First Steps Towards a Social Comparison Model of Crowds

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Abstract

Modeling crowd behavior is an important challenge for cognitive modelers. Unfortunately, existing computational models are typically not tied to cognitive science theories, and are rarely evaluated against human crowd data. We investigate a general cognitive model of crowd behavior, based on Festinger's Social Comparison Theory (SCT). We evaluate the SCT model on general pedestrian movement, and validate the model against human pedestrian behavior. The results show that SCT generates behavior more in-tune with human crowd behavior then existing non-cognitive models. Moreover, we examine the impact of the different SCT model components on the generated pedestrian behavior.

Introduction

Modeling crowd behavior is an important challenge for cognitive science and psychology (Le Bon, 1895; Allport, 1924; Turner & Killian., 1972). Accurate models of crowd behavior are sought in training simulations, safety decision-support systems, traffic management, and organizational science. Indeed, a variety of computational models have been proposed that exhibit crowd-like behavior in different tasks. For instance, cellular automata models are used to model pedestrian movements (Blue & Adler, 2000; Helbing & Molnar, 1997) or people evacuating an area in emergency (Helbing, Farkas, & Vicsek, 2000; Kretz, 2007).

Unfortunately, only a handful of existing models of crowd behavior have been evaluated against real-world human crowd data. Moreover, essentially no computational cognitive models have been proposed which are tied to cognitive science theory. Instead, existing models are often inspired by particle physics (modeling individuals as particles), or by cellular automata. Thus fitting in the models with a deeper cognitive model of humans, or the mechanisms of a cognitive architecture, is difficult.

Recently, we presented a novel cognitive model of crowd behavior (Fridman & Kaminka, 2007), which has two key novelties (compared to previous models): First, there is a single computational mechanism (algorithm) used to generate different crowd phenomena (Fridman & Kaminka, 2009); and second, it is inspired by social psychology theory. In particular, the model is based on Social Comparison Theory (*SCT*) (Festinger, 1954), a popular social psychology theory that has been continuously evolving since the 1950s. The key idea in SCT is that humans, lacking objective means to evaluate their state, compare themselves to others that are similar.

We believe that social comparison is a general cognitive process underlying social behavior of each individual in crowd. Unlike previous crowd models that concentrate on specific behavior, the SCT model can account for different crowd behaviors, depending on the perceptions and actions available to each individual (Fridman & Kaminka, 2007). However, while the SCT model proved superior to other computational models in behaviors-specific measures (e.g., the formation of lanes in bidirectional movement), it was never validated against human crowd data.

In this paper we evaluate the SCT model on the specific task of general pedestrian movement which includes individuals, couples, and groups, all walking with different speeds, and in different directions. We contrast the performance of the model with a popular baseline model (Blue & Adler, 2000; Helbing et al., 2000), and explore the impact of different parameters and model components (e.g., bounds) on the generated behavior. The evaluation was carried out by 39 human subjects who compared the behavior generated from the different models to movies of real-world pedestrians. The results clearly justify the the particular parameters selected in earlier work (Fridman & Kaminka, 2007), and also demonstrate the SCT model is superior to others in its fidelity to human pedestrian behavior.

Background and Motivation

Social psychology literature provides several views on the emergence of crowds and the mechanisms underlying its behaviors. These views can inspire computational models, but are unfortunately too abstract to be used algorithmically. In contrast, computational crowd models often ignore cognitive and psychological processes underlying human behavior. Moreover, only a little work was done in validating computational models against data of human behaviors.

General crowd psychology. A phenomenon observed with crowds, and discovered early in crowd behavior research is that people in crowds act similar to one another, often acting in a coordinated fashion, which is achieved with little or no verbal communication. Moreover, the crowd may cause its members to behave differently than they would have individually. There are several different theories that explain this crowd characteristics, focusing on the cognitive process underlying each individual within the crowd.

Contagion Theory (Le Bon, 1895) emphasized a view of crowd behaviors as controlled by a "Collective Mind", and observed that an individual who becomes a part of the crowd is strongly affected by it, to the extent that she is transformed into becoming identical to the others in the crowd. Le Bon explains the homogeneous behavior of a crowd by two processes: (i) *Imitation*, where people in crowds imitate each other; and (ii) *Contagion*, where people in a crowd behave very differently from the way they usually do, individually.

