From Eye to AI: Digital Phantoms for Medical Imaging

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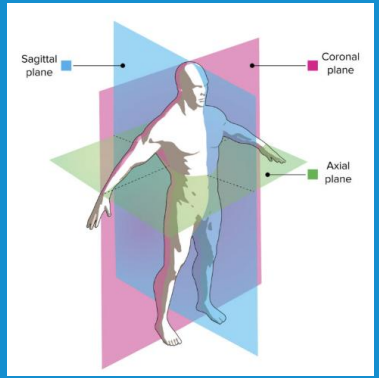
C. LIGHT TECHNOLOGIES

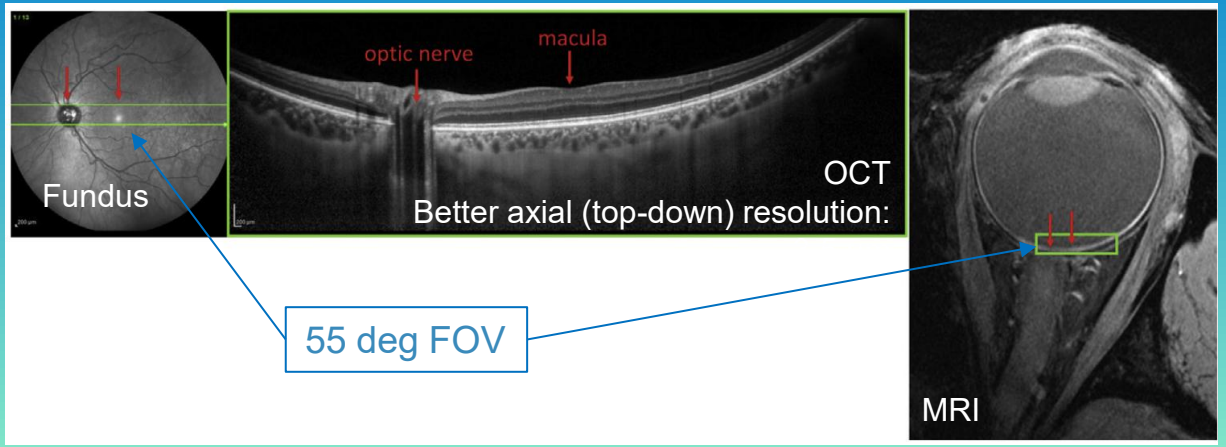
TSINGHUA UNIVERSITY 1911

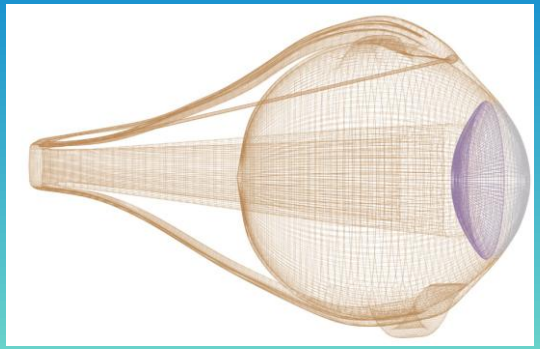
Welcome to From Eye to AI: Digital Phantoms for Medical Imaging

- **Course title:** From Eye to AI: Digital Phantoms for Medical Imaging
- A little about me: I'm Joe Xing, a technology professional and visiting professor at Tsinghua University. I’m passionate about innovation, problem-solving, and creating solutions that make a real impact



The adult eye is approximately 2.3 cm in length, comprising tissue structures that are often less than a millimeter in size





MR-EYE: High-Resolution MRI of the Human Eye and Orbit at Ultrahigh Field (7T)

What is a Digital Phantom

- The Shepp–Logan phantom is widely regarded as the starting point of digital phantoms in medical imaging
- Definition: A digital phantom is a virtual model of the human body (or part of it) that scientists use to safely test medical imaging systems and train AI, without needing real patients.
- Application example: Shepp-Logan Phantom can be used to test CT imaging processing and reconstruction algorithms (image blurring, contrast enhancement, filtered back projection, FBP, etc.).

