Ubicomp4D: Infrastructure and Interaction for International Development—the Case of Urban Indian Slums

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ABSTRACT

This paper attempts to re-imagine ubiquitous computing for populations in low-income and information-challenged environments. We examine information infrastructures in mid-sized urban slums of Mumbai and Bangalore in three ways—1) highlighting technologies supporting social networks, 2) examining underlying notions of trust and privacy in building information networks, and 3) discussing protocols and practices around shared access. We then discuss our thoughts on designing for low-income, low-literacy, and resource-challenged communities, presenting new ways to think about the design of ubiquitous technologies for international development. We argue for collaborative exchange between the established strengths of the Information and Communication Technologies for Development (ICT4D) and Ubicomp communities to generate new ways of shaping technologies towards poverty alleviation in previously neglected socio-economic contexts—"Ubicomp4D."

Author Keywords

ICT4D, India, mobile technologies, urban slums, low-income communities, trust, privacy, Ubicomp4D.

ACM Classification Keywords

H.5.m Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors

INTRODUCTION

An estimated 3 billion people, making up almost half of the world, live on less than $2.50 a day [1]. A billion are illiterate, and 900 million face food insecurity [2]. Urban migration is one of the root causes of accelerated poverty. Burgeoning megacities (populations of 8 million and above) and hyper-cities (populations of 20 million and above) attract thousands of migrants by the day, owing to the promise of socio-economic mobility [8]. In cities like Mumbai and Bangalore, urban planning and land pricing have led to acute stress in low-income populations, forcing them into slum dwellings in specific geographical locations. These slum settlements, also known as shantytowns, favellas, or townships, provide housing to a billion people across the world [3]. We believe that information and communication technologies (ICTs) can be adopted to fight poverty and its consequences in these locations. Specifically, given the population density and urban context, ubiquitous computing tools may prove particularly effective for international development in these environments.

The field of Ubicomp has traditionally explored solutions for (wealthy) western audiences and contexts. However, the use of computational devices has steadily penetrated into the developing world and largely ignored by Ubicomp research. Understanding the use and appropriation of technologies in such places is critical to understanding how billions of people may use and benefit from ICTs in the future. We introduce and explore the fusion of international development and ubiquitous computing in resource-crunched and unstable technology environments—Ubicomp4D. We define this as "the application of ubiquitous computing in addressing poverty-related issues." This intersection can enable low-cost, robust technological solutions in resource-constrained environments. It can have radical implications for ubiquitous technologies moving away from seamlessly wired environments to digitally unstable ecologies.

Weiser's original vision of Ubicomp called for an invisible, seamless, and ubiquitous set of computational components that allow for information processing in everyday objects and activities [32]. Fourteen years later, Bell and Dourish argued for a messy "Ubicomp of the present," examining high-tech, high-income ubiquitous environments in Korea and Singapore [5]. This messiness is evidenced in the hybrid nature of information networks in urban slums in metropolitan India.

Traditionally, social networks evolve through many informal communication and social exchanges. Information infrastructures are created around everyday requirements for work, education, health, mobility, and entertainment, and the

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mobile phone has emerged as the forerunner in binding and expanding existing networks. In addition, other domestic technologies, such as DVD players and television sets are enthusiastically embraced throughout these settings. We report findings from investigations in three low-income slum communities—Behram Baug in Mumbai, and Nakalbandi and Ragigudda in Bangalore—to present glimpses of existing practices with technologies, and to highlight the role of Ubicomp in development.

This paper is organized as follows. After a brief discussion of related literature, we describe the information ecologies in slum habitats. We present three vignettes to highlight the interplay of information ecologies, social networks, and technology usage. We then introduce diffusion agents who catalyze information diffusion and technology adoption in these environments. Finally, we discuss some design implications for Ubicomp4D, such as designing for human mediators, low costs, disruptions, and community, and the need for including development in the agenda of Ubicomp.

RELATED WORK

ICT4D

ICT4D (ICTs for Development) is an emerging research area concerned with twin challenges of addressing Millennium Development Goals, and designing technologies for resource-constrained environments. Innovations in this area address healthcare [28], agriculture [13], and education [20], to name a few. ICTs such as television, in combination with human info-mediation, are optimized for use in projects such as Digital Green [13]. Networking technologies, such as wireless protocols, have undergone major overhaul, in projects like DakNet [31]. Finally, there has been interesting work in user-centered design for development, e.g., user interfaces for non-literate users [25].

