Lode's Computer Graphics Tutorial

Raycasting II: Floor and Ceiling

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Introduction

In the previous raycasting article was shown how to render flat untextured walls, and how to render textured ones. The floor and ceiling have always remained flat and untextured however. If you want to keep the floor and ceiling untextured, no extra code is needed, but to have them textured too, more calculations are needed.
Wolfenstein 3D didn't have floor or ceiling textures, but some other raycasting games that followed soon after Wolf3D had them, for example Blake Stone 3D:

You can download the full source code of this tutorial here.

How it Works

Unlike the wall textures, the floor and ceiling textures are horizontal so they can't be drawn the same way as the wall. Drawing the ceiling happens the same way as drawing the floor, so only the floor is explained here. For drawing the floor, a technique called "floor casting" is used.

In short, the technique works as follows: after you've drawn a vertical stripe from the wall, you do the floor casting for every pixel below the bottom wall pixel until the bottom of the screen. You need to know the exact coordinates of two points of the floor that are inside the current stripe, two such points that can easily be found are: the position of the player, and, the point of the floor right in front of the wall. Then, for every pixel, calculate the distance its projection on the floor has to the player. With that distance, you can find the exact location of the floor that pixel represents by using linear interpolation between the two points you found (the one at the wall and the one at your position).

Once you've done all the floor calculations, out of the exact position you can easily find the coordinates of the texel from the texture to get the color of the pixel you need to draw. Because the floor and ceiling are symmetrical, you know the texel coordinates of the ceiling texture are the same, you just draw it at the corresponding pixel in the upper half of the screen instead and can use a different texture for the ceiling and the floor.

The distance the projection of the current pixel is to the floor can be calculated as follows:

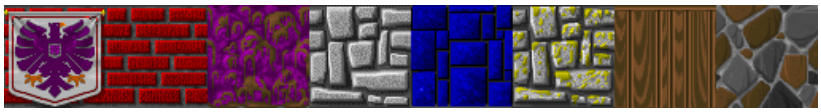
- If the pixel is in the center of the screen (in vertical direction), the distance is infinite.
- If the pixel is at the bottom of the screen, you can choose a certain distance, for example 1
- So all the pixels between those are between 1 and infinite, the distance the pixel represents in function of its height in

the bottom half of the screen is inversely related as 1 / height. You can use the formula "currentDist = h / (2.0 * y - h)" for the distance of the current pixel.
- You can also precalculate a lookup table for this instead, since there are only h / 2 possible values (one half of the screen in vertical direction).

The linear interpolation, to get the exact floor location based on the current distance and the two known distances, can be done with a weight factor. This weight factor is "weight = (currentDist - distPlayer) / (distWall - distPlayer)", and since the current pixel will always be between the wall and the position of the player, the exact position is then: "currentFloorPos = weight * floorPosWall + (1.0 - weight) * playerPos". Note that distPlayer is actually 0, so the weight is actually "currentDist / distWall".

The Code

The code tries to load the wolfenstein textures from the previous raycasting tutorial, you can download them here (copyright by id Software). If you don't want to load textures, you can use the part of code that generates textures from the previous raycasting tutorial instead, but it looks less good.



