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ON THE INCORPORATION OF THE PERSONALITY FACTORS  
INTO CROWD SIMULATION

by

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A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy in Modeling and Simulation  
in the College of Engineering and Computer Science  
at the University of Central Florida  
Orlando, Florida

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2007

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## **ABSTRACT**

Recently, a considerable amount of research has been performed on simulating the collective behavior of pedestrians in the street or people finding their way inside a building or a room. Comprehensive reviews of the state of the art can be found in Schreckenberg and Deo (2002) and Batty, M., DeSyllas, J. and Duxbury, E. (2003). In all these simulation studies, one area that is lacking is accounting for the effects of human personalities on the outcome. As a result, there is a growing emphasis on researching the effects of human personalities and adding the results to the simulations to make them more realistic.

This research investigated the possibility of incorporating personality factors into the crowd simulation model. The first part of this study explored the extraction of quantitative crowd motion from videos and developed a method to compare real video with the simulation output video. Several open source programs were examined and modified to obtain optical flow measurements from real videos captured at sporting events. Optical flow measurements provide information such as crowd density, average velocity with which individuals move in the crowd, as well as other parameters. These quantifiable optical flow calculations provided a strong method for comparing simulation results with those obtained from video footage captured in real life situations.

The second part of the research focused on the incorporation of the personality factors into the crowd simulation. Existing crowd models such as Helbing-Molnár-Farkas-Vicsek (HMFV) do not take individual personality factors into account. The most common approach employed by psychologists for studying personality traits is the Big Five factors or dimensions of personality (NEO: Neuroticism, Extroversion, Openness, Agreeableness and Conscientiousness).

In this research forces related to the personality factors were incorporated into the crowd simulation models. The NEO-based forces were incorporated into an existing HMFV simulated implemented in the MASON simulation framework. The simulation results were validated using the quantification procedures developed in the first phase. This research reports on a major expansion of a simulation of pedestrian motion based on the model (HMFV) by Helbing, D., I. J. Farkas, P. Molnár, and T. Vicsek (2002). Example of actual behavior such as a crowd exiting church after service were simulated using NEO-based forces and show a striking resemblance to actual behavior as rated by behavior scientists.

To my daughter Anita, wife Sudha,  
my parents and family

## ACKNOWLEDGMENTS

A commitment such as this could never be fulfilled alone, without the support and encouragement of family and friends. So many individuals have made significant contributions to enable me to complete this research work and I am grateful to each of them.

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I would also like to acknowledge the National Science Foundation (NSF) and US Army for their generous support towards this research work. My colleagues and supervisors at the office of Institutional Research deserve a great appreciation for their encouragement and support while I worked on my dissertation. Special thanks go to Dr. Lin Huf-Corzine at UCF for granting me professional development leave which enabled me to complete my dissertation while working at a full-time job.

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# CHAPTER ONE: INTRODUCTION

## Crowd Simulation Research

In recent years, several applications of computer simulation of crowds and crowd behaviors have gained importance. Crowd simulation within the research reported here is defined as a simulation of carefully defined virtual crowds consisting of individual agent models. This area of research has been applied to a wide variety of domains such as military, education, training, entertainment and human factors analysis [5]. Some of the applications are military force modeling [26], evacuation of large human crowds (example: sporting venues, concerts and demonstrations), simulator based trainings and game development. It is important to note that Crowd Simulation is a general area of research within which several are sub-topics. These sub topics include simulation of various animal groups, creation of virtual environment for crowd simulation [9], creation of human behavior models, incorporating psychological models, computer animation and computer vision based crowd behavior detection [21].



**Figure 1: Creation of Virtual Environment for Crowd Simulation [7]**

In the entertainment industry, crowd simulation really comes into its own in animated movies. Examples such as in the stampede scene in Disney's *The Lion King* and the colonies of ants in Dreamwork's *Antz* [17] exemplify this concept.



**Figure 2: Simulation with Random Crowd Movement [10]**

There are several companies that are currently developing products that cater to the animation and movie industry needs. Some of the products that are offered by these companies are finding applications in industries other than the entertainment industry. Massive Software is one such company that has several products for the entertainment industries. Their software *Massive* is a premier 3D animation system for generating crowd-related visual effects for film and television. Using *Massive*, an animator designs characters with a set of reactions to what is going on around them.

Craig Reynold's [14] work on animation of flocks of birds has inspired the recent trends in crowd simulation research. In his approach he treats each individual bird as a particle and models his simulation based on individual behaviors.

## **Crowd Simulation Research at University of Central Florida**

The University of Central Florida (UCF) focuses heavily on applied research and has several research facilities to cater to the research needs. The Institute of Simulation and Training (IST) is one of the major research facilities within UCF. At IST, one of the major research areas is modeling and simulation of behavior of individuals in teams and in crowds. Specific topics include both development of new basic science in behavior modeling and the development of new applications in the fields of emergency management. Clarke et al[1] is working on modeling interactions within a group of individuals with aggressive versus passive personalities. Research on dynamic military civilian crowd simulations [8] is conducted by Kaup et al. An interdisciplinary NSF funded research [4] on crowd simulation is underway and researchers at IST collaborate with several UCF departments. This is a multi-year project and the goal of the research is to model social dynamics. In all this simulation work, the one area that is lacking is the effects of human personalities on the outcome. There is an emphasis to research the effects of human personalities and add the results to the simulations to make them more realistic. The most popular approach among psychologists for studying personality traits is the five-factor model or Big Five factors of personality and the next chapter discusses them in detail.

### **“Big Five” Personality Factors**

In attempting to model and simulate human crowds, it is very important to know the major personality factors that affect behavior because personality, in addition to other factors, is a significant determiner of individual behavior. As mentioned earlier, the most popular approach among psychologists for studying personality traits is the Big Five factors or dimensions of



personality [21, 23]. The five factors are neuroticism, extroversion, openness, agreeableness and conscientiousness. These five factors were derived from factor analyses of a large number of self and peer reports on personality-relevant objective and questionnaire items [2]. It is important to define the characteristics and range of the five factors so they can be validated. These factors are dimensions and humans tend to vary continuously on them (say to the scale of 0-10). Also, these factors are stable [16], in part genetically heritable [17] and universal [19] for a single individual.

The big five personality factors can be summarized [12] as follows:

- i. Neuroticism - A tendency to easily experience unpleasant emotions such as anger, anxiety, depression, or vulnerability.
- ii. Extraversion - Energy, surgency, and the tendency to seek stimulation and the company of others.
- iii. Agreeableness - A tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others.
- iv. Conscientiousness - A tendency to show self-discipline, act dutifully, and aim for achievement.
- v. Openness to experience - Appreciation for art, emotion, adventure, unusual ideas; imagination and curiosity.

Based on the knowledge gained through the publications from the Personality Research Organization, nearly all clusters of personality-relevant characteristics can be brought under the Big Five [18] factors. There are certain analyses that suggest these five-factor criteria do not take into account all of the personality traits. But, these analyses do not imply that additional factors such as Religiosity, Honesty, Deceptiveness, Conservativeness are unrelated to the Big Five; for example, Honesty and Deceptiveness may be highly (negatively) related as opposite sides of the

same dimension. Nevertheless, these results suggest that several important personality traits lie beyond the Big Five. But, this research is confined to model and simulate the Big-Five personality factors.

### **Research Problem Statement**

The simulation and modeling of crowd behavior has been an active research area in recent years. Although a variety of parameters have been introduced into these models, few have considered the influence of individual personality factors on crowd behavior. The problem statement of this dissertation research is to modify the HMFV crowd model to incorporate the effects of forces based the “Big Five” personality factors. The effect of these NEO-based forces will be determined by simulating the crowd model within the MASON simulation framework. This research and its outcome augments the crowd simulation developed by Helbing et al.[20] The Helbing et al crowd simulation model is explained in detail in later sections.

### **Research Scope and Importance**

This research is in the technical area of modeling and simulation of the behavior of individuals in teams and in crowds and other social groups. In addition to adding to basic science in behavior modeling, this research will find application in a variety of areas. Among these application areas is the field of emergency management. The simpler model upon which this work is based is already finding applications in the area of emergency management of crowds and for the design of buildings for emergency egress.

An additional area of application of such models of collective human behavior is to the Improvised Explosive Device (IED) threat. The presence of IED's might be detected by modifying parameters of the crowd behavior appropriate for individual involved in IED activity. Such model predictions could be used as a template for detecting IED-related activity and anomalous behavior. For example, a suicide bomber might move against the flow of the crowd or otherwise behave in an anomalous fashion. The same models can be adapted to traffic to identify anomalous behavior by local drivers who may know of the location of roadside IEDs and avoid it.

The main objectives and goals of this research can be summarized as follows:

- Develop a simulation model of the Big Five personality factors that may enhance the existing crowd simulation models.
- Demonstrate the applicability of models with personality traits to several real situations (e.g. exiting from a church which is a highly social situation and compare the simulated behavior to its real counterpart using both quantitative and qualitative techniques).

## CHAPTER TWO: LITERATURE REVIEW

### Crowd Simulation Modeling

There has been a real interest in understanding crowd motions and behaviors for the last several decades. Crowd movement can be described as an interesting, yet complex phenomenon [15]. It is interesting because of the synchronized patterns and homogeneous motions that crowds exhibit. It is complex because there are too many variables involved in understanding the characteristics. When people with the same goal become an entity, they are called a mass or crowd. Psychologists have been interested in understanding this mass behavior [15]. The mass behavior and motion of people has also been studied as in computer models for a number of purposes. Numerous researchers are working on crowd simulation to develop applications that will cater to different industries.

There are several approaches to crowd modeling including psychological (behavioral) systems, particle systems and flocking systems [24]. These approaches are characterized by a group of individual participants along with their intelligence and decision making ability. Le Goff [6] described an approach to create a behavioral model of groups formed by heterogeneous entities. His concept of groups is related to an association of individual behaviors and the management of internal resources as well as a decisional process inherent in the group entity. Particle systems are those simulations that consist of many autonomous agents and all are controlled by certain physical rules. Bouvier [24] used particle systems adapted for studying crowd movements where human beings are modeled as an interactive set of particles. The motion of people is based on Newtonian forces as well as on human goals and decisions. They

introduced the concept of “decision charges” and “decision fields” modeled by using notions of the so called decision charges of a person, interacting with a surrounding decision field in the same way an electric charge is influenced by an electric field. Reynold’s [9] work on flocks of birds, shows realistic simulation of groups by applying simple local rules. The birds maintain proper position and orientation within the flock by balancing their desire to avoid collisions with neighbors, to match the velocity of neighbors and to move towards the center of the flock. With this background on the crowd simulation, the next sections attempt to describe crowd simulation of model Helbing et al.

### **The Helbing-Molnár-Farkas-Vicsek (HMFV) Model**

Helbing et al [15] have proposed a model based on physics and social forces in order to describe the human crowd behavior in panic situations. In the HMFV model, it is assumed that the pedestrian feels, and exerts two kinds of forces on others. These are social and physical forces. The intentions of a pedestrian not to collide with other people in the room or with walls and also to move in a specific direction (e.g., towards an exit) at a given speed is the social force. These social forces do not have a physical source [7]. But, as the crowd's density increases, the pedestrians are forced to collide and the physical forces of pushing and friction enter the picture. Thus, the force exerted on pedestrian  $i$  by pedestrian  $j$  has the form:

$$\vec{f}_{ij} = \vec{f}_{social\_repulsion} + \vec{f}_{pushing} + \vec{f}_{friction} \quad (1)$$

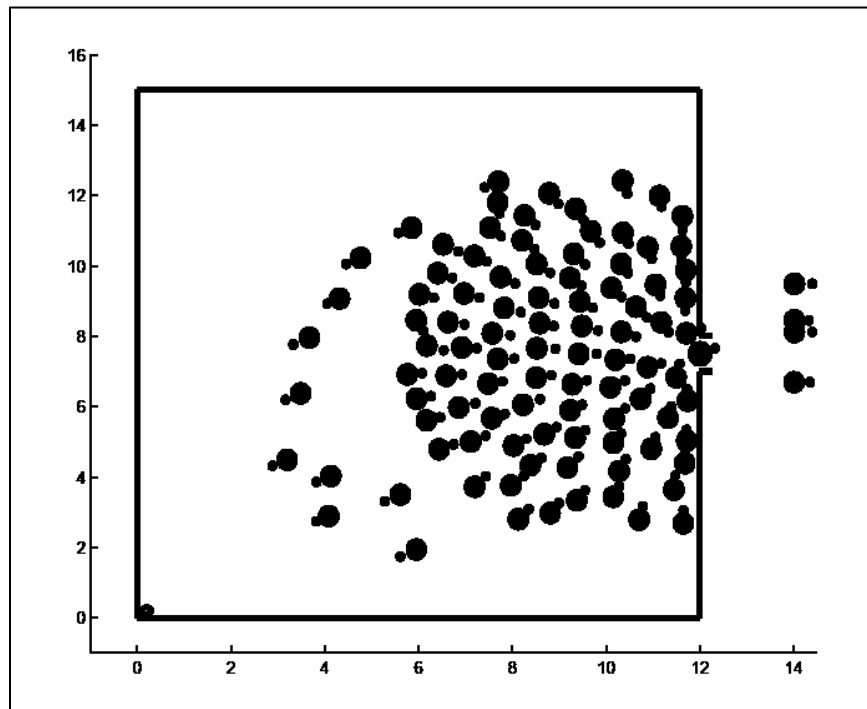
Where,

$$\vec{f}_{social\_repulsion} = Constant_B \times exponential\{interpersonal\ distance\}_{radial} \quad (2)$$

$$\vec{f}_{pushing} = Constant_k \times threshold(interpersonal\ distance)_{radial\ direction} \quad (3)$$

$$\vec{f}_{friction} = Constant_{\kappa} \times threshold(interpersonal\ distance)_{tangential} \quad (4)$$

In equation (1), the first term describes the social force, the second and third terms describe the physical forces of pushing and sliding friction between the two pedestrian bodies [7]. The form of the second and third terms ensures that they vanish when the pedestrian bodies are not in physical contact. An expression similar to that of the equation (1) holds for a force between a pedestrian and a wall or another immobile obstacle (such as furniture or column) in the room.



**Figure 3: HMFV Model Simulation of Non-panicking Crowd**

Figure 3 shows a representation of simulations based on the HMFV model. This is a snapshot of a non-panicking crowd. Larger circles represent bodies, and smaller ones, noses, of pedestrians; in this way, the direction of motion of a pedestrian becomes apparent. The majority of individuals are pressing to exit but the *excitement factor* is such that a number are moving counter flow “seeking” other exits. This subpopulation is easily detectible, and also suggests that individuals involved in IED activities can be easily detected as well.

As Helbing et al (2000) summarized, the HMFV model is able to reproduce such phenomena as: (i) formation of lanes in both uni- and bi-directional traffic, (ii) arc-shaped clogging at an exit when the crowd's desired speed of leaving the room is “too high”, (iii) inefficient use of alternative exits when the panic parameter  $p$  is either too small or too large, and (iv) oscillations of the pedestrian flux at a door, through which pedestrians are trying to pass in opposite directions. Based on the discussions on the HMFV model, it can be concluded that both do not provide pedestrians with any “intelligence” or decision-making capabilities. The dissertation research focused on developing modifications to the HMFV model that model personality factors.

### **Literature Search on Individual Personality Composition**

In order to find the values for the personality interaction matrix for different demographics a thorough literature search was conducted. There are several instruments available for the measurement of personality (e.g. NEO PI-R by Costa & McCrae) [26]. It was beyond the scope of this project to conduct a survey with such instruments for the purpose of finding values for the personality interaction matrix.

There were several literatures available on the “Big Five” personality dimensions, but there was not a specific reference available for the purposes of populating the personality interaction matrix. A book title “The Importance of Psychological Traits – A Cross-Cultural Study” written by John E. Williams, Robert C. Satterwhite and Jose L. Saiz has provided adequate correlation data between the Big-Five personality traits. The values provided in the book were primarily used for populating the MPF and it also provided personality combination of individuals in various countries. The authors observed data from twenty countries and meaningfully grouped the data into two major clusters. From the two clusters, the correlation data of individual personality factor combinations for United States and Pakistan were selected for our simulations. The reason for picking these two countries is that there is a significant difference in all the Big Five personality traits between the people in these countries.

### **“Big Five” Personality Modeling**

As mentioned in the problem statement, a goal of this project is to model the Big Five personality factors. The “Big Five” [29] personality model is the most widely accepted by psychologists. The five factors or dimensions of personality are: neuroticism vs emotional stability, extraversion vs introversion, openness to experience vs not open to experience, agreeableness vs antagonism, and conscientiousness vs undirectedness. Table1 provides additional information. The “Big Five” representation of personality dimensions can be used to capture the essence of individual differences in personality and provide insights into them. These five personality factors allow sufficient reliability within the personality domain while still keeping within manageable limits [21].



