You-biquitous Agents: an ecosystem of intelligent ambient devices

Mina Khan

***Abstract*— I propose the concept of aware ubiquitous devices that use ambient media to deliver information to individuals in contextually relevant scenarios. You-biquitous agents are not only meant to be assistive for user's personal needs, but also intended to be helpful to connect people with their friends, family, and the global society in a socially and environmentally responsible way. I discuss six examples (Figure 1) of You-biquitous agents to serve as agents that help enhance productivity, self-reflection, fitness, well-being, environmental sustainability, and global awareness. My research aims to quantify the efficacy of gamification techniques, social physics methodologies, ambient interfaces and machine learning techniques to give 'just-in-time' information to the users in their environment, without the user having to explicitly ask for the information or pulling out a device.**

I. INTRODUCTION

The concept of ubiquitous computing has been around for more than 15 years; in 1999, Mark Weiser wrote "The Computer for the 21st Century" and proposed devices that would "weave themselves in the fabric of everyday life until they are indistinguishable from it". However, if we look around us, there are not many, if any, examples of "calm", "ignorable" or "glanceable" technology. Calm technology is defined as one "which informs but doesn't demand our focus or attention [1], but the phones, tablets and laptops that have become pervasive today are hardly "ignorable" or "calm". Our current devices not only require explicit user action, but also impose a significant attentional and cognitive load on the user. Interruptions from the phone are well known to have a negative influence on productivity and emotional state [2, 3 , 4, 5, 6, 7] and the burdensome and attention-hoarding nature of technology isolates us from our physical and social environments.

Current technology is not only guilty of isolating us from our physical and social environments, but also does not actively surface useful and enlightening content in the most contextually relevant scenarios. Given our hectic lives, suboptimal daily behaviors and habits, and ignorance of information, there is no doubt that humans could greatly benefit from assistive technologies, but the state-of-the-art devices leave a lot to be desired in making our personal and social lives better. There has been ongoing research to study the effects of persuasive technology [8, 9, 10, 11, 12, 13, 14], especially using ambient and subliminal interfaces, but our environments are still devoid of impactful smart devices for users.

II. OBJECTIVES

My vision for ubiquitous computing is in line with Yvonne Rogers extended vision of Weisers calm technology that supports "creative and constructive" use cases [15]. Rogers points out that ubiquitous computing should "enables people, themselves, to be smarter and proactive in their everyday and working practices". I propose six devices (see Figure 1) that are a catalyst for effortless healthy-habit-forming and that nurture communication, learning and empathy using calm ubiquitous technology, ambient interfaces, P2P networks, and gamification. My research has a personal, social and global impact (see Figure 2) by connecting people to themselves and to the global population, and by leveraging the existing social web and P2P networks to motivate and incentivize people to adopt collective socially and environmentally responsible practices.

Fig. 1. Proposed You-biquitous agents

Since phone notifications can be annoyingly interruptive and require the user to pull out a device, I propose using ambient interfaces and subliminal signals that surfaces the most relevant and contextually appropriate information in the user's environment. My agents are aware/conscious of the users physical, social and computing environments, and

Fig. 2. Personal, Social, and Global Impact of You-biquitous agents

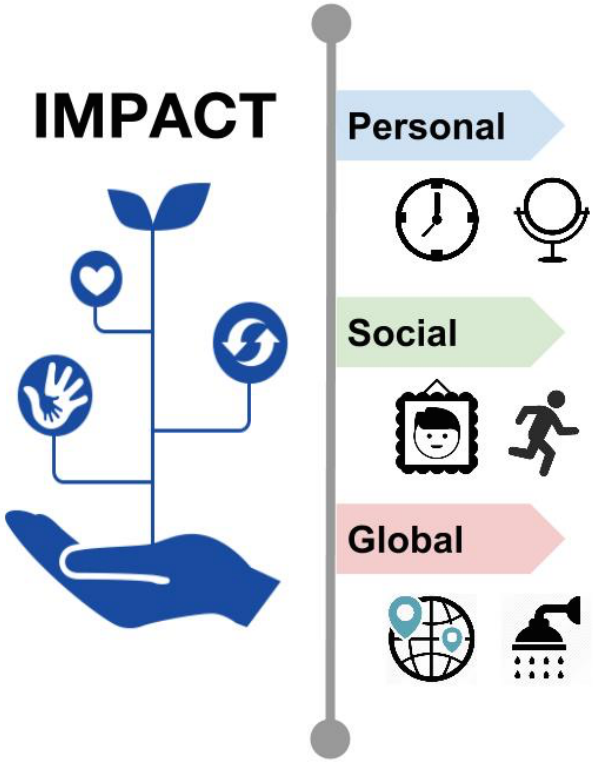


Fig. 3. *Light up my meetings* clock

also of users emotional and physical state. Consciousness entails optimum context awareness to maximize timely user engagement, and minimizes unnecessary user distraction by making customized applications that cater to the relevant needs of the user just-in-time. The agents are not rule-based cyber-physical agents, but adaptive agents that learn from user behavior over time. These intelligent agents are analogous to the smart software agents, such as Maxims email agent, Google Search and Google Now, that can predict user needs and recommend the best actions for the user. I aim to add the magic of smart adaptive agents to Internet of Things (IoT) or Ubiquitous devices that learn from the user over time and can predict user behavior.

Using "embodied virtuality", You-biquitous agents will pull the existing computers out of their electronic shells and embed ambient intelligence in user's environment to serve informative, assistive, and supportive purposes while minimizing cognitive load and engagement cost.

III. PROPOSED DEVICES

The devices are connected to the cloud and have three standard tiers of IoT devices: sensor layer for monitoring, computation layer for feedback, and application layer for control. In terms of the hardware, I have used Arduino Yun as a microntroller that is connected to the cloud Firebase database via WiFi, Arduino Flora to control Neopixels LEDs, Arduino Gemma to control LED stickers connected via conductive thread, and Analog and Digital LED strips. I also used Android and Android Wear applications with some of the devices.

