Visually-Guided Collective Behavior in Human Swarms

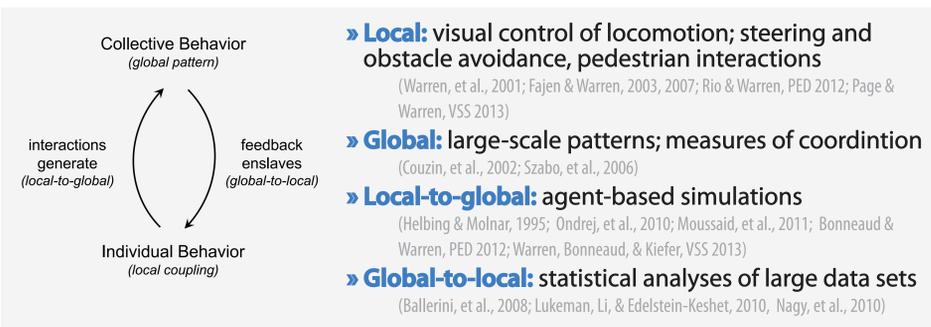Kevin W. Rio and William H. Warren

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QUESTION:

- Do global patterns of collective behavior in human crowds emerge from local interactions between neighbors?
- Can we derive information about these local interactions by analyzing crowds at the global level?

BACKGROUND:

- Human crowds (as well as bird flocks, fish schools, etc.) are thought to be examples of self-organized systems. They must be analyzed at both local and global levels (Sumpter, Mann, & Perna, 2012).

Collective Behavior *(global pattern)*

interactions generate *(local-to-global)*

feedback enslaves *(global-to-local)*

Individual Behavior *(local coupling)*

» **Local:** visual control of locomotion; steering and obstacle avoidance, pedestrian interactions (Warren, et al., 2001; Fajen & Warren, 2003, 2007; Rio & Warren, PED 2012; Page & Warren, VSS 2013)

» **Global:** large-scale patterns; measures of coordintion (Couzin, et al., 2002; Szabo, et al., 2006)

» **Local-to-global:** agent-based simulations (Helbing & Molnar, 1995; Ondrej, et al., 2010; Moussaid, et al., 2011; Bonneaud & Warren, PED 2012; Warren, Bonneaud, & Kiefer, VSS 2013)

» **Global-to-local:** statistical analyses of large data sets (Ballerini, et al., 2008; Lukeman, Li, & Edelstein-Keshet, 2010, Nagy, et al., 2010)
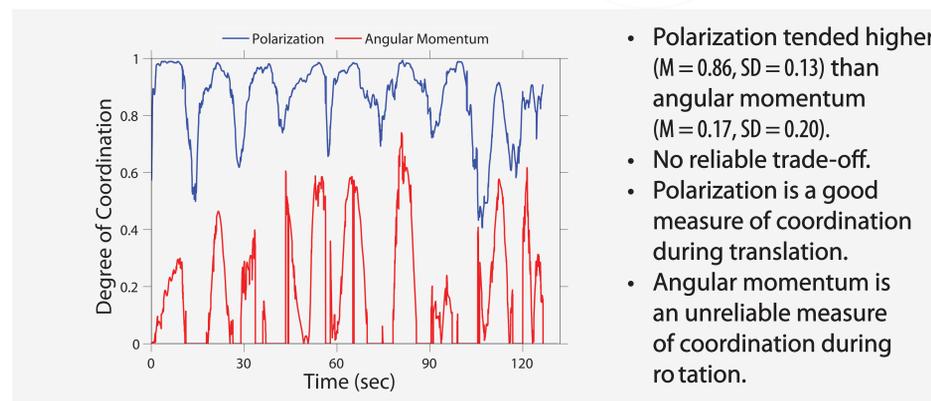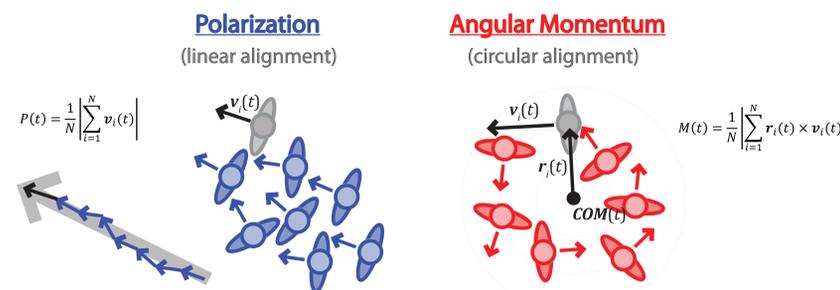
EXPERIMENT:

- Groups of 16 or 20 participants walked in a 12x20 m open area.
- Participants were instructed to randomly veer left or right while staying together as a group, remaining within bounds.
- No designated leader and no signal to turn.
- Each trial lasted 120 s; 3 (of 8) trials analyzed.

- Head positions were tracked at 60 Hz using a 16-camera motion capture system (Qualisys Oqus 500).

