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# The Ambient Digital Library

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## ABSTRACT

*Conventional digital libraries increasingly support remote access from mobile devices. However, the archetypical mobile user differs from the conventional user in a number of aspects; of these the most important is context. Synonymous with mobile computing is the context concept, and factoring the availability of select contextual elements into the design of digital libraries offers significant opportunities for adapting and personalising services for the mobile computing community. This paper proposes the Ambient Digital Library as a construct for integrating digital content, contextual parameters, and user models. In this way, a digital library may be made more accessible to a broader category of mobile user.*

*Keywords: Ambient Digital Library, Ambient Intelligence, Context, Digital Libraries, Mobile Computing, Mobile Computing Community*

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## INTRODUCTION

As the relentless growth of mobile computing continues, there is an increasing demand for new and innovative services in various general and specialist application domains. Developments in mobile communications have been of fundamental importance; accessing up-to-date information of various hues in practically real-time conditions is commonplace, particularly through the use of mobile internet technologies. As this scenario evolves, significant new markets will continually open up to innovative content providers.

Conventional libraries are frequently perceived as rather static conservative entities. Digital libraries, by their incorporation of digital technologies, may be perceived as more dynamic and responsive to user requirements;

yet this may be a false perception. Unless a proactive and innovative approach is taken to library design, a digital library may ultimately mirror its physical counterpart in being perceived as a largely static repository. Objectively, this situation is worse in that digital libraries by their very nature have opportunities to deliver a rich set of tailored services in diverse ways that are not available to their physical counterparts. Supporting mobile users in the fulfillment of various, albeit specialised, tasks is one example.

The Ambient Digital Library is proposed as an enabling construct for facilitating universal mobile access to information. Inherent in its design is an acute awareness of the dynamic nature of mobile users. The notion of context offers a vehicle by which this dynamic may be encapsulated. In this way, information can be filtered and prioritised in real-time according to the needs of the mobile user at any time juncture.

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## THE DIGITAL LIBRARY CONSTRUCT

Research in digital libraries has been ongoing since the early 1990s. Objectively, such libraries may be regarded as amongst the most complex forms of information systems (Fox & Marchionini, 1998) as many different disciplines, for example, databases, information retrieval and Web technologies, contribute to their definition and implementation. One of the inherent difficulties in a multi-disciplinary paradigm is that the expectations of various constituencies may differ. For example, researchers regard a digital library as constituting digital content assembled on behalf of some interested community while librarians focus on the institutional or service perspective (Borgman, 1999). For the purposes of this discussion, the former view is subscribed to.

In recent years, there has been significant effort directed towards establishing some theoretical foundations for digital libraries (Candela et al., 2010). One example of this is the Digital Library Manifesto (Ross, 2010), an initiative of the DELOS Network of Excellence. Such developments are essential if key challenges such as interoperability are to be overcome (Suleman, 2011). Despite a lack of formal foundations, many digital libraries have been developed, albeit in a rather ad-hoc fashion. A variety of subjects are covered, many in the sciences and humanities, for example, archaeology (Ravindranathan et al., 2004) and mathematics (Sylwestrzak et al., 2010).

Developments in mobile computing have led some researchers to investigate the issue of digital library access from mobile devices (Jensen, 2010; Marshall et al., 2001). DL2GO represents a framework for enabling editable and portable personal digital libraries (Kil et al., 2008). How the ubiquitous iPod may host a digital library has also been explored (Bainbridge et al., 2008). In Japan, a tsunami digital library has been developed with the expressed objective of supporting access via mobile phones (Imai et al., 2007).

A common characteristic of many digital libraries is the relatively static nature of content access and presentation. Synonymous with mobile users is the notion of context, a construct that seeks to encapsulate the dynamic nature of the mobile user in a multitude of dimensions. The objective of an Ambient Digital Library is to reflect this dynamic. Thus an Ambient Digital Library seeks to present its content to reflect the prevailing context of the mobile user. To do this, it is necessary that the digital corpus be tagged with additional metadata, and augmented with additional functionality, such that it can filter, personalise and contextualise content as user context demands.

## A REVIEW OF CONTEXT IN MOBILE COMPUTING

Context is a particularly attractive construct in mobile computing application. As understanding of the mobile computing paradigm matured, it became clear that the prevailing situation at the time of service invocation was dynamic and unpredictable; and that this would have significant implications for usability as well as other aspects of the software engineering process. Though the nomadic nature of the end-user became a critical differentiator from standard desktop computing, it was quickly realised that a significant opportunity existed for customising services according to the situation that the end-users found themselves. Thus interest in the potential and use of context in mobile computing increased.

