Parallel Distributed Processing of Transportation / Land Use Systems: Theory and Modelling with Neural Networks

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Abstract: We provide in this conceptual paper an overview of a parallel transportation / land use modeling environment. We argue that sequential urban modeling does not well represent complex urban dynamics. Instead, we suggest a parallel distributed processing structure composed of processors and links between processors. Each processor is a set of neurons and weights between neurons forming a neural network. For spatial systems neural networks have two main paradigms which are processes simulation and pattern association. Parallel distributed processing offers a new methodology to represent the relational structure between elements of a transportation / land use system and thus helping to model those systems. We also provide a set of advantages, drawbacks and some research directions about the usage of neural networks for spatial analysis and modeling.

Key words: Transportation, Land Use, Modeling, Parallel Distributed Processing, Neural Networks.

Article published in *Transportation Research C*, 1997, Vol. 5, No. 5, pp. 259-271.

INTRODUCTION

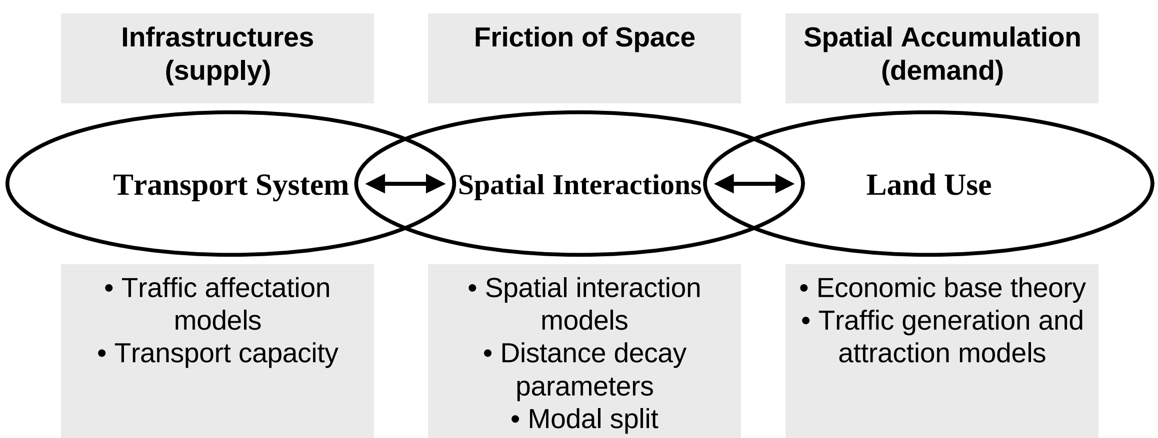
A key to understand urban dynamics lies in the analysis of patterns and processes of the transport / land use system. Land use can broadly be defined as the level of spatial accumulation of activities such as production, transaction, administration and residence with highly dynamical relationships between them. Obviously, the transport system supports several of these processes. More simply, urban land use reflects the nature of economic activities in an area as well as movements with other areas. There is however a limit to the accumulation of activities in an urban area that is apparent with the law of diminishing returns. When a limit is reached an area may lose its comparative advantages. The tendencies and limits of decentralization and sprawl of urban activities support this. Comparative advantages of a place vary over time and the transportation / land use system is in a permanent state of disequilibrium. A state of disequilibrium can be conceived

[1] The author would like to thank anonymous referees for helpful comments and suggestions.

as a continuing dynamic evolution of the system without a tendency to a precise and permanent state. The structural relationships between the elements of a system and the elements themselves can change over time.

Traditionally, transportation / land use modeling has essentially foresaw to understand disequilibrium and to propose alternatives resolving congestion problems of the transportation network and optimizing the accessibility level of land uses. We may acknowledge that there are many models, but few geographical theories behind these models. According to Macmillan (1989), models can be prototypes for theories, applications of theories or representations of the reality. However, no model is really efficient for synthesizing and forecasting the impacts of demographic and economic changes over such a system. Most models are static, deterministic and require too much data to be applicable in a real context, or are limited over a specific sector such as housing (Berechman and Small, 1988). White (1989) maintains that writing a set of equations to describe urban dynamic reveals nothing about the structural relations that these equations are modeling. In other words, equations that are appropriate for an historical period are not necessarily proper for another. Even equations developed for a specific urban system are often inapplicable elsewhere. A number of models adapt empirical urban theories to mathematical methods instead of adapting mathematical methods to urban processes and their dynamical relationships. This limits the potential of modeling as a useful tool for urban planning because using a model is a long process of implementation and calibration of its components. Over this, Openshaw (1986,1989) has shown that most models are based on theories that are rarely applicable in urban studies or planning. Despite efforts being made, the transport / land use system escapes efficient representation of its spatial and temporal dynamics.

We can however provide a basic conceptual representation of the transport / land use system (Figure 1). Between the supply of the transport system and the demand generated by the spatial distribution of land uses, spatial interactions express their relationships. However, spatial interactions are simply a static representation of the state of two dynamical systems. More simply, they are the spatial expression of relationship between transport supply and land use demand. Although of prime importance for geographers, spatial interactions are only a static dimension of a geographical system.



