Creating Smart and Accessible Ubiquitous Knowledge Environments

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Abstract. Digital libraries offer substantial volumes of declarative knowledge to the information society. This paper explores the extent to which current and future digital libraries, also known as ubiquitous knowledge environments, can be made sufficiently usable, accessible and smart to support an inclusive information society and the aspiration of universal access. Using a range of converging methods to evaluate a random sample of such digital library websites, it is concluded that, whilst they act as substantial and functional repositories for knowledge, there is potential to improve, particularly in accessibility and smartness. The current methods are validated through the substantial statistical significance levels and by the meaningful patterns found in the resulting data. A new measure of system smartness is introduced and found to provide a useful metric for present purposes, though it is clear that further work will be needed.

Keywords: digital library, smart, accessible, usable, ubiquitous knowledge environment.

1 Introduction

There is little doubt that digital libraries have contributed significantly to the provision of structured, declarative knowledge to online communities, students and scholars, who need to have substantial, accessible cognitive resources at their fingertips. Such libraries represent a major investment of both applied computing science and pedagogic expertise, so providing potentially very valuable support for through the building of smart learning environments. At the moment, digital libraries are often set behind monolithic interfaces that can offer an overwhelming richness of data. But that should not blind us as to their potential to provide smart, accessible, cognitive support for human learning in the context of the inclusive knowledge society [9].

What comes after the digital library? This paper explores the possibility of creating what has been called the ubiquitous knowledge environment or post-digital library. It aims to explore the accessibility, usability and smartness of digital libraries and their user interfaces. The first component has been to conduct an expert evaluation of a

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quasi-random sample of digital libraries to identify their potential to support inclusive, smart ubiquitous knowledge environments. The second component has been to conduct a literature review of ubiquitous knowledge environments development and innovations, in the light of the specific issues raised by the present data.

This work has been conducted within the framework of the ERCIM Working Group SESAMI (Smart Environments and Systems for Ambient Intelligence), raising questions like the following. Can digital libraries will become smarter and more accessible, thus creating the ubiquitous knowledge environments? The latter expression captures a possible convergence of technologies towards ambient intelligence and ubiquitous computing in the sense that such knowledge environments will move beyond the desktop or laptop to form part of our physical environment. Thus we are considering the creation of smart settings, with ubiquitous knowledge environments as a vital component. Access to the knowledge encapsulated would be accessed and processed through smarter everyday artifacts that deploy sensor data based responses in order to provide the users with relevant, user-model specific, situation-aware and context-of-use-aware knowledge at the point of use.

2 Expert Evaluations

In order to investigate the potential of smart, digital libraries, the first step is to evaluate current systems against the criteria of usability, accessibility and smartness. Usability is defined here as a suitable level of ease of use. Accessibility is defined as the lack of barriers that would prevent entry (completely or partially) to systems, their functions and contents. In universal access terms, this implicates the aspiration to achieve access by anyone, anytime and anywhere. Smartness is defined as the possession of functions and attributes by a system that would be judged to be intelligent in the case of a human operator, such that the probability of passing a cognitive version of the Turing Test would be increased. The term smart, as used here, does not necessarily imply true intelligence, merely a simulation of it.

2.1 Methods

A quasi-random sample of twenty digital libraries was generated by a Google search using the search terms “digital library”. From this sample of twenty, ten were randomly selected for evaluation of usability, accessibility and smartness on the basis of the following hybrid methodology that combined a number of converging techniques.

First, the method of behavioural walkthrough provided the overall context and rationale, using a subject expert (E) to generate the data. This method simulates a user’s reasoned action process at each step in the interactive dialogue, evaluating the extent to which the user’s beliefs, external stimuli and intentions to perform can act as prerequisites for the next interaction step [1].

