Sketch Map Analysis Using GIS Buffer Operation

Kohei Okamoto, Kei-ichi Okunuki, and Toshibumi Takai

Nagoya University, Department of Geography
464-8601 Nagoya, Japan
h44540a@nucc.cc.nagoya-u.ac.jp, nuki@lit.nagoya-u.ac.jp,
takainu@ss.iij4u.or.jp
http://www.geogr.lit.nagoya-u.ac.jp

Abstract. We developed a method to analyze sketch maps by GIS, and applied it to an actual case study. We found that analysis using buffer operation was more effective for sketch map analyses than other methods, such as the entire road length method and area method. After modeling the buffer method, an experimental study of the micro-genetic cognitive process was conducted on sketch maps from Japanese students and Brazilian residents in Japan.

1 Introduction

Increasing mutual affects are seen between spatial cognition research and GIS, and integration of the two has been attempted from various viewpoints (Kuhn et al., 2003). After GIS research evolved in the 1990s to GISc (Geographic Information Science), which examines basic problems concerning the use of GIS, interest in the spatial cognition of man as the GIS user has increased (Wakabayashi, 2003). Schuurman (2000) called this movement a 'cognitive turn' in GIS research.

GIS researchers were originally concerned with cognitive aspects in human-computer interaction; in other words, operation of GIS (Nyerges et al., 1995). Spatial cognition researchers, on the other hand, were seeking progress in systematic understanding of human spatial knowledge (Golledge, 1993; 1995). These directions led to polarization in the two fields of study; applied research such as for the development of visualization tools on the one hand, and conceptual studies such as classification of geographical knowledge on the other. Basic studies on how GIS can improve methods in spatial cognition study were left behind. This paper proposes a method for sketch map analysis, and examines its applicability in an actual analysis.

In previous studies on spatial cognition, having subjects draw sketch maps was a popular method to elicit environmental knowledge. Sketch maps have been regarded as external representations of cognitive maps (e.g. Matthews, 1992), although there has been some discussion as to whether or not sketch maps are an appropriate means for revealing cognitive representations (e.g. Blades, 1990).

Recently, sketch map research using GIS is seen (e.g. Forbus et al., 2003; Blaser and Egenhofer, 2000). The principal object of many of these studies is the

C. Freksa et al. (Eds.): Spatial Cognition IV, LNAI 3343, pp. 227–244, 2005

development of a visual tool or software to express and analyze sketch maps on GIS. We present a method of analyzing sketch maps by using an existing GIS operation, and apply this method to the task of distinguishing between route-type sketch maps and survey-type sketch maps. The hypothesis that people's cognitive maps simply develop from the route-type to the survey-type as their land experience increases has been challenged recently (e.g. Montello, 1998). We do not go deep into this issue, but focus on how to analyze external representations in sketch maps.

2 Sketch Maps in Spatial Cognition Research

The analytical methodologies used with sketch maps have consisted of analysis of contents (what is drawn in the map) and analysis of form (how the map is drawn). For the latter, there are three major subjects of analysis.

Subject 1: The drawing style of sketch maps (whether the drawing is linear or planar; in other words, whether it is sequential or spatial.)
Subject 2: The range and elaboration of sketch maps (the extent to which real geographical space is drawn, and the density of cognitive elements such as paths, nodes, and landmarks (Lynch,1960) drawn in the sketch maps).
Subject 3: Spatial relationships among the elements (distance and directions among the elements)

Of these, Subject 3 has been studied quantitatively since before the development of GIS. One example is the examination of distortions in cognitive maps by comparing the cognitive configurations with the actual ones (Wakabayashi, 1994: Lloyd, 1997). Analysis of Subjects 1 and 2 has been performed nonobjectively, relying mainly on visual judgment.

Subject 1 has been studied in terms of its relationship to the development of spatial cognition. It was suggested that as one grows older, one’s sketch maps change from route-type (linear drawings) to survey-type (planar drawings) maps. Many studies have shown that such changes occur both in ontogenetic development, that is, the development that accompanies the aging process from infancy (Hart, 1981), and in micro-genetic development, which is the development that comes with learning about a new place after migration (Lee and Schmidt, 1988; Humphreys, 1989). However, the criteria for route maps and survey maps in those studies were always ambiguous, and sketch maps were classified based on researchers’ visual estimates or general impressions. The classic work by Appleyard (1970) was not an exception, in that the method was conceptual in effect and quite difficult to apply to empirical studies.

Subject 2 has been understood in terms of its relation with spatial behavior. If one’s daily activity covered a wide area, the geographical space drawn in one’s sketch map would be large. The extent of action space has been discussed in relation with the actor’s mobility, which is affected by income or occupation, or the geographic size of the actor’s community, which is influenced by ethnicity. Orleans (1973) for instance, compared the sketch maps drawn by different ethnic and socio-status groups, namely Hispanic residents and wealthy white residents in the same urban area, and showed that the sketch maps by wealthy whites were more elaborate and covered a wider area, while those by Hispanic residents consisted of quite limited areas.

The range of a sketch map is also affected by development of spatial cognition. In general, the space represented by a survey map is more extensive than the space represented by a route map. Thus, it is important to assess the geographical space drawn in a sketch map. However, previous studies rarely quantified the range of sketch maps, only roughly estimating it in terms of the distribution of elements. Although a few studies attempted to measure the area, the methodology employed was not advanced.

In this paper we suggest a method using GIS for quantitative analysis of sketch maps. In particular, we focus on (1) analysis of the areas drawn in sketch maps in reference to actual geographical space, and (2) distinction of the forms of sketch maps.

3 Analysis of Sketch Maps Using GIS

As mentioned above, previous studies often focused on the range of sketch maps. Suppose, for instance, there was a sketch map where a person drew his/her neighborhood. On this sketch map, we may find the drawer’s home, stations, bus stops, parks, supermarkets, schools, railways, etc. We call each of these a geographical element. In order to understand the drawer’s cognitive map, we could consider the distribution of all elements on a sketch map. From the geometric viewpoint, each element is either a point-like element, a line-like element, or a polygon-like element. A building on a sketch map is a point-like element, a road network is a line-like element, and a park is a polygon-like element.

