Chapter 37
Reflections and Conclusions: Geographical Models to Address Grand Challenges

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Abstract This chapter provides some general reflections on the development of ABM in terms of the applications presented in this book. We focus on the dilemma of building rich models that tend to move the field from strong to weaker styles of prediction, raising issues of validation in environments of high diversity and variability. We argue that we need to make progress on these issues while at the same time extending our models to deal with cross-cutting issues that define societal grand challenges such as climate change, energy depletion, aging, migration, security, and a host of other global issues. We pick up various pointers to how we might best use models in a policy context that have been introduced in many of the applications presented within this book and we argue that in the future, we need to develop a more robust approach to how we might use such models in policy making and planning.

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37.1 Where Do We Stand in Modelling Geographical Systems?

The models dealt with in this book represent our most recent thinking as to how we might best represent geographical systems to describe the variety and complexity that confronts us in both our abstractions and our casual perceptions of the world around us. Agent-based modelling (ABM)[1] represents a softening of the rather parsimonious, aggregative, largely static models that we began with over 50 years ago. As we have argued throughout this book, this is because of what we have learnt about such systems but also because these systems have become more complex, and our models have been reduced in their severity. They are now richer and more descriptive, thus probably more informative but less predictive. Yet what we have been at pains to portray is not that ABM or cellular automata (CA) or microsimulation models substitute for any of those that have gone before, for they complement our knowledge. The array of modelling approaches now available provides us with a much greater menu of ideas, which we might apply to critical spatial problems. Of course, some of the applications in the past can now be done much more effectively with newer styles of theory and model, but all the approaches that have been developed build on this past, and in the kind of pluralistic world that we have implicitly adopted as anchoring our field, we consider all these approaches to have value.

One of the central issues in all of science is dramatically illustrated by our experience of ABM. It has long been regarded that good science can only be generated if theory is tested under controlled conditions, in laboratory contexts where extraneous events are excluded or at least accounted for in some definite way. As we have learnt more about the world, it has become increasingly clear that science has two faces: one where strong theory can be generated and tested in the classical tradition and one where such strong theory breaks down in more open applications. It is the latter that dominates our quest to apply scientific principles to more open problems and we thus face a dilemma. Some rather good and obvious examples are widely known. For example, weather forecasting, which is based on strong classical theory, is generally of weak predictability. When such theory and their models are put into the real world, such extensive variability based on extraneous unpredictable forces is simply unknown and this destroys strong predictions. Although we may be able to test and confirm or falsify the sorts of strong theory that underpin the hydrodynamics of controlled atmospheres, when it comes to making strong predictions in the wider context of the world's weather, this is simply not possible. In fact in our own field for geographical systems such as cities and regions, strong theory is even less likely to be possible because it is almost impossible to set up controlled human experimentation, and once what theory there is, is put to the test, the whole basis of any such knowledge that is culled from experiment, changes.

It is still an open question as to whether or not there are intrinsic differences between science and social science. Traditionally these have been assumed to relate to animate and inanimate matter – that physical systems are not able to manufacture

[1] ABM is also taken to mean Agent-Based Model (s) as well as Modelling.

their own destinies whereas human systems have that potential. But notwithstanding this point, which may not be resolvable in any case in the context of the variability that models of geographical systems need to work with, we must accept that strong prediction is not likely, nor is it appropriate. Thus the role of models is intrinsically different from that which was assumed 50 years ago. Models must be to inform rather than predict or if to predict, then these are entirely conditional on the context in which such prediction is made. To an extent, this is encapsulated in the notion of 'what if' experiments and scenarios, i.e. conditionals that are context dependent.

