Understanding Collective Crowd Behaviors: Learning a Mixture Model of Dynamic Pedestrian-Agents

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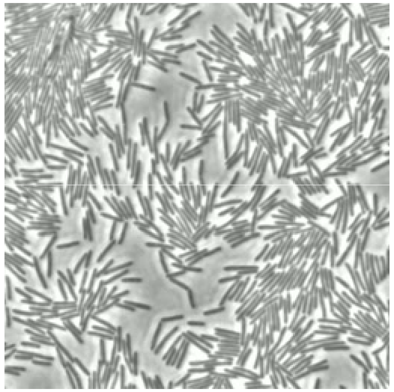
Collective Crowd Behaviors

- Examples of Collective Crowd Behaviors:

1. Bacterial colony



2. Fish school

3. Human crowd

4. Human crowd

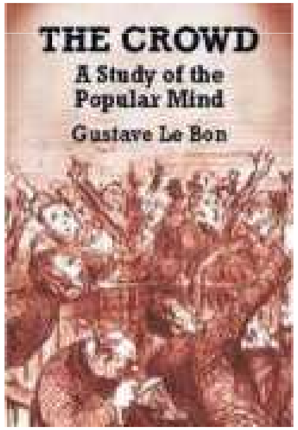
5. Human crowd

6. Traffic flow

Understand Collective Crowd Behaviors

- Features of Collective Crowd Behavior
  - ➢ Vanishing of individual personalities
  - ➢ New characteristics beyond individual behaviors
  - ➢ Shared beliefs and common goals

Crowd in Grand Central Station



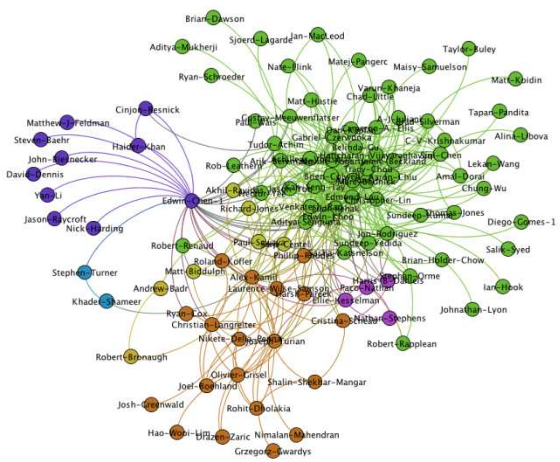
by Le Bon (1841~1931) in "The Crowd: A Study of the Popular Mind"

Related Work

- Biology and Statistical Physics
  - Exploring the mechanisms that lead to the collective movements
  - Studying the statistical principles and dynamics of the crowd behaviors

Related Work

- Social Networks and Complex Networks
  - ➢Studying how individuals are connected into collective communities
  - ➢Investigating how information propagates among complex networks



Related Work

- Computer graphics
  - ➢ Simulating virtual crowds in games and movies

Related Work

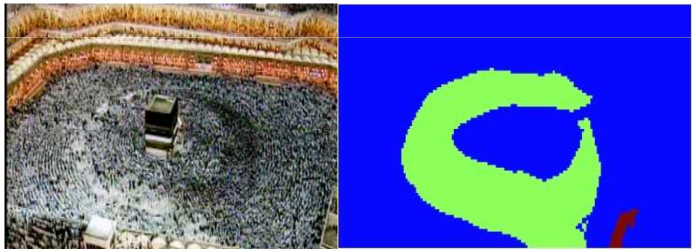
- Computer Vision
  - ➢ Learning and segmenting the motion patterns:

