Topics in Digital Heritage

Numerical Methods for Digital Reconstruction

Course number	CTP.49905	*Instructor*	Jin Woo Lee / 이진우
Credit hours	3-0-3	*Office location*	N25, #3232
Lectures	TR 17:30-19:00	*Office hours*	TBD
Classroom location	N25 #3229	*Email address*	TBD

Course Description

Welcome to the "**Numerical Methods for Digital Reconstruction**" course! This class covers both the theory and practice of ***numerically digitizing real-world objects on a computer***. By exploring how to transform real-world objects into forms that allow for audio and graphical interaction, we arrive at the question of what systems define our interactions with these objects in reality, and this course discusses how to understand these *through the lens of* ***physical principles*** *and* ***digital systems*** and recreate them by *implementing them on a* ***computer***.

> *Whether your interests lie in cultural heritage preservation, virtual instruments, game engines, architectural acoustics, medical imaging, or immersive XR, the numerical intuition you cultivate in this course will prove valuable across all these fields.*

Prerequisites/Corequisites

This course welcomes students from diverse backgrounds who share curiosity about numerical methods. Enthusiasm for hands-on learning is most important.

We will assume that students have completed the course or are familiar with:

- Fundamentals of **Linear Algebra**
- Fundamentals of **Digital Signal Processings** (or its equivalents)
- **Calculus** and fundamentals of Ordinary Differential Equations (ODEs)
- Any first course in **Programming** (C++, Python, etc.)

No prior experience required with:

- Partial Differential Equations (PDEs)
- Finite Element or Boundary Element software
- Computer Graphics or Audio Engineering
- Any senior/graduate-level advanced courses (e.g., Fourier Analysis, Numerical Analysis, etc.)

A solid foundation in linear algebra and calculus is by far the most important predictor of success. Students who find matrix operations and integration intuitive will be able to absorb new algorithmic ideas quickly; those who feel less confident in those areas are encouraged to review key topics in the first week using the supplemental resources listed below or any relevant materials (cf. intro to linear algebra from MIT OpenCourseWare).

Intended Learning Outcomes (ILOs)

By the end of this course, students will be able to…

1. Explain the **mathematical foundations of numerical methods** and identify which method is most appropriate **for a given digital reconstruction problem**.
2. Implement the numerical algorithms and **apply them to model physical phenomena relevant to graphics and/or audio** domain (e.g., wave propagation, elasticity, acoustic scattering).
3. Critically **evaluate simulation results** for accuracy, stability, and convergence, and articulate the trade-offs between different numerical approaches.

Course Materials

- *Textbook*
  There is no textbook for this course; all classes are conducted using lecture materials distributed online.
- *Supplemental readings*
  The following materials can help to better understand the course content. We highly recommend that students who wish to learn more about the course content read these.
  - J. Solomon, *Numerical Algorithms: Methods for Computer Vision, Machine Learning, and Graphics*. 1st ed. (CRC press). [Free Online] [Lecture Video]
  - S. Bilbao, *Numerical Sound Synthesis: Finite Difference Schemes and Simulation in Musical Acoustics*. 1st ed. (John Wiley & Sons). [Link]
- *Software and hardware requirements*
  Programming activity can be needed for the final project, and equipment for this will not be provided. Students are encouraged to use personal hardware, campus facilities, or cloud computing services. If access to these resources is challenging, please consult with the instructor, who will gladly explore options together.

Assessments

Criteria	Score	
Quizzes	0 %	• This assessment is in line with ILO 1. • The quiz will be taken during the class on the date marked as 'quiz' on the Course Calendar unless otherwise announced.
Problem Set Assignments	80 %	• See the Course Policies section for late assignments. • This assessment is in line with ILO 1 and ILO 2. • Assignments will be distributed via the portal after each class session.
Final Project	20 %	• Students will be asked to conduct their own final project and submit a report. More info can be found from below section. • This assessment is in line with ILO 1,ILO 2, and ILO 3.

