Commutation as an Emergent Phenomenon of Residential and Industrial Location Decisions: from a Microeconomic to a MMASS-based Model

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systems research
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The research framework

- Interdisciplinary research group on complex systems that involves computer scientists (DISCo) and economists (i.e. urban planning and design at ARCS)
- Thematic Institute on "Regional Innovation Systems and Complexity" (Wien, September 2004) - Exystence framework (http://www.complexityscience.org)
- An interdisciplinary collaboration aiming at

  providing domain experts with suitable and specific tools (methodological and software) to model socio-economic processes in residential and industrial development

The ARCS-DISCo collaboration

- Ecosystem Management
- Urban planning and design
- Landuse Management

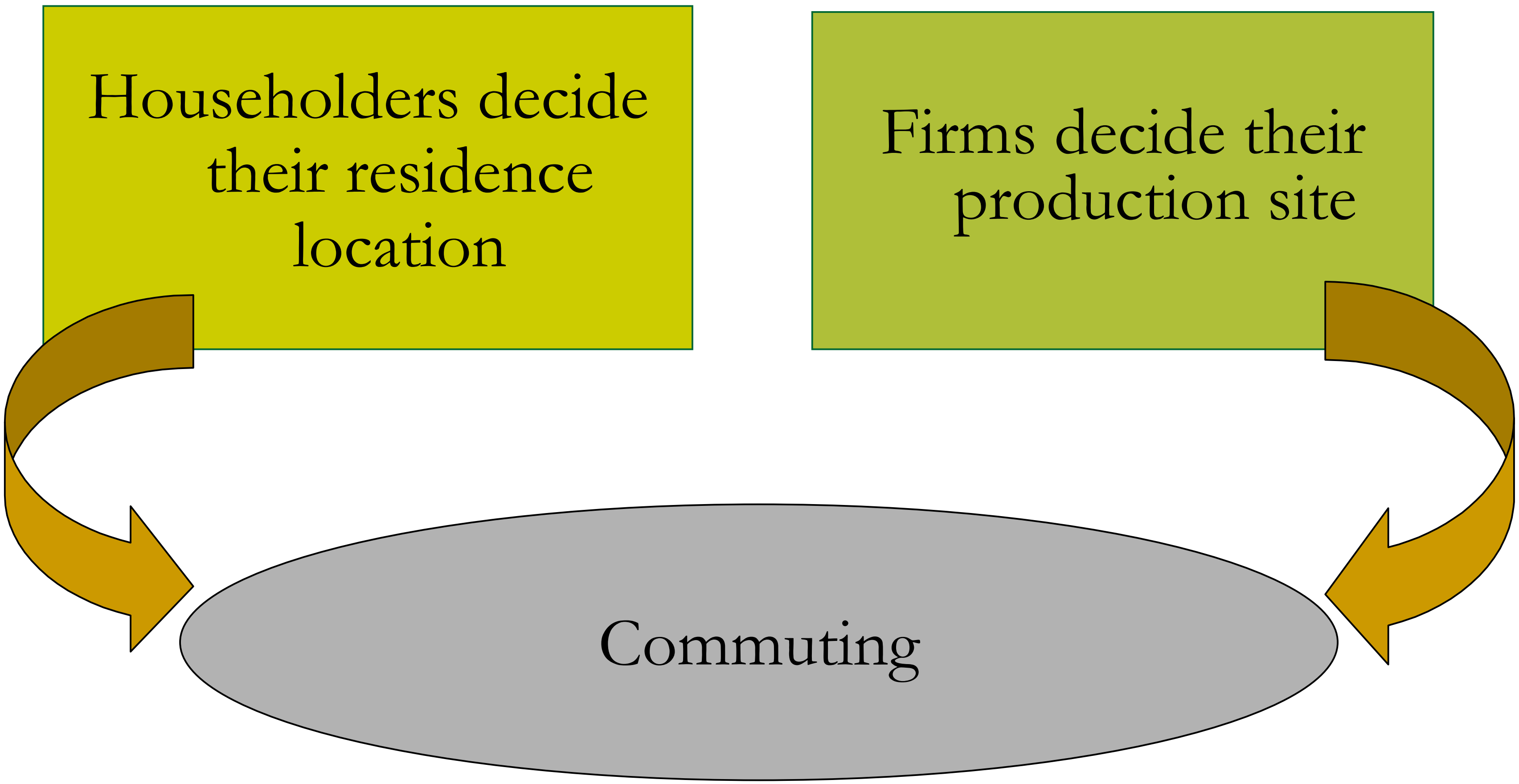
Supporting Landuse Management

