Human Behaviour Modelling as an Emerging Disruptive M&S Technology

Dr. Anthony Henry Dekker
Graduate School of Information Technology & Mathematical Sciences
University of Ballarat
AUSTRALIA

dekker@acm.org

ABSTRACT

Understanding social and organisational phenomena is important in structuring modern military organisations and in conducting modern military operations. Simulations incorporating human behaviour modelling are an important tool for developing such understanding. In this paper we survey some of the successes of simple human behaviour models, and outline the key factors in making more complex simulations epistemologically valid (e.g. valid theoretical constructs and justified selection of model parameters). Finally, we summarise some necessary steps for developing a true science of modelling and simulation for human systems, and mention some recent progress in this vein, such as work in the modelling of emotion.

1.0 INTRODUCTION

Modern military operations often have goals which are explicitly social in nature. Such operations include peace-keeping and operations other than war (OOTW), as well as warlike operations such as counter-insurgency, where success is measured largely in terms of social effects. Outcomes of such operations cannot be assessed solely with the physics of kinetic-energy weapons. While physics-based simulations may be adequate to assess whether a hostile armoured division can be destroyed by a planned operation, physics-based simulations are insufficient for assessing planned counter-insurgency operations or OOTW.

Where social effects are critical, simulations of human behaviour within society are necessary to assess the likely outcomes of different courses of action and to provide appropriate training to personnel. Furthermore, over-simplistic social simulations will not be sufficient for this purpose, since they will make inaccurate predictions. For example, some simulations of social behaviour in Iraq and Afghanistan [1, 2] have used the "Hierarchy of Needs" developed by Abraham Maslow [3, 4]. This theoretical construct suggests that human beings seek to satisfy five different kinds of needs in priority order: physiological needs, safety needs, love and belonging, esteem, and self-actualization. However, Dunne [5] suggests that Maslow's hierarchy, being inherently individualistic and "Western" in nature, is "non-deployable" to countries like Iraq, where the needs of the family, clan, or tribe often outweigh personal needs.

Social simulations are not only important for assessing the targets of military operations and OOTW, but they can also be usefully applied to one's own country. In particular, social factors within one's own country will determine the size and nature of the recruitment pool from which military personnel will be drawn. The size of the future recruitment pool determines future staffing levels, and therefore the degree of automation necessary in future military forces. In addition, the skills of the future recruitment pool will determine future training and doctrine policies. It is therefore important that both these factors are well understood.

In addition to modelling one's own society as a whole, it is also important to model one's own military organisation. Disruptive technologies, particularly information and communications technologies, affect the way that current forces operate, and provide options for new ways of operating. Edge organisations [6] are one well-known example. Organisational simulation is one important tool for assessing the strengths and weaknesses of alternate organisational structures and alternate ways of operating. In order to benefit maximally from disruptive information and communications technologies, it is important that the evolution of organisational structures, procedures, and tactics be guided by organisational simulation.

2.0 SIMPLE HUMAN BEHAVIOUR MODELS

For many applications, simple models of human behaviour have proved adequate in supporting decision-making. Dirk Helbing and others have successfully used very simple behaviour models in simulating emergency evacuation dynamics [7, 8]. Such models have shown, for example, the effectiveness of zigzag designs for evacuation passageways, and have helped to improve the safety of the annual Hajj in Saudi Arabia. The Hajj involves large numbers of pilgrims visiting specific locations, and this has led to injuries which have been addressed by both physical and organisational changes [7, 9].

Relatively simple human behaviour models incorporating economic decision-making have had success in predicting fluctuations in prices of various products [10, 11]. Combining models of disease biology with simple models of people's movements during the day allows the simulation of the spread of infectious disease [12, 13, 14]. Such models are helpful in setting policy on vaccination, quarantine, health education, and other public health issues. Similarly, physical models of rainfall etc. can be combined with simple models of decision-making about land use and crop-planting. This allows the prediction of agricultural outcomes, both in a historical context [15, 16, 17] and in guiding policies about present-day land use [18].

3.0 EPISTEMOLOGY OF HUMAN BEHAVIOUR MODELS

Simple models of human behaviour have proven successful partly because they *are* simple. Simple models are easier to calibrate to real-world data than more complex models, as well as being easier to validate and verify. Provided that they are based on valid theoretical constructs, simple models are more likely to succeed than more complex models, although simple models naturally have less ambitious goals.

