Mass-Computer Interaction for Thousands of Users and Beyond

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Abstract
We introduce Mass-Computer Interaction (MCI) as a natural evolution of Crowd-Computer Interaction (CCI) fostered by recent technical innovations and advances in large-scale sensing, processing, and interactive systems. MCI represents a sensible combination of (1) a very large number of end-users, usually in the order of hundreds or thousands, (2) very large physical settings, such as theaters and auditoriums, and (3) large-scale infrastructure, including distributed systems. We outline design challenges posed by the new Mass-Computer Interaction paradigm, elaborate on its defining characteristics, and provide a general-purpose model for MCI applications. These contributions are exemplified with SKEMMI, our general-purpose platform specifically designed for developing and deploying Mass-Computer Interaction applications.

Author Keywords
Audience-Computer Interaction, Crowd-Computer Interaction, Crowd computing, Large-scale systems.

ACM Classification Keywords
H.5. Information Interfaces and Presentation.

Introduction
Looking at the evolution of the number of computers, platforms, and devices per user, four main computing eras are commonly distinguished as having significant impact on Human-Computer Interaction (Figure 1). The "mainframe" era that concentrated one single time-

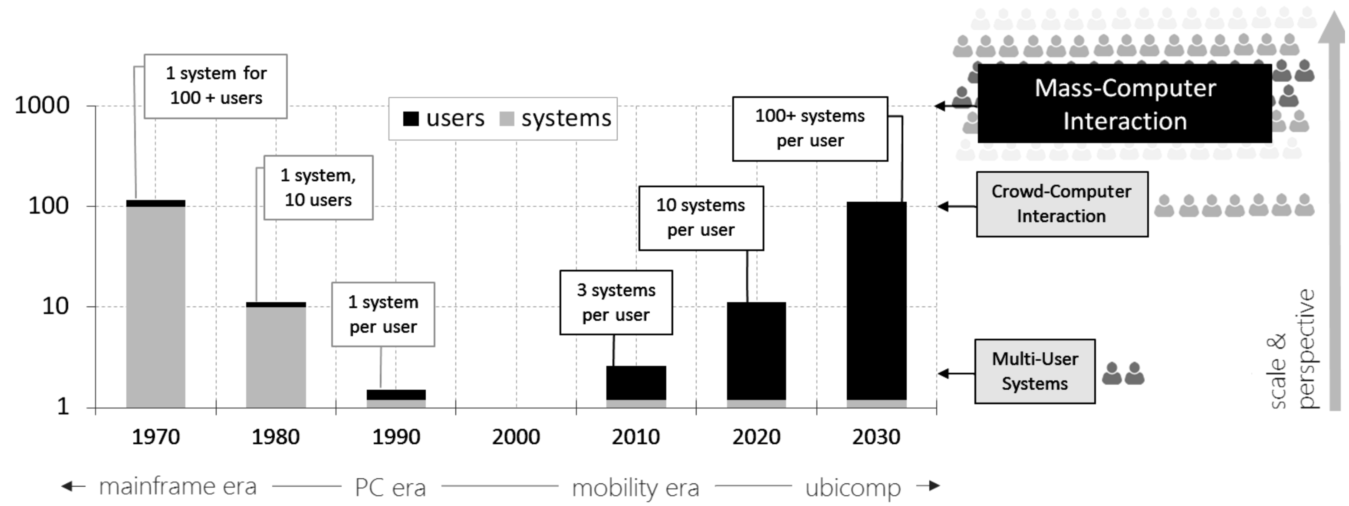

Figure 1. Historical evolution of the number of computing devices per user and the advent of Mass-Computer Interaction (MCI) as a new paradigm of interaction that involves the masses. In this work, we describe the MCI concept and outline challenges for HCI.

Figure 2. Some actual snapshots of a mass of users representative of SKEMMI, our general-purpose platform for developing and deploying MCI applications. The vision of MCI is to scale interactions to hundreds and thousands of end-users.

shared computer to a large number of users progressively evolved into the "personal computing" era, with one personal computer per user. We are now traversing, at fast speed, the exciting computing period of Internet-of-Things (IoT) devices, where connected users typically own and utilize 3.6 devices on average, a figure that is rapidly raising to an estimate of 10+ personal mobile and wearable devices in the near future [7]. In parallel, Computer-Supported Collaborative Work (CSCW) emerged to address the challenges posed by multi-user systems, for which the number of users is important, although not necessarily a large one. Finally, Crowd-Computer Interaction (CCI) [1] became relevant to HCI when a "crowd" was recognized as a coherent, large set of users interacting with the same system.

