Tutorial de Computação Gráfica de Lode

Fundição de Raios III: Sprites

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Introdução

Os artigos Raycasting e Raycasting II descreviam como fazer paredes e pisos texturizados, Mas algo está faltando. Em um jogo, um mundo com apenas paredes e pisos está vazio, Para um jogo funcionar, tem que haver guloseimas, inimigos, objetos como barris ou árvores, ... Estes não podem ser desenhados como parede ou piso, e, no época em que os jogos de raycasting foram feitos, também não podem ser desenhados como modelos 3D. Em vez disso, eles usaram sprites, imagens 2D sempre voltadas para você (para que sejam fáceis de desenhar e exijam uma única imagem), mas que se tornam menores se estiverem mais longe.

Você pode baixar o código-fonte completo deste tutorial aqui.

Como funciona

A técnica usada para desenhar os sprites é totalmente diferente da técnica de raycasting. Em vez disso, funciona de forma muito semelhante a como os sprites são desenhados em um mecanismo 3D com projeções, como no artigo "Pontos, Sprites e Movimento". Só que temos que fazer apenas a projeção em 2D, e algumas técnicas extras para combiná-lo com raycasting são usadas.

O desenho dos sprites é feito depois que as paredes e o piso já estão desenhados. Aqui estão as etapas usadas para desenhar os sprites:

- 1: Ao projetar as paredes, armazene a distância perpendicular de cada faixa vertical em um ZBuffer 1D
- 2: Calcule a distância de cada sprite até o jogador
- 3: Use essa distância para classificar os sprites, do mais distante para o mais próximo da câmera
- 4: Projete o sprite no plano da câmera (em 2D): subtraia a posição do jogador da posição do sprite e multiplique o resultado pelo inverso da matriz da câmera 2x2
- 5: Calcule o tamanho do sprite na tela (nas direções x e y) usando a distância perpendicular
- 6: Desenhe a faixa vertical dos sprites por faixa vertical, não desenhe a faixa vertical se a distância for maior que o ZBuffer 1D das paredes da faixa atual
- 7: Desenhe a faixa vertical pixel por pixel, certifique-se de que haja uma cor invisível ou todos os sprites seriam retângulos

Você não precisa atualizar o ZBuffer enquanto desenha as listras: como elas são classificadas, as mais próximas de você serão desenhadas por último, então elas são desenhadas sobre as mais distantes.

Como projetar o sprite na tela é explicado em matemática de renderização 3D completa (com matrizes 3D e câmera), para verdadeiros mecanismos 3D de rasterizador ou*traçador de* raios 3D, e não é explicado aqui no tutorial do*lançador* de raios. No entanto, aqui é feito em 2D e nenhuma classe de câmera sofisticada é usada. Para trazer as coordenadas do sprite para o espaço da câmera, primeiro subtraia a posição do jogador da posição do sprite posição, então você tem a posição do sprite em relação ao jogador. Em seguida, ele deve ser girado para que a direção seja relativa ao jogador. A câmera também pode ser distorcido e tem um certo tamanho, então não é realmente uma rotação, mas uma transformação. A transformação é feita multiplicando o relativo posição do sprite com o inverso da matriz da câmera. A matriz da câmera está no nosso caso
E o inverso de uma matriz 2x2 é muito fácil de calcular
Então você obtém as coordenadas X e Y do sprite no espaço da câmera, onde Y é a profundidade dentro da tela (em um verdadeiro mecanismo 3D, Z é a profundidade). Para projete-o na tela, divida X pela profundidade e, em seguida, traduza-o e dimensione-o para que fique em coordenadas de pixel.

Para colocar os objetos no nível, muitas coisas podem ser feitas. Cada objeto pode ter suas próprias coordenadas de ponto flutuante, não precisa ser exatamente no centro dos ladrilhos. Você pode fazer uma lista de cada objeto e fornecer suas coordenadas e texturas uma a uma, ou pode colocar os objetos fazendo um segundo mapa (uma matriz 2D) e, para cada coordenada de ladrilho, coloque um ou nenhum objeto, da mesma forma que colocar as paredes. Se você fizer isso, Em seguida, deixe o programa ler esse mapa e criar uma lista de objetos a partir dele, com cada objeto colocado no centro do bloco do mapa correspondente. As coordenadas no centro de um bloco são divididas pela metade, por exemplo, (11,5, 15,5), enquanto as coordenadas inteiras serão os cantos dos blocos.

