EcoPath: Adding Spatial, Social, and Gaming Contexts to Personal Tracking Systems

Joel Ross, Nadine Amsel, Robert Beckman, Bill Tomlinson
Informatics Department
University of California, Irvine

Abstract—**While many people desire to track aspects of their daily lives in order to live more sustainably, they may need support to sustain their own tracking efforts and to make meaning of their behaviors. Adding supplementary contexts (intellectual frames) to personally tracked data—such as a spatial context, a social context, or even a gaming context—can help to promote personal tracking and encourage continuous and varied sustainable behaviors. We have developed EcoPath, a mobile game in which users track the locations of their green activities (such as riding a bike or recycling trash), connecting these sites to define "paths" of sustainability. In the EcoPath game, users compete with friends over territory defined by their paths, thus adding a social gaming context to their actions as they make environmentally responsible choices. By adding spatial, social, and gaming contexts to tracking actions, this pervasive game may be an enjoyable way to help people maintain their personal tracking and sustainable behaviors over time.**

Keywords-personal tracking; pervasive games; location-based systems; sustainability

I. Introduction

For an increasing number of people, living in an environmentally sustainable manner is an important moral value. In order to gain a greater self-awareness of their behavior and to discover ways to reduce their environmental impact, people can adopt one of many personal tracking systems (e.g., [1-4]), which allow them to monitor different aspects of their behavior that may affect the environment. Such tracking systems involve either users manually entering data, or sensor systems that allow devices to automatically determine a user's context and information. Personal tracking systems are one form through which users can interact with and make use of the Internet of Things, and demonstrate a way of linking the physical world of human behavior with the virtual world of data representation. Furthermore, collecting data about one's personal life can, through self-reflection, support behavioral change, thereby making personal tracking systems an important component in supporting sustainable living and creating a greener planet.

Nevertheless, there are a number of barriers that may keep people from gaining the full benefits of personal tracking systems [1]. In particular, users may require support in order to continue tracking and altering their behavior over a long term. Users may lose motivation to continue tracking if they don't see immediate results from their efforts—results that may be especially hard to perceive with a problem as broadly scoped as environmental sustainability. Manual tracking may come to be seen as a chore, and even automated tracking requires user time to reflect upon and understand past actions. Indeed, users may need support in interpreting the data they have collected, understanding previous behaviors in order to effect actual change. Interpretation problems may arise from data that, when recorded, had been removed from its full context. For example, upon reviewing the data, a user may not remember the circumstances that caused a particular day's energy usage to be higher than normal. Personal tracking systems need to help users engage with their data, the actions that effected that data, and the behavior changes they can make in the future based on that data.

We propose that one method for lowering these barriers is to add supplementary contexts (intellectual frames) for the personal data collected and for the tracking process itself. By creating and including more contexts, we can give the data collected more dimensions of meaning, increasing the scope of the purpose of that information. Adding contexts can be as simple as adding another information channel to collected data, such as spatial information that tracks the location of energy usage as well as the time and amount. But extra contexts can also increase user engagement with the data by broadening its applicability, as with a social context—tracking information may be more common if users are voluntarily sharing their data with their friends and working together to change their behaviors. Moreover, supplementary contexts can increase motivation to use personal tracking systems by giving users other reasons to record their data. For example, by turning personal tracking into a game, the data gains a further dimension of meaning and the tracking itself may become more enjoyable, as users are playing a game instead of just performing data collection. These extra contexts work to strengthen the link between the physical, virtual, and even social worlds in personal tracking systems—stronger links that can perhaps more successfully promote behavior change.

To demonstrate how such supplementary contexts may be added to personal tracking systems, in this paper we present EcoPath: a pervasive game for supporting green behaviors. In EcoPath, users track the locations of sustainable actions they take, such as riding a bike or recycling trash. The spatial location of these actions is mapped as a "path" of sustainability—a trail showing where people have gone and how they have helped the environment. These paths

Research supported by NSF Grant IIS-0644415, a Sloan Research Fellowship, the Donald Bren School of Information and Computer Sciences, and the California Institute for Telecommunications and Information Technology (Calit2).

define territories that users compete over, participating in a location-based game. Users are able to see their territories and those defined by their friends on a map displayed on their mobile phone, as well as their current score as measured by the amount of territory they have acquired. The EcoPath game thus demonstrates how spatial, social, and game-based contexts can be added to tracking personal behaviors in order to make such tracking more engaging—users play a social pervasive game while they support the environment and live more sustainable lives.

This paper offers two primary contributions to understanding of the design of personal tracking systems. First, we begin by reviewing the use of different contextual framings in these systems, explaining how each of these contexts can be used to support personal tracking for environmental sustainability in particular. We argue that the combination of spatial, social, and gaming contexts can make tracked data more meaningful and engaging to the user. Second, we describe the design of the EcoPath system, a pervasive game that combines these supplementary contexts in support of tracking personal sustainability. This system may thus function as an example of how supplementary contexts can be used for designing individual interactions with the Internet of Things.

II. Personal Tracking and Sustainability

Personal information tracking (also known as "the quantified self" or "personal informatics") is defined by Li et al. as systems that "help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge" [1]. Such systems are a growing area of research in the fields of Ubiquitous Computing and Human-Computer Interaction, with the development of life-logging systems (e.g., [5]) that can help monitor and record events and aspects of people's daily lives. Self-tracking systems are increasingly being adopted by consumers, with the goal of mastering the "Data-Driven Life" [4]. For example, Mint (mint.com) helps automatically track users' financial data, and even popular social networking sites such as Twitter and Facebook perform a kind of life-tracking by recording and sharing daily thoughts and events.