A. 'Light up my meetings' clock: Productivity

1) Hypothesis and goal: 'Light up my meetings' clock (see Figure 3) is a simple ambient interface that shows the user their meeting times. It aims to increase user productivity as the user does not have to pull out their cellphone or laptop to check their calendar, and their calendar appointments are visible to them at a glance. I hypothesize that this display will be useful for users when they get up in the morning, because people tend to check their online calendars when they wake up and my ambient clock allows the users to see their appointments at a glance. This project is also careful to only light up the appointments on the clock at contextually relevant scenarios for the users, e.g. when the user wakes up or 30 minutes before a meeting. The ambient clock is a simple representation of presenting information in user's environment, but it is necessary to learn the best time and way to represent the time to users to avoid being a nuisance and dumping a lot of information on the user.

2) System design: The ambient clock comprises of 25 LED lights placed next to each half-hour count on an analog clock. The LEDs, corresponding to each half-hour, are turned on if the user has a meeting during that half-hour, otherwise they are off. Since analog clocks are 12-hour clock, we can only display appointments for the next 12 hours. The clock keeps track of a boolean variable, called showUserAppointments, which is set by the system to decide whether or not to show the appointments to users at a certain time. For example, it may not be ideal to have appointment lights on while the user is sleeping at night, but the lights can turn on if the user is nearby and has an appointment soon.

3) Experiment design and hypothesis testing: There are two main things to test in this system: i. Is the ambient

interface for calendar appointments useful for the user? ii. What is the best moment and time interval to surface the appointments to the user? The first question is simple to measure as we would compare our test subjects, who see their ambient clock with test subjects, who do not have the ambient clock, and measure the value of the ambient clock to test subjects who have it. The second question involves contextual awareness and we need a smart system that is not only aware of user's state, but also decides if a specific context is good to show user their appointments. We shall compare a machine learned model to a rule-based model for predicting when user needs to check the appointment. For a machine learning algorithm, I have set up a system using which users can request to see their appointments and the system will record when user requests for their calendar appointments. We can this data with online machine learning to decide appropriate times to inform the users about their meetings. We can use simple machine learning algorithms, such as decision trees with features like "need meeting time 10 minutes before the meeting", "need meeting time an hour before the meeting", etc. The benefit to using a machine learned model versus a rule-based algorithm is that machine learning algorithms are generalizable to a variety of users compared to a rule-based model. We can generate personalized rules for each user based on the machine learning algorithm, and test the efficacy of the system in meeting user needs.

4) Related work and my contributions: There has been a lot of research in ambient interfaces and Ishii et al [16] has even used clocks to navigate through temporal events. My goal for the ambient clock is to enhance user productivity by displaying information in the user's environment so that the user does not have to look up the information. By combining machine learning with ambient interfaces, I make the devices cognizant of the user's habits so that devices are not a annoying and give better effortless interactions to the user once the machine learning algorithm is trained better.

B. 'Connected heart' frame : Personal connections

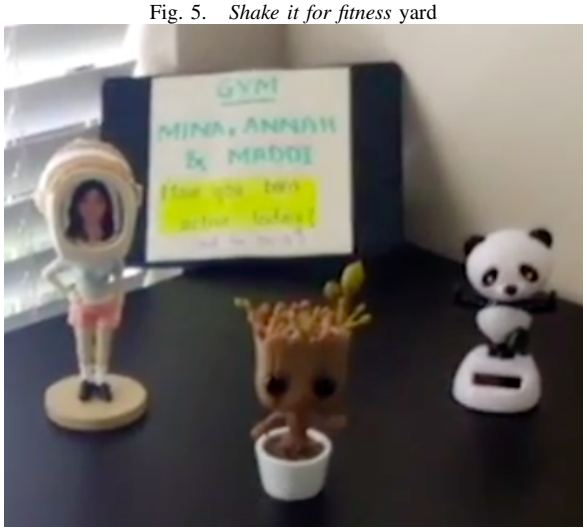
1) Motivation and goals: Several research projects have validated the use of ambient technology in connecting people [8, 17, 18, 19] and you-biquitous agents are a social web of things that have the potential to connect people and encourage a move from 'mindless isolation' to 'mindful connection' [20]. By allowing users to disseminate information with their trusted peers, you-biquitous agents can nurture support networks and connect us to our loved ones in subtle ways to reverse the trend of social isolation. 'Connected hearts' frame (see Figure 4) allow users to get information about the health, availability, happiness, and motivation levels of our loved ones just as a glance. The goal is to quantify the impact of ambient media in facilitating personal connections at a distance. I hypothesize that reducing the overload of exchanging information with our loved ones will result in increased peace-of-mind and closeness between loved ones.

2) System design: 'Connected hearts' frame has a set of four LEDs lights, representing the happiness, availability, health and motivation of our chosen peer. Each of the LEDs can be either green (to represent a positive state for the four types of user states) or red (to represent a negative state), for example Figure 4 shows the "Healthy" LED to be red, which means that the users healthy is not optimal, but the "Happy" LED is green, which means that the user is happy. My research is mostly concerned with representing the four different type of states of the user, irrespective of where the information about these states is coming from. There are several possible ways to gather information about the peer's happiness, availability, health and motivation, for example calendars can be used to populate the "busy" field, Facebook emotional status updates can be used to update "happy" and "motivated" fields, and we can have a custom questionnaire mobile application which the user can fill periodically to update their "health" state. In addition, it is also possible to leverage previous research to classify user moods based on mobile phone usage [21].

Fig. 4. *Connected heart* frame

3) Experiment design and hypothesis testing: The most critical evaluation criteria for 'Connected heart' frame is whether or not it is able to bring people closer and give them the comfort of knowing about their favorite peer's emotional state at a glance without having to text the peer. The effect on communication between individuals will be interesting to study. Like the ambient clock, it is important to learn to show the peer's information at a contextually relevant time for the user. The secondary goal of this project is to study how efficiently we can get information about the peer's state to the user and that will be determined by our techniques for getting information about the peer's state. We can make a simple application to allow the peer to choose their emotional state or infer the different states of the peer based on different signals and contexts.

