USC Viterbi
School of Engineering

Course ID and Title: CSCI 599, Introduction to Holodecks
Units: # 4
Term—Day—Time: Spring 2024 — Mon, Wed 5-6:50 pm

Location: TBD

Instructor: Shahram Ghandeharizadeh
Office: SAL 208
Office Hours: Mon, 12-1:30, Wed, 3:30-5 pm
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Catalogue Description
None. This is a seminar on a new topic.

Course Description
A holodeck enables users to see virtual objects without glasses and to interact with them without wearing gloves or bodysuits. Holodecks may occupy physical volumes such as a tabletop cuboid or sphere, a telephone booth, a self-driving vehicle, a room, a concert hall, a stadium, or other well defined spaces. This course introduces students to Flying Light Specks (FLSs) as miniature drones with Red/Green/Blue (RGB) lights that fly as swarms to illuminate a virtual object. These illuminations provide true depth, enabling a user to perceive a scene more completely by analyzing its illumination from different angles. In addition, students are introduced to FLS-matter, a swarm of miniature drones to generate the tactile (simulating skin receptors only) and kinesthetic (muscle sense of pushing or lifting objects with mass) senses. These concepts enable immersive and interactive 3D displays depicted in science fiction shows, e.g., Star Trek's holodeck. A holodeck will revolutionize the future of human communication and perception, and how we interact with information and data.

Learning Objectives
This course introduces students to:

- Programmable matter such as Claytronics, BitDrones, Roboxels, and FLSs.
- Encounter-type haptic devices.
- Centralized and decentralized algorithms for group formation.
- Collision prevention and detection techniques.
- Localization techniques.
- Matlab and MathWorks for rapid prototyping and evaluation of algorithms.
- Physics engines such as Airsim and Gazebo to conduct simulation studies.
- Virtual Reality, Augmented Reality, and Mixed Reality.
- Holographs.

Prerequisite(s): Principles of Software Development (CSCI 201)
Co-Requisite(s): None
Concurrent Enrollment: None
Recommended Preparation: Operating Systems (CSCI 356), AI (CSCI 360), Data Management (CSCI 485), Robotics (CSCI 445L).

Course Notes
All lecture material will be posted on the USC blackboard system prior to lectures. We will use Piazza for class discussions.

Technological Proficiency and Hardware/Software Required
Students should be proficient in design and implementation of concepts in different programming languages.

Required Readings and Supplementary Materials
Required readings and supplementary materials are based on recently published papers. USC students may use their provided ACM/IEEE/Springer digital library membership to download these papers for free.

Optional Readings and Supplementary Materials
[Optional course materials that are not required but recommended.]

Description of Assignments and How They Will Be Assessed
The course includes a class project. Students are encouraged to conduct their project on the numerous research topics related to the Flying Light Specks, FLSs.

Participation [if applicable]
In-class participation counts towards 10% of grade. This may include a student presentation of a paper.

Grading Breakdown

Assessment Tool (assignments)	**% of Grade**
Class Participation	10%
Exam 1	30%
Project Description	30%
Final Project Report	30%
TOTAL	**100%**

Grading Scale
The final letter grade is based on a curve.

Assignment Submission Policy
Exams will be graded promptly and returned in a week.
Project description and the final project report include an oral presentation.

Course-Specific Policies
In-class participation is a requirement.
No late reports are accepted. All deadlines are final.
Class participation may include students presenting technical papers.
Students who conduct original research are awarded with extra credit.

Attendance
This course is based on either recently introduced technical manuscripts or an adaptation of novel concepts for the exciting topic of holodecks. Some of these manuscripts are difficult to read. In-class attendance and participation is a requirement.

Academic Integrity

Unless otherwise noted, this course will follow the expectations for academic integrity as stated in the USC Student Handbook. The general USC guidelines on Academic Integrity and Course Content Distribution are provided in the subsequent "Statement on Academic Conduct and Support Systems" section.

