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Epidemic Simulation based on Intelligent Agents

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Abstract

This paper proposes an evolution of a model devoted to simulate the behavior city population and to integrate it with an epidemic agent driven simulator able to evaluate its diffusion and impacts. In facts, this model results now capable to evaluate the epidemics behavior among inhabitants, check hypothesis regarding virus diffusion as well as identify possible effectiveness of countermeasures, such as block of mass gathering events, school closure and even lockdown.

Keywords: Strategic Decision Making, Modeling & Simulation, Intelligent Agents, Epidemics

1. Introduction

Simulation of epidemics is one of those tasks where modeling and simulation should be used due to the complexity of the phenomena affected by this crisis (Bossomaier et al.,2009). Indeed, modeling was used since decades in order to study evolution of epidemics (Avalle et al. 1995) and to address specific diseases such as AIDS (Kaplan, 1989), Syphilis (Oxman et al., 1996), Hepatitis C (Deuffic et al., 1999) and COVID-19 (Peng et al., 2020). In facts, the advantage of applying Modeling and Simulation to epidemics is based on their ability not only to forecast most probable outcomes of current situation, but possibility to check numerous "what if?" hypotheses respect alternative decisions and containment policies.

For example, one of open topics in handling of COVID-19 pandemic is reopening the schools and its possible consequences (Melnick & Darling-Hammond, 2020). Indeed, school closure caused drop in education quality (Azevedo et al., 2020) and in several Countries it includes also the problem to address the "babysitter feature", considering that with closed Schools the parents could be constrained to stay at home to supervise and look after children. Furthermore, reopening of schools probably would lead to numerous close interpersonal contacts, which would spread infections, even considering that children are not expected to adopt proper measures of social distancing due to their young age and teenagers could act similarly due to their adolescent pulses (Wenzel & Battle, 2001; Bayham & Fenichel 2020; Stage et al., 2020). Considering this sum of reasons, simulation allows to evaluate outcomes of different decisions as well as take in consideration different aspects of epidemic, which may be known only with some level of precision.

Similar approach is also used in different contexts; for instance, to study diffusion of computer viruses (Hu & Wei, 2007). Obviously, in this case diffusion would depend mostly on different factors, such as protection measures and even network topology (Bruzzone et al., 2016; Chen & Carley, 2003).

2. Previous Researches on Epidemics & Disasters

In the past, the authors developed several solutions addressing crisis management in cities and urbanized areas (Avalle et al. 1999; 1995; 1996; Bossomaier et al.

2009)

HAITI simulator was developed shortly after 2010 earthquake in Haiti and addresses food distribution and crisis recovery issues taking into account human behavior factors such as stress, fatigue and aggressiveness (Bruzzone et al. 2012); by the way the Simulation Team model used for this case was IA-CGF EQ based on Intelligent Agents (IA) and it was presenting evidence of the risk of cholera epidemics confirmed after by facts (Chunara et al., 2012). Another interesting simulator developed by authors focuses on crises management in case of flood and spills of hazardous material and consequence on a region or large town (Bruzzone et al., 2018a; 2017). Moreover, in this case the use of multi-layer networks of IA resulted effective solutions able to model population's life cycle, commercial and recreational activities, transportation over different layers (e.g. private cars, buses, trains) as well as weather conditions. In facts, the authors developed also PONTUS (POpulation behavior, social Networks, Transportation and Urban Simulation) which is able to address several potential emergencies within urbanized areas (Bruzzone et al. 2018b).

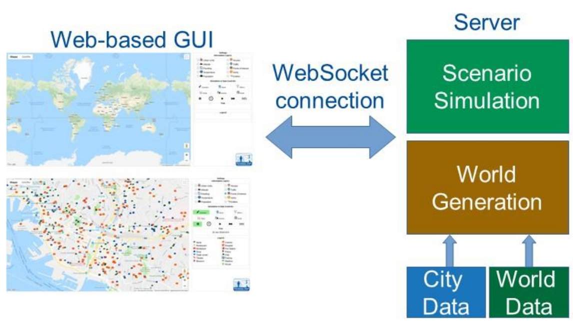

Figure 1. System Architecture

Indeed, PONTUS is a very efficient tool to study pandemic diffusion; for example, it takes into account single individuals along with a variety of parameters, such as age, sex, education, income etc. and simulates daily life cycles, which are based on the mentioned attributes. It generates several major categories of people: workers, students, retired persons, unemployed and assigns to every individual daily tasks based on its own macro category, parameters and habits (Bruzzone et al. 2018c)A worker's life cycle includes but is not limited to: morning routine and breakfast, moving to workplace using public transportations or private vehicles, working time interacting with colleagues, lunch near workplace or at home and back, second slot of working time and back home, possible shopping while moving from a place to another one and evening recreational activities at home or outside. Clearly, these life cycles are interactive and based on activities of other individuals (e.g. planning to go at the movies, avoiding overcrowded spaces, traffic jam, etc.) and are pretty different for distinct macro categories.

