Interactive Graphics, Final Project: "Almost Pacman" a.y. 2018/2019

Dario Benvenuti
1562938

January 10, 2019

Abstract

"Almost Pacman" is a simple project, built to show how some of the most important features in the interactive graphics' field can be handled with WebGl. The goal of the project was to build something similar to a simple video game, in which the user can move its character in a maze, trying to collect objectives. The final result is much more like a prototype than a fully developed video game, but in its simplicity it accurately shows the challenges that developers would encounter if graphic engines would not have existed. Everything was built in native Javascript and HTML, with the aid of WebGl only, from scene organization, to collisions detection, movement, animations and cameras. In its roughness, the project can easily be improved, adding real 3d models, shadows, various levels and game modes, in order to make it a real video game.

1 Introduction

In this paper, we are going to analyze, step by step, the main challenges that was faced in the development of the project, and the solutions taken.
Those can be categorized as:

- Designing the maze and how the users can move the character in it.
- Building the hierarchical structure.
- Moving and animating objects.
- Detecting, or preventing, as it fits better for our situation, collisions.
- Texturing the maze.
- Lighting the scene.

2 Design

Designing the project wasn't really a challenge, but, considering that the main goal was to build something very close to a video game, while coding everything with just Javascript and WebGl, clearly it needed to be designed to be as simple as possible.

- The design choice that had the biggest impact on the project, was to limit the user's freedom while moving the character. The whole scene is designed as a virtual grid, in which the character can move only from one tile to an adjacent one. This choice led to an incredible increase in the simplicity of the project, especially in animating the model and handling collisions with the maze's walls.

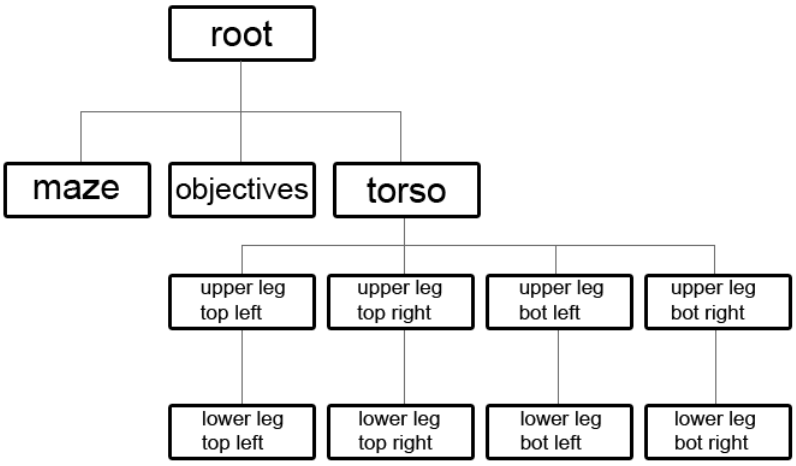
- Choosing a 3d model for our character that could be easy to build just through code, while not being as simple as the stylized human, was not so easy. At the end, considering that the project was born with a top-down view, choosing a stylized spider as our character, seemed a good option. The model was quite easy to build through code, and it shows the animations tailored for it even in the top-down view.
  Even later, when a more common over-the-shoulder view was added to the project, the model performs really well.

- Having two viewing modes, one top down and one over the shoulder of the character, following it, allows the user to have a clear idea of how the maze is done, and of how to navigate it. Obviously this leads to a straight forward completion of this "game", but at the same time lets the user fully experience the project. In the future, this project could evolve into a quite enjoyable game just by deleting the top down view, or restricting the time in that view at the user's disposal.

- In the over the shoulder viewing mode, we are using a perspective projection. This decision was made because we are using really basic lighting and texturing models, so, with an orthogonal projection, the user would have had a really hard time trying to navigate the maze. In the top down view, instead, the orthogonal projection fits perfectly.

3 The hierarchical structure

Considering that we are not using any scene management tool, building the hierarchical structure was a core part of this project.
We have various objects in the scene that needs to be able to be transformed independently, but that are all at the same level. So, as the root of our tree, we will keep an empty node, representing the scene. The maze, objectives and the spider will all be children of this empty node.
The spider can be considered as a sub tree, with the torso as its root node. Its 4 legs will be divided into upper parts and lower parts. All 4 upper parts are torso's children, and each lower part is the children of the corresponding upper one.