Shepp-Logan Phantom, 1974

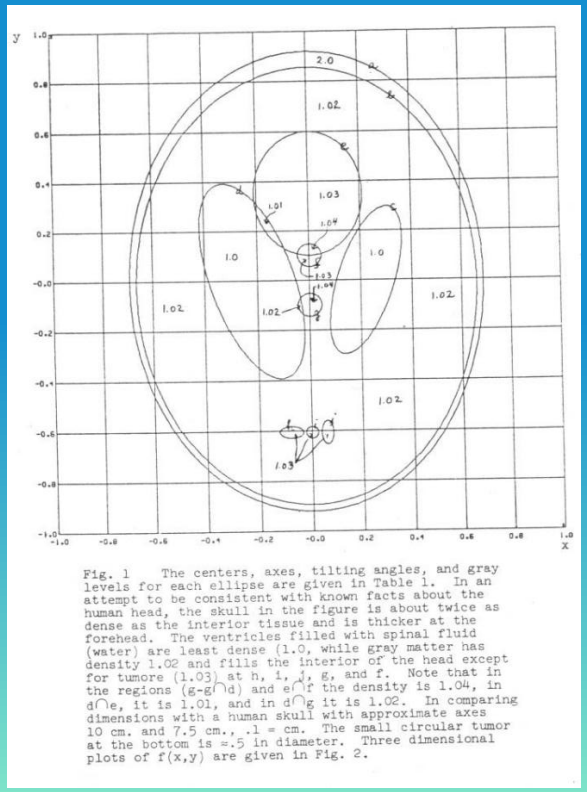


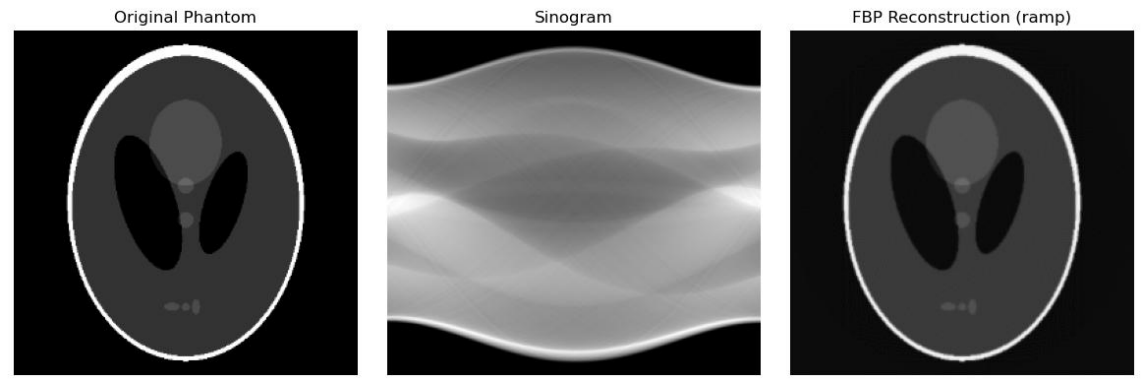
Fig. 1 The centers, axes, tilting angles, and gray levels for each ellipse are given in Table 1. In an attempt to be consistent with known facts about the human head, the skull in the figure is about twice as dense as the interior tissue and is thicker at the forehead. The ventricles filled with spinal fluid (water) are least dense (1.0, while gray matter has density 1.02 and fills the interior of the head except for tumore (1.03) at h, i, j, g, and f. Note that in the regions (g-g∩d) and e∩f the density is 1.04, in d∩e, it is 1.01, and in d∩g it is 1.02. In comparing dimensions with a human skull with approximate axes 10 cm. and 7.5 cm., .1 = cm. The small circular tumor at the bottom is =.5 in diameter. Three dimensional plots of f(x,y) are given in Fig. 2.

Why Phantoms Matter in Healthcare

- Digital phantoms are important in medical and healthcare space
  - Safe experimentation: Allow testing of imaging methods without exposing patients to radiation or risk
  - Ground truth known: You know the exact anatomy and tissue properties → perfect for evaluating accuracy of imaging and AI models.
  - Repeatable & flexible: Same phantom can be used in many labs worldwide → fair comparisons of algorithms.

