Agent-Based Modelling and Climate Change Adaptation:

Briefing Note for Discussion Seminar, Friday February 8, 2008

Peter Hayes, January 31-08

Global Cities Institute has undertaken a range of start-up investments with high potential impact in the urban climate change adaptation (CCA) field and drawing on resident research capacities at RMIT. These include creation and testing of decision tools to support cities in relation to adaptive watershed management, desalination, knowledge management, green building, and community response. GCI is testing a well-established scenarios methodology for exploring and embracing uncertainty at the organizational and community level. However, this technique is mostly qualitative and whilst powerful, requires supplementary, quantitative ways of testing strategies for robustness and policy salience in the face of complexity and uncertainty.

Agent-based modeling (ABM) is a candidate for such a tool within GCI. As Patt and Siebenhuner explain, ABM is suitable for simulating complex systems in order to investigating "emergent properties," that is, outcomes that have structural properties that differ from those of the agents themselves.[1] ABM is generically suited for issues in which many agents face the same problem, where the choices that are made influence the choices made by other agents (or via feedback loops, the future behavior of agent types, so called genetic learning), where technologies are applicable and must diffuse somehow via networks; that have spatial dimensions; or involve flows and non-linear effects (pedestrian flows, traffic jams etc are classic social dilemmas for which ABM has proven powerful tools for insight and policy analysis; or revolve around diffusion processes (eg HIV and internet viruses, demonstrate similar n-power rates of spread). ABM demands that agent values be specified, not ignored, in order to specify norms that may vary according to circumstance for an agent.

Thus, instead of whole system "Equation Based Modelling," ABM models the agents. There is no system as a whole, only the emergent properties of the simulated interaction of the agents given their attributed goals, decision-rules, the constraints faced and "sensed" by each agent, and action-rules plus iterative "learning" algorithms of the simulation. Simulations can be created that are compared to historical records to determine "fit" with datasets; or run forward to identify patterns of emergent behavior.

Climate change adaptation by cities is a classic instance of complex, bottom-up and multi-agent human behavior. Millions of households, hundreds of thousands of

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[1] A. Patt and B. Siebenhuner, "Agent Based Modeling and Adaptation to Climate Change," *Vierteljahrshefte zur Wirtschaftsforschung* (*Quarterly Journal of Economic Research*) 74(2): 310 – 320 at: www.vulnerabilitynet.org/OPMS/getfile.php?bn=seiproject_hotel&key=1140130223&att_id=953 Patt is now at IIASA in Vienna; the ABM work was done at the Potsdam Institute for Climate Research.

enterprises of various sizes, and thousands of government agencies from local, municipal, state and national governments constitute "multi-agent cities" at various scales. Cities in turn are embedded in global networks of trade, investment, finance, information, knowledge, and population flows. Urban growth, distinct land uses, planning and regulatory frameworks, formal and informal markets, and other processes structure the complex and often (usually?) unpredictable outcomes resulting from the interaction of these agents.

In the past two decades, agent-based modeling (ABM, not anti-ballistic missile, how the times have changed!) has emerged as an alternative to linear and deterministic modeling of highly complex situations. A good summary in the urban field is provided by Michael Batty (see Attachment 1).[2] The 2002 PNAS studies cover a wide range of ABM studies on stock markets, archeological records, farming, geopolitics, organizational change, etc. (see Attachment 2)[3] The 5 year (just finished) CRC on complexity included an urban complexity[4]; CSIRO also has a small ABM working group (CABM) within the CSIRO Centre for Complex Systems Science.

Global and accelerating climate change will affect cities in powerful and pervasive ways. Climate change will affect heat islands, disease vectors, water stocks and flows, air quality, waste and sewage removal, networked telecom, energy, and transport systems, building retrofit and new building design. Households, enterprises, and government agencies will all respond simultaneously to new kinds of sensors and early warning systems, many of which will provide only limited and often uncertain knowledge about locale-specific climate threats. Urban CCA is an analytic problem in which:

a) interactions between these heterogeneous agents in many types of CCA are *highly inter-dependent* in an iterative fashion, resulting from aggregated decision-making of many disparate agents (in this regard, risk perception and CCA choices are highly subject to social factors, and appear to have critical thresholds and "phase changes" as little Johnny found out to his chagrin, too late); the GCI-CCAP is working in this field at the community level.

