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# Making the Mainstream Accessible: Redefining the Game

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## Abstract

Research into improving the accessibility of computer games can enable us to better understand what makes a good gaming experience for all users. We discuss work carried out in developing AudioQuake (an adaption of Quake for blind gamers); specifically the techniques used for rendering information and the nature of this work in contrast to other accessible games (both research and commercial). Based on user feedback regarding the effectiveness of the methods employed in AudioQuake, techniques for not only imparting but allowing vision-impaired users to edit 3D structures are proposed. Taking into account the progress made so far, we make the case for future research work, which could benefit many different types of users and help increase accessibility in other areas such as education.

**CR Categories:** H.5.2 [User Interfaces]: Auditory (non-speech) feedback, Interaction styles (e.g., commands, menus, forms, direct manipulation), Theory and methods— [H.5.1]: Multimedia Information Systems—Artificial, augmented, and virtual realities

**Keywords:** Accessibility, Audiogames, Multimodal Interfaces, Usability

## 1 Introduction

In recent years, a small but thriving “accessible games” market has emerged to provide computer games suitable for disabled (mostly vision-impaired or blind) people. As a result of this the opportunity has been opened up for them to experience some of the more advanced types of computer game technology and enjoyment that sighted gamers have taken for granted for many years.

Academic research into incorporating accessibility and usability principles into games has become popular. Through the work of organisations such as IGDA [IGDA 2005; Westin 2004], AudioGames.net [AudioGames 2002; Velleman et al. 2004] and OneSwitch [Ellis 2002], the mainstream games industry is beginning to investigate the feasibility and benefits surrounding accessible gaming.

### 1.1 Background and Challenges

AudioQuake is the first adaption of an existing mainstream game designed specifically for sighted people that has been made

playable by blind gamers. It is unique in terms of the range of Internet-enabled gameplay modes it provides. At one level, it could be termed an “accessibility layer” for Quake<sup>1</sup>. However, the ethos of the project that surrounds the software is more general – it seeks to:

- Provide access not only to mainstream games, but also to their surrounding online communities and development tools<sup>2</sup>.
- Give people freedom to use and modify the game, support infrastructure and related tools to create improved accessibility/usability techniques and other 3D interactive applications based on the existing framework.
- *Ultimately be much more widely applicable beyond the area of computer games alone – we have aimed to keep the output of each stage as generic and well-documented as possible so that it can be of use elsewhere.*

The task as a whole was split into the following phases of research and development, most of which have been completed at the time of writing.

**Low-Level Game Accessibility** — This stage concentrated on the relatively low-level requirements and techniques involved in adapting a game to use a primarily auditory interface. This made it possible for blind gamers to play Quake [Atkinson et al. 2006b].

**Online Capability** — Inclusion in Internet games was always a goal of the project. Throughout 2005, after the low-level work was completed, an Internet-optimised version of the game was developed. This allows blind people to play with/against each other and interact, individually or on teams, as sighted gamers do (including the development of an accessible statistics-tracking web application) [Atkinson et al. 2006a]. After future research, a “fair play” system will be implemented to allow blind and sighted players to compete more evenly (initial results show this to be possible).

**Development Support** — Many modern 3D games can be regarded as development environments for creating innovative 3D applications. Previously, the power and availability of these environments were irrelevant to blind people as they were inaccessible. We have carried out work to reverse this trend and enable blind (and, in the future, other groups of disabled) users to benefit from and build upon them.

**Implicit Accessibility** — This phase will involve more research into audio design and features will be added to the engine accordingly, such as 3D audio and effects. The goal is to provide more natural, realistic clues as to the player's surroundings

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<sup>1</sup>the seminal first-person shooter from id Software, released in 1996

<sup>2</sup>We also aim to make as many features as possible rely only on mainstream hardware, so as to keep barriers to entry at a minimum.

(e.g. through the use of echoes to indicate sizes of rooms, using more realistic sounds to represent enemies). This should allow the available bandwidth between game and player to be more effectively used, whilst enabling them to get more enjoyment from the experience.

**Level Editing** — Other research being undertaken in parallel aims to allow users to edit their own game levels. This represents the last major barrier to blind people being able to produce complete games for both themselves and the sighted. The work is being carried out with generalisation in mind and has the further objective of making viewing and editing other types of 3D structures accessible in the future.

