Computer Animation Curriculum : An Interdisciplinary Approach

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Abstract

This paper presents a Computer Animation curriculum worth 2.5 *ECTS intended for graduate students enrolled in a Master's degree of Computer Graphics, Video Games and Virtual Reality. The content of the lecture fits the recommendations made for the topic of* Animation I *at the Computer Graphics Education Workshop [BCFH06] that was held in Vienna in* 2006*. The main novelty is, in addition to presenting a detailed curriculum, its interdisciplinary aspect. Indeed, while it is intended for a Computer Science degree, it also aims at teaching some artistic and software use aspects.*

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.7]: Three-Dimensional Graphics and Realism: Animation; —Computers and Education [K.3.2]: Computer and Information Science Education: Curriculum, Computer Science Education.—

1. Introduction

Computer Graphics is a field that keeps evolving fast. As a consequence, the content of graduate Computer Graphics lectures needs to be adapted from one year to the next. Nowadays, to be successful as a researcher or an engineer, one must have skills in different areas. In addition to standard scientific skills, it is highly desirable to possess knowledge on artistic aspects. However, teaching of Computer Graphics in general and Computer Animation in particular is still strongly separated between those two types of skills. On one hand, we find the Computer Science degrees that involve programming, math and physics. On the other hand, we find the Art degrees more focused on how to create animation movies by using modeling and animation software such as Maya [May09], 3ds Max [3ds09] or Softimage|XSI [Sof09] among others.

This hard separation is however not beneficial to the students. For example, a student in a Computer Science degree might be frustrated if he/she knows how to deform an object using equations but is unable to first create a 3*D* object to which to apply the deformation algorithm. It is also common that an artist needs to write or use a script for the software he/she is working with and the task is more difficult if that person doesn't understand anything to programming. Furthermore, it is important for team work that engineers and artists understand the work of one another. They need to collaborate and communication among them can be greatly improved if they know more about the work of the other. We thus believe it is important to teach students in an interdisciplinary way. Our Computer Animation lecture being part of a Computer Science degree, we have decided to also teach the use of modeling and animation tools.

The students also are eager to learn interdisciplinary content. Students of our Master's degree come from various backgrounds. Most of them however come from Computer Science degrees. When they are asked at the beginning of the class what they want to learn, most of them answer *Maya !*

The full Computer Animation lecture is compulsory and divided into two blocks: the first one deals with history of animation, principles of animation and animation techniques [WH02, Web05] while the second one addresses the scientific aspects of Computer Animation. Like the Computer Science or Art degrees, the nature of those two blocks is strongly separated. Even if the students learn principles of animation, they do not learn how to use software to create objects and animations to which to apply those principles. Our aim is thus to fill the gap in the scientific block of the lecture so that at the end of the course, the students have experimented with the entire pipeline. This paper presents the content of the scientific part of the lecture and shows how we

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make use of both programming tools and animation software to teach state-of-the-art animation techniques, state of current animation software, use and limitations of current software, current research problems as well as open problems. At the end of the course, students have an understanding of the existing commercial tools and their limitations but also knowledge of on-going research. This block accounts for 2.5 ECTS. In addition, the lecture is taught in English language.

The remaining of the paper is as follows: first, we explain how our lecture fulfills the requirements established at previous workshops, of the Bologna Process and of the Knowledge Base. Then, section 3 presents in details the curriculum of the lecture while highlighting its interdisciplinary aspect. Section 4 and 5 detail proposed assignments to evaluate the skills developed by the students as well as how they serve to improve the learning process. Section 6 describes how the students react to the proposed methodology. Finally, section 7 concludes and proposes some possible improvements.

2. Background

In 2006 it was mentioned and encouraged at the Computer Graphics Education Workshop in Vienna [BCFH06] that curriculum for basic and advanced Computer Graphics lectures be proposed. The course described here is an advanced lecture that we teach in the first year of the Master of Computer Graphics, Videos Games and Virtual Reality [†] of the Universidad Rey Juan Carlos, Madrid, Spain as basic Computer Animation (see Animation I in the report [BCFH06]). We also offer two advanced Computer Animation lectures for students in the second year of the Master's degree: Character Animation that corresponds to Animation II and Advanced Animation that details physically based animation techniques. Although this lecture has been created for graduate students, we believe it could be easily adapted for undergraduates. The key is to cover the same topics without detailing the most difficult techniques.

