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Quality of Experience in Affective Pervasive Environments

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Abstract

The confluence of miniaturised powerful devices, widespread communication networks and mass remote storage has caused a fundamental shift in the user interaction design paradigm. The distinction between system and user in pervasive environments is evolving into an increasingly integrated loop of interaction, raising a number of opportunities to provide enhanced and personalised experiences.

We propose a platform, based on a smart architecture, to address the identified opportunities in pervasive computing. Smart systems aim at acting upon an environment for improving quality of experience: a subjective measure that has been defined as an emotional reaction to products or services. The inclusion of an emotional dimension allows us to measure individual user responses and deliver personalised services with the potential to influence experiences positively.

The platform, *Cloud2Bubble*, leverages pervasive systems to aggregate user and environment data with the goal of addressing personal preferences and supra-functional requirements. This, combined with its societal implications, results in a set of design principles as a concrete fruition of design contractualism.

In particular, this thesis describes:

- a review of intelligent ubiquitous environments and relevant technologies, including a definition of user experience as a dynamic affective construct;

- a specification of main components for personal data aggregation and service personalisation, without compromising privacy, security or usability;
- the implementation of a software platform and a methodological procedure for its instantiation;
- an evaluation of the developed platform and its benefits for urban mobility and public transport information systems;
- a set of design principles for the design of ubiquitous systems, with an impact on individual experience and collective awareness.

Cloud2Bubble contributes towards the development of affective intelligent ubiquitous systems with the potential to enhance user experience in pervasive environments. In addition, the platform aims at minimising the risk of user digital exposure while supporting collective action.

for Ola

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Declarations

The author of this thesis declares that the work presented is original and all else is appropriately referenced.

Publications

- **The Railway Blues: Affective Interaction for Personalised Transport Experiences**, P. M. Costa, A. Vasalou, J. Pitt, T. Galvão, and J. Falcão e Cunha, in Proceedings of the 12th International ACM Conference on Mobile and Ubiquitous Multimedia, 2013.
  Findings obtained from a field study performed focusing on the personalisation of information services and immersive digital experiences

- **Assessing Contextual Mood in Public Transport: a Pilot Study**, P. M. Costa, J. Pitt, T. Galvão, and J. Falcão e Cunha, in Proceedings of the 15th International ACM Conference on Human-computer interaction with mobile devices and services companion, 2013.
  Results and lessons learnt from a pilot study conducted in a naturalistic environment for collecting user data

- **Investigating Mobile Quality of Experience in Public Transport**, P. M. Costa, J. Pitt, J. G. Vieira, J. Falcão e Cunha, and T. Galvão, in Proceedings of the 14th International ACM Conference on Human-computer interaction with mobile devices and services companion, 2012.
  Description of the developed platform for studying travellers in a urban public transport context, including both environment and user aspects

- **Cloud2Bubble: Enhancing Quality of Experience in Mobile Cloud Computing Settings**, P. M. Costa, J. Pitt, J. Falcão e Cunha, and T. Galvão, in the 3rd ACM Workshop on Mobile Cloud Computing and Services, 2012.
  Documentation of the Cloud2Bubble platform architecture, aiming at collecting environment and user data, including affective data

- **Smart Mobile Sensing for Measuring Quality of Experience in Urban Public Transports**, J. G. Vieira, T. Galvão, J. Falcão e Cunha, P. M. Costa, and J. Pitt, in the 2nd International Workshop on Smart Mobile Applications, 2012.
  Report on the mobile application developed to interface with travellers, supporting participatory and opportunistic sensing in a urban public transport environment

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1 Introduction

The convergence of powerful miniaturised devices, fast communication networks and remote computing infrastructures has caused a fundamental shift in the user interface design paradigm. These technological advances have resulted in an increased integration of technology in the environment, making it transparent for end users, while establishing the connection between the physical and virtual worlds, as envisioned by ubiquitous computing.

As a result, the distinction between systems and users in such ubiquitous environments is evolving towards a more pervasive and integrated loop of interaction between them. In this context, the environment in itself becomes a pervasive affordance, allowing systems to perceive users and react to their needs.

New input methods widen the spectrum of interaction, and are no longer restricted to traditional methods such as explicit actions and graphical interfaces. Implicit interactions enable the collection of users' behaviour, activity and internal state. These new dimensions open a number of opportunities for systems to actively address users' requirements. Simultaneously, risks of misuse of such personal digital information arise, by exploiting the available resources.

The emotional dimension, in particular, supports the evaluation of users' internal states as an emotional reaction to a specific experience. Therefore, in ubiquitous environments, user experience becomes a dynamic construct that may be individually assessed and influenced.

Furthermore, the affective response is defined as quality of user experience, that may be used as an utility measure in relation to a system's ability

to address users' supra-functional needs. Supra-functional needs include hedonic and emotional aspects of experience, in addition to their utilitarian requirements.

Empathy, in this context, is defined as the ability to address individual supra-functional requirements. Empathic systems explore this close relationship between users and systems in intelligent ubiquitous environments, by leveraging the existing technology for assessing users' needs and responding with the goal of enhancing the user experience.

In addition to enhancing quality of user experience, addressing supra-functional aspects of experience contributes towards wellbeing. On an individual level, wellbeing may be described as a combination of short-term affective states and long-term emotions. On a collective level, such platforms have the potential to empower collective action, by inspiring individuals to self-organise towards a common goal or solution.

1.1. Research Problem

The research described in this thesis aims at investigating the requirements for the design and development of empathic systems in a real-world environment, as well as evaluating its impact on human experience.

The research is focused on leveraging existing technology, in particular personal devices, as building blocks of intelligent ubiquitous environments. Personal mobile devices are used ubiquitously by users throughout the day and for a wide range of activities, providing a privileged component of the underlying loop of interaction. The loop of interaction enables the collection of both environment and personal data, supporting the evaluation of users' responses in relation to their surroundings and activities.

In addition to assessing user experience, its dynamic nature poses itself to the exploration of strategies for actively influencing the quality of experience. User influencing, however, presents a number of challenges related with the complexity of human behaviour, in addition to societal considerations that are intrinsic to ubiquitous systems.

Empathic systems, and the provision of affective-aware services, have other implications other than the direct influence over experience. Other entities involved, including economic and governance agents, may benefit from such systems. However, it is necessary to ensure that the users, the

main digital information generators are also the primary beneficiaries.

This thesis focuses on the following research questions:

- Can affective digital information be collected in a pervasive computing environment to monitor quality of user experience?
- Can a metric of user experience be estimated from personal and affective user data?

1.2. Aims and Objectives

This thesis proposes a software platform - *Cloud2Bubble* - that relies on a ubiquitous loop of interaction for assessing users' experience as an affective response to an environment. In addition, it explores the potential for influencing behaviour and quality of experience by addressing users' supra-functional requirements via the delivery of personalised services.

Prior to the design and development of the platform, an extensive review of previous work is conducted in order to gain a deep understanding of user experience as a dynamic construct and its relationship with human emotion and wellbeing. Thus, user experience requirements are identified, from ubiquitous and affective computing perspectives. Finally, the societal implications of such systems are discussed in their social, economic and privacy dimensions.

The specification of the software platform is based on the requirements identified, and include technical aspects, performance in relation to the societal impact and behaviour towards users' supra-functional needs. The specification and implementation of the platform intends to be a reference for future development of affective-aware systems, as well as a proof of concept in the evaluation of the underlying goals of the research, including the dynamic nature of user experience.

The domain of urban public transport is used as an evaluation, as it constitutes an exemplar smart environment: a sensor saturated environment and the need for optimising urban mobility. A review of the state of the art and requirements in this domain is conducted. This review provides the foundation for the identification of the needs of users as well as the target experience. The instantiation of the platform is executed in preparation for a field study with passengers.

Finally, a discussion of the results obtained is provided to explore the relationship between users and their environment and the impact on their daily activities - in particular commuters and the travelling experience. In addition, a set of design principles is presented, providing a concrete specification to the abstract concept of design contractualism, each of them specifying a mutual agreement between the system designer and the final user in six dimensions: benefit, empowerment, privacy, collectivity, awareness and sustainability.

1.3. Thesis Structure

The thesis is composed of eight chapters and its structure is illustrated in Figure 1.1. Following the introductory chapter, the narrative splits between *User Experience in Intelligent Ubiquitous Environments* as a generic theme for the thesis and *Intelligent Urban Mobility* as a domain of application. *Cloud2Bubble Specification* and *Implementation* follow, leading up to the *Instantiation in Urban Public Transport*. Subsequently the *System Evaluation* is presented and final *Conclusions*.

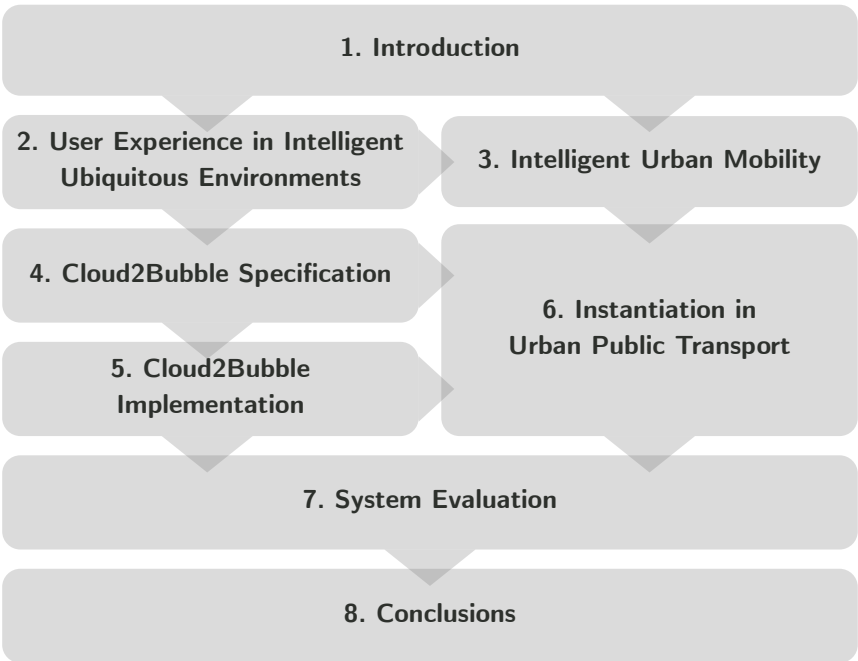


Figure 1.1.: Thesis structure

1.4. Thesis Outline

The outline of the thesis is as follows:

Chapter 2: User Experience in Ubiquitous Computing Environments

This chapter reviews the relevant technologies under the scope of intelligent ubiquitous computing systems, as well as interaction paradigms and societal implications. Finally, it provides a definition of user experience as an affective response in ubiquitous environments.

Chapter 3: Intelligent Urban Mobility

Review of urban mobility, and public transport in particular, as an instance of smart environments. This chapter identifies the activities and passenger needs in large urban areas in relation to transport and information services.

Chapter 4: Cloud2Bubble Specification

This chapter specifies the requirements and high-level architecture of a ubiquitous, affective-aware software platform. The requirements are divided into functional, non-functional and supra-functional requirements; the architecture identifies the main components and their role inspired by a smart system architecture.

Chapter 5: Cloud2Bubble Implementation

Describes the implementation of the software platform based on the previous specification. This chapter details the main components of the system: services, policies and entities. A review of the software packages supporting the development of the platform in provided, in addition to a methodological procedure for its instantiation.

Chapter 6: Platform Instantiation

The *Cloud2Bubble* platform is instantiated in the context of urban public transport, based on the methodology introduced and the urban mobility review from Chapter 3. The main steps are presented, including context modelling and user interface; as well as the main restrictions imposed by this domain of application.

Chapter 7: System evaluation

The studies conducted for evaluating the platform are presented, in Porto (Portugal) and London (UK), with a discussion of the results obtained and main findings. This chapter results in a set of design principles, derived from the research process, based on the potential of *Cloud2Bubble* to not only provide enhanced user experiences on an individual level, but also supporting collective action.

Chapter 8: Conclusion

The last chapter summarises the research performed and main findings, including recommendations for the identified limitations. Moreover, some further work is proposed focusing on the instantiation of the platform in another domain of application.

1.5. Statement of Contribution

The execution of the goals identified in the previous Sections results in the following contributions:

- an extensive review of ubiquitous environments and relevant technologies, including urban mobility environments, resulting in a definition of user experience as a dynamic affective construct;
- identification of the key components for the development of affective-aware ubiquitous environments, defining functional, non-functional and supra-functional needs towards empathic pervasive systems;
- a specification for the aggregation of environment and user data, including the definition of a metric of personalisation, without compromising privacy, security or usability;
- the implementation of a software platform based on the specification, together with a methodological procedure for its instantiation;
- the instantiation in the domain of urban public transport focusing on the commuting experience;

- evaluation of the developed platform in a controlled environment and in a public transport setting, identifying a number of benefits for affective-enabled information systems;
- a set of design guidelines that support the methodical design of ubiquitous systems, with an impact on both individual experience and collective awareness.

This thesis resulted in a user experience centric platform that aims at collecting and aggregating personal data to deliver personalised services in intelligent ubiquitous environments. In addition to user experience, the system may be leveraged as a socio-technical platform for user benefit, empowerment, awareness, privacy as well as collectivity and sustainability, as the main pillars for implementing design contractualism.

2

User Experience in Intelligent Ubiquitous Environments

2.1. Introduction

This chapter provides a review of user experience in the context of intelligent ubiquitous environments. The relevant technologies are reviewed focusing on the ubiquitous supporting infrastructures, and the personal devices that enable an affective interaction with users. As a result of the technological advances, the transparent integration of ubiquitous systems into the physical world raises a number of opportunities for interacting with users. Moreover, user experience is defined as an affective-dependent measurable construct and, to a certain extent, influenceable. User experience is associated with affective responses that contribute to overall wellbeing in ubiquitous environments. Finally, the ability to collect sensitive personal information integrated into everyday's activities raises concerns that are further explored.

2.2. Affective Computing

Emotion is a central human experience and plays an important role in human high-level cognition, including decision-making, planning and interaction [46]. The introduction of emotion as an additional dimension in the loop of interaction, between users and systems, enables the development of empathic systems, as envisioned by Affective Computing (AC). Empathy, in Human Computer Interaction (HCI), refers to the ability to recognise users'

affective states and adapt the system behaviour accordingly with the potential to effectively enhance human experience. In addition to more natural interactions with users, emotion or affective representation has the potential to enhance computer decision making [163].

An alternative approach to the affective states proposed by AC are affective interactions. In affective interactions, emotions are considered to be constructed in the process of an interaction, rather than a isolated state. Thus, computers passively support users in understanding their own emotions with the goal of making emotional experiences available for reflection, rather than actively detecting them [98]. In this continuous interaction, both physical and emotional, the decision to participate is left to the users, who may get involved in an affective loop [195, 97], that leads to a change in their attitudes and behaviour.

A growing area of interest that takes advantage of the emotional dimension in computing interactions is defined as captology - computers as persuasive technologies - or simply persuasive computing. Persuasive computing may be defined as technology designed to influence users attitudes and behaviours through persuasion and social influence [72]. Emotion, similarly to affective interactions, assumes a central role in the process of engaging users in such a reflective process, that potentially leads to behaviour adaptation.

Research in this field ranges from the development of wearable sensors and algorithms to process affective-related data to explore how computers can reduce negative feelings such as frustration and stress in a wide range of contexts. In the context of e-learning, for example, active tutoring systems rely on multimodal affective data to assess the level of frustration of a student to actively adapt the level of difficulty or help proactively [111]. As a result, students experience an enhanced learning environment avoiding negative feelings associated with failure and subsequently reengaging them in the learning process improving their performance. Perhaps an even more inspiring application of AC in a healthcare context, is the development of an automated system for aiding people diagnosed with autism in recognising other people's emotions [130].

2.2.1. Emotional Models

Research on human emotion and affect is active in a wide range of fields, including psychology, neuroscience, medicine and computer science. In addition, human emotion is complex in nature, performing different roles associated with evolutionary purposes and social interactions. In fact affective states are categorised according to a temporal structure in Figure 2.1. While emotion is usually short-lived and intense, mood is underlying and prolonged [45]. As a result, a number of diverging theories have emerged, attempting to explain and model affect, focusing on different aspects of emotion [25]. The more traditional perspectives on affect focus on: facial and body expressions as a result of evolutionary processes; embodiments combining expressions and physiology changes as the expression of emotion in itself; cognitive appraisals as directly affecting the person based on experience, goals and opportunity for action; and social constructs claiming that emotions cannot be explained strictly on the basis of physiological of cognitive terms, but require an additional social level of analysis.

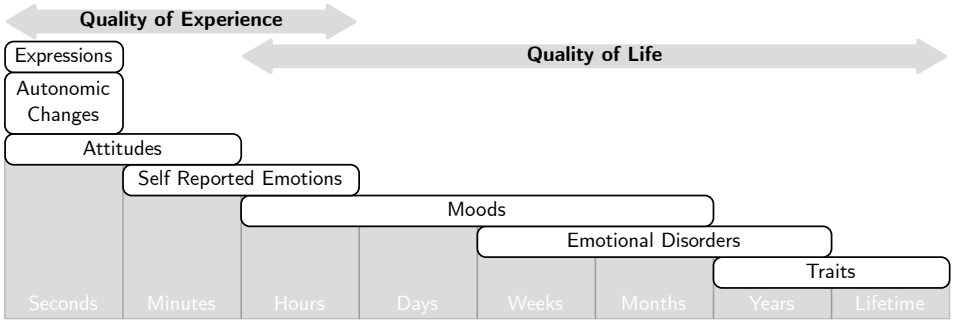


Figure 2.1.: Temporal characteristics of emotion categories, adapted from [45]

The modern perspectives on emotion are generated from the fields of neuroscience and psychology [25]. The former, based on neuro-scientific methods, investigates emotional processes and its neural correlates. Such methods provided evidence to support some existing theories, such as the relationship between cognitive and emotional processes. The later recognises emotions as a *"heterogeneous cluster of loosely related events"* and attempts to unify existing theories of emotion under a common framework. This common framework considers different perspectives of human emotion as

different concepts rather than different positions about the same topic.

In the context of AC, however, two main models of affect modelling prevail: a discrete model, based on the universality of human emotion as evolutionary processes and composed of a small set of basic emotions [60]; and a multidimensional emotional space where each dimension represents different levels of cognitive valence and arousal as a core feeling [176].

Basic Emotions

Ekman proposes a discrete model, composed of six basic emotions: happiness, sadness, fear, anger, surprise and disgust [60]. The emotions are, according to the model, distinguishable via unique characteristics of facial and body expressions (see Figure 2.2). This set of emotions appears to be part of human evolutionary process and are universally recognised, even between different cultures. Each of the emotions has distinct facial characteristics and are, therefore, recognisable via facial expression recognition methods.

Figure 2.2.: Model of basic emotions: anger, fear and disgust (top row) surprise, happiness and sadness (bottom row) [61]

A significant body of research has been conducted based on this discrete model of basic emotions. Systems provided with facial expression recognition are capable of identifying users' states and act accordingly. As an example, adaptive educational tools continuously adjust the difficulty level as a way of increasing engagement and improving learning performance.

Even though this model has become the standard in facial recognition, researchers are now starting to expand the set of emotions. Some studies have demonstrated the limitations the model in terms of number of emotions, ignoring more complex constructs such as engagement, confusion or frustration. In addition, the technological developments have allowed the implementation of more powerful systems, capable of expanding emotion capture [139].

Multidimensional Model

An alternative model, in Figure 2.3, as proposed by Russell is based on a two-dimensional circumplex model of emotion [176]. In this model, emotion is represented as a linear combination of two dimensions, as varying degrees of both cognitive valence and physical arousal. This model combines existing perspectives on emotion centered around core affects, i.e. a consciously accessible neurophysiological state described as a point in a valence-arousal space, equivalent to a *feeling* [25].

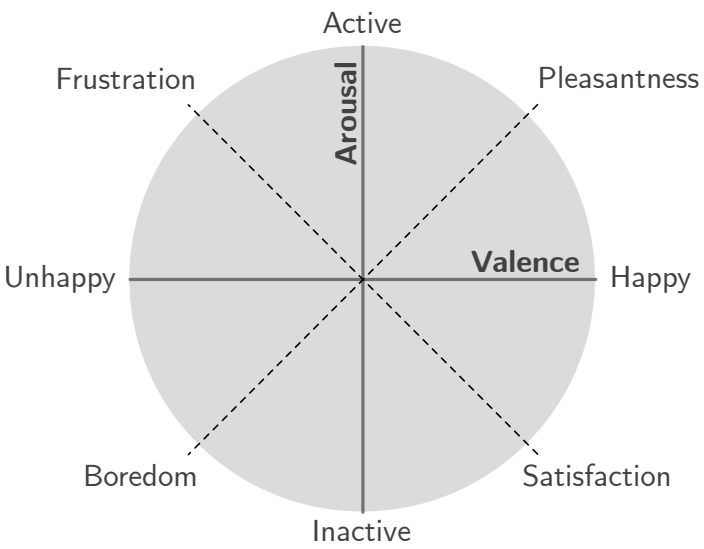


Figure 2.3.: Circumplex of emotion: Arousal vs Valence, adapted from [176]

The classification of an emotion in this model may be somewhat fuzzy, with minimum variations on either of the axis resulting in slight different affective states. This representation of emotion is therfore more natural to the human experience of emotion, where emotions usually overlap rather

than being discrete states that are independent from each other.

The two dimensions present in the model have different characteristics and are measurable in different ways. Valence, an intrinsically cognitive measure, indicates the level of pleasure or displeasure and may be inferred, for example, from facial expression or patterns of behaviour. Physical arousal, on the other hand, is physiological in nature, and may be measured via electrodermal activity and other physiological cues. Furthermore, a psychophysiological emotional map addresses the variations between measures and actual affective states resulting in an enhanced and personalised affective sensing [208].

2.2.2. Affective Sensing

Assessing users affective states in AC raises a number of challenges, not only associated with the underlying complexity of emotion in itself, but also with the collection of affective cues from users. There are a number of different methods for collecting affective cues, ranging from the self-report of emotion [170] and patterns of interaction with the device [83, 129], to physiology-based measures [26], with varying degrees of intrusiveness and complexity. As an example, brain imaging is complex to set up and intrusive due to the equipment required, even though new approaches aim at simplifying and automating the process (see Figure 2.9). In addition, body cues represent an increasingly important modality in affective sensing [113]. A sample of body-based measures of affect is presented in Table 2.1.

While each of the methods has its advantages and drawbacks, the combination of multiple methods leads to an increased performance in inferring affective states [102]. Multimodal sensing combines different methods, including body- and task-based ones [164, 54, 197].

An alternative to body-based sensing in naturalistic environments is the capture of different dimensions of user activity and behaviour in an everyday context. Such techniques rely on the analysis of patterns of behaviour, including location and social interaction, to infer mood variations [129] and even personality traits [154]. These tend to be valid for extensive periods of time, and therefore associated with mood, unlike the more instant affective state provided by body-based techniques.

The capture of user data in urban environments, however, involves a

number of challenges, in particular the role assumed by users of said environment. A people-centric approach proposes opposing levels of conscious involvement: *participatory* and *opportunistic* [27]. On the one hand, *participatory* sensing involves users in the data collection process explicitly. Users are asked to self-report aspects of their activity of behaviour, decide what data is shared and the level of privacy. On the other hand, *opportunistic* sensing relies purely on automated processes and the user does not participate and may not be aware of the fact, provided implicit privacy and security requirements are met.

Table 2.1.: Body-based measures of affect, adapted from [164]

Modality	**Comments**
Facial Activity	Facial expressions may differ significantly from genuinely felt feelings; variants include video, infra-red and thermal methods
Posture Activity	Good results discriminating between levels of interest in e-learning interactions
Hand Tension and Activity	High-pressure associated with frustration when handling objects, e.g.: mouse and steering wheel
Gestural Activity	Expression sensing in conducting music; alternative applications unexplored
Vocal Expression	Good at discriminating arousal
Language and choice of words	Promising for discriminating cognitive valence, limited to text input
Electrodermal activity	Detects changes in arousal but does not distinguish between positive and negative
Brain imaging	Promising for detecting neural pathways for determining arousal and valence

Even though a purely opportunistic approach provides better support for large scale deployment and diversity, the involvement of users may be required for raising awareness or due to technical limitations. Thus, systems are not, for the most part, based on one of the sensing methods exclusively. Instead, urban sensing tends to rely on a hybrid approach between participatory and opportunistic sensing [118]. Examples include the EmotionSense [170], a platform that collects both user and sensor data to infer affective states and moods; and MoodScope [125], a project that infers users' mood based on patterns of usage. These sensing projects, applied to

affective sensing, allow for the collection of affective states in urban environments. The ability to include user emotion in HCI, effectively immersing users in an interactive affective experience, contributes towards empathic systems with the benefit of providing for individual needs and states.

2.3. Ubiquitous Computing

In the world envisioned by ubiquitous computing (ubicomp), technology is so well integrated into everyday objects and activities that it disappears into the background. Users become unaware of interacting with computer systems, even though such systems support most of everyday activities [211], like sharing a lecture on a white-board or accessing information effortlessly.

Information processing is being increasingly integrated into everyday objects and activities, contributing progressively towards an ubiquitous computing environment. Ubicomp may be defined as machines that fit the human environment instead of forcing humans to enter theirs, and presents a number of challenges and opportunities across computer science: system design and engineering, system modelling, interface design, among others [211].

The idea of an invisible layer of technology that integrates with the environment and objects around us is not exclusive to ubicomp. Similar concepts with slight variations have emerged in research groups and initiatives around the world, including pervasive computing [180, 179], Everyware [90] and the Internet of Things [12]. These tend to be more focused on the technological challenges, like devices and interconnectedness. Ambient intelligence [186] and Smart systems, on the other hand, build upon them bringing the focus to user sensing and intelligent adaptation.

The technological requirements identified for ubiquitous environments have become a reality in the past years and are constantly evolving: cheap, low-power computers; wide spread communication networks; and software for ubiquitous applications. These advances have fundamentally changed the interaction paradigm, that is shifting from a desktop-based device to one where multiple devices act as portals to a virtual space [179] - commonly referred to as the *post-PC* paradigm.

A sensitive and responsive environment to the presence of people, with support for a wide range of activities builds upon this ubiquity, even for the

most mundane tasks such as switching the lights on in a room. However, in order to fully support these activities in a non-obtrusive way, intelligent systems require a deeper understanding of users wants and needs, even when not explicitly expressed by them.

2.3.1. Interaction paradigm

Even though ubiquitous computing raises a number of opportunities and challenges in a wide range of disciplines, the underlying goal has always been to develop machines that fit the human rather than forcing humans to fit the machine [211]. Thus, the development of a truly ubiquitous environment demands for a set of requirements on the user experience side, such as the capture of both explicit and implicit interactions, context-awareness and a continuous and smooth integration between the virtual and physical worlds, throughout multiple devices [179].

Current HCI models, however, are predominantly based on graphical interfaces and inadequate to the integrated ubicomp vision. An integrated interaction paradigm has yet to emerge, even though some consumer products have started to appear inspired by this vision, such as smartphones, navigation systems and personal activity trackers to name a few.

User interaction with systems has been evolving from the traditional input methods, such as using the keyboard and mouse on a computer, to a broader range and more implicit interactions. The ability to capture user interactions with the physical world, beyond the traditional graphical interface, enables the development of more human-like interactions [3]. For example, speech recognition makes a ubiquitous system responsive to explicit voice commands, but also allows for the implicit recognition of the internal affective state of the user [197].

The integration of ubicomp capabilities in the environment provides support for a continuous experience throughout different contexts and activities, also defined as fluent experience [74]. Such a seamless integration, however, requires the orchestration of a number of devices with different characteristics and capabilities, from personal mobile devices to large scale infrastructures. Thus, the capture of input and output is based on a multimodal approach, where different sources of input and output are used to assess and convey information [102].

The capture of natural interactions with the environment as system input increases significantly the amount and type of data collected. These large datasets, defined as big data, are complex in nature to store and process, not only due to the large size but also due to the intrinsic complexity between the entities involved. The correct interpretation of big data depends on the recognition of the context in which it takes place. Context is defined as any information that can be used to characterise the situation of an entity, i.e. a person, place or object that is relevant to the interaction between a user and an application [49].

The characterisation of the situational context of a particular entity is done by establishing the identity, location, time and activity: the *who*, *where*, *when* and *what*. These elements are the basis for determining *why* a situation is occurring and respond accordingly. For example, a museum visitor receiving information about the objects in the surroundings; however, if the same visitor starts moving quickly through different exhibitions, it may mean he is not interesting in that particular area and information about an alternative exhibition would be more appropriate.

While a truly integrated interaction paradigm, as envisioned by ubicomp, has yet to leave the research labs and emerge into the real-world, a number of projects and initiatives have made significant developments inspired by this paradigm. A successful example is the automotive navigation system, which provides reliable turn-by-turn directions to a specified destination. The success of this application in particular is, in part, due to the success in determining the context and integrating into the activity: the driver of the vehicle, independently of whom in particular, is the user; the location is restricted to known streets and roads and assisted by satellite navigation; the progress is recorded and tracked throughout the journey; and the activity of driving is assisted with common preferences, such as preferred type of roads. The final goal to reach a certain destination, is achieved with the assistance of the system, that is able to track and adapt in real-time with minimum user input.

In other domains, however, user context may be more complex to determine. Unlike identity, location and time, that are becoming relatively simple to obtain depending on the application, activity is fairly complex to assess in an uncontrolled environment unless specified, as it involves not only external but also user internal states and goals. Different models of

cognition have emerged to explain the relationship between users and the environment: namely activity theory, situated action and distributed cognition. The former provides the richest framework for explaining user activity and how it relates to the environment [147], and is the predominant one in HCI.

Activity-based Computing

Activity-based computing aims at shifting the focus from developing systems capable of performing isolated tasks, to supporting continuous activities [209]. An activity is seen as a subject acting upon an object in order to reach a desired outcome, by employing a set tools. Both the object and tools may be physical artifacts or less tangible constructs [147]. Activities are, therefore, mediation relationships between a group of elements, in Figure 2.4.

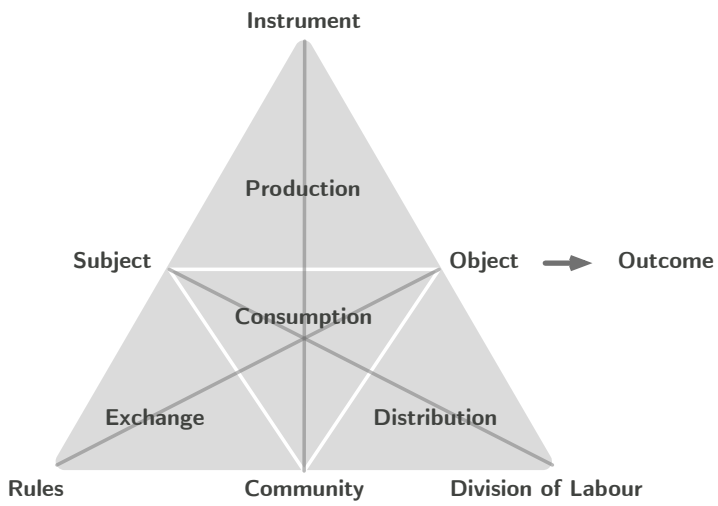


Figure 2.4.: Structure of human activity [147]

Support for human activities in ubiquitous systems translates into a set of requirements: management of a collection of work tasks; support for mobility by distributing activities throughout the environment; and support collaboration between users and tasks [16]. Activity-oriented systems provide users with an integrated environment with support to their needs. Tools such as the ActivityDesigner [124] allow designers to leverage and study human activities for the development of systems in well defined envi-

ronments.

Activities in less constrained environments, however, present a number of challenges related with the complexity of correctly inferring user activity. The recognition of an activity based on the observation of users actions and goals is not trivial. Different methods are being developed that leverage the pervasive availability of different devices and sensors in the environment to infer user activity. As an example, the mobile sensing platform [31] is composed of a wearable hardware prototype and data processing and inference techniques. This platform is able to successfully infer user activity in naturalistic settings, and resulted in two applications: UbiFit Garden for encouraging physical activity [36]; and UbiGreen for sustainable transportation habits [82]. An added benefit of such applications is the ability to influence users to pursuit a healthier lifestyle or more sustainable habits, respectively; a common goal with persuasive computing.

Most of the limitations present in early prototypes, related to the availability of sensors and other technical constraints, have now diminished. Personal mobile phones, for example, have made features and capabilities widely available, that not only facilitate individual activity recognition but also support the dynamics of entire communities [119].

2.3.2. Enabling Technologies

The convergence of technology, such as miniaturisation of computing devices, more reliable communication networks and the virtualisation of storage and processing, has paved the way for such a pervasive environment. The mass adoption of mobile phones and tablets has largely contributed to drive such innovations. This section provides an overview of the technologies that support current ubiquitous environments and how the frontier between physical and virtual worlds is being increasingly dissolved.

The trend of the Internet-of-Things has brought computing and communication capabilities to some of our everyday objects. Examples include scales that track body weight wirelessly (Figure 2.5a); light bulbs whose colour and brightness may be controlled via the internet on demand (Figure 2.5b); or even the ability to find keys effortlessly (Figure 2.5c). This technological immersion has enabled users to quantify a number of different aspects in their daily lives, including activities, states and performance.

The quantified self movement, as defined, combines wearable sensors and computing with self-tracking to improve quality of life [196].

(a) fitbit aria [70] (b) Philips hue [162] (c) StickNFind [192]

Figure 2.5.: Smart devices

Mobile Cloud Computing

Cloud computing refers to both software and hardware that are made available as a utility, just like electricity or gas. The term *Cloud* is used to convey the abstraction provided by such services, commonly referred to as Software-as-a-Service (SaaS), where software applications are delivered over the network to thin-clients and mobile devices [11]. Moreover, vendors refer to types of services depending on the level of abstraction: Infrastructure-as-a-Service (IaaS) for low-level services, such as physical or virtual computational nodes; and Platform-as-a-Service (PaaS) for intermediate services, which typically include an execution environment (see Figure 2.6).

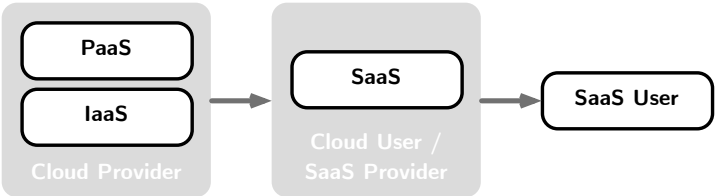


Figure 2.6.: Users and providers of cloud computing [11]

The flexibility provided by this platform has a number of advantages, one of which is the ability to access a user virtual space, that holds personal data and applications, via a number of different and heterogeneous devices. From a user perspective, a disadvantage is its implication on privacy and security concerns over personal digital data [135].

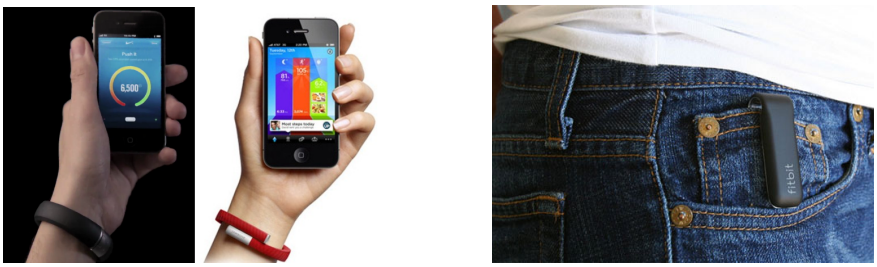
As an extension of this model, mobile cloud computing is focused primarily on the consumption of cloud-based services through mobile computing

devices. Even though the primary focus may be on mobile applications and browsers on smartphones, it is easily extended to a wide range of devices including wearable ones. Thus, it addresses the issues of data storage, interoperability of heterogeneous devices and pervasive access associated with them.

Wearable Devices

A number of personal devices that aim at interacting implicitly with the user in novel ways have been emerging, from watches with advanced features and other dedicated devices, to the integration of technology in everyday garments [167].

The category of personal activity trackers (PAC) has had a number of devices being released commercially with advanced features. PACs are mainly wearable devices provided with sensors for tracking, to a certain extent, the physical activity of the user. A pedometer, in its simplest for, is an example with the goal of counting the number of steps taken. More advanced devices may include location, heart rate and other measures of physical activity.



(a) FuelBand [149] and UP [105] (b) One [71]

Figure 2.7.: Personal activity trackers

The Fitbit One trackers, Jawbone UP and Nike+ FuelBand in Figure 2.7 are multimodal wearable devices that track user physical activity throughout the day and, in some cases, quality of sleep during the night. Users may then visualise the collected data, usually by pairing the device with a smartphone. Additionally, users may augment it manually with further information if they wish, such as calories intake or even mood. These devices, worn as bracelets or belt clips, aim at identifying user daily patterns based on a combination of opportunistic and participatory sensing to incentivise healthy living and wellbeing. These are some of the devices and activities

that enabled a quantified self [196], as defined earlier.

Other approaches go beyond physical activity and location, introducing physiological measures. Physiological computing aims at collecting psychophysiological measures to assess the internal state of users, including affective states, effectively extending the communication bandwidth [65]. Such measures include electromyography (EMG), electroencephalogram (EEG) and galvanic skin response (GSR) among others [7]. These methods are intrusive in nature due to the necessary equipment, and are used mainly in research or controlled environments. However, attempts of producing a consumer oriented product are starting to find their way out of research labs.

Figure 2.8.: Q Sensor [6]

The *Q Sensor* in Figure 2.8 collects GSR data, in addition to temperature and motion, via two electrodes that are constantly in contact with the user's skin [6]. The GSR is one of the simplest methods to obtain physiological data non-intrusively for measuring the level of arousal. This measure, when combined with valence, is an effective way of assessing users' mood (Section 2.2.1). The sensor is able to store and communicate the readings to a mobile device, enabling the collection of user personal data in-situ and allows for instant system adaptation.

The *Emotiv EPOC* in Figure 2.9 is a headset to measure EEG data aimed at gaming environments . The headset is equipped with a number of electrodes and other sensors to detect thoughts, feelings and expressions. The device is a simplified version of medical EEG equipment with a smaller number of electrodes, less complex setup and wireless data transmission. An application of the device combined with a mobile phone for augmented interaction has produced encouraging results, even

Figure 2.9.: Emotiv EPOC [62]

though it is clear that the technology is not ready for being used in an everyday context [26].

In fact, the smartphone assumes a central role in wearable computing. It tends to act as a connecting hub, as it allows for the centralised collection and visualisation of different sources of data. In fact smartphones have been used on a large scale to collect personalised data in different contexts. The *ginger.io* platform collects patients' patterns of behaviour via their mobile devices in relation to diabetes, to infer their health state in the context of healthcare [129]. A broader application, in the context of wellbeing, is the Mappiness mobile application, released in UK to investigate happiness in relation to context [128]. This application surveyed a large number of users over the course of several months to explore the correlation between context and mood.

2.3.3. Ubiquitous Systems

Ubicomp has been extensively researched in the past decade, with a number of initiatives and projects being developed in academic and commercial environments. The *Equator* [202] and *Oxygen* [136] projects, at University College London and Massachusetts Institute of Technology respectively, aimed at bridging the gap between the physical and virtual worlds by focusing on the integration of computerised devices with our lives. The Pervasive Adaptation Research Network (PerAda) [161], an european funded initiative, aimed at establishing a network of researchers and practitioners in the field of pervasive adaptive systems, including a number of projects focusing on different perspectives. Industrial approaches towards ubiquitous and pervasive computing are also being developed by a number of companies, including PARC, Microsoft and Intel. While this list of projects is far from being exhaustive, it demonstrates the broad interest in the area.

2.4. User Experience

User Experience (UX) is a broad term, commonly used to refer to both user-centric practices, i.e. support the design and development of systems; and as a field of study, i.e. focusing on studying user expectations and reflections, and how to enable certain experiences [174, 74]. Formally, UX

is defined as *"a person's perceptions and responses that result from the use or anticipated use of a product, system or service"* [101]. This definition addresses the intrinsic subjectivity of the term, it remains a vague one and does not sufficiently clarify all terms, such as anticipated use or interaction objects [123].

The subjectivity and dynamic nature associated with UX has allowed HCI to include hedonistic aspects of interaction into system design and development, in addition to the traditional utilitarian approach [122]. Different dimensions were adopted from the behavioural sciences and design, such as emotional, affective, experiential, hedonic and aesthetics [93]. All of these dimensions are present in the human experience that includes a wide range of interactions, including artefacts or events. The scope of UX in HCI, however, is limited to interactions with a system, service or object that a person interacts with through an user interface [123]. Face-to-face interactions, for instance, are excluded from this definition, which focuses primarily on the individual user.

Human experience, in relation to interactive systems, is based on a continuous loop of interaction. Users engaged in this loop perform actions that result in a system update of some sort. The user, upon receiving the feedback from the system may decide to perform another action, restarting the process. The possible actions are, in general, determined by the qualities of the object or environment, defined as affordances [86]. Affordances provide discoverability of actions, and were introduced to the field of interaction by Norman [150]. Affordances, in HCI, are associated with a perceptual dimension that allows users to discover systems' functions.

An interactive experience may be divided into three main types: *experience*, *an experience* and *co-experience* [74]. *Experience* refers to the *fluent* assessment of personal goals in relation to the surroundings without a delimited timeframe or particular task. *An experience* is characterised as a set of conscious interactions and is delimited in time, resulting in emotional or behaviour changes. Finally, *co-experience* introduces a social component and refers to sharing experiences with others. The ultimate goal is to transform *an experience* into *fluent experiences*, involving users not only in performing a task or action, but also their expectations and reflections about the interaction. The evaluation of a satisfactory outcome results, in part, in a positive sense of accomplishment, that underlies a *fluent experience*.

Immersive ubicomp environments aim at perceiving and adapting to users wants and needs. In fact users may not even be aware of the interaction with multiple systems [211]. In such an environment the original concept of affordance, based on explicit interactions, widens to include implicit ones, such as every physical action, thoughts and emotional states. As a result the human experience becomes indistinguishable from the explicit loop of interaction with the system [3, 167].

UX is directly related to users' internal states in immersive environments. Even though UX aims at producing positive fluent experiences, interactions with a system or service are highly influenced by different moods, resulting in divergent outcomes. Thus, UX design aims at providing *for* a positive experience, even though it cannot assure the outcome. Unlike designing functional requirements of a system, such as well defined features or behaviours, UX focuses on setting the context without making assumptions in regards to users internal states [123]. Affective computing, in contrast, goes a step further in actively sensing and counteracting negative affective states.

The focus on users rather than systems identified the need to satisfy both functional and supra-functional requirements [131]. While functional requirements aim at addressing users' instrumental and utilitarian needs, supra–functional ones focus on the emotional, social and cultural needs, resulting in more *empathic* systems that adapt to users internal state. As an example, addressing supra-functional needs in marketing research significantly influences satisfaction, adoption and loyalty [190].

In immersive interactive systems, the ability to assess users internal states in relation to an environment raises a number of opportunities to address and provide for their supra-functional needs, resulting in an empathic systems capable of supporting human decision-making [127] and wellbeing [194].

2.4.1. Quality of User Experience

The assessment of UX for an individual user is defined as Quality of User Experience, or simply Quality of Experience (QoE). QoE is a subjective measure related to users expectations and internal states for a certain experience with a product or service; a contrasting definition to the intrinsic characteristics of the product or service themselves, defined as Quality of

Performance [14].

The measure of the user reaction to products and services is not new to HCI and previous research, in fields such as hospitality or marketing, has linked quality with customer satisfaction and behavioural intentions. In this context, in addition to increased satisfaction, higher QoE results in a greater adoption and loyalty as well as willingness to pay more [14]. These results encourage the design of *compelling consumer experiences* [99], with benefits for both users and providers. Furthermore, in marketing research, consumer satisfaction is defined as an affective state that is the user emotional reaction to the experience of a product or service [190], establishing a causal relationship between an experience and the resulting affective state [134].

In the context of HCI, QoE may be defined as the degree to which a system meets users expectations for experience [17]. Furthermore, QoE encloses different aspects of interaction, efficiency, usability, aesthetics, utility and acceptability [143]. The integrated ubicomp environment enables the collection of a vast amount of environment and personal information, including affective data - known as big data due to its inherent complexity. Furthermore, the ability to assess affective states in context enables the measure of QoE in relation to an environment, where positive affective states, such as satisfaction and pleasure are associated with high quality experiences while frustration and boredom with low quality.

Emotion as an additional dimension of interaction between users and systems was introduced by affective computing. Affective computing aims at developing systems with the ability of recognise, interpret and simulate human affect, with the final goal of producing empathic systems [163]. Empathy emerges as a dynamic relationship between different elements of experience, including users, artefacts and designers [212].

2.4.2. Subjective Well-Being

Emotional reactions are part of what is defined, in the field of psychology, as Subjective Well-Being (SWB) [51]. In addition to affect, SWB includes a cognitive component based on the satisfaction with different aspects of personal life in the long term. As a result, *happiness* is defined in this context - and even used interchangeably with SWB - as a combination of life satisfaction and relative frequency of positive and negative affect.

This simplified definition provides a pragmatic approach for including these aspects of human experience in a range of domains, from healthcare to economics.

In economics, for example, SWB provides a framework for analysing economic behaviour, that is otherwise based on the traditional utility theory [128]. Utility theory, in short, relies on the assumption that an individual's behaviour is based on the maximisation of an utility function, that includes different measurable aspects, such as cost. Under conditions of completeness (the ability of an individual to determine preference), transitivity and continuity, a continuous utility function measures the desirability of a product or service, determining the preference ordering between them, rather than an absolute measure. The introduction of *happiness* as a measurable construct introduces other subjective explanations for the existing apparent sub-optimal behaviour, in relation to the defined utility function. SWB arises as an approximation to utility in the economic science that takes into account hedonic aspects [75].

Furthermore, new perspectives on economical growth argue that countries should focus less on gross domestic product (GDP) that measures the market value of a country's production. Instead, ecological economics, suggests that governments should focus on increasing SWB [206], as a measure of standard of living. SWB is, in general terms, associated with higher quality of life and longer longevity [50].