Such tracking services and technologies are frequently applied towards increasing personal environmental sustainability. Referred to as "eco-feedback technologies" [6], these systems use sensing technologies across the Internet of Things to inform users about when and how they may be negatively impacting the environment, and to help users reduce these effects. For example, UbiGreen [2] uses a variety of sensors to determine a user's mode of transportation and encourage greener methods of travel. A wide variety of Smart Meter technologies (e.g., [7],[8]) that can automatically track home energy usage are also being developed and deployed. These kinds of ubiquitous sensing systems are similarly being developed in support of "citizen science" [9], where people track not just their behavior, but details of the environment around them. Such distributed sensing systems are also important for understanding environmental impact, and can similarly be supported by the addition of supplementary contexts.

Because of their "personal" nature, many self-tracking systems support and promote *individual* behavior change, rather than institutional change. This focus on using technology to persuade individuals to improve their lifestyles fits in with common practices in research around sustainable HCI [10]. Nevertheless, some researchers have made the argument that pervasive systems for environmental sustainability should instead focus on sustainability at larger scales and within a broader social framework [11]. Just as participatory sensing [12] combines a large number of individual sensor readings to compile environmental knowledge, so should persuasive technologies work to combine individual actions into large-scale collective action. Adding spatial, social and gaming contexts to personal tracking may help to enable these broader changes and effects.

III. Contexts in Personal Tracking

In this paper, we suggest that by adding supplementary contexts to personal tracking, pervasive systems can encourage people to continue tracking their behavior over time, as well as increase their engagement with collected data. In this case, a *context* refers to an intellectual frame that gives meaning to information or an experience. As Dourish explains: "context is essentially about the ways in which actions can be rendered as meaningful" [13]. Thus by different contexts, we refer to the different ways in which information can be interpreted—understanding through points of view or lenses. Indeed, a particular action can be interpreted in a wide range of contexts, defined when the action occurs or even upon later consideration and reflection. Actions and information are found at the intersection of multiple types of situations and multiple layers of context, any or all of which can shape understanding.

Nevertheless, personal tracking systems often only treat information as existing within a single context at a time. Such systems are generally focused on only tracking a single behavior or topic, and frame that tracking in only a single way. For example, finance tracking systems such as Mint place all data in a financial context (and indeed frame the collection and reflection process as a kind of financial accounting), while life-logging systems such as SenseCam [5] track data in the context of "events"—aiming to record 'who', 'what', and 'where', rather than necessarily 'why'. In order to help make sense of the data they collect (and to increase ease-of-use), such systems encourage a single particular framing of that data's context. But we believe that rather than focusing on a single framing context, adding multiple contexts to tracked personal data can make that data more meaningful to users *because* of the variety of interpretations the contexts support. More ways of viewing and understanding tracked data can deepen users' insights into that data, as they approach their information through multiple lenses. Supporting a wider variety of contexts in personal tracking systems can thus allow for users to make better sense of their data, and to more actively engage with the process of collecting that data.

Below we describe three contexts that we believe may be particularly helpful for supporting an initial "sustainability" context in personal data tracking systems: spatial contexts, social contexts, and gaming contexts.

A. Spatial Contexts

Framing personal tracking in a spatial context involves considering the geographic location of collected data. Indeed, for many "context-aware" systems, the word 'context' is just a synonym for spatial location. Personal tracking systems that work within a spatial context are thus, at a basic level, systems for tracking a user's physical location. Although there are a wide variety of systems that can determine a user's or an object's location (see [14] for a classic review), such techniques have only recently begun to be used by consumers to track their personal location. This increase has likely been due to the growing ubiquity of consumer devices with embedded, accurate GPS receivers. These GPS-enabled devices have enabled location-tracking applications such as BreadCrumbz (bcrumbz.com)—a navigation system that allows people to create their own routes—though other research has looked at also using WiFi for personal location logging (e.g., [15]).

However, the majority of location-based services are focused not on location *tracking*, but on location *sharing*. Wildly popular services such as Foursquare (foursquare.com), Gowalla (gowalla.com), and Latitude (google.com/latitude) allow users to share their location with others—indeed, these systems are often framed as "social networking" services. Previous research (e.g., [16],[17]) has studied why people share locations with others (as well as the privacy concerns of such sharing), exploring how sharing helps users coordinate and maintain social connections. Although the sharing process of these systems does enable users to track where they have been in the past, self-reflection is not the primary goal or supported interaction. Thus despite how the technology has grown to support it, personal location tracking for self-knowledge is not very common: a spatial context is an underutilized framing for personal informatics.

Nevertheless, awareness of the strong link between travel and environmental impact (particularly in carbon emissions from driving) has made location tracking a useful functionality for understanding and increasing personal sustainability. Systems such as EcoRio (ecorio.org) and UbiGreen [2] track a user's location and mode of travel in order to inform the user about the carbon emissions from that journey. These kinds of projects demonstrate the importance of using a spatial context for promoting environmental sustainability. Living a green life involves understanding the effects of your behaviors on a large spatial scale [18], and viewing these behaviors within a spatial context can help with this understanding. For example, understanding not only your movements, but also the movements of products you buy (as with the "buy local" movement) can be a significant step towards reducing environmental impact[1]. Thus adding a spatial context to personal tracking can greatly help to provide a stronger link between a person's actions and their local and global environment.