In order to employ GIS for the analysis, it is necessary to conceptualize the space where these elements are distributed. In the research field of spatial analysis, researchers have proposed various methods to analyze a distribution of point-like elements (Bailey and Gatrell, 1996); however, there has been little success in developing methods to analyze a distribution of line-like elements or polygon-like elements. There has been no general method to understand a space where different types of element (for instance, point elements and line elements) are distributed. In this chapter, we will discuss such a method using GIS.

One critical issue here is how to consider the space where geographical elements are distributed. In the real world, when we move between two points, we can not usually move as the crow flies, but we move along roads. Thus, a space where elements are distributed is like a road network spread over a plain. One approach to analyzing the distribution of geographical elements, therefore, is to consider them in a linear network space.

Another method to analyze the distribution of elements is to assume that the space is Euclidean and one can move along a straight line between any two points. In other words, the distribution of geographical elements is analyzed in a planar space.

In the following, we will describe how GIS is applied to the analysis of sketch maps with these two methods.

3.1 A Method to Analyze Distribution in Linear Space: Entire Road Length Method

One method to quantify the extent of distribution is to measure the entire length of the roads drawn in sketch maps by using GIS. The area recognized is considered to be larger as the entire length is longer.

However, this method is insufficient for distinction between a route-type sketch map and a survey-type sketch map. For instance, the same length could be measured for the case in which one long road was drawn (route-type) and that in which many roads were densely drawn in a small area (survey-type). Although it is possible to analyze the distribution of geographical elements in a linear space by measuring entire road length by GIS, this method is not yet able to distinguish the forms of sketch maps.

3.2 A Method to Analyze Distribution in Planar Space: Area Method

The simplest way to analyze distribution in a planar space is to measure the area within the range where the drawn elements are distributed in the map, i.e. to measure the *drawn area*. However, the drawn area of a sketch map is usually ambiguous and needs to be defined. For that we now suggest the following method. The drawn area is defined as a polygon that is enclosed by the lines connecting landmarks and nodes at the edge of the sketch map drawing. A dashed line in Fig.2 indicates the drawn area, for example. By measuring the area of this polygon in actual space, we can describe the planar range of distribution quantitatively. It can be considered that the larger the area of the polygon, the larger is the acknowledged space.

However, this method holds one shortcoming. In the area method, the space within the polygon is all defined as a cognitive space. Even domains not actually recognized may be interpreted as being within the cognitive space.

3.3 Combination of Linear Space and Planar Space: Buffer Method

Although both the entire road length method and area method can analyze the range of the distribution quantitatively, there are problems with both. To overcome these problems, we propose a new method to analyze sketch maps. To explain this new method, we introduce the concept of *buffered regions*. The buffer regions are obtained by applying a buffer operation, which is implemented in GIS. The buffer operation selects only the parts of a map or those features that lie within a certain distance of a point, a set of points, a line, or an area (Clarke, 2002). We refer to the parts of a map as buffered regions and define these regions mathematically as follows. Let P be a point or a set of points, and a line or an area consist of the set of points. $B(P, h)$ is then the buffered region in buffer distance h from all the points in P. The buffered region is described as $B(P, h)=\{q|d\ (p, q) \leqq h$, for all $p \in P\}$, where $d(p, q)$ is Euclidean distance between any two points p and q. The new method we propose here is to obtain the area of the buffered regions within buffer distance h of all roads drawn on a sketch map. We call this method the *buffer method*.

Using the buffer method, it is possible to distinguish roughly between route-type and survey-type maps. In route-type maps, the area of the buffered region increases at the same rate as the buffer distance is increased. In the survey-type map, when the buffer distance is also increased, the rate of increase in the area of the buffered regions should become smaller after a certain point. Because the buffered regions will begin to overlap each other, the increase in the entire buffered region will be slowed. Based on this difference, the two forms can be distinguished. Also, the misunderstanding of unrecognized space for recognized space can be avoided, because this method identifies only the region a certain distance from a road (See 5.2 for .theoretical explanation).

4 A Sample Analysis of Sketch Maps Using GIS

In this chapter, we show a case study in which the above-described entire road length method, area method, and buffer method are attempted. Sketch maps of the neighboring areas around one's home were drawn by 35 Japanese and 19 Japanese-Brazilians living in Japan (e.g., Fig. 1). The Japanese were undergraduate students at the Hamamatsu campus of Shizuoka University. Their residences were

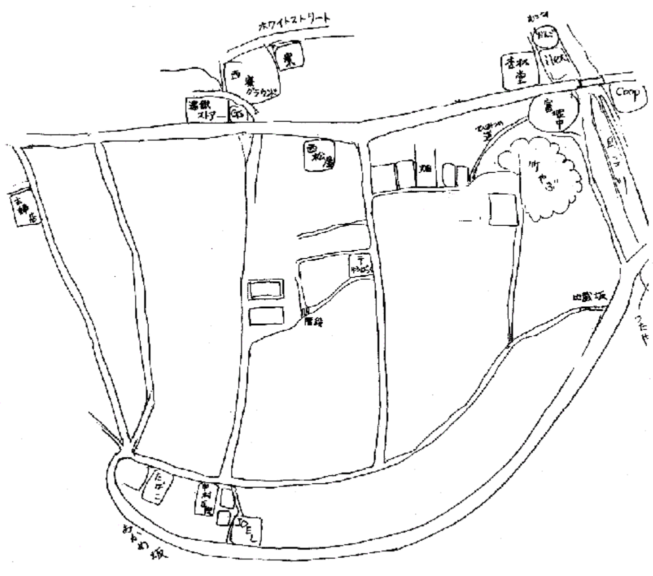


Fig. 1. A sketch map (Sketch map 1). The numbers in the sketch map are same as in Table 1