Intelligent ubiquitous environments, with the ability to continuously sense and act upon an environment provide a number of opportunities to enhance experiences in a variety of contexts and provide a platform for empowering members of a society to actively contribute to their communities resulting in an enhanced SWB.

2.5. Recommender Systems

Recommender Systems (RS) have attracted much attention in recent years, due to their ability to suggest new products and services to users based on their feedback, habits and personal profile. Such systems address the inherent complexity in locating an item or service in an overwhelming number of options, by providing information filtering and decision support tools [173]. Examples include the recommendation of products on e-commerce platforms

such as Amazon[1], and suggestion of new movies to watch on streaming websites such as Netflix[2]. While people find articulating what they like hard, they are very good at recognising it when they experience it [140]. Recommender systems exploit this feedback to predict ratings (absolute evaluation) or preference (relative order between alternatives) for new items and services based on a set of user characteristics and item attributes.

There are two main approaches to produce recommendations: content-based and collaborative filtering [5]. Content-based filtering is based on information and features of the items. New recommendations are based on the similarity with items that the user rated favourably in the past. This method is particularly relevant for items with well defined characteristics, such as text-based content, e.g. news articles and websites. Other type of media, however, may present challenges due to the complexity in obtaining or describe features. Collaborative filtering, on the other hand, recommends items based on the similarity of the user profile with other users, without requiring an accurate description of the item itself. Items rated favourably by other users with similar profiles are thus recommended on this basis. This method, however, requires a detailed user profile, which may be problematic for new users - a problem defined as *cold start* [114]. Other challenges arise in recommender systems, such as scalability – i.e. the processing power required to compute recommendations for a large item and user base – and sparsity, the relative low number of ratings given by users in relation to the complete item set. An alternative approach is based on a knowledge structure – knowledge-based systems – such as an ontology, to infer users' needs and preferences. One of such techniques, known as case-based reasoning, reuses information from previous recommendation sessions – composed of data related to users, items and their relationships – to identify relevant recommendations [173, 140]. These approaches are often combined in hybrid systems to avoid some of the existing limitations, resulting in more efficient recommendations [114]. The combination of these methods ranges from implementing both systems separately to a unified model. Implementing separate content-based and collaborative systems produces different recommendations that may then be merged together or individually selected, while a unified model proposes the usage of both content-based and collaborative

[1] www.amazon.com
[2] www.netflix.com

characteristics in a single system.

The collection of data for building a user profile may be performed using both explicit and implicit methods. Explicit methods involve the users in the feedback process, by asking them to rate items or choose the ones they like out of a collection. However, these are intrusive and may create unnecessary or unwanted interactions [5]. Implicit methods, on the other hand, rely on the analysis of behaviour and usage to infer a rating, e.g. viewing times, record of purchases or even social networking analysis. The trend for collecting increasingly detailed personal information implicitly is allowing recommender systems to produce more accurate results in a variety of fields non intrusively [5].

2.5.1. Mobile Recommender Systems

The increasing ubiquity of mobile devices and communication networks has allowed recommender systems to offer personalised and context-sensitive suggestions, while limiting the negative effects of information overload, that is particularly relevant in mobile contexts [173]. Mobile environments present an additional set of challenges, including device and communication networks limitations, the impact of the external environment and behavioural characteristics of users.

The central point in providing a recommendation service in a mobile environment is the ability to acquire context-sensitive information and the delivery of the recommendation in a wide range of naturalistic scenarios [15]. These Context-Aware Recommendation Systems (CARS), also called Mobile Context-aware Recommendation Systems (MCRS) [22], place a strong focus on exploiting context information to develop recommendations.

Capturing contextual user feedback, however, presents several challenges. In addition to the heterogeneous data sources, it requires spatial and temporal correlation; and raises validation and generalisation issues, associated with the multitude of contexts in which the same item may be experienced [85]. Unlike a product, such as books that remain unchanged independently of the reader, a service is experienced differently by different people [172]. For example, visiting a certain location may provide completely different experiences depending on weather conditions, social context and even personal mood. Furthermore, it is unclear how important

are each of the contextual factors, and to which degree they influence user ratings [15].

The delivery of service, on the other hand, plays an important role in establishing the relationship with the end user. System usability is such an important issue that even a recommendation that is not useful but correct can increase users' trust in the system [172]. The use of appropriate interface techniques remains a central component on mobile environments, from information presentation, to assisting with query generation and support for alternative methods of interaction [84, 114]. MCRS may be classified into three main categories of user involvement:

- Pull-based: recommended content is delivered upon explicit user request, based on current and historic context. Due to the control retained by the user, these are regarded as less intrusive;
- Reactive: recommendations are generated based on changes in the situational context, without requiring any user intervention. However, users may explicitly define the behaviour of the system;
- Proactive: these systems are based on predictive models to anticipate future context and prepare recommended content in advance. This approach has the added advantage of reducing functionality disruption in environments with less than ideal conditions.

Applications

The application of MCRSs has been focused on tourist experiences, including attractions, routes and tours. The *iTravel* system provides on-tour recommendations in a peer-to-peer environment, based on the premise that users who visit the same attractions are more likely to share similar tastes [213]. The SMARTMUSEUM system aims at recommending objects of interest in a museum setting based on users' general interests [175]. Similarly, an application based on user location in indoor retail environments relies on local positioning systems for recommending products of interest [66]. A different application aims at providing taxi drivers with optimised route recommendations based on historic usage [85]. Rather than relying on user rating to provide recommendations, however, this approach uses business performance as the metric to optimise. Finally, a more generic approach

proposes to follow the evolution of users' interests based on location, time and social connection, to provide future recommendations based on these indicators [22]. The delivery of personalised recommendations in mobile environments with the proposed characteristics has resulted in more efficient systems and increase in the overall user satisfaction [66, 142].

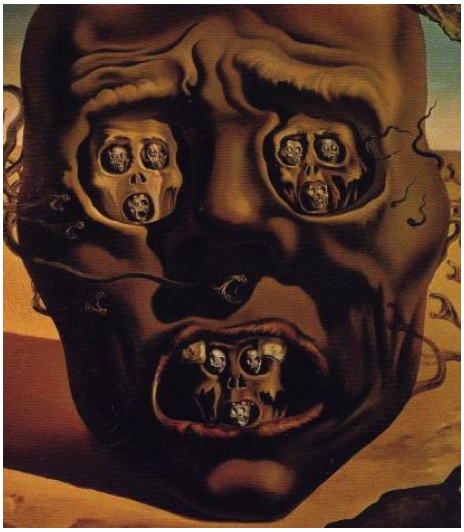
2.5.2. Emotion in Recommender Systems

Human emotion, described in Section 2.2, enables RS to increase the scope of item feature description, user profiling and feedback. In addition to the general fields that compose an item description, adding affective information has the potential to significantly improve the accuracy of recommendations [198]. As an example, the usage of affective metadata for paintings in a content-based system, in addition to fields such as author, support and style, resulted in more accurate recommendations. The art pieces in Figure 2.10 are both surreal oil on canvas paintings by Salvador Dalí, but they elicit very different emotional reactions. The usage of affective information in user profiling, on the other hand, improves greatly the ability to match similar users in collaborative systems, using personality traits [152] and emotional intelligence [88].

In addition, using an affective state as a reaction to a product or service, defined in Section 2.4.1 as Quality of Experience, provides a mechanism to non-intrusively assess user satisfaction and, consequently, provide feedback or ratings. In an interactive TV inspired setting, affective states were used to optimise the recommendation of a sequence of items (e.g. news stories, movie clips) to a group of users. In spite of the added complexity introduced by such constraints, and the evaluation of emotion in particular, the usage of affective states resulted in higher satisfaction rates [137].

Research conducted in the convergence of affective computing and recommender systems has produced interesting results, from item classification to affective recommendations. Facial expressions, due to their ability to convey emotional meaning, have been used to classify video items [106], as well as live feedback that is incorporated into users' profiles [10]. Music is arguably one of the most emotion-related media. Some research has focused on establishing a relationship between affect and musical structure for improving recommendations [116], while an alternative approach used

(a) Dream Caused by the Flight of a Bee



(b) The Face of War

Figure 2.10.: Surrealist paintings with different emotional reactions, based on [198]

film-music – due to its role in conveying emotional meaning – to produce suggestions [187]. Finally, a more general approach, proposes a model of affective metadata to describe affective information to be used in items and users description [199]. This model is based on the original circumplex of emotion [176]: a dimensional model composed of valence, arousal and dominance.

2.6. Smart Environments

2.6.1. Overview

A *Smart Environment*, also referred to as *Intelligent Environment* or *Ambient Intelligence*, refers to the convergence of ubiquitous environments and intelligent user interfaces [38]. The ability to sense the environment and assess human behaviour allows smart systems to adapt and respond to their occupants' needs autonomously. In addition to the optimisation of resource usage, the user-centric nature of these systems aims at a continuous adaptation with the main goal of enhancing user experience.

Smart systems add a layer of *intelligence* to ubiquitous environments,

leveraging the existing technological infrastructures and wide spread availability of computerised devices. In fact, six of the main characteristics present in smart environments denote its dependance on ubiquitous environments and artificial intelligence: sensitive, responsive, adaptive, transparent, ubiquitous and intelligent [39].

One of the main motivations behind smart environments is the overload experienced by users, due to products and services that are hard to use and difficult to understand [107]. The design and development of systems based on a user-centric approach results in a complete integration within the environment. Not only these systems become anticipatory and proactive freeing users from manual control but they also provide intelligent interfaces capable of interpreting and adapting to users, including their moods, activities and expectations.

The inclusion of artificial intelligence lead to the free adoption of the term *Smart*, prefixed to a wide range of common artefacts and systems. From radio frequency identification cards - smartcards - and smartphones as modular building blocks of smart environments [115]; to large urban infrastructures - smartcities - composed of different components such as energy - smartgrids - and smartbuildings [145].

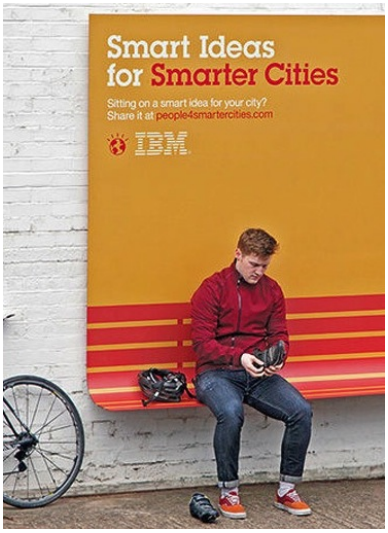


Figure 2.11.: IBM campaign [100]

The list of potential applications is extensive, and includes education, healthcare, retail and transportation. As an example, the ambitious, commercially-driven initiative by IBM poses itself to build upon some of the principles towards a *Smarter Planet* [100]. The initiative aims at leveraging existing technology to deliver smarter solutions to their clients, based on the collection and analysis of data an providing data-driven recommendations and development of systems (see Figure 2.11).

Furthermore, the benefits of such environments are not limited to the direct impact on users and their experience. Added benefits include the ability to persuade behaviour and attitude

change through personal and social influence [153]. Persuasive computing, as defined, aims at applying this influence for supporting change towards more sustainable habits [167] and an improvement of subjective wellbeing.

The MINDSPACE framework, developed for the development of governmental policy, outlines nine different aspects of human behaviour in response to external stimuli and how they impact the strategy for delivering information and incentivising change [55]. These aspects, in Table 2.2, were compiled to assist governance agencies in increasing the success of policy implementation. Successful examples include the increase in recycling and reduced gang violence. One of such aspects is affect, identified as a powerful tool to shape individual action.

Table 2.2.: MINDSPACE [55]

Aspect	**Comments**
Messenger	Heavy influence by who communicates information
Incentives	Responses to incentives shaped by predictable mental shortcuts, such as strongly avoiding losses
Norms	Strong influence by how the society acts
Defaults	The "go with the flow" of pre-set options
Salience	Attention is drawn to what is novel and seems relevant
Priming	Acts are influenced by sub-conscious cues
Affect	Emotional associations can powerfully shape actions
Commitments	Consistency with public promises and reciprocate acts
Ego	Acts leading to feeling better about the self

Behaviour influencing is used in public policy as an alternative to legislation. The ability to implement high-level policies through low-level behaviour influencing allows for well integrated and more successful results. For example, the incentivisation of the population to use public transport instead of private car as a way to cut carbon dioxide emissions. An alternative approach is focused on empowering individuals for shaping collective action, as a way of influencing behaviour towards a collective goal, that is neither specified nor imposed externally. Instead, the members of the community or social group are aware of the collective goal they want to achieve, and contribute actively through individual action. Such collective strategies, when applied in interactive systems, open a number of opportu-

nities towards behaviour incentivisation, that influences different aspect of society, such as more healthy living or sustainable habits.

Managing such a large number of devices, collective goals and personal desires raises a number of challenges, including technical specificities and conflict solving. Policy computing addresses this issue, enabling dynamic system behaviour configuration in large scale systems [109]. As a result, a goal for the system may be translated to a set of sub-goals that act locally. Reducing carbon dioxide, for instance, would be translated into a set of actions for incentivising user behaviour towards more sustainable travelling habits.

2.6.2. Applications

Smart environments are advantageous in a number of contexts at different scales [178], some of which described as follows:

Home

The application of intelligent technology in a home environment provides support for everyday living, reducing labour and improving quality of life. The ability to sense and adapt to the residents' preferences and activities allows systems to take action if necessary, by providing for comfort and entertainment as well as guidance in health and safety related issues. In addition, it facilitates efficient resource management and consumption, such as electricity and gas, by controlling appliances and heating.

Smart home initiatives tend to focus on the technical complexities that arise in developing such systems, including sensor networks and artificial intelligence. In addition to addressing more functional-oriented tasks, some projects have started to consider improving inhabitants' experience, for example through entertainment, e.g. playing a song after the user hums a few bars [76], and comfort levels, e.g. adjusting furniture settings automatically [91].

Healthcare and Assisted Living

A particular case of smart homes is focused on assisted living of the elderly and people with cognitive and physical challenges, allowing them to live

independent lives in their own homes. Furthermore, home-based or preventive care is preferred over institutions where the necessary monitoring may be provided in a more convenient and cost-efficient way. Nevertheless, healthcare in institutions and hospitals also benefit from a supporting system providing monitoring and wellbeing.

In such scenarios, rather than actively acting upon the environment with the goal of improving the experience, the technology enables target users to benefit from a higher quality of life, by supporting and assisting with certain aspects of everyday living in the home, that would be hard to perform otherwise. Issues regarding safety and trust with the different entities involved, however, have been raised in qualitative studies [148].

Retailing and Recommender Systems

The context of retailing is interesting for assessing customers' profiles and provide them with a personalised experience leading to higher sales. The automated collection of a personalised profile based on the interactions with the environment and different shops allows for the delivery of recommendations without the need for direct feedback and input. For example, an online movie streaming service may provide movie suggestions based on visits to the cinema or vice-versa. In addition to recommendations, product servicing may be scheduled based on the actual condition of the equipment rather than periodic checks or preventively rather than after breaking down.

Such systems aim at improving user experience by reducing the information overload, associated with such dynamic environments. Furthermore, adapting and responding to user needs, habits and emotions aims primarily at reducing the frustration typically associated with these environments [87].

Museums and Tourism

A related application to retailing is tourism, even though with slight different goals. A museum may be interested in guiding visitors to exhibitions they find interesting to enhance their experience, or a city may provide tourists with a personalised tour of the city for the same reason. The personalisation and assistance of such tours may also be based on a shared personal profile, acquired from interactions with the environment.

Unlike previous domains, one of the main goals is to provide users with

engaging and pleasant experiences. Thus, tailoring services to users interests results in a reduced amount of information - irrelevant or uninteresting information - and provides for a higher experience quality [169].

Education

The smart classroom envisions a learning environment with support for progress of individual students, interactivity in the classroom that infers intent and responds accordingly as well as inciting group discussion. In an e-learning context, a smart system may adapt the level of difficulty or provide help according to the performance, emotional and cognitive state of the student.

The contribution for an improved user experience in education relies on engaging students in the learning activities with positive results, leading ultimately to an increased level of knowledge. The process of incentivising towards active learning and avoid frustration contributes for enhanced education experiences [111].

Transportation

Transportation is a very desirable application for smart technologies, for drivers and passenger both in urban environment and long-distance journeys. A driver assistant may adapt the characteristics of vehicles to drivers, including their cognitive capacity and preferred routes. In urban public transport, the service may be dynamically adapted to demand and other environmental characteristics, while for passengers personalised recommendations based on their preferences may offer them an enhanced travelling experience.

In transportation influencing the quality of service may not always be possible, due to external constraints, e.g. traffic congestion or lack of resources. Travellers, however, may be proactively informed of the conditions, leading to an adjusted journey expectation. In public transport, as an example, avoiding the encounter with a negative incident impacts the travelling experience [80].

Smart Cities

The application of smart technologies at a large scale, such as urban centres, integrates various of the previous described examples, from homes to retailing and transportation. A smart city is able to continuously sense and dynamically adapt to its inhabitants and visitors while it optimises resource consumption, mobility and overall wellbeing. The idea of smart city has been gaining momentum [8]. Several initiatives are developing smart cities, such as the Living PlanIT initiative, that aims at building a smart city from the ground up, including physical infrastructures and software for resource management, adaptation and extensibility.

Smart environments have focused primarily on the technical challenges that arise in sensing and acting upon an environment, such as sensor networks and artificial intelligence. The improvement of quality of experience requires a more user-centric approach, in order to understand users needs and how to address them.

2.6.3. Societal Implications

The vision proposed by ubicomp has a significant impact on the economic, social and ethical values of society [21]. Even though the intention behind intelligent pervasive systems is to improve quality of life and security, it raises important moral questions, including fundamental ones such as universal equality and freedom. Thus, the loop of interaction underlying affective ubiquitous interactions requires a mutual agreement or social contract, that establishes how different entities interact with one another [166], a requirement that has been defined as *design contractualism*. This section discusses these issues and how system design, development and integration may address some of the raised questions [77].

Economics

The use of smart tags (radio-frequency identification) has completely transformed the product supply chain, allowing the different stakeholders involved in the process to manage stock and production more efficiently. The continued adoption of new technologies into shops, workplaces and homes allows for a much more detailed characterisation of consumption and even disposal. This immediacy leads to a *real-time economy*, where consumers

have access to detailed information about a product at any given time and purchase it if they so desire. From the producer or provider point of view, the ability to collect such detailed information allows them to target specific users based on their personal profile, including habits of consumption, demographics and even emotional state.

New business models are surfacing as a response to such a personalised and dynamic environment. In addition to product offering, services may be tailored to individual users and price adjusted dynamically: *pay-per-weight*. For example, the price for car insurance may be based on the instant style of driving and location, in addition to driver habits and characteristics, resulting in low premium when the vehicle is parked at home and higher when it is being driven carelessly, outside legal boundaries and dangerous areas.

A personal profile based on consumption habits and other personal information may constitute a serious privacy offence for some, while others may voluntarily provide such information in exchange for economical benefits [155]. Nevertheless, the ability to target specific users raises other issues. Providing access to only a sub-set of users based on their profile, thus discriminating others, constitutes a serious offence against the fundamental value of universal equality - one of the main pillars of contemporary societies. However, personal information is not only desired for commercial purposes. Authorities and governments may legally enforce the collection of such data, at which point it stops being a choice and becomes a duty.

Privacy

The flip side of ubiquitous environments is the invasive penetration of technology into everyday's activities, which may result in a feeling of being under constant surveillance. This has raised concerns in different factions of society. An interesting example is the *movement cloacker* in Figure 2.12, a device designed to allow users to *lie* about the activ-

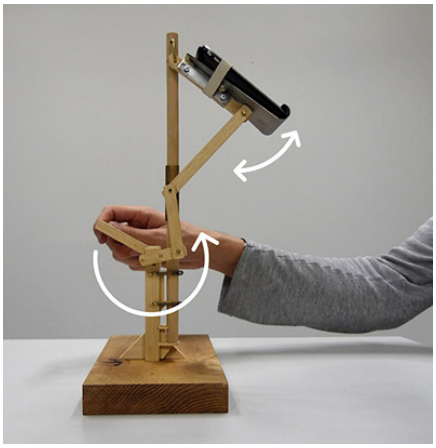


Figure 2.12.: Movement Cloacker [68]

ities sensed by mobile devices by simulating patterns of activity [68]. In some other cases, however, this privacy invasion tends to be *self-inflicted*, in exchange for economic or other benefits, which are key factors for the proliferation of such technology [182].

Privacy is, in any case, one of the main fundamental requirements to any democracy. It provides every individual with the option of excluding himself from social exposure. Even though privacy differs significantly between cultures, it may divided in four main categories:

- Empowerment: refers to the power of an individual to control the publication and distribution of personal information;
- Utility: may be used as an utility to prevent against unsolicited contact, minimising the amount of disturbance;
- Dignity: maintains the equilibrium between the entities involved, where one is not in advantage over the other;
- Regulating Agent: limiting the collection of personal information, as a way of preventing the formation of a decision-making elite.

In addition to this pragmatic view, privacy establishes different types of borders. It's the trespassing of such borders that constitutes a violation of privacy, and they can be grouped as follows:

- Natural: physical borders of observability and even facial expressions;
- Social: confidentiality within certain social groups, where an individual trusts that personal information shared won't leave the social circle;
- Spatial or temporal: refers to the partition of one's life into multiple and isolated parts in space and time, without one influencing the others;
- Ephemeral or transitory: a spontaneous action that disappears in time and one hopes will be forgotten.

The decision to grant access to personal information is therefore on the users side, who may or may not decide to share certain aspects of their lives

and its impact and results. Privacy, therefore, not a monolithic concept, but rather a fluid notion with a range of trust levels and needs [96]. The main challenge for ubiquitous environments in relation to users, is to provide a level of awareness, management and trust when sharing personal information, and what the consequences might be. A crucial component of ubicomp systems is the ability to engage users in a reflection process regarding their actions and implications [183].

Finally, the mere existence of an individual user profile presents risks. In addition to the most obvious leak of personal information - either accidental or intentional - resulting in the exposure of one's entire life, it threatens universal equality, as mentioned earlier.

A proposed solution is the Privacy by Design framework [28]. This framework provides a set of principles for the development of systems with embedded privacy features. The specified principles encourage the different entities involved in the design and development of systems to focus on privacy as a central element, without impacting negatively other functionality or user experience.

Social challenges

There are a number of social implications related to ubicomp systems. As environments become increasingly ubiquitous, so does the dependance on correct and reliable functioning of systems. Even though today most of the controls are easily overridden manually, that may not be possible, or desirable, in the future. With the delegation of decision making and instructions to systems, the perception of responsibility is, even if at an unconscious level, delegated to the machine.

The fusion between physical and virtual worlds addresses, in part this need. By making the user perceive that their actions have a direct effect on the object of interaction, rather than a computerised intermediary [78]. In addition, proactive intelligent systems may be at the risk of mimicking intentionality and, therefore, remove the sense of responsibility for those actions from users or providers [78]. Also at this level, reflection and awareness are relevant to engage users in understanding what ubiquitous computing is and its implications.

The main ethical and social concerns identified in future intelligent sys-

tems are as follows:

- Reliability: increased dependance on technology with millions of electronic entities, how can such complex systems assure predictability and dependability;
- Delegation of Control: with highly dynamic environments, continuously changing and prone to conflict of interests, new delegations of control are required as well as identifying the accountable parties;
- Social Compatibility: an integration within society calls for transparency and inertia, to allow humans to detect and adjust behaviour accordingly;
- Acceptance: a wide acceptance of such systems requires an understanding of the very nature and purpose of smart objects and the impact of such systems on human relationships with the environment.

2.7. Summary

This chapter introduced a number of technologies that support the development of affective intelligent ubiquitous environments, where systems are able to sense users implicitly and act accordingly towards an enhanced quality of experience. Empathic systems, with the ability to address users' supra-functional requirements, rely on an affective loop of interaction and personal digital information. Finally, quality of user experience was defined as a subjective measure of experience in such environments. The collection and processing of such information, however, raises privacy concerns and impacts both economical and social aspects of the general public. The next chapter focuses on the particular scenario of intelligent urban mobility, as a potential application for the identified technologies.

3 Intelligent Urban Mobility

3.1. Introduction

The domain of urban mobility is reviewed under the scope of smart environments, in particular urban public transport. The identified passenger supra-functional needs supported by the sustainable role that public transport plays on the development of urban mobility make this domain the perfect candidate for investigating user experience and wellbeing in naturalistic ubiquitous environments.

3.2. Smart Cities

Smart cities, as identified in Section 2.6, rely on Information and Communication Technologies (ICT) to sense and adapt the environment, with the goal of enhancing different aspects of a urban environment, from resource consumption to citizen wellbeing. A broader definition of the concept includes other aspects, not limited to the integration of ICT into everyday's activities, such as creativity and social capital [19].

Different definitions of what constitutes a smart city, focusing on different aspects of urban environments, such as industrial development, education, popular participation, technical infrastructure and others related to standard of living [29]. The focus on a particular sub-set of these characteristics results in other related concepts, such as the *intelligent city*, the *human city* or the *smart community* [146]. Each of these concepts is developed around a central core idea, supported by the technological and social systems: *intel-*

ligent systems focus on a layer of artificial intelligence based on the existing ICT; *human cities* emphasise the interpersonal relationships in urban environments; and *smart communities* leverage the existing social structures towards collective action.

Three main core components seem to emerge from smart cities: technology factors, composed of hardware and software infrastructures; human factors, based on creativity, diversity and education; and institutional factors, including governance and policy. These components are interconnected within the context of a large organic system [110], and cannot be treated in isolation in the context of smart cities. Furthermore, traditional theories of urban growth and development, combined with the three core components identified, result in six main dimensions that enable the assessment of the performance of a city as a smart city [29]. The six characteristics are as follows:

- Economy: competitiveness, entrepreneurship and productivity;
- People: social and human capital;
- Governance: public participation and social services;
- Mobility: ICT-infrastructure support and sustainable transportation;
- Environment: natural conditions and resource management;
- Living: quality of life, health and safety.

Each of these dimensions is broken down into a total of factors 31 factors and 74 indicators, covering a wide range of different urban aspects [29]. The performance on these dimensions indicates the economical competitiveness and resource efficiency of cities, as well as the level of citizen engagement in collective activities and enhanced wellbeing. A ranking of seventy european mid-sized cities identified Luxemburg as the *smartest* city in 2007, a list strongly dominated by Scandinavian cities. The evolution of a city may be tracked and assessed in different areas, where efforts for development may be focused on the most important aspects.

A more human-centric approach identifies wellbeing and sustainability as main factors for future development [181]. In densely populated areas a number of other challenges arise, such as urban mobility. The increasing

need for commuting long distances within the city using motorised transportation, and private vehicles in particular, has resulted in highly congested and polluted cities with a significant impact on both sustainability and quality of life [191]. Research supports the need for service personalisation taking into account travel attitudes and behaviours [18].

3.2.1. Urban Mobility

Urban mobility involves a number of different elements related to mobility and transportation in urban environments. The population growth in urban areas, combined with sub optimal mobility planning, has resulted in an increase in pollution and congestion levels in large urban centres. A renewed interest in urban mobility is aiming at addressing some of this issues by acting upon different mobility aspects [63]. Examples of the areas of action include improving free flowing by promoting walking and cycling as well as optimising the use of private and public transport; smarter urban transport by dynamically controlling service offering and characteristics to the needs of the city; or improving knowledge and raising awareness regarding urban mobility in its different areas of activity. In addition, greener and more secure urban networks as well as increased accessibility contribute towards a stronger urban mobility culture.

The increasing interest in urban mobility as an enabler of sustainable transport - including its environmental, economical and social qualities - has resulted in a number of research and development initiatives with the goal of improving public transportation networks' efficiency and satisfaction to foster a culture for mobility. The *civitas* initiative [34], as an example, is a european-wide project involving a number of european cities that aim at introducing transport measures and incentivisation towards sustainable urban mobility. Moreover, the european union has declared that *"high quality and affordable public transport is the backbone of a sustainable urban transport. Reliability, information, safety and ease of access are vital for attractive bus, metro, tram and trolleybus services, rail or ships."* [64].

Urban Public Transport (UPT) provides a number of benefits to a urban environment: economical efficiency, environmental sustainability and support for citizen wellbeing [191]. The city of Curitiba (Brazil) is considered as an exemplar implementation and systemic integration of UPT for

supporting a city expansion and development [141].

The city implemented a series of innovations focused on mobility to support its rapid expansion. The tube-shaped bus stops in Figure 3.1 have become iconic pieces of urban furniture associated with the successful bus rapid transit model. In addition, the widespread availability of bus stops was leveraged and transformed into environmental sensors and information displays. Supporting other areas of smart cities, from monitoring the city to engaging citizens in the different aspects of city governance.

Figure 3.1.: Bus Stop in Curitiba[1]

The incentivisation of citizen participation, and empowering them to actively contribute, has the potential to engage them in solving existing issues or simply assisting their community or social group. In this process, converting collective awareness into individual action relies on the existing social structures. The ability to leverage social capital allows communities and entire cities to contribute for a collective goal based on individual action. For instance, within a community, the collective decision to use less private transport to commute has a significant impact of pollution and congestion levels, that would otherwise be negligible if taken in isolation.

The recognition of the importance of engaging citizens, or travellers in the particular case of UPT, resulted in a new trend in data management focused on freely distributing available data to the public. The availability of data for public consumption not only has an engaging effect, but it empowers citizens to an active participation in city management and governance [48]. In London (UK), for example, an initiative by the Greater London Authority to make this type of data available resulted in the London Datastore [138], where citizens can access existing information and request other data sets. A substantial part of the datastore is focused on the public transport network, including live service information. As a result, a number of mobile and web-based applications emerged for assisting commuters, visitors and

[1]By Morio (photo taken by Morio) GFDL / CC-BY-SA-3.0, via Wikimedia Commons

other travellers. These applications are developed by active members of the community, who contributed their solution for better UPT information.

3.3. Intelligent Public Transportation Systems

In intelligent UPT systems, the sensor-saturated environment enables a detailed modelling of the environment. As a result, the information available to users is much richer, including live updates of the status of the transportation network. Providing UPT travellers with relevant information via Advanced Traveller Information Services (ATIS) has several benefits [30]: the provision of such services aims at retaining existing and attracting new customers; assisting governance entities in incentivising changes in transportation habits; and more importantly to travellers who receive relevant information about their journey.

From a travellers' perspective, information acquisition plays a significant role in the decision process, either actively - initiated by user - or passively - initiated by the information service. As a result, the type and quality of information influences the decision process on different levels. In addition to the traditional information, such as journey cost and duration, travellers are interested in other subjective characteristics, such as convenience and comfort [9]. They are also interested in being able to receive such information via a personalised and dynamic service that takes into account their personal preferences and needs. The dominant model of decision strategy used by providers is based on microeconomic consumer theory, where travellers are assumed to maximise the utility derived from different travelling alternatives. However, this model requires not only utilitarian aspect but also hedonic characteristics, as discussed in Section 2.4.2. Moreover, the relationship between service quality and satisfaction must consider travellers' affective dimension [81].

While ATIS provide a wide range of services suitable for different types of travellers, research suggests that arrival-time sensitive trips, such as commuting and business-related ones, and uncertainty increases the desire for information and consequently an increased use of ATIS [57]. Other aspects that influence ATIS usage include reliability, timeliness and coverage of information as well as service personalisation and modality.

In the last decades at-stop information displays have become ubiquitous

in large UPT networks, supported by ATIS. The shift from printed timetables to dynamic realtime information resulted in a number of benefits for the different stakeholders involved [57]. The main effects are described as follows:

- Reduced perceived waiting times: delivering real-time information affects passengers' expectations of wait time in a positive way;
- Positive psychological effects: in relation to personal expectations, UPT information reduces uncertainty and increases the sense of security and easy-of-use;
- Increased willingness to pay: a generalised willingness to pay for this type of services, even though some travellers consider them integral to the journey and not an independent service;
- Adjusted travel behaviour: the adjustment of expectation in relation to the journey allows travellers to better utilise their waiting time, improve their travelling efficiency or even trade-off between service characterises (e.g. letting a crowded bus go by if the next one is arriving shortly);
- Mode choice: impact on the mode of travelling in light of updated information;
- Higher satisfaction: customer satisfaction is positively impacted by delivering information;
- Better image: improvement of the overall *image* of the UPT service, including reliability and personal feelings.

The introduction of new information components in UPT infrastructures, such as automated fare collection systems, generate a new dimension of digital data, some of which focused on individual travellers. The collection of this information enables the analysis of travellers' behaviours and infer personal commuting needs and preferences, as well as provide UPT providers with relevant information such as effectiveness of incentives [120].

The ubiquitous environment, described in the previous Chapter, is allowing this personalised information services to migrate from physical locations spread throughout the UPT network to travellers' personal devices.

The ability to personalise services, and potentially recommend alternatives, associated with its ubiquitous access results in increased benefits in the dimensions identified earlier [210].

The convergence of ATIS development and service personalisation leads to mobile, multimodal dynamic and personal travel information services [121]. Furthermore, the development of smart cities, and smart mobility in particular, enables the design and implementation of personal services, with benefits for both travellers and providers.

3.3.1. Mobility Wellbeing

Quality of Experience, or *happiness*, in mobility is associated with short term positive and negative affective states.The notion of *happiness* as a measurable construct that contributes for the utilitarian economical model was introduced in Section 2.4.2. Its application in the context of UPT, enables the analysis of traveller behaviour based on a set of factors that go beyond journey cost and duration [9].

UPT commuters, in addition to being more likely to use ATIS, are also affected by travelling conditions to a larger extent than other travellers (e.g. leisure-related and visitors). In fact, subjective aspects such as attitudes and personality, have a greater impact than objective ones, such as duration and cost [157]. When offered alternative travelling options that explore different subjective aspects, commuters tend to experience an improved satisfaction with the overall service - either due to their preference for the new option or because their usual one is comparatively better [2]. However, commuters tend not to actively look for alternatives, due to their belief that the option is the best available or the effort associated with trying new ones.

The benefits from mobility wellbeing are not limited to the scope of transportation. The effects extend across other areas of personal life, and in the case of commuters, to the workplace (see Figure 3.2) [56]. In addition to its short term effects, longterm wellbeing and happiness are also affected [191]. In this context, opportunities arise to deliver personalised services that offer alternatives with the potential to enhance their QoE.

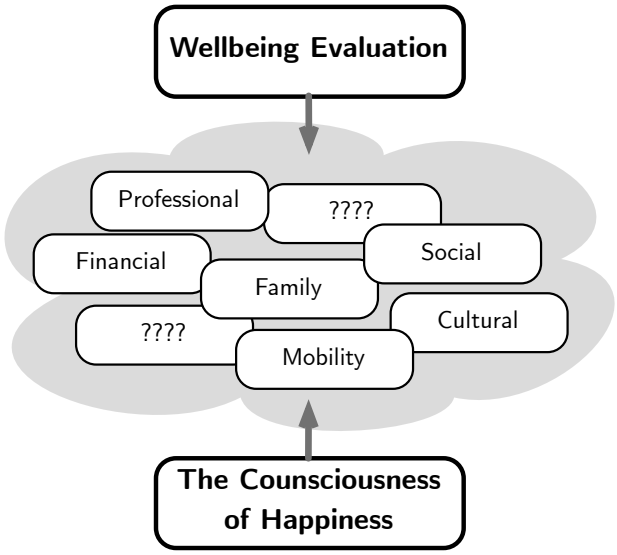


Figure 3.2.: Well-being evaluation and happiness assessement [56]

3.3.2. Travelling Behaviour

The incentivisation of travelling behaviour presents a number of challenges. While commuters, especially in densely urban centres, may have a large number of alternatives, they tend not to reconsider their options [2]. However, offering a personalised service has the potential to enhance their personal wellbeing and QoE. In addition, UPT providers also benefit from such a close relationship with travellers, leading to more efficient and sustainable transportation.

There is a growing interest in sustainable transport, that implies a balance between environmental, social and economical qualities of mobility [191]. UPT network management in itself has an impact on travellers, and may even conflict with their personal goals. Actively influencing their behaviour by providing them with the perspective of a better community or society via empathic services, has the potential to assist smart cities to achieve such goals, that is not limited to mobility and may be extended to other areas.

Empathic information services that take into account the individual travelling needs, preferences, as well as personality and overall wellbeing may suggest a suitable personalised alternative while engaging them in the process.

3.4. Passenger Experience

Passenger experience in UPT has been gaining attention in the last few decades, as service providers continuously look for ways to improve their service. The motivation for improving the quality of service is both economical and environmental. While passenger satisfaction results in increased loyalty and willingness to pay for the services offered, governance agencies see it as a way of supporting sustainable mobility. There is, therefore, a direct relationship between improvement of service quality and satisfaction [79].

Customer satisfaction is an important performance indicator that evaluates performance of products and services in relation to customer expectations. This measure is used in a wide range of industries as a differentiation factor. Several methods exist for measuring satisfaction, such as the SERVQUAL [159] and the Customer Satisfaction Index (CSI) [95]. While the SERVQUAL method pioneered the assessment of satisfaction as a function of expectations and perceptions, both methods rely on the same principle. Five main quality dimensions are used in the evaluation: reliability, assurance, tangibles, staff empathy and responsiveness. Even though SERVQUAL is one of the most widely used methods to assess satisfaction, CSI provides a more direct measure. The CSI method relies on direct numerical representation of the satisfaction rate, instead of an evaluation based on judgements expressed on a numerical scale, allowing quantitative techniques of analysis to be applied [58].

Several studies based on customer surveys have focused passenger satisfaction, including public and private means of transportation. The research suggests that passengers are affected by a variety of objective aspects and subjective characteristics of the travelling environment. Table 3.1 summarises some of the most important factors that affect journey quality [171, 53, 59, 185].

Passenger satisfaction is affected not only by instrumental functions, such as cost and duration, but also by other more subjective aspects such as feelings, comfort and convenience. All of the aspects have an impact on the satisfaction, or QoE, as defined in Section 2.4.1. Quality is, therefore, perceived by passengers as an important determinant of users' travel demand, that requires UPT providers to adjust the service to the attributes required by travellers in order to become more attractive and influence continued

Table 3.1.: UPT major service attributes

Attribute	**Definition**
Physical	
Reliability	Performance in relation to the planned service
Frequency	How often a service is offered during a given period
Speed	Velocity of the vehicle
Price	Monetary cost of travel
Information	Provision of information about a certain journey
Vehicle condition	Physical and mechanical condition of the vehicle
Cleanliness	Cleanliness of vehicle interior, seats, windows and exterior
Perceived	
Personnel	Helpfulness and empathy of personnel
Comfort	How comfortable is a journey including seating, noise and driver
Safety	How safe passengers feel from traffic accidents
Convenience	How simple and flexible is the service
Aesthetics	Appeal of vehicles and other areas
Personal	
Distress	Cognitive demand as a result of the usage of the service
Wellbeing	Elements that improve the experience, e.g. reading or relaxation
Environmental	Individual responsibility in caring for the environment
Self-expression	Usage of public services as an expression of personality

usage and modal shift.

In large urban areas, however, passengers have a number of service alternatives to perform a given journey. The intrinsic and instant characteristics of each of the options provides different levels of passenger satisfaction. A traveller-aware information service, supported by ATIS, may offer a personalised service that potentiates QoE in such environments. Alternatively, the notification of occurrences that are likely to result in a decreased QoE may be communicated to passengers before-hand, reducing the impact on their satisfaction.

The perceived service quality is not only defined as a function of the service characteristics but also how it is received [81]. In other words, pas-

senger satisfaction shares many of the QoE characteristics defined in Section 2.4.1. Furthermore, in an increasingly pervasive environment such as UPT, providers are turning to ICT for assisting them in addressing travellers' requirements, not limited to utilitarian but also hedonic needs. This environment, combined with the benefits associated with personalised services, that are able to address supra-functional needs, including preferences and internal state, provide all the required elements for enhancing user experience in UPT. In this context, a personalised transportation service with this characteristics has the potential to actively contribute to an increased QoE in urban mobility.

3.5. Summary

This chapter presented the opportunities in urban public transport for the design and implementation of an intelligent ubiquitous system with the goal of enhancing the travelling experience. A number of benefits derive from urban public transport for both passengers and the sustainable development of urban environments. The next chapter specifies a platform to provide the technological foundation for the design and development of affective ubiquitous systems.

4 Cloud2Bubble Specification

4.1. Introduction

This chapter introduces the technical specification of an intelligent ubiquitous platform, named *Cloud2Bubble*, based on the analysis from Chapter 2. The high-level specification of the platform is divided into three main categories: functional, non-functional and supra-functional. A representation of the central features of the platform is presented as use cases for the different entities involved: users, devices and system. Moreover, the loop of interaction between two abstract entities is introduced as a pivotal element of the system. The first entity, the *Cloud*, is based on a cloud-based infrastructure capable of collecting and processing information about an environment. The second entity, the *Bubble*, is focused on the increasingly sensor-saturated environment in which the collection of environment and user digital information becomes ubiquitous. This interaction between users and system supports a dynamic relationship with UX. The system is able to respond and adapt according to users' interactions, in order to provide for an enhanced experience. Finally, a high-level architecture is specified describing the main components and their purpose, based on smart environments.

4.2. Requirements

The opportunities identified in Chapter 2, as well as its associated risks, resulted in a set of high-level requirements, including functional, non-functional and supra-functional, that involves the different stakeholders of ubiquitous

environments. Rather than an extensive list, the following requirements aim at identifying the main functionality and characteristics at a higher level, that will support the development of a generic platform.

4.2.1. Functional

The following functional requirements define the required functionality and behaviour of the system.

Build environment model

The environment model is the representation of the physical world and holds a range of different characteristics of the environment, as well as interactions between entities. The model is based on the aggregation of data collected from sensors deployed in the environment, users' personal devices and, when available, additional external services. The resulting model constitutes the foundation for assessing different experience aspects of an environment.

Build personal profile

The personal profile is a collection of user-related features and qualities that define different individual preferences and needs. A profile is composed of user information, habits and internal states that are collected both implicitly and explicitly from different sources. This profile allows the system to reason upon unique user characteristics and respond accordingly.

Monitor user experience

UX, as an affective response to a given context of interaction, identifies episodes of interest and opportunities for the system to assess or actively intervene. A sub-optimal experience may be targeted for improvement, while a above average occurrences are marked as a reference. The monitoring of UX is based on the continuous update of the context model and the personal profile.

Enhance quality of experience

The enhancement of QoE, as a measure of the quality of an experience for a given user, derives from the identification of sub-optimal experiences.

The provision of an improved experience relies largely on the involvement of the user in the process of selecting an alternative, via delivering informative notifications or recommending alternative options. The direct action upon the environment is discouraged due to its negative impact on the user relationship with ubicomp and, therefore, out of scope of the project.

Behaviour Incentivisation

Behaviour incentivisation, based on the delivery of personalised services and improved UX, supports the application of policies as system wide defined goals. The goals are largely dependent on user behaviour and different strategies may be implemented to achieve behaviour adaptation without impacting UX significantly.

4.2.2. Non-Functional

The following non-functional requirements specify the quality properties of the system, that are associated with the quality of the service.

Reliability

The intrinsic *invisibility* associated with ubiquitous environments requires a high level of reliability from the systems responsible for bringing the physical and virtual world together. Reliability ensures the availability and correct functioning of the system and includes error recovery strategies, component and information dependability and identification of faulty elements. This requirement ensures a system may always be controlled if needed.

Security

The system maintains an extensive amount of context and personal sensitive information. The security of such resources is essential to prevent unauthorised access to sensitive data or usage for malicious or other purposes. In addition, unauthorised access to the processing infrastructure itself puts the system at risk, exposing its normal behaviour and operations.

Privacy

Ubicomp systems must ensure users' implicit and explicit privacy preferences and options, rather than be used as a tool to expose personal information. The privacy strategy is based on an agreement between users and system, where the collected data and its usage is transparent and clear. Simultaneously, individual preferences in regards to privacy options, data maintenance and distribution must be maintained and followed. This requirement encourages privacy functionality and practices to be embedded in the development of ubicomp systems.

Expandability

The expandability requirement aims at providing a robust platform upon which new functions and capabilities may be added. Thus, flexible behaviour adaptation and component addition are integrated within the foundation of the system, to ensure that system behaviour and technological infrastructures are being adapted and used for the benefit of users. As a result, users may use the platform as a tool to adapt to their own needs, or even to contribute towards solving an existing problem or implementing innovative applications.

4.2.3. Supra-Functional

Supra-functional requirements refer to the actions taken by the system to meet users' individuality and expectations, with the goal of having a positive effect. Unlike the previous functional and non-functional requirements, the system action cannot ensure the success of its actions. Instead, it provides users with the necessary context towards the specified goal.

User Experience

A user experience oriented strategy underlies the overall functioning of the system, being its main goal to satisfy for users' hedonic and affective requirements alongside their utilitarian ones. While it may not be possible to provide for such supra-functional requirements, the system assists the setting of a positive context or avoiding negative conditions.

Reflectivity

The development of systems that *disappear* into everyday's objects results in an oblivious and pervasive interaction. While such environment may offer a number of advantages, the personal boundaries of what is acceptable vary between users. Engaging the user in a reflective process about the role performed by the system, its benefits and drawbacks as well as the consequences and impact on everyday life and activities. This reflection is integrated in the strategy to be implemented by the system in different interactions rather than a single task to be performed in isolation.

Responsibility

Ubicomp systems have the ability, to a certain extent to act autonomously and adapt transparently to different conditions. Excluding users from the action of decision results in a decreased sense of responsibility, with an impact on the relationship between users and system. Rather than performing an adaptive action, providing users with informative suggestions and recommendations involves them in the decision making process with an increased sense of user responsibility for taking action.

Sociability

Users are integrated within a social environment, including local communities and society in general. The technological platform should integrate, and take advantage, of existing social capital to improve its capabilities. The integration of social promotes social inclusion, that some technology tends to indadvertedly neglect. In addition, leveraging social capital in ubicomp systems leads to collective and economical benefits derived from cooperation between individuals and groups.

4.3. Use Cases

A use case diagram typically describes functionality of the system, hiding its implementation and focusing on what goals may be achieved by the actors. The actor, in this context, specifies a role played by a user or any other entity (e.g. other systems) that interacts with the system. In such diagrams, the complexities of the system are hidden behind a *black-box* representation of

the system. Figure 4.1 is a representation of the main features available for *Cloud2Bubble* users.