**Table 1: Big Five Personality Factors**

<b>The “Big Five” Personality Domain Scales</b>		
	High Traits	Low Traits
Neuroticism (N)	anxious, moody, irritable, hostile	confident, optimistic
Extroversion (E)	upbeat, energetic, assertive, active, talkative, friendly	aloof, shy, reserved, interpersonally formal
Openness (O)	curious, imaginative, idealistic, original, enthusiastic	conservative, cautious, mild
Agreeableness (A)	altruistic, trusting, soft-hearted, sympathetic, warm, generous	suspicious, pessimistic, hard-hearted, demanding, assertive, impatient
Conscientiousness (C)	efficient, thorough, resourceful, organized, ambitious, industrious, enterprising	careless, lazy, impulsive, impatient, immature, moody, hasty

Since potential theory as used by Clarke and Otte [28] was found useful for modeling the dynamics of scalar or single dimensional personality factors, Clarke suggested a higher-dimensional analog should be useful for modeling the dynamic effects of the “Big Five” personality factors. The power of potential theory comes from its capacity to incorporate internal degrees of freedom into the theory, so that “action-at-a-distance” type forces can be obtained from simple variations of individual traits and social behaviors. If one could achieve the foregoing, then it follows that one could then draw upon an understanding of mechanical conservation laws, as well as the possibility of developing thermodynamical-like relationships between given statistical averages. Nevertheless there are limitations to such an approach that must be considered, since there are components of the social and physical forces which are not

conservative, and therefore, for which no mechanical-like potential will exist. But, there will also be aspects of it for which potentials will be found to exist and so the possibility of developing general minimization rules for certain aspects of social behavior should not be overlooked.

The summary of the literature search on Big Five personality factors is as follows. Each member of the crowd will have an internal state corresponding to one or more of the big five personality factors [23]. The introduction of these states should open the way to further development of models and simulations of behavior of individuals and crowds. The research should result in an increased understanding of the behaviors of crowds incorporating individuals of varying personality types. This should enhance the ability to design buildings for emergency egress and the combination of social and spatial factors should lead to insight into optimum building design and architecture for varying corporate cultures.

### **Crowd Simulation Frameworks and Approaches**

There are several approaches to integrating personality factors into a crowd simulation and to obtain results that reflect the real life scenarios. It is important to use a standard framework as this provides a more efficient follow on work. Such aspects as debugging and support issues are more efficient with standardization. Also, simulation frameworks such as MASON are appropriate for this research.

## **MASON Simulation Framework**

The MASON framework is an agent based discrete-event simulation library. This is developed in Java programming language and designed to be the foundation for large custom-purpose Java simulations. It is also designed to provide range of functionality for many lightweight simulation needs [3, 10]. MASON contains both a model library and an optional suite of visualization tools in 2D and 3D. MASON carefully delineates between model and visualization, allowing models to be dynamically detached from or attached to visualizers [10]. MASON is a joint effort between George Mason University's ECLab Evolutionary Computation Laboratory and the GMU Center for Social Complexity.

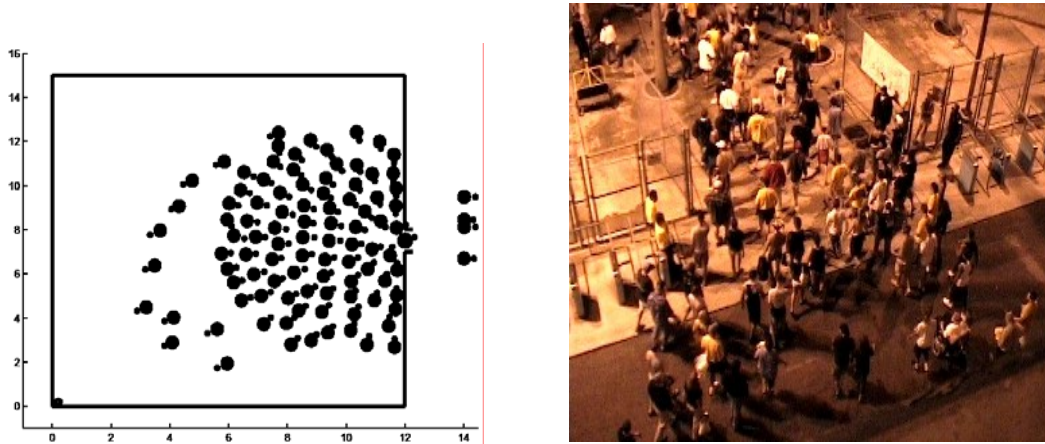
MASON features include:

- Fast, portable, small and 100% Java (1.3 or higher), and can produce results that are identical across platforms (Windows, UNIX, etc.)
- Models may be check-pointed and dynamically migrated across platforms.
- Models are self-contained and can run inside other Java frameworks and applications.
- Can generate PNG snapshots, QuickTime movies and 2D/3D visualization.

### **Preliminary Results and Validation of Methodology**

This research is based on previous work conducted by IST's crowd simulation group, particularly HMFV model, flocking model and social potential model by the IST's crowd simulation group which have been incorporated into the MASON frame work for current effort. They have been tested to obtain results that reflect real life in several ways. Figure 4 shows the snapshot of the results from non-panicking crowd simulation of the HMFV model and the real

video footage taken from a crowd exiting the Citrus Bowl. But the simulation lacks certain aspects of behaviors such as sub-grouping, as can be seen in the original video.



**Figure 4: Non-panicking Crowd Simulation (HMFV Model) vs Real Video**

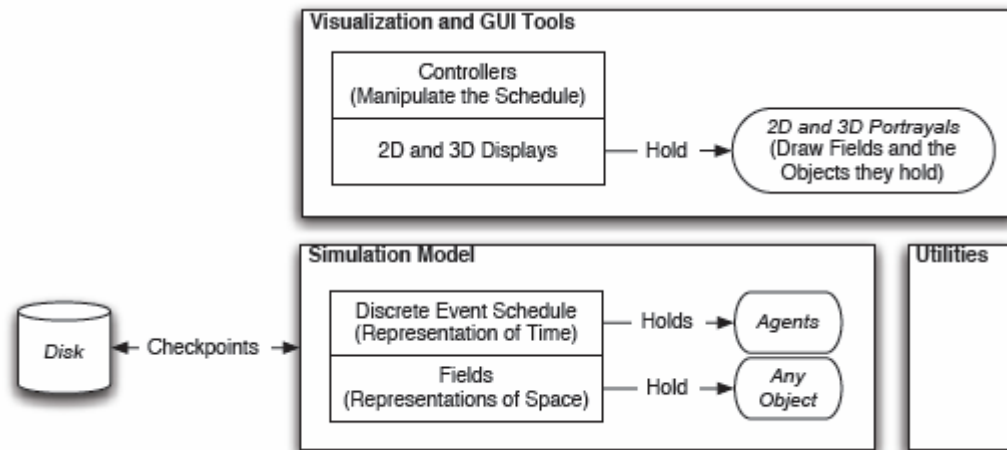
These results provided the background to the methodology used in this research work, particularly the use of the HMFV model to which personality factors were added. There were several real life videos recorded at venues like sporting events, churches and theme parks. The basic strategy of the research was to compare videos of crowd behaviors with simulations which included personality factors. The goal was to create simulations which reflected observed crowd behavior, such as sub-grouping.

## **CHAPTER THREE: RESEARCH METHODOLOGY**

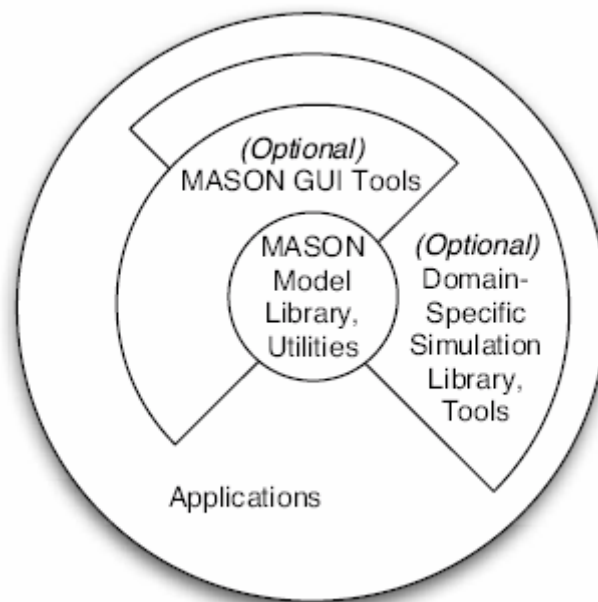
This section describes the methodology used to investigate the research questions and the tools that were developed. A brief introduction to the methodology is expanded in this section, which is organized around three major topics: (1) modification of the MASON simulation framework for crowd modeling and incorporation of personality factors, (2) data acquisition methods and (3) optical flow calculation methods.

### **Implementation of MASON Framework**

This dissertation research extends the scope of the models of crowd simulation to include the effects of the interactions of individuals with varying personality types. This is achieved by using techniques drawn from the physical theory of fields as suggested by Clarke. In order to model and run the simulation of personality factors, the first task was to understand and successfully install the MASON simulation framework. The objective was to reuse existing computer code. MASON provides extensive video capture features that are essential for this project to compare the results with the real crowd videos. It also supports recording of simulations as freeze frame or as movies. Since MASON is a JAVA based framework the simulations can be run on multiple platforms (e.g. UNIX, Linux, and windows).



**Figure 5: Basic Elements of the MASON Model and Visualization Layers [3]**



**Figure 6: MASON Layers [3]**

The research was conducted on the Windows platform. The HMFV model had been ported to the MASON framework by the UCF crowd modeling group under the supervision of Rex Oleson and extensively tested, providing several lessons learned.

## Modeling the Personality Factors

In order to model the personalities, it is important to know the forces that make up the personality factors. For example, from the Big Five, the personality factor “Extroversion” refers to "attitudes" and gives an idea of how a person orients and receives their energy. For an individual with an extroverted attitude, the energy flow is outward, and focuses on people and things. This individual is usually energetic, assertive, enthusiastic, action-oriented, and talkative.

### **Definition of Parameters Affecting Personalities**

Based on the literature available the forces affecting Big Five personalities are as follows:

- **Cohesion:** This force controls how close together the individuals will become. An extrovert will have a high level of cohesion since he is very upbeat, energetic and friendly to the other individuals in the crowd. This is an attractive force and in modeling extroversion this will be the weight used for summing the cohesion of the individuals.
- **Avoidance:** Avoidance controls how far apart the individuals want to be. An extrovert by nature will have a very low level of avoidance. This is a repulsive force and in modeling extroversion, this will be the weight used for summing the avoidance of the individuals.
- **Randomness:** This is the random force to be included in personality modeling. In modeling extroversion, this will be the weight used for summing randomness for the individuals.
- **Consistency:** Consistency controls how strongly the individual will stay on his/her previous path. It is hard to predict how consistent an extrovert will be as he may tend to

move back and forth based on impulse. This is an attractive force and in modeling this will be the weight used for summing the consistency of the individuals. Additional discussions are planned to validate any assumptions applied to this force.

- **Momentum:** Momentum controls how difficult it is for the individual to change movement. An extrovert, being an upbeat and energetic person, will continue with the forward movement. This is an assumption. This is an attractive force and in modeling extroversion, this will be the weight used for summing the momentum of the individuals.

### **Incorporation of Personality Factors into HMFV Model**

The main objective of incorporating personality factors is to enhance the existing crowd simulation framework to take into account the personality interaction parameters while computing the psychological forces imposed on individuals. The core of the framework has been enhanced with the personality interaction matrix and personality types such that each of the implemented models can include various personality profiles without any further modifications to the core of the framework. As of now, in addition to the core framework, only the HMFV model is enhanced to include the personality interaction parameter.

A mathematical model for the Big Five is designed based on the above mentioned forces. Conceptually, the model of the personality factor based forces take the form:

$$\textit{Personality Factor} = \Sigma \textit{Attractive Forces} + \Sigma \textit{Repulsive Forces} + \textit{Randomnes.} \quad (5)$$

The model has wide scope for adding additional forces as they become necessary.



In this research, two different approaches were used to include the personality into crowd behavior. In the first approach, the individuals in the crowd simulation are assumed to have one fixed personality type from the Big Five Personalities (N, E, O, A, C). The personality for individual is a scalar. A fixed matrix (reference table) is being used to determine the interaction between two individuals with specific personality types and the psychological forces they impose on each other. In the second approach, the individuals in the crowd simulation are assumed to have a combination of different personality types, instead of one fixed personality. The personality for an individual is expressed as a vector. A personality interaction matrix (MPF) is multiplied by the personality vectors of individuals to determine the psychological force imposed on each other.

### **Addition of Personality Forces to Base HMFV Simulation**

In our coding scheme, the *Individual* Java object represents an actual Individual in the simulation. This *Individual* class is enhanced to exhibit the personality type(s) of the actual Individual it represents in simulation. This is implemented in a way that allows an Individual to have a combination of different personalities or one fixed personality type. Also, a universal personality interaction matrix is defined. This personality interaction matrix determines the interaction between two given types of personalities and this interaction parameter is used to calculate the generated forces when individuals with those personality types interact.

An individual's personality composition is modeled as a vector (i.e. row/column matrix). In addition, a personality interaction matrix (MPF) is also implemented which defines the interaction parameter between different types of personalities. The interaction between two

individuals, *Ind1* and *Ind2* with their personality combinations, would take the form of a quadratic form:

$$|Ind1.vpers|^{transpose} [MPF] [Ind2.vpers] \quad (6)$$

Where MPF is a 5 by 5 matrix describing the interaction between different personality factors.

$$MPF = \begin{bmatrix} NtoN & NtoE & NtoO & NtoA & NtoC \\ EtoN & EtoE & EtoO & EtoA & EtoC \\ OtoN & OtoE & OtoO & OtoA & OtoC \\ AtoN & AtoE & AtoO & AtoA & AtoC \\ CtoN & CtoE & CtoO & CtoA & CtoC \end{bmatrix} \quad (7)$$

The force generated by the base HMFV simulation is modified to include the forces imposed by personality interaction, as below:

$$generated\_force = generated\_force * [Ind1.pers] TRANSPOSE * MPF * [Ind2.pers] \quad (8)$$

Since the personality combination for individuals is implemented as row/column matrix, the above equation results in multiplying the generated force by a scalar value.

The Crowd Simulation framework can be configured to have pre-defined or random personalities for the individuals in simulation. Based on our literature search we determined the appropriate Personality Interaction Matrix and personality composition for various demographics. A front end graphical user interface (GUI) was developed to change personality compositions without requiring code modifications. Simulations were run for ten iterations for each case. The final number of iterations was decided based on preliminary results. The

personality composition was modified based on the test cases and the simulation exercises were repeated.

### **Transition from Base HMFV Social Forces to Personality Modified Social Forces**

In the previous section, we discussed the mathematical model for the incorporation of personality factors and how it was added to the base HMFV simulation. This section deals with how the transition from base HMFV social forces to the personality modified social forces affect the simulation.

The basic equation for social force as implement in the HMFV model is:

$$Generated\_social\_force = a * Math.exp(-(r - 0.5 * (dind1 + dind2)) / b) / r \quad (9)$$

where,

$a$  is the amplitude of social forces and

$b$  is the range of social forces

When the Personality modified social forces are introduced, we have:

$$force\_multiplier = [Ind1.pers] TRANSPOSE * MPF * [Ind2.pers] \quad (10)$$

In the coding scheme, there are two weighing terms come into play  $\omega_1$  and  $\omega_2$ .

$$\omega_1 = c / (r + c) \quad (11)$$

and

$$\omega_2 = 1 - \omega_1 \quad (12)$$

Where,

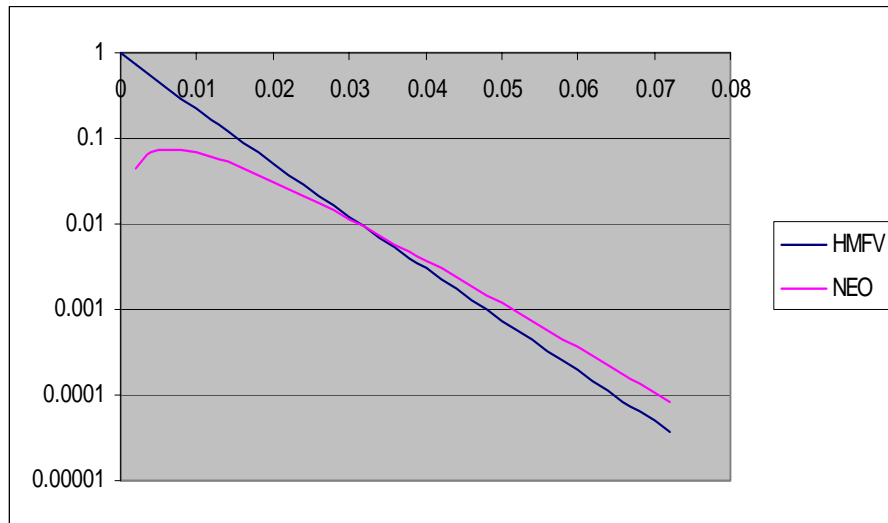
$r$  is the distance between individuals

$c$  is the change over range at which personality effects become significant.