(*Figure 1* The Transport / Land Use System)

There exists a duality between theories and practices, but there is a tendency as the field comes to maturity to integrate theoretical transportation / land use optimization concepts with operational planning practices (Comtois and Rodrigue, 1991; Pryor, 1987; Rodrigue, 1994). Regarding modeling, Berechman and Small (1988) demonstrate that dynamics, uncertainty, and agglomeration economies play a key role in the modelling of the urban structure. The uncertainty concept can be perceived as the set of urban processes escaping the planner s comprehension, control and forecast. Pumain, Sanders and Saint-Julien (1987) show that the urban structure and its evolution must not be considered as given, but has the result of complex interactions. It is precisely over these aspects that most of operational transportation / land use models are deficient. To overcome these deficiencies, Berechman and Small (1988) propose three alternatives: First, to add elements on agglomeration economies and dynamic adjustments over an existing model; Second, to add more realism and details to a dynamic model of agglomeration economies; Third, to create a new model.

We find the third alternative challenging. In this article, we will attempt to create a new model in the field of transportation and land use (see Webster, Bly and Paulley, 1988 for an extensive review of major models or Blunden and Black, 1984). A new methodology in the spatial economy of urban areas will be developed, based on a self-adaptable spatial model. Recent developments in Parallel Distributed Processing (PDP) have enabled geographers and regional planners with new tools and methodologies to simulate complex urban dynamics with the usage of neural networks. As a pattern and process associator, a neural network enables to transform the structural relationships between its elements and thus provides a self-adaptable model. Neural networks have seen limited, but expanding applications in the transport sector (see Dougherty, 1995). Their usage for modeling spatial structures and processes of transportation systems has been even more limited. By their attributes expressing spatial patterns of transport supply and demand, spatial interaction models were the firsts to be simulated with neural networks (Black, 1995; Fischer and Gopal, 1994; Openshaw, 1993). All these simulations concluded that they were more effective than conventional spatial interaction models. We will extend this approach to the field of transportation / land use systems.

DESIGNING A TRANSPORTATION / LAND USE PARALLEL MODEL

We assume that a transportation / land use system is a parallel system. A parallel system involves that its elements are affecting each other simultaneously in time and space. Until recently, the modeling of spatial systems has strictly involved the development of sequential models that were trying to represent a system in a straightforward logic with several steps. This has a fundamental drawback since systems do not work in a sequential manner. A classic example of this is the Lowry model (Lowry, 1964) where the employment per zone affected the population distribution which re-affected the employment. Iterations were performed until the results converged at some equilibrium point. Therefore, iterations are a way to express a parallel system with sequential equations, but only one parameter of the model changes for each step.

Concepts and Analogies

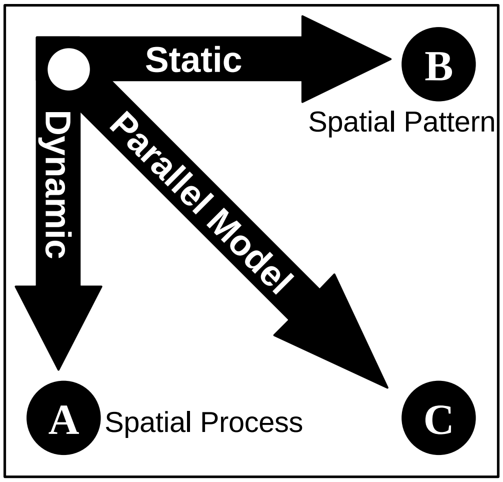
A true parallel model is not foreseeable without a true parallel computing structure, but actual sequential structures can simulate parallel behaviour. In fact, sequential and parallel models may follow the same structure and logic because programs that represent them are sequential. Basically, parallel processing involves the concept of granularity which is the relationship between the resources spent in coordination of the parallel system and the resources spent on its processing (Nolen, 1992). This concept applied to modeling entails that a part of the model affects the elements individually and another part affects the relationships between the elements. Therefore, by drawing an analogy with parallel hardware structures, we assume a parallel model PM is a set of processors p and a set of flows f between processors:

$$PM = \{p , f\} \quad (1)$$

For each element of the model there is a processor, which is an information-processing element. Processors process the equations related to the elements, while the flows are the outputs of processors towards other processors. This equation may look simple, but refers to a complex set of relationships related to spatial patterns and processes.

