

Giguesaur: Game Logic

Ashley Manson

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Co-Workers: Joshua La Pine & Shahne Rodgers

Supervisors: Geoff Wyvill & David Eyers

Department of Computer Science
University of Otago

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1 Introduction

Our vision for our completed Giguesaur application was allowing a classroom of children, each with their own iPad, to run around and solve a jigsaw puzzle together. Imagine a classroom full of kids where they are all trying to work on a single conventional jigsaw puzzle; such a scheme is in no way practical. Giguesaur on the other hand is a jigsaw puzzle game, that aimed to be more entertaining than a conventional jigsaw puzzle. The main goal of our project, besides all the design and technical subgoals, was simply to make an application that is fun for children to play and work together to solve a jigsaw puzzle.

1.1 Overview

The Giguesaur project is an application that is ran on iPads which allows a group of people to collaboratively solve a virtual jigsaw puzzle that is rendered using augmented reality. The virtual jigsaw puzzle is assembled on a ‘game board’ in the real world, where the game board is a checkerboard marker for the iPads camera to track. The jigsaw puzzle pieces that are rendered on screen will be shown to be superimposed upon the game board. The user is able to interact with the jigsaw puzzle by tapping the iPads screen, rotating and moving the iPad around while looking at the marker. The touch gestures and movement with the iPad allows the user to pickup, place and move the jigsaw puzzle pieces in the game. The iPads are connected to a central server ran on a Mac, which allows for multiple people to interact with the jigsaw puzzle.

1.2 Project Format

Due to the complexity and size of the Giguesaur project, it had to be divided into three different components, as no single person would have been able to achieve the aims and goals of the project in a single year. Joshua La Pine was in charge of developing the computer vision component of the project, which allows for the puzzle pieces to be rendered over top of the game board in the real world. Shahne Rodgers took charge of the networking component of the project, which was crucial in allowing more than one player to interact with the jigsaw puzzle. Finally my part of the project was to develop the game logic and render the game to the iPad’s screen.

1.3 Background

There are many jigsaw puzzle games that are available for iOS and other handheld devices, such as Magic Jigsaw Puzzles [1] and Jigsaw Puzzle [2], but the majority of them are limited in the way they look due to them using an orthographic projection to render the jigsaw puzzles. What this projection means is that the puzzle pieces of the jigsaw puzzle are flat on the screen, the player can only look at the jigsaw puzzle from top down, there is no depth and all the puzzle pieces are displayed as the same size. This is something that does not

work for the Giguesaur project as the puzzle pieces are rendered in a perspective projection, so when the jigsaw puzzle is rendered onto the game board it looks more realistic, as puzzle pieces that are further away from the camera are shown to be smaller than pieces that are closer to the camera. Another limitation of jigsaw puzzle games is the way they can be interacted with, by which I mean the way they can be solved. The puzzle pieces have to be placed into a predefined grid. Farms And Animals Puzzles [3] is an example of a game that has this grid layout for the puzzle pieces to be placed in. Figure 1 is a screenshot of Farms and Animals puzzle game which shows the limited orthographic perspective of the game. The grid means that all the puzzle pieces will be placed in the centre of the screen. This is something that was illogical for the project and I did not want to limit the scope of the game. I have made it possible for the jigsaw puzzle to be solved anywhere on the board, be it in the centre of the game board or off in a corner of the game board. I also believe that it makes for a more interesting game.



Figure 1: Screenshot of Farms And Animals Puzzles [4].

1.4 Why iOS?

iOS is a phone operating system made for Apple's mobile devices, which are similar in many ways such as hardware and software implementations. Android on the other hand is an open source operating system based on Linux, which is ran on a wide range of devices crossing multiple different versions of the operating system and adapted to a lot of different hardware. The devices that Android are ran on have a wide range of screen resolutions and processing power. We had decided that the Giguesaur game would be developed for iOS for a couple

of reasons. iOS hardware was more standardized than Android, as Apple are the only developers of iPhones and iPads. It made it easy for us to write the code, knowing that we would be relatively safe that what we developed would work on the majority of iOS devices, at least the ones with cameras. We couldn't be certain that any Android development of an application would work, nor would it have been possible for a forth year project to ensure that the application would have worked on all kinds of different Android devices. Apple also have a powerful and intuitive integrated development environment (IDE) called Xcode, that made development of the Giguesaur application very easy. With its detailed profiling tools and other features such as interface builders, it made it easier for us to develop and quickly prototype our ideas for the application.

