An Introductory Cou rse on Visualization

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Abstract

A Visualization course offered twice (1997/98 and 98/99) as an elective in the MSc degree on Electronics and Telecommunications at the University of Aveiro is presented. Its contents, bibliography and teaching methods are described. Some difficulties encountered during the preparation and lecturing of this course are identified.

1. Introduction

Taking into consideration that Visualization is becoming very important and useful in many areas, an introductory course on Vizualization seems a valid contribution to the curriculum of any post-graduation in science or technology and thus it was considered adequate as an elective course of the MSc in Electronics and Telecommunications offered at the University of Aveiro. This post-graduation program includes several courses and a thesis and aims to be a large spectrum degree encompassing mainly one of four areas of Electrical Engineering (Electronics, Telecommunications, Signal Analysis and Processing and Computer Science); this means that it can give formation either to future consumers or facilitators of visualization techniques and systems. This is the context where the referred introductory course was meant to exist; thus its general objective is to introduce the students to a new area which evolves rapidly, addressing the fundamental concepts, providing a basic foundation, good enough to allow and encourage them to apply or proceed work in that area. Stating this objective more specifically, this course should introduce the students to what Visualization is and can do, as well as it should make them appreciate its benefits and how current tools can be exploited in many application areas; it intends to give a consumer's perspective as well as a facilitator's perspective. However such a course should also serve other more general objectives related to training students to be able to perform the kind of work a post-graduated is expected to do; this involves training them on doing bibliographic research, using adequate working methods and correct technical communication (i.e. writing and speaking).

In the following sections a brief description of the general contents, bibliography and teaching methods used twice (1997/98 and 98/99) on the introductory course on Visualization will be presented. Some difficulties encountered by the author during the preparation and lecturing of this course are also identified.

2. General Contents

This course was designed to have 36 hours (24 lectures) spread along a semester; some of these lectures are dedicated to other activities as justified in section 3. The list of addressed topics, presented bellow, indicates the duration, focus and specific bibliographic references (briefly described in section 4) which have been used.

1- Introduction: definitions, history, goals and principles of Visualization (1 lecture)
2- Overview of Visualization applications (2 lectures)
3- Human Visual System (1 lecture)
4- Visual Representation of Quantitative Information (1 lecture)
5- Framework (1 lecture)
6- Visualization Techniques (4 lectures)
7- Foundations on the enabling technologies: Computer Graphics, Digital Image Processing and Human Computer Interaction (7 lectures)
8- Data Characteristics (1 lecture)
9- Visualization Products (1 lecture)

In the first lecture, corresponding to topic n.1, a general introduction to the area is made. Besides presenting the definitions and goals of Visualization, a focused approach to visualizing data is presented as a means to select adequate techniques to allow exploration, analysis and then presentation of data. The main references used are the books by Earnshaw and Wiseman, and Keller and Keller.

This first lecture is of great importance, it is intended to motivate the students and establish the focus and "philosophy" of the course. Two fundamental ideas are conveyed: a) Visualization is concerned with exploring data and information graphically as a means of gaining understanding and insight into the data (not just presentation graphics!) b) how to do

visualization? There is a need of a methodology for selecting visualization techniques, however no "recipes" exist. The focused approach described by Keller and Keller in the first section of their text is presented. To conclude, a set of images produced from seismic data (also from the book by Keller and Keller) is used to illustrate the incremental process one may expect while seeking the best way of visualizing data.

Topic n.2, is meant to give an idea of the large quantity of applications that Visualization finds in a great diversity of scientific and engineering disciplines. This should make the students aware of the importance and usefulness of Visualization, as well as allow them to better understand all the other topics of the course. This overview is given through the presentation of a large collection of visualization images obtained in a variety of disciplines and emphasising the kinds of information revealed rather than the details of the visualization techniques. A number of examples extracted from several bibliographic references is used (as the books by Brown et al., Keller and Keller, Brodlie et al., Earnshaw and Wiseman).

