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DEVELOPMENT OF THE CLIENT PART OF THE MULTIPLAYER ONLINE GAME ABOUT LABYRINTHS

Abstract*: This paper is devoted to researching the theory of mazes and developing a cross-platform game for mobile and desktop devices. Different algorithms for solving mazes were analyzed and the mathematical basis of the developed method of drawing mazes using computer graphics was considered.*

Key words*: solving mazes, mazes drawing, online games, Java, Android, iOS.*
Language*: English*
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Introduction

Currently there is a huge variety of games, including online games. Programming games for mobile devices is considered one of the most popular and growing area in development and is distinguished not by its bulk 3D models or the complexity of drawing all the textures, but by its original ideas, dynamism and, of course, the desire spend the user time interesting and in a quick format.

This article describes the development of an online game for mobile devices based on the theory of mazes. The main idea is that users will compete - who can pass a randomly generated maze faster. Each player starts the maze in his corner and must get to the opposite corner faster than his opponent. The players have one maze, but since the maze is automatically generated, it may turn out that for one user the path is more obvious. That's why it was a requirement for the game to add the ability to use different skills, to restore the game balance for each user.

The relevance of this work is that now in the app stores GooglePlay and AppStore there are no games with the passage of mazes with friends or in competitive mode. This idea extends the concept of a very popular theme in games - puzzles, or to be more precise - the theme of solving mazes.

Problem statement, analysis game development technologies, analysis of source code security methods

Since the goal is developing a client part of the cross-platform online game for mobile devices, as well as programming the algorithm of bot-opponent, to be able to play offline, then to achieve this goal it is necessary to perform the following tasks:

1. Analyze existing applications on similar topics, identify shortcomings, and formulate the competitive advantages of the future game;
2. Based on the analysis of competitive applications, develop a design that will appeal to the game's target audience;
3. Determine the stack of developing technologies;
4. Set up data retrieval from the server using WebSocket;

5. Design and implement player skills mechanics;
6. Develop an algorithm for solving the maze, by a bot-opponent;
7. To ensure the security of the application's source code;
8. Test the application with a focus group;
9. Publish the application on GooglePlay.

After review existing maze games, it was noticed that there are currently no apps in the Android and iOS app stores that combine genres such as racing and maze solving. Most apps have pre-generated levels and position themselves as a classic puzzle game. The disadvantages of existing applications (the games "Labyrinths and More" by Maple Media, "Labyrinth" by InfinityGames.io, "Maze" by WEGO Global studio were considered) are usually outdated design, lack of control over player movements, large number of ads, lack of online mode, lack of different game modes. Therefore, the creation this game is relevant.

When researching game development technologies, the libGDX framework was chosen to develop this game. LibGDX is a framework for cross-platform Java game development. Note that it is a framework, that is, it provides some basic tools package, but it is not an engine in its pure form. It differs in those developers can take care of resource storage and customize animations with code themselves. Only basic UI components are given. On the one hand, this slows things down at first because there is no visual interface for scene editing. On the other hand, it allows developers to learn game programming at almost the lowest level and customize everything as needed for a specific purpose. libGDX was chosen precisely because of the large amount of complex and specific logic involved in solving a maze, its generation, and the development of unusual game animations that are tied to the maze object. To meet these requirements, you need a very flexible tool, which libGDX is.

An important part is the analysis of source code security techniques, because when developing client applications, you should always keep in mind the security of user data and source code. Since the application is cross-platform, the security for both the iOS version and the Android version was considered in detail.

The first thing every developer should do before publishing his application is to add source code obfuscation [1]. The most common tool now for code obfuscation in Android applications and many other Java-based applications is ProGuard [2]. It is an open-source command-line tool that compresses, optimizes, and hides Java code. All ProGuard manipulations with bytecode can be divided into 3 main categories: Code shrinking, Optimisation and Obfuscation [3].

