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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]. 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].

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.

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/


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—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

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 cataracts5) 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 then 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 bluriness (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.
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 using the capability modelling technique, or use for acquiring and rendering data 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.
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 adaptions. Further details of the test procedure can
be found later.

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.

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. 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. 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

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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\(^\text{11}\).

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\(^\text{12}\) 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 tests 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\(^\text{13}\) required being solved. However, adaptions

\(^{11}\) 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

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![Figure 5: A set of documents used in the tests.](image-url)
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.

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 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”.

### Capabilities

<table>
<thead>
<tr>
<th>Condition</th>
<th>Lowest</th>
<th>Highest</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>0.2</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>M</td>
<td>0.0</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

### Ranges of Capabilities

<table>
<thead>
<tr>
<th>Condition</th>
<th>Worst</th>
<th>Medium</th>
<th>Best</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>STD</td>
<td>LOW</td>
<td>HGH</td>
<td>5</td>
</tr>
<tr>
<td>M</td>
<td>STD</td>
<td>LOW, HGH</td>
<td>HGH</td>
<td>1</td>
</tr>
<tr>
<td>M</td>
<td>STD</td>
<td>HGH</td>
<td>LOW</td>
<td>1</td>
</tr>
</tbody>
</table>

### Rankings

<table>
<thead>
<tr>
<th>Condition</th>
<th>Worst</th>
<th>Medium</th>
<th>Best</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>STD</td>
<td>LOW</td>
<td>HGH</td>
<td>5</td>
</tr>
<tr>
<td>M</td>
<td>STD</td>
<td>HGH</td>
<td>LOW</td>
<td>1</td>
</tr>
</tbody>
</table>

### Ranges 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.

**REFERENCES**


