Opportunistic Collective Experiences: Identifying Shared Situations and Structuring Shared Activities at Distance

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Despite many available social technologies for connecting at a distance, we don't always find opportunities to actively engage in shared experiences and activities with friends and loved ones, even though this kind of interaction is associated with increased social closeness. To better support active engagement in shared experiences and activities while also making it convenient to find opportunities for interacting in this way, our work explores the design of *Opportunistic Collective Experiences (OCEs)*, or social experiences powered by computer programs that identify opportune moments when users share situations across distance and structure shared activities in those situations. To support interacting with, programming, and executing OCEs, we developed *Cerebro*, a computational platform that consists of a mobile app that supports users' social interaction, an API for expressing the situations and activities that make up the interactional opportunity, and an opportunistic execution engine that checks for interactional opportunities and executes them when possible. Through a 20 day deployment study tested with groups of geographically-distributed college alumni (N=21), we found that OCEs promoted opportunities for active engagement; facilitated interactions that were socially connecting by structuring ways to engage in shared experiences and activities; and made actively engaging easier by identifying situations appropriate for interacting and structuring how to engage in activities in these situations. We contribute to CSCW (1) a novel interaction that facilitates engaging in shared experiences and activities at distance during coincidental moments; and (2) the design of systems to interact with, program, and execute these kinds of interactions.

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CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**; *Collaborative interaction*; *Social networking sites.*

Additional Key Words and Phrases: opportunistic interactions; collective experiences; social technologies; active engagement in shared experiences and activities

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1 INTRODUCTION

When friends and family are located close to one another, they often spend many daily situations actively engaging in shared experiences and activities with each other. For example, co-workers grab coffee during breaks or drinks after work, housemates watch TV side-by-side, and family members run errands or grocery shop together. Broadly, active engagement in shared experiences and activities can have a positive impact on people's relationships by improving interpersonal closeness and increasing how much they attend to and empathize with their co-experiencers [10]. People who are co-located can often actively engage with one another because opportunities to do so arise coincidentally as people go about their daily lives. For example, co-workers might bump into each other near the coffee machine, and household members might join others in the common space who are already watching TV. Given people's busy lives, many benefit from the convenience of coincidental opportunities to actively engage with others.

However, when people are physically distant, existing social technologies are limited in how they support people to both (1) *actively engage in shared experiences and activities* and (2) *find convenient opportunities* to have these interactions together. On the one hand, social networking sites (SNS) make it convenient for existing ties to keep up with each other's lives by passively consuming content (e.g., scrolling through feeds) and showing interest and support (e.g., one-click likes, or short replies to a post). However, SNS posts tend to highlight the content of people's individual lives and experiences, and do little to support active engagement in shared experiences and activities with others like we've seen above. On the other hand, other social technologies do support people's active engagement with one another, for example through video calls, playing games, or watching Netflix together during a "Zoom Party" [56]. While dedicating time to deeper conversations and structured shared activities enabled by such technologies is effective for connecting at a distance, scheduling dedicated time can be effortful, which can ultimately impact how often remote friends actually find the opportunity to actively engage in this way. As a point of contrast, social apps such as TikTok and Douyin [42] do not require scheduling dedicated time for connecting and instead support "short-form" active engagement through creating short videos of a shared activity that build upon the creations of others. But connecting in this way is still hardly convenient, as the task of identifying appropriate activities, situations, and ways to engage with others can require significant effort and is left entirely to the user.

To better support active engagement in shared experiences and activities while also making it convenient to find opportunities for interacting in this way, our first core contribution conceptualizes the design of *Opportunistic Collective Experiences (OCEs)*, or social experiences powered by computer programs that (1) identify coincidences across people's distributed situations that afford engaging in shared experiences and activities and (2) facilitate socially connecting interactions at a distance. OCEs are inspired by how active engagement with one another can arise coincidentally due to physical proximity [4, 37]: a person might chat with a coworker they see by the coffee machine, or bump into a friend at the bar and share a drink. Our work conceptualizes how social technologies might *identify and structure such opportunities for active engagement across distance*, so that people who are physically or temporally distant may nevertheless, at coincidental moments in their daily lives, find opportunities to actively engage in shared experiences and activities. For instance, an OCE may recognize an opportunity for interaction between two friends who are in similar situations (e.g., both drinking beverages at cafés, or walking outside in the rain) and suggest an activity they can both participate in that reflects their shared experience. OCEs might also structure opportunities for new forms of active engagement that take advantage of people's distributed contexts in support of an interdependent activity. For example, an OCE might support people co-creating a storybook with friends who each contribute a unique page in the story based on opportune situations they uniquely encounter in their day. In this way, OCEs create shared interactional spaces for connecting with friends and family at opportune moments that are grounded in people's respective situations, and provide interactional structures for effectively engaging in a shared experience or activity that those situations afford.

A core challenge in designing OCEs is helping to establish the interactional grounding needed for effectively connecting at distance. For example, when an OCE surfaces a moment in which two users are in a similar situation, the activity they engage in may not bring them closer if users do not end up attending to the relevant stimuli across their situations, or feel that they are working towards a joint goal. Thus, our second core contribution is a set of *OCE Design Guidelines* that recommend specific ways to frame the social experience, such as the aspects of the situation people should attend to or the interdependence that can be built into the activity in which they engage. We crafted these guidelines after examining existing theories and mechanisms for promoting social connectedness through in-person interactions (e.g., [10, 20]) and reasoning about how these mechanisms can be adapted for supporting people connecting at distance at opportune moments in distributed contexts.

As our third core contribution, we designed and built *Cerebro*, a computational platform that supports interacting with, expressing, and executing OCEs. Cerebro consists of three main components: (1) a mobile interface for users to engage in OCE interactions with each other, (2) a programming API for developers to express how opportunities for interaction can be structured based on coincidental situations, and (3) an execution engine that continually checks for opportunities for interactions and executes them when possible. Cerebro identifies interactional opportunities across people's distributed contexts by recognizing how a user's situation can match the needs of an OCE activity. Cerebro's machine representation of situations use mobile-context features including place, time, and weather to infer potential activities that can be performed in a user's environment (e.g., at a bar or café, raise a drink to perform a virtual "cheers") and shared contexts for active engagement (e.g., watching a sunset; stomping in puddles on a rainy day).

We studied the feasibility of our conceptualization of OCEs and the Cerebro system by testing with groups of college alumni friends who were interested in reconnecting with each other. As an instance of the more general challenges facing friends and family who wish to connect at distance, individuals in such college alumni groups are (1) typically physically distant after graduating and moving away from their campuses; (2) interested in reconnecting with each other; but (3) often leading busy early-career lives and thus do not always find opportunities to actively engage with their alumni friends. In a 3-week study in which two groups of college alumni friends ($N = 16$ and $N = 12$) used Cerebro, we found that OCEs promoted socially connecting interactions and created convenient opportunities for actively engaging with one another across distance. Users compared OCEs to other social networking sites and reported significantly higher levels of being a part of a group ($p = 0.03$) and of sharing similar experiences and engaging in joint activities ($p < 0.0001$) than when they make posts and replies in SNS feeds. Users attributed this difference to how OCEs were structured around shared experiences and activities rather than just about awareness of an individual's experiences. Additionally, 12 of the 14 respondents who shared an OCE interaction said that OCEs helped them interact with people who they knew from their pasts but normally do not reach out to. Along this vein, users felt that OCEs reduce the mental effort to decide if a moment is worthy to initiate an interaction by identifying appropriate everyday situations to participate; that OCEs provide a reason and grounding to interact by identifying coincidences when people shared situations; and that OCEs reduce the burden of thinking about how to interact by structuring how to participate in an experience. These findings provide early evidence that social technologies for identifying coincidences across people's similar situations and structuring shared interactions in these situations can effectively promote socially connecting interactions and make actively engaging easier between people who are physically distant.

2 RELATED WORK

Our work on Opportunistic Collective Experiences was informed by prior research on (1) social networking sites like Facebook, (2) computer-mediated communication channels for active engagement, and (3) social technologies that surface coincidental moments of colocation or shared activity. Despite many popular applications, it remains a critical challenge to design a social technology that helps to find convenient opportunities for connecting with friends and family at distance, and that support actively engaging in shared experiences and activities that help people feel closer to one another.

2.1 Social Networking Sites

Social networking sites (SNS) like Facebook, Instagram, and Snapchat make it convenient to maintain interactions with friends and family who live remotely. People can (a) maintain social-awareness by passively consuming the content of others' lives through scrolling through posts or browsing others' profiles [14] and (b) express social signals with little effort through one-click likes and reactions [13, 54]. However, these more passive forms of engagement are generally not effective at promoting social connection outcomes. For instance, previous research found that passive consumption on SNS (e.g., scrolling through feeds or browsing activity) is associated with increased loneliness [14] and is not linked to improvements in perceived social support [12]. Moreover, one-click communication on SNS (e.g., likes) is not associated with improvements in social closeness [13]. Perhaps, passively consuming or liking others' SNS posts are not as effective because SNS feeds are designed to help people share their individual experiences or "me now"-focused content [45], and their friends and family are constrained to passively engaging with this content that captures their past events and actions. In other words, interactions on SNS feeds become more one-sided and passive because of the individual-focused design paradigm. They do little to identify what is shared across people's experiences and perspectives, nor structure active engagement that involves collective participation in activities across people's respective situations.

While passive engagement with SNS feeds is not effective for social connection, active engagement on SNS, such as direct messaging or posting on someone's Facebook wall, is associated with increased social closeness [13] and decreased loneliness [14]. However, initiating a direct message with someone we do not talk to often (e.g., college alumni friends) can be effortful because people lack the necessary *interactional grounding* that helps determine appropriate behaviors (e.g., what to talk about) in a given moment [25]. Instead, conversations might start without a specific topic or purpose (e.g., "it's been a while, how have you been?") but then have the potential to become awkward [41]. While users can spend lots of effort trying to find that interactional grounding (e.g., finding a relevant conversation opener appropriate for the specific situation and relationship [24]), or users already have grounding with close friends with whom they already share a rich history of experiences, *SNS provide few supports for establishing interactional grounding which would make actively engaging easier.* In contrast, our work on OCEs seeks to create more opportunities for actively engaging with others at distance by providing and helping to establish interactional grounding explicitly. We hypothesize that this can lessen the effort required for initiating an interaction while also facilitating more effective interactions for connecting at distance.

2.2 Communication channels for active engagement

While making time to actively engage with remote friends and family can subsequently build a stronger sense of mediated presence [60] and is linked to reduced loneliness [14] and increased social closeness [13], we don't always find the time and planning such interactions remains costly. For example, when people are available at the same time, videoconferencing affords active engagement in conversations [5] and shared activities [46, 47, 62], thereby making it an effective channel for promoting feelings of closeness [11]. However, scheduling times for interaction over such channels is not always a convenient task [2]. Initiating a video call requires checking the remote availability and willingness to call before calling [5, 34]. The higher effort required for finding a dedicated time means that people don't always find the opportunity to call their friends or family, or connect as frequently as they might otherwise.