The third topic is concerned with the "human part" of the visualization process, which is essential. The capabilities and limitations of the human visual and information processing systems are briefly described, stressing that they have important implications for design and that users, in spite of sharing common capabilities and limitations, are individuals with differences which should not be ignored. The human visual system is the main subject and the lecture is based on a document prepared by the author which is included in HyperVis (an on-line tutorial on Visualization) and indicates specific bibliography.

In Topic n.4, the fact that visualization is not new in concept is stressed; most principles that have been used to produce good maps, scientific drawings and data plots apply to computer visualization. This lecture is based on the interesting work of E. Tufte (mainly the 1983 text but also the 1990 text, to support colour usage).

Topic n.5 presents a framework model describing Visualization systems in abstract terms; this framework will be used to present techniques, data characteristics, products and applications in the remaining lectures. As an introduction to this topic, models of scientific investigation and visualization process are presented. This lecture is based on the corresponding chapter of the reference by Blodlie.et al.

The concept of visualization technique, introduced in the previous topic as the responsible for generating and manipulating a graphic representation from a set of data and allowing investigation through user interaction, is developed in topic n.6. The three main elements of a visualization technique are described accordingly to the model used by Brodlie at al.; a classification and a notation for visualization techniques introduced by the same authors is used to support the study of a range of techniques, generic in nature and which can be tailored to different applications. These techniques are illustrated through several examples (extracted also from the references by Brown et al., Keller and Keller, among others).

Topic n.7 addresses the main aspects of Computer Graphics, Digital Imaging Processing and Human Computer Interactions needed to be able to understand the visualization techniques. Addressed issues are: a 2D S/W package, geometrical transformations and projections, specifying a view in 3D, colour, overview of the problems and methods to achieve realism, visibility, illumination and shading, histogram operations, filters and image transforms and general principles for user interface design. The explanation of these subjects has always in mind its use in Visualization and examples including Visualization techniques already introduced are used as much as possible.

Topic n.8 is concerned with data. A classification that seems suitable for describing different types of data identified within the used reference model is presented. An overview of data formats and data compression techniques is also presented; this overview can be supported by the reference on graphics file formats by Brown and Shepard.

A Visualization system is presented, ideally, as an integrated whole providing means to support the effective exploration of complex data. Topic n.9 presents a classification of visualization software and a variety of existing software products. The adopted classification is an hybrid between the classification used by Brodlie et al. and the one proposed by Brown et al.. The software buyer's guide included in Brown et al. is used to illustrate the great variety of existing commercial products and relevant characteristics which need to be considered in the choice of a S/W product. The study of this subject is complemented by demonstrations some of the students have to make on several of these products (as part of their assignments).

This is the general contents of the curriculum for the presented course as it has been applied on both academic years of 1997/98 and 1998/99. From the initial proposal of this course [1], the main change corresponded to a substantial increase on the number of lectures devoted to the enabling disciplines. The author had initially planned to spend a lesser amount of time on these subjects since elective courses on those subjects (Digital Image Processing, Computer Graphics and Human Computer Interaction) are

currently offered at the Department and it seemed reasonable to expect that students taking the Visualization course would have already some background on those subjects. The fact that none of the students, in both academic years, had that background came as a surprise; in fact it seems that, most of the students had made this choice in order to get some formation in those areas. For this reason, the author decided to increase substantially the amount of time devoted to enabling technologies; this option, although controversial from the point of view of a visualization curriculum, appeared to be the most reasonable choice for those students, possibly allowing them to benefit the most from the course.

The current contents of the course follows, in essence, what has been done by the community of Visualization educators [2,3,4]. It is expected to evolve, according to the experience obtained, each time it will be taught; however the author expects evolution to occur mostly in the specific way each topic is addressed, bibliography, sequence or duration of different topics, rather than on the overall structure.

