Modelling of Users' Capabilities

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ABSTRACT
Modern computer systems present great barriers to potential users who are too far away from being the "average user" for which they were designed. This means users that have unusual or limited devices (such as small-screen PDAs) and users with disabilities are quite likely to encounter great difficulty when trying to use certain mainstream systems. This paper presents a technique for incorporating personalisation into information retrieval systems in a low-level way. The technique—Modelling of Users' Capabilities—is described, as is a proof-of-concept test that was carried out. Conclusions are drawn from this test and ongoing work is discussed.

Author Keywords
Capabilities, Devices, Disability, User Modelling.

ACM Classification Keywords
H.1.2 User/Machine Systems; H.5.2 User Interfaces: Theory and methods, User-centered design.

INTRODUCTION

Existing research has shown that the "average user" for which most systems are designed does not exist and that many users are far enough away from this point such that it can be difficult or impossible for them to use mainstream computer systems [5]. One reason for this is that too much information, of varying quality, is presented. Another reason is that the information is not presented in an accessible way to the user. This has resulted in the development of a number of technologies that aim to reformat the information in an accessible way [4,7][1]. Unfortunately the end result can often be sub-optimal because such systems have to be retrofitted to existing systems that have been written to provide only the information that their "average user" will require [2][2]. Conversely: when designed well, a given system can be made significantly more useful for both "normal" and disabled users.

Problems arise due to the diversity of different user groups. The requirements of users in normal and extreme environments may be radically different—consider a user playing games or accessing the Internet with a desktop computer versus the same user carrying out the same activities on a mobile device. In fact, there is some correlation on the functional/capability level between "normal" users in extreme environments and various types of disabled user[3].

This is due in part to the capabilities of the user and device: on a mobile device with little screen space, the capability of a sighted user is decreased. A very similar effect occurs when a user with little or no sight wishes to access a normal desktop computer system: their diminished capabilities cause them to be able to deal with less information over a given time period than a non-disabled user. A user with poor motor control, however, may experience no difficulty with acquiring information but have significant problems communicating back to the computer system, thus slowing down the process of information retrieval.

A potential solution to these kinds of problems is an intelligent user modelling technique that: (a) could allow a computer system to make a reasonable decision about which rendering adaptations a user may require, at least semi-automatically; (b) apply these adaptations as automatically as possible and (c) be generic enough to be applicable in many situations and for many user types. The latter of these goals could be afforded by modelling the functionality of both devices and users in a similar way.

This paper introduces and presents the underpinnings of such a user modelling technique and a proof-of-concept test for the technique—modelling of users' capabilities. The motivations and basic principles are described, as well as

[1] and `http://gamescc.rbkdesign.com/`

[2] James Mazrui: What's in a PDF? The Challenges of the Portable Document Format; `http://www.afb.org/afbpress/pub.asp?DocID=aw060604`

[3] As noted by W4A 2006 (`http://portal.acm.org/toc.cfm?id=1133219`), mobile technology simulates some types of impairments that disabled users have.

possible extensions. A test scenario is given and the results of user testing are presented. The test tool was developed to embody the fundamental principles of capability-based modelling; a lot of further work could be carried out based on these ideas. Consequently, some emphasis is placed on how the technique could evolve in the future.

It is important to contrast the purpose of this modelling technique with existing work in improving accessibility in other, specific areas [3,6]. The existing work is both important and relevant, but the proposed technique addresses a different problem—that of bringing these disparate solutions *together*, under a shared modelling technique, combined with some "intelligence" (the possible nature of this is discussed later) that may be easily written into a system employing capability modelling. This integration is required to make the implementation of an array of possible intelligent adaptations practicable for implementation in real-world systems.

PROPOSAL: MODELLING OF USERS' CAPABILITIES

The proposed modelling technique is based on the idea that, for the purposes of personalised rendering of information, users should be modelled based on their functional *capabilities*—e.g. level of sight, hearing and ability to input data into the computer. The following are the key principles of this technique.

