Interactive Haptic Systems:

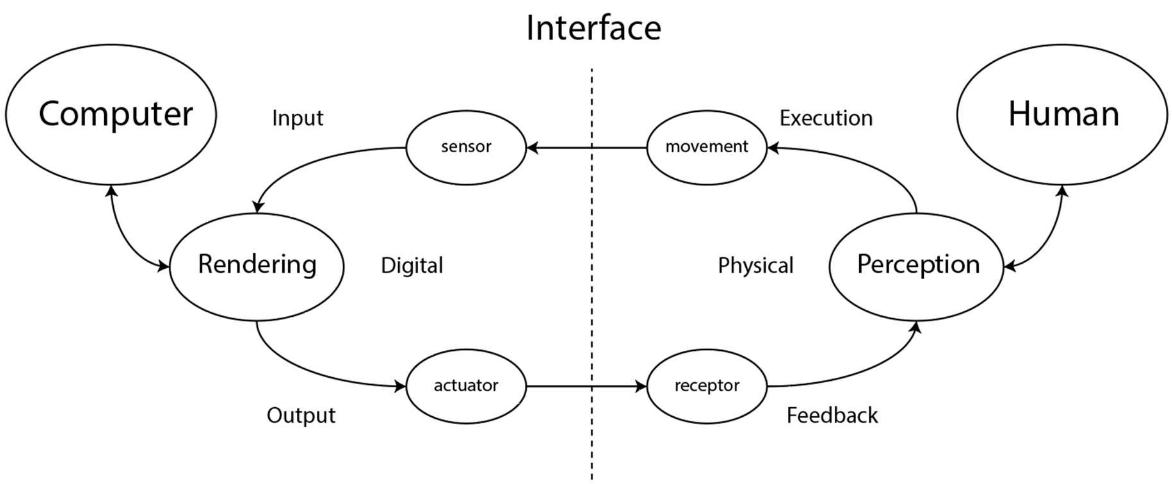
Course Description:

Curious about how humans interact with computers? This course explores system I/O from a human perspective, combining HCI, psychophysics, and haptics. Through hands-on mini-projects and a final project, students will learn about touch perception, user-centered design, and haptic device engineering, culminating in a demo day showcasing their haptic interaction projects. Additional key topics include actuator modeling, haptic rendering, and AR/VR applications.

Time and Location: Tuesday/Thursday in ECEB room 2017

Instructor Information:

Name: Craig Shultz **email:** shultz88@illinois.edu **Office Hours:** TBD



Topical Outline and Overview:

This course offers a deep dive into the world of interactive haptic systems, exploring the biological, psychological, and technological aspects of touch interaction. Students will experience hands-on learning through three mini projects and deliver a final project at the end of the term.

The first quarter of the course will cover topics user-centered design principles, passive and active touch perception, psychophysical methods and evaluation, and physiological underpinnings of haptics. Mini project 1 will have students performing a psychophysical experiment and analyzing the results. Students will be given a set of props (e.g. blocks with different widths) and will test subjects' ability to determine a system haptic parameter (perceived block width) but applying a psychophysical experimental protocol and analysis method in Python.

The second quarter will include engineering and design of haptic systems, including a deep dive on actuator selection and modeling as well as common haptic rendering techniques and modalities. Mini project 2 will have students implement and analyze a haptic vibration actuator using lumped impedance modeling. This system includes a resonance mass, spring, damper actuator, with students being asked to understand and fit the impedance response and acceleration response of the system by applying, recording, and fitting current and voltage measurements.

During the third quarter of the class, we will discuss the greater context interactive systems, and how haptics fits into it. Topics in this phase include rapid prototyping methods, input capture methods, and multimodal output rendering techniques, including visual, audio, and evaluation metrics, covering both quantitative and qualitative methods for assessing device performance and user experience. Low-cost platforms and SDKs for haptics will also be discussed as well as a broad survey of state-of-the-art in haptic devices, categorized by biological systems (cutaneous and kinematic) and form factors such as mid-air, surface haptics, wearables, and grounded devices. Real-world applications in AR/VR, medical fields, and gaming will be discussed, alongside the role of leading haptics companies like Meta, Apple, HaptX, Sony, Intuitive Surgical, and Razer. Mini project 3 will entail students developing and delivering a final project pitch which is motivated by the literature and given in class. They will gain additional presentation and research critique skills in this project, and additional custom hardware will be requested as part of this pitch.