Patterns and Processes

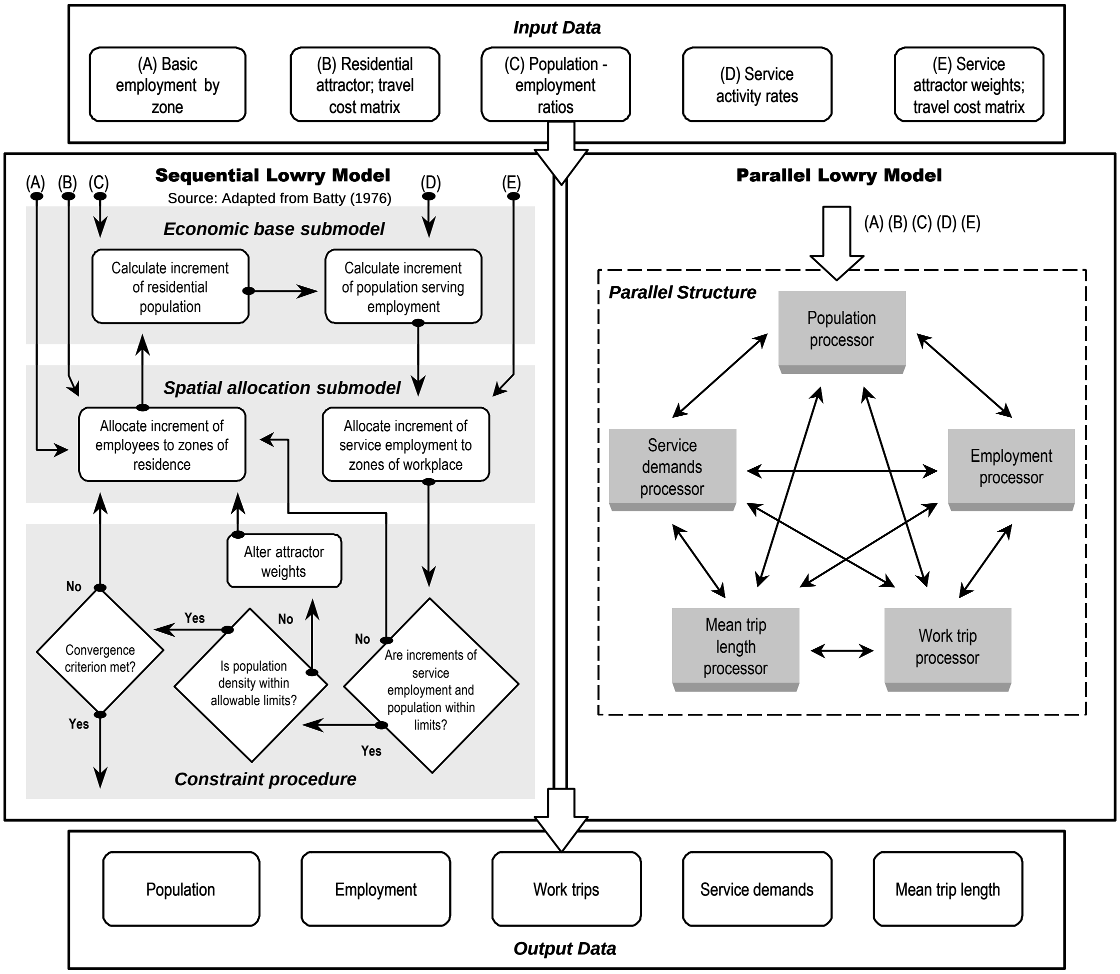
In regards to model a transportation / land use system, a parallel model can be used for two main purposes: process simulation and pattern association (Figure 2). While process simulation models an evolution of a system in time, pattern association tries to grasp the spatial structure involved such as land use classification problems (Rodrigue, 1995). Conceptually, these are two different approaches that were integrated in comprehensive transportation / land use models, but a parallel model could be more efficient to find relationships between the spatial distribution of economic activities and their evolution in time.



(A) Process Simulation: Models the evolution of a system from one state to another.
(B) Pattern Association: Models the spatial attributes of a system at a given point in time, that is the distribution of its components.
(C) Process Simulation and Pattern Association: Establishes a relationship between the spatial distribution of economic activities and their evolution in time.

(Figure 2 Patterns, Processes and Parallel Model*)*

Figure 3 presents a comparison between a sequential and a parallel Lowry model. We do not intend that a Lowry-like model is not relevant to transportation / land use planning, but that a parallel structure could efficiently represents the processing structure of the model. The sequential and the parallel Lowry model process and output the same variables. However, instead of having a straightforward structure to process the information, a parallel model assumes no specific order in the processing structure. From a given set of inputs, each processor performs its set of equations until it requires some information analyzed by another processor. For instance the employment processor calculates the basic employment according to some relationships with other elements such as the population. It waits until that information is available and then proceeds again. This is the same for all the processors. When all the processors have resolved their equations according to a set of criterion, they produce a set of outputs. If the parallel model was constructed following the same structure than a sequential Lowry model, the outputs would be the same. However, the parallel model can no longer be called a Lowry model because the only similarity lies in the inputs and the outputs. The processing structure is entirely different since each processor models simultaneously the patterns and the processes, while the Lowry model rely on a economic base submodel for the processes and a spatial allocation submodel for the patterns.