1.5 Augmented Reality

Augmented reality is the idea of superimposing virtual objects on top of the real world that looks convincing enough for someone to believe what they are seeing is actually physically real. Figure 2 has a game world being played on a simple coffee table. The game is a simple tower defence game where the user aims where the tower shoots by moving the iPhone around the table while the camera has a marker on the table in view. The marker on the table, of which is hidden under the projection of the defence tower, is what allows the game to get the required information to correctly pose the game objects onto the table. The idea of augmented reality is what we based the Giguesaur game on, using marker trackers to correctly pose the puzzle pieces onto the ‘game board’ so it gives the idea that we are interacting with jigsaw puzzle pieces in the real world.



Figure 2: Screenshot of ARDefender [5].

1.6 Game Logic

As I stated previously, I was in charge of developing the game logic for the Giguesaur game. This meant I had to create the logic for how jigsaw puzzle pieces interacted with each other and how the user interacted with the game. The jigsaw puzzle is made up of a grid with a specific number of rows and columns, where each part of the grid is a piece. Each piece has four edges, and an edge either has a neighbouring piece or not. If a piece edge has a neighbour, it is given the ID of its neighbour for that edge, if it has no neighbour, than the value -1 is given to that edge. An edge of a piece can be open, meaning it has not joined to its neighbour currently or closed meaning it has joined to its neighbour currently, or if the edge has no neighbour it is unjoinable, meaning it can't join or be joined to another piece for that edge. An unjoinable edge is the outside edge of the puzzle. Each piece of the puzzle has a unique ID, a position in space, or an x, y coordinate on the board, and a rotation with a value between 0 and 360 degrees. The z coordinate is assumed to be 0, so it is ignored. This is what makes up the game logic for the jigsaw puzzle. I made up my own data structure to store these details. All the pieces that are in the game are stored in an array, where the piece ID is the index of the array the piece is stored. The x, y coordinate determines where on the board the piece is displayed and the rotation affects the orientation of the piece. The board that the pieces are placed on has a width and length, which are along the x, y axis, which confines where the puzzle pieces can be placed, as all the pieces have an x, y coordinate. Figure 3 is a diagram of the above game logic.

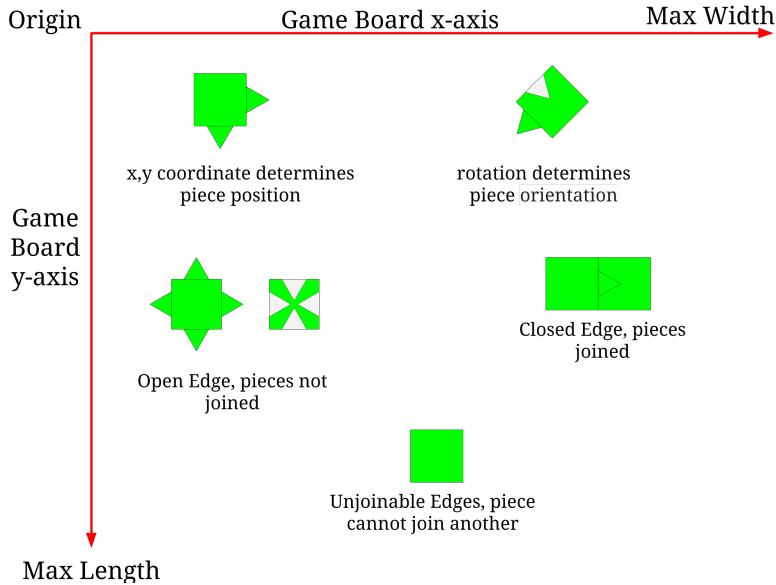


Figure 3: Diagram of the Game Logic.