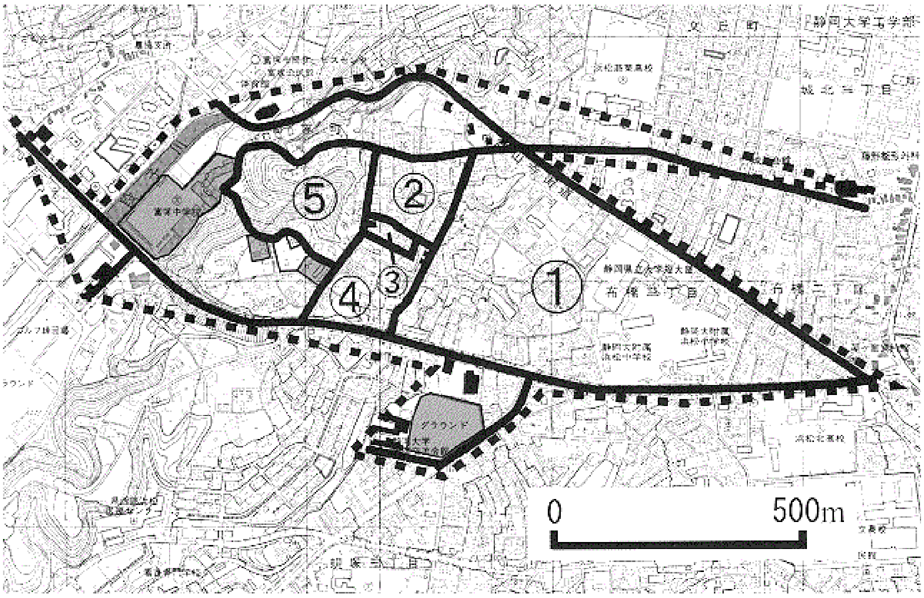
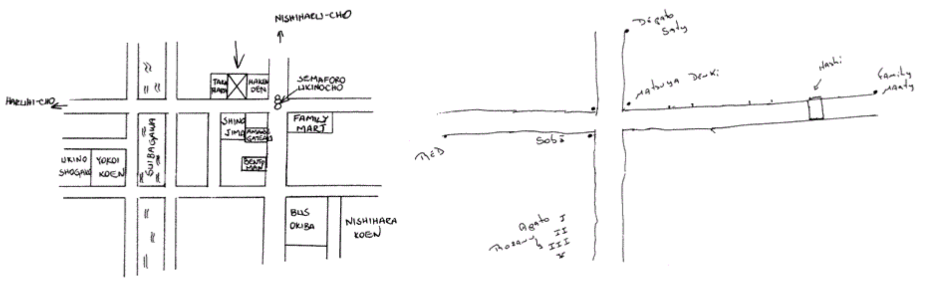


Fig. 2. A base map on which the elements of Fig.1 are traced. Drawn from a topographical map of Hamamatsu on a scale of 1/10,000. ①～⑤ are circuits, and the dash line indicates the drawn area



Sketch map 43 Sketch map 47

Fig. 3. A sketch map where the forms differ despite having the same entire road length. The numbers of the sketch maps are same as in Table 1

distributed throughout Hamamatsu city and its vicinity. The Japanese-Brazilians were mostly workers in automobile factories who lived in Nagoya, Toyota, and Toyohashi in Aichi prefecture and Hamamatsu in Shizuoka prefecture. They are descendants of migrants from Japan to Brazil. In 1990, the immigration control law was revised, enabling foreign nationals of Japanese ancestry to work as manual laborers. The population of Japanese-Brazilians then increased rapidly in Japan. Among the Brazilians who drew the maps, some spoke Japanese fluently, but very few read the Chinese characters used in Japan (Takai, 2004).