With respect to the Bologna Process requirements [FPA*06] for graduate studies, we address the following problems:

- Mobility of students and faculty. The lecture is taught in English language. We can thus receive students from abroad and our students get to improve their language skills.
- ECTS system. We follow the system of ECTS credits. While it is encouraged to create lectures worth 5 ECTS, this lecture is only 2.5 and can be combined with another half-lecture such as History of Animation (as it is currently) or Character Animation to form a complete lecture. This offers more flexibility to the students and to the professors.
- Course content and mobility. In the idea of teaching similar content as well as to improve the mobility of students, we share course content with the INP Grenoble, France. Our Master's Thesis subjects are also proposed there and students of this other university have the possibility to conduct their Master's research in ours. Although we offer this possibility to the students, they haven't taken advantage of it yet. In addition, the Animation lecture that is being taught at the Vienna University of Technology, Austria, is being taught by one of the professors of Grenoble. We thus share some content among three universities from three different European countries.

We also fulfill many requirements of the Knowledge Base for the Emerging Discipline of Computer Graphics created by the SIGGRAPH Education Committee Curriculum Working Group [LO06]:

- Professional issues. The interdisciplinary aspect of the lecture aims at facilitating team work and collaboration of group members of different specialties. The proposed semester project aims at improving on team work (project management, time management, collaboration), ethical issues and intellectual property. This is detailed in section 5.
- Course content for Animation. We cover the topics of time and motion; modeling; rendering; dynamics and procedural animation. If more time was dedicated to this lecture, it would be interesting to cover aspects such as particle dynamics. Character animation specifics (rigging, mo-cap, etc...) are covered in another lecture of our Master's degree.

3. Course Content

Animation is all about movement of objects, over time. Movement of an object should be understood as the displacement in space of that object, but also its deformation.

The lecture is divided into seven topics plus a general introduction. The first five topics introduce the necessary tools for deforming objects: representation of surfaces, modeling, geometry-based deformation techniques and physics-based deformation techniques with an introduction to collision detection and response. The two additional topics show the use of the presented techniques in two different contexts: skinning for character animation and plant modeling and animation. Character Animation is taught in the context of an optional lecture that uses this animation course as basics. Fluid animation and advanced physically based techniques are taught in another optional lecture (Advanced Animation). It is however a possibility to replace the two last topics by an introduction to fluid animation or other natural phenomena such as the animation of clouds or fire. If more time can be dedicated to the lecture, those additional topics could be treated. Although it doesn't fit in our Master's schedule, it would be great to add some lab hours where students can

[†] http://dac.escet.urjc.es/rvmaster/

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work on their animations while the teacher can directly answer them. Even if we encourage the students to come discuss their problems by email or during office hours, it is not as practical as having labs.

3.1. Introduction

Theory: The introductory class first presents the animation pipeline as composed of three main steps: the modeling of objects, their animation and their rendering. While the class mostly details the animation aspect, it is important that students understand that modeling influences the animation and that both influence rendering.

In addition we explain the animation loop and how it interacts with the rendering loop. We introduce the concepts of real-time versus non real-time animation and why the framerate of an animation is important, especially if haptic devices are added in the loop.

Practice: The practical part of the lecture consists in showing students how to create an animation using the Maya software. We teach them how to add keyframes, how to change the animation framerate and how to modify the animation curves.

3.2. Surface Models

It is essential that before teaching how to deform objects, we teach how to mathematically represent the objects. The most common types of surfaces used to represent a 3*D* object include polygonal, parametric, subdivision and implicit surfaces. Each type of surfaces has properties which make them a better or worse choice depending on the type of object and the type of animation that is performed.

Theory: We present a mathematical description of each surface type as well as the advantages and drawbacks of each with respect to ease of modeling and animating, animation and rendering speed, collision detection feasibility. For polygonal surfaces, normals of polygons as well as polygon-to-polygon intersection computations are explained.

Parametric surfaces are first introduced as parametric curves in 2 dimensions. We analyze the mathematical properties of normality, positivity, regularity, locality, *G*- and *C*-continuities, and convex hulls (useful for collision-detection). We give examples of both approximating (cardinal, Hermite) and interpolating (B-spline, NURBS, Bézier) splines. We then extend the formulation to patches and expose the related problem of adding details. As a solution, we present the patch stitching technique and the hierarchical B-splines [FB88].

