Culturally Based Design: Embodying Trans-Surface Interaction in Rummy

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ABSTRACT

We present culturally based design (CBD), a new paradigm for designing embodied natural user interaction (NUI) with digital information by drawing on customary ways that people use physical objects. CBD coalesces experiences, practices, and embodied mental models of pre-digital activities as a basis for the design of interactive systems. We apply CBD to address *trans-surface interaction*, the manipulation of information artifacts from one device to another. We develop Trans-Surface Rummy, because the game involves highly dynamic combinations of turn taking and non-linear out of turn play, while transferring information artifacts to and from private and social surfaces. Through the CBD process, we create the *trans-surface wormhole*, an embodied interface technique. We investigate the trans-surface wormhole's efficacy and other aspects of culturally based design with young students, and with elderly members of our local bridge club. We derive implications for the design of trans-surface interaction, and more broadly, from the process of CBD. We initiate a research agenda for trans-surface interaction.

Author Keywords

design models, culture, natural user interaction, sensemaking, affordances, games, elderly, embodiment

ACM Classification Keywords

H.5.2 Information Interfaces & Presentation: Interaction styles, Theory and methods

General Terms

Design; Theory.

INTRODUCTION

We develop culturally based design (CBD), a new paradigm for designing embodied natural user interaction (NUI) with digital information by drawing on customary ways that people use physical objects. Abowd and Mynatt pose a research challenge for ubiquitous computing: to address our desire for natural interfaces that facilitate rich communication between humans and computation, support common forms of human expression, and leverage our implicit actions in the world [1]. To answer this ubicomp NUI challenge, CBD invokes the *engaged familiarity* that Heidegger uses to describe our everyday dealings in the world [11]. Through the implicit mandate of *in-order-to*, people manipulate equipment and materials that are *ready-to-hand* to perform activities and accomplish goals.

CBD draws engaged familiarity from pre-digital contexts into computing to define a design method for answering the ubicomp NUI challenge. A panoply of new technologies for NUI have become available, including but not limited to stylus, capacitive multi-touch (iPhone), FTIR [9], ZeroTouch [16], and Kinect. The design of new interaction paradigms lags. When new modalities of interactive computing are introduced, it can be hard for designers and engineers to know what to do with them. How can designers formulate new approaches? How does one design the "killer app"? How do we engage diverse populations, such as the elderly?

Many interactive systems are built to improve productivity on tasks [24]. To meet the ubicomp challenge, CBD inverts the task-centered design paradigm. Task-centered design is valuable for addressing needs and requirements. CBD alternatively seeks "interesting" human activities that can serve as the basis for deriving new NUI design ideas. The CBD process identifies activities to represent with NUI systems based on how people use culturally-based embodied mental models to function in them through ready-to-hand action. Criteria include engagement in rich embodied interaction, information exchange, communication, and expression. Interesting activities, for example card play, may even seem frivolous. CBD leverages underlying repositories of experience and practice, which people routinely access through engaged familiarity. By using NUI technologies to mimic ready-to-hand embodied practices, CBD carries the pre-digital world forward. The knowledge derived by building these systems has the potential to inform new interaction techniques.

Tabletops are common artifacts across cultures, differentiated by situated particularities of form, use, function, and custom. People put many things onto tables, enacting social, informational, and physical functions. A CBD approach seeks pre-digital tabletop activities to represent with NUI technologies, as a source of design ideas. Cards, while less universal, have been widely used on tabletops. Card play dates back to the 13th century in China and Japan, and the 14th in Europe, with subsequent practice in India, Russia, and North America,

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including among Native Americans [10]. Cultural functions include divination, gambling, and recreation. Card play is practiced across generations, making it a resonant cultural source for interaction design. Cards function as units of information, expression, and social interaction; they afford hiding and revealing information [22]. They are manipulated with and in hands, on and across tabletops. The present research investigates card play as a means for addressing the design of what we christen as *trans-surface interaction*, in which people manipulate information artifacts across devices as part of sensemaking, ideation, and play.

To instantiate CBD, and investigate the design space of trans-surface interaction, we develop and evaluate a system for collaborative card play, Trans-Surface Rummy. A tabletop iPad functions as a shared workspace. Handheld iPhones function as private information spaces. Through a user study in our local community bridge club, the CBD process draws us to formulate stealth education methods for teaching the elderly about technology.

We present cultural and cognitive framing and background for culturally based and trans-surface interaction design. We develop Trans-Surface Rummy, including the design of symmetric subspaces of the shared social surface, of a new, asymmetric trans-surface interaction technique, the wormhole, and of a private hand workspace. We develop a mixed methods evaluation, with college students and elderly card players, including a fluidity analysis methodology for validating the trans-surface wormhole design. We develop implications for trans-surface interaction design, and more broadly, for CBD.

BACKGROUND

We integrate prior work involving culture, embodied mental models, trans-surface interaction design, and stealth learning. We then provide a brief description of the game of Contract Rummy, focusing on aspects of game play that make it interesting as a target for culturally based design.