Ground Truth

Reconstructed
Generated by algorithm

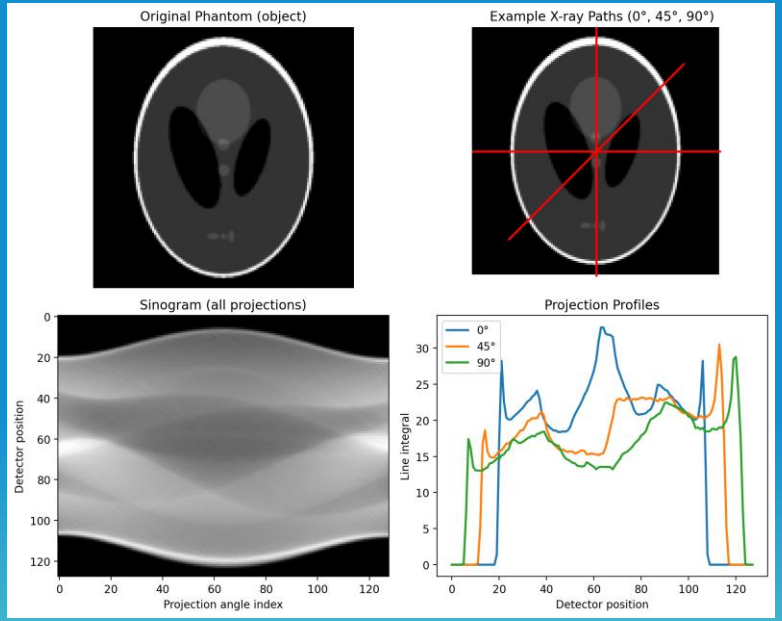


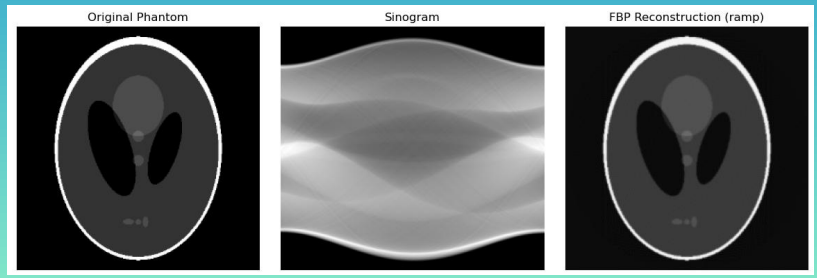
Homework #1 - Bonus

- Explore the Radon transform: the mathematics behind CT. Use Python (with skimage) to generate a Shepp–Logan phantom, compute its Radon transform (sinogram), and then apply the inverse Radon transform (FBP) to reconstruct the image. Compare the reconstruction with the original phantom and explain what you observe.

Hint:

- CT works by acquiring X-ray projections from multiple angles.
- Radon transform
- Inverse Radon transform – Filtered Back Projection (FBP), both available in skimage
- CT collects line integral as a function of the rotational angle and detector position (sinogram)





Course Journey

- 90 minutes each class

Foundations (Classes 1–8)

- **Class 1:** Intro & Course Overview
- **Class 2:** Unity3D Basics
- **Class 3:** Anatomy Meets 3D
- **Class 4:** Coding in Unity (C#)
- **Class 5:** Design Patterns in Unity
- **Class 6:** Materials & Lighting
- **Class 7:** Medical Imaging & Digital Phantoms
- **Class 8:** Version Control (GitHub)

Assessment (Class 9)

- **Class 9:** Midterm Exam

Advanced Topics (Classes 10–14)

- **Class 10:** AI & Synthetic Data
- **Class 11:** Unit Testing
- **Class 12:** Automated Testing & CI/CD
- **Class 13:** Advanced Simulation Fidelity
- **Class 14:** Biology → 3D Integration

Final Project (Classes 15–16)

- **Class 15:** Final Project Workshop
- **Class 16:** Final Presentations

Course Roadmap

Phase 1 – Foundations (Weeks 1–4)

Learn Unity3D basics and C# scripting.
Connect anatomy and biology data into 3D models.
Explore design patterns and rendering for realism.

Phase 2 – Building Skills (Weeks 5–8)

Develop your own digital eye phantom.
Add interactivity, lighting, and textures.
Learn software engineering skills: version control (GitHub).
Checkpoint: Midterm exam (Week 9).

Phase 3 – Advanced Applications (Weeks 10–14)

Generate synthetic imaging data for AI.
Apply unit testing and CI/CD for robust code.
Increase realism and fidelity in simulations.
Integrate biological data into your 3D models.

