Multiscale approaches to crowd dynamics and the reliability of data from experiments.

Comment on Human behaviours in evacuation crowd dynamics: From modelling to “big data” toward crisis management by Nicola Bellomo et al.

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In this interesting essay, focused on mathematical models for crowd dynamics specifically for the purpose of management of extreme events such as evacuation from complex environment, Bellomo et al. [2] provide a critical analysis and argue that kinetic models may provide well-suited tools to support decision making.

The critical aspects of crowd management, such as the interpretation of information and predictions by models' simulation, are well analyzed. Moreover, the complexity behind the crowd as a living system is presented in a convincing fashion. However, we believe that the modeling and validation strategies would be enriched by a more detailed discussion about the choice of scaling and the data set for validation. Here we focus on two main issues:

- A description of nano-scale and multi-scale models.
- A critical analysis of data from experiments.

The presentation of the modeling scale may encompass the *nano-scale*, intended as models which take into account internal dynamics of humans. This is relevant to represent the rational behavior of pedestrians (see [4, 6]) and

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also to describe in detail situations arising in evacuation through complex environment. In the latter case a 3D model of the whole body may be necessary to detect interactions when flowing through narrow passages and doors. For the former case, among the most notable work we cite the human locomotion model of Arechavaleta et al. [1] based on lab experiment of motion tracking. The model is based on the idea that pedestrians optimize a given cost over a controlled dynamical system. More precisely, humans control the speed of walk and the torsion of their body and, when walking, tend to minimize their energy. The latter is represented by a weighted sum of the velocity of the torso and the curvature of the trajectory. The precise system is given by the following equations:

$$\dot{x} = u_1 \cos(\varphi), \quad \dot{y} = u_1 \sin(\varphi), \quad \dot{\varphi} = u_1 \kappa, \quad \dot{\kappa} = u_2,$$

$$\min \frac{1}{2} \int_0^T (\alpha u_1^2 + \beta u_2^2) dt$$

where (x, y) is the torso position, φ its direction and κ its curvature. The controls u_1 and u_2 are bounded and the system's parameters were fit to experimental data: single pedestrians moved freely in a large gymnasium and were asked to naturally walk from starting position to a porch. The data encompassed more than 1500 pedestrian walks using 34 light reflective markers. Further commenting on the multi-scale approaches mentioned in the essay, we point out that the Wasserstein setting [4] is also amenable to justify the limit procedures of macroscopic models to kinetic ones (mean-field limits) and build multi-scale models. The latter may retain information on the macroscopic scale or used to split the population into leader and followers, see [5].

Human walking is supported by a highly complex cognitive process, which renders particularly difficult the avoidance of psychological biases when collecting data. Moreover, experiments on large crowds require the knowledge of statistical composition of local population to render experiments reliable. In particular the setting in which the experiment is performed may affect sensibly the experimental results and thus render their interpretation particularly challenging. In the literature four experimental settings are the most common: interviews, virtual reality, artificial environments and natural environments. Needless to say the first two settings are prone to large biases. In both cases pedestrians are not exposed directly to a walking environment,

but rather they may look at maps or navigate in an area using augmented or virtual reality. But also the third setting, where in a lab researchers reproduce a real environment using barriers, doors frames etc., can give rise to possibly misleading results. However, such risks may be reduced by not communicating the experiment purposes to participants. Natural environments can be tested using video cameras, but data processing from videos requires complex software and large computing capabilities and the experimental setting is less controllable.

To understand the challenges stemming from psychological biases, one may see the experimental results obtained in [3] on the Rutgers-Camden campus. Pedestrian trajectories were recorded on a path, which presented an obstacle (construction cone) placed just after a turn of the path of around 45 degrees. The main purpose of the experiment was to understand the preference of pedestrian in choosing the right or left path with respect to the obstacle. For the specific situation, the model of Arechavaleta et al. [1] would predict a preference for keeping the left, while social rules suggest to keep the right (in US people usually walk on the right side). Interestingly the experimental results strongly depend on the setting, with majority passing to the right when interviewed but to the left when observed not being aware.

Concluding data collection represents a major obstacle toward the understanding of crowd dynamics and the development of mathematical models.

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References

- [1] G. Arechavaleta, J.-P. Laumond, H. Hicheur and A. Berthoz, *An optimality principle governing human walking*, IEEE Transactions on Robotics, 24(1):5–14, 2008.
- [2] N. Bellomo, D. Clarke, L. Gibelli, P. Townsend and B.J. Vreugdenhil, *Human behaviours in evacuation crowd dynamics: From modelling to big data toward crisis management*, Physics of Life Reviews (2016) [in this issue].

- [3] M. Bravo, M. Caponigro, E. Leibowitz and B. Piccoli, *Keep right or left? Towards a cognitive-mathematical model for pedestrians*, Networks and Heterogeneous Media, 10(3):559–578, 2015.
- [4] E. Cristiani, B. Piccoli and A. Tosin, *Modeling of Pedestrian Dynamics*, MS&A: Modeling, Simulation and Applications, Springer-Verlag, 2014.
- [5] M. Fornasier, B. Piccoli and F. Rossi, *Mean-field sparse optimal control*, Philos. Trans. R. Soc. Lond. Ser. A Math. Phys. Eng. Sci., 372(2028):20130400, 2014.
- [6] S.P. Hoogendoorn and P.H.L. Bovy, *Simulation of pedestrian flows by optimal control and differential games*, Optim. Control Appl. Meth., 24:153–172, 2003.