Second, the following stages of cognitive walkthrough were adapted to fit in with the above method:

1. The expert (E) considers the initial appearance of the library.
2. E identifies the subject matter definition of the digital library.
3. E conducts ten searches for topics covered by the specific library (for example, "discover relevant information on topic x, where x is covered by the specific library").
4. E uses the mechanisms provided by the library to conduct searches, for example directed searches by author, title, content, key words, extended searches, etc. using available screen objects (menu items, buttons, command-line inputs and the like).
5. E chooses the action that seems most likely to make progress toward the objective.
6. E carries out the actions and evaluates the system's feedback for evidence that progress is being made toward the current objective.
7. The above steps are used to retrieve information from the library system and to explore the extent to which each digital library interface supports "exploratory learning", i.e. first-time use without formal training.

Third, from the Web Accessibility Initiative (WAI) advice about the evaluation of the accessibility of a website, the following two points were extracted:

1. Include all pages on which people are more likely to enter the site.
2. Include a variety of pages with different layouts and functionality.

Fourth, the expert used the following four questionnaires to generate estimates of the usability, accessibility and smartness (the order of completion was randomized for each library evaluation):

1. System Usability Scale (SUS),
2. Questionnaire for User-Interaction Satisfaction,
3. Simplex accessibility questionnaire and
4. Simplex smartness questionnaire.

Fifth, the first, main page was evaluated by the use of Bobby (Watchfire WebXACT) [13] for accessibility.

2.2 Results

For each of the questionnaires, an overall score was derived and expressed as a percentage of the maximum, possible score. These data were summarized in Table 1. The data were analyzed by a one-way, analysis of variance. It is clear that the digital library websites did reasonably well on usability (System Usability Scale (SUS) and User-Interaction Satisfaction), slightly less so on accessibility (Simplex accessibility) and much less so on smartness (Simplex smartness). The overall differences were indicated by analysis of variance, ANOVA, ($F = 192.02$, df. 3, 36, $p < 0.0001$). Rated smartness was substantially lower than ratings of the other attributes, i.e. usability and accessibility. The main source of the significant difference between conditions is that due to the Simplex smartness questionnaire in relation to the others ($F= 261.9$, df. 1, 9, $p<0.0001$). However, accessibility (Simplex accessibility) was rated lower than both measures of usability ($F=261.9$ and 520.83, df. 1, 18, $p< 0.0001$). A comparison of the System Usability Scale and the Questionnaire for User-Interaction Satisfaction, both measures of usability, clearly indicated that the minor differences between them were highly likely to be due to chance ($F = 0.002$, df. 1, 19, $p= 0.96$). This agreement of results between the two questionnaires provides additional validation for the present methods, as they are clearly showing substantial overlap and correlation (see below). The sizes of the obtained F ratios indicate that these results are likely to be robust to the influence of any departures from the assumptions that accompany analysis of variance.

Table 1. Average scores (%) for each library and questionnaire

Library ID	System Usability Scale (SUS)	Simplex accessibility	Simplex smartness	User Interaction Satisfaction
01	64.00	61.11	26.25	72.14
02	78.00	67.22	24.38	75.71
03	76.00	67.50	25.63	72.14
04	70.00	62.50	22.50	70.00
05	66.00	56.67	25.63	70.00
06	62.00	52.78	23.44	70.00
07	62.00	59.72	21.56	59.72
08	72.00	52.22	12.19	66.43
09	68.00	54.17	15.94	67.15
10	70.00	59.17	25.94	65.71
Column Sums	688 mean = 68.80	593.06 mean = 59.306	223.46 mean = 22.346	689 mean = 68.90

Second, the results of the Bobby (Watchfire WebXACT) [13] test are shown in Table 2. Here, the relatively low evaluations of accessibility are confirmed at a more detailed level. Surprisingly, all ten sites were found to fail the WCAG standards, though three (01, 04, 05) were passed at priority one only.

