Managing Scale Issues in Spatio-temporal Movement of Tourists Modelling

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EXTENDED ABSTRACT

People perceive, think, and behave differently at various spatial and temporal scales. Spatio-temporal modelling of tourist movements considers how people move about or why they exhibit certain movement behaviours. Research into spatio-temporal movements of tourists can be studied from a number of different aspects. Psychologists, for example, are concerned with understanding the cognitive aspects of why people move along particular pathways in preference to alternative pathways. Geographers and tourism researchers are more interested in how people move around particular locations and model what is observed in a visitors' movement.

However in developing simulation models that can be used to emulate tourism movement the issue of scale of movement in both time and space needs to be well understood. It is too simplistic to just apply the same model from one situation to another without thinking about the issues relating to scale.

This paper discusses the issues of temporal and spatial scale for the modelling of tourist movements in terms of definition of movement, movement tracking techniques, data acquisition, data analysis, and the transition between the scales using spatio-temporal "zooming theory". These findings have important implications when developing agent models.

The paper first discusses issues relating to measuring, modelling and analysing movement behaviour at two distinct scales, namely the macro and micro level. From this initial discussion the paper then applies techniques discussed to a specific study location at Phillip Island in Victoria. The first scale examined is the macro level which covers the whole of Phillip Island. At the micro scale tourist movement behaviour is examined for a specific geographic location, the Koala Conservation Centre. Modelling the spatio-temporal movement of tourists at the macro level aims to represent the general travel patterns of a variety of tourist types. However movements of tourists modelled at the micro level relies on real-time and detailed tracking of tourists in a confined geographic area. Location-based service provision, security, emergency management and tourist wayfinding decision making are dependent on micro-scale movements of tourists.

This paper not only represents the differences of tourist movement tracking and modelling methods between these two scales but also explains the transition of tourist movement between two scales using spatio-temporal zooming theory.

1 INTRODUCTION

The spatio-temporal modelling of tourist movements incorporates knowledge from a number of different research disciplines including psychology, tourism, computer science and geography. Psychology, for example, is concerned with an understanding into the cognitive aspects of why people move along particular pathways in preference to alternative pathways. Geographers and tourism researchers are more interested in how and where people move around particular locations and model what is observed in a visitors' movement. Researchers from these various disciplines have conducted movement behaviour viewed from different perspectives and have emphasised different research themes. However there is one fundamental and common aspect that needs to be addressed, and that is the variation in geographic scale in question. It is too simplistic to just apply same model from one situation (i.e. Phillip Island: a whole island including several attractions) to another (i.e. Koala Conservation Centre: a small attraction on Phillip Island) without thinking about the issues relating to scale.

This paper will explore scale issues in modelling spatio-temporal movement of tourists. What kind of issues relating to the spatio-temporal movement of tourists could be changed when the scale or geographic dimension is altered? Section 2 defines spatio-temporal movement of tourists at the macro and micro level scales. In section 3 tracking techniques for spatio-temporal movement of tourist at macro-level and micro-level are reviewed and summarised. Section 4 compares data models for the spatio-temporal movement of tourist modelling at both levels. Based on the data analysis in section 4, hierarchical theory and spatial and temporal zooming theory are applied in modelling spatio-temporal movement of tourists for the two spatial levels using Phillip Island as a case study. Movements at the macro level cover the attractions over the whole island, while movements at the micro level concentrate on one attraction, a small area known as the Koala Conservation Centre. Conclusions are drawn in section 5.

2 DEFINITION OF SPATIO-TEMPORAL MOVEMENT OF TOURISTS AT THE MACRO-LEVEL AND MICRO-LEVEL

The macro-level can be defined in terms of spatial scale, where movements are determined from one regional location to another some distance away (from several kilometres to hundreds of kilometres). At this level, the movement of tourists is conceptualized as being discrete and simplified as a sequence of movements in geographic space between one location to another. Detailed information of movements are simplified at this geographic scale (Hornsby & Egenhofer 2002). Macro-level movements are generally represented with a low level of spatial resolution. Usually the size of the study area is large. In terms of temporal scale, the movement of tourists at the macro-level is represented by a collection of time-stamps corresponding to the sequence of locations or attractions. Temporal attributes of movement are arrival time and duration for each attraction. Representing arrival times at a location or "point" can be highlighted when visited, where duration is represented by a variable symbol within a spatial model.

