Guest Editorial
Intelligence in Serious Games

SERIOUS games can be a game-changer for many individuals, and even our society as a whole. As an example, such games that are centered on empowerment and inclusion can help individuals with special needs or parts of the population to gain skills in a playful and fun way that can make a difference in their everyday lives. To best fulfill such an ambitious goal increasingly demands for computational intelligence to best grasp the player's attention, behavior, engagement, and game-progress while modeling often complex and demanding game environments. This includes (computational) emotional and social intelligence to allow to understand the player on different levels, motivate her or him, and optimally adapt the pace of learning. In addition, owing to the rapid development in mobile and body-worn sensor technology, games can be taken more and more into the real lives of players.

Likewise, the development of current and next-generation intelligent serious games demands not only for savoir-faire from the more traditional gaming perspective, but increasingly also for expertise in advanced machine learning, in particular from the targeted gaming domain. Accordingly, it appears crucial to bring together late-breaking achievements, findings, and methods across communities. These will include in particular disciplines concerned with lending tomorrow's serious games enhanced intelligence for the benefit of the players. Here, we subsequently provide an overview on the recent contributions collected in a special section on "Intelligence in Serious Games" and two adjunct articles. We then distill a concluding outlook added by recent developments in the field of machine intelligence.

I. Overview on the Contributions

A total of 11 submissions were received for this special section. Out of these, four were selected together for a special section—two further ones were featured separately in an earlier issue of the journal [items 1) and 2) in the Appendix]. The first two more general contributions introduce a design toolkit for characters in intelligent serious games and discuss optimal balance of game difficulty in the context of learning. In the other two contributions featured in this section, examples of intelligent serious games are featured. Both of these deal with socio-emotional skill training. The further two adjunct contributions follow a similar divide: a more theoretical contribution and an application use case are found.

Starting with the current section, in the contribution "A tool to design interactive characters based on embodied cognition" by Llobera and Boulic, the topic of interactive character design is handled in depth. The authors choose a decisional and behavior synthesis architecture for the implementation of their toolkit, which they integrated in the popular Unity3D game engine. The implementation requirements are thereby guided by embodied cognition principles. The resulting tool is marked by its modularity, scalability, and stability.

Subsequently, in the article "Implementing adaptive game difficulty balancing in serious games" by Hendrix *et al.*, the authors want to ensure serious game players to reach and remain within the state of "flow." To this end, they suggest a plan formed of six steps concerning the game difficulty balancing. Two use cases marked by different complexity serve to evaluate the validity of this concept—these are existent mobile serious games featuring fighting, puzzle-solving, and a purpose-built platform game. Their evaluation with 45 users in two studies provides further insight into difficulty balancing, and that player personalization is crucial. In particular, an encouraging tentative finding is that game difficulty balancing mechanisms from the entertainment game domain can be transferred to the serious game domain. The authors chose to employ scaffolded adaptive difficulty influencing learning aspects indirectly. Enabling such an approach in other settings and validating general applicability will be considered in future.

Moving to examples of intelligent serious games, the article "The ASC-Inclusion perceptual serious gaming platform for autistic children" by Marchi *et al.* includes two of the guest editors as authors, but has been peer reviewed and edited independently. It demonstrates the application of intelligent serious games in a perhaps somewhat less-expected setting: a game, and by that a computing system, teaching humans on emotional skills. In particular, the human players studied are children aged five to ten years with Autism Spectrum Condition (ASC). While these tend to have difficulties "interpreting verbal and non-verbal communication cues during social interactions," they often show high affinity toward technical predictable and controllable systems. The latter makes serious games appear as highly promising as an approach when teaching on socio-emotional skills for autistic children. The article introduces the ASC-Inclusion platform that features artificial intelligence (AI) for the recognition of facial expression, body gestures, and vocal emotion. Based on the idea of acting in order to learn recognition, it provides corrective feedback on the player's expression to children. It further provides opportunities for adult-child cooperative play. The authors introduce results of a clinical study demonstrating the effectiveness of such an approach: ASC focus group participants showed "evident generalized improvement in socialization and other symptoms present."