The course concludes with students working on and delivering on their final project, culminating in a "demo day" where they will share their project with the class and give a presentation of their results. The final project includes both a technical system, and a method of rendering information to a user using that system. As an example, students could use 2 haptic actuators applied to the arm and determine how haptic perception changes as the ratio of amplitude of the two actuators is modulated. Students can also choose from a small number of different actuators and configurations. In general, they must implement an embedded haptic system, and measure some psychophysical aspect of our perception of it. In parallel with final project execution will be a series of contemporary topic lectures, reserved for visiting lecturers or reading and discussion of cutting-edge research papers published in HCI and Haptics venues.

Final projects will be documented as a short research style paper, with an annotated bibliography and explanation of results. Students will leave the course with practical skills in haptic system design, a solid understanding of human touch, and the ability to evaluate the effectiveness of haptic devices.

Course Format:

There is no textbook for this course. It will be based on instructor's lecture notes and selected reference texts, a sample of which are given at the end of this syllabus. All content will be made available to the students on the course webpage. Throughout the course, each student will be assigned 2 lecture periods in which they are expected to help lead and facilitate discussion along with the instructor.

The beginning portion of this course will be lectures that cover haptic perception, psychology and physiology, culminating in a project where students will perform a psychophysical experiment on their classmates. Then, we will discuss engineering of haptic systems, with students implementing and modeling a known vibrator-based system using a lumped impedance model.

In the second half of the class, lectures will cover relevant research areas for haptics in HCI, and students will help lead discussions of contemporary research problems in the field. In parallel, students will pitch team projects of an embedded haptic interactive system, which they will build, characterize, and document for their final project.

Prerequisites:

1 of the following: ECE 470 Introduction to Robotics, ECE 403 Audio Engineering, ECE 402 Electronic Music Synthesis, ECE 473 Fundamentals of Engineering Acoustics, CS 418 Interactive Computer Graphics, or permission from the instructor.

Course Justification: This course brings together multiple fields of research, including engineering, psychology, neuroscience, and human-computer interaction. Focused on haptic perception and tactile devices, it dives deeply on the human side of human-computer interaction, giving students valuable tools and methods for building and evaluating interactive embedded systems, which they may not have acquired in their engineering training up to this point. These multi-disciplinary skills are vital for modern engineers and (potential entrepreneurs) who are interested in dynamic environments such as consumer electronics, medical devices, and interactive product design. It will cover the latest techniques and trends in modern HCI, bringing students up to speed in cutting-edge advanced research in the field.

Overlap: Overlaps with existing courses are minimal and complementary. Human-robot interaction is discussed in ECE 598 KDC Human Robot Interaction, but interaction in the context of general computing systems (HCI) is not covered. CS 598WY Tactile Sensing and Haptics focuses on haptics bit, but it is mainly centered around imbuing robots with tactile like qualities, not covering in-depth fundamentals of human haptic perception and core haptic actuation topics. ECE 403 Audio Engineering and ECE 402 Electronic Music Synthesis touch on similar themes of temporal signal rendering and speaker design, but do so from the lens of audio perception, not haptic perception. CS Courses on HCI, such as CS 565 Topics in Human-Computer interaction, focus primarily on existing computing platforms, and high-level application areas in surface, desktop, and mobile computing, but do not focus on the technical aspects of HCI input/output system.

Equipment, Software, Lab: Professor Shultz will assign specific lab days for open office hours in a small lab space in ECEB (room TBD) around Mini Project 2 and the Final Project. The embedded system used in this class is the Teensy 4.0 platform, based on an embedded ARM Cortex M7 MCU. (Teensy® 4.0). This will interface with a custom amplifier module (based on the recently released MAX98389) for Mini Project 2, and with various external peripherals (defined in the student's project pitch) for the Final Project. Students will be supplied with a basic electronics kit as part of this course, and will have access to debugging equipment, such as a high-speed oscilloscope and impedance analyzer (Red Pitaya - Swiss Army Knife For Engineers). The software language of choice will be Python, with special consideration given to NumPy, SciPy, Pyaudio, and PsychoPy libraries.