Culture

One side of Heidegger's engaged familiarity is rooted in culture. Kroeber and Kluckholn assembled concepts and definitions of culture, categorizing them as descriptive, historical, normative, and psychological [14]. Descriptive definitions address knowledge, beliefs, systems of thoughts, traditions, and customs. They include artifacts, technologies, and techniques. Historical definitions emphasize social heritage and tradition, the evolution of artifacts and processes, and everything that can be communicated. Normative concepts emphasize customs, traditions, attitudes, ideas, and symbols that constitute behavior patterns, forming a way of life. They include acquired or cultivated behavior, feeling, and thought. Psychological definitions are said to emphasize adjustment, such as the equipment and techniques by which people try to attain their ends, and standardized ideas, attitudes, and habits developed with respect to the satisfaction of human needs.

Geertz developed the concept of *situated knowledge*, implying that the layers of meaning that characterize what people know are deeply rooted in the particular places where they live, and concomitant people, relationships, roles, practices, artifacts, and experiences [6]. Suchman used the situated knowledge framework as the basis for the notion of situated action, fundamental for artificial intelligence, robotics, and context-aware HCI [26]. Star developed an ecological perspective on how computing infrastructures are situated in culture and practice [25]. Culturally embedded computing investigates how digital technology is situated in culture [23]. CBD inverts this paradigm, drawing on customary manipulations of non-digital technologies, and associated behavior patterns, processes, and movements, to design embodied interaction based on cultural practice.

Like other researchers, Thorensen uses specific situated contexts to drive integrated participatory action and research [27]. This is inherently valuable. As a methodology, CBD differs in its prescription to choose particular cultural practices to investigate specifically so knowledge situated therein can also contribute to human-centered computing in *other* contexts.

The 'workaday world' CSCW design paradigm prescribed the importance of going outside of formal work to wholly incorporate, "a melange of motivations, goals, practices, and social habits," including those, "not easily segmented into a series of tasks" [17]. This is kindred to the present approach, but its orientation nonetheless was based in work. *The present research emphasizes the need to investigate significant activities and artifacts from the full panoply of human experience, across our cultural gene/meme pool, as pre-digital instances of ready-to-hand knowledge that can inform NUI design solutions to the ubicomp challenge.* The rummy context serves as a culturally based source for designing trans-surface interaction. We choose the game Contract Rummy, because cards are transferred from private hands to and from a social tabletop through turn taking and more spontaneous interaction in which players override turns, and also because one author grew up playing it across generations of family and friends.

Embodied Mental Models

Heidegger's ready-to-hand is a phenomenological touchstone for embodiment. We connect affordance, mental models, and processes of cognitive restructuring to generally address CBD, and more specifically frame the rummy context, tabletops, cards, and trans-surface interaction. Cognitive restructuring processes are important, because they can play a significant role in ideation and the formation of mental models.

Another side of engaged familiarity connects cognition and action. We relate Gibson's concept of *affordance*, actionable properties of physical objects [7]. A person situated in an environment integrates embodied ready-to-hand knowledge with perceivable properties to manipulate actionable equipment and materials, i.e. affordances. CBD draws on cultural stores of knowledge that invoke "in-order-to" and thus inform ready-to-hand manipulation of equipment and materials, culturally situated as artifacts, through their perceived physical properties.

A key component of embodiment is how a human being is physically situated in a spatial environment. Kirsh analyzes ways in which people intelligently use space [13]. People use spatial arrangement to externalize the cognitive state of a

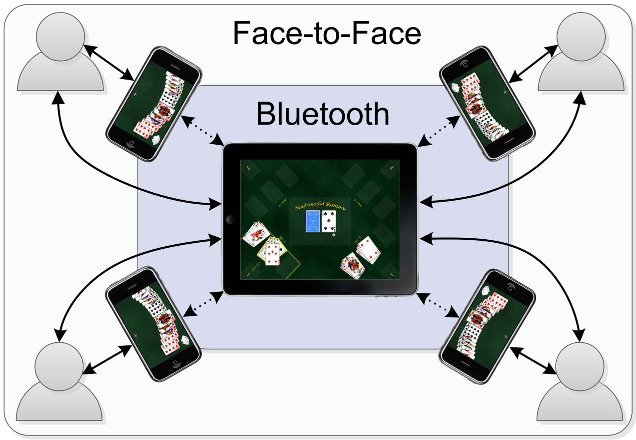

Figure 1. The game system incorporates private iPhone surfaces and a central social iPad surface. Dotted lines indicate digital communication. Solid lines represent touch and sight

task, assisting internal computation. Kirsh differentiates between informational and physical structuring by function: informational structuring serves the purpose of cueing cognitive events and processes inherent to a task; physical structuring constrains, to prevent specific actions. Restructuring occurs naturally to achieve both of these equally important functions, to externalize cognition during a task.

Glenberg shows that mental models are embodied by how they are experienced in situated contexts [8]. People combine affordances, knowledge, and goals through *meshing* processes. The affordances of an object are a function of the context in which they are perceived. How a person-as-body is situated with respect to affordances and larger environmental factors informs this process. As goals and the environment change, new possibilities for action, and associated mental models, emerge.

