CENTRALE NANTES

ENGINEERING PROGRAMME

2023-2024

Year 2 / Year 3

Specialisation option

Virtual Reality

OD RV

PROGRAMME SUPERVISOR
Jean-Marie NORMAND

Autumn Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 73 / 93	12	Core course	CPLUS FONRV IMAGRV MODRV	C++ Programming Fundamentals of Virtual Reality Real-time 3D computer graphics From physical geometry to 3D virtual models
UE 74 / 94	13	Core course	INTER MEDEVRV P1RV VISUS VSION	3D Interaction Industrial Software Development First Semester VR Project Scientific Visualization Computer vision and augmented reality

Spring Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 103 / 83	14	Core course	COARV COLLI CONFS P2RV TPRV	Advanced Concepts for Virtual Reality and Augmented Reality Collision detection and haptic feedback Virtual Reality Applications: Conferences Group VR Project Hands in VR: simulation and interaction in Virtual Reality

C++ Programming [CPLUS]

LEAD PROFESSOR(S): Rebecca FRIBOURG

Objectives

C++ is the historical programming language for Virtual Reality because of interactivity requirements. It is also a consequently used language and learning it can open many doors.
The goal of this course is to have the students create computer programs taking advantage of object-oriented concepts. For this, they will have to master object concepts (encapsulation, inheritance and polymorphism) as well as useful C++ extensions such as exceptions and containers.

In order to acquire operational knowledge of C++ programming, most of the course will be take the format of practical lab work. This course is a pre-requisite to many other courses of the Virtual Reality specialisation.

Course contents

- Reminder of C programming and algorithms
- Introduction to object concepts
- Objects in C++
- The Standard Library: containers, functors, algorithms, streams
- Exceptions
- Advanced C++ : casts and introspection

Course material

- OpenClassrooms https://openclassrooms.com/fr/courses/1894236-apprenez-a-programmer-en-c
  https://openclassrooms.com/fr/courses/7137751-programmez-en-oriente-objet-avec-c
- cplusplus.com http://www.cplusplus.com/doc/tutorial/

Assessment

Collective assessment: EVC 1 (coefficient 0.2)

Individual assessment: EVI 1 (coefficient 0.8)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	18 hrs	0 hrs	0 hrs	2 hrs

Fundamentals of Virtual Reality [FONRV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

After defining the basic concepts of Virtual/Augmented and Mixed Reality, this course will address the elements which allow the immersion of users into a virtual world as well their interaction with it. Firstly, the technical elements (sensorimotor interfaces), and secondly, the human factors (human senses and motor responses). The main fields of application will be presented. Design and evaluation of virtual reality applications will be addressed through case studies.

Course contents

- Definitions
- The concept of presence
- Design and evaluation of virtual reality applications
- Human senses and motor responses
- Stereoscopic vision
- Interfacing devices for Virtual Reality
- Introduction to Augmented Reality

Course material

Le traité de la réalité virtuelle. Ph. Fuchs et G. Moreau (Eds), Les Presses de l'Ecole des mines, 2006. Freely available fur students.

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	22 hrs	4 hrs	4 hrs	0 hrs	2 hrs

ENGINEERING - OD RV

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Real-time 3D computer graphics [IMAGRV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

The objectives are to 1/ understand the principles underlying the generation and rendering of real-time computer graphics, 2/ apply those techniques and algorithms in real-life examples by using the most common APIs both in academia and in industry.

This course presents the fundamentals of real-time computer graphics: 3D rendering, virtual cameras, representation of 3D objects by a set of polygons with colors, textures, etc. The ability to display computer generated images in real-time is a pre-requisite for many other computer graphic related application domains such as Virtual Reality, Augmented Reality, Scientific Visualisation or Video Games.

During the practical sessions, students will use the most common programming interfaces for real-time computer graphics such as OpenGL. Modern real-time rendering techniques such as shaders are also tackled using the Cg programming language in Unity3D. Finally, a last part of the module focuses on visually programming shaders in Unity (using ShaderGraph).