Beyond videoconferencing and other remote activities that require finding a dedicated time to connect, people can also turn to social applications that support "short-form" active engagement with friends and family at their convenience. For example, social apps like TikTok and Douyin [42] provide a medium for engaging in shared activities by creating short videos together by adding onto and remixing other users' posted videos or audio tracks. While these apps promote joint activities, they place the onus of identifying appropriate situations and ways to engage with others entirely on users, which requires significant effort and can be difficult to figure out. Fundamentally, these apps cannot know when nor facilitate how a person might be able to engage because *they lack a notion of how a person's situation may or may not provide the interactional grounding needed to participate in a particular shared activity.* In comparison, OCEs encode the situations in which the interactional grounding needed for participating in a shared activity is present, actively finds moments when people's current situation affords interacting in this way, and further scaffolds participating in ways that facilitate connecting with another. We expect that this can make "short-form" active engagement more accessible, convenient, and effective.

2.3 Social technologies that surface coincidental moments

Our work on OCEs follows earlier research on social technologies that surface coincidental moments in people's lives and use these moments as the seed for social interaction and connection. One area of research studies location-based mobile applications that use physical proximity to facilitate people interacting through opportunistic social matching systems [44], people nearby apps [29, 51], and place check-in apps [39]. Through making co-location known in situations when people did not know otherwise, these applications can support coincidental encounters by making it more convenient to coordinate in-person meetups [23, 39, 43, 44]. Other applications leverage the social meaning of real-world places (e.g., campus communities on YikYak [26] or Snapchat Stories; similar traveled routes on Journeys and Notes [17]) to ground situation-appropriate social interactions in virtual communities. Unlike these applications whereby the grounding for a social interaction is inherent in people visiting or inhabiting the same physical locations, in our setting people are physically distant, and the interactional grounding needed to engage in a shared activity must be actively *constructed*. We do this by drawing attention to similar and relevant aspects of people's situations across their disparate contexts, and structuring interactions in ways that connect people's activities across distance.

Another area of research considers how social technologies can bring awareness to (existing) coincidental actions and activities. Across physical spaces, prototypes have been developed to surface coincidental actions that might occur, such as when partners living apart happen to open a window or watch TV at the same time (e.g., [57]). These approaches typically require specialized outfitting of an environment, are often limited to actions in the home, and geared toward intimate couples. Online, researchers have studied how coincidental actions such as browsing the same web page [63] can provide a space for chatting and commenting with other users. While these techniques can surface coincidental actions and provide a shared, passive awareness of others, *they broadly lack an understanding of the kinds of shared experiences and interactions that can take* *place in these moments.* In comparison, our work on OCEs moves the research beyond surfacing coincidental actions to structuring shared *inter*actions that support more engaging and meaningful connection across a wider range of social relations and situations. To do this, we contribute new social technologies that (1) identify situations that afford meaningful interactions that arise in people's daily lives that would otherwise go unnoticed, and (2) facilitate joint activities in these situations without preplanning.

3 CONCEPTUALIZING OCES

Towards the goal of helping friends and family at a distance find opportunities to actively engage in shared experiences and activities, we envision a social technology we call Opportunistic Collective Experiences (OCEs): social experiences powered by computer programs that (1) identify coincidental situations for engaging in shared experiences and activities and (2) structure socially connecting interactions at a distance during opportune moments when such situations are present.

To facilitate the effective design of OCEs, we contribute in this section (1) *OCE Interaction Structures* which overview how various configurations of people's coincidental situations can enable opportunities for engaging in shared experiences and activities; and (2) *OCE Design Guidelines* which recommend specific ways to frame the social experience in these configurations, such as the aspects of the situation to which people should attend to when participating, or the interdependence that can be built into the activity in which they engage, that can facilitate interactions that promote social closeness.

3.1 OCE Interaction Structures: Creating Opportunities to Actively Engage

OCEs identify coincidental opportunities across people's physically distant situations for engaging in shared experiences and activities. To help OCE designers conceptualize how coincidental situations could enable engagement in shared experiences and activities, we developed four *OCE Interaction Structures* that extend how co-located interactions can promote social closeness [10, 20] and improve overall feelings of social connectedness [8] to people who are not co-located; see Figure 1. These interaction structures promote *shared experiences* when people are in similar situations (e.g., enjoying a morning beverage together); and promote unique contributions to *interdependent activities* through people's distributed contexts (e.g., contributing to a group challenge or making a collective artifact). Using these interaction structures, OCE designers can conceptualize different OCEs for opportunistically connecting friends and family to actively engage in shared experiences and activities at a distance.

3.1.1 Shared Experiences. Supporting shared experiences is important for social connection, as doing similar activities in a shared situation can increase social closeness and how much others think about and empathize with their co-experiencers [9, 10]. To structure opportunities to engage in shared experiences across distributed contexts, we conceptualized two interaction structures that find similarities in people's situational contexts to promote feelings of shared experiences despite a lack of physical co-presence (see left-half of Figure 1).

Shared Situational Context at the Same Time identifies similarities across people's seemingly independent situations at the same moment in time. For example, consider how opportunities for having a shared experience arise in-person when people "bump into" one another at a common place in their local community (e.g., friends have an encounter at a café and share a drink). We conceptualized how such shared experiences can be structured to take place at distance in our *Bumped* OCE where friends "virtually bump into" one another if they were both drinking coffee or tea at cafés simultaneously across their respective cities (see top-left of Figure 1).

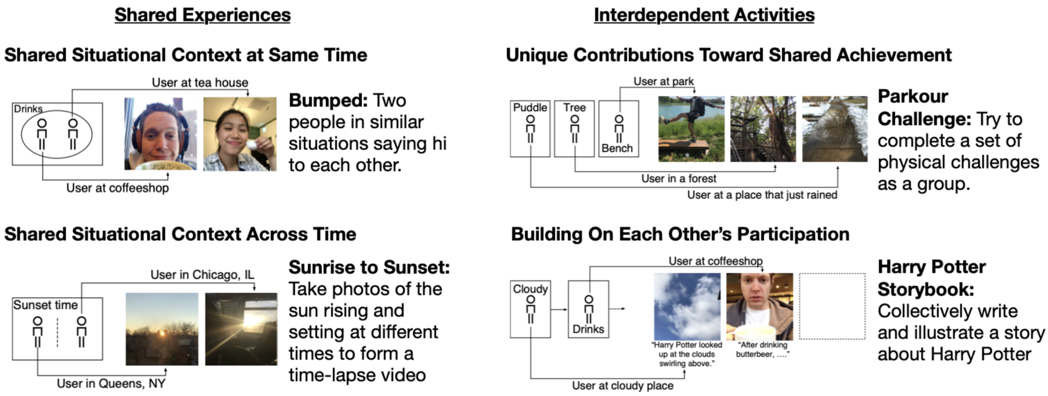


Fig. 1. OCEs can support a variety of interaction structures that connect people through shared experiences and interdependent activities.

Shared Situational Context Across Time promotes shared experiences when people share similar situations but at different times. Since people can often encounter similar situations through their days but not necessarily at the same time, this kind of OCE can bring together similar yet time-separated moments into a coherent, shared experience. For example, friends living in different parts of the world can have a shared experience of "watching a sunset together" by capturing their view of the sunset whenever it occurs in their locale, and then watching a time-lapse video of the sun setting constructed using the footage they each took when the sun was setting for them (see bottom-left of Figure 1).

3.1.2 Interdependent Activities. Interdependent activities are also an important avenue to promoting social connection, as activities that involve cooperation towards shared goals and where the achievement of those goals is positively *interdependent* on other's contributions lead to increased interpersonal closeness [20]. To support people engaging in interdependent activities through the opportunities that arise in coincidental situations, we conceptualized two interaction structures that allow people to construct a digital artifact together or achieve a collective goal by making contributions through their local situations (see right-half of Figure 1).

One interaction structure identifies opportunities for people to make *unique contributions towards a shared achievement* through their local contexts. For example, consider in-person activities such as scavenger or treasure hunts where individual efforts to explore for, pose near, and take pictures of physical items or landmarks lead to the achievement of a shared goal [52]. We can adapt this activity for at distance, opportunistic interactions by situating the set of challenges across people's respective situations. For example, a group of friends may try to complete a set of *Parkour Challenges* (see top-right of Figure 1) together whereby each person's physical environment may present opportunities for tackling particular challenges (e.g., when near a park bench, someone can capture a photo of themselves jumping over it).

The other interaction structure allows people to *build on each other's participation* when co-creating an artifact together. For example, consider in-person activities such as improvisational theatre games [22] and surrealist art activities like Exquisite Corpse [61] where people create stories or artifacts by collaboratively building upon what the previous person has contributed. Adapting these activities for at distance interactions—while also making use of people's unique contexts—we can envision an OCE where people collectively write a *Storybook*: a person writes a sentence describing a scene, and the following person contributes an image of themselves acting

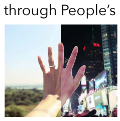
OCE Interaction Structures and Examples	Relevant Mechanisms	Design Guidelines
Shared Experiences: Connect People Who Are Doing Similar Activities in Similar Situations in Distributed Contexts 	*Shared attention to stimuli*, or awareness that others are attending to the same stimuli, promotes co-experiencing and thinking about co-experiencer. *Embodied mimicry and synchrony*, and the general coordination of movements, speech, and activity patterns, enhance the smoothness of interactions and foster liking.	Identify situations that provide a shared context for interacting and for joint actions, e.g., that contain common object affordances or afford similar actions across situations. Support people being aware of shared aspects of their individual situations and contexts to make co-referencing easy. Increase psychological proximity by using visual reminders to increase the salience of co-experiencing.
Interdependent Activities: Construct a Digital Artifact Together or Achieve Collective Goals by Making Contributions through People's Local Situations  	*Cooperation,* or working toward activities with shared achievements, supports bonding and a sense of being a part of a group. *Positive interdependence* in shared activities promotes meaningful interactions and increases social support and social closeness.	Create experiences in which the diversity of situations and contexts across people allows individuals to make unique contributions to achieving the interdependent activity. Create links across individual activities to increase positive interdependence and surface these links so people see how individual activities contribute to shared outcomes and artifacts.

Fig. 2. Design guidelines for OCEs that adapt mechanisms from co-located interactions for the design of opportunistic interactions at distance.

out the previous scene using what is available within their physical environment. This person then selects and describes the next scene for someone else to act out (see bottom-right of Figure 1).

While not exhaustive, these four interaction structures represent several key configurations of people's situations that can enable new forms of active engagement at distance. Along with the example OCEs we presented, these structures provide a starting point for OCE designers to think about how certain in-person shared experiences and activities can be adapted for coincidental interactions at distance, and for them to envision novel experiences that are enabled by people's unique situational contexts.

3.2 OCE Design Guidelines based on Mechanisms for Social Connectedness

Having introduced a set of OCE interaction structures, we turn our attention toward developing design guidelines for conceptualizing OCEs that help people build stronger social connections. To do this, we examined existing theory and studies on how mechanisms for co-located interactions—namely those involving *shared experiences* [8, 10, 15, 28, 55] and *interdependent activities* [1, 20, 21, 32, 33]—can improve social connections by increasing social closeness, teamwork, and trust. Then, we reasoned about how these mechanisms could be adapted for supporting people connecting at distance at opportune moments in distributed contexts. Figure 2 summarizes our design guidelines for OCE interaction structures that promote *Shared Experiences* and *Interdependent Activities*. For each type of interaction, we describe the relevant mechanisms from co-located studies and how they were adapted to inform the design of OCEs.