O código apresentado abaixo usa uma pequena lista de objetos em vez de um mapa.

```
[planeX   dirX]
[planeY   dirY]

____________1___________     [dirY      -dirX]
(planeX*dirY-dirX*planeY) * [-planeY  planeX]
```

O Código

O código tenta carregar as texturas do wolfenstein, com texturas extras para 3 sprites, você pode baixá-las aqui (copyright pela id Software). Se você não quiser carregar texturas, poderá usar a parte do código que gera texturas do tutorial de raycasting anterior, mas parece menos bom. Você também terá que inventar algo para os sprites, o preto é a cor invisível.

O código completo da coisa toda é dado, é semelhante ao código do Raycasting II, mas com código adicionado aqui e ali.

As novas variáveis para a conversão de sprites são a struct Sprite, contendo a posição e a textura do sprite, o valor numSprites: o número de sprites, o array de sprites: define as posições e texturas de todos os Sprites, a declaração da função bubbleSort: isso classificará os sprites e os arrays usados como argumentos para esta função: spriteOrder e spriteDistance e, finalmente, ZBuffer: este é o equivalente 1D do ZBuffer em um verdadeiro motor 3D. Na matriz de sprite, cada terceiro número é o número de sua textura, você pode ver qual número significa o que onde as texturas são carregadas.

```
#define screenWidth 640
#define screenHeight 480
#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},
  {8,8,8,8,0,8,8,8,8,8,8,4,4,4,4,4,4,6,0,0,0,0,0,6},
  {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}
};

struct Sprite
{
  double x;
  double y;
  int texture;
};

#define numSprites 19

Sprite sprite[numSprites] =
{
  {20.5, 11.5, 10}, //green light in front of playerstart
  //green lights in every room
  {18.5,4.5, 10},
  {10.0,4.5, 10},
  {10.0,12.5,10},
  {3.5, 6.5, 10},
  {3.5, 20.5,10},
  {3.5, 14.5,10},
  {14.5,20.5,10},

  //row of pillars in front of wall: fisheye test
  {18.5, 10.5, 9},
  {18.5, 11.5, 9},
  {18.5, 12.5, 9},

  //some barrels around the map
  {21.5, 1.5, 8},
  {15.5, 1.5, 8},
  {16.0, 1.8, 8},
  {16.2, 1.2, 8},
  {3.5,  2.5, 8},
  {9.5, 15.5, 8},
  {10.0, 15.1,8},
  {10.5, 15.8,8},
};

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

//1D Zbuffer
double ZBuffer[screenWidth];

//arrays used to sort the sprites
int spriteOrder[numSprites];
double spriteDistance[numSprites];

//function used to sort the sprites
void sortSprites(int* order, double* dist, int amount);

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[11];
for(int i = 0; i < 11; i++) texture[i].resize(texWidth * texHeight);
```

3 new textures are loaded: the sprites. There's nothing that stops you from loading more textures, or making the textures higher resolution.

```
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");

//load some sprite textures
error |= loadImage(texture[8], tw, th, "pics/barrel.png");
error |= loadImage(texture[9], tw, th, "pics/pillar.png");
error |= loadImage(texture[10], tw, th, "pics/greenlight.png");
if(error) { std::cout << "error loading images" << std::endl; return 1; }
```