However, the micro level can be considered as the determination of movements at a specific location where tourist movement patterns are localised in geographic extent. Movement is defined from one spatial point (x, y) to another rather than from one region to another. The sequence of movement can be represented accurately as a collection of spatial points in a coordinate system (x, y). Therefore micro-level movement is conceptualized as being continuous and represented with high spatial and temporal resolution. The size of the study area is generally small. Movements should be recorded continuously for discrete point locations. However whilst movements along a pathway are continuous, current technologies can only record locations at discrete points. For example GPS will record a designated location only when a receiver receives a signal from the satellites. Therefore it is necessary to utilise algorithms to predict locations where signals are missing (Pfoser 2002).

3 TRACKING TECHNIQUES FOR SPATIO-TEMPORAL MOVEMENT OF TOURIST AT MACRO-LEVEL AND MICRO-LEVEL

At the macro level, generally the information to be collected includes arrival time and duration of stay, the sequence of movements from one general location to another and the number of tourists at that location. In terms of the resolution required at the macro-level, movement of tourists can be tracked using a self-administered questionnaire. However the design of the questionnaire is the key component to acquire movement information. In addition, the extent of the geographic area and sampling method also has an affect on the accuracy of data collection. One technique that has been applied by

researchers is to follow tourists to record their movements, but this is time consuming and raises serious ethical issues (Broad & Smith 2004). However observation and interview could be used to obtain additional information. For example, direct observation combined with interviews can be used to identify specific reasons for behaviour patterns. Observation and interview emphasize the interaction and communication between tourists (Ryan 1995).

At the micro level, the level of detail of information is greater with high spatial resolution for small areas. The type of information required at the micro level revolves around detailed movement. This includes speed, direction, location, time, sequence and duration. At the micro level high-resolution techniques are required – for example GPS, timing systems, closed circuit television monitoring (camera based systems) and mobile phone tracking. Timing systems can record discrete location and time tourists' movement accurately, but in order to track the trajectory of movement of tourists a denser receiver network is needed, which could lead to high equipment costs (O'Connor et al. 2005). Closed circuit television monitoring—CCTV (camera based systems) are mainly used for surveillance. They can offer visual images of tourists. Therefore more detailed information of movements can be obtained, such as the postures and interaction between tourists. But accurate locations of tourists need to be extracted by software. Although such software has been developed (Heikkila & Silven 2004), both equipment and software are expensive and ethical issues relating to privacy are problematic. In addition, camera-based systems are limited to small areas. Mobile phone tracking is another mechanism for recording visitor movement. Again, this technology raises serious ethical issues relating to personal privacy. Compared to other tracking techniques the advantage of mobile phone tracking is that there is no additional equipment required. Until now few tourists could be tracked by this technique (VeriLocation 2004). GPS tracking is a relatively new technique used to acquire movement information of tourists. It can be used to obtain continuous movement information with high resolution. Because GPS techniques have been developed rapidly as the cost of equipment decreases it is becoming more and more popular for tourism research (Arrowsmith et al. 2005). An extension of GPS tracking is to use PDA (Personal Digital Assistant) technology. PDAs enable additional information to be acquired from or conveyed to the user rather than simply providing time and location. Hadley et al. (2003) for example, used PDA technology to convey points of interest to hikers along pathways in Kinglake National Park.

At the macro level, movement of tourists could be tracked by self-administered questionnaires and interview. Whilst at the micro level, direct observation, GPS tracking, timing system, camera-based systems, mobile phone tracking, PDA tracking could be used to track movement of tourists. Most effective tracking should incorporate a number of techniques, for example GPS backed up with self-administered questionnaires (Arrowsmith et al. 2005) Table 1 summarises the advantages and disadvantages of tracking techniques.

4 STORING SPATIO-TEMPORAL MOVEMENTS AT MULTIPLE SCALES

Information relating to the movements of tourists at both the macro and micro geographic scales can be stored in conventional relational database management systems. Linking the tourist entity to pathways (a second entity) can be undertaken by introducing a "Tourist_Movement" entity, of which time and location are stored for individual tourists.