B. Social Contexts

As with the social location-tracking systems described above, personally tracked information can also be positioned within a social context. A social framing views collected data as having a social basis, either in the source of the data (personal information is a product of a social interaction) or in the interpretation of the data (personal information is shared or compared with other social actors). Viewing tracked personal data as arising from a social context can help give meaning to that information, as users may get a stronger sense of how their behavior is positioned in their social lives. Similarly, sharing and comparing personal data in a social context can help users understand the relative significance of that data (e.g., "is how much energy I use a lot or a little compared to others?"), as well as potentially garnering social support for behavioral change. Thus most current personal tracking systems (in following a "Web 2.0" design philosophy) try to place information in some kind of social context even if that context is not the primary way of understanding information, as this social context can make information more meaningful and valuable to individuals, as well as encourage further use of the tracking system.

Previous research has begun to consider how social contexts can be used to help encourage environmental sustainability (e.g., [20]). For example, StepGreen [3] uses social network integration to suggest and encourage green actions for people to perform. This system also supports tracking these green actions (though unlike EcoPath, it does not position them spatially). By positioning sustainable goals within a social context and a social network, StepGreen seeks to strengthen the motivation to complete these goals and increase participation in greener living. Indeed, emphasizing social norms can be a significant motivator of sustainable behavior, as people are likely to adjust their behavior based on the actions of their social peers. For example, Goldstein et al. [21] showed that hotel guests are significantly more likely to reuse their towels and thus save water when appealed to through descriptive norms (e.g., "75% of guests who stayed in this room reuse their towels")—people identify with others in a social context, and thus adjust their behavior to match. Furthermore, these social connections can also be used to encourage collective action on a broader scale: Dourish [22] suggests that pervasive technologies such as social networking sites can be used to "show how particular actions or concerns link one into a broader coalition of concerned citizens, social groups, and organizations"—organizations that can then enact large-scale or institutional changes. In these ways, framing personal tracking in a social context can both support and extend behavioral change towards environmental sustainability.

C. Gaming Contexts

Lastly, we believe that framing personal tracking systems as games represents an under-explored method of supporting data collection and understanding. Positioning tracking as a game can encourage the monitoring process itself: users may track their data because they enjoy the gameplay, rather than for the potentially more difficult-to-maintain motive of seeking personal reflection. Indeed, a player's achievement within the game context (e.g., their "score") may provide a more intuitive way of understanding their advancement towards reaching behavioral goals, instead of a user needing to judge progress from potentially decontextualized readings and data. Thus a

---

[1] The transportation of people and goods produces 25% of global CO_2 emissions [19].

gaming context for personal tracking can better support analysis and interpretation of collected data—games provide an enjoyable framework for thinking about personal data and thus engaging in self-reflection.

Positioning personal tracking in a gaming context also helps support the addition of other supplementary contexts. For example, multiplayer games often also have a social context; whether players collaborate or compete, such games draw on elements of the social world in how players interact. Moreover, games are increasingly able to support a spatial context, particularly in the form of location-based or pervasive games [23],[24]. A *pervasive game* is "a game that has one or more salient features that expand the contractual magic circle of play socially, spatially or temporally" [25]. Most commonly, these are digital games that are integrated and expanded into the physical world. Pervasive gaming has emerged from the idea of pervasive computing and the Internet of Things—though instead of ubiquitous computing, we have ubiquitous play. As such, pervasive games are commonly enabled by spatial sensing technologies. In *Pirates!* [26], location-sensing technology enables players (as ship captains) to move around a physical arena, discovering virtual islands and challenging other physically proximate captains to battle. Similarly, *Human Pacman* [27] uses an augmented reality system to allow players to attempt to devour virtual cookies positioned in the physical world, all while avoiding other players. In these ways, the virtual game worlds are linked with the physical real world—in fact, *Treasure* [28] uses the seams in ubiquitous connectivity (i.e., disconnections within the Internet of Things) to affect strategy and gameplay. Thus pervasive gaming creates a link between the physical and virtual worlds that can also help to link the virtual representation of personal behavior created in personal tracking systems with the physical world actions that lead to that collected data.

Indeed, games can be a significant source of motivation for positive behavior change. Increasing amounts of time, money and research are focusing on "serious games"—games that are used for purposes other than just entertainment, such as for training or learning (see [29] for an overview). Successful, enjoyable games—especially video games—incorporate a large number of design principles that support learning new behaviors, such as dynamic levels of difficulty and developing tacit knowledge through repetition [30]. Pervasive games in particular can effectively support behavioral change, because of how actual behavior influences the game experience. For example, previous research has used pervasive games to successfully promote behavior change for increased personal health: *Fish'n'Steps* [31] has users play a game in which they try and grow a fish by walking more, while in *NEAT-o-Games* [32] users compete in a virtual race based on their actual physical energy expenditure. Both of these games can be seen as forms of personal informatics systems, in which users are logging their physical activity. But by placing this logging in the context of playing a game, researchers are better able to encourage behavior change in the form of greater amounts of real-world exercise. In this way, the addition of a gaming context has been shown to support personal tracking systems—support that we extend with the further additions of social and spatial contexts.