Intriguingly, defining context has proved problematic, despite it being a relatively intuitive concept. An examination of the literature will reveal a number of attempts at defining context including (Schilit et al., 1994; Dey, 2001). The International Standards Organisation (ISO) also has a formal definition (ISO, 1998). Conceiving another definition is inappropriate in this instance; however, it is useful to examine the various elements of context that may be harnessed in the delivery of services to mobile users. In this way, a better understand-

ing of the nature of mobile computing may be gained which can, in turned, be used to enlighten the process of designing digital libraries for mobile users. For the purposes of this discussion, the model proposed by Schmidt (1999) is considered. This model classifies context into human factors and physical environment. It is not a definitive model of context; rather it offers a classification scheme and structure for discussing and exploring some of the subtleties of context.

### Human Factors

Three broad categories of context may be considered under the heading Human Factors – user characteristics, social environment and task. Individual user characteristics are particularly important and have formed the basis of substantial research in user modelling (Adams & Gill, 2007) and personalisation (Tuzhilin, 2009) amongst others. The individual elements that constitute a user model typically involve a core of primitive information about the user, for example age, sex and language, etc. Depending on the nature of domain that the user model is required to support, various domain specific sub-models may need to be incorporated. Other contextual elements that could be considered include the user's emotional state and physiological state.

Tasks that users are undertaking form an indispensable component of their context at a given time. As people have an inherent capability to multi-task, this may be a problematic element of their context in that identifying the current task with a sufficient degree of certainty may prove impossible. However, if a service is aimed at a specific user activity, or applications domain, this uncertainty can almost be eliminated.

Social situation is likewise a difficult aspect of context to determine accurately. User's still have to explicitly switch off their mobile phones, or at least adjust them, when in certain social situations, a classic example being a theatre (Erickson, 2002). Though all the fundamental requirements seem to exist

for such an application – motivation, market, simple nature of the task, etc., the uncertainty involved in interpreting this single element of context has rendered the practical realisation of such a service impractical.

### Physical Environment

Context related to the physical environment may be considered under the headings – physical conditions, infrastructure and location. This later element of context – location is one that has grasped the imaginations of academia and entrepreneurs alike. Providing the location of a person can be ascertained, significant opportunities exist for filtering information in mobile services. In particular, the success of GPS as well as the E-911 and E-112 directives has ensured that availability of a technology that enables the determination of user positions quickly and accurately.

In the case of the infrastructure classification, aspects of the surrounding resources including computational and telecommunications-related would be considered. For example, a number of networks may be available included Third-Generational (3G), satellite-based as well as WiFi systems. Each offers its own respective advantages which may be taken advantage of in certain situations. Of course, satellite navigation systems, such as GPS, would also be included in this classification.

Physical conditions may include a number of detectable and/or measurable physical phenomena. Example includes light, temperature, ambient noise level and so on. Though such context elements are amongst the easiest to conceptualise and utilise, capturing them demands the availability of a suite of networked embedded sensors or a deployment of Wireless Sensor Networks (WSNs).

## DESIGN OF AN AMBIENT DIGITAL LIBRARY

In principle, a digital library should be accessible and of interest to everybody; in practice, digital libraries tend to focus on the needs of

distinct user groups. Ambient digital libraries follow this trend. Two potential user groups immediately spring to mind - tourists and students. Both frequently need instantaneous access to information that is pertinent to their context. The potential of digital libraries in the e-learning domain has been the subject of much research (Shih et al., 2011; Han, 2009; Morales Salcedo et al., 2005). In the tourist domain, a number of electronic guides have been described in the literature. Some of these use a customised digital content repository, for example Gulliver's Genie (O'Grady et al., 1999, 2007) while others have harnessed a more formal digital library construct (Hinze et al., 2006). For the purposes of this discussion, the tourist domain is considered, in the understanding that the issues raised are equally applicable in a number of mobile computing application domains.

Consider the case of an Ambient Digital Library that supports the delivery of multimedia presentations on attractions that the tourist encounters as they roam about some city or tourist attraction. Such presentations must adapt to the spatial context of the tourist, that is, their physical location and orientation, and be capable of being rendered on the tourist's device, usually of the tablet or smartphone genre. In addition the presentation must conform to individual user models. Hence, a sub-model for the tourist domain must be included in the overall user model. Thus the stages in providing the service may be summarised as follows:

1. Capture essential elements of the tourist's context on their device.
2. Interpret the context elements.
3. Identify multimedia content in the digital library that corresponds to the tourist current contextual state, if any.
4. Adapt the content according to device and network parameters, if necessary
5. Return content to tourist for presentation on their device

Thus as well as core multimedia elements and their associated metadata, it is necessary

for the digital library to incorporate models that facilitate the interpretation of context. A schematic diagram indicating the core components may be seen in Figure 1 and each of these is now described.