OCEs with **shared experiences** connect people who are doing similar activities in similar situations at the same time or across time but are doing so in distributed contexts. Prior research on co-located interactions show that *shared attention to stimuli*, or awareness that others are attending to the same stimuli, promotes co-experiencing and can amplify positive experiences and feelings of social closeness (e.g., [10]). Moreover, the general coordination of movements, speech, and activity patterns through *embodied mimicry and synchrony* enhances the smoothness of interactions and fosters liking [8, 15, 28, 55]. Adapting these mechanisms to OCEs, we can reconstruct these elements of effective co-located interactions in an OCE by (1) identifying situations that provide a shared context for interacting and for joint actions such as those that contain common object affordances or afford similar actions across situations [36, 59] (e.g., having a bowl of noodles that afford making a slurping noise); (2) making people aware of shared aspects of their individual situations and

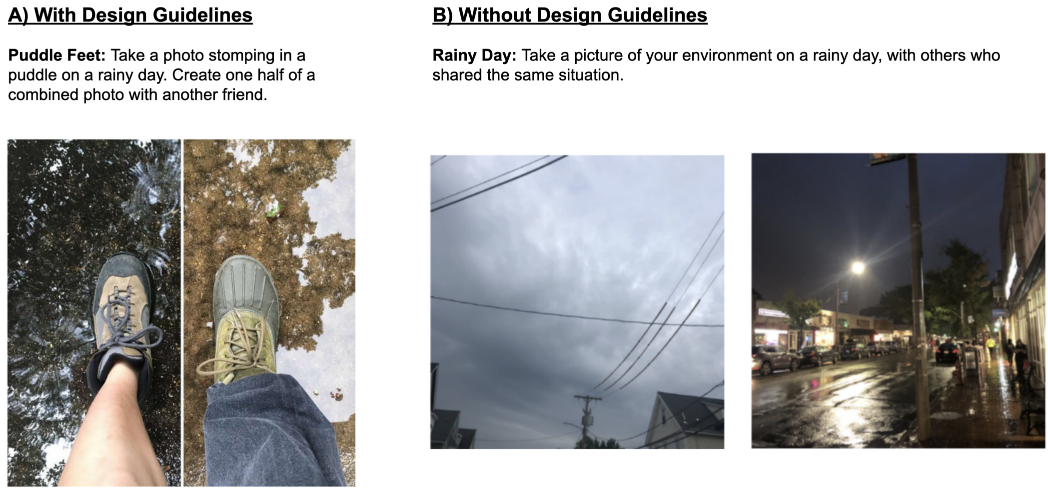


Fig. 3. Implementing two OCEs, with and without our OCE design guidelines: A) Implemented with the design guidelines, the "Puddle Feet" Half Half Photo OCE enables people to cooperate to make a collective artifact, while also encouraging people to take similar actions across their similar situations to highlight the shared aspects of their experience (e.g., stepping in a puddle on a rainy day); B) the "Rainy Day" OCE fails to use the design guidelines and may feel less socially connecting since people are not constructing a shared artifact, are not paying attention to the same objects or stimuli, and are not engaging in similar actions.

contexts to make co-reference easy [49] (e.g., utensils and bowls); and (3) using visual reminders that increase the salience of co-experience (e.g., seeing who you are slurping with) to increase psychological proximity and amplify feelings of social closeness [10]; see top of Figure 2.

OCEs with **interdependent activities** engage people to construct a digital artifact together or to achieve collective goals by making unique contributions through local situations. Prior research shows that *cooperation*, or working towards shared goals, facilitates social bonding and a sense of being a part of a group [1, 20, 21]. Moreover, *positive interdependence* in shared activities– or the extent to which participants must rely on one another's contributions to be effective– promotes more meaningful interactions and increases personal social support [31] and closeness [20, 32, 33]. Adapting these mechanisms to OCEs, we can develop OCEs that promote cooperation and require positive interdependence by (1) creating experiences in which the diversity of situations across people allow individuals to make unique contributions to achieving a shared outcome (e.g., contribute different latte art to form a coffee lovers mosaic); and (2) creating links across individual activities to increase co-dependence and surfacing these links so people see how individual activities contribute to the shared goal (e.g, invite people to take two halves of a single photo that connects their activities across their situations instead of just posting a picture of themselves); see bottom of Figure 2.

3.2.1 *Enacting OCE Design Guidelines.* To illustrate the potential benefits of creating OCEs that enact these design guidelines, consider for example the design of a photo sharing experience in which friends in similar situations capture a photo to highlight their shared experience. Figure 3 shows two OCEs that follow this general design. The OCE on the left, Half Half Photo, implements the design guidelines by inviting two people to each contribute halves of a collaborative photo that connects their activities across their situations (and was inspired by an existing photo concept used by a long-distance couple to highlight their shared travel experiences [7]). We hypothesize

Half Half Photo's design would promote a more socially connecting interaction by (1) instructing users to attend to similar stimuli across their situations (e.g., puddles on a rainy day), which would also allow them to perform similar actions (e.g., stomping in a puddle); (2) provides a format for people to engage in similar actions that visually mimics the actions of their partner (e.g., while taking a photo for the right half, a person positions their right foot to mimic their partner's left foot); and (3) engages people to co-create a collaborative photo by contributing a unique photo half from their own local situation.

The OCE on the right doesn't add these elements and just asks people to take a photo in their environment as part of a photo gallery. While people who participate will be in similar situations just like the Half Half Photo OCE, this OCE is less likely to be socially connecting because it (1) does not scaffold people to attend to similar stimuli or engage in similar actions across their situations; (2) does not provide a way for people's photos to visually build upon each other's contributions by visually mimicking each other's actions; or (3) does not engage people to contribute their photos as part of an interdependent activity to collaboratively construct a digital artifact.

4 CEREBRO

Interacting with, building, and running OCEs—social experiences *powered by computer programs*—requires (1) a front-end interface for users to engage in OCE interactions with each other, (2) programming constructs for developers to express the situations and interactional structures that give rise to opportunities for interactions, and (3) a backend system for monitoring opportunities for interactions and executing them when possible. *Cerebro* is our computational platform that enacts the conceptual vision of OCEs via three main components:

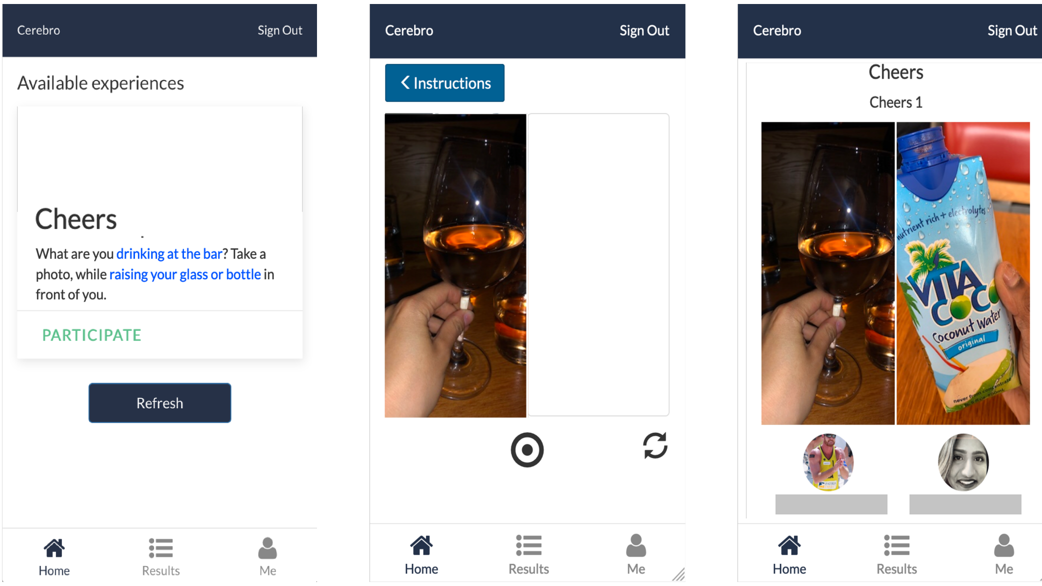
(1) The *Cerebro Mobile App* supports a user's social interaction in OCEs by surfacing to a user when their situation presents an opportunity to interact, scaffolding their participation in the activity, and highlighting the results of their collective participation in an OCE with other people.
(2) The *OCE API* enables developers to implement OCEs using a variety of interaction structures to create opportunities for engaging in shared experiences and interdependent activities. The OCE API provides the programming constructs for describing the situations that OCEs take place in, the interfaces for interaction, and the functions for progressing the state of an OCE as collective participation occurs.
(3) The *Opportunistic Execution Engine* is responsible for the execution of OCE programs during a deployment, and accomplishes this by continually monitoring users' changing situations and coordinating interactions when users' situations match the participation needs of an OCE.

The rest of this section describes each of the components of Cerebro, and provides rationale for their design.

4.1 Cerebro's Mobile App for Interacting with OCEs

Cerebro's mobile app supports existing groups of people who know each other interacting through OCEs. Members of a college alumni group, for example, can join on the app with others, and then expect to be given opportunities during coincidental situations to actively engage in shared experiences and activities together.

Cerebro supports structured, opportunistic interactions across time and distance by (a) surfacing to a user when their situation provides an opportunity for interaction, (b) guiding a user to participate in the shared experience or activity structured by the OCE, and (c) displaying the



(a) Receiving Notifications for Interactional Opportunities

(b) Participating in an Experience

(c) Viewing Results of Collective Participation in an Experience

Fig. 4. Steps for completing an OCE interaction in the Cerebro mobile app.

contributions of all participants in the OCE to highlight their interaction with each other; see Figure 4. We describe each of these interface capabilities below.

4.1.1 Surfacing an Interactional Opportunity to a User. The first step in facilitating interactions through OCEs is surfacing to the user that their current situation provides an opportunity for interaction. A user keeps the Cerebro mobile app running in the background on their device while they move about their daily life and waits for moments when their physical situation matches an OCE interaction opportunity. Upon matching, the user receives a notification telling them the name of the experience (e.g., "Virtual Cheers") and details of how their current situation allows them to join (e.g., "What are you drinking at the bar?"); see Figure 4(a).

Notifications of an interactional opportunity can include brief details of the activity and the situation in which it is intended to take place to help users determine whether they are able to and interested in participating. Moreover, notification messages can provide helpful interactional grounding by drawing attention to the shared situational elements for the OCE, ultimately providing users a sense of the shared interactional space through which they will be participating in the experience (e.g., both at a restaurant, both watching the sunset).

4.1.2 Scaffolding a User's Participation in an OCE. After a user chooses to participate in an OCE they were notified about, they are routed to that OCE's participation interface. Unlike other social technologies that allow users to participate by creating posts in a free-form manner, OCEs are more structured to promote shared experiences or interdependent activities and thus need a way to guide people's participation. For instance, for Half Half Photo, the interface guides a user to capture a photo to frame their respective half in their situation; see Figure 4(b).