Mobile Phones and Development

Mobile phones are often touted as the most promising platforms for ICT4D, owing to their tremendous uptake in low-income communities in the "global South." Explorations such as MILLEE [20] and Healthline [28] have targeted development problems by innovating applications for the mobile phones. Jensen has tracked economic benefits to the poor through the mobile phone, notably in a study on fishermen of Kerala [18]. Sociological studies addressing the fit of mobile phones to development point to a range of techno-social innovations—"missed calls" or "flashing" [27], and circulation and sharing of mobile phones [6]. Previous research has also studied the changes to social and business networks through mobile phones, including in India [12] and Jamaica [15].

Information Ecologies and Infrastructures

The field of Ubicomp has had a long-standing interest in infrastructures. Mainwaring et al. document the role of existing infrastructures in enabling, enforcing, or frustrating individuals and groups [24]. They contend that Ubiquitous computing is a vision of infrastructure that can be physical or social/interpersonal installations. We find a relevant and useful construct in "information ecologies"—systems of people, practices, values, and technologies in a particular local environment [25]. Ecologies denote continuous evolution and influences that shape and direct technologies and settings of use. These ecologies incorporate policies, social values, politics, legislature, and economic formations. We also extend the notion of infrastructure to "communication ecology," borrowing from communication research, referring to "the processes that describe people communicating with others through extended social networks comprising a mix of face-to-face, media and communication technologies" [30]. While maintaining a technology focus, this allows us to include multiple communication devices and extend inquiry into multiple social contexts that govern the act of communication itself. Thus, communication ecologies are not simply technologies or communication acts but a range of human activities and clusters that facilitate them.

METHODOLOGY

A Tale of Two Cities

We report from ethnographic studies of Mumbai and Bangalore slums. In Mumbai, we focus on the organization of social resources and information critical to maintain employment for persons managing enterprises requiring low capital (e.g., small shops or services). In Bangalore, we focus on domestic labor, as a profession and chore, and organization of space and resources. In order to focus solely on technological use and provide inspiration for design, we exclude gender differences factoring into technology ownership and use. The overlapping domains of domesticity and livelihood in low-income communities offer an overarching framework to study adoption and use of technology. We gauge tensions in the nature of information sources and exchange, and explore notions of trust and privacy in the communities. Finally, we map appropriations of traditional and new media and communication technologies.

We used a repertoire of ethnographic methods for eliciting data—participant observation, semi-structured interviews, surveys, photo diaries, and profile-building. All interviews were audio-recorded and anonymised. Surveys and scenarios were used to understand information sources in the neighborhoods and to gauge levels of trust in them. Photo diaries documented everyday life at work, home, and play (especially on weekends). Informants were recruited through snowballing, and compensatory gifts, such as utensils and bedspreads, were provided.

Behram Baug

Behram Baug is a mixed (religious, cultural, and economic) community with a radius of three km, 10,000 households and 50,000 people. Our studies in Mumbai spanned 4 months of investigation, focusing on 7 men and 3 women. All made a living offering small, neighborhood-based services. Family incomes ranged from Rs5000–8000 (˜100–170 USD) per month. The three women were 27–35 years old, educated at most up to secondary school, and all had children and two were married. One of them worked as domestic help in nearby upper class home, the second managed a home-based tailoring unit, and the third was a support-actor in television. The men were all in their mid thirties, educated up to

(a) (b)

Figure 1. (a) Behram Baug gully, and (b) a gathering at the mouth of a Ragigudda gully.

(a) (b)

Figure 2. (a) shows a television set, and (b) a DVD player, fridge, and television set.

secondary school, and are married with children. Four of them have families in native homes outside the city and sent money back. Five of them owned small businesses (subcontracting garments, a laundering outfit, a snack and beverage kiosk, a nuts and bolts store, and a mobile store). Two of them offered services: one drove an auto rickshaw in the neighborhood and the other was security personnel for an apartment complex.

Nakalbandi and Ragigudda

Our studies in Bangalore span 2 months at the time of writing this paper, with 22 women in the slums of Nakalbandi and Ragigudda. They are mid-sized communities of roughly 2000 households each. Most residents are migrants from Tamil Nadu, and can speak Tamil, Kannada, and sometimes Telugu. Our informant pool in Bangalore was exclusively women whose primary profession was domestic labor. The women varied in age from 20–70 years old. Education levels varied from no schooling to 10th-grade dropouts. Average family monthly incomes ranged from Rs2000–6000 (˜40–120 USD).