Subdivision surfaces are introduced with the example of Catmull-Clark that is fairly simple. We then teach how to read subdivision masks. We also present vertex versus edge splitting techniques and various approximating and interpolating subdivision surfaces. We show how they relate to splines without entering the mathematical details and refer to the SIGGRAPH course notes about subdivision surfaces [ZSD*03] for the student to home study. We propose a homework (detailed in section 4) related to this topic.

Finally we present the basics of implicit surfaces and how they can be used to model organic shapes (the blob tree [WGG99]). We highlight their interest for collision-detection and their high rendering times with the example of the marching cubes.

For each type of surface, we discuss the pros and cons: how many points need to be moved to create and deform the object, how mathematically expensive is the collision detection, how easily can the volume of the object be computed or how controllable the deformation is.

Practice: The practical part consists in creating objects with the different types of surfaces with Maya and observe the differences between the produced objects.

3.3. Modeling Techniques

Theory: Modeling techniques such as Revolve, Extrude, Sweep and Loft are presented. Although they are typically used for modeling, we show that they can also be used for animation. We detail the mathematical formulation in the theoretical part of the class.

Practice: In the practical part of the class, we show how to use each technique on the different types of surface (essentially polygonal and parametric in that case) with Maya (see figure 1).

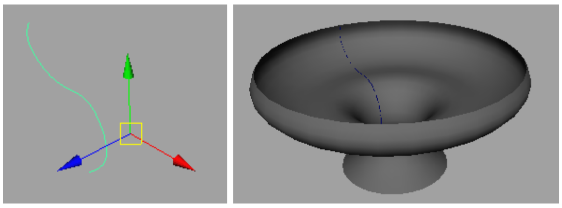

Figure 1: *An example of Revolve operation under Maya.*

3.4. Geometrically based Deformation Techniques

Geometrically based deformation techniques include all of the deformations that can be described by mathematics. They are not sufficient to generate dynamics animations. However, the artist generally prefer those techniques because they can precisely create the deformations they have in mind.

Theory: We present popular techniques such as Keyshape Interpolation (with an emphasis on the use of spline curves seen previously), Warping, Global Deformations [Bar84] (Scaling, Tapering, Bending, Twisting) and Free Form Deformations [SP86] and their extensions (EFFD, AFFD). We

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detail the mathematical equations to compute vertices deformations as well as the normals deformations in the case of global deformations. Although the math can be a little scary at first, by detailing how the equations are solved and illustrating the effect of each variable by manipulating the corresponding deformation tool under Maya helps a lot. One of the students who was beforehand allergic to math finally implemented an FFD deformation for his semester project (see figure 2) and mentioned he liked this part of the class very much, despite all the equations.

Practice: To explain to the students how some mathematical variables actually influence the deformation of an object, it is essential to show them how it *visually* works. In addition to presenting the tools in Maya (Scaling, Tapering, Bending, Twisting, FFD, etc...), we encourage the students to practice by asking them, as a homework (see section 4), to create an animation that combines the use of all those tools.

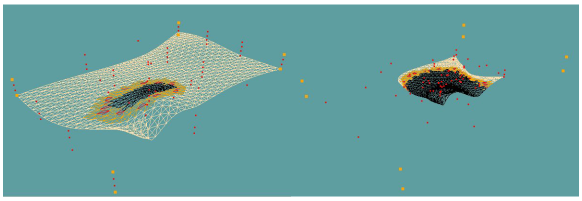

Figure 2: *An example of the use of FFD to create a paper crumpling and burning animation [MK06]. Results extracted from the semester project of Pablo Quesada.*

3.5. Physically based Deformation Techniques

Theory: Before introducing physically based deformation techniques, we briefly introduce some basic notions of physics of deformable objects (strain-stress curve, elasticity, viscosity, plasticity and fracture). We present the Lagrangian formulation for continuum mechanics as well as the concept of particles and the three Newton's laws.

As this class is taught in the first year of the Master's degree, we mainly detail the mass-spring model and its applications. We also present a few numerical integration techniques in details with their advantages and drawbacks so that the students have all the tools necessary to implement a mass-spring model as well as to understand why some integration schemes are better than others. Those include Euler explicit and Runge-Kutta schemes up to degree 4.