Here's the main loop which starts with raycasting the floors and walls, same code as before.

```
//start the main loop
while(!done())
{
  //FLOOR CASTING
  for(int y = 0; y < h; y++)
  {
    // rayDir for leftmost ray (x = 0) and rightmost ray (x = w)
    float rayDirX0 = dirX - planeX;
    float rayDirY0 = dirY - planeY;
    float rayDirX1 = dirX + planeX;
    float rayDirY1 = dirY + planeY;

    // Current y position compared to the center of the screen (the horizon)
    int p = y - screenHeight / 2;

    // Vertical position of the camera.
    float posZ = 0.5 * screenHeight;

    // Horizontal distance from the camera to the floor for the current row.
    // 0.5 is the z position exactly in the middle between floor and ceiling.
    float rowDistance = posZ / p;

    // calculate the real world step vector we have to add for each x (parallel to camera plane)
    // adding step by step avoids multiplications with a weight in the inner loop
    float floorStepX = rowDistance * (rayDirX1 - rayDirX0) / screenWidth;
    float floorStepY = rowDistance * (rayDirY1 - rayDirY0) / screenWidth;

    // real world coordinates of the leftmost column. This will be updated as we step to the right.
    float floorX = posX + rowDistance * rayDirX0;
    float floorY = posY + rowDistance * rayDirY0;

    for(int x = 0; x < screenWidth; ++x)
    {
      // the cell coord is simply got from the integer parts of floorX and floorY
      int cellX = (int)(floorX);
      int cellY = (int)(floorY);

      // get the texture coordinate from the fractional part
      int tx = (int)(texWidth * (floorX - cellX)) & (texWidth - 1);
      int ty = (int)(texHeight * (floorY - cellY)) & (texHeight - 1);

      floorX += floorStepX;
      floorY += floorStepY;

      // choose texture and draw the pixel
      int floorTexture = 3;
      int ceilingTexture = 6;
      Uint32 color;

      // floor
      color = texture[floorTexture][texWidth * ty + tx];
      color = (color >> 1) & 8355711; // make a bit darker
      buffer[y][x] = color;

      //ceiling (symmetrical, at screenHeight - y - 1 instead of y)
      color = texture[ceilingTexture][texWidth * ty + tx];
      color = (color >> 1) & 8355711; // make a bit darker
      buffer[screenHeight - y - 1][x] = color;
    }
  }

  // WALL CASTING
```

```
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 rayDirX = dirX + planeX * cameraX;
  double rayDirY = dirY + planeY * cameraX;

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

  //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 = (rayDirX == 0) ? 1e30 : std::abs(1 / rayDirX);
  double deltaDistY = (rayDirY == 0) ? 1e30 : std::abs(1 / 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 = (posX - mapX) * deltaDistX;
  }
  else
  {
    stepX = 1;
    sideDistX = (mapX + 1.0 - posX) * deltaDistX;
  }
  if (rayDirY < 0)
  {
    stepY = -1;
    sideDistY = (posY - mapY) * deltaDistY;
  }
  else
  {
    stepY = 1;
    sideDistY = (mapY + 1.0 - posY) * deltaDistY;
  }
  //perform DDA
  while (hit == 0)
  {
    //jump to next map square, either 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 (Euclidean distance would give fisheye effect!)
  if(side == 0) perpWallDist = (sideDistX - deltaDistX);
  else          perpWallDist = (sideDistY - deltaDistY);

  //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 = posY + perpWallDist * rayDirY;
  else           wallX = posX + 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;

  // How much to increase the texture coordinate per screen pixel
  double step = 1.0 * texHeight / lineHeight;
  // Starting texture coordinate
  double texPos = (drawStart - h / 2 + lineHeight / 2) * step;
```

```
    for(int y = drawStart; y<drawEnd; y++)
    {
      // Cast the texture coordinate to integer, and mask with (texHeight - 1) in case of overflow
      int texY = (int)texPos & (texHeight - 1);
      texPos += step;
      int 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;
    }
```

After raycasting the wall, the ZBuffer has to be set. This ZBuffer is 1D, because it only contains the distance to the wall of every vertical stripe, instead of having this for every pixel. This also ends the loop through every vertical stripe, because rendering the sprites will be done outside this loop.

```
    //SET THE ZBUFFER FOR THE SPRITE CASTING
    ZBuffer[x] = perpWallDist; //perpendicular distance is used
  }
```

After the floors and walls are finally drawn, the sprites can be drawn. This code is very unoptimized, a few improvements are explained later. First it sorts the sprites from far to close, so that the far ones will be drawn first. Then it projects each sprite, calculates the size it should have on screen, and draws it stripe by stripe. The matrix multiplication for the projection is very easy because it's only a 2x2 matrix. It comes in very handy again that they raycaster already used a 2D camera matrix, instead of representing the player with an angle and a position instead like some raycasters do.