Once a user participates in an OCE, the experience progresses so that other users may be matched to the experience and continue participating. For Half Half Photo, once a user takes the left half of the photo, the experience progresses so that a later user who chooses to participate would see in the interface the left half photo contributed earlier and use that to determine what they might do with the matching right half to form a coherent whole.

4.1.3 Highlighting the Results of Collective Participation in an OCE. Participants in an OCE can see the results of their and others' participation through a results interface during the experience or upon its completion. Upon completion, this can help users see what they have created together, for example by seeing how their friend had completed the Half Half photo that they had started; see Figure 4(c). During an experience, the results interface can give the participants a sense of their current progress towards a shared goal, or how a co-created digital artifact has evolved after another person built upon what was already contributed. For instance, friends may look to see which challenges still remain for the "Parkour Challenge," or read the next page of a story being collectively written and illustrated for a "Harry Potter Storybook." To keep users informed on the progress of an OCE, participants receive notifications when there are new contributions, and when an experience completes.

4.2 API For Implementing OCE Programs

Having described how users can interact with OCEs through the Cerebro mobile app, we turn our attention to designing an API for programming OCEs. In designing the API, we focus on three goals:

- *Provide high-level constructs for describing the key components of an OCE*, which are (1) the situations in which an OCE may take place; (2) the interactional activities and experiences that take place within those situations; and (3) the progression of the experience across time.
- *Provide simple ways to express the interactional structure of the OCE*, e.g., whether it's synchronous or asynchronous, or whether activities are occurring in a shared situational context or building upon one another.
- *Abstract away low-level details for executing OCEs* such as monitoring opportunities and coordinating users across situations.

In support of these goals, the *OCE API* supports writing an OCE using three programming constructs: (1) *needs*, which describe the configurations of people's situations required to participate, (2) *templates*, which are the interfaces for interactions, and (3) *callbacks*, which are functions that update the OCE program state to progress a collective experience as people participate in it. In what follows, we describe each API programming construct and how they provide concise ways to describe the interactional structure of the OCE while abstracting away the details of their execution.

4.2.1 Needs. A *need* is a programming construct for describing the situation that one or more users need to be in to be able to participate in an OCE. To define a *situation* in which a user can participate based on their current context, a developer creates a *situational context detector* that defines a predicate over *context features* that together describe the conditions that afford participation. For example, by using context features over place, time, and weather that are readily available through existing mobile-service APIs, a developer can describe the situation of walking through the park in the rain after work using predicates such as place = "parks"; weather = "raining"; and time between 5pm and 7pm. Representing situations by combining context features in this way can help developers link low-level, detectable contexts to the interactional opportunities that are present in certain situations. For example, context features can indicate potential activities that can be performed within a user's physical environment [19] (e.g., being at a park may support activities such as sitting on benches or walking on paths), or provide a shared setting for interacting (e.g., when the sun is setting, or when there are likely puddles from the heavy rain).

```
"needName": "Bumped photo",
"situation": {
  "detector": (coffeeshop || teahouse),
  "number": 2
},
```

(a) Shared Situation at Same Time

```
"needName": "Sunrise to Sunset photo",
"situation": {
  "detector": (sunrise || sunset),
},
"numberNeeded": 10
```

(b) Shared Situation Across Time

Fig. 5. Examples of using *needs* to program two OCEs. Needs encode the *situation* in which the experience takes place by creating *situational context detectors* using predicates over *context features*. Example (a) shows the needs definition for the "Bumped" OCE whereby 2 people participate when they are in a similar situation at the same time (e.g., simultaneously at coffee shops or tea houses). Example (b) shows the needs definition for the "Sunrise to Sunset" OCE whereby 10 people who are in similar situations across time participate when they capture a glimpse of the sunrise or sunset.

Beyond providing a language for defining the details of a situation, needs also provide a concise language for describing the interaction structure of the OCE. For shared experiences that connect people who are in the same situation at the same time, we can specify the number of people we need within the definition of the situation itself (i.e., the situation is one in which multiple people are in it simultaneously); see Figure 5(a). For shared experiences with people who (separately) encounter the same situation across time, we can specify the number of people who need to be in the situation outside of the definition of the situation; see Figure 5(b). For interdependent activities, we can describe OCEs with unique contributions to a shared goal by defining the various situations people need to be in, and OCEs that build on people's participation by dynamically adding new situations in response to what's been done so far (see callbacks below).

4.2.2 Templates. Templates are used to program the interactional activities and experiences that users can participate in when they are in the situations that are defined by needs. With templates, developers can quickly build new OCEs by including and re-using interface components that have been templated. Re-use of interface components can be useful if developers are using a common interaction across a variety of OCEs and situations. For example, we created Half Half Photo OCEs (described in Section 3.2.1) across a variety of different situations by re-using the Half Half Camera interface component. Beyond re-using code, since a created template or interface component can encapsulate a number of useful OCE design guidelines (e.g., ways to surface and highlight links across individual activities), making templates re-usable can help experience developers more easily enact effective design guidelines across a variety of similar OCEs.

4.2.3 Callbacks. Callbacks are used to conditionally update an OCE based on the state of the OCE and how it is progressing. Each callback consists of a *trigger* condition and a *callback function* that runs when the condition is met. For example, a callback can trigger when a new contribution is made, a specific need completes, or the number of total contributions reaches a certain number. Depending on the design of the OCE, the callback function can then add or remove needs or pass information to templates in order to progress or modify the collective experience.

Callbacks allow an experience designer to control how the OCE dynamically unfolds based on how it has progressed. We highlight below two use cases for callbacks. One use case is for OCEs based on the *Building On Each Other's Participation* interaction structure. Using callbacks, a developer can progress the experience based on the specific contributions of previous participants. For example, the "Storybook" OCE we had described allows participants to choose the setting in which the story takes place next (e.g., at a train station; on a cloudy day). To progress the story accordingly, a callback is triggered upon submission to create a new need based on the setting that

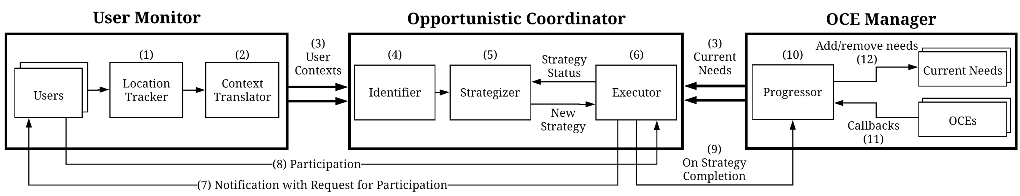


Fig. 6. The Opportunistic Execution Engine allows for real-time matching between users and their contexts to OCE needs. The *User Monitor* constantly monitors users' locations and updates their context features. User contexts and the current needs of the OCEs are sent to the *Opportunistic Coordinator*, where a strategy for opportunistically matching users to needs is created and executed. The Opportunistic Coordinator both monitors the execution of the strategy and listens for new user contexts, re-strategizing if needed. On strategy completion, the *OCE Manager* updates the current needs based on the OCE's callbacks and strategy output.

was selected. This ensures that the next participant will be in this setting when they illustrate what comes next in the story.

Another use case for callbacks is creating OCEs with multiple stages, or those that combine multiple interaction structures. For example, we could have a multi-level "Parkour Challenge" whereby once all the current challenges are completed, a callback can unlock advanced challenges that require multiple people to complete actions at the same time. To do this, a callback can monitor for when all current needs have been met, and only then trigger a callback function that adds new needs for each of the advanced challenges.

4.3 Opportunistic Execution Engine for Running OCE Programs

Running OCE programs requires an engine that continually checks for opportunities for interaction and executes them when possible. This engine must track changing *interactional resources* (users in specific situations) and tasks (needs), contextualize how a user's situational context maps to needs, and coordinate interactions when they match. Existing programming models for social and crowd computing [3, 35, 40, 48, 58] cannot effectively implement OCEs because they only model tasks and the *static characteristics* of people who are needed to complete them. Critically, they do not model dynamic characteristics of people, such as people's changing situations and environments, which are needed to determine what OCEs people can participate in.

To overcome the limitations of these existing programming models, we designed an *Opportunistic Execution Engine* that waits for interactional resources to become available at run-time and makes no a priori assumptions about how or if certain OCE needs will be fulfilled. To do this, the engine (1) monitors opportunities afforded by users' changing situations; (2) coordinates opportunities to needs as they arise; and (3) manages the progression of OCEs based on the completion of needs and their associated callbacks; see Figure 6.

4.3.1 Execution Flow. In our implementation, the engine begins execution in the User Monitor when a user's location changes. The Location Tracker (1) captures location updates and uses the Context Translator (2) to label the location data with context features, including place categories, weather conditions, and local time. These User Contexts, along with Current Needs from the OCE Manager, are passed along to the Opportunistic Coordinator (3).

The Opportunistic Coordinator begins by identifying what needs a user is eligible for (4). The Identifier evaluates the Situation Detectors for the current needs using the user's context features. The Strategizer, now knowing which users are eligible for which needs, begins to strategize how to fulfill the needs (5). This step considers how many users are needed to complete a need, including if multiple users are needed synchronously. If a strategy is found that can match the required users to a need, the Executor runs and monitors that strategy for the need (6) and notifies users to participate (7). When the user opens the notification, the front-end application loads the appropriate template based on the OCE and the need to which the user is assigned.

As the strategy executes, the Strategizer actively considers whether the strategy may need to be revised. Strategies are revised when either a change in resource is detected or when the current strategy is not receiving participation. If users' locations or current needs change, the system re-runs (2) through (5) to form a new strategy. For example, if a user that is currently assigned to a need changes their location and no longer matches the situation needed, this user would see the experience removed from their list of assigned experiences. If progress stalls, the Strategizer can re-strategize how to progress by removing the current user matched with the need and finding a new user, if possible.

When the Executor receives participation (8), it checks if the strategy is completed (9) and sends the data to the Progressor in the OCE Manager (10). The Progressor fetches the Callbacks for the OCE (11) and executes those ready to run based on the OCE's current state. The Callback may add or remove needs from the current needs based on the results from participation (12). Upon updating the current needs, the Identifier detects a change in resources and begins the process of strategizing to fulfill needs once again.

4.3.2 Implementation Decisions. Due to inaccuracies in context detectors, in practice, monitoring users' context and matching them to needs is bound to be an imperfect process. In our implementation, we sought to mitigate both *false positives* whereby a system thinks a user can engage in an OCE when they cannot; and *false negatives*, whereby opportunities for interaction are missed. For false positives, in early prototyping and iterative testing we found that Cerebro would incorrectly notify people who were passing by a location of interest (e.g., on foot, biking, or driving) but were not actually visiting it. To mitigate these occurrences, for our deployment, our implementation of the Context Translator ignores location updates from people who are "bicycling" or "in vehicle" and requires a user's place context to be sustained for a significant time period (e.g., > 60 seconds) to avoid notifying people who are just walking past. For false negatives, in early testing we observed missed opportunities when noisy or inaccurate location updates incorrectly reported a user's location as away from the place of interest while they were actually there. To mitigate this problem, we implemented a location tracker that attempts to provide more robust estimates by taking a weighted average of recent location updates that overweighs the more recent and higher-accuracy location updates.

