Route towards collective order in panicked human crowds

Ajinkya Kulkarni, Sumesh Thampi and Mahesh Panchagnula

1Department of Applied Mechanics, IIT Madras
2Department of Chemical Engineering, IIT Madras

Introduction

- Kumbh Mela [1, 2] and Hajj [7] witness \( \approx 10^6 \) people in confined spaces.
- Such large gatherings can pose grave danger to public health.
- Panic in crowds can lead to stampedes and deaths [5]
- Previous studies based on social-force model [6] ignore confinement effects.
- Focus of this study:
  - Investigate phase transitions in confined human crowds
  - Route towards transition from crush to collective motion

Modeling of human crowds

- A force-based modified Vicsek Model[4, 8] incorporating inertia is introduced.
- Each agent is a soft disk with mass \( m \) and diameter \( d \). \( N \) such agents are confined in a circular boundary.
- Forces experienced by each agent:
  - Interparticle force \( \rightarrow F_{pp,i} \)
  - Self-propelled force \( \rightarrow F_{sp,i} \)
  - Alignment force \( \rightarrow F_{align} \)

\[
\frac{d\vec{v}_i}{dt} = F_{pp,i} + F_{sp,i} + F_{align,i}
\]

\[
F_{pp,i} = \frac{-k_i\vec{d}}{d_i} \quad \text{if} \quad |\vec{d}| > 0
\]

where \( \vec{d} = (|\vec{r}_i - \vec{r}_j| - d) \frac{\vec{r}_i - \vec{r}_j}{|\vec{r}_i - \vec{r}_j|} \), is the separation of two particles \( i \) and \( j \)

\[
F_{align,i} = C_o_d (\vec{v}_i - \vec{v}_j)
\]

where \( C_o \) is a co-ordination coefficient that controls the coupling strength between the \( i \)th agent and its neighborhood crowd.

\[
F_{sp,i} = \sum_{j=1}^{N} \frac{m \beta_i \vec{v}_j}{|\vec{r}_i - \vec{r}_j|^3}
\]

where \( \beta_i \) is a unit vector in the direction of the velocity of the \( i \)th particle and \( \beta \) is a thrust coefficient.

Order parameter and phases observed

- 6120 monodisperse circular agents having diameter 0.5m and mass \( m = 60 \text{kg} \) in a circular confine diameter of 14m-26m, with agent density 4 agents/m².
- \( \beta = 0.01 \text{m/s}^2 \), \( k_o = 2.8 \times 10^3 \text{N/m} \), \( C_o = 0.2 - 1 \text{Pa.s} \)
- \( C_o \) chosen as the control parameter.

Order parameter: \( V_{avg} = \frac{1}{T} \int_0^T \langle \sum_i \vec{v}_i \rangle dt \)

- Panic factor [6] suitably modified as \( P = \frac{m \beta}{m \beta_c \sigma_{p,i}} \) shows interplay between individualistic behavior and flocking tendency.

Disordered state
- \( m \beta > C_o \sigma_{p,i} \)

leads to \( P \approx 1 \)

Ordered state
- \( m \beta < C_o \sigma_{p,i} \)

leads to \( P \approx 0.5 \) at \( r/R \approx 0.7R \)

Phase transition and Binder cumulant

- Thermal-like motion at low \( C_o \). Collective behavior at high \( C_o \).
- Hysteretic phase transition for increasing domain size \( R \).

\[
G = 1 - \frac{\sigma_i}{\sigma_{i}^{p,i}}
\]

\[
G = 1/3 \text{ for the disordered state.}
\]

\[
G = 2/3 \text{ for the ordered state.}
\]

Sharp dip indicates co-existence of two phases.

Mean Square Displacement and delay in transition

Recovering from a crush

- Investigating switching between disorder and order in the hysteretic loop.
- Imparting momentum impulse to selective agents in \( \beta \) in the disordered state.
- Radial preference for transition towards order.

References