An Interactive Presentation of Maple 3D Graphics in PDF Documents

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Abstract

The paper presents the authors' experience with including interactive 3D objects into PDF documents, starting with modifying 3D graphics in Maple, followed by its export into the VRML format, then its conversion to U3D with the use of Deep Exploration, and finishing with its embedding into a PDF document by means of pdfTEX and the `movie15` package. This procedure preserves the possibility of the user's interaction with 3D objects even in the final PDF document without the necessity of the local installation of Maple or other graphical programs. All supplemental materials that accompany this paper can be found online at the folowing URL: `http://www.math.muni.cz/~plch/eJMT/`.

1 Introduction

We believe that the PDF format need not be introduced in great detail. It has been dominating the field of digital documents for several years not only in scientific publications but due to its portability, it has also spread to the general public. It was this transferability of text documents between various platforms that lay behind developing the PDF format, the original idea being that the final document should look the same on all platforms and various hardware. The PDF format is, however, still being developed and is bringing new options. At present it is already possible to embed animations and video or audio recordings into PDF documents. One of the new features brought by the 1.6 version of 2004 is the possibility to insert 3D objects into electronic PDF documents independently of any further commercial applications. Such documents can be then viewed on any platform with the same results[1].

Embedding the 3D support into PDF gives, literally, a new dimension to this format. It is no longer necessary to limit ourselves to two-dimensional exports, projections and animations when presenting

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[1] Successful viewing and manipulation of 3D objects that appear in this document requires version 8.1 Adobe Reader (or higher).

3D data, it is possible to insert truly interactive 3D materials now. The interactivity of 3D objects in PDF includes rotation, moving, zooming, enabling extra lighting, using orthographic projection, and showing cross-sections. The document with embedded 3D objects has several important advantages in comparison with PDF containing only links to interactive versions of the graphics. In the first case a user works with one file only. He does need neither complementary graphic and animation files nor the internet connectivity.

The format used for saving the 3D geometry in PDF is the U3D format and also the new PRC format.

The Universal 3D (U3D) is an open file format for saving and transferring 3D data. This format was designed by the 3DIF consortium (3D Industry Forum) and later, in August 2005, it was standardized by Ecma[2] and became a universal standard presentation of 3D data of all kinds, enabling portability between various platforms.

2   Creating a 3D object in U3D

In order to create "mathematical" 3D objects, we can use the whole range of specialized or general mathematical programs, one of them being the Maple computer algebra system (`http://www.maplesoft.com/`). We have good experience with creating 3D graphics in this program (see [1],[6]) and so we focus only on describing the conversion of mathematical 3D graphics from the Maple program to the U3D format.

The up-to-date version of Maple[3] (12) does not offer the possibility of exporting 3D graphics into U3D. We have tested two ways for converting Maple graphics into U3D:

- saving graphics in Maple in DXF and VRML formats,

- saving graphics in Maple in MPL or JVX formats (by means of Maple library JavaViewLib), displaying the graphics with the use of JavaView[4] and then saving it in the OBJ or VRML formats.

The best results are obtained by exporting from Maple to VRML followed by the conversion into the U3D format by means of the commercial program Deep Exploration (Windows OS only)[5]

(`http://www.righthemisphere.com/products/dexp/`).

Let us now describe the simplest way to obtain a U3D file using Maple graphics. The method will be demonstrated using the following example (the result is displayed in Figure 1).

1. We create a picture in Maple (the picture is taken from [4]):

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[2]The international standardizing institution.

[3]Export into the U3D format has not been implemented into other mathematical programs so far either.

[4]A freeware application for displaying and editing 2D and 3D objects [3].