AudioQuake is a fully-working game that embodies most of our research to date and will be built upon in the future. The AGRIP<sup>3</sup> project is a collective name for this and other related work. It employs a Free Software development model, so that users, developers and researchers can easily make use of and collaborate on improving all aspects of the project in future.

## 1.2 Development Style and History

Throughout development, the AGRIP project has been shaped by community feedback. This incorporates that given by users via e-mail and using project mailing lists. Many comments from users and suggestions for improvements have been made. Using the mailing list approach has enabled a number of interesting discussions to take place *between* users of the software, thus giving us a greater insight into how effective the work has been.

Versions of AudioQuake have been demonstrated at Sight Village<sup>4</sup> 2004 and 2005. They have also been used as the basis of a number of game audio design and game programming workshops at the 2005 International Camp on Communications and Computers<sup>5</sup>.

Most recently, the core ideas and motivations behind the AGRIP project and how it is contributing to future research were presented at RNIB Techshare<sup>6</sup> 2005.

## 1.3 Focus and Contributions of this Paper

The approach taken by this project contrasts with other contemporary research [Velleman et al. 2004; Westin 2004; Archambault and Burger 2001] in the following ways.

**Adaption** — Whilst other projects often develop new game/engine platforms anew, this project modifies existing well-designed mainstream technology to improve its accessibility and usability for all. The goal is *not* to retrofit accessibility, but to show how properly-designed systems may be made accessible through the processing and rendering of information at separate levels.

**Generalisation** — An important aim is to use the project to develop a deeper understanding of accessibility barriers that can be used in the development of general techniques to deal with those issues. We hope to create “portable” solutions to accessibility problems, that can be used in other (academic and leisure) settings.

The rest of this paper expands on the user requirements, design decisions and other issues encountered so far in the final two phases of development described above – specifically rendering techniques that have been developed and accessible 3D structure editing, which is still under active development.

The proposed solutions for both problems are based on our experience and feedback given by users, as well as the methods used in other contemporary research. Therefore this paper is intended to be a comprehensive review of the state of the art, which also describes and attempts to justify our plans for future work.

## 2 Rendering: Defining the User’s Experience

During the development of the low-level game accessibility infrastructure, the focus was placed on providing the user with the information they needed to perform tasks such as local navigation and general interaction with the game. Techniques for the processing of the structural information that the visual rendering was based on, as well as the filtering and transformation of this information into the most appropriate format for our target audience (blind gamers) were developed (as discussed in [Atkinson et al. 2006b]).

To demonstrate that these techniques worked, they were coupled with a set of sounds that were created to impart the information that the system deemed appropriate for its users. The initial rendering style, created by using these sounds, is definitely not the only one that could be implemented. This section is a discussion of the main alternatives and their relative merits, based on our work, experience and other contemporary research.

### 2.1 Signals, Symbols and Earcons

The original rendering style implemented for AudioQuake was based on the idea of “earcons”<sup>7</sup>. This approach was taken for two main reasons.

**Time-Efficiency** — There is a limited amount of bandwidth between the computer system and user. In-game sounds were made as short and to-the-point as possible; providing the minimum information necessary to convey their message, in the smallest practical amount of time and with no noise or other random effects that might dilute that message.

The use of principles similar to parallel earcons [Brewster et al. 1995] have contributed to the design of AudioQuake’s earcons.

**Well-Defined Structure Improves Recognition** — Earcons do not intuitively map to real-world concepts [Sikora et al. 1995]; the mappings must be learnt by the user. However, their artificial nature can be used to great advantage: by ensuring that sounds relating to a given set of similar objects/events have a consistent structure, the user can naturally infer what the system is trying to tell them without having to learn the meaning of many disparate signals.

Three features afforded by the use of well-structured signals have been employed in the game to date:

<sup>3</sup>Accessible Gaming Rendering Independence Possible (hence the acronym!); <http://www.agrip.org.uk>

<sup>4</sup><http://www.qacsightvillage.org.uk/>

<sup>5</sup>for vision-impaired people; <http://www.icc-camp.info/>

<sup>6</sup><http://www.rnib.org.uk/techshare/>

<sup>7</sup>Structured sounds, often obeying musical conventions, that are designed to alert the user to an object or event. They do not “sound like” their referents.

**Consistency within Referent Types** — A “base earcon” structure is defined and certain properties of it are altered to alert the user to different states or types of a given class of object/event.

