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# A TOOL FOR TEACHING SPLINE METHODS IN A COMPUTER GRAPHICS COURSE

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## Abstract

The specialized mathematics knowledge covered in a computer graphics course is usually presented to students in an abstract way. Albeit, computer graphics is an application of this (abstract) mathematics, students may find it hard to link them together. In particular one of the most difficult topics to present in a pedagogical manner to junior students in a computer graphics course is spline methods (mathematical method for data smoothing) used for curve/surface modelling. This topic involves mainly the mathematics of parametric functions, piecewise functions, derivatives, matrices, and parametric/geometric continuities. Usually a student has a vague picture of the actual output of the application of this mathematics. Many educators have experienced that students may fully understand splines application, if and when they are assigned a software project to implement splines, and this understanding could still remain vague until the very last stages of the implementation. As an alternative, static pictures may be presented in class to provide an intuitive understanding of splines. This approach is, in effect, similar to viewing a picture in a textbook. A better alternative is for the educator to demonstrate real-time spline generation, since a picture is worth ten thousand words but a moving picture (animation) is worth ten thousand static ones. This paper presents an interactive software program which is used as a tool to introduce important concepts and algorithms of spline methods to computer science and computer engineering students. The software is specially developed for educational purposes, and generates spline curves.

**Keywords:** *Pedagogical Teaching Tools, Visual Learning, Teaching Computer Graphics*

## 1 INTRODUCTION

Splines are mathematical methods used to generate smooth curves or surfaces defined by a series of given points. The term spline is often used to refer to any curve or surface, because long before computers, a spline was a flat, pliable strip of wood or metal that was bent into a desired shape for drawing curves on paper. Splines are extensively used in the area of Computer Aided Design for modelling complex figures. The given points are called control points and they define the shape of the curve. In some spline methods the curve passes through the control points (called interpolation splines), and in some others the curve passes near the control points (called approximation splines) approximating their shape.

Two of the most well known approximation spline methods are Bezier and B-Splines. These are part of the syllabus of a computer graphics course, and a Computer Science or Computer Engineering student will usually take the course at his/her third or fourth year of study. A student will be taught the theory of the mathematics of splines, which involves parametric functions, piecewise functions, derivatives, matrices, and parametric/geometric continuities. Usually students find it very difficult to put all this mathematics together (Fisher et al., 2004; Shirley, 2002; Lowther and Shene, 2001; Fisher et al, 2004) and realize that, for example, a cubic B-spline curve which is given by the formula

$$Q_i(u) = \sum_{r=-3}^0 V_{i+r} b_r(u)$$

where  $V_{i+r}$  are the control points, and  $b_r(u)$  are the blending functions (or basis functions) and are defined by

$$b_{-0}(u) = \frac{1}{6}u^3$$

$$b_{-1}(u) = \frac{1}{6}(1 + 3u + 3u^2 - 3u^3)$$

$$b_{-2}(u) = \frac{1}{6}(4 - 6u^2 + 3u^3)$$

$$b_{-3}(u) = \frac{1}{6}(1 - 3u + 3u^2 - u^3)$$

will produce a smooth curve which is actually not one, but many curves put together with continuity between each other at their joints, and has the shape of the polygon produced by the control points. Figure 1 shows a B-spline curve defined by the points  $V_0, V_1, \dots, V_5$ . Also Figure 2 illustrates a B-spline surface (from left-to-right: control points, wire-frame surface, rendered surface).

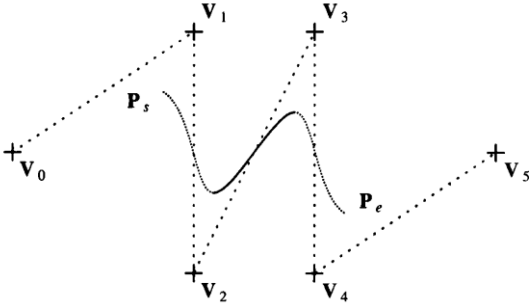


Figure 4. A B-spline curve.

