中国科学技术大学

计算机图形学实验报告

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目录

实验一

一、实验原理

1. Bresenham 算法

Bresenham 算法通过以下步骤来绘制直线：

1) 初始化起点和终点坐标。
2) 计算水平和垂直方向的距离差（dx 和 dy）。
3) 根据 dx 和 dy 的大小，决定像素点的移动方向。
4) 在每一步中，根据误差判断是否需要跳过一个像素点。

2. 中点椭圆绘制算法

中点椭圆绘制算法通过以下步骤来绘制椭圆：

1) 初始化起点和终点坐标以及长轴和短轴的半径。
2) 计算像素点的初始坐标和误差值。
3) 在每次迭代中，根据误差值决定下一个像素点的位置，并更新误差值。

3. 多边形绘制

多边形绘制通过以下步骤来实现：

1) 用户点击画布上的多个点来定义多边形的顶点。
2) 每次点击后，连接前一个点和当前点形成一条线段。
3) 最后，连接最后一个点和第一个点以闭合多边形。

4. 四联通漫水填充算法

四联通漫水填充算法通过以下步骤来实现：

1) 在多边形区域内任选一个点作为种子点。
2) 将种子点入栈。
3) 如果栈非空，栈顶像素出栈，并将出栈像素设置为填充色，按右、上、左、下的顺序检查四邻域的像素，如果像素不在边界且未填色，则入栈。
4) 栈空结束。

二、算法实现思路

1. 界面初始化

- 使用 tkinter 创建一个主窗口。
- 在窗口中创建一个画布（Canvas），用于绘制图形。

2. 事件处理

- 绑定鼠标点击和右键点击事件，以便在用户交互时触发相应的操作。
- 实现鼠标移动事件，以便在绘制多边形时实时显示线条。

3. 绘图功能

- 直线：使用 Bresenham 算法实现直线绘制。
- 椭圆：使用中点椭圆绘制算法（Midpoint Ellipse Algorithm）实现椭圆绘制。
- 多边形：用户通过点击画布绘制多边形的顶点，最后通过闭合线条形成多边形。

4. 填充功能

- 四联通漫水填充：使用队列实现迭代式的四联通漫水填充算法（Flood Fill Algorithm），填充多边形内部。

三、核心代码

1. 绘制直线

```
def bresenham_line(self, x1, y1, x2, y2, color=(0, 0, 0)):
    dx = abs(x2 - x1)
    dy = abs(y2 - y1)
    sx = 1 if x1 < x2 else -1
    sy = 1 if y1 < y2 else -1
    err = dx - dy

    x, y = x1, y1
    while True:
        self.put_pixel(x, y, color)
        if x == x2 and y == y2:
```

```
                break
            e2 = 2 * err
            if e2 > -dy:
                err -= dy
                x += sx
            if e2 < dx:
                err += dx
                y += sy
```

2. 绘制椭圆

```
def midpoint_ellipse(self, center_x, center_y, a, b, color=(0, 0, 0)):
    x = 0
    y = b

    # Region 1
    d1 = (b * b) - (a * a * b) + (0.25 * a * a)
    dx = 2 * b * b * x
    dy = 2 * a * a * y

    while dx < dy:
        self.put_pixel(center_x + x, center_y + y, color)
        self.put_pixel(center_x - x, center_y + y, color)
        self.put_pixel(center_x + x, center_y - y, color)
        self.put_pixel(center_x - x, center_y - y, color)

        if d1 < 0:
            x += 1
            dx += 2 * b * b
            d1 += dx + b * b
        else:
            x += 1
            y -= 1
            dx += 2 * b * b
            dy -= 2 * a * a
            d1 += dx - dy + b * b

    # Region 2
    d2 = ((b * b) * ((x + 0.5) * (x + 0.5))) + \
         ((a * a) * ((y - 1) * (y - 1))) - \
         (a * a * b * b)

    while y >= 0:
```

```
                self.put_pixel(center_x + x, center_y + y, color)
                self.put_pixel(center_x - x, center_y + y, color)
                self.put_pixel(center_x + x, center_y - y, color)
                self.put_pixel(center_x - x, center_y - y, color)

                if d2 > 0:
                    y -= 1
                    dy -= 2 * a * a
                    d2 += a * a - dy
                else:
                    y -= 1
                    x += 1
                    dx += 2 * b * b
                    dy -= 2 * a * a
                    d2 += dx - dy + a * a
            self.update_canvas()
```

3. 绘制多边形

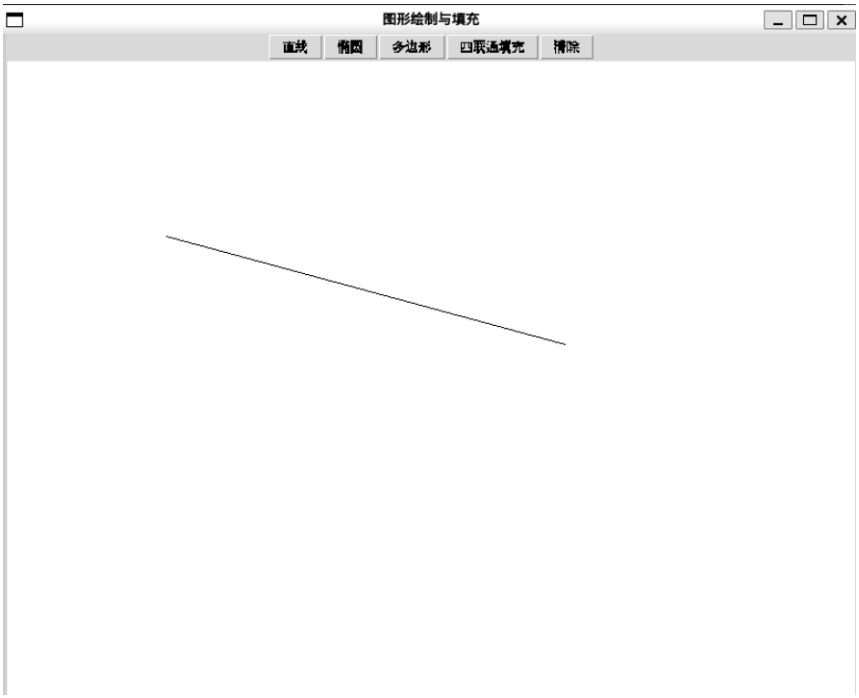
```
    def on_click(self, event):
        if self.mode == "polygon":
            self.polygon_points.append((event.x, event.y))
            if len(self.polygon_points) > 1:
                self.bresenham_line(int(self.polygon_points[-2][0]),
    int(self.polygon_points[-2][1]),
                                    int(self.polygon_points[-1][0]),
    int(self.polygon_points[-1][1]))
```

4. 区域填充

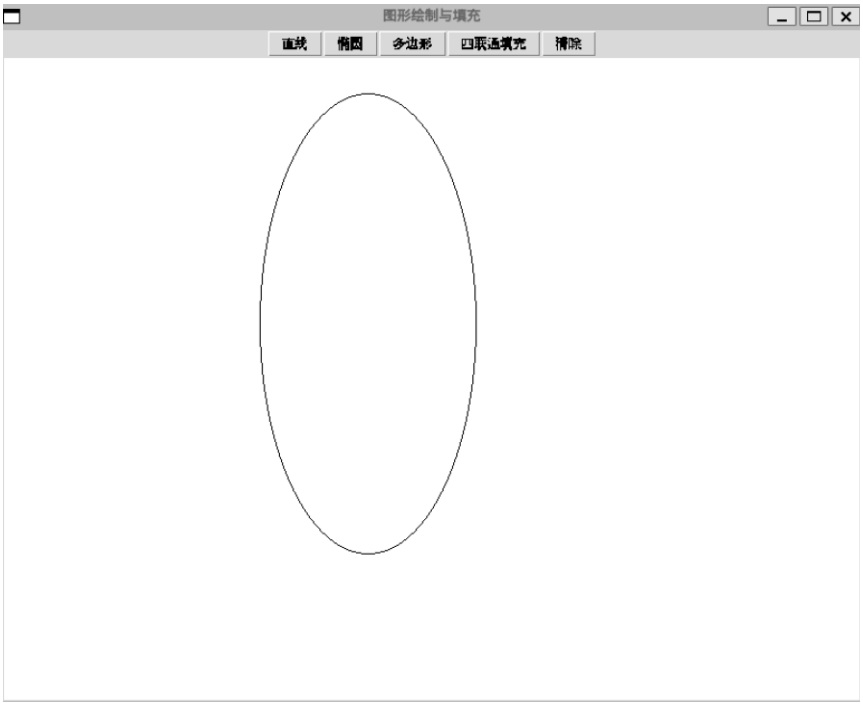
```
def perform_flood_fill(self, event, mode="four"):
        x, y = event.x, event.y
        boundary_color = (0, 0, 0)   # 假设边界颜色为黑色
        fill_color = (255, 0, 0)       # 填充颜色为红色
        if mode == "four":
            self.flood_fill_four_connected(x, y, fill_color=fill_color,
boundary_color=boundary_color)
            messagebox.showinfo("完成", "四联通填充完成")
        # 重新绑定鼠标事件
        self.canvas.bind("<Button-1>", self.on_click)
```

