Fluid Models for Dense Crowd Tracking

Progress Report on a New Effort (Start: Fall 2009)

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The Complexity Challenge

Complexity precludes individual tracking & behavior analysis in very large and dense crowd scenes

Examples of Driving Scenarios:

- Spectators entering or leaving a sport events
- Downtown sidewalk at noon
- Central underground station
- A bussy airport terminal
- An open air market
- Large polytical rallies

Big Picture Objective: Dynamic Resource Allocation

- **Develop low resolution tracking for dense crowds**
- **Integrate large and low density methods**

Crowd level(s)	continuum view	•sparse camera cover • low computational resources / area
Group level(s) Individual level }	individuall view	•dense camera cover • high computational resources / area

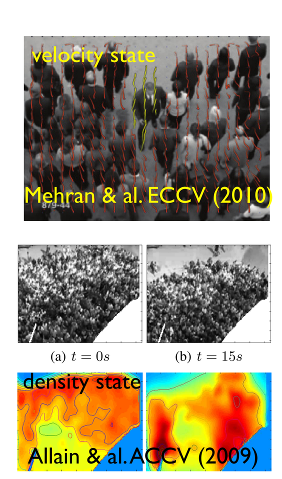
sparse resources | increased resources | dense resources

baseline surveillance | flagged area | flagged persons

Background: Physically Inspired Flow Models

Guiding Principle: Simplicity @ the limit to ∞

- Shift from individuals to mass flow
- State components:
  - the distributed velocity field
  - crowd / sub-population densities
- Physically inspired models:
  - statistical mechanics: granular flow models
  - fluid mechanics: continuum models
- Behavioral pattern ⇔ Values of model parameters
- Tracking ⇔ Real time model parameter estimation
- Event detection ⇔ Model invalidation, abrupt parameter changes



State of the Art in Crowd Flow Models

- Off-line simulation-based prediction and design optimization of safe public environment
- Off-line crowd behavior analysis from video data
- Real-time crowd behavior analysis: still "in diapers"
- Animation, motion synthesis

Our Choice of a Modeling Paradigm

•Option I: Granular flow / statistical mechanics ✗

- Advantages:
  - Well developed over 25 years
  - Natural representation of social behaviors
- Disadvantages:
  - Combinatorial complexity exclude real time utility

•Option II: Compressible fluid flow / fluid mechanics ✓

- Advantages:
  - Far simpler model
  - Galerkin approximations facilitate real time estimation
- Disadvantages:
  - A challenge to capture social phenomena with few parameters

Achievements To Date

Developed, refined, coded & validated a parameterized Navier-Stokes inspired model structure

- Multiple populations with
  - $\rho_i(\boldsymbol{x})$: *distributed* density of population # i
  - $\boldsymbol{u}_i(\boldsymbol{x})$ distributed velocity of population # i
  - $\boldsymbol{u}_{d,i}(\boldsymbol{x})$ distributed desired velocity of population # i
  - $\rho(\boldsymbol{x}) = \Sigma\rho_i(\boldsymbol{x})$: combined density
  - $\boldsymbol{u}(\boldsymbol{x}) = \rho(\boldsymbol{x}) \backslash \Sigma\rho_i(\boldsymbol{x})\boldsymbol{u}_i(\boldsymbol{x})$: locally averaged velocity
  - $\tau_i(\boldsymbol{u}_i)$ = *time constant of tracking desired path*

Momentum Eq

$$\partial_t(\rho_i \boldsymbol{u}_i) = \underbrace{-\nabla\cdot(\rho_i \boldsymbol{u}_i)\otimes \boldsymbol{u}_i}_{\text{Convection term}} + \underbrace{\frac{\rho_i}{\rho}(\mu\Delta\boldsymbol{u} - \nabla p)}_{\text{viscosity \& pressure forces}} + \underbrace{\frac{\rho_i}{\tau_i}(\boldsymbol{u}_{d,i} - \boldsymbol{u}_i)}_{\text{driving objective \& ground friction in population } \# i} + \underbrace{\rho_i \eta_i}_{\text{stochastic acceleration in population } \# i}$$

repelling potential ("pressure")

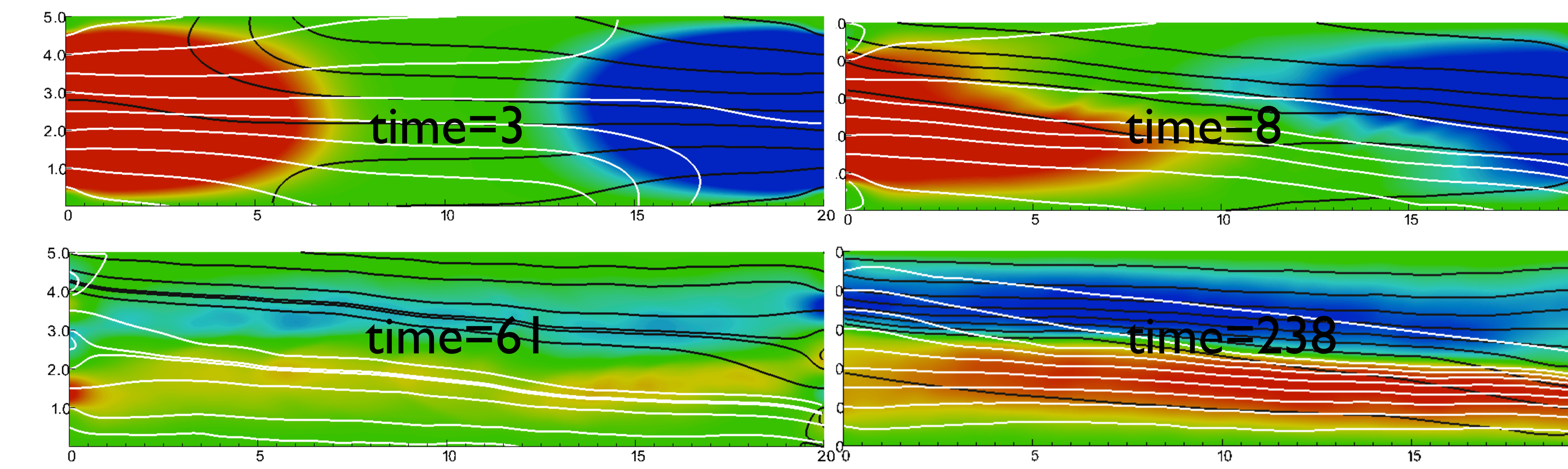
$$p = \frac{1}{1 - \frac{\rho}{\rho_{sat}}}$$