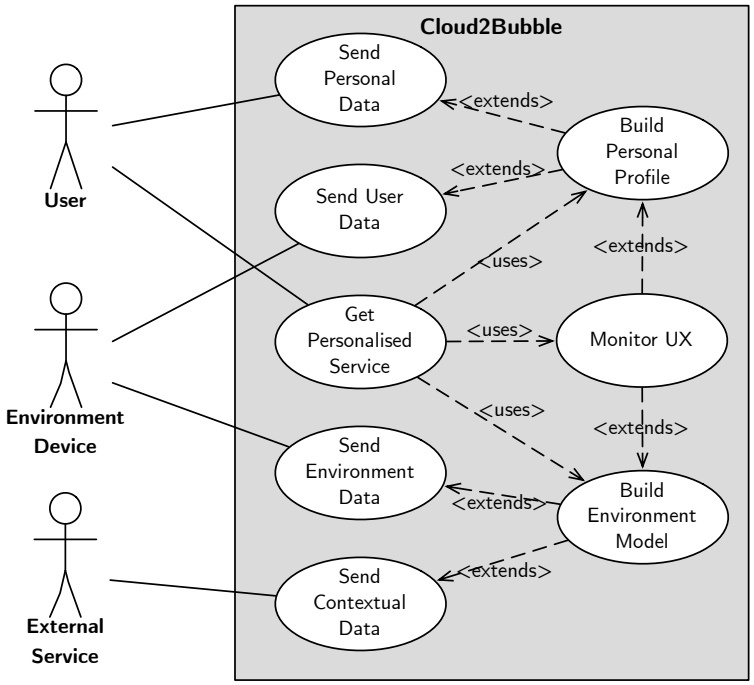


Figure 4.1.: Cloud2Bubble system, use case diagram

The diagram displays two main actors: users and environment devices. In addition, a third actor is depicted that provides an added layer of context that may be available, such as existing ATIS in a UPT environment. All of them contribute with digital information to the system. This information is composed of both participatory and opportunistic sensed data and enables a personal profile - characterising user preferences and state - and an environment model - representing the physical and social interactions between the different elements of the system. Finally, these two elements are the basis for matching the environment characteristics and user preferences, that allows *Cloud2Bubble* to assess and monitor UX - as a measure of the user affective state - and generate a personalised service. The actual specification of data requirements and services is left for the instantiation phase, when the context is defined, including the definition of context and identification of the experience to improve.

Cloud2Bubble provides a flexible platform for measuring UX and facili-

tates the incentivisation of users towards enhanced experiences. From this perspective, the typical use case diagram is inverted, where the system becomes an actor and the *black-box* a simplified representation of the user, who receives input from the actor. Figure 4.2 shows a representation of such diagram, with the main actions the system aims at performing on the user.

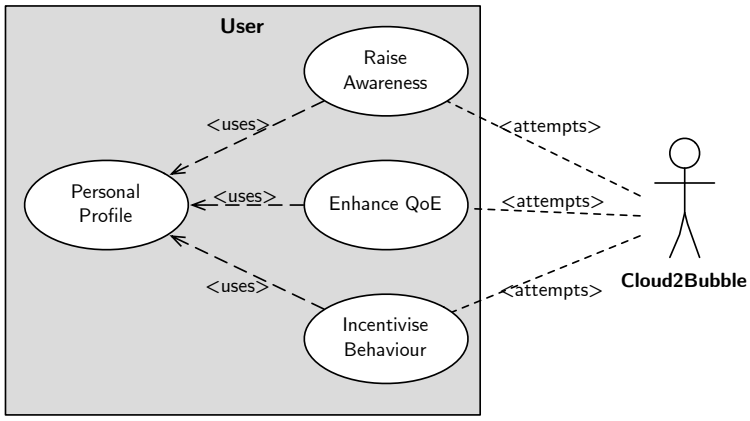


Figure 4.2.: User system, use case diagram

In this diagram, the inverted role of *Cloud2Bubble* as an actor performs basic functionality related to UX and behaviour. This simplified view relies on the capability to build a personal profile that combines preferences and needs with dynamic affective states. The notation used between the actor and use cases is adapted to convey the uncertainty in ensuring the final outcome, as an attempted action.

The relationship between user and system as a continuous loop - where one performs actions over the other in order to achieve a desired goal - is supported by the capability of assessing users' activity, intentional goals and affective state. This capability allows for monitoring UX and actively enhancing it, supporting the development of *empathic* aspects in the system.

4.3.1. Interaction loop

The design and development of an intelligent pervasive platform relies on a loop of continuous interaction between users and ubiquitous systems (see Figure 4.3). Similar approaches have defined this loop as the biocybernetic loop [167, 184] and the affective loop [89]. The established user experience-

centric approach focus primarily on the inclusion of users in the early stages of design and development. Increasingly dynamic systems enable the inclusion of such user-centric processes even after the system is deployed and integrate them in its functioning.

The proposed solution focuses on the interaction between two main elements. The first is a *Cloud*-based infrastructure inspired on smart environments, where data aggregation and information processing enables the monitoring of UX. The second revolves around users who are surrounded by an increasingly pervasive environment, interacting with different devices. This second element constitutes a *Bubble* that enables the collection of user data as well as the delivery of services tailored to their preferences and needs. The focus on the interaction between these two components is captured under the name *Cloud2Bubble*.

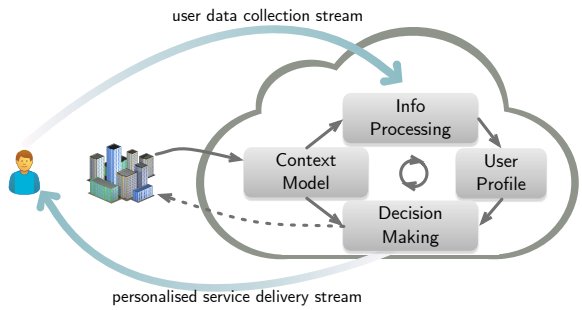


Figure 4.3.: Cloud2Bubble loop of interaction [43]

Interactions are not limited to explicit actions performed on devices or objects, as it is the goal of ubiquitous environments to make technology disappear into the background. Implicit interactions, including patterns of behaviour and internal states, become part of the input. A hybrid sensing approach, combining both opportunistic and participatory sensing, allows for the collection of a vast amount of personal information.

Wearable and other personal devices are gaining momentum, however not all objects are fully integrated within an ubiquitous system. Personal devices offer a window to a user personal space, with *"91% of people keep their phone within 3 feet, 24 hours a day"* [144].

Personal devices, such as smartphones and tablets, are central in the continuous expansion of ubiquitous sustem. They provide a deep integration into the lives and activities of users. Examples of input that may be

acquired include social interactions, patterns of behaviour, geographical location and motion. These devices are maintained by users in their intimate space, and taking advantage of these computational nodes offers a number of opportunities, and allow for a systemic collection of digital information.

In addition to the collection of data, personal devices provide a privileged platform for the delivery of personalised, relevant services. Providing users with new information raises, however, some of challenges, including intrusiveness, acceptance and reliability. In addition, delivering information with the potential to affect user behaviour or even influence it, raises ethical considerations.

Acting upon the environment, on the other hand, may be undesirable or not possible. The weather, as an example, is uncontrollable and the intervention must be focused on the user. A notification may be issued to a personal device as a reminder of the weather conditions. An intervention of this kind contributes to an overall positive experience by: setting users' expectations in relation to the meteorological conditions; and by offering a possible solution to mitigate the impact of the issue. The focus is, therefore, on the user and in exploring the potential of enhancing UX dynamically by delivering personalised services, suggestions and recommendations, rather then actively adapting the environment.

The capability of ubicomp systems to continuously collect environment and user data facilitate the creation and maintenance of an environment model and a personal profile. These elements, when combined, enable the monitoring of UX dynamically as well as delivering tailored services for enhancing UX. A cloud-based infrastructure provides the required level of abstraction, enabling the focus on the interaction with the users. The context modelling and user profiling, based on a number of environment and personal data streams, are aggregated on the main component of the platform, which continuously monitors user satisfaction and dissatisfaction and generates appropriate actions [42].

4.4. High-level Architecture

The conceptual *Cloud2Bubble* architecture, in Figure 4.4, is divided between a cloud-based infrastructure and physical interconnected devices spread through the environment [43]. The cloud, in this context, represents an ab-

straction over the infrastructure that maintains information and processes it. The physical devices range from sensors to personal devices and smartphones, as well as external systems.

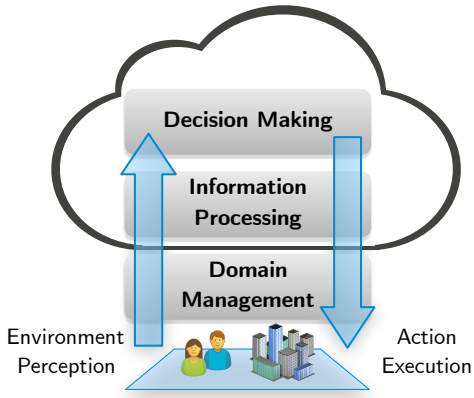


Figure 4.4.: Conceptual Cloud2Bubble architecture [43]

Typically, in smart environments, the flow of execution is divided into two phases: environment perception and action execution [38]. Environment perception is a bottom-up process, starting with user and environment data collection, which is transmitted and aggregated on the cloud-based infrastructure. The reasoning module on the top-level performs reasoning upon the state of environment and users. The second phase starts at the top-level with the generation of actions, if applicable. Action execution is then a top-down process, propagating the action to physical components and users, updating the system.

A set of technologies were reviewed in Chapter 2, relevant to synthesising affective and pervasive technologies with the goal of satisfying users' supra-functional requirements. This supra-functionality is related to hedonic aspects of user experience, satisfaction and other socio-cognitive features in relation to the system. While pervasive systems provide the platform for embedding ubiquitous technology into everyday's objects and activities, smart and adaptive systems add a layer of intelligence that is able to process a number of inputs with the goal of acting upon the environment for improving it – including enhancing users' experience and increasing overall efficiency. Recommender systems, on the other hand, leverage the interaction with the users to analyse patterns of behaviour and satisfaction with the goal of providing relevant and individual recommendations. Our ar-

chitecture draws from these ideas to assess users' experience in intelligent ubiquitous environments, by exploiting the affective loop of interaction.

The introduction of this emotional dimension enables affective-based adaptation to improve upon a metric of personal satisfaction, defined as quality of user experience. This measure based on users' affective states, allows *Cloud2Bubble* to incorporate hedonic aspects in the process, rather than relying on performance-based ones, e.g. adaptation of multimedia service delivery based on network bandwidth. In addition, the subjective metric of quality of user experience, subjective in nature, maybe primarily used as a rank-ordering attribute, and can be used in a similar way to recommender systems to define preference.

In addition to this affective-based adaptation, *Cloud2Bubble* incorporates some of the qualities necessary for supporting collective action including concerns with data collection and personalisation, trust and other societal implications, and support for inclusive design at a community level. The Open Mustard Seed (OMS) project[1], as an example of platforms for collective action, is committed to create an open data platform to enable users to share all their personal data within a legally constituted trust framework. Similar to *Cloud2Bubble*, this framework aims at providing a personal service that can securely store and process static and dynamic data about its users. the main goal of the OMS project is to provide an open-source framework that can be combined with other services to enable the development of diversified applications. While *Cloud2Bubble* shares this vision to a certain extent, it is focused on the affective-based interaction with users, that includes a metric of quality of user experience.

4.4.1. Smart System Components

The *Cloud2Bubble* platform is based on a smart system architecture [38]. The proposed smart environment architecture integrates physical devices, an enabling communication layer, information processing and decision making, present in Figure 4.5.

In the proposed architecture the physical layer is responsible for establishing the connection between physical components - i.e. sensors, actuators and other devices - and the main system. The communication layer deals

[1]ID3 – Open Mustard Seed framework: idcubed.org/open-platform/platform

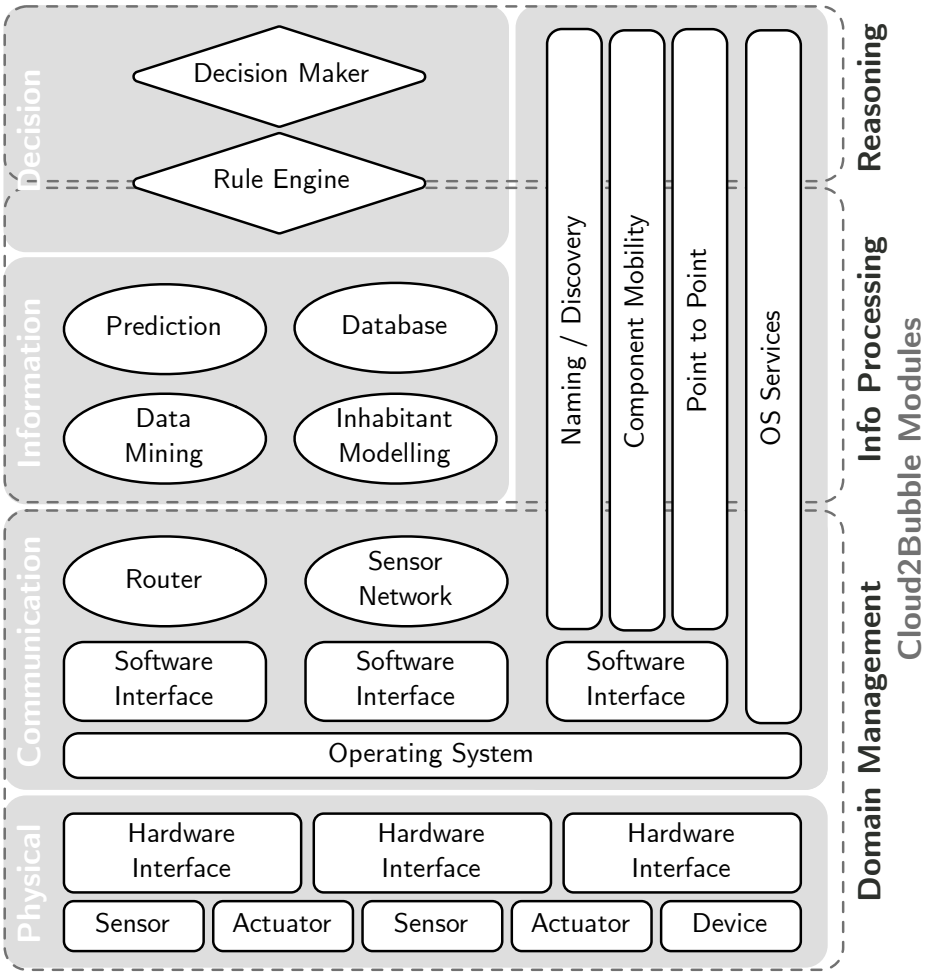


Figure 4.5.: Smart environment components, based on [38]

with the management of the different components into a network of environment devices, allowing the system to collect and aggregate data as well as performing actions to adapt to different conditions. The information layer transforms the collected data into a model representation of the environment and its users. Finally, the decision layer relies on these models to reason and generate actions towards a specified goal. In addition, this unified and interconnected structure allows smart environments to share relevant information between different contexts towards specific goals. For example, a user profile may be shared with new contexts for pervasive adaptation.These modules inspired the architecture of *Cloud2Bubble*, identified in Figure 4.5, and described in the next Sections.

4.4.2. Domain Management

The domain management module is responsible for establishing the connection between the physical and virtual worlds. This connection relies on a large number of computerised nodes, ranging from personal devices to everyday objects equiped with sensors and actuators. The information required by smart environments is collected and transmitted, mostly wirelessly, by these elements using wide spread communication networks. This highly heterogeneous and dynamic environment, composed of a pool of very different devices, capabilities and requirements, requires an equally highly adaptable system.

In addition to the commonly desired features, such as high-speed and self-organisation of the network, reliability and fault-tolerance are key aspects to take into account. In particular, component synchronisation and data fusion are complex issues in highly dynamic systems [23, 38]. The intrinsic level of uncertainty in these systems derives from the heterogeneous characteristics of the system, for example: different levels of quality of information provided by the devices; limited resources in certain nodes; or even malfunction of parts of the network.

A hierarchical typology of domain management enables independent behaviour at different levels of the hierarchy. For example, a temperature sensor at a low level reporting considerably higher temperatures could be faulty, while the aggregation of a number of sensors reporting a high temperature within a room could indicate a fire. In addition, this structure allows for the distribution of low-level operations into the devices such as data pre-processing, releasing network resources albeit with increased uncertainty.

In this context, policy computing provides behaviour configuration, capable of adapting to different contexts and user activities. Moreover, policy computing provides a tool for the definition of a high-level strategy that is cascaded down to lower levels of the hierarchy. For example, the high-level goal of reducing energy consumption in a household may be achieved through reducing the usage of certain appliances and engaging users in responsible energy consumption, levering the loop of interaction.

Policy computing provides a layer of abstraction for guiding decisions during the execution of a system. These are, however, not limited to resource

management, but cover a broader scope. Policies facilitate the declarative specification of business logic, a higher level of abstraction to large-scale systems and extensibility, allowing for additional behaviour specification dynamically [204].

Even though work on policy computing has been restricted to specific context, such quality of multimedia applications, novel approaches define a domain-independent model. The models may later be instantiated to particular areas, such as QoS and security, as well as domains, like telecom and healthcare [204].

This approach provides extensive support for dynamic behaviour and the concept is extensible to new areas, such as QoE. The ability to include measures of quality of user experience and incentivise user behaviour opens the possibility for a platform that incentivises behaviour and empowers users to actively contribute towards collective action.

4.4.3. Information Processing

In smart environments every data point is capturable, contributing for context-aware systems. However, the process of transforming several inputs into an internal model, raises a number of challenges related to data mining and fusion. Temporal reasoning, for example, facilitates the processing of a large amount of events, resulting in a responsive and up-to-date model of the environment.

From an information theoretic viewpoint, user behaviour patterns constitute uncertainty regarding their subsequent activities. The analysis of users' daily habits and routines reveals some well defined patterns which may be learned and predicted. Users' activities are thus considered a stochastic process with an associated uncertainty [20].

As described in Section 2.3.1, the context is characterised by four main parameters: identity, activity, location and time. The internal models support the description of such parameters, divided into two main elements: user profiling provides mainly identity and activity; and context modelling provides mainly location and time.

User Profiling

User profiling represents the characteristics, needs and preferences of a user, enabling a system to *"say the right thing at the right time in the right way"* [69]. They provide answers to the *who* and *what* associated with the context, described in Section 2.3.1. User profiling has been used as a user-centric tool during the software design and development phases, to raise awareness about the end-users and target their specific needs.

In the context of smart systems, user profiling facilitates the adaptive and dynamic behaviour, according to individual characteristics. The contents of a profile include personal information, personal preferences, needs and even affective internal state. While some of this information may be explicitly provided by the user, implicit interactions provide the required digital information to not only infer preferences and needs but also adapt over time. The usage of implicit interactions usually constitute a more flexible approach even though it may raise concerns related to privacy and security.

Profiling has been applied commercially with a considerable degree of success, as it is the case of online media services and e-commerce. These services base their recommendations on songs or videos previously watched or products bought by users, in combination with the ratings given, to recommend new content and promotional material. As a result, users' satisfaction improves leading to higher sales.

In smart environments, user profiling holds great potential for dynamically and continuously adapt to individual users leading to an enhanced user experience. This enables systems to provide personalised services or even act upon the environment to adapt certain characteristics, even if direct action is not ideal as discussed earlier. For example, provide an alternative commuting route in case the current one is congested.

The user profile specification in *Cloud2Bubble* not only describes users themselves, but also their relationship with a product, service or environment. It is, therefore, divided into two main sections: a generic section, that holds data relative to the user; and an expandable section that is associated with the domain of application. The main characteristics are identified in Table 4.1.

Specific attributes of a user profile are related to the context of application and define preferences and needs for a defined context. In the context

Table 4.1.: User profiling, generic attributes

Attributes	**Description**
Demographics	User description including gender, age, ethnicity, education and occupation
Privacy	Defines the privacy preferences for access and usage of personal data, defined at a global level and refined for different contexts
Internal State	Describes the internal state of the users at different timescales, including cognitive load, affective state, mood and personality traits
Activity	Current activity being performed by the user and internal goals
History	Historic user response in relation to the environment and system actions

of UPT options may include physical restrictions that are associated with transportation and other commuting preferences. The user profile is, therefore, a dynamic element of *Cloud2Bubble* that allows for its adaptation to different contexts and operability between different sections of the profile.

Context Modelling

Context modelling captures the state of an environment as a representation internal to the system and may vary significantly in level of depth and breadth. Approaches to building a context model go from simple key-value based models, where a list of attributes of an environment is paired with their respective values, to ontology based ones that describe the full spectrum of characteristics and interactions within an environment [193].

The context model allows *Cloud2Bubble* to identify the *when* and *where* of a context, where environment characteristics may differ between specific contexts of application. For example, the requirements of a home environment are different from the ones in a mobility situation, and while temperature may be a common characteristic to both contexts, vehicle vibration is certainly exclusive to transportation. The main aspects of context models are as follows:

- Environment

  Describes the physical characteristics and social interactions of the environment. These are used to model the internal structure of a given context, specifying the degree of impact on user experience. For example, a vehicle may defined as a single entity, due to its individual physical characteristics that may be considered in isolation. The conditions within a vehicle have an impact on its current passengers experience, but not on other travellers.

- Interaction

  The encapsulation of interaction between the different elements of an environment is also present in the context model. The interaction specifies how users interact with the environment and each other, providing relevant context about their habits and social interactions.

- Users and Behaviour

  Finally, the context model not only defines the environment characteristics but identifies who is present in such environment and how it relates to personal characteristics. The behaviour of the system, and how it addresses personal preferences and needs, relies on an accurate representation and processing of these elements.

In highly dynamic environments, however, context information may have different levels of imperfection due to technical limitations, regulation restrictions or component malfunctions [94]. The four main categories of imperfect information are: unknown, when no information is available; ambiguous, when different and incompatible data are available; imprecise, denoting an inexact approximation of the real state; and erroneous, in cases where the data available is incorrect. Failures of this nature must, therefore, be expected and accounted for in the design and development of systems.

Context models provide a platform for spatial-temporal reasoning in ubiquitous environments [20]. Spatial-temporal models provide the necessary information systems to infer knowledge about an environment. Event processing is an example of reasoning that relies on the analysis of a continuous stream of information to derive facts about an environment, that allows smart systems to continuously update their internal models.

4.4.4. Reasoning

The decision making is the top level component, concerned with determining the action to be taken in a given situation to optimise a performance metric, or utility of the system. The utility, in this case, is based on the resulting affective state as a measure of quality of user experience. Decision making algorithms establish a mapping between the state of the environment and its inhabitants, gathered from current and past observations. The performance metric is calculated at the relevant points in time, supporting the decision making process [40].

High complexity, related to the large amount of elements present in ubiquitous systems, are generally better cast as event-driven architectures. Such architectures wait until a new event is received to process new data. While smart systems in general aim at acting upon the environment in order to adapt to users, it may not always be possible or desirable. The reasons to do so vary from external factors, out of the scope of the system, to actions with an unwanted impact or against the system goals.

Smart systems may, in fact, have contradictory goals. Enhancing UX at an individual level may be incompatible with achieving a collective objective. For example, usage of private transportation for convenience by a user and reduction of carbon dioxide emissions. Raising users' awareness towards their impact within the community, and how their individual action impacts the greater good, is a way of involving and incentivising their behaviour, where the community or social group achieves a common goal.

Both the user profile and context model, identified earlier, play an important role in supporting the identification of sub-optimal QoE. Establishing the relationship of how users react to certain environment conditions, as an expression of experience, enables *Cloud2Bubble* to address those situations or incidents with the goal of improving user experience. In UPT, for example, the identification of a crowded vehicle allows the system to notify users who are sensitive to personal space and suggest alternatives, with potential positive results. Adjusted expectations for travelling or switching to a different yet more comfortable alternative are two possible outcomes for an enhanced travelling experience.

The importance of including the user perspective in adaptive systems was first described in [103]. In addition to environment information, the

combination of user's current state, behaviour and longer-term properties support the delivery of personalised services resulting in a higher utility of the system. Figure 4.6 presents the relationship between the information components, and how they result in a utility of the system.

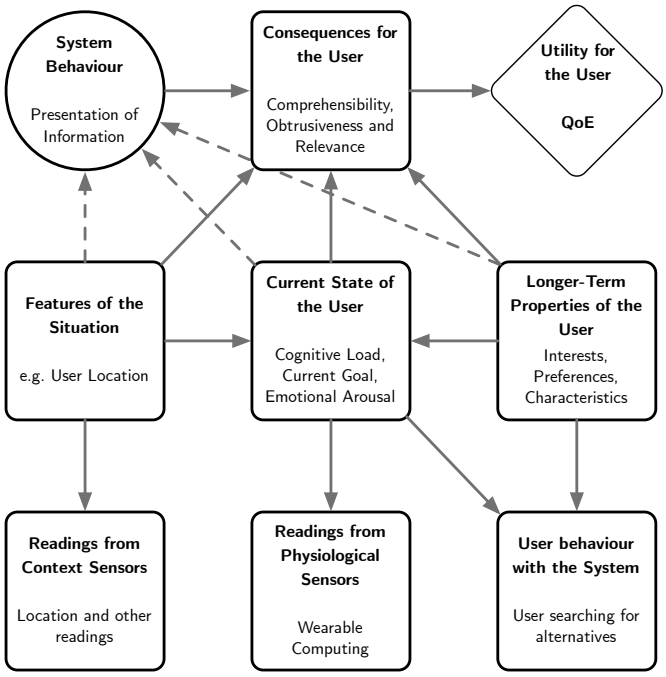


Figure 4.6.: User and context information, adapted from [103]

4.5. Summary

In this chapter the specification of the *Cloud2Bubble* platform was introduced. The specification was divided into functional, non-functional and supra-functional needs, as well as the central use cases for the entities involved. The specification includes the definition of the interaction loop between users and the system, upon which the development of the platform is based. Finally, the high-level architecture was described along with its main components and description of functionality. The next chapter describes the implementation of the software platform based on the specified system.

5 Cloud2Bubble Implementation

5.1. Introduction

This Chapter presents the implementation of the *Cloud2Bubble* platform. It details the main modules, specified earlier, as well as the different software packages. Each of the software packages describes its functionality and their contribution for addressing the platform requirements, identified in the previous Chapter. An overview of the system behaviour is provided, focusing on two main types of behaviour: request-based and event-driven behaviour. The deployment approach is also analysed, focusing on the strategies for distributing the platform through different nodes, namely the cloud-based infrastructure and personal mobile devices. Finally, a methodological procedure is presented to assist with the instantiation of the software platform in specific domains of application.

5.2. System Overview

The main elements that compose the platform, in the class diagram in Figure 5.1, are divided into three main categories:

- Entities

  The Entities, conceptually divided into *Cloudlet* and *Bubble*, maintain the state of the system, including their hierarchical structure; and encapsulate data regarding each of the individual entities. The *Cloudlet* entity holds context data, including environment state and

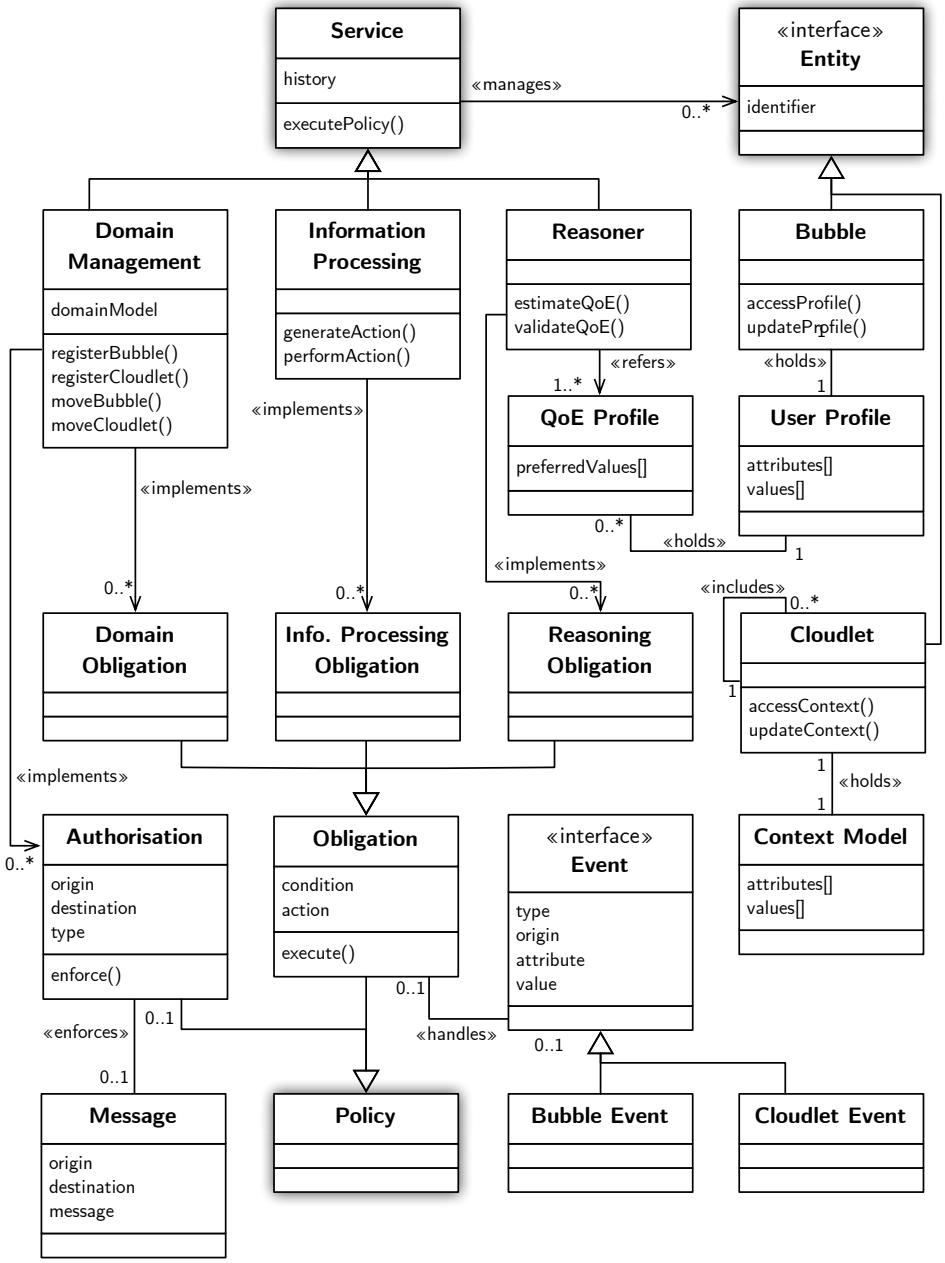


Figure 5.1.: Cloud2Bubble class diagram

the users in that space, and the *Bubble* maintains users' personal profiles with individual preferences, needs and characteristics. The hierarchical structure allows the system to maintain a relational structure between different entities, e.g. where is a user located or how two spaces are related.

- Services

  The services available in the platform implement the functionality of the main modules, divided into: Domain Management, Information Processing and Reasoning. Each of these services integrates in the workflow of the system, performing a specific function.

- Policies

  The policies define the behaviour of the system, from access authorisation to event handling. Policies are divided into authorisations - that define the levels of access between different entities of the system - and obligations - that implement the event-driven behaviour of each of the services.

The services identified are supported by a set of software packages that are used to target the requirements, described in detail in the next sections. In short, the main software packages are a policy system, a rule engine and a fuzzy inference system. The policy system provides low-level domain management of the different hardware and software components, manages authorisations as well as maintaining hierarchical and data structures. The rule engine provides high-level domain management, complex event processing and temporal reasoning. This module is also responsible for implementing action generation, with the goal of providing an enhanced user experience. Finally, the fuzzy inference system validates the actions for QoE optimisation in relation to the individual user profiles. Table 5.1 summarises the relationship between the platform services and software packages.

5.3. Main Services

The development of *Cloud2Bubble* includes a number of software packages, providing functionality for the different requirements identified in Chapter 4. Some of these requirements, however, have implications for the instantiation

Table 5.1.: Platform services and software packages

	Domain Management	Information Processing	Reasoning
Policy System	Low-level domain management; Authorisation enforcing	High-level domain management	-
Rule Engine	Context and user modelling	Event processing; Action generation	-
Fuzzy Inference System	-	-	UX monitoring and QoE estimation

and usage in naturalistic environments. For example, dynamic domain management is a desirable feature for sensing users and the environment, but raises challenges related to security and privacy. The following sub sections describe the implementation details and challenges faced in the modules specified.

5.3.1. Domain Management

Domain management constitutes the foundation of the platform and is responsible for maintaining the relationship between physical resources and the virtual world. As stated in Section 4.4.2, the complexity associated with a high number of heterogeneous devices requires a dynamic and adaptive solution. In this context, policy-based management provides extensible behaviour adaptation, from resource management (low-level) up to business logic (high-level). Policies enable the definition of system behaviour dynamically, without requiring the implementation of software code. For example, a low-level policy may define how a new hardware component, e.g. a sensor, is integrated in the existing infrastructure, while a high-level policy defines the processing and aggregation of data from that device with others.

A number of projects and initiatives have explored the design and development of intelligent ubiquitous environments, as well as the challenges raised, including the demand for a highly flexible and adaptive system and the ability to respond to the needs identified in the environment, as described in Section 2.6.

A common approach is to focus on a specific domain, addressing the iden-

tified needs and requirements. As a result, these projects tend to concentrate on the low-level details of implementation, including resource management and data fusion. Smart-system projects - such as smart homes - are an example where significant effort is concentrated in modelling the home, even if disconnected from other external infrastructures. On the other hand, a high-level oriented approach tends to focus on an abstraction of system behaviour adaptation and policy specification without directly addressing the challenges of the domain being implemented. The KAoS policy language [203], as an example, provides an ontology-based policy specification. While it provides a flexible approach to describe and incorporate a wide range of elements, it fails to support the underlying resource infrastructure directly. The rationale for using Ponder2 is its ability to bridge the gap between these two approaches, providing support for domain management and an integrated policy specification [188]. As such, the main features used are related to component management, including communication, event-based policy behaviour and resource access enforcing. *Cloud2Bubble* builds upon these features, by implementing its own context, including entities and structure, domain-specific behaviour and access authorisations.

Policy System

The Ponder2 platform provides a self-contained, stand-alone policy environment that may be applied to a wide range of contexts, from body sensor networks to urban planning. The Self-Managed Cell (SMC) pattern in Figure 5.2, implemented by Ponder2, is an engineering paradigm for structuring ubiquitous environments [188]. SMCs are independent entities that manage a set of heterogeneous software and hardware modules, with support for adding and removal of components, dealing with erroneous sensors and adapting automatically to users' activity or environment.

The core functionality is composed of discovery and policy services an and event bus. These elements allow the system to connect and manage different resources within and between SMCs. Moreover, interconnected SMCs are transparently linked via a common event bus that provides unified domain management features. As a result, higher-level services are abstracted from dealing directly with remote components. Other services may be added depending on its application, such as security and utility

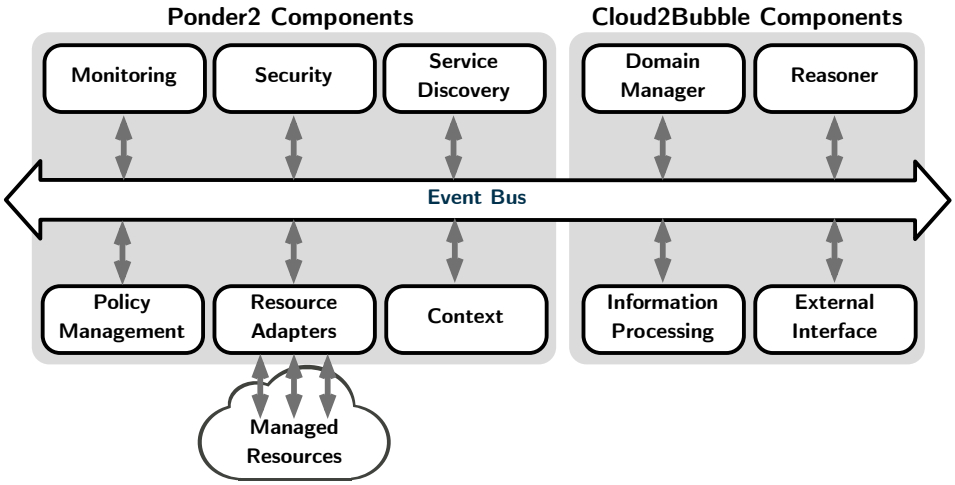


Figure 5.2.: Self-Managed Cell (SMC) architecture, adapted from [188]

functions to optimise performance. Therefore, components can be scaled according to the requirements, from single sensors to large-scale systems. The abstract domain management in Ponder2 is supported by the following main elements:

- Managed Objects: extend the capabilities of the platform, implementing services, external resource access and domain elements. A managed object is a Java class that implements the `ManagedObject` interface, provided by Ponder2, and makes its functionality available to the platform via user-defined keywords;

- PonderTalk: language used in Ponder2 for abstracting the communication between local and remote objects, accesses functionality exposed by the available managed objects and establishes the connection between all the available resources;

- Policies: define the behaviour of the system that is adaptable at runtime, divided into authorisations - that define access rules between different managed objects - and obligations - that specify event handling and actions.

Domain Model

The domain is organised in a hierarchical structure with two main entities in Figure 5.3: *Cloudlet* and *Bubble*. Conceptually, a *Cloudlet* incorporates the managed resources and users with a common spatio-temporal relationship. These may include environment sensors and actuators, public displays as well as personal devices. For example, in a smart home a *Cloudlet* for the living room would include all the electronic devices, e.g. TV set and games console; environment sensors such as temperature and luminosity; and users' own personal devices such as mobile phones and smart watches. The *Cloudlet* is the entity in which local context is maintained and updated using all the available resources, based on an event-driven architecture.

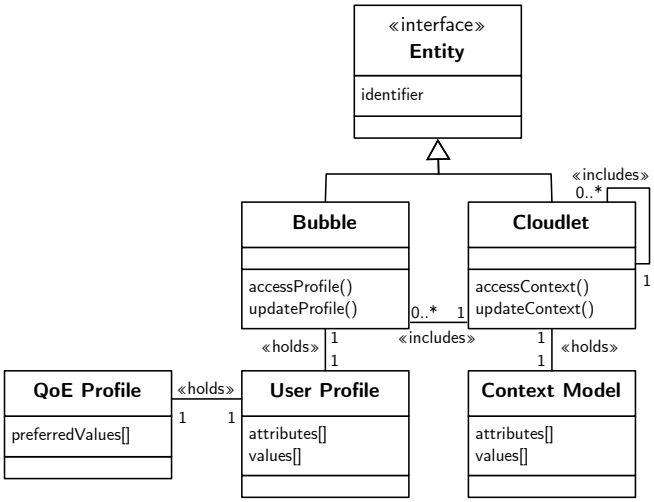
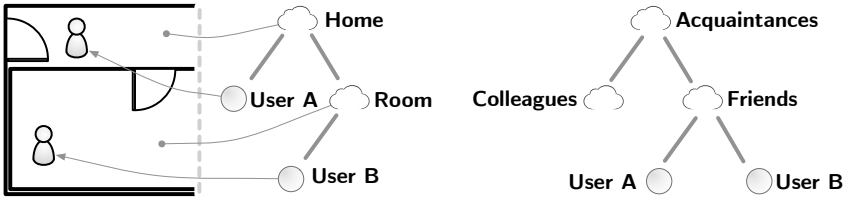


Figure 5.3.: Entities, class diagram

The *Bubble* entity is focused on the personal relationship between the user and the system, that relies on both implicit and explicit interactions with devices. A *Bubble* maintains personal context in relation to a unique user, including expressed preferences, internal state and personal needs. In the proposed domain model, a *Bubble* is a mobile entity that roams between different *Cloudlets*, mimicking the behaviour of a user in the environment.

While the relationships are mainly shaped by the physical properties and constraints of an environment, the management of the domain is not limited by physical constraints and thus other logical relationships could be included. For instance, the social network aspect of human relationship

may be implemented on a distinct domain level. A graphical representation of these entities and their relationship is shown in Figure 5.4.



(a) Physical-based structure [43] (b) Social-based structure

Figure 5.4.: Cloud2Bubble hierarchical structure

Each of these entities is implemented as a managed object in Ponder2, and are available for instantiation as needed. A managed object, implemented as a Java class exposing its methods via annotations, that may later be used by PonterTalk messages. For example, an annotated constructor of a class in Java would be available in Ponder2 for creating new instances, using the user-defined keyword. Furthermore, managed objects have the ability to receive and reply to platform wide commands in PonderTalk, enabling communication between entities.

Policy-based domain adaptation

The domain management is based on two main types of policies in Figure 5.5: Authorisations and Obligations. The authorisation framework in Ponder2 provides fine-grained control over both subject and target of an action, and implements conflict resolutions based on domain nesting precedence [201]. The authorisations between the two entities are enforced at four key points: inbound and outbound requests from both the subject and target sides. The authorisations framework in Figure 5.6 provides flexible and powerful methods for defining levels of access between entities. Authorisations are enforced at four Policy Enforcement Points (PEP) for preventing access to, for instance, an unauthorised target or protect the privacy of the subject by filtering target replies.

The model of levels of access between entities in the system follows a generic approach, and is defined as follows:

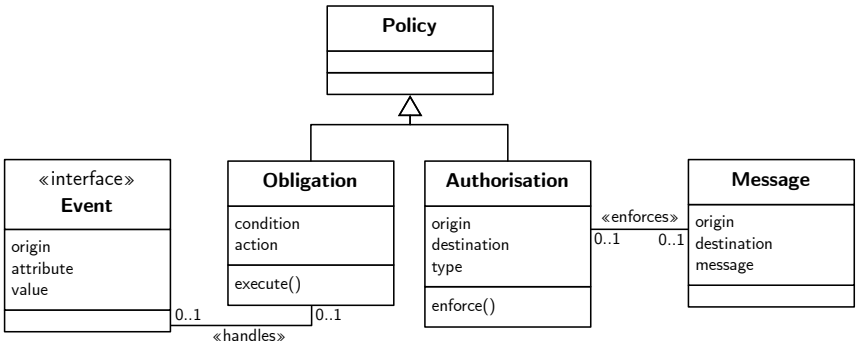


Figure 5.5.: Policies, class diagram

- Bubble to Bubble

  The direct action between *Bubble* entities is not authorised, for protection of direct unwanted access and due to the personal nature of information maintained.

- Bubble to Cloudlet

  The actions performed between *Bubble* and *Cloudlet* entities are authorised but restricted to child entities, i.e. when a *Bubble* entity is contained within the *Cloudlet* entity.

- Cloudlet to Cloudlet

  The actions between any *Cloudlet* entities are authorised, to enable the system to evaluate and recommend alternatives.

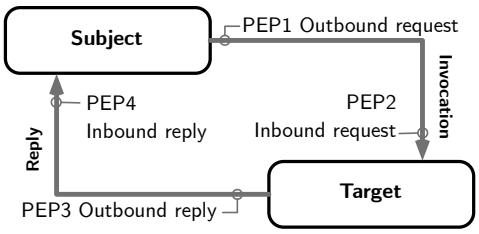


Figure 5.6.: Ponder2 authorisations framework and policy enforcement points (PEPs)

Other fine-grained policies may be defined, depending on the context of application or personal preferences. For instance, a user may define their own privacy that result in different policies. Due to the specificity of

such policies, they gain precedence over the ones specified for the platform, independently of being restrictive or permissive.

While the authorisations define the level of access between entities, obligations define the behaviour of the system. Obligations are rules that define system functionality and react to relevant occurrences in the system, defining its adaptive behaviour. Listing 5.1, for example, implements the update of the domain model based on an event. In Ponder2, an obligation subscribes to a specific event via the event bus; when a new event is generated, the condition is tested and the defined action is performed, subject to the authorisations as described earlier. Events specify the attribute names and values of relevant occurrences in the system and are not able to perform any operations.

```
// definition of Bubble event attributes
bubbleEvent := event create: #( "bubbleId" "type" "value" )
// subscribe to event and define policy behaviour
policy
  event: bubbleEvent;
  condition: [ :bubbleId :value | type == MOVE ];
  // MOVE event holds the Cloudlet 'id' in attribute 'value'
  action: [ :bubbleId :value |
    cloudlet := c2b/getCloudlet id: value.
    c2b/moveBubble id: bubbleId cloudlet: cloudlet.
  ];
```

Listing 5.1: Ponder2 obligation: updating the domain structure

These rules are responsible for implementing the adaptive behaviour of the system, however the support for event processing is limited. While the SMC provides a flexible and robust building block for an ubiquitous environment, the policy specification would benefit from a powerful rule engine with support for more complex tasks. The intrinsic extensibility of the platform allows for the introduction of other external components as services.

Services

Cloud2Bubble includes a set of services, in Figure 5.7, that implement the functionality supporting the specified requirements. The main services are:

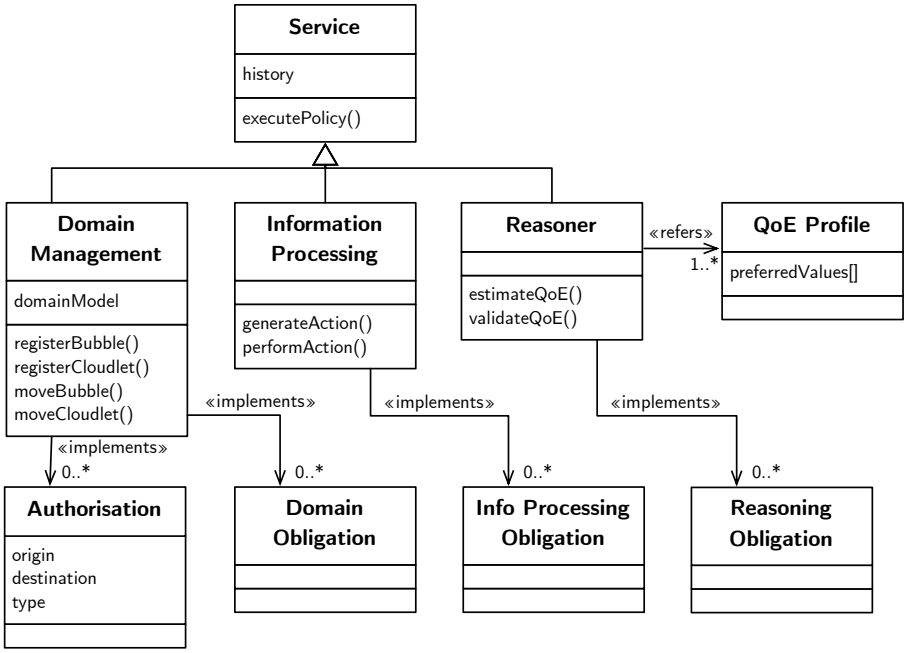


Figure 5.7.: Services, class diagram

- Domain Management Service

  The Domain Management Service is responsible for creating and maintaining the state of the entities in the domain, as well as their hierarchical structure, e.g. the processes of adding a new *Bubble* entity and assigning it to a *Cloudlet* entity. In addition it provides event routing to the Information Processing Service.