四、实验结果

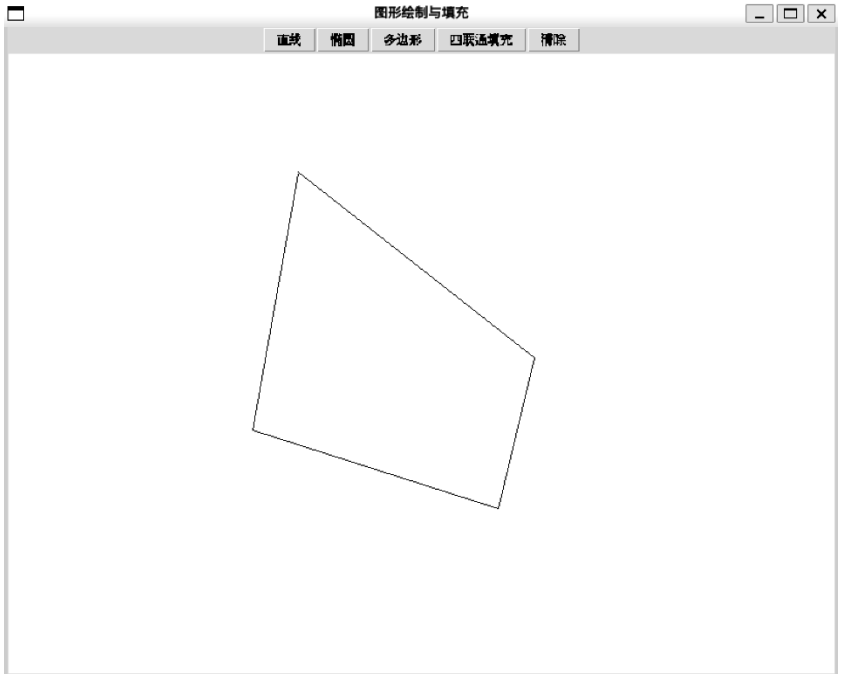
1. 直线



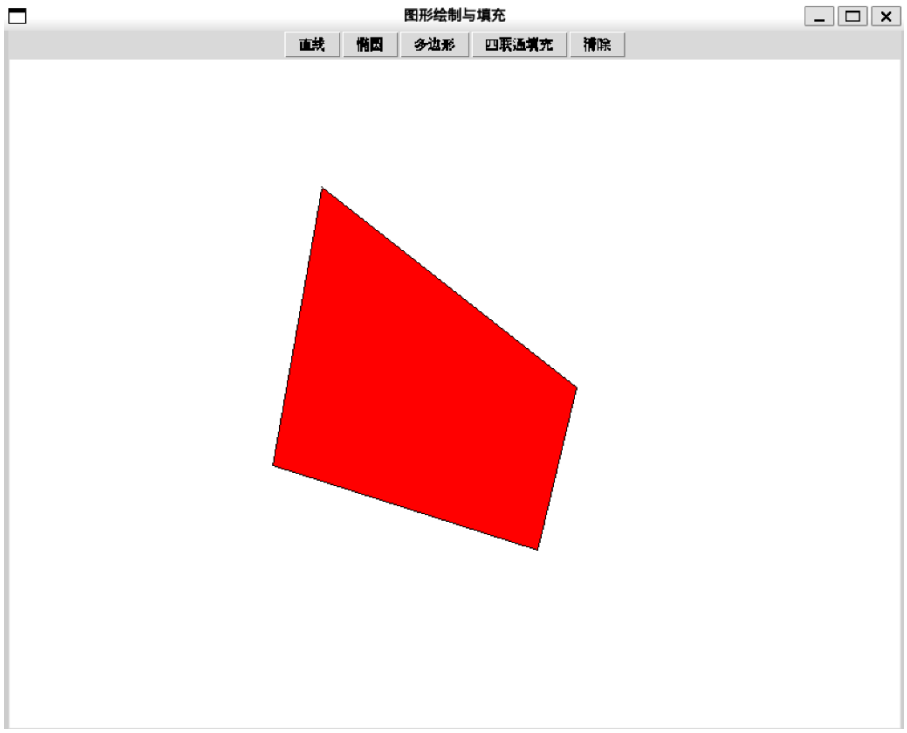
2. 椭圆



3. 多边形



4. 区域填充



实验二

一、实验原理

1. B 样条曲线（BSpline）

B 样条曲线是一种参数化的曲线，由一组控制点和节点向量定义。

节点向量分为内部节点和边界节点。内部节点均匀分布，边界节点与第一个和最后一个控制点重合。

B 样条曲线的形状可以通过调整控制点的位置来改变。

2. 贝塞尔曲线（Bezier Curve）

贝塞尔曲线是一种参数化的曲线，由一组控制点定义。

最常用的贝塞尔曲线是二次贝塞尔曲线和三次贝塞尔曲线。

贝塞尔曲线的形状可以通过调整控制点的位置来改变。

3. de Casteljau 算法

de Casteljau 算法是一种递归方法，用于计算贝塞尔曲线上的点。

该算法通过迭代地对控制点进行线性插值，最终得到贝塞尔曲线上的一点。

二、算法实现思路

1. B 样条曲线（BSpline）

a) 定义节点向量和控制点。
b) 使用递归公式计算 B 样条基函数。
c) 绘制曲线时，根据参数 t（范围在 0 到 1 之间）计算每个点的坐标。

2. 贝塞尔曲线（Bezier Curve）

a) 定义控制点。
b) 使用 Bernstein 多项式定义贝塞尔曲线。
c) 绘制曲线时，根据参数 t（范围在 0 到 1 之间）计算每个点的坐标。

3. de Casteljau 算法

a) 定义控制点。

b) 递归地对控制点进行线性插值。
c) 绘制每一层的插值点和最终的贝塞尔曲线。

三、核心代码

1. B 样条曲线（BSpline）

```
def draw_bspline(self):
    points = np.array(self.control_points)
    n = len(points) - 1
# 生成均匀二次 B 样条的节点
    t = np.linspace(0, 1, 100)
# 绘制曲线
    curve_points = []
    for i in range(n-1):
     if i + 2 <= n:
        # 计算二次 B 样条基函数
        for tj in t:
            x = (1-tj)**2/2 * points[i][0] + \
                (1/2 + tj - tj**2) * points[i+1][0] + \
                tj**2/2 * points[i+2][0]

            y = (1-tj)**2/2 * points[i][1] + \
                (1/2 + tj - tj**2) * points[i+1][1] + \
                tj**2/2 * points[i+2][1]
            curve_points.append((x, y))
# 绘制曲线段
    for i in range(len(curve_points)-1):
     self.canvas.create_line(curve_points[i][0], curve_points[i][1],
                             curve_points[i+1][0], curve_points[i+1][1],
                             fill="blue", width=2)
```

2. 贝塞尔曲线（Bezier Curve）

```
def bezier_curve(self):
    if len(self.control_points) < 2:
        return

    def bernstein(i, n, t):
        return comb(n, i) * (t ** i) * ((1 - t) ** (n - i))

    points = []
    n = len(self.control_points) - 1
```

```
        for t in np.arange(0, 1.01, 0.01):
            x = y = 0
            for i in range(n + 1):
                basis = bernstein(i, n, t)
                x += basis * self.control_points[i][0]
                y += basis * self.control_points[i][1]
            points.append((x, y))

        for i in range(len(points)-1):
            self.canvas.create_line(points[i][0], points[i][1],
                                    points[i+1][0], points[i+1][1],
                                    fill='red', width=2)
```