(Figure 3 Comparison between a Sequential and a Parallel Lowry Model*)*

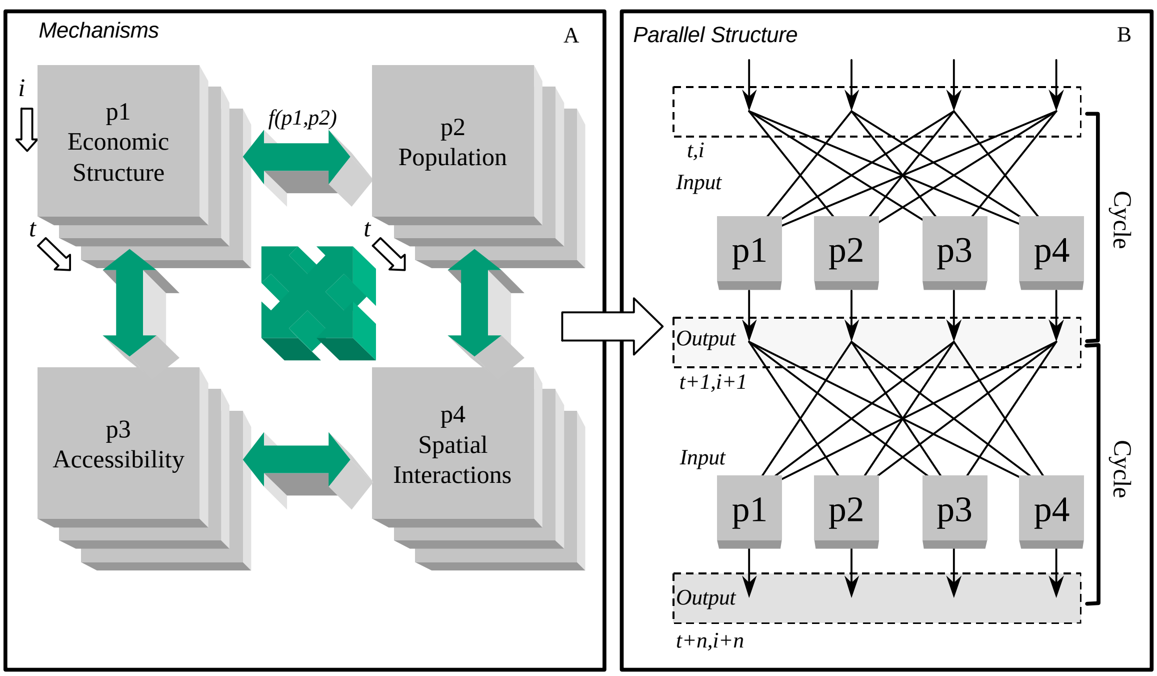
Mechanisms: States versus Equilibrium

By definition, the elaboration of a mechanism is a process of establishing the interrelationships between several concepts. In the proposed parallel model, the mechanisms are those related to land use changes. A change of one or several components will produce a change within all related components of the model if a minimal change that is defined as the *activation threshold* is reached. This implies that a transportation / land use system that is not sufficiently affected, will not have significant changes in the volume and in the spatial distribution of its activities. Land use and transportation networks are the results of processes of spatial accumulation over time.

A transportation / land use system cannot remain stable for a long period of time because internal dynamical factors such as the aging of transportation infrastructures and changes in the demographic and economic composition. In conventional modeling, these changes are causing disequilibrium, which will change the parameters of the model until some equilibrium is reached. Even so, we bring forward that there is no stability or equilibrium at all, because a transportation / land use system is continuously changing. Only the rate of change varies from some stability towards crises and instability. This underlines it is preferable to speak of a temporal state (the state at a specific point in time) instead of equilibrium in the case of spatial modeling.

Changes in the state of the transportation / land use system integrate themselves in to external factors such as the position of the city in the regional, national and international transportation systems. Some of the most powerful external factors are the creation of economic blocs, the international division of labour and the globalization of trade that affect location of a great number of economic activities (see for instance Knox and Agnew, 1995). Consequently, it is important to evaluate the theoretical mechanisms that control land use changes through the elaboration of their structure.

Most of modeling rests on the specification of functional processes between the components of the developed model. They jointly define the structure. To simplify the theoretical demonstration, we limit ourselves to four basic components of a transportation / land use system. These components are accessibility, spatial interactions, economic structure and population. Accessibility is the general capacity (transportation supply) of a transportation system within a delimited area. Spatial interactions are the movements of all modes between areas. The economic structure is the spatial accumulation of economic activities such as production and transaction. The population is the socioeconomic attributes of the inhabitants of an area.



(*Figure 4* Modeling a Transport / Land Use System with a Parallel Structure)

Figure 4a proposes a parallel structure to conceptualize the theoretical mechanisms of land use changes. The parallel model is based on the principle that a transportation / land use system evolves from a state (time *t*) to another (time *t+1*) and so on (time *t+n*). Each state is the result of the previous state and of the changes occurring between. Four processors represent the parallel model, one for each variable. Dimension t is therefore the process. A processor has also an i dimension related to the spatial pattern of the dimension t.

The conceptual linkages between each element composing the transportation / land use system are shown on figure 4b. In the chosen parallel structure, there are no links between the processors, except between each cycle. A cycle is the interval during which a processor resolves its set of inputs to produce outputs. Table 1 shows some basic theoretical and empirical assumptions of the relationship between each element implemented as a processor in a parallel transportation / land use model.