[5]When writing this paper we found a freeware program for the conversion into U3D – Meshlab (`http://meshlab.sourceforge.net/`). However, we have no practical expirience with it so far.
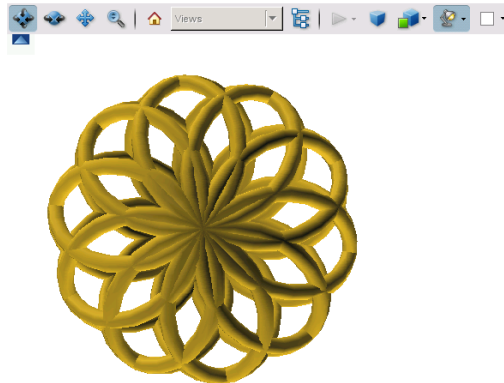
Figure 1: A graphical object in the U3D format

```
> m:=7:n:=10:Xt:=cos(m*t)*cos(n*t):
> Yt:=sin(m*t)*cos(n*t):Zt:=sin(n*t):
> f1:=plots[tubeplot]([Xt,Yt,Zt,radius=.05],t=-Pi..Pi,
> color=[1,.8,.1],ambientlight=[.4,.4,.4],numpoints=450,
> light=[75,50,1,.9,.5],orientation=[0,26],tubepoints=11,
> scaling=constrained,projection=.5,style=patchnogrid);
```

The export from Maple into VRML is executed with the command `vrml` from the `plottools` Package. The command

```
> plottools[vrml](f1,"fig1.wrl");
```

creates the file `fig1.wrl` in the required format. Nevertheless, not all parameters of the Maple graphics will be preserved by the export – we shall discuss the details in section 2.1.

2. We open the file `fig1.wrl` in Deep Exploration. It is, however, necessary to set "Flip coordinate system" in the menu "Settings" to the value "No", otherwise Deep Exploration will use a different coordinate system from Maple.

Before its final export to U3D, the graphics can be modified in Deep Exploration. It is possible to use various transformations such as moving, rotating, and scaling. The changes can be performed with a mouse in the scene, or transformation values can be substituted into the given table. Transformations are suitable for modifying descriptions, asymmetrical functions, contours, or grids. For example a grid created by the option `style=patch` must be slightly "pushed forward" in front of the object – so that it does not blend with the objects and is therefore made visible.

Before saving the graphical object it is further necessary to set the option "Convert To Double Sided" in the menu "Tools" – "3DTools", otherwise it can happen that the object will not be visible from the back view.

3. We save the graphics in the U3D format.

4. We embed the U3D file into a PDF document (details of this process are provided in section 3).

Figure 1 shows the embedded graphics with the tools of 3D Toolbar which is part of Adobe Reader. The Toolbar is displayed by placing the cursor on the picture. The Toolbar includes the options: zoom, spin, pan, enable extra lighting, change the background color; and you can also display or isolate only certain elements of the model. It is possible to use various render modes too (Solid, Transparent, Shaded Illustration etc.).

By means of Maple and Deep Exploration we can create not only interactive graphic objects, but also interactive animations. The following example (Figure 2) shows an animation for demonstrating the topic of function contours. Single objects (the function, plane and function contours) were created in Maple and exported one by one into VRML. The corresponding worksheet and the detailed description of the animation producing process can be downloaded from the above mentioned address.
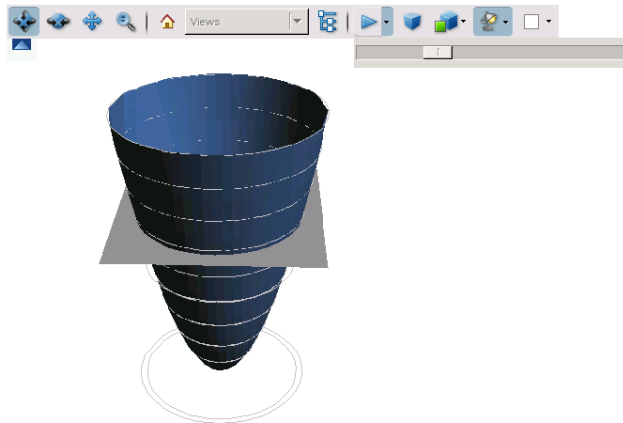