An example of this is the scheme adopted by the EtherScan RADAR. Earcons that indicate the presence of a creature follow a certain format that is able to inform the player where the creature is vertically in relation to them and if they are aiming directly at it. Different types of creature are represented by distinct timbres; sharper sounds correspond to more capable enemies.

**Variance across Referent Types** — Sets of signals used to represent different families of in-game objects make use of fairly dissimilar structures. This reduces the chance of errors in recognition.

**Natural Reference Points** — Most earcons include an in-built point of reference. It was found that this was useful because users were sometimes not able to perceive absolute position or pitch with sufficient resolution, especially whilst concentrating on other tasks.

Corner detection, for example, employs an earcon composed of a sound directly in front of the player, followed by another sound to the left, right or both the left and right, depending on which type of corner was found – a left turn, right turn or junction. A similar style of approach was used extensively in the AudioGPS system [Holland et al. 2002].

The main focus of this rendering scheme was to facilitate fast-paced gameplay, with the hope that after further research it could be used as a basis for allowing blind and sighted players to compete and cooperate.

Feedback from the AGRIP community<sup>8</sup> indicates that this style of presenting information facilitates fast-paced gameplay. Most of these users feel comfortable with and enjoy this style (see section 4 for details). A few players have utilised the consistency it provides to become highly skilled at navigation and aiming. This is very similar to a trend seen in sighted gamers: the most skilled players<sup>9</sup> often purposefully lower the graphical detail levels of their games so as to remove the noise caused by random graphical effects and allow them to concentrate on the gameplay.

## 2.2 Auditory Icons and Implicit Accessibility

An opposing scheme to the one already implemented and described above is a rendering scheme based entirely around intuitive real-world mappings and effects. This scheme would make use of auditory icons [Mynatt 1994] and technologies such as 3D sound and effects. The main characteristics of such a scheme would be as follows.

**Increased Fun through Immersion** — Beeps and whirs may provide exact information but can take the fun away from a game. By using auditory icons and audio textures [Röber and Masuch 2004] that sound like the real-world objects (or characterisations of the enemies) to which they refer, the game can be made more involving – this is one aspect of “Implicit Accessibility” as described in the introductory section.

**Information Implied by Effects** — Information normally conveyed by explicit signals in the original scheme could be re-

<sup>8</sup>the core group of users of our software, who give feedback and make suggestions via a mailing list

<sup>9</sup>those who are able to make money from gaming

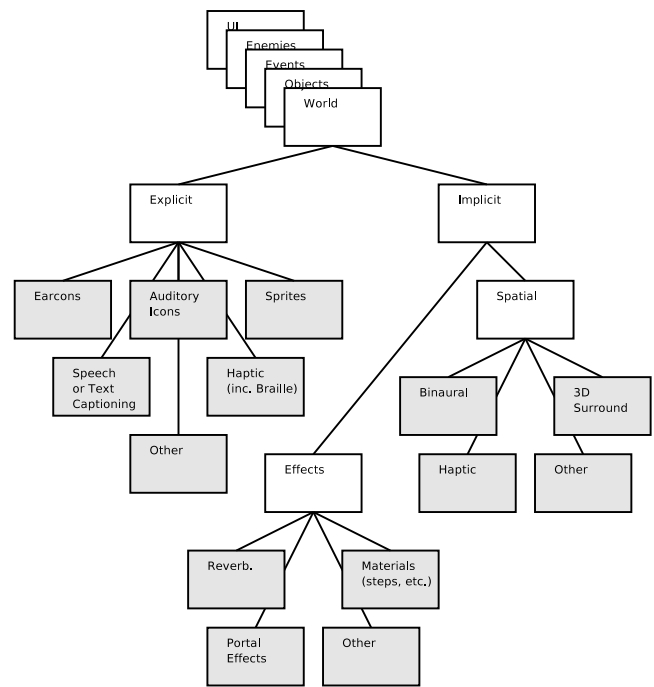


Figure 1: A taxonomy of rendering styles. Users should be able to choose any combination of rendering styles (the darker boxes) for each aspect of the game.

placed by more subtle clues, created by applying special effects (e.g. reverberations may indicate the rough dimensions of the spaces the user explores and spatial “tracer” sounds (such as air-movement through vents) could give clues as to the presence of open space and/or the direction of the exits [GMA Games 2001].

