SPATIAL MODELS OF INTERACTION AND ECONOMIC ARCHAEOLOGY

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Introduction[1]

Interaction is the main driver of historical, cultural, social and economical processes. If people would not interact, there would not be any social or economical practise, no cultural formation and no mentionable history to describe. Interaction is a very abstract concept which is involved in the interpretation of many phenomena and allows a unified approach. It covers for example trade, travelling craftsmen, social relations, war and knowledge transfer. The high degree of generalisation in the concept of interaction provides us with the opportunity to access interdisciplinary knowledge. In archaeology there are still very few contributions to a generalised concept of interaction on the one hand while on the other hand archaeologists very frequently deal with variants of interaction. Some examples from other disciplines show the nature, potential and heterogeneity of interaction models.

In physics interaction is the reciprocal effect of particles. The most famous example is the gravity which was first described by Newton in 1686. The interaction of charged particles in electromagnetic fields or weak and strong interaction are other examples from physics. Ecology investigates the interaction of man and environment.

Symbolic interactionism is a theoretical form of sociology. Blumer (1969) interprets symbols as something that provides objects with meaning and is the basis for interaction. The formation of meaning occurs during the process of communication. Social network analysis attempts a formal analysis of the systems of interacting actors.

In psychology the investigation of interaction in dyads is a common field of research. My behaviour depends on what suppositions I have, how I predict the others' behaviour and how I estimate and value the options for both actors. The alignment of actors during the dialogues is focussed in psycholinguistics (Garrod and Pickering, 2009). The interactive-alignment model of dialogue explains alignment beneath the level of knowledge transfer. In ethnology it was Malinowski (1922) who put the focus on interaction. His analysis of the phenomenon of kula ring shows that formal rules of exchange for certain goods can form social relations which are the basis for efficient exchange for other goods. Among the scholars influenced by Malinowski was Polanyi (1944) who systematised the types of exchange. He distinguished market economy, redistributive economy and reciprocity economy. Ethnological research makes clear that exchange consists of different components that complement each other and form a complex system.

The focus in geography lies obviously in spatial interaction. Ravenstein (1989) proposed some laws of migration among which the influence of distance and the size of the target city lead to the later formulation of the geographical gravity rule (Stewart, 1950). The probability of migrating to a certain destination grows with the size of the initial and the chosen city and falls with the distance. This rule was transferred from physics. Hägerstrand (1967) developed a theory of the propagation of innovation waves which was published in his book 'Innovationsförloppet ur kronologisk Synpunkt'. This concept starts also with the idea that short distance interaction is more likely than long distance interaction. He describes different mechanisms and phases of the spread of innovations.

One of the problems the economy deals with is the spatial interaction of producer and consumer. Under which conditions is interaction realised? Among the most important parameters are prices and transport cost. Several important theories have been developed to model structures of spatial interaction. The idea from von Thünen (1875) was that goods differ regarding the costs of transport to the market and the land lease. In an ideal economy the land use is determined by the profits that are possible. These profits depend on the transport costs. Von Thünens model consists of concentric rings around the market.

Weber (1922) does not ask for the land use but for the location of industry. Factories should be located where the sum of transport costs for transporting raw materials to the factory and products to the markets are minimal. If the location is not optimal another factory with better location can offer better prices. The optimisation of location determines the probability of interaction with consumers. The third German economic geographer to mention is Christaller (1933). He asked for the optimal size of market areas and formed the term 'central place'. Goods have specific scopes that depend on the local availability of raw material or goods, transport costs, production costs and possible market prices. If the distance between a market place and the consumer exceeds the maximal scope, if the costs are higher than the possible proceedings, then interaction will not develop. This idea allows the delimitation of the interaction area. Consumers prefer interaction with market places that allow a purchasing of goods for minimal prices. If we regard the transport costs this will then be the nearest market place. This idea allows the modelling of the market areas for each central place. The different scope of goods in combination with the return to the scale creates the development of hierarchies. This idea explains the different sizes of central places[2]. Fetter (1924) developed a similar concept for delimiting market areas with an advanced method that allows different transport rates but without the hierarchies. Tinbergen (1962) applies the gravity rule to economy.

Finally we have to mention Krugman (Fujita, Krugman and Venables, 1999). He does not offer a model for the optimisation of interaction structures on the basis of transport costs but a stochastic model where transport costs are influencing the emergent development of spatial interaction structures. A kind of hysteresis stabilises the existing structures.