Figure 2: An animation in U3D

2.1 Various difficulties while exporting from Maple into VRML

As we have already indicated, the graphics in a VRML file can have a different appearance from the generating Maple graphics whose features are set by the command `plot3d`. This subsection, therefore, deals with difficulties that can occur when exporting graphics from Maple to VRML. The commands

```
> vrml(plot3d(3*sin(x)*cos(y),x=-Pi..Pi,
> y=-Pi..Pi,tickmarks=[3,3,3],axes=frame),'file.wrl',
> tickback_color=brown,tickfore_color=yellow);
```

export the function with the axes. The tickmarks, however, will be displayed as cubes having descriptions on their sides. The result (Figure 3) is not, therefore, very suitable for mathematical publications ([5]).
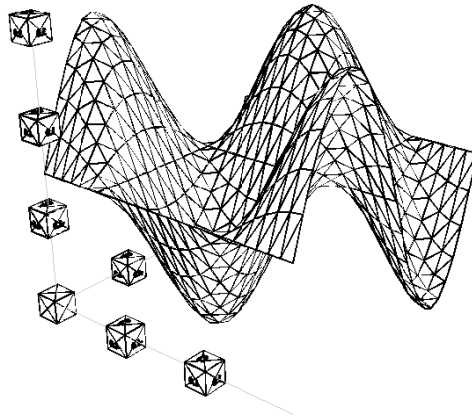

Figure 3: Exporting axes from Maple to VRML

As it is very often necessary to display the coordinate system in mathematical graphics, we have prepared the procedure `PlotAxes` for plotting the axes in Maple in such a way that the export to VRML (and then to U3D) preserves them. Its use can be demonstrated on the following example:

```
> func3_1:=plot3d(0.1*(2*x^3+4*x^2+ y^2-2*x*y),
> x=-sqrt(6)..sqrt(6),y=(x^2-2)..4,color=[.04,.98,.98],
> style=patch):
> func3_2:=plot3d(0, x=-sqrt(6)..sqrt(6), y=(x^2-2)..4,
> color=[.21,.08,.79]):  axes3:=plotAxes(4.5,4.5,5,.02):
> f3:=display([func3_1,func3_2,axes3]):
> vrml(f3,"fig3.wrl");
```

The axes are plotted by the procedure `PlotAxes` whose parameters are the lengths of the axes (x, y, z) and their thickness. The function and axes are displayed together by the command `display` and then saved to the `fig3.wrl` file, the result after the export is shown in Figure 4. This graphic can be used for illustration of finding absolute maximum and minimum values of $f(x, y) = (2x^3 + 4x^2 + y^2 - 2xy)/10$ on the set $M = \{(x, y) \in \mathbb{R}^2 \colon x^2 - 2 \le y \le 4\}$.

Graphics exported to VRML has the same ratio scale on all axes (in Maple, we set the same scales on axes by the option `scaling=constrained`). Thus, if we want to display a function which takes large values on some of the axes, it is convenient to perform a corresponding modification in Maple. For example if we want to illustrate that the function $f(x, y) = x^3 + y^3 - 3xy$ has a local minimum at the point $[1, 1]$, we must display the function in the neighborhood of this point. If we set $x \in \langle -1, 3 \rangle$, $y \in \langle -1, 3 \rangle$, then the values $f(x, y)$ lie in the interval $\langle -10, 40 \rangle$. When generating
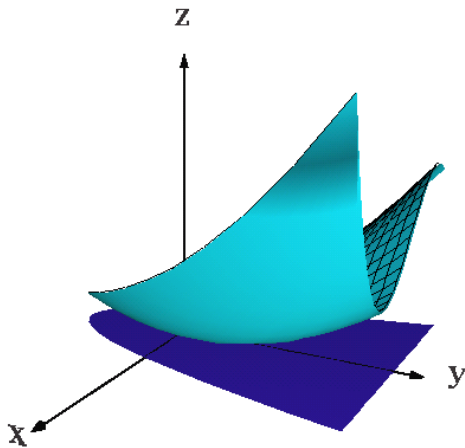
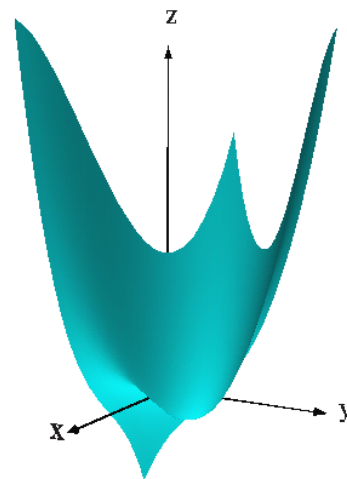Figure 4: The function and axes created by the `PlotAxes` procedure