Flow fields

Topic models

Trajectory clustering

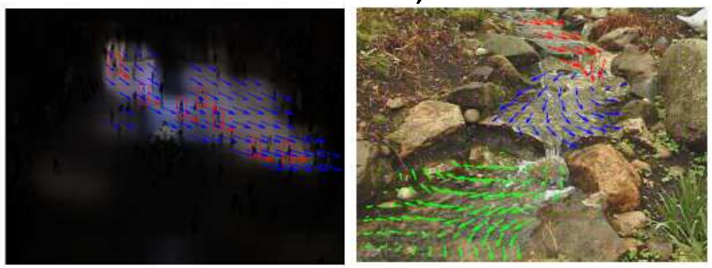
Ali CVPR’07



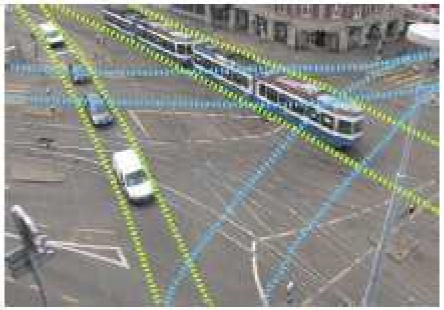
Hospedales ICCV’09

Makris SMC’05

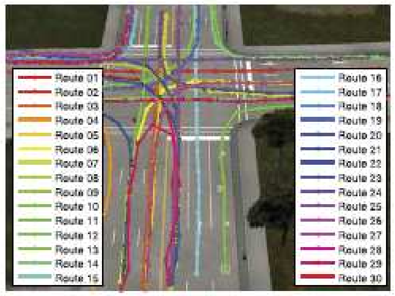
Lin CVPR’09, 10



Kuettel CVPR’10



Morris PAMI’11



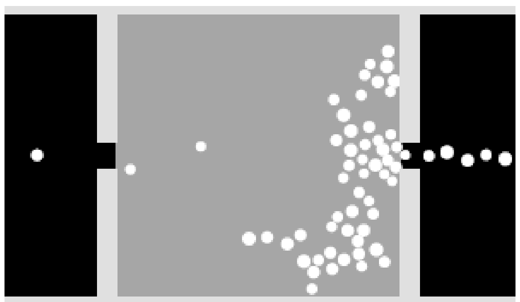
Related Work

- Computer Vision
  - ➢ Analyzing the social interaction between pedestrians:

Social-force model

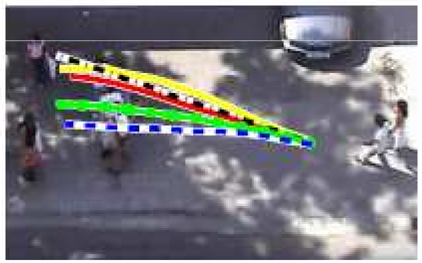
Helbing PRL'95, Nature'00

$$m_i \frac{d\mathbf{v}_i}{dt} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_W \mathbf{f}_{iW}$$



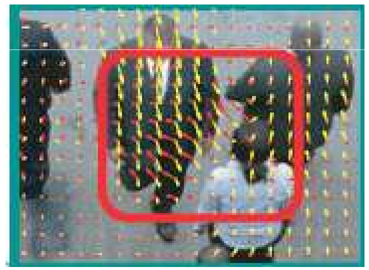
Tracking

Pellegrini ICCV'09



Abnormality detection

Mehran CVPR'09



Group detection

Ge PAMI'11

Interaction analysis

Scovanner ICCV'09

Our Work

- To quantitatively analyze crowd behaviors

  - Framework of **Dynamic Pedestrian-Agents**
  - Applications:
    - ✓Learning collective behavior patterns
    - ✓Recognizing collective behaviors
    - ✓Detecting abnormal behaviors
    - ✓Predicting future behaviors
    - ✓Estimating scene statistics

- Challenges:
  - Detection and tracking errors
  - Different collective patterns mixed

Contributions of Our Work

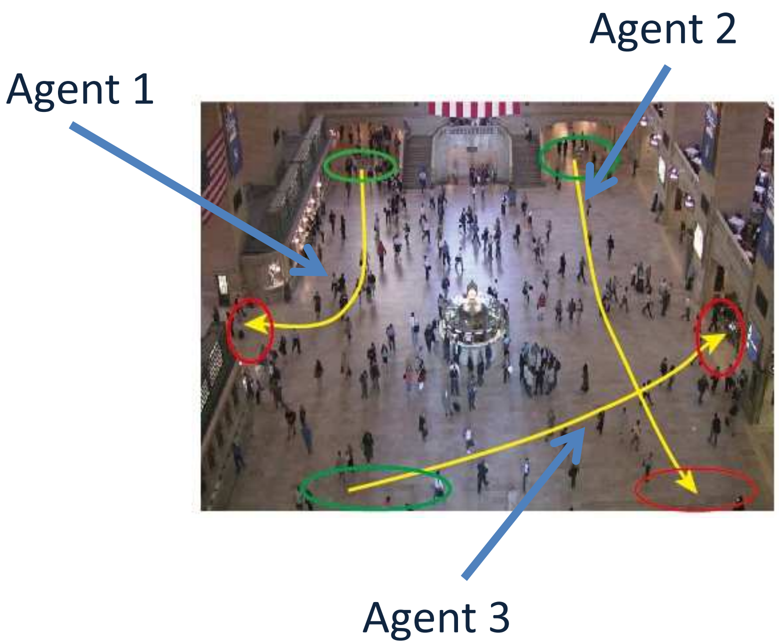
1. Agent-based modeling of crowd behavior

2. Three factors to analyze crowd behavior

3. Learning from highly fragmented trajectories

1. Agent-based modeling of crowd behavior

- Simple behavioral rules for multiple agents to generate complex behaviors
- Simulating crowds and classifying collective behaviors
- Integrating with social-force model