So far we have not explored this dilemma in detail for it is compounded by the fact that our systems of study are getting more complex as they evolve, and thus our theories and models tend to lag behind the systems that we observe. Moreover, our models also tend to change the very system that they attempt to simulate as we learn more about the world and apply more considered actions to its problems. In some respects, as soon as models came to be applied to geographical systems, their designers and users became quickly aware how problematic was the issue of validating them and using them to generate robust predictions. The very act of constructing the model soon became a focus of such efforts, imposing on the discipline what were usually inchoate and ill-defined problem contexts. The ideology of modelling quickly moved from notions about prediction to information, from making forecasts to providing informed advice concerning the problem in context. Despite the longevity of these notions, little has been done on pursuing the logic of using models in this way, for science in general and policy analysis in particular has been stymied by the dilemma of getting to grips with the uncertainty of scientific knowledge in the human domain. What has been done, and this is very clear from the various contributions in this book, is that as models have become richer to deal more effectively with the systems which they are designed to represent, the process of calibration, estimation, or validation against external, purportedly independent data has become more involved. For example, Ngo and See (2012) develop considerable detail with respect to model validation which is considerably more elaborate in its testing than that developed for more aggregate parsimonious models. Verification has come onto the agenda largely because as models have got bigger, it has become clear that simply defining a model and then assuming it runs as specified, generates considerable uncertainty. Indeed visualization of model data and outputs, even the processes of simulation, is essential because of errors that creep in during the process of assembling data, encoding algebra, and operating such models in complex computational environments.

One of our conclusions is that we must engage in a more vibrant and wide ranging discussion of formal theory and models of geographical and other social systems in terms of their validation. We need to continue to explore the limits of how far we can expect our models to replicate reality, to examine the conditions that we observe in the past and expect in the future with respect to what our models are able to say about different circumstances. We need to think much more out of the box about complexity, validation and the world that we wish to influence, following the exemplar of van der Leeuw (2004) who in his discussion of modelling the ancient past raises a series of dilemmas that are clearly different from attempts to simulate the contemporary past and the present. In the social sciences, there has always been an uncomfortable tension between developing theory for its own sake – curiosity driven knowledge – in contrast to theory that is practically inspired, particularly for circumstances where we ourselves are involved in making proposals and plans for designing the future, for resolving social problems and for engendering a better quality of life for all. We need to grasp this nettle more directly, and only by doing so, will we be able to reconcile the key issues involving the use of the new generation of models introduced in this book. It is highly likely that the future will be dominated by a plurality of model types and styles, and to confront this world, we will need a much clearer sense of where and when to use what particular model (Epstein 2008). This plurality has been anticipated and there is already some rudimentary research into how two or more models might be compared (Axtell et al. 1996). The idea that we build more than one model for any and every situation is growing. It was suggested many years ago by Greenberger et al. (1976) as counter-modelling but it has taken a long time in coming. It is a challenge that will underpin all others.

37.2 The Need to Address the Grand Challenges

Most of the applications of ABM presented in this book involve city systems in the mainstream traditions of urban geography, regional science, urban economics, and transportation modelling. Much of the field however, has been influenced by a more rural focus, particularly with respect to land cover modelling and applications to development in developing countries. Although the concept of an agent does differ between rural and urban, and across spatial scales, common applications deal with spatial structure, form, mobility and demographics. Most ABMs to date have focused on specific sectors rather than on comprehensive representations, except where, the tradition in urban modelling, large models such as TRANSIMS have attempted to model a wider range of sectors. As we have implied, many models still lie at the level of 'proof-of-concept' with a strong pedagogic focus, and the field is ripe for more focused applications.

Because ABM tends to be a generic style of modelling, it is often used as more of a toolkit to develop models, rather than as an exclusive framework for large scale applications. This however, is changing as we become more familiar with its potential, as evidenced by the large scale epidemiological, transportation, financial markets and the human immune system models currently being attempted (Castiglione 2003). However, the grand challenges which have dominated the social and policy sciences of late are not well represented so far in terms of these new styles of model. Currently most applications to geographical systems have focused on different activity or land use sectors, dividing the city system into housing markets, education and schools, the health sector, transportation, with specific spatial behaviours relating to crime, pedestrian flow and movement, segregation, traffic flow and related processes. In a developing countries context, there has been a focus on aid and development, but the bigger issues of energy, climate change, and security have rarely been tackled. As we have noted, there has been a focus in ABM on diffusion, particularly disease but it is timely to stand back and inquire into how such modelling styles can be best used to inform the really big, pressing questions that now dominate both local and global policy.