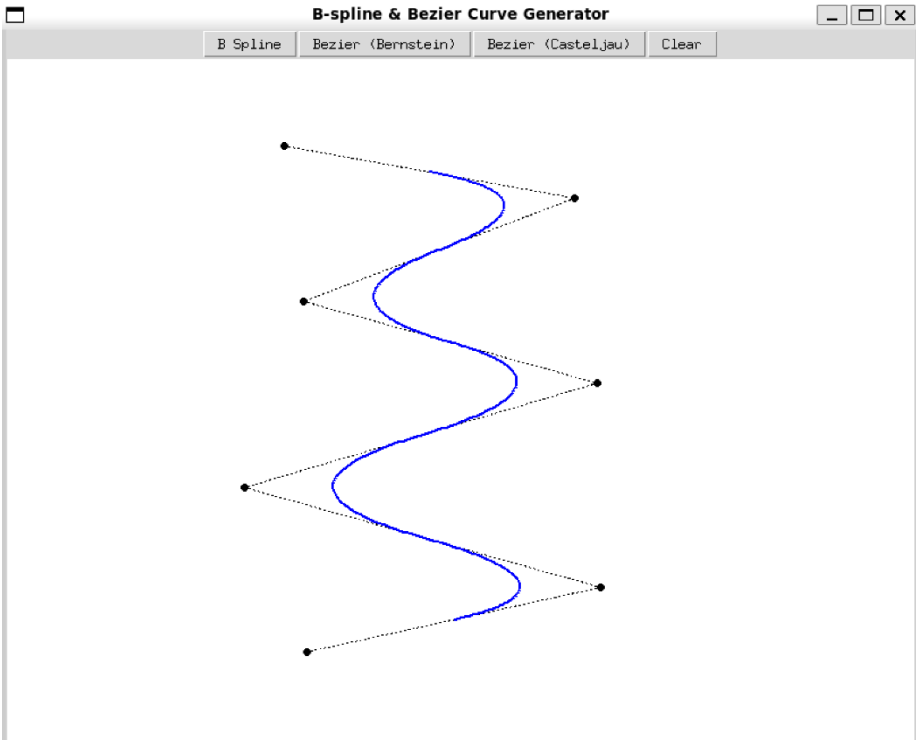
3. de Casteljau 算法

```
    def casteljau_curve(self):
        if len(self.control_points) < 2:
            return

        def de_casteljau(points, t):
            """
            递归实现 de Casteljau 算法，并返回每一层的插值点。
            """
            layers = [points]
            while len(points) > 1:
                new_points = []
                for i in range(len(points)-1):
                    x = (1 - t) * points[i][0] + t * points[i+1][0]
                    y = (1 - t) * points[i][1] + t * points[i+1][1]
                    new_points.append((x, y))
                layers.append(new_points)
                points = new_points
            return layers

        points_on_curve = []
        for t in np.arange(0, 1.01, 0.01):
            layers = de_casteljau(self.control_points, t)
            final_point = layers[-1][0]
            points_on_curve.append(final_point)

            # 可视化每一层的插值点和线条
            for layer in layers[:-1]:  # 不绘制最后一层的单个点
```

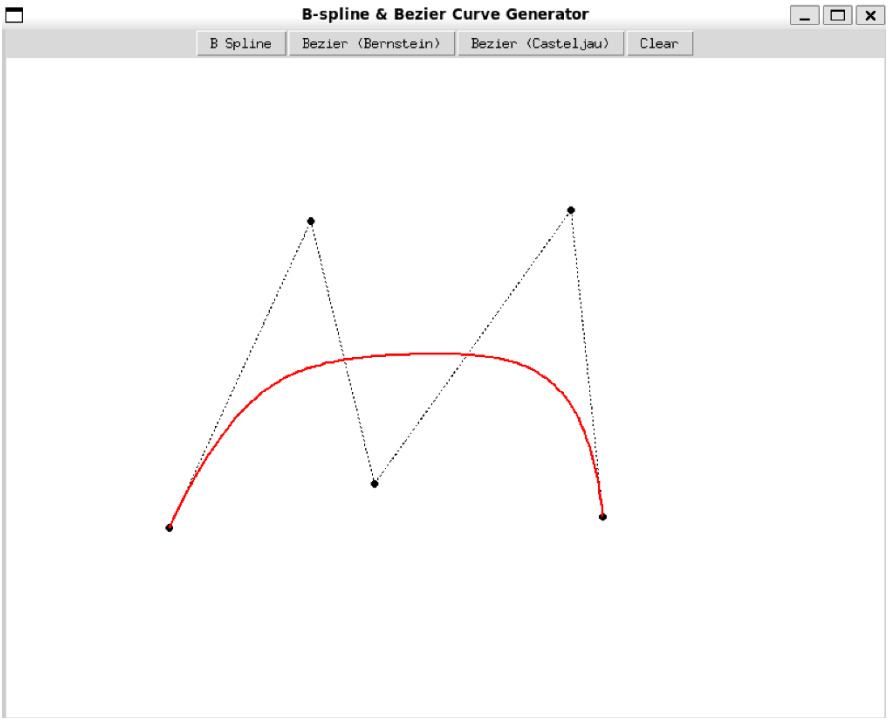
```
                    for i in range(len(layer)-1):
                        x1, y1 = layer[i]
                        x2, y2 = layer[i+1]
                        self.canvas.create_line(x1, y1, x2, y2, fill='lightgray', dash=(1,1))
                    for point in layer:
                        self.canvas.create_oval(point[0]-2, point[1]-2, point[0]+2,
point[1]+2, fill='orange', outline='')

            # 绘制贝塞尔曲线
            for i in range(len(points_on_curve)-1):
                self.canvas.create_line(points_on_curve[i][0], points_on_curve[i][1],
                                        points_on_curve[i+1][0],
points_on_curve[i+1][1],
                                        fill='green', width=2)
```

四、实验结果

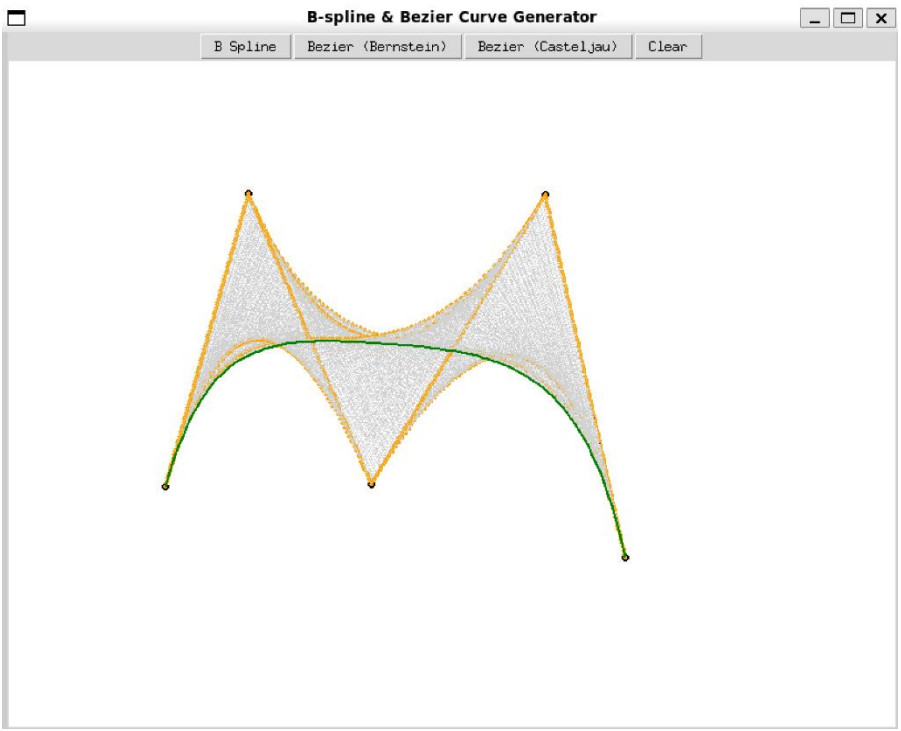
1. B 样条曲线（BSpline）



2. 贝塞尔曲线（Bezier Curve）



3. de Casteljau 算法



实验三

一、实验原理

Fractal Generator 是一个使用 Python 和 Tkinter 库创建的图形用户界面（GUI）应用程序，用于生成和显示两种基本的分形图案：科赫曲线（Koch Curve）和蕨类植物（Fern）。科赫曲线是一种递归生成的曲线，具有自相似的性质。蕨类植物则通过迭代变换矩阵来模拟其生长过程。

二、算法实现思路

1. 科赫曲线（Koch 曲线）

a) 科赫曲线是通过递归的方法生成的。基本思想是从一条线段开始，将其分成三等分，在中间一段上添加一个向外凸起的小三角形。
b) 通过递归地对每一小段重复这个过程，可以生成越来越复杂的科赫曲线。

2. 蕨类植物

a) 蕨类植物通过迭代变换矩阵来模拟其生长过程。基本思想是使用一组概率分布的变换矩阵，每次根据概率选择一个变换矩阵，将当前点进行变换。
b) 通过多次迭代，可以生成一棵看似真实的蕨类植物