Interactive dynamics

Social-force model

Collective dynamics

Our model

2. Three factors to analyze crowd behavior

➢Beliefs of Pedestrian

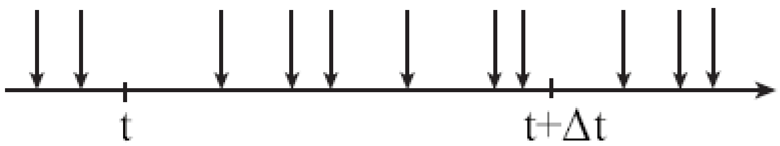
Starting point and destination

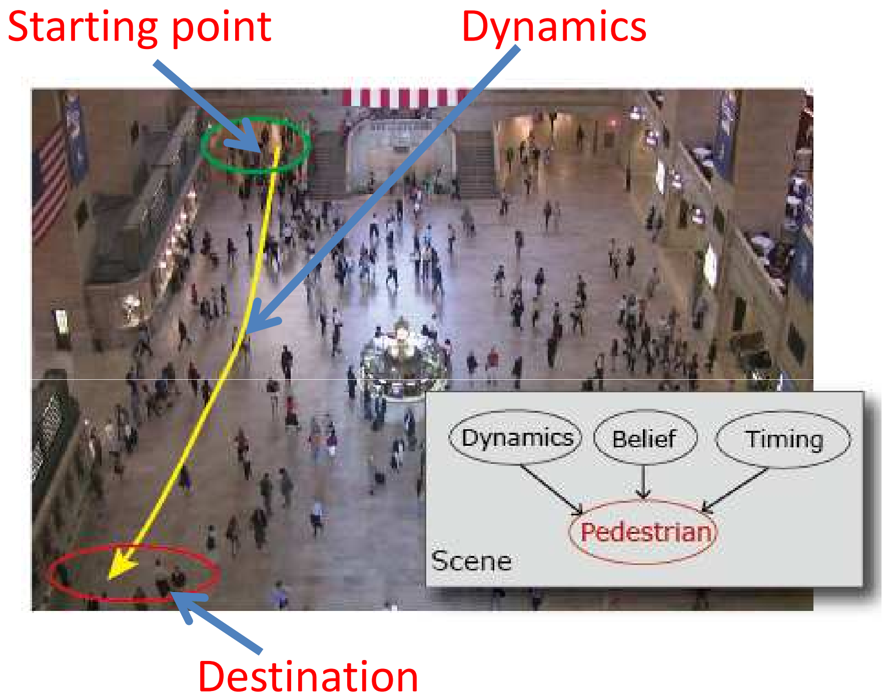
➢Collective Dynamics

Pedestrian movement patterns

➢Timing of Emerging

It determines population in the scene



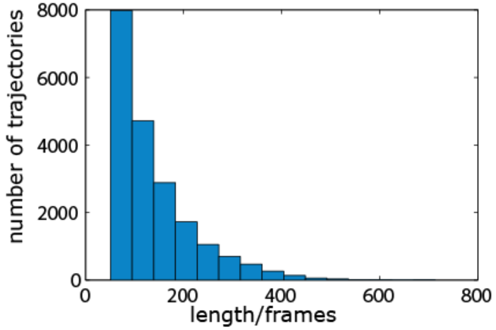


Every pedestrian is driven by one type of agents, and the whole crowd is modeled as a mixture of pedestrian-agents

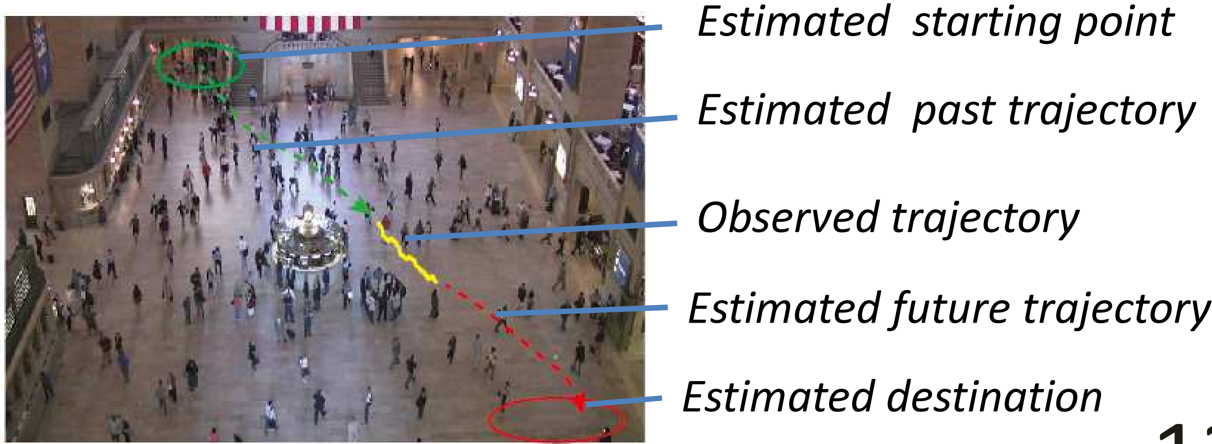
3. Learning from fragmented trajectories