Apart from complex projects which analyze cities as Systems of Systems (SoS), there are many solutions which are addressing some specific aspects of interest. For example, one of such tasks for urban simulation is prediction of land development in the future, which could be modeled using Cellular Automata (Barredo et al., 2003). Meanwhile, some models addressing influence of car parking type on generated emissions (Hoglund, 2004) or even operation of large scale smart grids in cities (Karnouskos & De Holanda, 2009). In 2009, in reference to a potentially disruptive pandemics (H1N1), Prof.Bossomaier, Prof. Bruzzone and Prof.Rosen were preparing specific agent based simulations to be able to face the crisis in Australia and considered the critical aspects of human behavior as well as the effectiveness and efficiency of different Media and Communication Policies (Bossomaier et al., 2009; Bruzzone et al.,2011).

3. The Simulator and Scenario

Hereafter the authors present VESTIGE (Virus Epidemics Simulation in Towns for Infection Governance during Emergencies), which is based on previously developed PONTUS. The model distinguishes between following states of infection in person: healthy, ill but not yet contagious, ill and could infect other units but does not demonstrate symptoms (not aware about his/her state), ill with symptoms (aware of his/her state, tends to stay at home), healed and dead. Indeed, VESTIGE keeps track on this data and allows to the user to check it as well as its variation in time as illustrated below.

Hence, each individual in the simulated town lives its daily life cycle while the model adjusts behavior of entities and simulates evolution of epidemics. Map view of the simulator is presented in the following figure.

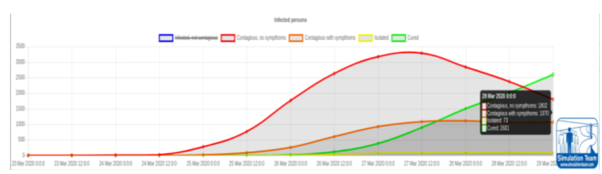

Figure 2. Infection trends: infected without symptoms (red), infected with symptoms (orange), isolated (yellow) and healed (green)

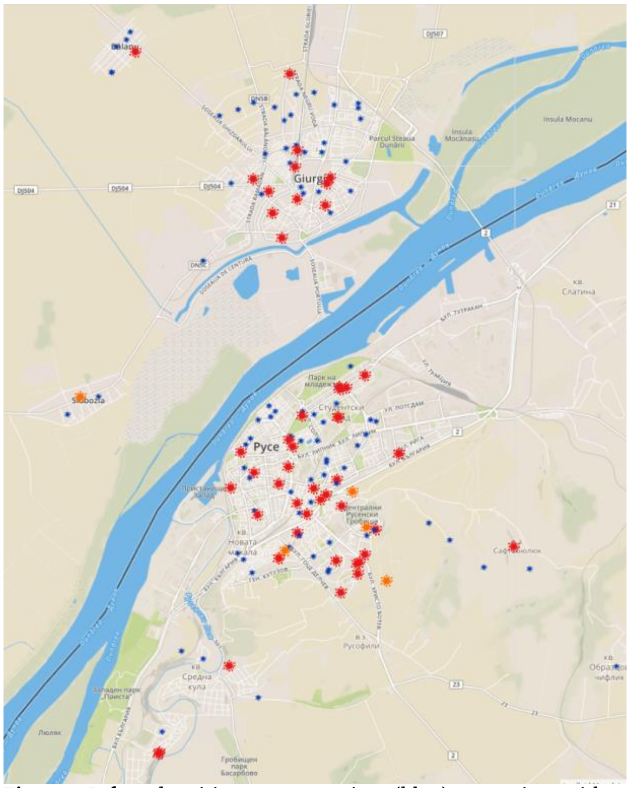

Figure 3. Infected entities: non contagious (blue), contagious without symptoms (red), contagious with symptoms (orange) and infected & isolated (yellow)

