Surviving Sepsis - a 3D integrative educational simulator

Filip Ježek *[1], Martin Tribula [2], Tomáš Kulhánek [2], Marek Mateják [2], Pavol Privitzer [2], Jan Šilar [2], Jiří Kofránek [2] and Lenka Lhotská [1]

Computer technology offers greater educational possibilities, notably simulation and virtual reality. This paper presents a technology which serves to integrate multiple modalities, namely 3D virtual reality, node-based simulator, Physiomodel explorer and explanatory physiological simulators employing Modelica language and Unity3D platform. This emerging tool chain should allow the authors to concentrate more on educational content instead of application development.

The technology is demonstrated through Surviving sepsis educational scenario, targeted on Microsoft Windows Store platform.

I. Introduction

The importance of electronic media in education has been unarguable in the last decade.

Traditional forms of didactic media, such as text, sound, picture or motion picture remain almost unaltered in digital media reflected almost unchanged in digital media. Their breakthrough enhancement has been achieved thanks to their indexation (for effective search) and accessibility from anywhere, eventually combined with a possibility of direct collaborative editing. Traditional e-learning platforms offer also various additional services on top of their usual content.

However, computer technology can certainly display greater educational possibilities, notably simulation and virtual reality (VR). VR is expected to become a crucial educational form of the future, especially in medicine, because it helps create experience instead of mere knowledge. Only mistakes and eventual reflection on the root causes of such misunderstandings lead towards true expertise [1].

The methods used in medical education could be classified according to immersiveness and a level of detail. Truly immersive virtual reality that enables medical students to acquire professional knowledge and skills without endangering a real person is the primary objective of a medical e-learning. A level of educational benefits usually rises with costs - from a simple book to seminar, or a physical training using physical models, mannequins or actors to real situations, which necessarily bring about the largest benefits.

New opportunities for medical education are found in virtual 3D worlds delivered over the internet. These can include a virtual patient - a programmed avatar linked to a simulation model — or possibly an avatar controlled by the teacher.

* corresponding author filip.jezek@fel.cvut.cz

[1] Department of cybernetics, Faculty of electrical engineering, Czech Technical University in Prague

[2] Institute of Pathological Physiology, First Faculty of Medicine, Charles University in Prague, Czech Republic

While the physical simulation is more complex and immersive, virtual simulation is more cost-effective in a larger scale. Often, both approaches are combined, using first a more detailed training with virtual simulation and theoretical introduction, and then a physical simulation to check the drill. As showed by [2], the educational effect of virtual patient is satisfyingly similar to a standardized patient.

A set of educational content and simulators have already been developed [3]. Still, it requires a lot of technical knowledge to develop a simulator. Hence, our mission is to create an environment for easy development, which enables the author to concentrate primarily on the content. The presented platform is another milestone in this effort. For the simulation part, a custom tool chain has been created, which allows the developer team to embed the Modelica models into simulators. The simulators are then used as learning objects for medical education, with or without the assistance of teachers.

II. Aim

The demands on immersiveness have been rising. As the technical possibilities expand, so are our expectations. In other words, what was satisfying a decade ago is now obsolete. This assumption holds not only in computer games, but in the field of medical education as well.

Recently, the research team has been in a close cooperation with several intensive care practitioners and scholars, namely from Military University Hospital Prague and AKUTNE.CZ. The cooperation has lead us into the area of problem-based learning in intensive care medicine. A node-based scenario description is often used to capture essential situations in acute medicine scenarios. We have combined the nodal-based approach with 3D virtual reality and our physiological simulation-based approach to achieve the best possible results from both.

Until now the conducted research/simulation has targeted a solo explanatory e-learning application for student home use. This tool was also used by teachers for explanatory purposes. From now on, the research/simulation aims to support the education in computer-equipped classrooms, where all students can take part in the simulation under a direct supervision of the teachers, who can lead the students in their own progress or stop the simulation in order to offer additional explanation.

The objective is to create a tool, which integrate all aspects needed for the lesson - simple educational simulators, results of complex model for detailed situation debriefing and the virtual reality node-based simulator.