Fig. 5. *Shake it for fitness* yard



4) Related work and my contributions: Digital photos have been previously used by Mynatt et al. to provide awareness of senior adults' day-to-day activities and promote peace of mind for extended family members [17] My goal is to convey compressed information to the user about their peer's emotional state and whether or not the peer is busy. The motive of this project is to have a glaceable medium hat allows people to effortlessly find out how their loved ones are feeling 'in the moment'.

C. 'Shake it for fitness' yard : Fitness and well-being

1) Motivation and goals: There are plenty of mobile applications for fitness, but many require users to actively remember to request information, imposing an unnecessary 'need-to-remember' cognitive load on the user. Even applications that allow push notifications are seldom contextually relevant, which means that the information can be a nuisance or distraction for the user, and the user may have to end up requesting the same information at a later time. The positive response received by the "Time to Stand" feature on Apple Watch shows that people like to be reminded of their well-being as long as the information does not interfere with or distract them from their important social and physical engagements. The goal of 'Shake it for fitness' yard is to put information about user's fitness activities in the user's environment. The setup implicitly reminds and hopefully, persuades the user to perform their fitness activities because their fitness activities would be reflected in their environment (see Figure 5).

Moreover, the system displays fitness activities for groups of friends so that friends can encourage and influence each other positively to be more fitness conscious. Users are likely to feel social pressure to be be fit as their data is available to their friends. In his book, "Social Physics", Sandy Pentland points out that during social experiments "people receiving social incentives maintain high levels of activity" and my devices will use ubiquitous means to connect people and give social incentives so that people can motivate each other. 'Shake it for fitness' yard focuses on behavioral psychology of groups to leverage social influence to develop healthy habits among groups.

2) System design: The system consists of a set of bobble heads, each representing one friend in the fitness group, and everyday, a friend's bobble head starts shaking when the friend fulfills their fitness goals for the day. Our primary goal is to display the information in a way that is most persuasive for the user, and the secondary motive is to collect the information about user's fitness activities. Depending on the fitness metric, we can collect fitness information from the device directly, for e.g. we can use Google Fit APIs to find out if the user has walked for an hour; alternatively, we may use a mobile phone application or ambient button where the user can indicate that they have accomplished their fitness goal for the day. We will employ game design principles and declare the most fit person in the group every week, which is expected to encourage healthy competition between users to be more fitness conscious.

3) Experiment design and hypothesis testing: There are two key factors to evaluate in this system:

i. the success of ambient interfaces in encouraging fitness activities: To evaluate the success of ambient interfaces, I shall use a mobile based fitness buddies system as a baseline to compare with our 'Shake it for fitness' yard. I shall compare the results from the two systems to measure if ambient interfaces are valuable in reminding and encouraging individuals and groups to be more fitness conscious.

ii. the effectiveness of social incentives in encouraging fitness activities: To measure the effectiveness of social incentives, I shall have a single player version of 'Shake it for fitness' yard, where there will be just one user, and compare the results for the single player version with the results of the social version with gamification techniques.

I will also evaluate if the system can influence individuals and the group to be more fitness conscious in the long-term, i.e. do the groups nd individuals continue to be fitness conscious after they are no longer using the system.

4) Related work and my contributions: There has been previous research on group fitness applications to use social incentives for mobile fitness applications [22] and game design strategies have also been looked into to encourage fitness conscious behavior [23]. Most of the applications use mobile phone reminders for fitness [24], but my work seeks to measure the efficacy of persuasive technology and gamification on a group's fitness via ambient interfaces.

D. 'Glowing shower-savings' garden

1) Motivation and goals: Just like people use fitness trainers, e.g. Zombie Run, the need for environmental sustainability calls for a personal trainer that encourages people to conserve water. 'Glowing shower-savings' garden tackles the challenges of sustainability using gamification, which has emerged as a successful technique in persuasive computing [25, 26], and ambient interfaces. My hypothesis is that ambient media that displays water consumption related information close to the source of water is more likely

Fig. 6. Shower Time

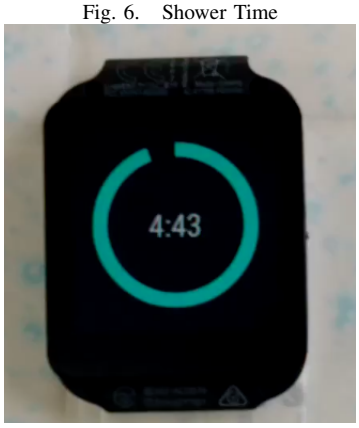
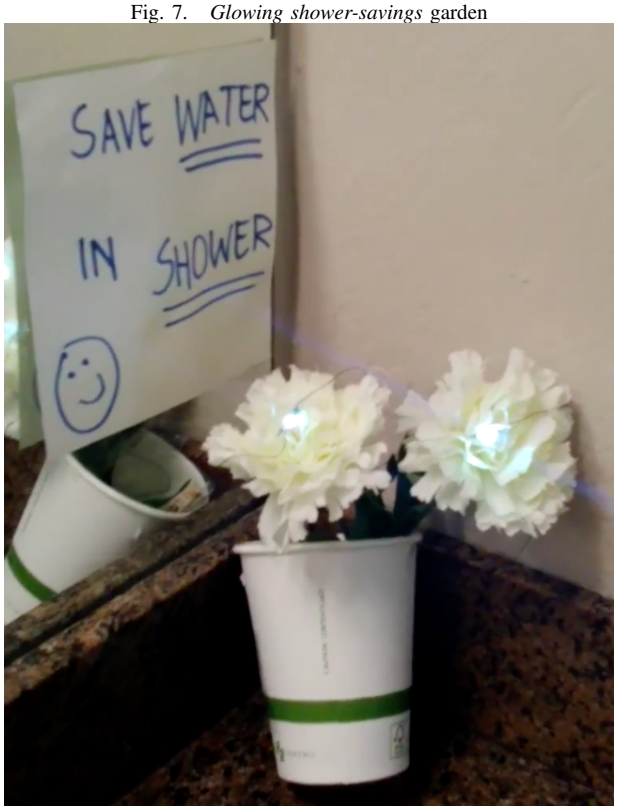


Fig. 7. *Glowing shower-savings* garden



to influence users to conserve water, compared to mobile phone applications where the user has to manually track their consumption. It was found in studies for UbiFit [27] fitness application that users found the UbiFit Garden very motivating and my goal is to motivate the user to conserve water using ambient interfaces that change user's environment based on the user's water consumption in the shower.