2 Achievements

2.1 Prototype

In the beginning of the project I developed a prototype of the Giguesaur game for MacOS, using some simple OpenGL routines to render the game. Working on the MacOS version helped when I was creating the game logic for the application, as I could quickly test my ideas for the game logic such as jigsaw puzzle piece interaction. It also allowed me to quickly try out ideas that would be time consuming on an iOS. What I achieved with the prototype is the following; It allowed me to get to grips with OpenGL, such as calling all the drawing routines and getting to grips with the coordinate system, I completed and implemented all the game mechanics for the game, such as picking up and dropping pieces and the snapping of pieces, and I also tested out using a perspective projection to render the game in a proper perspective. Figure 4 shows what the game looks like with a perspective projection. The broken up picture of the puppy [6] represents the jigsaw puzzle pieces, the green background represents the game board the pieces are places on, and the white boarders on the edge of the game board is the ‘out of bounds’ area of the game board, where the pieces could not be placed. It demonstrates pieces being snapped together, as some of the jigsaw pieces are directly adjacent.



Figure 4: Screenshot of a prototype running on the Mac.

2.2 Game Mechanics

2.2.1 Snapping Pieces

I wanted to enable a feature that allowed pieces to snap together, meaning if a piece was in a specified distance from its neighbour, the piece being placed back on the board would move so that the two pieces were right next to each other,

or they snapped together, which is shown in the Java Jigsaw Puzzle game made by Centurio [7]. This also has the added bonus of not having to rely on the user to carefully place pieces together. How the check is made to see if two pieces should snap together is by comparing the distances between the corresponding corner points, and if the distances are less than the snap variable, the pieces snap together. So if the piece being put back on the board is being snapped to its left neighbour piece, the original piece top left point and the neighbour's top right point are checked, as well as the original piece bottom left point and the neighbour's bottom right point. The reason two distances are checked is to make sure that piece rotations are taken into consideration when snapping pieces together, so as to avoid an unusual snap where a piece rotated 90 degrees snaps to its neighbour not rotated. When a piece is snapped to another piece, the piece saves the rotation of its neighbour as its own, so that when the change is rendered, they both have the same rotation when beside each other. For a puzzle to be considered solved, all the pieces should be snapped to their corresponding neighbours. Once a piece has snapped to its neighbour, a variable for that edge is set as closed, as well as the neighbour's edge. So if a piece has snapped to its right neighbour, its right edge is set as closed and the neighbour's left edge is set as closed. The check to see if the puzzle has been solved goes through all the pieces' edges to see if they are all closed.

2.2.2 Piece Rotations

Each piece has an x , y coordinate which defines where on the game board the pieces is rendered, they also have a rotation variable that defines how the piece is oriented on the game board. The rotation is around the z axis, where the z axis is pointing out from the screen. The addition of rotation for puzzle pieces added some complications to the logic of the game, in particular how I calculated the distance between pieces for snapping as well as rendering the pieces on screen with the correct rotations. Originally when I calculated the distance between pieces I had been doing a simple check to see if the pieces corner coordinates plus the length of a piece was in the range of the corner coordinates of its neighbour. This failed to work when piece rotations were added, as adding the side length to the coordinates did not take into consideration the rotation. As a replacement, I now calculate the distance between piece corners using Euclidean distance, as with this new distance measurement I do not have to think about the rotations of the pieces as the calculation will return the correct values. To apply the rotation to the piece itself I use the following simple formula:

$$\begin{aligned}x' &= \cos(\theta) \times (x - x_cen) - \sin(\theta) \times (y - y_cen) + x_cen \\y' &= \sin(\theta) \times (x - x_cen) + \cos(\theta) \times (y - y_cen) + y_cen\end{aligned}$$

Where x and y are the piece corner coordinates, x_cen and y_cen are the piece centre coordinates, θ is the piece rotation in radians, and x' and y' are the new corner coordinates. I do this for all four corners of a piece to get the correct rotated coordinates of the piece.