Interaction is mostly treated as a certain variant such as trade in the field of archaeology. Nevertheless there are some contributions to a more general discussion of interaction. Renfrew (1977) compares several theoretical interaction models. He prefers interaction over distance and observes that the resulting curve of fall-off follows some known distance decay functions. An exponential fall-off curve is interpreted as a down the line exchange, while a Gaussian fall-off curve is interpreted rather as a random walk. Hierarchical structure results in a waved fall-off curve. Sindbæk, 2007; Knappett, Evans and Rivers, 2008 have presented network type interaction models. Knappett and his colleagues were using an edge qualification based on gravity rules. The recent work by Windler (2011) attempts to apply Krugmans' theory on archaeological data. He shows that means of transportation can have significant impact on the spatio-economical settlement patterns even in prehistory.

The relevance of transportation costs in prehistoric economy is something which has to be investigated in more detail. This contribution attempts to deal with this question by applying a generalised concept for the research of interaction.

Models of Interaction

In this chapter I want to develop a coherent concept for basic analysis of interaction. A heuristic is presented which allows us to gain knowledge about interaction following some steps of simple analysis. The concept is focussed on universality, simplicity, modularity and quantification. We have to start with the definition of interaction. Interaction is the joint action of at least two partners. This definition is open to many aspects. It does not mean that the partners have to have the same intention and it does not mean that the action must be aimed at the partner. In the sense of this definition, opponents in a fight are partners as well as two individuals form the same side. Likewise sender and receiver of a message are partners. In this case we have communication which is a special case of interaction that comes along with most other types of interaction.

This contribution is focussed on spatial interaction which means that we are looking at the interaction between subjects that are attached to different locations. Without telecommunication movement is a precondition of interaction. There are three things which can move: people, goods and knowledge. Since we deal with interaction in general we are not forced to decide which variant is indicated by our archaeological material. Is it migration, trade or the diffusion of ideas? We can leave this question unanswered for the moment and let us turn to the characteristics of interaction. Which factors are influencing interaction? Among the countless possible factors there is one dominating: the distance. A general theorem is, that the probability of interaction decreases with distance. In generalized models distance is nothing but an interval-scaled reassurance for the relation of two partners. Usually we think of geometrical or geographical distances. The geographical distance can be a straight line between two points or it can be the orthodrome or the orthodrome projected to the actual relief. Furthermore the geographical distance can be constrained to networks like the systems of roads. Paths following roads are longer than direct connections but usually faster to travel. This leads us to economical distances which represent transport costs. Transport costs do not measure the length of the connective path but the costs of movement. The least cost analysis is a method to calculate transport costs on the basis of relief. Different transportation rates for different means of transportation and access costs for getting to the target of interaction may also be included. In most interaction models geographical distances are used but thought as a proxy for economical distances. Finally we have to mention cultural distances which are a measure for cultural differences which can be a friction for interaction. The explanation for the distance dependence of interaction is usually seen in economical causes as well as in probabilistic causes. It is likely to find the interaction partner first which lives nearest to me. Another important factor is the potency or size of partners. Usually we tend to access the most important person in a group and travel to the biggest cities because these are best visible to us and we presume to be rather successful with our aims of interaction with these partners. Applying our heuristic we will only apply distance and size in our interaction models and deal with other factor as disorders. Distance and size are very abstract which means that most factors can be included into these two categories. In many cases it is a problem to identify other factors so that excluding them form the basic models is useful. After a detailed analysis of model disorders other factors can be included in the model but this is not in the scope of this contribution. Before we discuss the models we have to find an empirical measure for interaction. Since it is not possible to count interactions in prehistoric times we have to deduce them from archaeological sources. The most common measure is the number of import finds which indicate individual interactions. Imports can be identified as foreign objects in a certain cultural milieu. Another method is to identify imports by means of scientific analysis of material. In both cases we need to know where the import came from. It depends on the regional scale of analysis whether we need the exact location or the region of provenance. Another method circumvents this problem. We can use the inverse cultural distance as a proxy for the intensity of interaction[3]. In this case we have the spectra of archaeological finds for two locations which serve as the data base for the calculation of cultural distances. Both the number of import finds and the cultural distances can be used as proxies for the intensity of interaction but they are not a linear function of interaction intensity. Models are tools to investigate systems of relations between objects. Models are simplified mappings for a special purpose (Stachowiak, 1973). A model depends on the objective of the research. There are not any universal models because the shape of a model is adjusted to a special objective. We have to choose a certain definition of objects and of the relations, to choose a certain mapping type including a certain simplification. An important aspect is the models specific degree of complexity. In the research process we try to get more and more complex models because they allow a better mapping of complex cases, an increasing amount of new knowledge but also require more sophisticated means for data and methods. In practice the reduction of complexity in models is necessary since simple models are easier to handle and they are focussed on relevant details and have a moderate demand for data and methods.

