A FLEXIBLE EXTENDED QUARTO! IMPLEMENTATION BASED ON COMBINATORIAL ANALYSIS

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ABSTRACT
Perfectly framed in the Serious Games thematic emerged Quarto!, a game created in 1991 that in not much more than a decade became the most awarded one of all time. Quarto! possesses eccentric features like contemplating common pieces for both players and each one choosing the piece the opponent must play. The authors’ vision consisted in modeling Quarto! in a computerized form, both logic and graphical user interface, thus providing a solid, flexible and interactive support for logical and strategic reasoning learning. Five progressive AI complexity levels were implemented, in order to accommodate several human player experience ranks. In addition to the original line and square alignments, structures with L and T designs were introduced, that in concurrence with their symmetry properties enhanced combinatory possibilities and complexified the game. Board assessment is particularly complex, due to the nature of the game. A key project contribution is the introduction of the concept of Quarticity as a specific heuristic game situation assessment. Experiments conducted with end-users revealed that the usage of the described system enhanced and accelerated both the rule set learning rate and generic strategic reasoning, when compared to a conventional board game experience.

KEYWORDS

1. INTRODUCTION

The Serious Games thematic has achieved numerous wide domain applications in the past years, and has consequently attracted spotlight interests of worldwide industries, organisations and governmental agencies. This expansion movement conducted to a massive access to these tools by new target audiences, namely the entertainment and education markets, alongside the funding organizations themselves [Smith2007]. Governmental and military organizations are also making use of these applications, mainly for training purposes, be it in the leadership and management areas, or in a more technical approach, using primarily simulation tools [Stone2005].

Perfectly framed in this context emerged Quarto!®. This game was created by Blaise Müller, in 1991. Its author drew inspiration from simple traditional games, such as Tic-tac-toe or Connect Four, having added a small further set of original rules, that has increased game addictiveness and complexity, which in turn, and in not much more than a decade, made this game the most awarded one of all time [Kerner2001].

In this paper, the authors propose the virtualization of the Quarto! game, by means of a 3D, interactive computer game, with full and extended game rule implementation, using the declarative paradigm, and merging it, using sockets, with a realistic OpenGL game modelling. In order to validate the resulting implementation, a preliminary experiment was conducted, with some test subjects playing the implemented version of the game, and comparing with a control group that played using traditional physical board.

The rest of this paper is structured as follows. Section two presents a description of the game and its rules. Section three describes the followed project approach and section four contains a description of some implementation details. Section five contains the results that were achieved with several test subjects and section six presents some conclusions and future lines of work.
2. GAME DESCRIPTION

Presenting itself apparently as a simple game, with a four by four square board and sixteen pieces, one of the distinctive features in Quarto! consists in the fact that the sixteen different pieces result of the combination of four distinguishing characteristics: color (dark or light), shape (round or square), height (tall or short) and hollowness (solid or hollow). Thus being, each piece can be univocally identified by the four characteristics it withholds – for instance, the leftmost piece in Figure 1 is the dark, square, tall, solid piece. Some examples of these pieces can be seen in Figure 1 below.

![Figure 1. Conventional Game Board](image)

At the beginning of the game, the pieces are positioned outside the board, and the ultimate goal is to establish a line of four pieces on the board – horizontally, vertically, or along a diagonal – or to define a square with side dimension of two, with at least one common characteristic.

Another distinctive feature in Quarto! is the composed nature of a play – a player not only places a piece on the board but also chooses the piece the opponent will play on the next move.

A typical game sequence consists in the draw of the first player, who selects one of the sixteen available pieces and handles it to his opponent, who in turn places it on any free square on the board; he must then choose one of the remaining pieces, thus repeating the whole process, until either the board is full – the game ends in a tie – or one of the players calls Quarto! – signaling his triumph. One important additional aspect is the fact that the winner does not need to have placed all four pieces himself, just the last one, which completes the alignment.