Course contents

1) Presenting the main algorithms used for displaying computer generated images

2) OpenGL:
- Introducing OpenGL: the most common low level graphical programming interface that allows real-time rendering of 3D objects. Presentation of the graphical pipeline.
- Geometrical Transformations: how can we go from a 3D object to a 2D image on a screen (model view and projection transformations, etc.).
- Z-buffer algorithm, backface culling, texture mapping, etc.
- Implementing and interacting with a simple 3D scene

3) Shaders
Shaders are programs to customise the graphical pipeline used to display in real-time 3D objects on a 2D screen. Presentation of the modified graphical pipeline allowing shaders. Writing shaders in the Cg programming language.

4) Visually programming shaders in Unity with ShaderGraph

After having studied shaders and their writing in code in Unity (programming in Cg and ShaderLab), we present how to use ShaderGraph to visually program shaders. This tool allows us to easily achieve more complex effects. Several sessions are dedicated to the presentation of this tool and the creation of two visual effects.

Course material

The OpenGL Programming Guide. Dave Shreiner, Graham Sellers, John Kessenich, and Bill Licea-Kane.
OpenSceneGraph Quick Start Guide. Paul Martz

Assessment

Collective assessment:	EVC 1 (coefficient 0.4)
Individual assessment:	EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	14 hrs	0 hrs	16 hrs	0 hrs	2 hrs

ENGINEERING - OD RV

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

From physical geometry to 3D virtual models [MODRV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

Define needs and mathematical basis of parametric surfaces and use of methods for mesh generation.

Geometric and physical models for virtual reality are required to create virtual worlds. It is essential to be able to represent 3D objects. This course presents different ways to represent 3D objects (meshes, tessellation, parametric surfaces, solid models, etc.) only digitally or from real objects (thanks to 3D scanner). Finally, in order to simulate physical phenomena in real time, we have to implement simplification model techniques to accelerate numerical calculations.

The module also includes an introduction to 3D modeling software: Blender. This introduction covers the Blender interface, creating simple 3D shapes with this tool, and simply animating 3D characters.

Course contents

1. Parametric Surfaces
- Introduction to parametric curves and surfaces: historical aspects
- Properties and limits of Bézier-surfaces
- Parametric surfaces : B-Splines, NURBS
- Tessellation, surface approximation by a point cloud

2. Mesh generation
- General introduction to volumetric mesh generation: classification structured/non-structured, conformity/non-conformity
- Structured mesh generation, link with Partial Differential Equations (PDEs)
- Non-structured mesh generation: Delaunay triangulation, frontal and mixed methods, quadtree/octree
- Space parametrization

3. Lab Work
- 3D scanning using a laser scanner and the Creform software
- 3D scanning based on photogrammetry using Photoscan
- Point cloud processing with CATIA
- Volumetric reconstruction using CATIA
- Reverse-engineering to nurbs-splines: surface lifting (GSD)
- 3D scan from scratch (Freeform IMA + FSK)

4. Tutorials for Blender

Course material

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	15 hrs	0 hrs	0 hrs	1 hrs

3D Interaction [INTER]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

Interaction between the user and the virtual world is inherent to Virtual Reality. Nevertheless, interacting with a 3D world raises important challenges that will be addressed in this module: navigating inside the virtual world, whatever its size, selection and manipulation of objects in a virtual and maybe complex environment that may contain numerous virtual objects.

In this course, you will study and implement different 3D interaction metaphors and use peripherals allowing you to interact with the 3D objects populating a virtual environment in a "natural" way, for example via voice commands, manual interactions (in use a Leap Motion) or via controllers from an Oculus Quest 2 HMD.

Course contents

- Introduction
  - Needs and motivation
  - Virtual environments
  - History of 3D interaction
  - Input devices
  - Output devices
- Interaction techniques
  - for selection
  - for manipulation
  - for navigation
- Interaction in augmented reality
- System control
- GUI, vocal control, gestural control, BCI, VirtualTools etc
- Performance evaluation

Course material

Assessment

Individual assessment: EVI 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	20 hrs	0 hrs	0 hrs	2 hrs

ENGINEERING - OD RV

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Industrial Software Development [MEDEVRV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

This course focuses on the various development tools aimed at enabling an engineer to work effectively within a team on IT projects.