The objectives will be all inside one node, just because we don't care if each objective doesn't transform independently. They will just rotate around their center, for the whole time, so it's definitely not a problem.
In order to code this structure, we used the classic "left child, right sibling" linked list.

```
function createNode(transform, render, sibling, child){
    var node = {
    transform: transform,
    render: render,
    sibling: sibling,
    child: child,
    }
    return node;
}
```

In order to traverse this structure, drawing each element with the right model-view matrix, we used the classic function based on a matrices stack.

```
function traverse(Id) {
  if(Id == null){
    return;
  }
  stack.push(modelViewMatrix);
  modelViewMatrix = mult(modelViewMatrix, figure[Id].transform);
  figure[Id].render();
  if(figure[Id].child != null) traverse(figure[Id].child);
  modelViewMatrix = stack.pop();
  if(figure[Id].sibling != null) traverse(figure[Id].sibling);
}
```

4 Moving and animating the elements

To animate objects in our scene, we will call an update function, inside the render function, if animations are enabled. This will lead to frame rate dependent animations, meaning that we update the transformation matrix of our object at each frame, so objects will move faster if we open our project on a machine with a monitor that can run with higher frames per second. Since 60 frames per second is still considered the standard between machines, we can do this without worrying too much of great distortions in our animations.
Our code will look like this:

```
function render()
{
    .
    .
    .
  if ( animationFlag )
      update();
  .
  .
  .
    requestAnimFrame( render );
}

function update() {

    // ------------------------------------------------------------ animate objectives

    nodesAngle[objective1Id]  += 0.5;
      nodesAngle[objective1Id+1]  += 0.5;
      nodesAngle[objective1Id+2]  += 0.5;
        .
        .
        .
      // ---------------------------------------- avoid overflow for objectives
          angles

    if ( nodesAngle[objective1Id]   >= 360 )    nodesAngle[objective1Id]  = 0;
        .
        .
        .

    // --------------------------- ROTATE THE CHARACTER ------------------------

    if ( characterRotation == 1){
      rotateCharacter();
      rotationCounter++;
      if ( rotationCounter == 20 ){
        rotationCounter = 0;
        characterRotation = 0;
        // ------------------------------ update direction
        if ( rotationDirection == 0 ){
          // -------------------------  we rotated left
          direction--;
          // ------ check correctness of the new direction
          if ( direction < 0 )
```

```
            direction = 3;
        }
        else{
          // -------------------------- we rotated right
          direction++;
          // ----- check correctness of the new direction
          if ( direction > 3 )
            direction = 0;
        }
      }
    }

    // -------------------------- MOVE THE CHARACTER -------------------------

    if ( characterMovement == 1 ){

      // ---------- if there will be no collision in the current movement direction
          , move the character

      if ( checkCollision(torsoX, torsoZ, direction) == 0 ){
        if (cameraMode > 0)
          topDownMove(direction);
        else
          firstPersonMove(direction);
      }

      // ----------------------------- update the movement frame counter and the
          maze texture

      movementCounter++;
      updateTexture();

      // ------------------------------ after 20 movement frames reset movement
          parameters

      if ( movementCounter == 20 ){
        characterMovement = 0;
        movementCounter = 0;
        torsoX = Math.round(torsoX);
        torsoZ = Math.round(torsoZ);

        // ------------------------------------------------------  check if the
            user has collected an objective

        if ( torsoX == 4 && torsoZ == -5 && objective1Captured == 0 ){
          objective1Captured = 1;
          objectivesCaptured++;
          // ------------------------ update the text in the html
          document.getElementById("objectivesDiv").innerHTML = "Objectives
              collected: " + objectivesCaptured;
          document.getElementById("objectivesDiv").style.fontSize = "20px";
        }
                .
                .
                .
      }
    }

    // ---------------------------- update hierarchical structure components
        involved in the animation

    initNodes(torsoId);
        .
        .
        .
}
```

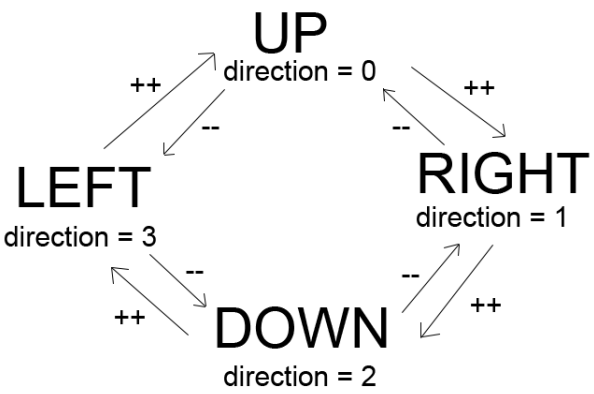
From the code we can notice these things:

- To animate objectives we are just increasing their rotation angles in the "nodesAngle" structure, that holds the rotation angles of all the components of our hierarchical structure. After increasing those values, we check if we have gone over 360, just to avoid overflow.
- In order to animate the spider we have divided its movement in 20 frames. Those 20 frames

will be divided again in 2 sections, each one of 10 frames. So, in the first half of the movement, we move 2 opposite legs of the spider forward and up, while the other 2 are moved backward, to simulate the fact that in real life those would not move at all, being the movement pin. In the second half of the movement, we just move each leg in the opposite way, to make everything return to its original position.