The concept of Finite Elements is also introduced (the details on how to solve them is part of the Advanced Animation course that we propose as an option in the same Master's degree).

Practice: We show how to *implement* a mass-spring model in Maya and how the Euler Explicit integration scheme can diverge very fast. We also present the mass-spring system of Maya that can be used on a lattice such as a piece of cloth. We show a more complex demo thanks to a home-made program as well as videos from various recent research papers so that the students see the possibilities of the technique. In addition, a homework where we ask students to integrate an equation by hand using an Explicit Euler and a Runge-Kutta 4 integration scheme is proposed (see section 4).

3.6. Introduction to Collision Detection and Response

Theory: Collision detection (with other objects or self-collisions) is often important to increase the plausibility of an animation. However, depending on which type of surface represents the object, it can be more or less trivial to compute. Implicit surfaces are the most efficient and we show that any given object can exist with different representations. For example, an object can be described as polygons for animating and rendering and as a hierarchy of spheres to detect collisions. We also present some data structures that can be used to help computing the collisions more efficiently (octree, kd-tree ...).

We present a few different techniques for collision response. Some techniques are adapted for geometrically based deformation techniques, like vertex displacement methods. Others, such as the Penalty method (adding a spring of rest length zero or epsilon between contact points) are more suited to physically based deformation techniques. Stochastic methods in the case where collisions can be missed is also an interesting approach to achieve real-time animations.

Practice: Maya has a build-in system for physics animation. We thus show how to create a piece of cloth using Maya nCloth tool and how *Passive* objects can be defined as colliding objects so that collisions are detected and treated.

3.7. Introduction to Skinning for Character Animation

Theory: In this lecture, we first present the structure of an articulated character that is composed of a skeleton and a polygonal skin. We first detail the mathematical description of rigid skinning, where a given vertex only depends on the transformation matrix of one bone. We extend this concept to linear blend skinning [LCF00] using 2 bones and more. We also show the drawbacks of the technique such as the collapsing joint default and the candy wrapper effect. However, we do not provide solutions. Those topics are developed in the optional lecture on Character Animation proposed as an option in the second year of the same Master's degree.

Practice: We illustrate the advantages and drawbacks of both skinning techniques (rigid and smooth) (see figure 3). Because this is one area where animators really spend hours, we show the students how to create both types of skinning under Maya. The automatic weight computation provided by the software is far from being satisfactory, and there is no

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satisfactory technique to date. The weights always need to be painted by hand and this is a tedious task. As we believe it is also good to show the students the limitations of a software (and hence, why research is important), we propose a third homework where the students are asked to create a simple smooth skinning animation. They are encouraged to paint the skinning weights by hand like an artist would do.

Figure 3: *On the left a rigid skinning on a female character. On the right, the same character in the same pose but deformed with a smooth linear blend skinning. Note the differences around the joints.*

3.8. Introduction to Plant Modeling and Animation

Plants are a very special type of object that needs dedicated modeling and animation techniques. We also believe it is an interesting and useful subject, but it could be replaced with fluid animation for example.

Theory: After introducing some necessary vocabulary (stem, node, bud) we present the L-systems as a modeling technique for plants [PL90]. We also detail their variants such as non-deterministic/stochastic L-systems, the use of context, and parametric/timed L-systems for animation.

As an alternative, plants can be modeled by standard polygonal meshes or parametric curves and deformed by any technique previously seen (for example, it is common to use a skeleton and a skinning technique to deform trees). We present a few geometric and physics-based grass and trees animation techniques while highlighting the use of all the deformation techniques we have seen in class.

Practice: We did not propose any practice so far but next semester, we intend to show the use of L-systems as it can be very tricky. Indeed, it is not always simple to generate a given shape from a set of rules. Under Maya, it would be interesting to show the use of Maya Fur and how it can be animated with the wind.

