Barcelona: Autonoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

Demographic agent-based simulation of Gambians immigrants in Spain

Cristina Montañola-Sales, Josep Casanovas Garcia
Departament d'Estadística i Investigació Operativa (DEIO) , Universitat Politècnica de Catalunya
Barcelona Supercomputing Center
Jordi Girona 1-3, 08034 Barcelona, SPAIN
Email: {cristina.montanola, josep.casanovas@upc.edu}

Adriana Kaplan-Marcusán
Departament d'Antropologia Social i Cultural, Universitat Autònoma de Barcelona
Bellaterra Campus, 08193 Bellaterra, Spain
Email: adriana.kaplan@uab.cat

Jose Maria Cela-Espín
Departament d'Arquitectura de Computadors (DAC) , Universitat Politècnica de Catalunya
Barcelona Supercomputing Center
Jordi Girona 1-3, 08034 Barcelona, SPAIN
Email: josem.cela@bsc.es

Abstract— **Changes in our society have created a challenge for policymakers, who confront a need of tools to evaluate the possible effects of their policies. Agent-based modelling and simulation is a promising methodology which can be used in the study of population dynamics. In this paper we introduce an agent-based simulation approach to project the population of Gambian migrants in Spain during 10 years. Our approach not only enables to simulate the life course of individuals, but also allows deeping on the movements, interactions, and behaviours of the target population. The model is able to capture individual characteristics and to overcome some data-related limitations with assumptions on behavioural rules. With this methodology, we want to show the potential of the tool with the study of a real case scenario.**

I. Introduction

Today, our society is inexorably shifting in form and nature lead by challenging transitions driven by social, economic, environmental and technological changes. Population dynamics influences every aspect of human, social and economic development. The research area that studies human population in relation to changes brought about by the interplay of births, deaths and migration is demography [1]. Demography is a field in geography that is often used as the basis for government policies in areas such as labour market, education, healthcare, social welfare and taxation. Among social research, it has greatly contributed to project people to guide societal planning [2]. Although population projections are simplified, uncertain representations of people, they are usually used as input to policy making and planning models in areas such as labour market, education, healthcare, social welfare and taxation.

In recent years simulation has gain popularity as a tool to understand the insights of social complexity. However, it has been little used in demographic research to help explaining dynamics [3]. Simulation methodologies provide the opportunity to develop a virtual laboratory for exploring and validating current and new approaches. The purpose is to avoid conducting real social experiments, which may be expensive, unethical or even infeasible.

In the past few years, the use of micro-level simulation models in population projection has become more widespread, especially in the field of migratory movements or human reproduction [3]. Taking profit of the increasing availability of data at micro level, microsimulation allows including individual-specific explanatory variables in the model. In microsimulation paradigm, modellers have to specify a random sampling process for each individual at each simulation time point, to determine the state of each individual at the next simulation time point. Many microsimulation tools have been built for certain public policies [4]–[7].

Despite microsimulation extensive use, this technique has two main limitations [8]. On one hand, it models individuals' behaviour in terms of probabilities which are supposed to match with preferences, plans and decisions. On the other hand, it simulates people at the individual level, not taking into account their interactions. Moreover, microsimulation requires realistic micro-data so it can be difficult to apply when appropriate data are not available [9].

Agent-Based Modelling (ABM) represents an alternative to cope with those limitations. Many demographic processes take place based on individual choice behaviour and interactions among people [10]. Therefore, ABM is interesting for demography for their capacity of generating personal event histories and producing estimates of the full distribution outcome. Moreover, ABM is particularly useful for projecting a population answering "what if" questions such as the effect of a certain policy on a specific demographic characteristic. It allows modelling the impact of personal decision making processes in strategic planning or government policies.

In this paper, we present an application of ABM in demographics. Section II revises the use of ABM in population dynamics studies and the latest tools available for agent-based simulation. The framework used for this study is introduced in Section III. Section IV presents the context of Gambian migration in Spain and explains the simulation case study we have conducted of Gambian immigrants in Spain.