Additionally, implementing the opportunistic execution engine involved making a number of practical decisions for how to coordinate among needs and experiences. For instance, the execution strategy has to make tradeoffs when selecting among multiple needs or experiences that a user can contribute to through their current situation. For our deployments, we implemented a simple priority system that prioritizes needs that have started but that have not yet completed. This attempts to mitigate situations where an OCE may draw one participant and then linger for a long time, which can lead to a poor user experience and an incomplete OCE. In future work, our architecture can be used to implement more sophisticated execution strategies that model the social-value of needs along multiple dimensions. For instance, prioritizing synchronous needs from the *shared situational context at the same time* interaction structure could provide increased social-value due to the contextual rarity [44] of people coincidentally participating at the same time together.

4.4 Technologies Used for Implementation

The Cerebro computational platform consists of the Cerebro mobile app, the OCE API, and the Opportunistic Execution Engine. The Cerebro mobile app is built as an iOS application packaged with Cordova and written in Meteor.js. The iOS front-end handles geolocation tracking, the presentation of notifications for when their situations afford participating, and the presentation of HTML-based Templates for participating in OCEs. The OCE API is implemented as a series of high level functions built in Meteor.js. Interface templates in Meteor.js are programmed declaratively, so developers need not worry about low-level details of maintaining connection to real-time, data changes. This makes it easier to implement synchronous OCEs in which users are interacting through the same interface template at the same time. The Opportunistic Execution Engine, a backend controller which handles the execution of OCEs and connection with the database model, was implemented in Meteor.js and uses MongoDB to store any needed data. Additionally, the User Monitor within the Opportunistic Execution Engine communicates with the Context Translator, which is implemented as a Python Flask microservice that uses the Yelp [30] and Open Weather [50] APIs to query for context features for a given location.

5 DEPLOYMENT STUDY

We conducted a pilot deployment study to demonstrate how OCEs promote opportunities for active engagement through shared experiences and activities between geographically distributed friends, specifically college alumni. We hypothesize that the situated nature of OCEs will increase active engagement as they prompt people to interact during opportune moments that arise in their daily lives, do not require pre-planning, and make initiating interactions easier. We ask:

RQ1: (How) do OCEs promote opportunities to actively engage at distance while making it easier to do so?

In addition, we argue that OCEs structured using our design guidelines provide shared experiences and interdependent activities that are socially connecting. We hypothesize that OCEs may be more effective than posts and replies on SNS for promoting feelings of having a shared experience together that go beyond simple awareness of what each person is doing. Moreover, as OCEs can scaffold participant contributions toward a shared goal, we also expect OCEs to increase the sense of belonging to a group. Thus we also ask:

RQ2: (How) do OCEs promote more socially connecting interactions than other SNS channels?

5.1 Method and Analysis

5.1.1 Participants. Given our focus on social connectedness at a distance, it was important that our participants previously shared a common affiliation, but are now geographically distributed. To achieve this, we recruited from college alumni groups and clubs. Recruiting groups (instead of individuals) ensures that each participant has multiple other friends with whom to engage in OCEs with. This is important because our goal is to enrich social connection among existing ties as opposed to establishing new relationships. The study population came from two close-knit communities with which the authors had direct associations with: The first was composed of alumni and current members of a mid-sized U.S. university research lab community, which we refer to as Lab; the second was composed of alumni from the graduating class of a very small U.S. college, which we refer to as Alum.

We recruited 28 total participants (16 from Lab and 12 from Alum) who filled out our sign-up and pre-study survey at the start of the 20 day deployment study. Due to voluntary drop-out and non-responsiveness, 21 of these participants completed our post-study survey instrument (14 Lab and 7 Alum). We compensated participants $30 for completing both surveys and installing the Cerebro app, but did not provide monetary incentive for using the app or participating in OCEs during the study. 10 of these participants (9 Lab and 1 Alum) accepted our offer to additionally interview them about their experience over a video call. We provided an additional $10 as compensation to those with whom we conducted post-study interviews.

5.1.2 System Deployment Procedure. Participants were instructed to download the Cerebro iOS app, use it over the 20 day period between May 26th and Jun 16th 2019 in their daily lives, and participate when they were able and available.

Two identical versions of OCEs were separately deployed for the two alumni communities so both study populations had the same set of OCEs available. This included the Half Half Photo OCE, in which pairs of participants contributed two halves of the same photo that connects their activities across similar situations; and the Storybook OCE, in which a group of participants composes a story by opportunistically contributing both photos from their surroundings that relate to the previous sentence of the story, and a new sentence to move the story along. These OCEs were implemented using the OCE design guidelines for *Shared Experiences* and *Interdependent Activities* that we reasoned would promote socially connecting interactions; see Figure 2.

We designed Half Half Photo variants with their respective activities for 11 distinct situations: (1) “Hand Silhouette” instructed users sharing sunny weather to take a picture of their hands both outstretched towards the sky covering the sun; (2) “Grocery Buddies” instructed users who were grocery shopping to take a combine picture holding similar grocery items; (3) “Cheers” instructed users who were at bar to raise their drink for a virtual cheers; (4) “Big Bites” instructed users to create a half half photo taking a big bite of their meal; (5) “Puddle Feet” instructed users who were outside while it was raining to stomp in a puddle; (6) “Eating with Chopsticks” instructed users at asian restaurants to create a combine photo of their meals; (7) “Book Buddies” instructed users at libraries and bookstores to share the cover of the nearest book that they were browsing; (8) “Leaf Mask” instructed users visiting a park to find a leaf nearby and take a picture covering their face with the leaf like a mask; (9) “Sunset Together” instructed users during sunset to create a hand heart with the view of the sunset in the center; (10) “Religious Architecture” instructed users who were visiting a place of worship to find common architectural elements; and (11) “Coffee with a Side of Laughs” instructed users to create a half half photo while drinking a beverage like coffee at a café. See the Appendix for screenshots of all of these Half Half Photo variants.

We designed one Storybook OCE where users contribute to a Harry Potter themed story. To provide story settings that grounded people’s story texts and illustrations, each user can choose from 6 distinct settings that would trigger when someone else’s situation matches the setting they chose: (1) “Swirling Clouds” triggers during cloudy weather; (2) “Drinking Butterbeer” triggers while at a bar; (3) “Hogwarts Express” triggers while at a train stations; (4) “Forbidden Forest” triggers at a park; (5) “Dinner at the Great Hall” triggers when eating at different restaurants; and (6) “Training in the Room of Requirements” triggers when at the gym.

5.1.3 Measures and Analysis. Our answers to the research questions are triangulated amongst three sources of data: (1) how users participated in experiences with each other on Cerebro as studied through completed artifacts and system logs of their participation; (2) users’ reflections on using Cerebro to connect with their alumni community, as captured by their responses to open-ended survey and interview questions; and (3) users’ Likert scale ratings of the social connectedness felt during interactions on Cerebro, interactions through direct/group messages on SNS, and interactions through posts/replies on SNS.

We analyzed completed artifacts and system logs of users’ interactions to understand to what extent Cerebro promoted opportunities for active engagement (RQ1). We counted the number of completed interactions per user and per OCE, tallied the situations (e.g., bars vs. grocery stores) in which participants contributed, and calculated participation rates based on how many opportunities users were presented with that led to successful contributions. To better understand how the situatedness of participating in OCEs provided opportunities for active engagement, we also analyzed aspects of their situations (e.g., objects in their environment) they used to engage in the joint activity or the shared experience with others.

Users' open-ended reflections about their use of Cerebro helped to answer how Cerebro created opportunities to actively engage and what about participating in an OCE made it easier to actively engage (RQ1). In the open-ended survey questions, we asked "Did Cerebro affect the opportunities you had to interact with people from [your alumni community], and if so, how?" and similarly coded their responses to other open-ended questions (e.g., unique aspects of their usage of Cerebro compared to direct/group messaging) for the theme of "affecting opportunities to interact with others." Open-ended reflections further informed results on how much the Cerebro interactions felt socially connecting, and whether the interaction structures and design guidelines to promote shared experiences and interdependent activities impacted their social connectedness (RQ2).

We compared the degree to which OCE interactions are social connecting to two common SNS channels: posts/replies and direct/group messages. Posts/replies refers to posting to one's own feed and receiving replies, or replying to others' posts. Direct/group messages refers to sending content to others or receiving content from others via direct or group messages. To perform the comparison, we used quantitative survey instruments to establish two measures of social connectedness. The first measured engagement in shared experiences and joint activities by using two 6-point forced-Likert items (1: Completely Disagree, 6: Completely Agree) where respondents answered "I get to share similar experiences" and "I get to engage in joint activities" with the people in their participant group, $\alpha = 0.76$. The second measured entitativity [38], or the sense of being a group. For this we asked four-questions along a 7-point Likert-scale (1: Not at all, 7: Extremely) where respondents answered "I feel a sense of togetherness", "I feel like a team", "I feel like a unit", and "I feel disconnected" (reverse coded), $\alpha = 0.86$. For analysis, we used a pairwise random-effects model, correcting for multiple comparisons using the Tukey method for p-value adjustment.

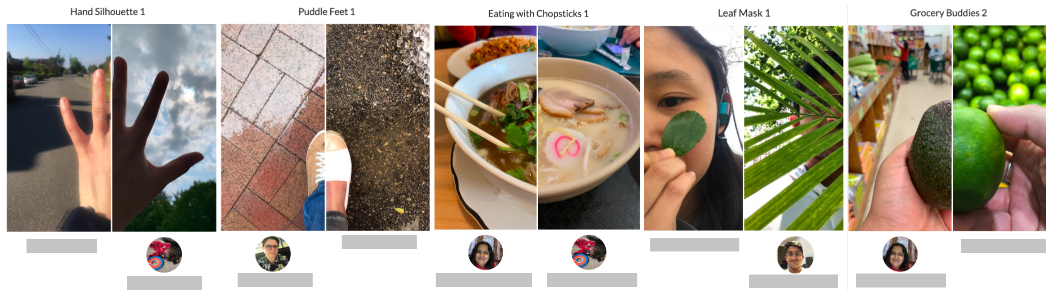
6 RESULTS

6.1 Cerebro promoted opportunities to actively engage and made it easier to do so

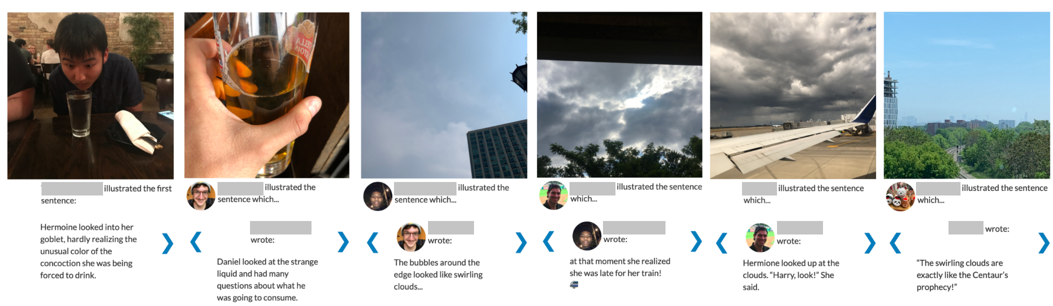
Collective participation in OCEs led to active engagement between geographically-distant participants. Over the 20 day study period, participants across 4 different time zones used Cerebro to create 36 Half Half Photos; see Figure 7(a). In addition, 6 people collectively wrote and illustrated one Storybook; see Figure 7(b). 14 of the 21 participants engaged with others in at least one OCE; among these 14 users, the average number of interactions per user was 4.7 and the median was 3.5. The user who participated the most had 13 interactions through OCEs.