Plot of trajectories

Histogram of lengths



- Estimating missing observations through model inference
- Regularizing the trajectories through estimating its starting point and destination



Dynamic Pedestrian-Agents

- **Beliefs:** $B = (\mu^s, \Phi^s, \mu^e, \Phi^e)$

$$p(\mathbf{x}_s) = \mathcal{N}(\mathbf{x}_s | \mu^s, \Phi^s),$$
$$p(\mathbf{x}_e) = \mathcal{N}(\mathbf{x}_e | \mu^e, \Phi^e).$$

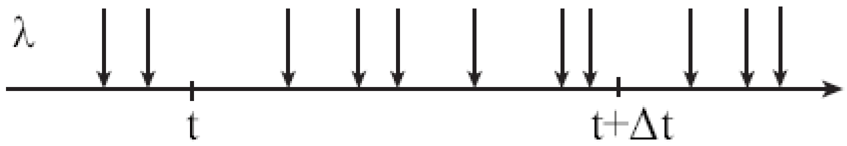
- **Dynamics** $D = (\mathbf{A}, \Gamma)$

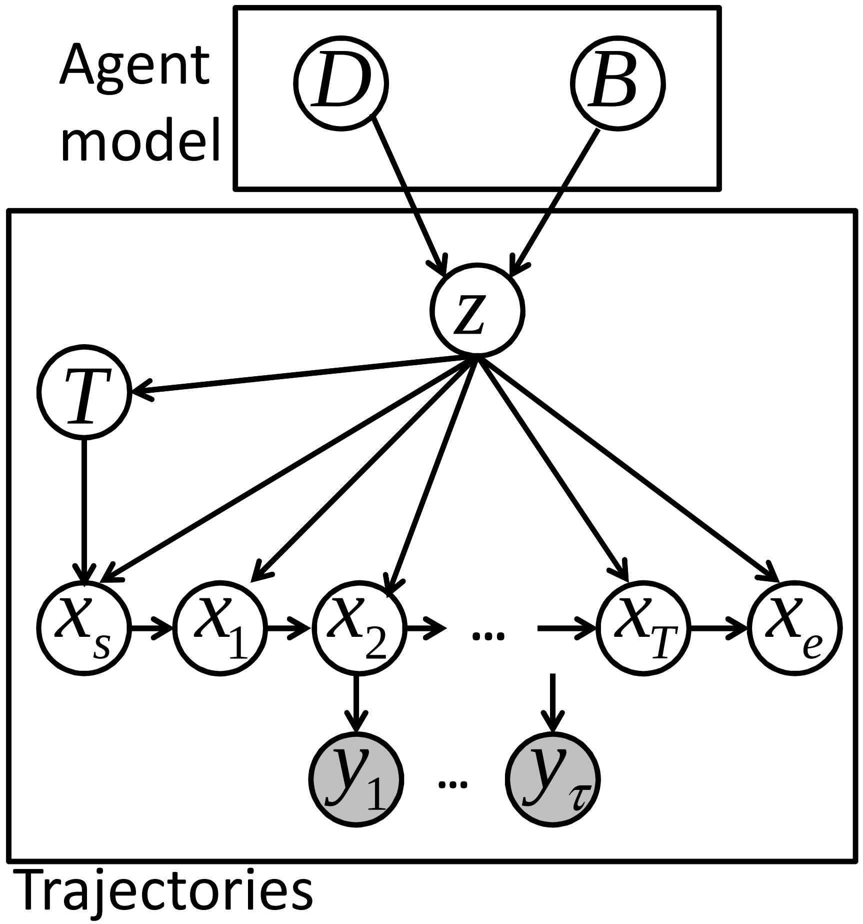
$$\mathbf{x}_t = \mathbf{A}\mathbf{x}_{t-1} + \omega_t, \quad p(\mathbf{x}_t | \mathbf{x}_{t-1}) = \mathcal{N}(\mathbf{x}_t | \mathbf{A}\mathbf{x}_{t-1}, \Gamma),$$
$$\mathbf{y}_t = \mathbf{C}\mathbf{x}_t + \varepsilon_t. \quad p(\mathbf{y}_t | \mathbf{x}_t) = \mathcal{N}(\mathbf{y}_t | \mathbf{x}_t, \Sigma),$$