Table 1: Some Relationships between Elements of a Transportation / Land Use Parallel Model

	Spatial Interactions	Accessibility	Economic Structure
Accessibility	The more a zone offers high transport supply, the more movements between zones will be inclined to use this zone as an axis of movement towards other zones. Inversely, the intensity of spatial interactions will determine the utilization level of the transportation network. A usage level higher than the capacity of transportation infrastructures creates congestion lowering the interaction level. There is a strong retroaction between supply and demand that influences the state of the system. Changes in accessibility have often an immediate impact over spatial interactions.	Accessibility influences itself only indirectly.	Accessibility influences the economic structure only indirectly.
Economic Structure	The presence of an economic activity generates movements of persons, goods and information. The nature of urban activities is very diversified, hence a number of diversified spatial interactions. A change in the economic structure influences the intensity of interactions that origins from and to that place. The spatial distribution, volume and nature of interactions influence the economic structure in two ways: first, interactions need transportation modes; second, the presence of interactions from one zone to another creates service activities.	The presence of transportation infrastructures gives an accessibility level that influences the nature of the economic structure. Accessible places generally have an important and diversified employment structure. The economic nature of a place will influence its complexity in transportation infrastructures and therefore its accessibility level by creating a demand. This underlines the relationships between the transportation supply given by accessibility and the transportation demand of economic activities.	The spatial accumulation of economic activities influences itself through the process of economies of agglomeration. Some types of economic activities such as services raise their efficiency if they are located nearby each other. Investments in one sector of the economy generate employment in related sectors and particularly in the service sector. This is called the multiplier effect.
Population	The population of a zone influences spatial interactions of persons, goods and information. For home-based trip purposes, residential areas are important generators of spatial interactions. A change in the distribution and the volume of the urban population leads to changes in the nature, distribution and the volume of interactions, particularly those related to passenger movements.	Accessibility influences the location of population because population, more specifically labour, looks for a transportation supply to travel to different urban zones. Some modal and intermodal accessibility such as port accessibility are less important in the location of population. This kind of accessibility influences the location of population through its importance for activities that generate employment. The presence of population is an incitative factor for the construction of public transit or any kind of transportation infrastructure related to movements of people.	The economic structure has a direct impact over the spatial distribution and the volume of population. The economic structure can be represented by the distribution of labour in economic activities. Changes in the economic structure affect labor supply and often the distribution of population. Inversely, the population of a zone influences the economic structure with the creation of a number of services. The labor supply of a population is a factor for the settlement of economic activities.

FORMULATION OF A PARALLEL TRANSPORTATION / LAND USE MODEL

Spatial Pattern

Land use represents the state at a given point in time of a transportation / land use system through its elements: spatial interactions (T_{st}), accessibility (A_{st}), economic structure (S_{st}) and population (P_{st}). Therefore, the spatial pattern (State) of a transportation / land use system *s* at time *t* (expressed as L_{St}) can be defined as a set of elements:

$$L_{st} = \{T^k , A^k , S^m , P\}_{st} \ \forall k,m \qquad 2$$

where spatial interactions and accessibility can be subdivided by modes *k*. The economic structure can also sub-divided by activity type *m*. The first conceptual element of the parallel model is thus related to the state of the transportation / land use system. Each element is the state (output) of a processor *p*. The result is the following relationship:

$$\begin{aligned} PM &= \{p, f\}_{st} \\ p &= \{S, P, A, T\}_{st} \end{aligned} \qquad 2$$

Spatial Processes

Now that the elements of the transportation / land use system have been defined, the next step in the elaboration of the parallel model consists in establishing the relationships of the elements on figure 4:

$$\begin{aligned} PM &= \{p, f\}_{st} \\ p &= \{S, P, A, T\}_{st} \\ S_{st} &= f\left\{\sum_{\forall i} P_{it}, \sum_{\forall i} A_{it}, \sum_{\forall i} T_{it}\right\} \\ P_{st} &= f\left\{\sum_{\forall i} S_{it}, \sum_{\forall i} A_{it}, \sum_{\forall i} T_{it}\right\} \\ A_{st} &= f\left\{\sum_{\forall i} P_{it}, \sum_{\forall i} S_{it}, \sum_{\forall i} T_{it}\right\} \\ T_{st} &= f\left\{\sum_{\forall i} P_{it}, \sum_{\forall i} S_{it}, \sum_{\forall i} A_{it}\right\} \end{aligned} \qquad 3$$

where: T_{it} = interactions of a spatial element of the system with other spatial elements at time *t*.

A_{it} = accessibility for a spatial element of the system at time *t*.

S_{it} = employment structure for a spatial element of the system at time *t*.

P_{it} = population for a spatial element of the system at time *t*.

f{...} represents the function that a processor must solve in order to calculate the impacts of one element over the others. The main problem behind equation 3 is how to estimate *f*{...}, which are the flows between processors? Since all transportation / land use systems have different levels of relationships between their elements, there is no unique equation that could represent all systems and each of them requires extensive calibration. Even if the relationships between elements (processors) vary in strength, their nature is basically the same for all systems. But how to overcome the calibration involved? To find an induction structure that would represent the set of functions in equations 3, we use a parallel modeling paradigm defined as the neural network.

