CENTRE FOR ADVANCE

Cellular Models of Urban Systems

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Abstract

Cellular automaton (CA) based models are increasingly used

ism which have been introduced by urban modellers in a bid for realism (see also White 1998). We suggest in section 4 that many of these operational variations may be seen as responses to the representational issues we have purposes. The combination of their activities is what causes ‘state transitions’. Seen in this light, it may be difficult to justify a pure state transition approach to rules in a cellular land use model. Rules must be understood as somehow embodying all this human activity. This raises the question of why human agents are not explicitly represented, and suggests that agent-based approaches may sometimes be more appropriate. There are cases in which cell transition rules may be appropriate, the most obvious being traffic simulation (Chopard, Luthi & Queloz 1996, Nagel & Schreckenburg 1992, Wahle, Neubert & Schreckenburg 1999) where cells are ‘vehicle-sized’ segments of road, and cell states represent occupancy by vehicles. Significantly, this is a realm where human autonomy is strongly constrained by rules of the road and the spatial structures in the urban case may offer significant insights for the use of CA in other domains, where similar observations apply.

2.3 Time in CA models: synchronous and asynchronous update

The representation of time in CA models is also of interest. Discretised 'time-steps' are at odds with the fluidity of temporal activity in reality, and the synchronous update of cell states is clearly questionable. Experiments with asynchronous update of cell states in abstract CA suggest that the dynamic implications of departure from synchronous update may be significant (Bersini & Detours 1994). This suggestion is supported by findings on path dependency and lock-in, which have received much attention in economics (Arthur 1989), and were also central to the early transfer of ideas from complexity science to regional modelling (Allen & Sanglier 1979), but may be missed in any straight-forward application of CA to urban simulation.

There are also difficult questions to be answered about the representation of events at many different temporal scales. The treatment of time in rigid CA raises problems for their application to the simulation of urban systems. In particular, questions about the spatio-temporal scale of models are raised, which are difficult to answer without circular reference back to the transition rules m2306Td(the)Tj 15.8394 0 Tdllegath

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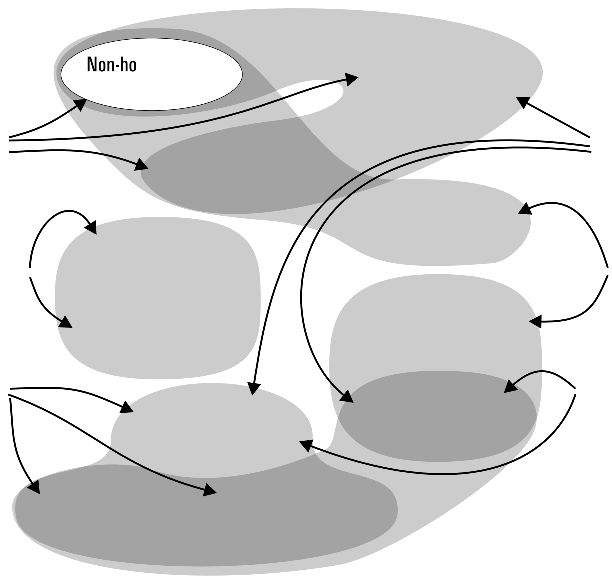
rather than industrial, for example). However, it can be difficult to reduce all of the activity in an urban cell to a single discrete description. This is particularly true of relatively coarse grids (at say 100m or more resolution). There is bound to be 'mixing'

3.3 Non-regular lattices

In practice, few urban CA models retain a spatially stationary lattice. The issue of regularity is often addressed conservatively by the introduction of ‘fixed’ cell states. Bodies of water and undevelopable land are obvious examples which effectively introduce irregularity and asymmetry (Clarke et al. 1997, White & Engelen 1997). Fixed cells may also be introduced to ‘protect’ the model from edge effects (White et al. 1997). Traffic models deliberately employ non-regular lattices because the traffic system’s spatial structure is non-regular (Chopard et al. 1996, Nagel & Schreckenburg 1992, Wahle et al. 1999). The kind of object-based cell suggested in section 2.1 naturally leads to asymmetric and non-regular lattice structures, and the resulting models lie somewhere between CA and boolean networks (Kauffman 1984), albeit with spatially stationary rules.

3.4 Asynchronous transition rules

Truly asynchronous cell update in urban CA is unusual. However, some models incorporate forms of asynchronous determination of cell state changes into a synchronously updating framework. In the work of Portugali (2000) on intra-urban migration, queues of agents who wish to enter or leave the city are sequentially allocated to available ‘properties’. Similarly in models of land use dynamics (White & Engelen 1993, 1997, White et al. 1997), a CA sequentially determines the spatial allocation of land use transitions, determined outside the model. In both these cases, the departure from synchronous operation is partly a response to the fact that the region is embedded in a wider world, and is not a closed system. In another example, Wu (1999) introduces asynchronous operation as a fundamental aspect of the system dynamics, when he relates a model of urban development driven by the appearance of ‘investment niches’, to the notion of self-organised criticality. Whatever the motivation for introducing asynchronous cell update, the fundamental dynamics of such systems are not at all clear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"all the simplifying assumptions of the basic cell-space model could be relaxed in principle: in practice of course, the result would be forbiddingly complex." She was suggesting that one of the attractions of CA is the potential they provide for insights into the relationships between processes at local scales and structures at global scales. Such insight, apart from its pedagogic value, also raises the possibility of a deeper understanding of the fundamental dynamics of spatial systems. But, as Couclelis's remark indicates, any insights which might be obtained are rapidly clouded by the ever more complicated refinement of additional model elements.

There is no obvious simple way around this dilemma, but we wish to tentatively suggest an approach which we hope to develop in more detail over time. The reason that the CA formalism has exerted such fascination in so many fields, is its high level of generality. When it comes to applying the formalism, however, "it is necessary to use more complex CA" (White 1998, page 112), with a resulting loss in generality of the insights, but a gain in the direct applicability of the models to real systems. One response might be for those interested in exploring the dynamics of spatial systems in more general ways, to develop some well-defined, specific departures from the CA formalism. A preliminary list of possibilities might include:

- *Strict formal CA with a small family of geographical process rules* Theoretical exploration of the behaviour of urban CA would be much assisted by agreement on a limited set of typical process rules whose behaviour could then be thoroughly explored and characterised. Segregation, growth, aggregation and diffusion processes are obvious candidates.

- *Cellular models with irregular lattice structures* This concept is foreshadowed by Takeyama & Couclelis's (1997) Geo-Algebra, and brought into clearer focus by the graph-based CA (O'Sullivan forthcoming). Such models might also be capable of modifying their lattice structure as a response to neighbourhood states (Semboloni forthcoming, has presented an example).

- *Agents in cellular models* The rules of a CA in an urban system ultimately reflect the behaviour of various human agents, and in many cases modelling the agents themselves seems more plausible. Portugali's (2000) Free Agents in Cellular Space model is a working example of this approach.

- *Asynchronous cell update* The limitation of CA models to synchronous update is problematic, and research into alternatives is required. One possibility seems likely to be using Petri nets in the definition of cell transition rules (see Gronewold & Sonnenschein 1998).

The purpose of focusing on particular variants and extensions of the CA formalism is to enable research into the general spatial dynamics of such systems, so that some of the potential for insight promised by initial

Semboloni, F. (forthcoming), ‘The growth of