Table 1. Results of analysis of sketch maps

	Sketch Map No.	length of residence (year)	entire road length (km)	drawn area (km^2)	N of circuit	area of buffered region (km^2)							A	N
						0	10	20	30	···	390	400		
Japanese	1	1	6.9	0.76	5	0	0.13	0.26	0.38	···	2.93	3.00	0.94	8.83
	2	2	6.7	0.71	10	0	0.13	0.25	0.36	···	2.56	2.62	0.74	11.82
	3	14	12.7	0.69	42	0	0.24	0.43	0.59	···	2.49	2.54	0.70	53.33
	4	2	8.9	0.91	14	0	0.17	0.33	0.48	···	3.18	3.25	1.08	18.03
	5	2	6.2	0.55	9	0	0.12	0.23	0.33	···	2.37	2.43	0.64	11.95
	6	1	9.0	0.82	14	0	0.17	0.33	0.48	···	3.27	3.34	1.13	16.41
	7	2	4.0	0.33	3	0	0.08	0.15	0.22	···	2.14	2.19	0.53	2.84
	8	2	4.4	0.47	3	0	0.09	0.17	0.25	···	2.25	2.31	0.58	9.36
	9	1	3.2	0.29	2	0	0.06	0.13	0.18	···	1.86	1.91	0.40	4.04
	10	2	7.2	0.78	8	0	0.14	0.28	0.41	···	2.88	2.94	0.91	8.39
	11	2	5.0	0.44	4	0	0.10	0.18	0.26	···	2.37	2.43	0.65	8.26
	12	20	14.6	2.95	14	0	0.29	0.56	0.83	···	7.35	7.48	3.84	19.34
	13	21	6.9	0.40	18	0	0.13	0.24	0.34	···	2.00	2.05	0.46	23.58
	14	20	4.5	0.42	7	0	0.09	0.17	0.24	···	2.01	2.06	0.47	10.04
	15	2	3.7	0.25	2	0	0.07	0.14	0.21	···	2.00	2.05	0.46	6.58
	16	2	3.9	0.45	8	0	0.08	0.15	0.21	···	1.83	1.88	0.38	8.12
	17	2	7.5	0.90	3	0	0.15	0.29	0.43	···	4.51	4.62	1.91	4.79
	18	20	9.2	0.80	15	0	0.17	0.32	0.45	···	2.69	2.76	0.81	31.46
	19	20	8.3	0.40	24	0	0.15	0.26	0.36	···	2.01	2.06	0.47	27.78
	20	2	4.6	0.55	3	0	0.09	0.18	0.27	···	2.60	2.66	0.76	3.80
	21	2	5.0	0.64	2	0	0.10	0.20	0.29	···	2.85	2.92	0.90	2.65
	22	2	4.5	0.48	9	0	0.09	0.17	0.24	···	1.67	1.71	0.31	10.20
	23	2	12.9	2.42	11	0	0.25	0.49	0.72	···	5.81	5.92	2.76	16.16
	24	16	6.6	0.63	9	0	0.13	0.25	0.35	···	2.86	2.93	0.90	11.95
	25	2	5.7	0.50	13	0	0.11	0.20	0.29	···	1.98	2.04	0.46	16.78
	26	18	15.5	1.80	20	0	0.30	0.59	0.85	···	5.04	5.14	2.24	28.97
	27	4	17.0	2.13	14	0	0.33	0.64	0.94	···	6.77	6.90	3.43	23.33
	28	19	3.0	0.26	5	0	0.06	0.11	0.16	···	1.50	1.54	0.25	5.53
	29	20	7.1	0.79	4	0	0.14	0.28	0.41	···	3.53	3.61	1.29	5.38
	30	21	1.6	0.16	4	0	0.03	0.06	0.08	···	1.08	1.12	0.10	5.93
	31	2	0.9	0.11	0	0	0.02	0.04	0.05	···	0.99	1.03		
	32	20	7.1	0.54	16	0	0.14	0.26	0.36	···	2.53	2.59	0.73	20.09
	33	2	1.4	0.04	5	0	0.03	0.05	0.07	···	0.86	0.90	0.05	5.36
	34	3	9.5	0.80	13	0	0.18	0.36	0.52	···	3.27	3.35	1.14	14.96
	35	3	7.9	1.28	6	0	0.15	0.30	0.45	···	3.44	3.51	1.23	8.86
Brazilian	36	8	5.1	1.03	1	0	0.10	0.20	0.30	···	3.74	3.84	1.43	2.59
	37	1	1.9	0.38	0	0	0.04	0.08	0.12	···	1.90	1.96		
	38	7	1.1	0.35	0	0	0.02	0.04	0.06	···	1.16	1.20		
	39	1	0.6	0.05	0	0	0.01	0.03	0.04	···	0.94	0.98		
	40	7	0.4	0.03	0	0	0.01	0.02	0.03	···	0.73	0.76		
	41	7	0.6	0.03	0	0	0.01	0.02	0.04	···	0.78	0.81		
	42	8	5.3	0.70	0	0	0.11	0.21	0.32	···	4.23	4.33		
	43	8	1.6	0.03	3	0	0.03	0.05	0.07	···	0.91	0.95	0.06	6.03
	44	6	1.8	0.07	1	0	0.04	0.07	0.11	···	1.54	1.59	0.27	2.88
	45	9	1.9	0.11	0	0	0.04	0.08	0.11	···	1.80	1.86		
	46	10	1.2	0.18	0	0	0.02	0.05	0.07	···	1.32	1.37		
	47	8	1.8	0.38	0	0	0.04	0.07	0.11	···	1.74	1.80		
	48	2	1.6	0.12	0	0	0.03	0.06	0.10	···	1.56	1.61		
	49	2	1.6	0.12	0	0	0.03	0.06	0.10	···	1.56	1.61		
	50	8	3.6	0.32	2	0	0.07	0.14	0.20	···	1.87	1.92	0.40	3.66
	51	7	1.7	0.05	2	0	0.03	0.06	0.09	···	1.41	1.46	0.21	2.95
	52	2	0.9	0.03	0	0	0.02	0.03	0.05	···	0.85	0.88		
	53	2	1.8	0.15	0	0	0.04	0.07	0.11	···	1.69	1.74		
	54	2	1.0	0.05	0	0	0.02	0.04	0.06	···	1.05	1.09		

Since the sketch maps like that in Fig. 1 cannot be directly analyzed by GIS, it is necessary to trace the roads and landmarks drawn in Fig. 1 onto a 1:2,500 scale digital map, as shown in Fig. 2. The polygons consisting of line segments among the landmarks and roads on the edge of traced map are subject to measurement by the area method. In the figure, ①～⑤ indicate the domains surrounded by roads. We simply call this the domain *circuit*.

After tracing all the sketch maps on digital maps, the entire length of roads, area of drawn range, number of circuits, and domain areas for each buffer distance are measured for each map (Table 1). Using these data, the entire road length method, area method, buffer methods are applied as follows.

4.1 Entire Road Length Method

This method is effective in quantitative analysis of linear space when the entire length of the drawn roads is measured. The longer the entire length, the larger the cognitive space is assumed to be. However, even if the entire road length was the same in two maps, it does not necessarily mean that the forms are the same. For example, the entire road lengths are almost the same in sketch map 43 and sketch map 47 in Fig. 3. However, map no. 43 is a survey-type map with the roads drawn densely in a small area, while no. 47 is a route-typ map with two roads simply drawn crossing (Fig. 3). As is shown here, the entire road length method is unable to distinguish the forms of sketch maps.

4.2 Area Method

The area method is effective in quantitative analysis of planar space. It is natural to assume that the drawn area of a planar survey map is larger than that of a linear route map. However, even if only a small area is drawn, the drawing style can be planar. For example, no. 43 in Fig. 3, as described in the previous section, is a survey-type map with quite small area. No. 47 is a route-type sketch map, but the drawn area tends to be overestimated as two roads cross perpendicularly. Thus, the area method is also unsuitable to distinguish route-type and survey-type maps.

4.3 Buffer Method

As mentioned before, both the entire road length method and area method can be used to analyze sketch maps quantitatively, but they both have problems. As a means to overcome these problems, we show a case study employing the buffer method.

We denote a set of all points on the roads drawn on a sketch map by P. Forty buffered regions are obtained by drawing buffered regions $B(P, 10\text{m})$, $B(P, 20\text{m})$,・・・, $B(P, 400\text{m})$ in buffer distance h=10m, 20m,・・・, 400m using GIS (because buffering is performed in 10m intervals between 10m and 400m). We calculate the area of each region, and obtain a scatter-plot graph where h is on the X axis, and areas of $B(P, h)$ are on the Y axis. The reason for changing the buffer distance in 10m intervals is that most of the blocks in the actual urban areas are larger than 10m square. So, even if we use the intervals shorter than 10m, the scatter-plot pattern is unlikely to differ.

Following the above procedure, we worked out graphs based on the sketch maps by Japanese and Brazilian subjects. Table 1 shows some of the areas of buffered regions that were obtained by moving buffer distance from 10m to 400m in 10m intervals. Figure 4 is a graph of sketch maps by 35 Japanese resulting of the above procedure. Each line corresponds to an individual sketch map by Japanese. The same procedure was applied to the sketch maps by the 19 Brazilians (Fig. 5).