TECHNIQUE	ADVANTAGES	DISADVANTAGES	SCALE LEVEL
GPS tracking	▪ High resolution ▪ Mature technology ▪ Ease to use ▪ Continuous measurement ▪ Uninstructive	▪ Low sample size-limited by equipment ▪ GPS signals blockage from buildings and foliage ▪ High risk of loss of GPS equipment ▪ Expensive	MICRO LEVEL
Timing systems	▪ Non-Intrusive ▪ High resolution ▪ High sample size	▪ Expensive ▪ Limited by battery life and data logger memory capacity	MICRO LEVEL
Camera-based systems	▪ High resolution ▪ Can work as surveillance, counting, and tracking tool ▪ Can identify unique individual	▪ Vibrations and changes in light, height, and temperature could degrade performance ▪ Expensive ▪ Intrusive/ ethical issues	MICRO LEVEL
Mobile phone tracking	▪ Non-intrusive ▪ Low-cost	▪ Privacy security issue ▪ Signals blockage from buildings and foliage ▪ Immature technique ▪ Low resolution ▪ Ethic issue	MICRO LEVEL
PDA Tracking	▪ High resolution ▪ Can communicate with tourists in real-time ▪ Can track their decision making process	▪ Intrusive ▪ Low sample size ▪ Signals blockage from buildings and foliage ▪ High risk of loss of PDA equipment ▪ Expensive	MICRO LEVEL
Manual observation and interview	▪ Can communicate with tourists ▪ Can classify vehicles more accurately ▪ Can count or track tourists more flexibly ▪ Can acquire non-spatial information of tourist ▪ Can track tourists' decision making process	▪ Intrusive ▪ Time-consuming ▪ Low resolution ▪ Low sample size	MACRO or MICRO LEVEL
Self-administered questionnaire	▪ Can acquire non-spatial and approximate spatio-temporal information of tourist ▪ Can count or track tourists more flexibly ▪ High sample size	▪ Intrusive ▪ Time-consuming ▪ Low resolution ▪ Low sample size	MACRO LEVEL

Table 1 Advantages and disadvantages of various counting and tracking techniques (Infodev 2004; Klein 1995; Skszek 2001).

If the attraction $A_{i,n}$ is used to indicate the spatial location of individual *i* at destination *n*, then the spatial movement sequence (itinerary) for tourist *i* is then represented as the set of attractions:

$$M_i = (A_{i1} A_{i2} \ldots A_{in}) \qquad \text{(Equation 1)}$$

This defines tourist *i* being at attraction A_{i1} at destination 1 and moving to attraction A_{i2} at destination 2. At the end of his or her trip tourist *i*

may be found at A_{in}. Here *n* is defined to be the last destination by tourist *i* in the study. Temporal movement is represented as an ordered set of arrival times relating to each destination. However, the arrival time is given as time points such as 9:30 am (or 09:30), or 9:31 pm (21:31). With this level of granularity therefore, it is hard to identify major time sequence patterns. For example, if one tourist arrived at attraction A at 16:00, attraction B at 20:00, and attraction C at 21:00. Another tourist arrived at attraction A at 16:01, attraction B at 19:59, and attraction C at 21:02. Should these two tourists have the same temporal movement pattern? The solution for this problem is to change the granularity of time points, or in other words, to categorise the time points into time intervals. If we define the time cluster TC_{ij} to indicate the arrival time cluster of individual *i* at destination *n*. The temporal movement for tourist *i* is then represented as the set of arrival time clusters: $M_i=(Tc_{i1}Tc_{i2}\ldots Tc_{in})$. This defines tourist *i* being destination1 at time cluster Tc_{i1} and moving to destination 2 at time cluster Tc_{i2}. At the end of his or her trip tourist *i* may be found at destination n at time cluster TC_{in}. Here *n* is defined to be the last destination by tourist *i* in the study.

The fundamental issue for grouping the time points is to decide the level of granularity. Time points could be categorised into a one-hour, two-hour, or even a six-hour time interval. Clustering can be used to group arrival time points into time intervals. Clustering is a method to group together instances that are similar to each other into one cluster. The members of the cluster should be similar to each other and be different from members of other clusters. Algorithms for clustering require a measure of 'distance' between instances. If the attribute values are numeric, Euclidean distance is usually used. For example, three clusters are identified using the Expectation Maximization (EM) clustering algorithm in the case study. Each cluster is given a label and meaning (see Table 2).