Grading Percentage Breakdown:

Overall Grade:
Mini Project 1: 20%

Mini Project 2: 20%

Mini Project 3: 20%

Final Project: 30%

Class Participation: 10%

Project Expectations: Mini Project 1 - Psychophysical Experiment

For this group project, you will design, execute, and present a psychophysical experiment. The assignment is broken down into four components:

1. Design of Experiment (40%): Develop a well-structured experiment using a validated protocol. Provide clear written instructions, effectively utilize participant time, and ensure that your method allows for meaningful interpretation of results.
2. Experimental Execution (40%): Conduct the experiment with care to minimize biases, ensure reproducibility, and gather data from 3+ participants. Use sound analysis techniques and incorporate automation where applicable.
3. Report and Presentation (15%): Present your findings clearly and professionally. Include well-formatted results, contextualize your conclusions, and ensure your presentation is well-organized.
4. Peer Assessment (5%): Complete a peer assessment survey to provide feedback on your group's collaboration.

Overall, focus on thorough planning, precise execution, and clear communication to achieve a high-quality project.

Project Expectations: Mini Project 2 - Physical Characterization (Individual)

For this individual project, you will conduct a thorough physical characterization of an actuator and turn in a detailed report covering the following components:

1. Mathematical Modeling (20%): Describe a lumped impedance model used to calculate Thiele/Small (T/S) parameters. Provide a clear description of your modeling process and results.
2. Data Collection (30%): Document your data collection methods, including validation and calibration procedures. Ensure consistency in your measurements and verify the linearity of your data.
3. Data Analysis (30%): Analyze the collected data by generating Bode plots and fitting a parameterized model. Assess how the system responds to different configurations (i.e. loading).
4. Comparison to Standard Method (20%): Perform the same measurements using professional hardware/software and compare the results. Evaluate whether your method captures the same data and discuss the reasons for any discrepancies.

Overall, focus on rigorous modeling, accurate data collection, thorough analysis, and critical comparison to industry standards to produce a comprehensive and insightful report.

Project Expectations: Mini Project 3 - Develop Project Proposal (Individual or Group Project)

For this project, you will develop a detailed project proposal, which can be completed individually or in a group. The project will be evaluated based on the following criteria:

1. Background and Motivation (35%): Clearly articulate the research question and provide thorough background research to justify its relevance. Include a draft of a related works section, surveying the existing literature. Clearly state the project's contribution and the anticipated outcomes.
2. Technical Methods (35%): Specify whether the project focuses on hardware, software, or a combination of both. Describe the psychophysical or evaluation methods that will be used. Detail the technical requirements and how they will be implemented.
3. Report and Presentation (30%): Submit a well-organized written proposal with defined milestones, budget, timeline, and a bill of materials. Ensure that the background and technical methods are clearly presented. Address project risks and outline strategies for mitigating them. The presentation should be compelling, concise, and well-researched.
4. Peer Assessment (5%): Complete a peer assessment survey to provide feedback on group collaboration if working in a team.

Overall, focus on a clear research motivation, well-defined technical methods, and a comprehensive proposal to demonstrate the feasibility and impact of your project.

Project Expectations: Final Project (Group Project)

For the final group project, you will deliver a comprehensive research project, including a report, presentation, and live demonstration. The project will be assessed on the following components:

1. Milestone Report (15%): Submit a written update detailing the current state of the project, along with 2-3 presentation slides. This in-class update should seek constructive feedback from classmates and the instructor.
2. Final Report (20%): Write a formal 2-3 page research paper that includes an introduction, background, methods, results, discussion, and references. Ensure the report is clear, concise, and follows ACM standards (a template will be provided).

3. Presentation (20%): Deliver an 8-10 minute presentation formatted like a research conference talk. It should cover the introduction/background, methods, data and results, discussion, and conclusion. Focus on clarity and engagement.
4. Working Demo (40%): Conduct a 5-10 minute interactive demonstration of your project. The demo should convincingly show that your interface works as intended. Allow classmates to experience it firsthand and guide them through the purpose, context, and conclusions of your project. Make the demonstration compelling and immersive.
5. Peer Assessment (5%): Complete a peer assessment survey to provide feedback on your group's collaboration.

