Cross-Sensory Futures: Rewiring Perception in HCI

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Abstract

Including a wide range of sensory modalities at the user interface has always been a key objective and a challenge of human-computer interaction. Over the years, this challenge has been examined through a range of lenses with unique underlying theoretical grounding and contributions; captured through notions such as media spaces, multimodal interaction and multisensory experiences, and addressed from different perspectives across physiology, psychology and technology. In this workshop, we will bring together researchers and practitioners to explore the potential of "cross-sensory interaction" as a delineated subject of study that builds on and expands our understanding of how sensory modalities can be leveraged in HCI research and practice. We will focus on the unique theoretical, design and engineering opportunities that "cross-sensory interaction" may offer as a sensitizing construct grounded in crossmodal cognition and neuroplasticity, and formulate a roadmap synthesising common challenges and open research questions to help enrich the space of sensory research in HCI.

CCS Concepts

• **Human-centered computing** → *HCI theory, concepts and models.*

Keywords

Cross-sensory Interaction, Crossmodal Cognition, Multisensory Experiences, Multimodal Interfaces

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1 Motivation

Research that explores the integration of a wider range of sensory modalities has a long-standing history in Human-Computer Interaction. However, the past few years have seen the emergence of new ideas for sensory interaction in HCI, with a particular focus on leveraging the potential of altering the perception and cognition across sensory signals and the impact that this may have on the design of interactive experiences. For example, Brooks *et al.* used an olfactory display to create thermal illusions in a VR interface [6]; Lin *et al.* demonstrated non-arbitrary correspondences between the tactile experience of tangible 3D printed objects and colour display [17]; and Degraen *et al.* enhanced the tactile experience of textured materials in VR using visual and haptic feedback [8]. These examples are grounded in the study of crossmodal cognition; the phenomenon where the signals we receive through one sense alter how we perceive and interpret signals received through another sense [34]. Such understanding stems from advances in cognitive neuroscience, specifically new understandings of neuroplasticity and sensory substitution that leverage the capacity of the brain to replace the functions of a given sense with another sensory modality [1].

We refer to this emerging trend in HCI research with the phrase *"Cross-sensory Interaction"*. In this workshop, we seek to explore the potential merit of "cross-sensory interaction" as a unique sensitizing concept within HCI research and practice; we ask whether and how "cross-sensory interaction" should be delineated as a subject of investigation, e.g. separate from and expanding on notions such "multimodal interfaces" and "multisensory experiences"; and seek to collectively discuss what added value such a delineation could bring to the study of sensory interaction in HCI.

1.1 Historical Overview of Sensory Research in HCI

Since its inception, HCI has always been interested in designing more intuitive, natural and rich interaction possibilities for people to engage with and through machines. This ambition could be traced all the way back to innovations such as Ivan Sutherland's Sketch Pad, which sought to expand on the then standard command-based interaction to include drawing, and pen-based gestures as additional interaction modalities, making it possible for a *"[user] and a computer to converse rapidly through the medium of line drawing"* [37]. The pushing for additional modalities of interaction was also emphasised in technological innovations such as the "Put-that-there" interaction technique by Richard A. Bolt, in which *"connected-speech recognition and position sensing in space have encouraged the notion that voice and gesture inputs at the graphics interface can converge to provide a concerted, natural user modality"* [5]. Bolt's system is regarded as a ground-breaking demonstration that highlighted the value of multimodal interfaces. A number of systems followed suite, expanding the traditional desktop experience and paving the way for the notion of "multimodal interaction", and with it a range of theoretical and technical contributions that expanded the space of interaction possibilities, permitting the flexible use of input and output modes, and the focus on the notion of "disambiguation" of their signals, to allow for greater precision and adaptations of "post-WIMP" interfaces. These developments have also led to the establishment of specialised conferences, such as the ACM ICMI in 1996, later merging with the workshop on Machine Learning and Multimodal Interaction (MLMI), and specialised journals, such as the Transactions on Interactive Intelligent Systems, in 2011 that includes multimodal interaction as one of its core areas of focus.