The distance calculated for the sorting of the sprites is never used later on, because the perpendicular distance is used instead. For sorting the sprites it doesn't matter if you take the square root of the distance or not, so no calculation time is wasted for that.

```
  //SPRITE CASTING
  //sort sprites from far to close
  for(int i = 0; i < numSprites; i++)
  {
    spriteOrder[i] = i;
    spriteDistance[i] = ((posX - sprite[i].x) * (posX - sprite[i].x) + (posY - sprite[i].y) * (posY - sprite[i].y)); //sqrt not taken, unneeded
  }
  sortSprites(spriteOrder, spriteDistance, numSprites);

  //after sorting the sprites, do the projection and draw them
  for(int i = 0; i < numSprites; i++)
  {
    //translate sprite position to relative to camera
    double spriteX = sprite[spriteOrder[i]].x - posX;
    double spriteY = sprite[spriteOrder[i]].y - posY;

    //transform sprite with the inverse camera matrix
    // [ planeX   dirX ] -1                                       [ dirY      -dirX ]
    // [               ]       =  1/(planeX*dirY-dirX*planeY) *   [                 ]
    // [ planeY   dirY ]                                          [ -planeY  planeX ]

    double invDet = 1.0 / (planeX * dirY - dirX * planeY); //required for correct matrix multiplication

    double transformX = invDet * (dirY * spriteX - dirX * spriteY);
    double transformY = invDet * (-planeY * spriteX + planeX * spriteY); //this is actually the depth inside the screen, that what Z is in 3D

    int spriteScreenX = int((w / 2) * (1 + transformX / transformY));

    //calculate height of the sprite on screen
    int spriteHeight = abs(int(h / (transformY))); //using 'transformY' instead of the real distance prevents fisheye
    //calculate lowest and highest pixel to fill in current stripe
    int drawStartY = -spriteHeight / 2 + h / 2;
    if(drawStartY < 0) drawStartY = 0;
    int drawEndY = spriteHeight / 2 + h / 2;
    if(drawEndY >= h) drawEndY = h - 1;

    //calculate width of the sprite
    int spriteWidth = abs( int (h / (transformY)));
    int drawStartX = -spriteWidth / 2 + spriteScreenX;
    if(drawStartX < 0) drawStartX = 0;
    int drawEndX = spriteWidth / 2 + spriteScreenX;
    if(drawEndX >= w) drawEndX = w - 1;

    //loop through every vertical stripe of the sprite on screen
    for(int stripe = drawStartX; stripe < drawEndX; stripe++)
    {
      int texX = int(256 * (stripe - (-spriteWidth / 2 + spriteScreenX)) * texWidth / spriteWidth) / 256;
      //the conditions in the if are:
      //1) it's in front of camera plane so you don't see things behind you
      //2) it's on the screen (left)
      //3) it's on the screen (right)
      //4) ZBuffer, with perpendicular distance
      if(transformY > 0 && stripe > 0 && stripe < w && transformY < ZBuffer[stripe])
      for(int y = drawStartY; y < drawEndY; y++) //for every pixel of the current stripe
      {
        int d = (y) * 256 - h * 128 + spriteHeight * 128; //256 and 128 factors to avoid floats
        int texY = ((d * texHeight) / spriteHeight) / 256;
        Uint32 color = texture[sprite[spriteOrder[i]].texture][texWidth * texY + texX]; //get current color from the texture
        if((color & 0x00FFFFFF) != 0) buffer[y][stripe] = color; //paint pixel if it isn't black, black is the invisible color
      }
    }
  }
```

After it all is drawn, the screen is updated, and the input keys are handled.