As a variant game option for beginners, Quarto! can be played considering only a subset of characteristics – for instance, a game may contemplate only color and shape of the pieces, thus making it easier for inexperienced players to get acquainted with the rules and game dynamic. In the same line of reasoning, the inclusion of the squared shape as a possible ending situation can be considered as an advanced game option, for experiences users.

Another important aspect about Quarto! is the rule set openness, which, as explained in more detail in the subsequent section, allows for the addition of new rules, as is the case of new geometrical outlines in which to end the game, besides the traditional lines and squares.

One must conclude that Quarto! possesses eccentric and peculiar features like contemplating common pieces for both players and each one choosing the piece the opponent must place in the board. One must also point out rule flexibility, that enables distinct difficulty levels, as well as rule set openness which permits its extension and game complexity improvement. Another specificity about the game is the fact that board assessment is particularly complex, due to the common nature of the pieces and the dependency from the ones already played and the others still available [EducationalLearningGames2001].

3. PROJECT APPROACH

With all this in mind, the authors’ vision consisted in modelling the described game in a computerized form, both logic and graphical user interface, with the intention of providing a solid, flexible and interactive support for logical and strategically reasoning learning. The game’s dynamic potentiates both cooperative
actions and temporary alliance formation, at its beginning, as well as individual offensive strategies and entrapment delineation, further on.

A collateral effect of the flexible nature of the game, both in terms of rule application and domain action interpretation, is the possibility of widening application domain to several distinct eclectic areas such as education, artificial intelligence or planning and control investigation. Each of the mentioned areas can be further detailed, as is the educational area, where learning can be defined in terms of general game rules understanding and application, at a lower level, or abstract logical reasoning capabilities training and development, at a higher one. In the artificial intelligence field, the most important aspect is the possibility to apply diverse algorithms, in order to simulate different player skill levels, and to test these algorithms against one another.

Regarding the graphical interface conception, it was forecasted that a meticulous, comprehensive and immersive reality modelling would enhance the player’s proactivity towards the software and therefore potentiate the possibility of achieving the desired goals.

Whilst all this is promoted via the flexible nature of the game’s rules, by allowing different increasing levels of complexity to be defined, it was also believed to be possible to further complexify the game, by extending existing rules and creating new difficulty levels by increasing the number of possibilities to win a game. This was achieved through the inclusion of L- and T-shaped geometrical designs as winning possibilities.

The original rules contemplated nineteen possible arrangements (ten considering only lines, and nine more, considering squares). The introduction of L- and T-shaped designs increased this number by seventy-two arrangements (twenty-four from the T-shaped alignments and another forty-eight from the L-shaped alignments), totalling ninety-one different geometrical possibilities of winning the game.

It was the authors’ desire to create a modular implementation, and with that in mind, a client-server architecture was envisioned, as can be seen in Figure 2. This allows not only for an independent development of the logic module and the user interface, but also the possible implementation of multiple different user interfaces or logic modules, in different implementation languages, using different paradigms, or technologies, since the only requirement is that the envisioned communication protocol is respected.

The communication protocol between the logical and user interface modules was designed and defined based on sockets, using the TCP/IP protocol, in order to guarantee the reliability of message deliverance and reception. This option also allows physical distribution of the two modules into separate, independent machines across a network.

The save log file kept by the user interface allows not only for a game to be paused and later resumed on a different machine, and even with a different user interface, but also allows games to be replayed, giving the players the opportunity to analyse the game and strategies used by the player himself and by the adversary. This is thought to be one of the key contributions to both game rule comprehension and advanced strategy learning.