linear dynamic system
with affine transform

- **Timings** Poisson process

$$p(n; \lambda) = \frac{(\lambda)^n e^{-\lambda}}{n!}$$





Model Inference: EM

$$\Theta^* = \arg\max_{\Theta} \sum_{k=1}^{K} \log p(\mathbf{y}^k; \Theta).$$

Experiments

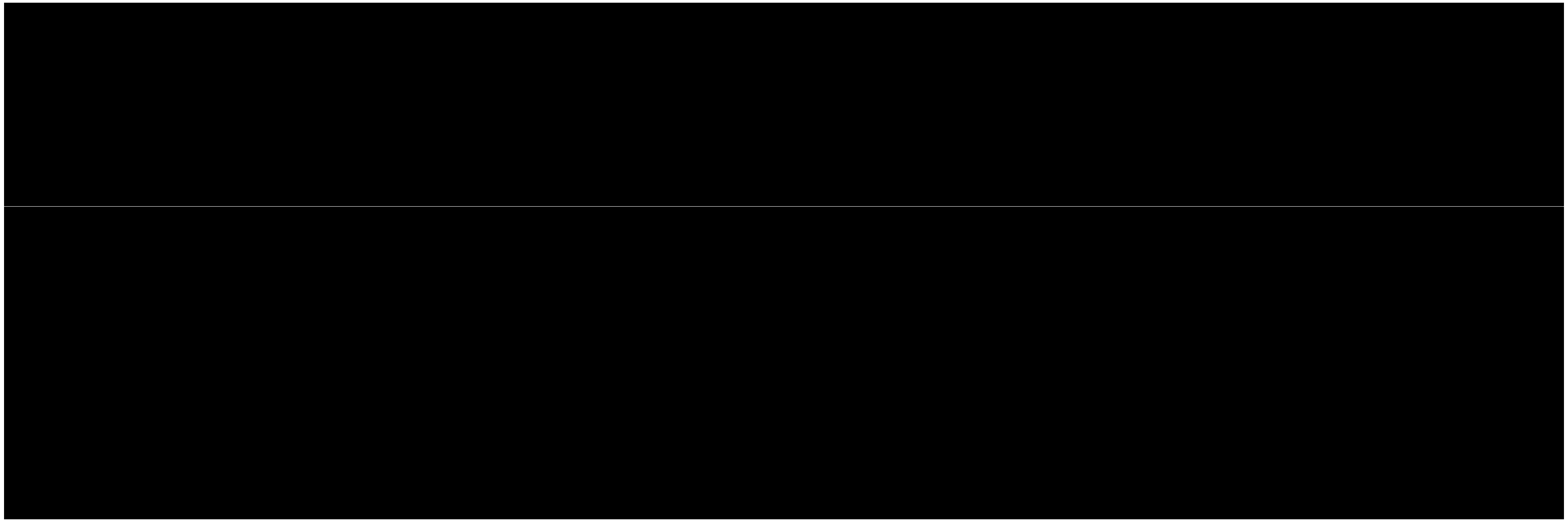
- Simulating Crowd
- Segmenting Semantic Regions
- Classifying Collective Behaviors
- Predicting Behaviors of Pedestrians
- Detecting Abnormal Behaviors

Experiments: Simulating Crowd

- Examples of learned dynamic pedestrian-agents

Experiments: Simulating Crowd

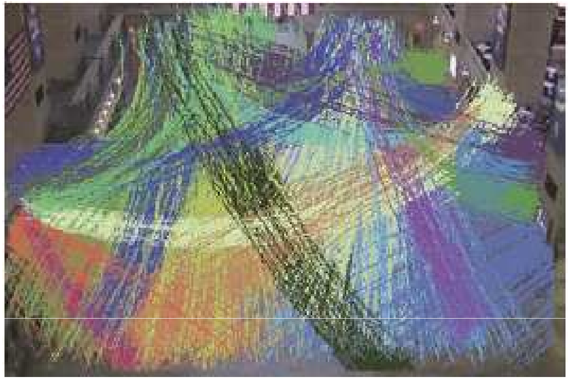
- A Demo Video



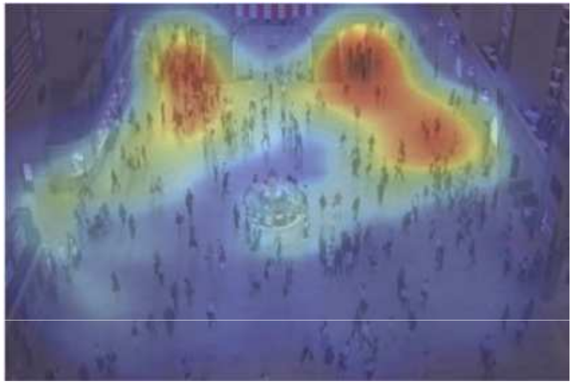
Real Crowd and Trajectories *Simulation*