Obtaining useful and valid results from more complex models of human behaviour requires paying attention to the epistemological aspects of simulation – that is, paying attention to applications of the theory of knowledge [19, 20, 21]. The traditional definition of knowledge is justified true belief [22]. In the context of simulations, this means that the output of the simulation can be traced back to empirically or theoretically justified knowledge of human behaviour, via a series of steps which are also justified [21]. In particular, we require:

- valid and appropriate theoretical constructs (Maslow's "Hierarchy of Needs" and Freud's psychological theories being examples of constructs of questionable validity);
- appropriate empirical data, validly collected through surveys [23], experiments, observation, video analysis, instrumentation [24], role-playing games [25], wargaming [26], etc.;
- valid mechanisms for translating empirical data into model parameters;
- valid and tested model-building techniques [27]; and
- verification and testing of the final model.

When one or more of these steps cannot be performed, the simulation model cannot be considered to produce knowledge (though it may still be a rich source of interesting hypotheses to be tested some other way).

3.1 Theoretical Constructs

The theoretical constructs used in models of human behaviour should represent the "most prominent causal relations" in the behaviour under consideration [28]. Valid theoretical constructs exist for individual human beings, but agreed-upon constructs with predictive validity are difficult to find for society as a whole. However, the emergence of social simulation models is driving research in this area.

3.2 Data Collection

Data collection methods are most advanced for individual humans and small groups. When modelling societies and other large groups of people, empirical data on individuals remains useful. However, it must generally be supplemented by surveys and other methods which collect data on society as a whole. The advent of communications technologies such as the Internet and Twitter also permits data to be collected electronically. For example, Google search trends can reveal information about disease outbreaks [29].

3.3 Model Parameters

There are two main approaches to translating empirical data into model parameters. Where parameters correspond directly to measurable quantities, it is possible to work forwards from the data. This has been done in, for example, epidemiological simulations. When doing this, care must be taken to avoid errors due to discretization effects [21]. It is also important to conduct sensitivity analysis, in order to determine how much the model depends on precise measurement of the empirical data [30].

The other approach to parameterisation is to work backwards, by comparing model outputs to corresponding measurable quantities. Parameters must then be adjusted so that the model gives the best possible fit to the data [21]. This requires searching a potentially enormous parameter space, and *genetic algorithms* or other sophisticated search strategies can assist with this [31]. This approach also presupposes a unique best-fitting parameter combination. This is more likely to occur if multi-objective optimization is used – that is, if the model output is required to fit several independent real-world data values [21, 32].

3.4 Testing

Simulation models must be *verified* to see whether they match their design. Testing is an important part of such verification [33, 34, 35]. It is important that test data not have been previously used for parameter selection, to avoid predictively useless models that simply replicate their calibration data [36]. Self-explaining agents complement traditional testing methods [37]. A self-explaining agent can output reasons for its actions, so that an agent's history can be presented as a "story." Unrealistic decisions in such a "story" can reveal implementation errors [21]. Plotting average values and distributions of model variables is also an important testing technique.

4.0 THE EMERGING SCIENCE OF SIMULATION

We are beginning to see an emerging science of modelling and simulation [38] that allows the production of models which produce epistemologically valid results, although it remains the case that the "need to develop simulations of systems that include human behaviour" is one of "the grand challenges facing us" [39]. Tolk *et al*. [40] suggest that way forward in this space involves the formalisation of an appropriate body of knowledge, while Zacharias *et al*. [41] highlight the need for interdisciplinary research. A true science of modelling and simulation will address not only epistemological issues (what we know), but also issues of ontology (what exists), teleology (what our goals are), and methodology (what we do) [42]. In particular, it is important that emerging bodies of knowledge include guidelines on which approaches are suitable for which goals.

A promising example of this is the work of Smajgl *et al*. [43], who provide a systematic approach to parameterization of social agent models. In their approach, summarised in Table 1, empirical data can be drawn from interviews, surveys, participant observation, field experiments, and role-playing games, depending on the nature of the topic being studied, and the goal of the specific simulation model.

Table 1: The five agent modelling steps of Smajgl *et al*. [43], with possible techniques at each step.