So, the actual generated force equation becomes:

$$generated\_force = generated\_force * (\omega_2 * force\_multiplier + \omega_1) \quad (14)$$

The plot in figure 7 shows how the transition takes place in the actual simulation. The personality force multiplier was interpolated from the value 1 ( $\omega_1=1$ ), no personality effect, to the full interaction value as a function of the physical separation of the individuals. Interpolation of weight  $\omega_1$  to  $\omega_2$  as a function of 'r' (distance between individuals), incorporates the personality factors. The factor 'c' is the change over range to personality.



**Figure 7: Transition from Base HMFV Forces to Personality Modified Forces**

## **Optical Flow Calculation Methods**

An important part of this research is to compare the real life crowd behaviors from video footage with simulation results. This was achieved by quantifying the real life video footage. By quantifying the real life video footage, we developed metrics that were compared to the similar metrics obtained from simulation videos. Calculating the optical flow measurements from the video footage serves as a good method for drawing the comparison. From optical flow measurements, the following parameters can be derived:

- (i) Velocity with which an individual travels from point A to point B
- (ii) Crowd density at any given location

This section explains the optical flow measurement methods used in this research.

### **Approach 1 – Using Image J Software**

The results from the crowd videos were initially quantified using the open source software *ImageJ* and its plugins (FlowJ and AVI Reader). FlowJ was used to compute all the flow fields and to provide optical flow results in (.csv) comma separated files. But this method was found to have several limitations. There was not an easy method to specify a specific segment of the video and obtain optical flow for that specific segment. The source code was not available to accommodate code modifications. So, another approach with *OpenCV* software was investigated.

### **Approach 2 – Optical Flow with *OpenCV***

The source code for *OpenCV* was readily available as well as documentation. Computations of optical flow are based on two main assumptions:

1. Brightness  $I(x, y, t)$  smoothly depends on coordinates  $x, y$  in the greater part of the image.
2. Brightness of every point of a moving or static object does not change in time.

*OpenCV* provides three methods for calculating optical flow between two images:

- Block Matching – This technique considers an image as divided into small regions or blocks that can overlap. The algorithm then tries to find and match every block of the first image to the second image of the same size that's most similar. The function searches in the neighborhood of some given point in the second image. All the points in the block are assumed to move by the same offset that is found. Different metrics (e.g. cross correlation, squared difference, etc.) can be used to measure similarity or difference between blocks.
- Lucas and Kanade Technique – This technique uses the optical flow equation for a group of adjacent pixels and assuming that all of them have the same velocity, the optical flow computation task is reduced to solving a linear system. It combines equations for more than two pixels and obtains the approximate solution by using the least square method.
- Horn and Schunck Technique – Horn and Schunck propose a technique that assumes the smoothness of the estimated optical flow field. This optical flow solution applies an iterative method for the purpose when a number of iterations are made for each pixel. This technique for two consecutive images seems to be computationally expensive because of iterations, but for a long sequence of images only iteration for two images must be done, if the result of the previous iteration is chosen as the initial approximation.

Due to the fact that the Lucas and Kanade technique is widely used and accepted, we selected it to calculate optical flow. Using *OpenCV* APIs, optical flow can be calculated between any two

given images of the input video, for example, every consecutive frame, every alternative frame, every 5th frame or every 10th frame. We used every 10th frame of the input video to calculate the optical flow. For the optical flow calculations the following *OpenCV* API is used:

```
cvCalcOpticalFlowLK(frame_A, frame_B, optical_flow_window_size, velX, velY)
```

where,

*frame\_A* is the first frame/image

*frame\_B* is the second frame/image (*frame\_A* + 10th frame)

*optical\_flow\_window\_size* is the Size of the averaging window used for grouping pixels.

*velX* is the Horizontal component of the optical flow of the same size as input images, 32-bit floating-point, single-channel.

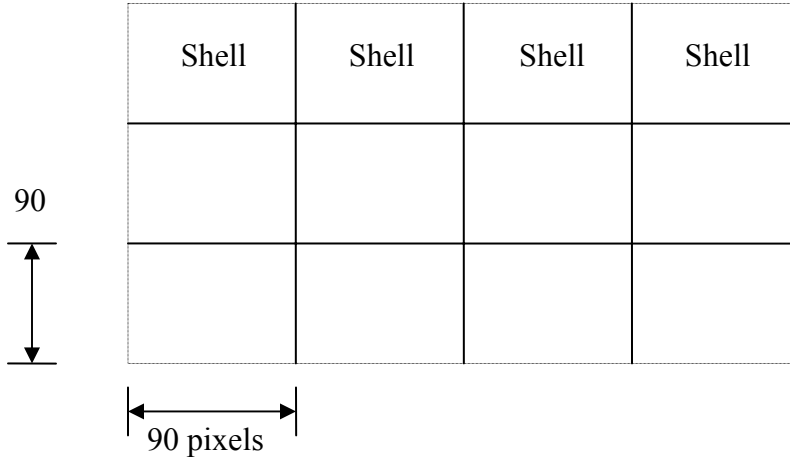
*velY* is the Vertical component of the optical flow of the same size as the input images, 32-bit floating-point, single-channel.

*velX* and *velY* return the velocity matrices for the displacement of every pixel between the given frames.

Following is the step by step process to calculate optical flow for the given input video:

- Find out number of frames in the input video and the frame size (height and width).
- Logically divide each frame into multiple shells each with size 90 pixels in height and 90 pixels in width.
- Starting from the first frame, calculate the velocity displacement matrices, *velX* and *velY* between every 10 frames using *cvCalcOpticalFlowLK OpenCV* API. Repeat this till last frame of the input video.
- Find the average horizontal and average vertical displacement value for each 90\*90 shell by averaging the *velX* & *velY* for all pixels in that shell.

- At the end, calculate the mean value of the average horizontal and average vertical displacements for each shell.



**Figure 8: Video Frame Divided into a 90 X 90 Pixel Shell**

Once we find the  $velX$  and  $velY$  for two frames, we find the shell-wise velocity displacement for each set of frames (frame1 and frame 10, frame 11 and frame 20, frame 21 and frame 30 and so on).

$$\text{For shell 1, } velX_{shell1} = \Sigma velX \qquad velY_{shell1} = \Sigma velY$$

$$\text{For shell 2, } velX_{shell2} = \Sigma velX \qquad velY_{shell2} = \Sigma velY$$

...

$$\text{For shell n, } velX_{shelln} = \Sigma velX \qquad velY_{shelln} = \Sigma velY$$

Now, calculate the overall mean,

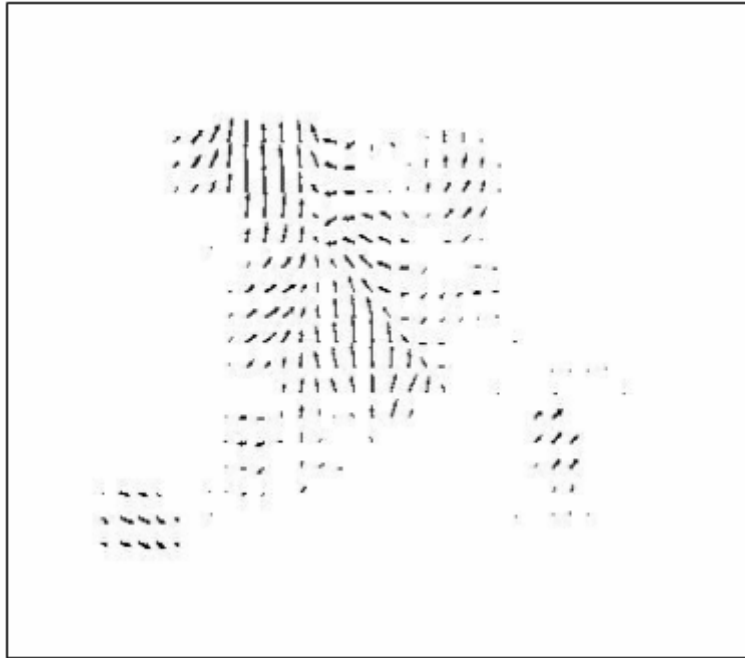
$$\text{For shell 1, } AverageVelX_{shell1} = \frac{\sum_{frame1}^{frameN} velX_{shell1}}{\sum_{frame1}^{frameN} velX_{shell1}} \qquad AverageVelY_{shell1} = \frac{\sum_{frame1}^{frameN} velY_{shell1}}{\sum_{frame1}^{frameN} velY_{shell1}}$$

$$\text{For shell 2, } AverageVelX_{shell2} = \frac{\sum_{frame1}^{frameN} velX_{shell2}}{\sum_{frame1}^{frameN} velX_{shell2}} \qquad AverageVelY_{shell2} = \frac{\sum_{frame1}^{frameN} velY_{shell2}}{\sum_{frame1}^{frameN} velY_{shell2}}$$



...

$$\text{For shell } n, \text{AverageVelXshell}n = \frac{\sum_{frame1}^{frameN} velXshelln}{frameN} \quad \text{AverageVelYshell}n = \frac{\sum_{frame1}^{frameN} velYshelln}{frameN}$$



**Figure 9: Vector Field of Optical Flow (Lucas-Kanade Algorithm)**

A typical velocity vector field of optical flow using Lucas-Kanade algorithm is shown in figure 9. The results from the *OpenCV* optical flow analysis are discussed in the results section.

## **CHAPTER FOUR: DATA ACQUISITION AND ANALYSIS**

### **Data Acquisition**

One of the objectives of this research is to compare the crowd simulation results with real life crowd situations. This comparison was done for both baseline HMFV simulations and HMFV simulation with personality factors included. The objective was to determine if personality factors could be seen in the simulations as compared with real life situations. The data collection phase involved real life video capture, extracting data from the real life videos, expert judgment of the simulation videos and finally data analysis.

### **Real Life Video Capture**

We used captured video footage of live events in public or private places where crowds can be observed such as sport events, concerts, schools, and theme parks. This effort on video collection was funded by an on-going NSF funded project. A group of graduate students lead by Mario Rosa captured video footage. Proper clearances were obtained from the UCF Institutional Review Board (IRB) prior to video taping. Captured video footage stored in a computer using video capturing devices. A standard process was designed and adopted for this purpose.

## Data Extraction from Video Footage

Data extraction from the video footage was a collaborative effort. The group of graduate students lead by Mario Rosa also contributed to the analytical portion of this effort as explained in this section. There were two methods employed in this process. The first one is the optical flow calculation methods that were explained in chapter 3. To capture the optical flow a front end GUI shown in figure 10 developed. Basically this front end software is used to pass the parameter to the *OpenCV* method '*cvCalcOpticalFlowLK*'. This front end tools helps to obtain optical flow for any specified video frame range and interval. It can create individual data for each frame specified and an average optical flow data file. A detailed user manual on how this tool can be used is available as an appendix to this dissertation.

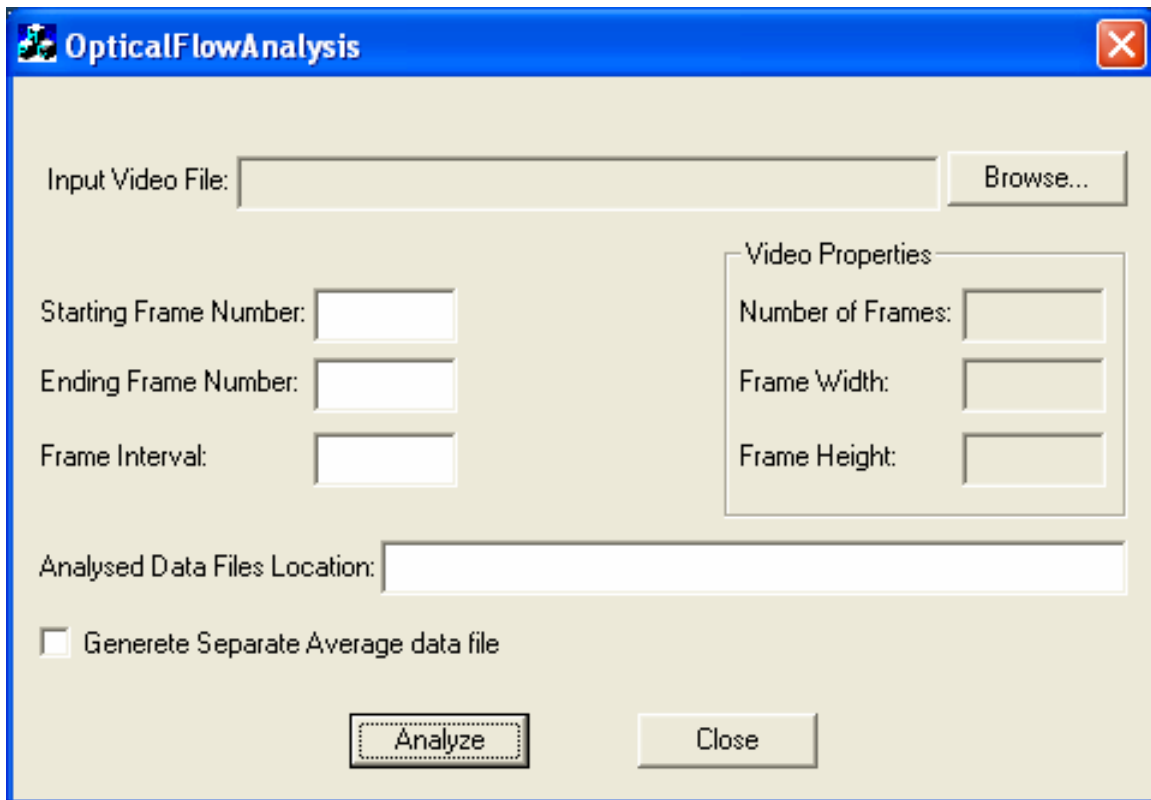


Figure 10: *OpenCV* Optical Flow Analysis Tool Interface

A typical average optical flow data file is shown in table 2. Basically the *OpenCV* software was set to provide the  $X$  and  $Y$  coordinates and the values of the velocity vectors  $V_x$  and  $V_y$  that represent the optical flow.

**Table 2: Optical Flow Output File Format of Video Footage**

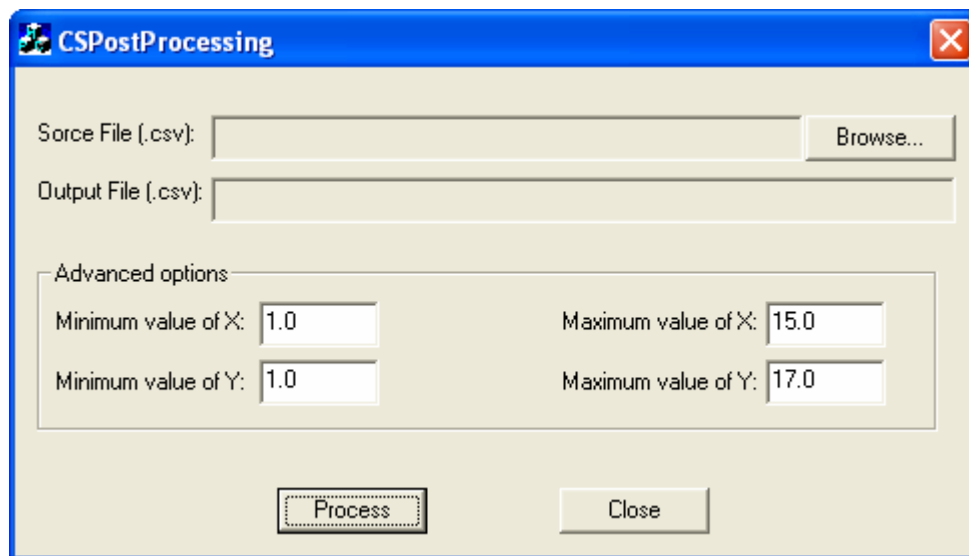
<b>Coordinates</b>		<b>Optical Flow Velocity Vector</b>	
<b>X</b>	<b>Y</b>	<b>V<sub>x</sub></b>	<b>V<sub>y</sub></b>
90	90	-0.016918	0.019407
180	90	0.132071	-0.01645
270	90	0.006213	-0.10174
360	90	0.000069	-0.00113
450	90	-1.959628	-7.95147
540	90	-2.38451	0.198616
90	180	0.231767	-0.20101
180	180	9.942951	-0.79474
270	180	-0.309685	-6.35951
360	180	-0.003441	-0.07066
450	180	-4.713269	-8.94748
540	180	0.248485	-15.6585

The second method was an analytical approach and was conducted by a group of graduate students. The real life video footages were divided into individual images in order to analyze them separately and extract crowd density and flux information. Crowd density was collected by recording the changes in number of individuals from frame to frame on fixed portions of the frames. Flux was recorded as the number of individuals crossing the boundaries of the fixed portions of the frames. With the help of video editing software, each frame of the footage was saved as separate file. As a standard practice, every 10<sup>th</sup> picture was used in the analysis. Two separate approaches were taken to accomplish the task. The first approach was to

manually extract the data from the images and the other was to extract data in an automated way. Data collected from this effort was very helpful in the validation process.