Overall, aim to deliver a thorough and polished project that includes well-documented research, an effective presentation, and an engaging live demonstration that clearly communicates the value of your work.

Class Participation Expectations (Individual)

Your participation in class is a key part of this course. The breakdown and expectations are as follows:

1. **General Attendance and Participation (20%)**:
    - Attend all lectures unless you have a valid excuse.
    - Engage actively during class through contributions to discussions, asking questions, and providing insights.
    - A mid-course review of participation will provide feedback on whether your engagement is on track.
2. **Lecture Discussion 1 (40%)**:
    - Thoroughly read the assigned materials before the discussion.
    - Prepare insightful questions to prompt engagement from your classmates.
    - Develop any visual aids or supplementary materials (slides, diagrams, handouts) to enhance the discussion and stimulate deeper conversation.
3. **Lecture Discussion 2 (40%)**:
    - Repeat the same approach as in Lecture Discussion 1: come prepared with questions and visuals to facilitate a meaningful discussion.
    - Focus on encouraging your peers to engage critically with the content, fostering a collaborative learning environment.

Draft Weekly Schedule:

Week	Session 1	Session 2	Projects Assigned and Due
0	[1] - 1/21 Syllabus, Introduction To Interaction, Man/Machine Model [Lecture]	[2] - 1/23 Action Cycle, Affordances, Signifiers, Mapping, Feedback [Reading/Discussion]	
1	[3] 1/28 Action Cycle, Touch Procedure, Active Touch, Haptic Box [Lecture]	[4] 1/30 Psychophysical Theory [Lecture]	
2	[5] 2/4 Psychophysical Methods [Reading/Discussion]	[6] 2/6 Mechanoreceptors and Anatomy [Lecture]	2/6 MP 1 Assigned
3	[7] 2/11 Illusions, Touch Perception [Lecture]	[8] 2/13 Haptic Devices Overview [Lecture]	
4	[9] 2/18 Presentation of Mini Project 1	[10] 2/20 Actuators - Types and Models [Lecture]	2/18 MP1 Presented
5	[11] 2/25 Vibrator Deep Dive [Lecture]	[12] 2/27 Mini Project 2 Assignment. Tutorial on Data Capture	2/25 MP1 Write-up Due 2/27 MP 2 Assigned
6	[13] 3/4 Haptic Rendering Techniques [Lecture]	[14] 3/6 Haptic Rendering Review [Reading/Discussion]	
7	[15] 3/11 Advanced Haptics Topics [Lecture]	[16] 3/13 Haptic SDKs and Platforms [Lecture] Mini Project 3 Assignment	3/13 MP 2 Write-up Due 3/13 MP 3 Assigned
SPRING BREAK			
8	[17] 3/25 Human-Centered Design [Reading/Discussion]	[18] 3/27 Intro and history of HCI [Lecture]	
9	[19] 4/1 Input - Types and Models [Lecture]	[20] 4/3 Final Project Pitches [Lecture]	4/3 MP 3 Pitches Due 4/3 Final Project Starts

10	**[21] 4/8 Multimodal Input/Output**	**[22] 4/10 HCI Evaluation [Reading/Discussion]**	
11	**[23] 4/15 Contemporary Topics – Surface Computing [Reading/Discussion]**	**[24] 4/17 Contemporary Topics – Tele-operation and Robotics [Reading/Discussion]**	
12	**[25] 4/22 Contemporary Topics – AR/VR Haptics [Reading/Discussion]**	**[26] 4/24 Contemporary Topics TBD**	
13	**[27] 4/29 Contemporary Topics TBD**	**[28] 5/1 Contemporary Topics TBD**	
14	**[29] 5/6 Demo Day!**	**[30] Final Project Presentations TBD**	**5/6 Final Project Demo TBD Final Project Write-up due**

Suggested Reading(s):

[1] L. A. Jones and H. Z. Tan, "Application of Psychophysical Techniques to Haptic Research," *IEEE Trans. Haptics*, vol. 6, no. 3, pp. 268–284, Jul. 2013, doi: 10.1109/TOH.2012.74.