In the vein of this progression, we introduce **Mass-Computer Interaction (MCI)**, a natural evolution of CCI fostered by recent innovations and advances in large-scale sensing, processing, and interactive systems. MCI consists in three characteristics that differentiate it, as a paradigm, from previous multi-user systems: (1) the size of the target user population, usually in the order of hundreds or thousands, easily scalable to even larger figures, (2) the size of the physical settings, such as theaters and auditoriums (Figure 2), and (3) the size of the infrastructure and interactive systems. This paper introduces key aspects of Mass-Computer Interaction, such as its differentiating characteristics from prior concepts of multi-user systems, which we exemplify with SKEMMI (www.skemmi.org), our general-purpose platform for developing MCI applications.

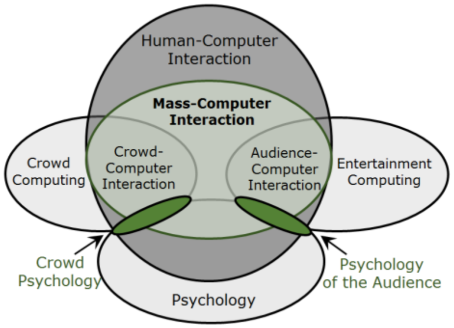

Figure 3. Scope of Mass-Computer Interaction as a Venn diagram.

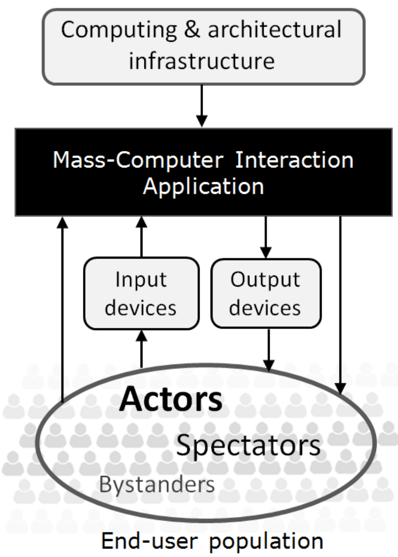

Figure 4. Architecture of a Mass-Computer Interaction application.

Related and Foundational Work

Our paradigm of Mass-Computer Interaction is a novel and timely shift of perspective driven by recent advances in large-scale sensing and distributed computing infrastructure with roots in crowd computing [1,6,7], psychology [4], and entertainment [7]. In this section, we overview prior concepts relevant to MCI.

Gustave Le Bon pioneered Crowd Psychology [4], for which he identified three processes: *submergence* that occurs when individuals start losing their individual sense as they are overwhelmed by the crowd, *contagion* when individuals tend to adopt the predominant ideas of the crowd, and *suggestion* that occurs when ideas and emotions are inspired by some form of shared unconsciousness created by the crowd.

Connecting the "crowd" and "computing" (Figure 3) has received many definitions, from which we prefer the one proposed by Parshotam [7]: *"a myriad of human intellectual tools that allow the exchange of ideas, non-hierarchical decision making, and full use of the world's mind space."* Crowd-Computer Interaction (CCI) [1,6] was introduced to address the interaction aspect in the form of *"an opportunistic network … to spread computation and collect results"* (the network-oriented perspective), *"a means for distributing human tasks to mobile devices"* (i.e., the perspective of Distributed User Interfaces [9]), and *"a form of human-computer interaction in which single actions from many individuals are aggregated to produce a different result that would not be possible otherwise"* [6]. Many developments followed the introduction of the CCI concept. For instance, Kaviani et al. [3] classified CCI users into *actors* (i.e., actual end-users), *spectators* (close to actors in the physical setting, but do not really participate), and *bystanders* (watch the scene from far away), which we also adopt for MCI (Figure 4). One challenge of CCI is to remove the barrier perceived by bystanders and spectators and turn them into actors. To this end, Hespagnol et al. [5] suggested the concept of "elastic experiences" to accommodate the number and heterogeneity of users and platforms involved by CCI systems.

Audience-Computer Interaction (ACI) [7] is a particular CCI instance, where the crowd consists of an audience of unacquainted individuals and/or groups brought together by their participation in and consumption of some genre of media. Audience-response systems are primarily focused on sustaining public engagement in events, such as festivals [13]. Audience silhouettes and kinesics have also been explored for creating social experience at a distance in the context of social TV [15].