Digital Object Identifier 10.1109/TG.2019.2955259

Concluding the present collection, the contribution "Serious games for training social skills in job interviews" by Gebhard *et al.* allows young job applicants to experience the process of an interview in a role play with a virtual agent. In this simulation, the dialogue with the scripted interviewing three-dimensional agent is powered by a social signal interpretation engine. Hence, emphasis is put on training social and behavioral skills. The contribution not only provides insight into the machine learning back-end of the socially empowered agent, but also introduces results of four studies carried out. These target the effect of the personality of the agent and the appearance of the environment on the player and the learning effect. The authors observe players' stress levels to be influenced by adapting the agent behavior. Similarly, they report environment changes—even if minor—to influence the player's learning performance. The studies also demonstrate the gain such an interaction has over a book-based job interview preparation, encouraging the use of a social signal processing enabled serious game-based learning platform.

As a first adjunct article to this special section, the article "Modeling users collaborative behavior with a serious game" by Berdun and Armentano [item 2) in the Appendix] highlights the importance of modeling users not only individually, but also as a group. Rather than following the conventional avenue of questionnaires or human observers to measure group collaboration behavior, the authors suggest to assess performance via collaboration in a serious game to overcome the observer's paradox. In their experiments, they are encouraged by observed accuracies to consider this approach as a potential substitute solution in future group assessment. A driving factor of the success is the joy experienced by the players.

Finally, in the second adjunct featured contribution "Machine learning techniques for analyzing training behavior in Serious Gaming," Gombolay *et al.* [item 1) in the Appendix] consider various machine learning approaches with the aim to lend (human) teachers within a serious-gaming environment a tool to aid monitor students' progress and plan further learning with serious games. The tool assesses player's performance, engagement, and recommends personalized lesson plans. The exemplary application domain is set by a serious-gaming platform for navy professionals. The authors decided for unsupervised approaches to identify different player behaviors and tactics the players develop. This is followed by a supervised approach to find effective such behaviors and player features, as well as the mentioned engagement. The recommendations for lesson plan are similarly trained in a supervised manner. The authors conclude stating that usability tests with actual teachers will be needed to confirm the usability based on the promising results found from a machine learning perspective.

II. Outlook

These contributions show the massive potential of using AI in serious games [item 3) in the Appendix]. The examples successfully go as far as teaching humans on behavioral and socio-emotional skills in use cases spanning from job interviews to autistic individuals [item 4) in the Appendix]. Given this potential and the current uprise in using AI and more specifically machine learning and deep learning, in particular, we can expect a rapid increase in intelligence in the next generation of serious games. In addition, the current push by the industry for AI-specialized chips will likely lead to increased availability of such intelligence even in mobile serious-gaming solutions [item 5) in the Appendix]. As these examples show, taking serious gaming into everyday environments can boost engagement and the effectiveness of the learning outcome. To realize such intelligent mobile serious gaming, AI would best become "green" in the sense of energy, computational power, and memory efficiency itself. The current progress in "squeezing" machine learning models [items 6) and 7) in the Appendix] is a good example of the effectiveness that is currently being reached. Similarly, increasing availability of efficient solutions for AI and deep learning in wireless communication settings [item 8) in the Appendix] can even allow demanding AI usage in mobile serious gaming even in online or multiplayer distributed settings.