3. Teaching Methods

As referred, the course is organised in 1h 30min lectures along a semester, i.e., two lectures a week; its distribution by the topics is indicated in the previous section. There are no practical classes; students are supposed to perform their assignments, under supervision of the teacher, but on their own time and with a high degree of autonomy. These students usually work full time (at the University or at enterprises), which makes very difficult to organise working sessions involving all the students; that is the reason why only 19 lectures are assigned to the topics, i.e., 5 are left open and are "sacrificed" to activities that could, otherwise, be performed in extra hours. These sessions have been devoted to:

- presenting some selected SIGGRAPH videos[1] with examples of applications (1 lecture)
- visiting facilities where people use visualization regularly in their work (1 lecture)
- presenting student's assignments (2 lectures)
- lectures by people that use or make visualization (1 lecture)

Until now two visits were organised, both related to Earth Sciences and inside the Campus, one to a Laboratory using Remote Sensing data and another to a Laboratory of Geophysics including some field demonstration on the acquisition of Ground Penetrating Radar data. Both visits where guided by researchers from those laboratories, showing the students which kind of work they are involved in and how they use at the moment, and they would like to be able to use, visualization techniques and tools. Some other laboratories exist at the University that can be visited in years to come, as in Chemistry and Environment.

The two lectures by external people that have been organised were concerned with visualization of Archaeological data and Geographical Information Systems; however a great variety of other subjects might be interesting.

As referred, general objectives of this course include training students on doing bibliographic search, using adequate working methods and correct technical communication (i.e. writing and speaking). Since these objectives are usually easier to achieve when the evaluation is based on practical assignments and the expected number of students in elective courses on this MSc is low, that was the type of evaluation used in both academic years (the course had 5 students in 1997/98 and 6 in 1998/99).

Each student has two different assignments, the first consists in giving an oral presentation of ≈ 40 minutes on some subject and the second, a more demanding assignment, consists in a work which in general involves some implementation (either developing code in some language as C++ or using a visualization S/W as IDL). Both assignments are proposed by the teacher taking into consideration the profile of each student (background, interests, etc.); however the students are told that they can propose their own assignment by presenting an extended abstract; these proposals may, of course, be rejected. On other courses, offered by the author of this work, some interesting proposals have been presented and accepted; however, on the Visualization course none of the students decided to do it, until now.

The choice of the subjects for the oral presentations as well as for the second assignment is related to the current interests of both the teacher and the students as well as to interests of other people (from the University or outside) that ask for collaboration in some specific visualization tasks. Along these two academic years the oral presentations have consisted mainly in S/W demonstrations (Matlab, IDL, Iris Explorer and OpenGL) or have addressed volume rendering algorithms. Second assignments have been related to the following interest areas:

[1] from SIGGRAPH Video Review Issue 108 - Scientific Visualization 95 which, in spite of having some years, still contains interesting examples; however a more recent issue already exists: SIGGRAPH Video Review Issue 124 - SIGGRAPH 97: Visualization Program, that could be interesting.

- visualization of archaeological data from a XV century shipwreck existing in the Aveiro Lagoon
- visualization of geophysical data obtained from Ground Penetrating Radar
- visualization of data related to the use of Location-Routing models of obnoxious facilities
- development of an hardware processor for volume rendering implemented with FPGAs
- development of evaluation methodologies for visualizations used in the study of epilepsy and involving data obtained from different modalities as surface electroencephalogram (EEG), depth electro-encephalogram (SEEG), tomography (CAT) or magnetic resonance imaging (MRI)
- development of evaluation methods for visualizations obtained using raycasting
- development of evaluation methods involving models of Human Visual System

For the supervision of many of these assignments the author had the invaluable collaboration of colleagues working in enabling technologies and application areas.

These assignments consist, in general, of a bibliographic research on the subject, a proposal of what work could be interesting to develop, an implementation of part of this work, a small technical report and a document written as a scientific paper. Most students put a lot of work and enthusiasm into these assignments and supporting them has been very interesting, however students typically take long time to finish their tasks. In spite of the fact that this course is not a research oriented course such as the one described by Banks [5], many of the recommendations and difficulties presented by this author are also applicable; the choice of subjects for the second assignment, its supervision and finally the preparation of the paper corresponds to a significant burden associated to the course; this solution is only viable for a very small number of students.