We have to distinguish empirical and theoretical models. Empirical models are mappings of observations. We can also speak of real models and reconstructions. Empirical models show how things are but not why. They do not reveal the participles which were applied during the genesis of objects. Theoretical models, ideal models or constructions were based on principles and show how things should be if we want to apply certain rules. Theoretical models cannot offer knowledge about the real world for itself. The moment in which knowledge emerges is the comparison of some theoretical with one empirical model. If a theoretical model fits to an empirical model we can transfer the knowledge about the principles to the empirical model. We can speak of an interpreted model which is an empirical model enriched with theoretical knowledge or vice versa. The above mentioned work from Renfrew is a good example for this concept. Renfrew works out an empirical model which consists of observations where the intensity of interaction is related to a geographical distance. Afterwards he compares the empirical model with the theoretical distance decay function. The theoretical model which fits best to the empirical model leads him to an interpretation. While Renfrew's concept is a very good research layout it lacks the universal applicability. In many cases the empirical fall-off curves do not fit to the available theoretical distance decay functions. At this point our heuristic takes effect. It allows an exploration of interaction and allows us to identify some influential parameters. More sophisticated analysis and more complex models are not excluded but prepared for a second phase of analysis. A full analysis of interaction has additionally to regard qualitative data and hermeneutic considerations. It would extend the size of an article and overcharge the current methodology to attempt such a holistic analysis therefore we leave this to a project in the future.

We will start with a very simple model which takes only the distance into account. Our model plots interaction against distance. This simple as well as universal distance graph is a useful tool which has several variants. On the interaction-axis we can use interaction intensity or the cultural distance as a proxy for inverse interaction. We already have discussed some different types of distances. Each type can be used on the distance-axis. We can plot values for individual distances and mean values for distance classes as well. For each distance value we can plot the associated interaction or the cumulative interaction. Both axes can be logarithmic.

Finally we have to decide from which point we want to look into the landscape. We can choose a certain location or all available locations. The later one overlays data from several points and considers only the distance to the target not the location of the reference point. Related to the discussed distance graphs are geostatistical semiovariogramms (Cressi, 1991) and G-, F- and K-functions from point pattern analysis (Illian, et al., 2008).

We could follow Renfrew and use certain distance decay functions as theoretical models. Instead we use a very simple model not even with a graphical representation: The intensity of interaction decreases monotonically and continuous with the distance. We can imagine a wide variety of functions which comply to these terms. We have not to distinguish these models in the first place because we can apply a Renfrew type analysis on them later. At the moment we are able to identify empirical models which do not allow such a treatment. We can think of functions with steps or non monotonic functions.

At this point we are coming to the next step in our concept. Now we have to find and identify the disorders in the simple models. Borders that cause a friction for interaction and result in steps in the distance curve are a very common phenomenon. Theoretical models that map borders are for example voronoi-graphs (Okabe, et al., 2000). In this case we assume that the border is located where the distance to two centres is equal. In most cases it is rather the economical distance than the geographical distances so that we have to apply the voronoi-graph in an economical space (Nakoinz, 2010). We also can try the voronoi-graphs in a cultural space as theoretical models.

The next step is to include other factors. First we can use multi factorial models that for example consider the size of interaction partners. This leads us to variants of gravity models. Theoretical models for finding borders for gravity models are available with weighted voronoi-graphs which are known as Xtent-model in archaeology (Renfrew and Level, 1979). The Hägerstrand-model is using time as a parameter as an addition. Complex models which are looking at the whole system instead of single interaction transactions are another possibility. The probability of one interaction is not only dependent on the parameters of partners and distance but also on other interactions. The Wilson-model (1970) which is based on ideas from thermostatistics is a well known example. A further model which calculates an optimal structure of the whole system is Christallers central place theory applied to spatial planning which is minimizing the costs of transportation in the whole system by searching for optimal locations for the supply centres.