2.2.3 Picking Up and Placing Pieces

To pick up a piece the user taps the image of the piece on the screen. That piece is then stored in the user's 'inventory' and they are no longer able to pick up another piece, until they have placed the piece that they are holding back onto the board. The inventory is just a term I am using to state if the user is holding or not holding a piece, meaning it can be easily checked to see if it is empty or not. The screen x, y coordinate from a finger tap is converted to a board x, y coordinate, z is ignored as it is assumed to be 0. If this is close enough to a piece then that piece is added to the user's inventory. When the user is holding a piece, it is moved to the iPads centre of the screen and projected onto the board, meaning the user has to rotate and move the iPad around to move the piece around the board. Once the user taps the screen again, where the piece is projected on the board is where the piece will be placed.

2.3 Port to iPad

Once I had established a working prototype for the Mac, the next step was to port the code to an iPad. The port proved to be more difficult than I had initially predicted. Firstly, OpenGL is handled completely differently with iOS than on a Mac, as it requires the use of OpenGL ES, of which I had no experience with before. OpenGL ES is a subset of OpenGL, and it does a lot of different things to do rendering in comparison. When using OpenGL ES with iOS, there is a lot of set up code that goes into getting to get anything to render. Such things like getting a reference to OpenGL ES context were required. As I had to learn the fundamentals of OpenGL ES, I based a lot of my set up code from Wenderlich tutorial [8] on how to create an OpenGL ES 2.0 application for iOS. Secondly, the majority of the libraries I had written for the Mac prototype had to be re-worked and re-written to work with iOS, as some things like data structures were not compatible across the different environments, for example, an 'NSPoint' on Mac cannot be used on iOS, instead it is replaced with 'CGPoint' and other small things like this popped up during the port. The initial port to iOS did not have a perspective projection, which is shown in figure 5. However, this was the first steps into getting the application onto an iPad, and I feel like this was some serious progress.

2.4 Integration

After Shahne, Josh, and I had spent the first semester working on our individual components of the Giguesaur project, it was decided it was time to begin the integration of the three components as it was predicted this would be a difficult process and would take some a lot of time to get everything working together. As per the prediction, integration did take a lot of time. Not only did we have issues of some of our code not being compatible, either by inconsistent data types or incorrect implementations of routines, but other issues popped up such as OpenGL and OpenCV having issues working together. There was little

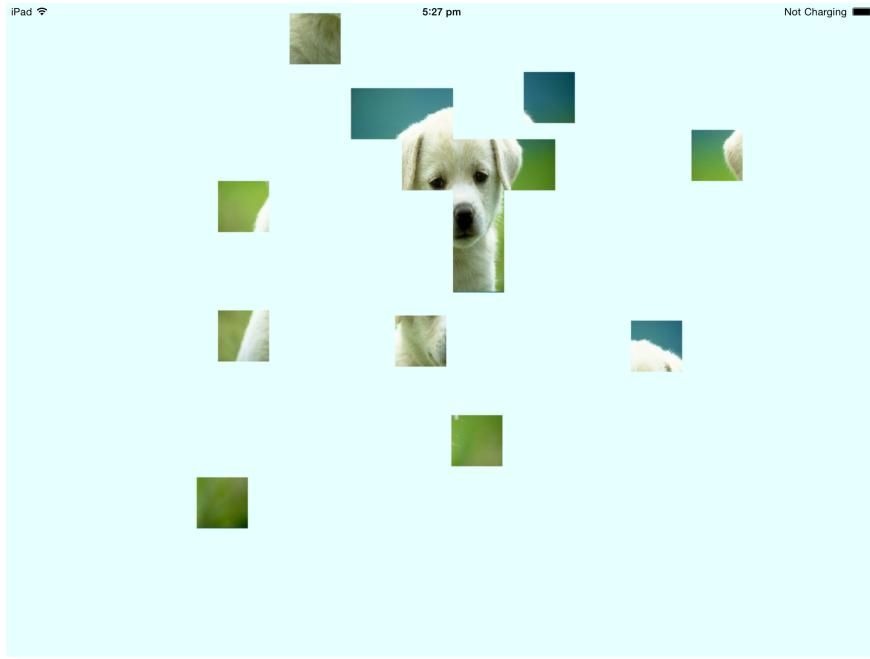


Figure 5: Screenshot of the first port to iOS.

to no issue with Shahne's and my part of the integration process, but on the other hand, Josh and I were having consistent trouble getting our parts working together. It resulted in Josh and my code being closely integrated, as we had to work together closely to get the application to properly render to the iPads' screen. The following subsections will go into more detail for my part being integrated with the two guys'.