This type of assignments have resulted very stimulating for the more interested students, however for less motivated students it is perhaps too demanding and may result frustrating both for the student and the teacher. For these reasons, the author is considering the possibility of maintaining this second assignment for volunteer students and give the alternative of an examination for the ones who are not so committed to visualization.

One of the main difficulties has to do with the writing of the "scientific paper", many students just don't like to write (and don't have enough experience) and a special attention is needed to this part of the work (as well as in the preparation of the oral presentation). Difficulty in writing is a general problem of our students, so some extra effort has been devoted to it, in this course. During a lecture, the teacher usually stresses the importance of communicating correctly any work and generally instructs the students how to do it before they start preparing their oral presentations or their papers; some bibliography on the subject of writing and speaking is also recommended [6,7]. The teacher also encourages students to write in English since it is the "lingua franca" in technology. The process of preparing the papers is iterative and some of them need as many as 3 or 4 iterations. Since the teacher and, in some cases, other people also have to invest effort, not only in the supervision but also in reviewing the paper they become co-authors; when the final version of a paper is ready it can be published as an internal note (in the Department's Journal), submitted to a conference or not used at all (accordingly to the nature and quality of the developed work and achieved results).

From the 5 papers of 1997/98, four were published as internal notes; modified versions of two were accepted at conferences organised in Portugal and one will be submitted to another conference. One of the assignments involved porting to a different platform an already existing S/W developed by someone who was far away and no longer working on the subject; in spite of the fact that the student has done enough work to succeed in the course, the obtained results did not justify their publication. This is always a risk of this kind of assignments and care should be taken to minimise it, however the author feels it is impossible to completely eliminate the possibility of "something going wrong".

Papers accepted in conferences should be presented by the students whenever it is possible; this opportunity should be viewed by students as a "reward" for having done a good work. From the institution perspective this should be considered as a valuable contribution to the overall quality and good name of the degree. For this reason it was possible, until now, to find institutional financial support for this activity, with the reasonable constraint of submitting papers only to conferences which imply low travelling expenses.

4. Bibliography

Knowing how to search for and use bibliography is an important part of any course, however at MSc level it is fundamental. At this level lectures are mainly meant to give the basic underlying theory and point out important issues, not to present them in detail; for these reasons a good bibliography is in fact fundamental, thus a select bibliography is given to

the students and the importance of having the capacity of obtaining new and adequate bibliography is stressed.

Due to the fact that Visualization is a relatively new discipline, no text books seem to be available (at least in the sense as they exist in other longer established disciplines as Computer Graphics or Digital Image Processing). To overcome this type of difficulty usually two alternatives exist: use several books and papers or write some notes to support the course. The second alternative, in the view of the author, is not interesting at MSc level, the students ought to consult several bibliographic references; however an experienced teacher may write some notes conveying his/her perspective on some of the topics. Since the author does not have enough experience in lecturing this course, even writing some notes seemed out of the question. Thus the book by Brodlie et al. was used as general support for the course. As it is stated in its preface:

" this book proposes a framework through which scientific visualization systems may be understood and their capabilities described. It provides overviews of the techniques, data facilities and human computer interface, that are required in a scientific visualization system.... the ways in which scientific visualization has been applied to a wide range of applications are reviewed"; and it seemed comprehensive enough to be used as a "guideline".

However since it is not a recent and detailed text, some other more up to dated or more detailed references were used as support for several topics as already mentioned in section II. Attempting also to provide the students with a bibliography that can be useful in their future activities, the author selected a small set of bibliographic references that covers the subjects addressed in the lectures. In the next sections the general usage of these bibliographic references is described and a commented bibliography is provided. A list of some other references which have been useful, for instance to support practical assignments, is also provided along with brief comments.

During the lectures, but mainly during the preparation of their assignments, students are strongly advised to become familiar with other possible sources of interesting references such as journals and conference proceedings as well as the different methods of getting them (as in libraries, throughout data bases, Internet). In fact, the University Library provides an information system which allows the remote bibliographic search in its databases, other portuguese databases and in services as INSPEC, which students are urged to use for their bibliographic research.