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[2] M. Batty, Complexity and Cities, MIT Press, 2005

[3] "Adaptive Agents, Intelligence, and Emergent Human Organization: Capturing Complexity through Agent-Based Modeling," *Proceedings of the National Academy of the Sciences* (US), May 14, 2002; 99 (Suppl. 3) , at http://www.pnas.org/content/vol99/suppl_3/

[4] See COSNet - the ARC Complex Open Systems Research Network, at http://www.complexsystems.net.au/ and if you look hard enough (via the wiki) you find COSNet's excellent site, Complex Dynamics of Urban Systems at http://www.complexsystems.net.au/wiki/Complex_Dynamics_of_Urban_Systems

b) new technologies are involved in many urban CCA measures, and *diffusion of technology* is a process that involves many agents and is subject to the kind of interdependent herding and other effects that arise from behavior of large numbers of people using imperfect information and facing uncertainty. ABM may provide insight into the conditions which might facilitate uptake of technologies such as those that GCI-CCAP has invested (eg desalination), or the types of barriers that will have to be surmounted.

c) bottom-up, locally initiated urban CCA will constitute the bulk of CCA. Indeed, many governments aim to stimulate "autonomous" adaptive capacity in their urban communities. Yet this locally driven, self-replicating (by demonstration effect) *CCA may result in social dilemmas and coordination problems* in "adjacent" communities. For example, dyking a river or shoreline in response to sea-level rise can displace and worsen the problem in the rest of a water system or shoreline. ABM might be used to show how alternative "soft" measures (such as retreat) might have different outcomes but also pose difficulties such as how to diffuse the "soft" technical measures involved in retreat, for example, involving property rights and compensation). In short, ABM may help to identify ways that cities may fall unwittingly into "mal-adaptation" traps; or to analyze existing mal-adaptation gridlocks (for example, urban property markets, residential codes, and slums in vulnerable areas in many low-lying and flood-prone cities) to show what must be done to overcome failures to adapt.

Some key questions for us are:

1) What overarching CCA dilemmas or policy tools do we want to explore, who are the agents in relation to this proposed strategy, what are their a)-c) characteristics, what simplified decision and action rules do they exhibit, and what data exists to validate the simulation at the level of resolution of the modeling? Is ABM the most suitable technique for this research?
2) How would a GCI ABM tool for urban CCA relate to the scenarios process? Would it be usable for a lead up to scenarios workshops to highlight key issues? Or could it be used after a workshop to examine the strategies to deal with uncertainty emerging from the workshop for robustness in application via simulation testing or "wind tunneling?"
3) Can ABM be applied to "cities" or local governments or communities as agents to help us prefigure the possible inter-city collaboration for CCA at a global level involving say 1-200 cities, to supplement or substitute for inter-state CCA cooperation and regulatory frameworks?
4) Can ABM for urban CCA be used by other GCI WGs to examine their own key research questions, drawing on the agent analysis and datasets compiled over time for each city?

5) What spatial problems are contained in the CCAP project portfolio that are particularly apt for ABM on a GIS platform (similar to the kind of work Colin Arrowsmith has done at RMIT); and does GCI have the resources to build and employ a GIS platform for its projects?
6) What AMB capacity is there at RMIT (we have already discovered some analysts we didn't know about only a fortnight ago). What ABM software is available at RMIT, apt to CCA analysis, and able to integrate with open source software to visualize outcomes, map complexity in the relations between problems, solutions, and agents and display these relationships; who are the external partners (especially at Melbourne and other Victorian universities)?
7) Who at RMIT engages in research on urban complexity?
8) Is CCA-ABM simulation a possible ARC linkage grant application theme? (this is under discussion with Colin Arrowsmith already).