- A way to express users' capabilities at a low enough level to be applicable to many types of user is required. This gives rise to their functional/sensory capabilities being measured, rather than having users being classified at a high level as "vision-impaired by macular degeneration" or "hard of hearing due to an accident at work".
- Similarly, the devices that are used to interact with a computer system should be modelled in the same way—properties and limitations imposed by them are just as important as those imposed by the user because both affect the channel of communication between user and computer.
- By working at the lowest practical level, it should be possible to frame the problem in a way that a computer can efficiently deal with.
- It would be helpful if the model could allow content to be assessed for accessibility to a given user in a given situation[4]—and suggest/perform adaptions semi-automatically. This would be afforded by the system being able to measure the users' capabilities and the capability requirements of data that is to be presented by the system.

[4] such as a sighted user with a mobile 'phone or a blind user with a notebook computer

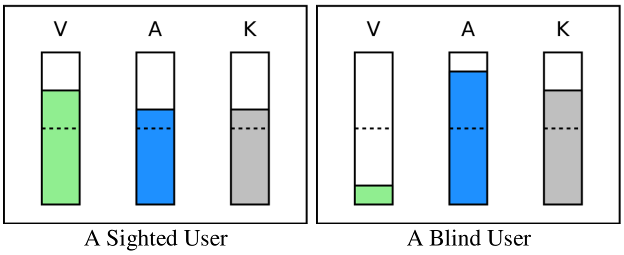


Figure 1: Example capability-based user profiles in 3 dimensions: visual (output); auditory (output) and keyboard (input).

The following subsections describe the technique further.

Channels

The model's highest-level view of a user is provided by a measure of their *capability* in a number of *channels*. Capability is a measure of the user's ability to receive information without error. Each channel is a particular modality of input/output that the computer and user can use to communicate with each other.

Figure 1 gives an example of how two different users may be represented at this level. The channels represented are considered from the perspective of the computer, so they are known as: visual (output); auditory (output) and keyboard (input).

Capability Maps

Depending on the dimensionality of a channel, more information may be required to direct the computer on how to present data to the user in an accessible way. For example, consider the visual channel, which is (usually) 2-dimensional in nature. If the user can see well, they may be able to clearly see the entire screen area. If they have a vision impairment (such as macular degeneration or cataracts[5]) however, they may be only able to see certain parts of the screen.

What is needed is a *capability map*—information that will allow the computer to determine where on the screen it can place information. If there is too much information than will fit in the areas of the screen that can be seen clearly, then less important information may be presented in areas that the user cannot see as well. The grading of importance of the content is beyond the scope of this paper, but some suggested approaches are covered elsewhere [1,4]. Figure 2 shows an example capability map for someone with macular degeneration. This condition can cause a loss of vision in specific regions and overall blurriness (which may be modelled as a low overall capability value for the channel due to it affecting the whole channel equally).

[5] Information on these conditions can be found at the RNIB's web site (`http://www.rnib.org.uk/`) under the "Eye Conditions" subsection of the "Eye Info" section.

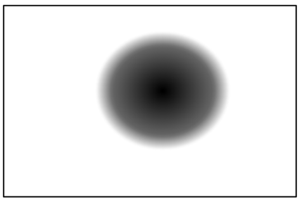


Figure 2: Example capability map for a person with macular degeneration.

The idea of capability mapping may be similarly applied to the proposed auditory channel—though would in that case be a 1-dimensional map—and the computer system's input channels—to reflect, for example, the user's input speed and/or any motor-control constraints.

Architecture

In order to create systems that allow the user model to inform adaptations to data being presented and to allow the user to further refine the presentation to their needs, a number of components must be successfully integrated—including a feedback loop so that the model may measure the users' changing abilities and preferences over time. The task of performing this integration is made even more daunting by the sheer volume of existing systems (operating environments, business applications, information retrieval systems) that one may wish to augment[6] using the capability modelling technique, or use for acquiring and rendering data[7] as part of a new system that gives the modelling a more central role.