Case Study

In the case study we are especially looking at observations which are indicating the relevance of transport costs. The method is focussed on simple models which are easy to apply. The case study is based on data which were collected during the DFG-SPP 1171 (Krausse, 2004) in the Project "Siedlungshierarchien und kulturelle Räume" (Nakoinz, 2013). A point was defined every 10 km in Baden-Württemberg where samples from the density of archaeological types were taken. The types were grouped in "Typenspektren", for example ceramics (=ts 26) or personal furniture (=ts56 [belts, needles and fibulae]). These "Typenspektren" allow the calculation of cultural distances as inverse proxies of interaction intensity.

We start our analysis with a distance graph that takes into account all possible locations as a starting point for interaction assessment. In general we see the anticipated shape of curve. The cultural distance grows with the distance, which means, that the interaction intensity decreases with distance. Indeed the shape is not exactly fitting into theoretical distance decay functions. There are some irregularities which divide the curve into four sections. Section 1 shows a steep initial step which corresponds well with the idea of high interaction inside a settlements' vicinity. In fact this initial step is rather a statistical phenomenon since it indicates the individual characteristics distinguishing a certain place from the local milieu. It follows a continuous and monotonic section. Section four shows through a step gradient the scope of usual interaction. This is not a certain barrier but a distance depended scope which might be caused by a travelling range with certain means of transportation. The

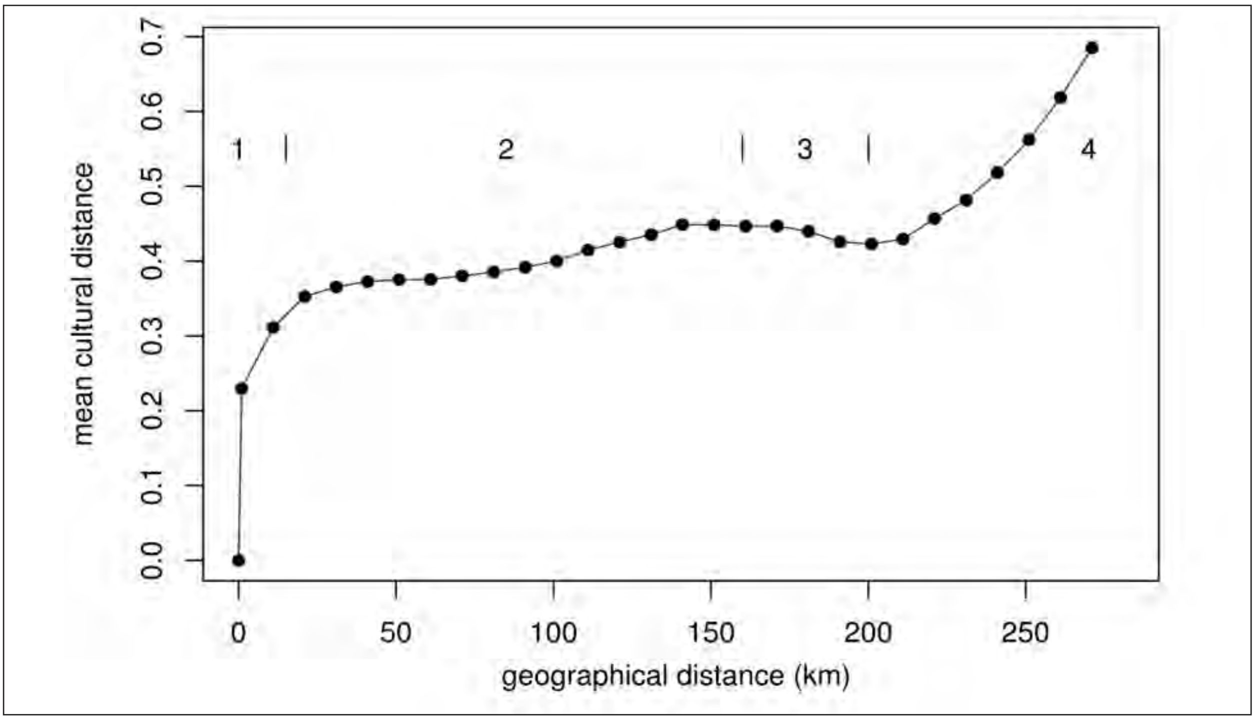


Fig. 1: Distance graph, statistical view point, average cultural distances from ts56 (Nakoinz in print. fig. 1).

scope of interaction at 200 km is undoubtedly a factor relevant to economics. The low gradient in section two indicates that transport costs are not negligible but are not of high relevance as well until the scope is reached. Section three is a kind of anomaly since the interaction intensity is decreasing a little. It seems that people are aware of the scope at 200 km and try to optimize the system by preferring distances a little below the scope. This again indicates that the transport costs are of minor importance within the scope and become suddenly important at about 200 km.