There are currently almost no useful publications on ABM in the arena of climate change adaptation.[5] Application to climate change adaptation in various sectors such as arid zone agriculture in southern Africa is commencing. I know of no applications to urban CCA.

This could be because it's really hard to do; because the tool is not apt in spite of what is outlined above (see cautionary note from Patt in Attachment 3); because there are more important questions to answer with other tools; or because people are just beginning to pay attention to CCA rather than CC mitigation, and therefore are starting to look for new tools that are suited to this research topic. I am not sure, but hopefully our session will help us improve our understanding of the state of ABM at RMIT, and whether it might be worth investing in ABM at GCI.

ATTACHMENT 1:

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[5] The references most often cited are: S. Moss et al, "Agent-based integrated assessment modeling: the example of climate change," *Integrated Assessment*, 2: 17-30, 2001. In reality, Moss *et al* argue against the application of fundamentally flawed economics (in particular, with cost-benefit variants) in the climate change field, and propose to substitute ABM simulation in a way that draws on stakeholders to verify relationships and data; but they do not act on their own call. M. Janssen and B. de Vries, "The battle of perspectives: a multi-agent model with adaptive responses to climate change," *Ecological Economics*, 26, 43-65, 1998, is another title with great promise and poor delivery. This paper introduces cultural theory to insist that differential perspectives(held by agents being Hierachists, Egalitarians, and Individualists) will induce different CC adaptive response. They define an energy-climate model (quantitative and general at the global level) and then run it with different values for variables and coefficients in the model (such as autonomous technological change or climate damages for a given level of energy use, etc) to determine the different outcomes depending on which agent's values and perspectives drive the model. Unsurprisingly, this procedure generates divergent global utopias and dystopias; they then layer in additional surprises that further reinforce the dominant paradigm via feedback loops. Their simulated "battle of perspectives" is interesting but barely draws on modern ABM. The most directly apt paper is the already cited Patt and Siebenhuner, but again, their paper contains no actual applications to climate change. This briefing note draws primarily on Patt and Siebenhuner, the PNAS series, and Batty and ignores the Moss and Janssen papers.

Cities and Complexity Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals
Michael Batty

Blurb:

As urban planning moves from a centralized, top-down approach to a decentralized, bottom-up perspective, our conception of urban systems is changing. In *Cities and Complexity*, Michael Batty offers a comprehensive view of urban dynamics in the context of complexity theory, presenting models that demonstrate how complexity theory can embrace a myriad of processes and elements that combine into organic wholes. He argues that bottom-up processes -- in which the outcomes are always uncertain -- can combine with new forms of geometry associated with fractal patterns and chaotic dynamics to provide theories that are applicable to highly complex systems such as cities.

Batty begins with models based on cellular automata (CA), simulating urban dynamics through the local actions of automata. He then introduces agent-based models (ABM), in which agents are mobile and move between locations. These models relate to many scales, from the scale of the street to patterns and structure at the scale of the urban region. Finally, Batty develops applications of all these models to specific urban situations, discussing concepts of criticality, threshold, surprise, novelty, and phase transition in the context of spatial developments. Every theory and model presented in the book is developed through examples that range from the simplified and hypothetical to the actual. Deploying extensive visual, mathematical, and textual material, Cities and Complexity will be read both by urban researchers and by complexity theorists with an interest in new kinds of computational models.

Sample chapters and examples from the book, and other related material, can be found at http://www.complexcity.info by clicking on the link to the left.

