Deep learning for Computer Vision and Extended Reality, 4 ECTS

Course instructors: Damien Muselet and Christophe Ducottet

Aim and learning outcomes:

The aim of this course is to provide students with all the knowledge they need to use, adapt or build a deep learning model in the context of computer vision. At the end of this course, they will be able to select or implement an architecture adapted to a specific task. They will be familiar with the main issues in deep learning and the traditional methods for dealing with them. Most common computer vision tasks will be covered, with a particular focus on those that improve the various stages of an extended reality system. These include depth estimation, lighting estimation, 3D vision, relighting and neural rendering models.

Course outline:

- Introduction to Machine Learning
  - Regression/Classification
  - Overfitting
  - Cross-validation
- Deep learning : Basics
  - Multi-layer perceptron
  - Classification
  - Gradient descent
  - Convolution and pooling
- Essential tools
  - Optimization
  - Regularization
  - Lack of data
  - Residual networks
- Architectures
  - Convolution
  - Pooling
  - Feature boosting
  - Main tasks
- Training
  - Super convergence
  - Multi-task learning
  - Distillation
- Data
  - Imabalanced classes

    - Self-supervision
    - Domain adaptation
- Generative Models
    - Variational auto-encoder
    - Diffusion models
- Neural Rendering
    - Nerf
    - Gaussian splatting

Assessment criteria: 2 written exam + Practical works

Prerequisites: Python coding and machine learning basis

Real time 3D/XR visualization, 4 ECTS

Course instructor: Philippe Colantoni

Learning outcomes
The first aim of this course is to understand the modern GPU architectures and capabilities. The second is to understand and apply the basic and advanced techniques of real-time 3D rendering in the context of XR. A focus will be placed on modern web technologies (WebGPU and WebXR) that will be used to implement these techniques.

Content
- GPU architecture
- Concept of the third dimension to create realistic 3D animations.
- The 3D rendering pipeline
- Lighting and materials
- Introduction to WebGPU and WebXR
- GPU programming with shaders
- Advanced 3D visualization techniques with **Three.js** (https://threejs.org/)

Modes of study
Course and practical works, active participation and a 3 days development sprint.

Teaching methods
- Lectures: 15 hours
- Practical work (during the lectures and specific sessions): 30 hours
- 3 days development sprint

Study materials
- The Graphics Codex, V2.17, by Morgan McGuire, 2011-2024
- The Book of Shaders - https://thebookofshaders.com
- Three.js (https://threejs.org/)

Evaluation criteria
(Written exam / written assignments / project work / …)
Theoretical examination (1h30) (50%), Practical works (50%)

Prerequisites
- Basic knowledge of HTML
- Basic knowledge of Javascript

Human Vision, 4 ECTS

Course instructor: Éric Dinet

Aim and learning outcomes:

The aim of the course is to provide a solid and integrated view of the human visual system with an emphasis on visual perception. This approach is complemented with notions of visual optics, retinal and cortical organization and neural processing of visual information. Although the course aims at a solid theoretical basis, practical issues and problem solving will be considered wherever appropriate and independent project development and research will be strongly encouraged.

On completion of this course the students will be able:

- to anatomically and functionally identify the main components of the human visual system.
- to identify the physical constraints imposed on the visual system and to relate them with the limitation on visual performance.
- to identify and to describe the main psychophysical aspects of human vision
- to use and to implement the basic psychophysical techniques.

Course outline:

- **Introduction to visual perception**
  Basic ocular anatomy. Transmission characteristics of the eye. Basic retinal anatomy. Visual receptors and transduction.
- **The retina**
  Scotopic and photopic vision. Retinal distribution of photoreceptors. Dark and light adaptation. Spatial resolution and spatial summation. Receptive fields and lateral inhibition. Temporal resolution and temporal summation.
- **Colour perception**
  Colour matching and the trichromacy. Spectral sensitivities of photoreceptors. Opponent-process theory of colour vision. Colour and lightness constancy. Acquired and inherited colour vision deficiencies.
- **The primary visual cortex**
  From retina to cortex. Basic organization of the cortex. Simple and complex cells. Maps and columns in the striate cortex.
- **Higher order visual areas**
  From the striate cortex to V2 and V3. Streams for information about What and Where. Perception of motion. Perception of objects and scenes.
- **The perception of space**
  Stereoscopic vision. Correspondence problem and disparity. Oculomotor cues. Monocular depth cues.

Lighting Science 2, 3 ECTS

Level: Advanced studies
Grading scale: 0 – 20
Primary language of instruction: English
Teacher in charge: Youri Meuret

Learning outcomes: In this course, students gain a fundamental understanding of the three main subcomponents of modern lighting fixtures: the light sources, the optics, and the thermal elements. By the end of the course, students know and understand the key electrical and optical operating principles of light-emitting diodes (LEDs), as well as the main advantages of these sources compared to alternative technologies.
A clear grasp of the ray-tracing algorithm enables students to realistically simulate illumination systems. Using the ray-mapping technique, they can design a variety of optical components for light-shaping applications, and understand the fundamental limits of such systems based on the conservation of étendue.
Students understand the primary causes and consequences of heat generation in LEDs and are able to quantitatively calculate these effects. They have insight into the main modes of heat transfer and learn to apply this knowledge for effective thermal management in LED lighting systems.
Contents: Part 1 : Light, light sources and LEDs / Part 2 : Optical modelling and design of illumination systems / Part 3 : Thermal management of LED lighting.

Study methods and assessment criteria
Study methods:
- self-study with lecture notes/recordings, and suggested literature.
- lectures (on campus).
- exercises/lab sessions: student work on a number of exercises or tasks, and submit their report online, at the end of the session.

Teaching methods
- lectures on campus (10h)
- online Q&A (4h)
- exercises/lab sessions online and on campus (10h)

Project, 5 ECTS

Supervisors: Damien Muselet, Christophe Ducottet, Philippe Colantoni and Eric Dinet.

The aim of this project is to apply all the knowledge acquired during the first and second semesters to a multidisciplinary project involving XR/VR/AR applications.
Students will form teams and select one of the suggested topics (with each team selecting a different topic) combining human vision, 3D rendering, deep learning, and computer vision. Each group will have access to a variety of devices, including VR/XR headsets, colour and multispectral cameras, multispectral lighting, LiDAR, professional cameras, geometric and colour checkers, and more.

Throughout the project, each team will be supervised by UJM teachers, and the objective is to apply all the knowledge acquired thus far to address a specific issue in a real-world application.

New topics will be proposed each year, and groups will be free to select their preferred topic or propose a new one, subject to supervisor approval.

This project will begin at the start of Semester 2, with students having reserved slots in their timetable to work on the project and meet with their supervisors.