Now we turn to certain viewpoints. While a statistical viewpoint allows us to detect distance dependant scopes, certain viewpoints show interaction resistors

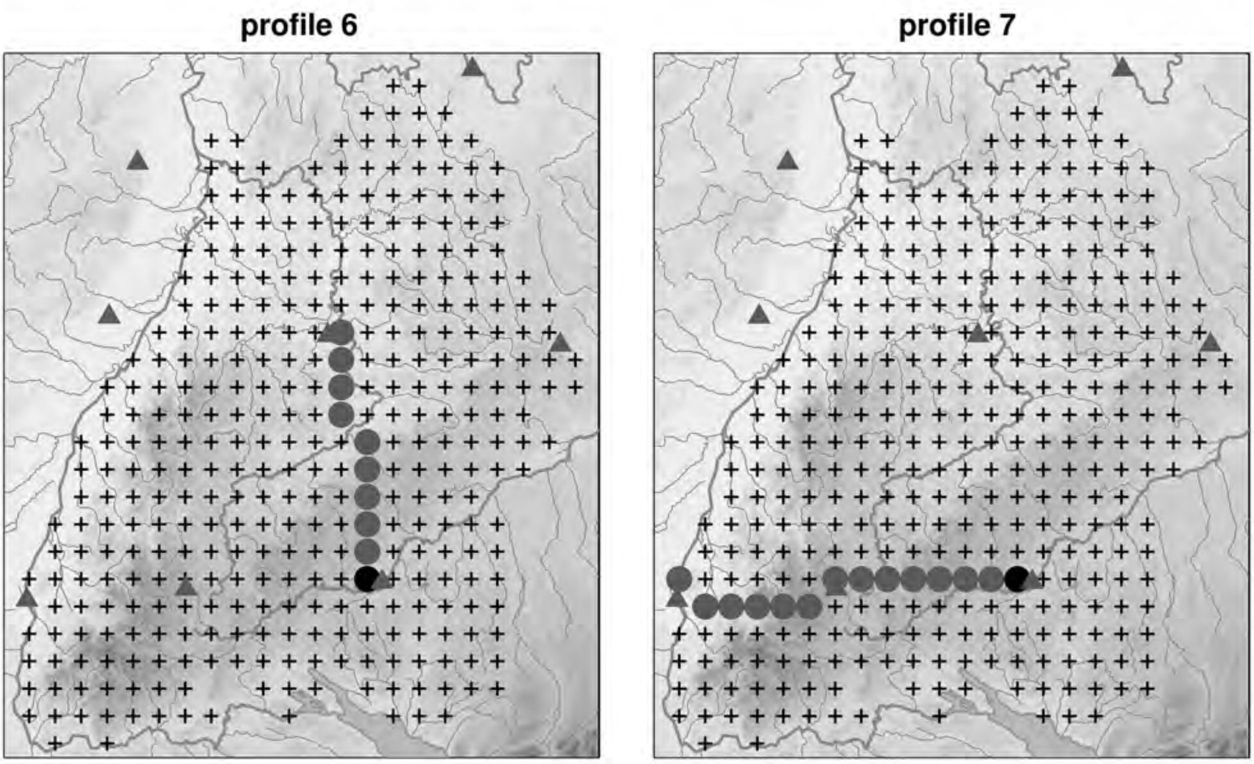


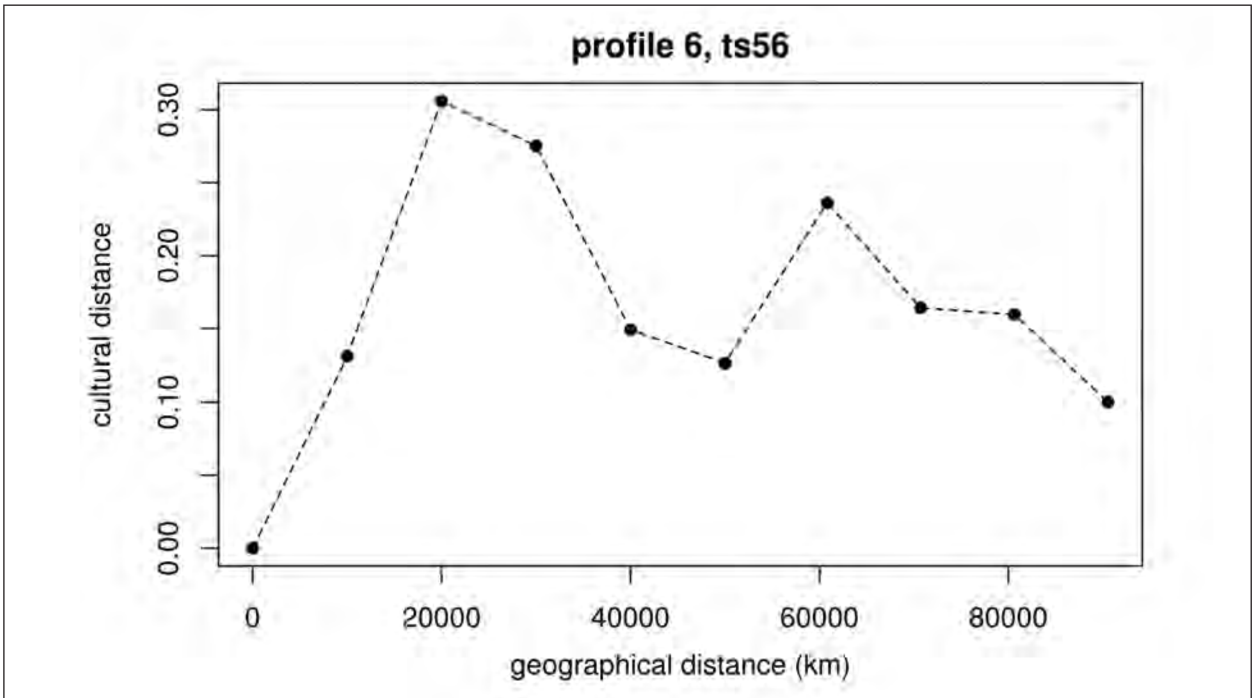
Fig. 2: The area of interest (Baden-Württemberg, Germany) with sample all points (crosses), sample points of profiles (circles), the starting point of the profiles (black circle) and the princely seats of Early Iron Age. Profiles 6 and 7 are from the case study.

and interaction conductors which correspond with certain features in the landscape. Both methods complement each other and are required for a full understanding of interaction. We select two profiles from the case study for this contribution. Profile six connects the Danube with the middle part of the Neckar and goes from the surrounding of the Heuneburg to the surrounding of the Hohen Asperg. Profile seven starts at the Heuneburg and runs along the Danube as well, over the Kapf and crossing the Black Forest to the Rhine at Breisach.

The distance graph from profile six shows an unexpected shape. After the initial step we find the maximum cultural distance followed by a local minimum and a further peak with decreasing values. Looking at the map we find the explanation for the peaks in the location at the Schwäbische Alb and in the Schönbuch. The sample points with lower cultural distances are located near the rivers Danube (starting point) and Neckar (point 6 and point 8-10). This indicates that rivers are important waterways in the system of transportation. Even small rivers seem to be included into this transportation network (Steinach, point 5). This is reasonable since water transport causes moderate transport costs and seems to be supported by section two of the first distance graph. It is remarkable