There have been requests for such an approach to be implemented from the AGRIP user community. It would certainly make Audio-Quake “feel” more like other popular accessible/audio-games [ESP Softworks 2001; Westin 2004] – though, we expect, at the loss of at least some of the speed and accuracy afforded by the symbolic rendering style. This is suggested as an area for future research.

## 2.3 User-Centred Flexibility

The above two rendering scenarios may be seen as opposing ends of a linear spectrum – one scheme promoting fast-paced gameplay based on explicit signals and the other promoting better immersion through the use of implicit cues. It could be imagined that some forms of hybrid rendering style may exist between them. Due to the varying nature of users’ requirements and the conditions in which they may interact with the system<sup>10</sup>, it could be beneficial to allow them to specify a scheme that is more suited to them, rather than forcing them to one of the extremes discussed above. A taxonomy of styles that could be used to build up such a hybrid scheme is given in figure 1.

Some proposed techniques (from existing literature and ideas generated within the AGRIP project) for allowing this are as follows.

<sup>10</sup>via visual, auditory or haptic interfaces, with certain different types of sensory preferences or impairments, for example

**“Sound Skins”** — Allowing the user to choose between predefined sets of earcons, auditory icons or sound textures for the rendering of game objects and events.

**Style Selection** — Give the user the option of specifying their preferred rendering styles for each major game element.

**Intelligent Style Selection** — Based on the user’s general preference and the current world state, the software should select the most appropriate rendering styles to give the user the information they need in the format(s) they favour.

An example of how intelligent style selection could be used follows: If the user is battling a group of enemies in a game, they need more accurate positional information about the enemies. Such information may be presented in preference to less important navigational cues, according to the principles developed to ensure effective usage of the (limited) bandwidth between the computer system and the user.

The system would choose the most appropriate rendering style based on guidelines such as those described below.

- The most informative rendering scheme, consummate with the user’s overall style preference (their position on the scale of symbolic–iconic rendering), should be used.
- The user’s preferred output medium (e.g. audio) may become overloaded at times when a lot of information is to be presented. If this occurs, less critical information should be “demoted” to an output medium (e.g. haptic/Braille) of lower preference to the user.
- Depending on the nature of output mediums/devices available, this demoted information may have to be presented at a lower resolution than it could have originally been (positional information may have to be reduced from two or three to one dimension, for example).

So far, adaptations targeted at blind users in particular have been discussed. However, once the processing of information has been decoupled from rendering, we are able to utilise many other different rendering styles to suit users with other needs.

The next logical step for AudioQuake is to better support vision-impaired gamers through the use of sprites and high-contrast colour schemes (as have been used in Terraformers [Westin 2004], as well as many GUI Desktop Environments). This could easily be achieved as all of the required information is already available to the rendering system.

### 2.3.1 Generalisation for Other Users

This brings us to the possibility of supporting non-disabled users better than they currently are. It has been asserted that there are similarities between designing interfaces for normal users in unusual environments and designing interfaces for users with unusual requirements in normal environments [Newell and Gregor 1997]. This implies that the techniques developed here and as part of other research projects may be of use for users of mainstream applications on devices such as PDAs and cellular telephones.

Further to this, it has also been asserted that a large percentage of adult computer users would benefit from some type of adaption to their needs in the systems they use [Forrester Research & Microsoft Corporation 2003]. On a similar note, websites are on average 35% easier to use for *everyone* if they comply with accessibility standards [Disability Rights Commission 2004] – in fact, the W3C’s

Web-Content Accessibility Guidelines borrow heavily from established usability principles [Web Accessibility Initiative 1999].

We submit that such an adaptive rendering system would be useful for many gamers. The popularity of the “Doom 3 Closed Caption” modification – and the subsequent inclusion of closed captioning in mainstream games by other developers – also supports this [Games[CC]].

Further research may also reveal guidelines (similar to those already established in the areas of Human Interfaces and Web Usability) that could provide heuristics for design decisions (such as how many of the different rendering styles proposed in figure 1 should generally be applied at once, both to different objects/events and the whole scene).

## 2.4 Benefits of Multimodality

The benefits of having multiple rendering “layers” extend further than being able to support users with varying requirements. It has been asserted that well-designed multimodal interfaces can provide some error-correction, at least for certain tasks [Suhm et al. 2001]. Additionally, providing reinforcement for the primary means of rendering can both aid cognition [Röber and Masuch 2004] and increase the user’s enjoyment of the experience [Velleman et al. 2004].