The examples mostly include supervised learning from an AI point of view, and partially unsupervised learning. However, they largely lack reinforcement learning. The current progress in deep reinforcement learning [item 9) in the Appendix] could lead to a dramatic change. As the examples from this section repeatedly show, adapting to the player on all levels seems crucial for the learning outcome and engagement. It seems promising to approach such intelligent adaptation by reinforcement learning [item 10) in the Appendix], i.e., learning from user reactions directly. In addition, current approaches in artificial creativity [item 11) in the Appendix] such as by generative adversarial networks [item 12) in the Appendix] or variational neural networks [item 13) in the Appendix] were not seen in the present contributions. However, it seems obvious that they bear massive potential in many of the use cases shown, such as to personalize a virtual agent or environment, adapt in real time to the context, and potentially even re-script game scenarios beyond creation of multimedia game content closer than ever to a player's needs. In combination, such reinforcement learning put together with artificial creativity could open up an entirely new immersion and effectiveness in serious gaming, which is yet to be exploited and explored. Further, given the lack of tools analysis and assessment of for serious games [item 14) in the Appendix], AI offers further use cases in the context of serious games.

With such temptation at hand to increase AI in serious games due to its availability—even in limited resource and mobile settings—and increasing abilities offered by AI such as affective and behavioral computing for socio-emotionally intelligent game engines and artificial creativity, it will be crucial to balance the AI aspects versus the actual game carefully [item 15) in the Appendix].

In addition, while perhaps less crucial than in other domains such as disease diagnosis, it will still be important to ensure explainability of AI [item 16) in the Appendix] also in a serious game context. This is because the serious games used for training and teaching come with great responsibility. Two examples from this special section serve to show this. On the one hand, serious games were used to train young individuals for their job interviews—in an unlucky setting, such a serious game might lower their chances rather than boosting them. In the worst case of the second example—teaching autistic children on socio-emotional skills—the result of a serious game-based training that "goes wrong" could be dramatic such as greater social exclusion of players in their daily lives. It seems obvious that there are numerous further ethical concerns to be considered with the rise of AI usage in serious games [item 17) in the Appendix].

AI in serious games offers huge potential to increase engagement and effectiveness of learning of their players. AI can power tomorrow's games' socio-emotional intelligence, help to massively personalize the gaming experience, and increasingly even create gaming scenarios, adjusted in real time, potentially in real life and mobile, ideally learning reinforced from player reaction—but it comes with ethical challenges that have to be met—ideally also by the developers [item 3) in the Appendix].

Acknowledgment

The guest editors would like to thank all the great reviewers for their thoughtful comments and efforts that helped in realizing this special section and ensure its highest quality.

This work was supported by the European Unions's Horizon 2020 Programme under Grant 688835 (DE-ENIGMA) and Grant 787476 (Com N Play Science).

Björn Schuller, *Guest Editor*
ZD.B Chair of Embedded Intelligence for Health Care & Wellbeing
University of Augsburg
86159 Augsburg, Germany
GLAM—the Group on Language, Audio & Music
Imperial College London
SW7 2AZ London, U.K.

Lucas Paletta, *Guest Editor*
Human Factors Laboratory
Joanneum Research
Forschungsgesellschaft mbH
A-8010 Graz, Austria

Peter Robinson, *Guest Editor*
Department of Computer Science and Technology
University of Cambridge
CB3 0FD Cambridge, U.K.

Nicolas Sabouret, *Guest Editor*
CNRS-LIMSI Lab
91400 Orsay, France

Georgios N. Yannakakis, *Guest Editor*
Institute of Digital Games
University of Malta
Msida MSD2080, Malta