4. Homework and Quizzes

We believe it is important to make the student work regularly during the semester and be active rather than passive. We've all been students before and witnessed that when there is no practical or theoretical exercise to do, common practice is to do nothing and start working two weeks before the final exam. While it is often sufficient to pass a class, it is not very efficient in terms of knowledge acquisition. Furthermore, the animation lecture covers a wide range of topics that are often abstract or difficult to understand. It is not possible to address all aspects in a single semester project. We have thus decided to experiment with two techniques to improve on this problem: homework and quizzes. Homework accounts for 10% of the final grade. Another 10% accounts for the quizzes in class and 30% for the final exam, hence half of the grade for the theory. The aim of homework and quizzes is to help students who work regularly without penalizing too much the ones who don't.

4.1. Homework

One of the goals of the homework is to make the students think a little bit further. During the 6 weeks of the class, we propose 3 homework (i.e., one every two weeks). The students have between one and two weeks to solve the problem(s). The three proposed homework equilibrate between theoretical aspects of the lecture and the use of Maya.

Homework1: The aim of the first homework was to show to the students the importance of surfaces and object representation and the advantages and drawbacks of the different techniques. They were asked a few problems such as how to project a point on a mesh, how to recognize spline basis functions or how to subdivide a polygonal patch using the subdivision mask of a given technique.

Homework2: The second homework focused on the use of Maya to create an animation by applying the modeling and deformation techniques we had seen in class such as twist, bend or Free Form Deformations. The best videos produced can be seen on a dedicated webpage[‡].

Homework3: The last homework was composed of two parts: the integration by hand of a given function using two different integration schemes (namely Euler Explicit and Runge-Kutta 4 over 10 timesteps) and the comparison of the results. The second part was the realization of an animation involving a simple skinned character. The best video produced are also online.

4.2. Quizzes

It is common practice in undergraduate classes in the US to do 5 minutes quizzes at the beginning of a class. Because we

‡ http://gmrv.escet.urjc.es/ zabador/APOspring08/APO08_videos.html

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don't think that the *surprising* aspect is very interesting, we let the students know when there will be a quiz in class so that they can read the course notes and for some, get motivation to finish the homework. While it is possible in a basic animation class, this becomes however difficult for more advanced topics. The type of questions that are asked have to be very simple and answered rapidly. Examples include asking the student to recognizing if a curve can be part of a B-spline basis, filling unknowns in a simple linear interpolation equation, naming one of the Newton's laws, naming a possible use of cross-product or answering a few true/false questions. Quizzes are supposed to be easy if the student has read the course notes and done the homework.

5. Semester Project

It has been identified by the SIGGRAPH Education Committee Curriculum Working Group [LO06] that professional issues concern team work, ethics, intellectual property and accessibility. The semester project we propose to the students addresses the first three issues mentioned in the context of animation.

The semester project consists of either a research and programming project or of the creation of an animation movie. The project should be worked on during the whole duration of the course which corresponds to a 1.5 months period. To do the semester project students have to form teams of ideally 2 people (although we also accepted teams of 1 or 3 persons). Each team chooses/designs one project to work on. The topic is up to the team. It can be anything they like. The only constraint on the project is that it has to be related to animation of deformable objects.

To be able to help the students do their projects as well as to be sure they are not off-topic, we ask them to write a project proposal during the first two weeks of the class. The project proposal should include a description of the project, the composition of the team, the planning and distribution of the tasks among students as well as the resources they plan on using. They have to submit the proposal by a deadline. 5% of the final grade is obtained if the deadline is reached (lost if not).

Afterwards, the students have the whole duration of the semester to complete their project and they have to turn in a report together with a video, some source code, a script or an executable of the program depending on what's suitable. They have a hard deadline to do so. The project accounts for 50% of the total grade (half for theory, half for practice) divided in 5% for the project proposal, 10% for the report and 35% for the results achieved.

In addition, they are asked to think about ethical and copyright issues especially if they use pieces of software they found on the Internet. The same problem of ethics might arise when writing the report. Some students had no problem copying and pasting an article they found on the Internet or entire sections of a research paper without giving appropriate credits and making it look like it was theirs. Thankfully, this happened inside a class project and we got a chance to explain to them why this type of behavior is not acceptable. In the two such cases we had, the students had no idea they were doing something wrong. The writing of a report thus proved very useful. We also ask the reports to be written in English language, which is not the mother-tongue of the students. This is a good exercise whether they go work in a company or start a Ph.D. after their Master. Most students enjoyed the exercise.