On the other hand, Convergence Theory (Allport, 1924) states that crowd behavior is a product of the behavior of like-minded individuals. According to Allport's theory, individuals become a part of the crowd behavior when they have a "common stimulus" with people inside the crowd; for example, a common cause (Allport, 1924). Allport agrees with Le Bon (1895) about the homogeneous behavior of the crowd.

Turner and Killian (1972) investigated Emergent-norm Theory, which hypothesizes that crowd members indeed imitate each other, but also create new norms for the crowd as the dynamics of the situation dictate. Thus while crowds are not entirely predictable, their collective behavior is a function of the decision-making processes of their members.

Specific models. Researchers have developed computational models for simulation of collective behavior. However, these models are not often tied to cognitive processes underlying individual behavior in crowd and have rarely been validated against human data.

For instance, to simulate pedestrian movements, Blue and Adler (2000) use Cellular Automata approach, Helbing et al. (Helbing et al., 2000) focus on physical and social forces of attraction and repulsion that underlying each simulated entity. A common theme in all of them is the generation of behavior from the aggregation of many local rules of interaction. These models ignore cognitive theories of crowds.

There are several models that account for psychological and cognitive processes underlying agent behavior in crowd. For example, Yamashita and Umemura (2003), propose a model for panic behavior in which each agent acts based on its instincts such as escape instinct, group instinct and imitational instinct. Osaragi (2004) proposed a model for simulating pedestrian flow by using the concept of pedestrian mental stress which may increase or decrease as a result of density. However, these models only focus on cognitive processes underlying specific behaviors like flocking or evacuation and not account for general individual behavior in crowd.

One of the challenges in modeling crowd behaviors is the validation process. There is a great absence of human crowd behavior data that simulated models can be compared against. Only a handful of investigations have utilized experiments to validate computational models against human data.

For example, Kretz (2007) proposes the Floor field-and-Agent based Simulation Tool model (FAST) which is an extension of probabilistic cellular automata and discrete-space, discrete-time model for pedestrian motion. The FAST model has been validated against human data. In particular, the model simulation results of evacuation scenario was compared to results of evacuation exercise at a primary school.

Wolff (1973) examined pedestrian behavior in typical city block, and noted on the coordinated behavior of crowd, in term of creation of lanes in bidirectional movement or spread effect in unidirectional movement. However, in this experiment no quantitative data was presented. To learn more about pedestrian flows (density, speed), Daamen and Hoogendoorn (2003) performed empirical experiments on human crowds, in particular in terms of movement of pedestrians. However, these experiment focused only on the movement of independent individuals, rather than families or friends.

Our long-term goal is to provide a single cognitive mechanism that, when executed by individuals, would give rise to different crowd behaviors, depending on the perceptions and actions available to each individual. In previous work (Fridman & Kaminka, 2007), we presented such a mechanism, based on Social Comparison Theory. The model was evaluated on specific pedestrian movement phenomena, such as creation of lanes in bidirectional movement; it was not evaluated against human pedestrian movement.

A Model of Social Comparison

Our research question deals with the development of a computerized cognitive model which, when executed individually by many agents, will cause them to behave as humans do in groups and crowds. We build on earlier work on the SCT crowd model, briefly described below; the interested reader is referred to (Fridman & Kaminka, 2007) for details.

According to social comparison theory, people tend to compare their behavior with others that are most like them (Festinger, 1954). To be more specific, when lacking objective means for appraisal of their opinions and capabilities, people compare their opinions and capabilities to those of others that are similar to them. They then attempt to correct any differences found.

Translated into an algorithm, we take each observed agent to be modeled by a set of features and their associated values. For each such agent, we calculate a similarity value $s(x)$, which measures the similarity between the observed agent and the agent carrying out the comparison process. The agent with the highest such value is selected. If its similarity is between the given bounds (S_{max} and S_{min}), then this triggers actions by the comparing agent to reduce the discrepancy. The upper bound (S_{max}) prevents the agent from trying to minimize differences with someone who is already sufficiently similar, since such differences are not meaningful. The lower bound S_{min} filters agents that are too dissimilar, and so should be ignored. Thus, within the bounds an agent compares itself with those that differ from it sufficiently to matter. In experiments, we examine the impact of SCT bounds on the generated simulated behavior.

To reduce discrepancy, we determine the list of features f_i that indicate a difference with the selected agent c. We order these features in an increasing order of weight w_i, such that the first feature to trigger corrective action is the one with the least weight. The reason for this ordering is intuitive, and we admittedly did not find evidence for it in the literature. However, in this paper we examine the impact of the correction order on the quality of the simulated behavior.