三、核心代码

1. 科赫曲线（Koch 曲线）

```
def koch_curve_points(self, start, end, depth):
    if depth == 0:
        return [start, end]

    # Calculate required points
    dx = end[0] - start[0]
    dy = end[1] - start[1]

    p1 = start
    p2 = (start[0] + dx/3, start[1] + dy/3)

    # Calculate the position of the peak point
    angle = math.pi/3    # 60 degrees
    p3x = p2[0] + (dx/3)*math.cos(angle) - (dy/3)*math.sin(angle)
```

```
        p3y = p2[1] + (dx/3)*math.sin(angle) + (dy/3)*math.cos(angle)
        p3 = (p3x, p3y)

        p4 = (start[0] + 2*dx/3, start[1] + 2*dy/3)
        p5 = end

        # Recursive calls
        curve1 = self.koch_curve_points(p1, p2, depth-1)
        curve2 = self.koch_curve_points(p2, p3, depth-1)
        curve3 = self.koch_curve_points(p3, p4, depth-1)
        curve4 = self.koch_curve_points(p4, p5, depth-1)

        # Combine all points (removing duplicates at joints)
        return curve1[:-1] + curve2[:-1] + curve3[:-1] + curve4
```

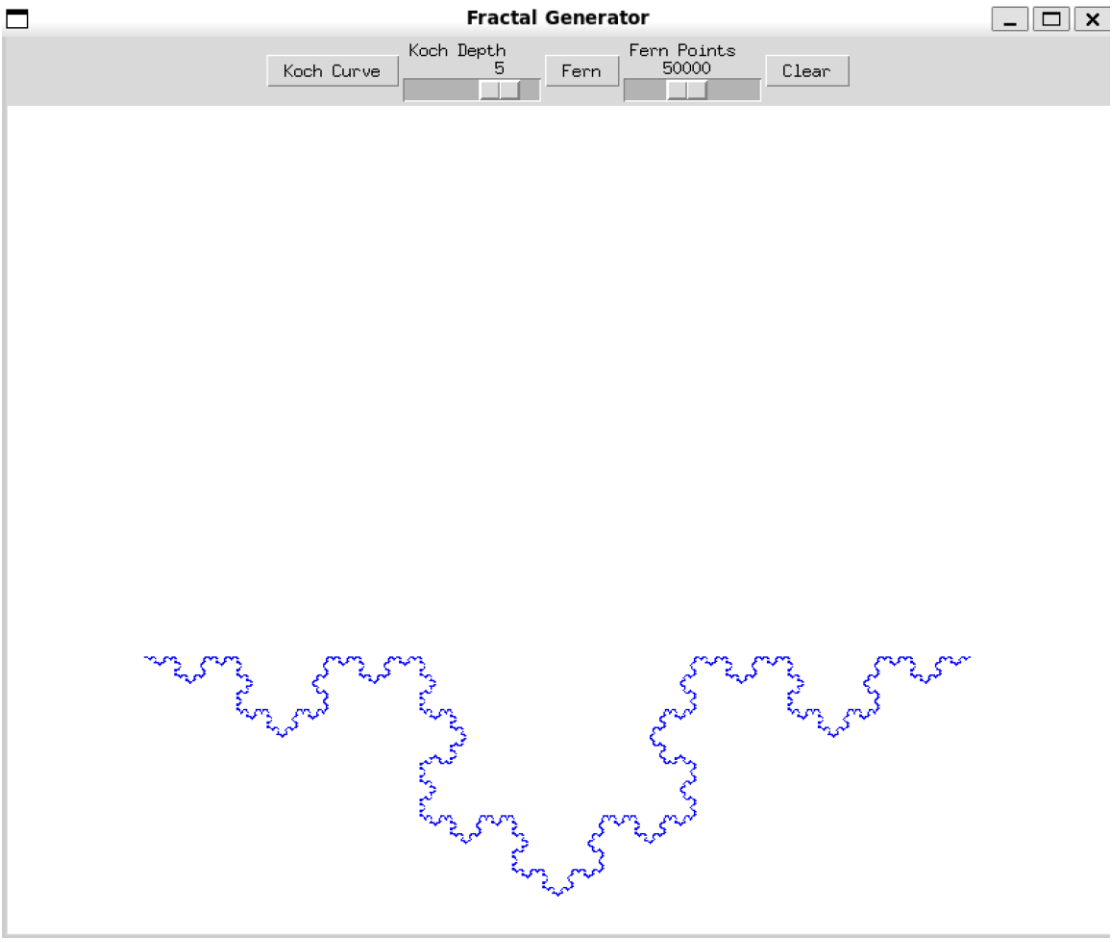
2. 蕨类植物

```
def draw_fern(self):
    self.clear_canvas()
    iterations = self.fern_iterations.get()

    # Transformation matrices and probabilities
    p = np.array([0.85, 0.07, 0.07, 0.01])  # Probabilities

    # Starting point
    x, y = 0, 0

    # Scale and translate coordinates to fit canvas
    def transform_coords(x, y):
        return (400 + x*70, 550 - y*70)

    for _ in range(iterations):
        r = np.random.rand()
        if r < p[0]:
            # Successive stems
            x_new = 0.85*x + 0.04*y
            y_new = -0.04*x + 0.85*y + 1.6
        elif r < p[0] + p[1]:
            # Left leaflet
            x_new = 0.2*x - 0.26*y
            y_new = 0.23*x + 0.22*y + 1.6
        elif r < p[0] + p[1] + p[2]:
            # Right leaflet
```

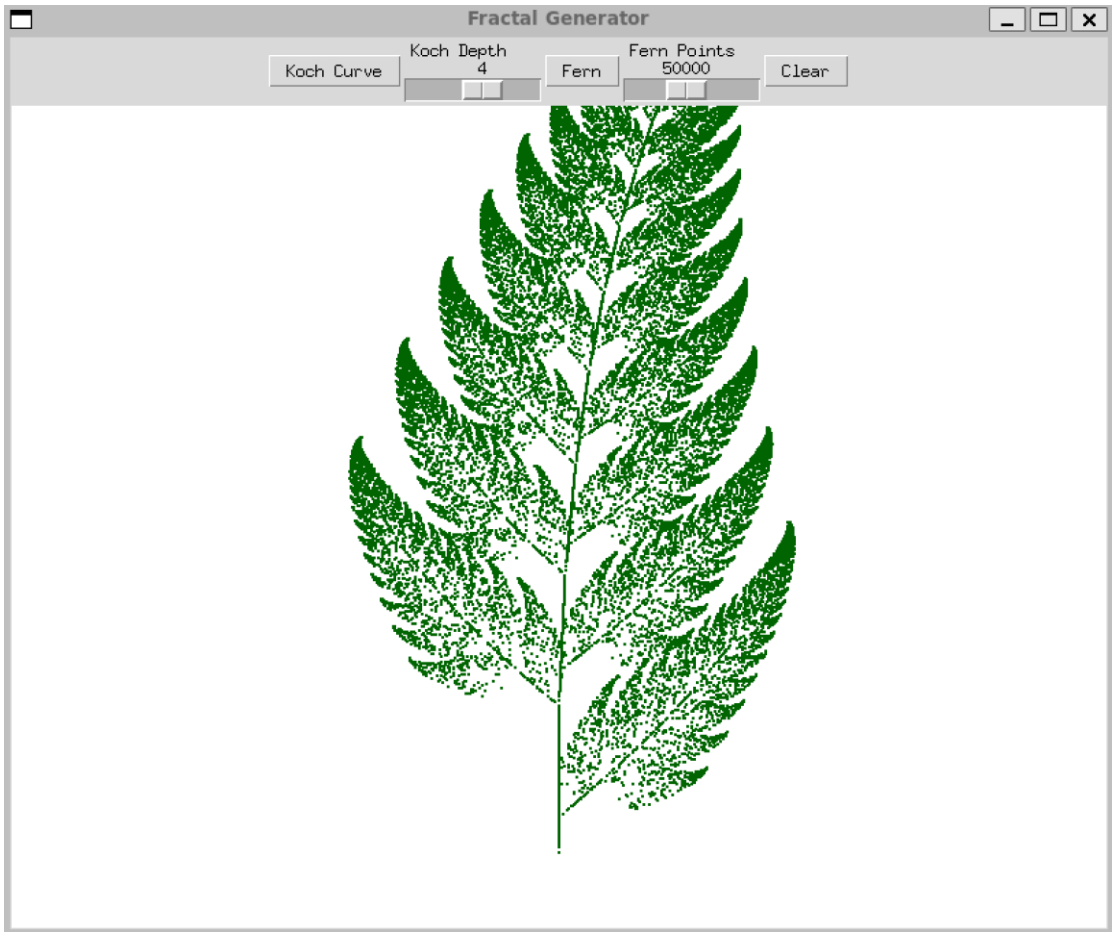
```
            x_new = -0.15*x + 0.28*y
            y_new = 0.26*x + 0.24*y + 0.44
        else:
            # Successive stems
            x_new = 0
            y_new = 0.16*y

        x, y = x_new, y_new

        # Transform and plot point
        plot_x, plot_y = transform_coords(x, y)
        self.canvas.create_rectangle(plot_x, plot_y, plot_x+1, plot_y+1,
                                     fill="dark green", outline="dark green")
```