In particular, VESTIGE analyses interactions between individuals taking into account the circumstances, such as density of persons per square meter, time of exposure, encounter in closed space or in fresh air, parameters of infection (safe ranges in buildings and outside, required exposure time), etc. Furthermore, type of interactions depends on surrounding situation, such as time and day of the week, temperature and precipitations. Each infection in the model is characterized also by other parameters which include average time between infection and start of symptoms, time between infection and possibility to infect others, information regarding initial situation (index case). All these aspects allow to simulate evolution of epidemics in the town and to study impact of containment measures on it (lockdown, school closure, suspension of particular activities and mass gathering events) (Bruzzone et al. 2014a; 2014b). In order to evaluate the simulator, the authors modified previously developed for PONTUS scenario. Indeed, it already includes all necessary information regarding infrastructures, population and environment which allows its fast extension to address new issues.(Bruzzone et al. 2013; Massei et al. 2014). In particular, the scenario is based on urban area with circa 100 thousand inhabitants, situated near a river which corresponds to a country border, contains a densely populated zone with numerous commercial, recreational and business activities, industrial and residential neighborhoods as well as several quite isolated villages. The area has moderately developed transportation infrastructure which includes roads, highways, railway and network of public transportation. Hence, it includes most of the elements typical for an urbanized area of a European country, which makes it perfect for simulation of virus diffusion.

4. Results

VESTIGE was tested in the presented scenario with different sets of initial conditions. For instance, it was checked with various quantity and location of infected individuals; indeed, case 0 requires big amount of time to generate dangerous level of diffusion if it is located in quite isolated village, while its appearance in downtown with numerous recreational facilities (e.g. cinema, bars) leads to immediate and rapid grow of infection. Another factor is related to individual characteristic of person, such as habit to spend free time with friends, type of work and even ethnicity and religion, which in some cases limits initial diffusion to a specific group.

The simulator demonstrated realistic behavior and allowed observation of several effects. First, while evolution of pandemic and trends remain statistically similar over the simulated area, due to stochastic nature of model even with fixed initial conditions the hotbed of infection varies drastically among runs. Indeed, the most significant difference is caused by case 0 person, his or her social contacts, work style and free time preferences. Indeed, it identifies which category of people hits the first wave of infection; for instance, if it is diffused among young classmates, colleagues in workplace or older retired friends.(Bruzzone et al. 2011)

The second very important observation is that even small variation of parameters of the disease impacts drastically evolution of entire situation. This aspect makes it particularly difficult to adapt the solution to study of new threats in case when many attributes of infection are still not known with sufficient precision, which could be observer in case of COVID-19 as for summer 2020 (Roda et al., 2020). Fortunately, in this case the simulation allows analysis of various "what if?" scenarios, so results of simulation could be used even after parameters of disease are known with higher precision. Indeed, VESTIGE allows parallel execution of different scenarios in order to check more hypothesis or even to brute-force solution.(Di Bella 2015)

For instance, in order to improve precision of modeling of COVID-19 pandemic it would be required to have such data as Infection Fatality Rate (IFR) per age and sex, details regarding transmission by children and asymptomatic persons as well as clarifications regarding transportation and infection5. mechanism (e.g. airborne transmission, droplets emitted during cough and sneeze).

6. Conclusions

VESTIGE resulted an effective approach in modeling the pandemics quickly and in detailed way, thanks to the previous experience in population modeling. This simulation solution rwas developed along first phases of covid-19 crisis and allowed to introduce epidemics models as well as containment actions. In this way it turns possible to evaluate different Courses of Actions and tto provide to the decision makers additional support in their process. In facts, VESTIGE represent a crucial tool for analysis of possible outcomes of scenarios and identification of most promising proposals for reducing negative impact of a pandemics. Indeed, based on specific hypotheses, VESTIGE is able to forecast evolution of pandemics allowing to develop risk analysis even under uncertainty and ambiguous conditions. Based on these aspects it is evident that simulation is fundamental to support decisions able to prevent and/or mitigate possible outbreak of seasonal flu or lethal viruses. It should be interesting to discuss why instead than using smart and advanced Simulation Solutions based on Intelligent Agents and Human Behavior Modeling, most Countries decided to apply basic statistics that, by definition, is unable to predict consequence of decisions. In case of covid-19 crisis, this attitude resulted in several hundred thousands additional casualties considering that the impact of decisions due to the incubation time and high percentage of asymptomatic people requires more than two weeks to be measured by statistical indicators. Many reasons could be identified in terms of weak cultural background, lack of strategic capabilities, in any case this evident myopia of decision makers and their analysts is confirmed also by the fact they were not even able to get benefits from statistical analysis obtained from other Countries that where temporal ahead in crisi development respect them. The authors hope for the better of Society that the knowledge of these techniques will proceed and even the diffusion of their use that corresponds to a great potential in mitigating a crisis. It is evident that pandemics have very low probability to be stopped or prevented despite the tools and methodologies used, at least in cases that generates disease and diffusion models similar to that one produced by SARS-CoV-2 virus. It is not possible to create an health care system and a safety/security capability able to deal with these cases at a sustainable costs over large population with current technologies. Therefore it is also evident that using correct models and evaluating properly risks of a pandemics before and during its evolution could result in drastically changing the casualties and the socio economical impacts.

