3GC3 Final Project

Emily Horsman

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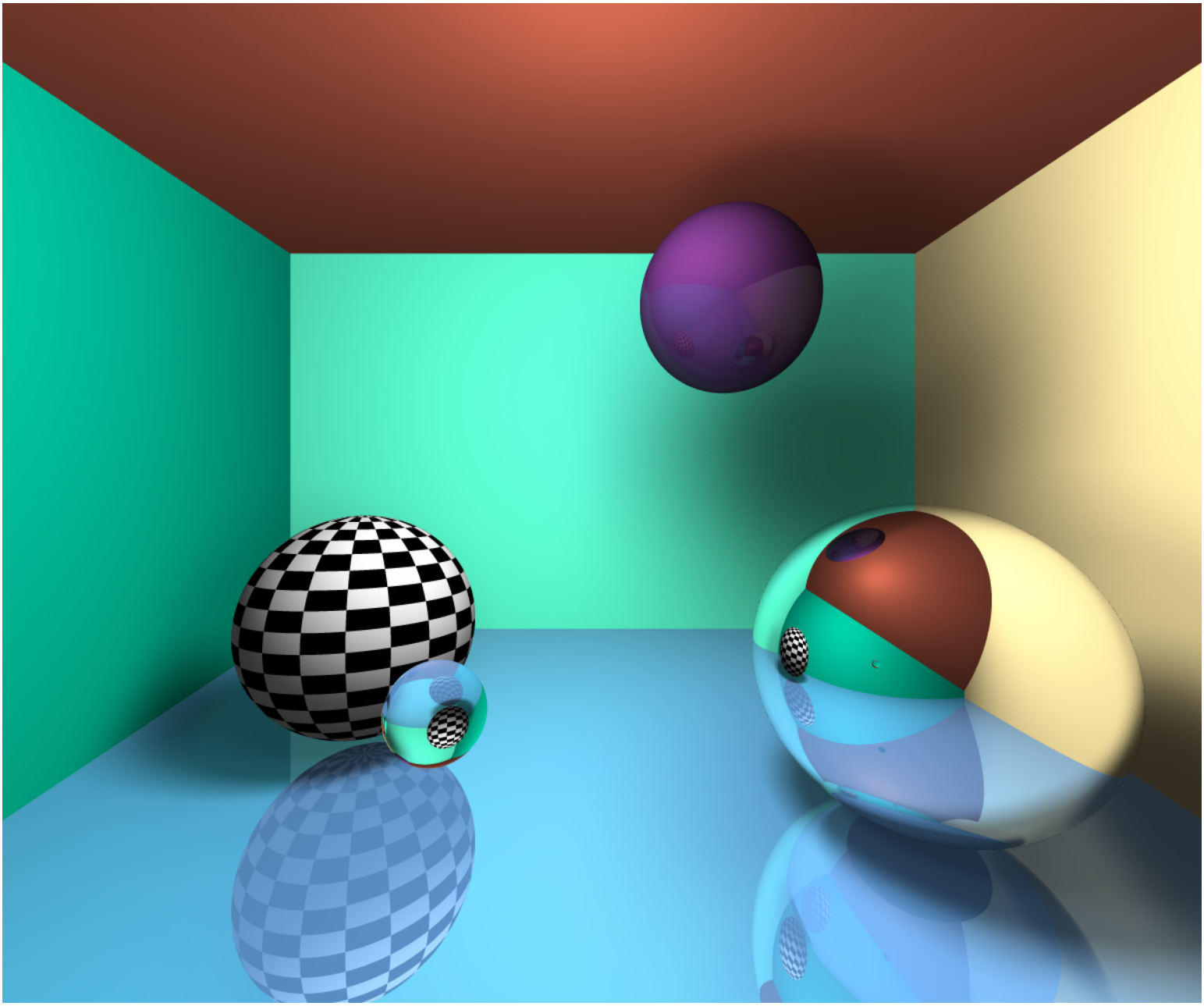


Figure 1: Reflective floor, 100% transparent sphere showing refraction, checkered sphere with texture mapping, mirror sphere. 64x random sampled anti-aliasing with 300 iterations for soft shadows. 13h50m of CPU time.

Contents

1 Feature Overview

- CPU-based ray tracer
- Output to PPM bitmaps and a GLUT window
- Scene files for configuring rendering and scene parameters, materials, lights, and objects
- Support for planes, spheres, and disks
- Color and checkered material with proper texture mapping for spheres
- Materials specify coefficients for: ambient, diffuse, and specular light; transmission; index of refraction
- Multi-threaded rendering with a configurable number of threads
- Rudimentary refraction (no Fresnel effect)
- Soft shadows achieved by "jittering" point lights and averaging multiple renders
- Anti-aliasing with both regular (uniform) and random sampling techniques
- Adjustable depth-of field and camera field of view

2 Execution

Running the ray tracer requires a scene file. The root of this repository includes `sample.scene` which will be used by default if no scene file is provided. Running `make` from the root of the repo will compile and run the ray tracer with the sample scene. Note that the sample scene file specifies `threads: 12` by default. This should be adjusted according to your system.

The image will be rendered to a PPM bitmap and a GLUT window. I highly recommend viewing the PPM bitmap, but the GLUT window is convenient for a quick glance.

2.1 Compile

```
$ make
<...compiling and linking...>
./Ray
=== Render Info ./sample.scene ===
Target              OpenGL, ./sample.ppm
Image Dimension     900 x 700
Threads             12
Max Depth           3
Anti-Aliasing       4
Sampling Method     Regular
Soft Shadows?       No
Iterations          1

Field of View       90
Eye                 0, 0, 0.25
Focal Point         0.5, 0.8, -2
Aperture Radius     Pinhole

Objects             9
Lights              1
```

2.2 Unit tests

There is a small suite of unit tests included. These primarily cover ray-object intersections.

```
$ make test
```

2.3 Generating documentation

This repository uses `Doxygen` to generate code documentation. It includes a minimally configured `Doxyfile`.

```
$ make docs
```

2.4 Run a scene file

The `Ray` executable accepts a single command-line argument for a scene file path.

```
$ ./Ray ./examples/DepthOfField.scene
```

2.5 Writing a scene file

Scene files are just plain text files containing sections separated by an extra newline. The best way to write new ones is to reference `sample.scene` and `examples/*.scene`.

Each section starts with a tag such as `Renderer` or `Material`. A tag is followed by properties in the format of `key: value`. Global parameters such as rendering (e.g., number of threads) and camera options (e.g., field of view) are placed under a `Renderer` and `Camera` section. Objects reference materials by an ID you give when writing the material. You must specify the material section before the objects which use it.

A minimal sample scene file is produced below.

```
Renderer
antiAliasing: 4
samplingMethod: random
useSoftShadows: true
iterations: 30
threads: 12
outputFile: ./minimal.ppm

PointLight
position: 0, 1, -1
radius: 0
intensity: 1
```

```
CheckerboardMaterial largeCheckers
color: 1, 1, 1
odd: 0, 0, 0
grain: 0.5
ambient: 0
diffuse: 0.9
specular: 0.1

Plane
material: largeCheckers
point: 0, -1, 0
normal: 0, 1, 0
```

Materials are tagged by their type, followed by their unique ID: `Material`, `CheckerboardMaterial`. Objects are tagged by their type: `Plane`, `Sphere`, `Disk`. A light is tagged with `PointLight`.

2.6 Guidance

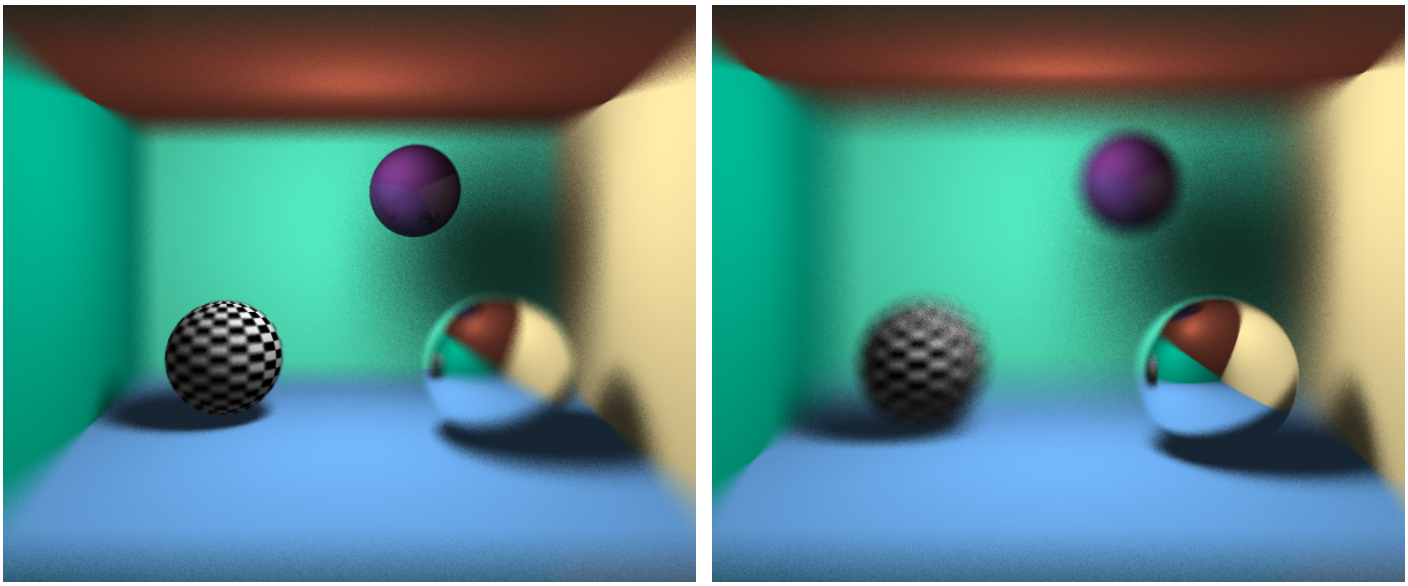
- Turning on soft shadows or using a non-zero aperture radius will require setting `iterations` higher to reduce noise. The precise value depends on the desired quality, effect (sometimes the noise is pleasant, like an artistically chosen film speed in photography), and computational resources.
- I've found `samplingMethod: random` to produce better quality images over `samplingMethod: regular`.
- Objects and lights are placed with $z < 0$. The camera `eye` is $z > 0$.
- Keep soft shadows off and iterations low while testing, and then increase these properties to the desired values.
- `antiAliasing: 4` will improve image quality considerably without much extra render time.

2.7 Scene file properties

Enumerations are delimited by pipes `|`.

Tag	Property	Type	Example	Description
Renderer	width	int	1200	
	height	int	900	
	maxDepth	int	10	Maximum recursion depth for specular and transmission rays.
	antiAliasing	int	16	Number of anti-aliasing samples per pixel, must be a square number.
	samplingMethod	string	`regular|random`	The type of anti-aliasing sampling.
	iterations	int	100	Render the image for n iterations and average the result.
	threads	int	4	Multi-threading.
	useSoftShadows	bool	`true|false`	Soft shadows will "jitter" point lights around their radius.
	outputFile	string	`./Scene.ppm`	Rendered image path.
Camera	fieldOfViewDegrees	int	45	
	lookAt	Vec3f	0.5, 0.5, -2	Focal point.
	eye	Vec3f	0, 0, 0.25	Camera position.
	apertureRadius	float	0.2	Use 0 for pinhole/infinite DOF. Higher values have larger DOFs.
PointLight	position	Vec3f	0, 1, -1.5	
	intensity	float	0.7	[0,1]
	radius	float	0.1	Must enable soft shadows in `Renderer`.
Material id	color	Vec3f	1, 0.1, 0.2	
	ambient	float	0.1	[0,1]
	diffuse	float	0.7	[0,1]
	specular	float	0.2	[0,1]
	transmission	float	1	[0,1] From opaque to 100% transparent.
	refractiveIndex	float	1.5	$\eta \geq 1$
CheckerboardMaterial id				Shares all `Material` properties.
	odd	Vec3f	1, 0, 0	Color of odd squares. `color` is for even squares.
	grain	float	0.5	Size of checkers.
Sphere	origin	Vec3f	0, 0.5, -1.5	
	radius	float	0.5	
	material	string	blue	Must be a previously tagged material.
Plane	point	Vec3f	0, -1, 0	Any point in the plane.
	normal	Vec3f	0, 1, 0	
	material	string	blue	Must be a previously tagged material.
Disk	origin	Vec3f	0, -1, 0	Any point in the plane.
	normal	Vec3f	0, 1, 0	
	radius	float	0.05	
	material	string	blue	Must be a previously tagged material.

3 Depth of Field



(a) `DepthOfField.scene` (b) `DepthOfField2.scene`

Figure 2: A scene displayed with two different focal points. These renderings have minimal noise reduction applied. It can be increased with the `iterations` property in the `Renderer` section of your scene file.

4 Soft Shadows

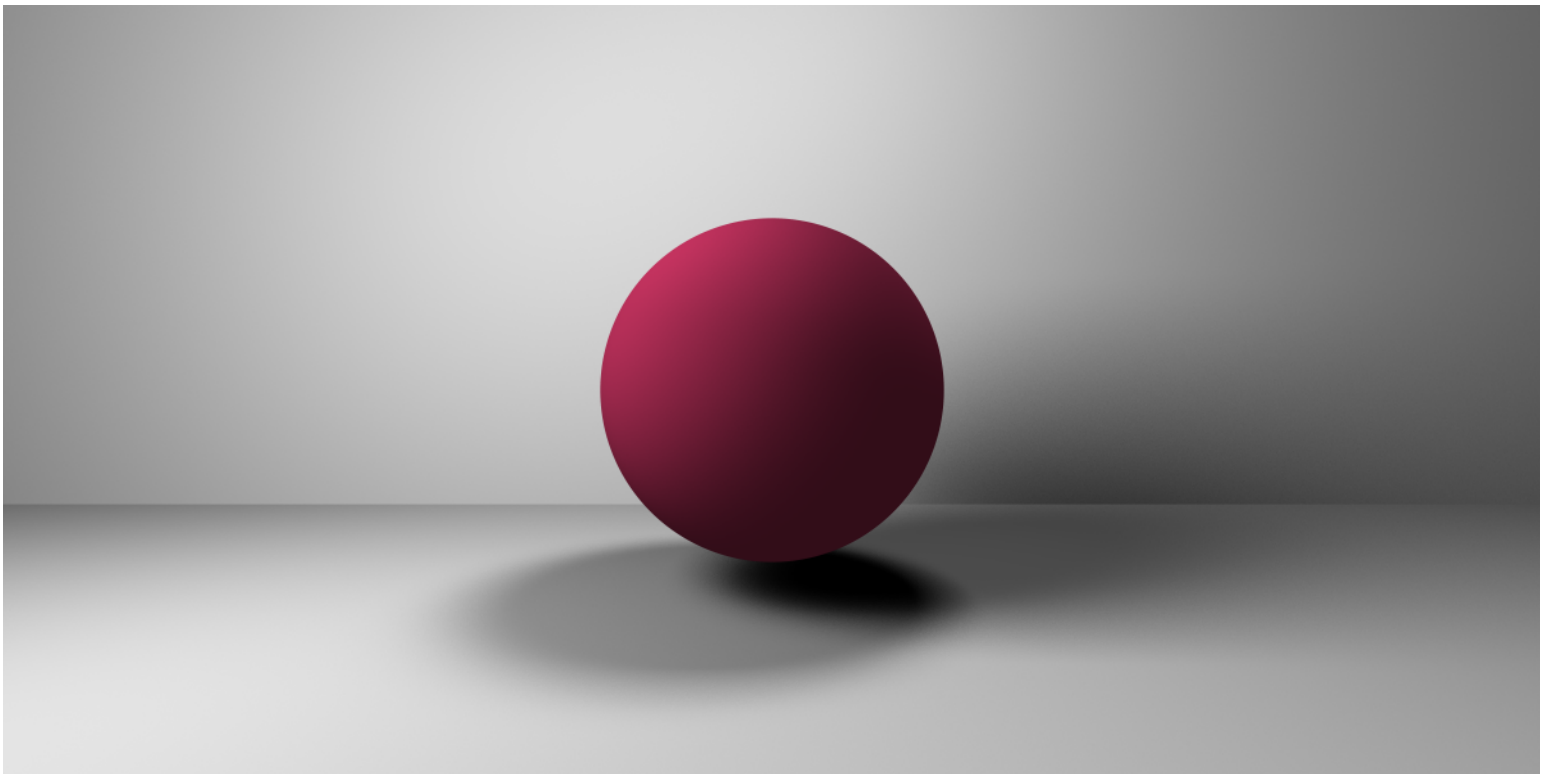


Figure 3: `SoftShadows.scene`. Two point lights with a radius of 0.6 and 0.3. The `Renderer` section has properties `useSoftShadows: true` and `iterations: 500`.

5 Refraction

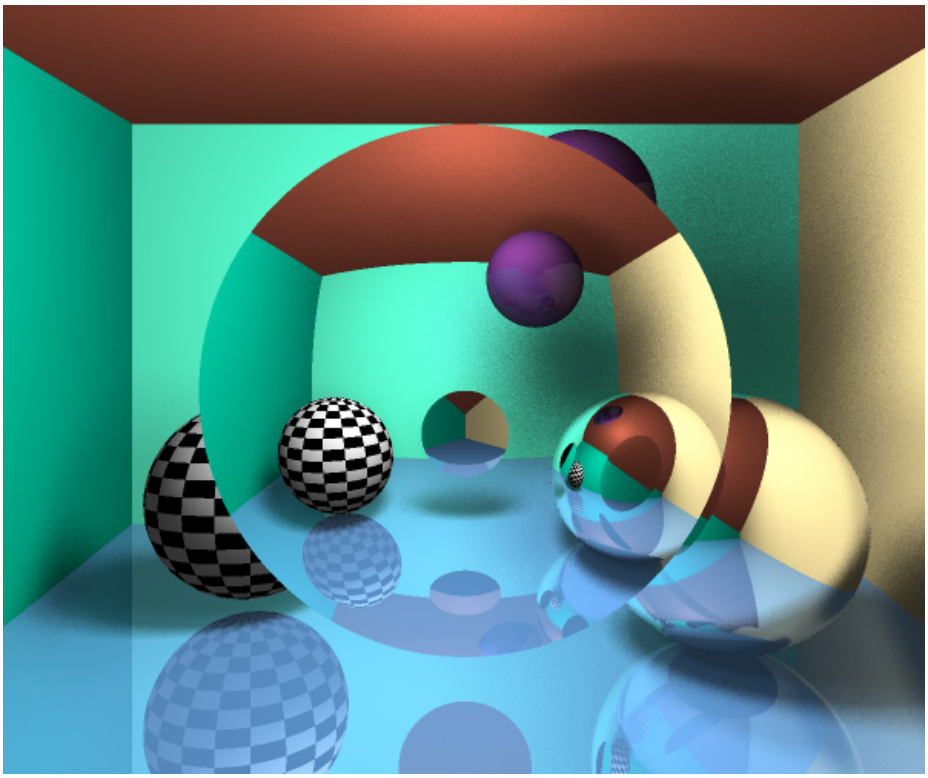


Figure 4: `DiskLens.scene`. A 100% transparent disk with a refractive index of 2.5 placed in front of the scene.

6 Reflection

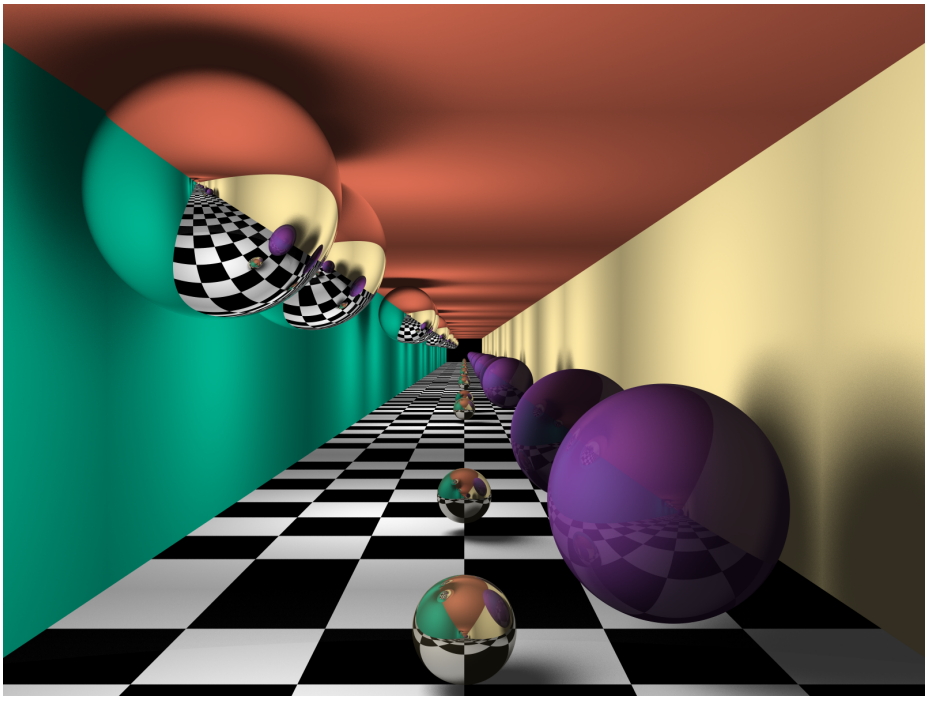


Figure 5: `HallOfMirros.scene`. Hall of mirrors with `maxDepth: 15` under `Renderer`.

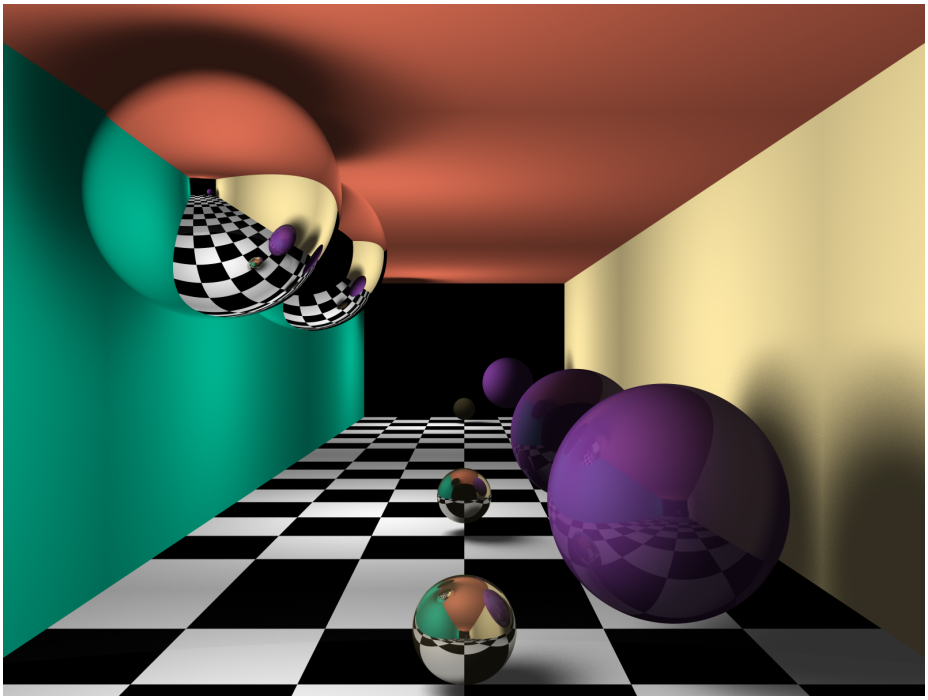


Figure 6: `HallOfMirros.scene`. Hall of mirrors with `maxDepth: 2` under `Renderer`.

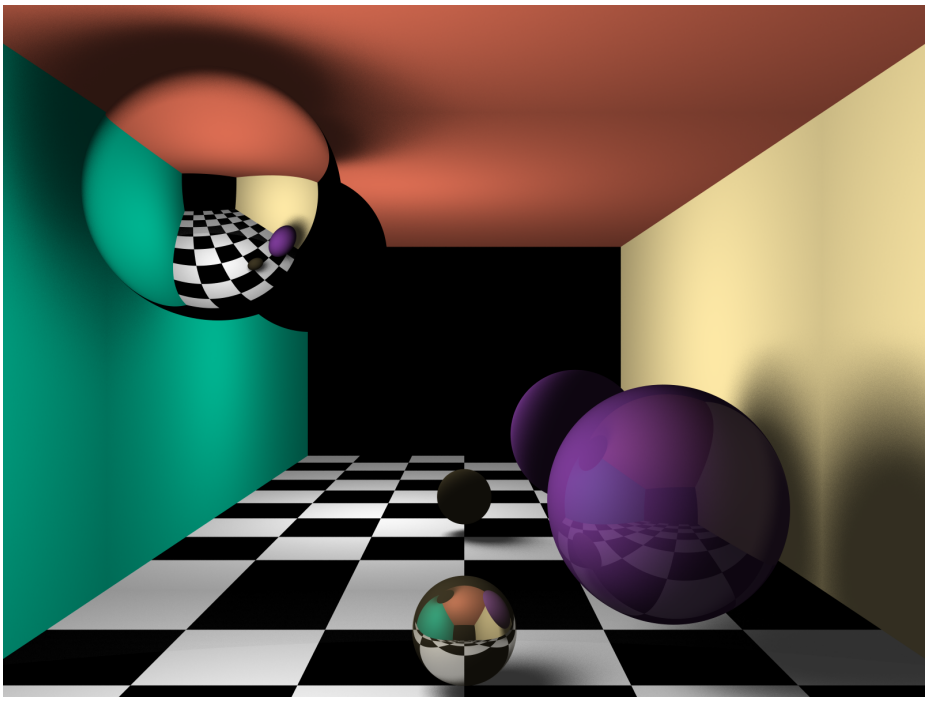


Figure 7: `HallOfMirros.scene`. Hall of mirrors with `maxDepth: 1` under `Renderer`.

7 Anti-Aliasing

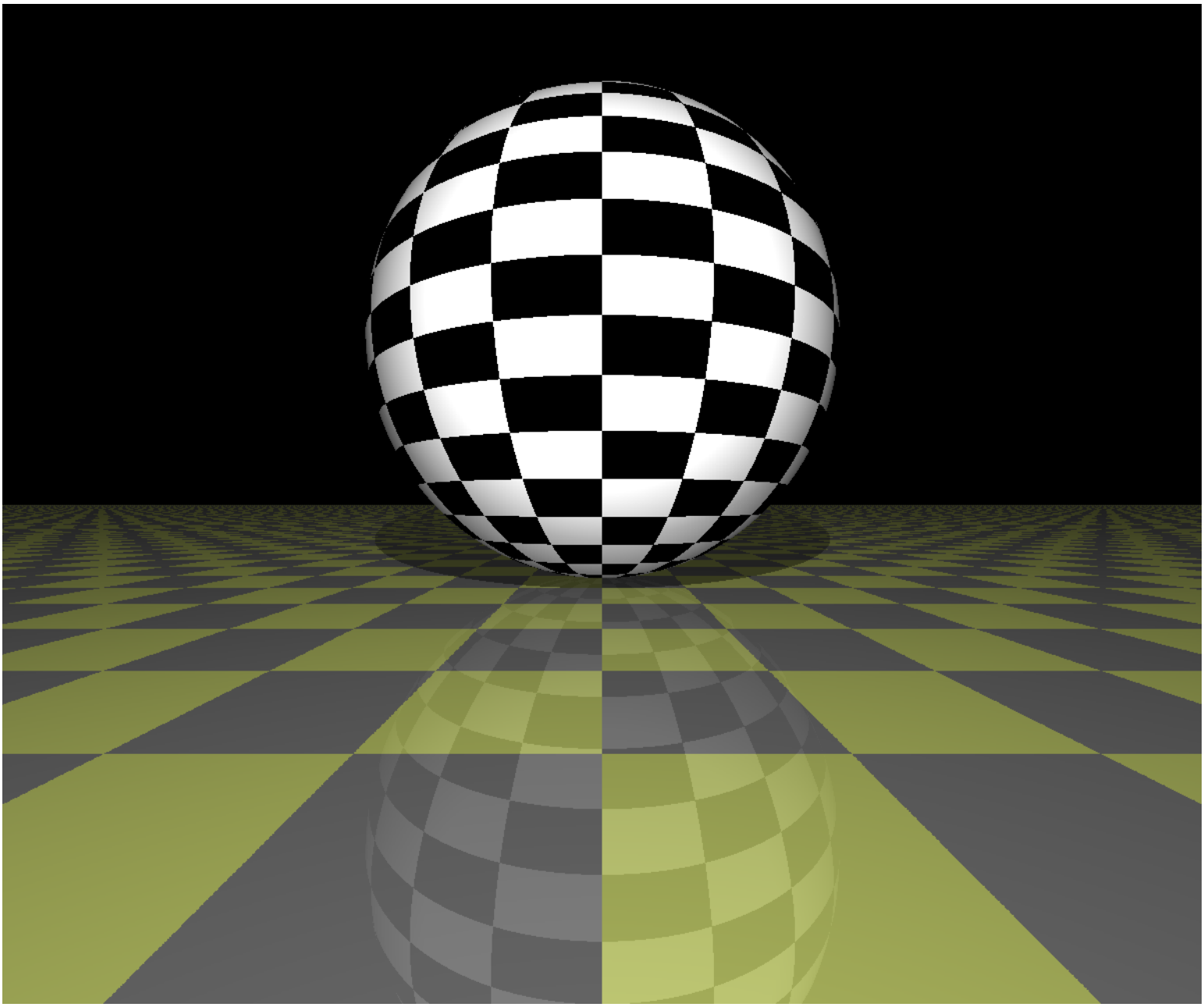


Figure 8: No anti-aliasing.

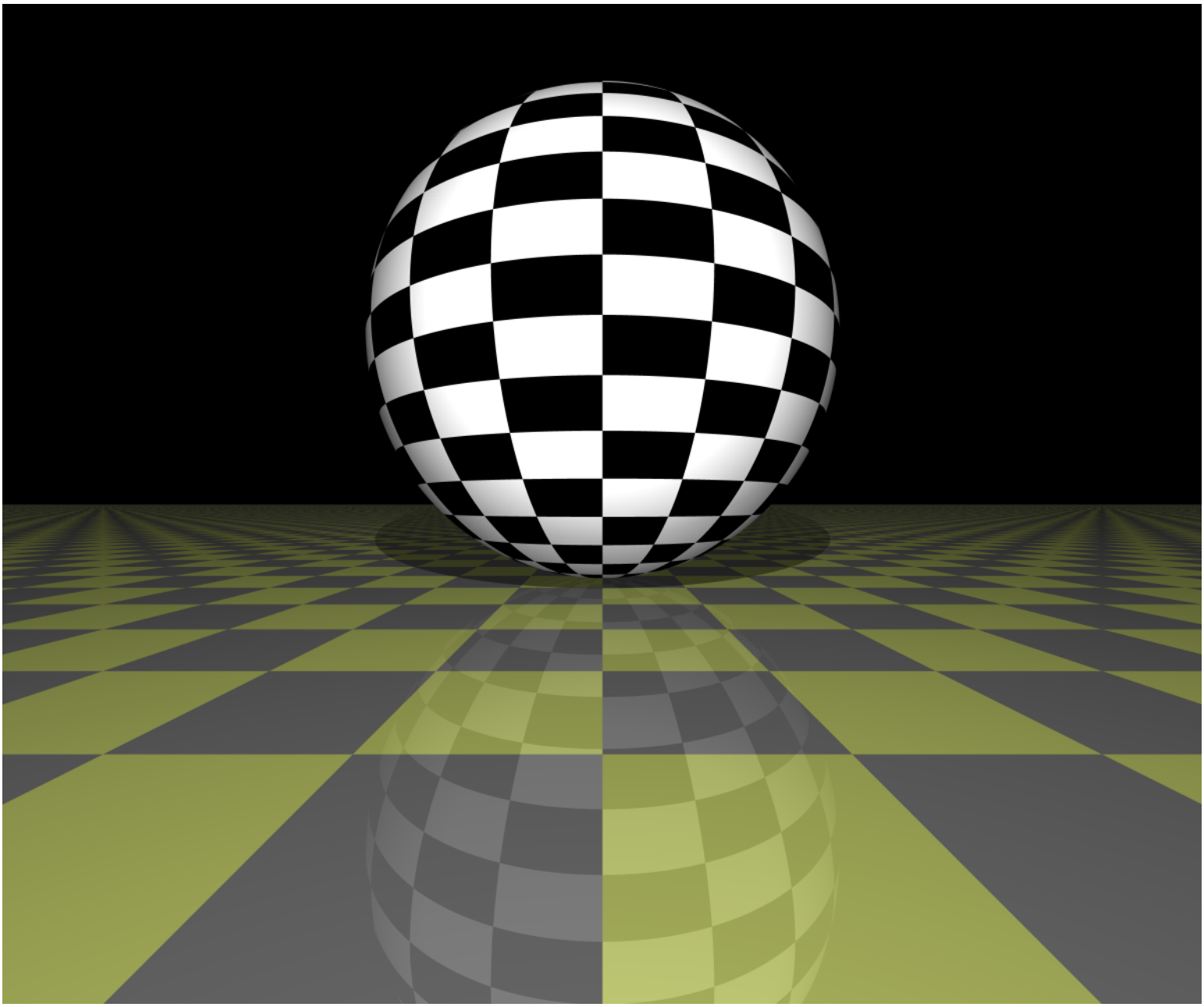


Figure 9: 64x AA using regular sampling.

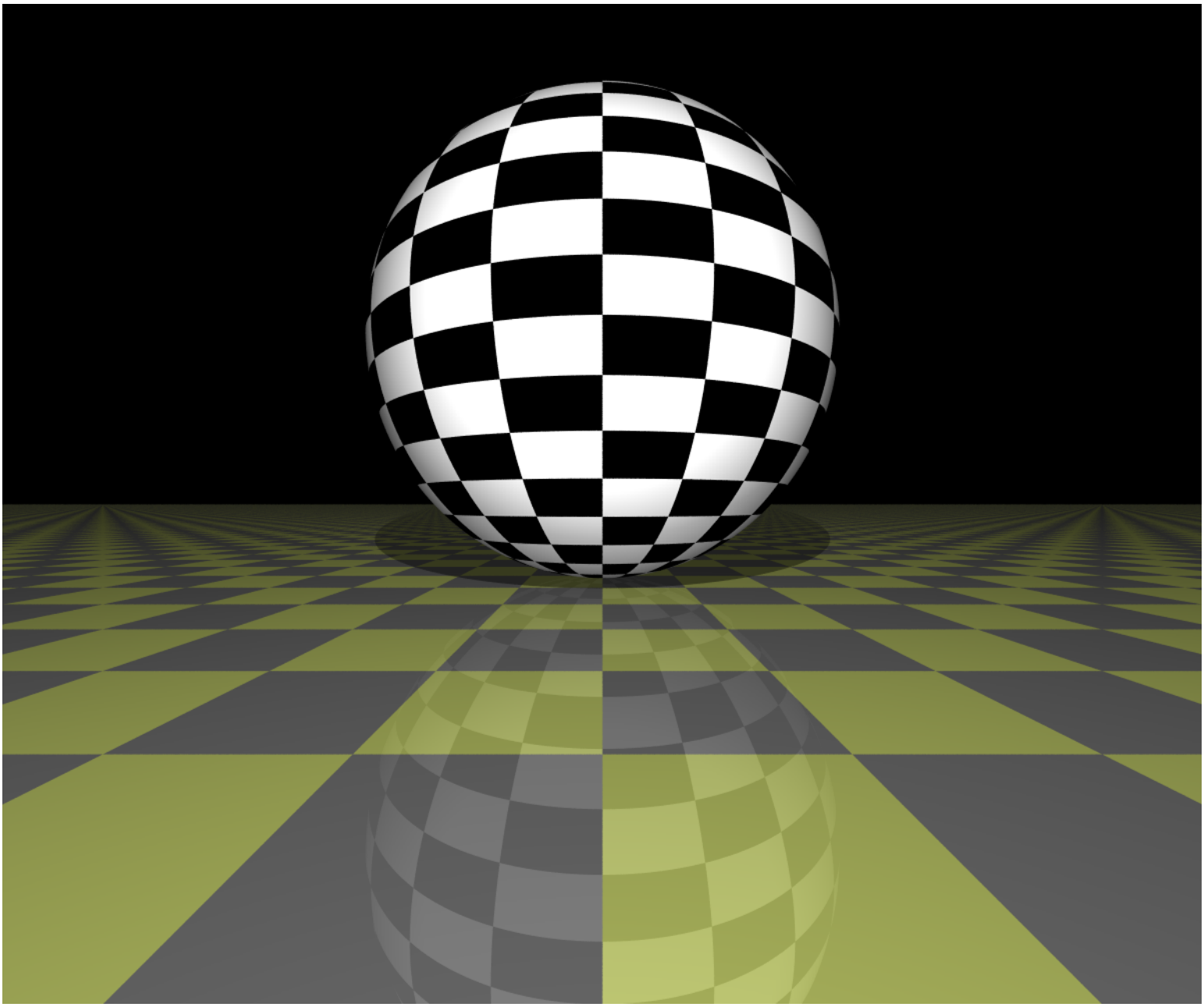
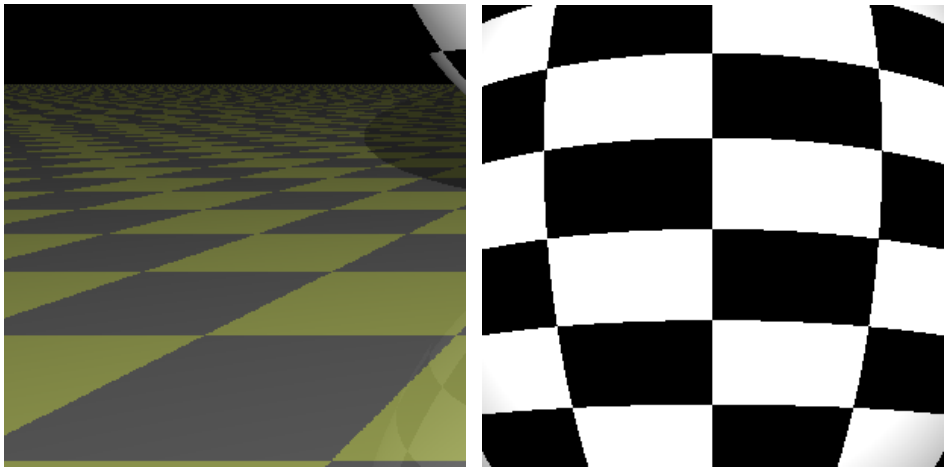
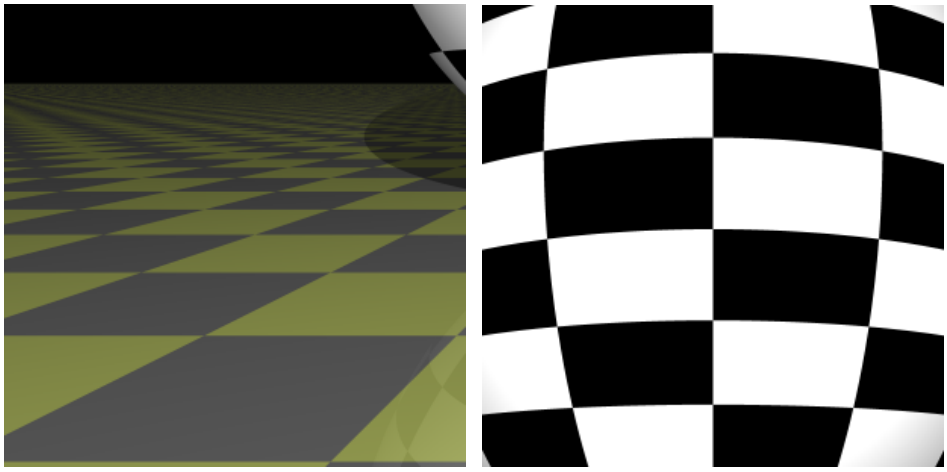


Figure 10: 64x AA using random sampling.



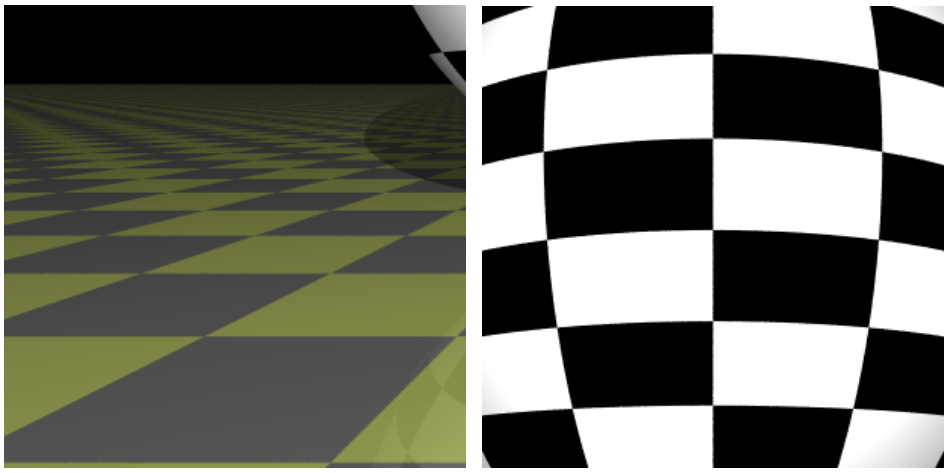
(a) Plane (b) Sphere

Figure 11: Vanishing plane and checkered sphere without anti-aliasing.



(a) Plane (b) Sphere

Figure 12: Vanishing plane and checkered sphere with 64x AA using regular sampling.



(a) Plane (b) Sphere

Figure 13: Vanishing plane and checkered sphere with 64x AA using random sampling.

8 What's Missing?

These are some things I'd love to do in the future but didn't have time for this semester!

- Quadric objects
- Fresnel effect
- Rendering lights in the scene
- 6-DOF camera
- Triangles with affine transformations
- Mesh files
- A regular grid or k-d tree for performance gains
- Specular highlights

9 References

These items are referred to throughout the codebase with `[n]`.

1. https://www.scratchapixel.com/lessons/3d-basic-rendering/ray-tracing-generating-camera-rays/generating-camera-rays
2. http://www.3dkingdoms.com/weekly/weekly.php?a=2
3. https://www.scratchapixel.com/lessons/3d-basic-rendering/introduction-to-shading/reflection-refraction-fresnel
4. https://graphics.stanford.edu/courses/cs148-10-summer/docs/2006–degreve–reflection_refraction.pdf
5. Chapter 10 of "Ray Tracing from the Ground Up" (Kevin Suffern)
6. http://cg.skeelogy.com/depth-of-field-using-raytracing/
7. https://stackoverflow.com/a/13686064/4909532
8. https://www.scratchapixel.com/lessons/3d-basic-rendering/minimal-ray-tracer-rendering-simple-shapes/ray-sphere-intersection
9. https://people.cs.clemson.edu/ dhouse/courses/405/notes/texture-maps.pdf
10. Exercise 18.1 from "Ray Tracing from the Ground Up" (Kevin Suffern) p.350