The first part of the code is exactly the same as in the previous raycasting tutorial, but is given here to situate where the new code will be. There's also a new map. This piece of code declares all needed variables, loads the textures, and draws textured vertical wall stripes. For the loading of the textures, please see the previous raycasting tutorial about getting the images or using an alternative way to generate the textures.

```
#define screenWidth 400
#define screenHeight 300
#define texWidth 64
#define texHeight 64
#define mapWidth 24
#define mapHeight 24

int worldMap[mapWidth][mapHeight]=
{
  {8,8,8,8,8,8,8,8,8,8,8,4,4,6,4,4,6,4,6,4,4,4,6,4},
  {8,0,0,0,0,0,0,0,0,0,8,4,0,0,0,0,0,0,0,0,0,0,0,4},
  {8,0,3,3,0,0,0,0,0,8,8,4,0,0,0,0,0,0,0,0,0,0,0,6},
  {8,0,0,3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,6},
  {8,0,3,3,0,0,0,0,0,8,8,4,0,0,0,0,0,0,0,0,0,0,0,4},
  {8,0,0,0,0,0,0,0,0,0,8,4,0,0,0,0,0,6,6,6,0,6,4,6},
  {8,8,8,8,0,8,8,8,8,8,8,4,4,4,4,4,6,0,0,0,0,0,0,6},
  {7,7,7,7,0,7,7,7,7,0,8,0,8,0,8,0,8,4,0,4,0,6,0,6},
  {7,7,0,0,0,0,0,0,7,8,0,8,0,8,0,8,8,6,0,0,0,0,0,6},
  {7,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,8,6,0,0,0,0,0,4},
  {7,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,8,6,0,6,0,6,0,6},
  {7,7,0,0,0,0,0,0,7,8,0,8,0,8,0,8,8,6,4,6,0,6,6,6},
  {7,7,7,7,0,7,7,7,7,8,8,4,0,6,8,4,8,3,3,3,0,3,3,3},
  {2,2,2,2,0,2,2,2,2,4,6,4,0,0,6,0,6,3,0,0,0,0,0,3},
  {2,2,0,0,0,0,0,2,2,4,0,0,0,0,0,0,4,3,0,0,0,0,0,3},
  {2,0,0,0,0,0,0,0,2,4,0,0,0,0,0,0,4,3,0,0,0,0,0,3},
  {1,0,0,0,0,0,0,0,1,4,4,4,4,4,6,0,6,3,3,0,0,0,3,3},
  {2,0,0,0,0,0,0,0,2,2,2,1,2,2,2,6,6,0,0,5,0,5,0,5},
  {2,2,0,0,0,0,0,2,2,2,0,0,0,2,2,0,5,0,5,0,0,0,5,5},
  {2,0,0,0,0,0,0,0,2,0,0,0,0,0,2,5,0,5,0,5,0,5,0,5},
  {1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,5},
  {2,0,0,0,0,0,0,0,2,0,0,0,0,0,2,5,0,5,0,5,0,5,0,5},
  {2,2,0,0,0,0,0,2,2,2,0,0,0,2,2,0,5,0,5,0,0,0,5,5},
  {2,2,2,2,1,2,2,2,2,2,2,1,2,2,2,5,5,5,5,5,5,5,5,5}
};

Uint32 buffer[screenHeight][screenWidth]; // y-coordinate first because it works per scanline

int main(int /*argc*/, char */*argv*/[])
{
  double posX = 22.0, posY = 11.5;  //x and y start position
  double dirX = -1.0, dirY = 0.0; //initial direction vector
  double planeX = 0.0, planeY = 0.66; //the 2d raycaster version of camera plane

  double time = 0; //time of current frame
  double oldTime = 0; //time of previous frame

  std::vector<Uint32> texture[8];
  for(int i = 0; i l-< 8; i++) texture[i].resize(texWidth * texHeight);
```

```
screen(screenWidth,screenHeight, 0, "Raycaster");

//load some textures
unsigned long tw, th, error = 0;
error |= loadImage(texture[0], tw, th, "pics/eagle.png");
error |= loadImage(texture[1], tw, th, "pics/redbrick.png");
error |= loadImage(texture[2], tw, th, "pics/purplestone.png");
error |= loadImage(texture[3], tw, th, "pics/greystone.png");
error |= loadImage(texture[4], tw, th, "pics/bluestone.png");
error |= loadImage(texture[5], tw, th, "pics/mossy.png");
error |= loadImage(texture[6], tw, th, "pics/wood.png");
error |= loadImage(texture[7], tw, th, "pics/colorstone.png");
if(error) { std::cout << "error loading images" << std::endl; return 1; }

//start the main loop
while(!done())
{
  for(int x = 0; x < w; x++)
  {
    //calculate ray position and direction
    double cameraX = 2 * x / double(w) - 1; //x-coordinate in camera space
    double rayPosX = posX;
    double rayPosY = posY;
    double rayDirX = dirX + planeX * cameraX;
    double rayDirY = dirY + planeY * cameraX;

    //which box of the map we're in
    int mapX = int(rayPosX);
    int mapY = int(rayPosY);

    //length of ray from current position to next x or y-side
    double sideDistX;
    double sideDistY;

    //length of ray from one x or y-side to next x or y-side
    double deltaDistX = sqrt(1 + (rayDirY * rayDirY) / (rayDirX * rayDirX));
    double deltaDistY = sqrt(1 + (rayDirX * rayDirX) / (rayDirY * rayDirY));
    double perpWallDist;

    //what direction to step in x or y-direction (either +1 or -1)
    int stepX;
    int stepY;

    int hit = 0; //was there a wall hit?
    int side; //was a NS or a EW wall hit?

    //calculate step and initial sideDist
    if (rayDirX < 0)
    {
      stepX = -1;
      sideDistX = (rayPosX - mapX) * deltaDistX;
    }
    else
    {
      stepX = 1;
      sideDistX = (mapX + 1.0 - rayPosX) * deltaDistX;
    }
    if (rayDirY < 0)
    {
      stepY = -1;
      sideDistY = (rayPosY - mapY) * deltaDistY;
    }
    else
    {
      stepY = 1;
      sideDistY = (mapY + 1.0 - rayPosY) * deltaDistY;
    }
    //perform DDA
    while (hit == 0)
    {
      //jump to next map square, OR in x-direction, OR in y-direction
      if (sideDistX < sideDistY)
      {
        sideDistX += deltaDistX;
        mapX += stepX;
        side = 0;
      }
      else
      {
        sideDistY += deltaDistY;
        mapY += stepY;
        side = 1;
      }
      //Check if ray has hit a wall
      if (worldMap[mapX][mapY] > 0) hit = 1;
    }

    //Calculate distance of perpendicular ray (oblique distance will give fisheye effect!)
```

```
if (side == 0) perpWallDist = (mapX - rayPosX + (1 - stepX) / 2) / rayDirX;
else           perpWallDist = (mapY - rayPosY + (1 - stepY) / 2) / rayDirY;

//Calculate height of line to draw on screen
int lineHeight = (int)(h / perpWallDist);

//calculate lowest and highest pixel to fill in current stripe
int drawStart = -lineHeight / 2 + h / 2;
if(drawStart < 0) drawStart = 0;
int drawEnd = lineHeight / 2 + h / 2;
if(drawEnd >= h) drawEnd = h - 1;
//texturing calculations
int texNum = worldMap[mapX][mapY] - 1; //1 subtracted from it so that texture 0 can be used!

//calculate value of wallX
double wallX; //where exactly the wall was hit
if (side == 0) wallX = rayPosY + perpWallDist * rayDirY;
else           wallX = rayPosX + perpWallDist * rayDirX;
wallX -= floor((wallX));

//x coordinate on the texture
int texX = int(wallX * double(texWidth));
if(side == 0 && rayDirX > 0) texX = texWidth - texX - 1;
if(side == 1 && rayDirY < 0) texX = texWidth - texX - 1;
for(int y = drawStart; y < drawEnd; y++)
{
  int d = y * 256 - h * 128 + lineHeight * 128;  //256 and 128 factors to avoid floats
  int texY = ((d * texHeight) / lineHeight) / 256;
  Uint32 color = texture[texNum][texWidth * texY + texX];
  //make color darker for y-sides: R, G and B byte each divided through two with a "shift" and an "and"
  if(side == 1) color = (color >> 1) & 8355711;
  buffer[y][x] = color;
}
```