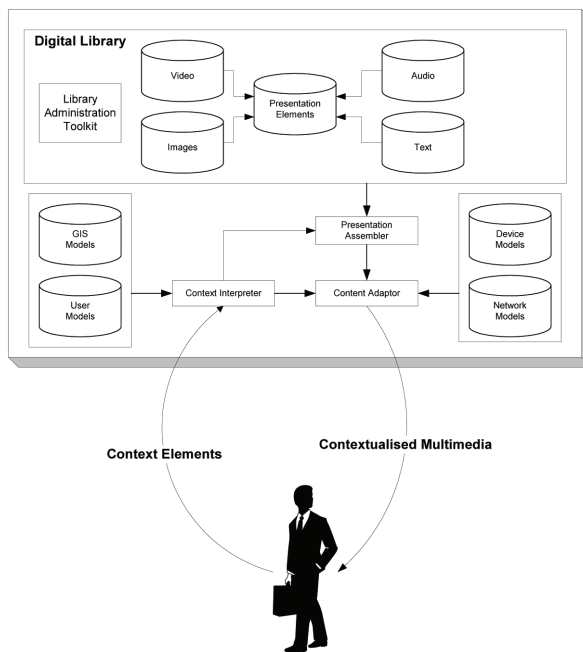
## Context Interpreter

Ascribing meaning to the contextual elements is of critical importance. The incoming context stream must be parsed to extract the individual context elements and, more importantly, to determine an estimate of the quality of each element so that a confidence factor may be established. Various thresholds of confidence can be established to guide potential action. A strong case can be made for maintaining a historical record of the context streams. Indulging in such a course of action offers interesting possibilities for predicting likely future action. However, this is an additional computational element that must be considered by the designer, thus the potential benefits accrued must be carefully weighted. In addition there are the ubiquitous issues of security and privacy for consideration.

## GIS Models

Resolving tourists' immediate spatial contexts demands the availability of a model of the environment in which they operate. This model should contain information about the tourist attractions and their environment such that the nearest one may be ascertained, and tourist behaviour classified, for example, are they converging on the attraction or moving away from it? At its simplest, the attraction may be geocoded, that is, a longitude and latitude position associated with it. However, it could be that irregular zones are defined around the attraction which, on being entered by the tourist, would trigger a presentation on that attraction adapted to the view point or orientation of the tourist. A number of options exist for modelling this information within the digital library but a Geographic Information System (GIS) is a logical choice. It must not be forgotten that there is significant amount of other information that could be of use to tourists including

Figure 1. As the mobile user roams, their context continuously changes



navigation services and mobile yellow pages that GIS components could effectively deliver.

To maintain quality, it is essential that the geodata in the digital library be of an exceptionally high standard. For encoding tourist attractions, the use of published maps from a reputable source is to be encouraged, as this is an area that can be controlled when constructing the digital library. In contrast, when spatial data from the roaming tourist is received, it can be difficult to determine its quality. Recall that standard GPS positions include a number of inherent errors resulting in such positions diverging from the true geographic position by up to 20 metres on average. Should the GPS signal be augmented in some way, for example via a Satellite Based Augmentation System (SBAS) such as the European Ground Navigation Overlay Service (EGNOS), the accuracy of the resultant position may be within 3 metres of the correct geographical position. Technically, the use of SBAS can be determined but additional information is needed and there is no guarantee that this will be provided. If

instead of using an SBAS, an approach based on telecommunications network topologies is adopted (Zhao, 2000) then the accuracy of the position supplied will vary significantly. It may be that an additional parameter must be specified that allows an estimate of the accuracy of the supplied position to be derived.

As well as ensuring quality, it is essential that all geodata is standardised on a single geodetic datum. GPS uses the World Geodetic System 1984 (WGS 84) but different countries adopt other geodetic datums. In particular, current GPS receivers can be configured to output position reading in whatever datum the user chooses. This is important because it enables the receiver to use local maps. From a digital library perspective, the designer has no control over the configuration of tourist's device. All they can do is ensure that the geodata conforms to a single standard, and, in certain situations, incorporate a translation facility.

Finally, the case of the indoor user must be considered. This situation is complex as satellite-based and telecommunication-based

techniques do not operate satisfactorily indoors; thus an ad-hoc solution is frequently adopted. This may involve deploying an infrastructure such as Ubisense (Steggles & Gschwind, 2005) or adopting a solution based on RFID tags. Ultimately, a model must be developed that allows the reconciliation of a tourist's spatial context with an object of interest. Indoor positioning remains an outstanding research challenge.