Towards Mass-Computer Interaction

Mass-Computer Interaction builds on all previously mentioned concepts and paradigms, as it incorporates a very large number of end-users that share a common experience, essentially driven by elements characteristic of mass psychology. Whereas CSCW emphasizes the collaboration between several users, CCI mainly focuses on a very large amount of users. We believe that MCI should not be expanded only along the user dimension. We providing our working definition for MCI:

> **Mass-Computer Interaction** is Human-Computer Interaction paradigm addressing a very large number of users, typically in the order of hundreds or thousands, which engage as a group in the context of a very large-scale physical setting and computing infrastructure and carry out tasks with a large set of input devices that determines a result not achievable otherwise that could be made observable on a very large output device.

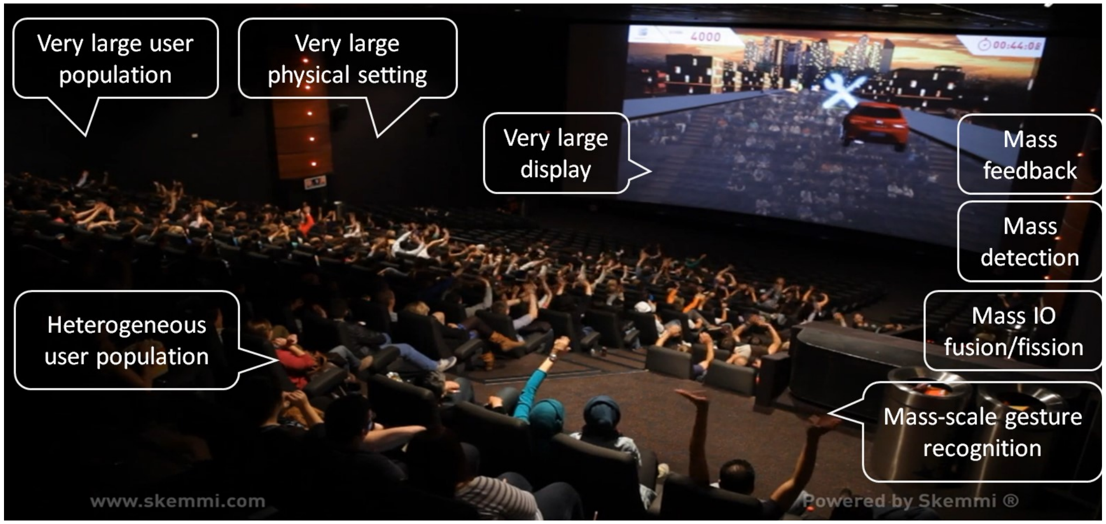

Figure 5. Example of advergaming, a Mass-Computer Interaction application (www.skemmi.com).

Tasks in MCI can be *collaborative* (when users contribute simultaneously), *cooperative* (users contribute, but not at the same time), *competitive* (users are divided into groups pursuing the same task, but in competition with other groups), or *coopetitive* (cooperative competition when groups cooperate for some sub-tasks, but remaining competitive for the high-level task).

SKEMMI: A Development Environment for Mass-Computer Interaction

SKEMMI is our general-purpose platform for developing and deploying MCI applications (Figure 5) built on a model-based approach of multimodal input signals [8]. SKEMMI implements computer vision techniques for mass detection, feature extraction and clustering, and incorporates augmented reality, multimodal high-level fusion [10], and multiple video projections. Mass clustering decomposes the input signals of the mass to form clusters (e.g., corresponding to a portion of the mass) to interpret their signals more accurately. SKEMMI has been deployed for specific instances of MCI applications known as "advergaming," i.e., a game genre aimed at advertising a specific brand. Advergames incorporate mass gesture interaction, advertisements, a massive co-located game, and very large team building. Note that a technical description of SKEMMI is beyond the scope of this paper, where we are interested in outlining the concept of Mass-Computer Interaction. Nevertheless, we refer to SKEMMI in the rest of the paper to exemplify how MCI characteristics can be implemented in practical systems. Figure 5 illustrates a mass experience created during a SKEMMI advergame running simultaneously in three theaters from Belgium, France, and the Netherlands, each comprising hundreds of end-users that perform synchronous hand and body gestures to interact with the game. In this example, teams of users perform series of body gestures at a specific pace to trigger commands that steer a car in a race.

Mass-Computer Interaction Characteristics

We outline characteristics of Mass-Computer Interaction, which we structure along the three main dimensions of the context of use: users, platforms, and environments. In doing so, we highlight the main differences between MCI and CCI, and exemplify the implementation of these characteristics in SKEMMI.