四、实验结果

1. 科赫曲线（Koch 曲线）



2. 蕨类植物


Fractal Generator
Koch Curve
Koch Depth
4
Fern
Fern Points
50000
Clear

实验四

一、实验原理

这个实验的目的是通过 Python 和 Tkinter 库创建一个简单的 3D 场景渲染器。渲染器使用光线追踪（Ray Tracing）的方法来计算每个像素的颜色，从而模拟光照效果和反射。

光线追踪的基本原理

1. **相机模型** ：假设有一个虚拟的相机，它从一个特定的位置（**camera**）朝向屏幕（Canvas）发射射线。
2. **射线生成** ：对于画布上的每一个像素，根据像素坐标计算出该像素在视图空间中的射线方向。
3. **光线追踪** ：从相机位置沿着射线追踪，检查射线是否与场景中的物体相交。
4. **光照计算** ：如果射线与物体相交，则计算交点处的光照效果，包括漫反射、镜面反射和环境光。
5. **颜色合成** ：根据计算出的颜色值将像素在画布上绘制出来。

二、算法实现思路

1. 初始化场景

a) 设置相机位置、光源位置和强度等参数。
b) 定义场景中的物体，如球体和地板，并为其设置颜色、反射率和镜面反射指数。

2. 射线生成

根据像素坐标计算出射线的方向向量。

3. 光线追踪

a) 从相机位置沿着射线方向追踪，检查射线是否与场景中的物体相交。
b) 计算射线与物体的交点，并确定在该点的颜色（包括直接光照和反射）。

4. 光照计算

a) 对于每个交点，根据光源的位置、法线、视图方向等计算漫反射和镜面反

射分量。

b) 环境光通过全局照明或者预设的环境颜色来处理。

5. 显示渲染结果

将渲染出的颜色值绘制到画布上。

三、核心代码

核心部分是光线追踪算法的实现，包括射线生成、物体检测和光照计算。以下是关键函数：

1. trace_ray 函数

这个函数负责沿着一条射线追踪，并计算交点处的颜色。

```
def trace_ray(self, origin, direction):
    aspect_ratio = self.width / self.height
    fov = math.pi / 3    # 60 degrees

    color = np.array([0.0, 0.0, 0.0])

    for y in range(self.height):
        for x in range(self.width):
            screen_x = (2 * (x + 0.5) / self.width - 1) * math.tan(fov/2) *
aspect_ratio
            screen_y = (1 - 2 * (y + 0.5) / self.height) * math.tan(fov/2)
            direction = self.normalize(np.array([screen_x, screen_y, 1]))

            # Trace ray and store color in buffer
            color += self.trace_ray(self.camera, direction)

    return np.clip(color / (self.width * self.height), 0, 1)
```

2. compute_lighting 函数

这个函数计算射线与物体交点处的光照效果。

```
def compute_lighting(self, hit_point, normal, view_dir, specular, color):
    # Ambient light
    ambient_color = np.array([0.1, 0.1, 0.1])

    # Diffuse lighting
    diffuse_color = np.zeros(3)
```

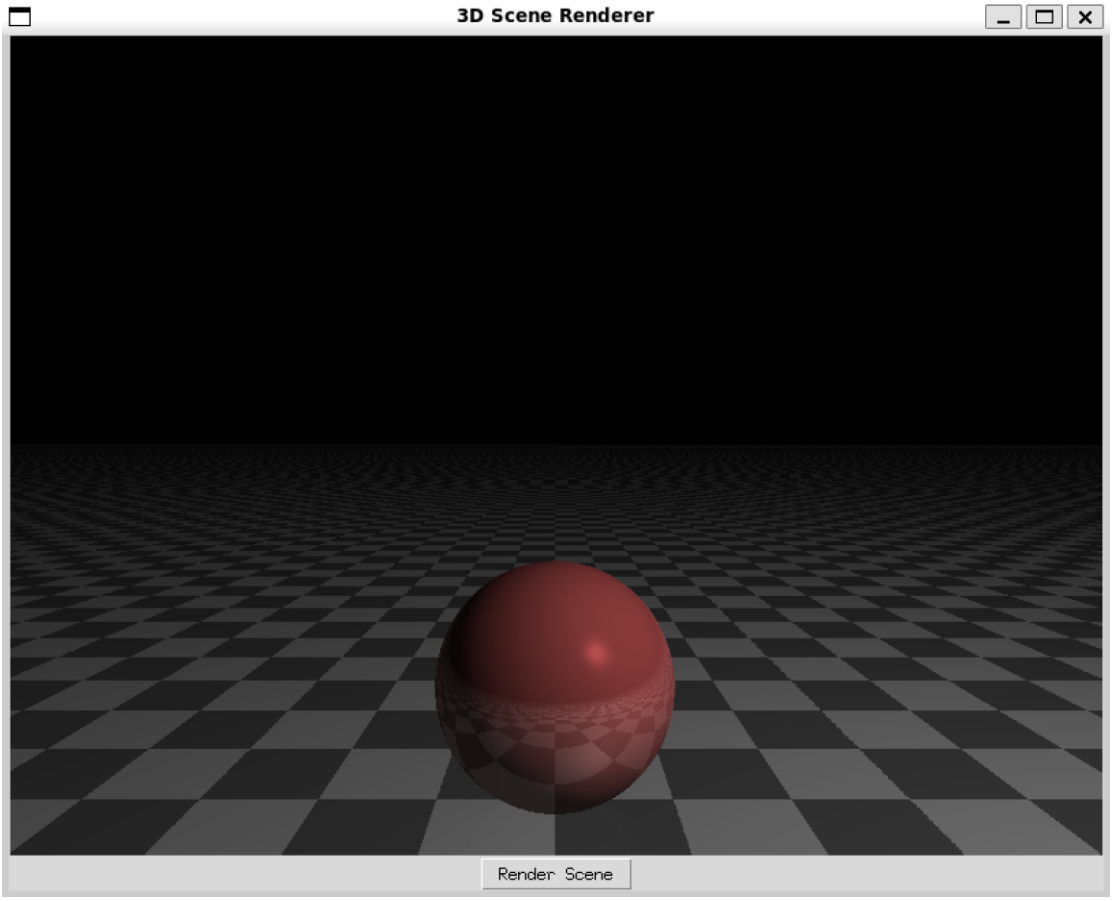
```
        for light in self.lights:
            light_dir = self.normalize(light - hit_point)
            diff = max(np.dot(normal, light_dir), 0)
            diffuse_color += color * diff

        # Specular lighting
        specular_color = np.zeros(3)
        for light in self.lights:
            light_dir = self.normalize(light - hit_point)
            reflect_dir = self.reflect(-light_dir, normal)
            spec = max(np.dot(view_dir, reflect_dir), 0) ** specular
            specular_color += color * spec

        return ambient_color + diffuse_color + specular_color
```

3. display_buffer 函数

将渲染结果显示在画布上。

```
def display_buffer(self):
    for y in range(self.height):
        for x in range(self.width):
            r, g, b = self.buffer[y, x].astype(np.int32)
            color = f'#{r:02x}{g:02x}{b:02x}'
            self.canvas.create_rectangle(x, y, x+1, y+1, fill=color, outline=color)
```

四、实验结果



附录

1. 实验一完整代码

```
import tkinter as tk
from tkinter import messagebox
from PIL import Image, ImageTk
import math
from collections import deque

class DrawingApp:
    def __init__(self, root):
        self.root = root
        self.root.title("图形绘制与填充")

        # 创建画布和 PhotoImage
        self.canvas_width = 800
        self.canvas_height = 600
        self.image = Image.new("RGB", (self.canvas_width, self.canvas_height),
"white")
        self.photo = ImageTk.PhotoImage(self.image)

        self.canvas = tk.Canvas(root, width=self.canvas_width,
height=self.canvas_height, bg='white')
        self.canvas.pack(side=tk.BOTTOM)
        self.canvas_image = self.canvas.create_image((0, 0), anchor=tk.NW,
image=self.photo)

        # 创建控制按钮
        self.control_frame = tk.Frame(root)
        self.control_frame.pack(side=tk.TOP)

        tk.Button(self.control_frame, text="直线", command=lambda:
self.set_mode("line")).pack(side=tk.LEFT)
        tk.Button(self.control_frame, text="椭圆", command=lambda:
self.set_mode("ellipse")).pack(side=tk.LEFT)
        tk.Button(self.control_frame, text="多边形", command=lambda:
self.set_mode("polygon")).pack(side=tk.LEFT)
        tk.Button(self.control_frame, text="四联通填充", command=lambda:
self.set_fill_mode("flood_fill_four")).pack(side=tk.LEFT)
        tk.Button(self.control_frame, text="清除",
command=self.clear_canvas).pack(side=tk.LEFT)
```

```
        # 初始化变量
        self.mode = "line"
        self.fill_mode = None
        self.points = []
        self.polygon_points = []
        self.drawing = False

        # 绑定鼠标事件
        self.canvas.bind("<Button-1>", self.on_click)
        self.canvas.bind("<Button-3>", self.on_right_click)
        self.canvas.bind("<Motion>", self.on_motion)

    def set_mode(self, mode):
        self.mode = mode
        self.fill_mode = None
        self.points = []
        self.polygon_points = []
        self.drawing = False
        print(f"模式切换为: {self.mode}")

    def set_fill_mode(self, fill_mode):
        self.fill_mode = fill_mode
        self.mode = "fill"
        print(f"填充模式切换为: {self.fill_mode}")

    def clear_canvas(self):
        self.image = Image.new("RGB", (self.canvas_width, self.canvas_height),
"white")
        self.photo = ImageTk.PhotoImage(self.image)
        self.canvas.itemconfig(self.canvas_image, image=self.photo)
        self.points = []
        self.polygon_points = []
        self.drawing = False
        self.fill_mode = None
        self.mode = "line"
        print("画布已清除")

    def put_pixel(self, x, y, color=(0, 0, 0)):
        if 0 <= x < self.canvas_width and 0 <= y < self.canvas_height:
            self.image.putpixel((x, y), color)

    def update_canvas(self):
        self.photo = ImageTk.PhotoImage(self.image)
        self.canvas.itemconfig(self.canvas_image, image=self.photo)
```

```
def bresenham_line(self, x1, y1, x2, y2, color=(0, 0, 0)):
    dx = abs(x2 - x1)
    dy = abs(y2 - y1)
    sx = 1 if x1 < x2 else -1
    sy = 1 if y1 < y2 else -1
    err = dx - dy

    x, y = x1, y1
    while True:
        self.put_pixel(x, y, color)
        if x == x2 and y == y2:
            break
        e2 = 2 * err
        if e2 > -dy:
            err -= dy
            x += sx
        if e2 < dx:
            err += dx
            y += sy
    self.update_canvas()

def midpoint_ellipse(self, center_x, center_y, a, b, color=(0, 0, 0)):
    x = 0
    y = b

    # Region 1
    d1 = (b * b) - (a * a * b) + (0.25 * a * a)
    dx = 2 * b * b * x
    dy = 2 * a * a * y

    while dx < dy:
        self.put_pixel(center_x + x, center_y + y, color)
        self.put_pixel(center_x - x, center_y + y, color)
        self.put_pixel(center_x + x, center_y - y, color)
        self.put_pixel(center_x - x, center_y - y, color)

        if d1 < 0:
            x += 1
            dx += 2 * b * b
            d1 += dx + b * b
        else:
            x += 1
            y -= 1
```

```
                dx += 2 * b * b
                dy -= 2 * a * a
                d1 += dx - dy + b * b

        # Region 2
        d2 = ((b * b) * ((x + 0.5) * (x + 0.5))) + \
             ((a * a) * ((y - 1) * (y - 1))) - \
             (a * a * b * b)

        while y >= 0:
            self.put_pixel(center_x + x, center_y + y, color)
            self.put_pixel(center_x - x, center_y + y, color)
            self.put_pixel(center_x + x, center_y - y, color)
            self.put_pixel(center_x - x, center_y - y, color)

            if d2 > 0:
                y -= 1
                dy -= 2 * a * a
                d2 += a * a - dy
            else:
                y -= 1
                x += 1
                dx += 2 * b * b
                dy -= 2 * a * a
                d2 += dx - dy + a * a
        self.update_canvas()

    def scan_line_fill(self, points, fill_color=(255, 0, 0)):
        if len(points) < 3:
            messagebox.showerror("错误", "多边形至少需要三个点")
            return

        # 找到多边形的边界
        min_y = min(p[1] for p in points)
        max_y = max(p[1] for p in points)

        # 对每一条扫描线
        for y in range(int(min_y), int(max_y) + 1):
            intersections = []

            # 计算扫描线与多边形边的交点
            for i in range(len(points)):
                j = (i + 1) % len(points)
                y1, y2 = points[i][1], points[j][1]
```

```
                    if min(y1, y2) <= y <= max(y1, y2):
                        if y1 != y2:
                            x = points[i][0] + (points[j][0] - points[i][0]) * (y - y1) / (y2 -
y1)
                            intersections.append(x)

            # 对交点进行排序
            intersections.sort()

            # 两两配对填充
            for i in range(0, len(intersections), 2):
                if i + 1 < len(intersections):
                    x_start = int(math.ceil(intersections[i]))
                    x_end = int(math.floor(intersections[i+1]))
                    for x in range(x_start, x_end + 1):
                        self.put_pixel(x, y, fill_color)
        self.update_canvas()

    def flood_fill_four_connected(self, x, y, fill_color=(255, 0, 0), boundary_color=(0, 0,
0)):
        # 获取目标颜色
        target_pixel = self.get_pixel_color(x, y)
        if target_pixel == fill_color or target_pixel == boundary_color:
            return

        # 使用队列实现迭代式的四联通漫水填充
        queue = deque()
        queue.append((x, y))
        while queue:
            current_x, current_y = queue.popleft()
            if 0 <= current_x < self.canvas_width and 0 <= current_y <
self.canvas_height:
                current_color = self.get_pixel_color(current_x, current_y)
                if current_color == target_pixel and current_color != boundary_color:
                    self.put_pixel(current_x, current_y, fill_color)
                    queue.append((current_x + 1, current_y))
                    queue.append((current_x - 1, current_y))
                    queue.append((current_x, current_y + 1))
                    queue.append((current_x, current_y - 1))
        self.update_canvas()

    def get_pixel_color(self, x, y):
        # 获取指定像素的颜色
        return self.image.getpixel((x, y))
```

```
    def on_click(self, event):
        if self.mode == "line":
            self.points.append((event.x, event.y))
            if len(self.points) == 2:
                self.bresenham_line(int(self.points[0][0]), int(self.points[0][1]),
                                    int(self.points[1][0]), int(self.points[1][1]))
                self.points = []

        elif self.mode == "ellipse":
            self.points.append((event.x, event.y))
            if len(self.points) == 2:
                center_x = self.points[0][0]
                center_y = self.points[0][1]
                dx = abs(self.points[1][0] - center_x)
                dy = abs(self.points[1][1] - center_y)
                self.midpoint_ellipse(int(center_x), int(center_y), int(dx), int(dy))
                self.points = []

        elif self.mode == "polygon":
            self.polygon_points.append((event.x, event.y))
            if len(self.polygon_points) > 1:
                self.bresenham_line(int(self.polygon_points[-2][0]),
int(self.polygon_points[-2][1]),
                                    int(self.polygon_points[-1][0]),
int(self.polygon_points[-1][1]))

        elif self.mode == "fill":
            if self.fill_mode == "flood_fill_four":
                if len(self.polygon_points) > 2:
                    # 提示用户点击填充点
                    messagebox.showinfo("提示", "请点击多边形内部的一个点进
行四联通填充")
                    # 绑定填充点点击事件
                    self.canvas.bind("<Button-1>", lambda e:
self.perform_flood_fill(e, mode="four"))
                else:
                    messagebox.showerror("错误", "多边形至少需要三个点进行填
充")

    def perform_flood_fill(self, event, mode="four"):
        x, y = event.x, event.y
        boundary_color = (0, 0, 0)  # 假设边界颜色为黑色
        fill_color = (255, 0, 0)      # 填充颜色为红色
```

```
            if mode == "four":
                self.flood_fill_four_connected(x, y, fill_color=fill_color,
boundary_color=boundary_color)
                messagebox.showinfo("完成", "四联通填充完成")
            # 重新绑定鼠标事件
            self.canvas.bind("<Button-1>", self.on_click)

        def on_right_click(self, event):
            if self.mode == "polygon" and len(self.polygon_points) > 2:
                self.bresenham_line(int(self.polygon_points[-1][0]),
int(self.polygon_points[-1][1]),
                                    int(self.polygon_points[0][0]),
int(self.polygon_points[0][1]))
                self.drawing = True

        def on_motion(self, event):
            pass

        def fill_polygon(self):
            if self.mode == "fill" and self.fill_mode == "flood_fill_four":
                if len(self.polygon_points) > 2:
                    # 提示用户点击填充点
                    messagebox.showinfo("提示", "请点击多边形内部的一个点进行四
联通填充")
                    # 绑定填充点点击事件
                    self.canvas.bind("<Button-1>", lambda e: self.perform_flood_fill(e,
mode="four"))
                else:
                    messagebox.showerror("错误", "多边形至少需要三个点进行填充")
            else:
                messagebox.showerror("错误", "请选择一个填充模式并绘制多边形")

def main():
    root = tk.Tk()
    app = DrawingApp(root)
    root.mainloop()

if __name__ == "__main__":
    main()
```