- Information Processing Service

  This service is responsible for processing all the incoming events that are related with environment updates to a rule engine. In addition, it keeps the representation of the structure between the domain manager and the rule engine updated. The rule engine performs complex event processing and action generation.

- Reasoner Service

  This service acts as a messenger between the main system and the reasoner to assess the validity of the actions generated by the rule engine, with the goal of optimising user experience. This service relies

on the user profile to assess and estimate QoE, that is used as an utility function.

5.3.2. Information Processing

Information processing, as described in Section 4.4.3, enables the system to perform context modelling and user profiling, the building blocks that enable reasoning upon environment characteristics and personal needs. The rule engine provides support for complex event processing and temporal reasoning. A set of rules is implemented for processing events generated throughout the platform, and transformed into a meaningful representation of the environment and users. The rationale for introducing a rule engine originates in the need for more flexible and powerful event processing capabilities. The rule engine provides such capabilities, including complex event processing and temporal reasoning, that *Cloud2Bubble* leverages by integrating with the existing domain structure and behaviour.

Rule Engine

The JBoss Drools (JBD) is a rule engine, based on an enhanced implementation of the Rete algorithm. The original Rete algorithm was designed for efficient pattern matching in large production rule systems [73]. JBD implements an enhanced version of the original algorithm, ReteOO, with added support for object oriented systems [189]. In addition to the rule engine core (JBD Expert) JBD provides extensive support for complex event reasoning and temporal reasoning (JBD Fusion).

Some research has focused on the design and development of policy reasoning based on the JBD, with support for ontology specification [205]. Such implementations were based on a generic policy model, shared among different domains of application and with specific language extensions to address particular needs. In addition to the flexibility in applying a common policy language to a wide range of contexts, it includes advanced support for policy reasoning, including conflict resolution and optimisation.

```
rule "Update Vehicle Sound Level"
  when // averages the sound level in the last minute
    $avgSound : from accumulate(
      Event(type == SOUND,
        $source : source, $value : value),
      over window:time(60s),
      average($value))
    $vehicle : Cloudlet(id == $source)
  then // updates the value of the vehicle sound level
    $vehicle.sounde = $avgSound;
    update($vehicle);
end
```

Listing 5.2: JBD Rule, update vehicle sound level

JBD is developed in Java and the definition of rules follows a similar pattern to Ponder2's obligations, facilitating its interoperability. Furthermore, it is composed of a set of modules that allow for the extension of functionality, including a rule engine, event processing and temporal reasoning. The support for complex event processing and temporal reasoning improves the ability of the system to process and adapt to complex situations that arise in a naturalistic environment, such as UPT among others.

The JBD was introduced to support the Information Processing Service in *Cloud2Bubble*, that may be executed within an independent SMC or integrated in an existing one. While the authorisations are implemented and enforced by the Ponder2 platform, the adaptive behaviour of the system was implemented on JBD. The events are therefore re-routed and processed in JBD. In addition, the domain was made available to the rule engine to support contextual reasoning. Listing 5.2 illustrates how sound level events generated within a vehicle are processed and result in the context update.

Listing 5.3 illustrates the event-based strategy integrating Domain and Information Processing services. Domain related events, e.g. create or move components, are processed directly by the Domain service. In contrast, information update is routed to the Information Processing service, to be further processed. Upon receiving this type of event, the Information Processing service adds new data to its facts base and, resulting in a state change, propagates that new state.

```
// Bubble related events (similar behaviour for Cloudlet)
when Domain Event do
    if Event is Create then
        Create new Bubble;
        Set Bubble Info;
        Generate Move Event;
    else if Event is Move then
        Find Bubble;
        Find Cloudlet with Bubble location;
        Add Bubble to Cloudlet;
    else
        Generate Info Event;
    end
end
when Info Event do
    Add Info to Facts Base;
    // adding new facts may trigger state changes and
       instantiation-specific rules
    if state changes then
        Update Bubble;
        Generate Domain Event;
    end
end
```

Algorithm 5.3: Domain and Information Processing services integration

Action Generation

The context model, maintained by the system, is updated upon processing of relevant events. This triggers the action generation, with the goal of addressing users needs and preferences in different circumstances. The generated actions may act directly upon the environment, e.g. via actuators, or provide a service to the potentially affected users. While acting upon an environment is possible in different ways, performing such actions without involving the user has a negative effect on the relationship and interaction with such systems. As stated in Section 4.2.3, doing so results in a reduced sense of responsibility and contradicts the defined non-functional requirements.

As an alternative, users may be included in the loop, providing them with personalised and relevant information about the context change, or even recommendations that result in a potential improved experience. While ensuring the quality of an experience is not feasible, providing such services assists users in improving it. Furthermore, action generation is specific to the domain in which *Cloud2Bubble* is instantiated. Each domain has its own specific requirements, and therefore the specification of the actions is performed at a later stage. The facilities that enable *Cloud2Bubble* to reason about the context state and decision making, however, are present in the platform.

Cloud2Bubble monitors the environment state and user profiles to estimate QoE, the utility measure that the system aims at optimising. However, due to the subjectivity and uncertainty in assessing QoE, action generation and decision-making involve a degree of uncertainty. The possible actions may be divided into two main groups: request- and event-based. Request-based actions tend to be reactive in nature and answer to direct user requests for QoE-based information. Furthermore, this information may be integrated with existing information services. For example, when searching for service alternatives, the results may include the expected QoE in relation to the environment conditions in addition to other utilitarian measures. Proactive actions, on the other hand, rely on the continuous monitoring of the environment to identify and provide relevant information at key moments, as a notification or suggestion, that may lead to an enhanced QoE.

5.3.3. Reasoning

The previous sections focused mainly on collection and aggregation of information, as well as its direct implications on users' privacy. The ability to reason about an environment enables a system to adapt its behaviour to achieve a specified goal. The usage of quantifiable measure enables the system to evaluate its performance in relation to an outcome. As an example, the performance of a network in terms of speed or latency may be measured using Quality of Service (QoS). A low QoS triggers the system to reallocate resources, improving its performance and contributing for an improved QoS.

```
when Domain Updated do
    Find child Bubbles;
    foreach Bubble do  Generate QoE Event;
end
when Info Request do
    Find parent Cloudlet;
    Generate QoE Event;
end
when QoE Event do
    Load FIS with Bubble;
    Evaluate FIS;
    Generate Estimate Event;
end
when Estimate Event do
    Find Bubble;
    Update Bubble;
    // may trigger other, instantiation-dependent actions
end
```

Algorithm 5.4: Information Processing and Reasoning services integration

In *Cloud2Bubble* this measure is based on the affective state as an emotional reaction to a service, defined as QoE. This measure is used to assess the UX performance of an intelligent ubiquitous system. The usage of QoE as an utility function enables systems to actively take action to improve experience in ubiquitous environments based on subjective factors. These actions may be defined as computing policies that adapt the system behaviour accordingly, by either providing for a positive experience or assisting with a negative one. The capability to provide enhanced experiences by acting on an individual-level presents a number of direct benefits for users, such as increased satisfaction and wellbeing. The rationale for using fuzzy logic is the capability of approximate reasoning, that facilitates the processing of incomplete or imprecise data. A fuzzy engine provides *Cloud2Bubble* with the fuzzy logic methods for estimating QoE based on a set of inputs. *Cloud2Bubble* integrates these methods with the context model and user profile to achieve a personalised estimative, based on both environment characteristics and personal preferences.

Fuzzy Logic

In addition to policies for system behaviour, the subjectivity and uncertainty in assessing QoE requires a flexible decision making component. As a result fuzzy logic was introduced, where a set of rules determines, for each user, how well an environment performs in relation to their profile. This module was implemented using the jFuzzyLogic package [32].

Fuzzy logic – a form of many-valued logic – allows for approximate reasoning rather than fixed and exact, having emerged from the development of the theory of fuzzy sets [214]. Fuzzy logic variables, unlike traditional binary sets, may assume a degree of *truthness*, or partial truth, ranging between completely false (zero) and completely true (one). Although the philosophical question of whether everything is ultimately describable in binary terms remains, in practical applications much data is in some state in between, with applications ranging from control theory to artificial intelligence.

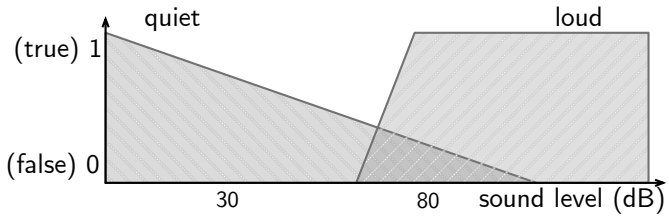


Figure 5.8.: Fuzzy sets, sound level

The level of *truthness* of a variable is defined by fuzzy sets, defining its degree of membership (in contrast to the traditional boolean notion of membership). For example, consider *sound level* as a variable and the intuitive characterisation as *quiet* and *loud*. Any value in the range between the reference levels of quietness (30dB) and discomfort (80dB) may be defined as both *quiet* and *loud*, with different degrees of *truthness*. Figure 5.8 illustrates how these membership functions may be defined for the two terms. These fuzzy sets support the process of transforming a numeric input into meaningful concepts, by defining the degree of membership for each of its sets, characterised by linguistic terms.

Fuzzy rules are conditional statements in the form:

```
IF x is A THEN y is B
```
(5.1)

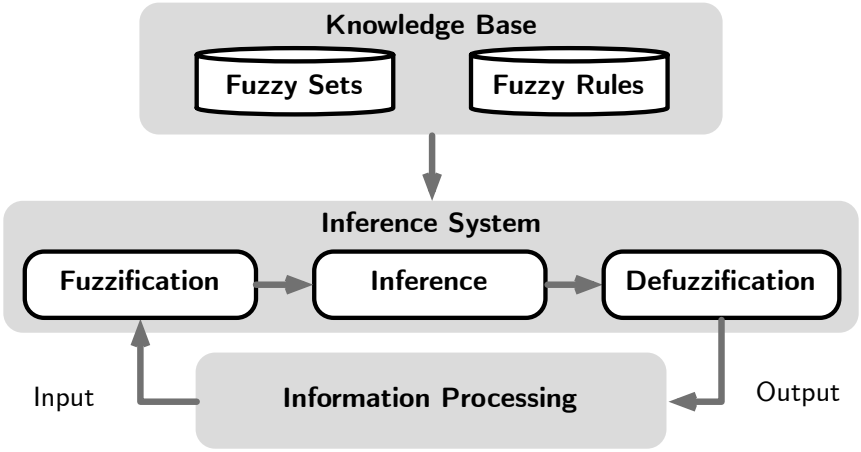


Figure 5.9.: Fuzzy Logic Controller (FLC), adapted from [33]

In Rule 5.1 x and y are linguistic variables e.g. sound level, while A and B are linguistic values determined by the defined fuzzy sets, e.g. quiet and loud. These rules are at the core of fuzzy rule based systems, such as the Fuzzy Logic Controller (FLC). FLCs, in Figure 5.9, are composed of a Knowledge Base (KB), typically specified by human operators in the form of linguistic rules, and an Inference System (IS) [104]. The KB is divided into rules and sets, as defined previously. The IS is divided into three main components: a Fuzzification interface, that transforms the crisp values of the input variables into fuzzy values; an Inference module, that combines these generated values with the information in the KB to perform the reasoning process; and a Defuzzifiction interface, which takes the result from the Inference module and converts it into the resulting crisp value.

The abstraction provided by the Fuzzification enables the reasoning upon imperfect sets of data. Continuing with the previous sound level example, QoE derived from sound level may be defined as follows:

```
IF Sound is Loud THEN QoE is Low
```
(5.2)

Having inferred QoE from the input value of sound level from Rule 5.2, the Defuzzification takes care of converting it to a final numeric value, using fuzzy sets for QoE and its linguistic terms, e.g. low, high. This final value may then be used, by our platform, to compare different alternatives and assess which one may enhance QoE.

```
FUNCTION_BLOCK sound_to_qoe

VAR_INPUT // input variable(s)
    sound : REAL;
END_VAR

VAR_OUTPUT // output variable
    qoe : REAL;
END_VAR

FUZZIFY sound // sound fuzzification sets
    TERM quiet := (0, 1) (90, 0);
    TERM loud := (60, 0) (80, 1) (100, 1);
END_FUZZIFY

DEFUZZIFY qoe // qoe defuzzification sets
    TERM low := (0, 1) (5, 1);
    TERM high := (5, 0) (10, 1);
    // defuzzification settings
    METHOD : COG; DEFAULT := 5;
END_DEFUZZIFY

RULEBLOCK inference
    // inference settings
    AND : MIN; ACT : MIN; ACCU : MAX;
    RULE 1 : IF sound IS loud THEN qoe IS low;
    RULE 2 : IF sound IS quiet THEN qoe IS high;
END_RULEBLOCK

END_FUNCTION_BLOCK
```

Listing 5.5: Sound to QoE FCL implementation

jFuzzyLogic is an open source Java implementation of the standard specification of a Fuzzy Control Language (FCL) [32], combined with a complete library for easy integration and extension of new features. The package specifies all the elements present in a FLC under a function block (see Figure 5.9) [33]. Each function block specifies input and output variables, including fuzzification and defuzzification strategies for each of the variables and finally the rules for inference. In addition to this, the processing strategies are also defined, such as the defuzzifier method e.g. center of gravity, activation and accumulation methods. Refer to jFuzzyLogic documentation

for a comprehensive list of methods and their implications.

Listing 5.5 provides an implementation of an inference module for the example used previously, with sound level as input and QoE as output. This example demonstrates how the different components are specified, including the definition of fuzzy sets. The fuzzy sets are modelled using piece-wise linear membership functions, under the format (x_i, y_i). The variables and their linguistic terms are then used in the inference rules. The linguistic terms are intended to be descriptive rather than precise definitions.

Events

Table 5.2.: Events description

Type	Origin	Attribute	Description
Create	Bubble	Identifier	Creates a new Bubble in the platform with the specified Identifier
Create	Cloudlet	Identifier	Creates a new Cloudlet in the platform with the specified Identifier
Move	Bubble	Location	Moves the originating Bubble to a new Location in the domain structure
Move	Cloudlet	Location	Moves the originating Cloudlet to a new Location in the domain structure
Update	Bubble	Domain specific, e.g. affective state	Updates the user profile associated with the originating Bubble, instantiation specific
Update	Cloudlet	Domain specific e.g. physical property	Updates the context model associated with the originating Cloudlet, instantiation specific

The rule engine subscribes to both *Bubble* and *Cloudlet*-generated events, each of which is associated with the respective entity, and identifies distinct state changes: the former related to the personal profile of a user and the latter related to the state of the environment. The update of the domain model, however, does not derive directly from the attributes of an event, but is rather subject to complex processing and reasoning. The vehicle sound

level example in Listing 5.2 demonstrates how the combination of several events may be used to update a property in the context model over time.

Events include four main properties: type, origin, attribute and value. While origin identifies the *Bubble* or *Cloudlet* generating the event, type specifies one of a set of actions to handle, described in Table 5.2. The pair attribute and value constitutes the payload of the event, with the specific data which is handled in accordance to the type of event. For example, an event originated from a *Cloudlet* of the type update will be handled by the Information Processing service for updating the context model. The attribute is openly defined, with a set of attributes that allow the platform to perform its basic operations, such as domain management, and can be extended with instantiation-specific attributes. The events are referred to as Domain, Information or Reasoning events, in accordance to the service handling them, with the same name. The distinction is mostly due to the technical requirement of converting them between software packages.

The implementation approach includes all types of attributes and is dynamically extensible. For example, if a previously unknown attribute is received for a *Cloudlet*, e.g. a new sensor device, the value is stored even if no immediate action is taking place. The definition of new rules will later define the behaviour, based on the new parameter. As a result, the effort to introduce new devices and functionality in the system is very low, providing a solid foundation for autonomous behaviour updates. Listing 5.6 implements the default behaviour of the system for unspecified events.

```
rule "Fallback for non-specified behaviour"
  when
    $event : BubbleEvent(bubbleId : id)
      from entry-point "EventListener";
    $bubble : Bubble(id == bubbleId)
  then
    modify($bubble) {
      setAttribute($event.getAttribute(), $event.getValue());
    }
end
```

Listing 5.6: JBD Rule, state update default behaviour

Context model

The context modelling is encapsulated within each *Cloudlet* entity. The attributes are maintained as attribute-value pairs that are continuously updated upon processing of new events originated from devices contained in that space.The access to the context model is maintained open, subject only to the high-level authorisations defined for the platform.

The context model is composed of a list of attributes – extendable for specific instantiations – and their respective values, as shown in Figure 5.3. These attributes tend to be numeric-based describing the physical environment, e.g. temperature in a room or number of people in a vehicle. These are then used as input for inference, as described in Section 5.3.3. The combination of an objective environment description with the subjective user-specific profile, allows *Cloud2Bubble* to generate a personalised estimation of an physical environment. This physical environment is also the basis for domain structuring, being one of the intrinsic attributes of the context model. Examples of other properties include room temperature, sound level, lighting and vibration. These values being constantly updated as new events arrive, subject to Information Processing service rules. As a result, the temperature may be the result of a combination of a number of temperature sensors, for instance, by averaging the different measures.

The distribution of context in a hierarchical structure facilitates the processing of localised events and actions. In addition, a global context model is available, based on the aggregation of related entities, e.g. calculating the temperature in a house based on several room temperatures. This implements the models required by the *Cloud2Bubble* specification.

User Profile

Similarly to the context model, user profiles are encapsulated within the respective *Bubble* entity. The attributes, also stored as attribute-value pairs, maintain personal information of an individual user. The information maintained, however, is divided into three main categories: internal state, stated preferences and personal information. In addition to the event-based update, where a profile may be updated based on data collected from sensor or other device, manual specification is also possible. Each of these categories refer to different aspects of a user profile and access may be defined

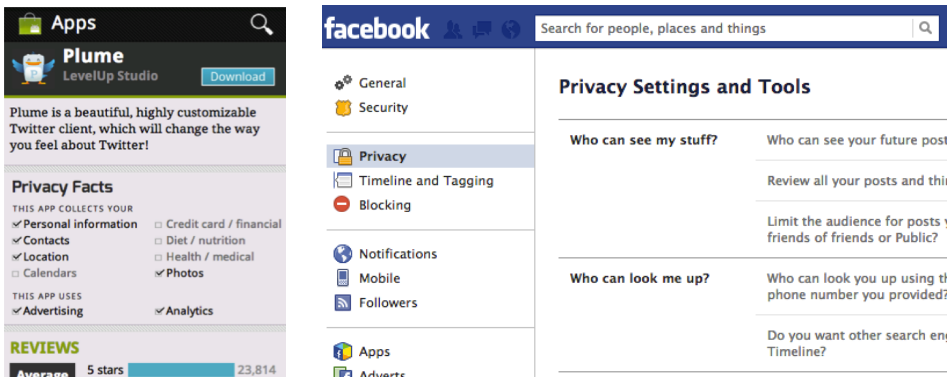
individually by the user.

Stated preferences include explicit settings, including platform behaviour and service delivery details, from receiving notifications to level of personalisation. For instance, manually setting the type and configuration of preferred environment characteristics. In addition to this, user profiles include demographic information, including age, education and occupation. These details constitute the user on a broad level, using demographic information, but also set the parameters that allow *Cloud2Bubble* to estimate QoE for an individual. These details are set as attribute-value pairs on the profile, that are easily accessed by the Reasoner service for building a user-specific inference system, described in the next Sub Section. Similarly to the context model, these attributes are defined for a specific instantiation. However, in addition to the location as a facilitator for domain structuring, the internal state is part of the platform. Thus, both dimensions of the circumplex of emotion – arousal and valence – are user-specific attributes. These dimensions are used as an important element in the QoE estimation, as it provides the implicit loop of interaction.

The modular definition of personal data relates to the notion of privacy as a non monolithic construct but rather a fluid notion with a different range of trust levels [96]. In the context of privacy, two novel examples emerge (see Figure 5.10): a proposed Android permission model [112]; and the Facebook personal data model [24]. The Android platform implements a set of permissions that users review and agree before installing a mobile application. The mobile device acts, in this instance, as a physical representation of a personal profile: holds personal information, is location aware and enables the collection other information such as social habits and patterns of usage. The permissions include access to some of the hardware features, such as internet access or location sensors; and personal data, such as the contact list. This model, however, is focused on permissions and research has demonstrated that a privacy-oriented model performs better and makes users more aware of the impact of the application [112].

The Facebook platform, on the other hand, implements a model of privacy where users may define what parts of their profiles are accessible. In this case, all personal information is already on the Facebook platform, that acts as a mediator between users and other application. In addition, Facebook apps must be granted permission to certain areas of a user profile, and denied

access to others. Efforts are being made to allow users to comprehensively understand their privacy options and its implications, in particular in a increasingly connected world.



(a) Privacy Facts [112] (b) Privacy Settings and Tools [24]

Figure 5.10.: Privacy management on Android and Facebook

The access to personal information is modelled as authorisation policies on Ponder2 [177], where an entity may not be granted access to parts of the profile. These granular authorisations have precedence over the ones defined globally. An example of an authorisation to access a profile is shown in Listing 5.7.

```
// define authorisation parameters
auth = (newauthpol
    subject: root/c2b/cloudlet
    action: "accessProfile"
    target: root/c2b/bubble
    focus: "t"). // t:target; s:subject
// set access conditions
auth reqcondition: [ :profileAccess | profileAccess == TRUE ].
```

Listing 5.7: Ponder2 authorisation, profile access

Estimating QoE

The implementation of an FLC component in *Cloud2Bubble* as the Reasoner service enables the platform to estimate QoE based on a number of inputs that relate to both environment and user. The implementation of this service was extended to support user-dependent sets, which enable the system

to target and estimate QoE for individual users, rather than generalising the same result for all users.

The service is used for evaluating QoE on request, for example, to estimate the expected QoE in a given environment and a specific user. While the fuzzy rules define the overall behaviour and are shared between all users, fuzzy sets are individualised and define the levels for individual users. The same environment conditions may then result in different estimations of QoE.

Fuzzy rules are defined globally, by a human operator, who specifies both input variables, linguistic terms and other specificities, such as methods for combining and calculating sets, as demonstrated in Listing 5.5. This however may be extended to include learning capabilities, that would lead to increasingly accurate results.

Fuzzy sets, on the other hand, are part of the user profile and defined individually. To this end, our implementation extends the language specification, to include modifiers that are populated prior to the inference execution. Listing 5.8 illustrates the placeholders for two linguistic terms of a generic input variable: `SET_VAR_A` and `SET_VAR_B`.

```
VAR_INPUT // input variable
    var : REAL;
END_VAR

FUZZIFY var // variable fuzzification sets
    TERM a := {SET_VAR_A}; // placeholders, to be replaced by
    TERM b := {SET_VAR_B}; // user-specific fuzzy sets
END_FUZZIFY
```

Listing 5.8: Generic fuzzification variable block

The reasoning service, prior to performing the inference evaluation, populates the file with generated piecewise linear functions, generated from user profiles. As a result, each evaluation is based on individual preferences and need, providing personalised estimations. The absence of certain characteristics from a user profile, however, does not prevent the execution of the evaluation, being these functions replaced by global values rather than user-specific.

```
Load FCL file;
// replace all placeholders
foreach input variable do
    foreach linguistic term do
        Search placeholder in FCL file;
        if placeholder exists then
            Create personalised Function;
        else
            Select default Function;
        end
        Replace placeholder in FCL file;
    end
end
Load FIS;
// set all inputs from Cloudlet
foreach input variables do  Set FIS variable;
// generate user-specific QoE estimation
Evaluate FIS;
```

Algorithm 5.9: User-specific fuzzy sets algorithm

The approach in Algorithm 5.9 enables the platform to be set to specific domains using intuitive rules, while the user-specific sets provide differentiation between them. In addition, this approach allows the system to progressively adapt to user specific needs, either explicitly defined by users or through learning supported by the continuous affective loop.

Rather than acting upon the environment, the primary focus is to inform the user and assist with alternatives to the current experience or inform of negative incidents. Providing information about the benefits of an action involves the user in the process, resulting in an adjustment of expectations. In addition, this information results in a greater user awareness of the overall system, as well as the impact of their actions. Thus, while the behaviour change may not necessarily result in a direct enhanced experience in the short term, it may contribute for it in the long-term, opening a number of other opportunities to explore. The implementation of the services described in this Section enable sthe adaptive behaviour of the system.

5.4. System Behaviour

This section describes the high-level behaviour of the system. The main features focused in this section are the domain update, including context model and user profile as well as the system response to direct user requests and environment events. An illustrative scenario will be used, based on UPT, to assist with the examples. In this context a *Bubble* embodies a single passenger and a *Cloudlet* represents a vehicle.

The event-driven architecture relies on the different components of the system to generate relevant events that reflect the state of the environment. The update of the domain allows the system to respond accordingly with the goal of optimising QoE. The events generated by the components, e.g. sensors and other devices, are low-level events that describe local details of the environment, rather than global aspects.

The low-level events are propagated to the Information Processing service, where complex processing and temporal reasoning take place. At this stage, events from multiple sources are combined to reach a more accurate representation of the environment, for example, determining the temperature in a vehicle based on multiple sensors. This processing allows the system to derive high-level events and trigger actions accordingly. The system behaviour is divided into request-based - responding to an explicit user request - and event-based - triggered by a change of state in the system and generating appropriate actions. Examples of this are shown in the Sub Sections 5.4.1 and 5.4.2.

5.4.1. Request-based behaviour

The request-based behaviour of *Cloud2Bubble* is, at least from a user perspective, very similar to other ATIS: the user performs a request with a set of parameters and receives a response accordingly. An example, in UPT is the request by a passenger for travelling options for a specific route or between two locations. Typically, an ATIS system provides the passenger with a list of alternatives, including price, duration and even real-time information.

Each of this alternatives, however, provides different experiences, not only due to service characteristics, but mainly due to their unique environment. The availability of a context model that specifies the environment in each of these travelling alternatives, and the unique user profile describing personal

preferences and needs, allows *Cloud2Bubble* to estimate individual QoE. As a result, in addition to cost and duration, the user may be provided with an expected QoE for each alternative.

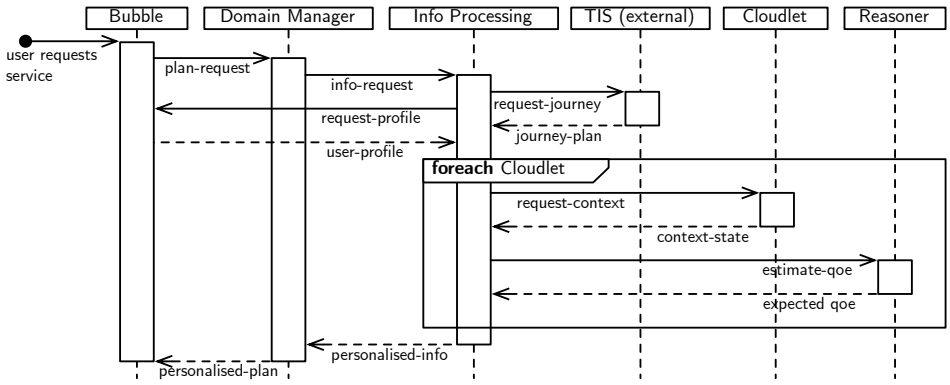


Figure 5.11.: Service request, sequence diagram

The process is illustrated in the sequence diagram in Figure 5.11, where the user request is propagated through the different components of the system, from the Domain Management and Information Processing Services, triggering the necessary policies. The role of the Information Processing Service, in this example, focuses on integrating an existing ATIS service, external to the platform, and the estimation of QoE for the user based on personal profile and context model. The combination of the ATIS, context model and personal profile information enables the system to estimate an expected QoE for each of the journey alternatives. The personalised journey plan is finally sent to the user, who is responsible for making the final decision.

5.4.2. Event-based behaviour

Event-based behaviour, as opposed to request-based behaviour, assumes a more proactive role. In this case, the system detects changes in the context and acts accordingly, without an explicit request from the user. The continuous domain update allows the system to identify potential situations where QoE is sub-optimal and act with the goal of improving it. In UPT there are a number of opportunities to integrate in the travelling activity. For example, passengers who commute everyday to work may be notified, even before boarding their usual service, that an alternative exists with the

potential to provide a higher QoE.

The delivery of such a personalised service, that may impact the decision of the user to use an alternative service in exchange for an enhanced experience, depends on the activity itself and how well it integrates in the decision process. The notification or suggestion of alternatives is opportune before the user boards the vehicle, but may lose its purpose during the actual journey. When within the vehicle, the type of service to provide assumes a different profile. An example of a service of this type, in London, is operated by double-decker bus drivers: the driver announces the availability of seats on the upper deck when the lower deck becomes crowded.

In Figure 5.12 the sequence diagram illustrates the process of actively delivering a service to users based on the environment conditions, that is limited to a notification with the goal of adjusting passenger expectations. The event triggers a reaction where the Information Processing Service, when updating the context state, selects all the *Bubble* entities that may be affected by the change, and generates a set of possible actions: a notification about the change. These actions are finally validated by the Reasoner Service, that estimates the expected QoE for each of the passenger based on the update, selecting only the relevant ones.

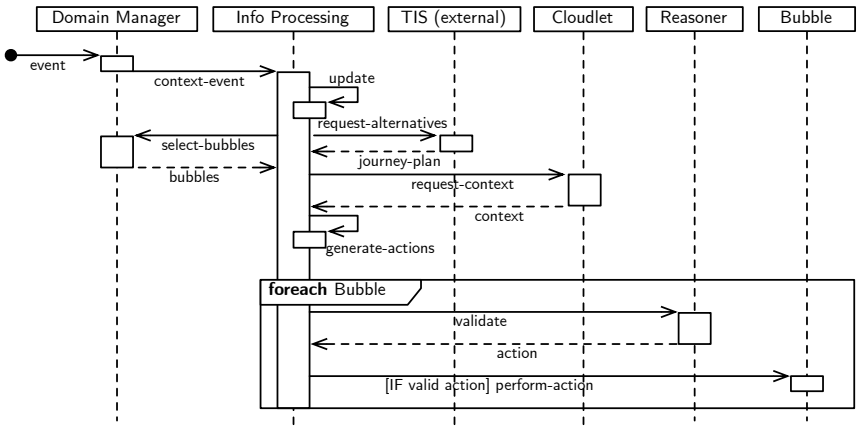


Figure 5.12.: Environment update and user notification, sequence diagram

5.4.3. Calculating QoE

While the main goal of *Cloud2Bubble* is to provide for enhanced experiences, the dependence on external factors and users internal states poses a number

of constraints. As a result, QoE provides an evaluation of the utility of the system as a subjective measure of experience. QoE constitutes the foundation for providing a personalised service, based on the environment conditions and personal preferences, but also to evaluate the effect of the system on users. In addition to providing a service based on an expected QoE, the continuous loop allows for an improvement of the user profile based on the actual environment conditions and user reaction. This allows profiles to be increasingly accurate in reflecting users' preferences and needs, but also enables the analysis of the long term impact on their overall wellbeing and satisfaction with the environment in general and UPT in particular.

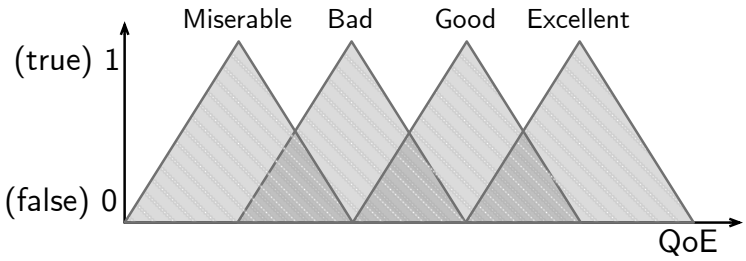


Figure 5.13.: QoE deffuzification dets

Using the fuzzy inference described in Section 5.3.3, the QoE is the result of a defuzzification. QoE is divided, for the purposes of *Cloud2Bubble*, into four levels: miserable, bad, good and excellent. The terms, however, are not intended as accurate descriptions of QoE, but rather descriptive terms that can be used intuitively in the definition of rules. The functions model QoE between 0 and 10, from miserable to excellent, respectively. The sets divide this range in four sections distributed evenly, as shown in Figure 5.13. These sets intuitively define the extreme terms coinciding with the range limits, both minimum and maximum, while placing moderate terms below and above the average.

These defuzzification sets map the output of the inference, where rules define the level of QoE according to the input. These are, as described earlier, instantiation specific. However, user internal state is an important part of this process and a set of four rules are defined for the platform, to support the conversion between affective state and QoE. These rules are a first approach and may be further developed to improve the impact of arousal and valence on estimated QoE. Thus, the following rules provide

the first definition:

- `IF Arousal IS Inactive AND Valence IS Happy THEN QoE IS Good`
- `IF Arousal IS Active AND Valence IS Happy THEN QoE IS Excellent`
- `IF Arousal IS Inactive AND Valence IS Unhappy THEN QoE IS Niserable`
- `IF Arousal IS Active AND Valence IS Unhappy THEN QoE IS Bad`

5.5. Architecture: Deployment Approach

The prototype implementation of *Cloud2Bubble* is focused on two main components: a cloud-based infrastructure and the interface with users based on personal devices. These components were identified due to the focus on the loop of interaction described in Section 4.3.1, and the ability to aggregate different sources of data and deliver personalised services.

In a naturalistic environment, however, a number of restrictions are imposed. The implementation of the *Cloud2Bubble* platform is based on the specification provided while it addresses some of these restrictions. Furthermore, the usage of a real-world environment raises a number of concerns and requirements that are described in the next Sections.

The main components differ in the software modules implemented, in Figure 5.14. While the information processing and reasoning modules are fully functional on the cloud-based infrastructure, the personal device version is limited to the domain management, routing all the relevant events to the services located in a different computational node. The flexibility of module management allows the scaling of the platform according to the requirements. The event bus provided by the SMC allows for a transparent communication of events between the different nodes.

5.5.1. Cloud-based Infrastructure

The cloud-based infrastructure is deployed on a Java-based execution environment. Even though at this stage the main services are concentrated in

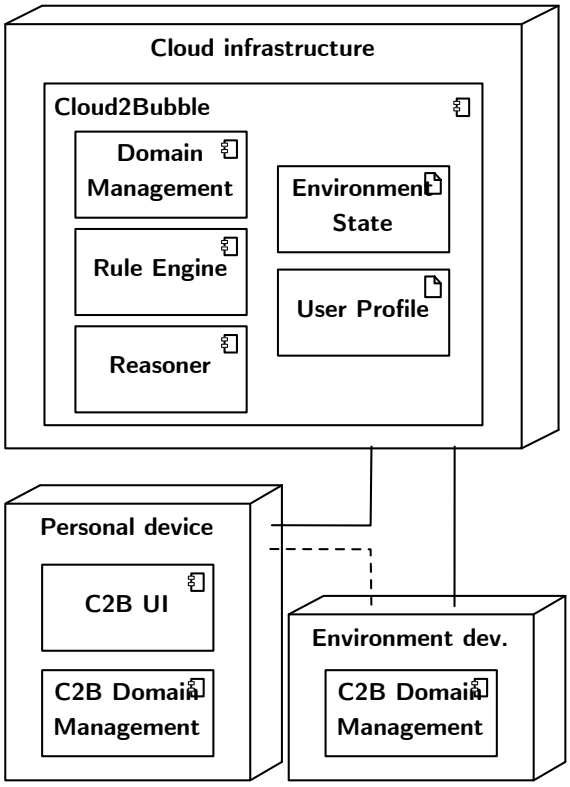


Figure 5.14.: Deployment diagram [43]

one main package, these may be distributed transparently according to the needs and resource demand. *Cloud2Bubble* is a PaaS (see Section 2.3.2), according to the model introduced in Chapter 2, since it provides the necessary tools and services for aggregating and processing data, without providing specific support for an environment or application in particular.

In the current implementation of the system, all the main services and data, including both context model and personal profile, are centralised in a single cloud-server. This facilitates information processing and decision making at an early stage of development for a proof of concept. The distribution of the resources by different computing nodes is intrinsically supported by Ponder2. Maintaining user profile on personal devices, as a way of ensuring users' complete control over personal information is possible, even though it raises other concerns regarding data storage and integrity. Losing of damaging the physical device would result in the loss of the user profile, for example.

5.5.2. Mobile device

A scaled down version of the platform for mobile devices was developed for the Android platform. While the migration of Ponder2 to be executed in this environment does not pose major challenges, it requires access to advanced features of the platform. One of the major obstacles is the implementation of the event bus due to the required access to advanced communications, i.e. local network broadcast. The unusual access to advanced features of the device, while not a technical constraint, may prevent users from using the application.

The prototype developed was focused on the domain management, for integration of the device in *Cloud2Bubble*, and the development of a graphical user interface, for direct interaction with the platform (see Figure 5.14). Features include the registration of the device as a *Bubble* in the system, trigger certain events and receive notifications. Ponder2 was executed as a single service, that was permanently active in the background. This approach allowed us to quickly convert a single device into a component of *Cloud2Bubble*, however a number of optimisations are desirable for a end-user application. Such optimisations include less resource intensive services and deeper integration with native functionality.

P2Android

Ponder2 provides a prototype extension of the platform to be executed in Android-based environments, called P2Android. The common execution environment, based on the Java language, facilitates this integration. The approach, however, links a number of Ponder2 resources directly to Android Activities. In this context, the role of an Activity is to display graphical interfaces and perform light computational tasks for a specific mobile application. As a result, P2Android does not provide a stable execution environment and is not able to support Ponder2 correctly. As an example, when the user switches between mobile applications, the corresponding Activity may be destroyed, resulting in the termination of P2Android, even though the mobile application may still be available in the background.

In order to solve this issue, Ponder2 was ported based on an alternative method, implementing a mobile application with a Service and an Activity. The core component of the platform was ported to the service, that is able to

be executed in the background without interruption. The activity is then linked to establish the connection with Ponder2 functionality as needed. The resulting application was successfully executed and integrated in the domain along with other nodes. The implementation of Ponder2, however, supports only device-to-device communication in local networks, limiting its application in other environments.

This approach consists of developing a mobile application that can be installed on personal mobile devices. While this allows for the integration of the mobile device as a node in the platform, these features should be implemented as part of the platform, rather than implemented as a mobile application. As an aside, it would be recommended that these features should be integrated in widely used platforms, such as Android and others.

5.6. Instantiation Methodology

The methodological procedure for instantiating the platform in a specific domain of application is constituted of the following six main steps:

- Domain Specification;
- Context Modelling;
- System Behaviour;
- User Interface;
- Implementation & Testing;
- Deployment;

The first two steps focus on the specification and modelling of the domain in which the platform is to be applied and can alternate between them, as knowledge about the domain deepens. The next three steps define how the system will behave, what interface will be used to interact with the user and its implementation details. These three steps may also alternate between them, however they are only started after the first two are completed, when the domain is well defined. Finally, the last step aims at deploying the system in its natural execution environment, where its performance may be evaluated.

Step 1: Domain Specification

In the first step, an investigation of the overall domain of application is performed, with the goal of identifying the main user activities, and how these may benefit from an intervention from *Cloud2Bubble*. In addition to the identification of key moments in the activity and potential services, this step aims at defining the hierarchical structure that will support the experience, estimation of QoE and delivery of personalised services. In UPT, one of the main target activities is commuting, where different moments allow for intervention with a relevant service with potential to enhance their experience.

Step 2: Context Modelling

The second step is related to the first one as it implements the data structures and their relationship that support the specification in the previous step. In addition, this step identifies the channels of communication that are available, from both the user and environment sides, including devices and external services as well as the definition of the environment and user characteristics to be maintained. In UPT, the main entities are vehicles, represented by *Cloudlet* entities - holding environment characteristics such as crowding and noise - and *Bubble* entities that encapsulate passenger information and preferences. In this context, existing ATIS provide extensive support for journey planning, while personal devices allows *Cloud2Bubble* to establish a personal communication with the passenger and their surrounding environment.

Some iteration between the two last steps may be necessary to refine the specification and modelling, as new aspects of the domain come to light. These establish the foundation for implementing specific behaviour.

Step 3: System Behaviour

This step defines the behaviour of the system in relation to the target activity and how to influence the experience. The definition of behaviour includes the factors that enable *Cloud2Bubble* to identify relevant moments, i.e. where sub-optimal QoE is present, as well as the actions to take to provide for an enhanced experience. The definition of behaviour relies largely on the context model and user profile, specified earlier, for estimating QoE

accordingly. In a commuting activity, an interesting moment to investigate is the period of time preceeding the actual journey, where an action may significantly impact user behaviour to explore other alternatives. In case a sub-optimal situation is detected a potential influencing behaviour may be based on providing other alternatives.

Step 4: User Interface

Having defined the behaviour, the next step focuses on defining the interface with the user and how to actually deliver the service. This step involves a more technical component, as it starts defining how the actions are reflected and communicated to the user and how their state is sensed. The mobile device is, in this context, a powerful resource that not only provides environment sensing capabilities, but a privileged channel of communication with the user. Sensing users, or passengers in UPT, becomes more participatory and allow us to explore their relationship with the environment and the travelling experience.

Step 5: Implementation & Testing

The final step aims at implementing the different components needed for *Cloud2Bubble* to perform, including: hierarchical and data structures, domain modelling, events and rules specification and user interface. The integration between these components and the targeted activity must be well defined and executed. An iterative process between these last three steps will help refine the system for a correct and accurate instantiation.

Step 6: Deployment

The final step aims at deploying the platform in the specified domain, leading to its execution and evaluation. The evaluation involves an aspect of technical feasibility and correctness, but also at exploring the impact of the system on QoE and user experience, both in the short and long terms. This step deals with the process of releasing the finalised instantiation, ensuring the capabilities of the execution environment and other restrictions.

5.7. Summary

This Chapter introduced the implementation of the *Cloud2Bubble* platform, including the different software packages that compose and implement the specification in the previous Chapter. In addition, the deployment approach is discussed in the context of ubiquitous environments. The system behaviour is demonstrated based on two main types of behaviour: request-based and event-driven behaviour. Finally, the methodological procedure for instantiation of the platform in a specific domain of application was presented. The next chapter is based on this methodology to instantiate the *Cloud2Bubble* platform in the UPT domain.

6 Instantiation in Urban Public Transport

6.1. Introduction

In this Chapter, *Cloud2Bubble* is instantiated in the context of UPT based on the methodology introduced in the previous Chapter, illustrated in Figure 6.1. In this domain, *Cloud2Bubble* aims at leveraging the existing infrastructures to collect and explore personal services and the potential to enhance experience. The targeted experience is therefore defined as well as the approach for measuring QoE.

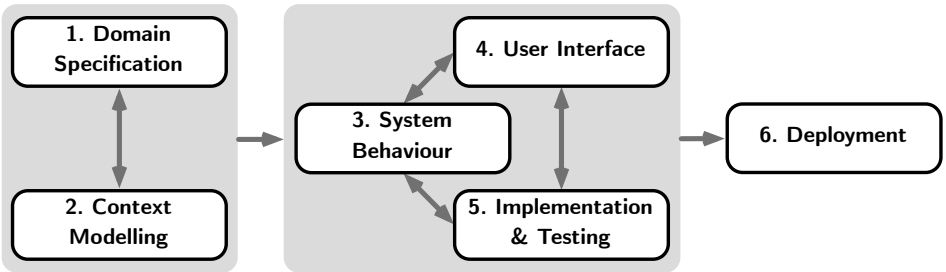


Figure 6.1.: Cloud2Bubble instantiation methodology

6.2. Domain Specification

The particular domain of UPT, introduced in Chapter 3, is the subject of instantiation and will be explored in this section under the scope of the *Cloud2Bubble* methodology.

6.2.1. Urban Public Transport Context

The application of *Cloud2Bubble* on a specific domain requires an investigation of the context focused on user needs but also the requirements and restrictions from service providers. The implementation of empathic UPT services has a number of benefits, from increased passenger satisfaction to resource efficiency, as explored in Chapter 3.

In UPT networks, the investment on state of the art monitoring and information technology enables the collection and modelling of the environment. The PRONTO project [108], as an example, relies on a number of in-vehicle deployed sensors for event detection. However, while advanced information systems are widely available and provide live information to passengers, event recognition technology is not always deployed or available for usage.

London (UK) and Porto (Portugal), the locations initially selected for conducting our research, pose some restrictions at this level. While both providers demonstrated interest and have plans to implement some of the features required for an extensive instantiation of the platform, they were not able to provide the necessary integration to conduct the proposed research. As a result, some aspects of the platform were adapted to accommodate the limitations and integrate the available infrastructures.

6.2.2. Travelling: An Experience

The definition of *experience* as a continuous stream of self talk encompasses the different activities performed during the course of the day, as well as interactions with the elements available in an environment [93]. Commuting may be defined as *an experience*: an activity that can be named and has a clear start and finish. Moreover, the act of travelling from the starting point to a destination is not limited to the UPT route between two locations, but includes the planning and travelling from the actual starting and end points, e.g. commuting from home to work includes walking to the station, see Figure 6.2.