that two separated systems of rivers are obviously integrated in one system of water ways. We get the impression that a majority of transport and interaction was done by means of water transport. Gaps in this system, like the connection from Danube to Neckar, were closed by selected land routes. This system of main routes was complemented by other land routes and allowed effective travelling with moderate transport costs at least within a certain range. Another study of cultural distances in this area also reveals the importance of water ways as transportation routes (Nakoinz, 2013). These observations leave us with the question, which effect the relief has on the transport costs? One would suppose that within the Highlands there are many areas resistant to interaction.

From the least cost path analysis we can learn about the impact of relief on transport costs. We use profile seven which runs from the Danube to the Rhine as an example. The least cost path as well as the cost for the travel from the starting point at the Heuneburg to each sample point in the profile is calculated. The first seven segments follow a more or less straight line along the sample points. Branching and small detours are negligible. The following point makes clear, that using big detours or alternative routes is useful to bypass obstacles and high friction areas. The southern route for example takes advantage from running along the Danube. It is interesting that this bypass is not the best solution to reach the Neckar and the Rhine. We have to be aware that this least cost path analysis uses certain parameters and different parameters would result in different routes. A more advanced analysis would first try to verify or calibrate the parameters with pathway indicators (Nakoinz, 2012) and then would use real sites as targets.