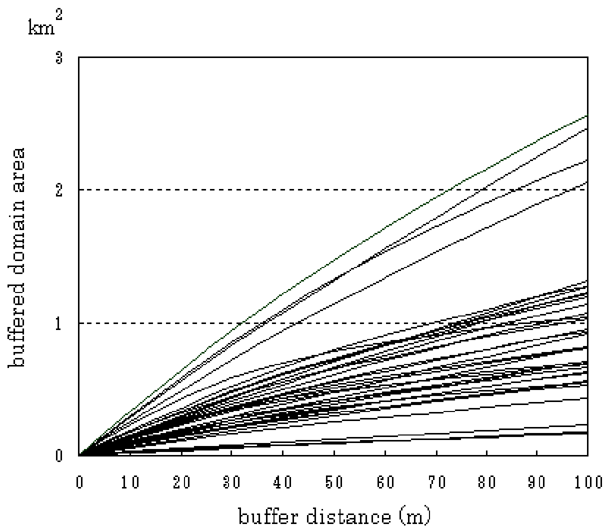


Fig. 4. The transition of buffered areas in each sketch map (Japanese)

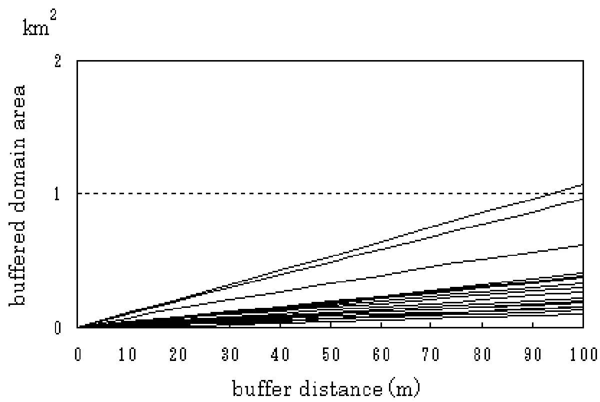
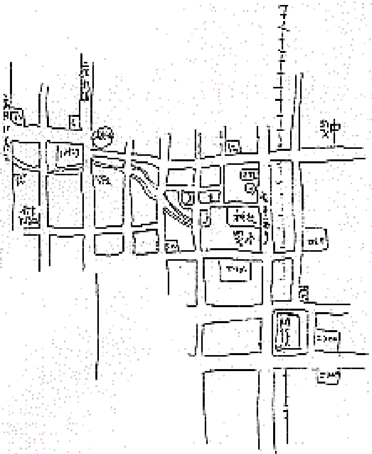
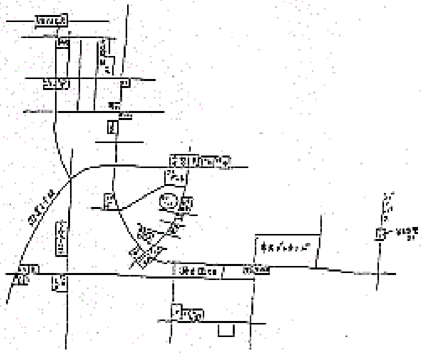


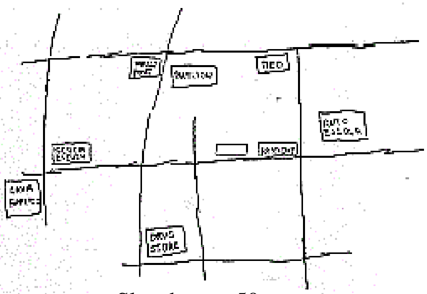
Fig. 5. The transition of buffered areas in each sketch map (Brazilian)



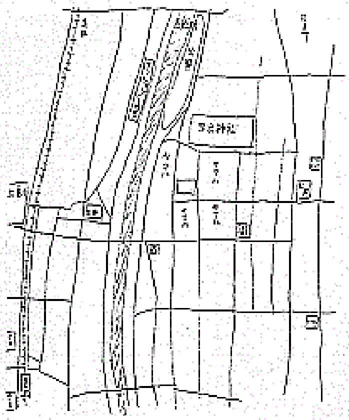
Sketch map 27



Sketch map 12



Sketch map 50



Sketch map 19

Sketch map 45

Fig. 6. Typical sketch maps that produce graph pattern 1-5. The numbers of the sketch maps are same as in Table 1

On these graphs, we can see visually how the areas of the buffered regions increase with an increase in buffer distance. We related every line on the graph with the forms of sketch maps, paying special attention to the inclination and the buffer distance that gives the greatest impact on the inclination, and found several patterns in the forms of graph showing the transition of the areas of buffered regions.

Pattern 1: The inclination at the origin is relatively large. The graph shows a narrow curve when the buffer distance is short. Sketch map that produce this form are survey-type maps, having large drawn area, and containing many circuits (Sketch map 27 in Fig. 6, for example).

Pattern 2: The inclination at the origin is in the mid-range. The graph curves moderately with increase in buffer distance. Sketch maps that produce this pattern of graph are survey-type maps, having large drawn area, but relatively few circuits (Sketch map 12 in Fig. 6, for example).

Pattern 3: The inclination at the origin is in the mid-range. The graph shows a narrow curve when the buffer distance is short. The drawn area in the sketch maps that produce this type of graph is small, but there are many circuits (Sketch map 19 in Fig. 6, for example).

Pattern 4: The inclination at the origin is relatively small. The graph curves moderately as the buffer distance increases. The drawn area in the sketch maps that produce this pattern is small, and the circuits are few (Sketch map 50 in Fig 6, for example)

Pattern 5: The graph extends in almost at same rate, or at a slightly increasing rate like a convex function. Sketch maps that produce this type of graph are route-type maps with no circuit (Sketch map 45 in Fig. 6, for example).

As shown the above, the forms of graphs can be criteria to roughly distinguish between survey-type or route-type sketch maps. Graph that trace an arc like a concave function (Pattern 1~Pattern 4) indicate a survey-type map, and graphs with a little change in inclination that trace an arc like a convex function (Pattern 5) indicate a route-type map. Also, with survey-type maps, once the graphs are distinguished as one of Pattern 1~Pattern 4, the forms of sketch maps can be classified more strictly.