In general this concepts are valid for most complex systems and we should outline that VESTIGE considers the Population and the City as System of Systems (SoS), taking into account people, human behaviors, epidemics, weather conditions, transportation networks, social interactions, containment actions, health care, etc.. These elements allow to conduct reliable risk analysis under different hypotheses and to update them dynamically based on the evolution of the situation and emerging symptoms, so this results in a capability to evaluate different policies as well as the consequences of alternative solutions to be adopted by the decision maker in various conditions and to compare them.

References

Avalle L, A.G. Bruzzone, F. Copello, A. Guerci, P.Bartoletti (1999) "Epidemic Diffusion Simulation Relative to Movements of a Population that Acts on the Territory: Bio-Dynamic Comments and Evaluations", Proceedings of WMC99, San Francisco, January

Avalle L., Bruzzone A.G., Copello F., Guerci A. (1996) "Determination and Quantification of Functional Parameters Relative to Contamination Vector Logic in an Epidemic Simulation", Proceedings of ESS'96, Genoa, October 24-26, Italy

Avalle L., Bruzzone A.G., Copello F., Guerci A. & A.Scavotti (1995) "Preliminary Analysis for the Creation of a Territorial Epidemic Simulation Model", Proc. of ESM95, Praha, June 5-7

Azevedo, J. P., Hasan, A., Goldemberg, D., Iqbal, S. A., & Geven, K. (2020). Simulating the potential impacts of covid-19 school closures on schooling and learning outcomes: A set of global estimates.

Barredo, J. I., Kasanko, M., McCormick, N., & Lavalle, C. (2003). Modelling dynamic spatial processes: simulation of urban future scenarios through cellular automata. Landscape and urban planning, 64(3), pp. 145-160.

Bayham, J., & Fenichel, E. P. (2020). Impact of school closures for COVID-19 on the US health-care workforce and net mortality: a modelling study. The Lancet Public Health.

Bossomaier, T., Bruzzone, A. G., Massei, M., Newth, D., & Rosen, J. (2009). Pandemic Dynamic Objects and Reactive Agents. Proc. of International Mediterranean Modeling Multiconference, Tenerife, Spain, September

Bruzzone A.G. (2018) "MS2G as Pillar for Developing Strategic Engineering as a New Discipline for Complex Problem Solving", Keynote Speech at I3M, Budapest, September

Bruzzone, A.G., Massei, M., Di Matteo, R. & Agresta, M. (2018a). Simulation of crisis affecting critical infrastructures and industrial plants. In proceedings of 8th International Defense and Homeland Security Simulation Workshop, DHSS 2018, pp. 81-87

Bruzzone, A. G., & Di Bella, P. (2018b). Tempus Fugit: Time as the Main Parameter for the Strategic Engineering of MOOTW. Proceedings of WAMS

Bruzzone, A.G., Sinelshchikov, K. & Di Matteo, R. (2018c). Population Behavior, Social Networks, Transportations, infrastructures & Urban Simulation for Decision Makers. 30th European Modeling and Simulation Symposium, EMSS 2018, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M 2018

Bruzzone, A.G., Agresta, M. & Sinelshchikov, K. (2017). Simulation as decision support system for disaster prevention. In proccedings of SESDE 2017, Barcelona, September

Bruzzone A.G., (2017) "Smart Simulation: IA, Simulation and SG as enablers for Creating New Solutions in Engineering, Industry and Service of the Society", Keynote Speech at International Top-level Forum on Engineering Science & Technology Development Strategy- AI and Simulation, Hangzhou, China

Bruzzone A.G., Massei M., Longo F., Maglione G.L., Di Matteo R., Di Bella P., Milano V. (2017a) "Verification and Validation Applied To an Interoperable Simulation for Strategic Decision Making Involving Human Factors", Proc.of WAMS, Florence, September

Bruzzone, A. G., Massei, M., Longo, F., Cayirci, E., di Bella, P., Maglione, G. L., & Di Matteo, R. (2016). Simulation models for hybrid warfare and population simulation. In Proc. of NATO Symposium on Ready for the Predictable, Prepared for the Unexpected, M&S for Collective Defence in Hybrid Environments and Hybrid Conflicts, Bucharest, Romania, October (pp. 17-21).