### Simulation Data and Video Capture

With the MASON framework properly set up, the HMFV crowd model was implemented. This model is XML (Extended Markup Language) driven which means all the configurations and simulations setups are implemented at the XML scripts. In the XML, details about the geometry of the simulation area, number of agents and their locations are specified. Also, this file contains tags to specify the movie capture and data collection (logging) options. By providing specific paths of the movie and data files, the data is stored in the desired folders. The simulation movie files are stored with .mov extension and playable with QuickTime software from Apple Computers. The data files are stored as comma separated files with .csv extension which are easy to parse and import into Microsoft Excel for further data analysis.



**Figure 11: Optical Flow Measurement Post Processing Tool**

**Table 3: Post Processed Optical Flow File Output of Simulation**

Shell Num	Average Vx	Average Vy	Num Of Individuals	Sum of square of Vx/Number of Summations	Sum of square of Vy/Number of Summations	(Velx & VelY)/Number of Summations
1	-3.48304	-1.61622	973	12.38286	3.033531	5.433219
2	-2.14498	-2.67307	1059	5.421978	7.953943	5.235215
3	-3.66228	-0.17156	155	13.50679	0.068314	0.642163
4	-2.82143	-0.06405	37	8.2029	0.166785	0.15966
5	1.959671	-2.72029	294	4.542925	7.883877	-5.23284
6	-0.10099	-3.00085	580	2.664813	9.61772	-0.18592
7	-3.17921	-1.55678	250	10.59443	3.175891	4.631551
8	-2.90128	-1.25467	124	8.826338	1.944869	3.710137
9	1.220601	-2.10796	23	1.56315	4.637281	-2.77304
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0

In table 3, the *Shell Num* represents the number of shells available in the video frame when it is divided into a 3 X 4 sections. For the purposes of comparing the optical flow data of simulation with the video footage, each shell represents 90 X 90 pixels. The average velocity vector data for the same number of pixels is specified in the *Average Vx* and *Average Vy* columns.

Table 4 shows the simulation test case setup. From the earlier discussion we know that the interaction between two individuals, *Ind1* and *Ind2* with their personality combinations, would take the form of a quadratic equation:

$$|Ind1.vpers|^{transpose} [MPF] [Ind2.vpers] - (15)$$

In the equation (15), the value for MPF matrix was derived from the literature and included in the XML configurations based on the demographics of scenarios. Also, the personality compositions for individual agents were specified based on the test cases (extroversion, neuroticism and American personality profile).

**Table 4: Simulation Test Cases**

<b>Case #</b>	<b>Test Case Geometry</b>	<b>Baseline HMFV</b>	<b>HMFV with Personality</b>
1	Crowd exiting a room with one exit	Yes	Yes
2	Crowd exiting from Citrus Bowl after UCF-Tulane football game	Yes	With Five separate groups of crowds with various personality compositions
3	Crowd exiting Holy Cross church service	Yes	With two separate groups of crowds with various personality compositions

There is a detailed discussion in the data analysis section on the results from these various test cases.

### **Relation between Crowd Motion and Optical Flow**

This section attempts to analyze the relation between crowd motion and optical flow and is adapted from Clarke [35].



To measure optical flow, the following assumptions are made:

1. Motion is produced only by people in the crowd.
2. Mapping between the physical space in which people move  $\bar{x} = (x, y)$  and the image space  $\bar{x}_I = (x_I, y_I)$  is assumed to be a simple scaling:  $x_I = Mx, y_I = My$  where the units of M are in pixels/meter.
3. The reflectivity and illumination of people and other elements in the scene are constant. This could be relaxed to allow these to be non-zero mean random variables uncorrelated with crowd motion.

The Lucas-Kanade algorithm expands the image intensity  $I$  in two dimensions as

$$I(x_I + \delta x_I, y_I + \delta y_I, t + \delta t) = I(x_I, y_I, t) + I_x \delta x_I + I_y \delta y_I + I_t \delta t + O(\delta^2)$$

Where  $I_x, I_y$  are partial derivatives of the image intensity, assuming  $I_t = 0$ .

Higher order terms  $O(\delta^2)$  are assumed to be negligible.

The Lucas-Kanade algorithm also assumes that the optical flow is locally constant so that within a neighborhood of  $(x_I, y_I)$ ,

$$I(\bar{x}_I + \delta \bar{x}_I, t + \delta t) = I(\bar{x}_I + \delta \bar{x}_I, t) + I_x (\bar{x}_I + \delta \bar{x}_I) V_x \delta t + I_y (\bar{x}_I + \delta \bar{x}_I) V_y \delta t.$$

If the neighborhood contains a processing window of size  $m \times m$  pixels, then there are  $m^2$  equations in the two unknown variables  $V_x$  and  $V_y$ . Lucas-Kanade solves this over-determined system using a pseudo-inverse technique with Gaussian weighting centered at  $\bar{x}_I$ .

When the image is of people moving in a crowd, the assumption of locally constant optical flow will be satisfied only when the neighborhood of  $\bar{x}_I$  falls within or outside the image of a person. This assumption is violated if  $\bar{x}_I$  is on the boundary of the image. However, it can

be argued that in this case, equation (1) holds with probability  $\frac{1}{2}$  when  $\bar{x}_I + \delta\bar{x}_I$  falls within the image of the moving person and with probability  $\frac{1}{2}$  when there is no change in I, that is  $I(\bar{x}_I + \delta\bar{x}_I, t + \delta t) = I(\bar{x}_I + \delta\bar{x}_I, t)$ , when  $\bar{x}_I + \delta\bar{x}_I$  falls outside the image of the moving person. In this case, the Lucas-Kanade algorithm would lead to an estimate of  $V_x / 2$  and  $V_y / 2$ .

The conversion factor between optical flow and physical velocity is  $K = M / fps$  where fps is the frame rate of the video (sequence of images) used for the Lucas-Kanade optical estimate. If a neighborhood of the pixel upon which the estimate is centered lies entirely within the image of the person, then the Lucas-Kanade optical flow estimate should give an accurate estimate of velocity of persons within the crowd. Similarly, the velocity estimate (zero velocity) should also be accurate if the neighborhood of the pixel lies entirely outside the person that is in the background.

Determining whether the pixel neighborhood is within or outside a person's image is equivalent to the very difficult problem of tracking a person in a crowd. Solving this problem would make it unnecessary to employ optical flow estimation techniques such as Lucas-Kanade. The proposed solution for relating optical flow to physical velocity is to average the estimates of optical flow  $V_x$  and  $V_y$  over regions of the image. These average flow values are then related to average physical velocity values that are determined by hand-counting methods.

To analyze the relation between averaged optical flow and averaged hand-counts, let  $N_k$  be the number of individuals within the crowd in the  $k^{\text{th}}$  averaging box of physical size  $L_x$  by  $L_y$ . Then  $N_k(t + \Delta t) - N_k(t) = (F^+_y + F^-_y + F^+_x + F^-_x)\Delta t$  where  $F_x^\pm$  and  $F_y^\pm$  are the number of people moving in/out of the right/left (top/bottom) edges of the averaging box per unit time; that is, the flux of people across the corresponding box edge.

Using  $N_{k+}$  to denote the number of individuals in box  $k$  and  $N_{k-}$  to denote the number of individuals in the box below the  $k^{\text{th}}$  one, the vertical fluxes take the form  $F_y^{\pm} = \pm v_y N_{k\pm} / L_y$ . Similarly, the horizontal fluxes are  $F_x^{\pm} = \pm v_x N_{k\pm} / L_x$ . Dividing by  $L_y$  corrects for the physical units and is intuitively motivated by thinking of the individuals in the averaging box as a “queue” of length  $L_y$  waiting to exit the box.

With reference to the Lucas-Kanade algorithm discussed previously, a relation between the fluxes and the optical flow can be derived. Relating first the optical flow to the physical velocity of individuals in the crowd;

$$V_x = K \frac{A_p N_k}{L_x L_y} v_x \text{ and } V_y = K \frac{A_p N_k}{L_x L_y} v_y, \text{ where } A_p \text{ is the average area of an individual (in same}$$

units as  $L_x$  and  $L_y$ ) so that the expression contains the ratio of total area of people to area of the averaging box within the image.

Substituting, the relations between optical flow and fluxes (hand-counts) are:

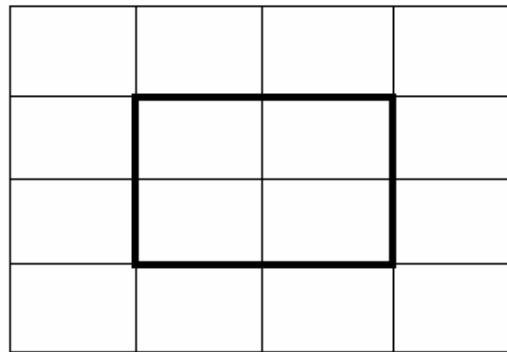
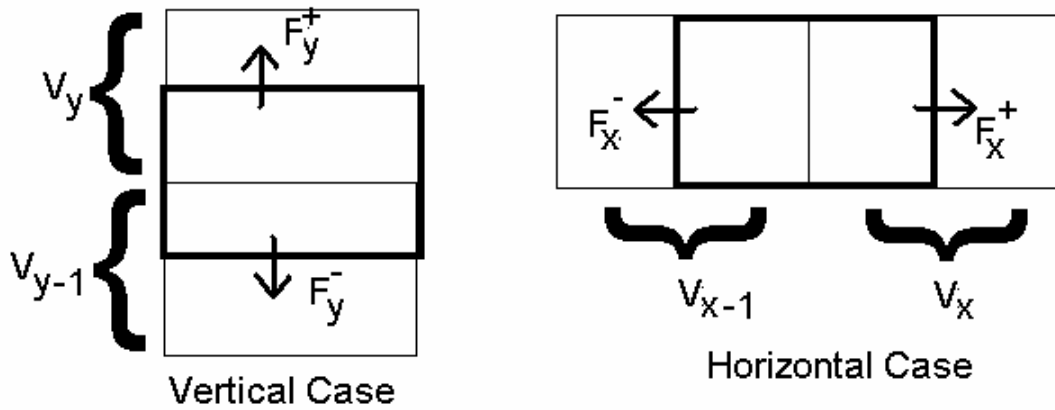
$$V_x = \pm K \frac{A_p}{L_y} F_x^{\pm}, \text{ and } V_y = \pm K \frac{A_p}{L_x} F_y^{\pm}$$

Note that the optical flows are independent of the total number of individuals  $N_k$  except as it affects the values of  $F_x^{\pm}$  and  $F_y^{\pm}$ . Since  $K$ ,  $A_p$ ,  $L_x$  and  $L_y$  are constant, the constant relating  $V_x$  and  $V_y$  to  $F_x^{\pm}$  and  $F_y^{\pm}$  can be determined by empirical calibration comparing optical flow with hand counts. An empirical approach such as this can accommodate uncertainties in the behavior of the Lucas-Kanade algorithm in complex scenes such as crowds. Also, by assuming a

typical value for  $N_k$ , values for  $v_x$  and  $v_y$  can also be derived from the optical flow values  $V_x$  and  $V_y$ .

In the above expression, the  $\pm$  ambiguity indicates that the horizontal (vertical) optical flow equals both the right (top) and the negative of the left (bottom) fluxes. This suggests that it might be better to use an overlapping grid to compare the hand-counted fluxes with the Lucas-Kanade optical flows. However, since the overlap is different for horizontal and vertical fluxes/flows, so the best approach might be to average the optical flow over a grid of boxes twice as fine as that used for the hand counts. In this way, optimum overlap for the vertical and the horizontal flux/flow comparisons can be generated by simple arithmetic.

Figure 12 illustrates Relationship between flux hand-counts and optical flow estimates using Lucas-Kanade method.



Flow Twice as Fine as Flux (Hand -Count)

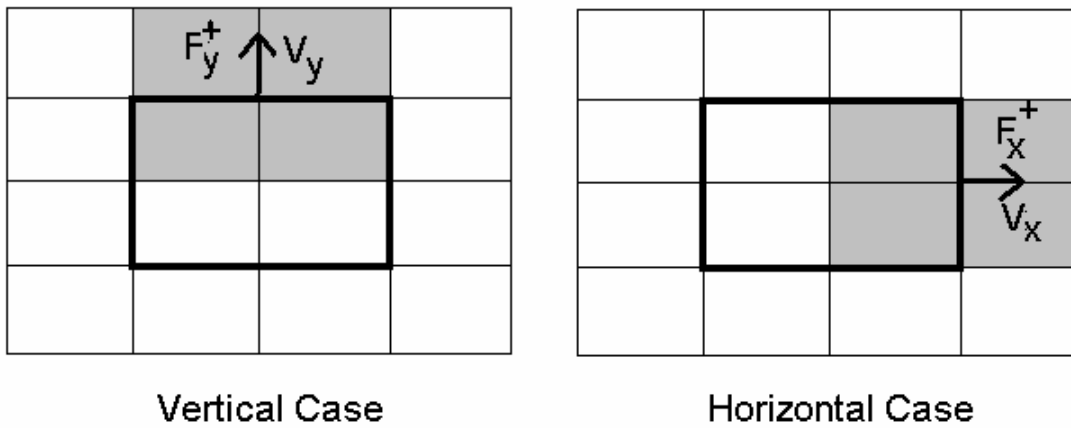


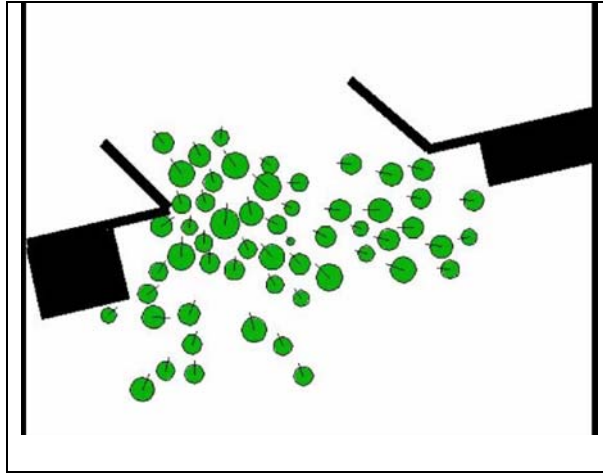
Figure 12: Flux Hand Counts and Optical Flow Estimates (Lucas-Kanade)

## **Data Analysis: Comparison of Optical Flow Measurement**

Data analysis is divided into two parts. First, the real-life video footage for various scenarios were analyzed using the *OpenCV* software and optical flow measurements consisting of velocity vectors were obtained. Based on the discussions in the section ‘Relation between Crowd Motion and Optical Flow’, an Excel macro was developed to obtain the velocity vectors. Appendix D shows how optical flow data is extracted from the Excel spreadsheet. Then baseline HMFV simulation for the similar geometry was performed and optical flow measurements were obtained from the raw simulation data using *CSPostProcessing* software. The optical flow results were compared.

### **Scenario 1: Crowd Exiting Stadium - Baseline HMFV Simulations**

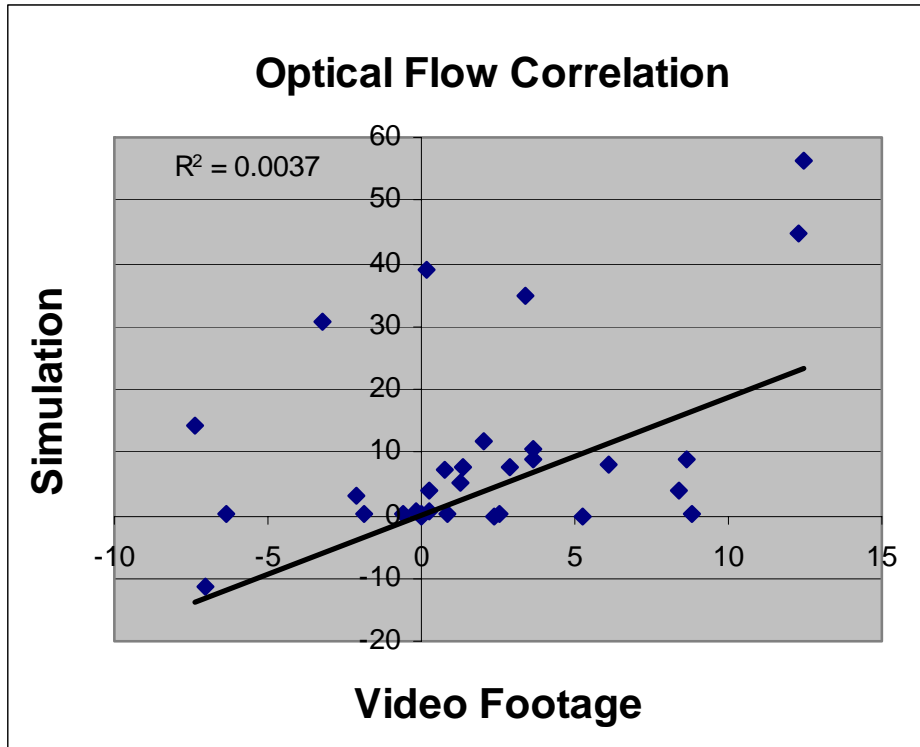
From the inventory of several video clips, the video footage of the crowd exiting from the Citrus Bowl after a UCF-Tulane football game was used in this analysis. Using the *OpenCV* software and Excel macro the average optical flow data that provides  $X$  and  $Y$  components of the velocity were obtained.