4.1. General usage of the selected bibliography

The first bibliographic reference (of the list presented in 4.2) is, as already mentioned, the one that will provide general guidance for the course. The following three references of the same list can also be used as support for several topics, as definition and goals of Visualization, overview of visualization applications, techniques, data characteristics, visualization products and case studies.

The most interesting reference by Tufte can be used to support the study of the history and principles of Visualization (independently from using computers).

The reference on graphics file formats can be used for the overview on the relevant issues to file formats and data compression.

The next five references can all be considered as text books of the so called enabling technologies of Visualization: Computer Graphics, Human Computer Interaction and Digital Image Processing; thus they can be used by the students to obtain a background on those technologies.

Finally, the last reference can be used to support the introduction to the Human Visual System.

4.2. List of main bibliography

- Brodlie, K., L. Carpenter, R. Earnshaw, J. Gallop, R. Hubbold, A. Mumford, C. Osland, P. Quarendon, *Scientific Visualization, Techniques and Applications*, Springer Verlag, 1992

This book was written to be a reference guide for the Visualization community on the technical aspects. A framework is described and used to present techniques, data characteristics, products and applications. In spite of not being up to dated in certain aspects it still gives a good overview of the main issues that should be addressed in an introductory course on Visualization.

- Brown, J., R. Earnshaw, M. Jern, J. Vince, *Visualization, Using Computer Graphics to Explore Data and Present Information*, John Wiley, 1995

Provides background on the field of visualization giving an overview of design issues, visualization market and various visualization products. It illustrates a wide variety of real-world applications through case studies.

- Keller, P., M. Keller, *Visual Cues*, IEEE Computer Society Press, 1993

It is intended to people confronted with the problem of discovering the meaning of their data sets. Using practical examples from many disciplines, it illustrates visualization techniques, tips and rules of thumb, that help to produce informative images.

- Scott Owen, G. et al., *HiperVis-Teaching Scientific Visualization Using Hypermedia*, (on-

line), ACM SIGGRAPH Education Committee, http://www.education .siggraph.org, 1996

It is a hypermedia document under development which addresses the fundamental topics of Scientific Visualisation.

- Tufte, E., *The Visual Display of Quantitative Information*, Graphics Press, 1983

It is concerned with the design of statistical graphics as well as with how to communicate information through the simultaneous presentation of words, numbers and pictures. It reviews the graphical practice in the last two centuries and seeks to account for the differences in quality of graphical designs.

- Brown, C., *Graphics File Formats: reference guide*, Manning Publications, Prentice Hall, 1995

It is a comprehensive guide to file formats used in computer graphics and related areas (including visualization). It discusses implementation and design of file formats focusing on the basic issues for its evaluation and development (as data types, organization and compression).

- Foley, J., A. van Dam, S. Feiner, J, Hughes, *Computer Graphics: Principles and Practice*, 2nd ed., 1990

This is considered the standard reference in Computer Graphics. It deals with the fundamental topics of this area in adequate depth, as well as with many others.

- Watt, A., F. Policarpo, *The Computer Image*, Addison Wesley, 1998

An updated coverage of subjects from the three fields of computer imagery which have previously only appeared in separate texts from Computer Graphics, Image Processing and Computer Vision in a coherent overview.

- Shneiderman, B., *Designing the User Interface-Strategies for Effective Human Computer Interaction*, 3rd ed. Addison Wesley, 1998

Provides a complete and current introduction to user interface design. It offers practical techniques and guidelines taking also great care to discuss underlying issues and to support conclusion with empirical results.

- Dix, A., J. Finlay, G. Abowd, B. Russell, *Human Computer Interaction*, 2nd ed., Prentice Hall, 1998

It is a text book in its area, providing a multidisciplinary perspective of the subject. It covers the basic psychology and computer technology involved and the interface between them, as well as usability and more advanced topics.

- Gonzalez, R. C., R. E. Woods, *Digital Image Processing*, Addison Wesley, 1992

It is commonly used as a text book in its area; it covers the fundamental concepts and methodologies for Digital Image Processing.