Perhaps the most focused of any of the models presented here are those involving microsimulation where policy questions are to the fore, specifically demographics. Aging, for example, is of central concern certainly in western nations but also in China, and such secular change can have an enormous impact on the structure of geographical systems that define populations and their life cycles. The models developed here by Wu and Birkin (2012) show how some really big challenges might be addressed in terms of changing life cycles but these have not yet been linked to other sectors where the impact of changing demographic profiles is likely to have an enormous impact on the spatial consequences of such change. It is only when these types of model are integrated in some way, coupled, that the level of comprehensiveness of the simulation is much increased, and that the real effectiveness in discussing the impact of these challenges on modern urban society and its cities can be thoroughly appreciated. To an extent, this is achieved via a loose coupling of various models, which tend to be different perspectives on how a variety of tools such as microsimulation, visualization, online mapping, and database organization for city simulation are being developed in the NeISS project (see http://www.neiss.org.uk/) but the extent to which the integration is based on coupling ABMs is not strong. Integrated modelling insofar as it exists for geographical systems has so far been based much more on aggregative models as, for example, in the climate change impact assessment of flooding in the Greater London region, which was based on an integration of various macro models such as input-output, land use transportation interaction (LUTI) models, land development using CA, and hydrological flood models (Walsh et al. 2011). The domain is thus wide open for more ambitious ABM simulation frameworks which integrate different models as well as interfacing them with appropriate policy analysis and stakeholder participation (Batty 2010).

In the next section, we will sketch some of the grand challenges that are key to social and public policy at the present time and suggest how ABM and related techniques might relate to some of these applications. Our focus is more on coupling, on how we use ABM to enrich and inform the dialogue, rather than on producing highly integrated structures that attempt complete comprehension. Moreover, we also see these grand challenges being informed by many different kinds of models, thus reinforcing our sentiments that in the future, many models, models at different levels of aggregation, both static and dynamic, will define the portfolio that decision-makers and scientist alike consider appropriate to the kinds of advice that science can bring to bear on these critical questions.

37.3 Climate Change, Energy Issues, Poverty, Aging and Migration: Can ABM Make a Difference?

Models of geographical systems tend to cut across the kinds of problems that are now widely regarded to be of major societal significance. The grand challenges that have emerged over the last 20 years involve themes that cross many sectors for which models are individually built and thus integrated modelling is usually required if these challenges are to be informed by the tools and methods presented in this book. In particular, the key challenges at present involve aging and demography, urbanization and migration, energy depletion, climate change, poverty (which is a recurrent issue), health and disease, and security and conflict. These are by no means all those that are identifiable, for at more modest scales, issues involving housing, financial markets and global trade all raise profound issues that cannot be tackled sector by sector. Moreover, technology change is compounding, complicating and continually changing the nature of these problems. This poses a dilemma, for our models tend to be focused on quite manageable and identifiable sectors and activities, whereas the grand challenges are cross-cutting. Indeed, these challenges tend to be important because they cannot be handled in traditional ways, by traditional models.

The quest therefore is to develop our models so that they can address pieces of these major challenges. ABMs in fact are rather focused on behaviours central to the way many of these big problems need to be resolved. Behavioural change is often a clear and obvious solution to some of these issues and ABMs have the potential to simulate such behaviours. However, one key paradox is that the grand challenges appear to involve changes in behaviour, which represent not a continuous evolution of current patterns of behaviour but often radical shifts. How we use models which simulate current patterns of behaviour which need to change if the key issues are to be resolved poses enormous difficulties for implementing and using models that are based on current and past patterns of behaviour. For example, shifts in responses to climate change such as adaptation involves changing behaviours to reduce their impact while mitigation policies will give rise to changed behaviours as a result of new policies designed to reduce the drivers of change such as carbon emissions.