Cognitive restructuring, in which a problem space is transformed into a cognitive schema that supports the formation of solutions, is an important stage of sensemaking [21]. Embodied forms of physical information artifacts support restructuring by affording manipulations that represent schema transformations. Interaction designers can use restructuring strategies to inform design by mimicking and supporting them in digital designs. An important part of informationally structuring objects is to highlight and hide affordances to manage what information is readily perceived [13]. We investigate the affordances of physical and digital playing cards, with regard to support for informational structuring, cognitive restructuring, and mental model evolution.

Trans-Surface Interaction Design

An issue for trans-surface interaction is the design of mappings of affordances and feedback for moving objects across surfaces. In physical reality, an object moves continuously from one surface to another. In the digital medium, surfaces are inherently disconnected.

Prior techniques for trans-surface interaction were developed without a situated use context. In Rekimoto's seminal direct manipulation Pick-and-Drop technique, an information object, or state, is exchanged by using a stylus to touch one surface, picking up the information, and then touching another surface with the same stylus. [20]. Hinckley's stitching enables using a stylus to drag an object across tablets [12]. The present CBD approach defines the trans-surface interaction mappings of wormholes based on card playing practice.

Recent research seeks physical continuity between surfaces [2]. Computer vision was used to track interaction above surfaces; projection fills in the space between. These solutions are cumbersome and costly. We hypothesize that by simply designing transitions that contextually mimic physical transitions, without visual continuity, it is possible to economically achieve fluid trans-surface interaction.

Stealth Education & Engaging the Elderly

The CBD method brought us into card games, which emerged as a means for involving the elderly with new technologies, because cards are an old means of entertainment. Stealth education uses games as a means to teach, by making learning a by-product of engagement in game mechanics [3]. We pose a different form of stealth education, teaching how new technology works through culturally based interaction. Seniors bring their engaged familiarity with a cultural activity, card play, into their experience of technology. They are confident when cards are ready-to-hand; this confidence helps them forget any fear of technology.

Card play has been used as an activity context to expose elderly to touch-based games [4]. The game involved a single human playing against a computer agent. An analogy based on physical interactions with cards created intuitive interactions. The researchers found their game helped older, inexperienced users become acquainted with digital technology. The present research adds the social dimension, engaging co-located players in trans-surface interaction to play cards. Prior findings, that seniors prefer co-located interaction [5], coincide.

Leonardi et al. recently suggested that touch-based gestural interfaces are suitable for adoption by the elderly, as a result of their physical directness [15]. Like Turner [29], we find value in considering the role of familiarity in people's experiences of computing systems. We synthesize these findings, integrating Heidegger, to use engaged familiarity as a basis for designing trans-surface interaction. The activity's grounding in culture serves, for the elderly, as a gateway for gaining confidence. Researchers can build on the resulting skills and confidence to potentially engage the elderly in other activities, such as health monitoring, with the new technologies.

Contract Rummy

Contract Rummy[1] is an interesting context for trans-surface CBD because of its *game mechanics*, actions taken by players within the rules of the game [22]. These game mechanics involve highly dynamic combinations of turn taking and nonlinear out of turn play, rapid transfer of cards between private and social surfaces, and iterative reorganization of the private hand to form strategy. These operations involve intensive social interaction, particularly at key junctures of play.

[1] The present system uses the rules for the rummy variant, Contract Rummy; by "rummy", we specifically mean Contract Rummy.

Figure 2. The social surface: a shared central space, and up to 4 symmetric individual player subspaces, at the corners. Each player subspace displays feedback, such as name, score, and cards remaining. When a player lays down, her melds are fanned out within her subspace.

Contract Rummy is played with two 54 playing card decks [19]. It requires players to construct *melds*: either a run or group. A *run* is consecutively ranked cards of the same suit (e.g. ♣4, ♣5, ♣6). A *group* is a set of same ranked cards (e.g. ♣3, ♠3, ◇3). A Joker can represent any card in a meld.

In play, a *round* consists of several turns. For each round, a *contract* specifies required melds. Undealt cards become the *stock*. A card initially drawn from the stock initiates the *discard pile*. Players take turns until one has no cards; players are penalized by points for their remaining cards. At the start of a turn, a player draws the top card from the discard or stock pile, attempting to privately construct contract melds. A player builds melds incrementally, over several turns, by informationally structuring cards in her hand.

When a player finishes her turn, she discards a card face up on the discard pile. In order to further remove cards from her hand, a player must 'lay down': building the melds set forth in the round's contract, then placing them on the table. As a player lays down, their melded cards become visible in the social space. On her turn, a player who previously laid down may 'lay off' cards by extending any existing public melds.

Contract Rummy play is characterized by unpredictable non-linear flows of control, involving Jokers and buying a card. The dynamic non-linear game mechanics necessitate mechanisms for fluid transfer of cards between surfaces. Some actions can be taken out-of-turn. These mechanics heighten social awareness and engagement. If a Joker is laid down, a player can substitute for it the card the Joker represents. This can occur rapidly, at any point during the game. Immediately following a discard, before the next player draws, any player can "buy" the top card from the discard pile. The buyer takes the top cards from the discard and stock piles as penalty for acting out-of-turn, placing both cards in her hand.