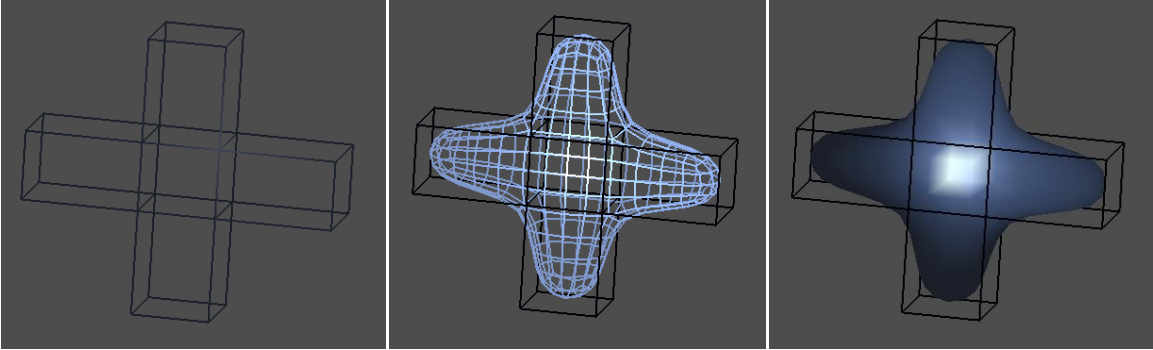


Figure 2. A B-spline surface.

When however an educator has a tool to demonstrate real-time spline generation, students find it much easier to understand the concepts, theory and applications of the methods. A number of researchers have also developed such tools (Fisher et al., 2004; Zhao et al., 1998; Zhao et al., 1999; Zhou et al., 1999).

This paper describes an interactive software program, designed for pedagogical purposes, that generates Bezier and B-spline curves. The program accepts any number of control points which define the shape of the curve. The user is able to move, as well as, add/remove control points. Also, the user can apply end-conditions to the curve. Furthermore the different segments are clearly illustrated in the animated graph. Some other options available are: show or hide the control grid, show or hide the control points and change the thickness of the curve. This tool can be used by an educator in the class as a teaching assistant tool, but also by a student doing an e-learning course.

## 2 THE INTERACTIVE SOFTWARE PROGRAM

The program calculates and displays cubic Bezier and B-spline curves. Firstly, the user is expected to enter a number of control points which will define the shape of the curve. Once the control points are entered the curve is drawn in the display area. Also, the user can apply several options and conditions to the curve that are found on the control panel which is on the right of the display area. The software is designed to allow the user to directly interact with it and see the results in real time. Figure 3 illustrates the user interface.