## User Models

To personalise digital library content, it is necessary to maintain models of individual users or groups. Recall that personalisation is very important in mobile computing scenarios as mobile devices are inherently limited in their capabilities, including screen real-estate and interaction modalities supported. Also, mobile users pay for their data payload; hence every effort should be made to ensure that content delivered to them is appropriate to their context. A user model is fundamental to achieving a personalisation solution. Two components may be distinguished in a tourist scenario: a base user profile component, and a cultural interest sub-model. The base user profile will contain details of the person age group, sex, nationality, languages spoken and so on. Augmenting this will be a number of sub-models, in this case a tourist model. How sophisticated these are will vary but the designer of the digital library will need to identify key salient characteristics of the end-user group. In this case, it is aspects of their cultural interests that of most interest, for example, art, literature, architecture and so on. Within these there may also be subcategories. Articulating all possible interest groups is likely to prove impracticable but, depending on the nature of the tourist attractions that the digital library is being designed to support, a core set of cultural interests should be identifiable.

A natural question concerns how these cultural interests should be identified. The first, and easiest, is to provide a mechanism where tourists can specify their interests. The second is to observe the tourist over time, and possibly adopt techniques such as collaborative filtering

to determine their interests. Ideally, elements of both approaches would be adopted; however, the time required to do this should not be underestimated. Finally, the case for treating the cultural interest model as a dynamic component should be considered. Though this involves computational overhead, as well as additional development time, it would enable the prioritisation of content; an important issue given the screen limitations of the average mobile device.

## Multimedia Elements

The multimedia documents that will be presented to a tourist will comprise of an appropriate combination of images, audio, video and text, amongst others.

- Video – videos of historic events and famous people telling some narrative about some arbitrary tourist attraction are just two examples of the kinds of video that may be stored in the digital library.
- Image – images of the attraction can be used to highlight certain aspects that should be brought to the attention of the tourists. A timeline of the history of the attraction is one illustration of the use of images. Frequently, a voiceover may accompany the image.
- Audio – audio forms a core media modality and may be utilised in various ways. History, anecdotes, as well as explanations of certain pertinent aspects of the tourist attraction are just some examples.
- Text – text is essential but its use should be minimised due to the difficulty in reading large amounts on small screens. There is one critical exception to this that should be actively considered. It is in case where the tourist has registered that they have hearing difficulties. For such users, the designer should ensure that a textual translation of all audio and video elements be made available.

All media elements must be tagged with the appropriate metadata that allow their content

to be reasoned about from a context and user model perspective. It should be noted in passing that many conventional digital libraries are hosts to significant culture-related repositories in a variety of formats.

## Presentation Elements

Presentation elements comprise small yet sufficient information snippets that can be combined to form full presentations. These elements link the individual media components together and enable their association with individual tourist attractions and tourist typologies.

The task of specifying these elements is of the most importance. While it is the task of the designer of the digital library to facilitate this process, it is unlikely that they are the most suitable person for specifying individual presentation elements. Such an individual must have a deep knowledge of the various tourist attractions and a mature understanding of tourists, their motivations, requirements and behaviours. Similarly in an elearning scenario, a knowledge of pedagogy would be essential. It is in this instance that the human element reigns supreme and it is no exaggeration to claim that the success of the digital library will be determined by those who ensure that the aggregation of content is coherent.

## Presentation Assembler

On identifying the multimedia content that is most appropriate to the supplied contextual parameters, the Presentation Assembler must structure and prioritise the content that will be dispatched and, possibly viewed, by the tourist. The second task concerns casting the entire presentation in a structural format such that it can be interpreted by the tourist's device. This is a difficult problem and one that is exacerbated by the lack of a clearly defined standard for multimedia presentations on mobile devices. One recommended approach is to adhere to a form based on HTML, such as the Synchronised Multimedia Integration Language (SMIL). Though conceived for desktop scenarios, WWW

technologies are now commonplace on mobile devices, albeit with some limitations.

How to structure a presentation is one of the more difficult decisions faced by the designer. A natural objective is to strive to make the content available to as wide an audience as possible. Given the diversity of the mobile device market, this can be quite a time-consuming and expensive task.

## Content Adaptor

In contrast to structuring the content, the adaptation of the content is a more straightforward endeavour. Content must be adapted in light of device characteristics and practical operating parameters of the wireless network. Hence, it is the requirement that all content in the library be stored in as high a quality as possible. Media converters can then be harnessed as the needs of the device in question dictate.