- Investigation on Agent-based Computational Economics (ACE)
  - How and why do economists develop agent-oriented models and simulations?
  - How works within ACE can be described according to concepts and notions defined in computer science? → agent architectures and behavioral models, interaction models, relationship between agents and their environment, …
  - Which tools could be provided to support them? → computational models, software platforms, analysis approaches and tools
- Starting from analogies and differences, formalize a set of fundamental requirements for agent-based simulation in economics
- In particular,
  - Experiment the application of the Multilayered Multi-Agent Situated Systems to model socio-economic processes in residential and industrial development
  - In particular, to study commuter traffic in urban regions can be studied as an emergent phenomenon of the decisions of heterogeneous agents

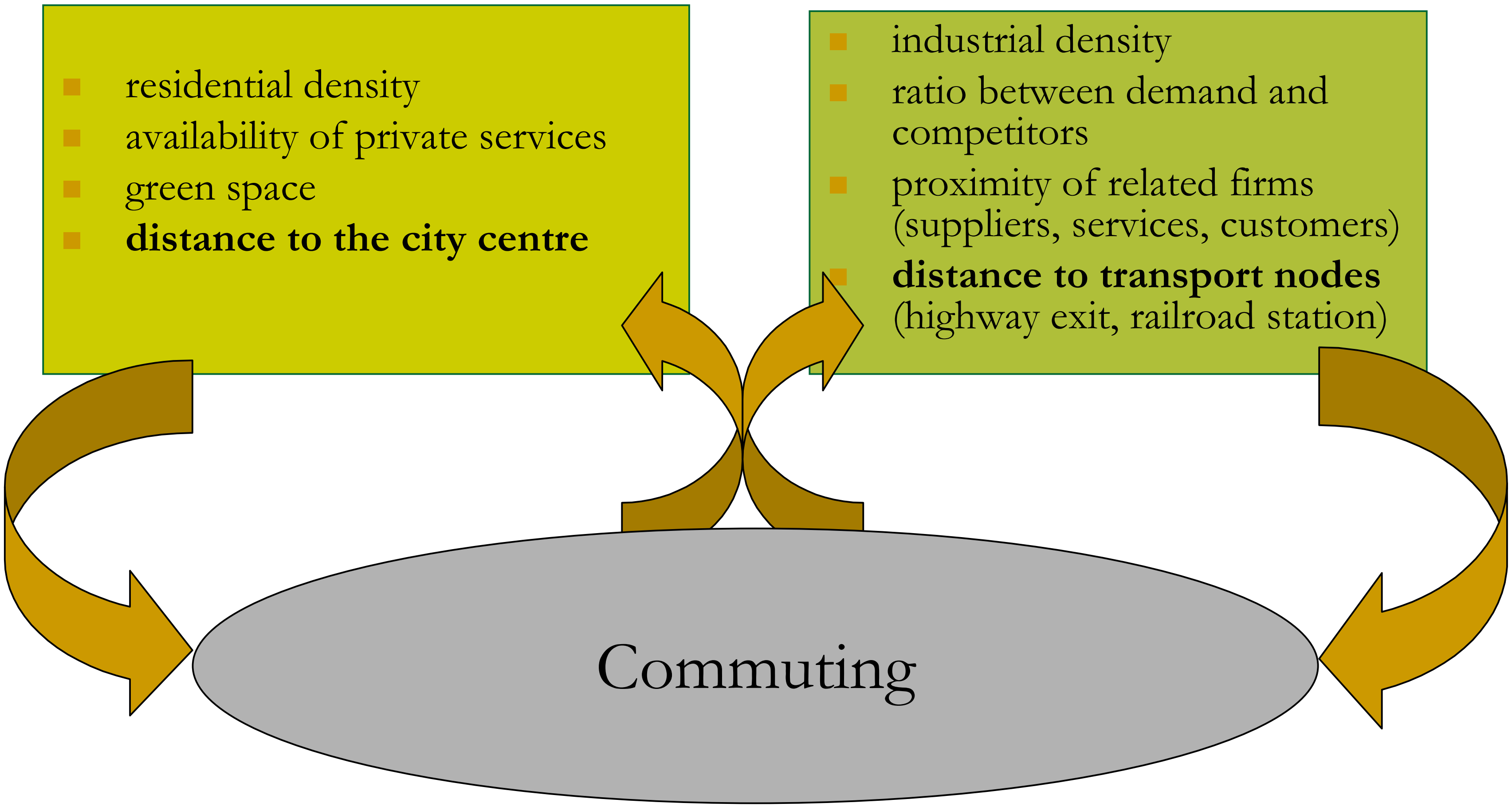
Commuting as self-organization of heterogeneous agents