EMPIRICAL SETTINGS

The multi-dimensional aspects of technology use cannot be discussed in isolation, without an understanding of the slum locality and context, so we provide a brief description of slum habitats and their technological penetration.

Slum Ecologies

All three slums were located in metro-core areas. Public transportation and proximity to major commercial venues aided in connectedness. In Behram Baug, burgeoning city expressways, high-end malls, and multiplex theaters cordoned the slum quarter. In the Bangalore slums, although domestic work provided the primary income, secondary incomes were accrued by weaving garlands, providing massage services, and selling "chaat" (snack) items and handkerchiefs. The slum quarter was an evolving assortment of small habitats, spatial layouts, and commercial enterprises. Migrants tended to collect in specific localities based on ethnic identities and follow specific business activities. Businesses comprised small-scale industries like metal workshops and auto spare parts garages, furniture stores, photo studios, fast-food joints, and shops selling small goods such as mobile phones, groceries, appliances, garments or jewelry.

Organization of Domestic and Other Spaces

A typical home in all three slums varied in size from one to three rooms of 100–200 square feet in total. Narrow concrete "gullies" (alleys) ran between houses, which were typically 3–4 feet wide (fig. 1). Constraints of space and resources forced compartmentalization of homes based on activities and functionality—kitchen area, television area, mattress area, storage area, and a washing/water storage area. Doors were usually kept open and every home typically had a constant influx of visitors—relatives, neighboring children and adults stopping by. Children played in the "gullies" while mothers sat on the doorsteps. Informal spaces were popular local landmarks like fast-food joints or video parlors. "Green spaces" such as playgrounds were used for cricket and street soccer, though male members exclusively inhabit these. Informal collective spaces for women were religious sites like temples and water pumps during hours of water supply when they were out to clean dishes, wash clothes, bathe kids, and perform other cleaning activities. These spaces served as "information hot-spots" of information sharing and exchange of neighborhood gossip.

Technological Landscapes

Electricity was the most pervasive technology in the slums we studied. It was, however, prone to frequent failures. Other pervasive technologies were entertainment and communication technologies (e.g., television sets, DVD players, and mobile phones, as shown in fig. 2.) and kitchen appliances, like gas stoves. Laborsaving technologies, such as washing machines, clothes irons, and water heaters were rare. Objects were crammed above and below devices (refer to fig. 2), due to space constraints. Despite strong face-to-face and word-of-mouth channels, subjects depended on telephones (mostly paid telephones) and mobile phones to maintain, expand, and regenerate socio-business ties and networks. The sizable migrant population moving to Indian metropolises in search of employment accounted for robust telecom usages to stay in constant touch, and send money and resources to families in native villages. The recent prosperity of surrounding neighborhoods resulted in a technological shift in the ecology. Businesses in Behram Baug, like used mobile handset stores, mobile hardware/software repairing, computer training institutes, and PC assembling sprung up inside the slum quarter due to availability of cheap space and labor. The technology diffusion effects in the ecology resulting from these enterprises are profound.

Always-on Technologies

Entertainment technologies, such as television and radio, were always-on. Every household in our population subscribed to cable television. Local-language soap operas, local news, cookery shows, and film songs were habitually consumed. In all three slums, the most popular mobile phone was the Nokia 2600—a phone with FM radio doubling up as always-on and a stationary entertainment source in the home. Privatization of the radio spectrum led to high uptake of modern, entertainment-based private channels.

THREE VIGNETTES—FAMILY TIES, JOBS CALLS, AND ENTERTAINMENT

We draw upon three profiles that highlight technology usage in regenerating social and business networks. They underscore how development (livelihoods) is intertwined with consumption, and maintenance of ties in the family, neighborhood, and village. These vignettes serve two purposes here—to act as windows into technology usage in our informants' lives, and to provide a contextual lens to understand cultural principles and social values, which serve as a base for future technology design.

Vignette 1 from Nakalbandi—Sharing Across the Family

Kannama, 70, is a widow and retired domestic worker. Her adopted son and "bahu" (daughter-in-law) live with her. She moved to Bangalore to escape her marital home after an unhappy marriage. Kannama owns a Nokia 2600 costing Rs2500 (50USD) second-hand, with an FM radio built into it. She uses the phone to maintain ties with her extended family and communicate with the local political party chapter. Kannama talks about phone usage,

"When I was still in service, I used my phone to make calls to potential employers and employment agencies. My employers would phone me for in-person interviews. Then (once employed), they would phone me on regular days and on special occasions for extra work, if there was any. Sometimes they host many guests or have a party, in which case I have to clean up the place and cook for them. I get paid extra for that. If not for the mobile, they would have had to visit my neighborhood to call me in person, which they would be hesitant about. It (the mobile phone) has been helpful to me."