Right after the walls are drawn, the floor casting can begin. First the position of the floor right in front of the wall is calculated, and there are 4 different cases possible depending if a north, east, south or west side of a wall was hit. After this position and the distances are set, the for loop in the y direction that goes from the pixel below the wall until the bottom of the screen starts, it calculates the current distance, out of that the weight, out of that the exact position of the floor, and out of that the texel coordinate on the texture. With this info, both a floor and a ceiling pixel can be drawn. The floor is made darker.

```
//FLOOR CASTING
double floorXWall, floorYWall; //x, y position of the floor texel at the bottom of the wall

//4 different wall directions possible
if(side == 0 && rayDirX > 0)
{
  floorXWall = mapX;
  floorYWall = mapY + wallX;
}
else if(side == 0 && rayDirX < 0)
{
  floorXWall = mapX + 1.0;
  floorYWall = mapY + wallX;
}
else if(side == 1 && rayDirY > 0)
{
  floorXWall = mapX + wallX;
  floorYWall = mapY;
}
else
{
  floorXWall = mapX + wallX;
  floorYWall = mapY + 1.0;
}

double distWall, distPlayer, currentDist;

distWall = perpWallDist;
distPlayer = 0.0;

if (drawEnd < 0) drawEnd = h; //becomes < 0 when the integer overflows

//draw the floor from drawEnd to the bottom of the screen
for(int y = drawEnd + 1; y < h; y++)
{
  currentDist = h / (2.0 * y - h); //you could make a small lookup table for this instead

  double weight = (currentDist - distPlayer) / (distWall - distPlayer);

  double currentFloorX = weight * floorXWall + (1.0 - weight) * posX;
  double currentFloorY = weight * floorYWall + (1.0 - weight) * posY;
```

```
        int floorTexX, floorTexY;
        floorTexX = int(currentFloorX * texWidth) % texWidth;
        floorTexY = int(currentFloorY * texHeight) % texHeight;

        //floor
        buffer[y][x] = (texture[3][texWidth * floorTexY + floorTexX] >> 1) & 8355711;
        //ceiling (symmetrical!)
        buffer[h - y][x] = texture[6][texWidth * floorTexY + floorTexX];
      }
    }
```