As can be seen from Table 1, the communication protocol is very simple, comprised only of five requests that can be made during a game and a sixth to terminate the connection to the server.
Table 1. Communication Protocol Messages

<table>
<thead>
<tr>
<th>Request</th>
<th>Reply</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>getPlay(mode, board, reserve, charactLevel, quartoLevel, level, piece)</code></td>
<td><code>[board, newReserve] / [newBoard, reserve]</code></td>
</tr>
<tr>
<td><code>validPlay(mode, board, reserve, piece, x, y)</code></td>
<td><code>yes / no</code></td>
</tr>
<tr>
<td><code>executePlay(mode, board, reserve, piece, x, y)</code></td>
<td><code>[board, newReserve] / [newBoard, reserve]</code></td>
</tr>
<tr>
<td><code>draw(reserve)</code></td>
<td><code>yes / no</code></td>
</tr>
<tr>
<td><code>quarto(board, charactLevel, quartoLevel)</code></td>
<td><code>yes / no</code></td>
</tr>
<tr>
<td><code>client shutdown</code></td>
<td><code>thread shutdown</code></td>
</tr>
</tbody>
</table>

The first message is used to obtain an automated play from the server. The second and third messages are used to validate and execute a play respectively. The fourth and fifth messages are used to inquire the server about game ending, either in a draw or win for a player, correspondingly.

In order to clarify the contents of the messages referenced in Table 1, the meaning of some of the keywords is described in Table 2.

Table 2. Protocol keyword interpretation

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Indicates if a piece is being placed on the board or selected to handle to the adversary</td>
</tr>
<tr>
<td>board / reserve</td>
<td>Game board / board containing the pieces that haven’t yet been played</td>
</tr>
<tr>
<td>newBoard / newReserve</td>
<td>The board or reserve after placing a piece / selecting a piece to give the opponent</td>
</tr>
<tr>
<td>charactLevel</td>
<td>Indicates which characteristics are being used to play</td>
</tr>
<tr>
<td>quartoLevel</td>
<td>Indicates which alignments are being considered as ending possibilities</td>
</tr>
<tr>
<td>level</td>
<td>The computer AI level</td>
</tr>
<tr>
<td>piece / x / y</td>
<td>The selected piece and its coordinates in a Cartesian coordinate system applied to the board or reserve</td>
</tr>
</tbody>
</table>

Within the vast realm of possibilities, the authors chose different paradigms for the two main modules. In respect to the server, the declarative programming language Prolog was chosen, and in particular, the SICSTus development system [Various2007]. The implemented user interface was made in C++, in concurrence with OpenGL [Shreiner2005]. The next section provides a more detailed explanation on the development of both logic module and graphical user interface.

4. IMPLEMENTATION DESCRIPTION

This section describes the implementation details for both logic and graphical user interface modules.

4.1 Logic Module

The development of the logic module took place in several phases. On a first stage, the adequate structures were designed in order to formally represent the standard set of rules and static game status – board occupation and available pieces. With these two essential pillars completely defined and tested, it became possible to perform unequivocal play validation and therefore game sequence substantiation. The enunciated set of features enabled, in combination with a simple text-based user interface, developed in Prolog just for expedite test purposes, the accomplishment of complete human versus human games. The next logical step was automatic game analysis implementation with the ultimate intention of permitting computer versus human or even computer versus computer game interaction. As a final step, the communication protocol was implemented and tested, with the official user interface (described below).

The first expected hurdle, derived from the enunciated game distinctive characteristics and that was necessary to overcome, was the design and implementation of an efficient and effective game situation evaluation function. Due to the practical incomputable state space dimension, its complete exploration and assessment had to be immediately discarded and a heuristic approach was directly adopted. This is one of the most idiosyncratic project contributions and consists in the introduction of the concept of Quarticity as a
specific heuristic game situation assessment. The cornerstone idea is to assess the number of distinct possibilities of forming a winning situation, depending on the pieces’ disposition on the board, alongside with the available ones. This assessment is refined with a weighting component that provides more importance to situations where only one piece is required and less influence to embryonic sequences of one or two pieces. Naturally, a possible successful alignment of three pieces which has, for example, more than one characteristic in common and there are various available pieces that complete the sequence is more worthwhile than a single common feature alignment with only one compatible piece available.