Appendix
Related Work

1) M. C. Gombolay, R. E. Jensen, and S.-H. Son, "Machine learning techniques for analyzing training behavior in serious gaming," *IEEE Trans. Games*, vol. 11, no. 2, pp. 109–120, Jun. 2019.
2) F. D. Berdun and M. G. Armentano, "Modeling users collaborative behavior with a serious game," *IEEE Trans. Games*, vol. 11, no. 2, pp. 121–128, Jun. 2019.
3) G. N. Yannakakis and J. Togelius, *Artificial Intelligence and Games*. Berlin, Germany: Springer Nature, 2018.
4) B. W. Schuller, I. Dunwell, F. Weninger, and L. Paletta, "Serious gaming for behavior change: The state of play," *IEEE Pervasive Comput.*, vol. 12, no. 3, pp. 48–55, Jul.–Sep. 2013.
5) K. Ota, M. S. Dao, V. Mezaris, and F. G. De Natale, "Deep learning for mobile multimedia: A survey," *ACM Trans. Multimedia Comput., Commun., Appl.*, vol. 13, 2017, Art. no. 34.
6) F. N. Iandola, S. Han, M. W. Moskewicz, K. Ashraf, W. J. Dally, and K. Keutzer, "Squeezenet: Alexnet-level accuracy with 50x fewer parameters and < 0.5 mb model size," p. 13, 2016, *arXiv:1602.07360*.
7) M. J. Shafiee, F. Li, B. Chwyl, and A. Wong, "Squishednets: Squishing squeezenet further for edge device scenarios via deep evolutionary synthesis," p. 4, 2017, *arXiv:1711.07459*.
8) C. Zhang, P. Patras, and H. Haddadi, "Deep learning in mobile and wireless networking: A survey," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 3, pp. 2224–2287, Mar. 2019.
9) A. Dobrovsky, U. M. Borghoff, and M. Hofmann, "An approach to interactive deep reinforcement learning for serious games," in *Proc. 7th IEEE Int. Conf. Cogn. Infocommun.*, 2016, pp. 85–90.
10) O. Rudovic, B. Schuller, C. Breazeal, and R. Picard, "Personalized estimation of engagement from videos using active learning with deep reinforcement learning," in *Proc. 9th IEEE Int. Workshop Anal. Model. Faces Gestures/Conf. Comput. Vis. Pattern Recognit.*, Jun. 2019, pp. 1–10.
11) A. Liapis, G. N. Yannakakis, and J. Togelius, "Computational game creativity." in *Proc. 5th Int. Conf. Comput. Creativity*, 2014, pp. 46–53.
12) K. Park, B. W. Mott, W. Min, K. E. Boyer, E. N. Wiebe, and J. C. Lester, "Generating educational game levels with multistep deep convolutional generative adversarial networks," in *Proc. 33rd Int. IEEE Conf. Games*, 2019, pp. 1–8.
13) R. A. Yeh, A. G. Schwing, J. Huang, and K. Murphy, "Diverse generation for multi-agent sports games," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2019, pp. 4610–4619.
14) E. A. Boyle *et al.*, "An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games," *Comput. Educ.*, vol. 94, pp. 178–192, Mar. 2016.

15) W. L. Johnson, H. H. Vilhjálmsson, and S. Marsella, “Serious games for language learning: How much game, how much AI?” in *Proc. 12th Int. Conf. Artif. Intell. Educ.*, 2005, vol. 125, no. 1, pp. 306–313.
16) W. Samek, T. Wiegand, and K.-R. Müller, “Explainable artificial intelligence: Understanding, visualizing and interpreting deep learning models,” p. 8, 2017, *arXiv:1708.08296*.
17) A. Baird, S. Hantke, and B. Schuller, “Responsible and representative multimodal data acquisition and analysis: On auditability, benchmarking, confidence, data-reliance & explainability,” p. 4, 2019, *arXiv:1903.07171*.

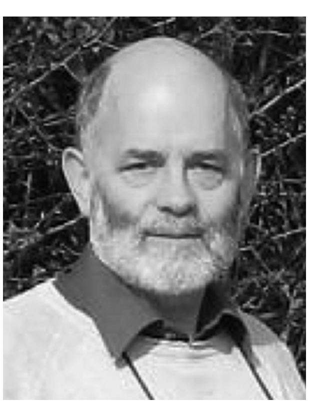
Björn Schuller (M’06–SM’15–F’18) received the Diploma in 1999, the Doctoral degree in 2006, and the Habilitation and Adjunct Teaching Professorship in the subject area of signal processing and machine intelligence in 2012 from Technische Universität München, Munich, Germany, all in electrical engineering and information technology.