A brief discussion of the key issues follows and example architectures for a system based on capability modelling are given. Figure 3 presents an overview of the proposed architecture.

Modelling Components

The following are required parts of a capability-based modelling system.

User Profiles: The users of the system, including their capabilities and capability maps for various channels, must be expressed electronically at an appropriate level for calculation.

Channels, Properties & Maps: Data on the channels available, their nature (dimensionality, size/bandwidth) must be available—at the same level as the profiles, so that little computational effort is required to deal with them.

[6] Though retro-fitting this is sub-optimal, it is also the only way that any shift towards using a new modelling technique will occur.

[7] The next step to adoption after augmenting existing systems is to use common parts of those systems for input and rendering, surrounding a core based on capability modelling.

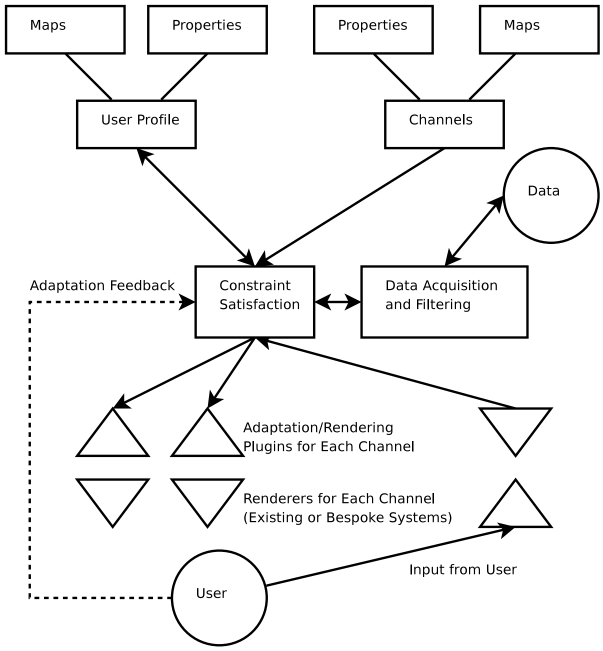


Figure 3: Diagrammatic representation of the proposed system architecture.

Data Analysis: The data that the system is to present to the user must be assessed so that any implicit capability requirements may be discovered. A simple way to achieve this is to use metadata to describe these requirements, but in future semi-automated analysis may be employed.

Links from Properties and Maps to Adaptations: The usefulness of the system will come from its ability to link the capabilities of the user and devices to formats that can be used for presenting data. This is a very domain-specific area and would contain rules—possibly informed by an expert—for carrying out the mapping.

For example: when adapting web pages, we may wish to consider contrast, font sizes, the presence of pictures and providing alternative means to navigate the site for motor-impaired users. In the case of adapting a computer game, we may wish to think about the modalities used to present navigational information and how, in each modality, that information might be expressed (e.g. mapping the presence of enemies to indicators on the screen, or in audio).

Constraint Satisfaction: The combination of properties of the channels used, any applicable maps and the "incoming" data (i.e. data to be presented) create a series of constraints that the computer most solve in order to work out the correct adaptions for the given user and set of devices (therefore channels and maps) in use.

For example: data containing a lot of text will likely be read aloud to someone who either cannot see or can only see when the text is rendered in an extremely large font. Information being presented on a small-screen device will likely need to be formatted so that only vertical scrolling is required

Adaptation & Interaction Components

To enable the modelling system to be useful it must be either embedded in, or at least adequately linked to, its surrounding systems—the programs that render the data and enable user interaction. The following processes and components are required.

Calibration: To ensure that the correct adaptations are made—and in reasonable amounts—the model needs to be calibrated for the particular user and set of devices in use. Ideally this process should be quick and carried out whenever the channels in use change and after certain time intervals, as the users needs are likely to vary over time.