The use of pervasive gaming for encouraging behavior change has also been extended into the domain of environmental sustainability. For example, *GreenSweeper* [33] creates a mixed-reality version of Minesweeper (though with unsustainable locations instead of mines), but the game aims to promote reflection on current environmental landscapes rather than self-reflection on tracked personal behaviors. *Power Agent* [34] turns tracking home energy usage into a game (with users competing against their neighbors), but does not include a location-based spatial context. In *Power Agent*, the social pressures built into the competitive game are the strongest motivational factors for changing behavior and reducing energy usage. Finally, the *UbiGreen* system [2] described above—a location-based system for tracking green travel—was identified as a game by its users, even though the researchers never framed it as such. This demonstrates how users in fact often *want* to turn tracking systems into games (or at least default to thinking about them as games)—the data based nature of such tracking lends itself to the achievement tracking found in many games. Gaming contexts thus can offer a strong supportive framing for personal tracking, as well as better enabling the inclusion of social and spatial contexts into these systems; the combination of these supplementary contexts have the potential to greatly support tracking personal behavior in a sustainability context.

IV. EcoPath

In order to demonstrate how supplementary contexts can be added and combined in support of personal informatics systems, we have developed a pervasive game called EcoPath. In the EcoPath game, users track the locations of green actions they may take, competing with other players to see who can perform the most sustainable actions in the widest area--as users track their behavior, they can also have fun by playing a social, location-based game. This form of tracking thus includes spatial, social, and gaming contexts that can promote increased usage and behavior change. By combining these contexts with the sustainability context of the personal tracking system, EcoPath can encourage the maintenance of continuous and varied sustainable behaviors as users go about their daily lives.

A. *Sustainable Paths*

The EcoPath game is founded on the idea of forming and identifying "paths of sustainability." With EcoPath, the locations of particular green actions performed by users are ordered temporally and linked into a path—a trail showing where people have gone and how they have helped the environment there. These kinds of paths thus introduce a strong spatial context into the tracking of personal behaviors that is currently underutilized, combining it with the temporal context common to tracking systems. Furthermore, actions that affect the environment can be grounded in a user's actual environment, as actions are more strongly tied to their location. Paths can also help to reveal new links between actions that have not previously been supported by green tracking systems. For example, a user may discover how riding their bike to work leads to them buy local produce at the farmer's market on the way, a sustainable behavior they would not have exhibited if

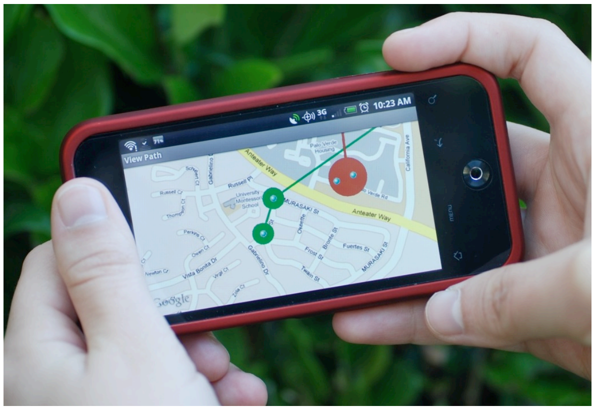

Figure 1. The EcoPath game allows users to track their paths of sustainable actions.

they took a car. Similarly, revealing these paths may identity strong and weak areas of sustainability as defined by place—users may realize that they perform lots of sustainable actions at home, but not at work. Thus paths of sustainability enable the addition of a spatial context for thinking about *where* one's personal environmental impact takes place, which can help to support future behavior changes.

Defining paths of personal behavior can also be positioned within a social context. Paths can potentially reinforce social links, indicating in space where users asynchronously meet—people's paths of sustainability may cross, join together, follow the same road, or eventually diverge, in a manner suggestive of the social context connecting the users. Indeed, such paths may even reveal previously hidden social relations, as with familiar strangers [35]. Establishing paths of sustainability can also be tied to constructing a personal social identity, such as through the demarcation of spatial and social territory. Paths may define "territory", either as the area covered by the paths (trails are themselves territory) or as the area surrounded by the paths (trails mark the borders of territory). Such territory can potentially be used in the construction and propagation of a personal identity—"I am the person (or kind of person) who is an actor within this territory." The establishment of territory can thus also support the establishment of a sustainable social identity.

Indeed, vying for control of this territory lends itself to positioning EcoPath as a game, thus allowing paths to support a gaming context as well as social and spatial contexts. Games that involve contest over territory have a long history, including classic examples such as Go, Risk, and Monopoly. Such territorial dominance is the mode of play in current social-networking location-based games such as Foursquare. In these games, users "check in" to locations they visit (such as a restaurant or a bar), earning points based on how often they visit. By checking in to a particular location the most, users can be the "mayor" of that venue—in a way, establishing that location as their territory. This type of territory-based game is incredibly popular: Foursquare alone has more than 500,000 registered players. EcoPath presents a similar form of location-based game, but instead of earning points just for checking in to a particular location, players earn points for completing sustainable actions along a path. In this way, the use of spatial paths enables the competition that drives gameplay.