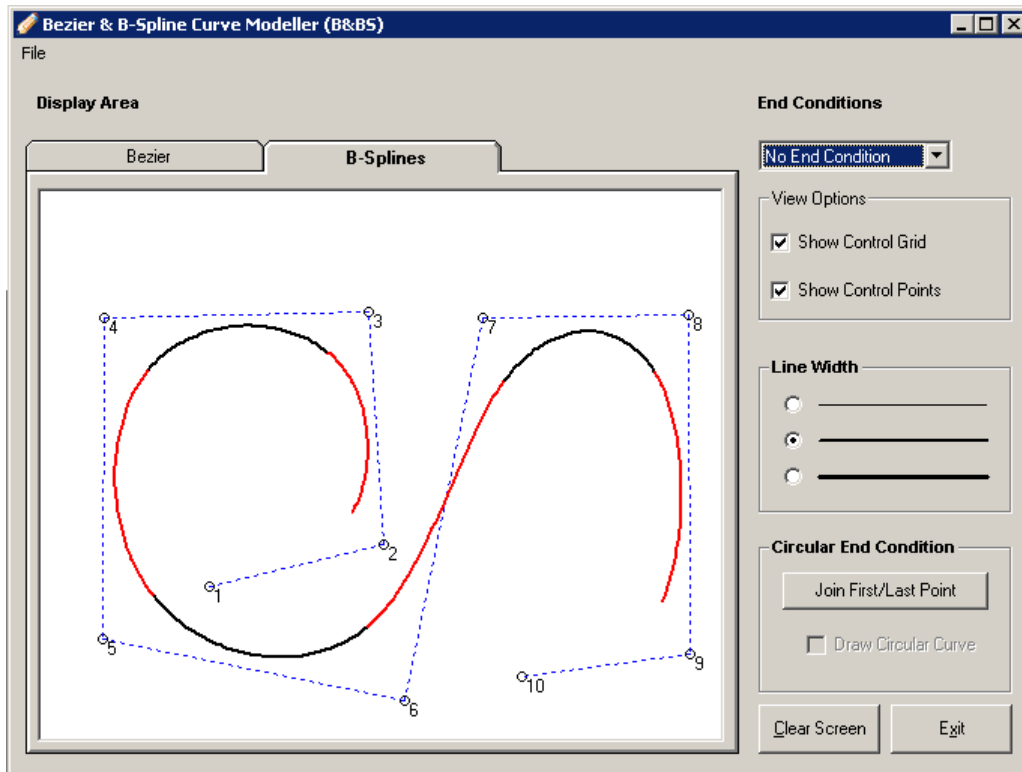


Figure 3. The interactive software program.

A control point can be moved or deleted and additional points can be entered at any position in the control polygon. The curve will be recalculated and the result will be displayed. In Figure 4 a control point numbered 6 is added and the resulting curve is illustrated.

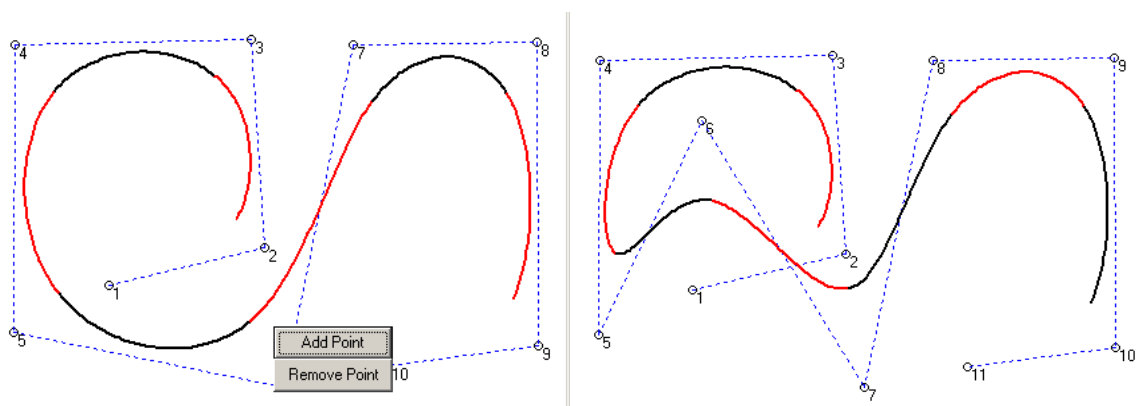


Figure 4. Adding a control point.

The most important property that some spline methods have, including Bezier and B-splines, is the “local control” property. This ensures that, if we alter the position of a control point only a part of the

curve will be affected. This is the reason why splines are very important in modelling. If we consider modelling a complex figure, such as the human body, it is desirable to introduce fine detail on the figure. For example, in order to model the muscles on the arm of a human we will move some control points near the arm and the rest of the body will not be affected, e.g. the legs. Using the software this property can clearly be presented to students. This is shown in Figure 5 where control point 8 is moved.

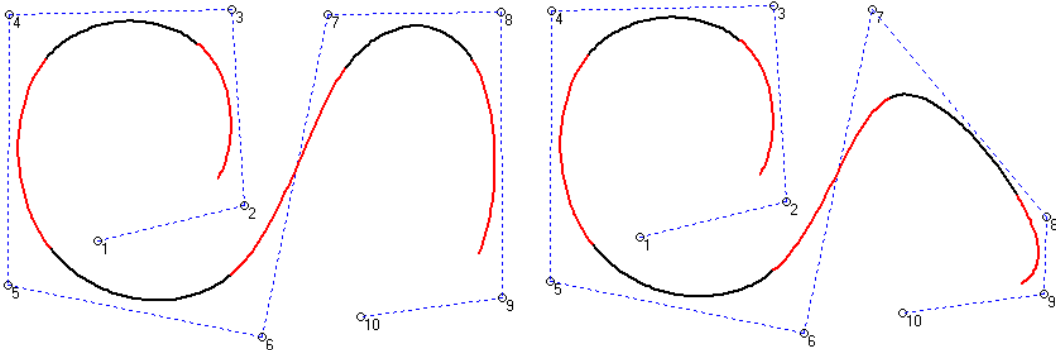


Figure 5. The local control property.