Time intervals	Labels of Time Categories	Meanings of Time Categories
07:00-16:15	1	Day
16:20-18:40	2	Late Afternoon
18:45-24:00	3	Night

Table 2 Time Categories

For example, for a tourist that moves from Cowes at 16:00 to the Nobbies at 18:00 ending their visitation at the Penguin Parade at 19:00 would be coded as '123'.

At the micro level, spatio-temporal movement of tourists is modelled to handle continuously changing data. Current tracking techniques such as GPS are able to obtain the position of a tourist at discrete times. Therefore in order to analyse or query continuous movement information, linear interpolation is used to predict in-between sampled positions. Collections of line segments that are drawn between sampled points comprise the trajectory of movement (Pfoser 2002) (See Figure 1

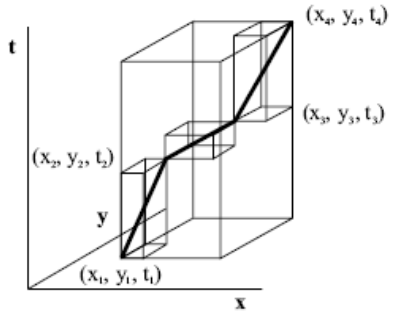

Figure 1 Approximating trajectories (Pfoser 2002)

5. SPATIO-TEMPORAL ZOOMING

5.1 Hierarchy theory

The different levels of scale (i.e. macro and micro) of spatial and temporal tourist behaviour can be hierarchically structured (Car et al. 2001). Higher levels of scale (macro level) are associated with higher levels of simplification. Spatial behaviour can be broken down into several spatial scales or hierarchical levels. For example, if we wish to drive from Melbourne to Sydney, a high level of abstraction is required to navigate (i.e. the highway that connects Melbourne to Sydney: Melbourne – highway – Sydney). However a low level of abstraction is required to move from home to the highway that connects Melbourne to Sydney. We are moving from a simple highway road network down to a complex road network of alternative pathways. Hierarchical structures can reduce the complexity of spatial reasoning, and enables the manipulation of the spatial reasoning to manageable levels (Timpf, S. & Frank 1997). The transition from one level of scale to another among the hierarchy can be interpreted by temporal and spatial zooming theory.

5.2 Spatial zooming theory

Scale plays a central role in understanding and interpreting spatial behaviour of geographic entities. People's perception of space, and spatial behaviour is scale-dependent and experience-based (Freundschuh & Egenhofer 1997). For example, a person who is familiar with a particular location will be able to pin-point that location with greater accuracy because of their spatial knowledge built through experience of that space. Lynch (1960) defines space at the micro level as a spatial node where space can be perceived from one position. At the macro level a spatial region must be explored, over time, from moving through the environment. Garling and Golledge (1989) opt for three levels of spatial scale in order to overcome the limitations with two levels. Their three levelled approach adopts 'room size' to represent small areas, 'building footprints and neighbourhoods' to medium area and finally large area are extended neighbourhoods where some movement is required to view all location in the area of interest.

The zooming lens of a camera can be used as a metaphor for moving between these scales of space. When the camera zooms in to a small scale of space, more detailed information of geographic entities show up. Conversely, if we were to zoom outwards to show a larger geographic area we can now contextualise the detailed information shown at large spatial scale (Bundapest 2003; Hornsby 2001; Searle 1985). This process is a single zooming action – see figure 3. One resolution is considered as one zooming 'step'. However new techniques such as the Level of detail (LOD) permit multiple zooming. Multiple zooming enables the user to see geographic location in terms of detail at the micro scale whilst maintaining a large spatial overview at the macro level (Frigioni & Tarantino 2003).