1. For each known agent x calculate similarity $s(x)$
2. $c \leftarrow \texttt{argmax}\, s(x)$, such that $S_{min} < s(c) < S_{max}$

3. $D \leftarrow$ differences between me and agent c

4. Apply actions to minimize differences in D.

To implement final step of the algorithm, we assume that every feature has associated corrective actions that minimize gaps in it, to a target agent, independently of other features. Festinger writes (Festinger, 1954, p.131): "The stronger the attraction to the group the stronger will be the pressure toward uniformity concerning abilities and opinions within that group". To model this, we use a gain function *Gain* for the action *o*, which translates into the amount of effort or power invested in the action. For instance, for movement, the gain function would translate into velocity; the greater the gain, the greater the velocity.

$$Gain \equiv \frac{S_{max} - S_{min}}{S_{max} - s(c)} \quad (1)$$

Validation Against Human Data

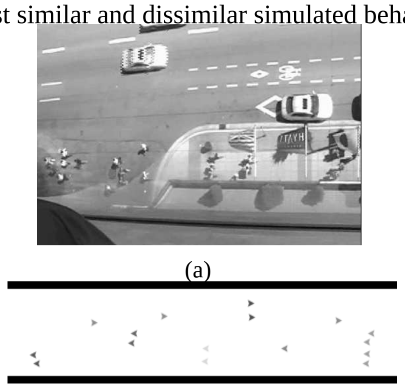
The SCT model was previously evaluated separately on different crowd behaviors (Fridman & Kaminka, 2007). In particular, different types of pedestrian movement phenomena (such as creation of lanes in bidirectional movement of individuals, movement in small groups with and without obstacles, etc.). When evaluated on such specific behavior, it is possible to use community-recognized standard measures, such as flow, number of lane changes, etc. However, when evaluating the model against human data, it must account for a fuller set of behaviors, all mixed together. For example, when watching pedestrians, we can observe people moving as groups like family, friends and couples or as individuals, all walking with different speeds in bidirectional fashion.

A different evaluation methodology is thus needed. One of the greatest challenge in modelling crowd behaviors is the great absence of human crowd behavior data that can be used as a basis for comparison. The main difficulty in creation of such data is that controlled experiments are complex to design, and costly to execute, since they have to be in large scale. There does not exist a standard methodology of evaluation; some researchers generate accurate behavioral data by engaging crowds in virtual environments (Pelechano, Stocker, Allbeck, & Badler, 2008), while others do qualitative comparisons of their models' predictions against movies of crowds, i.e., via observation experiments, e.g., (Helbing et al., 2000; Kretz, 2007). We follow the same approach. Below, we describe the observation experiments we executed to evaluate the SCT model on general pedestrian behavior.

Comparing to Human Behavior

In this experiment we focus on general pedestrian behavior where individuals and small groups (e.g., family and friends, couples) walk with different speeds in bidirectional fashion. Our hypothesis is that generating pedestrian behavior with SCT model is more in tune with human pedestrian behavior, compared to other models from the literature. We also want to examine the impact of the model components (bounds, correction order, gain) on the quality of the simulated behavior.

We used human crowd movies where different pedestrian behavior phenomena are presented (Figure 1(a)) and created screen-capture movies of different models of the same behavior (Figure 1(b)). We rely on experiments with human subjects which compare each of the resulting simulated behaviors to human crowd behavior. In addition, the subjects also voted for the most similar and dissimilar simulated behavior.



(a)

(b)

Figure 1: **Real (a) and Simulated (b) Pedestrian Behavior.**

Simulated Behavior: Experiment Setup. To simulate pedestrian behavior, we used Net-Logo. We define a sidewalk with 104 patches in length and 10 patches at width. To fit to human crowd density, the sample population comprised 30 agents. Agents were able to move in a circular fashion from east to west or in opposite direction with different speeds. Agents that belong to the same group have the same color. In order to create small groups, couples and individuals, we define our population with 15 different colors (a large number considering the population size). Agents were placed in random positions at the beginning of the experiment, each agent had limited vision distance of 10 patches and cone-shaped-field-of-view of 120 degrees.

Each agent has a set of features and their corresponding weights. For simulating pedestrian movement, we used the following features and weights: *color* (weight 3); *Walking direction* east or west (weight 2); and *position* (weight 1), given global coordinates. To account for the western cultural intuition that friends (and family) walk side-by-side, rather than in columns, we used another feature: The similarity in position along the x-axis - *X-Coordinate* (weight 0.5).