TRANS-SURFACE RUMMY

The Trans-Surface Rummy game system is constructed as a distributed network of mobile devices: an Apple iPad and 2–4 iPhones (Figure 1). The iPad serves as a common surface where social game information is presented and manipulated. Each iPhone serves as a private surface for the hand of an individual player.

Devices are connected by a Bluetooth Public Area Network. By communicating over Bluetooth, the system can operate in any environment, without need for an external network. The devices communicate via the open source Object Oriented Distributed Semantic Services (OODSS) framework [28]. OODSS facilitates serialization and distribution of information artifacts as message objects over the network.

We present the culturally based design of the social surface and the trans-surface wormhole information artifact transfer technique. We investigate the design of mechanisms for informationally structuring cards on the private surface.

Social Surface Design: Symmetric Subspaces

The social surface is composed of 4 individual player subspaces. These subspaces are situated symmetrically at the corners of the iPad, with the draw and discard piles at the center (Figure 2). Corner-based symmetry was chosen, in lieu of an asymmetric edge oriented layout, to create congruent player spaces around the iPad surface's 4:3 aspect ratio. Players lay down melds in their subspaces, affording easy view around the table. This structure is physically embodied, in that it situates each player and her private hand space with her social subspace, forming a basis for the trans-surface interaction design presented in the next section. An initialization dialog situates each player and their private surface iPhone at a particular corner subspace of the social surface.

Wormholes for Asymmetric Trans-Surface Interaction

Players transfer individual cards between private and social surfaces to execute core mechanics, such as discarding and drawing. We develop an interaction model for transfers based on the cultural practice of holding cards in a fan, and drawing and placing them when transferring to and from the table.

When playing card games that require managing many cards, common practice is for players to hold their hand in a fan. The player arranges cards in the fan to encode meaning and relationships. The physical shape of the fan affords transferring cards only in and out at the top (Figure 3). This embodied structure informs the design of trans-surface wormholes.

We design trans-surface interaction by mimicking pre-digital play. To move a card to the social surface, a player begins by *flicking* it through the top of the private surface, out of her hand. The card appears face down in the player's *trans-surface wormhole*, her corner region subspace of the social surface (see Figure 2). Spatial proximity embodies its connection with the private surface (hand). When a card reaches the wormhole face down from the private surface, the player must touch and move it across the social surface to play it where s/he wants, simultaneously revealing the previously private card. This technique is intended to be executed as one fluid transition, as with pre-digital cards. *Hypothesis: players will experience moving cards through the trans-surface wormhole as fluid, despite the lack of physical continuity.*

In reverse, from social to private, a player moves a card across the surface to her trans-surface wormhole. The card is sent to the player's private surface, animated as sliding in from above, into the hand. Embodied and culturally based design of the wormhole between social surface and private hand motivates our hypothesis that participants will fluidly engage its affordances and execute this interaction ready-to-hand.

The trans-surface wormhole hybridizes prior "wormhole" [32], and surface "stitching" [12] techniques, motivated by the mechanics of drawing and discarding playing cards. Unlike prior designs, source and destination spaces are asymmetric. The private surface's top edge is connected to a spatially oriented target GUI component on the social surface. The modeled interaction with physical cards is likewise asymmetric: the mechanics of inserting and removing a card out of a fan differ from placing a card on or picking up from a table.

Mental Models in the Private Hand

Each player builds a mental model about the cards in her hand, based on her goals in the context of the game. The mental model includes information about particular cards and their relationships to others in the player's hand, on the table, and in other players' hands. The player makes decisions based on this model to achieve goals.

In a traditional game, these relationships are embodied through the player's composition of cards in her hand. Typically, this composition is linear. The player arranges cards in ways that make relationships among them easier to perceive, embodying her understanding. Sometimes, we have observed more complex arrangement techniques (Figure 4).

Our private interface design affords recognizing and building potential melds. Players organize cards by moving them between two different spaces, each affording different manipulation interactions: a potential melds area of cards deemed essential to strategy, and an unmelded hand of other cards. Each space features mechanisms to help organize the cards.

Alas, the design breaks from the embodied affordances of how cards are organized pre-digitally. What is lost is the fluid flexibility afforded by composition of physical playing cards. In the evaluation, we will find that this flexibility is integral to sensemaking with playing cards.

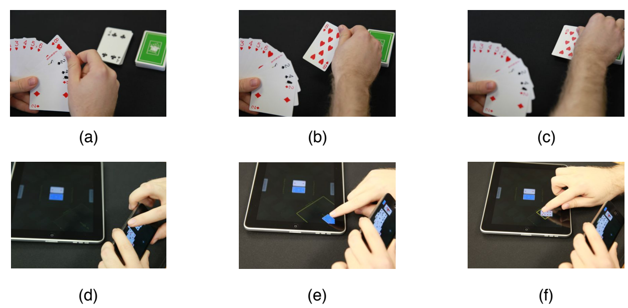

Figure 3. To transfer a physical card from to the table, the player begins by (a) selecting it and removing by upper edge from the fan of cards in the hand; (b) (with fluid transition) moving the card toward the table; and (c) placing the card on the table. Using the trans-surface wormhole technique: (d) selecting the card and sliding off the top of the phone; (e) transitioning to table to continue interaction; and (f) moving the card to the desired location on the social surface.