Bruzzone A.G., Massei M., Agresta M., Poggi S., Camponeschi F. & M. (2014a) "Addressing Strategic Challenges on Mega Cities through MS2G", Proc. of MAS2014, Bordeaux, September

Bruzzone, A., Massei, M., Longo, F., Poggi, S., Agresta, M., Bartolucci, C., & Nicoletti, L. (2014b). Human Behavior Simulation for complex scenarios based on intelligent agents. In Proceedings of the 2014 Annual Simulation Symposium (pp. 1-10), April

Bruzzone A.G. (2013) "Intelligent Agent-based Simulation for supporting Operational Planning in Country Reconstruction", International Journal of Simulation and Process Modelling, 8(2-3), 145-159.

Bruzzone, A. G., Massei, M., Madeo, F., Tarone, F., & Petuhova, J. (2011). Intelligent Agents for Pandemic Modeling. In Proceedings of the 2011 Emerging M&S Applications in Industry and Academia Symposium, SCS, April, pp. 23-30

Backfrieder, W., Bruzzone, A., Longo, F., Novak, V., & Rosen, J. (2012) "The 1st International Workshop on Innovative Simulation for Health Care", Vienna, Austria,

Bruzzone, A. G., Massei, M., Madeo, F., Tarone, F., & Petuhova, J. (2011). Intelligent Agents for Pandemic Modeling. In Proceedings of the 2011 Emerging M&S Applications in Industry and Academia Symposium, SCS, April, pp. 23-30

Chunara, R., Andrews, J. R., & Brownstein, J. S. (2012). Social and news media enable estimation of epidemiological patterns early in the 2010 Haitian cholera outbreak. The American journal of tropical medicine and hygiene, 86(1), 39-45.

Di Bella P. (2015) "Present and Futures Scenarios and Challenges for M&S terms of Human Behaviour Modeling", Invited Speech at I3M2015, Bergeggi, Italy, September

Massei M., Poggi, S., Agresta, M., & Ferrando, A. (2014) "Development Planning Based on Interoperable Agent Driven Simulation", Journal of Computational Science, 5(3), 395-407

Chen, L., & Carley, K. (2003). The impact of network topology on the spread of anti-virus countermeasures. In Proceedings of NAACSOS Conference.

Deuffic, S., Buffat, L., Poynard, T., & Valleron, A. J. (1999). Modeling the hepatitis C virus epidemic in France. Hepatology, 29(5), 1596-1601.

Höglund, P. G. (2004). "Parking, energy consumption and air pollution." Science of the Total Environment 334 (2004), pp. 39-45.

Hu, H., & Wei, J. (2007). Instant messaging worms propagation simulation and countermeasures. Wuhan University Journal of Natural Sciences, 12(1), 95-100.

Kaplan, E. H. (1989). What are the risks of risky sex? Modeling the AIDS epidemic. Operations Research, 37(2), 198-209.

Karnouskos, S., & De Holanda, T. N. (2009). Simulation of a smart grid city with software agents. In 2009 Third UKSim European Symposium on Computer Modeling and Simulation, IEEE, pp. 424-429.

Melnick, H., & Darling-Hammond, L. (2020). Reopening Schools in the Context of COVID-19: Health and Safety Guidelines from Other Countries. Policy Brief. Learning Policy Institute.

Oxman, G. L., Smolkowski, K., & Noell, J. (1996). Mathematical modeling of epidemic syphilis transmission: implications for syphilis control programs. Sexually transmitted diseases, 23(1), 30-39.

Peng, L., Yang, W., Zhang, D., Zhuge, C., & Hong, L. (2020). Epidemic analysis of COVID-19 in China by dynamical modeling. arXiv preprint arXiv:2002.06563.

Roda, W. C., Varughese, M. B., Han, D., & Li, M. Y. (2020). Why is it difficult to accurately predict the COVID-19 epidemic?. Infectious Disease Modelling.

Stage, H. B., Shingleton, J., Ghosh, S., Scarabel, F., Pellis, L., & Finnie, T. (2020). Shut and re-open: the role of schools in the spread of COVID-19 in Europe. arXiv preprint arXiv:2006.14158.

Wentzel, K. R., & Battle, A. A. (2001). Social relationships and school adjustment. Adolescence and education: General issues in the education of adolescents, 1, 99-118.