The described heuristic evaluation is used as the fundamental tool in what concerns to automated play decision. The logic module contemplates five different progressive artificial intelligence levels, in order to accommodate several human player experience ranks. The one considered to be the easiest is the random play, where the computer chooses a random place on the board to set the piece in play, and then chooses an also random piece to handle to the adversary. The next two levels are considered equivalent in terms of difficulty. While one attempts to minimize the current quarticity, the other acts as a greedy algorithm, trying to maximize the current quarticity of the board, regardless of the chances of winning or losing in the next play. The fourth level has a look-ahead capability, acting, in practice, as a one level minimax algorithm. Finally the fifth and most difficult level of artificial intelligence consists in a multilevel minimax algorithm implementation with alpha beta pruning [Norvig2003].

As postulated earlier, the game definition openness, especially in what concerns to winning combinations, allowed the introduction of new and more complex admissible winning geometrical forms. In addition to the original line and square alignments, structures with letter L and T designs were introduced, that in concurrence with their symmetry properties and standard rules interconnection, enhanced combinatory possibilities and complexified both alliances and entrapment strategies.

4.2 Graphical User Interface Module

On the other extreme of the project, and in what regards to the user interface, the modelling and environment design technical decision fell on OpenGL, in conjunction with the C++ programming language. This technology juxtaposition allows for the definition of an appealing interface, with multiple environments, each targeted to a specific audience, in order to improve game customization and as a result individual captivation. An additional aspect, closely related to this one, is the detailed modelling to scale of both board and pieces, using photorealistic textures, extracted from of the actual real life items, as shown in Figure 3 (left). Figure 3 (right) shows an additional texture, with the U.S. Capitol building as the background, using marble-based textures for both board and pieces. So, not only different user interfaces can be developed, but also different skins can be used within one single user interface, thus increasing the number of different gaming experiences a player can experiment, making the game even more enjoyable and captivating.

As can be seen in Figure 3, this interface presents both a global and an individual play timers on the top right corner of the interface. This allows players to keep a track on the time they spent playing and the time the opponent uses. Aside from giving players an idea of the level of experience of the opponent, it also offers the possibility to restraint plays to a defined maximum period of time, thus making the game even more exciting.
One last user interface cornerstone, as already mentioned in the previous section, is the possibility to replay a game, partial or completely. This feature was designed in order to enable an advanced and exhaustive play analysis, especially valuable for expert users, making possible self or opponent strategy learning and revising.

5. RESULTS

Having in mind the necessity to assess the impact of the followed approach against traditional methodologies, in terms of usability and learning curve improvement as well as strategic reasoning development, a detailed comparative study have been conducted.

A sample of ten subjects was chosen amongst undergraduate students without any previous knowledge of the board game. Randomly, these subjects were divided into two subsets: the blue and the red one. The blue group is the control set and subjects are intended to learn the game rules and practice through the traditional approach of playing against humans using a physical board and pieces. The red group subjects are intended to play the game only via interaction with the developed application, competing only against the computer, although they are able to consult the game rules in paper format as the blue group.

In order to achieve similar experiment conditions to both subject sets, so that results can be compared, the control group subjects played the game, indirectly, against the computer – as the red group – but having a human opponent that manipulated the physical pieces in the traditional board following the computer play indications. It is believed that the existence of a computer monitor in the environment does not affect the subject’s behavior as he\she does not see the screen [Campbell2001].

It was agreed to define three leveled experiments, in order to determine the subject’s individual game expertise. The first level corresponds to traditional basic game rule set knowledge; the second level to basic strategic reasoning where players compete against a greedy algorithm that tries to maximize immediate board value; and the third level matches both extended game rule set – with L and T shapes – and advanced strategic reasoning where players battle against a multi level minimax algorithm. In order to conclude the experiments conditions definitions, one must state that the success level that determined game level achievement was characterized by two consecutive triumphs.