2) System design: This application involves using sound, temperature and humidity sensors to keep track of water usage during the shower. The smart sensors learn from user patterns to be active in situations when the user is showering and sets personalized goals for the user. The users have an allotted time for their showers and there is a shower timer (see Figure 6) that displays the time passed since the user started their shower. If the user finishes the shower in the allocated time, the user's shower-savings garden (see Figure 7) starts glowing using LEDs, but if the user takes longer than the allocated time, the garden does not light up. Based on their water consumption, users are awarded badges, and promoted/demoted to other levels of the glowing shower-savings mobile game, which stores user's shower statistics over time.

3) Experiment design and hypothesis testing: There are two main hypothesis to test:

i. Does the shower timer encourage the user to conserve water? I shall conduct studies with a sensor timer display in the shower and with no timer display and evaluate whether the timer display shortens the shower time for the users.

ii. Does that glowing garden influence the users to conserve water during their shower? I shall design two experimental setups, one where test subjects will have the glowing garden and one where the test subjects won't have the garden, just the glowing shower-savings mobile game with their statistic. I shall compare the difference between user behavior in the two scenarios to measure the efficacy of the ambient display.

4) Related work and my contributions: Kuznetsov conducted research [28] has used sound sensors and ambient display to display water flow, but my goal is to use sensor fusion and machine learning to make sure that shower detection is robust and generalizabke without significant sensor calibration. Moreover, my agentss use gamification and ambient interfaces, i.e. the garden, to get people more involved using gamification techniques and beautiful environmental displays.

E. 'My happy reflection' mirror : Self-awareness and self-confidence

1) Motivation and goals: Research has been conducted to show the positive effects of power poses [29] on individuals, and smile has been proposed to be a powerful means to make oneself happy [30]. Based on research done in neuro-linguistic programming [31], I suggest that people could be encouraged to look at themselves in the mirror and reflect on themselves to feel good about themselves. Through 'My happy reflection' mirror, I aim to study how looking at the mirror and taking a picture can impact the short-term and long-term mood of an individual. By using expression analysis on the pictures of the users, I shall not only determine the mood of the user, but also potentially uplift the user's mood using jokes or quotes if they are sad, depressed or happy. The pictures can also be used as an everyday memory of the user over a long time and the system can also encourage users to annotate the images so that they know their thoughts on particular days. In the long-run, the goal is to make the user more self-aware and self-reflective.

2) System design: The mirror has an led strip on its frame (see Figure 8) that lights up to remind the user to look at themselves in the mirror for the purposes of self-reflection. The LED lights are used as an ambient spatial signal, strategically placed near the mirror so that the user

Fig. 8. *My happy reflection* mirror

has a spatial hint of the meaning of the lights. The LED lights on the mirror turn off after the user takes a picture of themselves in the mirror.

The mirror is contextually aware and turns off the LEDs when the prime user is not at home or not in the vicinity of the mirror. The mirror would need to learn the best time to turn on the lights and encourage users to take a picture, but the machine learning techniques for learning the best time for taking pictures is different from the machine learning methods used for 'Light up my meetings' clock and 'Connected hearts' frame because people usually check their schedule and chat with their peers everyday, so we can collect data about when they need their calendar or when they need information about their peers. But since they do not necessarily take a picture in front of the mirror every single day, gathering data to predict the best time for user to take a picture would be best made possible if the mirror were opportunistic and lit up LEDs in relevant contexts to encourage the user to take a picture. It keeps track of when the user takes a pictures and learns when the user is most likely to take a picture in different situations, e.g. over the weekend versus during a weekday, so that the user does not have to set a predetermined time, but instead, the system knows about the user's habits. Based on the context in which the user actually takes a picture, the mirror uses reinforcement learning to learn the best time to light up the LEDs so that the user takes a picture.

3) Experiment Design and Hypothesis Testing: I would like to answer the following questions using 'My happy reflection' mirror.

i. Are ambient interfaces, in particular LED lights, a good reminder for the user to take a picture compared to reminders on cell phone? I shall develop a mobile app that uses push notifications on mobile instead of LED lights on the mirror to encourage users to take a picture. There are two key metrics of success here: how annoying the notification system is, and how persuasive the system is.

ii. Can we use machine learning to learn the best personalized time to take a picture of the user? We will compare the efficacy of the system when the mirror has a machine learning algorithm to light up the LEDs versus when the user sets a predetermined time for the picture.

iii. Can we uplift the mood of the user based on their expressions in the picture? is the mood uplift, if there is any, long-term or short-term? Is there a correlation between user's pictures and their mood during the day?

I shall do facial expression recognition on the user's picture and show them messages accordingly to improve their mood and then evaluate the effects of the messages on the users short-term and long-term emotional state.

4) Related work and my contributions: Roger et al. showed that "twinkly lights" cause a significant change in user behavior even without the user noticing it [32]. Mirrors have been previously used in a project called "Memory Mirror" [33] to keep a 24-hour log of user's use of specified objects, but we aim to give persuasive and uplifting ambient signals, instead of dense information to the user. My goal in this project is not just evaluate the machine learning algorithms to calculate the personalized times for the users to take a picture, but also, more importantly, the psychological affect of the mirror and pictures on users. Research has been done to encourage self-awareness, self-love and self-regulation of humans [34, 35, 36, 37, 38] and I believe that even consciously glancing at oneself in a mirror everyday can cause significant change in an individual's feelings for themselves.