- We actually have 3 different functions to animate the spider, "rotateCharacter", "topDownMove" and "firstPersonMove". The one that will be called between the 3 depends from the camera mode that the user is using. If the user is in the top down camera mode, the spider can be moved up, down, left or right, pressing the right arrow key on the keyboard. So, in this case, "topDownMove" will be called, with the right direction to move the character. If the user is in the over the shoulder camera mode, the spider can be moved only forward, and rotated clockwise or anticlockwise. In this case, if the user moves the spider forward, pressing the up arrow key on the keyboard, "firstPersonMove" will be called. Instead, if the user presses the left or right arrow key on the keyboard, "rotateCharacter" will be called. The direction in which we have to move the spider while in top down view, and the one in which we have to rotate it while in over the shoulder view, are just integers set by the "onclick" function and passed to "rotateCharacter" and "firstPersonMove".

- The direction in which we have to move the spider while in over the shoulder view is a bit more tricky to handle, because even if the spider can be moved only forward, it doesn't mean that we move always in the same direction. So we will keep track of the direction that corresponds to the right "forward" in our grid, using this scheme:



  When a rotation key is pressed, we just increase or decrease the direction value, and the we check if we have gone lower than 0 or greater than 3.

- In each one of the 3 movement functions, we just increase or decrease the rotation angles of the legs that we need to rotate during the animation, in the "nodesAngle" structure, as we did with objectives.

- In order to actually move the spider, we just increase or decrease it's X and Z translation values, so that, after updating all the nodes and traversing again the hierarchical structure, it will be drawn in the right position of the maze.

- Those values are stored in two variables, "charX" and "charZ", that keeps track of the current top right vertex of the tile in which the spider is.

- The clockwise rotation animation is the same as the animation to move right in the top down view.

- The anticlockwise rotation animation is the same as the animation to move left in the top down view.

5 Collisions

From the animation's code that we saw before, we can notice that actually we are checking if there will be a collision before moving the spider. So, we can say that, instead of handling collisions, we

are actually preventing them to happen at all.
In order to do this, we just need 2 things:

- A data structure in which we hold the information needed to know if a given tile is part of a wall.
  For each tile with vertices (x1,z1),(x1,z2),(x2,z1),(x2,z2) that is part of a wall, we will have an entry in our structure like this; (x1, x2, z1, z2).

- A function to check if the tile in which we are going to move the spider is part of a wall.

```
1     function isAWall( x, z ) {
2
3       var i = 0;
4       var result = 0;
5
6       for ( i; i<walls.length; i+=4 ){
7         if ( walls[i] <= x && x <= walls[i+1] && walls[i+2] <= z && z <= walls
              [i+3] ){
8           result = 1;
9           break;
10        }
11      }
12
13      return result;
14
15    }
```

So, before moving the spider, we will simply call the "checkCollision" function, that will just check if applying the translation that is needed to perform the movement in the current direction will lead in a tile that is part of a wall:

```
1  function checkCollision( charX, charZ, direction){
2    // function used to check for a collision before moving the character.
3    // returns 1 if there will be the collision, 0 if there will be not
4    if ( direction == 0 ){
5      // ------------------------------------ moving up
6      if ( charZ > -5 && isAWall( charX+0.1, charZ ) == 0 )
7        return 0;
8      else
9        return 1;
10   }
11   else if ( direction == 1 ){
12     // ------------------------------------- moving right
13     if ( charX > -5   && isAWall( charX, charZ+0.1 ) == 0 )
14       return 0;
15     else
16       return 1;
17   }
18   else if ( direction == 2 ){
19     // ------------------------------------- moving down
20     if ( charZ < 4  && isAWall( charX+0.1, charZ+1 ) == 0 )
21       return 0;
22     else
23       return 1;
24   }
25   else if ( direction == 3 ){
26     // ------------------------------------- moving left
27     if ( charX < 4  && isAWall( charX+1, charZ+0.1 ) == 0 )
28       return 0;
29     else
30       return 1;
31   }
32   else{
33     // ------------------------------------- wrong direction
34     return -1;
35   }
36 }
```

6 Texturing

The texture used in this project is a procedural color texture, applied only to the maze. We will keep track, at each frame, of the distances between the spider and the 4 objectives; each objective has a different color, so, we will add to the texture an amount, proportional to the distance between the spider and it, of its color.
For example, the objective 1 is red, so, the nearest the spider is to it, the more red the maze will be.
In order to implement this, we need to:

- Obviously, keep track of all distances.
  This can be easily done, taking advantage of the fact that we know in advance the top right vertex of tiles with an objectives in it, so, we will just subtract those X and Z values, to the X and Z values of the spider.