- The reference microeconomic model focuses on
  - *households* (of employed persons) decide on their residence
  - *firms* on their location
  - other agents (e.g., regulation of land use by municipalities) are taken as given
- *Commuting* is both
  - a result of decisions of individual agents (i.e. an emergent feature in the urban system)
  - a feedback factor influencing the decisions of households and firms

Commuting as self-organization of heterogeneous agents



Commuting as self-organization of heterogeneous agents



Distance between locations*: an estimate of the time needed to reach a location from another according to the type of available connections (e.g. roads, underground, train line)*

Agents' behavior

- The ***behavior of firms*** is based on their location utility and a cost function of relocation in case of changing the site
- The ***behavior of households*** is based on a location utility function and a cost function which considers commuting and relocation in case of changing residence
- ***Commuting*** is a result of the choice of residence and the randomly determined job opportunities or losses (employed persons and jobs are differentiated by levels of qualification → not any job is accessible for every employed person)

Residential utility function and location factors

$$H: \alpha R + \beta S + \delta G + \gamma Dic - C1 \rightarrow max$$

Households H	H	
Residential density	R*	$R_i = H_i/B_i$, $R^*_I = R_i + \Sigma_j R_j e^{\wedge}{-\sigma} D_{ij}$, normalized: % of R’
Private services (relative supply)	S*/H	$S^*_I = S_i + \Sigma_j S_j e^{\wedge}{-\sigma} D_{ij}$, normalized: % of H
Green space	G*	$G^*_I = G_i + \Sigma_j G_j e^{\wedge}{-\sigma} D_{ij}$, normalized: % of A
Distance between I and j	D_{ij}	
Downtown distance	D_{ic}	normalized: % of D_{max}
Residential relocation cost	C1	
Residential area	B_i	