**Figure 13: Crowd Exiting Stadium - Baseline HMFV Simulation**

A similar geometry that represents the Citrus Bowl exit was developed by Rex Oleson and used in the simulation (figure 13). Simulation configurations are specified in a XML file `citrus_tulane.xml`. Ten simulation iterations were performed on the baseline HMFV model using this geometry and optical flow measurements were computed. Using the *CSPostProcessing* tool, the average velocity vectors were obtained.

The velocity vectors from the *OpenCV* on the Citrus Bowl video footage and the baseline HMFV simulation were compared and the correlation was obtained ( $R^2=0.0037$ ). This analysis provides good baseline results. The data table that builds the plot in figure 14 is available in Appendix C.



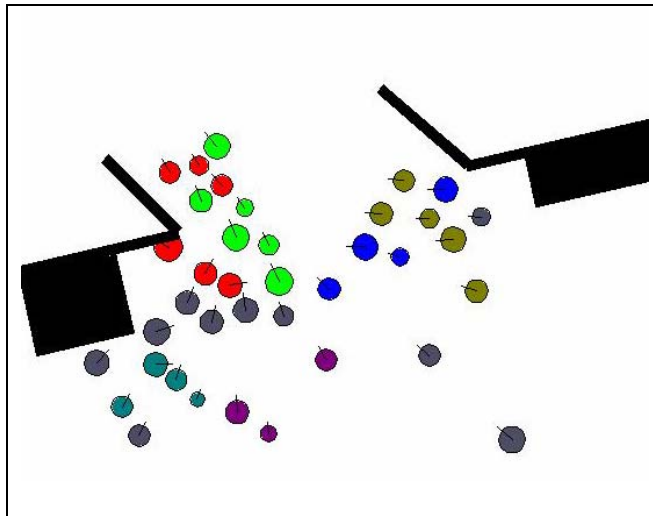
**Figure 14: Correlation of Baseline HMFV with Citrus Bowl Video**



## HMFV Simulations with Personality Factors Incorporated

Simulation results from two scenarios were chosen (i) Crowd exiting from the Citrus Bowl football stadium, (ii) Crowd exiting from the Holy Cross Church. There were three different simulations with varying personality factors for a total of six cases.

Case 1: Figure 15 shows the simulation of crowd exiting stadium with a typical American personality profile incorporated. The MPF matrix used in this simulation is shown in table 5. Table 6 lists the various groups that consist of a typical American crowd profile. The total number of individuals in this simulation  $N = 60$ .



**Figure 15: HMFV Simulation of Crowd Exiting Stadium (American Personality Profile)**

**Table 5: MPF Matrix for American Personality Profile**

	<b>N</b>	<b>E</b>	<b>O</b>
<b>N</b>	0.3	-0.1	-0.3
<b>E</b>	0.1	0.5	0.4
<b>O</b>	0.1	0.3	0.6

**Table 6: American Crowd Profile – Personality Factors Combination**

<b>Crowd Size = 60 Individuals</b>				
	<b>Group Size</b>	<b>N</b>	<b>E</b>	<b>O</b>
Group 1	12	1	0	0
Group 2	11	0	1	0
Group 3	8	0	0	1
Group 4	10	0.5	0.5	0
Group 5	4	0	0.5	0.5
Group 6	3	0.5	0	0.5
Group 7	12	0.3	0.3	0.4

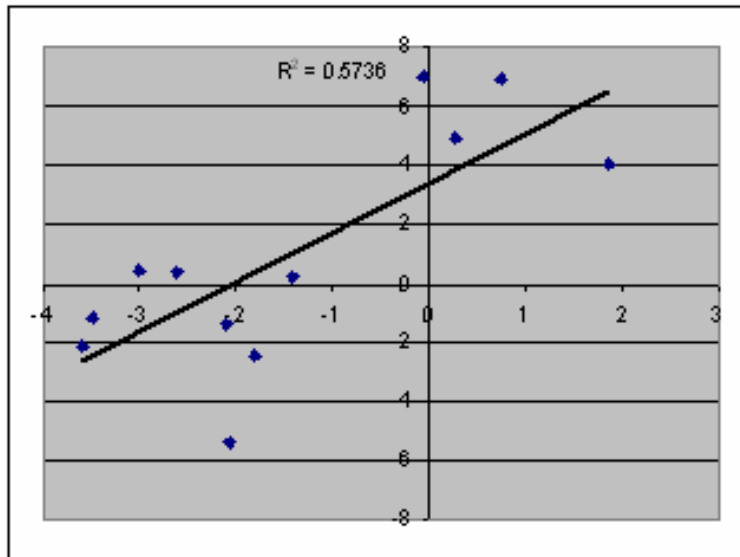
The plot in figure 16 show the correlation of velocity vectors obtained from optical flow calculations on simulations with personality factors that represent the American personality profile incorporated. This correlation data is an average of multiple simulation runs and it is observed that the correlation ( $R^2=0.5736$ ) has significantly increased in the simulation runs that included the personality factors.

**Table 7: Correlation Data – HMFV Simulation of Crowd Exiting Stadium**

**(With American Personality Profile)**

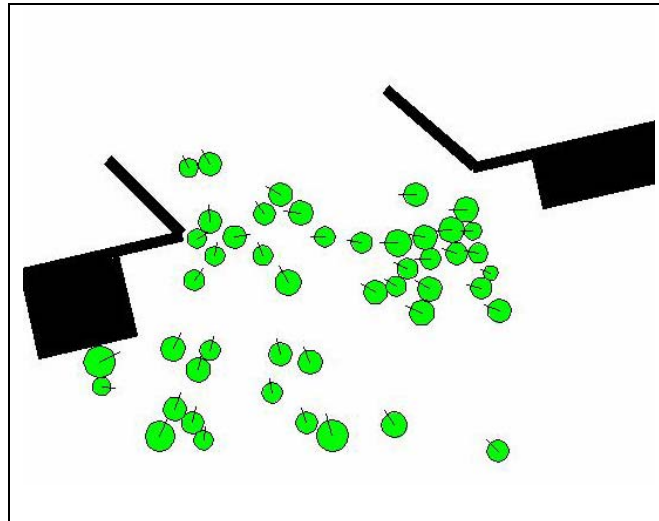
<b>Simulation Velocity Vector (Vx)</b>	<b>Video Footage Velocity Vector (AvX)</b>
-3.493101	-1.157517825
-2.065165	-5.396658975
-3.578393	-2.158801475
-2.613633	0.35487215
1.85618	4.034393575
-0.057941	7.006339875
-3.004011	0.420379975
-1.814782	-2.466138425
0.758056	6.945721575
0.272023	4.89809095
-1.417129	0.208026325
-2.101727	-1.407498025

Table 7 shows the correlation data for the HMFV simulation of crowd exiting the stadium with American personality profile incorporated.



**Figure 16: Correlation NEO-simulation with Citrus data, using American Personality Profile**

Case 2: Figure 17 shows the simulation of crowd with high extroversion exiting the stadium. The MPF matrix and high extroversion personality combinations used in this simulation are shown in table 8 and table 9. The total number of individuals in this simulation  $N = 60$ .



**Figure 17: HMFV Simulation of High Extroversion Crowd**

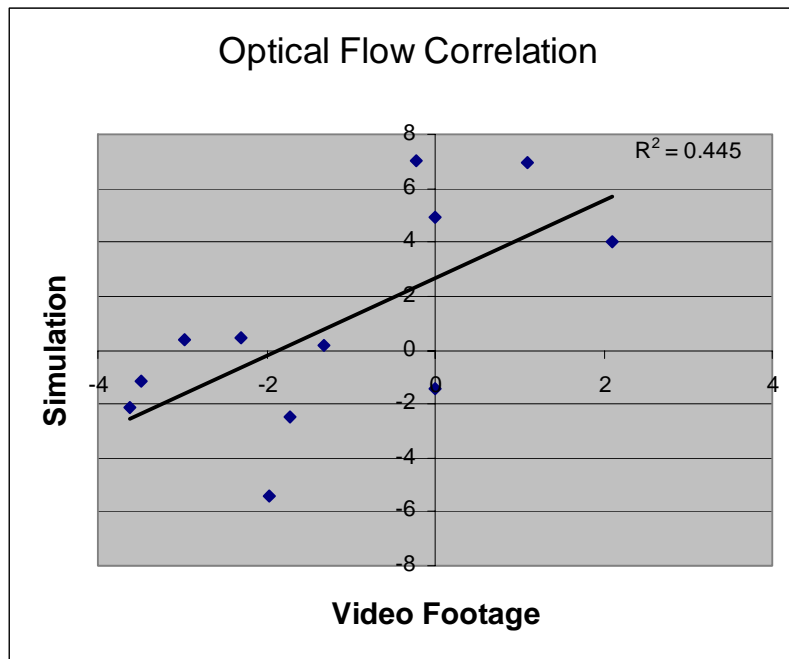
**Table 8: MPF Matrix for High Extroversion Crowd**

	<b>N</b>	<b>E</b>	<b>O</b>
<b>N</b>	1	-0.1	0
<b>E</b>	-0.1	1	-0.1
<b>O</b>	0	-0.1	1

**Table 9: High Extroversion - Personality Factors Combination**

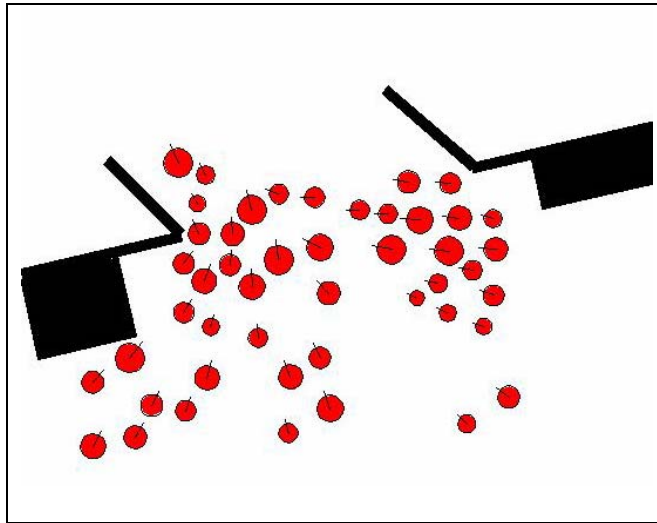
<b>Crowd Size = 60 Individuals</b>		
<b>N</b>	<b>E</b>	<b>O</b>
0	1	0

The plot in figure 18 shows the correlation of velocity vectors obtained from optical flow calculations on simulations of the highly extroverted crowd. This correlation data is an average of multiple simulation runs and it is observed that the correlation has increased in the simulation runs that included the personality factors. We can observe that the correlation ( $R^2=0.445$ ) is higher than the baseline HMFV and relatively closer to the American personality profile.



**Figure 18: Correlation NEO-simulation with Citrus data, using High Extroversion**

Case 3: Figure 19 shows the simulation of crowd exiting stadium with high neuroticism incorporated. The MPF matrix and high neuroticism personality combinations used in this simulation are shown in table 10 and table 11. The total number of individuals in this simulation  $N = 60$ .



**Figure 19: HMFV Simulation Crowd with High Neuroticism**

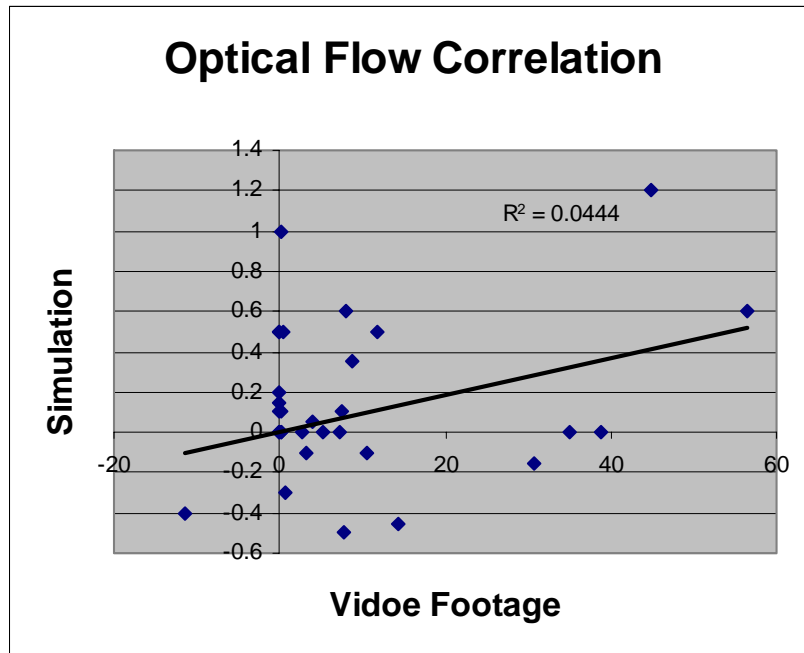
**Table 10: MPF Matrix for High Neuroticism Crowd**

	<b>N</b>	<b>E</b>	<b>O</b>
<b>N</b>	1	-0.1	0
<b>E</b>	-0.1	1	-0.1
<b>O</b>	0	-0.1	1

**Table 11: High Neuroticism - Personality Factors Combination**

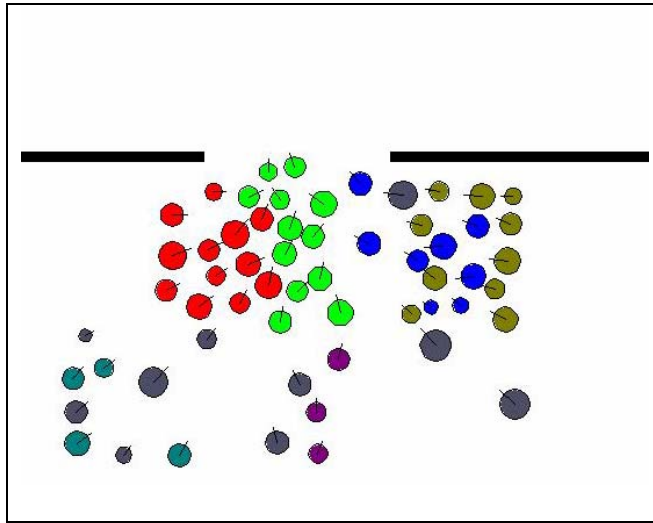
<b>Crowd Size = 60</b>		
<b>Individuals</b>		
<b>N</b>	<b>E</b>	<b>O</b>
0	1	0

The plot in figure 20 shows the correlation of velocity vectors obtained from optical flow calculations on simulations of the highly neurotic crowd. This correlation data is an average of multiple simulation runs and it is observed that the correlation has not significantly increased. The simulation does not appear to show behavior similar to the actual crowd as video taped.



**Figure 20: Correlation NEO-simulation with Citrus data, using High Neuroticism**

Case 4: Figure 21 shows the simulation of crowd exiting church with typical american personality profile incorporated. The optical flow correlation of the simulation with video footage presents a higher correlation compared to the baseline HMFV with no personality factors included. The correlation numbers ( $R^2$ ) from the highly extroverted crowd and highly neurotic crowd were very similar to that of the crowd exiting the stadium.



**Figure 21: Exiting Church – American Personality Profile**

From all these six cases (two scenarios and three personality profiles in each scenario) the average time for the crowd to exit the church and stadium was captured and shown in table 12. Also a representative video of the simulation was also captured for each case. These captured videos were shown to the expert panel for their opinions.



**Table 12: Mean Time for Crowd Exiting from Church and Stadium**

<b>Scenarios</b>	<b>Mean Time to Exit (in Seconds)</b>		
	<b>High Extroversion</b>	<b>High Neuroticism</b>	<b>American Profile</b>
Crowd exiting Church	96	12	80
Crowd exiting Stadium	64	8	45

### **Validation**

Face validity is concerned with how a measure or procedure appears generally to a group of subject matter experts. In this research establishing face validity provides a reasonable way to gain confidence in the research methods and the tools that were developed as part of this research. Also, correlation results from baseline HMFV and simulation with personality factors, serve as a good validation.

### **Report on Expert Panel Observations and Opinions**

The expert panel consisted of three Ph.D. behavioral scientists all of whom have significant experience in research relating to behavior and personality. The research experience of the three panelists ranges between 10 and 40 years. The panelists were interviewed

individually, but the analysis below is a combined summary of the points that they made. The panelists commented on the videos and simulations as they were shown and then made some additional observations.