We see how the mobile phone enables intra-class interactions, difficult otherwise.

Kannama shares her phone with her "bahu"—Priya, who often sends text messages to her electrician husband. She also carries the phone with her to tailoring classes. The mobile radio is always-on and in proximity to the family members. Priya's husband also receives phone calls on the same phone from customers. Talk-time depletion is common, and the phone is unattended for weeks until finances were restored to normal. Person-seeking (calling to speak to a co-present someone) and place-seeking (calling to speak to anyone in the locality) behavior facilitated by landlines is substituted by the mobile phone [29].

Vignette 2 from Behram Baug—Maintaining Job Calls

Shabnam, 27, single parent of two children attending primary school, is an actor in the television industry. She was born in Bangalore and moved to Mumbai with her family when she was 10 years old. She dropped out of eighth grade to get married. An unhappy marriage led to estrangement and a formal divorce. She got a much-needed break in the television industry seven years ago. Shabnam narrates,

"My sister had this friend who was working in the home of a TV producer. She made efforts to get me in. I've now reasonably established myself. I am a fighter. I am learning classical dance in a nearby school to enhance my ratings."

She is on the phone almost throughout the day for impromptu casting calls. Her mother and sister, who are her neighbors look after her home and hearth, bring children from school, and care for them through the day. Shabnam adds,

"My mobile is everything to me. I even keep it next to my pillow at night. I may get a call for a shoot any time if actors do not turn up at the studios."

She loves her mobile phone—a feature-rich phone with camera, FM radio, blue tooth, and large memory. Shabnam calls herself a 24/7 music enthusiast, by listening to her stored playlist or the FM radio on her phone. She has also stored pictures of her children ("good for gazing") and loaded four Hindi movies to watch during leisure hours at work. The mobile is also her "security guard" while returning home from work at night ("help is just a call away").

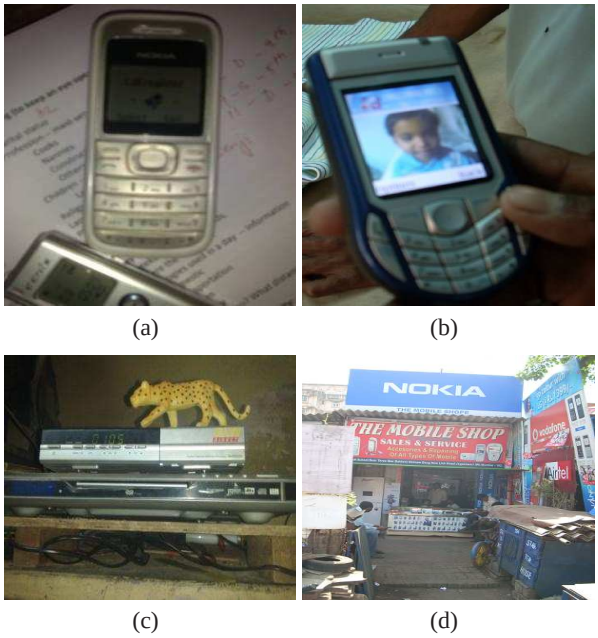
Shabnam offers an interesting perspective on the nature of mediation that the mobile phone brings to her business networking. She believes it is more useful to negotiate, plead, reject, or even fight over the phone than in person. Given the cutthroat nature of her job, it helps to build a "telephonic barrier" to mediate communication protocols or even heated emotional exchanges—

"It is easy over the phone. I am not seeing the face of the person I am crying to or fighting with. It helps me recover and begin a new day."

Vignette 3 from Ragigudda—Use of DVD players

Pushpa, 31, is a married domestic worker and the mother of three children. She is educated up to 10th grade under the Tamil language medium of instruction. Born and raised in Senji, Tamil Nadu, Pushpa moved to Bangalore after her marriage. On a typical day, she leaves for work before her children leave for school. Her day is packed, with domestic work in the morning, daily chores in the afternoon, and cooking in the evenings. She is employed in three households. Respite comes in the form of movies and music. Recently, Pushpa purchased a DVD player so she could avoid paying for tickets at the box office. DVDs are purchased locally in the grey market. They are shared and circulated among the residents of the neighborhood.