There are some areas of ABM that are well suited to developing insights into some of these global challenges. In fact the intersection between ABM and microsimulation modelling involves representing life cycle effects that incorporate issues of aging related to geodemographics and health. There are strong policy issues involved here with respect to the provision of facilities, particularly housing and health services, for different age groups. Wu and Birkin (2012) address these issues directly in one of their contributions here but the contributions from Leeds more generally, particularly from Malleson (2012) on crime, Harland and Heppenstall (2012) on education, and Smith (2012) on health, all inform these key issues. The various contributions on city size distributions from Gulden and Hammond (2012) and Pumain (2012) do not quite address migration although the elements of such modelling are implicit in their models, but as migration is likely to be a key challenge at every spatial scale as we become more mobile, then the seeds of how we might explore this through ABM are reflected in various of the contributions which deal with spatial interaction and movement.

Issues of security and conflict have been handled extensively at the micro-spatial scale in pedestrian models useful in testing evacuation scenarios. There is a lot of expertise in dealing with crowding in confined spaces as illustrated in the articles on crowd movements by Johansson and Kretz (2012) and on traffic congestion by Banos and Genre-Grandpierre (2012). Many of these challenges are global in scope and to address these will require generalizing many of these approaches to deal with large spatial scales. There is also considerable potential in many of the models reviewed here to simulate diffusion in many media. Simoes (2012) provides a direct example of such spatial simulations by modelling the spread of a childhood disease in Portugal, but it is easy to see how these kinds of models might be generalized to the global scale in the manner proposed by Epstein in the PACER (2011) project.

Mobility is central to these grand challenges and the models contained herein address these issues directly. There is the scale change of course in the way we have posed these challenges, for many applications here address these issues at a more local scale. For example, questions of compactness and sprawl intimately affect energy issues. Here we have reviewed various CA models that are being used to generate insights into such development (see Iltanen 2012; Barros 2012) but what we sorely need is to extend such models to explicitly deal with such activities. In fact, one problem in ABM is to represent actions and interactions in a sufficiently robust way to begin to generate predictions that deal explicitly with mobility and movement that can be matched against more aggregate observations. Indeed the need to aggregate from the individual level to a level where patterns are more meaningful is a technical challenge that is only just being addressed. Last but not least, development and aid are key to poverty and in some of the contributions here, particularly those dealing with development in developing countries at the finer scales of land cover, there are useful suggestions for showing how ABM can begin to address questions of equity and distribution.

37.4 Anticipating Future Forms of Modelling and Prediction

Our focus on modelling and simulation here has been pluralistic, focusing on ABM, the newest variant of geographical models but arguing that good models of geographical systems inevitably mix and match the best from many different simulation frameworks. Our best guess is that there will be many more examples in the future of a hybrid variety, which take the best tools and methods from different types, and produce model structures that combine the best of many worlds. In the future, integrated models of a hybrid type may well become the norm but perhaps the greatest changes will not come from new insights into how to model, but from new sources of data. A change in focus from what in the past has been meso-level approaches to the truly micro – local – and the macro – global – is possible. Dealing with routine fine scale spatial and temporal behaviours is more closely matched to ABM than location predictions of the more aggregate kind, while at the global level, the policy context is ripe to be informed by insights for a new class of aggregate ABM. These can combine the individualistic behaviours in such models with aggregates or groups treated as individuals at the highest levels.

It is tempting to second-guess new styles of model that might emerge which build on this evolution of the last 50 years. We are not able to do this but we can identify responses that appear promising: integrated and hybrid models, a sustained and direct approach to simulating spatial behaviour, which is something more than the tokenism that currently besets most behavioural simulations, a new sense of how models might be developed and used all the way from model specification through to implementation and validation with new ways of figuring out how such models can be used to inform the future, how new data sources might change what we consider important in simulation, and how many different and competing models of the same phenomena might be reconciled in the quest to enrich our understanding of key problems: these are all pointers to a future that will take this field further and improve its relevance to ongoing social challenges.

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