2.4.1 Network and Game Logic

For a lot of the game logic to work with the networking component, the game logic that handled piece snapping and checking for the puzzle being solved had to be moved into the server code. The reason for this is that all players in a game had to be getting the same information of piece locations as everyone else. As the piece snapping code has the chance to change the coordinates of pieces it had to be placed in the server, so when a piece did snap, all clients connected to the server got the updated piece location, so that it could be reflected when the game rendered the pieces in their correct places. The code that checks when a puzzle is solved seemed pretty logical to put it with the server code, as when it finds that the puzzle has been solved, the server can alert all players of this situation.

When a player attempts to pickup/place a piece on the game board, the client has to ask the server if this is a legal action or not. This was a simple change with my code to make this work, as the logic for picking up and placing pieces will call the routines from the networking component of the code, and once the server responds, than my code will either pickup/place a piece or take no action based on the response. Shahne had already prepared for this change to the code, so this was smooth integration of our parts of the project.

The only issue that occurred when integrating the network and game logic was that I had stored all my piece locations as floats, while Shahne had stored the pieces coordinates as integers, meaning that when the clients asked the server if it was legal to place a piece in a certain place, the server would then store the locations as integers, and update all clients of a possibly incorrect location. This seems quite innocent at first as the lost information is quite small, however my code that calculates piece snapping has a fractional component as a result after it computes and an integer would lose this information which made it insufficient, which shows if pieces were rotated to obscure angles, the result would calculate a float, the server however would interpret these as integers. The pieces than could have the possibility to snap together incorrectly and be offset from each other showing a visible line between them. The fix was to refactor the integer locations into floats which took some time.

2.4.2 Vision and Game Logic

The first issue we encountered when integrating the vision and game logic components was trying to get the puzzle pieces rendered over top the video feed coming from the camera. The issue we found here was that OpenCV was showing the video feed on a preview layer, which was separate from the layer that OpenGL was rendering too. So when we attempted to get the layers to work together, either the OpenCV layer would cover the OpenGL layer, or vice versa, meaning one layer was always hidden from view. Something we tried was to have the OpenGL layer use a transparent background, with the hopes that we would be able to see the video feed behind the OpenGL layer. However, what was behind the transparent background was just a white background which was the OpenGL default layer colour.

Due to the fact it didn't seem possible to have the use of two layers simultaneously we decided to have OpenCV create an image for each video frame, and with each frame, send it to the OpenGL rendering code to use as the background image for the OpenGL layer and load it in as a texture. Another issue arose from this change, for some reason that I was unable to fix, the image being sent from OpenCV was overriding the already loaded image for the puzzle. So when the application first started, the picture of the puppy would show up correctly, but as soon as the OpenCV routines kicked into gear and started sending images to OpenGL, the image of the puppy seemed to disappear and the base colour of the puzzle pieces was the only thing being rendered of the puzzle. So we

fixed one issue of not seeing what the camera could see but introduced another problem.

As I could not figure out why one texture was being overridden by the other, I decided to put trying to fix this issue on hold and move along with trying to get the pieces showing in perspective and superimposed over the game board, as the pieces were still showing up but with no texture on them. The issue that arised from here the computation of the model-view matrix. What we tried to do was have OpenCV compute the matrix so that we could use it display the puzzle pieces in perspective. However due to either a fault in Josh's code, or mine, the calculated model-view matrix failed to set the picesin a perspective projection, nor would the pieces show up on screen at all. It seemed that what ever we did to try and integrate the OpenGL with OpenCV would be meeted with failure.

Due to our problems of trying to get the vision and game rendering working together, it was decided that OpenCV would be used to render the puzzle pieces being superimposed on the game board. For this to work, the vision code gets a reference to the pieces array, gets and calculates the correct coordinates for the pieces in world space, than using some simple OpenCV drawing routines, draws the pieces over top of the game board. This allowed for not only rendering the pieces in a correct perspective, but also solving the issue of the puzzle textures not appearing, meaning pieces were rendering correctly. However due to OpenGL and OpenCV having different coordinate systems, the textures of the puzzle pieces were apperaring flipped when they were rendered to the screen, lucklily though this was an easy fix which just required reversing the texture coordinates of the so that they appeared correctly.