Step 1 **Identify distinct agent classes & their sequences of actions**	**Step 2** **Specify values of agent attributes**	**Step 3** **Determine parameters for behavioural rules**	**Step 4** **Develop agent types**	**Step 5** **Assign agents to agent types, possibly with cloning**
• Expert knowledge (EK) • Participant observation (PO) • Lab experiments • Interviews • Role-playing games (RPG)	• Survey • Census • GIS data	• Survey • Interviews • Field experiments • PO • RPG • Time-series data • EK	• Clustering & regression • Correlation & EK • EK alone • PO • Detailed spatial data combined with aggregated census data	• Proportional assignment • Census/GIS-based assignment • Monte Carlo assignment

The modelling of human decision-making is particularly important, since human decision-making is not necessarily rational [44]. However, in some cases it can be assumed that human beings choose the optimal course of action, and this can be modelled using techniques such as neural networks, genetic algorithms, machine learning, and game-tree analysis [45, 46]. Alternatively, human decision-making can be represented using heuristic rules [45].

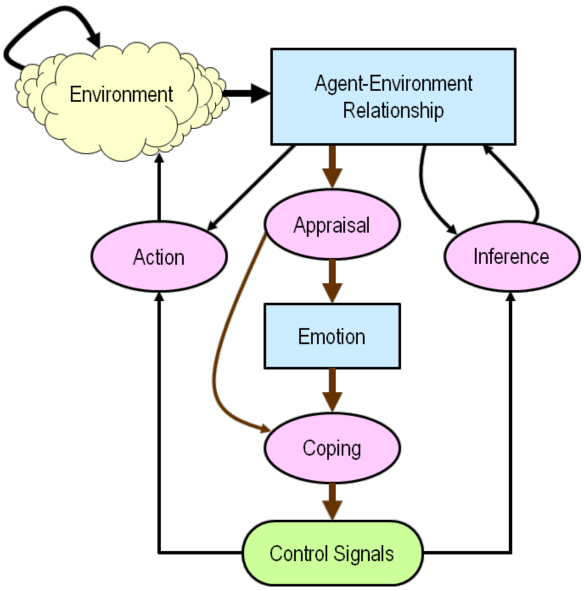

Figure 1: The emotional modelling approach of Marsella *et al*. [48, 49].

A complication in the modelling of human decision-making is the fact that "society is not composed of neutral actors but of emotional beings" [47]. Realistic models of human decision-making must often include an emotional element. A successful approach to modelling emotion is that of Marsella et al. at the

University of Southern California [48, 49]. As illustrated in Figure 1, this approach incorporates emotion in the appraisal of situations, in the making of inferences, and in deciding what actions to perform. This approach has been successfully incorporated in the Tactical Language and Culture Training System (TLCTS), which uses game technology for language and culture training [50]. This tool models the interaction of small numbers of human beings; it remains to be seen whether this approach can be extended to larger groups, although related models have been used to study panic in crowds [51].

5.0 DISCUSSION

Modelling human behaviour is important both in supporting military operations and in developing future doctrine, policies, and organisational structures. While simple models (such as those of evacuation dynamics or of epidemic spread) have proven successful in some domains, the challenge is to develop more complex models which are still epistemologically valid [21]. This requires:

- valid and appropriate theoretical constructs, which represent the "most prominent causal relations" in the behaviour under consideration [28];
- validly collected and appropriate empirical data (which may be a challenge to collect at the level of society as a whole, although data collection via the Internet may offer some options here);
- valid mechanisms for translating empirical data into model parameters (either working forwards from data to model parameters, or by working backwards to find the parameters giving the best fit between empirical data and model output);
- valid and tested model-building techniques; and
- verification and testing of the final model.

We are beginning to see an emerging science of modelling and simulation that systematically addresses these concerns. Such a science requires:

- the formalisation of an appropriate body of knowledge [40], using a consistent vocabulary [52];
- interdisciplinary research [41, 52], including collaboration between military and non-military (economic, sociological, agricultural, medical, etc.) simulation communities;
- building on successful models of individual humans and small groups (including successful models of emotion) in order to represent larger groups and complete societies;
- appropriate data collection [52]; and
- addressing issues of epistemology (what we know), but also issues of ontology (what exists), teleology (what our goals are), and methodology (what we do) [42].

Interdisciplinary online journals (such as the Journal of Artificial Societies and Social Simulation, jasss.soc.surrey.ac.uk), interdisciplinary conferences, and online data and model repositories (such as the NetLogo Modelling Commons, modelingcommons.org) offer a venue for building the body of knowledge that is required for this emerging science.