Code shrinking – the process of getting rid of code not used by the application. This process looks for unused methods, classes, variables and removes them from the bytecode, but we should not forget that some things can be triggered by the reflexive approach. For such cases you should use your own configuration rules for this process.

Optimization – the process of code optimization, to improve performance [4]. It does a huge number of things, each of which makes the code at least a little bit more productive. For example, if a class has only one subclass and the base class has never been created, Proguard combines these classes into one. Also removes methods which are used once, replacing them with inline constructs. Replaces enum with integer constants, removes inline constructs, and more.

Obfuscation – in a broad sense - reducing the source or executable code of a program to a form that preserves its functionality, but hinders analysis, understanding of algorithms and modification during decompilation.

In this application, communication with the server side is implemented using WebSocket technology [5]. It is widely used in modern web applications, initiated via HTTP, and provides long-term connections with asynchronous communication in both directions. To protect the data transmitted over the network using web sockets was used secure protocol wss, which works on top of the TLS protocol.

Introduction to Labyrinth Theory

A labyrinth is a structure, in two- or three-dimensional space, consisting of tangled paths to an exit [6]. In this paper, we will consider ideal labyrinths. An ideal labyrinth is a labyrinth without any loops and consisting of a single connectivity component. From each point there is exactly one path to any other point. The labyrinth has exactly one solution. In computer science terms such a labyrinth can be described as a spanning tree over a set of cells or vertices [7].

There are many types of labyrinths, in this work will be discussed only a few types, namely:

- Orthogonal-Labyrinth;
- Delta-Labyrinth;
- Sigma-Labyrinth.

An orthogonal labyrinth is a maze which is a standard rectangular grid in which the cells have passages that intersect at right angles. In the context of tessellation, it may also be called a gamma maze.

A delta maze is a maze that consists of intersecting triangles, where each cell can have up to three passages connected to it.

A Sigma Labyrinth is a labyrinth that consists of interconnected hexagons, where each cell can have up to six passages connected to it.

All these mazes are similar in that they are composed of regular polygons. This idea was applied to the software architecture to set up a more abstract visualization of the labyrinth on the screens of devices.

In addition to the fact that users will be able to compete, it is necessary to add the ability to play offline, that is, in the absence of an Internet connection. In order to keep the concept of a competitive mode instead of creating levels, it was decided to implement an opponent bot. There are several fundamental ways of completing mazes, each of which has its own features.

Recursive retrieval is an algorithm based on recursive depth-first search in a graph [8]. This algorithm will always find a solution, but not necessarily the shortest one. When choosing the direction of movement, the usual random is used, and the cell is marked as passed, if the chosen path turned out to be a dead end (does not lead to an exit), then the algorithm recursively returns to the cell where the choice was made and repeats the action again.

Deadlock filling is a simple algorithm for solving a maze that focuses on the maze, is always very fast, and does not use extra memory [9]. The idea is to scan the maze in advance, find all dead ends, and fill passages in the opposite direction until an intersection is found. It is also necessary to mark, those intersections to which other dead ends lead. This algorithm works well for a perfect maze, because eventually you will find that one solution. For regular mazes this algorithm will find several solutions, but for mazes without dead ends it will be useless.

Wall follower is maze solving algorithm which focuses on the player, always works quickly, and does not require the use of additional memory. The essence of the algorithm is that you must always turn in one direction when choosing a direction, which is very similar to the way people go through mazes. This method looks for any solution, not necessarily the shortest one in the case of a non-ideal maze. The algorithm will not work when the final goal is in the center of the maze and there is a closed loop around it, because the robot will bypass the center and eventually return back.

Now we describe the mathematical basis of the labyrinth drawing algorithm. When describing the algorithm, the following types of mazes will be considered:

- Orthogonal labyrinth (consists of square-shaped cells);
- Delta maze (consists of cells shaped like regular triangles);
- Sigma labyrinth (composed of cells shaped as regular hexagons).