Multimodal interfaces sought to identify and leverage naturally occurring forms of human communication through language and behaviour and employed a range of recognition-based technologies to do so [27]. However, one possible challenge with the notion of multimodal interaction, is that it ultimately found its way into a wide range of domains and fields of research, from HCI [e.g. 3, 28], and learning sciences [e.g. 31], to machine learning [e.g. 2] and linguistics [e.g. 4]. While this testifies to the importance of the "multimodal" concept, it might make it increasingly difficult to understand the specific advantages of this notion within sensory research in HCI. For example, modalities of interaction span a range of interaction possibilities and do not necessarily map specifically to sensory modalities of interaction. This is perhaps why HCI has seen a gradual shift towards notions such of "multisensory experiences" [26], "multisensory enhancement" [22], and "mulsemedia" (multiple sensorial media) [14], which developed in parallel with the proliferation of sensory technologies that do not only stimulate the sense of vision, hearing, and touch but also the so-called "chemical senses" of smell, and taste. Multisensory research then brought with it greater challenges of sensory integration, especially for taste and smell, as they are subjective and neurologically interrelated [26]. Valesco and Obrist suggested that multisensory experiences could be understood in terms of a reality-virtuality continuum [42]. For example, in a physical setting, Trotta *et al.* used analogue multisensory stimulation to enable people to feel, hear, smell, and taste dark matter inside an inflatable dome [40]. In a mixed reality setting, Tennent *et al.* augmented a physical swing through a visual-kinaesthetic experience, to create a hybrid experience that exaggerates players' sense of movement through visual feedback [39]. In a fully virtual example, Wilbertz *et al.* developed FaceHaptic in which moveable haptic feedback is used to convey thermal and fluid display to increase realism with VR experiences [43]. Research on multisensory experiences has also led to the emergence of new research communities, such as the Human-Food Interaction as active areas of inquiry (see [25]). The above examples highlight the shift towards more tightly coupled integration of sensory modalities, which also raised a range of theoretical and implementation challenges [42] (e.g. sensory overload [21], multisensory integration [36], sensory dominance [12], and crossmodal correspondences [32]) that have long been studied in psychology and crossmodal cognitive science, but were yet to feature explicitly within HCI research and practice.

1.2 The Emergence of "Cross-sensory Interaction" in HCI

Built on well-developed theoretical accounts in psychology and cognitive science [e.g., 32, 33, 41], more recently (likely from 2016), we saw the emergence of the study of crossmodal cognition in HCI [e.g., 13, 15, 23], with collective efforts on verifying and adapting perceptual theories through a series of user studies in interactive scenarios — a step further towards applied research and design practice. This entrance into HCI has focused on the study of correspondences and how these could be leveraged in the design of technology that integrates multiple sensory modalities. For example, Metatla et al. [23] explored the effect of crossmodal congruence on interactive engagement via a multisensory memory game. Results showed that congruent visual-audio feedback increased the perceived engagement of the game, while leveraging the incongruent design has the potential to improve challenge and entertainment. Finnegan *et al.* [13] showed that incongruent audio-visual displays improve distance perception in virtual environments. Fletcher-Hamilton *et al.* explored the experience of blind and visually-impaired users of sensory substitution devices and their potential for cross-sensory augmentation [15]. Metatla *et al.* identified crossmodal effects between tangible and olfactory stimuli and their relationship to emotional activation in children [24], which they then used to design more inclusive crossmodal storytelling tools for disabled and non-disabled children [7]. Cross-sensory research in HCI also moved towards the study of deformable interfaces. For example, Feng *et al.* employed the study of crossmodal correspondences to investigate links between affective reactions and tactile experiences in shape-change, particularly in the absence of visual information [10]; Fan & Coutrix [9] investigated how softness impacts users' perception of curvature [9]; Brooks *et al.* demonstrated how thermal illusions in VR can be elicited through olfactory stimulation [6], and Lu *et al* introduced the notion of chemical haptics, proposing a new class of haptic devices that provide haptic sensations by delivering liquid-stimulants to the user's skin [18]. Most recently, Steer *et al.* [35] investigated deformable shapes's crossmodal correspondences with colours and emotions; Palmer *et al.* [29] identified mappings across auditory, visual, and tactile modalities, exploring how a shape's form and visibility influence associations with pitch and brightness, and highlighting the role of stiffness in these correspondences; Roberts-Morgan *et al.* [30] examined cross-sensory metaphors, where qualities from one sensory modality are described through another (e.g., "a sharp smell"), across different age groups, exploring how age influences the creation of such metaphors; Teng *et al.* [38] designed a novel sensory substitution device, which uses a electrotactile-display, which are on the back of the users hand, that creates tactile images from a wrist-mounted camera, allowing a user to feel objects while reaching and hovering around them.