B. Playing EcoPath

As a pervasive game, EcoPath is played through people's mobile phones (currently, devices running the Android platform and equipped with embedded GPS receivers and cameras). Gameplay is designed to be integrated with people's normal actions—the game is played as people go about their daily lives. In this game, players use the system to document any environmentally preferable actions they may take: a user creates a "marker" at their current location to record the action. Although EcoPath users currently track and record their actions manually, the interaction paradigm and supplementary contexts found in this game can apply to automatic sensing systems as well.

To create a marker, a player uses the phone's embedded camera to take a representative picture of the action—for example, a user may take a picture of the bike they rode to work, of the trash they are recycling, or of the light switch they turned off. (Note that players choose for themselves what actions they define as "sustainable"; see Section V for further discussion). The picture helps to verify that the user did complete the action they are recording, as well as offers a visual representation and reminder of the action for later self-reflection. Users also write a short text description of the action to complement and explain the pictorial record. The picture and text description—together with the action's geographic position determined by the phone's built-in GPS and localization technologies—are uploaded to a central web server through the phone's normal data connection using HTTP.

The recorded sustainable action is shown on a map of the player's current location that is displayed on the mobile phone. The map displays the marker as a green circle centered at the action's geographic location. The new marker is attached by a green line to the previous recorded action, which is itself connected to the prior action, and so on in order to show the user's path of sustainability (see Figure 1). Thus as a user tracks more sustainable actions, their path grows in length and their territory (defined by the circles around the markers) increases. Players are able to trace their paths of sustainability, reviewing the pictures and descriptions of their recorded markers. In this way, the tracked sustainable behaviors are positioned in a supporting spatial context: actions are tied directly to a particular location, and the spatial history of a user's behavior can be seen and reflected upon. Nevertheless, markers and the attached paths do fade (becoming transparent) over time, giving users an incentive to continue performing sustainable actions in order to maintain their territory. Although users can view the history of their sustainable behavior, they are encouraged to focus on continuing to perform new, spatially located, green actions in the future.

The displayed map also shows the paths of the player's trusted (i.e., explicitly approved) friends, with players able to view the details of their friends' actions as well as their own. Indeed, users are able and expected to view and score other player's actions, rating them on a scale of 1 to 5 (with 1 being least green and 5 being most green; actions have a default rating of 3). The average rating of an action by other players affects that marker's size on the map, and thus a user's amount of territory. This group scoring system enables people to support one another's sustainable actions—in a way users can work together to identify particularly sustainable behaviors that they may perform. Furthermore, this scoring system allows for social moderation of actions taken within the game with a kind of reputation system [36]. Malicious users (players who "cheat" in recording actions) may be sanctioned socially outside of the game framework. This cooperative tracking and moderation system helps to place the gameplay within a strong social context: users are able to reflect on the social implications of their tracked actions (as the actions are rated by social peers), and moderation of the game is grounded within a person's social context rather than a pure gaming context. Social context is thus used both to support the interpretation of personally tracked actions, as well as to enable the tracking to be treated as a scored game.

To further assist with the interpretation of personally tracked sustainable behaviors while placing these behaviors within a gaming context, EcoPath includes a number of metrics for scoring personal achievement—there are multiple ways to earn "points" in the game. A player's primary score is based on the amount of territory they have accumulated, calculated as the sum of the average rating for each marker. This score acts as a measure of "overall sustainability", but can also be a way of scoring the user's personal tracking behavior (i.e., "how many notable actions have you recorded?"). In EcoPath, players are evaluated by the number of positive sustainable actions they take, rather than by the negative impact they may be having—this positive reinforcement may make the game more enjoyable and satisfying for the player. Players also have a score for "reach", calculated as the maximal distance between markers, measuring the overall width of the area in which they've performed sustainable actions. Increasing this score may motivate players to live sustainably in a broader scope than just their own homes or workplaces (though it may introduce a rebound environmental impact in encouraging people to travel). Finally, EcoPath has a score for player "focus", calculated as the density of markers over an area. This score aims to reward people who do not travel, but instead try to increase their sustainability within a single context—to have the greenest home, for example. The "reach" and "focus" scores allow the system to support and reward both users who have great *breadth* in helping the environment and those who have great *depth* in reducing their impact. The player with the highest "reach" and "focus" scores also gain a bonus to their overall score.

Overall, EcoPath's gaming context and gameplay aim to help support personal tracking and motivating sustainable behaviors. The gameplay itself integrates spatial and social contexts (particularly in the game's location-awareness and social moderation systems), which themselves can help to support personal informatics as described above. But moreover, by framing the EcoPath personal informatics system as a game, we hope to make it enjoyable to use, encouraging people to think about and track their behaviors as they go about their daily lives. By supporting this kind of self-awareness, EcoPath can help to inspire people to acknowledge their environmental impact and to live greener lives.