6.0 REFERENCES

[1] Chaturvedi, R., Mellema, S., Chaturvedi, A., Mulpuri, M., & Pinczuk, G., (2008). "Continuous Validation Framework: A Case Study of SEAS and Afghanistan," *Interservice/Industry Training, Simulation & Education Conference* (*I/ITSEC*), Orlando, Florida, Paper No. 8362.

[2] Adelantado, M. & Mathé, J.-M. (2009). *Using Agent Based Distillation to Explore Issues Related to Asymmetric Warfare* (Report RTP-MP-MSG-069). NATO Research & Technology Organisation. ftp.rta.nato.int/public/PubFullText/RTO/MP/RTO-MP-MSG-069/MP-MSG-069-23.doc

[3] Maslow, A.H. (1943). "A Theory of Human Motivation," *Psychological Review* **50** (4), pp. 370–96.

[4] Maslow, A.H. (1962). *Toward a Psychology of Being*. New York, NY: D. Van Nostrand.

[5] Dunne, J.P. (2009). "Maslow is Non-Deployable: Modifying Maslow's Hierarchy for Contemporary Counterinsurgency." In P. Holmes-Eber, P.M. Scanlon, & A.L. Hamlen (Eds.), *Applications in Operational Culture: Perspectives from the Field* (pp. 15–28). Quantico, VA: Marine Corps University Press.

[6] Alberts, D.S. & Hayes, R.E. (2003). *Power to the Edge*. Washington, DC: CCRP Press. www.dodccrp.org/files/Alberts_Power.pdf

[7] Helbing, D. & Johansson, A. (2009). "Pedestrian Crowd and Evacuation Dynamics," *Encyclopedia of Complexity and Systems Science* (Meyers, R.A., ed.), Springer-Verlag, 6476–6495. Available online at www.ethlife.ethz.ch/archive_articles/100727_Massenpanik_Helbing_sch/Pedestrian_Crowd_and_Evacuation_Dynamics_Helbing.pdf

[8] Longo, F. (2010). "Emergency Simulation: State of the Art and Future Research Guidelines," *SCS M&S Magazine* **1** (4). www.scs.org/magazines/2010-04/index_file/Files/Longo.pdf

[9] Helbing, D., Johansson, A., & and Al-Abideen, H. Z. (2007). "The Dynamics of Crowd Disasters: An Empirical Study," *Physical Review E* **75**, 046109. Preprint at arxiv.org/pdf/physics/0701203.pdf and supplementary information at www.trafficforum.ethz.ch/crowdturbulence/

[10] Heppenstall, A., Evans A., & Birkin, M. (2006). "Using Hybrid Agent-Based Systems to Model Spatially-Influenced Retail Markets," *Journal of Artificial Societies and Social Simulation* **9** (3), paper 2, jasss.soc.surrey.ac.uk/9/3/2.html

[11] Perugini, D., Perugini, M., Clarke, B., & Frdelja, J. (2011). "Customer Behaviour Modelling for Predicting Future Demand," *Water: Journal of the Australian Water Association*, May 2011. Available at www.intelligentsoftware.com.au/images/stories/File/Perugini%20forecasting.pdf

[12] Eubank, S., Guclu, H., Anil Kumar, V. S., Marathe, M.V., Srinivasan, A., Toroczkai, Z., & Wang, N. (2004). "Modelling disease outbreaks in realistic urban social networks," *Nature* **429**, 180–184.

[13] Stroud, P., Del Valle, S., Sydoriak, S., Riese, J., & Mniszewski, S. (2007). "Spatial Dynamics of Pandemic Influenza in a Massive Artificial Society," *Journal of Artificial Societies and Social Simulation* **10** (4), paper 9, jasss.soc.surrey.ac.uk/10/4/9.html

[14] Manfredi, P. & D'Onofrio, A., eds. (2013). *Modeling the Interplay Between Human Behavior and the Spread of Infectious Diseases*. Springer-Verlag.

[15] Dean, J. S., Gumerman, G. J., Epstein, J. M., Axtell, R. L., Swedlund, A. C., Parker, M. T., & McCarroll, S. (2000), "Understanding Anasazi culture change through agent-based modeling," in Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes (Kohler, T.A. & Gumerman, G.J., eds.), Oxford University Press, 179–205.