### **Description of the Scenarios and Simulations Exhibited to the Panel**

The two scenarios were: (1) a crowd exiting from a church, a Catholic Church located in Orlando, Florida, and (2) a crowd exiting from a stadium, the Citrus Bowl after a UCF football game in 2005. The video taken of these two events has been used in previous work conducted by the crowd simulation team at IST. For each scenario there were three different personality profiles simulated: (1) a high extroversion group, (2) a high neuroticism group, and (3) an American profile group. These conditions were combined into a 3x2 factorial experiment, with three personality conditions for each of the two scenarios. The same arrangement and number of individuals in the crowd provided the initial condition for the simulations run under each scenario. The initial crowd arrangements for the two scenarios differ however, because of their different environments.

## **Summary of Behavior Observed in Video Footage**

### Crowd Exiting Church:

- Several social behaviors are observed such as people talking to each other (sub-grouping) and a person handing out a flyer.
- The individuals in the crowd exhibit the common goal of reaching the exit.
- The speed at which they exit is determined by the degree of social interaction, geometry of the environment and other factors (such as a sore foot, age and inter-personal distance).
- The crowd exhibits typical characteristics of exiting by maintaining appropriate order and inter-personal space.

### Crowd Exiting Football Stadium:

- The crowd is focused on exiting the stadium (shared goal).
- The crowd shows some level of sub-grouping (i.e., social behavior), but not as much as in the church video.
- A group of individuals joining the crowd from the right side manages to move at the same speed without disrupting the larger group.

### Comparison of Two Video-taped Scenarios

- More social behavior is evident with the church scenario than the stadium scenario.
- The church crowd moves more slowly than does the stadium crowd.
- The church crowd takes up most of the space at the exit; the stadium crowd does not.

## Summary of Behavior Observed in Simulations

### Crowd Exiting Church:

- With the high extroversion and American profile groups, the crowd exhibits:
  - The common goal of exiting the church.
  - Some sub-grouping but not to the degree seen in the video (e.g., person handing out a flyer and people moving around him).
  - In the high extraversion simulation, the crowd tends to sub-group more than in the groups with the other personality profiles.
- The American profile crowd is fairly slow which appears to reflect social behavior. This may be due to highly extroverted personalities dominating group dynamics.
- The American personality profile crowd is almost as slow and exhibits some sub-grouping, as compared with the high extroversion group.
- The neurotic crowd moves very quickly – unrealistically so.
- In the neurotic crowd simulation, an individual appears to be going in circles. This is a valid crowd behavior as seen in emergency situations such as concert crowds on a rampage.

### Crowd Exiting Football Stadium:

- In case of high extroverted and the American personality profile crowds, there is some sub grouping exhibited.
- An individual in the neurotic crowd is caught behind a gate.
- In the case of the American profile, the extroverts are not clustering to any significant degree.

- In the American profile group exiting the stadium, the crowd is seen reacting to the natural barrier (corner of the gate at the stadium exit). The extroverts are not pushing their way to get out and instead appear to wait for others to pass.
- In the American profile crowd, a individual with a neurotic personality seems to push the next person in getting out.

Similarities noted in behavior between church video footage and simulations:

- For the high extroversion and American profile simulations, the crowd exhibits:
  - The common goal of exiting the church.
  - Some sub-grouping, but not to the degree evident in the video (example: person handing out a flyer and people moving around him)
  - Tighter personal space in the video than in the simulations.
- In the high extraversion simulation, the crowd tend to sub-group more than in the simulations than is the case with the other personality profiles.

Similarities noted in behavior between stadium video footage and simulations:

- The extroverted crowd is moving slowly and the exit through a narrow passage at the very end - top left side of the simulation. (There is a small gate that the crowd is passing through to get to the parking lot. The way points specified in the simulation seems to determine this path.)
- In the case of the high extroverted and the American personality profile crowds, there is some sub-grouping exhibited.

## **Realism of Simulations - Overall Assessment**

### Points relating to the realism of the simulations:

- The simulations seem to capture elements of real crowd behaviors as seen in the corresponding video.
- Simulation of crowds with personality shows a shared goal of exiting the church and sub-goals exhibited as seen in the footage.
- The simulation effort is successful in simulating differences among various personality traits.
- This is a great first step towards modeling personality.

### Points relating to how simulations can be improved for greater realism:

- The simulation should include crowd dynamics based on situational variables such as time pressure, end goal, geometrical limitation as these variable tend to have a bearing on personality phase change for an individual.
- The individuals in the crowd can be better graphically represented and sub-groupings can be enhanced.

### **Did the Research Achieve the Stated Goals?**

Yes. Behaviors definitely can be seen in the simulations which mimic the behaviors seen in the videos. The panel suggested follow-up for future research scope are: The simulation should include crowd dynamics based on situational variables such as time pressure, end goal, geometrical limitation as these variable tend to have a bearing on personality phase change for an individual.

## Concerns and Caveats

All individuals have some combination of all five personality factors, i.e., a typical extrovert will have some element of other four personality factors. These factors may tend to change state depending on the situation, which means that the individual will behave/react differently in a crowd (their personality will change) depending on the situation. Future research should take this factor into account.

- Neuroticism may not lead to lack of interaction all the time. It may also lead to inappropriate interaction, which could slow other people down. How the model can capture those kind of situations (example from his conversation: *'it is the aliens not really the fire'*)? They also made a point that modeling personality is a very complex task.
- What is the reason for the speed change between the neurotic and extraverted crowd? The crowd with high neuroticism appears to move unrealistically fast.
- The graphical simulation of sub-group formation in the simulations needs to be enhanced. Future research should find a way to identify the sub-groups (by highlighting or similar technique).
- In the church, the natural barriers do not seem to cause anomalies; however, with the stadium simulations, some individuals appear to become trapped.
- The extroverted crowd in the stadium scenario moves slowly and then exits through a narrow passage at the very end (top left side of the simulation). Why? **Answer:** There is a small gate that the crowd is passing through to get to the parking lot. The way points are specified in the simulation determines this path.

- One of the expert panel members suggests that extroverts dominate the crowd, and slow down the other individuals as they try to interact (attractive force?)

Will reducing the number of extroverted individuals, make the crowd move faster?

This is a good issue for follow-up research.



## **CHAPTER FIVE: CONCLUSION AND SCOPE**

By adding personality factors to the base simulation we have developed a significant modification to the HMFV model. Incorporation of Big Five personality factors into the base HMFV model has helped make the individuals in the crowd behave intelligently. Grouping and sub-grouping of individuals demonstrate that there are some social behaviors exhibited by the individuals in the crowd. The results also show significant correlations of the simulations with the real-life crowd situations. In all these simulations, the majority of individuals are pressing to exit but the excitement factor is such that a small number of individuals are moving counter flow "seeking" other exits. This subpopulation is easily detectable, and suggests that individuals involved in IED activities can be easily detected as well. The research suggested would focus on a situation which might shed light on war-fighter missions.

Developing an analytical method to quantify the real-life video footage using optical flow techniques was another significant contribution that resulted from this research. By obtaining the optical flow measurements from the video footage using an open source software code has provided a platform for strong validation of simulation results. We are currently creating a software package that will include documentation on how to implement personality to any of the future crowd simulation models that will emerge from the crowd simulation research program at IST. A draft of this manual is included in Appendix A. Creating a user manual will greatly aid the simulation and training community.

## Scope

Ongoing research aims at considering individual differences in age, gender, culture and ethnicity to increase the value of crowd simulation both in operational and training contexts. The explicit incorporation of gender, ethnicity, age, and cultural differences as factors in the model will ensure broad applicability of the research to crowd control in nations other than the U.S. Cultural differences have a significant effect on personal space and thus social behavior. For example, Japanese prefer a larger surrounding space than Americans, while Italians prefer a smaller personal space. Reaction to physical contact between cultural groups also varies. Finally, no matter which specific model is implemented, it will be of limited use until its results can be compared against measured data on pedestrian dynamics. Thus, the greatest need in this field at the moment seems to be to obtain observational data relevant to the existing models.

Also, from the review of the expert panel opinions and suggestions, it is evident that the simulations reflected some aspects of real behavior. For example,

- Simulation of crowds with personality traits included shows a shared goal as well as sub- goals as exhibited in the footage of the crowd exiting the church.
- The simulation effort is successful in simulating differences among various personality traits.
- The crowd is seen reacting to a natural barrier (corner of the gate at the stadium exit).

The panel concluded that the research represents a contribution to the modeling and simulation body of knowledge, specifically as it provides initial evidence that social behavior can be emulated with mathematically-driven crowd simulations.

**APPENDIX A: CROWD SIMULATION PACKAGE INSTALLATION**

The software development that is undertaken as part of this research is delivered as a package. The package consists of the crowd simulation project and various in house developed tools for analysis and validation of simulation.

Package installation:

1. Copy the CrowdSimulationPackage.zip file to your computer's C:\
2. Extract the CrowdSimulationPackage.zip to C:\CrowdSimulation

Following is the list of individual components of the package with their pre-requisites, execution and build steps.

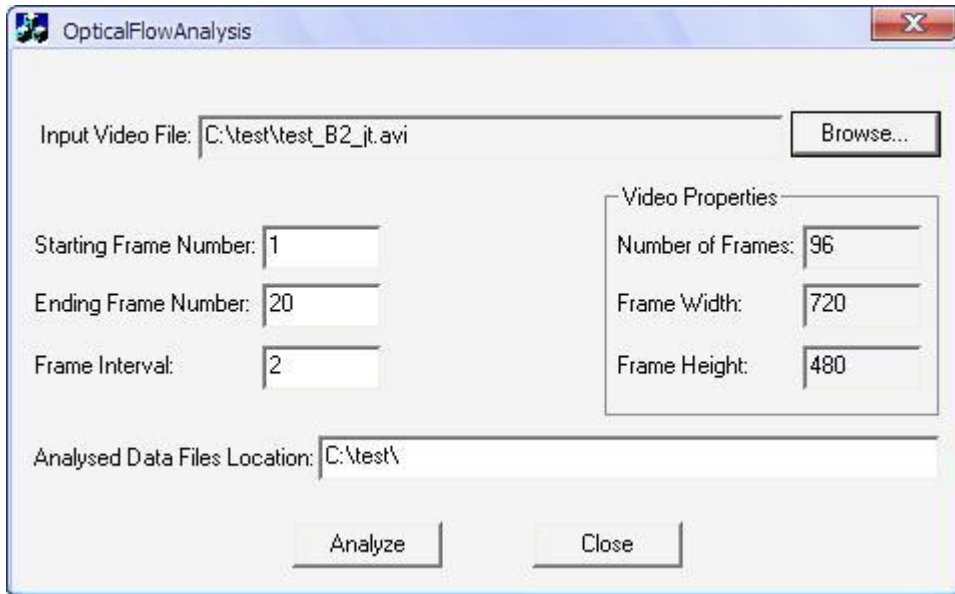
### Optical Flow Analysis Tool

- Pre-requisites:

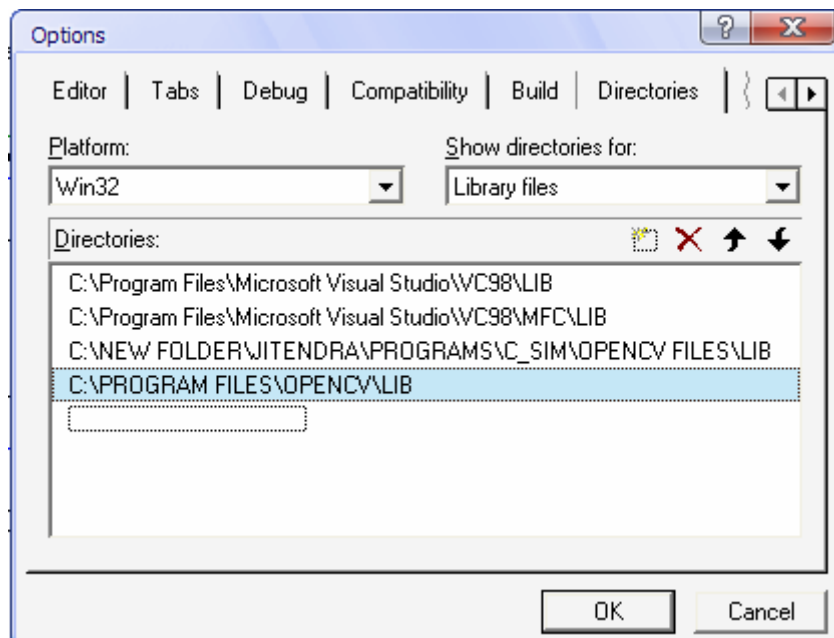
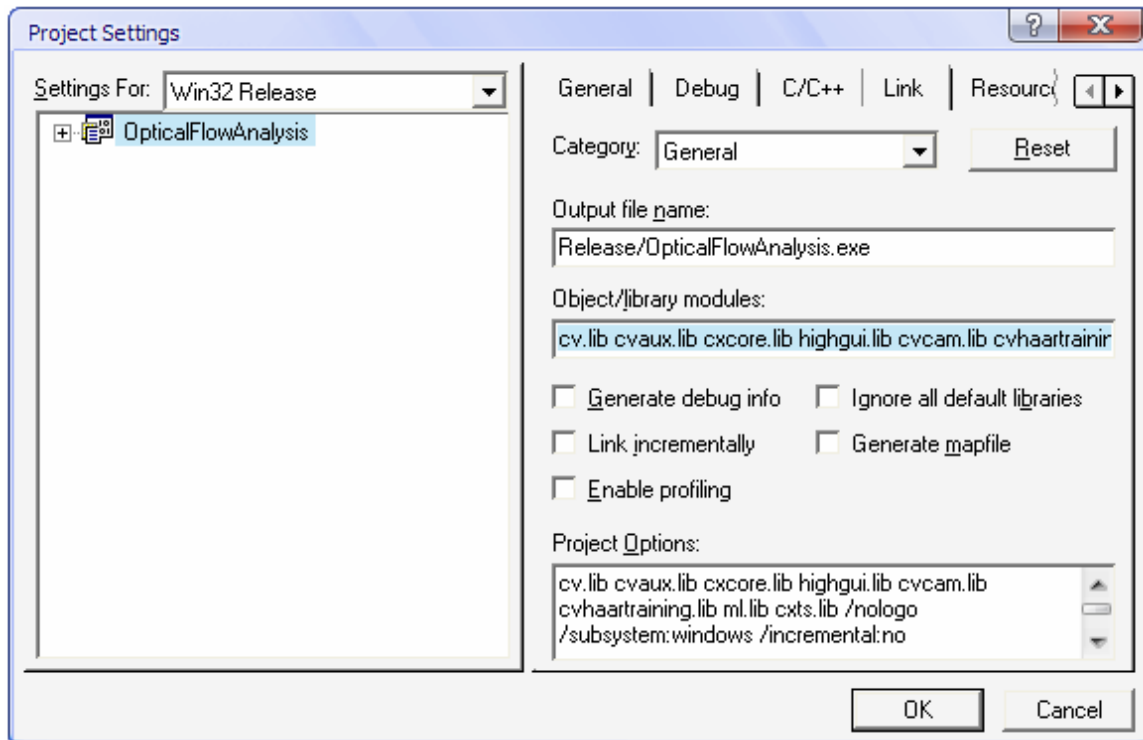
Run time dependencies	
<i>OpenCV</i>	Refer to the link - <a href="http://sourceforge.net/projects/opencvlibrary/">http://sourceforge.net/projects/opencvlibrary/</a> , to get download and installation instruction for <i>OpenCV</i>
Build time dependencies	
Microsoft Visual Studio 6.0	Refer to the link - <a href="http://msdn2.microsoft.com/en-us/vstudio/aa700914.aspx">http://msdn2.microsoft.com/en-us/vstudio/aa700914.aspx</a> , to get download and installation instruction for MS Visual Studio 6.0
<i>OpenCV</i>	Refer to the link - <a href="http://sourceforge.net/projects/opencvlibrary/">http://sourceforge.net/projects/opencvlibrary/</a> , to get download and installation instruction for <i>OpenCV</i>

- Execution steps:

1. Run the Optical Flow Analysis tool by double clicking on  
“C:\crowdSimulation\Executables\OpticalFlowAnalysis.exe”.



- Compile and build steps:
  1. Open the project file  
“C:\crowdSimulation\development\OpticalFlowAnalysis\OpticalFlowAnalysis.dsw” in  
Visual Studio 6.0.
  2. Add the *OpenCV* libraries and their path for project setting, as show below.



