Formulating a Crowd State Prediction Problem for Application to Crowd Control

Brooks A. Butler[1], Philip E. Paré[1], Mark K. Transtrum[2], Sean Warnick[2]
[1]Purdue University [2]Brigham Young University

Introduction

Protecting crowds at events such as protests is a challenging problem due to the dual issues of **preserving freedom of expression** and **protecting the public from crowd violence**. This project takes an important step towards **predicting crowd violence** by creating a non-linear model for live crowd behavior, then performing state estimation on the model through linearization around the crowd emotion equilibrium.

Modeling Live Crowd Behavior

Goal - Model both violent and non-violent modes of crowd behavior

Our agent-based crowd model tracks the evolution of three states:

- Emotion
  - Agent emotion is represented by the pleasure, arousal, dominance model [1] of emotion as a vector in $\mathbb{R}^3$.
- Position
  - We consider agent movement as point moving around a plane in $\mathbb{R}^2$.
- Opinion
  - Agent opinion is modeled as a vector in $\mathbb{R}^n$, where n is the number of relevant opinions
  - Positive values denote a supporting viewpoint while negative values denote an opposing view

All agents are given fixed personality parameters as defined by the OCEAN personality model [2].

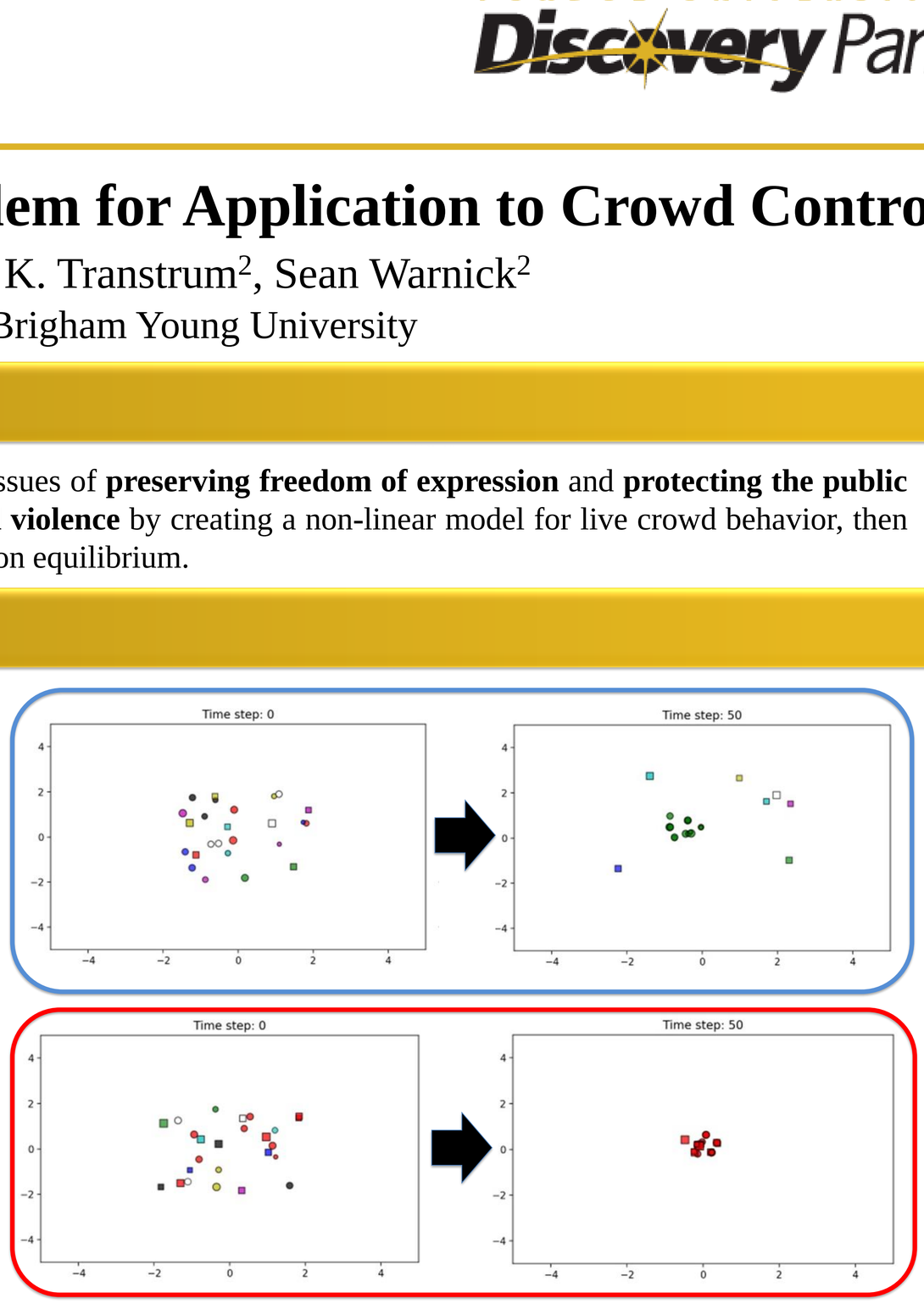

Figure 1: Simulations of 25 agents exhibiting non-violent (BLUE) and violent (RED) modes of behavior based on initial agent emotion and agent opinion. Opinion sign and magnitude is represented by shape and size respectively, position is plotted in $\mathbb{R}^2$, and the emotion value is represented by color.