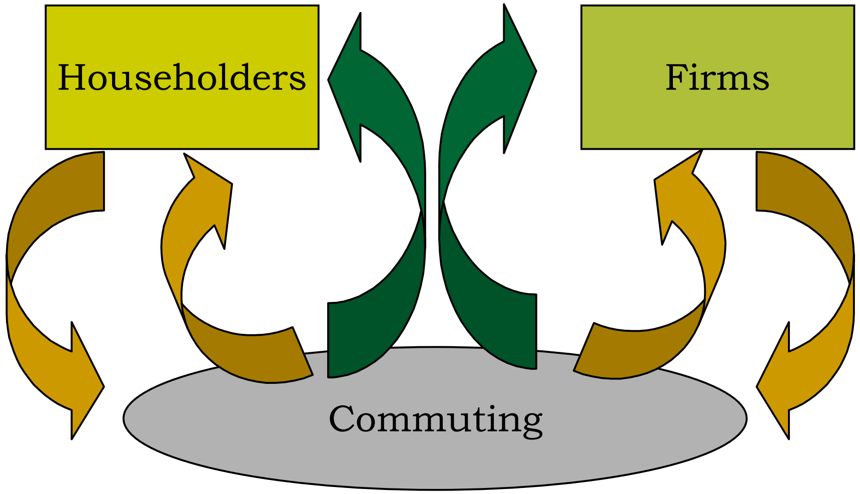
Industrial utility function and location factors

$$F: \varphi I + \lambda P + \mu X + \pi Din - C2 \rightarrow max$$

Firms F	F	
Industrial density	I*	$I_i = F_i / M_i$, $I^*_i = I_i + \Sigma_j I_j e^{-\sigma D_{ij}}$, normalized: % of I'
Demand / competition ratio	P*	$P^*_i = (H_i + \Sigma_j H_j e^{-\sigma D_{ij}}) / (S_i + \Sigma_j S_j e^{-\sigma D_{ij}})$
Cluster (relative supply)	X*/F	$X^*_I = X_i + \Sigma_j X_j e^{-\sigma D_{ij}}$, normalized: % of F
Distance between i and j	D_{ij}	
Transport node distance	D_{in}	Normalized: % of D_{max}
Industrial relocation cost	C2	
Industrial area	M_i	

Influences and feedbacks

- The decisions on residential and industrial locations, as well as the random job matching, leads to commuter flows between the locations which, in turn, enter the residential choice of households
- Further feedback: the change in residential and industrial density



Classes of householders and preferences

		Residential preferences			
		α R	β S	δ G	γDic
Highly qualified suburbanites	(Q=1)	--	0	++	-
Highly qualified urbanites	(Q=1)	+	++	0	++
Less qualified suburbanites	(Q=2)	-	0	++	-
Less qualified urbanites	(Q=2)	0	+	0	+

- Householders and firms are heterogeneous
- Classes of agents apply different weights to each location factor

Classes of firms and preferences

		Location preferences			
		φI	λ P	μ X	π D_{in}
Private services	(S)	0	++	+	0
Cluster firms	(X)	-	0	++	-
Large scale manufacturing	(V)	--	0	0	-
Utilities	(U)	0	0	0	0

Transition probabilities of households

			Probability per age class		
			-30	*31-45*	*45-60*
Highly qualified suburbanites	→	Highly qualified urbanites	Low	very low	Negligible
Highly qualified urbanites	→	Highly qualified suburbanites	low	very high	High
Less qualified suburbanites	→	Less qualified urbanites	very low	negligible	Negligible
Less qualified urbanites	→	Less qualified suburbanites	negligible	low	very low

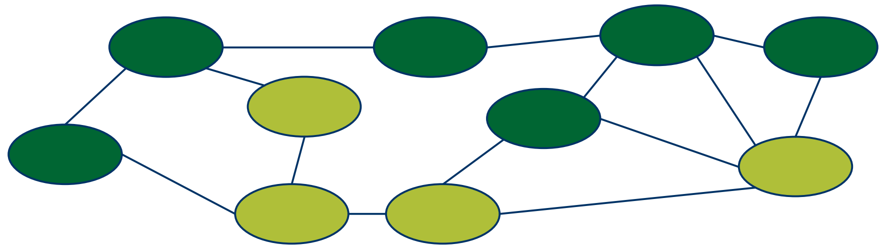
How have model parameters been determined?