Although the method is more objective compared with classification directly by subjective impression of sketch maps, it still retains some ambiguity in that it gives visual references, such as the forms of graphs.. In order to develop a more objective method, mathematical consideration of the relationships between the interval of buffer distance and the increase rate of the area of buffered region (buffered area) is necessary. In the following chapter, we will attempt a basic mathematical consideration.

5 Modeling the Buffer Method

5.1 Relationship Between Buffer Distance and Buffered Area (Route Map)

A route map is a representation structured by movement along a road, and a survey map is a collective representation consisting of relationships among multiple locations. Also, a survey map is not an ego-centered representation (Hart and Moor, 1973). Given these characteristics, it is possible to define a representation without circuits as a route map, and a representation with circuits as a survey map. There is only one route between two locations on a network with no circuit, whereas there are plural routes on a network with one or more circuit, and plural routes produce survey knowledge. Therefore, we define a sketch map with no circuits as a route-type map, and a sketch map with one or more circuits as a survey-type map.

In the modeling of buffer method, buffering on a line with length *k*, which is the simplest route map, is considered here. In this case, the buffered area *Y*(*X*) in buffer distance *X* is:

$$Y(X) = \pi X^2 + 2kX \tag{1}$$

This is a quadratic curve, and its rate of increase always increases for $X >= 0$. Therefore, as described in the previous section, the graph draws an arc of a convex function.

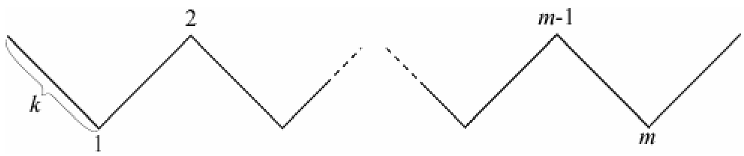


Fig. 7. A route which winds vertically by a move in length *k*

However, when a route turns vertically *m* times with every move in length *k*, as shown in Fig. 7, the buffered area in buffer distance *X* is:

$$Y(X) = (\frac{\pi - 4}{4} m + \pi) X^2 + 2k(m+1)X \tag{2}$$

In this case, a coefficient of X^2 is negative for *m*>=15, when the graph traces an arc of a concave function. Consequently, the form of graph does not identify whether the sketch map is a route map. We avoid this problem by setting a condition with a route map in which the number of circuits is 0.

5.2 Relationship Between Buffer Distance and Buffered Area (Survey Map)

Here a sketch map such as that in Fig. 8 is considered. This map consists of streets in a lattice-like form in which *a* length square is divided into *n* x *n* grids. *a* indicates the range of the drawn area, and n indicates the density of a drawn road network; that is, elaboration of the sketch map. a^2 corresponds to the area of the drawings, and n^2 corresponds to the number of circuits. When n=1, the number of circuits is 1, and the figure becomes a square loop road without inner branches.

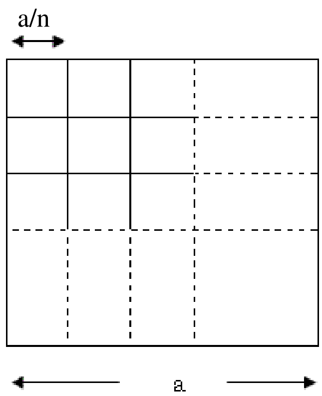


Fig. 8. Survey map with n × n grids

Buffering is performed on these roads. When the buffer distance is $a/2n$, the sections between the grids are fulfilled. Therefore, the area of buffered region $Y(X)$ is written as follows:

$$Y(X)=\begin{cases} -(4n^2-\pi)X^2+4a(n+1)X, & \text{for } X \le a/2n \\ \pi X^2+4aX+a^2, & \text{for } X \ge a/2n. \end{cases} \tag{3}$$

The first derivative of $Y(X)$ is:

$$\frac{dY(X)}{dX}=\begin{cases} -2(4n^2-\pi)X+4a(n+1), & \text{for } X \le a/2n \\ 2\pi X+4a, & \text{for } X \ge a/2n. \end{cases} \tag{4}$$

and the second derivative is:

$$\frac{d^2Y(X)}{dX^2}=\begin{cases} -2(4n^2-\pi), & \text{for } X \le a/2n \\ 2\pi, & \text{for } X \ge a/2n. \end{cases} \tag{5}$$

Since n is a natural number in the above, $(4n^2-\pi)$ >0 is maintained. From equation (3), we find that $Y(X)$ changes as X increase as in Fig. 9.

The typology described in chapter 4 is supported by equations (4) and (5). That is, when $\frac{dY(0)}{dX}=4a(n+1)$, $X \le a/2n$, we have $\frac{d^2Y(X)}{dX^2}=-2(4n^2-\pi)$.

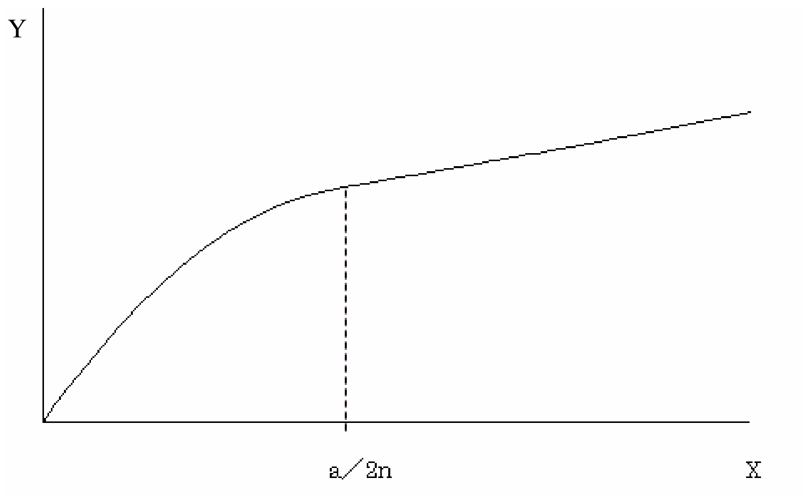


Fig. 9. Relationship between buffer distance and buffered area in survey map

Therefore, when both *a* and *n* are large, the inclination at the origin is relatively large. This produces a graph that curves steeply as buffer distance increases (Pattern 1). When *a* is large and n is small, the inclination at the origin is moderate, and the graph curves moderately as buffer distance increases (Pattern 2). When *a* is small and *n* is large, the inclination at the origin is moderate, and the graph curves teeply while buffer distance is small (Pattern 3). When both *a* and *n* are small, the inclination at the origin is relatively small, and the graph shows a moderate curve as buffer distance increases (Pattern 4).