It is easy to see that all current maze types are a set of regular polygons. This property of cells was taken as the basis for the implementation of the labyrinth drawing algorithm. Namely, the property of a regular polygon, which says that any regular polygon can be inscribed into a circle. Accordingly, to dynamically calculate the size of the cell, it was decided to count the radii of the circles circumscribed around the cell.

First of all, it became clear that it is necessary to know the values of the angles for each type of labyrinth, namely the angle between the radii that lead to neighboring vertices (Fig. 1) and the starting angle from which the calculation of the coordinates of a particular wall will begin (Fig. 2).

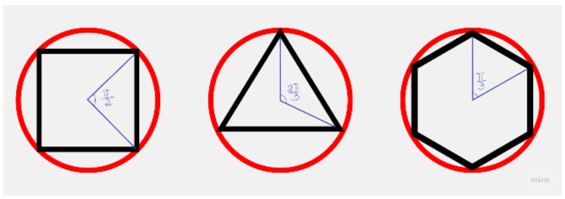

Fig 1. The angle between the radii that lead to neighboring vertices

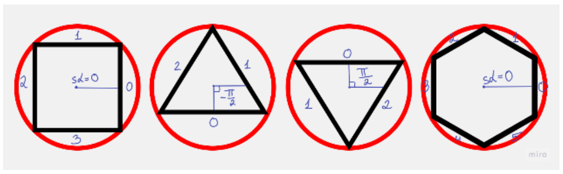

Fig 2. The starting angle between the abscissa axis and the perpendicular to the zero side of the polygon

Each side has been numbered, the starting angle is the angle between the abscissa axis and the perpendicular dropped on the zero side.

The problem with triangular mazes is that two types of cells must be supported at once. A triangle whose horizontal side is at the bottom and whose horizontal side is at the top. Accordingly, the base starting angle was chosen as $-\pi/2$, and the second starting angle is shifted by π if the sum of the cell coordinates is odd.

Knowing the starting angle (startA), the angle between the radii ($d\alpha$) drawn to the neighboring vertices and the wall number (number), you can uniquely determine the angles relative to the perpendicular to the zero-side using the following formulas:

$$\alpha_1 = startA + number \times d\alpha - \frac{d\alpha}{2}$$
$$\alpha_2 = \alpha_1 + d\alpha$$

Then it is necessary to calculate the coordinates of each vertex. To do this, you need to know the radius of the circle circumscribed around the cell and its center.

The length of the radius is calculated dynamically depending on the size of the maze in X and Y. The basic idea is to divide the corresponding View size (width or height) by the number of cells on the same axis. And this idea is slightly different from the maze implementation. After the X and Y radii have been found, the minimum of them is taken and the labyrinth is centered relative to the parent View. The formulas for calculating the radius of different types of labyrinths look like this:

1) Orthogonal labyrinth:
$$rX = \frac{screenWidth}{M \times xCoef}$$
$$rY = \frac{screenHeight}{N \times yCoef}$$
$$r = min(rX, rY)$$

2) Delta labyrinth:
$$rX = \frac{screenWidth}{(M + 1) \times xCoef}$$
$$rY = \frac{screenHeight}{N * yCoef}$$
$$r = min(rX, rY)$$

3) Sigma labyrinth:
$$rX = \frac{screenWidth}{(M + 0.5) \times xCoef}$$
$$rY = \frac{screenHeight}{(N + 0.5) \times yCoef}$$
$$r = min(rX, rY)$$

where M – horizontal maze size, N – vertical maze size.

The formulas for calculating the radius use some coefficients xCoef, yCoef, which are responsible for the ratio of the distance between the centers of the cells to the radius of the circle circumscribed around the cell (Fig. 3). They are calculated using primitive trigonometric formulas from the triangles that make up the radii of the circles circumscribed around neighboring cells.