## 3 3D Structure Representation & Modification

As 3D environments are used more often in our society, for work and leisure, there are numerous opportunities to include disabled people in them. Such opportunities include games; Collaborative Virtual Environments (CVEs); public information services<sup>11</sup> and possibly even modern art.

The techniques presented and cited in this paper go much of the way to affording people with sight loss access to 3D environments. Since our current work has made these techniques applicable to contemporary 3D engines, it is hoped that they will be adopted and improved by others. One major hurdle that remains, however, is to allow blind people to *create* 3D environments.

The common technique for 3D modelling/level editing software is to allow the user to construct and modify parts of the world via a GUI that features a real-time preview of their creation so that they can receive feedback on changes quickly. This is, of course, inaccessible to certain groups of people.

A preliminary architecture and some of the low-level components of an *adaptable* level description system have been developed, based on our experience with other areas of the project. This architecture is presented in figure 2 and its benefits, for all users, described below.

The design applies the same principles used in AudioQuake to improve the accessibility of constructing 3D structures for both disabled and non-disabled people:

**A Layered Approach** — By decoupling the rendering/UI from the underlying data and processing, the possibility for multiple different front-ends is created. These front-ends have many potential uses:

<sup>11</sup> such as the Virtual International Space Station, which was created using the Unreal (game) Engine.

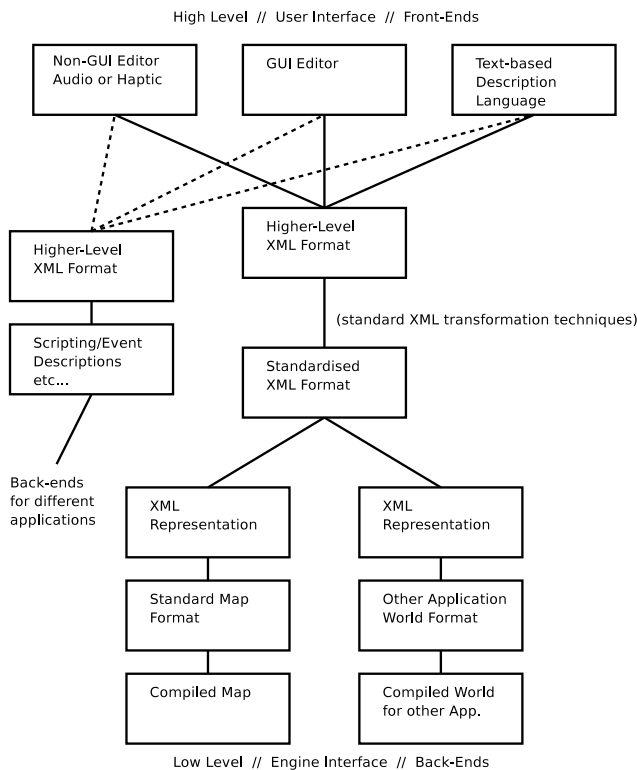


Figure 2: Proposed architecture for an adaptable editing system for 3D applications and games.

- Increasing accessibility (e.g. a structured text or natural language front-end).
- Improving usability for the author or end-users (e.g. programs that are able to check the structures created for common semantic errors in a given domain<sup>12</sup>).
- More novel methods such as the creation and modification of structures by computer programs. A simple use of this could be to map data from real-world maps to the given 3D application. More interesting scenarios include the dynamic generation of future gameworlds based on the player's progress so far<sup>13</sup>.

**Format Standardisation** — Adopting an open standard for defining 3D worlds (such as X3D or CrystalSpace map format [X3D Consortium ; Arendash 2004]) would allow different front-ends to create worlds or structures for different 3D engines and applications. This could result in both data and skills being more easily transferred between different 3D design projects. A side effect would be that the benefits described in the previous point above would be applicable to all engines for which a back-end had been developed<sup>14</sup>.

**Awareness & Equality Increase** — An important goal of the AGRIP project is a social one; to promote equality amongst

<sup>12</sup>Such as violation of building standards, the creation of difficult-to-navigate floor-plans and so on.

<sup>13</sup>This complements current game design techniques such as open-ended character development and could well serve to increase replay value.