978-1-4244-9270-1/15/©2015 IEEE

III. METHODS

A. Modelica

Modelica is an equation based language to model physical systems. The use of Modelica has grown rapidly in industry over the past decade and has drawn a lot of attention. The most detailed monography was published recently by Peter Fritzson [4]. Unlike traditional procedural languages, such as C++ or designated modeling languages or even block-oriented visual languages (Matlab Simulink), the present research is not focused on the computing procedure or input-output inference. Instead, the equations are stated and the solver enabled to process the causality [5]. Together with our Physiolibrary [6], the research team has managed to develop and maintain large (thousands of equations) models, which are necessary in integrative physiology.

B. Physiomodel

Physiomodel ([7]) represents the latest version of a HumMod:golem edition [8] has been derived from HumMod model [9]. The presented version has been developed using Physiolibrary [6] and notably improved, especially in acid-base. Well-arranged objects and design patterns used in Physiolibrary have made the whole complex model lucid and easy to work with. Our colleagues who are preparing medical training using Simulator report, that most demanding task in fitting virtual patient to new scenario is finding the right parameter, Physiomodel is designed to make this task easier.

C. Unity

Unity3D platform has proven its utility not only among game developers, but anytime 3D engine is needed. The main cause for choosing it though was its support of .NET language. Indeed, Unity3D could use scripts and libraries written in .NET and export its scenes as .NET project. The scene then could be controlled from .NET as a regular view layer. In this way, the team has prepared a scene with a lying patient and all medical devices and supplies with several stages, which are being gradually uncovered throughout the game.

D. Bodylight platform

Bodylight platform enables the use of Modelica on .NET platform. Modelica deploys a multi-step simulation method. After equation sorting, pruning and manipulation, it compiles a model to the common procedural language using Susan templates [10]. Then, the translated model is linked with a numerical solver and built into executable. The translation is intercepted by targeting it to C# language, using an appropriate template and then linking it directly to our own F# implementation of IDA solver from SUNDIALS [11]. Unlike using separate solver, this method makes it possible to have solver as a portable library, independent of the target system.

The Bodylight platform was initially prepared for rapid development of Silverlight simulators, noted in results section. Silverlight platform has been profiled as web-based and multiplatform with the use of Moonlight by Mono project. This concept was already applied by other teams [12]. However, Microsoft discontinued the development of Silverlight in 2013 and the plugin is planned to be removed by the end of the 2015.

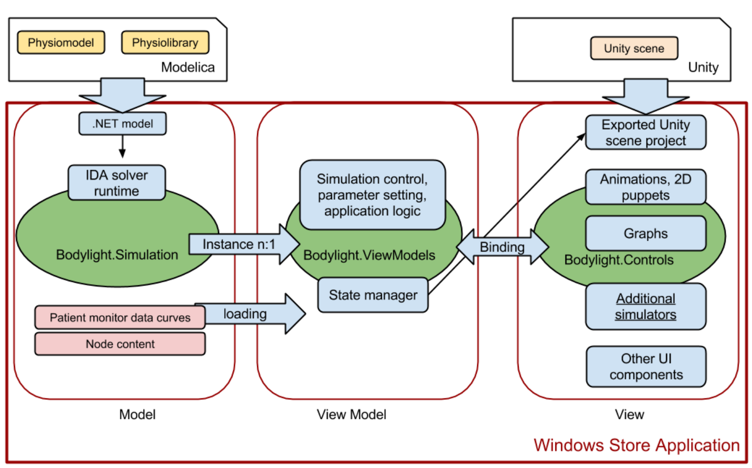
Still, Silverlight is a part of .NET framework and it is possible to share codebase within the .NET languages family. We have added conditional translation with minor changes, so as to make possible to build for Windows Store target as well. Since the model part of the Model-View-ViewModel pattern [13] (MVVM) is envisaged to be unrelated to the view as a part which is different on either platform, only minor changes were needed to make the code portable. The team has created a new project which targets Windows Store and uses conditional translation for the changes. This approach opens the possibility for both platforms to be build from single codebase.