12 of 14 participants reported that Cerebro helped them interact with existing ties that they normally do not reach out to. When asked how their Cerebro usage affected their opportunities to interact with their alumni community, participants said that Cerebro has given them the opportunity *"re-interact with people [they] hadn't seen in a long time"* (P17) or have not *"talked to since graduation"* (P15). These findings suggest that OCEs can be useful for connecting casual friends who are now physically distant, like college alumni, who might not normally find opportunities to actively engage with each other.

Through our analysis, we found that Cerebro made actively engaging easier by (1) identifying opportune moments during a user's daily life that are appropriate for participating; (2) creating shared interactional grounding through people's shared situations; and (3) structuring how one should participate in shared activities within these situations. We review each of these below.



(a) Half Half Photo Example Results



(b) Storybook Results

Fig. 7. Examples of how participants actively engaged in OCEs together.

First, Cerebro recognized opportunities to actively engage across a variety of situations, including going grocery shopping, experiencing a rainy day, and visiting a library or bookstore. Collectively, participants in the Half Half Photo OCE participated across all 11 variants of the experience. For example, in one version users "combined" their soup and noodle bowls while eating at asian restaurants, while in another they matched a lime to an avocado while grocery shopping; see Figure 7(a). In the Storybook activity, one person photographed their glass of beer while at a bar, while another user continued the story on a cloudy day; see Figure 7(b). Participants found interacting through these opportune moments in their daily lives enjoyable and convenient. 4 users mentioned that they enjoyed getting to actively engage during everyday situations. For example, P3 said *"I loved being able to take something mundane like my commute and make it a meaningful social experience."* When asked what was unique about using Cerebro compared to posting on social media, one user said: *"I feel like the difference between that and Cerebro is that for Snapchat so you have to be thinking about it to do it... when...I have to think of moments that are Snapworthy, I never do that...whereas in Cerebro... it pings me [during] very casual... everyday [moments]... and [participating in this experience] is easy for me because I'm just here"* (P12). These results suggest that identifying opportunities for interaction in everyday situations may have reduced the mental effort that is typically required to decide if a moment is worthy of initiating an interaction with.

Second, by grounding interactions in people's shared situations, Cerebro helped remind participants of the commonalities between them and their friends at distance and made it easier to interact through these shared moments. For example, P19 said *"There's a normalcy to these experiences... like going grocery shopping or just being outside... that makes me remember that people I don't interact with* *often are still around and doing similar things to what I'm doing."* By helping users recognize their shared situations and surfacing opportunities to interact while they are in them, the interactional grounding that Cerebro provided made it easier for people to start interacting. P10 said: *"Cerebro is able to create some of that shared context via experiences that thereby allows me to more easily connect with the said person... it usually doesn't come across my mind to message my friends about my experiences... but in this particular case, with proper context detection, Cerebro helps me publish my experiences whilst enjoying sharing the experiences with others whom I know readily."*

Third, the ways that Cerebro structures how one should participate helped make interacting more convenient. For example, P19 felt that *"Cerebro sort of forces an interaction to happen, in the best way possible, when I don't have anything particular to say or show to a person. I guess I don't have to work as hard to open new interactions with people I haven't spoken to in a while. Taking a picture is a lot less anxiety-inducing than 'Hi, it's been a while, how's it going?'"* By structuring how people might engage in a shared activity, Cerebro may have helped to reduce the burden and anxiety that is typically required to start new interactions with someone they haven't interacted with recently. 3 participants described that they enjoyed that Cerebro's structured interactions provided a reason to interact. For example, P21 liked that *"Cerebro gave me a chance to connect with people I don't often speak to, but that I liked from [my Alum group]. It was nice not to feel like I had an explicit reason to reach out to a person."* This illustrates how structured interactions that guides how a user can actively engage with others can make initiating an interaction less of a burden on users than channels like direct messaging which require more energy and commitment to initiate a directed communication.

6.2 Cerebro interactions were socially connecting by structuring ways to engage in shared experiences and activities

We found that users who participated in OCEs using Cerebro found their interactions to be more connecting than their experiences making Posts/Replies on SNS and about as connecting as Direct/Group Messages on SNS. Figure 8 presents the results of the quantitative comparisons across our two measures of social connectedness for the 14 participants who engaged in at least one OCE. Cerebro interactions were rated higher than Posts/Replies in terms of the "Sharing Similar Experiences and Engaging in Joint Activities" scale ($p < 0.0001$, $\mu_{cerebro} = 4.36$, $\mu_{posts} = 2.36$). In addition, Cerebro promotes greater sense of being part of a group as compared to Post/Replies ($p = 0.03$, $\mu_{cerebro} = 3.61$, $\mu_{posts} = 3.0$). When comparing Cerebro and Direct/Group Messages, our quantitative results did not show a significant difference across both a sense of being part of a group ($p = 0.44$, $\mu_{cerebro} = 3.61$, $\mu_{direct} = 3.89$) and sharing experiences and activities ($p = 0.95$, $\mu_{cerebro} = 4.36$, $\mu_{direct} = 4.25$).

Participants felt more involved in each other's lives while engaging in shared experiences on Cerebro than when making posts/replies on SNS. For instance, a participant who lives on the opposite-side of the country from their alumni friend described, *"Just knowing that what I was doing was explicitly something that [my friend] was doing as well... Not only was it a reminder of them, it's a reminder that I'm around too"* (P6). Another user described how daily moments became less lonely: *"what I liked is the common experiences - for example, showing that you're [riding] on a train, [watching] a sunset, or drinking a coffee. Some parts of my routine that feel lonely became less lonely because I got to share a moment knowing that someone else from [my alumni community] was doing something similar"* (P3). In contrast, participants found posts/replies to be less personally connecting than Cerebro. For example, P7 said, *"On Snapchat and Instagram... you see people's stories... the person is posting about their day or whatever they're up to.... But you're not really a part of that if you're not at a restaurant or walking on the beach [like them]... they don't actually have to think about you while they're posting the story."* While posts/replies on other SNS allow convenient

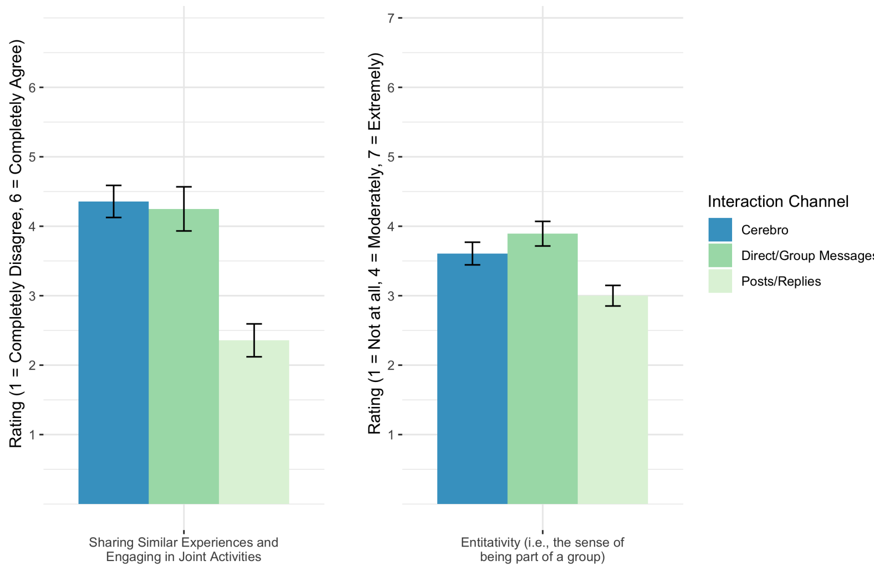


Fig. 8. Our study asked participants to rate Cerebro and two other interaction channels found on SNS (Direct/Group Messaging and Posts/Replies), measured against two constructs of social connectedness ("Sharing Similar Experiences and Engaging in Joint Activities" and "Entitativity"). Cerebro was rated higher than Post/Replies for both *Sharing Similar Experiences and Engaging in Joint Activities* and *Entitativity*, and about the same as Direct/Group Messaging along these two social connection constructs.

sharing and engaging around the content of an individual's experience, they are less personally connecting than Cerebro, which instead structures interactions around shared experiences. This evidence suggests that structuring participation in similar activities in shared situations can be more socially connecting than isolated postings on traditional SNS.

Participants also felt the experiences were more personally connecting when engaging in interdependent activities on Cerebro than when making posts/replies on SNS. As P7 described, *"for Cerebro, it's cool because you and the other person are trying to have a common goal... there's already something draws you towards each other, whether it's two sides of the same picture or writing a common story... and makes it feel it a bit more real... where you're actually a part of that person's life and that person will think about you... you're more involved in the other person's life."* Cerebro's structured, interdependent activities, like collaboratively creating a digital artifact together, impacted how personally involved this user felt while interacting with their friend. Participants contrasted Cerebro with posts/replies, which seemed to lack an interdependence in what each person contributed in the interaction. For example, one user noted that *"when people do [reply on Snapchat], it'll be a Snap with a caption or some text... but I don't have this expectation they are going to do something interesting to match [my] post‘‘* (P11). Another user expressed similar limitations when replying to content posted within a group chat: *"Somebody posts an article... or Someone posts a meme... we'll all react to it. It's like a one trail conversation... group chats are often just people talking about one person's comment"* (P3). These examples suggest that repliers on traditional SNS may be more peripheral in the interaction, given that it is not necessary to have unique individual contributions to achieve a shared goal. This suggests that Cerebro can promote friends feeling more involved in each others' lives because the cooperation required to achieve a shared goal leads to social bonding and feeling a part of a group.

6.3 Remaining Obstacles

Despite the initial successes of our pilot deployment study, we also observed several obstacles in promoting opportunistic interactions at a distance within situations that arise in people's daily lives. While Cerebro helped to create opportunities for active engagement, the median participation rate was only 3.05%; in other words, users were notified on average many times more than they actually participated. In our analysis, we found that the low participation rate can be attributed mainly to 3 causes: (1) inaccuracy in situation detection; (2) personal situations and contexts; and (3) personal hesitations.

First, when asked what prevented their participation, 11 of the 21 participants cited inaccuracies with situation detection, that is, being notified for experiences that did not match their situation or what they were doing. For example, one participants said, *"I would be prompted to participate in an experience when it was not actually relevant to what I was doing, like it would give me an incorrect weather experience, or detect that I was near a restaurant and ask me about my meal even if I was not eating"* (P16). 4 participants said that they started to ignore all notifications due to initial inaccuracies, which could explain lower participation rates through the remainder of the study.