[Include information regarding grade outcomes a student may expect if found in violation, such as: If found responsible for an academic violation, students may be assigned university outcomes, such as suspension or expulsion from the university, and grade penalties, such as an "F" grade on the assignment, exam, and/or in the course.]

Please ask the instructor [and/or TA(s)] if you are unsure about what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

You may not record this class without the express permission of the instructor and all other students in the class. Distribution of any notes, recordings, exams, or other materials from a university class or lectures — other than for individual or class group study — is prohibited without the express permission of the instructor.

Use of Generative AI in this Course

Students may use generative AI to improve the written English of their report. With advanced courses, Generative AI makes a lot of mistakes. It is the responsibility of the student to read the technical manuscripts and verify technical correctness of their reports.

Solutions to assignments and projects that are technically flawed will get a score of zero.

Course Evaluations

Course evaluation occurs at the end of the semester university-wide. It is an important review of students' experience in the class. The process and intent of the end-of-semester evaluation should be provided. In addition, a mid-semester evaluation is recommended practice for early course correction.

Course Schedule: A Weekly Breakdown

Week 1: FLS Displays & Claytronics

1. Shahram Ghandeharizadeh. 2021. Holodeck: Immersive 3D Displays Using Swarms of Flying Light Specks [Extended Abstract]. In ACM Multimedia Asia, Gold Coast, Australia, December 2021, Pages 1–7. Read extended arXiv version https://arxiv.org/abs/2111.03657

2. Ivan E. Sutherland. 1965. The Ultimate Display. In Proceedings of IFIP Congress. 506–508.

3. S.C. Goldstein, J.D. Campbell, and T.C. Mowry. 2005. Programmable matter. Computer 38, 6 (2005), 99–101. https://doi.org/10.1109/MC.2005.198

Dig Deeper (Optional Reading):

- Allen McDuffee. 2014. A Holodeck Videogame Designed to Train Soldiers, Wired. Jan, 2014. See https://www.wired.com/2014/01/holodeck/.
- Febretti, Alessandro et al. "CAVE2: a hybrid reality environment for immersive simulation and information analysis." *Electronic Imaging* (2013).
- A. Maglo, G. Lavoue, F. Dupont, C. Hudelot. 3D Mesh Compression: Survey, Comparisons, and Emerging Trends. ACM Computing Surveys, Vol. 47, No. 3, Article 44, Feb 2015.

Week 2: FLS Illuminations & Group Construction (Matching Problem)

4. Shahram Ghandeharizadeh. 2022. Display of 3D Illuminations using Flying Light Specks. In ACM Multimedia, Lisbon, Portugal, October 2022.

5. Hamed Alimohammadzadeh, Heather Culbertson, Shahram Ghandeharizadeh. An Evaluation of Decentralized Group Formation Techniques for Flying Light Specks. In ACM Multimedia Asia, Taipei, Taiwan, December 6-8, 2023.

Dig Deeper:

- 5. Preis R. 1999. Linear Time 1/2-Approximation Algorithm for Maximum Weighted Matching in General Graphs. In STACS 99: Proceedings Symposium on Theoretical Aspects of Computer Science. 259–269.
- Anna Chmielowiec, Spyros Voulgaris, and Maarten van Steen. 2014. Decentralized Group Formation. Journal of Internet Services and Applications 5, 1 (2014). https://doi.org/10.1186/s13174-014-0012-2
- Avis David. 1983. A Survey of Heuristics for the Weighted Matching Problem. Networks 13 (1983), 475–493.

- Jaap-Henk Hoepman. 2004. Simple Distributed Weighted Matchings. CoRRcs.DC/0410047 (2004). http://arxiv.org/abs/cs.DC/0410047.
- Edmonds Jack. 1965. Paths, Trees, and Flowers. Canada Journal of Math. 17 (1965), 449–467.
- Tutte W. 1947. The Factorization of Linear Graphs. Journal of London Mathematics Society 22 (1947), 107–11

Week 3: Encounter-Type Haptics (Guest Lecturer Heather Culbertson)

6. Victor Rodrigo Mercado, Maud Marchal, and Anatole Lecuyer. 2021. Haptics On-Demand: A Survey on Encountered-Type Haptic Displays. IEEE Transactions on Haptics 14, 3 (2021), 449–464.