II. AGENT-BASED DEMOGRAPHIC SIMULATON

Despite agent-based modelling useful features, there has been a limited use in the area of demography. [11] used this approach to explore the interplay between the demographic system and the cultural system in an artificial society of hunter-gatherers. Other researchers used it to project past migrations in Germany [12] or to understand residential dynamics in Israel [13]. Among most recent works, ABM has been applied to study student migrations in the UK [9], to examine patterns of infection and immunity [14], to understand environmental migration in Burkina Fasso [15], and to see how changing family structures in the UK population may influence the provision of health care [16].

As a result of the growing popularity of ABM in many fields, several tools have been developed in the last years to explore the complexity of social systems, enabling the execution of generic ABMs [17]–[20]. In most of them, ABM is commonly used for small scenarios because the number of agents and interactions between them can be extremely large in some case studies. However, in the case of policy models, both the amount of compute power required and detailed micro-level data are significant.

III. YADES: A PARALLEL SIMULATION TOOL FOR DEMOGRAPHICS

There is general interest in using individual-based simulation (such as micro-simulation and agent-based simulation) with larger sample sizes in demographic simulation models. This raises a performance issue because individual-based simulation is relatively slow if the model includes a large number of individuals and the simulation time unit is very small. The execution time will be even worse when the sampling process in each individual requires a complex regression model. It should be noted that the simulation execution time depends not only on the processor speed but also the memory capacity. If the model includes a large number of individuals, it might require more memory than the memory capacity of a single-processor computer which will cause memory swapping. Hence, it is possible that sequential simulation might be too slow. Parallel simulation may offer an alternative.

In this work we used Yades, a agent-based simulation tool for demographics which can profit high performance computing capabilities [21], [22]. It provides the placeholders for different demographic processes such as fertility, mortality, change in economic status, change in marital status, and migration. The main advantage of this approach is the ability to run large agent-based scenarios, when other tools present limitations. Moreover, Yades particularly focus on demographic simulation might facilitate modellers the development of demographic related models.

To help on specifying ABMs, Yades incorporates an interface and it features automatic code generation. In that way modellers can define the set of variables and components that will define the simulation model. They should be able to reap the performance offered by parallel computers transparently. Thus, Yades has three components: a web user interface, a demographic simulation library and the simulation code generator. The web user interface allows demographic modellers to specify demographic model components in a number of representations familiar to demographers such as regression and statistical distribution function. The simulation code generator can produce the corresponding C++ code that is linked to the demographic simulation library which uses a scalable parallel discrete-event simulation engine. The generated code is ready for compilation using a target C++ compiler. The demographic simulation library supports both sequential and parallel execution of the simulation model. The resulting framework is shown in Figure 1.

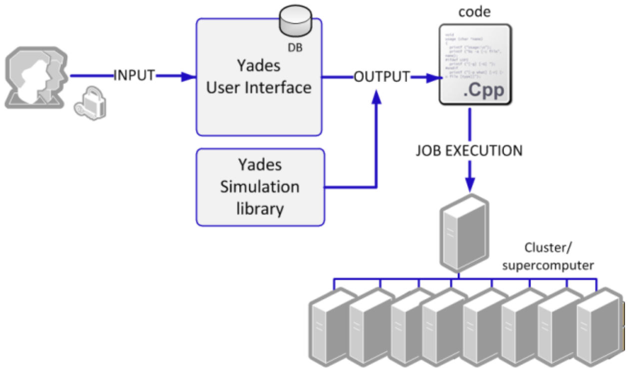

Figure 1. Yades simulation framework

Yades was implemented using μsik parallel discrete-event simulation library [23]. It supports both sequential and parallel execution of the simulation model and has shown good scalability in previous studies [24]. Yades adopts the process interaction world-view in which a simulation model is formed by a set of interacting *agents*. Agents communicate through events. Multiple agents can be mapped onto a *PopulationSimulator* that is run on top of a processor. A machine can have more than one processor (e.g., in multi-core architecture).

There are two types of agents in Yades: *family unit* and *region*. A family unit is defined as a single independent individual or two independent individuals living together (as married, in civil-partnership, or in cohabitation) and any dependent individuals (children). A family unit may receive events which are related to five demographic components that may change the system states. Modellers can specify models for five demographic components: fertility, a change in economic status, a change in marital status, migration and mortality. The fertility component determines whether a female individual will give birth, based on the characteristic of the female individual and the current calendar time. The model returns the time when the baby is due. Similarly, modellers can use the characteristic of an individual and the current calendar time to determine a new economic status of that individual.