During one of our "hanging out" sessions, Pushpa wants to



(a) (b) (c) (d)

Figure 3. (a) Kannama's phone, (b) Shabnam's mobile phone, with a picture of her daughter, (c) Pushpa's DVD player, and (d) Pandey's mobile phone store.

show us one of her favorite movies—"Gilli." A short electricity outage is followed by restoration. The video out cable of the DVD player was removed for an earlier clean-up. Since Pushpa does not know how to operate the DVD player, her son, 6, plugs the cable, inserts, and plays the DVD. She smiles,

"Their father (her husband) usually operates these devices. But, he has not been in town for a year now. I can never learn how to operate them. Too complicated for me! They (her son and daughter) tried to teach me, but I can never get the hang of it. I don't know how I can watch movies without assistance from my son or daughter."

Thus, we see how the viewing of "Gilli" is made possible with the help of Pushpa's son, in proximity to her. We explain this mode of technology use in the Proximates subsection.

FINDINGS

Composition of Information Ecologies

Information is an important component of communications, livelihoods, entertainment, and commerce. Information ecologies offer a lens for examining the interdependencies and interactions between people and technologies. This understanding is important to supplement, compliment, or rethink interactions in Ubicomp.

The complex and dense information environments in these slums are patchworks of social actors, technologies, and cultural norms. Information flows in these communities were heavily human-centered and governed by limited literacy, resources, and pre-ICT dynamics. Cable TV and radio channels provided a variety of information, especially mid-day shows for women, local news, healthcare broadcasts, and fashion programs. Mobile phones were important mediators in existing networks, and contributed to information flows by connecting two parties anytime, anywhere [12]. In addition to these media outlets, our data point to other information agents at work—family (parents, spouse, siblings, children, and relatives), non-family peer (neighbors, friends, coworkers, employees, or persons of other communities), and non-family expert (NGO worker, doctor, teacher, employer, and priest).

Unaffordable Internet connectivity, limited digital literacy skills, and difficult-to-use mobile phone user interfaces created dependencies on alternate, human, oral sources for information. Strong information sources with vested, altruistic, or activist interests (e.g., NGO workers) acted as primary sources in Bangalore. They provided ad-hoc information on a range of topics such as personal hygiene and education loans. Members of the community active with NGOs and external social networks formed a secondary level of information diffusion. Television soaps and films portraying female, middle-class and virtuous male protagonists were considered strong sources for current affairs, lifestyle choices, and aspirations. In Behram Baug, businesses survived on regular daily interactions with several agencies, i.e. retailers, agents, employees, customers, and clients. Our subjects running small enterprises, stores, and services were dependent on the informal nature of demand and supply of goods and services of not only the neighborhood, but also the sprawling metropolis of Mumbai.

Unpacking Privacy and Trust

Understandings of trust in technologies, as held by the community, are imperative to any researcher interested in introducing or augmenting information technologies. Goecks and Mynatt define trust as, "the degree of belief that, for a particular situation, an entity (an individual or a system) has the capacity to harm the individual but is not expected to exercise this capacity" [14]. Trust-based problems for Ubicomp include access control, data exchange with strangers, and using services in unknown environments [22]. In contrast, the slum communities had little information stored on technological networks or databases; instead, all information was oral. Even with a mobile phone, semi-literate users rarely stored identity-based information, partly due to lack of penetration of mobile remittances and other phone-based applications. Research strongly identifies direct, face-to-face contact as guiding trust and interactions in information entities [23]. This, however, may change when interfaces become accessible to non-literate users and digital literacy skills increase.

To begin exploring this area, we elicited notions of trust in information entities. In our sites, trust enjoyed numerous and sundry definitions based on the information source—reliability, obedience, respect, reputation, and authority, were terms used to describe trust. The notion of trust in maintaining stable livelihoods was built into the numerous everyday social networks and was a renewable and regenera-

tive process through constant social interactions. Technologies, particularly mobile phones, mediated trust-building as socio-business affinities reach outward for network expansion. Pandey, one of our 10 subjects in Mumbai, owned a mobile store that was steadily expanding in the last couple of years. What his father began as a grocery store 25 years ago, had become a busy mobile re-charge, accessories, and repair store (fig. 3). Although his family ran the store, Pandey needed to maintain several outbound associative networks; a slew of external agents were required to maintain his steady business of selling re-charges and top-up coupons. Next, the retailers in other parts of town who supplied handsets and accessories provided support. Since profit margins were tiny, price and quality of services were critical in ensuring the success of a business, assured by nurturing trusted relationships with business intermediaries through persistent interactions.