V. A SUSTAINABILITY GAME

The EcoPath game is intended to increase people's environmental sustainability by supporting the personal tracking of their environmentally preferable behaviors. This game attempts to support green behaviors at all stages of The Transtheoretical Model [37] of behavior change. This psychological model (also known as the "Stages of Change" model) can be used as a framework for motivating change for sustainability [38]. To varying extents, EcoPath functions to support change at each of the five stages in this model. For users in the *pre-contemplation* stage, EcoPath potentially provides a fun way of getting players to realize that their actions have an impact on the environment—by framing EcoPath as a pervasive game, players may join without having explicit green motivations. As a personal tracking system, EcoPath supports users in the *contemplation* stage, as they can begin to reflect on the extent of their sustainable actions. EcoPath also supports *preparation*, particularly as players may discover new ideas about green actions they can take from the paths of others—the actions of social peers can suggest new behaviors for a player to adopt. And the game explicitly supports *action*, as users need to take (behavior-exhibiting) actions in order to play the game. Finally, EcoPath seeks to support *maintenance* of these actions by encouraging players to continue performing sustainable actions and living green lives. Players can also slowly increase the scope of their sustainable actions as green behaviors (such as turning off lights or carpooling to work) become internalized. In this way, EcoPath can encourage sustainable actions from a variety of players with a range of motivational levels.

Note that in EcoPath, the environmental sustainability of a particular action is determined ad-hoc by the users, not by an *a priori* belief enforced by the game of what is considered green. Users define for themselves what types of actions they believe to be sustainable, shaped by their individual circumstances. For some users, turning off the lights to save energy may be worth tracking, while for others installing solar cells to capture renewable energy is a more appropriate action (as in [39])—the greenness of a particular behavior is relative to a person's situation). In this way, EcoPath views the tracked behaviors with a more phenomenological approach [13], giving users the ability to interactively define what is meant by the events they track. Although the system aims to support a variety of contexts (i.e., environmental, spatial, social, and gaming) for understanding personally tracked information, the exact meaning of the recorded data may be constantly reinterpreted by the user—particularly the question of "what is a sustainable behavior?" Furthermore, this interpretation of the relative sustainability of a particular action is also strongly influenced by a user's social circle and circumstances, as players can socially evaluate each other's actions. Users and their communities determine the appropriateness of an environmentally preferable action.

By treating environmental sustainability as a relative measure, we seek to better ground individual behaviors in individual contexts. A person's desire to be sustainable may be restricted by their circumstances: for example, while driving less may reduce a person's environmental impact, if that person lives 25 miles away from their place of work (and their town lacks a robust public transportation system) then altering their driving behavior may be infeasible. A person's desire to live sustainably needs to occur within a variety of existing infrastructures that may not support the behaviors they wish to exhibit or the lifestyle they wish to lead. EcoPath acknowledges this potential limitation, and supports people living as sustainably as they can given their circumstances. In this way, by defining sustainability in a relative manner, we can avoid making sustainability a moral choice available only to those with the economic means to afford it [40]. Indeed, the very question of "what is sustainable" may only be answerable relative to a particular context—measures of sustainability by their very nature as measurements attempt to capture a complex interaction between human behaviors and the environment [41]. The EcoPath game works to ground the complex idea of sustainability in players' own lives and contexts.

Environmental sustainability is an abstraction for understanding human interactions with a set of exceptionally complex systems (e.g., ecological and climate systems). The relationships between human behaviors and systems such as global climate change are almost intractably complex—yet reducing our environmental impact requires understanding these interactions. Thus systems for the tracking of a vehicle's miles-per-gallon, a home's energy usage, or a person's carbon footprint are all attempts to construct simplified models that reduce this complexity in order to support behavior change. Furthermore, methods for understanding and dealing with complex systems become even more important as embedded sensor systems become more ubiquitous, collecting more and more data about our environment and making our perception of complex ecological systems even more intricate. In order to reduce our impact on the environment, we need to understand how to act within these complex systems.

Nevertheless, *games*—video games in particular—are another context in which simplified models of complex systems play an important role. Games often present complex systems of interlocking causalities, statistics, and rules that people readily internalize and enjoy manipulating. For example, millions of players understand and engage with countless permutations of thousands of abilities, items, and characters in online games such as World of Warcraft. Players in games learn to successfully act within these complex systems, with the games themselves functioning as training platforms. Thus we believe that, in general, games can provide effective abstractions and models for interrogating the relationships between human behavior and environmental impact—just as EcoPath uses a gaming context to frame the tracking of personal behavior. By embedding sensing and computational systems within games, we believe we can help people more easily understand and reduce their environmental impact. Nevertheless, further research is still needed into ways that games (or particular aspects of games) can be combined with an embedded Internet of Things in order to promote sustainable behaviors as people go about their daily lives.

VI. Future Work

We are currently launching a pilot study of the EcoPath system in order to rigorously test how users interact with and play the game. We will explore how each supplementary context affects users behavior and experiences with the system—for example, how the social context of shared paths affects people's enjoyment of the game and willingness to track and reflect upon their green behaviors. This study will provide further insights into the use of supplemental contexts to support personal tracking and other ubiquitous systems. Indeed, other research might explore the multiplicity of contexts used for interacting with the Internet of Things, and how these contexts can be combined in order to best shape the user experience.

Other future work could look at how supplementary spatial, social, and gaming contexts can be used to support collaborative efforts and collective action. For example, EcoPath's infrastructure for tracking the locations of sustainable actions could be used to help coordinate large-scale environmental efforts. Coastal cleanup groups such as the Surfrider Foundation (surfriderfoundation.org) could use EcoPath's spatial context to determine what parts of a beach have been cleaned, and use the social and gaming contexts to motivate greater action as volunteers compete to cover the most territory and pick up the most trash. EcoPath may also help such organizations better reflect upon and understand their cleanup process, identifying paths people tend to take or where larger efforts may be needed. Thus supplementary contexts for pervasive tracking systems can help collaborative, large-scale environmental efforts to be more productive and effective.

