15-464/15-664 References for April 24, 2019 – Crowds

Often, thinking about crowd models starts with very simple force-based modeling. Forces due to attractors (e.g., the current goal) and constraints (e.g., avoid collisions) are accumulated and each agent's movements respond to those forces. To get started thinking about this kind of model, take a look at Craig Reynolds' boids page: http://www.red3d.com/cwr/boids/

Here is an example of a paper that builds on these ideas:

Pelechano N, Allbeck JM, Badler NI. Controlling individual agents in high-density crowd simulation. InProceedings of the 2007 ACM SIGGRAPH/Eurographics symposium on Computer animation 2007 Aug 3 (pp. 99-108). Eurographics Association. http://dl.acm.org/citation.cfm?id=1272705

Very early research on human crowds included the research by Dirk Helbing on social forces.

Helbing, Dirk, and Peter Molnar. "Social force model for pedestrian dynamics." *Physical review E* 51, no. 5 (1995): 4282. https://arxiv.org/abs/cond-mat/9805244

Helbing, Dirk, Illés Farkas, and Tamas Vicsek. "Simulating dynamical features of escape panic." *Nature* 407, no. 6803 (2000): 487. http://www.coss.ethz.ch/publications/supporting/escape-panic.html

Another early influential point of view was to treat crowds as a continuum, similar to a fluid simulation:

Treuille A, Cooper S, Popović Z. Continuum crowds. InACM Transactions on Graphics (TOG) 2006 Jul 30 (Vol. 25, No. 3, pp. 1160-1168). ACM. http://grail.cs.washington.edu/projects/crowd-flows/

Neither of these models capture the detailed structure of individual behavior in crowds. We spoke about two papers that used data-driven techniques with a straightforward strategy of looking up the next action for each actor from the database. From these papers, interactions between characters did occur, however, they occured somewhat spontaneously, due to the local context of the character.

Lee, Kang Hoon, Myung Geol Choi, Qyoun Hong, and Jehee Lee. "**Group behavior from video: a data-driven approach to crowd simulation**." In Proceedings of the 2007 ACM SIGGRAPH/Eurographics symposium on Computer animation, pp. 109-118. Eurographics Association, 2007.
http://mrl.snu.ac.kr/research/ProjectVideoCrowd/group_behavior.html

Lerner, Alon, Yiorgos Chrysanthou, and Dani Lischinski. "**Crowds by example**." In Computer Graphics Forum, vol. 26, no. 3, pp. 655-664. Blackwell Publishing Ltd, 2007.
https://www.youtube.com/watch?v=obe5uO56cTI
https://graphics.cs.ucy.ac.cy/research/downloads/crowd-data

Avoiding collisions is always a challenge with crowds. We spoke about the ORCA model, which introduces the concept of velocity obstacles to ensure collision avoidance.

Van den Berg, Jur, Ming Lin, and Dinesh Manocha. "Reciprocal velocity obstacles for real-time multi-agent navigation." In *2008 IEEE International Conference on Robotics and Automation*, pp. 1928-1935. IEEE, 2008. http://gamma.cs.unc.edu/ORCA/

The next three papers took a look at how people actually walk together in small groups, recognizing common formations and proposing techniques that help actors to maintain such formations in more and less crowded scenarios.

Peters, Christopher, and Cathy Ennis. "**Modeling groups of plausible virtual pedestrians**." IEEE Computer Graphics and Applications 29, no. 4 (2009): 54-63. http://ieeexplore.ieee.org/document/5167488/

Moussaïd, Mehdi, Niriaska Perozo, Simon Garnier, Dirk Helbing, and Guy Theraulaz. "**The walking behaviour of pedestrian social groups and its impact on crowd dynamics**." PloS one 5, no. 4 (2010): e10047. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0010047#pone-0010047-g006

Karamouzas, Ioannis, and Mark Overmars. "**Simulating and evaluating the local behavior of small pedestrian groups**." Visualization and Computer Graphics, IEEE Transactions on 18, no. 3 (2012): 394-406. https://sites.google.com/site/ikaramouzas/groups

We looked at the PowerLaw algorithm, which suggests based on a large quantity of observed data that people act based on the estimated time to collision.

Karamouzas, Ioannis, Brian Skinner, and Stephen J. Guy. "Universal power law governing pedestrian interactions." *Physical review letters* 113, no. 23 (2014): 238701. http://motion.cs.umn.edu/PowerLaw/

This perception paper discusses how shoulder motion adds to our perception of realism in crowd scenes:

Hoyet L, Olivier AH, Kulpa R, Pettré J. Perceptual effect of shoulder motions on crowd animations. ACM Transactions on Graphics (TOG). 2016 Jul 11;35(4):53. https://www.youtube.com/watch?v=d4UAqQWsqWw

This recent paper tries to obtain smooth, collision free, and anticipatory crowd behavior using concepts related to implicit integration.

Karamouzas, Ioannis, Nick Sohre, Rahul Narain, and Stephen J. Guy. "Implicit crowds: Optimization integrator for robust crowd simulation." *ACM Transactions on Graphics (TOG)* 36, no. 4 (2017): 136. https://people.cs.clemson.edu/~ioannis/implicit-crowds/

This paper begins to get at a concept of how we evaluate and compare crowd simulation algorithms quantitatively.

Karamouzas, Ioannis, Nick Sohre, Ran Hu, and Stephen J. Guy. "Crowd space: a predictive crowd analysis technique." In *SIGGRAPH Asia 2018 Technical Papers*, p. 186. ACM, 2018. https://dl.acm.org/citation.cfm?id=3275079