E. Overall design

Overall design integrates all the described features using the MVVM pattern. The 3D scene from Unity3D is exported to Visual Studio project and added to View layer, together with other user-interface parts controls. Modelica model is translated to C# and together with the solver and static data forms the model layer. The View model holds the application state and establishes communication between the layers.

The educational content is held separately to simplify maintenance and enable a rapid content-centered development. That includes question nodes (question,

Figure 1. Schematics of application integration. Modelica and unity are exported into .NET equivalent



answers, explanatory and next nodes, which are all in plain text xml format) and simulated patient monitor curves. The physiological model is automatically generated from Physiomodel and kept in Modelica, some of the logic is kept hard-coded in the ViewModel layer though.

The combination of techniques described above has already acquired Utility model protection.

IV. Results

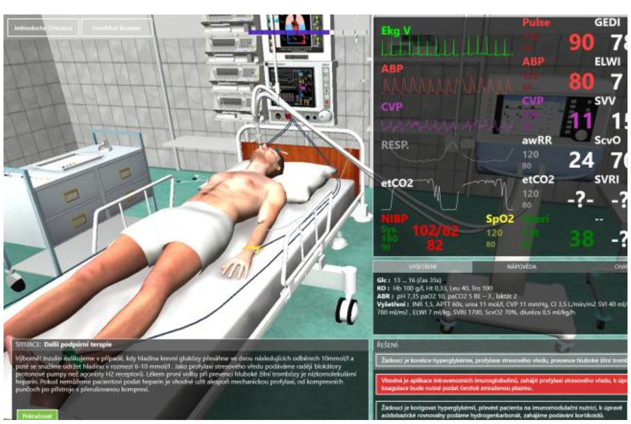
Some initial results of Bodylight framework were already published, namely set of five educational simulator for course of Biomedical engineering by Ježek [1] and Simple circulatory simulator by Tribula [14].

Based on tools described above, our latest contribution is the Surviving Sepsis, a virtual patient node-based scenario educational game for drill exercise of severe sepsis. This application integrates multiple approaches into one:

- Educational content similar to existing node-based games, as described in [15], but enhanced with other modalities, such as 3D virtual presence, familiar outputs from patient monitor, and explanatory part. This guides the student through a complicated case to check and maintain the knowledge. 3D scene is modeled after real medical devices modeled after the real operating room with all common devices (Fig. 2). The student is guided through node-based simulation of the sepsis.
- Physiological simulator of simplified human circulation gives additional explanatory information during the lecture, as seen on Fig. 3.
- Detailed physiological information for initial state of the patient, results from PhysioModel (Fig. 4).
- The teachers module enables all instances of the application to connect onto server and send it to progress and identification, so the teacher could stop the progress, adjust the explanation or chat with students (see Fig. 5).

This application is still considered as a prototype, as the Physiomodel is not well adjusted to the patient's state yet.

Figure 2. Node based simulator in action. Note the virtual patient in intensive care unit with all required devices, noted in the scenario.



This requires collaboration of domain experts, i.e. medical practitioners. Only after evaluation of the feedback from using the simulator in class, it is possible to finalize the development.

Figure 3. Simulator of simplified circulation helps understand underlying dynamics.

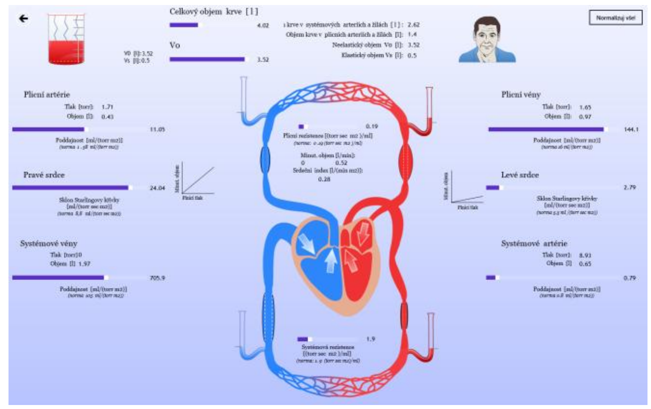


Figure 4. Physiomodel (here named as Hummod) browser shows detailed information about initial patient state.