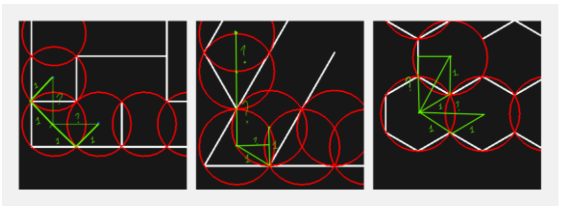
Fig 3. Distances between adjacent circles

To calculate the coordinates along the abscissa and ordinate axes of a particular vertex, the following formulas are used:
$$x = centerX + r \times cos(\alpha)$$
$$y = centerY + r \times sin(\alpha)$$

The latter formulas use the coordinates of the center of the cell (centerX and centerY). The following formulas are used to calculate the center basically, and are expanded for each implementation:
$$centerX_{ij} = j \times r \times xCoef$$
$$centerY_{ij} = i \times r \times yCoef$$

In the case of a triangular labyrinth, the center of each vertex that stands on a place where the sum of the indices is odd is shifted additionally vertically by half of the radius. In the case of a labyrinth consisting of hexagons, on odd rows the center is shifted horizontally by $r \times cos(\frac{\pi}{6})$.

Software implementation

As noted, the game was developed in Java using the libGDX framework, which allows you to develop cross-platform applications, making a simple scalable design.

To ensure that during the game all the players' movements were as natural as possible and it was easier to control the mechanics of movement and collision of objects, it was decided to use the physics engine Box2D [10], which allows you to easily add physical properties of objects in declarative form.

For communication with the network, we chose the WebSocket network communication protocol, because it is necessary to keep a constant connection to the server during the game, to transmit data as quickly as possible in a convenient format. As the serialization, the text format of JSON data representation was chosen, which is notable for its security and simplicity.

The project consists of several modules, namely:
- Android module;
- iOS module;
- Core module.

The android module contains only the configuration of the game, as well as the launch of the application itself for the Android system. There is not much code in this module, because Java is the development standard for this system and the Core module is fully embedded in the application.

The iOS module requires additional customization of some components because Java does not compile for iOS in its classic form. In order to make the application work cross-platform, RoboVM technology is used, which translates the main iOS SDK libraries into Java code, allowing you to write classic native code using Java.

The Core module is basic and describes the main logic of the application. All screens are reproduced using the built-in SDK libGDX - Scene2d [11]. Complex components need to be drawn on the screen using classical methods. The architecture of the module follows the basic principles of SOLID and is split into several modules so that the use of different types of mazes does not complicate the work [12].

The mobile application communicates with the server using the WebSocket communication protocol. All data are serialized in JSON. Thus, data about the coordinates of the user will be transmitted to the server, and the server in turn broadcasts this data to the opponent. To make the coordinates equivalent for different screen resolutions, a technology is used to scale the screen to a predetermined size so that the entire design of the application and the labyrinth itself looks adaptive.

UI layout in libGDX is not very powerful, because first of all this framework is designed for game components development. If native UI development for Android or iOS has a huge number of built-in components that can easily reproduce even the most complex design, here there are only a few such objects, so many UI components were custom written in-house.

First of all, it was necessary to think about how the navigation between the screens of the application will be implemented and how to store the state of the screen [13]. For this purpose, the auxiliary abstract classes SimpleScreen and RootScreen were written, which described the basic logic for screen configuration, namely:

- Initializing auxiliary tools;
- Configuring adaptivity;
- Configuring OpenGL;
- Clearing memory;
- Working with the keyboard.

Using the principle of dependency injection each screen is passed to the ScreenManager object, which implements the navigation between screens.

To keep the layout simple, we developed a simple implementation of the Constraint Layout analog from Android, which allows you to bind screen components together. It did not consider possible mathematical operations for stretching and dynamic determination of object coordinates, but it allowed writing UI in a much more flexible way.

Since there are many different similar components in the application design, an auxiliary class was written in which the styles for the main elements are described.