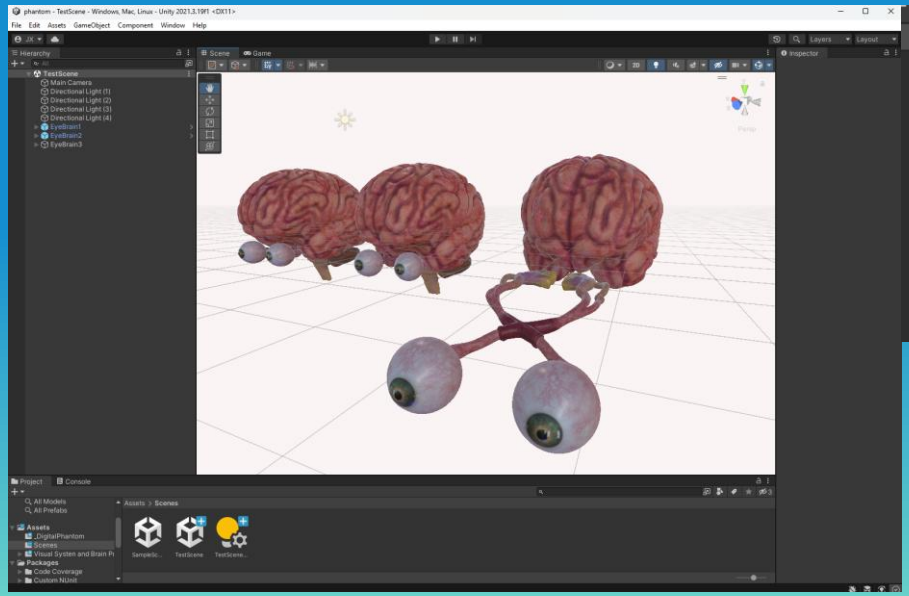
Phase 4 – Project & Showcase (Weeks 15–16)

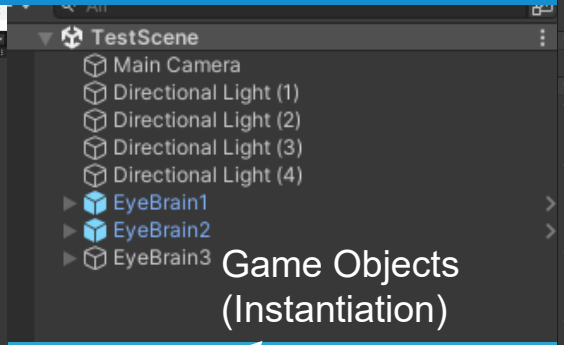
Workshop: Build and refine your final project.

Presentation: Showcase your digital phantom to the class.

Unity3D sneak peek demo

- Unity3D is a powerful game engine used to create interactive 2D and 3D applications. It combines a scene editor (to place models, lights, and cameras) with C# scripting (to control behavior).

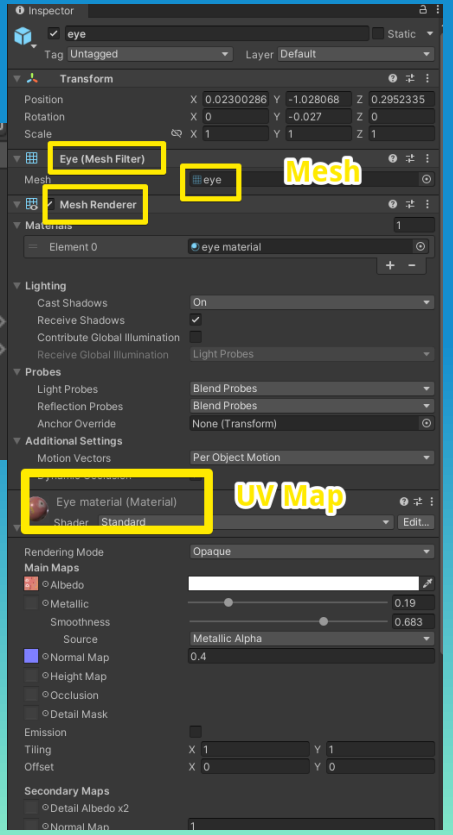




Game Objects (Instantiation)

Prefab (class, template, blueprint)

Mesh (vertices, triangles, UVs)