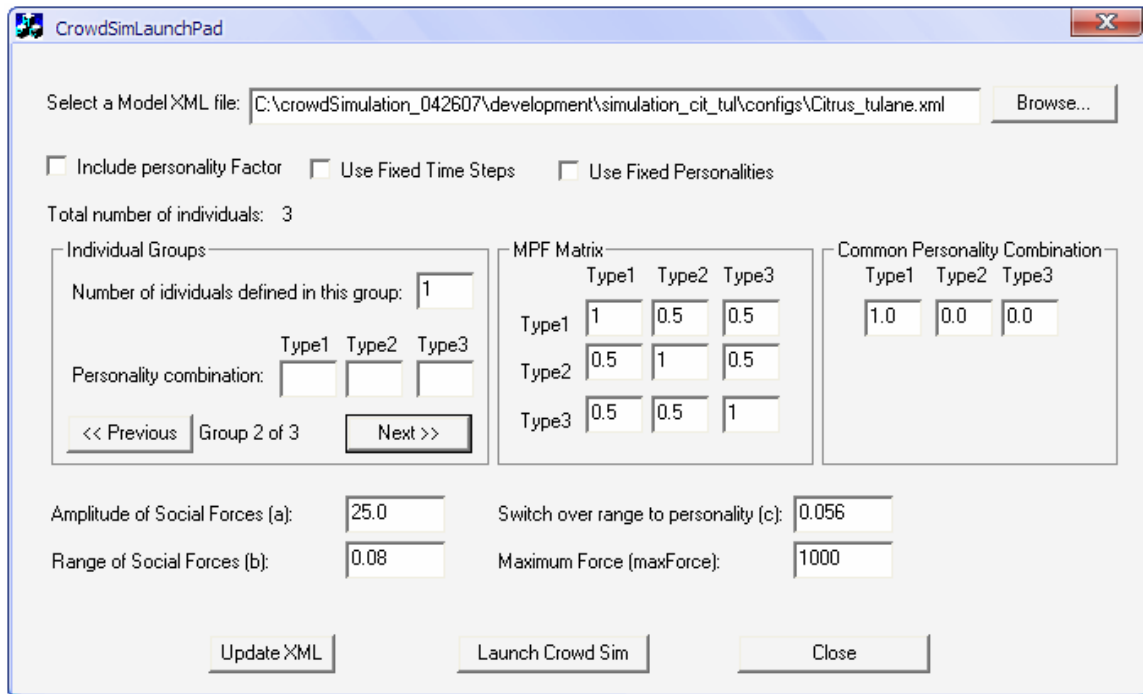
3. Build the project.

## Crowd Simulation Launch Pad (Configurable Crowd Simulation)

- Pre-requisites:

Run time dependencies	
Microsoft XML Parser (MSXML)	Refer to the link – <a href="http://msdn2.microsoft.com/en-us/xml/bb190622.aspx">http://msdn2.microsoft.com/en-us/xml/bb190622.aspx</a> , to get download and installation instruction for MSXML Parser
Build time dependencies	
Microsoft Visual Studio 6.0	Refer to the link – <a href="http://msdn2.microsoft.com/en-us/vstudio/aa700914.aspx">http://msdn2.microsoft.com/en-us/vstudio/aa700914.aspx</a> , to get download and installation instruction for MS Visual Studio 6.0
Microsoft XML Parser (MSXML)	Refer to the link – <a href="http://msdn2.microsoft.com/en-us/xml/bb190622.aspx">http://msdn2.microsoft.com/en-us/xml/bb190622.aspx</a> , to get download and installation instruction for MSXML Parser

- Execution steps:
  1. Run the Configurable Crowd Simulation by double clicking on “C:\crowdSimulation\Executables\CrowdSimLaunchPad.exe”.
  2. Select the xml file Crowd Simulation by clicking on Browse button.
  3. Once the xml is loaded, all the personality related attributes with their values will be displayed on GUI.
  4. Change these parameters (personality combinations, MPF matrix, etc) as needed.
  5. Update the xml and launch Crowd Simulation.



**NOTE:** The launch pad makes a copy of original xml file before applying the changes.

- Compile and build steps

1. Open the project file

“C:\crowdSimulation\development\CrowdSimLaunchPad\CrowdSimLaunchPad.dsw” in Visual Studio 6.0.

2. Build the project.



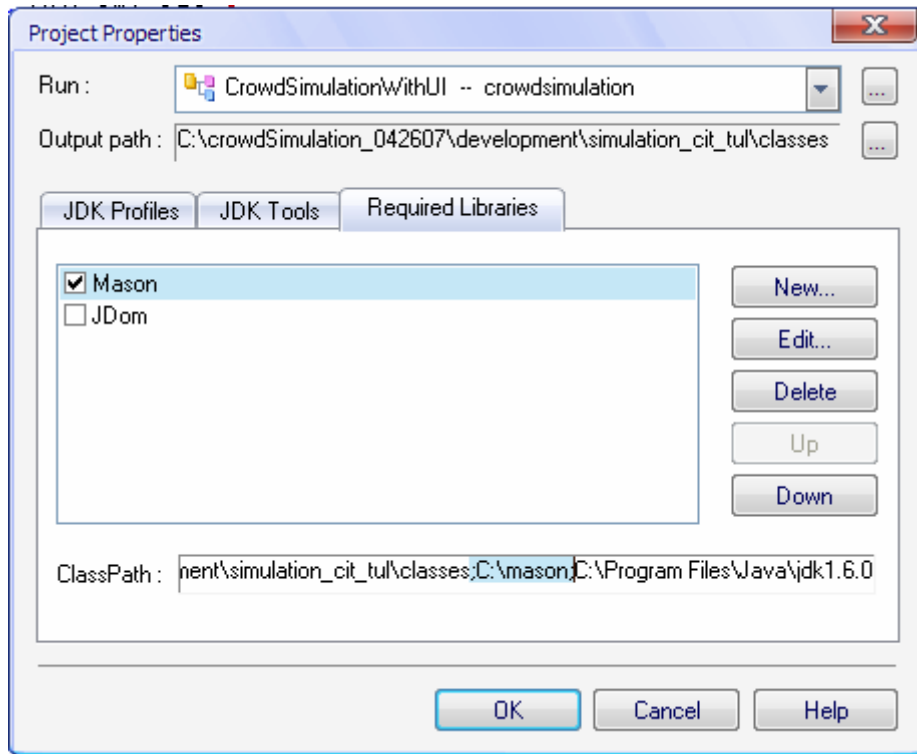
## Crowd Simulation with Personality

- Pre-requisites:

Run time dependencies	
JDK 6.0, JRE 6.0	Refer to the link <a href="http://java.sun.com/javase/downloads/index.jsp">http://java.sun.com/javase/downloads/index.jsp</a> , to get download and installation instruction for JDK/JRE
JMF 2.1.1e	Refer to the link <a href="http://java.sun.com/products/java-media/jmf/">http://java.sun.com/products/java-media/jmf/</a> , to get download and installation instruction for JMF
Java 3D 1.4.0_01	Refer to the link <a href="http://java.sun.com/products/java-media/3D/">http://java.sun.com/products/java-media/3D/</a> , to get download and installation instruction for Java 3D
MASON	Refer to the link <a href="http://cs.gmu.edu/~eclab/projects/mason/">http://cs.gmu.edu/~eclab/projects/mason/</a> , to get download and installation instruction for MASON
Build time dependencies	
JCreator LE 3.50	Refer to the link – <a href="http://www.jcreator.com/">http://www.jcreator.com/</a> , to get download and installation instruction for JCreator LE 3.50
JDK 6.0, JRE 6.0	Refer to the link <a href="http://java.sun.com/javase/downloads/index.jsp">http://java.sun.com/javase/downloads/index.jsp</a> , to get download and installation instruction for JDK/JRE
JMF 2.1.1e	Refer to the link <a href="http://java.sun.com/products/java-media/jmf/">http://java.sun.com/products/java-media/jmf/</a> , to get

	download and installation instruction for JMF
Java 3D 1.4.0_01	Refer to the link <a href="http://java.sun.com/products/java-media/3D/">http://java.sun.com/products/java-media/3D/</a> , to get download and installation instruction for Java 3D
MASON	Refer to the link <a href="http://cs.gmu.edu/~eclab/projects/mason/">http://cs.gmu.edu/~eclab/projects/mason/</a> , to get download and installation instruction for MASON

- Execution steps:
  1. Run the Crowd Simulation with personality by double clicking  
“C:\crowdSimulation\Executables\RunCrowdSimulation.bat”.
- Compile and build steps:
  1. Open the project file  
“C:\crowdSimulation\development\simulation\CrowdSimulation.jcw” in JCreator.
  2. Add the class path for MASON, as show below.
  3. Build the project.

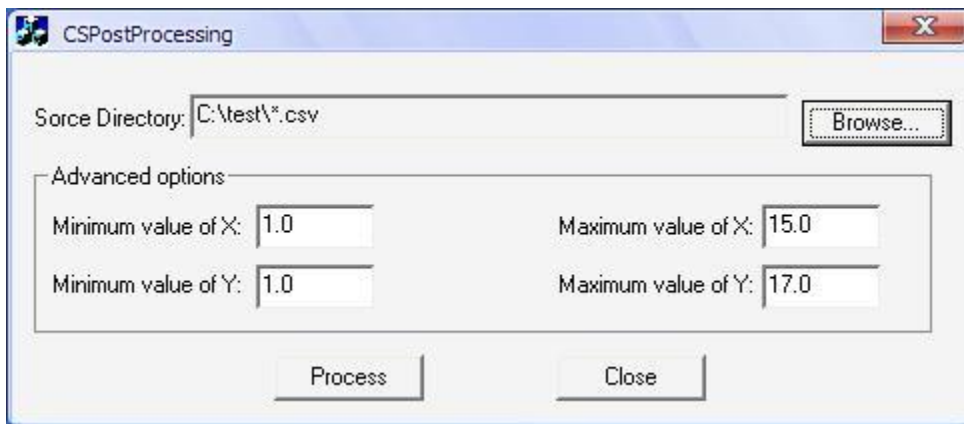


## Processing of Simulation generated data files

- Pre-requisites:

Run time dependencies	
None	
Build time dependencies	
Microsoft Visual Studio 6.0	Refer to the link - <a href="http://msdn2.microsoft.com/en-us/vstudio/aa700914.aspx">http://msdn2.microsoft.com/en-us/vstudio/aa700914.aspx</a> , to get download and installation instruction for MS Visual Studio 6.0

- Execution steps:
  1. Run the Optical Flow Analysis tool by double clicking on  
“C:\crowdSimulation\Executables\CSPostProcessing.exe”.
  2. Select the source directory for the Simulation Generated Data Files.
  3. Specify the minimum and maximum values for X and Y.
  4. Click on Process.



- Compile and build steps:
  1. Open the project file  
“C:\crowdSimulation\development\CSPostProcessing\CSPostProcessing.dsw” in Visual Studio 6.0.
  2. Build the project.

### **Personality Patch for Base Crowd Simulation**

Installation steps:

1. Overwrite the file  
“C:\crowdSimulation\development\simulation\src\crowdsimulation\AppConfig.java” with  
the one under “C:\crowdSimulation\development\Personality Patch for Base Simulation”.

2. Overwrite the file

“C:\crowdSimulation\development\simulation\src\crowdsimulation\entities\individual\individual.java” with the one under “C:\crowdSimulation\development\Personality Patch for Base Simulation”.

3. Place the file HMFVModelWithPersonality.java from

“C:\crowdSimulation\development\Personality Patch for Base Simulation” under “C:\crowdSimulation\development\simulation\src\crowdsimulation\actioncontroller”.

4. Place the file HMFVStrategyWithPersonality.java from

C:\crowdSimulation\development\Personality Patch for Base Simulation under C:\crowdSimulation\development\simulation\src\crowdsimulation\actioncontroller\strategy\.

5. Place the ‘utils’ folder from “C:\crowdSimulation\development\Personality Patch for Base Simulation” under “C:\crowdSimulation\development\simulation\src\crowdsimulation”.

6. Add the file

“C:\crowdSimulation\development\simulation\src\crowdsimulation\utils\Matrix.java” to the CrowdSimulation project.

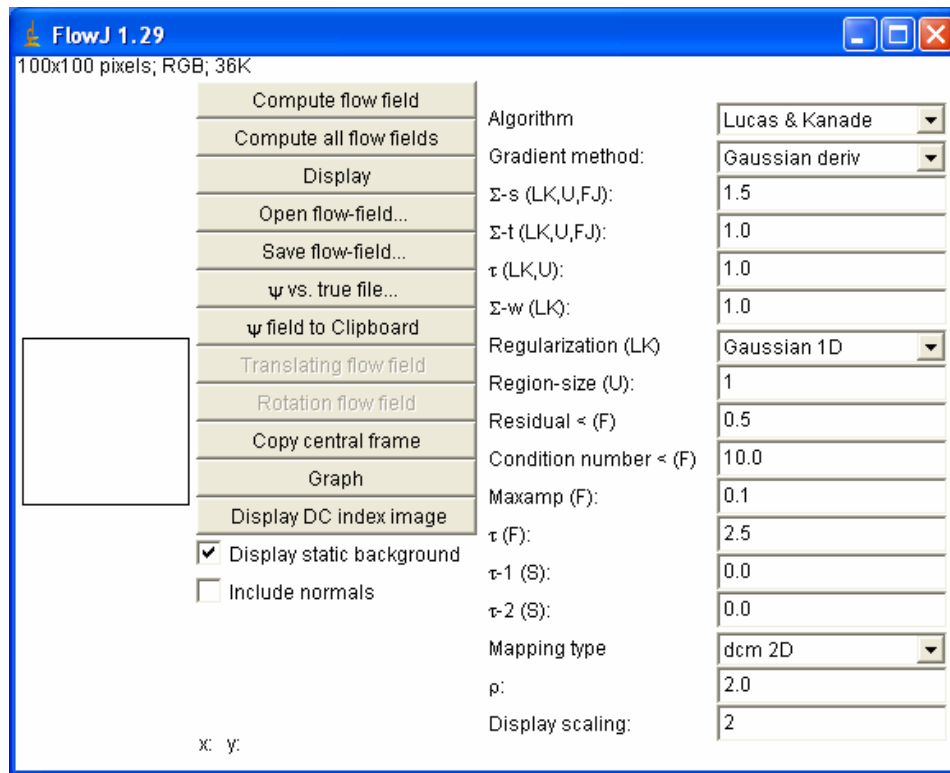
7. Place the personality configuration files from “C:\crowdSimulation\development\Personality Patch for Base Simulation” under “C:\crowdSimulation\development\simulation\configs”.

8. Build and run the project.

## **APPENDIX B: USING IMAGEJ SOFTWARE**

Using the open source software ImageJ and its plugins (FlowJ and AVI Reader), an attempt was made to quantify results from the crowd videos. FlowJ computed all the flow fields and provided optical flow results in (.csv) comma separated files. The following procedure was adopted in attempting to quantify results from the crowd video using ImageJ/FlowJ software.

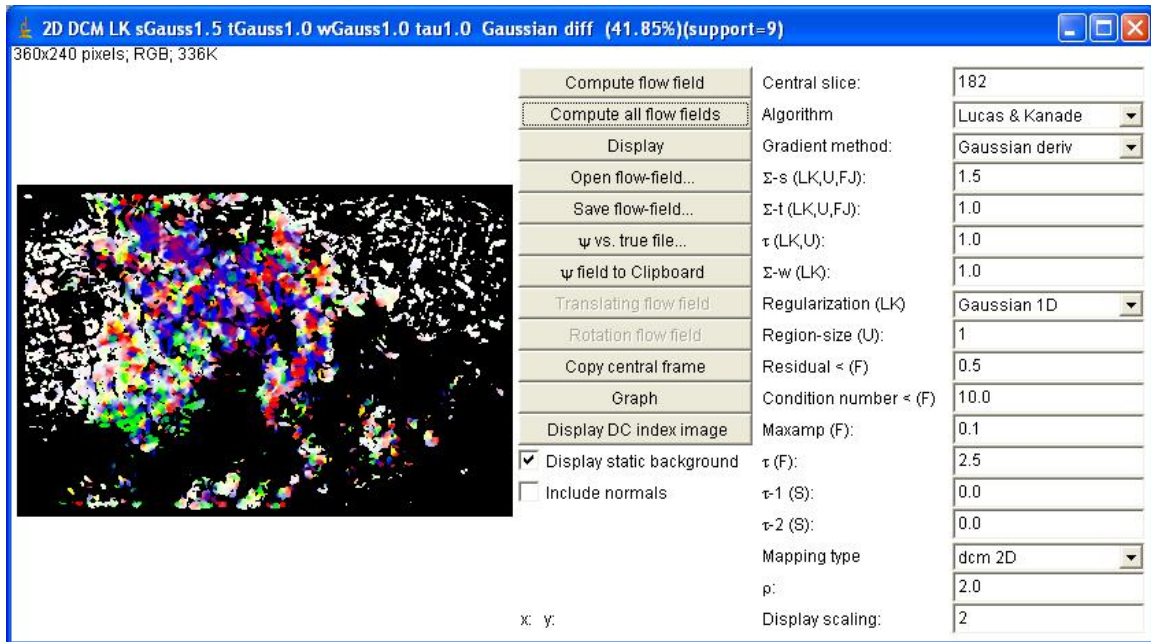
- 1) ImageJ software was downloaded and installed (<http://rsb.info.nih.gov/ij/>).
- 2) FlowJ and AVI Reader plugins were downloaded and installed in the ImageJ environment (<http://bij.isi.uu.nl/index.htm>).
- 3) The AVI Reader plugin is required to read the crowd video in AVI format and it is downloadable from the ImageJ website. There were several problems encountered with reading the available videos into the ImageJ environment due to the embedded audio and file size issues and they are listed below:
  - a. ImageJ does not process videos with audio embedded in them. To remove the audio within the video files, a freeware software program called Virtualdub was used. VirtualDub can be downloaded from <http://www.virtualdub.org/>.
  - b. When the audio was removed using VirtualDub, the file size increased threefold.
  - c. With VirtualDub software the videos were decimated to the order of '6' and the video size was reduced to 360 X 240 pixels. This resulted in the reduction of the video file size.
  - d. The video file size was further reduced (due to the limitations in ImageJ in loading larger file sizes) by removing the colors in the video (Mono video).
- 4) When the desired video file (as developed in step 3) is read using the AVI Reader into ImageJ, the FlowJ plugin is invoked. Picture 1 shows the FlowJ user interface.