Privacy is another serious issue confronting Ubicomp, largely stemming from invisible computational artifacts and continuous sensing. As a counterpoint to this challenge, privacy in our sites was socially driven. As we note in the slum ecologies section, doors were usually kept open, there was a constant influx of visitors, homes were tiny in size, and walls were thin (both physically and socially). Territorial, communicational, and informational privacy were forged around orality. All information was orally created, maintained, stored, guarded, shared, and transmitted through face-to-face or voice-based phone channels. Forging privacy in an open, transparent, and unsecured physical environment was a social exercise, where information was managed in day-to-day conversations. We see the clever use of the mobile phone to manage social networks and information, sharing or withdrawing per demands of context.

Social Agents in Technology Diffusion

Members in the community with relative proficiency in reading, writing, and digital skills helped bring technology closer to non-literate users. While these community information diffusers may exist in any ecology [6] [27], they configure differently in various contexts; the urban slum is one such unique configuration.

Limited technology penetration led to expansion of information boundaries, otherwise inaccessible to the community, through human mediation. Members of the community or family served as technology aids for semi- or non-digitally literate members. Consider the case of Chennama, 60. She was illiterate and owned a phone, but she could not operate it without assistance. However, she had the resource of digitally-literate neighbors, who could dial a number, hand over the phone to Chennama, and terminate the call once she finished a conversation. Notice that in vignette 3, Pushpa's son played the role of a information diffuser by hiding the complexity of the DVD player from her. Sangeetha, 39, was illiterate but her daughter read the newspaper aloud every morning. Saroja's (32) neighbor helped her with using the camera feature of the mobile phone (fig. 4). The presence of proximate digitally-literate members influences the collective digital/-literacy capabilities of the social unit.

(a) (b)

Figure 4. (a) Sangeetha's children read out from a newspaper, and (b) Saroja's neighbor sets up the camera of her phone, while children look on.

Configurations and Management of Shared Usage

Economic necessities coupled with cultural principles and social structures manifest as shared usage of technologies. We discuss three dimensions of shared use—time sharing, financial management, and identity management.

Time Sharing: Technologies such as TV and radio find collective audiences. Time and frequency sharing were prominent in these communities, where usage allocations were based on the dynamics of preferred content, the consumer, and the controller of access to these technologies. Similar to [29], tensions between the imperative to share and to control were visible in our ethnography. During the day, control over television channels was largely in the hands of women watching soap operas and cookery shows. In the evenings, children gained control over the television buttons to watch cartoons. Men returning home from work watched film-based programs along with family. Sharing was not restricted to friends and family, but also done with visiting children and adults who may be neighbors. As noted earlier, DVDs were actively circulated in these neighborhoods in both family and social circles. A refrigerator in a household contained items of neighbors or friends who lacked an appliance for refrigerating food. Mobile phones were shared across and sometimes between households. Kannama and Pushpa's vignettes highlight sharing practices "in-situ."

Financial Management: We observed several forms of financial ownership in shared usage. Ownership can be either single or collective and likewise, and the user can be collective or individual. Television and radio are examples of common family ownership, and both collective and single viewerships were common during parts of the day. Mobile phones spanned a variety of models, with ownership varying across families. Financially independent women tended to own their phones independent of the rest of the family. Although it was possible for a family to own multiple phones, they usually maintained only one active SIM. Mobile phones were important communication technologies in connecting various linguistic, religious, and professional groups to each other and extending family networks, especially the migrant community of domestic worker women and single men, who sent money back to villages. Male, causal daily wage earners in the Mumbai slum shared boarding, lodging, and a mobile phone. Some owned separate SIM cards but most simply shared a single number. Sometimes, they pooled money collectively to buy a SIM card.

Identity Management: Technologies designed for individual use were customized for collective use. When we asked the Mumbai daily-wage earners if they had any ways of customizing the mobile phone for each user—

"Oh yes. The music aficionado in our group has ways to download music in the hand set, blue tooth and all, and has set caller tunes for those who call regularly to talk to any of us. We recognize the caller from the tune and the concerned person picks up the phone."

This rich anecdote highlights management of shared artifacts for individual use, and presents insights into media sharing. It points to a key person finding ways to download and transfer music, and helping others become familiarized with the more complicated, high-tech features of the phone. Owning a personal phone is a definite aspiration, but norms of sharing override concerns of privacy, security, and personal identity.