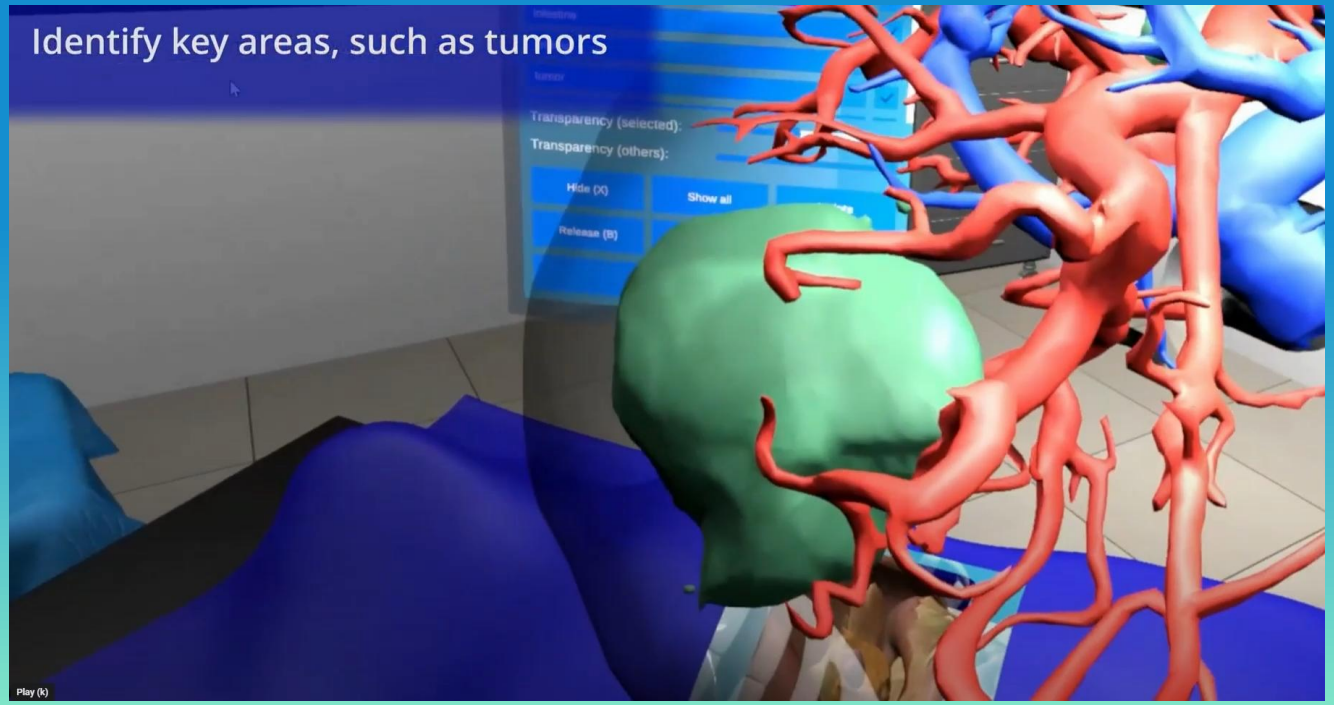


Materials (shaders, textures, colors)

Final Project Sneak Peek

- The Digital Eye Phantom

In this final project, you will create a **digital phantom of the human eye** in Unity3D, complete with anatomical structures and realistic **fixational eye motions** (drift, tremor, microsaccades). These motions will be injected into Unity to animate the eye and simulate real behavior. For an advanced option, you can integrate **SOFA (Simulation Open Framework Architecture)** with Unity to add biomechanical realism.



Wrap-Up & Next Class

- **Unity3D Basics**
  Game Objects, Prefab, Game Object as Containers that carries mesh, mesh filter, mesh render, collider (physics), material, shades, texture, etc.

  Scripts (C# Code), MonoBehaviour, custom behavior, logic, and interactions

  Unity Lifecycle Methods (Event Functions)

```
void Awake()
{
    // Called when the script instance is being loaded
    // Runs before Start()
    // Good for: Setting up references, initializing variables
}
```

```
void Start()
{
    // Called on the first frame when the script is enabled
    // Runs after Awake()
    // Good for: Initial setup, finding other GameObjects
}
```

```
void OnEnable()
{
    // Called every time the GameObject becomes active
    // Runs when: GameObject is enabled, scene loads, script is enabled
    // Good for: Re-initializing when object becomes active
}
```

```
void OnDisable()
{
    // Called when the GameObject becomes inactive
    // Runs when: GameObject is disabled, scene unloads, script is disabled
    // Good for: Cleanup, stopping coroutines
}
```

Discussion

- **What could doctors do with a digital phantom that they can’t do on a real patient**

Digital phantoms give doctors and engineers a safe, flexible “sandbox” to explore ideas, test technology, and train AI, all without risk to a human patient.

They can train AI models with massive synthetic datasets, something not possible with limited real patient scans.

Doctors can simulate rare or dangerous conditions that may never appear in their clinic but are critical for training.

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THANKS

DO YOU HAVE ANY QUESTIONS?

contact@joexing.me