This emerging body work demonstrates a clear focus on leveraging crossmodal cognition and brain neuroplasticity to investigate novel forms of sensory experiences in HCI. It shows a convergence in research methodology and commonality in technical engineering and design challenges. In particular, cross-sensory research requires high levels of sensory display control, grounded in theoretical accounts of perception and cognition. In spite of those efforts, however, the challenge remains: how should we leverage crossmodal cognition and neuroplasticity in HCI? Adding more sensory modalities at the interface, while it can increase naturalness, engagement, richness, etc., must be done carefully because there are underlying effects across sensory modalities that may impact design objectives. We proposed that this brings a potentially unique and exciting new direction for sensory research in HCI.

1.3 Workshop Objectives: Towards "Cross-sensory Interaction"?

In this workshop, we aim to explore the notion of cross-sensory interaction and its delineation as a sensitizing theoretical construct in HCI research that explores how sensory elements of interaction shape interactive experiences.

Incorporating sensory modalities in interactive experiences is increasingly enabled through technological advances [11, 19, 20]. Yet, the potential impact of sensory percepts on one another, and therefore on the overall experience they support, is not always considered in the design, engineering and evaluation of interactive technology. In this workshop, we will bring together researchers and practitioners from across the CHI community to create opportunities for open discussion, sharing knowledge and experiences around the notion of cross-sensory interaction and its place in HCI research. This includes: collectively establishing whether and how the notion of cross-sensory interaction could be a useful construct to organise and coordinate research endeavours in our field; constructing an initial outline of the space of cross-sensory HCI research, exploring its potential theoretical groundings and technical realisation challenges. To achieve this, we aim to pull together expertise from computer science, human cognition, design and fabrication to generate open discussion in a workshop with lightning talks, demo presentations, break-out activities and group discussions. Participants in this workshop will engage in these activities to help define a roadmap for future research. Specifically, this workshop will address the following key topics:

- Discuss and clarify the notions of multimodal, multisensory and cross-sensory interaction. Identifying their research focus, methods, and research communities associated with these notions and the usefulness of their delineation in research paradigms and design practice.
- Identify the nuances between multisensory and cross-sensory perception based on recent advances in the field of psychology and empirical works from HCI research and practice.
- Establish the notion of cross-sensory interaction and discuss the significance of this notion for the HCI community, i.e., is it necessary? if so, why? If not, why not? how can this notion help us advance our understandings of human perception, and interactive possibilities enabled through a wider range of sensory modalities.
- Explore the translational role of this notion: from lab research in cognitive psychology to applied research in HCI, and to theory-based interaction design and engineering efforts.
- Identify existing paradigms of cross-sensory research in HCI, and propose a roadmap for future research that integrates scientific knowledge of cross-sensory perception and cognition, design theory, tools, and contextual factors.

2 Length of the Workshop and Expected Size of Attendance

This will be a **long workshop**, consisting of two 90-minute sessions with a break in between. We aim to create an interactive and provocative space where participants explore how cross-sensory interaction can "rewire perception" in HCI through debates, creative labs, and collaborative roadmapping. We anticipate **around 25–35 participants**, supported by a diverse team of organisers with expertise across HCI, psychology, design, and fabrication. This size allows us to run parallel small-group activities (e.g., debates, breakout labs, and gallery walks) while still maintaining cohesion in plenary discussions. The organising team has substantial experience facilitating CHI workshops and interactive formats, ensuring participants are guided effectively through the fast-paced and experimental nature of the sessions.

3 Organisers

The workshop has a broad international group of organisers, including established and early-career researchers and students across academia and industry; with expertise in HCI, Psychology, Design and Fabrication.

Oussama Metatla is an Associate Professor (Reader) of Human-Computer Interaction at the University of Bristol. He is Co-Director of the Bristol Interaction Group and leads the Diverse-Ability Interaction Lab, where he and his team investigate how to move beyond traditional conceptions of assistive technology to design, engineer and evaluate technologies that can support inclusive interactions between disabled and non-disabled people across a range of groups, domains, and contexts. He was previously an EPSRC Research Fellow (2016-2021) pushing the agenda of inclusive cross-sensory education technologies for blind and visually impaired children in mainstream schools, and he has recently been awarded an ERC Fellowship (2023-2028) to consolidate his research agenda on diverse-ability interaction, focusing on investigating how cross-sensory perception and embodied cognition could radically change the landscape of inclusive interaction design.