Figure 5: Different scales on axes

the 3D graphics for this example, we use the function $f(x, y)/5$ in Maple and the result (Figure 5) produces a better representation of the function than if the original function was displayed in the given intervals.

Another possibility is to generate the original function and then to modify it in Deep Exploration by means of the function "Scale".

Because of the mentioned problems with axes, it is advisable not to use the parameter `axes` in Maple. Axes descriptions (or any other texts) created by the command `textplot` are kept, however their size and color set by the parameters `font` and `color` change. Generally, it is necessary to re–modify the descriptions in Deep Exploration specifically, the graphics size, place and rotation.

When setting the color of the object in Maple, it is possible to use the fixed color name or the RGB palette as a parameter of the option `color`. However, if we set the color depending on the coordinates, it is not displayed in the final VRML file.

In a similar way, some render modes as `patch`, `hidden`, `wireframe`[6] are kept by the conversion, others change. For example, if we use the option `patchcontour` for displaying the function surface in Maple, the contours are not preserved by the export. Thus, if we need to draw the contours, we must plot them as an independent object (the command `spacecurve` from the `plots` Package) and then display them together with the function.

3 Embedding a U3D graphical object into a PDF document

The U3D graphical object we obtained can be embedded into a PDF document either by means of the commercial product Adobe Acrobat3D (`http://www.adobe.com/products/acrobat3d/`) or we can use the typesetting system TEX and the `movie15` package ([2]). In the following we shall

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[6]If we set the render mode to `wireframe` in Maple, it will not be possible to change the render mode by "Toolbar" in the final PDF document (for example to "Solid").

deal with the non–commercial way, i. e. TEX and the `movie15` package. We use pdfLATEX (the required version at least 1.20) for direct PDF output. If a PDF document is generated in the LATEX → `dvips` → `ps2pdf` sequence, it is necessary to invoke `graphics` and `hyperref` packages after invoking the `movie15` package. As already mentioned, to display the final document correctly we must use the 8.1 Adobe Reader (or higher).

We invoke the package in the source file by the command

```
\usepackage[3D]{movie15}
```

and the embedding of the graphics itself will be performed by the command `\includemovie` whose syntax is:

```
\includemovie[options]{width}{height}{file.u3d}.
```

A detailed description of all options for including 3D graphical objects can be found in the manual to the `movie15` package. We shall only mention some of them.

The option `3Dlights=<lighting scheme>` sets the lighting of the object, the default lighting scheme is as specified within the 3D artwork.

The option `3Dbg=<r> <g> <b>` sets the background color of the canvas. We can use only fixed point real numbers in the range from 0 to 1.

The option `3Drender=<render mode>` determines the render mode.

We consider the most important options to be those that affect placing an object in the scene. In the following, we shall, therefore, focus on it.