7. Muhammad Abdullah, Minji Kim, Waseem Hassan, Yoshihiro Kuroda, and Seokhee Jeon. 2018. HapticDrone: An Encountered-type Kinesthetic Haptic Interface with Controllable Force Feedback: Example of Stiffness and Weight Rendering. In Proc. IEEE Haptics Symposium. IEEE, 334–339.

Dig Deeper:

- Lawrence H. Kim and Sean Follmer. 2019. SwarmHaptics: Haptic Display with Swarm Robots. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). Association for Computing Machinery, New York, NY, USA, Paper 688, 1–13. DOI:https://doi.org/10.1145/3290605.3300918

Week 4: Sensors for Localization

8. T. Phan, H. Alimohammadzadeh, H. Culbertson, and S. Ghandeharizadeh. An Evaluation of Three Distance Measurement Sensors for Flying Light Specks. In International Conference on Intelligent Metaverse Technologies and Applications (iMETA2023), Tartu, Estonia, September 18-20, 2023.

9. P. Kao, H. Chang, K. Tseng, T. Chen, H. Luo, and Y. Hung. VIUNet: Deep Visual-Inertial-UWB Fusion for Indoor UAV Locations. IEEE Access, Volume 11, 2023.

10. Hao Xu, Luqi Wang, Yichen Zhang, Kajie Qiu, and Shaojie Shen. Decentralized Visual-Inertial-UWB Fusion for Relative State Estimation of Aerial Swarms. In 2020 IEEE International Conference on Robotics and Automation (ICRA) 31 May - 31 August, 2020. Paris, France

Dig Deeper:

- C. Chen, S. Rosa, Y. Miao, C. Lu, W. Wu, A. Markham, N. Tigoni. Selective Sensor Fusion for Neural Visual-Inertial Odometry. IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), 2019.
- F. Xiao, S. Zhang, S. Tang, S. Shen, H. Dong, and Y. Zhong. WiSion: Bolstering MAV 3D Indoor State Estimation by Embracing Multipath of WiFi. IEEE Transactions on Vehicular Technology, Vol 72, No 1, January 2023.

- S. Wang, Y. Wang, X. Bai, D. Li. Communication Efficient, Distributed Relative State Estimation in UAV Networks. In IEEE Journal on Selected Areas in Communications, Vol. 41, No. 4, April 2023.
- P. Moron, J. Queralta, T. Westerlund. Towards Large-Scale Relative Localization in Multi-Robot Systems with Dynamic UWB Role Allocation. https://arxiv.org/abs/2203.03893

Week 5: User Safety

11. S. Ghandeharizadeh and L. Garcia. Safety in the Emerging Holodeck Applications. In CHI 2022 Workshop on Novel Challenges of Safety, Security and Privacy in Extended Reality, April 25, 2022.

12. Colgate, Ed, Antonio Bicchi, Michael Aaron Peshkin, and James Edward Colgate. "Safety for physical human-robot interaction." In *Springer handbook of robotics*, pp. 1335-1348. Springer, 2008.

Dig Deeper:

- Matteo Rubagotti and Inara Tusseyeva and Sara Baltabayeva and Danna Summers and Anara Sandygulova. Perceived Safety in Physical Human–Robot Interaction—A Survey. Robotics and Autonomous Systems. Vol. 151, 2022, https://doi.org/10.1016/j.robot.2022.104047
- Sami Haddadin, Alin Albu-Schaffer, Gerd Hirzinger. Safety Evaluation of Physical Human-Robot Interaction via Crash-Testing. In Proc. Robotics: Science and System (RSS}, 2007.

Week 6: Quadcopters in Action

13. Jonas Auda, Nils Verheyen, Sven Mayer, and Stefan Schneegass. 2021. Flyables: Haptic Input Devices for Virtual Reality using Quadcopters. In Proc. ACM Symposium on Virtual Reality Software and Technology (VRST). 1–11.