A new marital status can be modelled based on the characteristics of the individual (or individuals for a couple) and the current calendar time. If the new status is either married or cohabitating, modellers need to define the criteria that will be used to match the individual to another individual from the list of prospective partners (i.e. we use a closed marriage model). If a suitable partner is found, then a 'family formation' event will be scheduled for both individuals. Otherwise, the individual will be added to the list for a fixed duration. If a partner still cannot be found at the end of the duration, an event will be sent to remove the individual from the list.

Modellers also need to specify a model that is used to determine whether a family unit is going to migrate. If the destination is in another country (emigration), the family unit will simply be removed from the simulation. Finally, in the mortality component, modellers need to model the time when an individual will die based on the characteristics of the individual. Commonly used methods, such as life table and survival function can be used for the mortality component.

The second type of agent in Yades represents a region where a number of families live. This agent will handle domestic migrations, immigration, changes in simulation parameters and periodic reports. Yades allows users to have regions with different population characteristics. Figure 2 shows how the demographic scenario is mapped on a distributed architecture as already described.

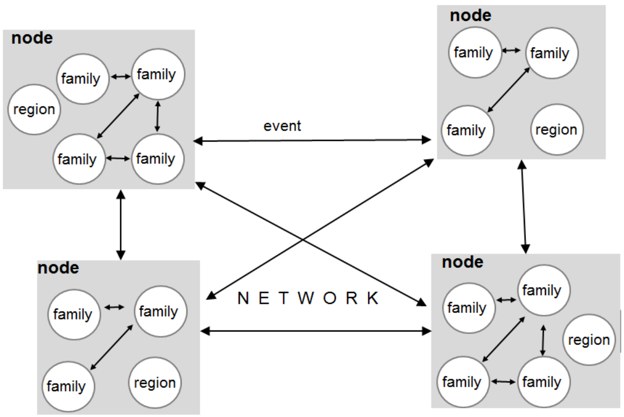

Figure 2. Mapping of agents in the physical architecture

IV. SIMULATION OF GAMBIAN MIGRANTS IN CATALONIA

In our paper, we propose to use Yades to understand the demographic evolution of Gambian community in Spain. The Gambia is a small country in the Sub-Saharan Africa. Despite its small size, its migration rate has been quite high last 30 years. According to the World Bank, in 2010 Spain received the 34.15% of emigrants from the Gambia, being the leading destination country. In the region of Gambia movements outside the country are perceived as a familiar strategy and follow two differentiate patterns: surviving and mobility [25]. Mobility movements generally answer to a familiar project, where the household does a significant financial investment. That is the reason why migrations are due to a process of selection in the origin, to maximize the success of the project.

The case under study carries out an analysis of the evolution of the population of The Gambia between 2000 and 2010. The period is interesting for research because migration flows from Sub-Saharan Africa (including The Gambia) to Spain increased significantly. Spanish economy prospered in that decade probably increasing the expectancies of Gambian migrants and increasing migration movements.

The Gambian is the four largest Sub-Saharan African group of emigrants in Spain, with a total of 20,639 people, according to the 2011 census of Spanish National Institute of Statistics (INE). It is the group of emigrants in Spain with the highest fertility, the higher proportion of children under 16 years old and the lowest proportion of people older than 65 [26]. Thus, we are facing a young population, with very high fertility rate (Total Fertility Rate in 2001 was approximately 8 children per woman). Moreover, Gambian emigrant group shows an unequal sex and age distribution as we can see in Figure 3.

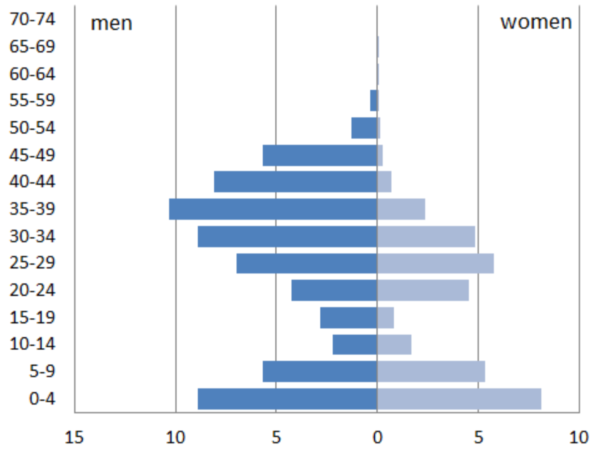

Figure 3. Gambian population pyramid in 2001. Source: INE 2001 census

The gender disequilibrium shows two different migratory strategies [27]. From one hand, the high masculine proportion, especially when compared to other African migrants in Spain, might respond to economic reasons in the origin. On the other hand, low women proportion might be a consequence of family reunification processes. Moreover, most of Gambian emigrants have mainly a rural origin.