Renderer(s): Adaptions informed by the model have to be affected by a renderer of some kind. This may well be part of an existing system (in the proof-of-concept testing carried out, the LaTeX typesetting system was used, for example). Interfaces to existing rendering systems for each channel will need to be developed (possibly as plug-ins for such existing systems—such as web browsers, games, audio output drivers and the like).

A Feedback Loop: It is very important to ensure that the changes made to the presentation of information are actually of use to the user. This may be done by forming a feedback loop, through which they may indicate to the system how successful it was. If embodied using a technique based on neural nets or fuzzy sets, the model may be able to learn a more refined version of the user's capabilities and preferences as they change over time.

METHOD: PROOF-OF-CONCEPT USER TESTING

A prototype of the modelling technique described above was created and tested with users with simulated vision impairments. The test scenario involved the user reading a document consisting of text (considered to be of primary importance for the tests) and a figure (of secondary importance). Three versions of the document were prepared: one with fairly standard formatting; one with minor adaptions for the user's condition and another with major adaptations. Further details of the test procedure can be found later[8].

The purpose of the testing was to ascertain if further development and testing of the technique on a larger scale (as detailed in the conclusions section below) should go ahead.

Figure 4: The glasses used in the tests.

Participants

One of the problems with usability testing, especially with minority groups, is that it is very hard to: (a) find and organise the participation of users, due to the relatively low geographic density of such specialist groups and (b) know when the system prototype is in a suitable state to be tested with a reasonable chance of success. Capability-based modelling seeks, when more fully developed, to better inform the design and testing process, giving a good rough idea of the system's accessibility to given user types and making success in real user tests more likely. This will also reduce pressure on the minority groups to take part in such tests.

Simulation

As this insight is not currently available and for the above practical reasons, it was deemed that testing with disabled people would not be possible for the initial trial[9]. Instead, a simulation was created using non-disabled users who were (temporarily) given vision impairments.

The vision impairments were affected through the use of specially-designed spectacles that simulated various conditions, 2 of which were used in the tests: (1) an overall loss of visual acuity, which put the participant just below the level of sight required for driving in the UK, and (2) macular degeneration, causing severe loss of visual acuity and loss of vision in a certain area (mainly the left-centre).

The spectacles were made by an organisation with extensive experience in the field[10]. Figure 4 shows the glasses used in the tests.

Justification

Though there are many potential pitfalls with an approach like this for *final* testing, it is believed that sufficient precautions were taken for this proof-of-concept exercise to give the results sufficient resolution. The purpose of this

[8] Please note that, due to space limitations, the test code and documents could not be given in this paper. They are, however, available from the authors.

[9] It *is* planned for future trials, however.

[10] Vision Impairment North-East (VINE) Simulation Package; `http://www.vine-simspecs.org.uk/simspecs.htm`

testing was to determine if the concept may be valid, so that future development and rigorous testing could be justified[11].

In these tests, the modelling technique was used with only one channel (video), so the possible effects of—for example—real vision-impaired people performing better due to superior ability in other modalities (such as hearing) would not have had chance to take effect. Participants were also instructed to not simply move their heads to allow them to see areas of the screen that were obscured[12] and this was verified by the researcher overseeing the tests.

Prototype

The prototype is an implementation of the user modelling technique proposed in the previous section. To make it useful in the document-reading scenario detailed above, interface code was written to link it into the LaTeX typesetting system's toolchain. The actual rendering of the results was carried about by a combination of LaTeX and a PDF viewer. The processes and components used in the test are described below.

Profile Storage: As the test involved only one channel, the capability values and map for the channel were hardcoded and edited for each user, after calibration.

Links to Adaptations: A number of properties relating to the video channel were coded into the prototype test tool. These included font size and a determination as to whether the inclusion of a figure may make any difference to the user (in the tests, the figure was always displayed, to see if this determination was accurate or not). Other properties, such as the possible layouts for the output documents, were coded as output templates—the content of each document was then injected into the chosen layout template.