14. Parastoo Abtahi, Benoit Landry, Jackie Yang, Marco Pavone, Sean Follmer, and James A Landay. 2019. Beyond the Force: Using Quadcopters to Appropriate Objects and the Environment for Haptics in Virtual Reality. In Proc. ACM CHI Conference on Human Factors in Computing Systems. 1–13.

Dig Deeper:

- Yousef Alghamdi, Arslan Munir, and H. La. 2021. Architecture, Classification,and Applications of Contemporary Unmanned Aerial Vehicles. IEEE Consumer Electronics Magazine (2021), 1–10.
- Soon-Jo Chung, A. Paranjape, P. Dames, S. Shen, and Vijay R. Kumar. 2018. A Survey on Aerial Swarm Robotics. IEEE Transactions on Robotics 34 (2018), 837–855.
- Hazim Shakhatreh, A. Sawalmeh, Ala Al-Fuqaha, Zuochao Dou, Eyad K. Almaita, Issa M. Khalil, Noor Shamsiah Othman, A. Khreishah, and M. Guizani. 2019. Unmanned Aerial

- Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges. IEEE Access 7 (2019), 48572–48634.
- Jonas Auda, Martin Weigel, Jessica R. Cauchard, and Stefan Schneegass. 2021. Understanding Drone Landing on the Human Body. In Proceedings of the 23rd International Conference on Mobile Human-Computer Interaction (MobileHCI '21). 1–13. https://doi.org/10.1145/3447526.3472031
- Viviane Herdel, Lee J. Yamin, and Jessica R. Cauchard. 2022. Above and Beyond: A Scoping Review of Domains and Applications for Human-Drone Interaction. In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22). 1–22. https://doi.org/10.1145/3491102.3501881

<u>Week 7: Collision Avoidance, Detection, Planning, Prevention</u>

15. Hang Sun, Juntong Qi, Chong Wu, and Mingming Wang. 2020. Path Planning for Dense Drone Formation Based on Modified Artificial Potential Fields. 39th Chinese Control Conference (CCC) (2020), 4658–4664

16. Ravinder Kumar Jyoti, Mohit Kumar Malhotra, and Debasish Ghose. 2021. Rogue Agent Identification and Collision Avoidance in Formation Flights using Potential Fields. In 2021 International Conference on Unmanned Aircraft Systems (ICUAS). 1080–1088. https://doi.org/10.1109/ICUAS51884.2021.9476866

17. Jiayi Sun, Jun Tang, and Songyang Lao. 2017. Collision Avoidance for Cooperative UAVs With Optimized Artificial Potential Field Algorithm. IEEE Access PP (08 2017), 18382–18390. https://doi.org/10.1109/ACCESS.2017.2746752

Dig Deeper:

- O. Khatib. 1985. Real-Time Obstacle Avoidance for Manipulators and Mobile Robots. In Proceedings. 1985 IEEE International Conference on Robotics and Automation, Vol. 2. 500–505. https://doi.org/10.1109/ROBOT.1985.1087247
- J. van den Berg, D. Wilkie, S. J. Guy, M. Niethammer and D. Manocha. LQG-obstacles: Feedback control with collision avoidance for mobile robots with motion and sensing uncertainty. In *2012 IEEE International Conference on Robotics and Automation*, 2012, pp. 346-353, doi: 10.1109/ICRA.2012.6224648.
- X. Zhang, A. Liniger and F. Borrelli, "Optimization-Based Collision Avoidance," in *IEEE Transactions on Control Systems Technology*, vol. 29, no. 3, pp. 972-983, May 2021, doi: 10.1109/TCST.2019.2949540.
- D. Fox, W. Burgard and S. Thrun, "The dynamic window approach to collision avoidance," in *IEEE Robotics & Automation Magazine*, vol. 4, no. 1, pp. 23-33, March 1997, doi: 10.1109/100.580977.
- B. Han, T. Qu, X. Tong, J. Jiang, S. Zlatanova, H. Wang, C. Cheng, Grid-optimized UAV indoor path planning algorithms in a complex environment, International Journal of

Applied Earth Observation and Geoinformation, Volume 111, 2022, 102857, ISSN 1569-8432, https://doi.org/10.1016/j.jag.2022.102857.