Upon further investigation, we were able to trace inaccuracies and mismatches in situation detection to two primary sources: low-level context detectors and high-level situation expressions. For low-level context-detectors, place detectors sometimes mapped users to places they were not visiting or assumed a user in a dense-urban area to be at multiple places in an area at once because the location-matching was too coarse. For example, P4 noted, *"I also got a ton of false positives - like my bus stop was apparently tagged as an Asian food restaurant and a bar, because every morning I'd get notifications to do activities while I was waiting for the bus."* We also found that the weather API sometimes provided incorrect hour-by-hour weather, which matched users to rainy weather experiences when it wasn't actually raining for them. These examples show how low-level context detectors can reveal their inaccuracies when tested in real-world use cases, and that the implementation of these context detectors and their underlying context models may need to be refined for them to be useful.

For high-level situation expressions, we found that what we programmed as our situation detector didn't always sufficiently capture all the relevant details needed for participating. For instance, one user was matched to the Puddle Feet OCE because the weather was rainy where they were; however, they were unable to stomp in a puddle because they were indoors. For the Big Bites OCE, even though we specified types of restaurants that might serve food requiring a big bite, one participant couldn't photograph themselves taking a big bite because the food they ordered didn't require big bites. These examples reflect a general challenge that OCE developers face in expressing their idea of a situation accurately and in ways that are detectable using available context features.

Despite these issues, some users tried their best to participate given their current situation regardless. For example, when asked what they enjoyed about the experience of using Cerebro, one user said: *"also it was kinda fun adapting the prompt to my surroundings - like the prompt didn't always match my surroundings perfectly... [like] I am at a bar, get 'Cheers', but I have finished my beer, so had to improvise a little"* (P4). In another instance, a user was notified for Puddle Feet while indoors, so they improvised by pressing their feet up against a window covered in rain drops. So, while OCE developers may generally prefer more accurate situation detectors than not, it is worth noting the joy that can come from improvising and recognizing the value of allowing for improvisation in OCEs.

Second, beyond inaccuracies in situation detection, users sometimes didn't participate even when the detected situation afforded engaging in the OCE because their personal situation didn't. 12 of the 21 participants described several types of scenarios in which they were busy or otherwise unavailable when notified: when already engaged in a real-life social interaction (e.g., *"I also didn't participate if I felt too awkward taking my phone out to take a picture of a specific action in front of people I was spending time with"*); when trying to accomplish another task on the phone (e.g., *"I was checking my phone for a specific reason, so kind of just swiped past the notification"*); or when real life tasks took higher priority (e.g., *"There were also sometimes where I* could *have done the experience but was in a meeting, or at work, or like trying to wrangle my bike off the train and it was therefore infeasible or low-priority for me"*). These examples underscore how it is important to consider other notions of appropriateness, such as a user's personal context that indicates whether they are available or interruptible, in addition to the situational context of what's needed for the interaction.

Third, some OCEs prompted users to engage in ways they felt personally uncomfortable with. 4 participants felt awkward when asked to engage in particular activities, such as taking a selfie with a big bite of food in their mouth. A user was hesitant to participate in the Hand Silhouette OCE because *"I was alone and did not want to look weird taking pictures of my hands"* (P21). These findings highlight the importance of not only designing interactions that are socially connecting based on theory, but also ones that users would feel comfortable engaging with.

7 DISCUSSION AND FUTURE WORK

Having demonstrated how OCEs can promote active engagement in socially connecting interactions that fit into our lives, we revisit the core ideas behind OCEs, discuss how they may generally inform the design of social technologies for connecting at distance, and suggest directions for future research.

7.1 Identify Situations with Shared Interactional Grounding and Structure Shared Experiences and Activities within these Situations

Compared to the design of other social technologies for connecting at distance, OCEs are distinguished in that they identify shared situations and structure shared activities in those situations to help establish interactional grounding. Through studying how college alumni used OCEs, we found that OCEs helped users find opportunities to actively engage with friends who live physically distant with whom they do not frequently interact. Users who interacted with OCEs found that they made it easier to actively engage with friends who live at a distance than initiating direct communication. This is because OCEs identified opportune moments in users' everyday routines that are appropriate for participating; created shared interactional grounding through people's shared situations; and provided structured activities that lowered the effort needed to initiate an interaction and engage in a shared activity. In other words, by forging connections across people's individual situations, OCEs created a shared interactional space that gave people a reason to actively engage with one another while making it easier to do so.

While our work focused on using OCEs to create opportunities for shared interaction, our study also revealed the potential for a completed OCE to serve as its own interactional grounding for promoting further interactions. Participants noted that by having shared an experience or enjoyed a laugh through an OCE together, they would feel more comfortable with interacting with the other person if given a future opportunity. One way to promote further interactions is through the completed OCE itself. For instance, by adding ways to react and comment on a completed OCE, one could imagine the completed OCE as a "joint post" that provides a space for interacting further that users can return to. Joint posts exist on SNS: for example, Facebook Friendversary posts [16] resurface past shared memories and experiences (e.g., a photo from the last time friends hung out in-person) to create interactional grounding that sparks interactions and conversations in the present. However, unlike resurfacing a photo from a past shared experience that could have only happened in person, joint posts that result from completed OCEs can create the grounding for further interactions that is based on a newly shared experience or activity that took place at distance.

While the potential is there, in our deployment users didn't have a way to comment and react to completed OCEs. As a consequence, only a few participants reached out to one another after completing an OCE; those who did used messaging channels outside of Cerebro, and with closer friends whom they sometimes exchange messages. Several participants agreed that having other ways to interact with one another in the app could reduce the barrier to following up after completing an OCE. These sentiments echo prior research, which found that direct communication is more difficult when there is not a channel for commenting in the same context as the content that provides interactional grounding [41].

Beyond simple affordances for commenting and reacting to completed OCEs, there is a broad opportunity to consider how a completed OCE can serve as the interactional grounding needed for future interactions that extend and sustain experiences and social interactions beyond a coincidental moment. One potential idea is to form micro-communities around repeated interactions with the same people through a set of experiences that build on one another. For example, we could have an OCE that proposes an opportunistic ramen slurping competition one week, and then in the next week asks everyone who previously participated if they wanted to slurp ramen together again. The experience starts off with an opportunistic interaction but later creates opportunities for people to intentionally connect with one another, for example, by finding a regular time to eat at ramen shops around the world together. Through this example, we can see how the shared interactional space an OCE creates need not be ephemeral; it can start in a coincidental moment, and later persist and flourish into a sustained space for connecting.

7.2 Design Situated Interactions for Social Connection

To ensure that active engagement at a distance through OCEs is actually socially connecting, we conceptualized a set of OCE design guidelines that recommends ways to make use of people's situations and structure shared activities that help scaffold people's participation. The OCEs deployed in our studies implemented these design guidelines. OCEs for shared experiences, such as raising a glass to "virtually cheers" while having a drink, or stomping into a puddle on a rainy day, identified situations that provide a shared context for interacting, e.g., that contain common object affordances or afford similar actions across situations. OCEs for interdependent activities, such as collectively writing and illustrating pages in a storybook, or completing two-halves of a single photo together, created links across individual activities to increase positive interdependence and surfaced these links so people could see how individual activities contribute to shared outcomes and artifacts.

In our deployment study, users pointed out how elements of the OCE matching our design guidelines helped them to connect. Users who participated by doing similar activities in similar situations felt that they were more a part of each other's lives, whereas the feeling was more detached when a person posts about their individual lives on SNS but others are not doing the same activity as them. In addition, users who cooperated to create digital artifacts (e.g., complete two halves of the same photo, tell one section of an evolving story) felt that they were engaging in a group bonding activity, and enjoyed seeing how people's individual contributions built towards a common goal. While our results are promising and suggest that the design guidelines may have contributed to creating socially connecting experiences, future studies can directly test for the effectiveness of the design guidelines by comparing OCEs implemented with or without them (as we demonstrated using Figure 3) for achieving social connection outcomes.

7.3 Support the Expression, Detection, and Presentation of Interactional Opportunities

Identifying an appropriate set of situations for enacting an OCE is critically important as it provides the grounding in which shared experiences take place. However, our study results show that identifying appropriate situations for shared interactions is an ongoing challenge. Our analysis highlighted a variety of challenges that result from inaccuracies in situation detection; a lack of awareness of personal situations and contexts; and a need to respect and address personal hesitations. While we expect there is no single solution that addresses the many issues that can arise, in what follows, we outline three directions for future research on identifying situations appropriate for shared interactions: (1) supporting the construction and refinement of *concept expressions* that define the interactional opportunity; (2) improving situation and context detection; and (3) designing alternative models for how users are presented with interaction opportunities.

7.3.1 Constructing Concept Expressions using Available Context-Features. In order for creators to implement OCEs that identify appropriate interaction opportunities, they need ways to express their concept of a situation to machines that can then automatically detect such situations across distributed contexts. While the OCE API provided a language for an OCE creator to specify a situation using context features, bridging from a creator's idea of a conceptually rich situation (e.g., grabbing a big bite) to a machine representation built using available context features is difficult as it requires creators to make sense of the available features and how they may or may not apply. In our deployment, we found that the *concept expression* that is programmed may not accurately capture the creator's concept of appropriate situations for interaction in a way that can be accurately detected by the system and acted upon by the user. For instance, we found that concept expressions can be underspecified when a creator uses one feature to express a concept (e.g., weather is "rainy" for a situation that affords jumping in puddles) but forgets other *interacting features* that also need to be met (e.g., user must be "outdoors", not "indoors").

To address such issues, future work on *authoring tools* can better support creators in the process of constructing a machine representation of the situation. For example, to help creators forage for and recall interacting features, an authoring tool might recommend ones that historically have interaction-effects with the features they are currently using in their construction (e.g., if using weather features, also consider indoors vs outdoors; if using place-based features, consider how time of day may affect types of activities or if the business is open vs closed). Moreover, an authoring tool can provide affordances for searching context-feature hierarchies to help creators discover other relevant or similar situations in which the OCE can take place (e.g., that afford similar actions, or have similar objects or object affordances). This can help broaden the set of situations (and thus opportunities) in which an OCE interaction can take place.

Beyond recalling and foraging for features, creators need better tools for analyzing and visualizing the execution of their concept expressions so that they can better understand how a situation detector may actually enact itself across real-world use cases. This can help creators see how their concept expression may actually play out, and recognize issues in either their conception of the situation or in particular low-level context features that may be too inaccurate to be useful. As the process of constructing effective concept expressions is likely to be iterative and non-linear, we expect tools that explicitly consider a creator's needs in their process of continually refining a concept expression to be particularly useful.