Having the experiments conditions and definitions in mind, in the course of analysis of Figure 3, one shall state that subject A had to play two games with a random level algorithm impersonated by a human opponent before he\she was able to accomplish two straight victories. Still with this illustration in mind, one might marginally tend to state that the interactive approach has a positive impact in game rule learning, although a higher experiment cardinality set is needed to fully affirm this outcome. Nevertheless, subjective data provided by post-game interviews support it as red team elements showed higher levels of motivation.

Figure 4 illustrates the data provided by the second level experiments where it is visible that not only none of the conventional group elements was able to attain a clean sheet but all of them needed more training games, when compared to level one experiments, to achieve basic domain specific strategic reasoning levels. Considering the red group, not only the number of games needed to master an immediate greedy algorithm is, in average one game short, but element I was able to reduce the learning period and element H continued to record a clean sheet.
Extended rule set and advanced multi-level strategic reasoning acquisition levels are illustrated in Figure 5, where it is visible that the interactive computer game approach group attained impressive results when compared to the conventional one, as sixty percent of the red group elements outperformed eighty percent of the blue group and, in average, the new approach elements needed one point six less games to accomplish the same level of advanced game expertise.

As previously briefly referred, also subjective data was collected throughout the practical experiments through means of short interviews. These surveys confirmed the unbiased collected data as interactive computer game group elements consistently stated to be more motivated and interested than the control group. Another relevant feature was the self-assessment indicator: once again the red group stated to be more aware of their potential and effective knowledge as they reported that competing with a pre-defined computer algorithm with a given difficulty level was better as they had not to face natural human performance dissimilarities.

At a more technical level, the system’s global architecture performed with the desired robustness levels, been able of efficiently perform all experimental games without concerns. Also the developed five levels of artificial intelligence produced consistent results as tests conducted within the program itself, by means of executing numerous games between different algorithms, corroborated the previsions about the difficulty levels, each one being superior to the ones beneath it.

6. CONCLUSIONS

Having in mind the initial enunciated hypothesis, the project description and the depicted results, one shall clearly state that the prior questions were answered in a positive way. In other words, the conducted experiments stated that the usage of a fully automated and interactive gaming environment deeply enhances the subject’s learning rates and reduces the time gap to reach similar strategic reasoning levels. Furthermore, through the effectuated quizzes, the playing satisfaction levels were also superior when considering the interactive tool group as well as its elements have reported to be more motivated. Another key positive feature of the proposed approach was that by playing against a pre-defined algorithm, subjects have stated that they were able to better self-assess their performance and skill level.

Concerning the game engine and reality mimic, one must surely state that not only all the traditional game rule set was translated into the developed software but more advanced rule variations were added
successfully. Also all the board game mechanics was efficiently translated into its virtual representation and the graphics realism was as well achieved by means of the usage of photorealistic textures and scale modeling.

Moreover, the global system's architecture proved to be an efficient and reliable solution as both the decision game analysis engine module, built in ProLog, and the interface layer rooted in OpenGL performed as desired along all the experimental games. Furthermore, the communication layer based on TCP/IP sockets established itself as a reliable, flexible and scalable option.

Despite the success of the proposed approach, there are several future work areas already pointed out. In this domain, one may first address the ones that are most likely to enhance the game immersion sensation so that collateral objectives are attained such as greater and faster strategic reasoning levels. This could be reached by applying augmented reality techniques such as the ones described in [Silva2007], so that end-users would be able to simultaneously play against a computer algorithm and freely manipulate the virtual board in the real world. Another possible improvement in this area would be the system’s communication architecture remodeling so it would be able to enable games between two humans connected through out a social network. It is believed that the existence of a ranking system would allow greater human to human interaction in more motivational domain and in a categorized way. In a slightly different domain, but also with the intention of promoting the learning rate velocity and accuracy, it is intended to add to interactive game design, the possibility of next play advice. In other words, an inexperienced player could ask the computer an advice concerning the next best move accompanied by a brief justification in natural language. With this approach, not only the mechanics of the game would be greater perceived by the user but also the semantic value and justification of each play.

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