VII. Conclusion

In this paper we have presented EcoPath, a system for tracking personal green behaviors that uses supplementary spatial, social, and gaming contexts to encourage continuous and varied sustainable behaviors. These kinds of supplementary contexts can be used to support a wide variety of ubiquitous and pervasive systems, giving more dimensions of meaning to the link between computational systems and user understanding. Indeed, the use of multiple contexts demonstrates how a variety of channels may be used to connect real users with virtual computation systems [42]. By creating deeper and stronger connections between the physical and the virtual worlds (including the virtual worlds defined by games), we can give people a greater understanding of how their actions affect the environment and how they can live greener and more sustainable lives.

Acknowledgment

The authors thank the Social Code group.

References

[1] I. Li, A. Dey, and J. Forlizzi, "A stage-based model of personal informatics systems," *Proceedings of the 28th international conference on Human factors in computing systems*, Atlanta, Georgia: ACM, 2010, pp. 557-566.

[2] J. Froehlich, T. Dillahunt, P. Klasnja, J. Mankoff, S. Consolvo, B. Harrison, and J.A. Landay, "UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits," *Proceedings of the 27th international conference on Human factors in computing systems*, Boston, MA: ACM, 2009, pp. 1043-1052.

[3] J. Mankoff, S.R. Fussell, T. Dillahunt, R. Glaves, C. Grevet, M. Johnson, D. Matthews, H.S. Matthews, R. McGuire, R. Thompson, A.

Shick, and L. Setlock, “StepGreen.org: Increasing energy saving behaviors via social networks,” *ICWSM 2010*, Washington D.C.: AAAI, 2010.

[4] G. Wolf, “The Data-Driven Life,” *The New York Times*, Apr. 2010.

[5] S. Hodges, L. Williams, E. Berry, S. Izadi, J. Srinivasan, A. Butler, G. Smyth, N. Kapur, and K. Wood, “SenseCam: A Retrospective Memory Aid,” *UbiComp 2006: Ubiquitous Computing*, 2006, pp. 177-193.

[6] J. Froehlich, L. Findlater, and J. Landay, “The design of eco-feedback technology,” *Proceedings of the 28th international conference on Human factors in computing systems*, Atlanta, Georgia: ACM, 2010, pp. 1999-2008.

[7] J. Karlgren, L. Fahlén, A. Wallberg, P. Hansson, O. Ståhl, J. Söderberg, and K. Åkesson, “Socially Intelligent Interfaces for Increased Energy Awareness in the Home,” *The Internet of Things*, 2008, pp. 263-275.

[8] S.N. Patel, S. Gupta, and M.S. Reynolds, “The design and evaluation of an end-user-deployable, whole house, contactless power consumption sensor,” *Proceedings of the 28th international conference on Human factors in computing systems*, Atlanta, Georgia: ACM, 2010, pp. 2471-2480.

[9] E. Paulos, R.J. Honicky, and B. Hooker, “Citizen Science: Enabling Participatory Urbanism,” *Handbook of Research on Urban Informatics: The Practice and Promise of the Real-time City*, 2008, p. 414.

[10] C. DiSalvo, P. Sengers, and H. Brynjarsdóttir, “Mapping the landscape of sustainable HCI,” *Proceedings of the 28th international conference on Human factors in computing systems*, Atlanta, Georgia: ACM, 2010, pp. 1975-1984.

[11] M. Foth, E. Paulos, C. Satchell, and P. Dourish, “Pervasive Computing and Environmental Sustainability: Two Conference Workshops,” *IEEE Pervasive Computing*, vol. 8, 2009, pp. 78-81.

[12] J. Burke, D. Estrin, M. Hansen, A. Parker, N. Ramanathan, S. Reddy, and M.B. Srivastava, “Participatory sensing,” *ACM Sensys World Sensor Web Workshop*, 2006.

[13] P. Dourish, “What we talk about when we talk about context,” *Personal and Ubiquitous Computing*, vol. 8, Feb. 2004, pp. 19-30.

[14] J. Hightower and G. Borriello, “Location systems for ubiquitous computing,” *Computer*, vol. 34, 2001, pp. 57-66.

[15] J. Rekimoto, T. Miyaki, and T. Ishizawa, “LifeTag: WiFi-Based Continuous Location Logging for Life Pattern Analysis,” *Location- and Context-Awareness*, Springer, 2007, pp. 35-49.

[16] L. Barkhuus, B. Brown, M. Bell, S. Sherwood, M. Hall, and M. Chalmers, “From awareness to repartee: sharing location within social groups,” *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, Florence, Italy: ACM, 2008, pp. 497-506.

[17] S. Consolvo, I.E. Smith, T. Matthews, A. LaMarca, J. Tabert, and P. Powledge, “Location disclosure to social relations: why, when, \& what people want to share,” *Proceedings of the SIGCHI conference on Human factors in computing systems*, Portland, Oregon: ACM, 2005, pp. 81-90.

[18] B. Tomlinson, *Greening through IT*, Cambridge, MA: MIT Press, 2010.

[19] International Energy Agency, *Worldwide trends in energy use and efficiency: Key insights from IEA indicator analysis*, http://www.iea.org/papers/2008/Indicators_2008.pdf: 2008.