- Several sets of parameters have been tested in the simulation runs to exogenously determine
  - residential preferences → changes probabilistically according to an assumed household life cycle
  - industrial location preferences → constant
  - generation and loss of jobs → based on the national industrial activity
- Parameters that are determined exogenously and may change discretely over time
  - upper limits of density
  - transport infrastructure (traffic capacity)
  - regulation of land use (zoning)
- Transition probability is estimated according to the frequency of households
- Qualification level does not change according to age

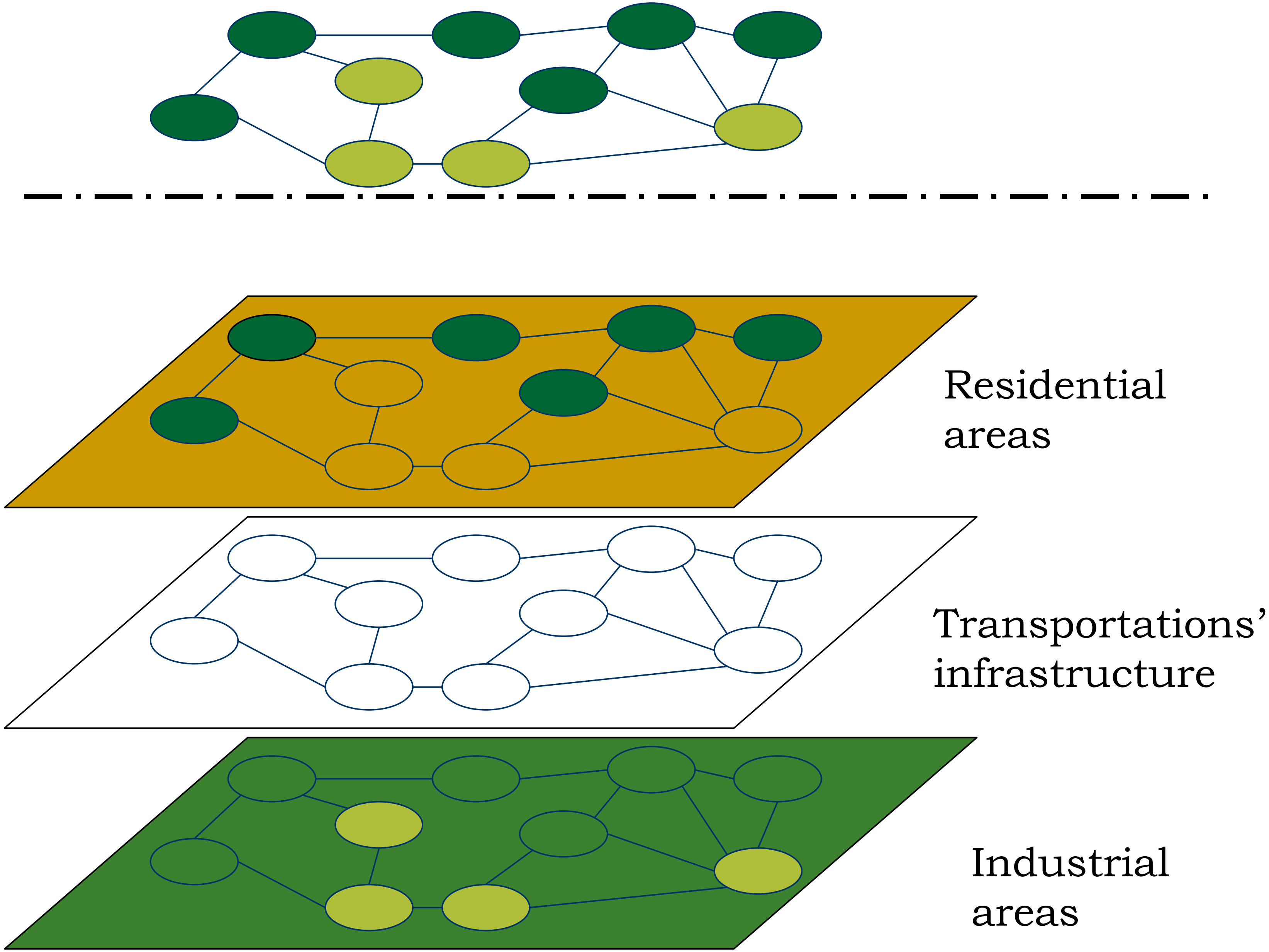
Why MMASS among MAS-based models?