He is currently a Professor of Artificial Intelligence with the Department of Computing, Imperial College London, London, U.K.; a Full Professor and the Head of the ZD.B Chair of Embedded Intelligence for Health Care and Wellbeing, University of Augsburg, Augsburg, Germany; and co founding CEO and current CSO of audEERING. He has (co-)authored five books and more than 800 publications in peer-reviewed books, journals, and conference proceedings, leading to more than 25 000 citations (h-index = 74).

Dr. Schuller, was the Coordinator of the European ASC-Inclusion project, providing an emotionally intelligent and serious game for autistic children. He was the Editor-in-Chief of the IEEE TRANSACTIONS ON AFFECTIVE COMPUTING and is an IEEE Computer Society Golden Core Awardee.

Lucas Paletta received the doctoral degree in computer science from the Graz University of Technology, Graz, Austria, in 2000.

He is the Key Researcher and Head of the Human Factors Lab, Joanneum Research Forschungsgesellschaft mbH, Graz, Austria. His research focuses on measurement technologies for human perception analyses; computational modeling of human mental processes, such as attention, situation awareness, and psychophysiological context; and future emerging assistance technologies for social inclusion and well-being. He was the coordinator of MASELTOV, a European project that developed a mobile mixed reality game for social inclusion of recent immigrants.



Peter Robinson received the Bachelor of Arts and Ph.D. degrees from the University of Cambridge, Cambridge, U.K., in 1974 and 1979, respectively, both in mathematics.

He continued with a year of post-graduate study in mathematics before joining the Computer Laboratory, where he was sponsored by the BBC to work on Graphic Design with Computers under Neil Wiseman. He is currently a Professor of Computer Technology with the Department of Computer Science and Technology, University of Cambridge, Cambridge, U.K., where his research concerns problems at the boundary between people and computers. This involves investigating new technologies to enhance communication between computers and their users, and new applications to exploit these technologies. The main focus for this is human–computer interaction, where he has been leading the work for some years on the use of video and paper as part of the user interface. Recent projects have involved the inference of people’s mental states from facial expressions, vocal nuances, body posture and gesture, and other physiological signals, and also considered the expression of emotions by robots and cartoon avatars. This has led to reflections of what it means to be human in an age of increasingly human-like machines.

Nicolas Sabouret received the Ph.D. degree from the University of Paris XI, Paris, France, in 2002.

He is currently a Professor with the School of Computer Science, University Paris-Saclay, Saint-Aubin, France. He is conducting his research at LIMSI-CNRS. He is working on multi-agent interaction, affective computing, and knowledge representation and reasoning. He is a specialist of human behavior modeling and automated reasoning for autonomous agents and conversational agents. He is one of the main actor of the French interest group on Artificial Companions, Affects and Interactions (ACAI), and he was the Scientific Coordinator of the TARDIS European project, whose goal was to design a serious game based on job-interview simulation for supporting inclusion of young NEETs.

Georgios N. Yannakakis (S'04–M'05–SM'14) received the Ph.D. degree in informatics from the University of Edinburgh, Edinburgh, U.K., in 2006.

He is currently a Professor and the Director of the Institute of Digital Games, University of Malta, Msida, Malta. He does research at the crossroads of evolutionary computation, computational creativity, affective computing, and game artificial intelligence. His research has been supported by numerous national and European grants (including a Marie Skodowska-Curie Fellowship) and has appeared in *Science Magazine* and *New Scientist*. He has authored or coauthored more than 220 papers in the aforementioned fields and his work has been cited broadly.

Dr. Yannakakis is currently an Associate Editor for the IEEE TRANSACTIONS ON GAMES and was an Associate Editor for the IEEE TRANSACTIONS ON AFFECTIVE COMPUTING and IEEE TRANSACTIONS ON COMPUTATIONAL INTELLIGENCE AND AI IN GAMES. He was the recipient of several rewards for journal and conference publications, including the IEEE Transactions on Affective Computing Most Influential Paper Award and the IEEE Transactions on Games Outstanding Paper Award.