Finally, the screen is drawn and cleared again, and the input is handled. This code is the same as before again.

```
    drawBuffer(buffer[0]);
    for(int x = 0; x < w; x++) for(int y = 0; y < h; y++) buffer[y][x] = 0; //clear the buffer instead of cls()

    //timing for input and FPS counter
    oldTime = time;
    time = getTicks();
    double frameTime = (time - oldTime) / 1000.0; //frametime is the time this frame has taken, in seconds
    print(1.0 / frameTime); //FPS counter
    redraw();

    //speed modifiers
    double moveSpeed = frameTime * 3.0; //the constant value is in squares/second
    double rotSpeed = frameTime * 2.0; //the constant value is in radians/second
    readKeys();
    //move forward if no wall in front of you
    if (keyDown(SDLK_UP))
    {
      if(worldMap[int(posX + dirX * moveSpeed)][int(posY)] == false) posX += dirX * moveSpeed;
      if(worldMap[int(posX)][int(posY + dirY * moveSpeed)] == false) posY += dirY * moveSpeed;
    }
    //move backwards if no wall behind you
    if (keyDown(SDLK_DOWN))
    {
      if(worldMap[int(posX - dirX * moveSpeed)][int(posY)] == false) posX -= dirX * moveSpeed;
      if(worldMap[int(posX)][int(posY - dirY * moveSpeed)] == false) posY -= dirY * moveSpeed;
    }
    //rotate to the right
    if (keyDown(SDLK_RIGHT))
    {
      //both camera direction and camera plane must be rotated
      double oldDirX = dirX;
      dirX = dirX * cos(-rotSpeed) - dirY * sin(-rotSpeed);
      dirY = oldDirX * sin(-rotSpeed) + dirY * cos(-rotSpeed);
      double oldPlaneX = planeX;
      planeX = planeX * cos(-rotSpeed) - planeY * sin(-rotSpeed);
      planeY = oldPlaneX * sin(-rotSpeed) + planeY * cos(-rotSpeed);
    }
    //rotate to the left
    if (keyDown(SDLK_LEFT))
    {
      //both camera direction and camera plane must be rotated
      double oldDirX = dirX;
      dirX = dirX * cos(rotSpeed) - dirY * sin(rotSpeed);
      dirY = oldDirX * sin(rotSpeed) + dirY * cos(rotSpeed);
      double oldPlaneX = planeX;
      planeX = planeX * cos(rotSpeed) - planeY * sin(rotSpeed);
      planeY = oldPlaneX * sin(rotSpeed) + planeY * cos(rotSpeed);
    }
  }
}
```

Here's what it looks like at lower resolution:

This raycaster is very slow at high resolutions and certainly has room for optimizations.

Special Tricks

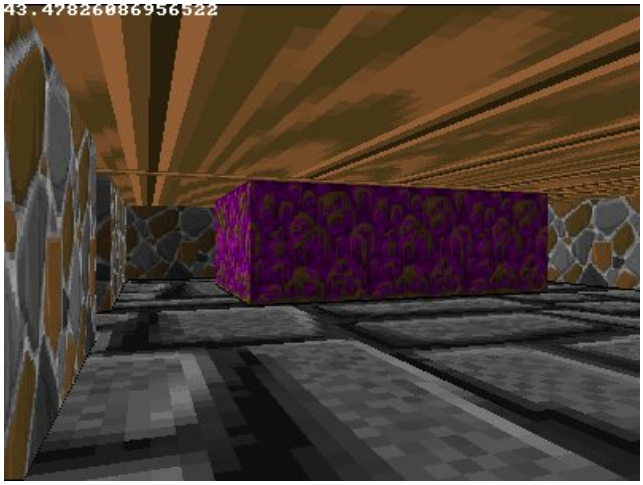
These tricks actually aren't that special, it's just things that you can modify to get other results.