Week 8: Review for Midterm and Exam

Week 9: Matlab

Week 10: Spring Break

Week 11: Manufacturing

18. Fang, W. Chen, L., Zhang, T., Chen, C., Teng, Z., Wang, L. Head-mounted display augmented reality in manufacturing: A systematic review. Robotics and Computer-Integrated Manufacturing. Volume 83, October 2023, 102567.

19. Fang, W., Hong, J. Bare-hand gesture occlusion-aware interactive augmented reality assembly. Journal of Manufacturing Systems. Volume 65, October 2022, Pages 169-179.

Week 12: Localization/Positioning System

20. Adam Smith, Hari Balakrishnan, Michel Goraczko, Nissanka Priyantha,Tracking Moving Devices with the Cricket Location System, Proc. 2nd USENIX/ACM MOBISYS Conf., Boston, MA, June 2004.

Dig Deeper:

- Nissanka B. Priyantha, Anit Chakraborty, Hari Balakrishnan, **The Cricket Location-Support system**, Proc. 6th ACM MOBICOM, Boston, MA, August 2000.
- Hari Balakrishnan, Roshan Baliga, Dorothy Curtis, Michel Goraczko, Allen Miu, Nissanka B. Priyantha, Adam Smith, Ken Steele, Seth Teller, Kevin Wang, Lessons from Developing and Deploying the Cricket Indoor Location System, November 2003. (Preprint.)
- This paper describes the lessons learned from Cricket v1 and how Cricket v2's design builds on these lessons.
- Yanying Gu, Anthony C. C. Lo, and Ignas G. Niemegeers. 2009. A Survey of Indoor Positioning Systems for Wireless Personal Networks. IEEE Commun. Surv. Tutorials 11, 1 (2009), 13–32. https://doi.org/10.1109/SURV.2009.090103
- Souvik Sen, Dongho Kim, Stephane Laroche, Kyu-Han Kim, and Jeongkeun Lee. 2015. Bringing CUPID Indoor Positioning System to Practice. In *Proceedings of the 24th International Conference on World Wide Web* (*WWW '15*). International World Wide Web Conferences Steering Committee, Republic and Canton of Geneva, CHE, 938–948. DOI:https://doi.org/10.1145/2736277.2741686
- Jiang Xiao, Zimu Zhou, Youwen Yi, and Lionel M. Ni. 2016. A Survey on Wireless Indoor Localization from the Device Perspective. *ACM Comput. Surv.* 49, 2, Article 25 (June 2017), 31 pages. DOI:https://doi.org/10.1145/2933232

- *C. Watson. Permanent Magnet-Based Localization for Growing Robots in Medical Applications, Dissertation.*

<u>Week 13: 3D Acoustics</u>

21. Mehra, Ravish and Raghuvanshi, Nikunj and Antani, Lakulish and Chandak, Anish and Curtis, Sean and Manocha, Dinesh. 2013. Wave-Based Sound Propagation in Large Open Scenes Using an Equivalent Source Formulation. ACM Trans. Graph. 32, 2, Article 19 (April 2013), 13 pages. https://doi.org/10.1145/2451236.2451245

22. Shiguang Liu and Dinesh Manocha. 2020. Sound Synthesis, Propagation, and Rendering: A Survey. CoRR abs/2011.05538 (2020). arXiv:2011.05538 https://arxiv.org/abs/2011.05538

Dig Deeper:

- D. Miljković, "Methods for attenuation of unmanned aerial vehicle noise," *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, Opatija, Croatia, 2018, pp. 0914-0919, doi: 10.23919/MIPRO.2018.8400169.
- Nikunj Raghuvanshi and John Snyder. 2018. Parametric Directional Coding for Precomputed Sound Propagation. ACM Trans. Graph. 37, 4, Article 108 (July 2018), 14 pages. https://doi.org/10.1145/3197517.3201339.
- H. Bi, F. Ma, T. D. Abhayapala and P. N. Samarasinghe, "Spherical Array Based Drone Noise Measurements and Modelling for Drone Noise Reduction via Propeller Phase Control," *2021 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA)*, New Paltz, NY, USA, 2021, pp. 286-290, doi: 10.1109/WASPAA52581.2021.9632719.
- B. Kang, H. Ahn and H. Choo, "A Software Platform for Noise Reduction in Sound Sensor Equipped Drones," in *IEEE Sensors Journal*, vol. 19, no. 21, pp. 10121-10130, 1 Nov.1, 2019, doi: 10.1109/JSEN.2019.2927370.

<u>Week 14: Noise Reduction</u>

23. Xu, H., Kong, D. Qian Y., Tang X. Motor noise reduction of unmanned aerial vehicles. Applied Acoustics. Volume 198, September 2022, 108979.

24. Narine, M. Active Noise Cancellation of Drone Propeller Noise through Waveform Appr eform Approximation and Pitch-Shifting Approximation and Pitch-Shifting. Master Thesis, Computer Science Department, Georgia State University.

Dig Deeper:

- Miljković. Methods for attenuation of unmanned aerial vehicle noise. *2018. In the 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2018, pp. 0914-0919, doi: 10.23919/MIPRO.2018.8400169.

- W. Herkes, R. Olsen, and S. Uellenberg. 2012. The Quiet Technology Demonstrator Program: Flight Validation of Airplane Nois Reduction Concepts. In 12th AIAA/CEAS Aeroacoustics Conference (27th AIAA Aeroacoustics Conference). https://doi.org/10.2514/6.2006-2720 arXiv:https://arc.aiaa.org/doi/pdf/10.2514/6.2006-2720

Week 15: Project Presentations

Course Schedule

	Topics/Daily Activities	Readings/Preparation	Deliverables
Week 1 Jan 8	FLS displays, Claytronics & Catoms,	Ghandeharizadeh FLS displays, Sutherland Ultimate Display, Goldstein Catoms	3D Illuminations Matter for the Holodeck
Week 2 Jan 15	Group Construction, Matching Problem	Preis centralized algorithm, Chmielowiec decentralized algorithm	Centralized and decentralized algorithms to form groups
Week 3 Jan 22	Encounter-Type Haptics (Guest Lecturer Heather Culbertson)	Rodrigo Haptics-On-Demand, Abdullah HapticDrone	Encounter-Type Haptics
Week 4 Jan 29	Sensor for Localization	Phan et. al. Three Distance Measurement Sensors.	Localization of FLSs.
Week 5 Feb 5	User Safety (Guest Lecturer Luis Garcia)	Ghandeharizadeh & Garcia Safety in Holodeck App	User Safety
Week 6 Feb 12	**Project Reports due 2/28** & Quadcopters	Auda Flyables, Abtahi Beyond the Force,	**Class Projects** Quadcopters in different applications
Week 7 Feb 19	Collision Detection & Avoidance	Sun APF Path Planning, Jyoti Rogue Agent, Sun APF Collision Avoidance	Artificial Potential Field (APF) Algorithm
Week 8 Feb 26	**Review for Exam 1** **Exam 1 is on 3/4**		
Week 9 Mar 4	Introduction to Matlab & Mathworks	Motion illumination using FLS	Abstractions & modeling
Week 10 Mar 11	Spring Recess	Spring Recess	Spring Recess
Week 11 Mar 18	Manufacturing	Fang et. al. AR in Manufacturing	Industry 4.0 and 5.0, AR and MR
Week 12 Mar 25	Indoor Positioning System	Smith Cricket	Device tracking techniques
Week 13 Apr 1	3D Acoustics	Mehra Wave-Based Sound Propagation	Sound in games
Week 14 Apr 8	Noise Reduction	Herkes Quiet Technology	Suppress drone noise
Week 15 & 16 Apr 15 & 22	**Project Presentations**	**Project Presentations**	**Project Presentations**
FINAL			Refer to the final exam schedule in the USC *Schedule of Classes* at classes.usc.edu.