- Fishler, M., O. Firschein, *Intelligence, The Eye, the Brain and the Computer*, Addison Wesley, 1987

Uses an integrated approach on human and machine intelligence, using knowledge from several areas as computer science, cognitive science, linguistics, biology anthropology and psychology.

4.3. Other bibliography

Other bibliographic references have been used to support either specific topics of the lectures or practical assignments. These references include papers published in journals and proceedings of conferences as well as books. A list of some of the books (the ones the author considers may be most useful to a reader of this work) is included.

- Tufte, E., *Envisioning Information*, Graphics Press, 1990

Presents a collection of exemplary designs representing all types of information, widely distributed in time and space, through which design excellence in complex data representation is identified and explained. Includes an interesting chapter on how to use colour.

- Earnshaw, R., N. Wiseman, *An Introductory Guide to Scientific Visualization*, Springer Verlag, 1992

A book intended for readers new in the field, gives a quick summary of what Scientific Visualization is and can do. Can be indicated as an easy to read introduction to the subject.

- Travis, D., *Effective Color Displays: Theory and Practice*, Academic Press, 1991

Addresses perception, displays and colour models. Provides practical guidelines to the effective use of colour, without disregarding theoretical foundation. It is a useful text for designers wanting to use colour.

- Kaufman, A., *Recent Trends in Volume Visualization*, 2nd IEEE EMBS International Summer School, June 1996, Berder Island, France, 1996

Provides a survey of volume visualization and its trends with a focus on biomedical applications.

- Rosenblum, L., R. Earnshaw, J. Encarnação, H. Hagen, A. Kaufman, Sklinenko, G. Nielson, F. Post, D. Thalman, *Scientific Visualization Advances and Challenges*, IEEE Computer Society, Academic Press, 1994

Demonstrates techniques, examines diverse application areas and addresses relevant issues in Scientific Visualization.

- Grinstein, G., H. Levkowitz (eds.), *Perceptual Issues in Visualization*, Springer Verlag, 1995

Addresses issues in the field of applied perception, provides a portrayal of the problems that can be

addressed towards increasing the effectiveness of information displays.

- Lichenbelt, B., R. Crane, S. Naqvi, *Introduction to Volume Rendering*, Prentice Hall, 1998

Provides an introduction to volume rendering concepts and presents an organised logical progression through the volume rendering pipeline; it also contains a CD-ROM with source code which results very useful for practical assignments in the subject.

- Murray, J., W. VanRyper, *Encyclopedia of Graphics File Formats*, O'Reilly Associates, Inc., 1994

Provides detailed technical information on nearly 100 file formats; it also includes chapters on graphics and file format basics.

5. Conclusions

Offering this course has not been an easy task for the author, which have encountered several difficulties; she hopes this work may give a positive contribution to whom it may be interested in preparing a course on visualization.

Perhaps the first and main difficulty encountered in the preparation of the course is related to the lack of text books offering comprehensive approaches to the field; this implies not only a great effort in searching for adequate bibliography but also (and perhaps more important) a great effort of organisation and systemisation of the topics to address. This problem can be tackled with the (direct or indirect) help of other more experienced educators and working-groups in the area which publish papers, organise workshops and maintain on-line sites containing useful information (as SIGGRAPH, EUROGRAPHICS, AGOCG). After the initial effort of putting together a curriculum that makes sense, it is necessary to decide on the best approach for the kind of students one is expecting to encounter, to collect and choose the specific materials to the lectures and last (but not least) to choose the subjects and type of practical assignments and the evaluation to be used. All these choices have to be re-evaluated every time the course is offered based on the accumulated experience of the teacher and feedback from the students. The search for new up-to-dated bibliography as well as the choice and preparation of practical assignments which could result interesting have been the greatest concerns of the author of this work. These concerns are also expected to be the main concerns in the years to come since the proposed curriculum is based on the curricula of similar courses offered in several European and American Universities and it is expected to evolve mostly in the specific way each topic is addressed, bibliography, sequence or duration of different topics, rather than on its overall structure.

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