Emotion Dynamics Model

Let $e_i[k] \in \mathbb{R}^3$ represent the emotion of agent i at time step k, then

$$e_i[k+1] = e_i[k] + \Delta e_i[k] \quad (1)$$

where $\Delta e_i[k]$ is the change in emotion for agent i defined by

$$\Delta e_i[k] = A_i(e_i[k] - e_i^*) + \lambda(s_i, e_{j\neq i}) \quad (2)$$

where $A_i \in \mathbb{R}^{3\times 3}$ is a linear model defining the rate of convergence of agent i to their resting emotion e_i^* when unaffected by other agents.

We define the effect of other agents j on agent i as the **emotional contagion factor** [3] defined by

$$\lambda(s_i, e_{j\neq i}) = \frac{1}{N-1}\sum_{j\neq i}^{N} d_{ij} e_j q_j s_i h_j \quad (3)$$

where N is the number of agents in the crowd, d_{ij} is a distance penalty, e_j is the emotion of agent j, q_j and s_i are the extroversion and emotional susceptibly of agents j and i respectively, which are defined by personality parameters, and $h_j \in \{-1,1\}$ is a non-linear signed term.

We use the term h_j to determine whether agent j contributes positively to agent i's emotion or has an opposing effect defined by

$$h_j = 1 - ReLU[-\operatorname{sgn}\left(e_{A_j} e_{D_j}\right) - \operatorname{sgn}(o_i^T o_j)] \quad (4)$$

where e_{A_j} and e_{D_j} are the values of arousal and dominance respectively for agent j and $o_i^T o_j$ measures the difference in opinion between agents.
This term allows for both opposing emotional effects among agents that disagree in addition to enabling violent behavior in the model.

State Estimation

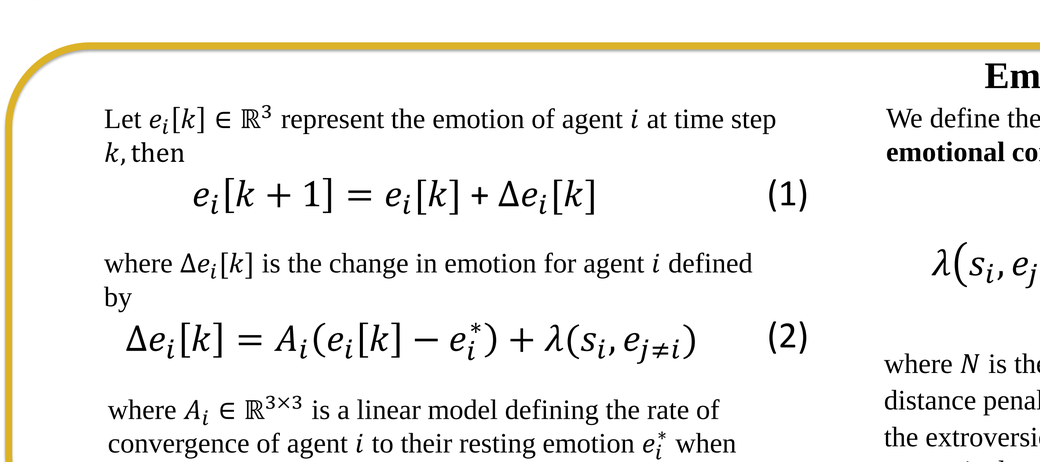

Figure 2: An example of emotion state predictions (dotted lines) versus actual state values (solid lines) for the nonlinear crowd emotion dynamics system for a two-agent crowd where the linearized model given to the state estimator assumes incorrectly that all personality parameter values are average.

Goal – *Predict* violence in multi-agent systems given limited information

- Crowd emotion states are predicted using a state observer on a linearized model, assuming agent position is known.
- We must know the crowd **equilibrium** to perform state estimation.
- Precise knowledge of individual personality and opinion is **not necessary** for zero-error convergence.

Future Work

- Detailed and rigorous study of crowd emotion equilibrium
- Studying the interplay of dynamic opinions and crowd emotion
- Parameter tuning and in-depth analysis of the simulated model
- Rigorous study of observability conditions
- Validation on real crowd data

References

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[3] Libi Fu, Weiguo Song, Wei Lv, and Siuming Lo. Simulation of emotional contagion using modified SIR model: A cellular automaton approach. *Physica A: Statistical Mechanics and its Applications*, 405:380–391, 2014.

Email: brooksbutler@purdue.edu