[16] Axtell, R.L., Epstein, J.M., Dean, J.S., Gumerman, G.J., Swedlund, A.C., Harburger, J., Chakravarty, S., Hammond, R., Parker, J., & Parker, M. (2002), "Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley," *PNAS* **99** (3, Suppl), 7275–7279. www.pnas.org/content/99/suppl.3/7275

[17] Janssen, M.A. (2009), "Understanding Artificial Anasazi," *Journal of Artificial Societies and Social Simulation* **12** (4), paper 13, jasss.soc.surrey.ac.uk/12/4/13.html

[18] Heppenstall, A.J., Crooks, A.T., See, L.M., & Batty, M., eds. (2012), *Agent-Based Models of Geographical Systems*, Springer-Verlag.

[19] Becker, J., Niehaves, B., & Klose, K. (2005). "A Framework for Epistemological Perspectives on Simulation," *Journal of Artificial Societies and Social Simulation* **8** (4), paper 1, jasss.soc.surrey.ac.uk/8/4/1.html

[20] Frigg, R. & Reiss, J. (2009). "The philosophy of simulation: hot new issues or same old stew?" *Synthese* **169**, 593–613.

[21] Dekker, A.H. (2012), "Epistemological Aspects of Simulation Models for Decision Support," presentation to 5th Epistemological Perspectives on Simulation Conference, San Antonio, TX, 10–13 October.

[22] Audi, R. (2003). *Epistemology: A Contemporary Introduction to the Theory of Knowledge*, 2nd ed. London: Routledge.

[23] Boero, R. & Squazzoni, F. (2005). "Does Empirical Embeddedness Matter? Methodological Issues on Agent-Based Models for Analytical Social Science," *Journal of Artificial Societies and Social Simulation* **8** (4), paper 6, jasss.soc.surrey.ac.uk/8/4/6.html

[24] O'Connor, A., Zerger, A., & Itamic, B. (2005). "Geo-temporal tracking and analysis of tourist movement," *Mathematics and Computers in Simulation* **69** (1–2), 135–150.

[25] Dray, A., Perez, P., Jones, N., Le Page, C., D'Aquino, P., White, I., & Auatabu, T. (2006). "The AtollGame Experience: from Knowledge Engineering to a Computer-Assisted Role Playing Game," *Journal of Artificial Societies and Social Simulation* **9** (1), paper 6, jasss.soc.surrey.ac.uk/9/1/6.html

[26] Perla, P.P. & McGrady, E. (2011). "Why Wargaming Works," *Naval War College Review* **64** (3). www.usnwc.edu/getattachment/413220cd-a209-4447-bac2-af6cdaeabd4f/Why-Wargaming-Works

[27] Cioffi-Revilla, C. (2010). "A Methodology for Complex Social Simulations," *Journal of Artificial Societies and Social Simulation* **13** (1), paper 7, jasss.soc.surrey.ac.uk/13/1/7.html

[28] Galán, J.M., Izquierdo, L.R., Izquierdo, S.S., Santos, J.I., del Olmo, R., López-Paredes, A., & Edmonds, B. (2009). "Errors and Artefacts in Agent-Based Modelling," *Journal of Artificial Societies and Social Simulation* **12** (1), paper 1, jasss.soc.surrey.ac.uk/12/1/1.html

[29] Ginsberg, J., Mohebbi, M.H., Patel, R.S., Brammer, L., Smolinski, M.S., & Brilliant, L. (2009). "Detecting influenza epidemics using search engine query data," *Nature* **457**, 1012–1014. See also www.google.org/flutrends/about/how.html

[30] Smith, E.D., Szidarovszky, F., Karnavas, W.J., & Bahill, A.T. (2008). "Sensitivity Analysis, a Powerful System Validation Technique," *The Open Cybernetics and Systemics Journal* **2**, 39–56.

[31] Stonedahl, F. & Wilensky, U. (2010). "Evolutionary Robustness Checking in the Artificial Anasazi Model," *Proceedings of the AAAI Fall Symposium on Complex Adaptive Systems: Resilience, Robustness, and Evolvability*, November 11–13, Arlington, VA.

[32] Samanta, S. & Mackay, D.S. (2003). "Flexible automated parameterization of hydrologic models using fuzzy logic," *Water Resources Research* **39** (1), 1009.

[33] Balci, O. (1997). "Verification, Validation and Accreditation of Simulation Models," *Proceedings of the 1997 Winter Simulation Conference*.