<sup>14</sup>This is the same way that cross-platform, cross-language compilers such as GCC work – by having front and back ends target a common intermediate language.

gamers and allow further integration of disabled people. By highlighting that well-designed mainstream technology can be made accessible, this goal can be achieved. Applying these principles to 3D content creation may well increase awareness and equality, even if only by a small amount, as a side-effect to the above advantages it would afford us all.

As indicated in the diagram above, a similar approach could also be applied to related aspects of 3D applications such as in-game cinematic sequences. This could well be achieved in an integrated manner by including other namespaces into the XML-based standard for defining structures (such a technique is used by the DocBook standard to incorporate SVG and MathML into DocBook documents, for example). So far the lower levels of the level description system have been developed and research is ongoing.

It should be borne in mind that we do not expect to give blind people an in-depth understanding of lighting and texturing issues – primarily we're discussing the definition of structure alone. However, this layered approach allows for the use of semi-automated approaches to deal with the problems these issues pose. One approach is to use the idea of styles/sheets to apply pre-defined texture or lighting themes to a map. In a collaborative environment, the layered approach can be used to separate the definition of structure from appearance and sighted assistance can be brought in to apply textures and lights to the structure.

### 3.1 Not Just Games

As with many aspects of the AGRIP project's work (and the views expressed in literature this review cites), the goal is to produce results that can be applied in areas additional to games. It is clear that the above system may be of use for editing and verifying 3D structures which may be used in other systems than games. However, there are other potential uses of the work.

Increasingly, visualisations and Collaborative Virtual Environments (CVEs) are beginning to be used in the workplace as well as computer games at home. It is our opinion that we should concentrate considerable effort on making these technologies accessible to as many people as we possibly can *before* they become mainstream – currently adoption in the workplace is slow, partly due to issues involving the average work environment [Brock et al. 2003], as well as the difficulty of navigation [Yang and Olson 2002] (another area in which accessible gaming research may make contributions).

## 4 User Survey

Members of the AGRIP mailing list and wider accessible gaming community, who have played AudioQuake before, were invited to answer a short web-based questionnaire. The survey was designed to ascertain users' opinions of the game and project as a whole, in order to gauge the project's success and reception of our future development plans. Figure 3 shows the results collected in the relevant part of the survey; 20 users took part. The full text of the questions asked is given in Table 1.

From examining the data collected, we can draw some conclusions.

- The need for a map editor is highlighted – the vast majority of users surveyed want more research and development to be carried out in this area.
- Given that most accessible gamers are not necessarily advanced computer users, the number of people developing, or thinking about developing, modifications and games is quite

1	Do you think that AudioQuake represents a welcome development in accessible gaming (i.e. is making mainstream games like Quake accessible a good idea)?
2	Do you think that AudioQuake, when originally released in 2004 (then known as AccessibleQuake), represented something new in the field of accessible gaming?
3	Do you like playing AudioQuake?
4	Would you like other mainstream games to be made accessible in a similar way?
5	Would you like to see AudioQuake development continue in future (for your information, the current roadmap is available at our web site)?
6	Would you like an accessible map (game level) editor to be created for use with this and possibly other similar 3D games?
7	Do you develop, or plan to develop, modifications for AudioQuake, or accessible games based on it?

Table 1: Full list of questions corresponding to the answers in the chart

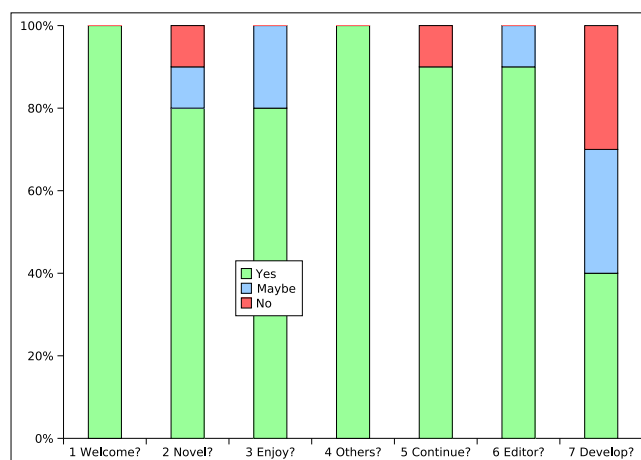


Figure 3: Chart depicting user satisfaction survey results

high. However, one of the main goals of the project is to encourage development, so this is an area that needs attention to ensure that goal is met.