Experiments: Simulating Crowd

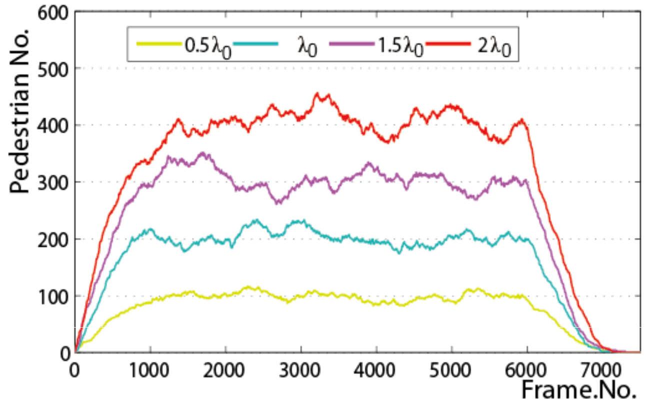
- Statistics of the crowd from simulation



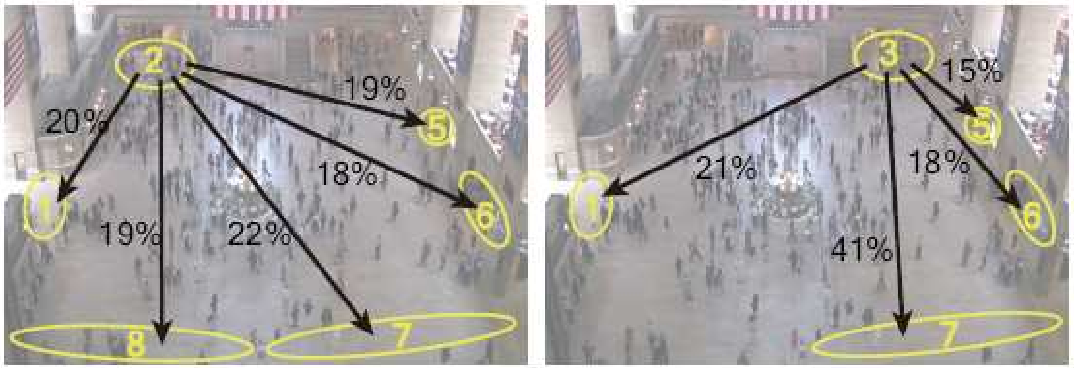
Simulated trajectories from our model



Population density map estimated from simulation

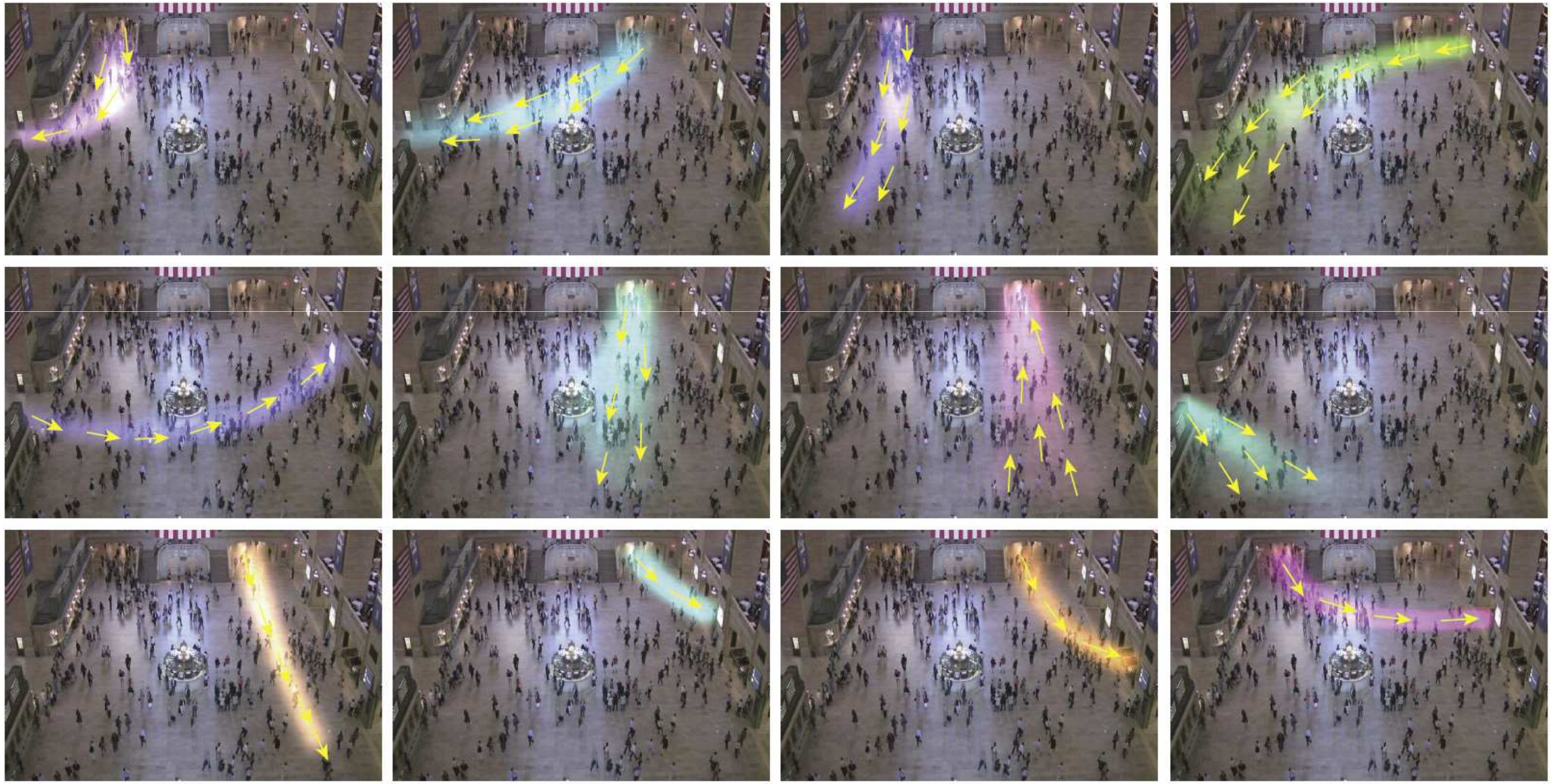


Scene capacity variations estimated from simulation



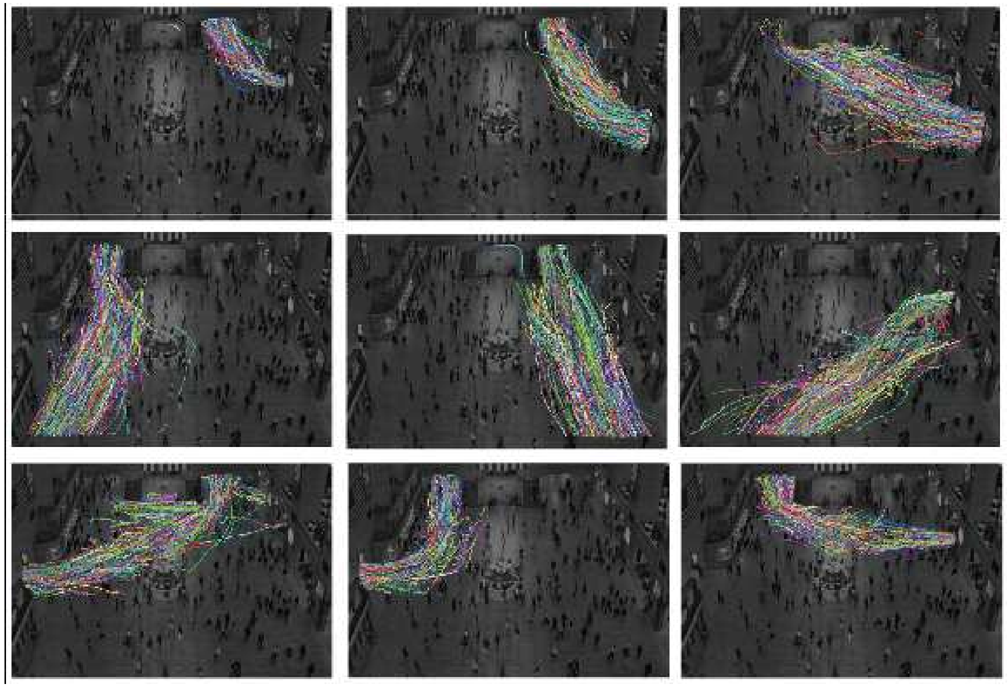
Pedestrian flow transition ratios

Experiments: Segmenting Semantic Regions

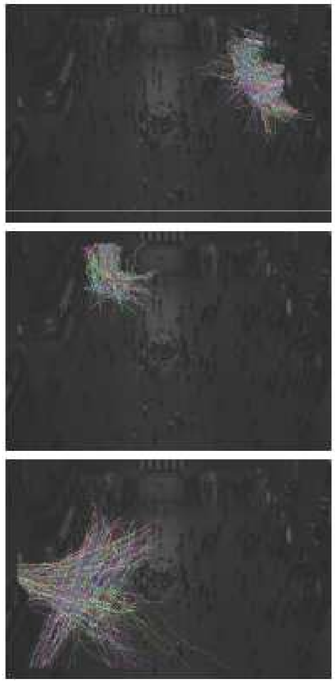


Experiments: Classifying Behaviors