[34] Page, E.H., Canova, B.S., & Tufarolo, J.A. (1997). "A Case Study of Verification, Validation, and Accreditation for Advanced Distributed Simulation," *ACM Transactions on Modeling and Computer Simulation* **7** (3), 393–424.

[35] Oberkampf, W. L., Trucano, T. G., & Hirsch, C. (2003). *Verification, Validation, and Predictive Capability* (Report SAND 2003-3769). Sandia National Laboratories.

[36] Duong, D. (2010). "Verification, Validation, and Accreditation (VV&A) of Social Simulations," *Proceedings of the Spring Simulation Interoperability Workshop*, Orlando, FL, April 12–16.

[37] Harbers, M., Meyer, J.-J., & van den Bosch, K. (2010). "Explaining Simulations Through Self Explaining Agents," *Journal of Artificial Societies and Social Simulation* **13** (1), paper 4, jasss.soc.surrey.ac.uk/13/1/4.html

[38] Dekker, A.H. & Suarez, E.D. (2013), "Towards a Science of M&S: The 5th Epistemological Perspectives on Simulation Conference," *SCS M&S Magazine* **4** (1).

[39] Crosbie, R. (2010), "Grand Challenges in Modeling and Simulation," *SCS M&S Magazine* **1** (1), www.scs.org/magazines/2010-01/index_file/Files/article_Crosbie.pdf

[40] Tolk, A., Davis, P.K., Huiskamp, W., Klein, G.L., Schaub, H., & Wall, J.A. (2010), "Towards Methodological Approaches to Meet the Challenges of Human, Social, Cultural, and Behavioral (HSCB) Modeling," *Proceedings of the 2010 Winter Simulation Conference*.

[41] Zacharias G.L., MacMillan, J. & Van Hemel, S.B., eds. (2008). *Behavioral Modeling and Simulation: From Individuals to Societies*, National Academies Press, www.nap.edu/catalog/12169.html

[42] Tolk, A. (2012). *Ontology, Epistemology, and Teleology for Modeling and Simulation: Philosophical Foundations for Intelligent M&S Applications*, Springer-Verlag.

[43] Smajgl, A., Brown, D.G., Valbuena, D., & Huigen, M.G.A. (2011). "Empirical characterisation of agent behaviours in socio-ecological systems," *Environmental Modelling & Software* **26** (7), 837–844.

[44] NATO (2009). *Human Behavior Representation in Constructive Simulation*, NATO RTO Technical Report TR-HFM-128, www.cso.nato.int/pubs/rdp.asp?RDP=RTO-TR-HFM-128

[45] Villamor, G.B., van Noordwijk, M., Troitzsch, K.G., & Vlek, P.L.G. (2012a). "Human decision making for empirical agent-based models: construction and validation," *International Congress on Environmental Modelling and Software*, Leipzig, Germany. Paper available online at www.zef.de/module/register/media/21fd_Villamor_et%20al_%20decision%20making.pdf

[46] Dekker, A.H. (2010). "Agent-Based Simulation for Counter-IED: A Simulation Science Survey," *Proceedings of SimTecT 2010*, Brisbane, Australia, 31 May–3 June.

[47] Hamburg, D.A. (1963). “Emotions in the perspective of human evolution.” In *Expression of the Emotions in Man* (Knapp, P.H., ed.), New York, NY: International Universities Press.

[48] Gratch, J. & Marsella, S. (2005). “Evaluating a computational model of emotion,” *Journal of Autonomous Agents and Multiagent Systems* **11** (1), 23–43.

[49] Marsella, S. & Gratch, J. (2009). “EMA: A process model of appraisal dynamics,” *Cognitive Systems Research* **10** (1), 70–90.

[50] Johnson, W.L. & Valente, A. (2009). “Tactical language and culture training systems: Using AI to teach foreign languages and cultures,” *AI Magazine* **30** (2). Paper available online at www.aaai.org/ojs/index.php/aimagazine/article/view/2240

[51] Tsai, J., Bowring, E., Marsella, S., & Tambe, M. (2013). “Empirical evaluation of computational fear contagion models in crowd dispersions,” *Journal of Autonomous Agents and Multiagent Systems* **27** (2), 200–217.

[52] Numrich, S. & Tolk, A. (2010). “Challenges for Human, Social, Cultural, and Behavioral Modeling,” *SCS M&S Magazine* **1** (1), www.scs.org/magazines/2010-01/index_file/Files/article_Numrich-Tolk.pdf