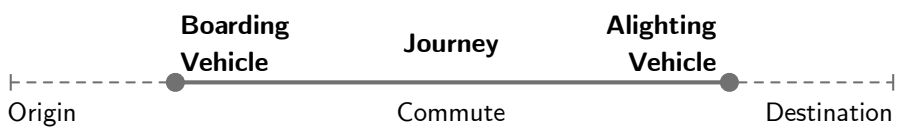


Figure 6.2.: Commuting and journey timelines

The travelling experience is therefore not limited to the in-vehicle journey, but includes the moments that precede and follow that activity. The limited scope allows us to implicitly include passenger expectations, as well as the reactions to the journey. Requesting passengers to actively participate in the evaluation of the journey, e.g. via their personal mobile devices, results in a reflective process that allows them to become more aware of the characteristics of the service, since commuters tend to not pay attention to their surroundings due to being accustomed [2].

6.2.3. Commuting Satisfaction and QoE

Measuring QoE in UPT, or passenger satisfaction in Section 3.4, is based on the affective reaction that results from the expectations and perceptions from using a product or service. Satisfaction is usually assessed via questionnaires performed during or after a journey experience - that may or may not be included in the physical activity of travelling.

In order to explore the relationship between commuters and the travelling environment, a questionnaire was developed based on the Customer Satisfaction Index (CSI). This method was chosen due to its potential direct application in quantitative analysis and facilitated integration within the *Cloud2Bubble* structure. The questionnaire was designed to collect travellers' affective states as well as perception in relation to the environment. Due to the constraints imposed by a mobile-based device, both physical and cognitive requirements, a reduced number of items were included for users to evaluate. These, however, include some of the most important aspects of public transport, identified in Section 3.4, to be evaluated on a continuous scale between 1, low satisfaction, and 10, high satisfaction.

6.3. Context Modelling

6.3.1. Hierarchical Structure

The specification of the UPT domain identifies a number of entities with a complex structure between them: passengers, vehicles and other supporting structures like bus stops and train stations. In order to facilitate the focus on the travelling experience and the investigation of the relationship between users and the environment, some of the domain complexities were simplified.

As a result the entities are based on the representation of the physical structure, where a vehicle in UPT is defined as a *Cloudlet* entity, and the users, including their profiles, are encapsulated in *Bubble* entities.

While the representation of the overall domain, including routes and bus stops, provides a more detailed description of the environment, it significantly increases complexity without providing added benefits for the chosen experience. These features are, however, providing by existing infrastructures, such as the supporting ATIS, that enable the coordination between existing services, such as journey planning, with the ones proposed to enhance user experience.

The privacy policies, as defined for the *Cloud2Bubble* platform, are appropriate for this scenario. No passenger is allowed to access other passenger details, and a vehicle is only able to access passengers that are currently on board. Communication between vehicles is, however permitted. Therefore, no further adaptation is needed. The result of this access configuration is transmitted to the passenger under a mutual agreement that specifies how their data is handled.

6.3.2. Context model and User profile

Based on the identified environment characteristics that impact passengers experience, the context model will maintain data relative to:

- Location: sensor or route based;
- Sound level: amplitude sensed by the microphone;
- Atmosphere: ambience in vehicle, including cleanliness and other passengers;
- Comfort: level associated with crowding and other vehicle characteristics.

Similarly, the user profile stores a number of personal attributes:

- Affective state: reported by the user, or sensed;
- Demographics: personal profile including age, education and occupation;

- Commuting satisfaction: subjective evaluation of journey conditions.
- Preferences: stated preferences in relation to journey characteristics and application behaviour.
- Commuting history: past journeys, used to assess the long term effect on satisfaction;

Maintaining these data supports the investigation of the relationship between user affective state and environment satisfaction, as well as its characteristics. As a result a number of attributes were implemented, together with the respective rules, detailed in Appendix B.

6.4. System Behaviour

While the main goal of the system is to monitor and influence QoE in UPT, the restrictions imposed to the instantiation of the platform led to a division into two stages: the first one aims at collecting data, to investigate of the relationship between passengers and the surrounding environment; and a second stage aiming at identifying the impact of such services on passengers through semi-structured interviews.

6.4.1. Monitoring QoE

In order to support the monitoring of QoE, as well as establishing the relationship with the service characteristics, a number of policies were implemented to process environment data, resulting in the context model and user profile. The event processing is logically divided in relation to the element of origin: *Cloudlet*- and *Bubble*-based events.

The *Bubble* events, in addition to generating profile information in relation to the user, are also the foundation to maintaining the hierarchical structure. For example, when a passenger boards the vehicle, the corresponding *Bubble* entity is transferred to the *Cloudlet* representation of the vehicle. This structure assists the platform in identifying and locating users that are affected by certain environment characteristics. In addition, this structure allows personal smartphones to be used and environment sensing devices. For example, the noise in a vehicle may be sensed via a personal

device. The aggregation of different data sources results in a robust context model, that may later be used to estimate QoE.

The authorisation policies, as described earlier, were not modified. However, individual users may define their own, more or less restrictive ones, if they so desire. For instance, users may define what sensors are active in the mobile device, and if the application is authorised to issue personalised notifications.

6.4.2. Influencing QoE

This stage is based on the findings obtained on the previous stage, as it relies on the identification of patterns of satisfaction and dissatisfaction with the UPT service. Ideally, both stages could be performed simultaneously, where the first would inform the second progressively. A basic personal profile could be set, to provide the platform with a starting point and improve from there. The identification of this basic profile is, however, part of this research. The added difficulty is the inability to process the data in real-time, as it was not possible to establish a partnership with the UPT providers.

Influencing the UPT experience, however, has a great potential to enhance QoE. Two examples, based on the estimation of QoE, are possible. The first responds to user requests and integrates the estimated QoE, such as list of journey alternatives, providing QoE in addition to duration and cost. The second example could go a step further and notify the user of the expected QoE proactively, integrated in their daily commute. In both cases, delivering a service of this type has the potential to adjust the expectation towards commuting that may lead the user to find a more suitable alternative or simply be prepared to face a sup-optimal experience.

6.5. User Interface

The interface with the user is built around three key moments of interaction: the first requires users to manually start the sensing process; the second stops sensing as soon as the journey is finished; and the third consists of a evaluation questionnaire to be filled shortly afterwards. The sensing samples the available sensors from the user device, allowing the system to

build an approximate model of the environment in-vehicle. Simultaneously, this process was simplified as much as possible to minimise its impact and maintain ecological validity, while involving and raising users' awareness.

6.5.1. Personal Mobile Device

The mobile device may be used to collect data, both from the environment and the user, as well as delivering information. In addition, it acts as a hub for devices to connect and send data (see Figure 6.3). For instance, wearable devices in Section 2.3.2 connect to the device, that will subsequently transfer data to the *Cloud2Bubble* platform.

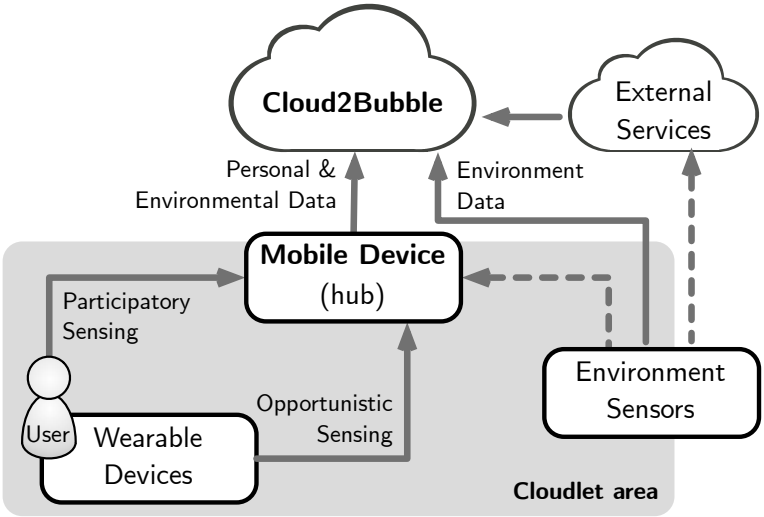


Figure 6.3.: Mobile device as a central hub [207]

A mobile application allows the platform to leverage the personal device, as it is often present in most daily activities throughout the day. Ideally, the implementation of such mobile application would benefit from the integration of different data sources, however some of them are not always available or have limitations in a naturalistic environment. For instance, the usage of location-based services to infer UPT usage requires local resources to be active leading to battery consumption and may even raise privacy-related concerns, while the communication network may not be available in the underground.

The prototype developed at this stage relies on a hybrid sensing approach, combining opportunistic and participatory methods to collect environment

and user data. Users are asked to actively input data at key moments of interaction in their daily travelling habits as a way of exploring their relationship with the environment and investigate the potential in the delivery of personalised services.

In addition, an explicit description was provided via the mobile application and a more detailed version available on the user manual in Appendix E. The description stated clearly what type of data was being collected, the intrinsic anonymity, data handling and usage. The disclosure of such details in the beginning, supported by the protection of personal privacy, established a mutually agreement between the parts, contributing for the unconcerned usage of the application.

6.5.2. Hybrid sensing

The application developed relies on hybrid sensing to collect user and environment data. While participatory sensing relies solely on users for input, opportunistic sensing focuses uniquely on the available sensors to collect data. A hybrid approach tends to combine the advantages of both sides resulting in higher quality sensed data with minimal user input [118].

Android-based smartphones are provided with a number of sensors, including location and motion-based ones. This sensors have been used in different contexts, from activity or affect recognition [117] to bus route validation [160]. In addition, using the device as a central hub allows the collection of other data sources, such as wearable devices and others sensors deployed in the environment, providing a scalable solution for enriching data collection.

The Android platform alone provides support for motion (accelerometer and gyroscope), environmental (thermometer, barometer and photometer) and position (location and compass). However, due to the heterogeneity of devices, the sensors available and their accuracy differ substantially from device to device. Nevertheless, all the available sensors are collected and transmitted to *Cloud2Bubble*. Personal wearable devices like the Q Sensor - a bracelet for collecting user affective data - are paired with the smartphone via a communication interface, e.g. Bluetooth, to aggregate additional data.

Collecting and transmitting data is a resource intensive process in terms of storage and communication. In order to improve the efficiency of the appli-

cation, some pre-processing was performed on the raw data. Acceleration, in particular, is a case where fine-grained sampling is required to model in-vehicle comfort, generating a large amount of raw data. In Table 6.1, the list of supported sensors is presented with the pre-processing methods. These sensors are sampled at approximately 5Hz, the same frequency used by the Android platform for monitoring screen orientation changes.

6.5.3. Experience Sampling

The usage of the application by travellers, on a first stage, is focused on exploring the relationship between users and the travelling environment as well as the feasibility of the platform in delivering enhanced experiences in intelligent ubiquitous environments. The Experience Sampling Method (ESM), from the field of psychology, is a research method to collect data from participants in-situ and with ecologically validity [37]. ESM facilitates the collection of both quantitative and qualitative data from a number of participants over time. Typically, users are asked to respond to short questionnaires about their thoughts and feelings while immersed in the activity, reducing the cognitive bias associated with recall-based techniques, e.g. interviews and surveys.

Traditionally, users are prompted to fill a questionnaire during a day in relation to the theme being studied. The ubiquity of personal devices has enabled the usage of this technique at a mass scale. The Mappiness application, as an example, is publicly available for the iPhone and prompts users at random times during the day to report their feelings and surroundings based on the ESM [128]. This particular application has collected data from over 55.000 people in the UK, and displays live affective information on the Mapiness website[1], including a map and hedonimeters [35].

A particularly interesting implementation of this method is focused on studying mobile privacy [133]. In this case, the participants are prompted to fill the questionnaire shortly after performing an action. Part of the questionnaire is an area where the participants are asked to write a memory phrase: a word or sentence about that specific moment in time. Based on this input, the participants are able to recall the situation and discuss it during the contextual interviews.

[1]Mappiness mappiness.org.uk

The ESM complimented with contextual interviews is a powerful method to obtain ecologically valid data in-situ, supported by a memory phrase that allows for memory priming and explore aspects of the experience in detail. In the context of UPT, we are interested in obtaining data about a single journey. The collected data - both quantitative and qualitative - facilitates environment and user modelling, as well as exploring the potential of empathic services. The mobile application samples a number of sensors during the journey, prompting the user to fill in the questionnaire in Table 6.2 shortly afterwards. Furthermore, the open feedback field constitutes the memory phrase, that is used during contextual interviews to explore the travelling conditions and potential services.

6.6. Implementation & Testing

In addition to the configuration of *Cloud2Bubble* behaviour, to reflect the logical structure of the components as well as environment and user data, a mobile application was developed to act as a sensing device and interface with the user. The development of an application to be used in a naturalistic environment, however, raised some challenges in integrating the device with the platform, requiring the implementation of a set of additional modules.

6.6.1. Cloud-based infrastructure

The architecture described in Section 5.5 relies on the integration of the different hardware components in a unified platform, at the expense of individual device aggregation. Such an integrated approach, however, requires access to advanced features that could be used for malicious purposes in the real world. For example, Ponder2 requires an Android permission used for local network broadcast. This is however an uncommon request, that would certainly raise concerns amongst the users. In addition, the current implementation of Ponder2 on the mobile device is not optimised for efficient energy consumption, that would significantly impact users' device usage. In order to prevent the concerns involved in releasing such software publicly, a middle layer was implemented to mediate the communication between the central node and the mobile devices. While the ability to connect a device directly to *Cloud2Bubble* was maintained, an alternative module was imple-

mented with the goal of addressing the concerns previously identified. The module provides a set of web services, based on the representational state transfer (REST) protocol. A REST-based web-service, or RESTful, is designed to transfer representations of resources, and relies on a client-server architecture. The communication is typically initiated by the client with a request, that is then processed by the server and an appropriate response returned. The web-service provides communication with the core modules of the platform via a standardised web service channel (see Figure 6.4). This module is based on the Google App Engine (GAE), a PaaS platform that provides automatic resource management for web applications. GAE was chosen due to the implementation flexibility and integration with Android. The implemented web services allow external clients to dispatch any collected data to *Cloud2Bubble* transparently, that is either stored for further analysis or transformed into meaningful events, according to the specific needs.

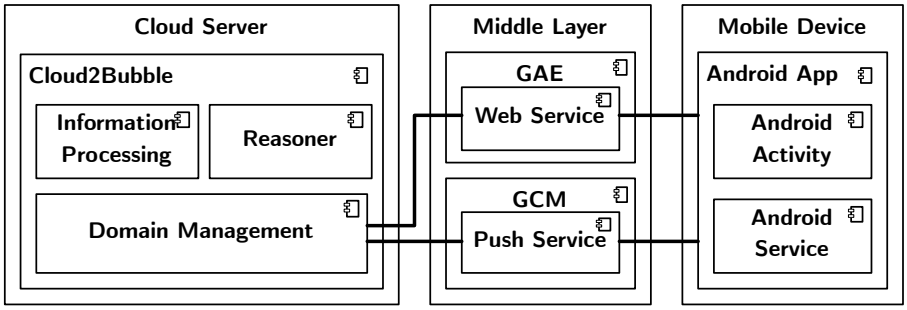


Figure 6.4.: Cloud2Bubble, Web Services integration

Two main sets of data are generated on the mobile device side and transferred using web services: sensed data and user feedback. These data are transformed into representations of the in-vehicle environment and user profile that are then processed by the platform. The delivery of services, on the other hand, relies on a different method of communication, initiated by the platform. The Google Cloud Messaging (GCM) service allows servers to send push messages and data directly to the device, handling all aspects of the communication automatically. The usage of these two modules, GAE and GCM, to support the communication between mobile devices and *Cloud2Bubble*, facilitates significantly the usage of passengers' personal smartphones to conduct research.

6.6.2. Mobile Application

The mobile application, developed for the Android platform, implements the user interface and the integration with the *Cloud2Bubble* platform. The user interface integrates features of the application with key moments of the travelling experience, using the opportunity to perform environment sensing and requesting user feedback. The state diagram in Figure 6.5 shows the flow between user and mobile application, and how it is supported by the *Cloud2Bubble* platform.

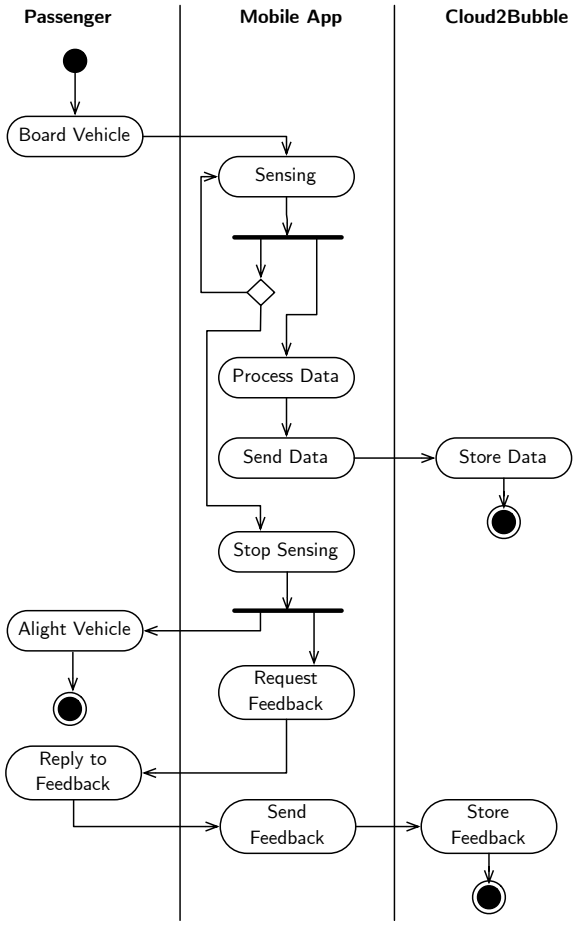


Figure 6.5.: Journey, state diagram

The Android architecture provides developers with two different components: Android Activities for implementing graphical interfaces; and Android Services for performing background computational work. This distinction allows applications to execute services in the background, releasing

enough resources for the device to be used in other tasks.

Background Service

The background service supports the continuous device sensor sampling, data pre-processing and transfer to the platform via the available web service. In addition, the system is able to store the data and transmit it at a later stage, in case communication networks are not available, e.g. when in a tunnel or underground. Table 6.1 lists the sensors sampled, as well as the method for pre-processing.

Table 6.1.: Sensor collection details

Sensor	**Pre-Processing**
Microphone	sound amplitude [13]
Accelerometer	comfort level [126]
Location	no processing
Temperature	interval average
Pressure	interval average
Relative Humidity	interval average
Luminosity	interval average
Proximity	no processing

Sensors are typically sampled at a rate of 5Hz - the same rate used for monitoring screen orientation changes - resulting in a large amount of sensed data. In order to optimise data storage and transmission, the mobile device processes the raw data in intervals of 2 seconds. While sensors values such as temperature and location may be simply averaged or sampled at a slower rate, sound and acceleration require a different processing method.

The acceleration obtained from the accelerometer sensor was converted to a comfort level, according to the ISO 2631 standard [126]. The calculation of the comfort level is based on a logarithmic scale that uses vehicle vibration and is divided into six levels, ranging from comfortable, with vibration levels under 83dB, to uncomfortable, with vibration levels over 103dB. Then, the comfort level is transmitted to the *Cloud2Bubble* platform and processed accordingly. Similarly, the sound level is calculated using the sampled sound amplitude through the device microphone.

The sensed data is stored progressively during the journey and transformed into a JSON document. JSON refers to the text-based data for-

mat, derived from the JavaScript language. These documents, based on the JSON schemas in Appendix Section B.6, are then sent via the RESTful web service, and contain the following elements:

- Bubble identification;
- Sampled environment;
- Journey details:
  - Vehicle type and Route;
  - Start and Stop locations;
  - Date, Time and Duration;

The feedback data, obtained from the passenger after the journey, is based on a similar method, containing the *Bubble* identification, affective state, satisfaction evaluation and the open text entry. All transactions were logged for facilitating data analysis. Algorithm 6.1 illustrates how the object types received by the web service are then converted to different event types, resulting in the required domain structure on *Cloud2Bubble*.

```
switch read JSON Document do
    case User
        // Create a new Bubble based on user object type
        Generate Bubble Create event;
    case Journey
        // Cloudlet based on a single journey
        Generate Cloudlet Create event;
    case Feedback
        // Update user profile with reported feedback
        Generate Bubble Update event;
    case Sensed
        foreach Sensing do
            // Update context model with sensed data
            Generate Cloudlet Update event;
        end

endsw
```

Algorithm 6.1: Web service to events conversion

Interface Activity

Table 6.2.: Questionnaire Items

Attribute	Term	Definition
Personal		
Valence	Happy	Cognitive valence of affective state
Arousal	Relaxed	Physical arousal of affective state
Environment		
Sound	Noise	Sound level in-vehicle
Saturation	Crowding	Experienced crowding in-vehicle
Smoothness	Smooth	Driving quality of the service
Ambience	Ambience	Overall feeling including cleanliness, vehicle condition and other passengers
Service		
Speed	Speed	Time spent travelling
Reliability	Reliable	Performance in relation to planned service
Feedback	Feedback	Open text entry for user feedback

The main interface, in Figure 6.6, allows passengers to input data about the journey, as described in the previous Section, and actively participate in the process. The main features include start and stop journey sensing, editing preferences and their personal profile as well as provide journey feedback.

The elements included in the questionnaire, in Table 6.2, cover the main aspects of travelling, and range between low and high satisfaction. In addition, an open text entry is available, where users are encouraged to include episodes that particularly impacted their experience - both positive and negative ones. The open feedback enriches the collected data from users and provides a memory phrase to be used later on during the contextual interviews, to prime the participants' memory.

6.6.3. Usability Testing

Before proceeding to the field with the mobile application, a session of usability testing was conducted to assess the usability of the application and the comprehensibility of the questions about the environment. For this purpose a functional prototype was designed and implemented. This session resulted in a number of changes, that were implemented in the final version.

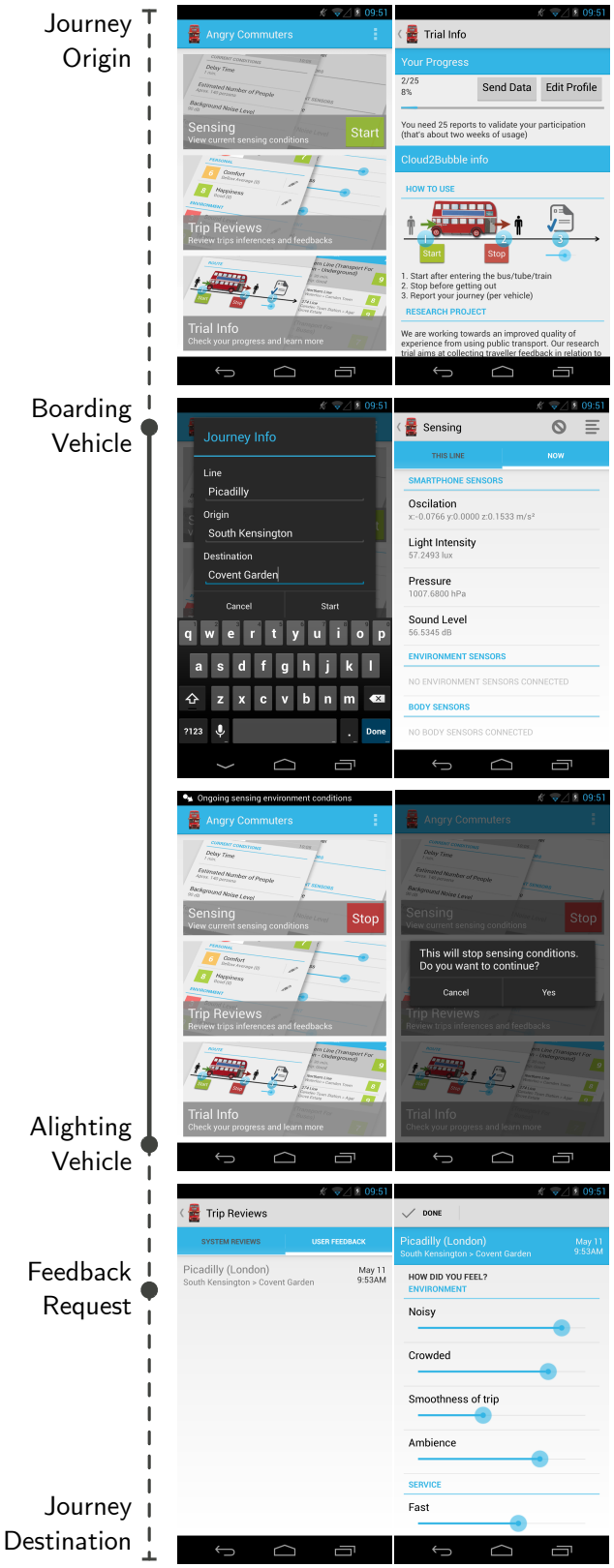


Figure 6.6.: Angry Commuters mobile application flow

The lab-based usability testing was conducted in April of 2012 at Imperial College London and the selected participants were recruited via personal invitation. They were asked to fill in pre- and post-test questionnaires covering demographics and profile, e.g. public transport and smartphone usage as well as thoughts and opinions about the application (Appendix C). During the test, they were given a set of tasks to complete related with the main use cases and encouraged to think aloud while doing so. The descriptive statistics of the participants can be found in Table 6.3.

Table 6.3.: Descriptive statistics of usability testing participants

	(N = 6) n
Current Occupation	
Researcher	4
Professional	2
English Speaker	
Native	2
Foreign	4
Gender	5 male / 1 female
Age	M = 26.8 (4.99)

The session was composed of three different scenarios covering a wide range of features, including the main sensing and feedback form (Appendix D):

- Scenario 1: sensing a journey, including a wearable device and checking information about the current vehicle;
- Scenario 2: plan a journey assuming a personal profile, and correcting the inferred comfort measure;
- Scenario 3: receiving a notification about an unexpected event with a suggestion.

The tests were performed using a non-functional prototype, where all interactions were simulated, through with a pixel-perfect user interface. These were designed to take the user through the range of features expected from a mobile application of this type. However, only a sub-set of those features was implemented on a first stage, for collecting data for analysis in our study.

Results

Overall, all users performed well and were able to complete the three tasks, showing no major issues with either the interface or the concepts associated with the overall experience. The users reported the interface to be intuitive, able to convey information well and, conceptually seemed to integrate well in a UPT environment. This integration, however, requires a pilot study in a real environment, with the goal of assessing it in a naturalistic environment. Furthermore, due to the limitations with the final application, a pilot study allows us to assess the performance of the overall system prior to a full scale field study.

The users identified a group of issues with the interface developed, that were addressed during the implementation of the final version. The most important changes were related to the layout used to indicate the progress of journey sampling, as well as input of route information. Some of other the suggestions include wording throughout the application, e.g. *"Trip History" vs. "Journey Reviews"*, and facilitate data input, e.g. autocomplete and memorisation, due to the restrictions associated with device limitations and the chosen environment.

In addition to testing the graphical user interface and its relation to the commuting experience, the terms used in the feedback form were also validated. In order to facilitate interaction and readability, a more colloquial tone was used. Thus, the users were asked to define each of the terms in their own words. Both native- and foreign-speakers were able to correctly describe the different aspects of affective state, environment and service characteristics, validating the one-word terms used for self-report satisfaction.

6.7. Deployment

The last step of the instantiation of the platform consists of the deployment of the application in a naturalistic environment. The main goal, at this stage, is to assess the impact of the system in the domain of UPT - i.e. how it affected the overall environment - and its effect on QoE - i.e. how are users reacting to the usage of the platform. The mobile application was made publicly available, including a clear description of its purpose and data

handling policies. The web-service and messaging services were deployed on third party infrastructures, and the main *Cloud2Bubble* node was deployed on a local machine.

6.8. Summary

This Chapter presented the instantiation of the *Cloud2Bubble* platform in the specific domain of UPT. Having specified and modelled the domain, including the target experience and the different entities, the instantiation focused on defining the behaviour of the system aiming at exploring QoE in-situ. Due to restrictions imposed by the environment intrinsic to the distribution of the mobile application to the public, a set of changes and auxiliary software packages were implemented. In addition, the direct QoE influencing was left to a second stage of instantiation, to be executed with a more extensive support from UPT providers. The user interface was tested in a controlled environment with a set of users to ensure its live performance. Finally, the solution was deployed and ready to be used. The next Chapter presents the evaluation of the system.

7 System Evaluation

7.1. Introduction

The evaluation of *Cloud2Bubble* is divided into a general trial, with the goal of comprehensively test the platform in a controlled environment; and field studies in the domain of UPT, to explore different aspects of the system. After the first trial, the system was evaluated over the course of two studies. The first pilot study was conducted in the city of Porto (Portugal) and aimed at obtaining early user and environment data and assess the feasibility of the overall design. Following the pilot study, a field study was conducted in London (UK) at a larger scale and for a prolonged period of time to explore the relationship between user and the travelling experience. The results obtained are analysed and discussed, resulting in relevant findings in the context of UPT in particular. Finally, a set of design principles is identified, contributing for the development of intelligent ubiquitous environments in general.

7.2. Cloud2Bubble Evaluation

In Chapter 5, the implementation of the *Cloud2Bubble* platform was described. In order to evaluate it, an experiment was conducted in a lab setting to ensure all the components and features perform as expected. In addition, this experiment aims at exploring, in a controlled environment, how QoE is affected by the surrounding conditions and the ability of the system to anticipate this change. Thus, in order to explore the effect of

different environment conditions on users' emotional responses, the levels of noise and luminosity were manipulated while the participants performed a cognitive task. We thus hypothesise the main outcomes of this experiment in relation to the effect on overall QoE to be as follows:

- H1: Higher levels of noise have a detrimental impact on on QoE;
- H2: Lower levels of lighting have a detrimental impact on QoE.

Due to the nature of the test, described in the following Sub-Section, we do not expect the performance to be related to either the environment conditions or participants' QoE (H3). In addition to this, the *Cloud2Bubble* platform was configured to estimate an expected QoE based on environment conditions and affective state. We expect this basic configuration to predict this change in QoE (H4).

7.2.1. Methods

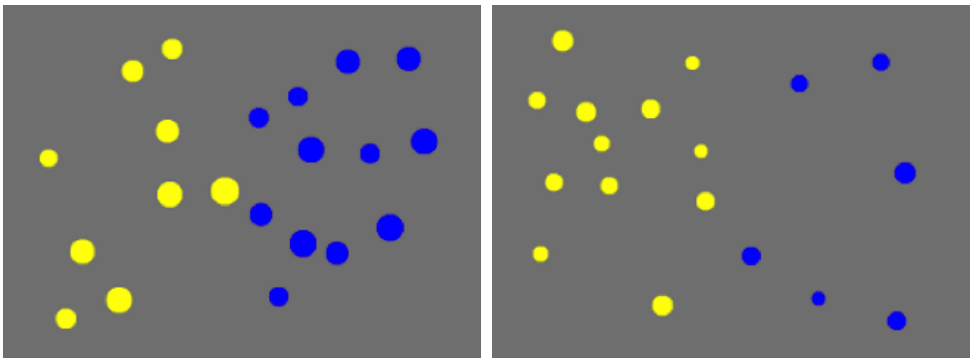
Platform Configuration

The system was setup with a basic configuration, for estimating QoE based on users' self-reported affective state and sensed environment conditions. Thus, a number of fuzzy sets and rules were implemented, in Appendix A. All data interactions and estimations were recorded, though no action was taken since our objective was to investigate the ability of the application to collect and process data. These data were later analysed and assessed.

The *Cloud2Bubble* platform was distributed between a computer, running the cloud-based version of the platform, and a mobile device to sense the environment. The environment conditions, e.g. noise and luminosity, were then manipulated, while the mobile device measured these changes. The environment was modelled as a single *cloudlet* for the room, containing the environment conditions, and a *bubble* for the participant with its personal reported data. User profiling was based on the assumption that all users respond to similar environment conditions, thus no individualised profiles were developed at this stage.

Cognitive Test

The experiment carried out engaged participants in a test for assessing their approximate number system, a cognitive system that supports the estimation of the magnitude of a group without relying on language or symbols [92]. The application chosen to perform this test, Panamath (freely available on the authors website[1]) was configured to run for three minutes, excluding reaction time, with the predefined configuration. Two groups of circles, yellow and blue, were shown on screen for a short period of time, and participants were then asked to estimate the larger group (see Figure 7.1).



(a) 9 yellow vs. 12 blue (b) 12 yellow vs. 6 blue

Figure 7.1.: Panamath screenshots, used for assessing the cognitive approximate number system

The participants were also asked to self-report their QoE as well as affective state before and after each test.

7.2.2. Participants

The participants were 24 graduate students and postdocs from Imperial College London. The participants, known to the researcher conducting the experiment, were invited to participate. However, during the execution of the experiment, and due to limitations related to the location chosen, external factors interfered in the tests, e.g. external noise.

As a result, 3 of the 24 participants were discarded. In total, 21 participants were retained, with ages between 21 and 38 years old ($M = 28.9$, $SD = 4.9$), of which 33% are female.

[1]Panamath: panamath.org

7.2.3. Design and Procedure

Upon arriving, participants were invited to sit in a quiet in front of a computer. They were provided with an information sheet, describing the experiment and main terms, in Appendix A, and were asked to sign a consent form prior to starting the session. In addition, a short trial of 1 minute was provided, to help them familiarise with the objective and procedure of the cognitive test.

The tests were repeated, in random order, for the different combinations of environment conditions: quiet and light (QL), noisy and light (NL), quiet and dark (QD), noisy and dark (ND). For each of them, the participants self-reported their QoE and affective state both before and after taking the test.

The sessions lasted between 20 and 30 minutes, with 3 to 5 minutes per test. This resulted in 168 valid observations, complete with test performance, noise level and luminosity, as well as pre- and post-test QoE, arousal and valence.

Independent Variables

Two environment characteristics were manipulated, resulting in four different conditions:

- Quiet and Light (QL): The room was well lit and set with a low level of noise. This is the control condition, as it exposes the participants to reasonable conditions in a work environment: the measured level of noise was around 35 dB and the lighting around 500 lux, generated by a fluorescent lamp. The room is in fact used for meetings and student tutorials;

- Noisy and Light (NL): In this condition the level of noise was raised from 35 dB to around 65 dB, based on a cafe ambient sound[2];

- Quiet and Dark (QD): In this condition the lights were turned off, reducing the lighting to around 10 lux, providing a dark ambience to the room;

[2]Rainy Cafe: rainycafe.com

- Noisy and Dark (ND): Finally, this condition is a combination of the two previous ones, with a noisy background and dark ambience.

These manipulations, and the derived hypothesis, are based on the recommendations by Health and Safety Executive[3], a national independent institution for work-related health, safety and illness.

Dependent Variables

The dependent variables used for investigating the effect of environment conditions on the participants are:

- QoE: A self-evaluation representing participant satisfaction in relation to their overall experience in session, measured on a continuous scale between 0 and 10;
- Test-performance: The test result provided by Panamath, based on the Webber fraction, a ratio defining the accuracy in differentiating small and large sets.

In addition, the affective state was also self-reported, based on Russell's dimensions: physical arousal and cognitive valence, both of which measured on a continuous scale between 0 and 10. The affective state was used for estimating QoE, in combination with the values of noise and luminosity.

7.2.4. Results

The analysis of the collected data used for investigating the effects of environment conditions on QoE and test performance as well as the system's ability to predict QoE.

Environment Conditions Effect

In order to explore the effect of the environment conditions, in Table 7.1, a two-way factorial analysis of variance (ANOVA) was conducted for each of the tests in the four existing conditions (QL, NL, QD, ND), focusing on the change in QoE before and after each test. The results show a significant difference between them ($F(2.18) = 4.37$, $p < 0.01$), supporting the

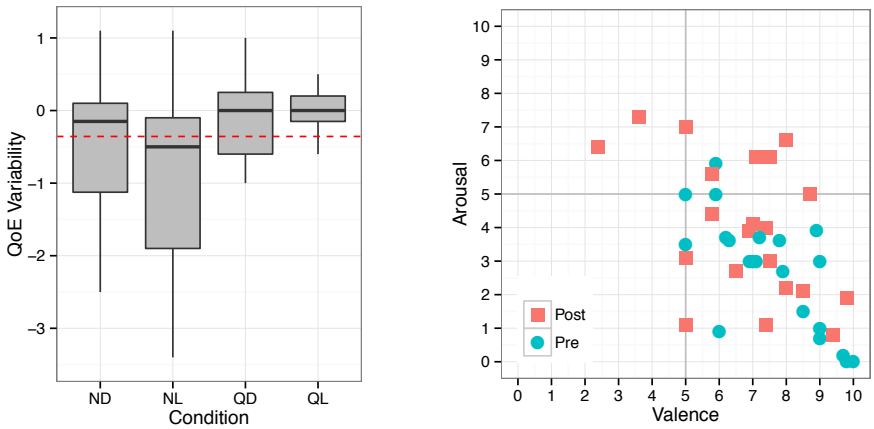
[3]HSE: hse.gov.uk

Table 7.1.: Results from environment effects on QoE

Condition		Mean	SD
Quiet Light (QL)	Pre	7.35	1.67
	Post	7.40	1.56
Noisy Light (NL)	Pre	7.02	1.97
	Post	6.20	2.17
Quiet Dark (QD)	Pre	7.30	1.82
	Post	7.31	1.58
Noisy Dark (ND)	Pre	7.00	1.76
	Post	6.32	2.10

thesis that environment conditions have an impact on QoE, represented in Figure 7.2a.

Planned Dunnett's comparisons were performed, comparing the control condition (QL) to the others (NL, QD, ND). The difference between QL and NL confirms the detrimental effect of noise on QoE ($z = -2.8$, $p < 0.05$). This effect is also noticeable in Figure 7.2b, with affective states before the test closer to high valence and low arousal – typically associated with relaxation and happiness – while after the test there seems to be a slight shift towards low valence and high arousal.



(a) Variability of QoE per Condition (b) Affective States in NL condition

Figure 7.2.: Variability of QoE and Affective States

However, the difference between QL and QD was non-significant, suggesting that luminosity did not affect the participants. In fact, some of the users

voiced their opinion in relation to the unsuitability of the installed fluorescent lamp, for being too strong in their opinion, or their personal preference towards darker environments. Finally, the difference between QL and NL was marginally significant ($z = -2.34$, $p = 0.05$), confirming the detrimental effect of noise but not luminosity. In conclusion, the results support H1: higher levels of noise have a detrimental effect impact on QoE, but do not support H2: lower levels of lighting have a detrimental effect on QoE.

Cognitive Test Performance

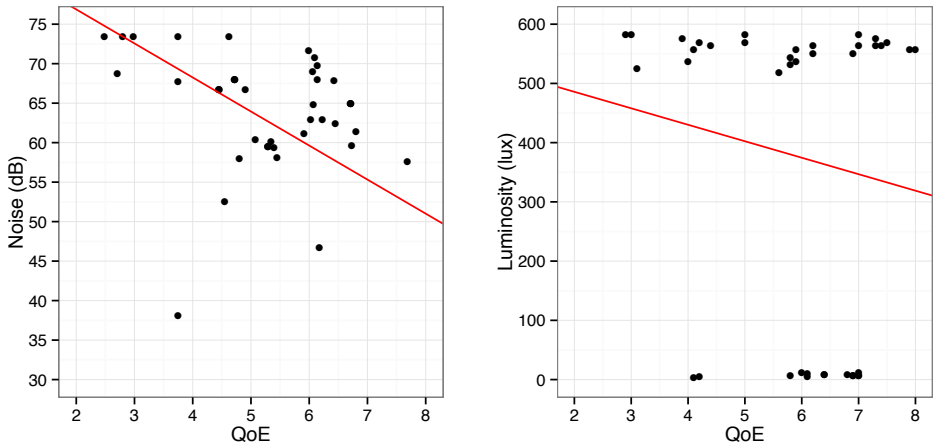
Participant performance was investigated in relation to condition and QoE. Firstly an ANOVA was performed for test performance, similar to the previous one. The results confirmed that test performance was unrelated to condition, with non significant results. In addition, a correlation was performed between test performance and QoE, which showed a week coefficient with non significant results. The independence between test performance, room condition and participant QoE supports H3: the execution of the test is independent of its outcome.

QoE estimation

Our final analysis aims at investigating the ability of the system to predict changes in QoE. The system relies on the sensed values of noise and luminosity, combined with reported affective state, to generate an estimation of QoE. Figure 7.3 shows the corelation between the two environment conditions and the resulting QoE: noise presents a moderate, significant correlation while luminosity is non significant, as expected from our previous analysis.

The variability of self-reported and system-estimated QoE was thus analysed and labeled as *positive*, *negative*, according to the direction in which it changed. These were then compared, counting valid estimations when the values coincided, and invalid otherwise. This method relies on the assumption that recommendations may be produced based on comparison of QoE rather than its absolute value. The system was able this change for 79.8% of the observations, supporting H4: the basic configuration of the system is able to predict change in QoE.

In order to assess the quality of our predictions the mean square error



(a) $r = -0.69$, $p < 0.001$ (b) $r = -0.18$, $p = 0.09$

Figure 7.3.: Noise (left) and Luminosity (right) correlation coefficients

(MSE) method was used. This method calculates a coefficient based on the error between observed and estimated values. The resulting MSE coefficient is 5.68 out of 10 – the scale used for QoE. This value indicates that, even though the system is able to predict direction, the quality of prediction is not very accurate and it may be further improved. Firstly, due to differences between participants, individual profiles as supported by *Cloud2Bubble* support more accurate predictions, e.g. the sensitivity towards environment conditions. Secondly, the assumption of a lower QoE due to lighting conditions was not valid and resulted in a number of erroneous estimations.

Final Considerations

The results obtained support 3 of the 4 hypothesis initially formulated: H1 confirmed the impact that environment conditions may exert on users' QoE, namely noise; H3 validated the detachment between environment conditions, QoE and test performance; and H4 shows the ability of the system to correctly estimate QoE change, though with low quality. However, H2 was not supported by the analysis performed, which is likely due to a combination of inappropriate environment setting and personal preference. While the former hints at an improvement to the current workplace conditions, the latter shows that differences between users' is present and the flexible

approach of *Cloud2Bubble* is able to accommodate individual user profiles.

In addition, the conduction of this experiment allowed us to comprehensively test the developed platform and its different components. Both server and mobile based modules performed as expected in data collection, from both user and environment, as well as QoE prediction with a reasonable degree of correct values. This result allows us to confidently progress to the next stage and exploit the platform in the field studies.

7.3. UPT Studies

Two evaluation studies were conducted in the cities of Porto (Portugal) and London (UK) with the goal of exploring the user experience in a UPT environment.These studies were conducted with the goal of investigating the performance of the platform in a real-world environment, in addition to exploring the impact of different environment conditions on individualised QoE.

7.3.1. Methods

The conduction of the field studies is based on the platform instantiation described in Chapter 6. The combination of the cloud-based component of *Cloud2Bubble* and the developed mobile application, enable us to collect self-reported and sensed data from a naturalistic environment. Two studies were conducted: a pilot study in Porto (Portugal) and a field study in London (UK). While both follow the same structure and procedure, the pilot study aims at validating the experiment design and the performance of the developed platform for the purposes of the evaluation. Following, the field study implements some of the early findings and conducts the experiment on a larger scale.

7.3.2. Study Design

The study design is divided into two main components: data collection and contextual interviews. Data collection comprises both quantitative and qualitative data. On the first stage, the participants used the application to report their individual journeys for a period of time, including affective states, satisfaction with UPT and an open area for describing occurrences.

In addition, the mobile application sensed the journey, and using the participatory sensing, collected a number of journey characteristics. The second stage included semi-structured interviews with a selection of participants, that focused on different aspects of the overall experience as well as specific journeys. This experiment is based on a between-subject design with repeated observations, followed by a debrief session with some participants. The format of the study includes quantitative and qualitative research.

The quantitative data, collected through the developed mobile application, includes opportunistic and participatory sensed data: the device sensors were used to collect environment data (e.g. noise and acceleration) and the participants asked to provide further detail (e.g. route and mode). In addition, the participants provided their satisfaction via a feedback form, augmented by an open text area for further considerations.

The analysis is divided into the investigation of self-reported data and its relationship with sensed data. Firstly, the levels of satisfaction and affective states are analysed to explore the relationship between the two, and investigate how the environment conditions impact the participants' affective responses. Secondly, these will be analysed with the sensed data, in order to investigate how the actual environment conditions have an impact on different travellers.

The qualitative data is based on semi-structured interviews conducted after the data collection period, that allows for a flexible exploration of themes rather than a rigorous set of questions. The interview explored the interaction with the application, the experience in public transport, personal data collection and finally some individual journeys. The protocol is available in Appendix B.1.

Independent Variables

The journey conditions constitute the independent variables:

- Sensed, using participatory sensing:
  - Start and Stop stations: manually added;
  - Mode of transport: manually added;
  - Time and Duration: calculated between Start and Stop moments;
  - Location: coordinates sensed using the location sensor;

  - Noise level: sound level sensed using the microphone;
  - Luminosity: luminosity level sensed using the device's lux sensor;
  - Vibration: acceleration sensed using the device's accelerometer;
  - Temperature: temperature sensed using the device's thermometer.

- Self-Reported on a continuous scale between 0 and 10, as defined previously:
  - Ambience;
  - Saturation;
  - Noise;
  - Vibration;
  - Speed;
  - Reliability.

Dependent Variables

The affective state, divided into arousal and valence as defined in Section 2.2.1, composes the dependent variable in this study for the quantitative analysis. Both dimensions are measured on a continuous scale between 0 and 10: arousal is presented as relaxation ranging between stressed and relaxed; and valence presented as happiness ranging between unhappy and happy.

7.3.3. Pilot Study: Porto (Portugal)

The first evaluation study was conducted in Porto (Portugal) over a period of two weeks during June 2012. The main goal of this pilot study was to evaluate the feasibility and performance of the system in a naturalistic environment, as well as to gain a deeper understanding of the relationship between travellers and their environment while in transit. The results were then used for improving the experiment design that was conducted on a larger scale.

Setting

Figure 7.4.: Metro do Porto[4]

The urban area of Porto (Portugal) includes approximately 1.3 million people in an area of 389km^2. Porto is served by an extensive UPT network, composed of mainly bus and metro services (see Figure 7.4), provided by STCP and Metro do Porto entities respectively. The unification of services converged in a single smart card - *andante* - allowing users to travel using different services and modes for completing their journeys. In addition, other UPT providers operate other local services in the outskirts of the city, or between cities and towns.