Spatial zooming between macro level and micro level represents the transition from the conception or planning level to the practical level. The level of detail is defined by the user, planner or researcher, will depend on the application. For example, for tourist movements around Phillip Island from one attraction to another, one can be viewed at the macro level, or for movements around a particular attraction such as the Koala Conservation Centre, at the micro level. Then, the camera zooms in on the Koala Conservation Centre and the resolution increases from 1:150000 to 1:30000. Therefore the individual tourist movement in this small area becomes evident and parameters of movement such as the position, speed, direction and time can be studied in more detail (Freundschuh & Egenhofer 1997; Muehrcke & Muehrcke 1992)(see Figure 3). Zooming out from the micro level to the macro level can be undertaken by two steps: selection and amalgamation. Selection keeps the nodes (attractions) needed at the macro level and hides the non-selected nodes from view. Amalgamation redraws the path connected the attractions(Stell & Worboys 1999; Timpf, S. & Kuhn 2003). Zooming in from the macro level to the micro level is the process of partition of space. Motion information is stored in a hierarchical structure. The top of the hierarchy contains the least detailed motion information whilst the bottom, the most detailed (Timpf, Sabine 1998).

5.3 Temporal zooming theory

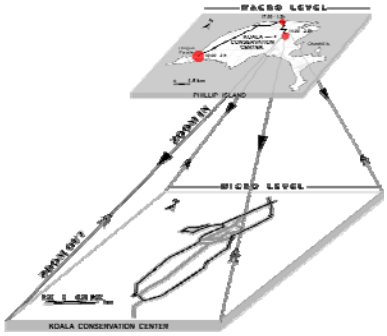

Figure 3 Spatial zooming of tourist movements between the macro and micro scale

Geographic entities can be perceived and examined in not only different levels of spatial resolution but also different levels of temporal detail. The changes in geographic entities are usually modelled in multiple steps (discrete timestamps or instances). Each step is represented as one state or 'view'. The degree of detail included in each view is dependent on the level of temporal resolution, defined in seconds, minutes, hours, days, weeks, or years. Zooming these temporal granularities alter the level of detail of information included in the model. A coarser-grained view of an object over time incorporates less detailed information or greater level of 'abstraction'. While a finer-grained view of an object over time is more detailed or 'articulated'. Transition from abstraction to articulation is an expanding process, whereas the shift from articulation to abstraction is a compressing process. These shifts among the different levels of temporal resolution of objects are referred to as *temporal zooming* (Hornsby 2001; Hornsby & Egenhofer 1999).

The temporal movement at the macro level can be considered as in terms of hours, days, weeks or years with low resolution. However temporal movement at micro level is usually defined in

minutes or even seconds with a high level of resolution.

5.4 Spatial and temporal zooming

Figure 4 shows spatial-temporal zooming applied to a case study of tourist movements at Phillip Island At the macro level, on the left side of graph, general movement patterns from one attraction to another on Phillip Island. The movements occur over one day.

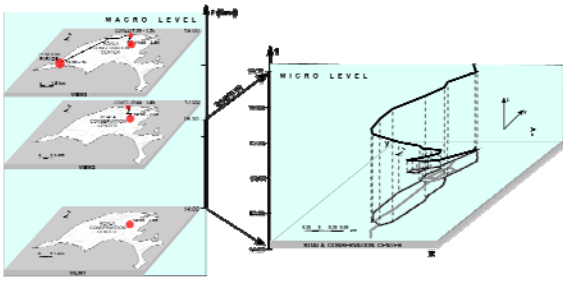

Figure 4 Temporal zooming of tourist movements between the macro and micro scale

6. CONCLUSION

Scale plays an important role in modelling spatio-temporal movement of tourists. In this paper scale issues related to spatio-temporal movement of tourists modelling are reviewed and summarised in terms of definition of movement, movement tracking techniques, data mode, data analysis, and spatio-temporal zooming theory. Scale is discussed as part of a hierarchical structure. The number of levels of hierarchy (scale) is dependent on the application. In a case study on Phillip Island spatio-temporal movement of tourists is considered at two levels: the micro and macro level. Movement at the macro level covers the attractions for the whole island, while movements at the micro level concentrate on one attraction, such as the Koala Conservation Centre. Transition between these two levels is explained by spatio-temporal zooming theory. Spatio-temporal movements of tourists at the macro level aims to represent the general travel patterns for tourist marketing or facility management. However movements of tourists at the micro level emphasis on real-time tracking, local-based service, security or emergency management.

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References

Arrowsmith, C, Zanon, D & Chhetri, P 2005, 'Monitoring Visitor Patterns of Use in Natural Tourist Destinations', in C Ryan, S Page & M Aicken (eds), *Taking Tourism to the Limits: Issues, Concepts and Managerial Perspectives*,, Elsevier, The Netherlands, pp. 33-52.