Figure 4. Participant informationally structuring their private hand with physical cards. In the bottom row of cards, the player has a complete run that she intends to play later in the game. In the upper row, the player holds several incomplete melds.

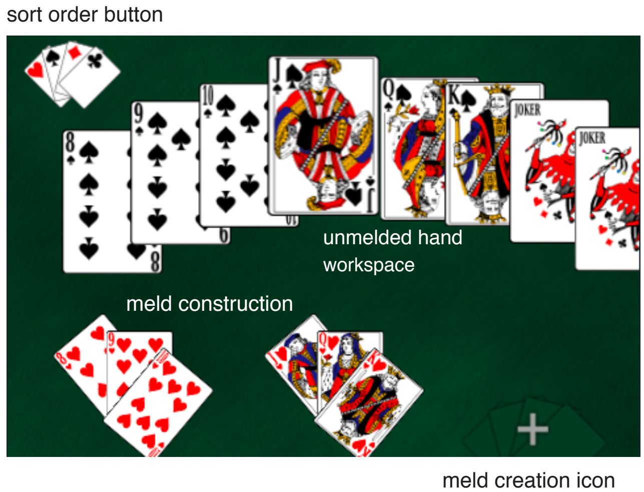

Figure 5. Workspaces and controls within the private surface.

Meld Construction Workspace

The bottom of the private surface is reserved for the meld construction workspace (Figure 5, bottom). At any time, a player may construct up to four potential melds. When these melds satisfy the contract, she can play them during her turn, to lay down.

A player creates a new meld by dragging a card onto the meld creation icon. Construction continues by dragging cards into existing melds. Each potential meld is sorted automatically. Cards missing from runs are represented as gaps in the fan. A player enlarges a meld by tapping it, affording dragging cards back into the unmelded hand or directly to other melds.

When a player believes she has satisfied the contract, she specifies melds to send to the social space, toggling them using a swipe gesture. Once she has selected sufficient melds, the lay down button appears. When touched, melds are transferred from the private space to the social surface. Cards in unused melds remain in the player's hand.

Unmelded Hand Workspace

The private unmelded hand workspace stores other cards, serving as a tool for recognizing potential melds (upper half of Figure 5). Initially, all of a player's cards are here. To facilitate building and invoking mental models of strategy, this space sorts constituent cards in multiple configurations. A player toggles between sorting criteria by tapping the sort order button (upper-left in Figure 5): rank then suit, or suit then rank. These configurations afford recognition of potential groups or runs, respectively.

Users can also swipe across the unmelded hand workspace to select a focus card, which is displayed 10% larger. The focus card is displayed in the center, enabling the user to arrange fewer cards on one side of the focus, resulting in more space between them. This simulates how a player might adjust the spacing of physical cards in her hand.

EVALUATION

We conducted a continuous iterative design process of prototyping and formative user studies. Subsequently, we performed a summative user study, to evaluate the wormhole, interaction, and culturally based design in Trans-Surface Rummy. We observed participants playing Contract Rummy using the trans-surface system and pre-digital decks of cards. We observed a total of 24 participants, six groups of four. Participants were recruited as groups of friends or at least acquaintances. Fourteen players had previously played some variation of rummy. Eight participants were recruited from local bridge clubs. These participants had a mean an age of 73 (SD = 7.67). The remaining 16 were university students (mean age 22; SD = 1.90). Participants received 25 USD gift cards as compensation.

Participants played three rounds of rummy using pre-digital cards, and three rounds using the trans-surface system. This order of this independent variable was counterbalanced across groups. Each participant completed a pre- and post-questionnaire. They were video-recorded while playing (30 fps). Video records were analyzed to derive qualitative and quantitative data. Before playing, participants were read a script of the rules. They were invited to ask questions.

Fluidity Analysis Methodology

We devised a coding scheme to evaluate the design of the trans-surface wormhole technique. We coded the video, categorizing each occurrence of a player transferring a card from private to social surface, or in the physical condition from hand to table, as fluid or non-fluid. We characterize fluid transfers as those in which players smoothly transition from flick off the top of the private surface to moving their hand to the social surface to play the card. In other occurrences, participants hesitated for more than than 3 frames of video (100 ms), or moved their hand toward their body or face between flicking and starting to move their hand to the social surface. These two conditions were classified as non-fluid. We coded the physical condition in the same manner. Transfers that could not be seen in the video, were initiated by the proctor present at the study, failed to result in the card being transferred to the table, or did not result in the card being played on the social surface, were not counted.

There were 3 coders; each analyzed 4 groups. Each group was analyzed by 2 coders. From these codes we computed the percent of transfers that were executed fluidly for each player in each round. Inter-rater reliability was computed as the Pearson's Correlation Coefficient of fluidity ratings for each pair of coders (see Table 1). One participant is excluded from the results because it was unclear to coders if his interactions, in which he often used two hands, were fluid.