mass conservation

$$\partial_t \rho + \nabla\rho\cdot\boldsymbol{u} + \rho\nabla\cdot\boldsymbol{u} = 0$$

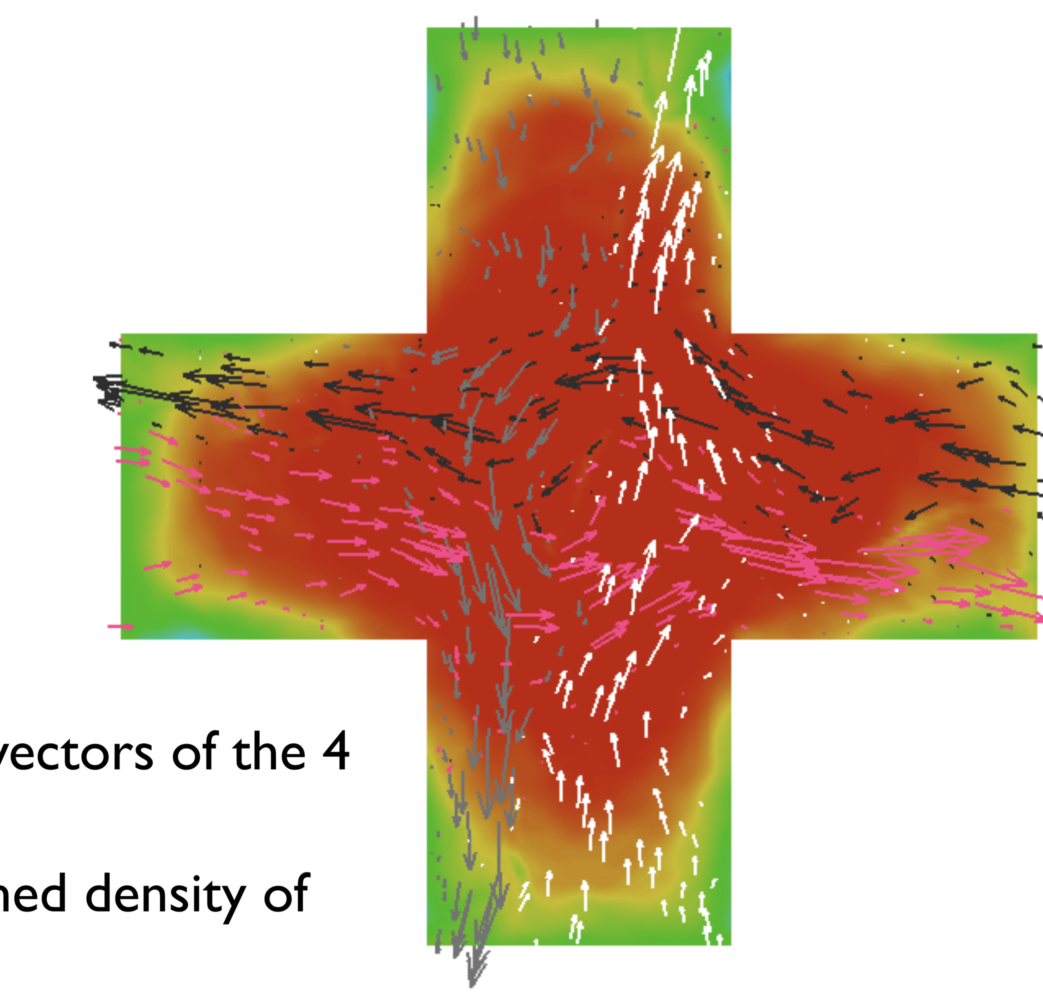
Validation: Reproducing Generic Social Patterns

Example: Spontaneous lane formations by pedestrian walking in opposite directions, in a corridor



- pedestrians enter, using the entry's full width
- color code: total mass flux. Red: left-to-right population dominates. Blue: Right-to-left population dominates.
- White curves: Streamlines of left-to-right population. Black curves: Same for right-to-left population

Example: A 4 populations / crossing corridors variant



- Arrows: momenta vectors of the 4 populations
- Color code: combined density of all pedestrians

Present & Near Future Effort

- Real time model parameter estimation from benchmark video data sets
- Model refinement to match a large number of populations and complex geometries. Driving scenario: Pedestrians heading to different platforms and exits in an underground station
- Large influx / density variations
- Stochastic dominance over targeted motion (an open market scenario)

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