F. 'Global humans' network : Global awareness

1) Motivation and goals: Even though the internet should ideally connect people uniformly, we see filter bubbles and wisdom of flocks on the internet. The problem is that information by itself is a weak connector and we need to first strengthen the human bonds globally before people can start caring about global news. The media is, unfortunately, biased and not representative of the global population, and this problem has been studied in depth by Ethan Zukerman, who has pointed out that in some cases "atoms are more mobile than bits" and has suggested "rewiring" of the cosmopolitan. I hypothesize that without the human bonds, people may not feel the need to invest time and effort to look up information about different areas of the world. Global awareness will be much easier to create when people are connected across cultures, races, socio-economic levels and countries. 'Global humans' network will connect people around the globe to add human context to international stories so that international news is not just a number, but a human face, for people. 'Global humans' network is intended to develop a gradual bond between people from different countries and cultures, and thus, promote cultural and global awareness because we tend to care more about places where we have our family and friends.

2) System design: Wall of Frames is a social network for connecting with people around the world and sharing

Fig. 9. *Global humans* new weekly connection

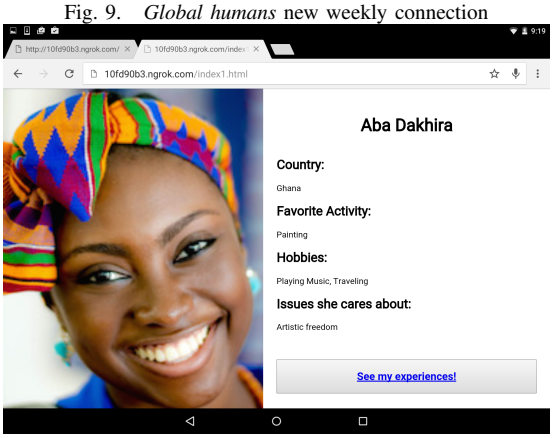


Fig. 10. *Global humans* picture from connection

Fig. 11. *Global humans* news

Fig. 12. *Global humans* display

international, cultural, social and economic experiences. A user signs in with their Facebook login, and each week, the user connected with a new global human connection (see Figure 9), who is two or more nodes away from the user on Facebook, and are living in a culturally and socially different environment that the user. Before connecting, both the user and the global connection are able to see the Global Connections profile each other, and the profile contains the country represented by the user, issues that the user cares about, languages spoken by the user and favorites activities of the user. Once the connection is accepted by both parties, the global human shares a picture (see Figure 10) from their life with the user and the user reciprocates by sending a picture from their lives. Pictures are a powerful medium as they circumvent the language barrier and can be made available in user's ambient environment. The success of "Humans of xx" Facebook pages shows that pictures can convey interesting socio-economic and cultural information about different places. The system also shows top news from the countries (see Figure 11) where the user has made global connections in to the user so that they may associate international news with their international friends. As users make more international connections, thy get more familiar with the culture, social norms and politics of their connection's countries. When the user has a new 'global humans' connection suggestion or breaking news from their friends country, the LED light on the display (see Figure 12) turns on at the next most free moment of the user to get the user's attention.

3) Experiment design and hypothesis testing: There are two key question in this research:

i. What is the level cultural exchange though pictures between users from different socio-economic and cultural background via our system? The results will be mainly qualitative and I shall evaluate the changes in user awareness as a result of making new global connections.

ii. What is the change in the level of interests of the users in the news pertinent to their connection's countries? Again, this is qualitative and would need to be evaluated by conducting interviews with the participants.

4) Related work and my contributions: There are not many, if any, social networks that solely exist to connect people from different countries and cultures, and my work would be unique as a social network for cultural awareness. I would not only find out the best matches for people in their extended Facebook networks, but also convey to them news which is important to their friends. Convery relevant news involves ranking news carefully, especially since I want to avoid stereotypical news, which is normally showed on mainstream media. Also, finding the best match for a user

is an interesting problem that will involve evaluating a lot of factors that may count for a good match. Finally, the Global Humans network would need to be cognizant of the user's idle moments and daily patterns so the pictures of user's connections are made available at contextually relevant moments. There has been previous research to recognize user's idle moments using mobile phone usage [39, 40], and Global Humans network would need to learn when the user is most likely to be engaged with global peers and global news. Personalization is key as research shows that "effectiveness of community awareness applications depend not only on lightweight interfaces, but also information content communicated through these interfaces" [9].

IV. KEY CONSIDERATIONS

The system touches two broad research fields: Human-Computer Interaction, and Machine Learning.

A. HCI

It is essential to note that even though we want You-biquitous agents to be mostly "invisible" in users environment, it is equally important that the devices part of the You-biquitous agents ecosystem need to surface and become visible for the user in contextually relevant scenarios. Ambient media is perfect for communicating information at the "periphery of human perception [41] and previous research, such as ambientROOM [16, 42], has been conducted to make information available using ambient display media such as ambient light, shadow, sound, airflow, and water movement. You-biquitous agents would require the perfect balance of the four theoretical considerations of ambient information systems, i.e. Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis [43], to minimize attentional load and optimize information delivery.

You-biquitous agents will employ not just tangible interfaces, but also "embodied interaction" [44] to combine the physical presence of the devices with the participation and engagement of the user. The interaction design would need to be engaging and require a simple mental model for contextually aware applications so that the applications are predictable for the user. A value-sensitive and ethnography sensitive design approach is also key and there are several previously researched considerations [45], like psychological well-being, physical well-being, privacy, informed consent, and trust, that will be relevant to my project. In short, You-biquitous agents requires a careful study of ambient interfaces, human-centered experience design, ethnomethodology and interaction design to define the physical and digital affordances of the system.