NEURAL NETWORK MODELING OF A PARALLEL TRANSPORTATION / LAND USE SYSTEM

Neural networks are mathematical models that simulate parallel information-handling features of biological systems made up of many simple elements called neurons (Korn, 1991). The representation of the information is based on the pattern of connections between neurons of the network (Caudill, 1990). Standard neural networks are organized as a set of layers sequentially processing a set of inputs. One of the original aspects of neural networks is their capacity for induction. Given a set of examples, a neural network model will represent the relationships into an inference structure that can be used for deductions. The objective of neural network modelling of a parallel system is to find a configuration of weights for a processor that produce estimated results similar to the observed results. Therefore, a processor can be trained to answer properly to a set of inputs to produce a set of outputs. This would enable to solve equation 3. The elaboration of a neural network processor in a parallel model can be divided in three stages similar to those brought forward by Fischer and Gopal (1994). First, the definition of the neural network, that is the determination of input, output and hidden units. Second, the calibration by the configuration of the weights through a training strategy, and third the integration in the parallel model *PM*.

1) Definition of the Neural Network Processor

Let a neural network processor in a parallel model *PM* be expressed by *net(p)*. For each processor *net(p)*, we use three layers, the input, intermediate and output. The intermediate layer is the internal processing structure of a neural network. In the lines that follow, we define a standard back-propagation neural network model where the input layer X_p of processor *p* is defined by:

$$X_p = \{ X_i, X_j, \ldots, X_{nX} \mid X = L_{st} \} \quad \textbf{4}$$

and the intermediate layer Y_p by:

$$Y_p = \left\{ Y_i, Y_j, \ldots, Y_{nY} \mid Y_j = \sum_{\forall X_i} O_i^X W_{(i,j)}^{XY} \right\} \quad \textbf{5}$$

and the output layer Z_p by:

$$Z_p = \left\{ Z_i, Z_j, \ldots, Z_{nZ} \mid Z_j = \sum_{\forall Y_i} O_i^Y W_{(i,j)}^{YZ} \right\} \quad \textbf{6}$$

and where: X_i = Input neuron *i*.

Y_i = Intermediate neuron *i*.

Z_i = Output neuron *i*.

nX = Number of input neurons.

nY = Number of intermediate neurons.

nZ = Number of output neurons.

$W_{(i,j)}^{XY}$ = Weight of the connection between neuron X_i of layer X and neuron Y_j of layer Y.

O_i^X = Output transfer function of neuron *i* of layer *X*.

The output transfer function of neuron *i* of input layer X_p (O_j^N) is defined by:

$$O_i^X = \frac{1}{1 + e^{-(X_i + q_i)}} \qquad 7$$

where Q_i is a bias. Equation 7 is applied again to layer Y_p to produce outputs on layer Z_p (see equation 6). Therefore, a set of inputs from layer X_p can be processed by the intermediate layer Y_p to produce an output layer Z_p.

2) Learning in a Neural Network Processor

Learning in a neural network is an iterative process where the weights ($W_{(i,j)}^{XY}$, see equations 5 and 6) are adjusted until the calculated outputs of the neural network correspond to the observed results. To do so, the outputs of a processor *p* derived from equation 4, 5, 6 and 7 are compared with the desired results to see if the total error (*E*) is less than a fixed error margin (*EM*):

$$E_i = \frac{1}{2}\sum_i (D_i - Z_i)^2$$
$$E = \sum E_i \qquad 8$$
$$E \leq EM$$

where: D_i = the desired output for neuron *i*.

Z_i = the output of neuron *i* at output layer *Z* calculated by the network.

E_i = the error of neuron *i*.

To be consistent with the parallel model, the error margin *EM* is equal to the error field *e*. If the total error is greater than the error margin, the weights between the layers are readjusted according to the delta learning rule (Sejnowski and Rosenberg, 1986):

$$\Delta W_{ij}(t+1) = b(d_j^b O_i^a) + a\Delta W_{ji}(t) \qquad 9$$

where: b = the learning constant.

a = the momentum constant.

d_j^b = the error signal of neuron *j* of layer *b*.

O_i^a = the output of neuron *i* of layer *a*.

We assume that layer *a* precedes layer *b*. The subscript *t* indexes the presentation number. For the output layer *Z*, d_j^Z is defined by:

$$d_i^Z = (D_i - Z_i)Z_i(1 - Z_i) \qquad \textbf{10}$$

else, for the intermediate layer Y_p:

$$d_i^Y = Y_i(1 - Y_i)\sum_{\forall Z_i} d_j^Z W_{ij}^{YZ} \qquad \textbf{11}$$

This procedure is repeated recursively until the output error *E* is less than a fixed error margin.