Among the students, 11 decided to create a pure programming project, 6 worked on an animation movie, 3 created a movie by implementing Maya scripts in MEL and Python, 1 implemented Maya scripts and 1 developed a video game. They formed groups of one or two students except for one group that exceptionally was made of three.

Most of the projects gave very good results. Two of them were outstanding: one programming project that was submitted as a research paper and an animation movie that will be submitted to an animation festival in the coming months. We believe that one of the reasons of the success of the semester projects is that the student are *free* to decide on which topic they want to work. It makes the project more interesting to them and they can explore and learn more than if they were assigned a traditional programming project.

Among the best projects were the *Bubbles* video game that resembles Tetris but with physically deformable bubbles; the implementation of a 2D mass-spring system for a puppet animation; the creation of a system to animate fibers (paper currently under review); the implementation of the Pressure Model of Soft-Body Simulation paper (see figure 4); the implementation of a Paper Burning and Crumpling research paper (see figure 2); the realization of the *Among Bubbles* movie; and the very interesting scripts under Maya that re-create basic Maya commands as a learning tool. The videos corresponding to the best projects can be found on a dedicated webpage[§].

6. Evaluation of the Lecture by the Students

6.1. Homework and Quizzes

At the end of the class, we asked the students to fill a form anonymously to tell us what they liked about the class and what they disliked. Not a single student complained about the quizzes and homework while 17% of them explicitly mentioned that they enjoyed this system, especially the homework and problems to solve. They also found the grading well-balanced among the different theoretical and practical exercises.

§ http://gmrv.escet.urjc.es/ zabador/APOspring08/APO08_videos.html

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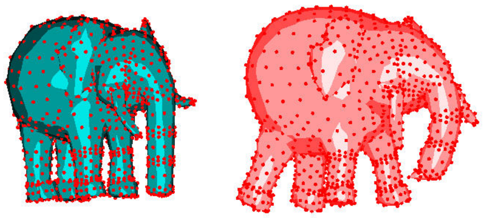

Figure 4: *Results of the implementation of a pressure model of soft-body simulation [MO04]. In addition, the student improved the model by adding temperature varying pressure. Results extracted from the semester project of Olivier Dumas.*

6.2. English Language

39% of the students complained about the fact that the class was taught in English. Some of them have quite a low level and despite all the efforts in trying to speak slow, write most of the things onto the blackboard and distribute course notes, some students found it hard to follow. However, 1 student actually enjoyed the fact that the class was in English and even if the other ones found it difficult, they agreed on the fact that is was good for them. The reasons given included the chance to improve their English while being enrolled in a graduate degree that doesn't offer language classes; the fact that it prepares to read scientific papers; and the fact that it improves students mobility.

For the final exam, the students were given the possibility to answer the questions in English or in Spanish. About half of them chose to answer in English.

Except two students, they all thought that writing the project report in English was a good idea and were happy to do so. At least one of them is now considering writing his Master's thesis in English.

6.3. Content and Duration of the Lecture

All students were satisfied with the content of the class and all of them were more than happy with the dual aspect scientific/artistic. They also declared the content was what they expected and that the numerous examples and videos shown in class helped a lot understanding sometimes difficult concepts. The only drawback was about the duration of the class. They thought it was too short and they would have liked more lectures. However, considering the number of lectures we are currently offering, it seems hardly possible to dedicate more hours to animation.

7. Conclusion

Last Spring was the second offering of our novel Master's degree. While the first group of students was not representative, the second was composed of 28 registered students, 22 of which actually came to class, completed the semester project and took the final exam. The experiment of proposing homework and quizzes was successful. The students rather liked it and those who actually did the homework got better grades at the final exam.

The results of the final exam were good in the sense that most of the students passed the class and were able to make a synthesis of all of the techniques seen in class.

The students enjoyed the freedom for the semester projects very much. They did better than expected and learned about professional concerns such as making a timetable, respecting deadlines, ethics and team work.

Despite the complaints about the English language chosen to give the lecture, 20 students out of the 22 took the optional Character Animation class the following semester, also taught in English by the same professor.

Next semester, we plan on teaching this lecture the same way. Eventually we will start earlier in the semester so that the students get more time to work on their projects.

Ideally in the coming years, we would like to create a textbook so that the class would be easier to follow by the students. That would also help harmonizing the content of Computer Animation lectures among various universities.

Acknowledgments

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