Thus, students will be able to build quality applications by collaborating with different members of a team. This course includes the use of version managers, the implementation of UML, agile working methodologies and good programming practices.

All of these concepts are approached theoretically, then put into practice during a team project spread over several sessions in C++, then an application on Unity in C#.

Indeed, Virtual Reality and Augmented Reality projects are more complex for working effectively in a group, and specific working methods will also be addressed.

Course contents

1) Code version management
   - Git command line
   - Git desktop
   - Git applied to Unity
2) Unified Modeling Language (UML) applied to development
   - Class diagram
   - Object diagram
3) Agile methodology
   - Presentation of non-agile methods
   - Presentation of agile methodology (Kanban/Scrum)
4) Code Metric
   - Generation and reading keys
5) Cmake
   - Syntax and Usage
6) Code documentation
   - Good practices
   - Tools to generate documentation 'automatically'
7) Two small group projects, allowing you to apply the different concepts.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	12 hrs	12 hrs	0 hrs	0 hrs

First Semester VR Project [P1RV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

The goal of this first project is to further develop the notions that have been covered during the first semester, in particular C++ programming and OpenGL programming.

Students may propose project topics, with the requirement that they find a faculty member to validate and supervise their project. Projects are undertaken in groups of two.

Course contents

After choosing a subject students have to :
- write specifications that need to be validated
- distribute the work between them
- develop an application
- write a final report
- prepare a final presentation
- throughout the project, students have to send regular reports so that their supervisor can monitor the project's progress

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	1	0 hrs	0 hrs	0 hrs	32 hrs	0 hrs

Scientific Visualization [VISUS]

LEAD PROFESSOR(S): Vincent TOURRE

Objectives

This course aims to illustrate digital technologies to visualize scientific data. It addresses concepts of visualization (data types, geometry and topology), graphic rendering and visual perception. Practical sessions are proposed using VTK library and ParaView software.

The main objective is to make students familiar with the main rendering techniques for scientific visualization, use visual perception to design efficient visualizations and understand the current issues in this scientific field.

Course contents

- Introduction to scientific visualization: definitions and issues
- Introduction to VTK and ParaView
- Scalar field visualization
- Volume rendering
- Vector field visualization
- Scientific visualization in virtual reality (interactions, immersion)

Course material

Assessment

Collective assessment: EVC 1 (coefficient 0.25)

Individual assessment: EVI 1 (coefficient 0.75)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	8 hrs	12 hrs	0 hrs	2 hrs

Computer vision and augmented reality [VSION]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

This course aims at illustrating the mathematical tools that allow computers to extract useful information from images: image segmentation, object detection, pose computation, etc.

In order to acquire practical knowledge of computer vision and augmented reality, the course will include an initiation to OpenCV library with many lab sessions ranging from basic image processing to pose computation for Augmented Reality and 3D reconstruction.

Course contents

- Sensors, image construction
- Image processing
- Feature point detection, tracking
- Initiation to the OpenCV library
- Camera calibration
- Pose computation for augmented reality
- Tracking in image sequences
- 3D Reconstruction

Course material

Computer Vision: Algorithms and Applications. Richard Szeliski 2010 (http://szeliski.org/Book/)

Learning OpenCV. Gary Bradski & Adrian Kaehler. 2008

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	6 hrs	0 hrs	25 hrs	0 hrs	1 hrs

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Advanced Concepts for Virtual Reality and Augmented Reality [COARV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

The objective of this module is to tackle advanced concepts related to Computer Graphics, Virtual Reality and Augmented Reality. This course is divided into two phases:
- a "flipped classroom" phase where a number of documents and resources are made available to students who need to prepare them independently over the duration of the module;
- a grouped "mini-project" phase (4 or 5) in Unity 3D with the aim of taking over and continuing an existing project.

Course contents

The "flipped classroom" part of this module covers the following topics:
- Development of an Augmented Reality application under Unity using the Vuforia library.
- Introduction to ray tracing by developing an application from scratch.
- Introduction to WebGL development.
- Optional: Advanced rendering with OpenGL.

The "Unity Project" part aims to strengthen teamwork skills, task distribution and technical skills in Unity.