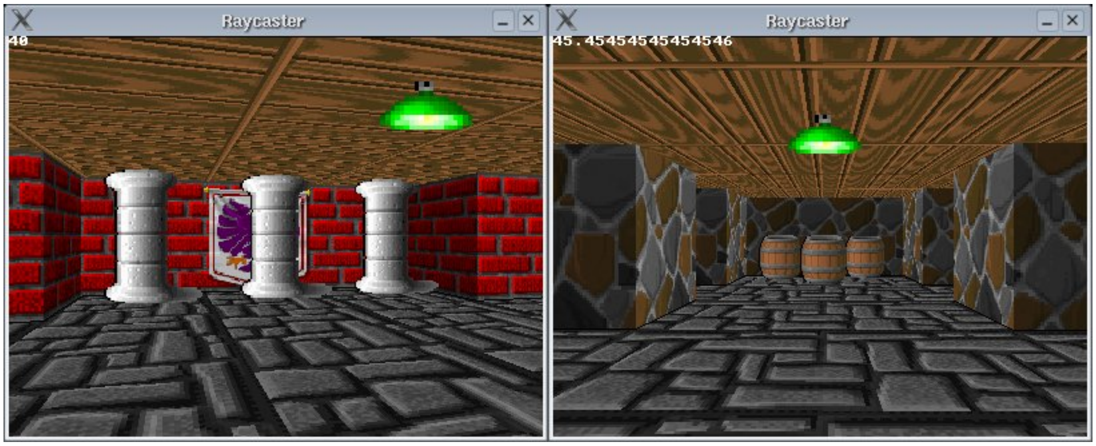
```
    drawBuffer(buffer[0]);
    for(int y = 0; y < h; y++) for(int x = 0; x < w; x++) buffer[y][x] = 0; //clear the buffer instead of cls()

    //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);
    }
  }
}
```

The sortSprites sorts the sprites from farthest away to closest by distance. It uses the standard std::sort function provided by C++. But since we need to sort two arrays using the same order here (order and dist), most of the code is spent moving the data into and out of a vector of pairs.

```
//sort algorithm
//sort the sprites based on distance
void sortSprites(int* order, double* dist, int amount)
{
  std::vector<std::pair<double, int>> sprites(amount);
  for(int i = 0; i < amount; i++) {
    sprites[i].first = dist[i];
    sprites[i].second = order[i];
  }
  std::sort(sprites.begin(), sprites.end());
  // restore in reverse order to go from farthest to nearest
  for(int i = 0; i < amount; i++) {
    dist[i] = sprites[amount - i - 1].first;
    order[i] = sprites[amount - i - 1].second;
  }
}
}
```



The green light is a very small sprite, but the program still goes through all its invisible pixels to check their color. It could be made faster by telling which sprites have large invisible parts, and only drawing a smaller rectangular part of them containing all visible pixels.

To make some objects unwalkthroughable, you can either check the distance of the player to every object when he moves for collision detection, or, make another 2D map that contains for every square if it's walkthroughable or not, this can be used for walls as well.

In for example Wolfenstein 3D, some objects (for example the soldiers) have 8 different pictures when viewing it from different angles, to make it appear as if the sprite is really 3D. You can get the angle of the object to the player for example with the atan2 function, and then choose 1 of 8 textures depending on the angle. You can also give the sprites even more textures for animation.