ATTACHMENT 2:

“Adaptive Agents, Intelligence, and Emergent Human Organization: Capturing Complexity through Agent-Based Modeling,” *Proceedings of the National Academy of the Sciences* (US), May 14, 2002; 99 (Suppl. 3) , at http://www.pnas.org/content/vol99/suppl_3/

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PERSPECTIVES

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Atachment 3:

Dear Peter,

I know of the SEI project [RMITers will find one output of this project at http://www.ouce.ox.ac.uk/~mnew/research/publications/bharwani_phil_trans_royal_soc_2005.pdf], but I don't know others. While I was at the Potsdam Institute for Climate Impact Research (PIK), I was asked to lead an exploratory group on the ABM and climate adaptation and vulnerability. One of the goals was to have a model that could contribute to PIK's efforts at integrated modeling. We struggled for a year and a half, and eventually gave up. We decided that ABM was simply not a good tool for looking at adaptation. The only thing we did was the paper you read, which I don't think was very good or particularly honest about how limited we saw the uses of ABM (since we were asked to write a paper saying how great ABM was).

Our first step was to realize that ABM can potentially offer insights when the interactions between agents in a system matters more than the interaction between agents and a central planner. We decided that adaptation, at least some kinds of adaptation, seems to fit this class of system fairly well. But then we started asking whether within this class of system there were particular problems that ABM was especially suited to.

First, we concluded, ABM can show how fairly "simple" systems (e.g. not many agents, or not many rules, or very limited interactions) can actually be quite complex, and in some cases leading to some interesting emergent properties that are not really predictable. This is what the Sugarscape model shows. We initially thought that this fit the adaptation problem, but then we had second thoughts. Indeed, it would come as no great insight to realize that adaptation is complex, and we couldn't think of a model telling us anything we didn't already know in this direction.

Second, we concluded, it can occasionally answer puzzling questions about how a system has been observed to function, including whether its observed behavior is consistent with the assumptions about individuals' decision rules. This is what Schelling did in Micromotives and Macrobehavior, way back when, and what Lansing did in his study of Balinese rice farming (Priests and Programmers). A precondition for this kind of problem is that there have already been a puzzling observation of how a system operates (e.g. Lansing started with the observation that Bali rice farming managed by the priests worked much better than when it was managed by a team of agronomists; Schelling observed that racial segregation occurred even when people wanted to live in integrated communities). In these cases, ABM shows that it is possible for a system to function in particular, usually counterintuitive, way. We tried really hard to think of something to do with adaptation that would fit this kind of problem, and we gave up.

So, ABM is good to show how a seemingly simple system is surprisingly unpredictable, and to show how a complex system can function in surprising ways. But it is terrible to actually make any predictions about how a system will function in the future, or how to make a system function better in the future, which seems like the issue with adaptation. We couldn't think of any adaptation-related problem for which ABM would provide us insights that we wouldn't get more easily and more reliably from some other method.

The PIK leadership were not happy with us. They were thinking of climate models (GCMs), which in a sense are like ABMs, with each space in the three dimensional grid is like an agent, in that it passes some of its properties (thermal energy, kinetic energy, partial pressures) on to its neighbors. So they thought, why can't you do the same with people. The problem of course is that the physical laws describing how parcels of air and water interact are a lot simpler and a lot more accurate than the social science theories describing how people interact with each other. If elected officials matter for adaptation policy, and if we can't predict with much accuracy who will win the next election, then an ABM model has to include those elected officials as agents but can not specify their decision rules, and rapidly becomes useless. We would do far better to simply tell qualitative stories, or use some econometric analysis, or something else equally non-ABM-like.

I would be interested in your reaction to these thoughts!

Cheers,

Tony

On 28 Jan 2008, at 07:24, Peter Hayes wrote:

Dear Anthony Patt,

I read your 2005 paper on ABM and CC adaptation with interest. Have you or anyone you know actually completed applications of modern ABM to complex, bottom up CC adaptive response, eg cities? (I am aware of the IIED-SEI project on arid farming in Southern Africa).

We are exploring initiating some work along these lines at RMIT University (where I convene the urban climate change adaptation program of the new Global Cities Institute alongside our work on climate change from Nautilus Institute in SF, which I direct).

I would be grateful for your advice,

Regards,

Peter Hayes