These factors of Gambian population make an impact on local population structures in Spain. Gambian emigrants exhibit a distinctive pattern from the rest of migrants, i.e. they tend to reside only in certain areas, dispersed across the various regions, with the largest concentrations in Catalonia (76.16% in 2011), and work in agricultural sectors, domestic services, construction, or the service industry.

Our model considers the aspects which best characterize the Gambian emigrant population in Spain: high fertility, partnership trends, deaths, labour market, and mobility. Data was obtained from census and country surveys on migration patterns. Behavioural rules were built from ethnographic records of anthropological studies [25], [26], [28]. The simulation results have been compared to the observed distribution of the Gambian population in 2010. Through the implementation of behavioural simple rules at the individual level, the heterogeneity of the group and its residential mobility is captured in the model. Despite some simplifications made to study this phenomenon, the projected population presents similarities with statistical records and encourages us to further enhance the tool.

The proposed case study suits well the high-degree complexity of general ABMs because the development of the population is affected by a large number of interrelated and dynamics factors: gender, age, economic level, family, matchmaking and reproduction patterns, life cycles and so on. Moreover, the proposed ABM is interesting for studying these particular phenomena since it provides a way to gain insight of the population at an individual-level. Thus, with our work we show the potential of agent-based simulation on group dynamics with a real case study. Furthermore, this work will increase Yades credibility for the community of modellers, showing the possibilities ABM tools can provide to assist them in the understanding of demographic processes to guide decision making or exploration of "what if" situations.

References

[1] R. Pressat, *Demographic analysis*. Chicago: Aldine Atherton, 1985.

[2] P. Rees, "Demography," in *International Encyclopedia of Human Geography*, R. Kitchin and N. Thrift, Eds. Oxford: Elsevier, 2009, pp. 75–90.

[3] F. C. Billari, F. Ongaro, and A. Prskawetz, "Introduction: agent-based computational demography," in *Agent-Based Computational Demography*, F. C. Billari and A. Prskawetz, Eds. Heidelberg, Germany: Springer Physica-Verlag, 2003, pp. 1–17.

[4] R. Leombruni and M. Richiardi, "LABORsim: An Agent-Based Microsimulation of Labour Supply--An Application to Italy," *Comput. Econ.*, vol. 27, no. 1, pp. 63–88, 2006.

[5] C. O'Donoghue and H. Redway, "Modelling migration in Pensim2: a dynamic microsimulation model of the British pension system," in *Presented at the 2nd General Conference of the International Microsimulation Association, June 8th to 10th, 2009, Ottawa, Ontario, Canada*, 2009.

[6] F. J. Dahlen, "LaMPsim - an open source microsimulation tool in development," in *Presented at the 2nd General Conference of the International Microsimulation Association, June 8th to 10th, 2009, Ottawa, Ontario, Canada*, 2009.

[7] S. Zinn, J. Gampe, J. Himmelspach, and A. M. Uhrmacher, "MIC-core: A tool for microsimulation," in *Proceedings of the 2009 Winter Simulation Conference, WSC 2009, Austin, TX, December 13-16*. 2009, pp. 992–1002.

[8] P. Davidsson, "Multi Agent Based Simulation: Beyond Social Simulation," in *Multi-Agent-Based Simulation*, vol. 1979, S. Moss and P. Davidsson, Eds. Springer Berlin Heidelberg, 2001, pp. 97–107.

[9] B. M. Wu and M. H. Birkin, "Agent-based extensions to a spatial microsimulation model of demographic change," in *Agent-based models of geographical systems*, Springer, 2012, pp. 347–360.

[10] W. Jager and M. A. Janssen, "Diffusion processes in demographic transitions: a prospect on using multi agent simulation to explore the role of cognitive strategies and social interactions," in *Agent-Based Computational Demography*, F. C. Billari and A. Prskawetz, Eds. Heidelberg, Germany: Springer Physica-Verlag, 2003, pp. 55–72.