Time Permitting

Holograms

25. Chenliang Chang, Kiseung Bang, Gordon Wetzstein, Byoungho Lee, and Liang Gao, "Toward the next-generation VR/AR optics: a review of holographic near-eye displays from a human-centric perspective," Optica **7**, 1563-1578 (2020).

26. Xiong, J., Hsiang, E., He, Z., Zhan, T., & Wu, S. (2021). Augmented reality and virtual reality displays: emerging technologies and future perspectives. *Light, Science & Applications, 10*.

Physics Engines Airsim and Gozebo

27. N. Koenig and A. Howard. Design and Use Paradigms for Gazebo, An Open-Source Multi-Robot Simulator. In IEEE/RSJ International Conference on Intelligent Robots and Systems, pages 2149–2154, Sendai, Japan, Sep 2004

28. S. Shah, D. Dey, C. Lovett, and A. Kapoor. AirSim: High-Fidelity Visual and Physical Simulation for Autonomous Vehicles. In Field and Service Robotics, 2017.

Self-Assembly

29. Saldaña, David & Gabrich, Bruno & Li, Guanrui & Yim, Mark & Kumar, Vijay. (2018). ModQuad: The Flying Modular Structure that Self-Assembles in Midair. In 2018 IEEE International Conference on Robotics and Automation (ICRA). IEEE Press, 691–698. 10.1109/ICRA.2018.8461014.

30. D. Saldaña, P. M. Gupta and V. Kumar (2019). Design and Control of Aerial Modules for Inflight Self-Disassembly. In *IEEE Robotics and Automation Letters*, vol. 4, no. 4, pp. 3410-3417, Oct. 2019, doi: 10.1109/LRA.2019.2926680.

Immersive Human Computer Interaction System

31. Serrano, R., Morillo, P., Casas, S., & Cruz-Neira, C. (2022). An empirical evaluation of two natural hand interaction systems in augmented reality. *Multimedia Tools and Applications*.

Dig Deeper:

- Lu, G., Shark, L., Hall, G., & Zeshan, U. (2011). Immersive manipulation of virtual objects through glove-based hand gesture interaction. *Virtual Reality, 16*, 243-252.
- Tijana Vuletic, Alex Duffy, Laura Hay, Chris McTeague, Gerard Campbell, Madeleine Grealy, Systematic literature review of hand gestures used in human computer interaction interfaces, International Journal of Human-Computer Studies, Volume 129, 2019, Pages 74-94, ISSN 1071-5819, https://doi.org/10.1016/j.ijhcs.2019.03.011.

Data Physicalization

32. S. Sandra Bae, Clement Zheng, Mary Etta West, Ellen Yi-Luen Do, Samuel Huron, and Danielle Albers Szafir. 2022. Making Data Tangible: A Cross-disciplinary Design Space for Data Physicalization. In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22). Article 81, 1–18. https://doi.org/10.1145/3491102.3501939

33. Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and Challenges for Data Physicalization. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). 3227–3236. https://doi.org/10.1145/2702123.2702180

Swarms
34. Craig W. Reynolds. 1987. Flocks, herds and schools: A distributed behavioral model. In Proceedings of the 14th annual conference on Computer graphics and interactive techniques (SIGGRAPH '87). ACM 25–34. https://doi.org/10.1145/37401.37406

35. S. -J. Chung, A. A. Paranjape, P. Dames, S. Shen and V. Kumar, "A Survey on Aerial Swarm Robotics," in *IEEE Transactions on Robotics*, vol. 34, no. 4, pp. 837-855, Aug. 2018, doi: 10.1109/TRO.2018.2857475.

