A Study of People's Sketching Habits in GIS

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Abstract

Sketching is traditionally associated with doodling simple strokes on a piece of paper. Only few professionals outside of design and the fine arts have recognized the expressive power of this intuitive modality. However, sketching seems particularly well suited to capture objects and situations in a spatial environment, such as geographic space. To learn more about the techniques and strategies people use when sketching, a survey of sketching was conducted. The study showed that paper and pencil sketches contain mostly simple and abstract objects that are composed of only few strokes. The spatial configuration of a scene is primarily expressed through the topological ordering of objects relative to each other. Metric relationships are used to refine spatial configurations. These and other findings suggest that sketching is an appropriate modality to interact with a computer where one wants to describe and capture object configurations in a spatial environment, such as a geographic information system (GIS).

Keywords: Freehand sketching, human computer interaction, human subject testing, multi-modal user interfaces, spatial querying, spatial information retrieval in GIS.

1 Introduction

Sketching has been used to visualize, record, and exchange information for hundreds of years. Despite its proven expressiveness, sketching has not yet become a frequently used modality to interact with computer systems. Geographic information systems (GISs) have a particular need for such advanced forms of user interaction, because they frequently involve complex and heterogeneous data structures that are difficult to describe when non-visual tools and techniques are used. This paper is, therefore, primarily concerned with sketches drawn in a geo-spatial environment.

Although sketching skills can differ considerably from one person to another, it seems that most everybody is able to draw a sketch or understand a sketched scene that was drawn by somebody else. The reason for this common base of interpretation is possibly a set of reoccurring patterns, symbols, or sketching strategies that people use when they are sketching. This correlation between certain elements of a sketch may even be more pronounced between sketches that are drawn within the same application domain.

The primary motivation for studying the sketching behavior of people is that a thorough understanding of people's sketching habits is an essential requirement for the development of techniques that allow for an automated interpretation of freehand sketches. The focus of this investigation is, therefore, on collecting and analyzing a comprehensive base of information about how people sketch within a typical geo-spatial context. This on the other hand may serve as the foundation for the development of sketch-based applications in GIS (Blaser 1999; Blaser and Egenhofer 2000).

1.1 The Roots of Sketching in Computer Science

Visual interaction with computer systems goes back to Sutherland's Sketchpad in the early sixties. (Sutherland 1963). However, at that time the term *sketching* was rather used in the sense of *visually constructing* objects instead of drawing them freehandedly. We use the term sketching in the latter sense. Freehand sketches play an important role in fields, such as psychology or spatial cognition, where so-called *sketch maps* are used to visualize or infer people's mental models of space. (Appleyard *et al.* 1970; Kuipers 1978; Billinghurst and Weghorst 1995). Other applications involving sketches are more specific, focusing on a particular domain, such as architecture (Goldschmidt 1991; Gross 1996; Leclercq 1999). Because a sketch is a visual representation of something, perception and interpretation are important issues to consider as well (Marr 1982; MacEachren 1995).

Using sketching to interact with computer systems is relatively new. Sketching is less discrete and constrained than other frequently used input modalities, such as typing or using a computer mouse (Blaser *et al.* 2000). Hence, the flexibility of freehand sketches made it difficult for early computer systems to assess strokes. The first applications based on a freehand sketching paradigm focused on simple line-strokes, such as drawing gestures (Lipscomb 1991). However, it was not until the development of Apple’s Newton and 3Com’s Palm Pilot that a more direct interaction (Ziegler and Fähnrich 1988; Shneiderman 1990; Shneiderman 1997), based on stroke recognition and handwriting (Teulings *et al.* 1988) became more popularly available.

A sketch is essentially an accumulation of multiple line-strokes and therefore, research in the field of sketch interpretation has lagged that of gesture recognition. Sketches have been used, however, to create templates to retrieve images from large image (Kato *et al.* 1992; Hirata and Kato 1993; Del Bimbo and Pala 1997) or architectural (Gross 1994) databases. Other sketch-based applications use sketches to intuitively construct diagrams (Citrin and Gross 1996) or to provide user interface designers with an easy tool to experiment with the layout of new computer interfaces (Landay and Myers 1995; Chok and Marriott 1996). More recently sketching has been introduced into GIS for query spatial information (Egenhofer 1996b; Blaser 1997).

1.2 Why Sketching?—An Alternative Form of User Interaction in GIS

Today’s user interaction in GIS is not much different from that in other application domains (Draper 1996). That is, a user typically has to rely on keyboard, mouse, and occasionally a digitizing tablet to interact with a computer system. Many common tasks are executed via pull-down menus, buttons, or dialog boxes. While this form of interaction has its benefits for simple applications, such as text processing or bookkeeping, it has serious limitations when more complex and less sequentially structured processes or information are involved. Relying on traditional modalities to solve such complex tasks frequently leads to unintuitive and cumbersome interaction procedures, which often result in high training efforts and many operational errors. The main reason for this limitation is that pointing and typing are inadequate and not flexible enough to deal with interrelated information as it is frequently encountered in today’s information age systems (Egenhofer 1990; Egenhofer 1996a).