These results point to the current status of digital libraries, as a basis for identifying where further developments could be made to enable them to contribute to the emerging information society and for universal access as a goal for society. Whilst we can conceive of a website having good accessibility accompanied by low usability, the present sample of digital websites shows the opposite problem. According to the present questionnaires, these websites showed poorer accessibility than usability, a finding supported by the use of Bobby to indicate accessibility problems at the coding level and above. However, smartness or intelligence would seem to provide the main focus for progress. If we are to move towards the goal of universal access in the information society, it is likely that we will require smarter systems and interfaces to do so.

Turning to the smartness questionnaire, a consideration of the items in the questionnaire, it is clear that some items are more demanding than are others. For example, “system recognizes my ID” does not require much smartness but “recognizes humor” seems much more demanding, requiring more “smartness”. To check this possibility, each item was rated for required level of smartness and this level was correlated with the smartness scored derived for the websites, resulting is a very significant correlation ($r = 0.60$, $p < 0.001$). Clearly the digital libraries did better on the lower level items but much poorer on the higher level items. This results, validates the scale and points to those aspects of smartness that need to be improved.

Table 2. Bobby based evaluations of accessibility

		Automatic checkpoints			Manual checkpoints		
Library ID		**Priority 1**	**Priority 2**	**Priority 3**	**Priority 1**	**Priority 2**	**Priority 3**
		status & errors	status & errors	Status & errors	status & errors	status & errors	status & errors
01	*	√ 0	1	11	9	19	9
02	*	15	0	37	43	45	10
03	*	2	1	1	22	20	8
04	*	√ 0	0	9	26	30	9
05	*	√ 0	0	9	26	30	9
06	*	1	3	13	11	17	10
07	*	95	3	25	12	19	12
08	*	18	4	19	7	15	8
09	*	3	7	12	11	19	11
10	*	1	8	6	6	18	9

* does not comply with WCAG

These results underline the need for work to develop smart interfaces for digital libraries if they are to contribute to the information society in a more accessible way. The following tables show which items of the smartness were rated as good (see Table 4) and those rated as less good (see Table 3). In the table, each item is quoted along with its question number and the total score across the ten digital libraries. Ten is the lowest possible score i.e. ten ratings of 1, where 1 is the lowest rating. A score of ten means that all ten digital libraries were given the lowest rating (1) on the given questionnaire item.

An inspection of the above, low rated items suggests that they are those that tend to require smarter performance or human-like qualities, as compared with those given slightly better ratings, which tend to require only the appropriate provision of information in response to requests. However, one of the purposes of the present research is to explore the range of possible items from those that strongly require human-like qualities and thus that simply require a response to requests for information. The distinction is not as clear-cut as would be first assumed, for two reasons. This questionnaire will be developed rigorously, according to psychometric principles. First, items may be found to share factors that relate to other distinctions. Second, new factors and items may be found that blur the presently offered distinction. On a conceptual note, users like us may not be able to distinguish human-like qualities from simulations of those qualities and so they remain of interest for ambient intelligence applications.

A consideration of the correlations between questionnaire scores, shown in Table 5 below, does not show a clear-cut profile. However, questionnaire three (smartness) shows the lowest correlation, indicating that questionnaire one (usability) and questionnaire three (smartness) are probably measuring substantially different aspects of the perceptions of these systems. Questionnaire two (accessibility) seems to relate well to questionnaire three, but apparently there is some tendency for usability and accessibility to correlate positively if not perfectly, even when they take different levels.

Table 3. Items which were given low ratings

Questions	**Question number**	**Question score** min = 10 max = 100
Recognizes finer categories of people	9	10
Uses commonsense to answer questions	14	10
Takes account of my expertise when answering questions	19	10
Responds to my emotional state	20	10
Recognizes humor	21	10
Recognizes irony	22	10
Can use numbers to make calculations	24	10
Can use logic	25	10
Uses hunches	26	10
Uses good judgment	27	10
Understands the structure of knowledge areas	29	10
Can solve problems	30	10
Can recognize patterns in data	31	10
Recognizes important changes	32	10