- Due to problem features and peculiarities
  - It explicitly describes the spatial structure of agent environment: multilayered network of sites
  - MMASS agents can be characterized by heterogeneous behaviors that are space-dependant
  - Interactions between MMASS agents are space-dependant
  - Multilayered spatial structure (i.e. multiple situated MAS can coexist and interact): heterogeneous aspects that contribute to the behavior and dynamics of the whole system can be described by distinct MAS situated in distinct (but interconnected) layers of the spatial structure

The proposal



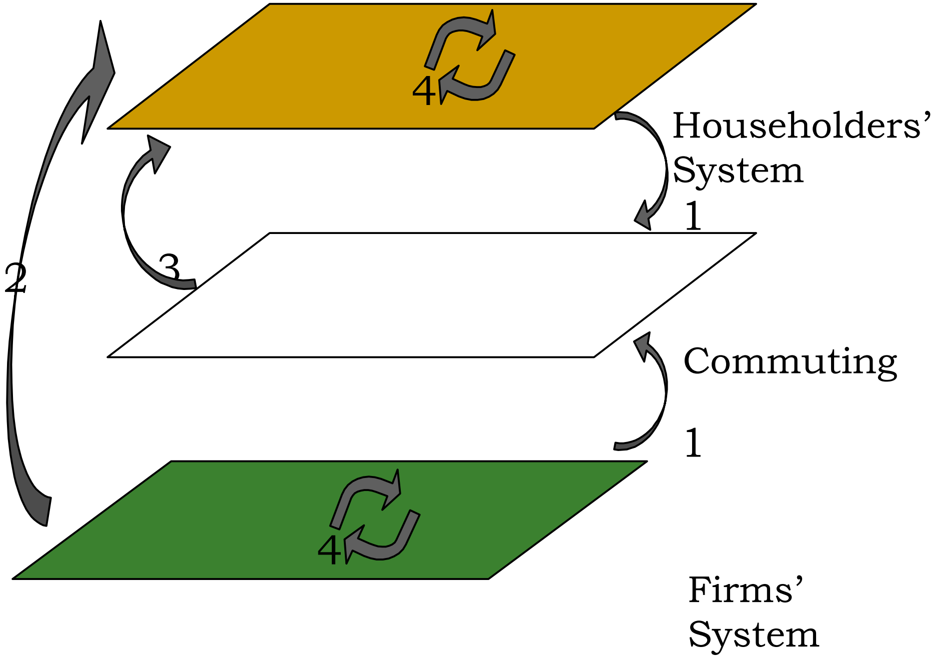
- Territory
  - Discrete set of locations where either residential or industrial buildings are allowed
  - An edge exists between two locations only when some transportation infrastructure (e.g. road, train line) exists between them (useful and available information can be associated to each graph node and edge)
- MMASS agents represent system entities that perform some kind of decision-making process (according to their features and state and the ones of the environment they are situated in)



Residential areas
Transportations' infrastructure
Industrial areas

Influence between systems

- *Householders' and Firms' systems* → *Commuting*: commuting is the result of decisions of householders and firms
- *Decisions in Firms' System* → *Householders' System*: a firm may move to a location that may cause a change in decisions of some householders (not bidirectional: since the availability of 'manpower' is not considered as a fundamental factor in firms' decisions)
- *Commuting* → *Householders' System*: the level of commuting is one of the main elements in householders' decisions (it is not a factor influencing firms' decisions)