Broad, S & Smith, L 2004, 'Who Educates the Public about Conservation Issues? Examining the role of zoos and the media', paper presented to the International Tourism and Media Conference, Tourism Research Unit, Melbourne.

Bundapest, V 2003, 'Network Of Knowledge In A Virtual Landscape', in K Nyiri (ed.), *Philosophy, Psychology, Education.*, Passagen, Vienna.

Car, A, Taylor, G & Brunsdon, C 2001, 'An analysis of the performance of a hierarchical wayfinding computational model using synthetic graphs', *Computers, Environment and Urban Systems*, vol. 25, no. 1, pp. 69-88.

Freundschuh, S & Egenhofer, M 1997, ' Human Conceptions of Spaces: Implications for Geographic Information Systems', *Transactions in GIS*, vol. 2, no. 4, pp. 361-75.

Frigioni, D & Tarantino, L 2003, 'Multiple zooming in geographic maps', *Data & Knowledge Engineering*, vol. 47, no. 2, pp. 207-36.

Garling, T & Golledge, RG 1989, 'Environmental perception and cognition', in EH Hadley, D, Grenfell, R & Arrowsmith, C 2003, 'Deploying Location-Based Services for nature-based tourism in non-urban environments', paper presented to the Spatial Sciences Coalition Conference, Canberra, September 2003.

Heikkila, J & Silven, O 2004, 'A real-time system for monitoring of cyclists and pedestrians', *Image and Vision Computing*, vol. 22, no. 7, pp. 563-70.

Hornsby, K 2001, ' Temporal zooming', *Transactions in GIS*, vol. 5, no. 3, pp. 255-72.

Hornsby, K & Egenhofer, MJ 1999, ' Shifts in Detail through Temporal Zooming', paper presented to Tenth International Workshop on Database and Expert
Systems Applications, Florence, Italy.

Hornsby, K & Egenhofer, M 2002, 'Modeling Moving Objects over Multiple Granularities', *Annals of Mathematics and Artificial Intelligence*, vol. 36, no. 1-2, pp. 177-94.

Lynch, K 1960, *The image of the city*, MIT Press, Cambridge [Mass.].

Muehrcke, P & Muehrcke, J 1992, *Map use:Reading, Analysis, and Interpretation*, JP Publications, Madison, WI.

O'Connor, A, Zerger, A & Itami, B 2005, 'Geo-temporal tracking and analysis of tourist movement', *Mathematics and Computers in Simulation*, vol. 69, no. 1-2, pp. 135-50.

Pfoser, D 2002, 'Indexing the Trajectories of Moving Objects', *IEEE Data Engineering Bulletin*, vol. 25, no. 2, pp. 3--9.

Ryan, C 1995, *Researching tourist satisfaction : issues, concepts, problems*, Routledge, London ; New York.

Searle, JR 1985, *Minds, Brains and Science.*, Harvard, Cambridge, Mass.

Stell, JG & Worboys, MF 1999, 'Generalizing Graphs using amalgamation and selection', paper presented to Advances in Spatial Databases, 6th Symposium.

Timpf, S 1998, 'Map Cube Model - a model for multi-scale data.' paper presented to 8th International Symposium on Spatial Data Handling (SDH'98), Vancouver,Canada.

Timpf, S & Frank, AU 1997, 'Using hierarchical spatial data structures for hierarchical spatial reasoning', in SC Hirtle & AU Frank (eds), *Spatial Information Theory - A Theoretical Basis for GIS (COSIT'97). Lecture Notes in Computer Science 1329*, Springer Verlag, Berlin-Heidelberg, vol. 69-83.

Timpf, S & Kuhn, W 2003, 'Granularity Transformations in Wayfinding', in C Freksa, W Brauer, C Habel & KF Wender (eds), *Spatial Cognition III. Lecture Notes in Artificial Intelligence*, Springer Verlag, Berlin-Heidelberg, pp. 77-88.

VeriLocation 2004, *Now providing mobile location services to over 15,000 customers from 192.com, Phonetrack, LocateMobiles, Easy Reach and Trace A Mobile.*, 23/09/04, <http://www.verilocation.com/default.aspx>.

Zube & GT Moore (eds), *Advances in environment, behavior, and design*, Plenum Press, New York, vol. 2, pp. 203-36.