Fig. 3: Distance graph view point at Heuneburg, profile 6, average cultural distances from ts56.



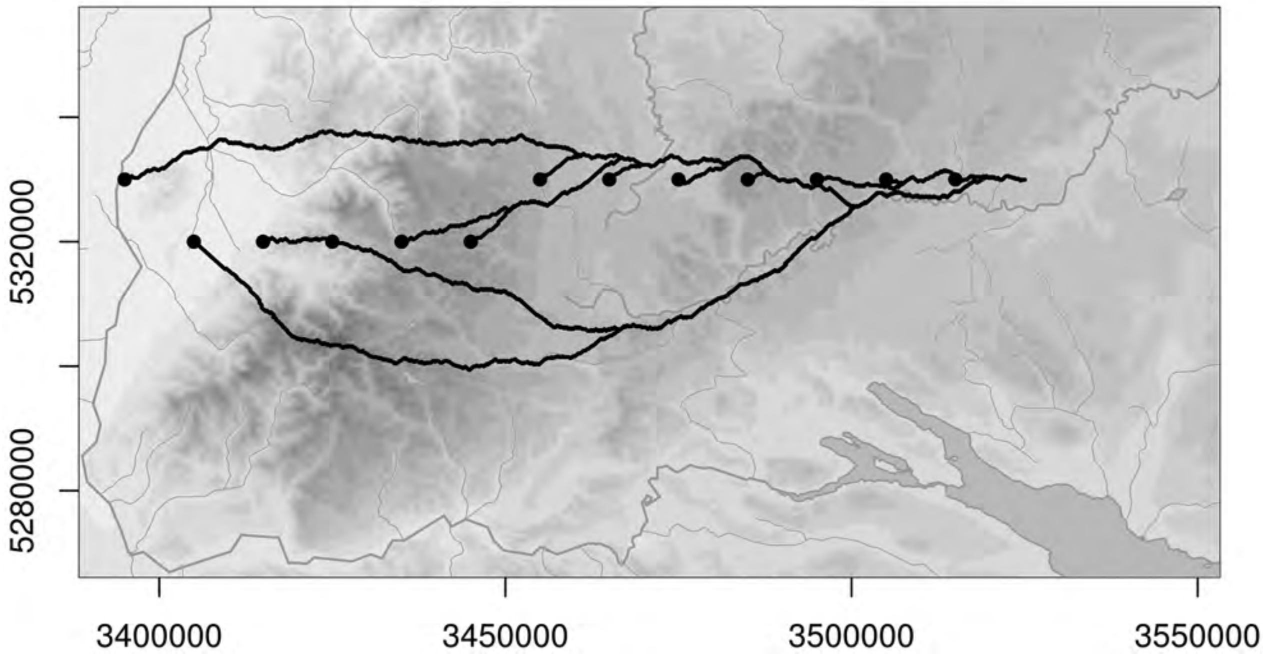
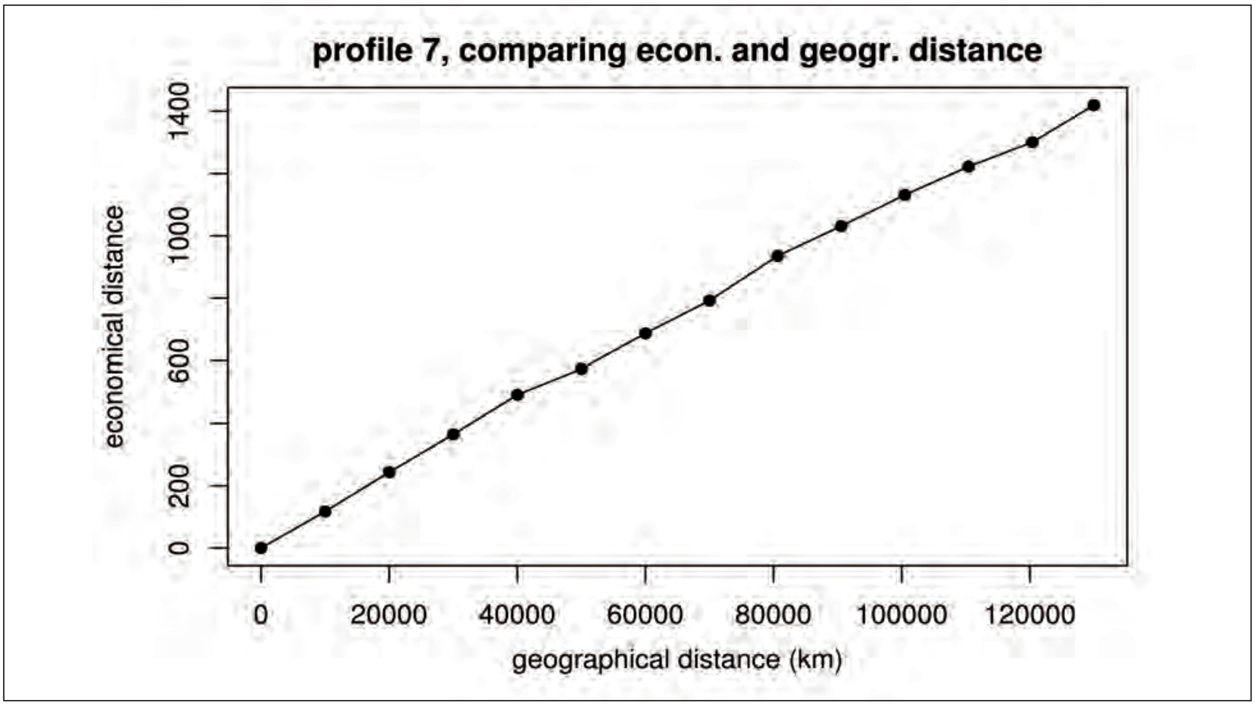