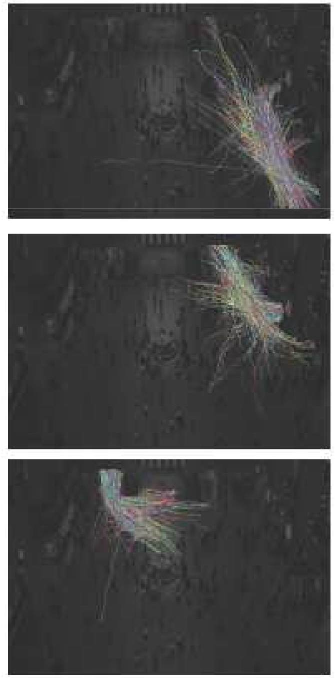
- Trajectory clustering



Ours



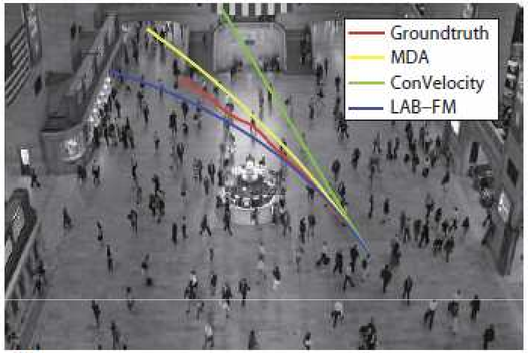
Spectral clustering (Wang ECCV'06)



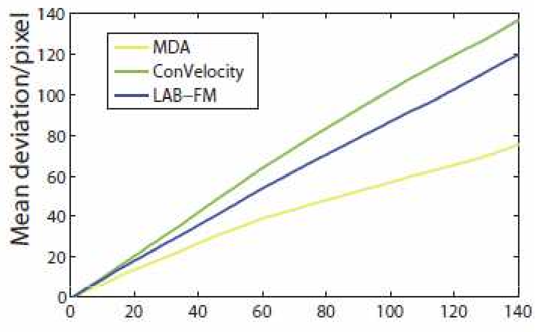
HDP (Wang CVPR'08)

Experiments: Predicting Behaviors

- Estimating the future path of pedestrians

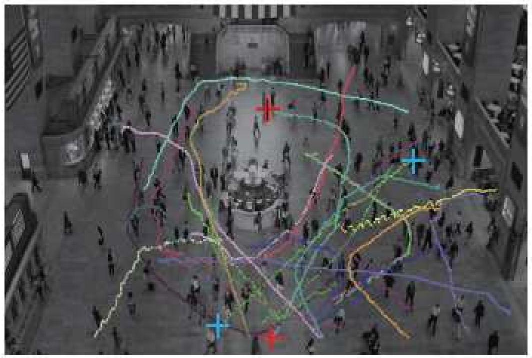


A)



B)

- Detecting abnormal behaviors



Abnormal trajectories

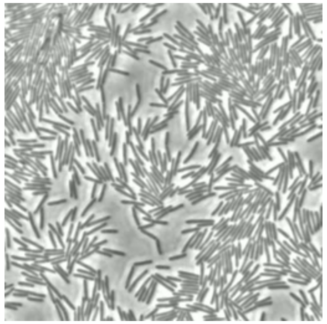
Abnormal: sudden turning

Abnormal: running

Conclusion

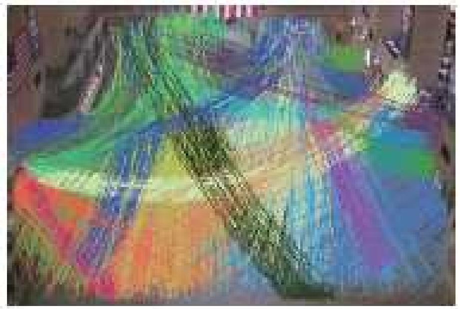
- Agent-based models are used to learn collective crowd behaviors and to simulate crowds.
- *Dynamics, Beliefs, and Timing* are proposed to model pedestrian-agents.
- Learning crowd behaviors from highly fragmented trajectories.
- Various applications to crowd simulation, scene segmentation, collective behavior classification, abnormality detection and behavior prediction.

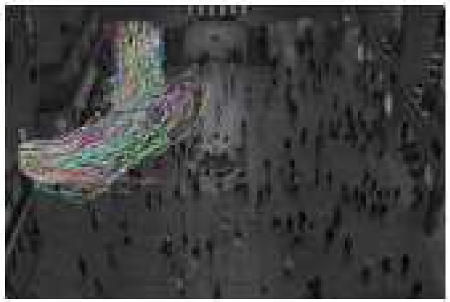
Questions



- Enquiry: zhoubolei@gmail.com
- Data (video, trajectories) can be found at my homepage.

Frame No.508: Current pedestrian number=15





Abnormal: sudden turning