B. Machine Learning and Data Analysis

Low cost sensors and mobile devices give us simultaneous and continuous access to events in the cyber-physical and social environment of the user, and allow us to be contextually aware of the users environment [46]. Contextual intelligence is the key to You-biquitous agents because we do not want to consume the attentional bandwidth of the user for information that misfits users context and needs. To this end, we would need to identify important user scenarios for each of the different You-biquitous agents, such as if the user is at home for the *My happy reflection* mirror or if the user is taking a shower for *Glowing shower-savings* garden or if the user is in a state to use the *Global humans network*. We can get rich user context signals, such as user location and activity, from user's mobile phone and combine those signals with sensor data, such as proximity signals, from You-biquitous agents to effectively classify user context for the devices in the You-biquitous agents ecosystem.

Intelligent agents need to be adaptive and anticipatory of users personalized daily patterns, needs and behavior. Simple rule-based, reflex agents fail in the event of changing users needs and so our cyber-physical system would build trust and competence over time by learning about user needs using machine learning, especially reinforcement learning. To this end, my system could benefit from evolutionary-inspired distributed learning techniques, and I propose the use of learning classifier systems that are ideal for rule-based systems (condition/action) and knowledge extraction [33, 47]. In particular, Anticipatory Learning Classifier Systems and Factored Reinforcement Learning seem good for my agents as each system starts with limited data and a set of condition/action rules [48]. I hypothesize that the smarter the devices, the easier it will be for users to make them a part of their daily lives.

V. FUTURE WORK

A. Ambient Interfaces using Programmable Material and 4D printing

There are two reasons that I think Programmable materials [49, 50, 51, 52, 53, 54] are the future for ambient interfaces:

i. Programmable materials can be power-conserving interfaces:

LEDs and other electronic circuits need a constant supply of power to maintain their "ON" state. However, programmable materials can be used to create meta-stable states that have relatively long-lived stability but state transitions can happen by by adding energy to the system because meta-stable are theoretically unstable. As a result, programmable materials are highly dynamic in form and function, and yet almost as cost-effective as other materials. I shall use small local changes in the programmable material to ripple to all of the material and cause a change in state of the entire structure using interconnected structures.

ii. Changing shapes and structures in the users environment using 4D origami may be aesthetically pleasing:

It was suggested by Cheok et al. [55] that compared to non-living media, living media was more effective as ambient media. Paper origami has been considered as a low-tech means of conveying information in the electronic 'popables' project [56, 57]. I propose using 'living environments' [58, 59, 60] to give beautifully transform user environments based on changes in user behavior to encourage the users by not only putting information in their environment, but also

beautifying their environment as a reward for good user behavior.

B. Augmented Reality (AR)

Instead of just focusing on physical interfaces, I see that there a possibility to use the virtual elements of augmented reality to give people information through ambient interfaces and the combination of AR and ambient intelligence has been recently considered [61, 62]. There are two main advantages of using augmented reality for ambient devices:

i. there are no additional physical devices required as the information may be represented by overlaying information on the user's environment. Though there is a drawback here because the AR device may not be worn at all times by the user, and it may be tough to inform the user about situations in contextually relevant scenarios as the user may not even have the device on. Compared to AR, physical ambient interfaces are more permanent and visible in the user's environment.

ii. augmented reality would serve as a great means of giving information to the user in public spaces so that user-specific information is shared with only a specific user. As augmented reality devices, such as Google Glass, Microsoft HoloLens and Epson Moverio, become increasingly prevalent, I suggest that AR will be a key ambient display in public spaces for user-specific information and tags, e.g. grocery list reminders in different aisles of supermarket for different users.

VI. CONCLUSION

My research roughly follows the idea hexagon by Ramesh Raskar. There is an x+y approach in which I combine ambient intelligence, contextual awareness, reinforcement learning, social physics and IoT to get effortless smart ambient assistants that inculcate self-awareness and social inclusion. IoT is a hammer, which can be used to make or break our society, and I envision it as a constructive tool and have identified as many logically possible nails as I could to test my hammer.

If predictions about the forthcoming exponential growth of IoT devices is to be believed, IoT will have a huge influence on our daily lives and out of the 7 devices an average person is expected to have by 2020 [63], I would like at least one of those to be conscious "You-biquitous agents" that connect people and pop the isolation bubbles created by technology. My research underlines the interfaces of future devices that will have contextual intelligence and shall display information using spatial and ambient signals so as not to impose an informational and cognitive load on the user while delivering the same or even more information to users than the existing technology. You-biquitous agents will use ambient media to surface information to the user with minimum engagement cost, and rely on machine learning to predict the best time and content of the information to be presented to the user. You-biquitous agents will be adaptive to user's changing needs to offer personalized experiences and my research will involve maximizing the personal, social and global impact of You-biquitous Agents.

REFERENCES

[1] Weiser, Mark and Brown, John Seely (1995). "Designing Calm Technology".

[2] Adamczyk, P. D., and Bailey, B. P. If not now, when?: the effects of interruption at different moments within task execution. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (New York, NY, USA, 2004), 271278.

[3] Bailey, B. P., and Konstan, J. A. On the need for attention-aware systems: Measuring effects of interruption on task performance, error rate, and affective state. Computers in Human Behavior 22, 4 (2006), 685 708.

[4] Craik, F. I., Govoni, R., Naveh-Benjamin, M., Anderson, N. D., et al. The effects of divided attention on encoding and retrieval processes in human memory. Journal of Experimental Psychology-General 125, 2 (1996), 159179.

[5] Czerwinski, M., Cutrell, E., and Horvitz, E. Instant messaging: Effects of relevance and timing. In People and computers XIV: Proceedings of HCI, vol. 2, British Computer Society (2000), 7176.

[6] Kreifeldt, J. G., and McCarthy, M. E. Interruption as a test of the user-computer interface. In JPL Proceeding of the 17th Annual Conference on Manual Control (1981), 655667.