7.3.2 Detecting User's Situational Contexts. System designers can improve the identification of appropriate situations by developing better models for detecting a user's situational context. Our study results highlight that incorrect matches to interaction opportunities can sometimes be caused by incorrect detection of the context features that describe a user's situation. Despite our efforts to mitigate false positives in place context features (see Section 4.3.2 on Implementation Decisions), users were sometimes still matched to opportunities available at places that they were not visiting. Detecting a user's precise place context is particularly difficult in dense areas such as city business districts and malls where a user's location data is noisy and they are in the vicinity of multiple places of interest. To address this issue, system designers are advised to develop models that can reason about the likelihood across multiple potential place-contexts using context-features beyond location data alone [53]. These models could account for patterns that apply across most users (e.g., users generally visit coffee shops in the morning and get food at restaurants during lunch or dinner time) or can be personalized to individual users' routines (e.g., if a user goes to the same bus stop to commute rather than to eat at a restaurant nearby). Models of users' routines can be learned through usage data [6], or elicited by asking users directly during an app configuration phase (e.g., "How often do you visit coffee shops in the morning?") or during usage (e.g., "You visit this location frequently, but have not participated in experiences here. Please help Cerebro label this place: Home, Work, Bus Stop, Other").

In addition to improving models of users' location context, we need better ways to model users' personal and social context in order to better identify appropriate situations for interacting. We found in our study that users would not participate in experiences when they were unavailable due to real-life factors, such as being preoccupied with personal tasks or being already engaged in other in-person social interactions. This is a dimension of situation appropriateness that we did not consider in our models of detecting user's situations, but it is an important factor when determining if a moment is appropriate for engaging with others who are at a distance. Future improvements can be made by incorporating models of user interruptibility and in-person social context [27], which would allow a system to better reason about whether a moment is appropriate for turning a user's attention to opportunities for interacting at distance.

7.3.3 Presenting and Selecting Interactional Opportunities. While we expect better authoring tools and context detectors to improve the accuracy and appropriateness of situations that a system can detect and present to users, situation expression and detection are unlikely to be perfect and there will always be some tradeoff between notifying users of good opportunities for interacting that may otherwise go unnoticed and disrupting them with opportunities that aren't actually accurate, appropriate, or of interest to them. In our implementation and deployment, the system is solely responsible for presenting good opportunities. In future work, we can explore ways to share this responsibility with the user, so that the system curates a list of potential activities that a user might be able to perform in their current situation (e.g., [18]) but it is ultimately up to the user to select from this list. This allows a user to select OCEs that they are actually able to participate in from a list the system curates as its "best guesses" (e.g., an activity they can perform if their food had not arrived; an activity where they take big bites of their meal; or an activity designed to involve the participation of other in-person friends). In this way, this approach can be especially useful in cases where the system can only actually detect some aspect of context (e.g., if they are at a restaurant) but not others (e.g., whether or not the meal they ordered arrived).

8 CONCLUSION

This paper presents Opportunistic Collective Experiences (OCEs): social experiences powered by computer programs that are opportunistic and structured. OCEs are opportunistic: they identify coincidental situations that afford active engagement at a distance. OCEs are structured: they facilitate socially connecting shared experiences and activities during these situations. As OCEs identify the coincidental moments when shared situations exist and structure how to engage in shared experiences and activities, they establish interactional grounding to make it easier for users to actively engage. Unlike direct messaging channels that are unstructured and free-form, OCEs take away the burden of users having to figure out when, why, and how to initiate an interaction. At the same time, OCEs are socially connecting by highlighting shared aspects of people's experiences and emphasizing user's collective involvement. This is in contrast to isolated postings of individual experiences on social media feeds, which can encourage passively engaging in ways that are not socially connecting.

Our work on OCEs provides social experience creators and researchers with insights on how to design opportunistic, structured social interactions that occur at distance. Further, the computational platform we developed demonstrates how social technologies can shift away from supporting the posting of individual experiences and passively engaging with these posts toward supporting actively engaging in shared experiences and activities through our daily lives. We envision future OCE designers can create richer social experiences using OCEs, perhaps through a progression of shared experiences and activities that build and sustain social connections over time in ways that are even more effective but that remain convenient for users. For OCEs to be effective, we will also need better tools, technologies, and interactions for identifying and surfacing appropriate situations for engaging at a distance. Future work can better support expressing and refining concept expressions to machines, improve detection of users' situational contexts, and explore alternative models for presenting OCEs that share the responsibility of detecting appropriate situations between the system and the user.

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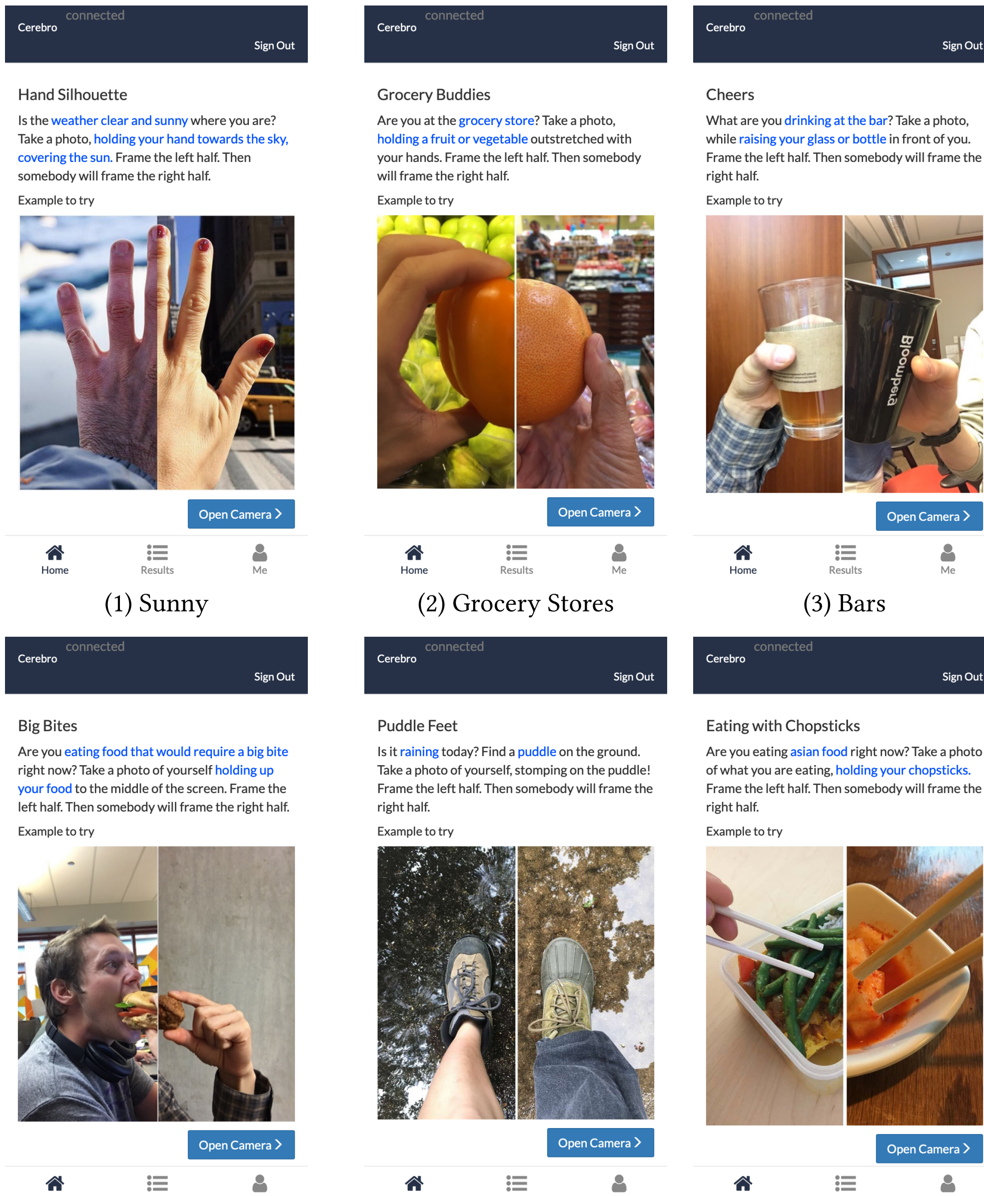
10 APPENDIX: HALF HALF OCE VARIANTS



(1) Sunny (2) Grocery Stores (3) Bars

(4) Restaurants Serving a Big Bite (5) Rainy (6) Asian Restaurants

Fig. 9. First 6 of the 11 Half Half OCE variants by shared situational context

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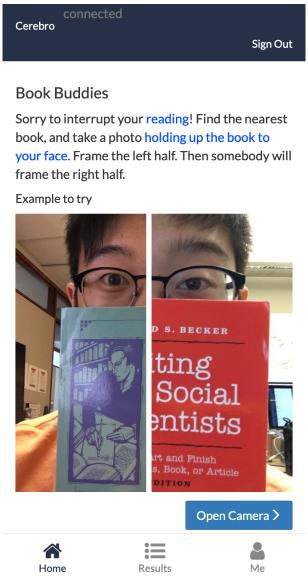
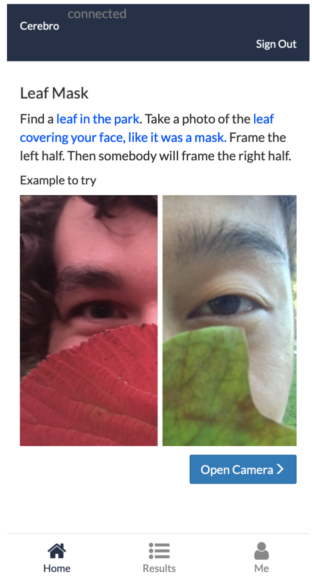
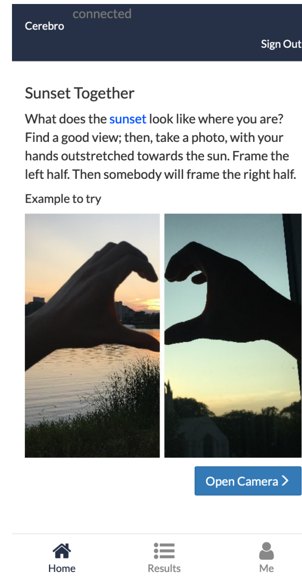


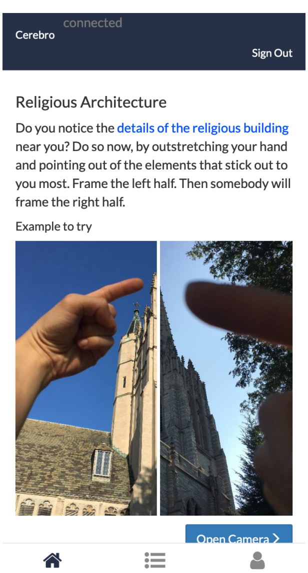
(7) Bookstores/Libraries



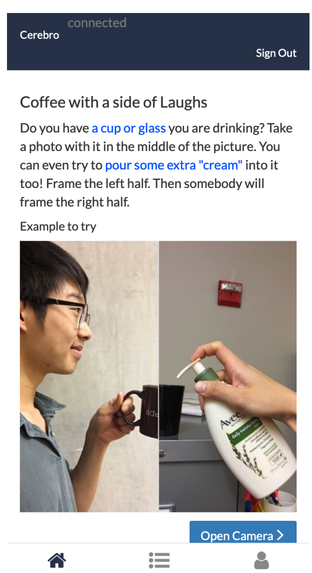
(8) Parks



(9) Sunset



(10) Places of Worship



(11) Cafés

Fig. 10. Remaining 5 of the 11 Half Half OCE variants by shared situational context