Table 4. Items which were given better ratings

Questions	**Question number**	**Question score** min = 10 max = 100
Can identify the meaning of received data	12	11
Has good manners	23	12
Responds to subtle details	28	13
Clarifies questions before answering	5	14
Understands that I have specific expertise	7	15
Takes account of my interests when answering questions	18	15
Uses knowledge to answer questions	13	16
Understands that I have specific interests	6	17
Provides error free messages	11	18
System recognizes my profile	2	23
System recognizes my ID	1	26
Useful help system provided	17	27
Offers more information than that requested	8	55
Answers questions	4	54
Needs only limited amount of input from the user	10	55
Provides useful feedback	16	55
Can provide search results in order of relevance	15	65
Responds to simple searches well	3	77

Table 5. Correlations between questionnaires

	Questionnaire 1 (usability)	Questionnaire 2 (accessibility)	Questionnaire 3 (smartness)	Questionnaire 4 (usability)
Questionnaire 1				
Questionnaire 2	0.58			
Questionnaire 3	-0.045	0.60		
Questionnaire 4	0.52	0.47	0.40	

2.3 Discussion

The sample of digital libraries considered here could all be seen as valuable resources that contained considerable volumes of scholarly information that were being made available to the user who was willing to use the system diligently. There was no indication that they were not highly functional and priceless sources. However, that is not the present focus. Using a variety of converging methods of expert evaluation, it is clear that the random sample of ten digital library websites could be developed further in usability, accessibility and smartness (in increasing order of potential). It is worth pointing out that usability was seen as significantly better than accessibility, demonstrating that these two measures of "user friendliness" are neither synonymous nor closely linked. The direction of the difference is also interesting, since it shows that the achievement of a reasonable level of usability can be accompanied by a significantly lower level of accessibility, whether the latter is measured by questionnaire or by an automatic evaluation system. Scores of usability and accessibility tended to be positively correlated, even though the latter was rated at a lower level than the former. Scores on the smartness questionnaire and one of the usability questionnaires were not well correlated, suggesting that the usability and smartness of a system are not synonymous.

There is considerable interest in the concept of the smart system and that is why we have set out to produce a questionnaire with which to evaluate system smartness. Without confusing simulation with reality, there might be a parallel between attempts to measure system smartness and human intelligence, the latter is a field of research that is to vast to consider here (but see [3]). If so, then the aspiration to produce a useful and valid measure of system smartness is only in its infancy. The present efforts can only pave the way for something better.

3 Literature Review of Post-digital Library Development and Innovations

In summary, the first component of this work demonstrated the potential to develop the smartness of the digital library, as well as its accessibility. It also identified those aspects of system smartness that were served well and less well by current systems. It also turned out that the functionality of these digital library systems exceeded their usability, which, in turn, was superior to their accessibility as measured by questionnaire and by the Bobby system. The second component of this work looks at current and potential developments in this field that address the issues raised by the current data, by the inspection of a set of relevant, key papers.

3.1 Key Papers

Here we have selected a sample of papers that show the way forward for such developments of accessibility and smartness. Stephanidis *et al.* [11] have argued that these two system aspects should be considered as related, arguing that digital libraries can cope with user diversity through the smart use of adaptivity. Liddy *et al.* [6] are working to provide smart access to a wide range of digital resources for a diverse range of different users. They started with Internet based, question answering services using human experts to interpret questions, to search databases and supply answers. The next stage in their work is the simulation of human operators by the application of unmediated natural language processing of texts and queries. Kling and Elliott [4] took another approach arguing that digital libraries should be designed to achieve “organizational usability”, namely the effective integration of systems into the aims and objectives of current organisations. Nardi *et al.* [8] have worked to create smart agents that can extract semantics from library documents so that they can be used to infer users’ high level goals, based upon simple user activities, in order to meet user requirements in a smarter manner. Li *et al.* [5] discuss one important digital library, CiteSeer, in order to evaluate the future development of this system. Their conclusions match those of the present paper to a significant extent. They argue that the new architecture of CiteSeer should be redesigned on the basis of scalability, flexibility, self-adaptivity, service-based and user-orientation, a mix of usability, accessibility and smartness. Stone *et al.* [12] present an intelligent digital library for biologists, based on advanced data mining techniques, using a framework which combines conventional library structures with an object-oriented methodology. Shang *et al.* [10] present a new intelligent agent-supported system for active, student centered learning. The important point is that this system makes use of current Internet, digital library and multiagent concepts. Lin and Hauptmann [7] show that the digital libraries can be provided with novel and innovative interfaces, reporting a wearable, digital library that can be used to support personal conversations. Such a system collects records of conversations and retrieves summaries of these conversations when needed to support new interactions. Finally, Chen *et al.* [2] provide a smart meeting room system that uses an intelligent agent based system, services, sensors, a semantic web ontology, logic reasoning, security policies and privacy policies.