RE-IMAGINING UBICOMP TOWARD DEVELOPMENT

We believe many issues surrounding poverty in low-literate and poor communities could be addressed through the combined strengths of the Ubicomp and ICT4D research communities. While aspirations in the low socio-economic strata described here are increasingly incorporating the technological dream, successful adoption is shaped by infrastructural and human capacities. Efforts in ICT4D strive to fulfill development goals and improve the quality of life in poor communities via technology solutions. This is a slow, uphill process, but through hard work and imagination, effective impact can be achieved [11].

Alleviation of poverty is a social, economic, cultural, infrastructural, and political effort and ICT4D brings together experts in all of these disciplines. Ubicomp, with its vision of improving human experience by embedding anywhere/everywhere technology can effect real progress in the goal of eradicating poverty. It mirrors and compliments the multidisciplinarity and socio-economic focus of ICT4D by creating better user experiences through technologies. There is a sweet spot for Ubicomp4D riding between exploratory, "proximate future" vision [5] of Ubicomp and the groundedness of ICT4D in working with existing, constrained resources for immediate impact. A starting point is to begin thinking about opportunities and challenges for designing technologies for low-income environments.

DESIGN CONSIDERATIONS FOR UBICOMP4D

1. Infrastructural Considerations

Leveraging Human Mediators: A recurring theme in our findings is the important role played by human mediators in various stages of technology usage. They play prominent roles in bridging (digital) literacy differences in a community. Broadly, this implicates the incorporation of human mediation in ubiquitous computing environments [26] for low-income communities. Incentive-based structures, such as Digital Green, incorporate extension workers, who actively enable information diffusion and check ground realities [13]. The Storybank project made use of NGO mediators in gathering user-generated media [19]. As noted in the findings section, family and community mediators play important roles in enabling and aiding usage of devices. Design can exploit the ubiquitous and fluid nature of family, friends, neighbors, and community members, by incorporating the mediator entity. Human labor is often cheaper than technological interventions in these contexts. While automation of processes may result in efficiency, it may deter users from using the system due to unfamiliarity, requisite digital literacy, or usability issues. The human-mediated model ensures greater usability and cheaper costs. It also reinforces existing social networks and contributes to the length of project sustainability.

Designing for Disruptions: Design has to account for the high prevalence of technical irregularities in slum habitats. Slum infrastructures are fraught with scarcity and obsolescence of devices and software. Interactions are far from seamless; imperfections and disruptions range from infrastructural failures to constraining economic and cultural realities. Communication chains and networks are mended, negotiated, forged, re-used, and worked-around through human mediation. Chalmers and MacColl argue that seamful design is "letting everything be itself, with other things," where uncertainty and inaccuracy can be turned into positive design approaches [7]. The seams here, however, go beyond being "beautiful"—electricity failures, lack of Internet, economic constraints, talk-time depletion, and customary social protocols are socio-technical impediments. Aoki et al describe a hybrid approach to bridge these gaps—by relying on common capabilities of a mobile phone, such as SMS, and using hybrid networking architecture by employing Delay Tolerant Networking [4]. Store-and-forward protocols, like DakNet, and asynchronous design can minimize dependencies on network infrastructures [31]. Hardware innovations in Ubicomp4D must be robust and tolerant to heat and dust. Domestic appliances and automobiles that need repair or mobile phones that need talk-time recharge go unattended due to economic constraints. Design must also account for electricity and battery failures. Technologies must be designed for interrupted use or non-use (lack of use), as forms of use.

Innovate on Low-cost Technologies: The correlation between income and media expenditure is a clear indicator of why technologies must be low cost to achieve mass impact. Instead of introducing costly instrumentation, ubiquitous computing researchers might innovate on existing technologies, such as adding computational capabilities to television, radio sets, and DVD players. Mobile phone use is higher in relatively higher-income households in the slums. The future of innovation, however, must not restrict itself to the mobile phone. There are other possibilities—inexpensive large displays, phone projectors, computer-TV, environmental sensors, to name a few—that could dramatically enhance the quality of life. In addition to the initial investment, operation, data subscription, and maintenance costs must be low. Inter-operability and linking of devices can help in borrowing computational capabilities of neighboring devices, augmenting the overall computation.

Designing for Context-awareness: Two common approaches in context-aware computing are: to capture context as a cue for information retrieval, or, more commonly, to adapt device behavior to correspond its usage [10]. At least three challenges are evident in the slum context: (i) Creating new data sets—there is hardly any pre-existing computerized data upon which to link behavior to a user, more generally in the developing world context, (ii) The one-to-one interaction model breaks down—mapping device behavior to a unique user is difficult in shared usage, and (iii) Sensing context is problematic—high ambient noise, dust levels, and packed environments lead us to rethink sensing models.