3.1   The optimum position of the object in the scene

The position of an object in the scene (Figure 6) is specified by the vector $\overrightarrow{COO}$ having direction from the origin of the coordinate system to the center of the object (the option `3Dcoo`), by the vector $\overrightarrow{C2C}$ having direction from the center of the object to the location of the virtual camera (the option `3Dc2c`), and by the distance ROO of the virtual camera from the center of the object (the option `3Droo`). In addition, we can set the camera's aperture angle by the option `3Daac` and rolling of the camera around the optical axis by the option `3Droll`.

If these parameters are not set, the virtual camera would be situated in the position $(0, 0, 0)$ and `3Droo=0, 3Dcoo=0 0 0, 3Dc2c=0 -1 0, 3Daac=30, 3Droll=0`.

Considering the fact that calculating the optimum setting of these parameters is quite difficult, it is convenient to use the command `\movieref` with the parameters `3Dcalculate` or `3Dgetview` which can help us determine the values of the above mentioned parameters.

The following construction can be used for determining such distance of the virtual camera that the whole object (or a group of objects) is visible:

```
\includemovie[toolbar,label=label_1]
{\linewidth}{\linewidth}{file.u3d}\\
\movieref[3Dcalculate]{label_1}{Calculating the optimum distance}
```
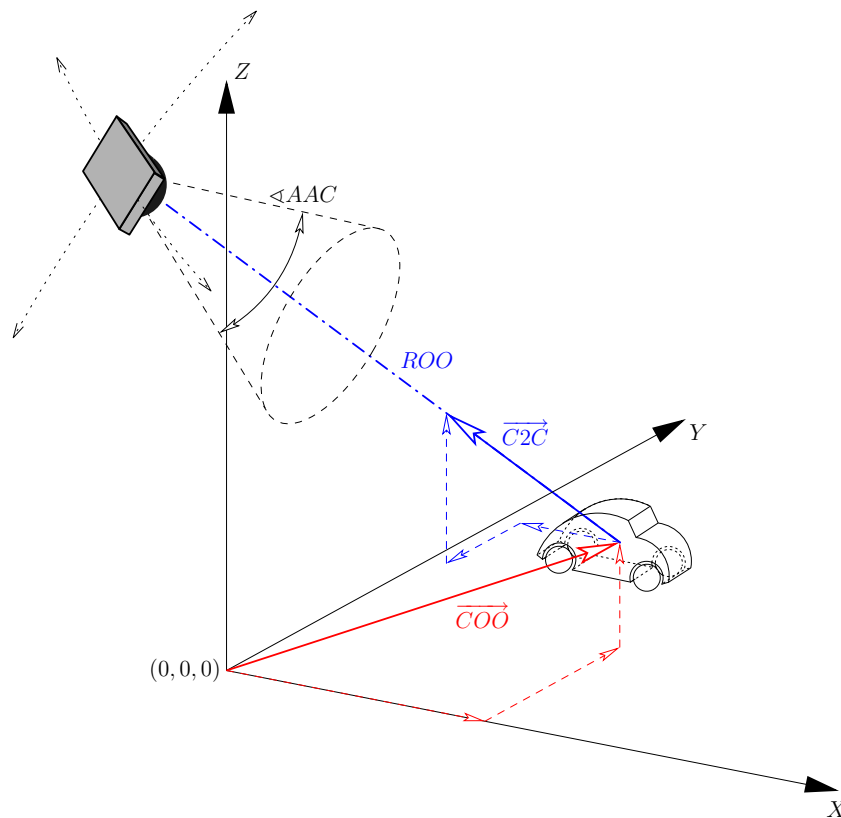
Figure 6: Position of the object in the scene, taken from [2]

Now we compile and recompile the document (until there appear no more warnings). The final PDF document includes the link called "Calculating the optimum distance". After we click the link, a dialogue box with the optimum values of `3Droo`, or also `3Dcoo` appear. We copy the settings into the source text and remove the command creating the link. Thus we leave only the command `\includemovie` and add the number parameters:

```
\includemovie[toolbar,label=label_1,3Droo=23.33,
3Dcoo=0 0.55 15]{\linewidth}{\linewidth}{file.u3d}
```