RESULTS

We use mixed methods to assess the efficacy of the culturally based design of the trans-surface interaction. We present qualitative and quantitative findings about the fluidity of trans-surface wormhole use. We compare results across the pre-digital and trans-surface conditions, young students versus

Coders	1&2	2&3	1&3	Mean
	0.81	0.85	0.87	0.84

Table 1. Coder pair inter-rater reliability scores.

the elderly, and with regard to early and later rounds of play. We present qualitative data regarding the design of the private hand interface for organizing player's cards, with regard to fluidity and embodied support for mental model formation. We report on the experiences of elderly participants, with regard to comfort, enjoyment, learning, and fluidity.

Trans-Surface Wormhole Fluidity

In the trans-surface and pre-digital conditions, we found on average 78% and 93% respectively of interactions were executed fluidly. A *t*-test indicated the difference was statistically significant ($p < 0.001$). In the trans-surface condition, we found a correlation of 0.38 ($p < 0.002$) between round number and the average percent of fluid transitions. In round one, 68% of transitions were executed fluidly versus 86% in round three. This indicates fast learning of the trans-surface wormhole technique as a fluid embodied trans-surface interaction.

In the trans-surface condition, elderly participants executed only 67% of interactions fluidly, while the younger student participants executed 82% fluidly, a significant difference ($p < 0.002$). No statistically significant difference based on age group was observed in the pre-digital condition.

Sometimes, in both the trans-surface and pre-digital conditions, non-fluid interactions occurred when players initiated a transfer and then had second thoughts. Participants left the card on the social surface while reconsidering. In other cases, participants preparing to swap a card for a Joker would transfer a card to the social surface, then wait until their turn, to make sure they didn't get stuck with the Joker's high value. In such instances, participants used the affordances of card playing media to ready actions to be executed in the future. The NUI trans-surface wormhole afforded this embodied cognition in a manner similar to the all-physical cards.

We observed how players experienced the trans-surface interaction. In one instance, an elderly player demonstrated to another player how to initiate a card transfer by swiping her finger in the air in an arc much larger than the screen. This shows how she perceived the interaction as extending off of the device and into the space between surfaces. While a majority of the participants activated card transfers with their index fingers, we also observed participants use a thumb to slide cards off the top of phone in a gesture mimicking how cards are drawn from a fan. This suggests that for these participants, prior play with physical cards influenced trans-surface experiences.

We also observed elderly participants, before becoming familiar with the interactions, tap cards, as if they were buttons, trying to draw or discard them. We expect this was due to previous experience with interfaces in which the primary mode of interaction was activating buttons. More direct manipulation was not a form of interaction that elderly participants expected from digital interfaces. In contrast, we observed younger participants attempt to flick cards, expecting that the interface incorporated inertial simulation. The contrast in kinds of attempts shows differences in familiar digital interaction between younger and elderly participants.

Flexibility of the Private Hand

Qualitative and quantitative data indicate that players put high value on flexibility in arranging their private hands. While they appreciated the digital system's capability to automatically sort cards in the unmelded hand, they wanted to be able to customize its ordering, beyond the constraints of sort-by-rank or by-suit. We observed participants dragging cards in the unmelded hand across the array trying to place them in a new location. which did not work. When asked about the disadvantages of the digital game, participants reported:

> "Cards could be organized by players' preference, but doesn't allow for multiple options on say, two melds, to be easily discernible."
> "Hard to arrange hands."
> "I wish I could have moved my cards around in my hand instead of making the groups at the bottom."

Participants were also asked in the post-questionnaire, via a semantic differential, how strongly they agreed with the statement: "I could organize my hand to help me consider options," for the forms of rummy (1 = strongly disagree; 5 = strongly agree). A Wilcoxon signed ranks test indicated a significant difference between responses for trans-surface and pre-digital forms of the game ($p < 0.05$). The average result was a 3.66 ($SD = 1.04$) for trans-surface and a 4.33 ($SD = 0.816$) for pre-digital, indicating that indeed participants found the flexible arrangement capability of tangible cards more supportive of embodied cognition.

Experiences of the Elderly

All 8 elderly participants reported lack of experience using the iDevices. When asked if they were more comfortable after the study, participants reported a mean value of 3.75 ($SD = 1.38$), 5 being strongly agree and 1 strongly disagree. Elderly participants reported they enjoyed playing the digital form of the game with a mean value of 4.25 ($SD = 0.886$). There was no significant difference with their reported enjoyment of playing with physical cards. Student participants reported more enjoyment in playing the trans-surface form ($p < 0.001$).

In round 1 of the digital condition, there was no significant difference between the fluidity of elderly and younger players. In round 3, the elderly executed 74% of transfers fluidly, while students executed 92% fluidly; the difference was significant ($p < 0.05$). This suggests that initially younger players were as likely to stumble in fluid execution of the trans-surface interaction as were elderly players, but in later rounds, perhaps due to reduced motor dexterity or learning ability, the elderly did not execute the interactions as fluidly.