The different coordinate systems of OpenGL and OpenCV resulted in reverse logic for snapping of puzzle pieces as well. As I had written my routines with the y-axis going bottom-up as OpenGL does it, OpenCV has the y-axis going top-down. The change to my code that I had to do to make this work was when calculating whether a piece can snap to its up/down neighbour, reverse the result, so when a piece would have snapped above a piece, it will now snap below it.

Now the rendering the setting up of the frames is being handled by the OpenCV routines, and my OpenGL code is being used to render the frames to the iPads screen after each frame update.

2.5 Rendering

I was using OpenGL to do the rendering of the Mac prototype build and the initial port to iOS, however in the final integrated application, OpenCV was being used to create an image that is passed to the OpenGL code for it to be rendered to the screen. The reason it is done this way is because the puzzle piece textures have to be copied over top of the frame coming in from the camera,

which requires some extra processing to ensure the textures are shown correctly, rather than having the puzzle pieces being rendered over the video feed coming from the camera. Once the client receives an image file from the server, the OpenCV routines take the file and converts it into a OpenCV image matrix for processing. As the main image makes up the entire puzzle texture, it has to be split up into sections for each puzzle piece that needs to be displayed on the game board. The number of pieces determine the number of sections there will be as each puzzle piece will need its own section of the texture. Then for each puzzle piece, if it is meant to be displayed currently, the OpenCV routines will copy the associated section of the texture to the image frame.

3 Results

We have managed to build a functional application, where multiple people can play with the same instance of a jigsaw puzzle game, picking up and placing back down pieces, all the while trying to solve the puzzle on screen. Figure 6 shows what the game looks like. The puzzle pieces are rendered over top of the game board which is represented by the checkerboard, each piece has its own rotation which is on display here. All the pieces are simple square polygons on screen, this is due to OpenCV's limited drawing capabilities with its drawing routines, as OpenCV can only do simple geometric shapes. The puzzle can be solved by having all the puzzle pieces placed together in their correct positions, the server will do a check to see if the puzzle has been solved or not, by going through each piece in an array, checking to see if each pieces' edge has been closed or not.

4 Conclusion

4.1 Future Work

There are still a couple things that I have missed out on implementing for the game logic and rendering of the Giguesaur application. Firstly, puzzle pieces are still only simple square polygons. In future, this would be changed so that pieces have curved edges, similar to figure 1 earlier in the document, where you can see the curved edges of pieces. The curved edges to pieces would not only make the game look more like jigsaw puzzle game, but it would also allow for players to easily solve the puzzle rather than having to match the images on the current puzzle pieces. This would be implemented using a random number generator that would choose a certain number of points along the each pieces edge, and then map vertices along each point, which would hopefully generate a curve. Secondly, the application is quite slow, with it only running at a maximum of five frames per second, performing even worse than that on average. This is caused by the OpenCV functions that compute the perspective projection matrix. The routines are looking for a checkerboard pattern every frame from the camera, which is what causing the huge bottleneck in the application. Another slow



Figure 6: Screenshot of the final build running on an iPad.

down to the application could be due to how we are rendering the game, as each frame from the camera is being processed and sent to the OpenGL code for rendering. If we had more time to experiment we could attempt to try have the puzzle pieces being rendered over top of the video feed coming from the camera. We may have to change how the rendering is being done or how we get access to the camera feed however, due to the problem of overlapping layers. Finally, there is no real way to know when you as a player are holding a puzzle piece. As of right now, when a player picks up a puzzle piece it moves to the centre of the screen and than gets projected onto the game board. This would be used to show where, if the player were to tap the screen, the piece would be placed back onto the board. What should be happening is when a player picks up a piece it should show a larger image of the puzzle piece in the centre of the screen with it being partially transparent, and be casting a shadow where the piece will appear on the game board.

4.2 Discussion

I believe we have achieved what was set out for the project. We have created a complicated and large piece of software that has

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