[7] Gillie, T., and Broadbent, D. What makes interruptions disruptive? a study of length, similarity, and complexity. Psychological Research 50, 4 (1989), 243250.

[8] Julie A. Kientz, Shwetak N. Patel, Brian Jones, Ed Price, Elizabeth D. Mynatt, and Gregory D. Abowd. 2008. The Georgia Tech aware home. In CHI '08 Extended Abstracts on Human Factors in Computing Systems (CHI EA '08). ACM, New York, NY, USA, 3675-3680.

[9] Qiang Alex Zhao and John T. Stasko. 2002. What's happening?: promoting community awareness through opportunistic, peripheral interfaces. In Proceedings of the Working Conference on Advanced Visual Interfaces (AVI '02), Maria De Marsico, Stefano Levialdi, and Emanuele Panizzi (Eds.). ACM, New York, NY, USA, 69-74.

[10] Ham, J., Midden, C., Beute, F.: Can ambient persuasive technology persuade unconsciously?: using subliminal feedback to influence energy consumption ratings of household appliances. In: Proceedings of the 4th International Conference on Persuasive Technology, vol. 29. ACM (2009)

[11] Riener, A.: Subliminal persuasion and its potential for driver behavior adaptation. IEEE Transactions on Intelligent Transportation Systems 13(1), 7180 (2012)

[12] Riener, A., Kempter, G., Saari, T., Revett, K.: Subliminal Communication in Human-Computer Interaction. Advances in Human-Computer Interaction (2011)

[13] Chalfoun, P., Frasson, C.: Subliminal cues while teaching: HCI technique for enhanced learning. Advances in Human-Computer Interaction 2011, 2 (2011)

[14] B. J. Fogg. 2002. Persuasive technology: using computers to change what we think and do. Ubiquity 2002, December, pages.

[15] Yvonne Rogers. 2006. Moving on from weiser's vision of calm computing: engaging ubicomp experiences. In Proceedings of the 8th international conference on Ubiquitous Computing (UbiComp'06), Paul Dourish and Adrian Friday (Eds.). Springer-Verlag, Berlin, Heidelberg, 404-421.

[16] Hiroshi Ishii, Craig Wisneski, Scott Brave, Andrew Dahley, Matt Gorbet, Brygg Ullmer, and Paul Yarin. 1998. ambientROOM: integrating ambient media with architectural space. In CHI 98 Conference Summary on Human Factors in Computing Systems (CHI '98). ACM, New York, NY, USA, 173-174.

[17] Elizabeth D. Mynatt, Jim Rowan, Sarah Craighill, and Annie Jacobs. 2001. Digital family portraits: supporting peace of mind for extended family members. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '01). ACM, New York, NY, USA, 333-340.

[18] Hidenori Fujita and Kazushi Nishimoto. 2004. Lovelet: a heartwarming communication tool for intimate people by constantly conveying situation data. In CHI '04 Extended Abstracts on Human Factors in Computing Systems (CHI EA '04). ACM, New York, NY, USA, 1553-1553.

[19] Nana Hamaguchi, Daisuke Asai, Masahiro Watanabe, and Yoko Asano. 2014. Investigating the Effective Factors of Communication for Family Members Living Apart. In Proceedings of the 16th International Conference on Human Interface and the Management of Information. Information and Knowledge in Applications and Services - Volume 8522, Sakae Yamamoto (Ed.), Vol. 8522. Springer-Verlag New York, Inc., New York, NY, USA, 373-382.

[20] Society minds, technology doesnt: Yvonne Rogers at TEDxBarcelona

[21] Kiran K. Rachuri, Mirco Musolesi, Cecilia Mascolo, Peter J. Rentfrow, Chris Longworth, and Andrius Aucinas. 2010. EmotionSense: a mobile phones based adaptive platform for experimental social psychology research. In Proceedings of the 12th ACM international conference on Ubiquitous computing (UbiComp '10). ACM, New York, NY, USA, 281-290.

[22] Chen, Yu, and Pearl Pu. "HealthyTogether: exploring social incentives for mobile fitness applications." Proceedings of the Second International Symposium of Chinese CHI. ACM, 2014.

[23] Campbell, Taj, Brian Ngo, and James Fogarty. "Game design principles in everyday fitness applications." Proceedings of the 2008 ACM conference on Computer supported cooperative work. ACM, 2008

[24] Haughay, Allen P., and Benjamin Rottler. "Systems and methods for providing automated workout reminders." U.S. Patent Application 12/363,272.

[25] Huber, Martina Z., and Lorenz M. Hilty. "Gamification and sustainable consumption: overcoming the limitations of persuasive technologies." ICT Innovations for Sustainability. Springer International Publishing, 2015. 367-385.

[26] Hamari, Juho, Jonna Koivisto, and Tuomas Pakkanen. "Do persuasive technologies persuade?-a review of empirical studies." Persuasive Technology. Springer International Publishing, 2014. 118-136.

[27] Sunny Consolvo, David W. McDonald, Tammy Toscos, Mike Y. Chen, Jon Froehlich, Beverly Harrison, Predrag Klasnja, Anthony LaMarca, Louis LeGrand, Ryan Libby, Ian Smith, and James A. Landay. 2008. Activity sensing in the wild: a field trial of ubifit garden. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08). ACM, New York, NY, USA, 1797-1806.

[28] Kuznetsov, Stacey, and Eric Paulos. "UpStream: motivating water conservation with low-cost water flow sensing and persuasive displays." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2010.

[29] Carney, Dana R., Amy JC Cuddy, and Andy J. Yap. "Power posing brief nonverbal displays affect neuroendocrine levels and risk tolerance." Psychological Science 21.10 (2010): 1363-1368

[30] https://www.psychologytoday.com/blog/prefrontal-nudity/201208/smile-powerful-tool

[31] Bandler, Richard, Judith DeLozier, and Leslie Bandler. Neuro-Linguistic Programming. Info-Medix, 1981.