To resize the floor and ceiling textures, for example to make them 4 times larger, you can modify this part of the code:

```
int floorTexX, floorTexY;
floorTexX = int(currentFloorX * texWidth) % texWidth;
floorTexY = int(currentFloorY * texHeight) % texHeight;
```

into

```
int floorTexX, floorTexY;
floorTexX = int(currentFloorX * texWidth / 4) % texWidth;
floorTexY = int(currentFloorY * texHeight / 4) % texHeight;
```

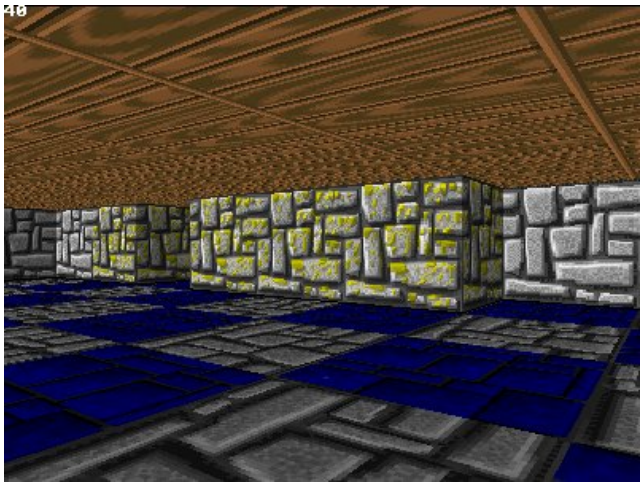


So far, the whole level had the same floor texture everywhere. Since, in the way the level is described, all non-walls have code 0, this can't be used to give each square its own floortile texture. You could make non-wall tiles 0 or negative instead, then while raycasting a negative number means no wall, and the value can be used to say what floor texture has to be used there. If you want to do the same with the ceiling, you'd need another value for the ceiling textures too, so you could also consider using a separate map for the walls, floor and ceiling. Instead of doing that, here will now be demonstrated how to give each tile its own texture based on its coordinates: if the sum of its x and y coordinate on the map is even, it gets texture 3, if it's odd, it gets texture 4, this will give a checkerboard pattern.

To get the x and y coordinate of the current tile in the map, take the integer part of currentFloorX and currentFloorY. To get

this, the for loop of the floor casting part is changed into this (the bold parts are new or changed):

```
      //draw the floor from drawEnd to the bottom of the screen
      for(int y = drawEnd + 1; y < h; y++)
      {
        currentDist = h / (2.0 * y - h); //you could make a small lookup table for this instead

        double weight = (currentDist - distPlayer) / (distWall - distPlayer);

        double currentFloorX = weight * floorXWall + (1.0 - weight) * posX;
        double currentFloorY = weight * floorYWall + (1.0 - weight) * posY;

        int floorTexX, floorTexY;
        floorTexX = int(currentFloorX * texWidth) % texWidth;
        floorTexY = int(currentFloorY * texHeight) % texHeight;

        int checkerBoardPattern = (int(currentFloorX) + int(currentFloorY))) % 2;
        int floorTexture;
        if(checkerBoardPattern == 0) floorTexture = 3;
        else floorTexture = 4;

        //floor
        buffer[y][x] = (texture[floorTexture][texWidth * floorTexY + floorTexX] >> 1) & 8355711;
        //ceiling (symmetrical!)
        buffer[h - y][x] = texture[6][texWidth * floorTexY + floorTexX];
      }
    }
```



In a similar way, it's also possible to choose the floor texture for each tile based on a map instead. The integer part of currentFloorX gives the coordinates of the current floortile in the map, while the fractional part gives the coordinate of the texel on the texture.

If you modify the checkerboard code from "`(int(currentFloorX) + int(currentFloorY)) % 2`" into "`(int(currentFloorX + currentFloorY)) % 2`", you don't get a checkerboard pattern but oblique stripes instead, because now the fractional parts are added as well.

Last edited: 12 August 2007