The integration of alternative modalities into user interfaces to improve this situation appears to be a promising approach, notably for applications dealing with spatial information, such as GISs (Egenhofer and Kuhn 1999). Two particularly interesting user modalities are *sketching* and *talking*. People use and practice these modalities daily so that they develop a high level of expertise. Both modalities have specific advantages for certain application areas (Blaser 1997); however, sketching is especially well suited to describe spatial scenes (Blades 1990; Oviatt 1997). This characteristic is of particular interest for the retrieval of spatial information, since most current spatial query mechanisms are still based on a formulation of textual query language statements (Goldschmidt 1991; Blaser *et al.* 2000).

Compared to textual query languages, such as SQL (Egenhofer 1992), a visual language, such as a sketch, reflects a spatial scene in a much more objective way. As a result, sketches are less susceptible to spatial interpretation errors and ambiguities. Because of their visual and clear nature, sketches are also well suited to describe *complex* spatial situations. Objects in a sketch can be annotated, visually emphasized, or aggregated to larger entities. The use of symbols or diagrammatic representations can further enhance the semantics of drawn objects.

1.3 How to Assess People's Sketching Behavior

To investigate how people sketch and to study the components of geo-spatial sketches we have conducted a survey, in which human subjects were asked to draw freehand sketches according to different written scenarios (Blaser 1998). The following sections describe the setup of the survey, offer a synopsis of our observations, and discuss the results.

2 Experimental Setup

The survey was sent by mail and included a complete set of written instructions. Of the 56 individuals that were asked to participate, 32 (57%) subjects completed the survey. Five additional surveys were sent out prior to the actual survey to assess the survey's quality and to obtain a preview of the results that were to be expected. These preliminary surveys were further used to establish a set of sketch evaluation guidelines as well as for designing the database that would hold the survey results. The five preliminary surveys were not included in the final interpretation of the survey.

Each participant was asked to draw three sketches based on three individual written task descriptions. Additionally, the participants were asked some task-related questions for each sketch and some general questions at the end. Time was not an issue for our interpretation. However, we made it look like it was important to complete the survey quickly. This approach was thought to keep the participants from drawing pictures instead of drawing sketches. A detailed description of the experimental setup can be found in Blaser (1998) and the complete survey questionnaire, including cover letter and the coding guidelines can be downloaded from ftp://mustang.spatial.maine.edu/pub/SQbS/Survey.zip.

2.1 Surveyed Participants

The surveyed group of people can be divided into those familiar with GISs and those that are not. The first group consists of students and faculty of the Department of Spatial Information Science and Engineering at the University of Maine in Orono. The second group includes individuals from the US, Germany, Switzerland, and India with various professional (non-GIS) and cultural backgrounds. The groups include 11 female and 21 male participants. The age of the surveyed individuals ranged from 25 to 57 years. Of the possible total of 96 sketches, 91 sketches were evaluated and interpreted. The five remaining sketches were either not drawn (3) or inadequate for an interpretation–The two sketches that were disregarded were drawn so poorly and contained so many unclassifiable elements that even a manual interpretation turned out to be very difficult.

2.2 The Survey

As a consequence of the international setup, the survey was prepared, with identical content, in English and in German,. This allowed all participants to read the survey in a familiar language. The survey included the following elements:

- A cover letter with a general description and an explanation of the purpose of the survey.
- A page with general instructions that explained how to complete the survey.
- A written description for each of the three sketching problems, each with a set of six related questions and with space for further comments.
- A printed screen for each sketching problem that could be used to draw the sketch.–This page was a screenshot of a mockup of a sketch-based application.
- One page with general questions.

Each of the three sketching scenarios has a different purpose and context. The first scenario (*Familiar Scenario*) is about sketching a spatial situation with which the participant is well acquainted. Accordingly, it can be assumed that the participant has more knowledge about the spatial situation than he or she would actually draw in a sketch (Blades 1990). Hence, one can anticipate that such a sketch contains only a set of prominent objects, essential for describing the scene. It can further be expected that the depicted representation is meaningful and consistent with the scene in reality.

The description of the second scenario (*Unfamiliar Scenario*) asked the participants to draw a sketch of a spatial situation with which they are unfamiliar. Here we expected to obtain sketches that are fragmented and unreliable. Because of the surveyed participant's unfamiliarity with the environment, objects and landmarks are likely to differ considerably from those in the *Familiar Scenario* (Lynch 1960). Spatial, representational, or semantic errors (e.g., a police station that is remembered as a post office) are also more likely to occur within such a setup.

The final sketching problem (*Imaginary Scenario*) requested the participants to create an imaginary spatial scene, solely based on a written description. The description is intentionally ambiguous and some important information is missing. