Final Exam Review
Part 2
Lecture 14: Color

- Why is it that we can get away with just three values for color (e.g., R-G-B)?
- What are the rods and cones, and how many types of each are there in the human visual system? What can you say about how they are distributed in the retina?
- Describe some of the different color spaces that are used to express color.
- An alternative to RGB color space is the CIE color space, with X, Y, and Z primaries. What is Y in this color space? What problem with RGB color space does the CIE color space solve?
- Given a color space expressed by some three-dimensional basis, can it be converted into any other basis through a linear operation? (True or False)
- What is gamma correction? Give an example where gamma correction is useful.
- What is high dynamic range imaging? How could you capture high dynamic range information for a real scene?
- What is tone mapping? Can you think of a good algorithm for tone mapping? What would you want to preserve?
Lecture 15: Ray Tracing (Part 1 of 2)

- Explain the differences between primitive partitioning vs. space partitioning for acceleration data structures. Give examples of each. Give pros and cons for each.
- How would you update a bounding volume hierarchy when objects move? How would you update an octree?
- Know how to construct a bounding volume hierarchy (bounding spheres or bounding boxes), a quadtree (2D) or octree (3D), and a KD-tree.
- Know how to traverse any of these trees to test for ray-object intersections along a ray (e.g., to find the first object hit by the ray or to test visibility).
- What is ray-casting?
- What is a shadow ray? What is a shadow map? What are some pros and cons about the treatment of shadows in rasterization (using the shadow map) and in ray tracing (by tracing a shadow ray or rays)?
Lecture 15: Ray Tracing (Part 2 of 2)

- What is an environment map? How can it be used to handle reflections? What are pros and cons of using an environment map (in a rasterization approach) vs. casting reflection rays (in ray tracing)?
- Give some ways in which ray tracing can be parallelized. List as many opportunities as you can think of.
- What is ray packet tracing and how does it exploit the graphics hardware for efficiency? When will ray packet tracing be effective and when will it not?
Lecture 16A: BVH

- Compute ray - bounding box intersection
- Construct a bounding box hierarchy for a given collection of objects.
- Calculate traversal order of a bounding box hierarchy for a given ray.
- What is the Surface Area Heuristic (SAH) and what goals is it trying to achieve?
- Explain how to choose a bounding box partition using the SAH
- (from last week) Be able to distinguish between object-centric (primitive partitioning) acceleration structures and space-centric (space-partitioning) acceleration structures
- (from last week) Know the difference between these acceleration structures, how to build them, how to traverse them, and when to use each type:
  - bounding box and bounding sphere hierarchies
  - KD-trees
  - octrees
  - grids
Lecture 16B: Radiometry

- Visible light consists of a small range of wavelengths along the spectrum from gamma rays to radio waves.
- Energy of a photon depends on wavelength (and speed of light, and Planck’s constant)
- What is radiant energy?
- What is flux?
- What is irradiance?
- Why (how) does irradiance depend on the angle between the light source and a patch of surface area?
- How does irradiance fall off with distance?
- What is a solid angle?
- What is radiance, and how many dimensions do you need to capture the radiance in a scene (i.e., to capture a light field)?
- What is radiant intensity?
- (Bonus) Characterize the spectral signatures of different familiar light sources.
- (Bonus) Figure out how to read a Goniometric diagram
Lecture 17A: The Rendering Equation (Part 1 of 2)

- Ray tracing algorithms make use of radiance estimates to build up an image of a scene. What is radiance? Why is radiance the fundamental quantity of interest? How are radiance estimates used to compute the color that would be observe by a camera at a point on a material surface?

- What is the difference between radiance and irradiance? Between incident and exitant radiance?

- Explain and illustrate with a sketch all of the terms in the Rendering Equation.

- Draw diagrams to illustrate reflection for (1) a perfectly specular (mirror) surface, (2) a glossy surface, (3) a diffuse surface, (4) a retroreflective surface

- What is a BRDF? What are the inputs and outputs of a BRDF function?

- How would you measure a BRDF? If you were to mount a camera and light source on two robot arms, how many degrees of freedom (joints) would you need to do these measurements?
Lecture 17A: The Rendering Equation (Part 2 of 2)

- Given a ray and a surface normal, calculate the direction of perfect reflection
- Given a ray, a surface normal, and indices of refraction, calculate the direction of perfect transmission using Snell’s Law.
- What is Fresnel reflection? Sketch curves to illustrate the effect for dielectrics vs. conductors as we have seen in class. Label your axes. Informally, what does this effect show?
- What is subsurface scattering?
- How can we extend the idea of BRDF to subsurface scattering? What additional parameters must be sampled?
Lecture 17B: Sampling Introduction

- How do we use the trapezoidal rule to integrate a function?
- How does work increase with dimensionality of our function?
  - This is why we typically use Monte Carlo integration in graphics!
- Give a high level overview of the process of Monte Carlo integration
- What is a probability density function (PDF)?
- What is a Cumulative Distribution Function (CDF)?
- The Inversion Method can be used to correctly draw a sample from a PDF.
  - Sketch the overall step by step process for using the Inversion Method.
Lecture 18A: Sampling

- Give a high level overview of the process of Monte Carlo integration
- What is a probability density function (PDF)?
- What is a Cumulative Distribution Function (CDF)?
- The Inversion Method can be used to correctly draw a sample from a PDF.
  - Sketch the overall step by step process for using the Inversion Method.
  - Work through how to use it to sample solid angles from a hemisphere
- What is rejection sampling? Show how to use rejection sampling to sample area of a circle, volume of a sphere, directions on a sphere, and solid angles from a hemisphere.
- Use one of the sampling methods we discussed to correctly accumulate incident irradiance on a surface patch.
- What is importance sampling?
- How do we obtain an unbiased Monte Carlo estimator when the probability density function is not uniform?
Lecture 18B: Monte Carlo Path Tracing

- What is Russian Roulette? How does Russian Roulette help us to obtain unbiased samples in path tracing?
- If we choose to continue tracing a ray in a Russian Roulette scenario, we will reweight the value provided by this ray by some factor. What is the weighting factor and why is it used?
- Another point of view on the Rendering Equation is to sum up light energy contributions from emitted light, paths of length 1, paths of length 2, etc. Be prepared to explain what effects you would see when tracing out paths of various lengths (color bleeding, reflections, caustics, etc)
Lecture 19: Variance (Part 1 of 2)

- Be familiar with the following expression for Monte Carlo integration. What is the role of each term?

\[ I = \lim_{n \to \infty} V(\Omega) \frac{1}{n} \sum_{i=1}^{n} f(X_i) \]

- What is expected value?

- What is variance?

- Give an example of how we can reduce variance in our rendered results in a path tracing algorithm without increasing the number of samples.

- What does it mean for an estimator to be consistent?

- What does it mean for an estimator to be unbiased?

- Give a concrete example of how a renderer could give a biased estimate of an image. Is the renderer in your example consistent? Explain your answer.

- Give five examples of how you can reweight samples in a path tracing algorithm in order to do importance sampling.

- What are the main ideas behind bidirectional path tracing?

- How would you enumerate all possible paths in a scene?
Lecture 19: Variance (Part 2 of 2)

- How does Metropolis-Hastings sampling work?
  Assume you have code to generate random paths and code to mutate existing paths. Write pseudocode for Metropolis-Hastings path tracing.

- Is this algorithm consistent? Is it unbiased? Is it efficient? For what kinds of scenes would this algorithm be best suited? Explain your reasoning for your answers to all of these questions.

- What is Stratified Sampling?

- Why is it preferred to random sampling?

- Hammersley and Halton points are pseudo random sampling techniques to generate points with low discrepancy. What is discrepancy? Why do we want to generate low discrepancy samples?
Lecture 20A: Global Illumination Summary

- Give a concise one sentence description of each of the following rendering algorithms that makes it clear the differences between them. Use a diagram to illustrate your description:
  - Rasterization
  - Ray casting
  - Ray tracing
  - Path tracing
  - Bidirectional path tracing
  - Metropolis Light Transport
  - Photon Mapping
  - Radiosity

- Which of these algorithms are best for capturing reflective surfaces? caustics? color bleeding? subsurface scattering? refraction? ... 

- Briefly explain bias and consistency. If you want a consistent renderer, which of the above can you choose? why? If you want an unbiased renderer, which can you choose? why?
Lecture 20B: Intro to Animation (Part 1 of 2)

- How were the first animations created? How were the first films created? Give some examples.
- Describe some of the first computer generated animations, giving the developer / artist and timeframe.
- Animations are created from keyframes. How do we interpolate between those keyframes?
- Why do we avoid splines of degree higher than three in computer graphics?
- Write a cubic polynomial $P(t)$ in parameter $t$, which may describe a cubic spline.
- What are the constraints for $P(t)$ to interpolate endpoints $p_1$ at time $t=0$ and $p_2$ at time $t=1$?
- What are the constraints for $P(t)$ to have tangent vector $r_1$ at time $t=0$ and $r_2$ at time $t=1$?
This pair of constraints describes a Hermite spline. Derive the polynomial coefficients for the Hermite spline and write the cubic polynomial in terms of $p_1$, $p_2$, $r_1$, and $r_2$.

