Spatial Analysis and Forecasting: Identical Units Artificial Neural Network

Ph.D. Candidate, Planning and Policy Sciences, University of Tsukuba. Dupret Georges
Planning and Policy Sciences, University of Tsukuba Koda Masato
Planning and Policy Sciences, University of Tsukuba Koshizuka Takeshi

1) Introduction

In a given location on a map, the population's density is influenced by local factors, as topography or land use laws, and by its proximity to the centres in the region. We can divide these influences in two groups: local influences and centres' influences, the last depending on the relative position of the location whose population density we are interested in. A given location being generally influenced by various centres, these influences mingle. Therefore, the proposed method should be able to approximate the individual centres' influences and the way all these influences combine to result in the actual population density.

2) The Model

a) Requirements for the model

We need an instrument to map the explanatory variables (population density in all points, centres positions and characteristics, relative positions of the centres to the points where we estimate the population density...) to the dependent variable: the population density in our example. Various methods exist to accomplish this, consisting essentially in fitting a given function to the data by adapting its parameters. The disadvantage of these methods is the implicit assumption made on the behaviour of the system by the choice of the function, unless the function is a universal approximator. Moreover, to be able to generalise, the function need to be well behaved outside the set of points that was used to adjust the parameters. Artificial Neural Networks (ANN) have these properties, and they can be considered as a generalisation of the polynomial fitting and linear regression.
The model also need to preserve the spatial relations between the input data, without these relations being explicitly inputted for each point but the one important to represent the map. If we fail to meet this requirement, the number of data become quickly intractable.

b) Model's description

If we admit that the centres' influences decrease with distance, we can limit our analysis to the closest centres to the point where we estimate the population density.
Each centres' influence can be mapped by a ANN, these influences being mapped in turn to the population density. The resulting neural network is composed of identical units, one per centre, as represented in figure 1 (the inputs corresponding to the relative positions of the centres among themselves have not been represented).
Many symmetry relations exist among the parameters of the network. The identical units parameters are the same because switching two of them (figure 1) should not modify the output. Switching two identical units impose also some symmetries in the parameters associated with the inputs of the relative positions of the centres. These symmetry relations among parameters actually constrain the network architecture to. reproduce the spatial relations existing between the inputs.
It can be proved that the layer whose neurones are represented by squares can be removed.

c) Spatial Analysis

The Artificial Neural Networks the model is composed of are able to map any function provided the number of neurones in the hidden layer is sufficient. Practically, this number is reasonable, and the number of parameters remains small enough so that there is no overfitting of the data.
The identical units of the network in figure 1 have all the same parameters, which means that we can add an hypothetical centre to the network, and compute the resulting population density map with this new centre. To forecast the impact of a new train line, the new stations can be add to the list of the centres and the new map computed with these new inputs. On the other hand, we can isolate the centres' influences by removing all the identical units but one.

3) Test on the Generalisation Ability

The test consists in the following steps:

1) We construct two reference maps, one with 3 and another with 4 centres.
2) We adjust the model parameters to reproduce the map with three centres.
3) We add an identical unit to the model and compute the new map.
4) We compare the four centres map produced in 1) with the map computed in 3).

The result of this test is positive, the model proved to be able to produce the four centres map with minimum distortions. Moreover, if we remove all identical units but one, the network answer compute a single centre map, isolating correctly the influence of an individual centre.

5) References

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Hewitson B. C. and Crane, R. G. (1994). Neural Nets: Applications in Geography. Kluwer Academic Publishers, Dordrecht / Boston / London.

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5) Figures

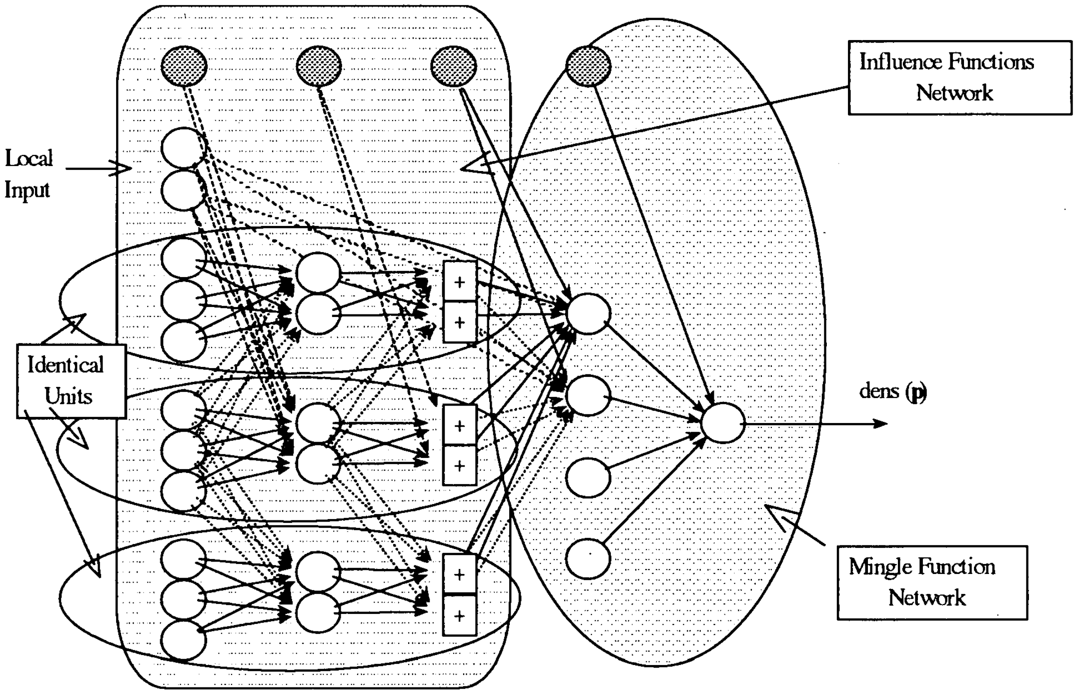
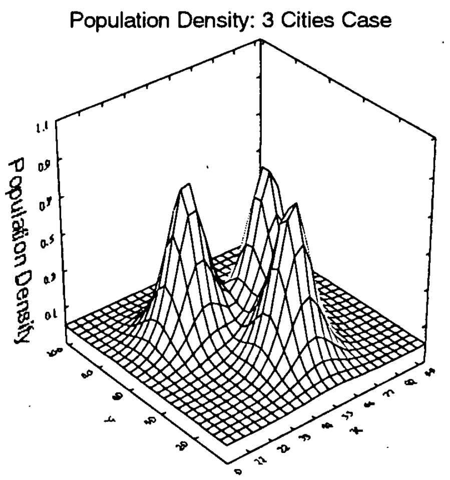
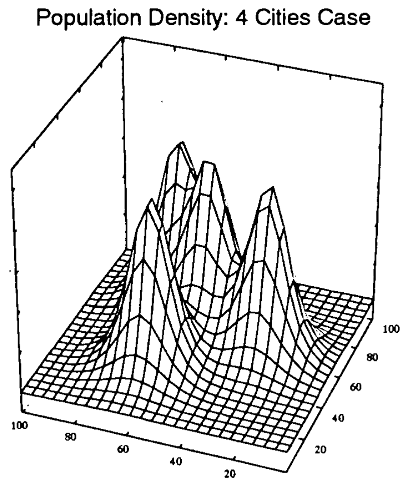


figure 1





figures 2 & 3