Additionally, other properties, such as end-conditions and circular splines can also be illustrated (Figure 6).

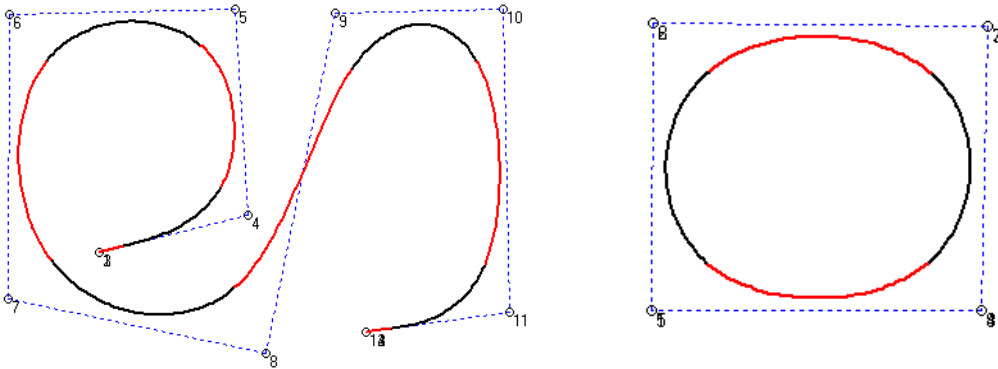


Figure 6. A treble end-condition and a circular B-spline.

This section described some of the features the software program offers to the user. It is suitable for educational purposes as it allows students to visualize spline curve generation and properties in real time. It combines both interactivity and user friendliness as the curve segments are displayed in two different colors, black and red, so that the different pieces (polynomials) of the curves are clearly indicated.

### 3 RESULTS

The computer graphics course was introduced in the Computer Science BSc path at the university in the fall 2003 semester, and since then it has always been taught by the same lecturer in both the fall and spring semesters. The interactive software program was introduced as a teaching tool for the four semesters of (Fall/Spring 2007 and 2008). The final examination included always two questions on the material of spline modelling, which carried 30 grade points from the whole examination paper. The result of this introduction may be depicted in the grades of the students on these two questions before and after the use of the software program. More specifically, the average grade of the two questions for all classes taught prior to the introduction of the software program was estimated to be 17.2/30. The corresponding estimate for the post software program period was 21.6/30. In other words, the average

grade for the two questions rose by 4.4/30 grade points. These results may provide evidence that the use of the software program in class does actually assist both the lecturer in presenting material in a more efficient manner, as well as, the student in understanding abstract concepts better. In qualitative terms the students have at several points of times, both orally and in writing (in the course/lecturer evaluation survey), been expressed positively above the software tool. They specifically described it as “very helpful”, “simple and user-friendly”, “would be nice if we had such tools to use for several not easy to understand concepts in this and other courses”, etc.

#### **4 SUMMARY AND CONCLUSIONS**

This paper presents an interactive software program that is used as a tool in the computer graphics course to illustrate spline methods to students. We have used it at our university for the last few years and by means of comparing the students’ performance in the specific topic of the course before and after the introduction of the software tool, and also by considering the students’ comments, we come to the conclusion that students understand easier and in more depth the theory and application of spline methods with the use of the software tool.

The main purpose of the software is to generate Bezier and B-spline curves by accepting from the user any number of control points which define the shape of the curve. Additionally, the software allows the user to move the control points, add a new control point between any control points that have been already entered or remove any control point. Also, the user is able to apply end-conditions to the curve. There are some additional options available such as showing or hiding the control grid, showing or hiding the control points and changing the thickness of the curve.

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