[32] Yvonne Rogers, William R. Hazlewood, Paul Marshall, Nick Dalton, and Susanna Hertrich. 2010. Ambient influence: can twinkly lights lure and abstract representations trigger behavioral change?. In Proceedings of the 12th ACM international conference on Ubiquitous computing (UbiComp '10). ACM, New York, NY, USA, 261-270.

[33] Learning Classifier Systems: Looking Back and Glimpsing Ahead by Jaume Bacardit , Ester Bernad-Mansilla , Martin V. Butz.

[34] Strack, Fritz, Leonard L. Martin, and Sabine Stepper. "Inhibiting and facilitating conditions of the human smile: a nonobtrusive test of the facial feedback hypothesis." Journal of personality and social psychology 54.5 (1988): 768

[35] Baumeister, Roy F., Todd F. Heatherton, and Dianne M. Tice. Losing control: How and why people fail at self-regulation. Academic Press, 1994.

[36] Childers, John H. "Looking at yourself through loving eyes." Elementary School Guidance and Counseling (1989): 204-209.

[37] Sten Govaerts, Katrien Verbert, Erik Duval, and Abelardo Pardo. 2012. The student activity meter for awareness and self-reflection. In CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12). ACM, New York, NY, USA, 869-884.

[38] Ian Li, Jodi Forlizzi, and Anind Dey. 2010. Know thyself: monitoring and reflecting on facets of one's life. In CHI '10 Extended Abstracts on Human Factors in Computing Systems (CHI EA '10). ACM, New York, NY, USA, 4489-4492.

[39] Martin Pielot, Tilman Dingler, Jose San Pedro, and Nuria Oliver. 2015. When attention is not scarce - detecting boredom from mobile phone usage. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15). ACM, New York, NY, USA, 825-836.

[40] James Fogarty, Scott E. Hudson, Christopher G. Atkeson, Daniel Avrahami, Jodi Forlizzi, Sara Kiesler, Johnny C. Lee, and Jie Yang. 2005. Predicting human interruptibility with sensors. ACM Trans. Comput.-Hum. Interact. 12, 1 (March 2005), 119-146.

[41] Ishii, H., & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. Proceedings of the CHI 97 Conference on Human Factors in Computing Systems. New York: ACM.

[42] Craig Alexander Wisnesk, The Design of Personal Ambient Displays.

[43] Zachary Pousman and John Stasko. 2006. A taxonomy of ambient information systems: four patterns of design. In Proceedings of the working conference on Advanced visual interfaces (AVI '06). ACM, New York, NY, USA, 67-74.

[44] Douris, P, Where the action is: The Foundations of Embodied Interaction, Cambridge, MA. MIT press 2001.

[45] Batya Friedman and Peter H. Kahn, Jr.. 2000. New directions: a value-sensitive design approach to augmented reality. In Proceedings of DARE 2000 on Designing augmented reality environments(DARE '00). ACM, New York, NY, USA, 163-164.

[46] Anind K. Dey, Gregory D. Abowd, and Daniel Salber. 2001. A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. Hum.-Comput. Interact. 16, 2 (December 2001), 97-166.

[47] What is a Learning Classifier System? Holland et al.

[48] Anticipatory Learning Classifier Systems and Factored Reinforcement Learning by Olivier Sigaud, Martin V. Butz, Olga Kozlova, Christophe Meyer.

[49] Programmable materials Skylar Tibbits, Kenny Cheung, (2012) "Programmable materials for architectural assembly and automation", Assembly Automation, Vol. 32 Iss: 3, pp.216 - 225

[50] Tibbits, S.J.E. (2010), Logic matter: digital logic as heuristics for physical selfguidedassembly, Masters of Science thesis, MIT Press, Cambridge, MA.

[51] Tibbits, S. (2011), Code: from design and machines to selfassembly, DigitalFUTURE Exhibition, Tongji University, Shanghai, August

[52] Tibbits, S. (2011). A Model for Intelligence of Large-scale Self-assembly. ACADIA 11: Integration through Computation [Pro-ceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)], Banff, Canada. pp. 342-349.

[53] E. Hawkes, B. An, N. M. Benbernou, H. Tanaka, S. Kim, E. D. Demaine, D. Rus, and R. J. Wood, Programmable matter by folding, PNAS 2010 107: 12441-12445.

[54] Qi Ge and Conner K Dunn and H Jerry Qi and Martin L Dunn, Active origami by 4D printing, Applied Physics Letters 103 (13), 131901

[55] Cheok, Adrian David, et al. "Empathetic living media." Proceedings of the 7th ACM conference on Designing interactive systems. ACM, 2008.

[56] Jie Qi, Blooming paper flowers. http://technolojie.com/blooming-paper-flowers/

[57] Qi, Jie, and Leah Buechley. "Electronic popables: exploring paper-based computing through an interactive pop-up book." Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction. ACM, 2010.

[58] Beesley, Philip, and Rachel Armstrong. "Soil and protoplasm: The Hylozoic Ground project." Architectural Design 81.2 (2011): 78-89.

[59] Beesley, P., Gorbet, R., Ohrstedt, P., and Isaacs, H. (2010). Hylozoic Ground: liminal responsive architecture (1st ed.). Cambridge, Ont.: Riverside Architectural Press.

[60] Beesley, P. (2006). Responsive architectures: subtle technologies 2006 Riverside Architectural Press.

[61] Curran, K., McFadden, D., and Devlin, R. (2011). The Role of Augmented Reality within Ambient Intelligence. International Journal of Ambient Computing and Intelligence (IJACI), 3(2), 16-34. doi:10.4018/jaci.2011040102

[62] Remagnino, P.; Foresti, G.L., "Ambient Intelligence: A New Multidisciplinary Paradigm," in Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on , vol.35, no.1, pp.1-6, Jan. 2005

[63] The Internet of Things: How the Next Evolution of the Internet Is Changing Everything, Dave Evans 2011