2. 实验二完整代码

```
import tkinter as tk
```

```
import numpy as np
from scipy.special import comb  # 确保正确导入 comb

class CurveDrawer:
    def __init__(self, root):
        self.root = root
        self.root.title("B-spline & Bezier Curve Generator")

        # 创建画布
        self.canvas = tk.Canvas(root, width=800, height=600, bg='white')
        self.canvas.pack(side=tk.BOTTOM)

        # 控制按钮
        self.control_frame = tk.Frame(root)
        self.control_frame.pack(side=tk.TOP)

        tk.Button(self.control_frame, text="B Spline", command=lambda:
self.set_mode("bspline")).pack(side=tk.LEFT)
        tk.Button(self.control_frame, text="Bezier (Bernstein)", command=lambda:
self.set_mode("bezier")).pack(side=tk.LEFT)
        tk.Button(self.control_frame, text="Bezier (Casteljau)", command=lambda:
self.set_mode("casteljau")).pack(side=tk.LEFT)  # 新按钮
        tk.Button(self.control_frame,
text="Clear",command=self.clear_canvas).pack(side=tk.LEFT)

        # 初始化变量
        self.mode = "bspline"
        self.control_points = []

        # 绑定鼠标事件
        self.canvas.bind("<Button-1>", self.on_click)
        self.canvas.bind("<Double-Button-1>", self.on_double_click)

    def set_mode(self, mode):
        self.mode = mode
        self.clear_canvas()

    def clear_canvas(self):
        self.canvas.delete("all")
        self.control_points = []

    def draw_point(self, x, y, color="black"):
        self.canvas.create_oval(x-3, y-3, x+3, y+3, fill=color)
```

```
def draw_control_polygon(self):
    if len(self.control_points) > 1:
        for i in range(len(self.control_points)-1):
            x1, y1 = self.control_points[i]
            x2, y2 = self.control_points[i+1]
            self.canvas.create_line(x1, y1, x2, y2, dash=(2,2))

def draw_bspline(self):
    points = np.array(self.control_points)
    n = len(points) - 1

# 生成均匀二次 B 样条的节点
    t = np.linspace(0, 1, 100)

# 绘制曲线
    curve_points = []
    for i in range(n-1):
     if i + 2 <= n:
        # 计算二次 B 样条基函数
        for tj in t:
            x = (1-tj)**2/2 * points[i][0] + \
                (1/2 + tj - tj**2) * points[i+1][0] + \
                tj**2/2 * points[i+2][0]

            y = (1-tj)**2/2 * points[i][1] + \
                (1/2 + tj - tj**2) * points[i+1][1] + \
                tj**2/2 * points[i+2][1]

            curve_points.append((x, y))

# 绘制曲线段
    for i in range(len(curve_points)-1):
     self.canvas.create_line(curve_points[i][0], curve_points[i][1],
                             curve_points[i+1][0], curve_points[i+1][1],
                             fill="blue", width=2)

def bezier_curve(self):
    if len(self.control_points) < 2:
        return

    def bernstein(i, n, t):
        return comb(n, i) * (t ** i) * ((1 - t) ** (n - i))

    points = []
```

```
        n = len(self.control_points) - 1

        for t in np.arange(0, 1.01, 0.01):
            x = y = 0
            for i in range(n + 1):
                basis = bernstein(i, n, t)
                x += basis * self.control_points[i][0]
                y += basis * self.control_points[i][1]
            points.append((x, y))

        for i in range(len(points)-1):
            self.canvas.create_line(points[i][0], points[i][1],
                                    points[i+1][0], points[i+1][1],
                                    fill='red', width=2)

    def casteljau_curve(self):
        if len(self.control_points) < 2:
            return

        def de_casteljau(points, t):
            """
            递归实现 de Casteljau 算法，并返回每一层的插值点。
            """
            layers = [points]
            while len(points) > 1:
                new_points = []
                for i in range(len(points)-1):
                    x = (1 - t) * points[i][0] + t * points[i+1][0]
                    y = (1 - t) * points[i][1] + t * points[i+1][1]
                    new_points.append((x, y))
                layers.append(new_points)
                points = new_points
            return layers

        points_on_curve = []
        for t in np.arange(0, 1.01, 0.01):
            layers = de_casteljau(self.control_points, t)
            final_point = layers[-1][0]
            points_on_curve.append(final_point)

            # 可视化每一层的插值点和线条
            for layer in layers[:-1]:  # 不绘制最后一层的单个点
                for i in range(len(layer)-1):
                    x1, y1 = layer[i]
```

```
                            x2, y2 = layer[i+1]
                            self.canvas.create_line(x1, y1, x2, y2, fill='lightgray', dash=(1,1))
                    for point in layer:
                            self.canvas.create_oval(point[0]-2, point[1]-2, point[0]+2,
point[1]+2, fill='orange', outline='')

        # 绘制贝塞尔曲线
        for i in range(len(points_on_curve)-1):
            self.canvas.create_line(points_on_curve[i][0], points_on_curve[i][1],
                                    points_on_curve[i+1][0],
points_on_curve[i+1][1],
                                    fill='green', width=2)

    def on_click(self, event):
        self.control_points.append((event.x, event.y))
        self.draw_point(event.x, event.y)
        self.draw_control_polygon()

    def on_double_click(self, event):
        if self.mode == "bspline":
            self.draw_bspline()
        elif self.mode == "bezier":
            self.bezier_curve()
        elif self.mode == "casteljau":
            self.casteljau_curve()

def main():
    root = tk.Tk()
    app = CurveDrawer(root)
    root.mainloop()

if __name__ == "__main__":
    main()
```