Model Calibration: Users were shown a list of words in various font sizes (using sans-serif fonts, as these are considered easier to read on-screen). They were asked to read the smallest word for which they could comfortably identify each letter. The word chosen implied a certain font size, which in turn implied a certain capability level.

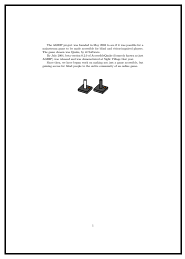
The calibration of the capability map is described shortly.

Constraint Solving: As only one channel was used, no constraints[13] required being solved. However, adaptions (such as layout, font face and size) still needed to be calculated, based on the given overall capability value and map for the channel.

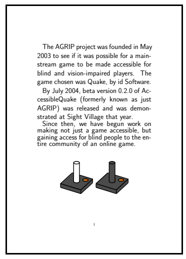
[11] as one of the authors is vision-impaired, the tests could be judged to be as realistic as possible.

[12] though vision-impaired people may do this, the effects are different because of the fact that obstructions in their eyes are internal, not a few centimetres in front of the cornea

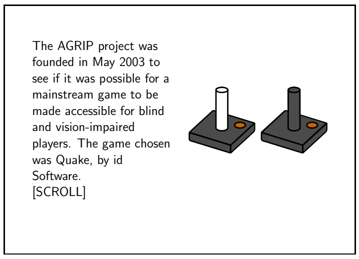
[13] which, in a production system, may be used to enable the system to determine the possibilities of using different output and input modalities for different parts of the data



A4; no scrolling required



A4; scrolling required



Full-screen with page breaks; scrolling via spacebar

Figure 5: A set of documents used in the tests.

Implementation of Maps

A simple, yet still fairly effective, way to implement maps was used in this test. The screen was divided into a number of regions (a 2-dimensional array). The elements of the array were set to 1 or 0 to indicate if the corresponding area of the screen was visible to the user. Part of the test procedure involved asking the user which side of the screen was more visible and inputting this information into the prototype modelling program.

Procedure

The tests were carried out with 12 research students and staff at the authors' institution. The objective was to see if alterations made to a document by the prototype tool helped mitigate the effects of certain simulated vision impairments.

The participants were divided into two groups of 6. One group was assigned the overall visual acuity impairment (henceforth referred to as condition "O") and the other group was given the macular degeneration impairment (condition "M").

Each user from each group was presented with three documents: a standard (not adapted) document; a slightly adapted document and a highly adapted one. Three different sets of content for these documents were used in order to prevent the participants from being able to memorise the words and figures, thus skewing results.

Figure 5 shows one set of documents (greatly reduced in size). Please note that the first two documents in the figure would have been presented using the "fit page width" zoom option in the PDF viewer—meaning that scrolling may

Standard Documents (STD)						
Con	Possible	Time (s)	Error (%)	ErrTime	Fig?	Useful?
O	2	135.0	80	29	5	0
M	2	105.7	90	74	6	0
Low-Adaptation Documents (LOW)						
Con	Possible	Time (s)	Error (%)	ErrTime	Fig?	Useful?
O	6	48.7	80	1	6	5
M	5	57.6	38	36	6	1
High-Adaptation Documents (HGH)						
Con	Possible	Time (s)	Error (%)	ErrTime	Fig?	Useful?
O	6	38.9	0	0	6	6
M	6	43.7	1	2	3	6

Table 1: Summary of results across adaptation type.

have been necessary to read all of the text, dependent on the font size selected by the chosen capability level. The latter (HGH) variant was presented in full-screen mode and the user was instructed to use the spacebar, as opposed to the mouse wheel, to scroll[14].

A calibration step, as described above, was carried out. After this, the 2 adapted versions of the documents were generated by the prototype according to the results of the calibration. All three documents were then shown to the user. The following measurements were taken.