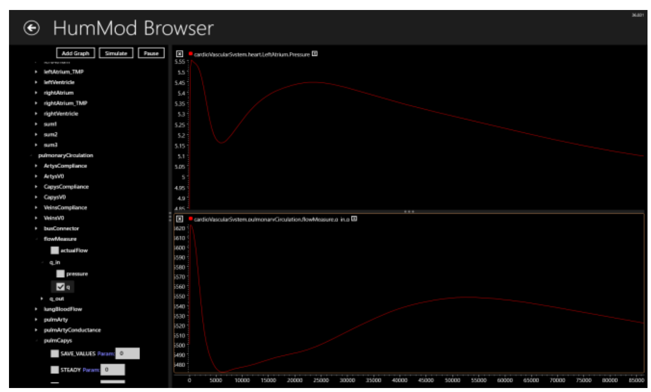
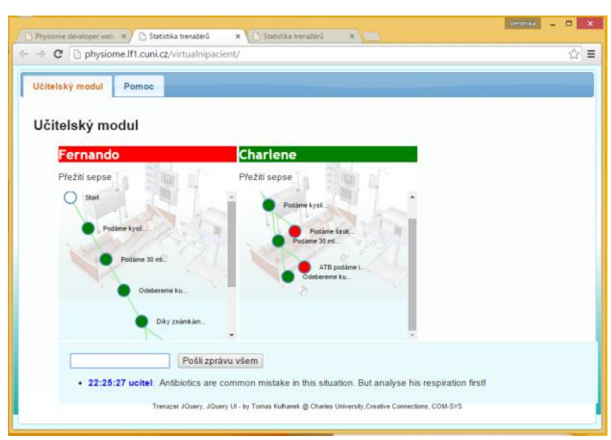


Figure 5. The teachers module allows to track the students' progress and communicate with them



V. Discussion and Future Work

As the content is kept mostly in a structured plaintext, it makes not only easy maintenance, but also enables rapid development of similar node-based simulators. The most demanding task would be to prepare the 3D scene and provide well-though scenario. Since another version has not yet been implemented, some minor settings may be still hidden in the ViewModel layer.

Although the Hummod, the base model of used Physiomodel, is one of the largest model of integrative physiology [16], the precise fit of the virtual patient data from the scenario was impossible. It was presumably due to two reasons: first one is the limited level of details included in the model (e.g. the domain of immunity, which plays an important role in this scenario, is not incorporated) and second, the data presented to the students as the patient state are inconsistent, because they are derived from experience of domain experts only. This implies that the value of indicators A and B could be typical for a given state, but never at the same time. For didactic purposes though (and from experience) they were given inconsistent state. It seems, that the theory of having consistent physiological model is limited by didactical purposes and that the value fitting would still be combined from data given from physiological model, trends and own experience. This requires continual clinico-physiologic research to prove the possible variabilities.

Our simulators have not yet been put into wide use at the faculty. It is mostly because teachers tend to use their own lecturing style and materials rather than adopt new technologies. Although we have received a very positive student and reviewers response to our educational simulators, their overall benefits remain arguable, as only a small number of teachers actually use them. Also, no quantified study on results improvement has been conducted.

Currently, it is possible to target only a single platform of Windows Store Applications. This is suitable for our computer classroom, but may become problematic for further distributiuon to other faculties and universities. In future versions, the team plans to move all the payload to the unity platform, which will enable targeting different platforms with only slight changes in the view layer.

Also, the procedure of creating scenarios should become as content driven as possible, i.e. all the scenario data should be loaded from external source, in order to make alterations and new versions easier to maintain. Overall, the team continues its efforts to create tools to push more attention to the content sphere. The rest is rather a manual work, which can be performed by machines.

VI. Conclusion

This paper presents a new milestone on the way towards the use of true virtual reality in medical education and training. Nowadays, it is possible can combine complex physiological simulations, nodal-based clinical scenarios, 2D and 3D graphics in one learning object.

The combination of physiological simulations and nodal-based clinical scenarios proves to be mutually beneficial. The functioning of all the components has been tested on one example intensive care scenario: Surviving Sepsis in Czech language. This application demonstrates the employed tool-chain and integrating possibilities.