2. Interactional Considerations:

Designing for Orality and Non-literacy: Almost all information is stored in oral, human networks, as opposed to electronic or even paper documents. Information extraction, storage, processing, and usage are primarily oral and lead to informal, fluid, and negotiable use of the stored information. Information channels (social or technological entity that carries information) and networks (paths) build trust simultaneously, by word-of-mouth and face-to-face interactions. Since literacy levels are diverse in these environments, computing technologies can cater to larger audiences if they are designed for the lowest common denominator—non-literacy. Generous use of voice and visual modalities other than text dovetail into current oral and non-literate practices. Visual and voice-based systems such as Experiential Computing, Text-free UIs and HealthLine explore alternate modalities [17] [25] [28].

Multi-purpose Design: Resource constraints open up explorations of multi-purpose spaces, objects, and technologies. An everyday example is the creative way of cramming objects over and below the television (fig 2). In addition to serving as communication devices, mobile phones are used as recreational devices, as evidenced in film-based ringtones, wallpapers, and FM radio. Design needs to accommodate the multifarious aspects of entertainment, information delivery, and communications targeting devices like the television sets, DVD players, portable music players, and other technologies that are already used and perceived as shared. Multi-purpose design also inter-twines with financial constraints, and offers greater value for money. Instrumentation must be flexible, so when the nature of problem changes, it can adapt.

Designing for the Community: Ownership models in slum communities are diverse and device-dependent. Social capital —the infrastructure of social relations as well as the information that is transmitted between actors via their social networks—arises out of bounded spaces and ensuing trust relations. Sharing norms in family and community spaces like kitchens, warehouses, shops, and informal neighborhood spaces, extend into usages of technological goods like mobiles, DVDs, and scooters.

Multiple roles govern mobile phone usages—purchaser, owner, possessor, operator, and user [6], and any of these roles may be plural (i.e., multiple owners, operators, or users). Device sharing also involves various social and physical configurations, such as children sitting on the floor while watching television, or being in close contact with the person who helped dial a number. Shared technologies raise two important concerns: i) the security concern of guarding information across various users, and ii) making design share-friendly.

Security: Privacy is difficult to guard in these settings, but it is crucial to understand existing models of security. Familial and communal accesses to the mobile phone demand high levels of information transparency. People release, withhold, and share information depending on the contextual nature of exchange among sources and recipients. As a result, tight security [21] [22] may disrupt and possibly destroy existing notions of trust, privacy, and information management.

Design: Diversity of user ecology—varying informational needs, literacy levels, numeracy levels, or digital literacy levels, across a shared unit—is a challenge in the design of shared technologies. Technologies like the mobile phone are "fluid" [9], owing to their flexible and adaptable design, allowing users to adopt and adapt across literacy and economic strata. Similar to the personal computer, mobile technologies could provide customized information resources within shared
spaces. User profiles allow for demarcation of user preferences. Local user-led appropriations are already visible, as in the example of multiple caller tunes as a means of distinguishing call recipients for a shared phone. We see a preference for personalization and not technological privacy, as in Inkpen's study on sharing domestic technologies [16].

Another important consideration is the physical placement of technologies. Locating technologies in safe but restricted areas can undermine usage or reinforce existing divides. Formal and informal community collectives, as noted in the slum ecologies section, are opportunistic places for ubiquitous computing. One can envision large or public display installations in these locations, imbuing a strong sense of community in technology design.

CONCLUSION

We have highlighted how people of low socio-economic strata are already creatively using existing technologies. Contrary to popular assumptions, low-income communities facing technology deficits actively appropriate ICTs for livelihood and entertainment benefits. However, designing for poverty alleviation amidst existing technology deficits is a challenge for Ubicomp4D. A starting point for Ubicomp4D researchers is collaborations with local and grassroots partners; exchanges between local experts and technology experts could be fruitful. Our thoughts on design are not exhaustive; nevertheless, they are representative and demonstrate a need for explorations in Ubiquitous Computing for marginalized users. Although our sites of investigation are urban Indian slums, poverty is rampant in much of the "global South" and parts of the "North," —both urban and rural. Our hope in articulating usages and outlining design considerations in slums is to create a conversation among researchers of Ubicomp

about designing technologies for low-income communities, and moving the field ahead to build a global community.

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