3. 实验三完整代码

```
import tkinter as tk
import numpy as np
import math

class FractalGenerator:
    def __init__(self, root):
        self.root = root
```

```
        self.root.title("Fractal Generator")

        # Create canvas
        self.canvas = tk.Canvas(root, width=800, height=600, bg='white')
        self.canvas.pack(side=tk.BOTTOM)

        # Control panel
        self.control_frame = tk.Frame(root)
        self.control_frame.pack(side=tk.TOP)

        # Koch curve controls
        tk.Button(self.control_frame, text="Koch Curve",
command=self.draw_koch).pack(side=tk.LEFT)
        self.koch_depth = tk.Scale(self.control_frame, from_=1, to=6,
orient=tk.HORIZONTAL, label="Koch Depth")
        self.koch_depth.pack(side=tk.LEFT)
        self.koch_depth.set(4)

        # Fern controls
        tk.Button(self.control_frame, text="Fern",
command=self.draw_fern).pack(side=tk.LEFT)
        self.fern_iterations = tk.Scale(self.control_frame, from_=10000, to=100000,
                                        orient=tk.HORIZONTAL, label="Fern
Points")
        self.fern_iterations.pack(side=tk.LEFT)
        self.fern_iterations.set(50000)

        # Clear button
        tk.Button(self.control_frame, text="Clear",
command=self.clear_canvas).pack(side=tk.LEFT)

    def clear_canvas(self):
        self.canvas.delete("all")

    def draw_line(self, x1, y1, x2, y2, color="black"):
        self.canvas.create_line(x1, y1, x2, y2, fill=color)

    def koch_curve_points(self, start, end, depth):
        if depth == 0:
            return [start, end]

        # Calculate required points
        dx = end[0] - start[0]
        dy = end[1] - start[1]
```

```
        p1 = start
        p2 = (start[0] + dx/3, start[1] + dy/3)

        # Calculate the position of the peak point
        angle = math.pi/3    # 60 degrees
        p3x = p2[0] + (dx/3)*math.cos(angle) - (dy/3)*math.sin(angle)
        p3y = p2[1] + (dx/3)*math.sin(angle) + (dy/3)*math.cos(angle)
        p3 = (p3x, p3y)

        p4 = (start[0] + 2*dx/3, start[1] + 2*dy/3)
        p5 = end

        # Recursive calls
        curve1 = self.koch_curve_points(p1, p2, depth-1)
        curve2 = self.koch_curve_points(p2, p3, depth-1)
        curve3 = self.koch_curve_points(p3, p4, depth-1)
        curve4 = self.koch_curve_points(p4, p5, depth-1)

        # Combine all points (removing duplicates at joints)
        return curve1[:-1] + curve2[:-1] + curve3[:-1] + curve4

    def draw_koch(self):
        self.clear_canvas()
        depth = self.koch_depth.get()

        # Set up initial line (centered horizontally, in lower third of canvas)
        start_x = 100
        end_x = 700
        y = 400

        points = self.koch_curve_points((start_x, y), (end_x, y), depth)

        # Draw the curve
        for i in range(len(points)-1):
            x1, y1 = points[i]
            x2, y2 = points[i+1]
            self.draw_line(x1, y1, x2, y2, "blue")

    def draw_fern(self):
        self.clear_canvas()
        iterations = self.fern_iterations.get()

        # Transformation matrices and probabilities
```

```
            p = np.array([0.85, 0.07, 0.07, 0.01])    # Probabilities

            # Starting point
            x, y = 0, 0

            # Scale and translate coordinates to fit canvas
            def transform_coords(x, y):
                return (400 + x*70, 550 - y*70)

            # Draw points
            for _ in range(iterations):
                r = np.random.random()
                if r < p[0]:
                    # Stem
                    x_new = 0.85*x + 0.04*y
                    y_new = -0.04*x + 0.85*y + 1.6
                elif r < p[0] + p[1]:
                    # Left leaflet
                    x_new = 0.2*x - 0.26*y
                    y_new = 0.23*x + 0.22*y + 1.6
                elif r < p[0] + p[1] + p[2]:
                    # Right leaflet
                    x_new = -0.15*x + 0.28*y
                    y_new = 0.26*x + 0.24*y + 0.44
                else:
                    # Successive stems
                    x_new = 0
                    y_new = 0.16*y

                x, y = x_new, y_new

                # Transform and plot point
                plot_x, plot_y = transform_coords(x, y)
                self.canvas.create_rectangle(plot_x, plot_y, plot_x+1, plot_y+1,
                                             fill="dark green", outline="dark green")

def main():
    root = tk.Tk()
    app = FractalGenerator(root)
    root.mainloop()

if __name__ == "__main__":
    main()
```

4. 实验四完整代码

```
import tkinter as tk
import numpy as np
import math

class Scene3DRenderer:
    def __init__(self, root):
        self.root = root
        self.root.title("3D Scene Renderer")

        # Canvas setup
        self.width = 800
        self.height = 600
        self.canvas = tk.Canvas(root, width=self.width, height=self.height, bg='black')
        self.canvas.pack()

        # Create image buffer
        self.buffer = np.zeros((self.height, self.width, 3), dtype=np.float64)
        self.z_buffer = np.full((self.height, self.width), float('inf'))

        # Scene parameters
        self.camera = np.array([0, 2, -6])
        self.light_pos = np.array([5, 5, -5])
        self.light_color = np.array([1, 1, 1])
        self.ambient = 0.1

        # Initialize scene objects
        self.init_scene()

        # Render button
        tk.Button(root, text="Render Scene", command=self.render_scene).pack()

    def init_scene(self):
        # Define scene objects
        self.sphere = {
            'center': np.array([0, 0, 0]),
            'radius': 1.0,
            'color': np.array([0.7, 0.3, 0.3]),
            'specular': 50,
            'reflectivity': 0.3
        }

        self.floor = {
```

```
            'y': -1,
            'color': np.array([0.5, 0.5, 0.5]),
            'specular': 10,
            'reflectivity': 0.1
        }

        # Checkerboard texture for floor
        self.checker_size = 1.0

    def normalize(self, vector):
        return vector / np.linalg.norm(vector)

    def reflect(self, vector, normal):
        return vector - 2 * np.dot(vector, normal) * normal

    def sphere_intersect(self, origin, direction):
        b = 2 * np.dot(direction, origin - self.sphere['center'])
        c = np.linalg.norm(origin - self.sphere['center'])**2 - self.sphere['radius']**2
        delta = b**2 - 4*c

        if delta < 0:
            return None

        t1 = (-b - np.sqrt(delta)) / 2
        t2 = (-b + np.sqrt(delta)) / 2

        if t1 < 0 and t2 < 0:
            return None

        return min(t for t in [t1, t2] if t > 0)

    def floor_intersect(self, origin, direction):
        if abs(direction[1]) < 1e-6:
            return None

        t = -(origin[1] - self.floor['y']) / direction[1]
        return t if t > 0 else None

    def get_floor_color(self, point):
        # Checkerboard pattern
        x = math.floor(point[0] / self.checker_size)
        z = math.floor(point[2] / self.checker_size)
        if (x + z) % 2 == 0:
            return self.floor['color']
```

```
        return self.floor['color'] * 0.5

    def compute_lighting(self, point, normal, view_dir, specular, color):
        # Ambient light
        intensity = self.ambient

        # Direction to light
        light_dir = self.normalize(self.light_pos - point)

        # Diffuse lighting
        diffuse = max(np.dot(normal, light_dir), 0)
        intensity += diffuse

        # Specular lighting
        if specular > 0:
            reflect_dir = self.reflect(-light_dir, normal)
            spec = max(np.dot(reflect_dir, view_dir), 0) ** specular
            intensity += 0.5 * spec

        return np.clip(color * intensity, 0, 1)

    def trace_ray(self, origin, direction, depth=3):
        if depth <= 0:
            return np.zeros(3)

        # Check sphere intersection
        t_sphere = self.sphere_intersect(origin, direction)

        # Check floor intersection
        t_floor = self.floor_intersect(origin, direction)

        # Find closest intersection
        if t_sphere is None and t_floor is None:
            return np.zeros(3)

        if t_sphere is None:
            t = t_floor
            hit_point = origin + direction * t
            normal = np.array([0, 1, 0])
            color = self.get_floor_color(hit_point)
            specular = self.floor['specular']
            reflectivity = self.floor['reflectivity']
        elif t_floor is None:
            t = t_sphere
```

```
                hit_point = origin + direction * t
                normal = self.normalize(hit_point - self.sphere['center'])
                color = self.sphere['color']
                specular = self.sphere['specular']
                reflectivity = self.sphere['reflectivity']
            else:
                t = min(t_sphere, t_floor)
                if t == t_sphere:
                    hit_point = origin + direction * t
                    normal = self.normalize(hit_point - self.sphere['center'])
                    color = self.sphere['color']
                    specular = self.sphere['specular']
                    reflectivity = self.sphere['reflectivity']
                else:
                    hit_point = origin + direction * t
                    normal = np.array([0, 1, 0])
                    color = self.get_floor_color(hit_point)
                    specular = self.floor['specular']
                    reflectivity = self.floor['reflectivity']

            # Compute lighting
            view_dir = self.normalize(-direction)
            color = self.compute_lighting(hit_point, normal, view_dir, specular, color)

            # Compute reflection
            if reflectivity > 0:
                reflect_dir = self.reflect(direction, normal)
                reflect_origin = hit_point + normal * 1e-4  # Offset to avoid self-
intersection
                reflect_color = self.trace_ray(reflect_origin, reflect_dir, depth-1)
                color = color * (1 - reflectivity) + reflect_color * reflectivity

            return color

        def render_scene(self):
            aspect_ratio = self.width / self.height
            fov = math.pi / 3  # 60 degrees

            for y in range(self.height):
                for x in range(self.width):
                    # Calculate ray direction
                    screen_x = (2 * (x + 0.5) / self.width - 1) * math.tan(fov/2) *
aspect_ratio
                    screen_y = (1 - 2 * (y + 0.5) / self.height) * math.tan(fov/2)
```

```
                    direction = self.normalize(np.array([screen_x, screen_y, 1]))

                    # Trace ray and store color in buffer
                    color = self.trace_ray(self.camera, direction)
                    self.buffer[y, x] = np.clip(color * 255, 0, 255)

        # Display the rendered image
        self.display_buffer()

    def display_buffer(self):
        # Convert buffer to hex colors and display on canvas
        for y in range(self.height):
            for x in range(self.width):
                r, g, b = self.buffer[y, x].astype(np.int32)
                color = f'#{r:02x}{g:02x}{b:02x}'
                self.canvas.create_rectangle(x, y, x+1, y+1, fill=color, outline=color)

def main():
    root = tk.Tk()
    app = Scene3DRenderer(root)
    root.mainloop()

if __name__ == "__main__":
    main()
```