Course Expectations and Policies

- **Attendance** is not checked in person at a specific time each session, but the quiz answer sheets will be collected in person during class.
- **Quizzes** are distributed on paper before class begins and must be completed within a maximum of 15 minutes without the use of books, computers, or electronic devices. No quiz score will be given for unexcused absences.
- **Problem Set (Pset) Assignment** is expected to assess the level of understanding on the course material.
    - A total of ***eight graded Psets*** will be assigned. So ***each Pset contributes to 10% of your final grade***.
    - Pset 0 will ***not*** be graded. This is solely intended as a survey on the backgrounds relevant to the course. The answer for Pset 0 will be distributed later, and we encourage students to use it to evaluate their own level of understanding for better gauging the course workload.
- *Submission Policy*
    - **Assignment Submission Format**: All submissions except quizzes must be submitted to the portal in electronic document format. Students experiencing technical difficulties are kindly requested to notify us in advance via email or visit during office hours.
    - **Assignment Late Submission Policy**[1]
        - **All documents** to be submitted, including the final report, are referred to as ***'assignments.'***
        - All assignments must be submitted by the **due date 23:59 KST**
        - Any assignment submitted after the deadline is classified as a ***'late submission.'***
        - ***Late submissions (without prior approval)*** *will receive* ***only 50%*** of their final assignment score.
        - ***Prior approval of exceptions*** *for the late submissions are* ***permitted up to twice*** per semester. You may use a ticket by completing this Google Form ***before*** the assignment deadline. The new deadline will be ***extended by three days*** for those who submitted the form. However, the submitted form will be invalidated in the following cases:
            - If forms are submitted for two or more assignments, the late exception will be accepted only for the first two assignments, and any subsequent requests will be disregarded.
            - If the form is submitted after the deadline, it will not be accepted, and the assignment score will still be halved.
            - You cannot use the exception form to extend the same assignment twice.
            - If you submit the assignment late even after the three-days deadline extension granted via the exception form, a 50% penalty will still apply, and the ticket will still be considered used.
        - In short: ***All assignments must be turned in by the deadline; if you anticipate a delay, fill out an exception form in advance to extend the deadline by three days, up to twice in the semester***.

Final Project

Students will individually design and execute a unique final project. The core objective of this project is to ***simulate a physical, sound-producing object or instrument in a digital environment***. To ensure success, everyone will have an opportunity to propose their project ideas early in the semester and receive feedback from the instructor.

Ideal Project Paths. Your project should ideally follow one of these two approaches:

1. **Analysis & Simulation**: Simulate an existing real-world musical instrument on a computer and demonstrate how closely the simulated sound matches the original.

[1] Should you have any questions, please feel free to reach out to the instructor for clarification.

2. **Design & Verification**: Design a completely new instrument digitally, simulate its acoustics, physically construct the instrument based on that design, and verify the acoustic match between the two.

Deliverables

- **In-Class Presentation**: A live presentation of your project to the class.
- **Final Report**: A comprehensive written report documenting your methodology and results.

Grading & Evaluation Metrics (20% of Total Grade)

1. **In-Class Presentation** (10% of Total Grade)
    a. Clarity: How clear, organized, and accessible is your explanation?
    b. Depth: Does the presentation demonstrate a deep, foundational understanding of the underlying principles?
2. **Final Report** (10% of Total Grade)
    a. Relevance: How effectively does the project apply and integrate concepts covered in class?
    b. Impact: How closely does the simulated audio achieve realistic, authentic sound quality?
    c. Rigor: How thoroughly and critically did you validate and analyze your final results?

Other Tools/Resources/Tips

- *AI Acceptable-use Statement*
  Use of generative AI tools in this class is allowed in ways that *support* your own learning and creativity, *not replace* them. If you judge that using an LLM will genuinely help your productivity and understanding, that judgment is respected, and you may use such tools for activities like brainstorming ideas, generating example images to clarify concepts in presentations, and creating first drafts of code or text. However, the use of LLMs is ***not*** permitted for answering quizzes, writing reports/assignments, preparing any evidence or documentation that is submitted as a final result, or for any class activity not explicitly listed as allowed. In short, use these tools thoughtfully and transparently, and always ensure that the work you submit ultimately reflects your own understanding and decisions.
- *Office Hours*
  All students are warmly welcomed to visit the course instructor during office hours. For questions or consultations related to the course, you can meet the instructor by visiting the office during the office hours listed in this syllabus. Except for special circumstances, the instructor is always present in the office during office hours, so you may simply drop by. However, if you wish for an individual consultation, cannot visit during office hours, or prefer to schedule smoothly without waiting, you may also send an email in advance.
    - ***Open Office Hour Day*** on ***Week 15 (12/08)***
      There will be no class on this day. Students may gather at a location of their choice to complete their projects. The instructor will be in the classroom during this time, so students are welcome to visit if they wish. The instructor can assist visiting students with their inquiries (such as project or class-related group or individual consultations).

Inclusivity Statement

KAIST is committed to fostering an inclusive and respectful environment, and this classroom will reflect that commitment. Here, every student will be treated with dignity and valued as a vital part of our community. I warmly welcome and respect individuals of all backgrounds, beliefs, ethnicities, nationalities, gender identities, sexual orientations, and religious or political perspectives—as well as all visible and invisible differences. Every

member of this class is responsible for upholding a culture of respect, inclusion, and mutual support. If at any time you feel that these principles are not being maintained, please come speak with me.