Min S. Li is a Senior Research Fellow at the University of Bristol. Her research interest is the computational understanding of how brains process the spatio-temporal properties of multisensory stimuli. Her PhD in experimental psychology focused on the integration and segregation of audio-visual stimuli, and later she worked with older adults to investigate how vision's used to compensate for age-related deteriorating sense of touch. More recently she helped develop the Augmented-Reality-Musical-Ensemble system where musicians can make ensemble practices with virtual partners in a headset, before she joined the Dive lab to work on cross-sensory interaction between visually-impaired and sighted young children.

Feng Feng is a Postdoctoral Researcher at Aarhus University and a visiting researcher at the University of Bristol. She has a background in both Cognitive Science and Industrial Design. Her research draws upon theories of enactivism, multi-sensory and cross-sensory perception, and constructive design research. Her work translates theories from these areas into application research in HCI, for example, constructing frameworks to scaffold affective and multi-sensory interaction design. More recently, her works has introduced cross-cultural perspectives to broaden understandings of sensory perception and affective experience in HCI.

Cameron Steer is a Lecturer at the University of West England (UWE). His research focuses on the development of deformable and shape-changing interfaces that add a physical layer to our digital worlds. This work centres around developing novel prototypes and design principles for multisensory tangible interactions. He's also a doctoral supervisor in UWE's Computer Science Research Centre (CSRC), where this research is being explored through creative application domains.

Michael J. Proulx is a Research Scientist at Reality Labs Research (Meta). He is also Professor in Cognition and Technology at the University of Bath where he is Director of the Crossmodal Cognition Lab in the Department of Psychology. He is also co-founder and Co-Director of the REVEAL (REal * Virtual Environments Augmentation Labs) Research Centre, Co-Investigator for CAMERA 2.0 (the UKRI Centre for the Analysis of Motion, Entertainment Research and Applications), and a doctoral supervisor in the Centre for Digital Entertainment and ART-AI (Accessible, Responsible, and Transparent Artificial Intelligence) in the Department of Computer Science. He is a Fellow of the Society for Experimental Psychology and Cognitive Science of the American Psychological Association, and Fellow of the Royal Institute of Navigation.

Meike Scheller is an Assistant Professor in the Department of Psychology at Durham University researching how humans learn to use novel sensory information in everyday life. She has a background in Systems Biology and Cognitive Neuroscience. Her PhD focused on the effects of developmental cross-modal plasticity on multisensory integration in sighted and visually impaired individuals. At Durham University she studies the plasticity of information processing to sensory experience and higher-level concepts, such as the self. She is interested in how the (developing) human brain learns to abstract and use natural statistics of the environment in order to transform sensory information into perceptual representations and to, ultimately, guide adaptive behaviour.

Tegan Roberts-Morgan is a PhD candidate working on cross-sensory correspondences in early childhood, exploring how young children connect sensory experiences such as touch, smell, and emotion, with a focus on the role of cross-sensory metaphors. She is currently involved in the inclusiveXplay project, which explores cross-sensory social play for the early development of blind and sighted preschoolers. The project aims to change the way we design assistive technologies for blind and visually impaired children by integrating notions of cross-sensory experiences with social engagement and sighted peers.

4 Workshop Plans

4.1 Pre-workshop: website, recruitment & community

We will build a website that hosts information, including call for participation, workshop's organizers, news and announcements, and paper submission instructions, which will be hosted on the Diverse-ability Interaction Lab[1] and Bristol Interaction Group server [2]. We will recruit participants by sharing the link to the workshop website on relevant mailing lists and social media outlets (e.g. CHI-ANNOUNCEMENTS, Mastodon, Bluesky and Linkedin.) We will ask interested participants to submit either a statement of interest (1-2 pages) or a position paper (2-8 pages). We will ask submissions to address the key topics stated above. Organiser will review and select 10-15 submissions. Prior to the workshop, we will ask authors of accepted submissions to contribute to a Miro board or a Padlet where we collect and map out interests, initial ideas and talking points that will form the basis for the cross-sensory interaction activities road-map discussion at the workshop. We will circulate this road-map summary to all attendees one week before CHI.

4.2 Workshop Activities & Structure

The workshop will run across two 90-minute sessions. Activities are designed to be highly interactive and provocative, combining short provocations, structured debates, creative group work, and collaborative roadmapping. Table 1 provides the schedule.

Introduction and framing: Organisers will open with a short overview of the workshop's motivation, aims, and provocations, and introduce the collaborative tools that will be used throughout.

Lightning rounds: Participants will give rapid-fire ignite talks (2–3 minutes each) to introduce their position papers and provocations. At least one slot will be allocated to a live demo-led provocation.