3) Parallel Structure with Neural Networks Processors

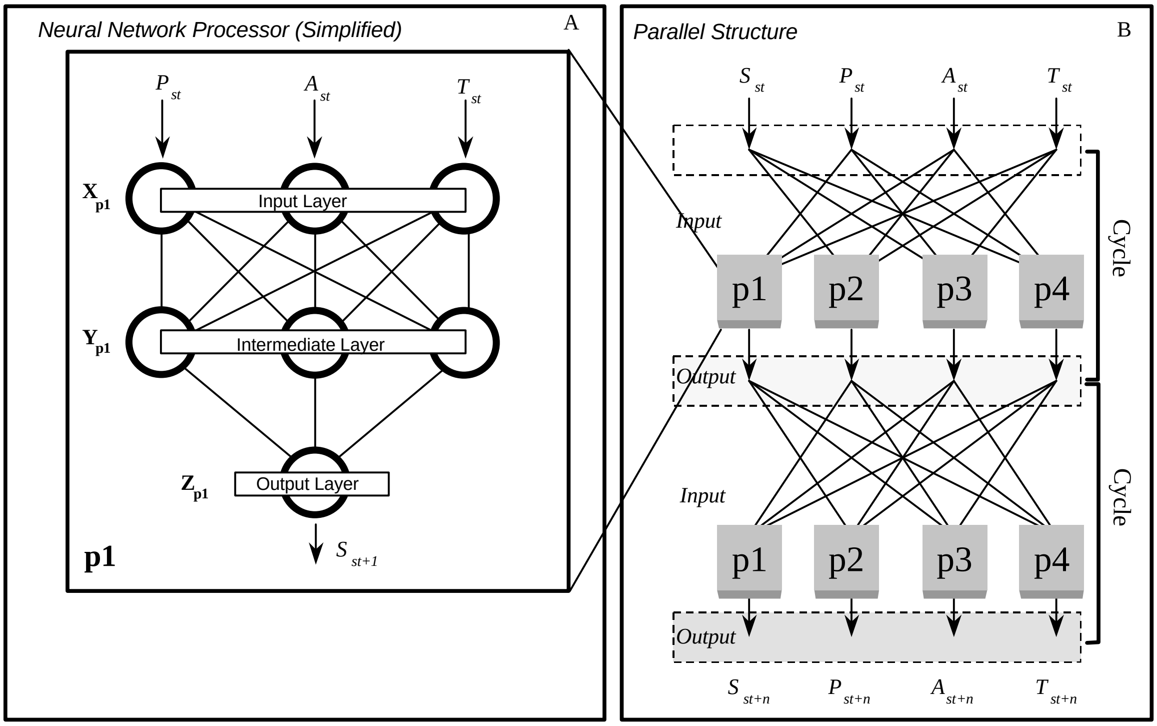
With the usage of neural network processors developed on the previous sections, the parallel model (equation 3) becomes:

$$\begin{aligned} PM &= \{p, f\}_{st} \\ p &= \{S, P, A, T\}_{st} \\ S_{st} &= net(S_{st}) \\ P_{st} &= net(P_{st}) \\ A_{st} &= net(A_{st}) \\ T_{st} &= net(T_{st}) \end{aligned} \qquad \textbf{12}$$

which is our parallel structure using neural networks (Figure 5). The flows between processors are subject to a set of constraints. The parallel structure of figure 5b works as follows:

- First, we assume that all neural network processors have been trained to produce a set of outputs with a given set of inputs. For instance, processor *p1* produces element S_{st} from an input of elements P_{st}, A_{st}, and T_{st}. It thus completes a cycle.

- Second, all the elements are inputted to the processors, which are producing their respective outputs. With the chosen parallel structure the procedure is done simultaneously and no processor has to wait for information from others because there are no links between processors for a cycle (from time *t* to time *t+1*). The same process can be repeated with elements at time *t+1* to find results at time *t+n*. In this case the accuracy of the prediction drops sharply.



(Figure 5 Parallel Modeling Structure Using Neural Networks Processors*)*

DISCUSSION

The developed model is not an optimization of transportation and land use, but rather a parallel simulation procedure of the urban dynamics that can be used as a planning tool. This procedure is highly flexible because neural network processors do not have goals except than to simulate the probable impacts of given changes on their inputs. Most models are looking for an optimal transportation / land use system. But, is it necessary to look for an optimal level to attain a functional one? This question remains pertinent as each city is a complex transportation / land use system with multiple constraints and where an optimal level often cannot be conceived by planners. An optimal city is strictly a theoretical city where transportation problems are causing few losses of comparative advantages for land use zones. This is a fundamental part of the problematic of city planning. Cities offer the planner a set of possible alternatives, but no single optimal since no city can afford all the structural transformations required for an optimal state.

Sequential and Parallel Models

From an operational point of view, there is an exponential growth of the complexity of the parallel structure as the number of elements increases. Granularity becomes and issue as the number of processors does, as expected in all computational problems. However this is not really a constraint with the computational power of actual systems, even personal computers. We have advanced that parallel and sequential models follow the same logic, so, outside computational reasons, why use a parallel structure?

- First, parallel distributed processing offers a new conceptual framework in transportation / land use modelling. One parallel paradigm, the neural network, is a powerful pattern associator, process simulator and a self-calibrating model. Neural networks are well known to work with incomplete and noisy data. Therefore, the usage of neural networks for modeling is more efficient when large amounts of empirical information are available and when processing structures are ill defined.
- Second, elements affecting each other concomitantly instead of sequentially is more realistic but much more difficult to conceptualize. There is no specific order in the relationships. For instance, a sequential model could consider that elements *A*, *B*, *C* and *D* influence each other in that particular way: $A \rightarrow B \rightarrow C \rightarrow D$. In a parallel model, all elements could influence each other in any order and the level of relationship flows between processors would vary accordingly. Of course, some relationships are conceptually impossible and the planner must limit himself with a set of possible relationships (see table 1).