Picture 1

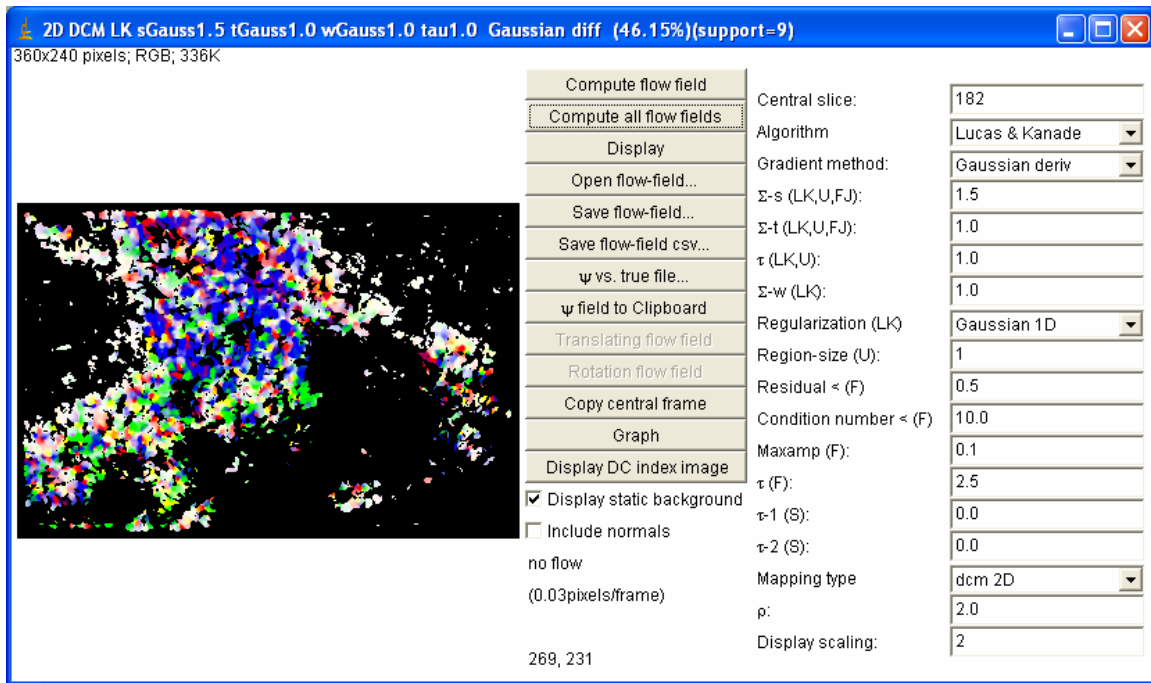
- 5) In FlowJ, “Compute all flow fields” button was invoked to calculate the optical flow fields. The resultant image after the calculations is shown in picture 2.





Picture 2

- 6) The resulting plot (in picture 2) did not provide adequate information to understand the results and to decipher quantified numbers on the crowd video.
- 7) It was decided that if we could get the actual numbers that generate this plot, we might understand the results better.
- 8) Some of the Java classes were modified and the FlowJ user interface was changed to add a new button “Save flow field csv ....”. Picture 3 shows the modified FlowJ user interface.



Picture 3

9) After all the flow fields are computed (as mentioned in step 1-5), a .csv file (comma delimited file) can be generated, by pressing the button “Save flow field csv ...”.

While attempting to analyze the data, it was found that the resulting CSV file was too large for Excel. A Java program (CSV Splitter program) was written to split the file into a desired size grid and write separate small files for each cell in the grid. To run this program, JRE (Java Runtime Engine) should be installed on a pc and the files Splitter.class and Splitter.prop should be added to a known folder in the computer, along with the CSV file to be split.

Steps to run this program:

- From the command prompt, go to the folder where the CSV file is located by issuing the DOS command ‘cd <dir name>’. To execute the Splitter program, the following command should be issued at the DOS prompt: ‘Java -cp. Splitter’. This will result in the desired number of smaller file outputs based on the number of grids specified.

- The grid size and video frame size can be modified in the `Splitter.prop` property file (opens in notepad). The other variables that can be modified are: the prefix of the resulting file names, source directory of the CSV file to be split and the destination directory where the resulting smaller files will be placed.
- An Excel macro was developed to analyze the smaller files based on the information from the Lucas and Kannede method that was used in the FlowJ analysis. This macro was designed to run a batch operation on all the files in the results folder and provide consolidated information.

While analyzing the results, we found that this method had several limitations. There was no easy method for specifying a particular segment of the video and obtaining optical flow for that specific segment. The source code was not available to accommodate code modifications, so another approach with *OpenCV* software was investigated.

## **APPENDIX C: OPTICAL FLOW DATA EXTRACTION**

This appendix describes how optical flow data (velocity vectors) from a video footage is calculated. Using the *OpenCV* software the raw optical flow data is obtained as shown in table 7.

**Table 13: Raw Optical Flow Data from *OpenCV***

<b>Raw Optical Flow of Video Footage</b>			
<b>X</b>	<b>Y</b>	<b>V<sub>x</sub></b>	<b>V<sub>y</sub></b>
90	90	-0.52531	-0.31388
180	90	0.26368	-0.0776
270	90	0.206379	0.115241
360	90	3.552041	-0.91153
450	90	9.747472	-6.59773
480	90	3.009652	-2.37053
90	180	-2.6232	-3.73823
180	180	-1.74524	-2.51539
270	180	0.520507	-0.6841
360	180	11.85865	-6.33226
450	180	12.20424	-10.6103
480	180	2.821518	-3.38251
90	270	-5.94893	-8.32013
180	270	-3.29612	-11.1891
270	270	4.035544	-10.8913
360	270	13.1899	-11.1617
450	270	10.2947	-12.6345
480	270	2.683867	-4.59178
90	360	-5.90295	-9.33046
180	360	-6.43864	-13.3319
270	360	2.04045	-14.3239
360	360	8.759469	-13.2078
450	360	5.522497	-12.171
480	360	1.091298	-2.7

Note: Table 7 is only for illustration purposes and there are several rows that were truncated from the actual raw data file.

**Optical Flow Data from Video to Compare with Manual Count**

An Excel macro that was designed for the data analysis moves the data to the right columns in the spreadsheet as shown in table 8 and table 9.

**Table 14: Rearranged Optical Flow Data – Horizontal**

Shell	90	180	270	360	450	540	630	720
90	0.525312	2.6232	5.948927	5.902954	3.144697	0.143662	-0.1402	-1.18641
180	-0.26368	1.74524	3.29612	6.438635	5.47189	-0.12504	-0.04195	-0.05093
270	-0.20638	-0.52051	-4.03554	-2.04045	0.121842	0.097947	0.973175	-0.05529
360	-3.55204	-11.8586	-13.1899	-8.75947	-2.09831	0.197001	4.179868	4.766798
450	-9.74747	-12.2042	-10.2947	-5.5225	-1.7585	1.26887	3.80946	1.680605
480	-3.00965	-2.82152	-2.68387	-1.0913	-0.19704	-0.14543	0.068291	0.071636

**Table 15: Rearranged Optical Flow Data – Vertical**

Shell	90	180	270	360	450	540	630	720
90	0.31388	3.738233	8.320132	9.330464	5.18582	-0.08514	-0.03912	0.025669
180	0.077598	2.515385	11.18913	13.3319	9.885095	1.894777	-0.04804	-0.19243
270	-0.11524	0.684101	10.89129	14.32392	14.63477	6.992026	1.504985	-0.09886
360	0.911528	6.332256	11.16165	13.20781	14.26753	7.027015	4.408872	4.765614
450	6.597733	10.61029	12.6345	12.17103	8.119957	5.240778	4.227412	1.315758
480	2.370527	3.382514	4.591782	2.699996	0.627033	-0.15879	-0.07348	-0.26488

**Table 16: Optical Flow with Calculated Velocity Vectors (Vx and Vy)**

		Vy		Vy		Vy		Vy	
		2.026056		8.825298		2.55034		-0.00672	
Vx	0.130816		3.403372		5.239544		-0.04088		-0.61867
		0.790461		12.43406		8.351666		0.291414	
Vx	-1.87921		-7.40115		-3.1941		1.361998		2.355755
		6.112952		12.29375		8.663821		3.679414	
Vx	-6.37856		-7.00108		-2.14233		1.250296		0.876121
		2.87652		3.645889		0.234124		-0.16918	

**Optical Flow Data from Video to Correlate with Simulation**

In the next step the macro averages the correct shells as explained in the section ‘Relation between Crowd Motion and Optical Flow’ so the X and Y components of the velocity vectors are calculated.

**Table 17: Optical Flow Data from Simulation and Video Footage**

Shell Num	Simulation Data		Video Data	
	Average Vx	Average Vy	OF Vx	OF Vy
1	-3.496493	-1.459539	-1.15752	-1.66127
2	-1.918064	-2.934072	<b>-5.39666</b>	<b>-10.5429</b>
3	-3.857786	-0.282969	-2.1588	-4.22014
4	-3.201722	-0.136468	0.354872	0.063478
5	1.937923	-2.632332	4.034394	-1.95316
6	-0.027361	-3.283276	7.00634	-12.3962
7	-2.915848	-2.040124	0.42038	-10.7303
8	-2.279324	-1.228412	-2.46614	-2.64515
9	1.06801	-2.374628	6.945722	-5.74027
10	-0.03968	-2.674702	4.898091	-8.02433
11	-1.357066	-2.397123	0.208026	-3.45725
12	-2.170043	-1.99878	-1.4075	-1.3012

**Table 18: Recopied Data for Ease of Charting for Correlation**

Average Vx	OF Vx	Average Vy	OF Vy
-3.496493	-1.157517825	-1.45954	-1.66127
-1.918064	-5.396658975	-2.93407	-10.5429
-3.857786	-2.158801475	-0.28297	-4.22014
-3.201722	0.35487215	-0.13647	0.063478
1.937923	4.034393575	-2.63233	-1.95316
-0.027361	7.006339875	-3.28328	-12.3962
-2.915848	0.420379975	-2.04012	-10.7303
-2.279324	-2.466138425	-1.22841	-2.64515
1.06801	6.945721575	-2.37463	-5.74027
-0.03968	4.89809095	-2.6747	-8.02433
-1.357066	0.208026325	-2.39712	-3.45725
-2.170043	-1.407498025	-1.99878	-1.3012

## **APPENDIX D: SAMPLE XML CONFIGURATION FILE LISTING**



The following XML code shows the configurations for the Citrus Bowl geometry with mixed personality combinations defined for the individuals in the crowd.

```

<?xml version="1.0"?>
<!--
This is a config file used to setup a multi exit room configuration
using the HMFV model.
-->
<configuration xmlns="http://tempuri.org/config.xsd">
  <log type="DataLogger" fileName="../logs/dataLog.csv" logLevel="1" consoleOutput="false" fileOutput="true"
allForces="false" model="HMFV"/>
  <world width="17" height="13" scale="32" discretization="100"/>
  <terminate time="60"/>
  <movie></movie>
  <obstacles>
    <!-- Left Fence-->
    <obstacle type="Rectangular" force="1" location="0 7.1" width="4.4" height=".3" angle="347"/>
    <!-- Left Fence Gate-->
    <obstacle type="Rectangular" force="1" location="4.2 6.3" width="2.8" height=".3" angle="225"/>
    <!-- Right Fence-->
    <obstacle type="Rectangular" force="1" location="12 4.3" width="7.0" height=".3" angle="347"/>
    <!-- Right Fence Gate-->
    <obstacle type="Rectangular" force="1" location="12 4.5" width="3.13" height=".3" angle="221"/>
    <!--turnstile - 1-->
    <obstacle type="Rectangular" force="1" location="0 7.4" width="2.7048" height="2.1985" angle="347"/>
    <!--turnstile - 2-->
    <obstacle type="Rectangular" force="1" location="13.6 4.1" width="3.5048" height="1.5" angle="347"/>
  </obstacles>
  <paths>
    <path id="1" name="path1">
      <waypoint x="6" y="5.5" radius="1"/>
      <waypoint x="4.2" y="3.0" radius="1"/>
      <waypoint x="0.0" y="2.0" radius="1"/>
    </path>
  </paths>
  <randomGenerators>
    <generator id="1" type="normal" mean="0.6" stdDev="0.1"/>
  </randomGenerators>

  <model type="HMFVModel">
    <personalities random="No" commonPersonality="Yes">
      <!--Shiva, change the below matrix entry-->
      <personality matrix="0.3 0.3 0.4"/>
      <MPF matrix="1 0.5 0.5 0.5 1 0.5 0.5 0.5 1"/>
    </personalities>

    <individuals number="6" time="3" diameter="genID=1" violenceRating="0" color="10 180 10"
personalityMatrix="1.0 0.0 0.0">
      <paths>
        <path id="1" weight="1"/>
      </paths>
    </region>
  </model>
</configuration>

```

```

        <obstacle type="Rectangular" force="1" location="3.5 5" width="3" height="4"
angle="0"/>
    </region>
</individuals>
    <individuals number="6" time="3" diameter="genID=1" violenceRating="0" color="10 180 10"
personalityMatrix="0.0 1.0 0.0">
    <paths>
        <path id="1" weight="1"/>
    </paths>
    <region>
        <obstacle type="Rectangular" force="1" location="5 5" width="4" height="4"
angle="0"/>
    </region>
</individuals>
    <individuals number="4" time="3" diameter="genID=1" violenceRating="0" color="10 180 10"
personalityMatrix="0.0 0.0 1.0">
    <paths>
        <path id="1" weight="1"/>
    </paths>
    <region>
        <obstacle type="Rectangular" force="1" location="9 5" width="4" height="4"
angle="0"/>
    </region>
</individuals>
    <individuals number="5" time="3" diameter="genID=1" violenceRating="0" color="10 180 10"
personalityMatrix="0.5 0.5 0.0">
    <paths>
        <path id="1" weight="1"/>
    </paths>
    <region>
        <obstacle type="Rectangular" force="1" location="11 5" width="3" height="4"
angle="0"/>
    </region>
</individuals>
    <individuals number="4" time="3" diameter="genID=1" violenceRating="0" color="10 180 10"
personalityMatrix="0.0 0.5 0.5">
    <paths>
        <path id="1" weight="1"/>
    </paths>
    <region>
        <obstacle type="Rectangular" force="1" location="1 9" width="4" height="4"
angle="0"/>
    </region>
</individuals>
    <individuals number="3" time="3" diameter="genID=1" violenceRating="0" color="10 180 10"
personalityMatrix="0.5 0.0 0.5">
    <paths>
        <path id="1" weight="1"/>
    </paths>
    <region>
        <obstacle type="Rectangular" force="1" location="5 9" width="4" height="4"
angle="0"/>
    </region>
</individuals>

```

```

        <individuals number="5" time="3" diameter="genID=1" violenceRating="0" color="10 180 10">
        <paths>
            <path id="1" weight="1"/>
        </paths>
        <region>
            <obstacle type="Rectangular" force="1" location="1 9" width="4" height="4"
angle="0"/>
        </region>
    </individuals>
    <individuals number="2" time="3" diameter="genID=1" violenceRating="0" color="10 180 10">
        <paths>
            <path id="1" weight="1"/>
        </paths>
        <region>
            <obstacle type="Rectangular" force="1" location="5 9" width="4" height="4"
angle="0"/>
        </region>
    </individuals>
    <individuals number="1" time="3" diameter="genID=1" violenceRating="0" color="10 180 10">
        <paths>
            <path id="1" weight="1"/>
        </paths>
        <region>
            <obstacle type="Rectangular" force="1" location="9 9" width="4" height="4"
angle="0"/>
        </region>
    </individuals>
    <individuals number="1" time="3" diameter="genID=1" violenceRating="0" color="10 180 10">
        <paths>
            <path id="1" weight="1"/>
        </paths>
        <region>
            <obstacle type="Rectangular" force="1" location="13 9" width="4" height="4"
angle="0"/>
        </region>
    </individuals>
    <individuals number="1" time="3" diameter="genID=1" violenceRating="0" color="10 180 10">
        <paths>
            <path id="1" weight="1"/>
        </paths>
        <region>
            <obstacle type="Rectangular" force="1" location="11 5" width="3" height="4"
angle="0"/>
        </region>
    </individuals>
</model>
</configuration>

```

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