Structured debate: Participants split into two groups to debate contrasting perspectives (e.g., "cross-sensory interaction as a distinct paradigm" versus "an extension of multisensory interaction"). Arguments will be documented through maps, sketches, or diagrams to capture tensions and synergies.

Creative breakout labs: Participants work in small groups through different lenses — theoretical, design, and ethics/inclusion — to produce tangible artefacts (storyboards, mappings, sketches) envisioning future directions.

Gallery walk & synthesis: Groups present back their artefacts in a fast-paced round. Facilitators synthesise outcomes into a shared roadmap of challenges and opportunities.

Closing discussion: The workshop will conclude with a collective roadmap consolidation and discussion of follow-up actions (e.g., collaborative publications, Dagstuhl seminar, or a future CHI

[1]https://dive.ousmet.com
[2]https://biglab.co.uk

Table 1: Workshop Schedule: Two 90-minute sessions focusing on provocation, debate, and co-creation.

Time (minutes)	Activity
Session 1: Framing & Provocation (90 min)	
0:00 – 0:10	Welcome and framing: introduction to goals, provocations, and structure.
0:10 – 0:40	Provocative lightning rounds: short ignite talks and a demo-led provocation.
0:40 – 1:20	Structured debate: groups argue contrasting positions on cross-sensory interaction; argument maps and sketches produced.
1:20 – 1:30	Wrap-up: visual capture of key provocations and transition to Session 2.
Session 2: Co-Creation & Roadmapping (90 min)	
0:00 – 0:45	Creative breakout labs: groups explore theoretical, design, and ethics/inclusion lenses, producing visual artefacts.
0:45 – 1:10	Gallery walk & synthesis: groups present artefacts in a fast-paced round; facilitators synthesise into a roadmap.
1:10 – 1:30	Closing and next steps: collective discussion, community building, and roadmap consolidation.

submission). The session ends with an open provocation to carry forward into the CHI community.

4.3 Post-workshop Plans

We are aiming for five main actions as post-workshop follow-up plans: (1) We will publish participants' statements of interests and position papers on the workshop webpage and submit them to the Free Open-Access Proceedings for Computer Science Workshops [3]; (2) We will invite the wider CHI community to join the workshop Slack group to enable continuous and broader conversion on the workshop outcomes; (3) We will capture the discussions and ideas generated through the workshop and submit them as an article to the ACM Interactions Magazine [4]; (4) We will use the momentum of the workshop and the above follow-up actions to invite interested participants to a Dagstuhl Seminar[5] to continue and deepen the conversation around the notion of cross-sensory interaction. The ultimate aim is to produce a joint paper (potentially a future CHI submission) that synthesises ideas, formulate open research questions and outline challenges across the diverse fields engaged in cross-sensory interaction research; (5) Finally, we will aim to repeat this workshop as a series in order to track changes in and evaluate the landscape of HCI and Cross-sensory Interaction research.

4.4 Accessibility

To maximise the accessibility of the workshop, we will ask participants to confidentially express any specific access needs prior to the workshop, and then work with the conference workshop chairs and student volunteers to ensure that these needs are met. We will ensure that there are opportunities for breaks throughout for those who need them, provide live captioning via native services in tools such as Microsoft Teams [16]. The online tools (Miro and Padlet) will allow for multiple forms of contributions to the workshop discussions both before and during the workshop [44]. To maximise access to visually-impaired and blind participants, we will encourage participants to announce their names upon speaking, and actively ensure that any images used or visual artefacts are described fully. We will also ensure that dietary requirements are noted and accommodated as appropriate.

[3]https://ceur-ws.org
[4]https://interactions.acm.org
[5]https://www.dagstuhl.de/en/seminars/dagstuhl-seminars

5 Call for Participation

"The integration of multiple sensory modalities at the user interface has been a longstanding objective in HCI. This approach opens up exciting possibilities for designing more immersive, natural, and engaging interactive experiences. However, we do not fully understand how to accurately map each sensory modalities for cross-sensory interaction and therefore it may affect design objectives. This workshop will bring together cross disciplinary researchers to discuss the theoretical grounds of cross-sensory interaction in HCI and explore the potential approaches of research methodologies, design and implementation. Potential participants should submit 1-2 pages of statement of interest or 2 to 8 pages of position papers (in ACM CHI Publication Formats), that addresses at least one of the key topic(s) of the workshop. The submissions should also include a statement on the potential goals of the research and the problem(s) it aims to address. For more information, visit (website TBD) or contact (email TBD)."

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