If we want to influence the rotation of the object in the scene, it is helpful to use the command `\movieref` with the parameter `3Dgetview`.

```
\includemovie[toolbar, label=label_2, 3Droo=23.33]
{\linewidth}{\linewidth}{file.u3d}\\
\movieref[3Dgetview]{label_2}{Calculating the optimum view}
```

In the final PDF document, we can thus see the object which we place to the required position by means of Adobe Reader Toolbar. If we use the option `toolbar`, it will be displayed by placing the cursor on the frame. Alternatively we can call the Toolbar by a right–click (Show Toolbar / Hide Toolbar).

Clicking on the link we open a dialogue box with the parameters values `3Dcoo`, `3Dc2c`, `3Droo`, `3Droll` and `3Daac` which correspond to the current view in the Reader. The values are of the following syntax

```
{<coo_x> <coo_y> <coo_z>}{<c2c_x> <c2c_y> <c2c_z>}
{<roo>}{<roll>}{<aac>}
```

Then we copy individual values to the corresponding parameters of the command `\includemovie`. When using this construction it is convenient to write the subtracted parameter `3Droo` into the command `\includemovie`.

The command `\movieref[3Dgetview]` can be also used to create the named views of the scene. The following example (Figure 7) shows the function $f(x,y) = \frac{xy}{x^2+y^2}$ from various views which are possible to select by clicking on the links ([7]).
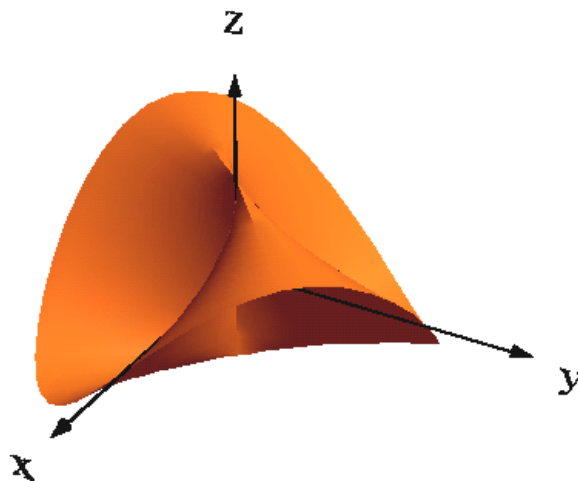
Various views of the given function – Top View, Bottom View and Back View.

Figure 7: Hyperlinks to predefined views

4   Conclusion

Implementing the support for inserting interactive 3D objects into the PDF format has a considerable effect on the possibilities of creating electronic mathematical publications. Interactive mathematical graphics can be now embedded into texts of high typographic quality, prepared by the system pdfTEX.

The final document preserves the possibility of the user's interaction with the 3D object. Our experience shows that interactive graphics created in the Maple program can be relatively easily converted into the U3D format and embedded into PDF documents.

At present there is only one step of the process that requires commercial software for the conversion into U3D. Apart from the Deep Exploration program described in this paper it is also possible to use Acrobat 3D Toolkit for that conversion. This program is provided with Acrobat 3D and is being developed with the cooperation of Adobe and the Right Hemisphere company (i.e. the creators of Deep Exploration).

However, as this area is undergoing an intensive development we can hope that soon it will be possible to export 3D objects from Maple into U3D either directly or with the JavaView program[7]. Creating interactive mathematical texts will then be even simpler than at present.

References

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[7] Plch R., Šarmanová P.: *Interaktivní 3D grafika v HTML a PDF dokumentech*, Zpravodaj CSTUG **18** (2008), č. 1–2, ISSN 1211-6661.

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[7]This program also enables exporting the Maple graphics into the VRML format, however, this export yields results which differ from the direct export from Maple (there are especially color differences).