Porto is also one of the cities involved in the *civitias* initiative and has been a case study for a number of innovations in urban mobility. The *move-me* service [156], as an example, aggregates transportation data from different sources to offer a unified information service to passengers as a result of the efforts and innovations implemented.

Participants

The recruitment of subjects for the pilot study was based on a questionnaire composed of three main sections: travelling habits, smartphone usage and improvements suggestions for public transportation. The questionnaire was distributed via mailing lists and social networking platforms, resulting in a total of 172 respondents, with a wide range of characteristics and backgrounds.

The suggestions provided by the respondents demonstrate an interest in the improvement of some of the travelling characteristics. In addition to cost and duration-related attributes, a considerable amount of suggestions were based on other aspects of the service, such as dynamic and personal information services as well as subject qualities of experience like comfort and entertainment.

The most active respondents in the questionnaire, and who contributed

[4]By diogoperez74 (photo taken by diogoperez74) CC-BY-SA-3.0, via Flickr

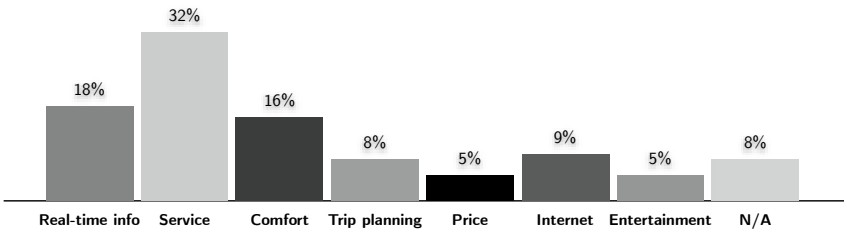


Figure 7.5.: Improvement suggestions by category

the most for the suggestions in Figure 7.5 were pre-selected for our study. In addition, the selection was focused on the following criteria: commuter in the area of Porto and user of android-based mobile phones. As a result, a total of 10 subjects, represented in Table 7.2, were invited to participate in the pilot study and offered a retail voucher for their contribution.

Table 7.2.: Descriptive statistics of pilot study subjects

Attribute	**(N = 10) %**
Completed Education	
High-School	30%
Bachelor degree	30%
Masters degree	40%
Current Occupation	
Student	80%
Professional	20%
Travelling Mode	
Bus	60%
Metro	80%
Gender	60% male / 40% female
Age	M = 24.1 (4.43)

Procedure

The study was divided into two main stages: a period of data collection and a debriefing session. After confirmation of their availability, they were asked to install the mobile application on their personal mobile devices and instructed to report all the journeys in public transport. In addition to the application, a user manual was made available with detailed instructions on

how to use the application and how to report a journey in Appendix E. The process, described in detail in Section 6.5, integrates with three moments of interaction: when the journey starts, when it finishes and shortly after for some feedback. The study resulted in 110 valid journeys, providing over 26 hours of in-trip data and subjective feedback about the travelling environment.

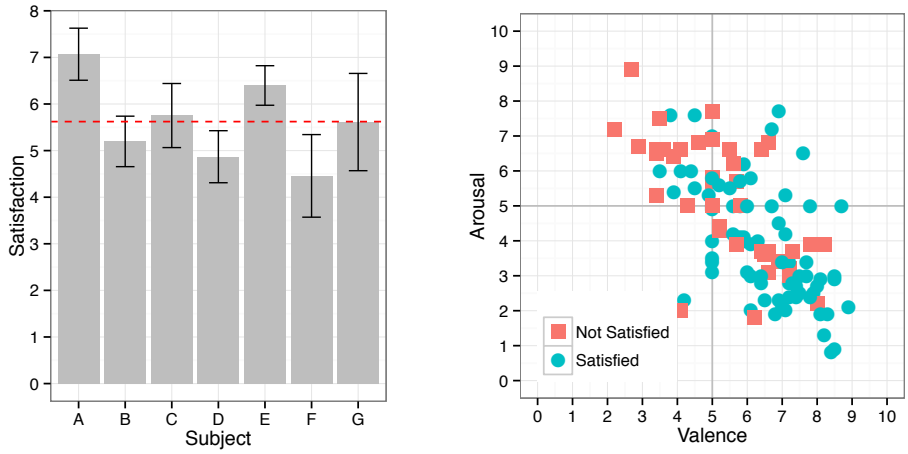
This period of data collection was followed shortly after by a debrief session, consisting of individual interviews. The interviews were aimed at exploring the ecological validity of the application itself, as well as its effects on behaviour towards travelling and other potential services. In addition some of the individual journeys were discussed during the interviews based on the feedback provided and its effects on the travelling experience.

Results

The outcomes of this pilot study may be divided into technical enhancements, data requirements and early contextual mood findings. A set of technical enhancements were identified, some of them in the early stages of the experiment. Even though the application was tested with different versions of the Android platform, the existing fragmentation in software versions and hardware models revealed faults in the application, that were corrected during the experiment. For the same reason, the sensors available vary considerable between devices and collecting data for an extended period of time resulted in a high consumption of battery, as well as incompatibility with other applications or usage. As a result, some of the users restrained themselves from using the application, in particular when the battery was at a low level. The collection of sensor data was thus revised and limited to the most common ones: microphone and accelerometer. Location-based sensors were also deactivated and the route details were provided by users.

The data collected, while insufficient at this stage to perform a robust statistical analysis, provides some insights in preparation for the conduction of the study at a larger scale.

Figure 7.6a shows individual satisfaction, that is aggregated in Figure 7.6b. Overall, there seems to be an association between satisfied states with the lower right quadrant (high valence, low arousal), as well as dissatisfied states with the upper right quadrant (low valence, high arousal). This trend be-



(a) Individual Satisfaction

(b) Affective State and Satisfaction

Figure 7.6.: Aggregated Affective States and individual Satisfaction

tween two quadrants suggests that QoE may be described as an association between them, as overall affect.

Measures and descriptive results are shown in Table 7.3. Firstly, it suggests a correlation between the measured satisfaction environment characteristics (see Figure 7.6). Moreover, certain aspects of the travelling environment seem to impact a dimension of affect more than the other, e.g. reliability tends to impact arousal, while crowding has a stronger effect on valence. This separation indicates two main group of recommendations: for UPT providers, guidelines for managing their efforts on providing a positive impact; and for travellers, tailored recommendations with the potential to enhance their travelling experience. In addition to a set of satisfaction factors that are common to most of the participants, individual preferences are also perceivable. This suggests that personal recommendations would be even more beneficial if based on individualised profiles, rather than a single common one for a group of users.

Finally, the interviews with the users revealed that the application was well integrated with the travelling experience and therefore is an ecologically valid solution. The introduction of automated methods for activating and deactivating journey sensing were suggested by, for example, detecting the usage of the personal travel card. However, the manual operation resulted in users being more aware of their commute and therefore make them reflect on

Table 7.3.: Measures and descriptive results

Measure	**M (SD)**	**Aggregated**	
Valence	5.92 (1.59)	Affect	
Arousal	4.49 (1.74)	5.85 (1.51)	
Noise	5.41 (1.88)		
Saturation	5.00 (1.99)	Setting	
Smoothness	5.14 (1.66)	4.93 (1.28)	Global
Ambience	4.98 (1.57)		5.22 (1.21)
Speed	5.62 (1.76)	Service	
Reliability	5.69 (2.02)	5.80 (1.61)	

their travelling, as expected. The explicit data handling agreement provided at the beginning of the study resulted in an unconcerned adoption, even with the collection of sensitive data such as location and microphone. Users reported that they trusted the conduction of the experiment, in addition to being performed by well-known academic entities.

The pilot study was an important step in the conduction of our studies with users in a naturalistic environment. This allowed us to validate our solution and improve some aspects. From a technical perspective, some of the challenges were addressed, namely the reduction of energy-demanding sensors usage and the improvement of data collection interaction, e.g. replacing location-based sensors with user-based input. The early findings seem to point towards a relationship between affective state and satisfaction, pertinent to our analysis, between arousal and valence values, corresponding roughly to satisfaction and frustration.

7.3.4. Field Study: London (UK)

The second evaluation study was conducted in London (UK) in the last quarter of 2012. Based on the findings obtained in the pilot study, a number of changes were implemented to improve the application performance and study outcomes. This second study is focused on exploring the relationship between commuters and the travelling environment as well as the interest in personalised information services in this domain. In spite of the limitations uncovered during the pilot study, include the usage of mobile device sensors, the design follows a similar approach to the one used previoulsy.

Setting

Figure 7.7.: London iconic buses[5]

The urban area of London (UK) is composed of approximately 8 million inhabitants and is served by one of the largest and oldest UPT networks in the world, including bus, metro, tram, boat and other services. Transport for London (TfL) is responsible for most aspects of the transport system and unifies the different UPT providers under a single entity, facilitating the access through a single smart card - the *oyster* card.

TfL provides over 25 million journeys per day [200] and has introduced a number of initiatives in recent years to improve information services. This initiatives include live updates and free access to different data sources, empowering end users to analyse, process and utilise the data in innovative ways. Popular uses include location-based mobile applications displaying live departure bus and metro times and augmented reality applications showing the location of nearby stations.

Participants

The mobile application was made publicly available on the official Android distribution channel (Google Play Store) and the description included the purpose of the application, main goals and a link to a website [41], where more detailed information was available. The mobile application was advertised via mailing lists, social networking platforms and other media websites. In addition, some mass circulation publications demonstrated interest in featuring the application, resulting in a higher number of downloads. The users were offered a detailed travelling report upon completion of a predefined number of valid reported journeys, lasting for approximately two to three weeks.

The mobile application was downloaded to 200 mobile devices during the period of the experiment. However, most of the downloads did not result in active participants, due to a lack of interest or a stronger incentive to participate. In total, the participation of 30 subjects with valid observations

[5]By Sou'wester (photo taken by Sou'wester) CC-BY-SA-3.0, via Flickr

in the study resulted in 696 journeys.

Table 7.4.: Descriptive statistics of field study subjects

Attribute	**(N = 30) %**
Completed Education	
High-School	3%
Bachelor degree	28%
Masters degree	38%
Doctoral degree	31%
Current Occupation	
Student	33%
Professional	67%
Gender	69% male / 31% female
Age	M = 30.6 (SD = 8.3)

Procedure

The study was mainly focused on collecting a large amount of quantitative data over an extended period of time. Nevertheless, a sub-set of the subjects were invited for individual interviews to validate the findings and assess the performance of the study. The mobile application was modified for this stage to include an illustrative diagram and a very short description for assisting users in using the application in-transit. The application also collected demographic information, including age, education and occupation. In addition, more detailed information was available on the project website [41] and a direct form of contact was available for clarifying further questions if needed.

The procedure for in-transit data collection and feedback was not changed, as it proved to be ecologically valid, considering the restrictions imposed. The progress, i.e. the number of completed observations versus the desirable amount, was made visible to incentivise users to report the required number of journeys. The overall progress of the study was sent to users who demonstrated interest on a weekly basis, including number of participants and journeys reported.

Results

The data collected at this stage provided a solid base for analysis and lead to significant results and interesting findings. The descriptive results and measures are presented in Table 7.5. The data supports some of the early findings from the pilot study, in addition to providing new insights into QoE in UPT domains.

Table 7.5.: Measures and descriptive results

Measure	**Satisfaction M (SD)**	**Aggregated**	
Valence	5.11 (2.11)	Affect	
Arousal	4.76 (2.01)	5.21 (1.90)	
Noise	4.47 (2.08)		
Saturation	4.95 (2.68)	Setting	
Smoothness	5.72 (1.86)	5.35 (1.50)	Global
Ambience	5.09 (1.66)		5.49 (1.35)
Speed	5.79 (2.13)	Service	
Reliability	5.79 (2.01)	5.79 (1.87)	

The data displays a strong placement around the axis between the frustration and satisfaction-related quadrants of the emotional model in Figure 7.8 and is consistent with the levels of satisfaction measured. There is a tight relationship between the measured environment conditions and the affective state, that indicates overall satisfaction with that particular travelling experience. The matching between the actual environment conditions - as sensed by the mobile device - and the affective state allows us to identify dynamically the factors that influence a travellers' experience. This identification leads, ultimately, to opportunities for enhancing experiences. The next section discusses the collected data in context.

The results obtained, shown in Figure 7.8 confirm the tendency observed in the pilot study: that the resulting affective states are mainly distributed between two quadrants. These two quadrants correspond to low satisfaction (low valence and high arousal) and high satisfaction (high valence and low arousal). Thus, the measured affective states were fitted to a single line, named Affect in Figure 7.8, as a representation of QoE.

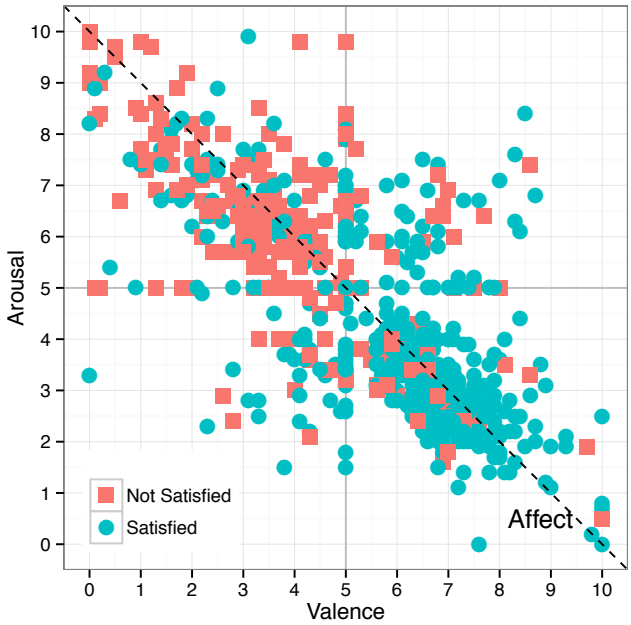


Figure 7.8.: Subjects' affective states

7.3.5. Results

The quantitative data analysis is focused on exploring the relationship between the different components of environment and satisfaction, or QoE. An exploratory analysis was performed, to investigate these different aspects. A number of relevant interactions were found relevant to our study, described in the following sections.

Satisfaction and Quality of Experience

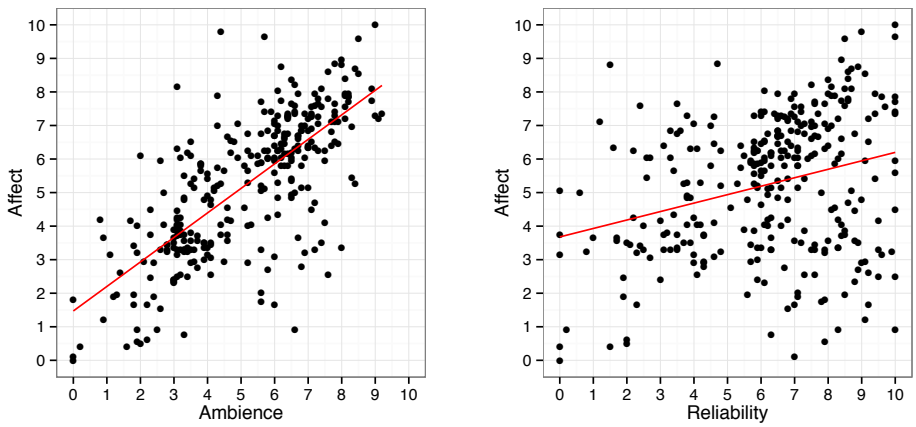
The first analysis aims at establishing the relationship between the satisfaction with different environment components, and dimensions of affect, including arousal and valence. As stated previously, the affective states were combined into a single measure, by fitting the values to the line labeled Affect in Figure 7.8, that corresponds to overall QoE in our study. As a result three main affective-related measures were investigated: arousal, valence and affect.

Table 7.6 presents the correlations between the satisfaction with individual environment characteristics and measures of affect, valence and arousal.

Table 7.6.: Satisfaction vs. affective state correlation ($p < 0.001$)

Satisfaction	Affect	Valence	Arousal
Noise	0.43	0.42	(0.37)
Saturation	0.58	0.61	(0.46)
Smoothness	0.41	0.42	(0.35)
Ambience	0.72	0.68	(0.67)
Speed	0.33	0.25	(0.36)
Reliability	0.29	0.24	(0.29)

The results reveal the importance of the vehicle setting, namely the impact of ambience and crowding, to be greater than the characteristics of the service itself. The reliability of the service, in particular presents a very low correlation coefficient with the final outcome. Figure 7.9 illustrates the contrast between the two: on the left there is a clear trend of higher affect with higher satisfaction levels of ambience, while on the right there is a bigger dispersion resulting in a lower correlation coefficient. Perhaps contrary to intuition, noise does not present a very strong correlation with satisfaction levels. This was further explored in the contextual interviews, in the next Section, unveiling some behaviour characteristics of travellers.



(a) Ambience vs. Affect ($r = 0.72$) (b) Reliability vs. Affect ($r = 0.29$)

Figure 7.9.: Ambience and Reliability correlations ($p < 0.001$)

Overall, the environment characteristics seem to be more correlated with satisfaction than service characteristics. In order to have a more global view, satisfaction indexes were generated to aggregate the different aspects

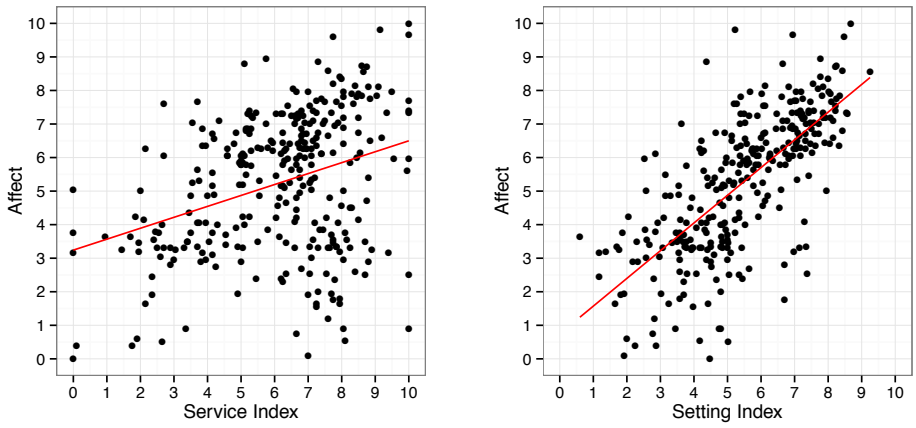
of travelling. These *indexes* were calculated based on the satisfaction expressed for each of the evaluated attributes both globally and per blocks, as present in Table 7.5. While the global index comprises all of the measured attributes, the division in blocks focuses on different characteristics. Two main blocks compose the satisfaction evaluation: UPT *service* and in-vehicle *setting*. Two methods were used to calculate the *index*: the arithmetic mean as the baseline and a weighed mean. The weighted mean is based on previously surveyed importance weighting [58, 47]. However, the arithmetic and weighed means resulted in very similar results and are thus treated as one. The calculated index was then compared with the expressed affective state - as the indicator of QoE. QoE is calculated as the overall affect, fitted to the connecting line between two quadrants: (high arousal and low valence) and satisfaction quadrants (low arousal and high valence). The result is in the table of correlations 7.7.

Table 7.7.: Baseline index vs. affective state correlation ($p < 0.001$)

Index	Affect	Valence	Arousal
Global	0.59	0.56	(0.53)
Setting	0.62	0.61	(0.54)
Service	0.28	0.23	(0.30)

As shown in Table 7.7, there is a moderate correlation coefficient present ($0.53 < r < 0.62$), between satisfaction index and QoE [44] - a value in accordance to previous work ($0.19 < r < 0.69$) [47]. In this context, a moderate correlation is expected due to the restricted number of attributes measured against the unlimited number of factors affecting passengers [1]. It is noteworthy the significant impact of *setting* on satisfaction in comparison to *service*, suggesting a stronger impact by the in-vehicle conditions rather than service itself as noted earlier. Figure 7.10 compares both indexes, where the slope is noticeably steeper for setting when compared to service. The difference in environment conditions and service characteristics supports the thesis that the surrounding environment impacts QoE and, consequently, providing travellers with personalised experiences enhances their overall satisfaction.

The usage of the weighted index, mentioned earlier, improved slightly these relationships, however no significant variation was noted. This is in agreement to the interviews, where the participants noted that reliability



(a) Service Index vs. Affect ($r = 0.34$) (b) Setting Index vs. Affect ($r = 0.71$)

Figure 7.10.: Service and Setting correlations ($p < 0.001$)

and speed were not a significant factor likely due to the high availability of alternative services and frequency.

Predictable Quality of Experience

In order to gain a deeper understanding of the impact and magnitude of the different travelling characteristics, a regression analysis was performed. The regression analysis allows us to estimate how QoE changes when one of the environment conditions varies while others remain unchanged. These values are widely used for prediction and forecasting, e.g. some methods used in recommender systems suggestions rely on this type of estimates.

To evaluate the prediction of QoE based on the environment characteristics, and based on our study design, a hierarchical linear regression was employed. A simple linear regression models the relationship between dependent variables, i.e. the affective state, and predictors, i.e. journey conditions. A hierarchic, or multilevel, linear regression facilitates the analysis of nested data when there is a natural hierarchical structure [52], such our studies performed in UPT. The within-subjects design, resulting in repeated measurements of the same user over time, needs to be taken into account. There are two levels represented: the first one accounts for the repeated observations of the same subject; and the second level for the variance between subjects. The data analysis was performed using the “nlme” package

in R [165], and three separate investigations were performed: the first consisting of the global affect; and two for each of the affective dimensions separately.

Table 7.8.: Affect regression analysis

	Value	SE	p
(Intercept)	0.63	0.37	0.09
Noise	(0.04)	0.04	0.27
Saturation	0.20	0.03	0.00
Ambience	0.50	0.05	0.00
Smoothness	0.08	0.04	0.09
Reliability	0.06	0.05	0.17
Speed	0.05	0.04	0.23

The regression for affect, in Table 7.8, shows that both saturation and ambience have a significant impact on travellers' QoE. In accordance with the results obtained previously, the magnitude of ambience is higher than saturation, both of them quantified in the Table. The regression values correspond to an increase of 0.50 and 0.20 in QoE for every unit of ambience and saturation satisfaction, respectively.

In contrast, other values of setting, such as noise and saturation, as well as service, namely reliability and speed, do not seem to significantly explain affect. These questions were explored during our interviews with the travellers. In addition, two other regressions were performed, with the goal of exploring the two separate measures of affect.

The regression for valence, the cognitive component of affect, in Table 7.9, strengthens the findings obtained previously, when focusing on this affective component. Both saturation and ambience significantly impact the outcome, with slightly higher magnitudes: 0.29 and 0.52 respectively. Smoothness, though at a lower magnitude, also has an effect on valence, with a 0.14 increase per unit.

The regression for arousal, the physical component of affect, in Table 7.10, reveals the importance of speed and not smoothness, in addition to saturation and ambience. Similarly to smoothness in Table 7.9, speed has a weaker impact in the results, with a magnitude of only 0.12. Reliability did not reach significance ($p = 0.07$), but it suggests that also this component may have an impact on arousal when comparing to valence. Moreover, the

Table 7.9.: Valence regression analysis

	Value	SE	p
(Intercept)	0.29	0.41	0.49
Noise	(0.04)	0.05	0.49
Saturation	0.29	0.04	0.00
Ambience	0.52	0.07	0.00
Smoothness	0.14	0.06	0.01
Reliability	0.02	0.06	0.68
Speed	(0.01)	0.05	0.81

significance of the intercept, suggests that arousal is the dominant component in the overall estimation of QoE, which is likely due to the impact that UPT may have on how stressed a traveller feels. Valence, on the other hand, does not translate directly to a commuting experience or a journey, with a lower impact on happiness.

Table 7.10.: Arousal regression analysis

	Value	SE	p
(Intercept)	1.03	0.41	0.01
Noise	(0.06)	0.05	0.18
Saturation	0.12	0.03	0.00
Ambience	0.50	0.06	0.00
Smoothness	0.02	0.05	0.74
Reliability	0.10	0.05	0.07
Speed	(0.12)	0.05	0.01

This separate regression analysis for both affective dimensions shows that some aspects have a more significant impact on valence, e.g. smoothness, while others contribute more for arousal, e.g. speed. Ambience may incorporate a different number of tangible and subjective characteristics and is therefore expected to have a stronger impact on affective states. This separation between different components suggests different approaches for actively improving travellers experiences, as well as the prioritisation of measures in relation to the expected outcomes. For instance, focusing on increasing the speed of a service may be less efficient than increasing its capacity, when comparing their magnitudes.

Given a set of environmental characteristics, the regression model is able to predict, with a certain degree of confidence, the expected QoE. This

opens a number of opportunities, such as the expected QoE in-vehicle based on sensed data, from either users themselves or sensors deployed in the environment.

Proposed Statistical Model

Based on the previous findings, a regression model is proposed for the dependent variable QoE and with two independent variables: saturation and ambience. In addition, a further reduction in the observations was conducted. As a result, the number of observations was reduced from 687 to 484, corresponding to the cases where either of the independent variables was left unchanged. This reduction was employed as a way of focusing on the cases where the QoE variation was associated with the variables directly.

The proposed model is able to explain 55% of the variation in QoE ($R^2 = 0.55$, $F(2, 481) = 301.3$, $p < .001$). A representation of our model is shown in Figure 7.11, where an increase in ambience ($b = 0.17$, $t(454) = 7.32$, $p < .001$) and saturation ($b = 0.52$, $t(454) = 13.54$, $p < .001$) results in a improved QoE.

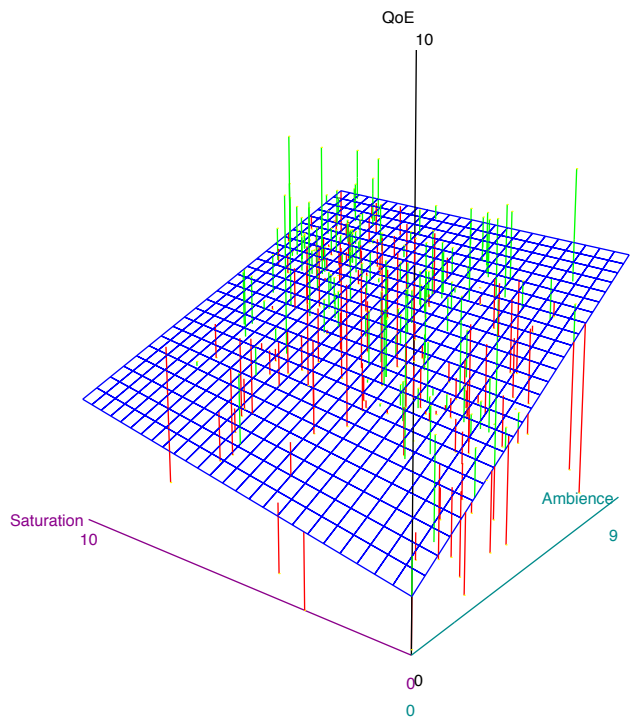


Figure 7.11.: Proposed model: regression plane with residuals

Sensed Data

Similarly to what had been observed in the pilot study, the collection of sensed data in a naturalistic environment presented challenging complications. One the one hand, the variability of the devices' capabilities, in terms of available sensors (e.g. lack of environment sensors) and quality of sensed data (e.g. low fidelity of sensors), results in low quality information and does not constitute a reliable source of data. On the other hand, the natural usage of such devices does not allow for a descriptive collection of environment characteristics, e.g. playing a game affects the device motion while keeping it in a pocket will affect the sensed sound level and others. For this reason, it is recommended for environment characteristics the usage of independent sensors or devices rather than using personal devices as the primary source. These include, on the users' side, the exploitation of wearable technology and other participatory methods; and deploying environment sensors for collecting environment-related data. A different approach towards collecting environment data would solve the issues associated with using solely the mobile device. For example, by deploying sensors in-vehicle that measure the different aspects of the travelling experience. The identified needs suggest the implementation by UPT providers of sensors capable of measuring number of passengers in a vehicle, noise, temperature and vibration. However, this invalidated our further investigation into the environment characteristics and their impact on users.

Qualitative Data Analysis

Our qualitative data analysis was conducted on two data sources: participants' responses to the open-ended question (presented at the end of each journey) and the semi-structured interviews held with a subset of participants. A total of twelve interviews were conducted, based on the format in Appendix B.1. Using thematic analysis, patterns were organised into themes until we were able to describe new data through our coding scheme. During the coding process, special attention was given to the environmental conditions our participants regarded as problematic as well as the ways in which they coped with the environmental disturbances that previous work had identified [185].

The first section of the interview focused on exploring the performance of

the mobile application in integrating and collecting personal information. The participants were satisfied with its integration in their commuting experience and they felt that the features were well designed. The navigation was intuitive and the feedback form relevant to the UPT environment. Some of the reported issues included excessive battery consumption related to the usage of the sensors; and the lack of motivation for a prolonged usage of the application. The participants lacked a sense of impact of their contribution and considered it to be *"cumbersome at the end of the second week"*, rather than a fruitful activity. Overall, the application was used for most of the journeys during the period of usage. However the two main factors for not using it were either due to battery concerns or simply because they forgot. While measures were taken to reduce the number of sensors used in subsequent versions of the application, a more elaborated solution is required to involve users in the activity. For instance, the implementation of notifications reminding users at pre-defined times, e.g. at usual commuting times; or a more integrated approach, involving UPT providers in an automated sensing process, e.g. start sensing when the travel card is activated. The discussions with the participants confirmed the quantitative analysis in showing that the perception of environmental characteristics could lead to either positive or negative transport experiences. It also confirmed a raised awareness in regards to the environment conditions, leading them to consider some aspects of their commute.

We probed them to explain how they coped with problematic journeys and what their travelling preferences were. Following [132], we also asked contextual questions, where participants' earlier responses to the open-ended question were used to queue their memory. This allowed them to reconnect with a particular journey and revisit their experiences with us. Examining the subjective experience of individuals is important, as it allows us to capture richer data around individual differences regarding travelling experiences and preferences that our statistical analysis might mask. The identified themes are organised as follows:

1. **Impact of journey conditions**
   This theme embodies the effect of journey conditions on travellers experience, including positive and negative aspects. Based on users' reports and inspired by our statistical analysis, these are divided into

the following:

a) **Travelling environment**
Travellers refer to environment conditions as a cause for both positive and negative experiences, that are not directly related to UPT service and tend to be more related to cognitive pleasure.

b) **Service characteristics**
The characteristics and different aspects of a UPT service tend to be associated with negative occurrences and result in physical displeasure, mostly because they do not meet expectations.

2. **Development of coping strategies**
This theme refers to the strategies, developed by travellers, to cope with the different situations occurring in a UPT environment. These strategies are divided into:

a) **Heuristics to avoid the negatives**
Commuters, and experienced travellers in general, develop heuristics based on past negative experiences to guide themselves towards less negative conditions; this strategy is not, however, employed towards positive conditions.

b) **Engaging in the positives**
Travellers resorted to immersive digital experiences as a way of shielding themselves against unpleasant or undesired environment conditions, used in combination with other strategies at times.

3. **Receptivity of personalised services**
This theme focuses on the receptivity of personalised services, that were not only well received but in some instances requested by travellers. Personalised services are not necessarily changes in the UPT service, but refer to the notification of negative experiences, suggestion of more suitable alternatives or even the delivery of digital experiences.

Impact of Travelling Environment

The travelling environment proved to be an important factor for travelling satisfaction, in particular ambience. As one participant said, *"I like to listen*

to people's stories and conversations, when there's a friendly atmosphere". A second traveller reported trying to take scenic routes if possible, with others mentioning a *"nice view"* out the window or enjoying *"sunny days"* when they need to travel. While these provided positive moments, a number of negative experiences are also related to the contextual environment, such as *"noisy children"*, *"smelly buses"*, *"people arguing"* and even *"squeaky breaks"*. These factors, though not directly related to the provision of service, were decisive factors in travellers' experience. As noted by another participant: *"Everything was fine up to the point when some people started arguing, I just wanted to leave the train"*. Participants also requested for *"newer buses with better lighting and suspension"* as well as more considerate drivers, with one participant regarding a bus journey: *"The bus driver was just accelerating and breaking hard all the time, it was horrible"*. All of the interviewed participants had gone through an environment-related experience that contributed to a better or worse experience, independently of the service characteristics.

Despite their shared agreement about these characteristics, individual differences were found in the relative importance each participant assigned to these conditions. A total of 66% travellers showed a strong preference towards a non-crowded environment. One participant argued that *"as long as I get a seat I'm happy"*. By contrast, 41% preferred a quiet environment. Consider the following response: *"I like to read in my commute and the noise distracts me a lot"*. The importance of this factors may seem, at first, contradictory to our findings in the statistical analysis. However, the non significance of these factors may be explained by the relative importance for a sub set of travellers. Noise, as an example, is of little importance for travellers who usually listen to music or even play games on their devices, effectively shielding them from the negative travelling aspects.

Impact of Service Characteristics

Service characteristics were found to influence participants' appraisals of their transport environment. Firstly, the providers oftentimes set certain expectations. Frequent bus users found it difficult to form perceptions of reliability and had come to accept this ambiguity. As one participant noted: *"I don't really know how to assess reliability. The [bus] timetable says 8 to*

12 minutes. I can only consider a bus unreliable if it's canceled when I'm in it". Train users, on the other hand, had constant access to arrival information through the announcement boards which also flagged train delays. As a consequence, these travellers were acutely aware of delays and expressed more annoyance about minor disturbances to the service. Moreover, as we described above, some disturbances, e.g. packed early morning commutes, were felt by participants to be more predictable as a result of their repeated exposure to them. Other situations were seen as less predictable with travellers finding it difficult to adapt to these sudden changes.

Other service factors contributing to low satisfaction include service cancelation and sudden negative occurrences created by this *"apparent"* mismanagement – at least from the travellers perspective, who do not fully comprehend why their service needs to be cancelled. For instance, the sudden crowding of a train due to cancelation of other trains. Other participants noted the announcements to be too loud, annoying and unnecessary. One participant even noted the announcements were detrimental in bringing to the travellers attention the inefficiency of the UPT network: *"announcements noting delays due to faulty signalling"*, ironically hinting at the upgrade of track signalling rather than announcing it. On the other hand, the way UPT staff handle certain situations was in itself a factor, for instance *"unhelpful drivers when the bus is cancelled"* suggest better training to attenuate the impact of these negative occurrences.

Heuristics to Avoid the Negatives

Travellers, for the most part, did not actively seek out to create positive conditions or experiences, which is likely due to the utilitarian function of UPT. However, coping strategies were available to assist them in improving or enhancing the journey. When it came to responding to negative transport experiences, at least two strategies had been developed, present in 83% of the interviewees. The usage of past experiences in troublesome journeys was one of such heuristics, for example, avoiding specific routes at certain times of the day. These heuristics extend to a range of different travelling behaviours, that are learned when users first start using UPT, but soon stagnate to what they think to be an *optimal behaviour*, corresponding to a sense of commuting proficiency.

These heuristic-based strategies are employed in a wide range of situations. These include modes of transport and routes depending on the day of the week (e.g. weekday, weekend), time (e.g. peak hours) and even period of the year (e.g. Summer, Winter); weather conditions influenced the behaviour, with travellers preferring to use the bus with sunny, spring-like weather. Even though adaptable behaviour is present, changing routes was not usual, even when several options exist, due to the idea that a certain route is the *best*, either due to duration or comfort. Only one traveller admitted to using different routes *"just for a change. I get bored with using the same route everyday."*. In contrast, other travellers become experts in their daily commute, with some going as far as finding an area of the platform of departure that allows them to reduce time or distance at their destination. Finally, other irregular occurrences also impacted this adaptive behaviour, even if less predictable, like high profile events e.g. concerts and football matches.

Engaging in the Positives

In addition to trying to avoid negative occurrences, travellers engaged in a range of activities that, directly or indirectly contributed to enhance their experience. As one participant humorously pointed out *"I snoozed for a while, so who knows [what went wrong]"*. One other pointed out, for a particular journey¿ *"was eating, so I didn't really pay attention to anything"*. Curiously, this same act may have been the cause of dissatisfaction for other travellers. In fact TfL is actively trying to raise awareness for such issues and incentivise travellers to improve their behaviour, through its "Together for London" campaign. The messages include "I won't play my music out loud", "I won't drop litter" and, pertinent to our fellow traveller, "I won't eat smelly food". This campaign tries to enhance the social context as a way of impacting the overall travelling experience. In fact, taking advantage of this existing social capital is one of the ways to contribute for the overall experience [151].

In our interviews, however, the tendency for self isolation was predominant. Several participants engaged in activities they considered pleasant, from reading to playing games. Some were, however, not compatible with the environment conditions, paradoxically increasing frustration: *"I prefer a*

quiet environment, otherwise I can't read". On the other hand, some activities had effectively supplanted the actual environment, shielding travellers from *external* influences. These immersive digital services were thus a very effective method and provide a powerful mechanism for addressing individuals and assisting them in enhancing their QoE. Engaging in such immersive experiences included listening to music – an activity that is not interrupted throughout the full travelling cycle – reading a book or watching a video – both of which are more cognitive demanding in terms of attention – and finally playing games on a mobile device, often resulting in full isolation. In the words of one participant: *"when I'm playing a game I forget everything around me"*.

These services hold great potential in enhancing QoE, as they constitute a mechanism to provide for positive experiences by immersing travellers in digital experiences. These can be personalised to individual preferences and needs, effectively engaging them in positive activities.

Receptivity of Personalised Services

Finally, the topic of personal information collection and sharing was discussed. Overall, the participants did not feel the collected data was intrusive, even though it included a considerable amount of personal information. The collection of personal data, for some, was intrinsic to the usage of mobile applications and internet in general: *"We already have our entire lives on social networking platforms"*. There was, however, a lack of understanding about the impact in providing such personal information and its real value to other external entities. Nonetheless, the participants felt confident in sharing such information due to the clear data handling policy: *"There really is no problem in providing any information, I trust that everything is anonymised."*. There is, therefore, an implicit trust relationship between the participants and the entity responsible for the experiment, based solely on the information provided.

The potential of UPT service personalisation, based on the provided information was well received by the participants. Reflecting upon their travelling experience revealed some personal preferences towards certain types of services, ranging from route estimated time of arrival to avoidance of crowded or noisy vehicles. Due to the flexibility of the UPT network, all

the participants were willing to adapt their commuting if that resulted in more pleasant experiences. In fact, some of them change route to avoid certain unpleasant travelling aspects depending time and day, based on their personal experience.

In spite of the lack of motivation or incentive for a continuous usage of the application, the delivery of personalised services was very attractive and there was an consensus that *"those services would be worth all personal data"*. A mismatch between the amount and type of data provided and the resulting service, that is symptomatic of the current digital services practice. Even though there was a strong interest for such services, the participants tend to view them as a normal evolution of ATIS and are reluctant to pay for them, in particular when they provide their own personal data, perhaps a first realisation of the intrinsic value of personal digital information.

Individualised Needs

There are significant differences between participants, both in the aspects that influence the QoE but also in the strategies used by them to cope or enhance their travelling experience. Some of the travellers showed a strong preference towards non-crowded journeys, while others did not seem to be particularly affected; noise also seemed to have a similar effect.

Coping strategies were employed by different types of users, according to the factors that had a strong impact. Most of the participants did not actively seek out to create positive episodes, which is likely due to the utilitarian function of UPT. In contrast, at least two main strategies were identified in response to negative episodes. Some of the subjects used past experiences as a heuristic, e.g. avoiding certain times of the day or specific routes. Others developed methods to deal with undesirable characteristics that were perhaps unavoidable, e.g. listing to music or reading a book.

The individual needs and strategies used for the travelling experience encourage the development of personalised services that address individual needs and lead to an improved QoE.

7.4. Design Principles

The investigation of user experience in intelligent pervasive environments, the specification and implementation of the *Cloud2Bubble* platform and its evaluation in the domain of UPT culminates in a set of principles for the development of intelligent ubiquitous systems. The five design principles derive from the different stages involved in the design, implementation, instantiation and evaluation of the platform, focusing on individual engagement, collective action and societal implications. These principles provide a concrete fruition to the abstract concept of design contractualism [166], and originate from own work (benefit and empowerment) as well as previous work that is considered to relevant for the platform (privacy, reliability and collective awareness):

- Design for Benefit
  Recognises users as main contributors in intelligent systems, and thus the primary beneficiaries of service personalisation and delivery;
- Design for Empowerment
  Inspired by the idea of generativity, providing users with the appropriate resources empowers them to take action and actively contribute;
- Design for Privacy
  Drawing from the Privacy by Design framework, some privacy and data protection guidelines are revisited in context;
- Design for Reliability
  Making interaction with technology and its impact explicit allows users to be in control of their activities
- Design for Collective Awareness
  Exploiting big data and raising awareness supports the orchestration of individual action to address societal challenges

7.4.1. Design for Benefit

Intelligent pervasive systems rely heavily on big data for inferring patterns of user behaviour and, in turn, generate actions that increase their usage. User engagement is, therefore, essential for generating the required resource

of digital information in such systems. In this context users are not only the consumers but also the producers of digital information - or *prosumers*. The collection of personal data, both explicit and implicitly, enables the identification of a range of personal preferences and needs - from utilitarian to hedonic and emotional - that sustain the appropriate adaptive behaviour.

The role of users as main contributors – with their personally generated data as a central element of intelligent pervasive systems – entails the retribution as beneficiaries of the adaptive behaviour. Users will happily trade data, including highly sensitive data, in exchange for enhanced services.

In the interviews conducted, in Section 7.3.5, the participants showed a clear interest in being *rewarded* for their contribution. In their view, and given the participatory nature of the study, both the effort involved in the approach used, and their personally generated data were seen as valuable assets. While the continuous development of sensing technology combined with the increasing trend of personal information sharing contribute to alleviate their effort, it is the actual data that constitutes the real value in this contribution–benefit relationship. As a result, the participants were interested in being involved in a simplified version of the mobile application, requiting less interaction, in exchange for a beneficial service. The *receptivity of personalised services* theme supports this, identified in our qualitative analysis. Consider the following illustrative response: *"those services would be worth all personal data"*. Beneficial services, however, are dependent on personal needs and preferences. The participants demonstrated their interest in a range of different information services and even immersive digital experiences, that would assist their own commute: some participants were interested in detailed transit information, while others wanted to know the level of crowding or noise in the vehicle. In addition to the direct relationship between contribution and benefit, addressing users interests acts as an incentive for continuous usage; rather than providing a personalised service that benefits a third party, for example, a sale benefiting a company based on personal profiles or merely governmental policy.

Cloud2Bubble was specified with the primary goal of providing for enhanced experiences by addressing individual supra-functional requirements. In this context, enhanced experiences are the result from providing personal data and the incentive for continuous engagement and other forms of social capital. Other goals may include other entities, such as commer-

cial or governmental ones, but only secondary to users main interests. In our studies, users demonstrated their interest in providing personal data in exchange for a experience oriented service. The recommendation in instantiating *Cloud2Bubble* is to benefit users as the primary goal, that also includes other forms of collective behaviour.

7.4.2. Design for Empowerment

The *generativity* [215] qualities, present in some systems, allows users to build and use them in new and different ways; and to generate and extend new uses beyond the original ones. Making necessary resources available enables users to actively contribute towards an activity or solution, but also understand the cause of a problem and how their behaviour may result in a positive impact. The disposition of users to adapt their behaviour suggests a genuine tendency to be proactive. Thus, making the necessary resources available enables users to actively participate. The result of releasing public data by some local authorities, for example the transport authority in London, provided tools for commuters to analyse and build upon this resource. Some of the results include mobile and web-based applications to raise awareness about local issues, e.g. criminality or education, or assist members of the community. In the context of smart grids, providing users with a visualisation of the overall usage of the grid allows them to take action, collectively, to avoid overload and the consequential service interruption [168].

In our qualitative analysis, deriving from an instantiation of our platform, this aspect emerged from a number of behaviours and coping strategies. In a UPT context, a number of opportunities arise to provide users with the necessary resources for contributing to an enhanced travelling experience. The *development of coping strategies* theme, illustrates major strategies that travellers employed with existing resources, and that may be leveraged. In addition to avoiding the negatives, by using past experiences or information services, travellers engage in positive experiences shielding them negative ones. The participants showed some aspects of this generativity in the current usage of existing resources, such as using online service countdowns to make decisions before arriving at the bus or train station – which could be in itself transformed into some sort of personalised service.

The result of making resources available and providing an extensible platform that members of a community or a social context can take advantage, empowers them to take action and actively contribute to solve or improve existing circumstances. The generativity [215] aspect of *Cloud2Bubble* supports the creation of new and unforeseen features and services, by making resources available and extensible to members of the society, including an instantiation methodology in Section 5.6.

7.4.3. Design for Privacy

Privacy is one of the cornerstones in the development of pervasive computing environments and has a number of implications in the way users interact and use the system. The collection of different sources of data, sometimes implicitly and without awareness, raises a number of challenges and concerns. These issues and their implications have been the focus of much research and a set of guidelines have been compiled into the Privacy by Design (PbD) framework [28]. This framework is intended as a reference for embedding privacy and data protection throughout the entire lifecycle of technologies, from early design stage, deployment and disposal. From a user's perspective, privacy is a complex and malleable concept that is dependent on a number of factors, including situation and social context. The same tools that enable the collection and processing of such information must include equally capable features to ensure the privacy requirements and preferences are met. Secondly, such a vast and complete source of personal data becomes a very desirable resource due to its potential in characterising people's preferences and patterns of behaviour in detail.The collected data must therefore be handled and processed in accordance to the clearly specified and agreed terms, or contract [166].

The domain specification in *Cloud2Bubble* provides a secure environment for data storage and, more importantly, the tools for complete user control over privacy preferences. The granular specification of access levels to different personal profile elements and in relation to specific environments, in Section 5.3.1, allows users to define different levels of access that reflect their preferences. Privacy functionality is thus embedded in the system, ensuring its integrity [28]. The recommendation for an instantiation of *Cloud2Bubble*, in addition to ensuring that users' preferences are met as well as the stor-

age and handling of data, is to ensure users' have a clear understanding of what personal data is being collected and what is its purpose for the service. Furthermore, users should maintain ownership and control over their personal data and thus any requests met, such as investigation of own data and deletion upon request.