Put your result in matrix form.

Give properties of the Hermite spline in terms of continuity ($C_1$, $C_2$, etc..), interpolation, and local control.

What type of spline has $C_2$ continuity and interpolation, but not local control?

What type of spline has $C_2$ continuity and local control, but does not interpolate its key points?

What are Catmull-Rom splines? How are tangents computed for Catmull-Rom splines?

What are blend shapes and where are they used? What exactly is interpolated when using blend shapes for animation?
What you should know

What is a blend shape?

What are cage based deformers?

What is linear blend skinning?

Understand how to set vertex positions for a mesh using any of the above approaches.

What is forward kinematics? Work out the forward kinematics solution for a simple character.

What is inverse kinematics? Work out the inverse kinematics solution (including calculating the Jacobian) for a simple character.
Lecture 22: Jacobian for IK and Optimization

- Be able to analytically compute the Jacobian for a simple character and use it to do inverse kinematics.
- Know why the Jacobian transpose technique is a “cheat” or an approximation to the inverse kinematics solution at a point.
- Give several examples where optimization is important in computer graphics.
- Be able to describe an optimization problem in standard form and give a simple example.
- How do you know you have a minimum of an objective function in an optimization problem without constraints? What properties must be true?
- What is gradient descent?
- How can we improve upon gradient descent?
Lecture 23: Dynamics and ODEs

- What is the “animation equation”?
- What is the difference between an ODE and a PDE? Give some examples of systems we can simulate by integrating an ODE.
- Sketch an overall system for simulating an ODE using a block diagram. Be clear about what is the state, how you advance the state forward in time, and what integrator you are choosing.
- When is the Euler-Lagrange equation useful?
- Be able to work through a simple example of obtaining dynamic equations of motion using Lagrangian mechanics.
- Describe how to put together a mass-spring system to simulate cloth.
- What are the forces on each cloth “particle”?
- What is Forward Euler integration and what is its disadvantage? Can you show a simple example where it fails?
- What is Backward Euler integration and what are its pros and cons?
- What is Symplectic Euler integration?
What is the difference between a PDE and an ODE? Give examples of when you might use each one and why.

Interpret this sentence using an equation and a diagram: Solving a PDE looks like "use neighbor information to get velocity (...and then add a little velocity each time)"

Burger’s equation is first order in time and second order in space. What does that mean? What are the orders of the Laplace equation? The heat equation? The wave equation? Be able to figure out the order of an equation from an expression of the equation itself.

What are examples of questions we can answer using the Laplace equation, the heat equation, and the wave equation respectively?

Outline the basic strategy for solving a PDE.

What is the Laplace operator? Write it out as a sum of partial derivatives.

Copy down the heat equation from the slides. Write out the process of solving this equation using Forward Euler integration.

Copy down the wave equation from the slides. Write out the process of solving this equation using Forward Euler integration.
Lecture 25A: Rigid Body Dynamics

◆ What parameters are needed to specify the configuration of a rigid body? What are the time derivatives of these parameters?
◆ Suppose we represent rigid body state as position, orientation, linear momentum, and angular momentum. What is the time derivative of this state vector as a function of forces and torques acting on the body?
◆ How do we use these derivatives to advance the position and orientation forward in time using Forward Euler?
◆ Express the time derivative of a rotation matrix using two methods.
◆ If we represent a rigid body as a collection of particles, what is its mass? Its center of mass?
◆ Sketch out a block diagram for simulating a rigid body similar to the block diagram used for simulating particles.
◆ Is inertia of a rigid body constant in world coordinates? If not, how do we compute it?
◆ Give two methods for handling collisions (computing collision forces).
Lecture 25B: Dynamic Control of Characters

- What does a controller do in a physics based animation of a character? Use the example of a character that must balance. How could a controller help the character achieve balance instead of falling on the ground like a rag doll?
- What exactly is controlled? How might you use an existing software package such as ODE to set up a simulated character with a balance controller?
- What is PD control?
- How can we use PD control to drive the character to a desired pose? to track a desired motion?
- What is needed to specify a walking motion to a controller?
- What is needed to specify quadruped gait?
- We saw an example of learning a quadruped gait. In this example, do you know what was learned (i.e., what were the optimization parameters)?