3.2 Summary of Findings

The findings and objectives of the above studies can be captured by consideration of surface (interface) or the deep structures of the post-digital library, shown in Table 6.

Table 6. Overview of reviewed findings

Authors	Description	Interface	Deep structure
Stephanidis *et al.* (2000)	cope with user diversity through the smart use of adaptivity	√	
Liddy *et al.* (1994)	unmediated natural language processing of texts and queries	√	
Kling and Elliott (1994)	effective integration of systems into the aims and objectives of current organizations	√	
Nardi *et al.* (1998)	smart agents to extract semantics from library documents, used to infer users' high level goals, based upon simple user activities	√	
Shang *et al.* (2001)	a new intelligent agent-supported system for active, student centered learning that makes use of current Internet, digital library and multiagent concepts	√	
Lin and Hauptmann (2002)	a wearable, digital library that can be used to support personal conversations	√	
Li *et al.* (2006)	argue that the new architecture of CiteSeer should be redesigned for scalability, flexibility, self-adaptivity, service-based and user-orientation	√	√
Stone *et al.* (2004)	an intelligent digital library for biologists, based on advanced data mining techniques, combining conventional library structures with an object-oriented methodology	√	√
Chen *et al.* (2004)	a smart meeting room system that uses an intelligent agent based system, services, sensors, a semantic web ontology, logic reasoning, security and privacy policies	√	√

3.3 Discussion

It is clear from even a brief review that the issues and concerns identified in the first component of this work (usability, accessibility and smartness) can be addressed in a varied number of ways in order to enable digital libraries to contribute to the development of an inclusive, information and knowledge society. However, it is also clear that, if this sample is at all representative, much of the concern with accessibility and smartness is focused on aimed the interface rather than the deep structure of the digital library.

Overall, digital libraries provide an invaluable source of knowledge about a wide range of subjects. There can be few working scholars who do not make use of them. They are, at the moment, set behind monolithic interfaces that are typically accessed from the desktop or laptop environments. Surprisingly, however, the sample of libraries evaluated here clearly needed improvements in both accessibility and smartness. (The smartness questionnaire items used here are provided in tables four and five above. The accessibility and usability questionnaires are available from the authors). Clearly, if digital libraries are to form the basis for the realization of ubiquitous knowledge environments, they will become smarter and more accessible. If that can be achieved, then there would be a possible convergence of technologies like digital libraries, artificial intelligence (in the weaker sense of simulating human behavior), ambient intelligence and ubiquitous computing. The substantive contents of such knowledge environments could be unleashed into the external, physical world rather than staying on the desktop or laptop. If so, the present methods of questionnaire based evaluation would focus not only on significant components of the smart environment like the smart digital library, but more so on an evaluation of the overall, smart environments themselves. These methods, or their successors, could be used to design and evaluate better ubiquitous knowledge environments. Access to the knowledge encapsulated would be accessed and processed through smarter everyday artifacts that deploy sensor data based responses in order to provide the users with relevant, user-model specific, situation-aware and context-of-use-aware knowledge at the point of use.

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