Course material

https://raytracing.github.io/books/RayTracingInOneWeekend.html
https://openclassrooms.com/fr/courses/3979376-creez-votre-propre-fps-en-webgl
https://unity.com/shader-graph

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	12 hrs	0 hrs	20 hrs	0 hrs	0 hrs

Collision detection and haptic feedback [COLLI]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

Collision detection is the building block of physical engines, which govern interactions between dynamic objects in a digital environment. This course will introduce you to the algorithms allowing you to efficiently calculate collisions between different geometric primitives commonly used in 3D image synthesis (3D points, curves, planes, triangular or quadrilateral facets, etc.) as well as the different bounding volumes that can be used to improve the efficiency of collision calculations.

Force-feedback, thanks to the use of haptic devices, can reproduce tactile and force stimuli for the user when interacting with virtual objects. To this end, it is necessary to detect collisions between parts of the human body and virtual objects, both accurately and very quickly (around 1KhZ according to Brooks' law).

The concepts presented in this module are followed by numerous practical exercises carried out directly in Unity.

Course contents

- Collision detection
  - General principles of collision detection
  - Geometric basis
  - Ray tracing
  - Bounding boxes
  - Space partitioning
- Haptic rendering
  - Physics engines
  - Overview and scientific foundations
  - Statics / Dynamics and friction
  - Mechanical simulation of rigid solids
- Devices
  - Haptic device and force-feedback
  - Pseudo-haptics

Course material

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	20 hrs	0 hrs	0 hrs	2 hrs

ENGINEERING - OD RV

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Virtual Reality Applications: Conferences [CONFS]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

This series of conferences is fully organized by our partner CLARTÉ in Laval for one week of the second semester. Several industrial and academic speakers are invited to share their vision and use of Virtual Reality. Practical sessions are also available using CLARTÉ's state-of-the-art equipment.

Apart from the series of conferences, students will take part in a 1.5/2 days Hackathon where they will develop a prototype of VR or AR application benefiting from CLARTÉ's hardware and expertise.

Course contents

Examples of speakers: Renault, PSA Peugeot-Citroën, Airbus, MiddleVR, INRIA Rennes, etc.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	20 hrs	0 hrs	0 hrs	0 hrs

Group VR Project [P2RV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

The goal of this project is to apply on a practical basis the concepts covered during the second semester.

In particular, students will have to develop a functional prototype of an application involving VR, AR or other complex notions (e.g. Computer Vision).

Students may propose project topics, with the requirement that they find a faculty member to validate and supervise their project. Projects are undertaken in groups of minimum four.

Course contents

After choosing a subject students have to :
- write specifications that need to be validated
- distribute the work between them
- develop an application
- write a final report
- prepare a final presentation
- throughout the project, students have to send regular reports so that their supervisor can monitor the project's progress

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	2	0 hrs	0 hrs	0 hrs	48 hrs	0 hrs

ENGINEERING - OD RV

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Hands in VR: simulation and interaction in Virtual Reality [TPRV]

LEAD PROFESSOR(S): Jean-Marie NORMAND

Objectives

To create interaction between the virtual world and reality: how to transfer a real object into the virtual world and how to simulate / interact with simple tools. Thanks to haptic devices and real-virtual links, it is possible to manipulate physical objects through real time simulation of the virtual world.

This course will look at the use of tools dedicated to Computer Aided Design for Virtual Reality (Dassault Système's 3DExperience) as well as software covered in the other courses of this specialization (3D scanner for 3D modeling, 3D interaction, etc.).

In addition, part of this module is devoted to sound immersion: through the use of the PureData software, students will be introduced to the concepts of spatial sound and must develop an application incorporating 3D sound spatialization.

Course contents

The entire course is conducted through practical sessions. Students will gain hands-on experience of Virtual Reality through involvement in short projects alongside industry experts or researchers.
The project topics are:
- Tracking and kinematics of the human body
- Modeling 3D scene in Blender
- Assembly / maintenance / ergonomics - haptic
- Spatializing objects and 3D scenes (PureData)
- Advanced 3D photogrammetry
- Interactive virtual factory using 3DExperience: reverse-engineering of a real product and manipulation of the 3D model in VR

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	16 hrs	0 hrs	0 hrs	0 hrs