Some observations on the proposal

- Suitability of the adoption of the MMASS approach for the considered problem
- MMASS allows modelers to
  - represent all the elements of the microeconomic reference model
  - better separate different elements involved in the complex system dynamics (e.g. territorial and decisional ones)
  - explicitly represent influences, feedbacks and interactions between sub-systems
  - simpler updating and incremental improving of the model.
- MMASS provides domain experts with a sw platform to develop simulation software in order to experiment, validate, and update the model

Conclusions and future works

- The here presented work is still ongoing
- Next activities will concern
  - Detailed specification of
    - agent behavioral models: according to the behaviors of agents described by the microeconomic model
    - interactions and influences between sub-systems
  - Development of a simulation system based the MMASS-based model (exploiting the MMASS platform)

Why an agent-based model?

- Over much of its history economic theory has been preoccupied with explaining the optimal allocation of scarce resources
- The notion of an optimal solution equilibrium between supply and demand of goods has become the central concept in economics
- In order to be able to analyze partial and total equilibrium models, they have to be extremely simplified.
- It is especially the, usually necessary, assumption of *homogeneity* (i.e. a single agent called 'representative') that misses important aspects of economic reality
- Traditional economics focuses primarily on the market as a selection mechanism, but neglects the market as a cause of variation and innovation
- Of course, there have been many theories (e.g. [Schumpeter, 1999]) dealing with the evolution of economic systems, but they always lacked the rigor of equilibrium economics
- For evolutionary models new methods were required, and agent-based modeling approach suggests interesting research directions. This approach is certainly adequate for analyzing economic models characterized by heterogeneity of agents, bounded and contradicting rationalities of agents, strategic behavior, imperfect information, imperfect competition, and other factors leading to out-of-equilibrium dynamics [Arthur et al., 1997]
- Agent-based modeling helps to understand the economy as a coevolutionary system, linking the economic macrostructure to the microeconomic behavior of individual agents (Batten, 2000). However, for a really evolutionary model of the economy, it is not sufficient to build agent-based models only to explain the emergence and change of relations between agents (e.g. as suggested by network models). Agent-based modeling has also to contribute to the understanding of the emergence and change of behavioral norms, organizations and institutions, which, at present, seems to be a much more difficult task (Tesfatsion, 2003)

Why an agent-based model?

- Self-organization models, used to explain urban development or traffic flows, are not new. Until now, most models have focused on one of these issues only. So far there have been only few attempts to deal with urban development and traffic flows in a combined model in order to understand their mutual interdependence
- As far as urban development is concerned, the limits of equilibrium-based approaches have led to an increased interest in simulation which is better able to capture the complex dynamics of interactions between heterogeneous agents. Cellular Automata (CA) have been the most frequently applied method (Portugali, 1999). The fact that already simple rules can lead to complex dynamics and the direct applicability on spatial processes have made CA to a widely used tool for analyzing patterns of urban development that are characterized by self-organization. One of the first CA-models in economic research analyzed the emergence of social segregation caused by the preference of people to live in the neighborhood of other people belonging to the same social class (Schelling, 1969). Other CA-models concerned land use patterns and their change over time (e.g. Colonna et al., 1998). As far as traffic is concerned, simulation has been used as a tool to improve traffic planning and management of traffic flows. For this purpose CA as well as MAS-based models have been proposed (e.g. Raney et al., 2002; TRANSIMS). Agent-based traffic simulation models are especially useful, because they enable the identification of each individual car, truck, bike or pedestrian. As a consequence, it is possible to analyze individual objectives, route plans, search and decision strategies (Batten, 2000) as well as effects of learning and changes of strategies on the traffic flows (Raney et al., 2002)
- We claim that economy researches requires dedicated and more specific tools (both at the methodological and software levels) to be applied to this growing and interesting direction. Moreover, we claim that researches and studies on agents in computer science are ready to provide these modeling and computational tools in order to fruitfully support economy theory.