Scaling Sprites

It's pretty easy to let the program draw the sprites larger or smaller, and move the sprites up or down. To shrink the sprite, divide spriteWidth and spriteHeight through something. If you halve the height of the sprites, for example the pillar, then the bottom will move up so that the pillar appears to be floating. That's why in the code below, apart from the parameters uDiv and vDiv to shrink the sprite, also a parameter vMove is added to move the sprite down if it has to stand on the floor, or up if it has to hang on the ceiling. vMoveScreen is vMove projected on the screen by dividing it through the depth.

```
      //parameters for scaling and moving the sprites
      #define uDiv 1
      #define vDiv 1
      #define vMove 0.0
      int vMoveScreen = int(vMove / transformY);

      //calculate height of the sprite on screen
      int spriteHeight = abs(int(h / (transformY))) / vDiv; //using 'transformY' instead of the real distance prevents fisheye
      //calculate lowest and highest pixel to fill in current stripe
      int drawStartY = -spriteHeight / 2 + h / 2 + vMoveScreen;
      if(drawStartY < 0) drawStartY = 0;
      int drawEndY = spriteHeight / 2 + h / 2 + vMoveScreen;
      if(drawEndY >= h) drawEndY = h - 1;

      //calculate width of the sprite
      int spriteWidth = abs( int (h / (transformY))) / uDiv;
      int drawStartX = -spriteWidth / 2 + spriteScreenX;
      if(drawStartX < 0) drawStartX = 0;
      int drawEndX = spriteWidth / 2 + spriteScreenX;
      if(drawEndX >= w) drawEndX = w - 1;


      //loop through every vertical stripe of the sprite on screen
      for(int stripe = drawStartX; stripe < drawEndX; stripe++)
      {
        int texX = int(256 * (stripe - (-spriteWidth / 2 + spriteScreenX)) * texWidth / spriteWidth) / 256;
        //the conditions in the if are:
        //1) it's in front of camera plane so you don't see things behind you
        //2) it's on the screen (left)
        //3) it's on the screen (right)
        //4) ZBuffer, with perpendicular distance
        if(transformY > 0 && stripe > 0 && stripe < w && transformY < ZBuffer[stripe])
        for(int y = drawStartY; y < drawEndY; y++) //for every pixel of the current stripe
        {
          int d = (y-vMoveScreen) * 256 - h * 128 + spriteHeight * 128;  //256 and 128 factors to avoid floats
          int texY = ((d * texHeight) / spriteHeight) / 256;
          Uint32 color = texture[sprite[spriteOrder[i]].texture][texWidth * texY + texX]; //get current color from the texture
          if((color & 0x00FFFFFF) != 0) buffer[y][stripe] = color; //paint pixel if it isn't black, black is the invisible color
        }
      }
    }
```

When uDiv = 2, vDiv = 2, vMove = 0.0, the sprites are half as big, and float:

Put it back on the ground by setting vMove to 64.0 (the size of the texture):

If you make vMove even higher to place the sprites under the ground, they'll still be drawn through the ground, because the ZBuffer is 1D and can only detect if the sprite is in front or behind a wall.

Of course, by lowering the barrels, the green light is lower too so it doesn't hang on the ceiling anymore. To make this useful, you have to give each sprite its own uDiv, vDiv and vMove parameters, for example you can put them in the sprite struct.

Translucent Sprites

Because we're working in RGB color, making sprites translucent is very simple. All you have to do is take the average of the old color in the buffer and the new color of the sprite. Old games like for example Wolfenstein 3D used a palette of 256 colors with no logical mathematical rules for the colors in the palette, so there translucency wasn't so easy. Change the following line of code

```
if((color & 0x00FFFFFF) != 0) buffer[y][stripe] = color; //paint pixel if it isn't black, black is the invisible color
```

into

```
if((color & 0x00FFFFFF) != 0) buffer[y][stripe] = RGBtoINT(INTtoRGB(buffer[y][stripe]) / 2 + INTtoRGB(color) / 2); //paint pixel if it isn't black, black is
```

To make them more translucent, try something like

```
if((color & 0x00FFFFFF) != 0) buffer[y][stripe] = RGBtoINT(3 * INTtoRGB(buffer[y][stripe]) / 4 + INTtoRGB(color) / 4); //paint pixel if it isn't black, black
```

You can also try more special tricks, for example translucent sprites, that make the walls behind them of negative color:

```
if((color & 0x00FFFFFF) != 0) buffer[y][stripe] = RGBtoINT((RGB_White - INTtoRGB(buffer[y][stripe])) / 2 + INTtoRGB(color) / 2); //paint pixel if it isn't bl
```

To be useful for a game, it would be more handy to give each sprite its own translucency effect (if any), with an extra parameter in the sprite struct. For example the green light could be translucent, but a pillar certainly not.

Last edited: 2020