15-464/15-664 References for April 24, 2023 – 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 a collection of research based on tracking individuals and developing behavior models informed by data. The following website is a good reference (scroll down to see multiple projects):
http://gamma.cs.unc.edu/REACH/CrowdT/

Here is a representative paper:

Kim, Sujeong, Aniket Bera, Andrew Best, Rohan Chabra, and Dinesh Manocha. "Interactive and adaptive data-driven crowd simulation." In *2016 IEEE Virtual Reality (VR)*, pp. 29-38. IEEE, 2016. http://gamma.cs.unc.edu/DDPD/

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

The following paper offers a survey on this topic:

Nicolas, Alexandre, and Fadratul Hafinaz Hassan. "Social groups in pedestrian crowds: review of their influence on the dynamics and their modelling." *Transportmetrica A: transport science* 19, no. 1 (2023): 1970651.
https://www.tandfonline.com/doi/pdf/10.1080/23249935.2021.1970651

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/

Simulation with the power law was made more stable with implicit integration in this paper:

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): 1-13.
https://people.computing.clemson.edu/~ioannis/implicit-crowds/

The following 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

These authors have also published a short and readable guide to anticipatory collision avoidance with games in mind:

Guy, Stephen J., and Ioannis Karamouzas. "Guide to anticipatory collision avoidance." In *Game AI Pro 360*, pp. 159-172. CRC Press, 2019.
http://www.gameaipro.com/GameAIPro2/GameAIPro2_Chapter19_Guide_to_Anticipatory_Collision_Avoidance.pdf

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

A recent position based dynamics approach includes a frictional contact model, long range collision model, and viscosity for cohesion:

Weiss, Tomer, Alan Litteneker, Chenfanfu Jiang, and Demetri Terzopoulos. "Position-based real-time simulation of large crowds." Computers & Graphics 78 (2019): 12-22.
https://www.sciencedirect.com/science/article/pii/S0097849318301699
https://www.youtube.com/watch?v=iC8KHkoZR8k&t=3s

There are a number of models of character personality and emotion that we did not get a chance to cover. The OCEAN, PEN, and OCC models are examples. Here is one example paper that focuses on how individual emotion and the spreading of individual emotions affects group dynamics:

Jiang, Hao, Zhigang Deng, Mingliang Xu, Xiangjun He, Tianlu Mao, and Zhaoqi Wang. "An emotion evolution based model for collective behavior simulation." In *Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games*, pp. 1-6. 2018.
https://www.youtube.com/watch?v=NF4yC3TdjQ4

Another important issue is how the crowd behavior is scripted or designed. This recent paper presents an interesting and fine-grained approach:

Colas, Adèle, Wouter van Toll, Katja Zibrek, Ludovic Hoyet, A-H. Olivier, and Julien Pettré. "Interaction Fields: Intuitive Sketch-based Steering Behaviors for Crowd Simulation." In Computer Graphics Forum, vol. 41, no. 2, pp. 521-534. 2022.
https://www.youtube.com/watch?v=raHHI8VwBL8

You can find a recent review paper on crowds here:

Yang, Shanwen, Tianrui Li, Xun Gong, Bo Peng, and Jie Hu. "A review on crowd simulation and modeling." Graphical Models 111 (2020): 101081.
https://www.sciencedirect.com/science/article/pii/S1524070320300242