The rationale for feature priorities, as represented in their weights, follows from our intuition and common experience as to how pedestrians act. Positional difference (distance, side-by-side) is the easiest difference to correct, and the least indicative of a similarity between pedestrians. Direction is more indicative of a similarity between agents, and color (which we use to denote sub-groups within the crowds) even more so. For instance, if an agent sees two agents, one in the same direction as it (and far away), and the other very close to it (but in the opposite direction), it will calculate greater similarity to the first agent, and try to minimize the distance to it (this may cause a lane change) and only then try to locate itself on the same X-coordinate.

The similarities in different features (f_i) are calculated as follows. $f_{color} = 1$ if color is the same, 0 otherwise. $f_{direction} = 1$ if direction is the same, 0 otherwise, $f_{distance} = \frac{1}{dist}$, where $dist$ is the Euclidean distance between the positions of the agents and finally, $f_{x-coordinate} = 1$ if x-coordinate is the same, 0 otherwise. Each agent calculates $s(x)$ according to the model. If the chosen feature for closing the gap is distance, then the velocity for movement will be multiplied by the calculated gain *Gain*. For other features (which are binary), the gain is ignored.

We wanted to examine the impact of the SCT model components on the quality of the simulated pedestrian behavior. In particular, we wanted to examine the impact of SCT bounds (S_{min} and S_{max}), gain function, and correction order on the generated behavior. We define seven models, each emphasizing a different SCT component. The models are explained below, and summarized in Table 1.

First we wanted to examine the impact of SCT bounds on the generated pedestrian behavior. We hypothesize that more narrow bounds will provide more similar behavior to individual model. To examine this hypothesis, we define the following models:

- SCT-B-2-6.5 We set S_{max} to 6.5 (practically: no agent too similar) and S_{min} to 2 (which means that agents that differ only in distance and in X-axis are not consider similar). The gain is calculated according to Eq. 1 and the correction order is from the low weight features (distance) to high weigh features. In this domain agents cannot change their color, thus, the last corrected feature is direction. Our hypothesis that this model will provide most similar behavior to human pedestrians.
- SCT-B-5-6.5 We set the S_{min} to 5 which mean that agents that similar at least in color and direction are consider to be similar. Thus, in this model only agents with same color and direction will move together.

Another component that we want to examine is the impact of correction order on simulated pedestrian behavior. In the SCT-H-L model we define the correction order to be from high to low. Our agents cannot change their colors, and in this model if the selected agent is moving in opposite direction, the agent will first change it direction and then will try to close the distance gap.

Finally, we wanted to evaluate the importance of the gain in the model. We define the following models:

- SCT-NoGain Defined to be without the gain function (i.e., gain is constant 1).
- SCT-G-C2 The gain function is constant (2).
- SCT-G-C3 The gain function is constant (3).
- SCT-G-C4.5 The gain function is constant (4.5).

The various SCT models are contrasted with the *individual choice* model, commonly used in pedestrian crowd research (Blue & Adler, 2000; Helbing et al., 2000). In the individual model, when forward movement of an agent is blocked, an agent will arbitrary chooses different lane. Each agent make its decisions independently of its peers. This model has been shown to be qualitatively compatible with pedestrian motion, and is often used as a baseline technique in crowd research (see, for instance, (Kretz, 2007)).

Comparison to Human Crowd. In order to compare to general behavior and not to be connected to specific video clip, we used several video clips of human pedestrian behavior and several screen-captured movies for each model. In the simulated behavior we created three screen-captured movies for each model that was randomly chosen for each subject. In human behavior we used two sets of video clips that were taken from different locations and in different times. The first set of movie clips were taken in the morning in downtown Vancouver, during rush hour. People are mostly walking individually, and only few are moving in small groups. The second set of movie clips were taken in the afternoon in a street that leads to the Eiffel tower in Paris, during leisure time. Most of the pedestrians are families and friends that move in small groups, or as couples. Each real-world video clip was cut to be one minute long. To generate a one-minute clip in the simulated behaviors, each model was executed for 5000 cycles (6 minutes), and the last minute was used.