- A notable portion of users were not sure if they liked the game. This could be attributed to the unconventional rendering style used. Comments received (such as those found in figure 4) seem to back this up and provide impetus for carrying out future work in the personalised rendering areas discussed above.

Due to the audio-centric nature of the game, selected comments from the users are included in figure 4, to give the reader an impression of the gameplay experience and a qualitative idea of how the project has been received.

## 5 Future Plans

This review of the current progress of the AGRIP project and how it fits in with (and differs from) other research has left a lot of questions open for subsequent research to answer. Some of the main areas we hope to focus on in the future are outlined below.

- Improving and testing the solutions to 3D accessibility, including structure editing, developed so far.
- Further developing the rendering techniques presented here and testing them using a wider range of people.
- Generalising them and ascertaining how effectively they can be used in other areas; in other 3D engines and mediums such as academic material and real-world navigation.

Further issues that are being researched currently but are out of the scope of this paper are: local navigation (part of the low-level game accessibility issues); improving real-world mobility and spatial awareness; accessible interaction and collaboration between players and teaching blind students programming concepts using systems based on game technology.

### 5.1 Links to Education

Research into the potential usefulness of game-like technology for education is gathering momentum [NESTA and EA 2005; Gee 2003]. It is important that any future developments in this area promote inclusion for all users. The use of high technology doesn't guarantee a usable experience for everyone (as the web has shown us [Disability Rights Commission 2004]) but the use of technology such as that behind AudioQuake could help in a number of ways.

**Providing Access** — Areas of education which rely on the understanding of complex data structures such as trees, hypertext documents or 3D structures may be made accessible.

**Improving General Usability** — Techniques developed to improve accessibility may well lead to the discovery of better general usability principles for mainstream users.

**Integration** — Any method that allows disabled students to partake in the same educational courses or jobs as non-disabled people improves their social integration and allows them to contribute to and benefit from such interaction on much more even terms.

These are also areas for future work, but are suggestions aimed at the wider community. The output of the AGRIP project is, to our

“I think the ESR needs to more accurately and swiftly reflect the player’s position and what’s around them, especially enemy targets. I find there is a lag between position change and new feedback data, such that often, even though I hear that an enemy is within range, the enemy is not in fact. I’d also love to see more done with 3-D audio mapping of terrain. A GREAT job has been done overall, and I wholeheartedly encourage continued development of this application and its myriad uses.” –User 1

“Audio Quake is the only game I play regularly any more. I’ve played it the most out of all the games I’ve played and purchased.” –User 2

“We really need a map editor. Some standard maps can be used by AG users, but especially for new users, we need to be able to create maps with lots of right angles and grid-like layouts. For the experienced players, the game loses novelty with out new areas to play. New areas/maps cause experienced users to come up with new strategies.” –User 3

“Why are you working with the first game of Quake?” –User 7

“I would like to see Audio quake utilize controllers that have force feedback capabilities. Being able to detect or identify objects within the game using touch and feel would be great and in some respects better than sound identification. Right now, there are so many sounds and noises within the game that it’s become distracting. I think utilizing some sort of voice command system might be interesting also. ...” –User 20

Figure 4: Selected comments from surveyed users

knowledge, the only accessible 3D application development platform that is licenced as Free Software and is aimed at providing people from such varied domains with a way to further accessibility in those areas.

## 6 Conclusions

This work shows that even some of the most time-critical and competitive mainstream computer games can be made accessible to people with vision impairments and sight loss. The techniques developed for ensuring the rendering of the gameworld caters to the needs of the user are performing well, but there is still significant scope for improving those techniques; making them applicable to users with other disabilities – including those *without* disabilities – and using them in other applications, such as 3D structure overview and editing.

We have discussed how the development of AudioQuake builds on, but also contrasts with existing research in this area. We have also proposed, based on past experience and user feedback, a number of new areas in which the techniques developed could be used.

## 7 Acknowledgements

We would like to thank the community that has evolved around the AGRIP project for its continued support and constructive criticism – special thanks go to those in both our and the wider accessible gaming communities who took part in the survey. This project would not have been possible without the release of engine technology to the community by id Software, the help of the Quake and QuakeWorld community (including members of QuakeSrc.org, ZQuake and QuakeForge), or the sponsorship of the Grundy Educational Trust. Thanks to Loughborough University for endorsing this project and allowing the results to be disseminated Freely.

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