5.3 Expected Values for Area, Number of Circuits, and Entire Road Length

From formula (3), the following equation is obtained when buffer distance X is large enough:

$$a^2 = (8-\pi)X^2 + Y(X) - 4X\sqrt{(4-\pi)X^2 + Y(X)} \tag{6}$$

Therefore, the following index is obtained:

$$A(X, Y(X)) = (8-\pi)X^2 + Y(X) - 4X\sqrt{(4-\pi)X^2 + Y(X)} \tag{7}$$

When buffer distance is small in equation (3),

$$n^2 = -\frac{1}{8}\frac{d^2Y(X)}{dX^2} + \frac{\pi}{4} \tag{8}$$

Therefore, the following index is also obtained:

$$N\left(\frac{d^2Y(X)}{dX^2}\right) = -\frac{1}{8}\frac{d^2Y(X)}{dX^2} + \frac{\pi}{4} \tag{9}$$

A and *N* are indices for a^2 and n^2 in Fig. 1 respectively. Thus, *A* indicates the drawn area (the extent of cognitive space) and *N* indicates the number of circuits.

A and N correspond to the expected values for an area and number of circuits obtained by the buffer method.

5.4 Relationship Between Expected and Actual Values

Using the data for buffer distance and buffered areas in Table 1, the expected values of the drawn areas and the number of circuits are obtained by (7) and (9) for each sketch map:

$$A(400, Y(400)) = (8-\pi)\times 400^2 + Y(400) - 4\times 400\sqrt{(4-\pi)\times 400^2 + Y(400)} \tag{10}$$

$$\begin{aligned} N\left(\frac{d^2Y(X)}{dX^2}\right) &= -\frac{1}{8}\frac{d^2Y(X)}{dX^2} + \frac{\pi}{4} \\ &\approx -\frac{1}{8}\frac{1}{\Delta X}\left(\frac{dY(X+\Delta X)}{dX} - \frac{dY(X)}{dX}\right) + \frac{\pi}{4} \\ &\approx -\frac{1}{8}\frac{1}{\Delta X}\left(\frac{Y(X+2\Delta X) - Y(X+\Delta X)}{\Delta X} - \frac{Y(X+\Delta X) - Y(X)}{\Delta X}\right) + \frac{\pi}{4} \\ &= -\frac{1}{8}\frac{1}{\Delta X^2}\left(Y(X+2\Delta X) - 2Y(X+\Delta X) + Y(X)\right) + \frac{\pi}{4} \end{aligned} \tag{11}$$

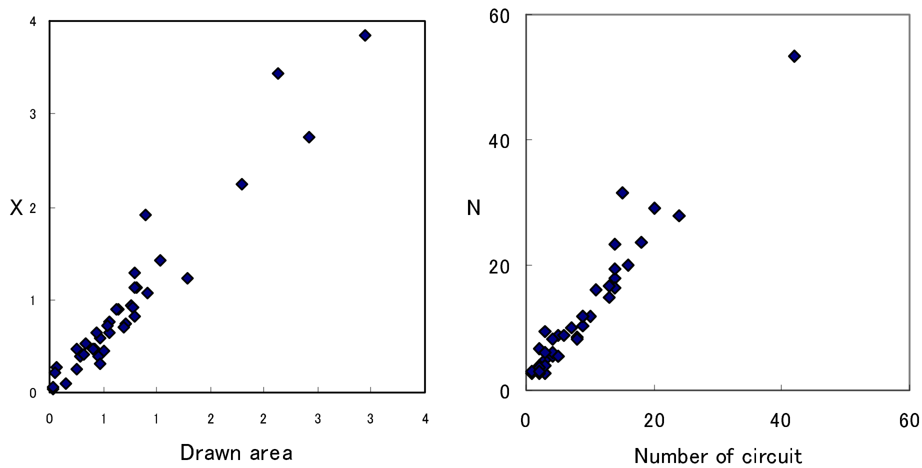


Fig. 10. Relationship between actual values and expected values. Left: drawn area and A. Right: number of circuit and N

When we depict the expected values obtained above and the actual values of areas and number of circuits that were measured directly from the sketch maps onto a correlation diagram, strong correlations are seen for two values (Fig. 10). This suggests the effectiveness of the buffer method, and that the model in Fig. 8 appropriately typifies a wide variety of survey-type sketch maps. Parts of the procedure shown in Fig. 2 as a measure of calculating the drawn area remain ambiguous; however, the buffer method can measure the drawn areas more objectively.

6 Examination of Micro-genetic Development

In this chapter, we examine micro-genetic development by looking into the relationships between the forms of sketch maps and the length of current residence of those who drew the maps.

The first subject for inquiry is the development from a route map to a survey map. Based on the definition that the number of circuits is 0 in a route map, only one of 35 sketch maps by Japanese corresponded to a route map. On the other hand, 14 out of 19 sketch maps by Japanese-Brazilians are route-type, and only 5 are survey-type. The reasons many Brazilians do not obtain survey-type knowledge are considered to be a limited proficiency in reading the Chinese characters used in Japan, a lack of landmark knowledge attributed to difficulties in learning the characteristics of Japanese buildings, and inexperience with the Japanese address indication system (Takai, 2004). An additional reason may be that their area of activity is small and daily travel patterns have relatively little variation compared to Japanese university students.

The Japanese-Brazilians can be roughly divided into two groups: those who have resided in Japan less than 3 years and those who have resided 6 or more years (Table 1). All the individuals in the former group drew route-type maps, while 5 out of 12 individuals in the latter drew survey-type maps with one or more circuits. This shows a tendency for micro-genetic development.