Several of the elderly expressed interest in the iDevices during the study. One participant asked the proctor to clarify what the devices were. Another said that they thought it would be fun to play with their grandchildren. One remarked, "It is fun, but who is going to actually have all of these [indicating the iDevices]". Another participant jokingly asked in the post survey, "Do we get iPhones now?" The findings show that the relative foreignness of the embodied NUI technologies to the elderly, as situated by CBD, was neither a barrier to interest and motivation, nor, by and large, to use.

IMPLICATIONS: TRANS-SURFACE INTERACTION DESIGN

We distill implications for design of two levels. Before raising general implications of CBD, we begin with 3 implications for trans-surface interaction design between private surfaces and a social tabletop. Two are related to fluidity: one involves the efficacy of the trans-surface wormhole technique, which substitutes cultural for physical continuity; the other involves the importance of enabling flexible arrangement. A third implication involves using embodied properties of physical space as a basis for situating related digital information.

Substitute Cultural for Physical Continuity

Trans-surface interfaces can indexically reference the physical continuity of pre-digital cultural contexts. The data validate the trans-surface wormhole's efficacy for fluid trans-surface interaction. Participants quickly learned to execute trans-surface transfer of a playing card by flicking it off the iPhone and smoothly transitioning to interact with it on the tabletop. They were not bothered by the absence of physical playing cards' continuity; they did not mind the gap between surfaces. Most participants quickly discovered and executed the wormhole for trans-surface interaction without explanation. The initial effect was not affected by age group. However, younger participants learned to be almost perfect, while the elderly did not learn as quickly. Future research will investigate whether practice over a longer time frame mitigates this.

Substituting culturally based continuity for physical continuity is a valuable design principle. The increasing ubiquity of multi-surface environments means people will want to integrate their use by moving information and distributing control. Lack of physical continuity in digital interactions can be overcome through experientially based conceptual schemas derived from engaged familiarity. We have shown that in context, trans-surface interactions can be designed to activate embodied mental models of fluid interactions. Users execute resulting NUI in the same fluid manner as pre-digital practice. Thus, designers can support fluidity without relying on costly modalities such as vision-based tracking and intermediate projection.

Contexts of trans-surface interaction vary. Documents in a meeting are handled differently than playing cards. Sheets may be ripped off a notepad and handed directly to a co-worker or copies dispersed collaboratively around a table from a pile. Business cards and photographs are more like playing cards. Perhaps their similar physical affordances will enable transfer of these techniques to other activities. In construing implications, it is important to abstract playing cards as units of information. People have been working with cards, documents and other information artifacts for ages. This history of interaction experiences serves as a repository of knowledge that can be leveraged by designers to create intuitive and fluid trans-surface interactions.

Enable Flexible Arrangement of Information Artifacts

One of the great affordances of physical information artifacts is the flexibility with which we may arrange them to informationally structure our environments. One lesson learned is the integrality of this characteristic. The provided computational mechanisms to aid in human recognition of melds did not, for users, offset loss of flexibility. Flexibility enables more complex and meaningful informational structuring.

Flexibility is deeply embedded in the cultural understanding not only of playing cards, but of physical objects in general. Kirsch found that people manage the spatial arrangements of physical objects to categorize, and simplify choice, perception, and internal computation [13]. Not supporting fluid spatial arrangement of playing cards contradicted our participants' embodied mental models, and in doing so hindered their ability to make sense of and operate their hands.

Because we used CBD to contextualize our investigation of trans-surface interaction in card play, we were able to realize the importance of flexible arrangement. If we had simply begun with transferring documents or business cards, we might not have considered it. Part of the evolution of card play has been the culturally based development of techniques for managing and making sense of information artifacts. These techniques have been optimized. Thus, computational aids, such as automatic sorting and organizing, must be implemented with manual overrides, keeping the user in control.

Interaction designers must take care in understanding culturally based practice. Sometimes the affordances of new media warrant significant change from practice with original media. However, this must be measured against starving the formation of embodied mental models and associated affordances that form the basis of physical interaction in-order-to.

Embodied Properties of Physical Space

Personal regions of social space and flicking cards off the top of the phone were designed based on embodied properties of physical space. Corner-based symmetry was effective for structuring each individual's social subspace, referencing the embodied positioning of users and their private surfaces. This delineated individual sensemaking on the social surface, where others can watch. The positioning of the stock and discard piles in the center gives all users symmetric access.

Similarly, embodied spatial relationships inform users' processes of mental model formation, understanding that cards afford flicking from a private phone to the trans-surface wormhole on the shared social surface. Players hold a fan of physical cards in one hand, and use the other to draw from the top. Flicking from the surface's top recontextualizes this tradition. The mental model of the trans-surface wormhole depends on spatial orientation, and proximity of the user's body, hands, phone, and social subspace.

IMPLICATIONS: CULTURALLY BASED DESIGN

Having investigated trans-surface interaction design as an example of embodied culturally based design, we now consider implications of and for CBD, itself. We point out how CBD serves as a generative source of metaphors for interaction design. We present implications that result from contextualizing embodied interaction design in culture, and consider the importance of investigating transferability. We finish by assessing the potential for systems developed with the CBD method to support stealth teaching.