We build a web based experiment which enables the subjects to participate in their free time. First we presented a brief description about the experiments. The subjects were told that the purpose of the experiment is to compare each of the simulated behaviors to human crowd behavior. However, the purpose of the simulation is not to simulate each seen pedestrian in the human crowd, but to simulate the general pedestrian behavior. The experiment was carried out in two phases, a training phase that was presented to the subjects after the experiment description, and an experiment phase.

The experiment was carried out using 39 adult subjects (males: 28). Additional 6 subjects were dropped due to technical reasons (such as network problems that prevented them from watching the clips). The subjects were ask to watch the human pedestrian movie that was randomly chosen in each experiment. Then, they were ask to watch screen-captured movie of each model that was also chosen randomly. After each simulated movie, the subjects were ask to rank the seen behavior, that followed by question: To what degree the seen simulated behavior is similar to previously seen human behavior? (1—not similar, 6—most similar). At the end of the experiment, we ask the subjects additional two questions: What simulated movie was the most similar to human behavior and what simulated movie was the most dissimilar. To control for order effects, the order of presentation on the page was randomized.

Initially we wanted to compare eight different simulated behaviors to human pedestrian behavior, the individual choice model and seven SCT models. We run a short pilot in which we presented to three subjects the experiment and afterwards ask their opinion. All subjects claimed that the experiment was too long. Moreover, they claimed that SCT-B-2-6.5 model provide very similar behavior to that of SCT-

Component	SCT-B-2-6.5	SCT-B-5-6.5	SCT-H-L	SCT-NoGain	SCT-G-C2	SCT-G-C3	SCT-G-C4.5
Smax	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Smin	2	5	2	2	2	2	2
Gain	Eq. 1 (func.)	Eq. 1 (func.)	Eq. 1 (func.)	1 (const)	2 (const)	3 (const)	4.5 (const)
Correction Order	L-H	L-H	H-L	L-H	L-H	L-H	L-H

Table 1: **SCT Models**

H-L model and similar behavior was also observed in models SCT-NoGain, SCT-G-C2, SCT-G-C3 and SCT-G-C4.5. Thus, we reduced the number of different models that presented to the subjects. In the experiment phase we compared between four simulated behaviors. We used the Individual-choice model, SCT-B-2-6.5, SCT-B-5-6.5 and one of randomly chosen SCT-NoGain, SCT-G-C3 and SCT-G-C4.5 models. The models SCT-H-L and SCT-G-C2 were used only in the training phase, and their results were not used.

Results

We first wanted to examine the ranking of the models in comparison to the actual crowd. The results are summarized in Figure 2. The categories in the X-axis correspond to different models. The Y-axis correspond to grades of the compared models. Each set of bar shows the mean and median results. A higher result indicates improved fidelity, i.e., greater similarity to human pedestrian behavior.

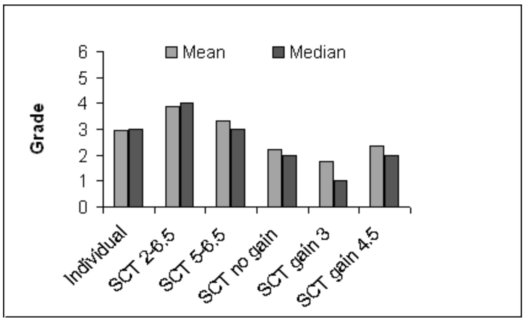


Figure 2: **Comparing to human pedestrian - Results**

The results clearly demonstrate that the SCT-B-2-6.5 model provide most higher results than the compared models. While it may seem that the SCT-B-2-6.5 model results is close to Individual and SCT-B-5-6.5 models results, according to t-test (two-tailed) SCT-B-2-6.5 was found to be significantly different than the Individual model ($p = 0.001$) and significantly different than SCT-B-5-6.5 ($p = 0.03$).

Another hypothesis underlying the experiment is that SCT model with narrower bounds (S_{min}, S_{max}) will provide closer behavior to individual model behavior, but not the same. Indeed, the results demonstrate that SCT-B-5-6.5 is lying in between the SCT-B-2-6.5 and individual models. According to t-test (two-tailed) SCT-B-5-6.5 was found to be significantly different than SCT-B-2-6.5 ($p = 0.03$) and significantly different than the Individual model ($p = 0.017$).

Our last hypothesis was that SCT models without the gain function will provide less similar behavior to human pedestrian behavior. The results clearly demonstrates that SCT-NoGain, SCT-G-C3 and SCT-G-C4.5 models in which the gain is fixed, get the lowest results.