[11] D. Read, "Kinship based demographic simulation of societal processes," *Journal of Artificial Societies and Social Simulation*, vol. 1, no. 1, 1998.

[12] F. Heiland, "The collapse of the Berlin Wall: Simulating state-level East to West German migration patterns," in *Agent-Based Computational Demography*, F. C. Billari and A. Prskawetz, Eds. Heidelberg, Germany: Springer Physica-Verlag, 2003, pp. 73–96.

[13] I. Benenson, I. Omer, and E. Hatna, "Agent-Based Modeling of Householders' Migration Behavior and Its Consequences," in *Agent-Based Computational Demography*, F. C. Billari and A. Prskawetz, Eds. Heidelberg, Germany: Springer Physica-Verlag, 2003, pp. 97–115.

[14] N. Geard, J. M. McCaw, A. Dorin, K. B. Korb, and J. McVernon, "Synthetic Population Dynamics: A Model of Household Demography," *Journal of Artificial Societies and Social Simulation*, vol. 16, no. 1, p. 8, 2013.

[15] D. Kniveton, C. Smith, and S. Wood, "Agent-based model simulations of future changes in migration flows for Burkina Faso," *Globlal Environmental Change*, no. 21, Sumplement 1, p. S34 - S40, 2011.

[16] E. Silverman, J. Bijak, J. Hilton, V. D. Cao, and J. Noble, "When Demography Met Social Simulation: A Tale of Two Modelling Approaches," *ournal of Artificial Societies and Social Simulation*, vol. 16, no. 4, p. 9, 2013.

[17] N. Collier, "Repast: An extensible framework for agent simulation," *Nat. Resour. Environ. Issues*, vol. 8, no. 1, p. 4, 2001.

[18] S. Tisue and U. Wilensky, "NetLogo: A simple environment for modeling complexity," in *Proceedings of the International conference on Complex Systems, Boston, May 2004*, 2004, pp. 16–21.

[19] N. Minar, R. Burkhart, C. Langton, and M. Askenazi, "The swarm simulation system: A toolkit for building multi-agent simulations," Technical report. Santa Fe Institute. 1996.

[20] Mason. Available at http://cs.gmu.edu/~eclab/projects/mason/

[21] B. S. S. Onggo, "Parallel discrete-event simulation of population dynamics," in *Proceedings of the 40th Conference on Winter Simulation*, 2008, pp. 1047–1054.

[22] C. Montañola-Sales, J. Casanovas-Garcia, J. M. Cela-Espín, B. S. . Onggo, and A. Kaplan-Marcusan, "Parallel simulation of large population dynamics," in *Proceedings of the Winter Simulation Conference, 8-12 December 2013, Washington D.C.*, 2013.

[23] K. S. Perumalla, "µsik: A Micro-Kernel for Parallel/Distributed Simulation Systems," in *Proceedings of the 19th Workshop on Principles of Advanced and Distributed Simulation*, 2005, pp. 59–68.

[24] B. Onggo, C. Montañola-Sales, and J. Casanovas-Garcia, "Performance Analysis of Parallel Demographic Simulation," in *Proceedings of the 24th European Simulation and Modelling Conference, 25-27 October 2010, pp. 142-148*, 2010.

[25] A. Kaplan, "From Senegambia to Spain migration process and social integration," *Monogr. Migr. Eur. J. Int. Migr. Ethn. Relations*, vol. 43/44/45, pp. 52–65, 2005.

[26] C. Bledsoe, R. Houle, and P. Sow, "High fertility Gambians in low fertility Spain: mutually entailed lives across international space," *Eur. Assoc. Popul. Stud. Work. Anthropol. Demogr. Eur. Max Plank Inst. Demogr. Res. Rostock*, 2005.

[27] A. Domingo, D. López-Falcón, and A. del Rey, "Current status and trends of African migration to Spain," in *Papers de Demografia - Centre d'Estudis Demogràfics*, 2010.

[28] C. Bledsoe, "The demography of family reunification: from circulation to substitution in Gambian Spain," *Max Planck Inst. Demogr. Res. Work. Pap. 1006*, vol. 53, pp. 1–31, 2006.