[2] K. Pfeuffer, H. Gellersen, and M. Gonzalez-Franco, "Design Principles and Challenges for Gaze + Pinch Interaction in XR," *IEEE Computer Graphics and Applications*, vol. 44, no. 3, pp. 74–81, May 2024, doi: 10.1109/MCG.2024.3382961.

[3] C. Shultz and V. Shen, "Designing for haptics," *XRDS*, vol. 29, no. 1, pp. 39–43, Sep. 2022, doi: 10.1145/3558193.

[4] V. Hayward and K. E. Maclean, "Do it yourself haptics: part I," *IEEE Robotics & Automation Magazine*, vol. 14, no. 4, pp. 88–104, Dec. 2007, doi: 10.1109/M-RA.2007.907921.

[5] K. E. Maclean and V. Hayward, "Do It Yourself Haptics: Part II [Tutorial]," *IEEE Robotics & Automation Magazine*, vol. 15, no. 1, pp. 104–119, Mar. 2008, doi: 10.1109/M-RA.2007.914919.

[6] S. J. Bolanowski Jr., G. A. Gescheider, R. T. Verrillo, and C. M. Checkosky, "Four channels mediate the mechanical aspects of touch," *The Journal of the Acoustical Society of America*, vol. 84, no. 5, pp. 1680–1694, Nov. 1988, doi: 10.1121/1.397184.

[7] S. J. Lederman and R. L. Klatzky, "Hand movements: A window into haptic object recognition," *Cognitive Psychology*, vol. 19, no. 3, pp. 342–368, Jul. 1987, doi: 10.1016/0010-0285(87)90008-9.

[8] O. Schneider, K. MacLean, C. Swindells, and K. Booth, "Haptic experience design: What hapticians do and where they need help," *International Journal of Human-Computer Studies*, vol. 107, pp. 5–21, Nov. 2017, doi: 10.1016/j.ijhcs.2017.04.004.

[9] M. Ziat, "Haptics for Human-Computer Interaction: From the Skin to the Brain," *Found. Trends Hum.-Comput. Interact.*, vol. 17, no. 1–2, pp. 1–194, Mar. 2023, doi: 10.1561/1100000061.

[10] H. Tan, S. Choi, F. Lau, and F. Abnousi, "Methodology for Maximizing Information Transmission of Haptic Devices: A Survey," *Proceedings of the IEEE*, vol. 108, pp. 945–965, Jun. 2020, doi: 10.1109/JPROC.2020.2992561.

[11] S. G. Hart, "NASA Task Load Index (TLX)." Jan. 01, 1986. Accessed: Sep. 05, 2024. [Online]. Available: https://ntrs.nasa.gov/citations/20000021488

[12] B. P. Delhaye, K. H. Long, and S. J. Bensmaia, "Neural Basis of Touch and Proprioception in Primate Cortex," in *Comprehensive Physiology*, John Wiley & Sons, Ltd, 2018, pp. 1575–1602. doi: 10.1002/cphy.c170033.

[13] J. J. Gibson, "Observations on active touch," *Psychological Review*, vol. 69, no. 6, pp. 477–491, 1962, doi: 10.1037/h0046962.

[14] T.-H. Yang, J. R. Kim, H. Jin, H. Gil, J.-H. Koo, and H. J. Kim, "Recent Advances and Opportunities of Active Materials for Haptic Technologies in Virtual and Augmented Reality," *Advanced Functional Materials*, vol. 31, no. 39, p. 2008831, 2021, doi: 10.1002/adfm.202008831.

[15] S. J. Bensmaia and J. J. DiCarlo, “Steven Hsiao: In Memoriam,” *Neuron*, vol. 85, no. 3, pp. 458–461, Feb. 2015, doi: 10.1016/j.neuron.2015.01.015.

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[17] E. R. Kandel, J. D. Koester, S. H. Mack, and S. A. Siegelbaum, “Touch,” in *Principles of Neural Science*, 6th ed., New York, NY: McGraw Hill, 2021. Accessed: Aug. 19, 2024. [Online]. Available: neurology.mhmedical.com/content.aspx?aid=1180641576