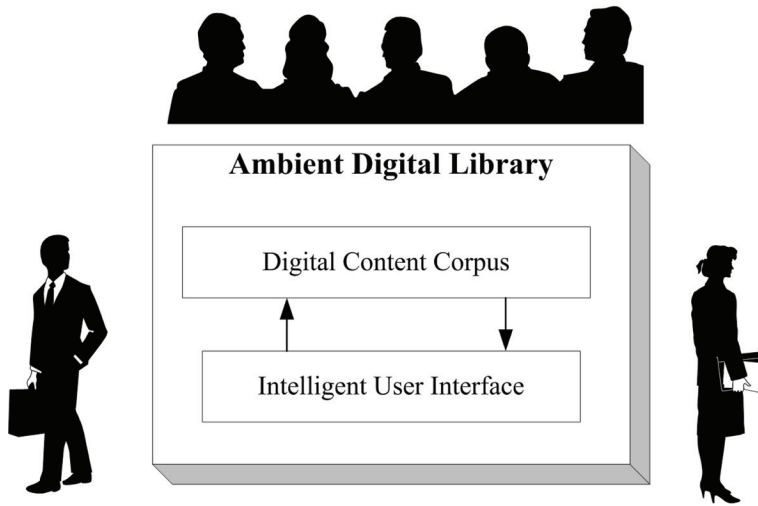
## Device Models

Given the range of devices on the market, it is necessary to maintain a record of each device so that its capabilities for rendering multimedia files, amongst others, may be identified. In practice, it is probable that a subset of the devices available will be identified and supported. The situation may be exacerbated by interim OS and software upgrades.

## Network Elements

Network operational parameters, in particular, supported data-rates, are contextual elements that may need to be considered. In practice, the eventual data-rate experienced by the subscriber is influenced by the number of concurrent subscribers sharing the data channel. From a network operator's perspective, this makes good sense both technically and commercially. However, it does make predicting the download time with any certainty impossible, although over time, a picture of network behaviour can be predicted. This introduces a level of uncertainty into the process, when for example, a video file may need to be downloaded but in the time it

Figure 2. Realizing an ambient digital library via intelligent user Interface



takes to accomplish this, the tourist has already walked past the attraction in question. There is also the ubiquitous issue of cost.

## DISCUSSION

Mobile computing is an inherently different usage paradigm from the classic desktop computing paradigm and the designers of digital libraries for such users must take cognisance of this. The concept of context is an essential construct for differentiating services and adapting services to the prevailing circumstances of the mobile user. During the previous discussion, the mobile tourist domain was considered, reflecting experience garnered from prior research (O'Grady et al., 2005). Though focusing on the cultural needs of tourists, it can be seen that the concepts addressed are equally applicable in a number of mobile application domains including mobile learning and mobile commerce.

In essence, when the design of the digital library is reflected upon, it can be seen that the incorporation of the context construct demanded the development of an adaptive or intelligent interface to the library. The core library corpus of multimedia data is essentially static. It can be accessed in a number of ways and serve a

number of different user communities (Figure 2). Thus, the task facing the designer is the provision of an interface to the library that takes into account the needs of various end-user typologies, of which the mobile tourist is just one instance. In modelling the library as constituting a corpus component and an interface component, the designer is acknowledging the diversity of the end-user base and practically defining an architecture that enables the necessary extensibility for addressing this diversity. Such a view complements the vision articulated in Ambient Intelligence (AmI) where the Intelligent User Interface (IUI) mediates between the user and their environment. In an Ambient Digital Library scenario, the IUI mediates between the user and the digital library through a filter of context and personalisation.

Though the content and use of the digital library suggests a predominantly static nature, this is unlikely to remain the case for much longer. A newer generation of smartphones incorporates digital cameras, video recorders and software that, in general, facilitate the construction of simple multimedia documents. Blogging and social networking harness these facilities in mobile contexts. Thus over time, it can be realistically envisaged that such content may find its way into digital libraries, in response

to user group expectations. Such developments pose an interesting selection of design and technical challenges. For example, the centralised control model that has been traditionally exercised will have to be relinquished and methods of enabling ad-hoc content addition, classification and storage be developed. In addition, the retrieval process will pose further challenges.

## CONCLUSION

As the popularity of mobile computing increases, the demand for new and sophisticated services will likewise increase. Thus current proprietors of, and prospective developers of, digital libraries need to factor the requirements of such users into their designs. Context offers an intuitive construct for adapting services to the immediate needs of mobile users. The Ambient Digital Library proposes the harnessing of intelligent interfaces as a means for providing context-aware and personalised digital library services for the mobile user community.

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