proposed an EA-based framework to evolve the parameters of a modified SFM in order to match *macroscopic* crowd features (i.e., the crowd densities). Wolinski et al. [18] also suggected several macroscopic metrics for model calibration based on EAs.

There are two major differences of our proposed approach compared to these methods. First, most existing EA-based approaches focus on tuning parameter settings of specific models (e.g., SFM and RVO2) based on videos [18], assuming a predefined set of rules can capture different crowd dynamics well under different situations. However, this may not be the case as crowd behaviors are complex and stochastic in nature. Thus, not only the parameters but also some behavioral rules need to be evolved and applied to a specific situation to reproduce the observed crowd behaviors. Zhong et al. [10] has demonstrated GP-based approaches can be applied to find behavioral rules of crowd in order to match the simulation results with the empirical data. In this paper, we use a GP-based approach to allow both rule structure and parameter evolving in order to search for the most fit rules to influence (control) crowd behaviors. Second, the EA-based optimization approach has seldom been applied in crowd control, which *explicitly* intervene the crowd behaviors besides the implicit behaviors rules. In this paper, we define and differentiate two sets of rules and parameters that implicitly and explicitly influence crowd's behaviors, respectively. Implicit rules mimic intrinsic rules that agents follow to define their navigational and collision-avoidance behaviors, while explicit rules are defined for crowd control intervention. Existing EA-based approach has been focused on the implicit set optimization in order to achieve realistic simulation results; whereas we will focus on optimizing the explicit set that may represent some crowd control strategies which can be maneuvered by planners to better manage large crowds.

2.2. Existing crowd control methods

Automatic crowd control is an emerging research topic in crowd studies. Traditionally, two main levels of controlling measures are adopted for crowd control [19,3]. On the *aggregated* level, interventional measures are applied to regulate and improve the overall crowd flow by artificially setting up spatial and/or temporal constraints on the crowd. For example, spatial constraints such as barriers or fences are usually used to separate crowd flow in front of a bottleneck entrance and to direct the crowd in S shape queues in many crowded scenarios. Temporal intervention such as releasing a large crowd in batches with freeze time in between is another common control measure. Such interventional measures usually serve as general guidelines based on past experience and are almost fixed at the pre-planning stage of a new crowd scenario. While on the *individual* level, some regulators geared with different non-lethal weapons/tools are arranged to guide and ease hotspots within the crowd in realtime to prevent crowd incidents. This level of crowd control is subject to the dynamic change of the current crowd status, and thus it is a challenge for planners to optimize the deployment of such regulators before the actual events. In summary, crowd control is a complex task with the combination of various factors and procedures to intervene the crowd dynamics in a desired manner. Due to the dynamic interactions of crowds, crowd control solutions/strategies cannot merely reply on empirical guidelines, and on-site intervention strategies need to be studied according to the dynamics of crowd. In this context, agent-based models with proper calibration can be used to test individual solutions/strategies in realtime through simulation-based *what-if* analysis.

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