The size of the user population determines the maximal number of end-users that can be involved simultaneously. This characteristic impacts mass performance and the strategies to carry out the corresponding task. While CCI normally accommodates at most 100 users [11,13], MCI involves from several hundreds to thousands of users that all engage simultaneously. SKEMMI ran with 500 co-located users, but also with 900 users distributed in three groups in three different countries.

User privacy and security needs to guarantee that all user-specific data remain private and secure. This characteristic already applies to CCI, but must be reinforced for MCI because of the larger number of users involved. Concerns about privacy increase with the number of people that are not acquainted and, probably, do not wish to get acquainted. Thus, end-user data should not be dispatched in MCI. The same applies for the environment: no location information should be exploited for other purpose than the MCI task.

Environmental mass awareness captures all the aspects of the environment that are relevant for supporting the MCI task, such as *audience awareness* or the level of *social engagement*. SKEMMI increases social engagement and interaction memorability up to 67%, emotionally outperforms other brand activations by a factor of two, and fosters creation of new communities, such as brand fans (http://www.skemmi.com/mass_advergaming/).

Users' heterogeneity determines the user profiles involved in a MCI system. While CCI should be designed to support various user groups, such as public users, registered users, and administrators [5,6,7], MCI takes into account more specific user categories, such as bystanders, spectators, and actors [3] (Figure 4). In inclusive settings like a theater, all users are primarily actors, some of them being spectators, but becoming actors because they rapidly feel engaged in the interaction. Other parameters are *mass type* (i.e., explicit if an explicit relationship is established among the members of the group or implicit if no such relationship exists), *mass density* (i.e., the number of users per physical surface unit), the *mass center* (i.e., the center of the most frequent actions), the *mass shape* [12], etc.

User/task representation specifies how individual users are represented as part of the mass and how they contribute to the common task. User input can be *implicit* (i.e., the representation is internal to the system), *explicit* (the representation is externalized by the system, such as in the form of an aura, avatar, symbol, or character) or *mixed* (the representation is both user-defined and system-rendered, such as a picture, personal avatar, or representative icon).

The size of the physical platform specifies the type and scale of I/O devices. While CCI has been demonstrated with wall displays [3], MCI specifically demands very large screens (e.g., IMAX) for output to reach hundreds or thousands of users effectively. This setup is repeated for every running instance at any location.

Platform independence concerns supporting various sensors, protocols, and operating systems. CCI typically targets a predefined ecosystem of sensors, devices, and platforms with a limited degree of flexibility [11]. Contrarily, Mass-Computer Interaction should remain as autonomous as possible with respect to the platform to ensure multiple types of interaction. For instance, SKEMMI supports both *contact* devices (such as touch panels) and *contactless* input (mass behavior is detected via a very large multi-video-camera setup).

The size of the physical environment specifies the type and scale of the setting where MCI is implemented. While CCI gathers people in a moderately-sized location, e.g., near a large display [3], MCI requires a location of size that scales to the number of end-users, e.g., an entire theater or several theaters simultaneously, indoor or outdoor (such as Graffito [13] that enables interaction during outdoor festivals).

Modality independence refers to different interaction modalities on top of platform independence. For instance, SKEMMI supports massive gesture recognition of 3D body gestures as opposed to individual gesture recognition [2]. Several interaction modalities may be exploited [7], such as presence detection, full-body recognition, body posture, body silhouettes [15], facial expression, gaze detection, speech recognition, gesture interaction, remote control, and touch interaction.

Mass I/O fusion and fission. Users produce individual signals that need to be fused by mass clustering, while the output should be subjected to multi-level fission [10] at the individual, cluster, and mass levels of granularity. SKEMMI displays individual signals via a pulsing aura and shows scores at the level of a user, a cluster of users (e.g., a region), a group (e.g., a team in an auditorium), and the mass, which promotes social recognition and stimulation in competition. This principle also covers the signals emitted by devices owned by end-users [3] and how they are processed.

Conclusion

Mass-Computer Interaction is the natural evolution of Crowd-Computer Interaction for larger scales, involved platforms, devices, and environments towards real mass experiences. (Video demonstrations are available at https://vimeo.com/skemmi). The vision of MCI pushes CCI beyond its limits and enhances it with new dimensions beyond simply considering a large amount of users. The new technical and experience-related requirements of Mass-Computer Interaction set the bar very high to ensure fluid interaction for large masses (especially when contactless interaction is involved), an unprecedented challenge for HCI. We are looking forward to see how the community will embrace our ideas, further develop the MCI concept, implement and deploy mass-experiences for our future era of mass-interactive computing. How crowd psychology could also inform MCI represents a unique opportunity for this purpose.

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