To communicate with the server using the WebSocket protocol, several layers of abstraction were written over the core solution provided by the LibGDX package. This allowed the WebSocket implementation to be substituted into the core module as needed. This measure was necessary because the iOS module only allowed to implement the connection using native methods.

It was almost impossible to write a WebSocket implementation for iOS using native methods. In order to achieve this, we decided to use RoboVM framework, which made it possible to write native iOS code, using Java [14]. This is achieved by the fact that inside the framework the bridge of communication with iOS system is implemented using Objective-C. However, a very limited number of functions are available.

After a basic WebSocket implementation for the iOS platform was written, a bug was discovered that by default iOS methods do not send a Pong frame, to a Ping message from a server. As a result, server was closing the connection after some delay. That's why Pong message sending was implemented separately.

Once the labyrinth data have been obtained from the server, it was needed to learn how to display it on the screen, and give it physical properties in this way, observing the following requirements:

- Ability to abstractly display all types of labyrinth;
- Ability to scale on new labyrinth types;
- The corners of the labyrinth walls should not hinder the player's movement.

First of all, a class was written that contains the necessary characteristics of cell angles for each type of labyrinth: orthogonal, delta labyrinth, and hexagonal labyrinth.

The second step was to write a class with the following abstract methods, the implementation of which depends on the specific type of maze:

- Getting the center of a cell by coordinate;
- Calculation of the radius of the circle circumscribed around the cell, depending on the size of the labyrinth and the space provided to it;
- Obtaining the ratio of the distance between the centers of neighboring cells to the radius of the circumscribed circles.

After that the method of creating a physical polygon, which consists of maze walls, was implemented. Its main feature is that the corners of the maze are small circles with a radius of half the wall thickness. This was done so that players could effortlessly pass the joints between the walls and make turns at high speed.

Since the game is cross-platform, it is necessary to support control in different ways for different systems. To do this, the InputController abstraction was written, and a factory pattern was implemented, which substitutes the necessary implementation depending on the environment.

To control from the computer, the arrow keys are used, which allows the user to conveniently direct the player in the desired direction, but because of this the user cannot control the strength of the impulses transmitted to the player and he moves always at the same speed.

To control from mobile devices, a joystick was implemented, which appears in the place where the user pressed the screen. Thanks to this solution, it is possible to control the player's speed, which greatly simplifies the control for experienced users.

To describe the physics of the player's movement, as well as his interaction with other objects in the maze, we used the Box2d library. For example, the player's object was matched with the parameters of density and friction force in order to make all its movements on the screen seem real and physical. And only the walls of mazes are static objects, through which you cannot pass, and they cannot move.

All movements in the system are non-linear and are realized by impulses and forces that act on objects in a certain way. In order to set impulses in Box2d library, it is necessary to pass a vector object with values of impulse projections on abscissa and ordinate axes [15]. It is always necessary to remember about memory optimization and not to allocate objects in frequently called methods. For this purpose, each class of "moving" object has a temporary vector object, to which certain values are set if necessary. This solution allows you to allocate less unnecessary memory and reduce the load on the garbage collector.

The entire code was designed to scale to new implementations of the various objects in the system, that's why there is an abstraction for each object. Obtaining the coordinates of the opponent is one of the most important parts of the program, and there are two implementations for it: online and bot. If the user takes too long to find the game or does not have access to the Internet, he is automatically offered to compete with the bot, which logic is on the client.

The basis of the algorithm is set by emulating communication with the network. This is achieved using the basic multithreading techniques available in Java. First, in a separate thread pool, the maze, and the path, which bot will follow are generated, and then information about this data is sent to the event listener.

Then the bot starts to send the coordinates of the opponent to the event listener in a separate thread with some delay. The delay and speed constants were calculated empirically by testing on devices with different power.

The main goal when writing the code for the bot was to achieve maximum physicality of its movements, imitating human errors and inaccuracies in movement with a certain probability. Thus, the speed of the bot is non-linear and varies within certain limits.