Experiment

Tracking helmets

Tracking data

Central participant

Neighbors

(x,y) & Heading data
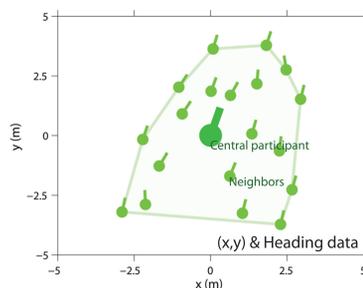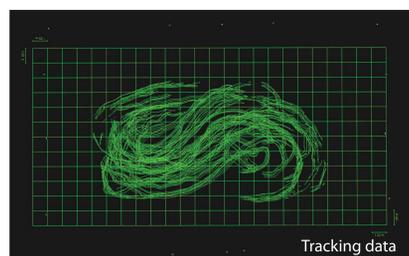
RESULTS:

» GLOBAL MEASURES:

- Attempt to identify an 'order parameter' that ranges from 0 to 1, with 1 = maximal coordination and 0 = no coordination.
- Two candidates are group polarization and angular momentum (Couzin, et al., 2002).

Polarization (linear alignment)

$$P(t) = \frac{1}{N}\left|\sum_{i=1}^{N} v_i(t)\right|$$

$v_i(t)$

Angular Momentum (circular alignment)

$v_i(t)$

$r_i(t)$

$COM(t)$

$$M(t) = \frac{1}{N}\left|\sum_{i=1}^{N} r_i(t) \times v_i(t)\right|$$

- Polarization tended higher (M = 0.86, SD = 0.13) than angular momentum (M = 0.17, SD = 0.20).
- No reliable trade-off.
- Polarization is a good measure of coordination during translation.
- Angular momentum is an unreliable measure of coordination during rotation.

» LOCAL COUPLING: HEAT MAPS

- Estimate the influence of neighbors on an individual in the swarm.
- Compute pairwise statistics on central participant and each neighbor.
- Aggregate data across time-steps & trials.
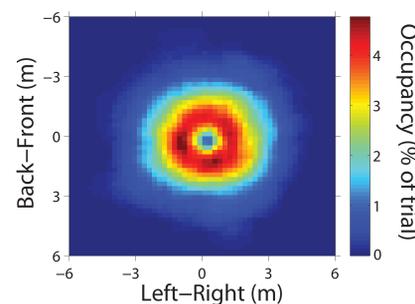
- Neighbors most likely to be found within a circle of radius 1 - 2 m.
- Exclusion zone with radius 0.25 m.
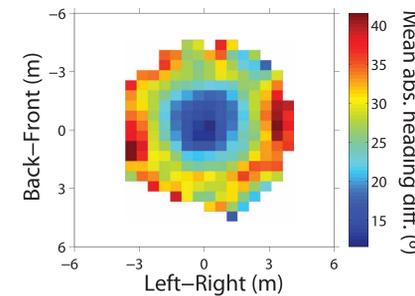
- Absolute heading difference increases radially outward.
- Strong local coupling that falls off rapidly with distance.

» LOCAL COUPLING: METRIC v. TOPOLOGICAL DISTANCE

- How many neighbors influence a pedestrian?
- Two leading hypotheses: all neighbors within a fixed distance (metric), or a fixed number of nearest neighbors (topological) (Ballerini, et al., 2008; Lukeman, Li, & Edelstein-Keshet, 2010).
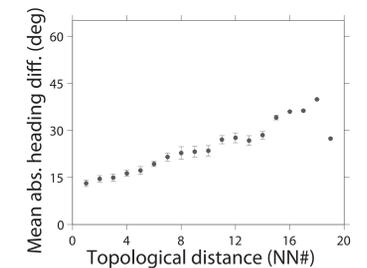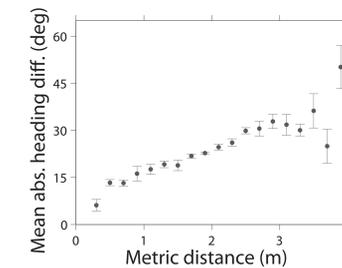
- Mean absolute heading difference increases approximately linearly with both metric and topological distance. Suggests chain of local interactions.

- Vary density: if interaction is metric, pedestrian should be influenced by more neighbors at higher density; if topological, same number.
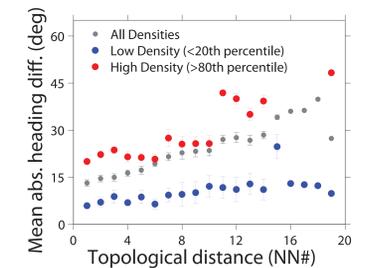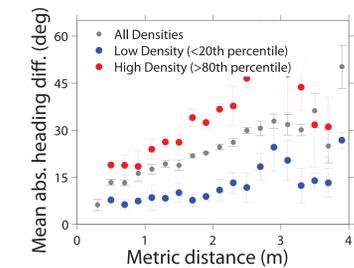
- For a given distance, absolute heading difference is greater at high densities.
- Suggests a mixed solution: each neighbor's influence decays as a function of both metric and topological distance.

CONCLUSIONS:

- Group polarization, but not angular momentum, is a useful measure of coherence, and may serve as an order parameter to enslave individual behavior.
- Individuals have a strong local coupling to their neighbors, which decays with both metric and topological distance, suggesting a chain of local interactions.
- Global and global-to-local analyses of human crowd dynamics, while limited, can be a useful complement to experiments at the local and local-to-global levels.

FUTURE WORK:

- Directly investigate local coupling by testing participant walking in a virtual crowd.
- Test metric and topological hypotheses by explicitly manipulating density.
- Use information about local coupling field to inform agent-based simulation of crowd dynamics (see Bonneaud & Warren, PED 2012; Warren, Bonneaud, & Kiefer, VSS 2013).

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