- The time required to read each document (if it was readable at all).
- The mistakes[15] made whilst reading the document (if it was readable at all).
- If the user could see (describe, recognise) the figure.
- If the user felt the level of adaptation presented by the document was useful—i.e. enabled them to read it.

Participants were also asked for their overall opinion of the adaptations presented by the three different documents.

RESULTS

The results described above were collected and further processed. Some derived metrics were calculated: (a) the percentage error for each document reading and (b) the product of this error rate and the time it took to read the document ("ErrTime"). The ErrTime metric gives an idea of how difficult the user found it to read the document—the higher the number, the higher the difficulty. If no mistakes were made, then the value is 0. In the case that the document could not be read, ErrTime was recorded as "N/A".

[14] people with severe vision impairments or blindness would not use the mouse and many would not be able to read paper-based documents, such as the STD and LOW variants discussed

[15] words read incorrectly, missed words, or words in the wrong order

Condition	Capabilities: Lowest	Highest	Mean
O	0.2	0.6	0.4
M	0.0	0.4	0.3

Table 2: Ranges of capabilities encountered.

Condition	Rankings: Worst	Medium	Best	Participants
O	STD	LOW	HGH	5
O	STD		LOW, HGH	1
M	STD	LOW	HGH	5
M	STD	HGH	LOW	1

Table 3: Participants' rankings of the adaptation types.

Summaries for Each Adaptation Type

Table 1 contains a summary of the average result values for each condition and adaptation type. Not all (6) participants in each vision impairment group were able to read the STD and LOW adaptation types; participation is indicated in the "Possible" column. The "Fig? " and "Useful? " columns show how many of the 6 participants in each group found the figure and document readable, respectively.

These summaries indicate that the amount of adaptation required is proportional to the severity of the vision impairment. They also show that the methods of adaptation were largely successful—layout adaptation was necessary to allow those with condition M to read the document, however the figure could have been more legible if it had been kept in the centre or left areas of the screen.

Complete (raw data) tables of results are available from the authors.

Ranges of Capabilities

The capability values that were ascertained during the calibration stage of the experiment tell us how much or little the glasses affected the sight of the participants. A summary of these results is presented by table **2**.

Rankings of Adaptations

Participants were asked to rank the documents in terms of readability, from worst to best. Table **3** shows the results.

CONCLUSIONS

From the results presented in the previous section, we can observe a number of facts and trends, as follows.

- The adaptations made certainly helped participants read the documents.
- Further properties (colour, contrast) would be useful.
- A more refined map/layout and calibration system would be of use in future systems.
- Some adaptations expected to be useful only for group M were also useful for group O.
- There is considerable variation in the capabilities (especially in group O). This indicates that there is also

considerable variation in the participants' underlying sight—and, therefore, that capability-based modelling may be of use to non-disabled people, when further developed.

The results lead us to conclude that the concept of capability modelling may well be valid and that further research is required to more rigorously test this hypothesis. Such testing will need to be carried out after the technique is developed further and capable of providing adaptations that real disabled people (such as those with sight loss, motor control and hearing loss, for example) would benefit from.

Future Work

It is clear that the system has potential but requires significant further development. Ongoing work at the authors' institution towards this goal includes the following.

- More extensive (multi-channel, other scenarios and disabilities) testing.
- Work on allowing the model to cope with changes in user capabilities over time.
- Investigating how portable the model may be to other problem domains.
- Investigating how the technique may be made more useful to those *without* disabilities.
- Integrating the modelling technique with systems that can grade the relevance of information.

The overall goal of the project is to encourage the design of adaptable systems *by creating user models that are as generic as possible*. By taking personalisation into account throughout the design and development phases, systems can be made more useful for most users—presenting the relevant content in the desired way. Such systems can also be made more accessible for users with particular special needs, because instead of having to retro-fit some assistive technology, the core adaptation techniques are already part of the system and only their parameters may need to be changed.

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