[20] J. Mankoff, D. Matthews, S.R. Fussell, and M. Johnson, “Leveraging Social Networks To Motivate Individuals to Reduce their Ecological Footprints,” *System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference on*, 2007, p. 87.

[21] N.J. Goldstein, R.B. Cialdini, and V. Griskevicius, “A Room with a Viewpoint: Using Social Norms to Motivate Environmental Conservation in Hotels,” *Journal of Consumer Research*, vol. 35, Oct. 2008, pp. 472-482.

[22] P. Dourish, “Points of Persuasion: Strategic Essentialism and Environmental Sustainability,” *Persuasive Pervasive Technology and Environmental Sustainability, Workshop at Pervasive 2008*, 2008.

[23] C. Magerkurth, A.D. Cheok, R.L. Mandryk, and T. Nilsen, “Pervasive games: bringing computer entertainment back to the real world,” *Comput. Entertain.*, vol. 3, 2005, pp. 4-4.

[24] M. Montola, J. Stenros, and A. Waern, *Pervasive Games: Theory and Design*, Morgan Kaufmann Publishers Inc., 2009.

[25] M. Montola, “Exploring the edge of the magic circle: Defining pervasive games,” *Proceedings of Digital Arts and Culture*, 2005.

[26] S. Björk, J. Falk, R. Hansson, and P. Ljungstr, “Pirates! using the physical world as a game board,” *Proceedings of Interact 2001*, 2001, pp. 9-13.

[27] A.D. Cheok, S.W. Fong, K.H. Goh, X. Yang, W. Liu, and F. Farzbiz, “Human Pacman: a sensing-based mobile entertainment system with ubiquitous computing and tangible interaction,” *Proceedings of the 2nd workshop on Network and system support for games*, Redwood City, California: ACM, 2003, pp. 106-117.

[28] L. Barkhuus, M. Chalmers, P. Tennent, M. Hall, M. Bell, S. Sherwood, and B. Brown, “Picking Pockets on the Lawn: The Development of Tactics and Strategies in a Mobile Game,” *UbiComp 2005: Ubiquitous Computing*, 2005, pp. 358-374.

[29] B. Sawyer and P. Smith, “Serious games taxonomy,” *Presentation at The Serious Games Summit at the Game Developers Conference 2008*, 2008. Available: http://www.seriousgames.org/presentations/serious-games-taxonomy-2008_web.pdf

[30] J.P. Gee, *What video games have to teach us about learning and literacy*, Macmillan, 2007.

[31] J. Lin, L. Mamykina, S. Lindtner, G. Delajoux, and H. Strub, “Fish’n’Steps: Encouraging Physical Activity with an Interactive Computer Game,” *UbiComp 2006: Ubiquitous Computing*, 2006, pp. 261-278.

[32] Y. Fujiki, K. Kazakos, C. Puri, P. Buddharaju, I. Pavlidis, and J. Levine, “NEAT-o-Games: blending physical activity and fun in the daily routine,” *Comput. Entertain.*, vol. 6, 2008, pp. 1-22.

[33] H. Lin, K. Liu, and N. Sambasivan, “GreenSweeper: A Persuasive Mobile Game for Environmental Awareness,” *Ubicomp 2008 Sustainability Workshop*.

[34] A. Gustafsson, C. Katzeff, and M. Bang, “Evaluation of a pervasive game for domestic energy engagement among teenagers,” *Comput. Entertain.*, vol. 7, 2009, pp. 1-19.

[35] E. Paulos and E. Goodman, “The familiar stranger: anxiety, comfort, and play in public places,” *Proceedings of the SIGCHI conference on Human factors in computing systems*, Vienna, Austria: ACM, 2004, pp. 223-230.

[36] P. Resnick, K. Kuwabara, R. Zeckhauser, and E. Friedman, “Reputation systems,” *Commun. ACM*, vol. 43, 2000, pp. 45-48.

[37] J.O. Prochaska and W.F. Velicer, “Behavior change: The transtheoretical model of health behavior change,” *American Journal of Health Promotion*, vol. 12, 1997, pp. 38-48.

[38] H.A. He, S. Greenberg, and E.M. Huang, “One size does not fit all: applying the transtheoretical model to energy feedback technology design,” *Proceedings of the 28th international conference on Human factors in computing systems*, Atlanta, Georgia: ACM, 2010, pp. 927-936.

[39] A. Woodruff, J. Hasbrouck, and S. Augustin, “A bright green perspective on sustainable choices,” *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, Florence, Italy: ACM, 2008, pp. 313-322.

[40] P. Dourish, “Print This Paper, Kill a Tree: Environmental Sustainability as a Research Topic for Human-Computer Interaction,” *LUCI Technical Report LUCI-2009-004*, 2009.

[41] M.S. Silberman and B. Tomlinson, “Toward an ecological sensibility: tools for evaluating sustainable HCI,” *Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems*, Atlanta, Georgia: ACM, 2010, pp. 3469-3474.

[42] B. Tomlinson, M.L. Yau, E. Baumer, J. Ross, A. Correa, and G. Ji, “Richly Connected Systems and Multi-Device Worlds,” *Presence: Teleoperators & Virtual Environments*, vol. 18, Feb. 2009, pp. 54-71.