CBD: A Source of Design Metaphors

While CBD can provoke the creation of new interaction metaphors, it inverts the construct. In describing the original design process for the desktop metaphor at PARC, Liddle articulates that the goal of metaphors is not to imitate the physical world, but to provide abstractions to which users can relate [31]. The CBD method is, in fact, to directly imitate physical world activities with NUI technologies and systems, and to derive metaphors from resulting simulations. Answering Abowd and Mynatt's ubicomp NUI challenge [1], the goal, through this process, is to discover implicit actions that people are familiar with, ready-to-hand, and apply them to facilitate rich communication between humans and computation. CBD can result in the design of metaphors, like card flicking and waving. These abstractions result from processes that begin with direct imitation of physical world activities.

Context and Transferability

Design of digitally mediated interaction incorporates many techniques, including affordances, mappings, and feedback [18]. We designed the trans-surface wormhole technique from mental models of how cards move and are manipulated. Prior trans-surface interactions have been designed in more generic contexts [12]. While context-free empirically motivated interaction design may be fruitful, in a contextualized activity designers can rely on the cultural understanding of users to create expressive and efficient interactions.

Further, though CBD develops interaction in contextualized activities, we hypothesize that it will sometimes be possible to abstract CBD-derived techniques, that interactions derived from one cultural context will be transferable to others. When can users transfer functional understanding of an interaction technique beyond the original situated context to others? How can such mental model transfers be supported? Future research will investigate the *transferability hypothesis*.

Future work will explore how easily people learn to use trans-surface wormholes for exchanging business cards, web pages, and other information. What will be the impact of indexically referring to the context as a metaphor, as in, "Transfer the document from your phone to the tabletop as if it were a playing card?" We suspect that with familiar referents, such as playing cards, recontextualizing culturally based interactions will still activate embodied mental models. CBD shifts the focus to activating embodied mental models in order to contextualize activities that are at once partially physical, cognitive, and customary.

CBD Engenders Stealth Education

Non-technical populations, such as many elderly users, challenge interaction design [30]. Problems arise as a result of gaps in knowledge of commonly used interaction techniques among varying demographics. CBD addresses this by recontextualizing the experience-base of target populations.

Elderly participants were quickly able to play Trans-Surface Rummy. They leveraged their engaged familiarity to confidently manipulate digital cards ready-to-hand. Their experienced in-order-to mandate of playing cards trumped their fear of technology, resulting in excitement. As with other card play, they wanted to share this with friends and family.

CBD can provide a basis for stealth education tools that introduce new technologies to diverse populations, such as the elderly, by presenting embodied digital representations of cultural activities that evoke engaged familiarity. In the case of card play, players are not just familiar; they are aware of their own proficiency. This gives them the confidence to overcome uncertainty and engage with technology. The power of familiar activities as a cultural repository of knowledge, accessible for stealth education, should not be underestimated.

CONCLUSION

With the emerging advent of NUI technologies, developers and researchers seek to meet the ubicomp challenge by creating new intuitive interaction techniques. Cultural activities can serve as a source not only for new interaction metaphors, but further, for gestures, visual representations, and activity contexts. We have shown that CBD enables creating effective interactions that engage participants' embodied mental models. For example, they fluidly transferred information artifacts through the wormhole despite the physical discontinuity inherent in trans-surface interaction.

We as designers have much to learn from the information artifacts all around us. They are the product of cultural processes that have been influenced by generations of use and experience. It is important that we do not backtrack in our development of new interfaces for working with information artifacts. As our evaluation shows, flexibility is a critical affordance of physical information artifacts. Sensemaking systems should support people's natural skill of fluidly structuring artifacts informationally.

Designers can use CBD to cross barriers to reach non-technical populations. We focus on the application of culturally based digital experiences as a gateway for less technical populations to learn new technology. These experiences serve as an environment for inexperienced users to learn about and build confidence with unfamiliar technology.

We hypothesize that under some conditions, culturally based designs derived in one context will be effective in others. In future work we will explore to what extent and under what conditions we can initiate design in one context, and then recontextualize the results. This research must address questions of how to catalyze the activation of users' embodied mental models, and how readily will they be reactivated without stimuli from the original context.

The fluidity with which participants manipulate information artifacts through the private-social workspaces wormhole begins demonstration of embodiment's potential contribution. The sensing and display capabilities of popular devices enable a new NUI era, in which ready-to-hand surfaces, as equipment, recognize and respond to each other in a manner similar to how people do. Instead of people carrying around isolated blocks of computing, islands, we need to discover new methods that enable dynamic, synergetic forms of trans-surface interaction in-order-to expand the collective power of spontaneous gatherings of computers, displays, sensors, and people. Thus the present research initiates a research agenda of rich, responsive trans-surface interaction design.

We must embrace and draw from the deep and wide cultural repository of human experiences. Just as the gene pool spans diverse biological ecologies, from the Amazon to Siberia, and all between, so humanity possesses a rich pool of cultural experiences which can contribute fundamental resources to embodied interaction design. The transferability hypothesis leaves us wondering: what practices of what peoples have the potential to make what crucial contributions to the design of human-centered ubiquitous computing? We look forward to forging collaborations to explore this design space.

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