When we ask the subjects: "What simulated behavior was the most similar to human behavior?" The SCT-B-2-6.5 model gets the highest number of votes. To the question: "What simulated behavior was the most dissimilar to human behavior?", the subjects answered with the SCT-NoGain, SCT-G-C3 and SCT-G-C4.5 models. The answers to these two questions are shown in Figure 3.

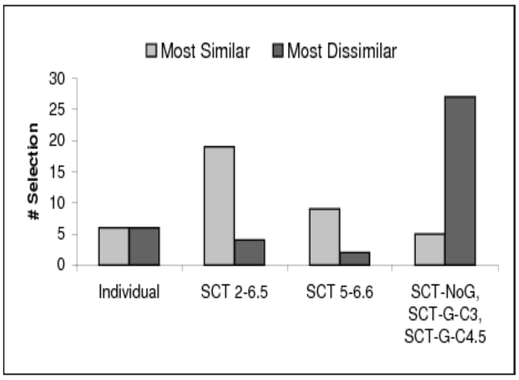


Figure 3: **Most similar/dissimilar: Results.**

Discussion

The SCT model, described and evaluated above, stands on two conceptual cognitive science legs. First, it draws a connection between social comparison theory and crowd behavior. Second, it interprets social comparison theory as admitting superficial comparisons, i.e., at the level of visible differences between agents, in addition to cognitive differences (e.g., intentions). We address these two issues below.

Social Comparison in Crowds. To the best of our knowledge, social comparison theory has never been connected to crowd behavior phenomena. However, we believe that social comparison theory may account for some important characteristics of crowd behavior, as it clearly addresses processes in groups, and no limit is placed on group size.

We focus here on one of the primary characteristics of crowds is the similarity between individuals' behaviors. This is explained by a process of *imitation* (Le Bon, 1895), convergence of like-minded individuals (Allport, 1924), or emerging norms (Turner & Killian., 1972).

Social comparison processes can give rise to this phenomenon. Festinger writes (1954, p. 124): "The existence of a discrepancy in a group with respect to opinions or abilities will lead to action on the part of members of that group to reduce the discrepancy". Indeed, one implication of SCT is the formation of homogeneous groups. Festinger notes (1954, p. 135):"The drive for self evaluation is a force acting on persons to belong to groups, to associate with others. People, then, tend to move into groups which, in their judgment, hold opinions which agree with their own“. This quote, in particular, seems to be compatible with (Allport, 1924).

Do people engage in surface comparisons? Festinger hypothesizes (Festinger, 1954, p. 117): "There exists, in the human organism, a drive to evaluate his opinions and his abilities". Thus a question that emerges with respect to the mechanisms described here is whether in fact the type of surface comparisons are admitted by social comparison theory.

There has been extensive research clarifying the concepts "abilities" and "opinions". Smith and Arnkelsson (2000) explain that ability evaluation refers to person performance at specific task. Festinger itself provide a link between ability and performance: "abilities are of course manifested only through performance which is assumed to depend upon the particular ability" (1954, p. 118). He then provide an example: “Thus, if a person evaluates his running ability, he will do so by comparing his time to run some distance with the times that other persons have taken.” (1954, p. 118).

Moreover, the meaning of opinion comparison, was also extensively investigated during the years. Goethals and Darley (1977) relate this concept to "Related Attributes Hypothesis" meaning people will prefer to compare with others similar to them on attributes that are related to their opinion or performance. Festinger provide the basis for this research claiming: "If persons who are divergent from one’s own opinion or ability are perceived as different from oneself on attributes consistent with the divergent, the tendency to narrow the range of comparability becomes stronger" (1954, p. 133). Goethals and Klein provide an example which directly admit surface comparisons: "An individual evaluating his or her tennis-playing ability. He or she might compare with others who are about the same age, who have the same degree of recent practice and comparable equipment, and who are the same sex" (Goethals & Klein, 2000, p. 25).

Summary

SCT is a cognitive model proscribing crowd behavior, inspired by Festinger’s social comparison theory (Festinger, 1954). A key novelty in SCT is its promise of domain-generality. However, while SCT has been evaluated against existing models in specific tasks, it was not validated against human crowd data.

This paper presented validation of SCT model (and competing models) against human crowd behavior. We evaluate the SCT on pedestrian phenomena and showed that SCT model generated pedestrian behavior more in tune to human pedestrian behavior. The results are promising, and support the general applicability of the SCT model. We are currently exploring the use of SCT in this and other domains.

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