Some Drawbacks

The developed parallel model, along with the usage of neural networks for modeling the spatial economy, has several drawbacks:

- First, a neural network is a static pattern associator, it captures the current structure of relationships between elements, but as the nature of relationships is changing (with new economic and technological conditions for instance), the neural network model is likely to be far less accurate. This weakness is also to be shared with existing models. If a neural network processor is trained with a too small error margin, it will simply replicate perfectly the relationships with very few potentials for generalization and prediction. This is often referred as overfitting. Experiments in the field of neural networks have demonstrated that an error margin from 5 to 10% enables the network to have a good potential for generalization without losing too much accuracy (see Anderson and Rosenfeld, 1988). Neural networks should therefore be trained with an error margin similar to the error associated with the variables they use.
- Second, instead of starting from a set of equations and comparing their results with real data for calibration, a neural network directly captures the relationships between elements. Without that induction procedure, a neural network has no deduction potential. For instance, a spatial interaction equation is purely deductive, as it does not need any data for its definition, only for its calibration. In order to do the same thing, a neural network can be used in two ways. First, with observed flows, a neural network can model the spatial interactions of a system. This is the most desirable alternative. Second, when the observed flows between spatial entities are not

available, a neural network can be used to copy the results of a spatial interaction model. In that case, a neural network is no better than the spatial interactions model it replicates.

- Last, we must bring forward the problem of representational relevance, or more simply the black box syndrome. The capability of establishing relationships between variables is a strong point in favor for the usage of neural networks as modeling tools. However, the internal processing structure is somewhat masked by layers of neurons, making it difficult although possible to evaluate the exact contribution of each variable in the model. Furthermore, neural networks, as powerful pattern associators may be used to find irrelevant relationships between variables. Given enough iterations in their learning phase and a sufficiently complex internal structure, a neural network could find relationships between all its input. It is interesting to find hidden relationships between variables, but when does hidden becomes irrelevant, or worse incoherent?

Some Directions

Although areas where neural networks can be used for modeling spatial processes are numerous, such as spatial analysis (Fischer, 1994), in regards of transportation / land use planning we may pinpoint some specific application domains and directions:

- Parallel structures and neural network models. A significant part of future directions of research involve experiments with several other types of parallel structures and neural network models. In this paper we have showed a fully connected parallel structure where each processor is a standard back propagation neural network model. Other types of neural networks are also possible (see Korn, 1991), but using the back propagation model is suitable for most situations.
- Spatial patterns and processes. How well parallel processing and neural networks can be used to find relationships between spatial patterns and processes? For instance, a spatial interaction neural network model basically captures the spatial pattern of movements between zones of origins and destinations the spatial interaction matrix. As a pattern association paradigm the neural network can be used in this case to replicate the matrix to another problem. As a process simulation paradigm the neural network model could be applied to the same spatial system to evaluate the impacts of change in one (or several) of its components. In this case, we assume that spatial patterns and processes are closely linked.
- Levels of planning. These address different types of problems related to strategic (long term) and operational planning (short term). For short-term processes, we may use neural networks to investigate transport problems such as traffic affectation models, and logistical operation of freight (such as the traveling salesman problem), all requiring massive computation to find non-optimal solutions. This aspect is far more the domain of transport engineers and is of limited concern in transportation / land use planning. Transportation / land use processes, like most spatial processes, are more occurring on the long term. The assignment of infrastructure is often undertaken in view to produce a specific spatial pattern. By training neural networks with known spatial structures (the states of transportation / land use systems) in a given set of conditions, it could be possible to use them to evaluate the impacts of planning strategies on other spatial structures. We may call this planning strategy spatial pattern inference.

CONCLUSION

A transportation / land use system is a complex spatial system composed of several elements representing the level of spatial accumulation. Elements are variables used to express the state of a system at a given point in time. Therefore, variables related to the geographical attributes of spatial interactions, accessibility, economic structure and population jointly define the functional land use. We have suggested that sequential urban modeling does not well represents complex urban dynamics. Instead, we have proposed in this conceptual paper a parallel distributed processing structure composed of processors and links between processors with a specific parallel internal structure. Each processor is a set of neurons and weights between neurons forming a neural network.

Parallel distributed processing offers new methodologies to represent the relational structure between elements of transportation / land use systems and thus helping to model those systems. Progresses in artificial intelligence offer new perspectives to be considered for modeling processes such as predicate calculus, heuristics, expert systems and reasoning under uncertainty (see Partridge and Wilks, 1990; Rich and Knight, 1991). Above all, it is worth rethinking the concepts and methodologies behind modeling (and sometimes its relevance), so that this approach could be at least considered (instead of falling out of favor) in the process of transportation / land use planning.

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