Roboxels & Bit-Drones
36. William A. McNeely. 1993. Robotic graphics: a new approach to force feedback for virtual reality. In Proceedings of IEEE Virtual Reality Annual International Symposium. 336–341. https://doi.org/10.1109/VRAIS.1993.380761

37. Antonio Gomes, Calvin Rubens, Sean Braley, and Roel Vertegaal. 2016. BitDrones: Towards Using 3D Nanocopter Displays as Interactive Self-Levitating Programmable Matter. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (*CHI '16*). Association for Computing Machinery, New York, NY, USA, 770–780. DOI:https://doi.org/10.1145/2858036.2858519 Presentation: https://www.youtube.com/watch?v=OBHmqsay7CA

38. Mario Lorenz, Sebastian Knopp, Philipp Klimant, Johannes Quellmalz, and Holger Schlegel. 2020. Concept for a Virtual Reality Robot Ground Simulator. In 2020 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct). 36–38. https://doi.org/10.1109/ISMAR-Adjunct51615.2020.00024

Dig Deeper:
- Ryo Suzuki, Clement Zheng, Yasuaki Kakehi, Tom Yeh, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2019. ShapeBots: Shape-changing Swarm Robots. In Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19). 493–505. https://doi.org/10.1145/3332165.3347911
- Sean Braley, Calvin Rubens, Timothy Merritt, and Roel Vertegaal. 2018. GridDrones: A Self-Levitating Physical Voxel Lattice for Interactive 3D Surface Deformations. In Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18). 87–98. https://doi.org/10.1145/3242587.3242658
- Calvin Rubens, Sean Braley, Julie Torpegaard, Nicklas Lind, Roel Vertegaal, and Timothy Merritt. 2020. Flying LEGO Bricks: Observations of Children Constructing and Playing with Programmable Matter. In Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20). 193–205. https://doi.org/10.1145/3374920.3374948

Statement on Academic Conduct and Support Systems

Academic Integrity:
The University of Southern California is a learning community committed to developing successful scholars and researchers dedicated to the pursuit of knowledge and the dissemination of ideas. Academic misconduct, which includes any act of dishonesty in the production or submission of academic work, comprises the integrity of the person who commits the act and can impugn the perceived integrity of the entire university community. It stands in opposition to the university's mission to research, educate, and contribute productively to our community and the world.

All students are expected to submit assignments that represent their own original work, and that have been prepared specifically for the course or section for which they have been submitted. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s).

Other violations of academic integrity include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), collusion, knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university. All incidences of academic misconduct will be reported to the Office of Academic Integrity and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see the student handbook or the Office of Academic Integrity's website, and university policies on Research and Scholarship Misconduct.

Please ask your instructor if you are unsure what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

Course Content Distribution and Synchronous Session Recordings Policies
USC has policies that prohibit recording and distribution of any synchronous and asynchronous course content outside of the learning environment.

Recording a university class without the express permission of the instructor and announcement to the class, or unless conducted pursuant to an Office of Student Accessibility Services (OSAS) accommodation. Recording can inhibit free discussion in the future, and thus infringe on the academic freedom of other students as well as the instructor. (Living our Unifying Values: The USC Student Handbook, page 13).

Distribution or use of notes, recordings, exams, or other intellectual property, based on university classes or lectures without the express permission of the instructor for purposes other than individual or group study. This includes but is not limited to providing materials for distribution by services publishing course materials. This restriction on unauthorized use also applies to all information, which had been distributed to students or in any way had been displayed for use in relationship to the class, whether obtained in class, via email, on the internet, or via any other media. (Living our Unifying Values: The USC Student Handbook, page 13).

Students and Disability Accommodations:
USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each

course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

Support Systems:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

988 Suicide and Crisis Lifeline - 988 for both calls and text messages – 24/7 on call
The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline is comprised of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new, shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL) – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

Office for Equity, Equal Opportunity, and Title IX (EEO-TIX) - (213) 740-5086
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - (213) 740-0776
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.

USC Campus Support and Intervention - (213) 740-0411
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity, Equity and Inclusion - (213) 740-2101
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call
Non-emergency assistance or information.

Office of the Ombuds - (213) 821-9556 (UPC) / (323-442-0382 (HSC)

A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

Occupational Therapy Faculty Practice - (323) 442-2850 or otfp@med.usc.edu
Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.