The Japanese subjects can be divided into a group that has resided in the current location for less than 4 years, that is, the student group who moved to Hamamatsu city to go to university, and a group with residence in the city for 10 or more years. The only student who drew a route-type map belonged to the former group. For the remaining 34 individuals, we examined the difference in the forms of survey maps for the short residence group and long residence group. A Wilcoxon rank-sum test for A and N as in section 5.4. indicated no significant difference in A, but a significant difference in N at a 5% significance level. This result suggests that the drawn area does not become larger but the contents become more elaborate with increase in length of residence.

7 Conclusion

We herein proposed a method to analyze sketch maps by GIS, and applied it in an actual case study. In addition to the entire road length method for analysis of linear space and the area method for analysis of planar space, we introduced a buffer method to analyze sketch maps to which the former two methods are not applicable. GIS analysis of sketch maps was practiced by applying each method to the analysis of the neighborhood sketch maps drawn by Japanese and Japanese-Brazilians. As a result, classification of route maps and survey maps, and description of their characteristics including drawn range and elaboration was done according to number of circuits and the values of A and N obtained by buffer method. The findings indicate that the buffer method with GIS is effective as a method for sketch map analysis, which enables automatic distinction of the forms of sketch maps. A specific advantage of the buffer method was the ability to obtain easily and objectively the approximate value of the area drawn in survey map. We used these values to analyze the micro-genetic development shown in sketch maps.

In this study, we traced the roads drawn in the sketch maps onto a digital map, and applied buffering on the roads. This method focused especially on paths among other elements of a cognitive map. Further examination of the method by applying it to other elements such as landmarks and edges is needed. In order to develop a more versatile model, which is applicable to a greater variety of relationships in buffer distance and buffered areas, further mathematical consideration is also needed.

References

Appleyard, D.(1970): Styles and methods of structuring a city. *Environment and Behavior*, 2, pp.100-117.

Bailey, T.C. and Gatrell, A.C. (1996): *Interactive Spatial Data Analysis*. Longman Scientific & Technical, Harlow.

Blades. M.(1990): The Reliability of Data Collected From Sketch Maps. *Journal of Environmental Psychology,* 10, pp 327-339.

Blaser, A. and Egenhofer, M. (2000): A visual tool for querying geographic databases. Di Ges, V., Levialdi, S. and Tarantini, L. eds.: *AVI2000--Advanced Visual Databases*, Salerno, Italy, pp. 211-216.

Clarke, K.C.(2002): *Getting Started with Geographic Information Systems, 4th edition*, Prentice Hall, Upper Saddle River.

Forbus, K., Usher, J. and Chapman, V. (2003). Qualitative spatial reasoning about sketch maps. *Proceedings of the Fifteenth Annual Conference on Innovative Applications of Artificial Intelligence*, Acapulco, Mexico.

Golledge, R.G.(1993): Geographical perspectives on spatial cognition. Garling, T. and Golledge, R.G. eds.: *Behaviour and Environment: Psychological and Geographical Approaches.* Elsevier Press, pp.16-46.

Golledge, R.G.(1995): Primitives of spatial knowledge. Nyerges, T.L., Mark, D.M., Laurini, R., and Egenhofer, M.J. eds.: *Cognitive Aspects of Human-Computer Interaction for Geographic Information System (NATO ASI Series D83).* Kluwer Academic Publishers, pp.29-44.

Hart, R.A.(1981): Children's spatial representation of the landscape: lessons and questions from a field study. Liben, L.S., Patterson, A.H. and Newcombe, N. eds.: *Spatial Representation and Behavior across the Life Span*, Academic Press, pp.195-233.

Hart, R.A. and Moore, G.T.(1973): The development of spatial cognition: a review. Downs, R.M. and Stea, D. eds.: *Image and Environment: Cognitive Mapping and Spatial Behavior*. Ardine, pp.246-288.

Humphreys, J.(1989): Place Learning and spatial cognition: a longitudinal study of urban newcomers. *Tijdschrift voor Economische en Sociale Geografie,* 81, pp.364-380.

Kuhn, W., Worboys, M. and Timpf, S. eds.,(2003); *Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT) 2003*. Springer: Berlin.

Lee, Y. and Schmidt, C.(1988): Evolution of urban spatial cognition: patterns of change in Guangzhou, China. *Environment and Planning* A 20, pp.339-351.

Lloyd,R.(1997): *Spatial Cognition: Geographic Environments*. Kluwer Academic Publishers.

Lynch, K.(1960): *The Image of the City.* MIT Press.

Matthews, M.H.(1992): *Making Sense of Place: Children's Understanding of Large-Scale Environments*. Harvester Wheatsheaf.

Montello, D.R.(1998): A new framework for understanding the acquisition of spatial knowledge in large-scale environments. Egenhofer,M.J. and Golledge. R.G. eds.: *Spatial and Temporal Reasoning in Geographic Information Systems*. Oxford University Press, pp.143-154.

Nyerges, T.L., Mark, D.M., Laurini, R., and Egenhofer, M.J.(1995b): Cognitive aspects of HCI for GIS: an introduction. Nyerges, T.L., Mark, D.M., Laurini, R., and Egenhofer, M.J. eds.: *Cognitive Aspects of Human-Computer Interaction for Geographic Information System (NATO ASI Series D83)*. Kluwer Academic Publishers, pp.1-8.

Orleans, P.(1973): Differential cognition of urban residents: effect of social scale on mapping. Downs, R. and Stea, D. eds.: *Image and Environment: Cognitive Mapping and Spatial Behavior* Aldine, pp.115-130.

Schuurman, N.(2000): Critical GIS: Theorizing an emerging science. *Carto- graphica Monograph*, 53, pp.1-107.

Takai, T.(2004): Spatial cognition of Japanese-Brazilians in Japanese urban space. *Geographical Review of Japan*, 77, pp.523-554. (in Japanese)

Wakabayashi, Y.(1994): Spatial analysis of cognitive maps. *Geographical Reports of Tokyo Metropolitan University*, 29, pp.57-102.

Wakabayashi, Y.(2003): Spatial cognition and GIS. *Geographical Review of Japan*, 76, pp.703-724. (in Japanese)