Academic integrity statement

In this course, I will hold you to the high standard of academic integrity expected of all students at the Institute. I do this for two reasons. First, it is essential to the learning process that you are the one doing the work. I have structured the assignments in this course to enable you to gain mastery of the course material. Failing to do the work yourself will result in a lesser understanding of the content, and therefore a less meaningful education for you. Second, it is important that there be a level playing field for all students in this course and at the Institute so that the rigor and integrity of the Institute's educational program is maintained.

Violating the Code of Academic Conduct (Honor Code) in any way (e.g., plagiarism, unauthorized collaboration, cheating, etc.) will result in official Institute sanctions. Possible sanctions include receiving a failing grade on the assignment or exam, being assigned a failing grade in the course, having a formal notation of disciplinary action placed on your KAIST record, suspension from the Institute, and expulsion from the Institute for very serious cases. Please review the Code of Academic Conduct and related resources (e.g., working under pressure; how to paraphrase, summarize, and quote; etc.) and contact me if you have any questions about appropriate citation methods, the degree of collaboration that is permitted, or anything else related to the Honor Code of this course.

Special Accommodations and Disability Support Services

If you need disability-related accommodations, I encourage you to meet with me early in the semester. If you have not yet been approved for accommodations, please contact Support Center for Students with Disabilities (phone: 042-350-2164 / office location: E11-214). I look forward to working with you to assist you with your approved accommodations.

Mental Health

As a student, you may experience a range of challenges that can interfere with learning, such as strained relationships, increased anxiety, substance use, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may impact your ability to attend class, concentrate, complete work, take an exam, or participate in daily activities. Support for undergraduate and graduate students is available through the KAIST Student Counseling Center. For urgent situations at night or outside working hours, please refer to the following 24-hour resources:

- KAIST Student Counseling Center Online Counseling
- KAIST Student Counseling Center Call: 042-350-7942
- KAIST Health Promotion Center/Medical Office (Medical/Emergency Guidance)
- National Suicide Prevention Lifeline: 1393
- KAIST Campus Safety Office

Note: Actual department names and contact information may vary based on campus announcements. Please check the KAIST Portal or each department's notice for the latest information

Course Calendar

Class				*Assignment*	
Week	Date	Topic	Agenda	Material	Due Date
1	09/01	Course Introduction		Pset 0 (not scored)	09/04
	09/03	Numerics and Error Analysis			
2	09/08	Linear Systems 1		No Assignment	N/A
	09/10	Linear Systems 2		No Assignment	N/A
3	09/15	Eigenvectors	Quiz	No Assignment	N/A
	09/17	Singular Value Decomposition		Pset 1	09/24
4	09/22	Nonlinear Systems	Quiz	Pset2	10/01
	09/24	Chuseok Holiday (No Class)		No Assignment	N/A
5	09/29	Iterative Linear Solvers	Quiz	No Assignment	N/A
	10/01	Specialized Optimization Methods		Pset 3	10/08
6	10/06	Interpolation	Quiz	No Assignment	N/A
	10/08	Numerical Integrations		Pset 4	10/15
7	10/13	Numerical Differentiation	Quiz	No Assignment	N/A
	10/15	Automatic Differentiation		Pset 5	10/22
8	10/20	Midterm Exam Week (No Class)		No Assignment	N/A
	10/22				
9	10/27	Ordinary Differential Equations (ODEs) - I	Quiz	No Assignment	N/A
	10/29	Ordinary Differential Equations (ODEs) - II		Pset 6	11/05
10	11/03	Partial Differential Equations (PDEs) - I	Quiz	No Assignment	N/A
	11/05	Partial Differential Equations (PDEs) - II		Pset 7	11/12
11	11/10	Project Proposal Presentation	Presentation	No Assignment	N/A
	11/12	Wave Propagation	Quiz	No Assignment	N/A
12	11/17	1D Wave Equation and Stability Analysis		Pset 8	11/24
	11/19	Stringed Instruments	Quiz	No Assignment	N/A
13	11/24	Wind Instruments		No Assignment	N/A
	11/26	How to CAD - I		No Assignment	N/A
14	12/01	How to CAD - II		No Assignment	N/A
	12/03	How to 3D Print		No Assignment	N/A
15	12/08	Open Office Hour Day (No Class)		No Assignment	N/A
	12/10	Final Project Presentation	Presentation	No Assignment	N/A
16	12/15	Final Exam Week (No Class)		***Final Project Report***	12/17
	12/17			*Strict Due Date!*	