Fig. 4: Least Cost Path analysis for profile 7.

We have calculated the minimal transport costs to reach each sample point. Intuitively we would suppose that the costs to reach points in the mountains would be relative high compared with the geographical distance. On the other hand the costs to reach points near rivers should be comparable low. A graph which plots the economical distance, which is nothing but transportation costs based on the least cost path analysis over the geographical distance along the profile, informs us about the facts. The straight shape of the curve emphasises, that there is a pronounced correspondence between economical and geographical distances. Geographical distances can be used as good proxy for estimating economical distances.

This result persists only if we allow the use of alternative routes. An analysis which calculates the small segments between sample points would possibly have a different result. Since we have to presume the existence of a developed transportation network we have to allow the choice of a decent route. This implies a good knowledge of the transportation system. This

Fig. 5: Economical distances and geographical distances for each sample point on profile 7.



knowledge must have been available at least for a range of about 200 km.

A known choice of routes in combination with a developed transportation network accounts for the low gradient in section two of the first distance graph. According to this exploratory case study transportation costs seem to play a minor role compared with the distance scope and cultural borders[4]. This does not contradict the result, that more remote areas are clearly marked with a degree of interaction which is lower than the average. The results indicate a tight connection of interaction with the transportation network. Each point can be reached with moderate transport costs which can be approximated by a linear function of the geographical distance but more remote points are reached less frequently.

Result

Interaction plays a substantial role in several disciplines. This paper presents a unified access to the different phenomena of interaction. The presented heuristic is focussed on very simple analysis and is the basis for more advanced interaction models. The subdivision into simple models, disorders and more advanced models allows an exploitative analysis using simple methods in gaining substantial results. Distance graphs of various types are used as a basic tool. The viability of this approach is shown in a case study exploring the role of transport costs. The result is that we can observe a scope for normal interaction at 200 km. People seem to be aware of this scope and try an optimisation of interaction activities by preferring distances a little below the scope. Mountains can be observed as travelling obstacles which reduce the interaction intensity. This effect seems not to be caused by extraordinary high transport costs, since a detour allows avoiding many obstacles. More likely the distance from main transport routes results in a lower probability to reach these points. This surprising result, that travelling obstacles are significant rather because of structural isolation than of extraordinary travelling effort, has to be verified in further analysis. If this result is confirmed, the transportation network is the key to understand interaction structures. In addition cultural travelling obstacles seem to be an important parameter.

Notes

1 An extended discussion of spatial interaction models can be found in Nakoinz in print.
2 Further details on central place theory can be found in Nakoinz, 2009; 2013 and forthcoming.
3 Nakoinz, 2013; in print.
4 See indications in Nakoinz, 2013.

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