The bot should not move from cell to cell exactly evenly, so the movement from one cell to another was divided into several steps. With each step the bot tends to the center of the next maze cell, but with some probability it gets a deviation from the course by a small number of degrees.

A modified recursive return algorithm was used to implement the maze solution for the bot. The main difference from the basic algorithm is that the bot can detect a dead end ahead of itself with a certain probability. This modification was added in order to emulate human attempts to look at the path it is moving ahead of itself and predict when to change the direction of its movement. To achieve this, the recursive pathfinding function returns the length to a dead end or the end of a maze, as well as a flag about whether the path is victorious. If the path is victorious, the bot can also, with a certain probability, either choose it or make a mistake and go the other way first. In this way human errors are simulated. The probability of right and wrong choices depends exponentially on the length to a dead end or a winning square.

The game provides the ability to add player skills that allow the user to interact with an opponent. First, an abstract PowerUp class was written, which describes the general logic for all abilities.

Every characteristic power up has a duration and a cooldown time. Common ability methods include:

- Getting the current status of the ability (started, in progress, finished);
- Getting the current progress from 0 to 1, where 0 is the beginning and 1 is the end;
- Getting the current cooldown progress from 0 to 1;
- Drawing with basic geometric shapes or with complex animations using pre-generated sprites;
- Skill launching.

It was also provided for further development of the application, namely the addition of monetization through the purchase of in-game goods. And each ability has the possibility of a certain number of levels. At a basic layer, the higher level gives the longer duration, and the shorter cooldown, but this logic can be extended for a specific implementation.

Now in the game already implemented 3 different types of abilities, some of which give pluses to the player, and some add to the difficulty of solving the maze opponent, namely:

- Darkening the opponent's screen;
- Freezing your opponent;
- Illuminating the right path.

Screen darkening works like this: that after activating the ability the opponent can only see a small area of the screen around himself, so he can't view the path far and he must move at random. The player who triggered the ability continues to see the entire maze.

To achieve this result, filled rectangles are first drawn on top of the maze, at some distance from the opponent on each side. After that the remaining corners are painted by consecutive drawing of circles.

Freezing the opponent does not allow the opponent to move for a while. This is accompanied by an animation of the formation and subsequent destruction of ice on the opponent's character. In this case a sprite animation was used, which is different in that from an image with a large set of frames each time a new one is cut out, in a predetermined sequence.

Since all skills run for a certain amount of time, the animation must run gradually, according to the time of the ability. Therefore, the basic sprite animation algorithm was adapted as follows:

1. Gets the current progress of the ability action time;
2. Calculates the frame number that corresponds to the current progress;
3. Crops the frame with position that was calculated in the previous step.

Illuminating the correct path allows the user to see several nearby cells of the path to victory. The constant of the number of illuminated cells depends on the level of the ability. This ability is good because it allows the user to find the exit even if the screen darkening ability was used on him.

To implement this ability, it is first necessary to find the correct path to the end of the labyrinth. In this case, as well as with the bot, the recursive return method was used as the algorithm for solving the maze. Also, as with any other animation, it is necessary that the path is highlighted gradually, depending on the current progress of the ability action.

This animation changes the transparency of the color so that the path disappears and appears smoothly. In order not to allocate a lot of unnecessary memory, the color array is generated in a static application context.

Approbation and testing

When the user enters the application, he sees the main screen of the app with the following menu items (Fig 4.):

- Play;
- Choose skin;
- Settings.

Also a randomly generated labyrinth is displayed on the main screen each time.

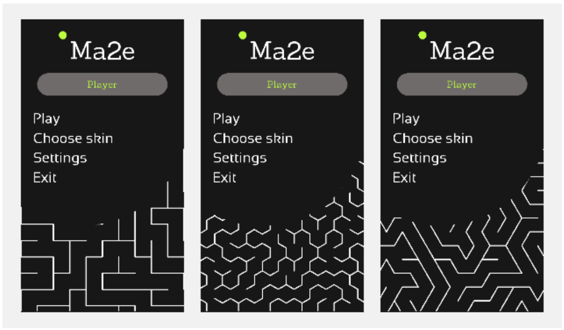

Fig 4. Main application screen with different types of mazes.