- Determine how to transform the distance from the spider to a certain objective to the relative amount of color, in RGB components.
  This could be a bit more tricky, since we have a yellow objective. This leads to the R and G component to be produced by two different sources. In order to avoid interference, we will convert distances to an exponential function, and then use a proportion to end up with a value between 0 and 255.

```
    function mapDistance( positionX, positionZ, objective ){
  var distanceX = 0;
  var distanceZ = 0;

  var distance = 0;
  var maxDistance = 1;

  if ( objective == 1 ){
    distanceX     = positionX - objective1X;
    if (distanceX < 0 )
      distanceX   = distanceX * (-1);
    distanceZ     = positionZ - objective1Z;
    if (distanceZ < 0 )
      distanceZ   = distanceZ * (-1);
    distance    = distanceX + distanceZ;
    maxDistance   = maxDistance1;
  }
  else if ( objective == 2 ){
    .
    .
    .
  }
  .
  .
  .
  distance = Math.pow(distance, 5);
  maxDistance = Math.pow(maxDistance, 5);
  return 255*distance/maxDistance;
}
```

- Update the texture after every movement of the spider:

```
    function updateTexture(){
  // compute rgb components from distance
  red   = 100 + mapDistance( torsoX, torsoZ, 1) + mapDistance( torsoX, torsoZ,
       2);
  green   = 100 + mapDistance( torsoX, torsoZ, 3) + mapDistance( torsoX,
      torsoZ, 2);
  blue  = 100 + mapDistance( torsoX, torsoZ, 4);
  // avoid to have components greater than 255 ( since R and G components have
       2 sources )
  if ( green  > 255 ) green   = 255;
  if ( blue   > 255 ) blue  = 255;
  if ( red  > 255 ) red   = 255;
  // compute the texture
  computeTexture();
}
```

- Finally, compute the texture.

```
    function computeTexture(){
  for(  var  i = 0;  i < texSize ;  i++ ){
    for(  var  j = 0;  j <texSize ;  j++ ){
      image[4*i*texSize+4*j ]  = red;
      image[4*i*texSize+4*j+1] = green;
      image[4*i*texSize+4*j+2] = blue;
      image[4*i*texSize+4*j+3] = 255;
    }
  }
  configureTexture(image);
}
```

In order to apply the texture only to the maze, we will use a flag that will be sent to the shader. There, if the flag is 1, it means that we are drawing the maze, and so we will multiply the fragment color by the corresponding texel color.
Since we are using a color texture, mapping from texture coordinates to object coordinates is trivial.

7 Lighting

Nothing special is done with respect to lightning in this project.
We have a light source, standing above the spider, that will follow it in its movements.
In order to compute the light, we compute the normal for each triangle that we draw and send it to the vertex shader. There, we will do the classic computation:

```
void main()
{
  // ----------------------- LIGHT COMPUTATION -----------------------
  pos = -(modelViewMatrix*vPosition).xyz;
  light = lightPosition.xyz;
  L = normalize(light-pos);
  E = normalize(-pos);
  NN = vec4(vNormal,0);
  H = normalize(L+E);
  N = normalize((modelViewMatrix*NN).xyz);
  // -----------------------------------------------------------------
  fColor = vColor;
  fUsingTexture = usingTexture;
  fTexCoord = vTexCoord;
  fPosition = vPosition;
  gl_Position = projectionMatrix * modelViewMatrix * vPosition;
  if ( cameraMode < 0.0 ){
    gl_Position.y = -gl_Position.y;
  }
```

To have a smoother lightning, we will let the fragment shader interpolate this result accross vertices:

```
void
main()
{
  // ----------------------- LIGHT COMPUTATION -----------------------
  vec4 fColorPhong;
  vec4 ambient = ambientProduct;
  float Kd = max(dot(L,N), 0.0);
  vec4 diffuse = Kd*diffuseProduct;
  float Ks = pow(max(dot(N,H), 0.0), shininess);
  vec4 specular = Ks*specularProduct;
  if (dot(L,N)<0.0){
    specular = vec4(0.0, 0.0, 0.0, 1.0);
  }
  fColorPhong = ambient+diffuse+specular;
  fColorPhong.a = 1.0;
  if ( fUsingTexture == 0.0 )
    gl_FragColor = fColor*fColorPhong;
  else
    gl_FragColor = fColor*fColorPhong*texture2D(Tex0, fTexCoord);
}
```

8 Following camera