7.4.4. Design for Reliability

The vision of ubiquitous computing to transform everyday's objects into computing nodes, results in a transparent integration of both physical and virtual worlds. An unintended consequence of this integration is the increasing unawareness, from a user interaction perspective, resulting in a reduced sense of responsibility and an apparent detachment between user action and system behaviour [78, 98].

Involving users in a reflective process, effectively engaging them in the process of deciding what action to take by the system, results in an increased awareness of their individual actions, as well as its impact on a collective level.System behaviour should thus be clear and involve users in the decision process; rather than autonomously deciding and acting upon the environment. This explicit engagement allows them to evaluate the system performance and reliability, ensuring the system behaviour is well understood and expected.

The instantiations of *Cloud2Bubble*, as defined in Section 5.6, are recommended to define explicit and reflective interactions, as demonstrated in Chapter 6. The result of this, in the context of UPT, led travellers to be aware of their interactions with the platform and travelling context, which allowed them to evaluate their travelling behaviour and consider alternative services.

7.4.5. Design for Collective Awareness

Collective awareness is a central element for users to understand how their individual actions contribute to the greater whole, by being aware of the same data and share the same legal, social and cultural context. Thus, collective awareness constitutes a mechanism for the direct, effective and inclusive ways for citizens to respond to societal challenges that require synchronised action, such as definition of policies, achieving sustainable changes

and participation in democratic processes. Individual action is then translated from an isolated activity, perceived primarily as local-only and with little or no global effect, to collective action, where a social group or community actively contributes towards a commonly solution or activity.

The combination of technological resources, including networks of sensors and big data, with personal networks and social capital, enables the development of platforms that aim at engaging citizens in addressing societal challenges, e.g. by providing the necessary tools for citizen interoception and realisation of individual contribution [67, 168]. For instance, establishing the relationship between individual and collective action allows users to perceive their individual contribution towards the improvement of conditions on a global level [4].

The inclusion of QoE in the loop of interaction between users and platforms, in Section 4.3.1, provides a mechanism to assist in assessing users' needs as well as a way of delivering a personalised service. Furthermore, this supra-functional based personalisation has the potential to effectively impact users' behaviour, for example, commuters' adaptive behaviour to new services, in Section 7.3.5, where offering a personal and relevant information service (e.g. noise and crowd levels) results in adjusted behaviour to avoid uncomfortable services.

7.5. Summary

This chapter presents the studies conducted to investigate the relationship between users and ubiquitous environments in the context of UPT. The results were analysed and discussed, that resulted in a number of valuable insights and relevant findings. Due to their focus in UPT, some of these insights are directly applicable in the development of ATIS, but are also relevant to intelligent ubiquitous environments. A set of six design principles were identified that provide the guidelines that result from the experience in designing and applying the *Cloud2Bubble* platform and that inform the future development of such smart systems.

8 Conclusions

In the context of intelligent ubiquitous environments, a number of user experience-centric opportunities arise. These opportunities include, on an individual level, improving quality of user experience, by addressing supra-functional needs through service personalisation; and on a community or group level, a wider and more significant impact on collective action, by raising awareness and empowering individuals to actively contribute for a common solution. The same resources that enable these opportunities, such as personal digital information and a sensor saturated environment, are simultaneously at risk of being used of other less considerate purposes. For instance, exploitation of private data for economical benefit or the enforcement of unwanted policies.

This thesis focuses on the existing opportunities in smart environments for enhancing quality of experience and providing a foundation for collective action, as well as identification of the risks associated with such environments. While the focus was on answering the research questions initially proposed, the work developed constitutes a stepping stone in answering more complex and broader questions. These broader questions relate to the impact that affective-oriented ubiquitous environments may have on quality of user experience.

8.1. Summary

The research conducted in this thesis resulted in the following outcomes:

- a review of empathic user experience in the context of intelligent ubiq-

uitous systems;

- the definition of quality of experience based on users' affective response in a ubiquitous environment;
- a review of the importance of urban mobility, and public transport in particular, in supporting the sustainable development of smart cities;
- the identification of the main components, including functional, non-functional and supra-functional needs, and high-level architecture of an experience-centric platform;
- the implementation of a proof of concept platform accompanied by a methodological procedure for its instantiation;
- an instantiation of the platform in the context of urban public transport;
- an evaluation of the platform in a controlled environment, as well as the instantiated system based on two field studies, in London (UK) and Porto (Portugal), leading to insights for both transport and general intelligent information systems;
- a discussion of the impact and opportunities of the *Cloud2Bubble* platform, resulting in a set of design principles for the design and development of ICT systems for design contractualism.

8.2. Limitations

The research carried out was subject to some limitations, here specified.

Firstly, the specified requirements and proposed implementation were developed under a broad scope. This allowed for a deeper investigation into the implications and requirements of user experience centric smart environments. The proof-of-concept instantiation in public transport, however, was subject to a narrower scope and focused primarily on the collection of user and environment data, leaving the active service delivery aside. In addition, a broader study requires the cooperation with external entities, such as the public transport providers, and other external resources that were not available at this stage, in spite of the efforts made to involve them.

Cloud2Bubble builds upon on a set of software packages that constitute the foundation of the platform, and focuses on addressing users' supra-functional needs towards an enhanced user experience. While in a controlled environment the software performs as expected, the deployment of the platform in a real-world environment required adaptations to face the limitations posed. As a result, the architecture of the system was modified to allow users' personal devices to communicate directly with the system, rather than integrating them as main components. At this stage the impact of this modification was not significative, since in both studies the main goal was to collect personal and environment data. The inclusion of a more dynamic interaction between the different elements of the system requires a deeper integration, that also explores the feasibility of integrating personal devices on the platform.

The pilot study was an important step in the process of development of this research to assess the feasibility of the study. It revealed, however, that some of the sensing data initially targeted would be challenging to obtain - due to device restrictions or sensor noise and unavailability. The following field study was therefore modified to incorporate these findings, with a smaller set of data sources.

The sample size of the field study in London (UK) provided a reasonable amount of data for analysis and discussion. However, the demographic profile of the participants was skewed towards higher education participants, which may not be an exact representation of the population. In spite of the efforts made for distributing the application - and the high number of downloads - a relatively small percentage of users adhered to the study.

Finally, the *Cloud2Bubble* platform, while developed with smart environments in mind, was instantiated and investigated in a specific domain of application. The characteristics of the domain, as well as its impact on users and ability to adapt to the identified needs may be specific to a subset of all possible domains of application. The application on other domains would be beneficial to strengthen the implementation of the platform and its ideas.

8.3. Further Work

The research carried out opens interesting avenues for further development. *Cloud2Bubble* was developed to a prototyping stage, primarily focused on the questions raised through the course of this investigation. The platform is, however, open for further development that enables the continued research on quality of experience influencing services and its impact on collective awareness.

From the user perspective, the findings support the development of personalised services with the focus on addressing supra-functional needs. Affective recommender systems, for example, may include emotion as a factor for recommendation of products or services. The offering of personalised services in smart environments relies on common technology, such as the definition of a user profile and preferences.

Finally, the instantiation of the platform on other domains of application within the scope of smart environments presents a number of opportunities and challenges for expanding service personalisation and collective action to different contexts and how they integrate in an experience enhancing environment. The following Sub-Sections are based on the developed methodology to provide an overview on an alternative instantiation of the *Cloud2Bubble* platform.

8.3.1. Design Principles

The design principles, presented in Section 7.4, derive from both own work and external sources, as identified. The work presented, however, may be revisited and further expanded to include other aspects that are relevant to *Cloud2Bubble* as a platform for collective action, namely Self-Governance and Emergence. These two relevant concepts are briefly described as follows:

Design for Self-Governance

Collective awareness platforms require the organisation of citizens to solve societal challenges. This not only requires synchronised collective action but also self-governance: the ability of a group to exercise all of the necessary functions of power without intervention from any authority which they cannot themselves alter. In social-ecological systems, as an example, self-

organisation ensured the maintenance of natural resources in a sustainable equilibrium, rather than a centralised governing body [158]. These have, in fact, produced quite the opposite result in some instances.

Design for Emergence

In large and complex systems, as it is the case in social groups or communities, changes in the state of affairs are often unaccompanied by their supporting platforms. These rapid changes in social, technological and physical environment, require a new type of intrinsically adaptive platforms that are able to combine top-down control and coordination with bottom-up emergence and adaptation.

In the development of our studies, in particular during the interviews with the users, it was noticeable the need for an adaptable ATIS platform, able to incorporate preferences and needs as they emerge. For example, the ability to provide personalised services according to travellers needs or even offer novel immersive services to assist them while in transit.

8.3.2. The Workplace as a Domain of Application

This section provides an overview of how the methodology proposed may be applied to alternative domains of application. Pervasive environments, and smart cities in particular, provide a number of other applications. For illustrative purposes, the workplace is going to be used.

Domain Specification

The workplace lends itself naturally to an experience enhancing experience. In an office environment, the conditions and social interactions influence workers wellbeing and performance. Let us take the hot-desking scenario, as an example. In some organisations, desks are shared between multiple workers in different time periods. This dynamic context offers a number of opportunities to assess and influence workers experience, based on the surrounding environment as well as coworkers.

Data Modelling

A simple model would provide support for the different physical spaces. For example, a *Cloudlet* entity may represent an office and perhaps, in the case of open plan offices, sub-areas of the same room. One other level of modelling would provide support for the existing social structure in the workplace, for instance to assist users in finding coworkers in the office, in case they are working on the same project, or even avoid for other reasons. The *Bubble* entity on its turn encapsulates all the worker personal information.

System Behaviour

The system may provide workers with a personalised service that suggests what area of the building they would feel more comfortable or productive. For instance, find a quiet area, a well lit meeting room, based on sensors spread in the building; or even the localisation of relevant coworkers. The utility measure, in this domain, may be related with productivity as a function of wellbeing in the workplace and, therefore, directly related to QoE.

User Interface

The usage of personal computers for professional use provides a direct channel of interaction with workers, and integrates seamlessly in their daily working experience. In addition, mobile devices may provide more context, for the same reasons that make them attractive in the public transport scenario. Similarly, services may be delivered directly to the device upon relevant moments, such as suggesting an office upon arrival to the building.

Implementation & Testing

The implementation of the final solution includes the development of tools that integrate within the platform used by workers. For example, a small application installed on their computers or laptops that assists them with enhancing their working experience. Similarly, a mobile application synced with the platform would provide an even wider range of possibilities.

Deployment

This stage focuses on deploying the *Cloud2Bubble* instance in order to start acquiring information about the environment leading to service delivery, that must include the provision of service to coworkers throughout a range of contexts. The final deployment would enable the investigation of the effectiveness of the system for improving working conditions and worker performance.

8.3.3. Commercial-oriented Applications

Personal digital information is becoming increasingly relevant, in particular to provide personalised services. In addition to the benefit for the user, having access to this data is attractive for a wide range of commercial and governmental entities, as discussed.

Inspired by the affective aspect that facilitates service personalisation and the implications involved in maintaining and processing personal digital data, we propose a model to mediate this relationship. A cloud-based model, defined as Empathy-as-a-Service (EaaS), provides a unified personal profile that is harvested via multiple user interactions in a wide range of domains. The idea of a unified personal profile is not new, and was discussed previously. One of the main goals is to ensure users' privacy and security requirements are met, while providing the necessary infrastructure for a personalised service. There is room for innovation in targeting the emotional dimension that contribute not only to single experiences, and to wellbeing in general.

The proposal of an EaaS model is common to the different layers of the service, in Figure 2.6, allowing external entities to integrate it as needed, from the infrastructure to service levels. The EaaS model is responsible for collecting and aggregating different data sources, as well as maintain privacy preferences and ensuring its security and correct usage. From an external provider point of view, the service is available to identify the personal needs of their users; or identify a group of users with a certain need. The tailoring of services is then made according to the specific needs, without compromising privacy, security or usability.

8.4. Final Comments

This thesis resulted in a user experience centric platform that aims at collecting and aggregating personal data to deliver personalised services in intelligent ubiquitous environments. The research conducted focused primarily on the first research question, related to investigating the collection of personal digital information and exploring its societal implications. The development of these systems creates resources and functionality that, when applied responsibly, benefits individual users and society in general. On the other hand, there is a risk of exploitation of these platforms to achieve other, less considerate, objectives. There are, therefore, a number of opportunities to proceed towards delivering personalised services and support collective action. In addition, a set of design principles ensures the development of socio-technical platforms focused on user benefit, empowerment, awareness, privacy as well as collectivity and sustainability, as the main pillars for implementing design contractualism.

A

Cloud2Bubble Experiment

A.1. Participant Information Sheet

We are conducting research about affective interactions with computer systems for assessing and influencing quality of user experience in ubiquitous computing environments. We are currently investigating the relationship between environment conditions, user satisfaction and emotional reactions. A software platform is currently collecting environment and user data to explore how these following dimensions relate:

- Wellbeing: measures overall user satisfaction with a situation or an experience;
- Happy: cognitive pleasure, ranging from unhappy to happy;
- Relaxed: physical arousal, ranging from relaxed to tense.

You are invited to participate in this research and we would appreciate any assistance you can offer, although you are under no obligation to do so, and you may choose to end the experiment at any time.

Participation involves a visit to our laboratory at Imperial College London, for approximately 20 minutes. If you agree to participate, you will be asked to perform a set of short tests using the developed prototype. Your interactions with the application will be recorded and you will be asked to provide feedback throughout the duration of the experiment.

All the information you provide and recorded data will remain anonymous and used solely by the researchers within the scope of this project.

Your name will not be used in any reports arising from this study. The information collected during this study may be used in future analysis and publications and will be kept indefinitely. At the conclusion of the study, a summary of the findings will be available from the researchers upon request.

If you do not want to participate, you don't have to give any reason for your decision, you may withdraw at any time during the session and you can also ask for the information you have provided to be withdrawn at any time.

If you agree to participate in this study, please first complete the consent form attached to this information sheet. Your consent form will be kept separately from your data so that no-one will be able to identify your answers from the information you provide.

Thank you very much for your time and help in making this study possible. If you have any questions at any time you can contact the responsible.

A.1.1. Consent Form

I have been given an explanation and understand the purpose of this research project. I have had an opportunity to ask questions and have them answered. I understand that at the conclusion of the study, a summary of the findings will be available from the researchers upon request.

I understand that the data collected from the study will be held indefinitely and may be used in future analysis.

I understand that I may withdraw myself and any information traceable to me at any time without giving a reason, and without any penalty.

I understand that I may withdraw my participation during the session at any time. I agree to take part in this research by completing the session.

I agree for my data, collected during this session, to be used in future research reports and publications about this project.

A.2. Fuzzy Sets

The variables are modelled using piece-wise linear membership functions.The linguistic terms are intended to be descriptive rather than precise definitions.

A.2.1. Input Variables

Luminosity (lux)
Dark: $(x_0, y_0) = (0, 1), (x_1, y_1) = (150, 0)$
Light: $(x_0, y_0) = (150, 0), (x_1, y_1) = (1000, 1)$
Noise (dB)
Quiet: $(x_0, y_0) = (0, 1), (x_1, y_1) = (30, 1), (x_2, y_2) = (50, 0)$
Average: $(x_0, y_0) = (45, 0), (x_1, y_1) = (52.5, 1), (x_2, y_2) = (60, 0)$
Loud: $(x_0, y_0) = (55, 0), (x_1, y_1) = (80, 1), (x_2, y_2) = (100, 1)$
Arousal (reported)
Active: $(x_0, y_0) = (0, 0), (x_1, y_1) = (10, 1)$
Inactive: $(x_0, y_0) = (0, 1), (x_1, y_1) = (10, 0)$
Valence (reported)
Unhappy: $(x_0, y_0) = (0, 1), (x_1, y_1) = (5.5, 0)$
Happy: $(x_0, y_0) = (4.5, 0), (x_1, y_1) = (10, 1)$

A.2.2. Output Variable

QoE
Miserable: $(x_0, y_0) = (0, 0), (x_1, y_1) = (1.25, 1), (x_2, y_2) = (2.5, 0)$
Bad: $(x_0, y_0) = (2.5, 0), (x_1, y_1) = (3.75, 1), (x_2, y_2) = (5, 0)$
Good: $(x_0, y_0) = (5, 0), (x_1, y_1) = (6.25, 1), (x_2, y_2) = (7.5, 0)$
Excellent: $(x_0, y_0) = (7.5, 0), (x_1, y_1) = (8.75, 1), (x_2, y_2) = (10, 0)$

A.3. Fuzzy Rules

- `IF arousal IS inactive AND valence IS happy THEN qoe IS good`
- `IF arousal IS active AND valence IS happy THEN qoe IS excellent`
- `IF arousal IS inactive AND valence IS unhappy THEN qoe IS miserable`
- `IF arousal IS active AND valence IS unhappy THEN qoe IS bad`
- `IF noise IS loud THEN qoe IS bad`
- `IF luminosity IS dark THEN qoe IS bad`

A.4. Descriptive Statistics

Table A.1.: *Cloud2Bubble* evaluation, descriptive statistics

Variable (N)	**Mean (SD)**	**Range**	**Group (N)**	**Mean (SD)**	**Range**
Age (21)	28.90 (4.86)	23-38	Female (7)	28.57 (5.28)	23-38
			Male (14)	29.07 (4.66)	25-38
Performance (84)	.14 (.04)	.07-.26	Female (28)	.14 (.04)	.7-.21
			Male (56)	.14 (.04)	.9-.26
QoE (168)	6.99 (1.86)	1.5-10	Pre (84)	7.17 (1.78)	1.5-10
			Post (84)	6.81 (1.92)	1.8-10
Arousal (168)	3.15 (1.97)	0-9.1	Pre (84)	2.93 (1.86)	0-8.3
			Post (84)	3.37 (2.05)	0-9.1
Valence (168)	7.24 (1.81)	1.1-10	Pre (84)	7.39 (1.71)	2.1-10
			Post (84)	7.09 (1.89)	1.1-9.9
QoE Est. (168)	5.86 (1.60)	2.5-8.8	Pre (84)	6.00 (1.60)	2.6-8.8
			Post (84)	5.73 (1.60)	2.5-8.8
Sound (168)	56 (13)	31-73	Quiet (84)	47 (12)	31-69
			Noise (84)	64 (9)	34-73
Lumix (168)	311 (269)	4-583	Light (84)	487 (172)	4-583
			Dark (84)	136 (230)	4-583

B

Public Transport Study

B.1. Interview Protocol

The semi-structured interview includes the questions in the following sections, with flexibility to explore different aspects of the study as they emerge during interview. There are two sections: a general one, focusing on the overall study; and a second one, depending upon user consent, more specific targeting individual journeys.

B.1.1. Interview Script

Hi, thank you for participating in this study. I would like to ask you to record this interview, if that's ok. The recording will be used for research purposes only and remain confidential.

The data you provided so far by recording and reporting your journeys allows us to have a better understanding of the commuting experience in public transport and how it may be improved. The goal of this interview is to explore your personal views on this study.

The interview is composed of a set of general questions and, if you agree, we will focus on some individual journeys as well. Do you have any questions before we start?

- You used the mobile application in the last few weeks, can you tell me about your experience?

Application related questions

I would like to ask you about your interaction with the mobile application.

- How would you describe its usage? What were the positives? And the negatives?
- Could you explain me how was the application flow integrated with your daily commute? Can you describe the Start, Stop and Feedback moments?
- Focusing on the feedback form, how relevant do you think it was to describe the environment? Would you add any other aspect?
- Since you started using the application, what would be the ratio between your reported and unreported journeys?

Environment related questions

- Let us focus a bit more on the overall environment, and not only on the interaction with the application.
- How do you think the usage of this application impacted your consciousness about the journey conditions and characteristics?
- How do you think it impacted the way you feel about commuting? And perceive it?
- In relation to your mood while travelling, do you feel affected by your commute? Do you think those changes are tied to any specific conditions?
- Can you describe your mental process to report your mood? Did you do it in relation to the journey in isolation; or as an overall feeling you were experiencing on that period of time?

Specific journey questions

Comment: As an example, the interviewee is asked to describe a specific journey, in particular for the ones where a positive or negative comments was provided. The goal is to explore that specific experience, its cause and how it may be either avoided or repeated.

I would like to explore some of the journeys your reported.

- Could you tell me about the journey on *(date)*, at *(time)*?
- You reported *"(comment)"*, would you be able to describe this situation?
- How do you think this situation could be solved / improved / replicated?
- What would you personally do to solve / improve / replicate the scenario?

Data collection and sharing questions

The final part of this interview is related to personal information.

- Are you aware of the data being collected? How intrusive do you think collecting such personal information is?
- Do you see yourself using this application outside this study? How would you be interested in continuing using it?
- What type of services would you be interested in getting from this application in a commuting scenario?

I don't have any further questions. Is there anything you would like to ask me? I would like to thank your participation once again. Feel free to contact us at any time, should any questions arise.

B.2. Fuzzy Sets

B.2.1. Input Variables

Luminosity (lux):
Dark: $(x_0, y_0) = (0, 1), (x_1, y_1) = (150, 0)$
Light: $(x_0, y_0) = (150, 0), (x_1, y_1) = (1000, 1)$
Noise (dB):
Quiet: $(x_0, y_0) = (0, 1), (x_1, y_1) = (30, 1), (x_2, y_2) = (50, 0)$
Average: $(x_0, y_0) = (45, 0), (x_1, y_1) = (52.5, 1), (x_2, y_2) = (60, 0)$

Loud: $(x_0, y_0) = (55, 0), (x_1, y_1) = (80, 1), (x_2, y_2) = (100, 1)$
Vibration (dB):
Smooth: $(x_0, y_0) = (0, 1), (x_1, y_1) = (88, 1), (x_2, y_2) = (103, 1)$
Rough: $(x_0, y_0) = (88, 0), (x_1, y_1) = (103, 1), (x_2, y_2) = (150, 1)$
Speed (kmh):
Slow: $(x_0, y_0) = (0, 1), (x_1, y_1) = (14, 1), (x_2, y_2) = (18, 0)$
Moderate: $(x_0, y_0) = (14, 0), (x_1, y_1) = (18, 1), (x_2, y_2) = (29, 1), (x_3, y_3) = (33, 0)$
Fast: $(x_0, y_0) = (29, 0), (x_1, y_1) = (33, 1), (x_2, y_2) = (100, 1)$
Arousal (reported):
Active: $(x_0, y_0) = (0, 0), (x_1, y_1) = (10, 1)$
Inactive: $(x_0, y_0) = (0, 1), (x_1, y_1) = (10, 0)$
Valence (reported):
Unhappy: $(x_0, y_0) = (0, 1), (x_1, y_1) = (5.5, 0)$
Happy: $(x_0, y_0) = (4.5, 0), (x_1, y_1) = (10, 1)$

B.2.2. Output Variable

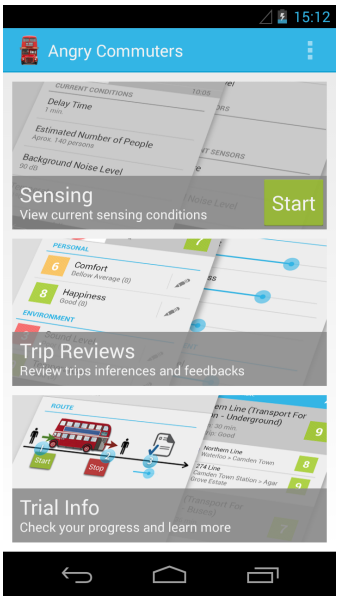
QoE:
Miserable: $(x_0, y_0) = (0, 0), (x_1, y_1) = (1.25, 1), (x_2, y_2) = (2.5, 0)$
Bad: $(x_0, y_0) = (2.5, 0), (x_1, y_1) = (3.75, 1), (x_2, y_2) = (5, 0)$
Good: $(x_0, y_0) = (5, 0), (x_1, y_1) = (6.25, 1), (x_2, y_2) = (7.5, 0)$
Excellent: $(x_0, y_0) = (7.5, 0), (x_1, y_1) = (8.75, 1), (x_2, y_2) = (10, 0)$

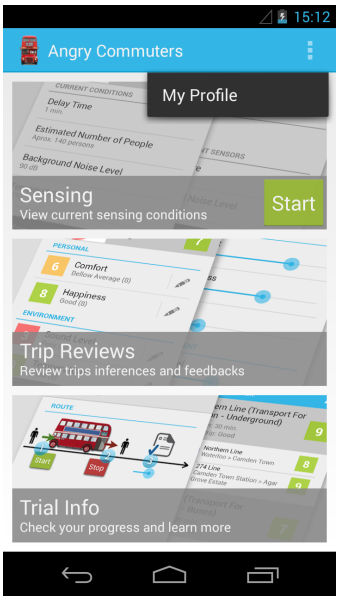
B.3. Fuzzy Rules

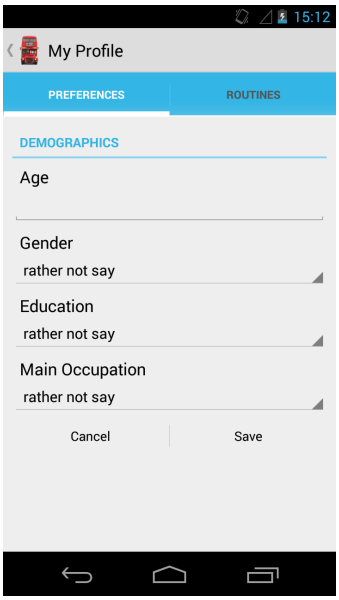
- `IF arousal IS inactive AND valence IS happy THEN qoe IS good`
- `IF arousal IS active AND valence IS happy THEN qoe IS excellent`
- `IF arousal IS inactive AND valence IS unhappy THEN qoe IS miserable`
- `IF arousal IS active AND valence IS unhappy THEN qoe IS bad`
- `IF noise IS loud THEN qoe IS bad`

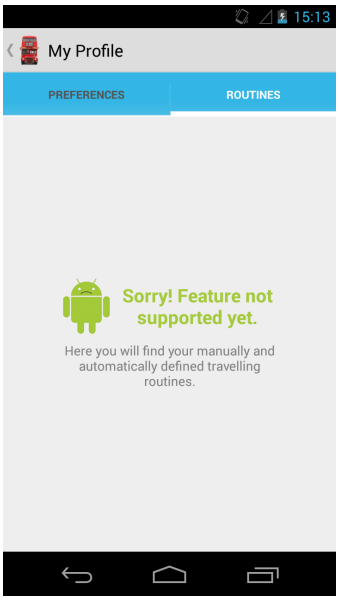
- `IF luminosity IS dark THEN qoe IS bad`
- `IF vibration IS smooth THEN qoe IS good`
- `IF vibration IS rough THEN qoe IS bad`
- `IF speed IS slow OR speed IS fast THEN qoe IS bad`
- `IF speed IS fast AND vibration IS rough THEN qoe IS miserable`
- `IF noise IS quiet AND vibration IS smooth AND speed IS moderate THEN qoe IS excellent`

B.4. Mobile Application Screens

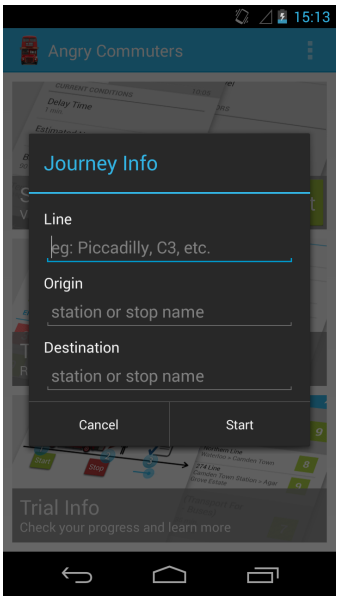

15:12
Angry Commuters
Sensing
View current sensing conditions
Start
Trip Reviews
Review trips inferences and feedbacks
Trial Info
Check your progress and learn more

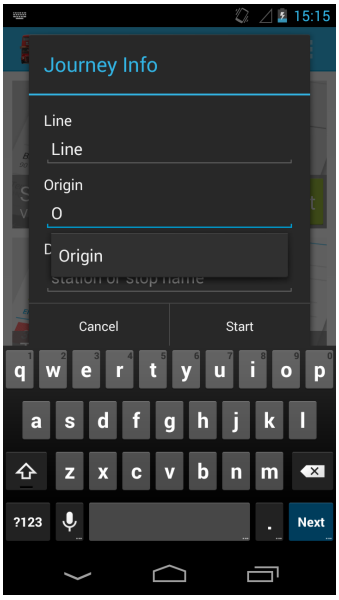

15:12
Angry Commuters
My Profile
Sensing
View current sensing conditions
Start
Trip Reviews
Review trips inferences and feedbacks
Trial Info
Check your progress and learn more

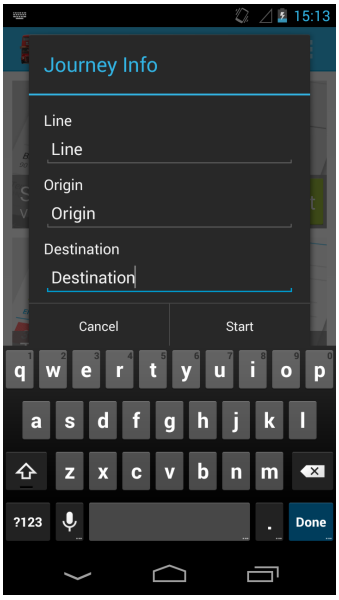

15:12
My Profile
PREFERENCES
ROUTINES
DEMOGRAPHICS
Age
Gender
rather not say
Education
rather not say
Main Occupation
rather not say
Cancel
Save

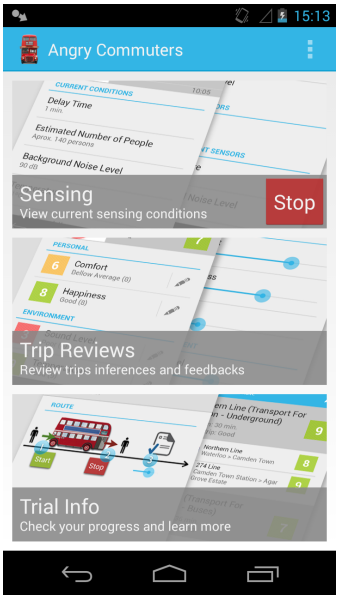

15:13
My Profile
PREFERENCES
ROUTINES
Sorry! Feature not supported yet.
Here you will find your manually and automatically defined travelling routines.

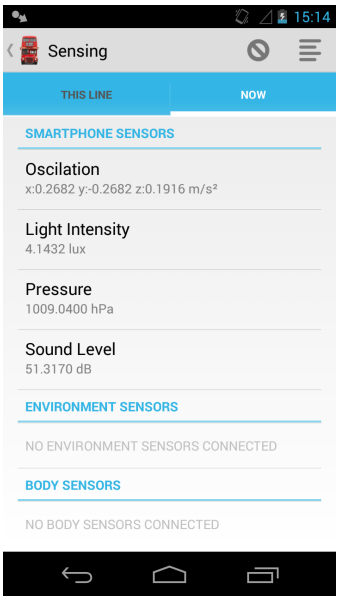

15:12
Trial Info
Your Progress
4/25
16%
Send Data
Edit Profile
You need 25 reports to validate your participation (that's about two weeks of usage)
Cloud2Bubble info
HOW TO USE
Start
Stop
1. Start after entering the bus/tube/train
2. Stop before getting out
3. Report your journey (per vehicle)
RESEARCH PROJECT
We are working towards an improved quality of experience from using public transport. Our research trial aims at collecting traveller feedback in relation to

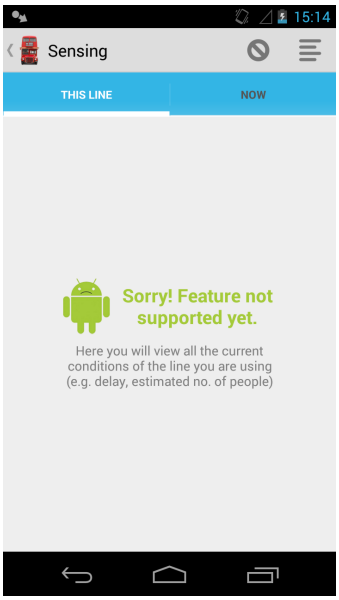

15:13
Angry Commuters
Journey Info
Line
eg: Piccadilly, C3, etc.
Origin
station or stop name
Destination
station or stop name
Cancel
Start
Trial Info
Check your progress and learn more

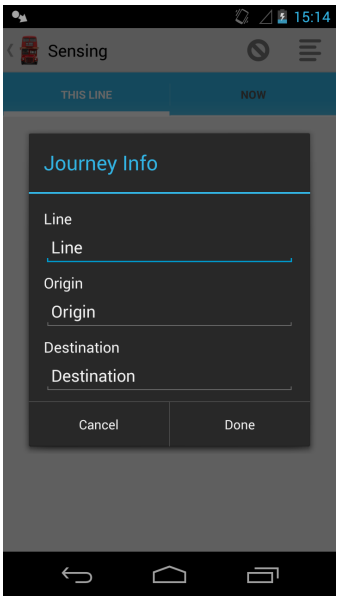

15:15
Journey Info
Line
Line
Origin
O
Origin
Cancel
Start
Next

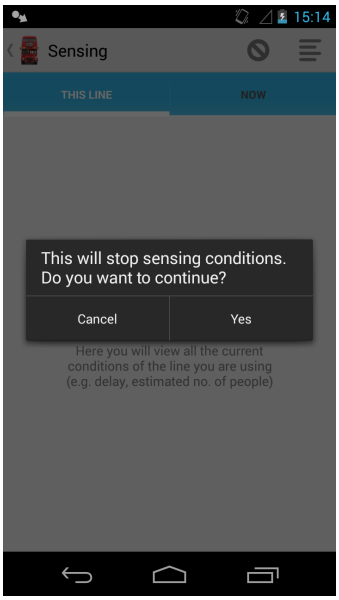

15:13
Journey Info
Line
Line
Origin
Origin
Destination
Destination
Cancel
Start
Done

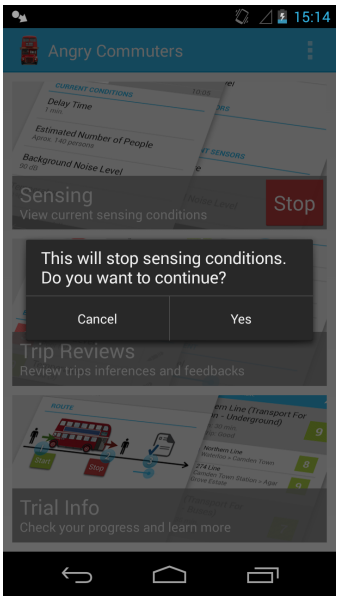

15:13
Angry Commuters
Sensing
View current sensing conditions
Stop
Trip Reviews
Review trips inferences and feedbacks
Trial Info
Check your progress and learn more

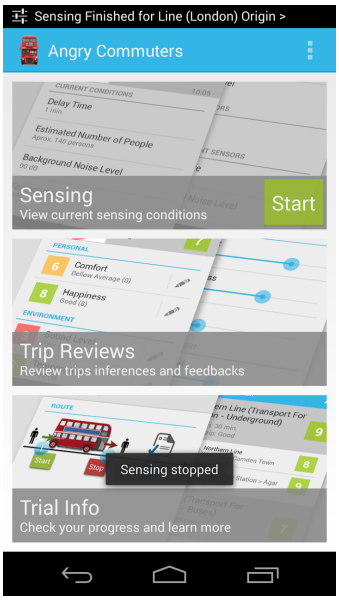

15:14
Sensing
THIS LINE
NOW
SMARTPHONE SENSORS
Oscilation
x:0.2682 y:-0.2682 z:0.1916 m/s²
Light Intensity
4.1432 lux
Pressure
1009.0400 hPa
Sound Level
51.3170 dB
ENVIRONMENT SENSORS
NO ENVIRONMENT SENSORS CONNECTED
BODY SENSORS
NO BODY SENSORS CONNECTED

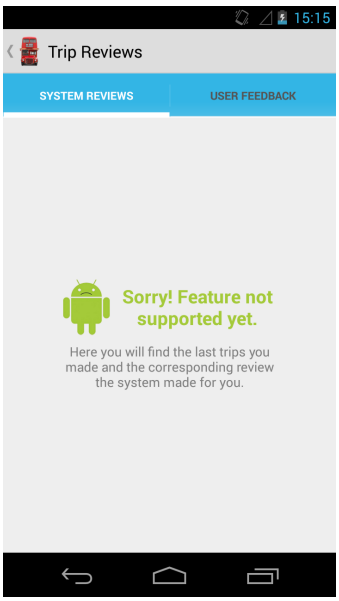

15:14
Sensing
THIS LINE
NOW
Sorry! Feature not supported yet.
Here you will view all the current conditions of the line you are using (e.g. delay, estimated no. of people)

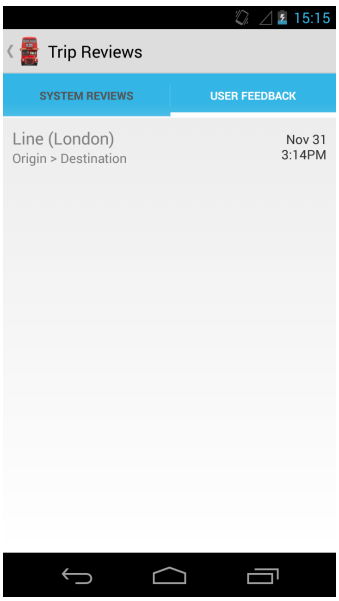

15:14
Sensing
THIS LINE
NOW
Journey Info
Line
Line
Origin
Origin
Destination
Destination
Cancel
Done

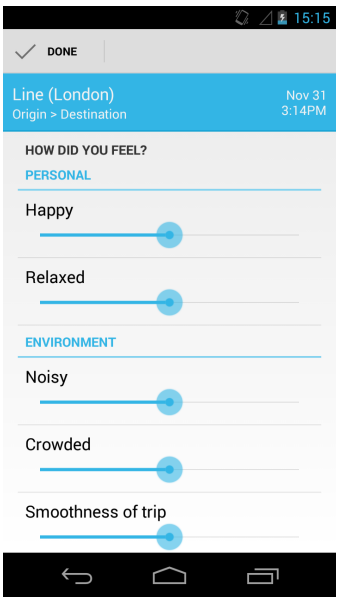

15:14
Sensing
THIS LINE
NOW
This will stop sensing conditions.
Do you want to continue?
Cancel
Yes
Here you will view all the current conditions of the line you are using (e.g. delay, estimated no. of people)

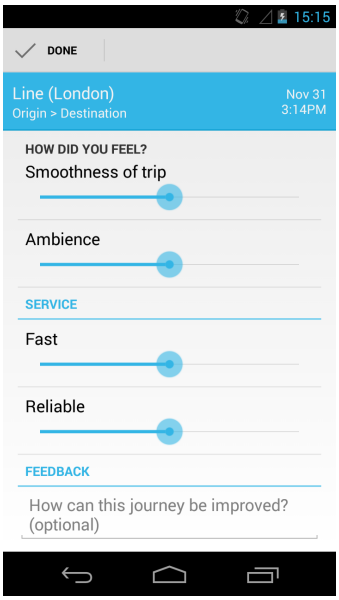

15:14
Angry Commuters
Sensing
View current sensing conditions
Stop
This will stop sensing conditions.
Do you want to continue?
Cancel
Yes
Trip Reviews
Review trips inferences and feedbacks
Trial Info
Check your progress and learn more

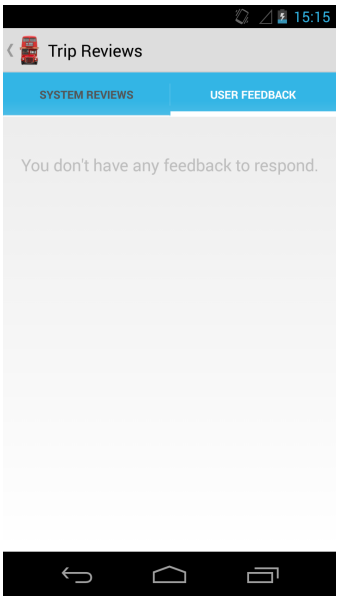

Sensing Finished for Line (London) Origin >
Angry Commuters
Sensing
View current sensing conditions
Start
Trip Reviews
Review trips inferences and feedbacks
Sensing stopped
Trial Info
Check your progress and learn more

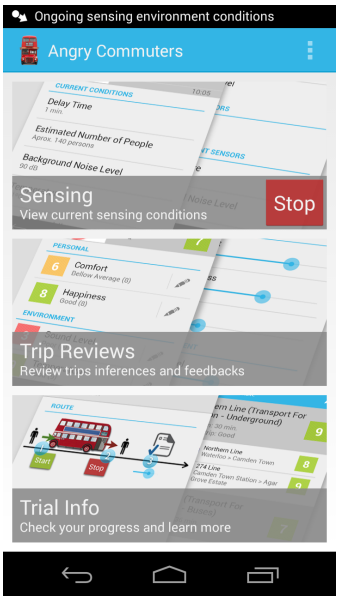

15:15
Trip Reviews
SYSTEM REVIEWS
USER FEEDBACK
Sorry! Feature not supported yet.
Here you will find the last trips you made and the corresponding review the system made for you.

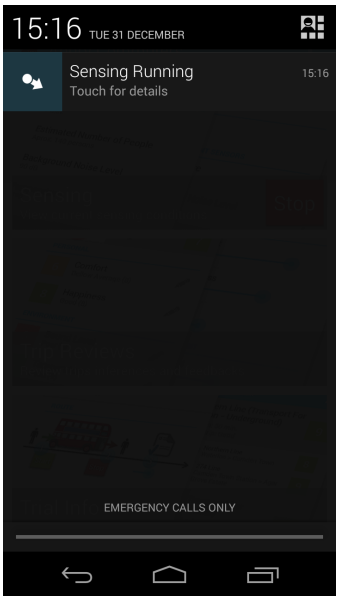

15:15
Trip Reviews
SYSTEM REVIEWS
USER FEEDBACK
Line (London)
Origin > Destination
Nov 31
3:14PM

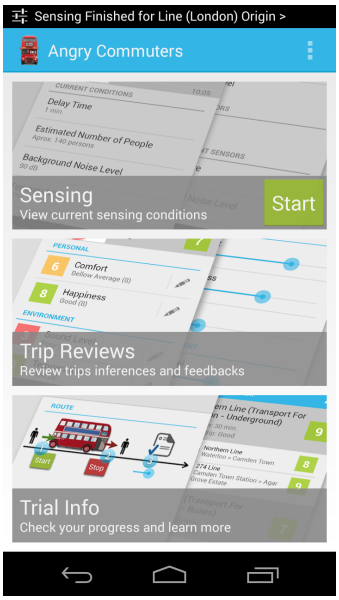

15:15
DONE
Line (London)
Origin > Destination
Nov 31
3:14PM
HOW DID YOU FEEL?
PERSONAL
Happy
Relaxed
ENVIRONMENT
Noisy
Crowded
Smoothness of trip

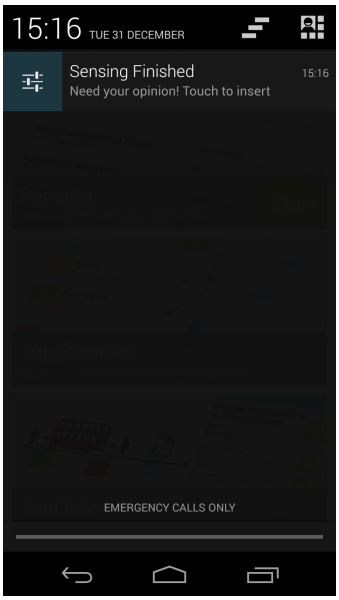

15:15
DONE
Line (London)
Origin > Destination
Nov 31
3:14PM
HOW DID YOU FEEL?
Smoothness of trip
Ambience
SERVICE
Fast
Reliable
FEEDBACK
How can this journey be improved? (optional)


15:15
Trip Reviews
SYSTEM REVIEWS
USER FEEDBACK
You don't have any feedback to respond.