The user can pick the color of his character from the preselected options. All colors have been chosen so that the player is perfectly visible on the screen.

Once the user has chosen his color and entered his nickname in the text box, he can start the game. He is given several types of game to choose from (Fig. 5):

- Play online (the opponent is selected automatically);
- Play with friend;
- Play with bot.

In the case of the game online and the game with the bot further are the same steps, namely the loading screen appears, during which the maze is loaded, the initialization of the resource and all other preparatory work.

In the case of choosing the game with a friend, the user is shown his unique code and invited to enter the code, which is shown on the friend's screen. After entering the code on one of the devices the game process begins and then it does not differ from the format of the game online or with a bot.

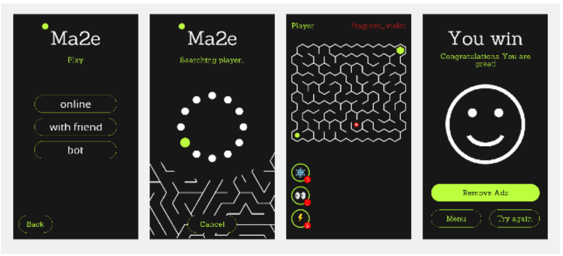

Fig. 5. The sequence of screens after the start of the game

For testing the game, it was decided to use the testing method with the help of a focus group. The first step was to publish the application on Google Play in internal testing. A minor number of users were invited by mail in order to test the application for bugs and to fix the most global ones before a larger testing.

After internal testing, the app was published into beta testing with link access. A Google form was designed for users to collect feedback and understand where the game should be improved, what users lacked, what users pay more attention to during the game.

After analyzing the results of the survey, it was decided to add a learning system to the game in the first place, in the form of videos or hints for the first games. Many users could not intuitively understand how certain skills work. In the future, an ability store will be added, as well as a player inventory, so that you can always clearly see how and why to use certain power-ups.

Conclusion

We have developed a mobile and desktop application of the game. In the course of the work, to achieve the set goal, the following tasks were completed:

- The games available on Google Play and the App Store with a similar theme – maze walkthroughs - were analyzed. Currently, we found that there is no game that allows you to compete with other players in real time, and there is no opportunity to play against a bot. All games are aimed at passing specific levels, which are compiled in advance by the developers;
- Developed a design that contains a harmonious color scheme, thoughtful UX for the user, so that it was clear how to play, and what are the possibilities of the game;
- Different methods for developing cross-platform games were analyzed and based on this analysis, a framework for Java, LibGDX, was chosen. The choice was explained by the flexibility of this framework, as well as by the specificity of the application, which was difficult to overlap with other solutions;
- Connected to a remote web server using WebSocket technology. Written our own wrapper over the basic implementation provided by the LibGDX library package to setup iOS support for the application;
- Based on the analysis of competitive applications and other games, we developed abilities for characters that set the interest of the game and make it more dynamic. The structure of abilities was designed in such a way as to allow you easily expand the set of available abilities;
- An opponent bot algorithm was implemented to play without an Internet connection. This was a necessary requirement, because the concept of the application does not include levels, and you need to be able to play even in places remote from the Internet;
- The application was tested by a focus group, information was gathered for its further development. After that the first version of the game was uploaded to Google Play. Before the app was published all the source code was obfuscated with the Proguard tool. There were also configurations for automatic code optimization.

At the moment we are working on publishing the application to AppStore and alternative platforms for publishing Android applications. Also, we are considering the idea of monetizing the application based on the addition of in-app purchases. Additionally, various ideas for improving the game mechanics, adding different skills, and other user interaction with the game are being considered.

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