VII. Acknowledgements

The described research has been supported by the project No. SGS13/203/OHK3/3T/13 of the Czech Technical University in Prague and by the projects PRVOUK P/24/LF1 and SVV 260157/2015 of the Charles University in Prague.

References

[1] F. Ježek, M. Tribula, J. Kofránek, J. Kolman, P. Privitzer, and J. Šilar, “Sada výukových simulátorů - výsledky vývoje frameworku Bodylight,” in *sborník příspěvků MEDSOFT*, 2013, pp. 38–48.

[2] B. Lok, R. E. Ferdig, A. Raij, K. Johnsen, R. Dickerson, J. Coutts, A. Stevens, and D. S. Lind, “Applying virtual reality in medical communication education: current findings and potential teaching and learning benefits of immersive virtual patients,” *Virtual Real.*, vol. 10, no. 3–4, pp. 185–195, 2006.

[3] J. Kofranek, “Atlas of Physiology and Pathophysiology-Web Based Simulators for Medical Education,” *Med. 2.0 Conf.*, 2013.

[4] P. Fritzson, Principles of Object-Oriented Modeling and Simulation with Modelica 3.3: A Cyber-Physical Approach. Wiley-IEEE Press, 2014.

[5] D. Schwarz and L. Dušek, COMPUTER APPLICATIONS, SYSTEMS AND NETWORKS FOR MEDICAL EDUCATION. Facta Medica, 2014.

[6] M. Mateják, T. Kulhánek, J. Šilar, P. Privitzer, F. Ježek, and J. Kofránek, “Physiolibrary - Modelica library for Physiology,” in *Proceedings of the 10th International Modelica Conference, March 10-12, 2014, Lund, Sweden*, 2014, pp. 499–505.

[7] Open Source Physiology Consortium, “Physiomodel.” 2015.

[8] J. Kofránek, M. Mateják, P. Privitzer, M. Tribula, T. Kulhánek, J. Šilar, and R. Pecinovský, “HumMod-Golem Edition: large scale model of integrative physiology for virtual patient simulators,” in *World Congress in Computer Science*, 2013.

[9] R. L. Hester, A. J. Brown, L. Husband, R. Iliescu, D. Pruett, R. Summers, and T. G. Coleman, “HumMod: a modeling environment for the simulation of integrative human physiology,” *Front. Physiol.*, vol. 2, 2011.

[10] P. Fritzson, P. Privitzer, M. Sjölund, and A. Pop, “Towards a text generation template language for Modelica,” in *Proceedings of the 7th International Modelica Conference (Modelica’2009)*, 2009, pp. 20–22.

[11] A. C. Hindmarsh, P. N. Brown, K. E. Grant, S. L. Lee, R. Serban, D. E. Shumaker, and C. S. Woodward, “SUNDIALS: Suite of nonlinear and differential/algebraic equation solvers,” *ACM Trans. Math. Softw.*, vol. 31, no. 3, pp. 363–396, 2005.

[12] J. Wang, “Silverlight-Based Distance Teaching Application,” in *Information Computing and Applications*, Springer, 2012, pp. 133–137.

[13] R. Garofalo, Building Enterprise Applications with Windows Presentation Foundation and the Model View ViewModel Pattern. Microsoft Press, 2011.

[14] M. Tribula, F. Ježek, P. Privitzer, J. Kofránek, and J. Kolman, “Webový výukový simulátor krevního oběhu,” in *sborník příspěvků MEDSOFT*, 2013, pp. 197–204.

[15] D. Schwarz, P. Štourač, M. Komenda, H. Harazim, M. Kosinová, J. Gregor, R. Hůlek, O. Smékalová, I. Křikava, R. Štoudek, and Others, “Interactive algorithms for teaching and learning acute medicine in the network of medical faculties MEFANET,” *J. Med. Internet Res.*, vol. 15, no. 7, 2013.

[16] K. Wu, J. Chen, W. A. Pruett, and R. L. Hester, “Hummod browser: An exploratory visualization tool for the analysis of whole-body physiology simulation data,” in *Biological Data Visualization (BioVis), 2013 IEEE Symposium on*, 2013, pp. 97–104.