Ongoing sensing environment conditions
Angry Commuters
Sensing
View current sensing conditions
Stop
Trip Reviews
Review trips inferences and feedbacks
Trial Info
Check your progress and learn more


15:16 TUE 31 DECEMBER
Sensing Running
Touch for details
15:16
EMERGENCY CALLS ONLY


Sensing Finished for Line (London) Origin >
Angry Commuters
Sensing
View current sensing conditions
Start
Trip Reviews
Review trips inferences and feedbacks
Trial Info
Check your progress and learn more


15:16 TUE 31 DECEMBER
Sensing Finished
Need your opinion! Touch to insert
15:16
EMERGENCY CALLS ONLY

B.5. Descriptive Statistics

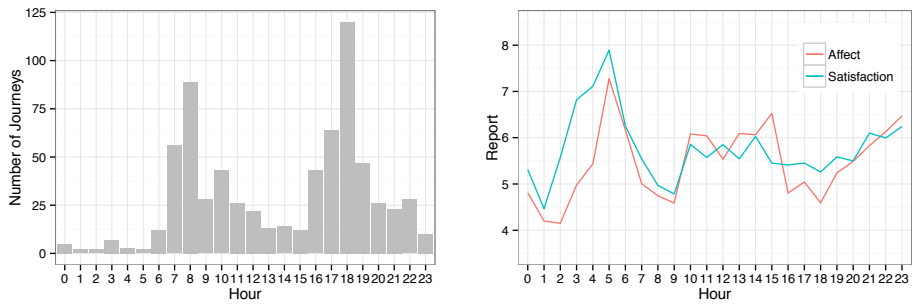
Table B.1.: UPT field study, descriptive statistics

Variable (N)	Mean (SD)	Range	Group (N)	Mean (SD)	Range
Age (29)	30.55 (8.31)	21-58	Female (9)	31.9 (4.6)	27-39
			Male (20)	30.0 (9.6)	21-58
Arousal (698)	4.75 (2.01)	0-10	Bus (229)	5.42 (2.03)	.1-10
			Train (468)	5.16 (2.0)	0-10
Valence (698)	5.18 (2.11)	0-10	Bus (229)	5.41 (1.98)	.2-10
			Train (468)	5.07 (2.16)	0-10
Noise (698)	5.53 (2.07)	0-10	Bus (229)	5.73 (1.91)	0-10
			Train (468)	5.44 (2.15)	0-10
Saturation (698)	5.04 (2.68)	0-10	Bus (229)	5.65 (2.40)	0-10
			Train (468)	4.75 (2.76)	0-10
Ambience (698)	5.09 (1.66)	0-9.4	Bus (229)	5.27 (1.41)	.8-9
			Train (468)	4.99 (1.76)	0-9.4
Smoothness (698)	5.72 (1.86)	0-10	Bus (229)	5.47 (1.80)	1.5-9.2
			Train (468)	5.84 (1.89)	0-10
Reliability (698)	5.78 (2.01)	0-10	Bus (229)	5.27 (1.53)	0-9.6
			Train (468)	6.04 (2.16)	0-10
Speed (698)	5.79 (2.13)	0-10	Bus (229)	5.40 (2.01)	0-10
			Train (468)	5.98 (2.16)	0-10
Sound (569)	61.9 (8.1)	2.4-73.6	Bus (187)	65.8 (6.8)	37.1-73.4
			Train (382)	60.1 (8.0)	2.4-73.6
Lumix (420)	81.4 (169.9)	0-1166.8	Bus (125)	119.8 (224.5)	0-1166.8
			Train (295)	64.6 (137.8)	0-954.1
Vibration (569)	47.5 (9.6)	.2-53.3	Bus (187)	49.8 (3.4)	10.3-53.3
			Train (382)	46.4 (11.3)	0.2-53.3
Location (0)	NA (NA)	NA	NA	NA	NA
Duration (698)	17:58 (14:09)	0:26-59:59	Bus (229)	16:15 (12:35)	0:44-59:59
			Train (468)	18:49 (15:02)	0:26-59:59

B.5.1. Comments

cheaper; stuck in traffic; app crashed suddenly; less kids; my shoulder hurts badly, needed a seat; people stop pushing the button multiple times for the same stop; driver was crazy; clean bus; smelly; left the phone on the seat the whole time; don't really know how to judge reliability based on one single trip, so I didn't change it; nice view; less squeaky breaks; not having the people that spit chewing gum on the floor; can you see from the oscillation data that I was playing abduction the whole trip? Hahaha; old man complaining about

foreigners; I was eating, wasn't paying attention. nothing was above my comfortable threshold; bus to the door, really cool; Removal of noisy girls. ; I took the wrong metro grr; I had to carry heavy bag so was really unhappy ; I had to carry some heavy bags so didn't enjoy it; I was after drinks after work; left 4mins late; train was one min late and arrived 4 min late.; was 1min late and arrived 4mins late at the destination; left 4 mins late arrived 8 mins late.; return to Wimbledon is a hassle and unreliable. number of times it terminated at phipps bridge put me of travel; late as always; left 5mins late arrived 6 mins late; was 2 mins late today due to previous delayed trains; A touch late arriving; was fine; quite crowded difficult to get off; on time for a change. more like this!; Previous train was canceled, this train full with no seats. More carriages, don't cancel trains; Train full and slow; metropolitan trains to wait until jubilee train opens doors; victoria line very crowded, no fresh air till oxford st. after this stop was fine-got a seat!; noisy due to air conditioning and very cold.; too crowded. need more frequent buses during rush hour; had a little girl spelling out loud all the words that her mum was saying. annoying!; less delays; too crowded; reduce the noise from the tracks. it was very cold. ; messages on the train are too loud.; passenger emergency alarm pulled. very slow; newer buses with better lighting and suspension ; was meant to go to Victoria but terminated early driver unhelpful ; better signaling on the track; Not be cancelled after 1 stop; No more loud kids getting on and sitting right behind me please !; No loud children or old bigots !; no screaming kids and yelling parents; Not being hungover would have been a good start...; I snoozed for most of it so who knows...; Cleaner bus; The bus was vibrating so strongly that my glasses were bouncing around on my nose !; Not be held at Barons Ct due to a problem with the train behind ! (was going to Hammersmith); No drunk Scotsman trying to make conversation...



(a) Number of Journeys vs. Time of Day

(b) Affect and Satisfaction Reports vs. Time of Day

Figure B.1.: Journeys and user reports over time

B.6. Data Schemas

```
{
    "title": "Journey",
    "description": "Describes a single journey details.",
    "type": "object",
    "properties": {
        "local_id": {
            "description": "Device specific journey identifier"
    ,
            "type": "integer"
        },
        "start_time": {
            "description": "Date and time of start of journey",
            "type": "datetime"
        },
        "end_time": {
            "description": "Date and time of end of journey",
            "type": "datetime"
        },
        "line": {
            "description": "Train/bus service line used",
            "type": "string"
        },
        "origin": {
            "description": "Station/stop of origin",
            "type": "string"
        },
        "destination": {
            "description": "Station/stop of destination",
            "type": "string"
        }
    },
    "required": ["local_id", "start_time", "end_time", "line",
    "origin", "destination"]
}
```

Listing B.1: Journey object schema

```
{
    "title": "User",
    "description": "Describes user profile.",
    "type": "object",
    "properties": {
```

```
        "id": {
            "description": "User identifier, based on device",
            "type": "integer"
        },
        "age": {
            "description": "User's age",
            "type": "integer"
        },
        "gender": {
            "description": "User's gender",
            "type": "string"
        },
        "education": {
            "description": "User's education level",
            "type": "string"
        },
        "occupation": {
            "description": "User's current occupation",
            "type": "string"
        }
    },
    "required": ["id"]
}
```

Listing B.2: User object schema

```
{
    "title": "Feedback",
    "description": "Describes the feedback for a journey",
    "type": "object",
    "properties": {
        "journey": {
            "description": "Identifies the journey it belongs",
            "type": "Journey"
        },
        "user": {
            "description": "Identifies the user",
            "type": "User"
        },
        "arousal": {
            "description": "Happy feedback",
            "type": "integer"
        },
        "valence": {
            "description": "Relaxed feedback",
```

```
            "type": "integer"
        },
        "sound": {
            "description": "Noise feedback",
            "type": "integer"
        },
        "saturation": {
            "description": "Crowding feedback",
            "type": "integer"
        },
        "smoothness": {
            "description": "Smooth feedback",
            "type": "integer"
        },
        "ambience": {
            "description": "Ambience feedback",
            "type": "integer"
        },
        "speed": {
            "description": "Speed feedback",
            "type": "integer"
        },
        "reliability": {
            "description": "Reliable feedback",
            "type": "integer"
        },
        "comment": {
            "description": "Open text feedback",
            "type": "string"
        },
    },
    "required": ["journey", "arousal", "valence", "sound", "
    saturation", "smoothness", "ambience", "speed", "
    reliability"]
}
```

Listing B.3: Feedback object schema

```
{
    "title": "Sensed",
    "description": "Reports all sensed data for a journey",
    "type": "object",
    "properties": {
        "journey": {
            "description": "Identifies the journey it belongs",
```

```
            "type": "Journey"
        },
        "timestamp": {
            "description": "Date and time of sensing",
            "type": "array",
            "items" : {
                "type": "datetime"
            }
        },
        "acceleration": {
            "description": "Accelerometer sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "humidity": {
            "description": "Humidity sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "latitude": {
            "description": "Location latitude sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "longitude": {
            "description": "Location longitude sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "light": {
            "description": "Luminosity sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
```

```
        "pressure": {
            "description": "Pressure sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "proximity": {
            "description": "Proximity sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "sound": {
            "description": "sound sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        },
        "temperature": {
            "description": "Thermometer sensed data",
            "type": "array",
            "items" : {
                "type": "long"
            }
        }
    },
    "required": ["journey", "timestamps"]
}
```

Listing B.4: Sensed object schema

C

Questionnaires

Pre-Usability Test Questionnaire

I. Public Transport

What modes of transportation do you use on your usual journeys?

_ Bus _ Coach _ DLR _ Rails _ River _Tram _ Tube

What is the main purpose of your Public Transport usage?

_____

How often, on average, do you use Public Transport for:

More than once per day	About everyday	2 to 6 times a week	Once a week, or less	Only when needed
( )	( )	( )	( )	( )
( )	( )	( )	( )	( )

While in-transit, how do you browse for journey alternatives?

_____

What are the main factors for deciding a journey alternative?

_ Duration _ Time _ Cost _ Mode _ Other _____

In what area do you usually use Public Transport?

eg, start and stop destinations in your usual commute)

_____

What is your opinion about your journey experience?

	Bad	Below Average	Neutral	Above Average	Good
Comfort	( )	( )	( )	( )	( )
Timeliness	( )	( )	( )	( )	( )
Crowded	( )	( )	( )	( )	( )
Noisy	( )	( )	( )	( )	( )
Easy to Plan	( )	( )	( )	( )	( )
Easy to Commute	( )	( )	( )	( )	( )
Public Info	( )	( )	( )	( )	( )

II. Smartphone Usage

How comfortable do you feel using mobile devices?

_ Uncomfortable _ Not very comfortable _ Netral _ Comfortable _ Very Comfortable

What kind of mobile phone(s) do you use on a regular basis?

_ Android OS based _ iOS based _ Windows based _ Other _____

I use my smartphone for:

_ voice communication (calls, video calls, skype)
_ internet (browsing, news, social networking)
_ services (information, banking, shopping)
_ instant messaging (SMS, messaging)
_ entertainment (music, films, games)
_ productivity (writing documents, photo editing)

Do you use any journey planning app, or realtime transit information on your device?

_ Yes, the app(s) is/are: _____
_ No

Post-Usability Test Questionnaire *(1/2)*

I. Tasks

I understand the purpose of the task:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1.1	( )	( )	( )	( )	( )
1.2	( )	( )	( )	( )	( )
1.3	( )	( )	( )	( )	( )
1.4	( )	( )	( )	( )	( )
1.5	( )	( )	( )	( )	( )
1.6	( )	( )	( )	( )	( )
1.7	( )	( )	( )	( )	( )
1.8	( )	( )	( )	( )	( )
2.1	( )	( )	( )	( )	( )
2.2	( )	( )	( )	( )	( )
2.3	( )	( )	( )	( )	( )
3.1	( )	( )	( )	( )	( )
3.2	( )	( )	( )	( )	( )

The tool assisted me in completing the task:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	*Area reserved for the researcher*	
						Duration	*Comments*
1.1	( )	( )	( )	( )	( )	_____	_____
1.2	( )	( )	( )	( )	( )	_____	_____
1.3	( )	( )	( )	( )	( )	_____	_____
1.4	( )	( )	( )	( )	( )	_____	_____
1.5	( )	( )	( )	( )	( )	_____	_____
1.6	( )	( )	( )	( )	( )	_____	_____
1.7	( )	( )	( )	( )	( )	_____	_____
1.8	( )	( )	( )	( )	( )	_____	_____
2.1	( )	( )	( )	( )	( )	_____	_____
2.2	( )	( )	( )	( )	( )	_____	_____
2.3	( )	( )	( )	( )	( )	_____	_____
3.1	( )	( )	( )	( )	( )	_____	_____
3.2	( )	( )	( )	( )	( )	_____	_____

Post-Usability Test Questionnaire *(2/2)*

II. Prototype

I understand the purpose of the application and its functioning.
_ Strongly Disagree _ Disagree _ Neutral _ Agree _ Strongly Agree

I would like to use this application in my own commuting scenario.
_ Strongly Disagree _ Disagree _ Neutral _ Agree _ Strongly Agree

Navigating through the different application was easy and intuitive.
_ Strongly Disagree _ Disagree _ Neutral _ Agree _ Strongly Agree

III. Comments

Please provide us with your comments, suggestions and recommendations.

_____
_____
_____
_____
_____
_____
_____

Quality of Experience in Public Transport, Participant Selection

This questionnaire will be used in the selection of participants for an experiment to assess the journey quality in Public Transports between May and June 2012. Your contribution is essential to the success of this project.

I. Public Transport Usage

Do you use Public Transport on a regular basis?

_ Yes, and I own a subscription *(eg, monthly ticket, pre-paid ticket)*
_ Yes, but I don't own a subscription _ No

How often, on average, do you use Public Transport for:

	More than once per day	About everyday	2 to 6 times a week	Once a week, or less	Never
your main activity (work, college, ...)	( )	( )	( )	( )	( )
other purposes (leisure...)	( )	( )	( )	( )	( )

How much time do you spend, on average, in a single journey?

_____

What modes of transportation do you use on your usual journeys?

_ Bus _ Coach _ DLR _ Rails _ River _Tram _ Tube

In what area do you usually use Public Transport?

eg, start and stop destinations in your usual commute)

_____

In what way do you think your journey experience can be improved?

tell us your ideas and suggestions for service improvements

_____
_____
_____
_____

II. Mobile Device Usage

What kind of smartphone(s) do you use on a regular basis?

_ Android OS based _ iOS based _ Windows based _ Other _____

I use my smartphone for:

_ voice communication (calls, video calls, skype) _ instant messaging (SMS, messaging)
_ internet (browsing, news, social networking) _ entertainment (music, films, games)
_ services (information, banking, shopping) _ productivity (writing documents, photo editing)

III. Demographic Information

Age _____ **Gender** _ M _ F **Contact** (e-mail) _____

Main Occupation

_ Work Full Time _ Work Part Time _ Student Full Time _ Student Part Time
_ Not working _ Unemployed _ Retired

Level of Education

_ Less than High School _ High School _ Bachelor's degree _ Master's degree _ Doctoral degree

I'm willing to actively contribute with daily, anonymous reports on my Public Transport experience through my smartphone during the course of this experiment. _ Yes _ No

D

Mobile Application Usability Test

D.1. Participant Information Sheet

We are conducting research into affective ubiquitous computing for enhancing quality of experience in urban public transport at Imperial College London. We are investigating new ways to support peoples' travelling decisions based on their emotional states and environment conditions. A smartphone application will be developed as an interface with the commuter. In order to explore our ideas, we are involving regular travellers in the design, usability testing and evaluation of the application prototype. This study, in particular, focuses on testing design ideas for better serving the general public.

You are invited to participate in this research and we would appreciate any assistance you can offer, although you are under no obligation to do so, and you may choose to end the test at any time.

Participation involves one visit to our laboratory at Imperial College London, for approximately 30 minutes. If you agree to participate, you may be asked to perform a number of tasks using an application prototype. The scenarios and tasks will be fully explained. You will be asked to navigate through the prototype to accomplish the tasks provided. The activities you undertake and the time you spend working on each task will be digitally recorded together with synchronised video. You will be asked to fill in a short questionnaire about your age, education level and existing experience with the tasks and technology, as well as a short questionnaire on your experience afterwards. This is a test of the application; we are not testing

you. If you find something difficult to use, chances are that others will do as well. This test is simply a mean of evaluating the application design, to discover any issues we need to address and improve its usability.

All the questionnaire information you provide and recorded data will remain anonymous and used solely by researchers whithin the scope of this project. Your name will not be used in any reports arising from this study. The information collected during this study may be used in future analysis and publications and will be kept indefinitely. At the conclusion of the study, a summary of the findings will be available from the researchers upon request.

If you do not want to participate, you don't have to give any reason for your decision. If you do participate, you may withdraw at any time during the session and you can also ask for the information you have provided to be withdrawn at any time.

If you agree to participate in this study, please first complete the consent form attached to this information sheet. Your consent form will be kept separately from your questionnaire data so that no-one will be able to identify your answers from the information you provide.

Thank you very much for your time and help in making this study possible. If you have any questions at any time you can contact the responsible.

D.1.1. Consent Form

I have been given an explanation and understand the purpose of this research project. I have had an opportunity to ask questions and have them answered. I understand that at the conclusion of the study, a summary of the findings will be available from the researchers upon request.

I understand that the data collected from the study will be held indefinitely and may be used in future analysis.

I understand that I may withdraw myself and any information traceable to me at any time without giving a reason, and without any penalty.

I understand that I may withdraw my participation during the session at any time. I agree to take part in this research by completing the session.

I agree/do not agree for my digital and video recordings, taken during the session, to be used in future research reports and publications about this project.

D.2. Usability Test Script

Title: Smart Mobile Sensing for Measuring Quality of Experience in Urban Public Transport

Persona and Context

You are a worker/student in London with a fixed/semi-flexible schedule. In addition, you go to your workplace/college every day using urban public transportation. You downloaded the application, and you expect it to suggest you alternative routes. You were guided through the steps explaining it how the application works. Finally, you have a wearable device, e.g. a smartwatch, capable of collect affective readings, compatible with the application.

Scenario 1

Today you go to work/college and you want to collect the data from the journey to support the quality of journey inference.

Tasks

1. You enter the vehicle. Start collecting the application data for the trip.
2. Connect your smartphone to your smartwatch, so you may collect personal affective data.
3. Ensure the application is receiving data from your wearable device.
4. While travelling you want to navigate through the application. What is the delay of the current vehicle you are in?
5. You have to make a call so you exit the application. When you are finished, check your personal profile.
6. You realise your profile is wrong so you want to edit. Change preferred temperature to 18°C to 20°C interval.
7. You arrived at the workplace/college, stop sensing.

8. When you received a notification, provide your feedback for the journey.

Scenario 2

You have had the application for some time now and gathered enough personal information from your trips. Today you want to go play tennis with a friend on the other side of town and you decide to use public transportation.

Tasks

1. Plan the trip from the closest station to the tennis complex, pick your preferred alternative.
2. You decide you will play tennis at this time every week and you do not want to plan it every time. Find a way to receive notifications in the following weeks when the conditions are not the best for you.
3. You finished your trip and you received one notification, but you are late and do not have time to respond now.
4. Later on you device to review the journey. You decide the comfort inference is not correct and decide to correct it.

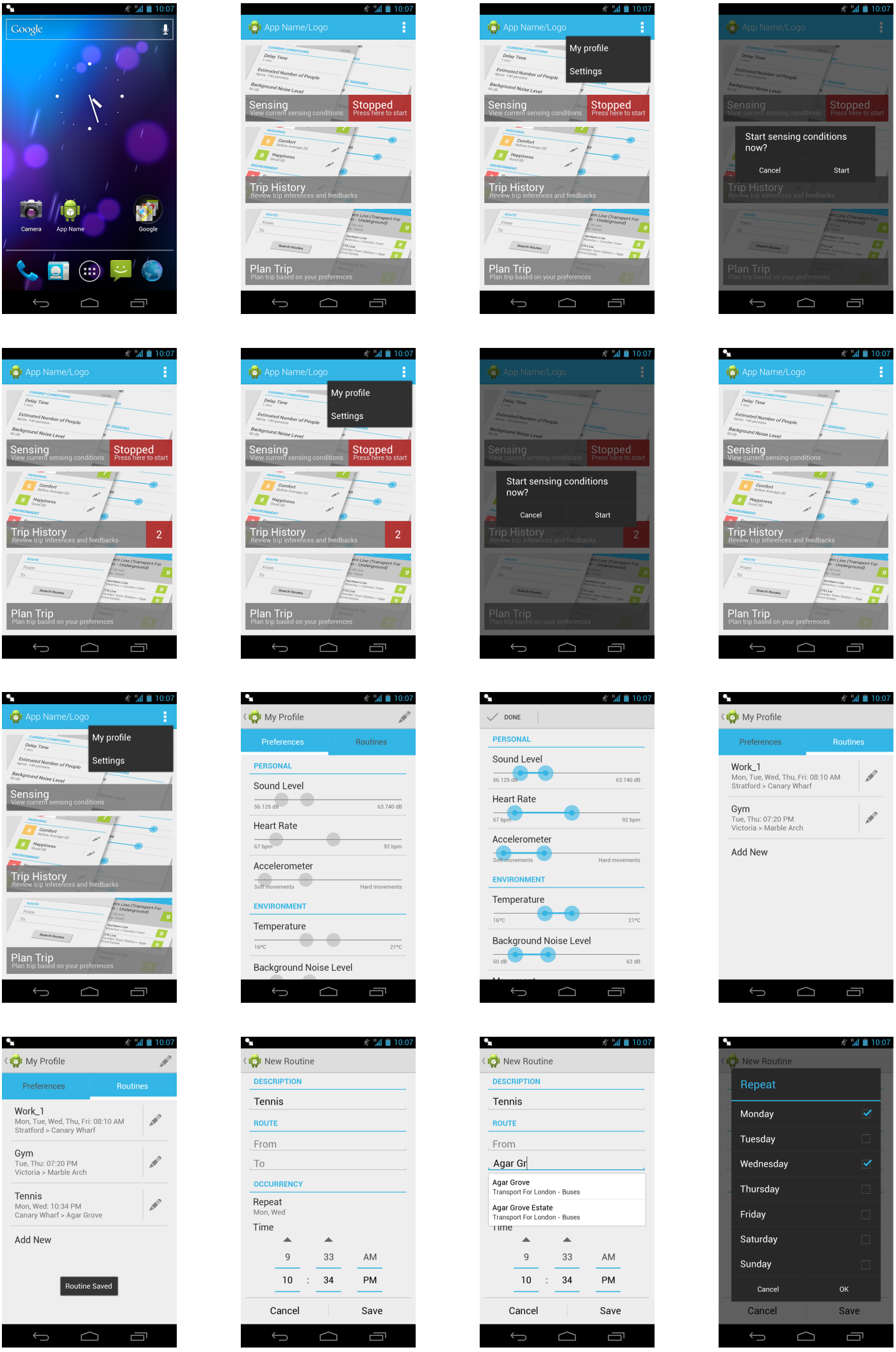
Scenario 3

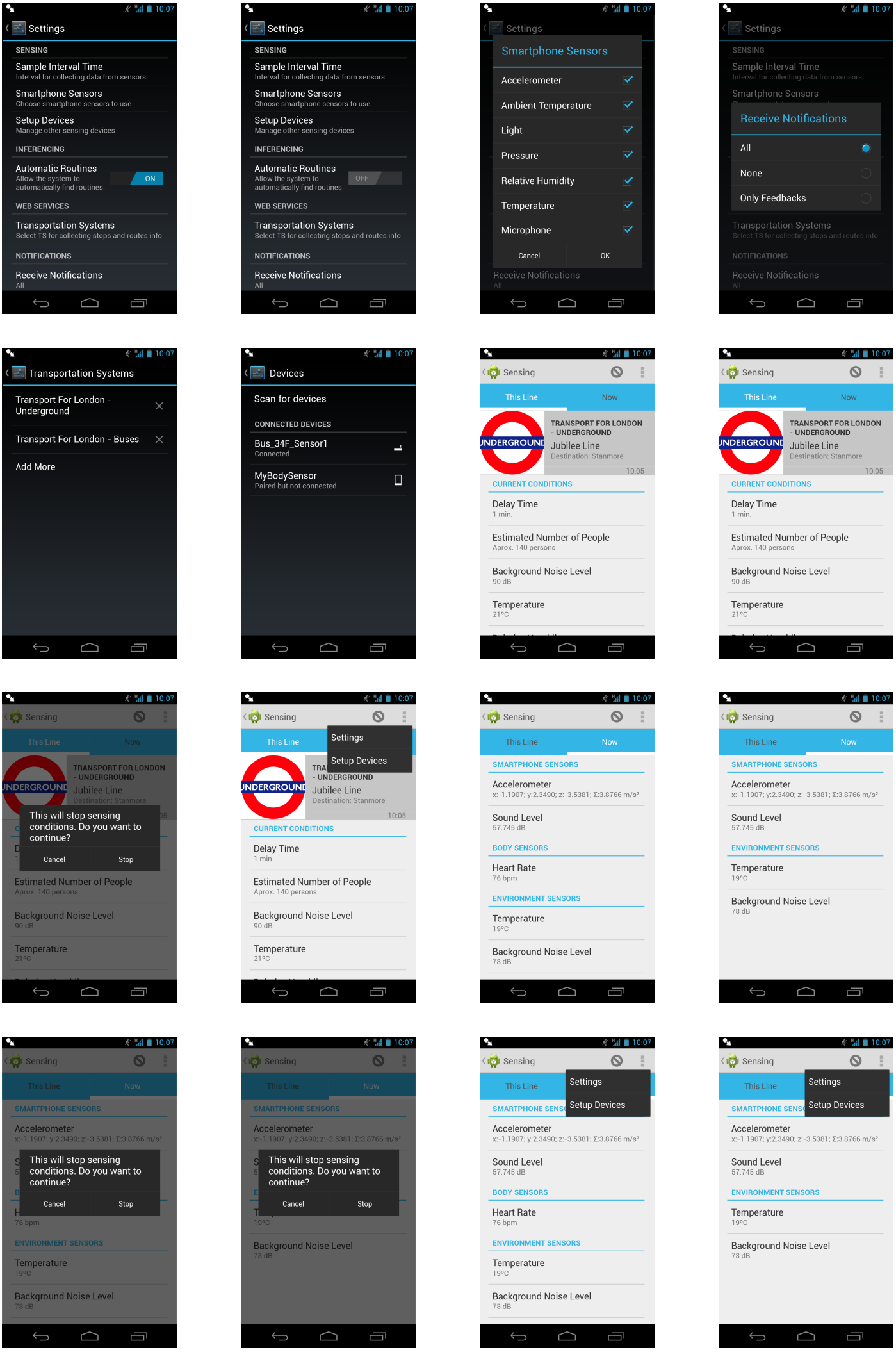
You are coming back home from work in the afternoon. However, today there is a special event in the city, making public transportation more crowded than usual. You receive a notification on your smartphone.

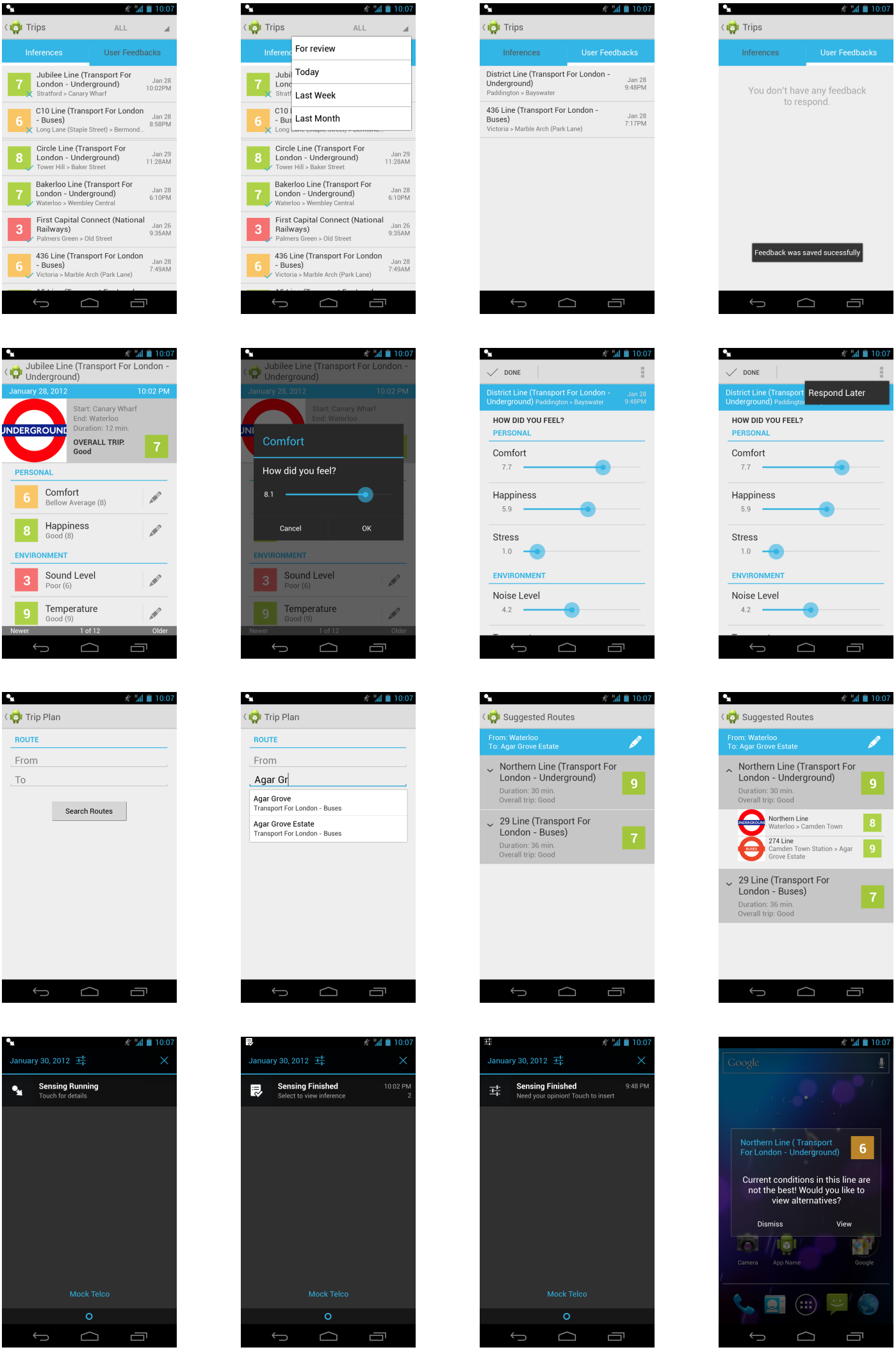
Tasks

1. How are you going to get home today?
2. You have to do some shopping in a different location from. How would you plan for an intermediate destination?

D.2.1. Prototype Screens


10:07
Google
Camera
App Name
Google
App Name/Logo
Sensing
View current sensing conditions
Stopped
Press here to start
Trip History
Review trip inferences and feedbacks
Plan Trip
Plan trip based on your preferences
My profile
Settings
Start sensing conditions now?
Cancel
Start
2
My Profile
Preferences
Routines
PERSONAL
Sound Level
56.125 dB
63.740 dB
Heart Rate
67 bpm
92 bpm
Accelerometer
Soft movements
Hard movements
ENVIRONMENT
Temperature
16ºC
21ºC
Background Noise Level
DONE
Work_1
Mon, Tue, Wed, Thu, Fri: 08:10 AM
Stratford > Canary Wharf
Gym
Tue, Thu: 07:20 PM
Victoria > Marble Arch
Add New
Tennis
Mon, Wed: 10:34 PM
Canary Wharf > Agar Grove
Routine Saved
New Routine
DESCRIPTION
Tennis
ROUTE
From
To
OCCURRENCY
Repeat
Mon, Wed
Time
9
33
AM
10
34
PM
Cancel
Save
Agar Gr
Agar Grove
Transport For London - Buses
Agar Grove Estate
Transport For London - Buses
Repeat
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
OK


10:07
Settings
SENSING
Sample Interval Time
Interval for collecting data from sensors
Smartphone Sensors
Choose smartphone sensors to use
Setup Devices
Manage other sensing devices
INFERENCING
Automatic Routines
Allow the system to automatically find routines
ON
OFF
WEB SERVICES
Transportation Systems
Select TS for collecting stops and routes info
NOTIFICATIONS
Receive Notifications
All
Smartphone Sensors
Accelerometer
Ambient Temperature
Light
Pressure
Relative Humidity
Temperature
Microphone
Cancel
OK
Receive Notifications
All
None
Only Feedbacks
Transport For London - Underground
Transport For London - Buses
Add More
Devices
Scan for devices
CONNECTED DEVICES
Bus_34F_Sensor1
Connected
MyBodySensor
Paired but not connected
Sensing
This Line
Now
TRANSPORT FOR LONDON - UNDERGROUND
Jubilee Line
Destination: Stanmore
10:05
CURRENT CONDITIONS
Delay Time
1 min.
Estimated Number of People
Aprox. 140 persons
Background Noise Level
90 dB
Temperature
21ºC
This will stop sensing conditions. Do you want to continue?
Stop
Settings
Setup Devices
SMARTPHONE SENSORS
Accelerometer
x:-1.1907; y:2.3490; z:-3.5381; Σ:3.8766 m/s²
Sound Level
57.745 dB
BODY SENSORS
Heart Rate
76 bpm
ENVIRONMENT SENSORS
Temperature
19ºC
Background Noise Level
78 dB


10:07
Trips
ALL
Inferences
User Feedbacks
7 Jubilee Line (Transport For London - Underground) Jan 28 10:02PM
Stratford > Canary Wharf
6 C10 Line (Transport For London - Buses) Jan 28 8:58PM
Long Lane (Staple Street) > Bermond...
8 Circle Line (Transport For London - Underground) Jan 29 11:28AM
Tower Hill > Baker Street
7 Bakerloo Line (Transport For London - Underground) Jan 28 6:10PM
Waterloo > Wembley Central
3 First Capital Connect (National Railways) Jan 26 9:35AM
Palmers Green > Old Street
6 436 Line (Transport For London - Buses) Jan 28 7:49AM
Victoria > Marble Arch (Park Lane)
For review
Today
Last Week
Last Month
District Line (Transport For London - Underground) Jan 28 9:48PM
Paddington > Bayswater
436 Line (Transport For London - Buses) Jan 28 7:17PM
Victoria > Marble Arch (Park Lane)
You don't have any feedback to respond.
Feedback was saved sucessfully
Jubilee Line (Transport For London - Underground)
January 28, 2012 10:02 PM
Start: Canary Wharf
End: Waterloo
Duration: 12 min.
OVERALL TRIP: Good
7
PERSONAL
6 Comfort Bellow Average (8)
8 Happiness Good (8)
ENVIRONMENT
3 Sound Level Poor (6)
9 Temperature Good (9)
Newer 1 of 12 Older
Comfort
How did you feel?
8.1
Cancel
OK
DONE
District Line (Transport For London - Underground) Paddington > Bayswater Jan 28 9:48PM
HOW DID YOU FEEL?
PERSONAL
Comfort 7.7
Happiness 5.9
Stress 1.0
ENVIRONMENT
Noise Level 4.2
Respond Later
Trip Plan
ROUTE
From
To
Search Routes
Agar Gr
Agar Grove
Transport For London - Buses
Agar Grove Estate
Transport For London - Buses
Suggested Routes
From: Waterloo
To: Agar Grove Estate
Northern Line (Transport For London - Underground)
Duration: 30 min.
Overall trip: Good
9
29 Line (Transport For London - Buses)
Duration: 36 min.
Overall trip: Good
7
Northern Line Waterloo > Camden Town
8
274 Line Camden Town Station > Agar Grove Estate
9
January 30, 2012
Sensing Running
Touch for details
Sensing Finished
Select to view inference
10:02 PM
2
Need your opinion! Touch to insert
9:48 PM
Mock Telco
Google
Northern Line (Transport For London - Underground)
6
Current conditions in this line are not the best! Would you like to view alternatives?
Dismiss
View
Camera
App Name
Google

E

Mobile Application User Manual

Angry Commuters
User Manual

London, November 2012

Contents

Goals

The main goal of this study is to collect user data from a sample of regular passengers, or commuters, representative of the potential future users. The data collected is obtained through the Angry Commuters application and sent to a server for further analysis. This information enable us to analyse in what way journey conditions influence the perception and experience of each traveller. Thus, this experiment will allow us to explore comfort patterns for each individual traveller.

What is *Angry Commuters*?

1. *Angry Commuters* is a mobile application that enables the interaction between a central system and users. From the app is possible to collect or sense certain environment variables while in transit. This collection of data is done through smartphone sensors and other sensors installed throughout the public transport network. These data is aggregated with the emotional state of the user based on their perception of the journey, using participatory sensing.

2. After a journey, all the information is sent to a cloud-based system through the communication network where it is processed. This enables the generation of user profiles, with preferences based on the context-emotional correlations identified. The profile will become increasingly accurate with a higher number of reported journeys.

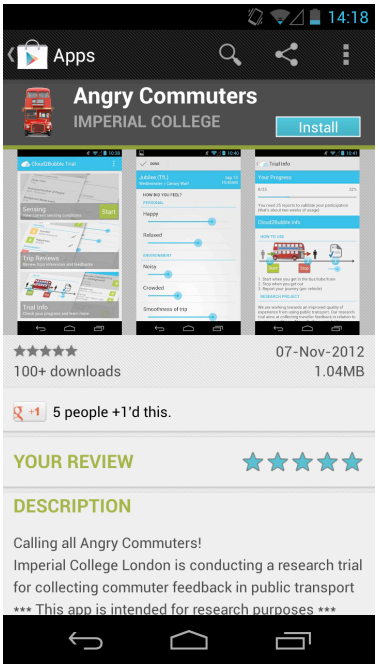
3. Finally, with access in real-time to public transport conditions as well as user profiles (including their daily/weekly routines) *Angry Commuters* aims at informing the user through the smartphone of alternatives with the potential to provide an enhanced travelling experience. In addition, it allows for a personalised search for better alternatives at any given moment.

> **Note: Given the project's early stage of development, the application is focused on stages 1. and 2. described above.**
>
> **More information available at http://www.cloud2bubble.com/case-studies/experiment/**

1. Install

You may install Angry Commuters via the Google Play Store:

1. Search for “Angry Commuters” on the Google Play Store app;
2. Press “Install” at the top of the screen;
3. Read and accept the app permissions to initiate the download and installation;
4. When finished, press “Open” and find it on your app list.
5. Quando terminado, pressionar “Abrir” ou encontrá-la na sua lista de aplicações.



Alternatively, you can install it through the browser via:

https://play.google.com/store/apps/details?id=com.cloud2bubble.trial

Spread a little empathy on your journey to work with the Angry Commuters app - The Next Web
http://tnw.to/mJrx

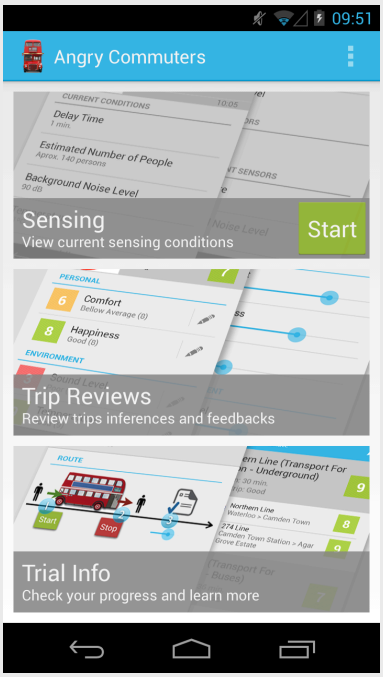
20 Best Android apps this week - The Guardian
http://www.guardian.co.uk/technology/appsblog/2012/nov/09/best-android-apps-boots-echofon

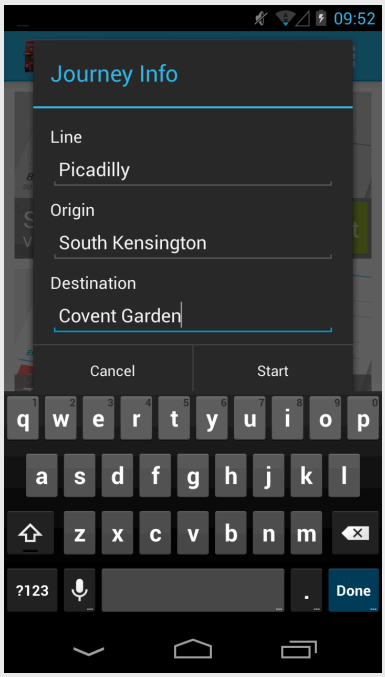
Best Android apps this week - Stuff Magazine
http://www.stuff.tv/best-android-apps-week/news-7

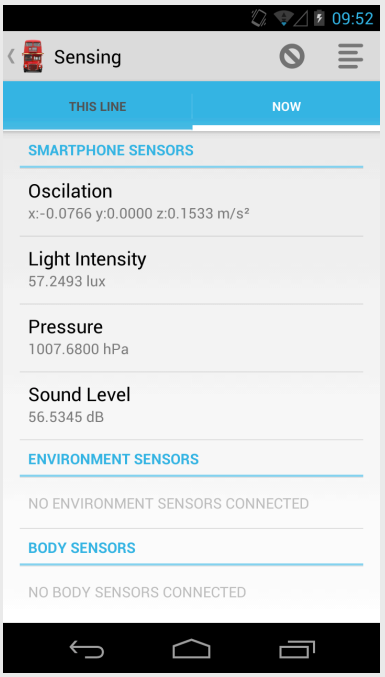
2. Using the Application

Angry Commuters follows a simple structure, the following descriptions provide an overview of the main features available on this version of the application.

2.1. Overview







1. Main Screen

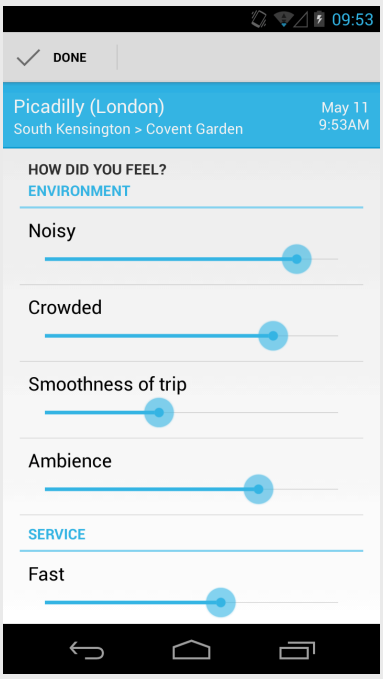
- start journey sensing with “Start”
- press the “Menu” option for extra options
- “Sensing” is not available until the data collection is initiated

2. Journey details

- input journey details
- memory for previous journeys
- these details may be added at any point during the journey, however they will be needed before finishing

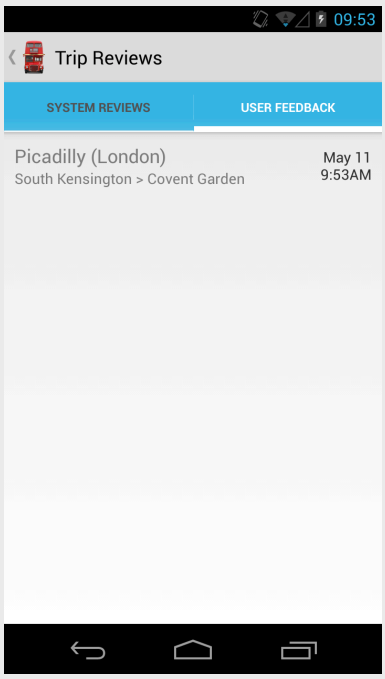
3. Sensing

- “Now” show live details as they are being collected from the sensors
- the options at the top lead to screens (7) and (2) respectively
- “This Line” not implemented



4. Journey Feedback

- move the sliders according to your satisfaction with the journey
- insert optional comment
- press “Done” when finished
- may be filled in later, at users’ own convenience



5. Revisions List

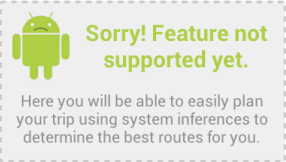
- “User Feedback” shows journeys awaiting for user feedback
- chronological order: most recent at the top
- “System Reviews” not implemented

6. Trial Info

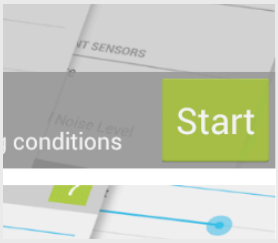
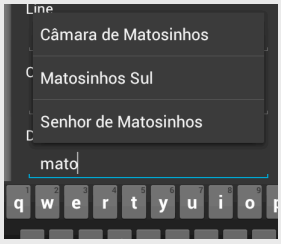
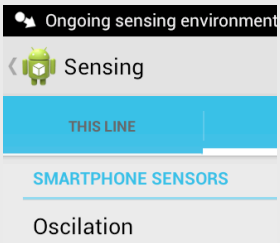
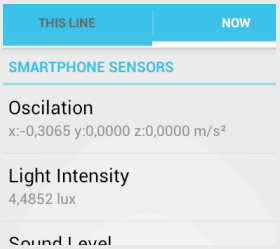
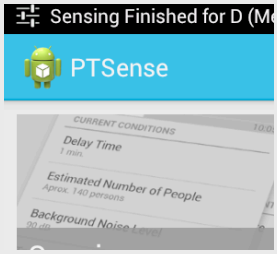
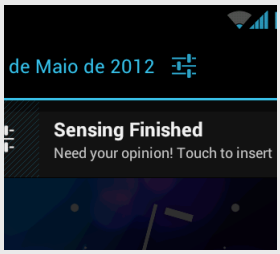
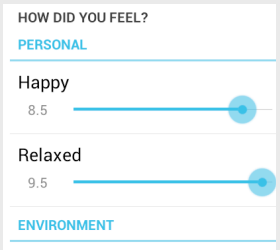
- edit personal profile: age, gender, education and occupation
- quick instructions on how to use the application
- progress bar showing number of reported journeys

Note: The screens shown are taken from the Android 4.0 version. The look may vary in older versions of the platform.

Note: Not all features are implemented at this stage. This image is shown for the features that are not available, with a description of its functionality.



2.2. Usage Example

			
1. Press **"START"** on the main screen to initiate journey sensing *after* boarding the vehicle	**2.** Insert **journey details** at any point: beginning, during or end	**3.** The **notification** shows the state of data collection	**4.** Inspect what data is being collected and current values.
			
5. STOP journey sensing *before* leaving the vehicle, on the main screen or in Sensing	**6.** The **notification** show the pending feedback for that (or more) journeys	**7.** Press the notification at the top at any point, or go to Trip Reviews later	**8.** Provide your journey **feedback** with an optional comment

3. Data Handling and Privacy

The process of data collection is only active while Sensing is active, for sensor data, via the feedback form and the personal profile. The sensors used are: microphone, location, motion, temperature, luminosity and barometric pressure. Support may vary depending on your device model, and may be deactivated on the Settings screen.

All data is collected anonymously, no personal identifiers are included in the data. A unique identifier is generated when the application is installed, that allows us to group journeys from the same source, however, it doesn't identify the individual in any way.

We would like you to use the application continuously to provide us with a reasonable amount of data. You can check your progress on the Trial Info screen. If you wish to stop contributing you may do so at any time, deleting the application will erase the unique identifier used to collect data.

If you wish, we can provide you with a summarised report of your personal contribution. To do so, please contact the researchers, as you will need to provide a form of data identification. Finally, any personal generated data will be deleted upon request.

4. Contacts

You can get more information about the project visiting www.cloud2bubble.com
At this stage of the project, your contribution is essential for us to explore and improve the quality of your commute. Your feedback is highly appreciated. For further questions, suggestions or any other comments, please contact:

- **Pedro Maurício Costa**
  pm.costa@imperial.ac.uk
  Imperial College London

Happy commuting!

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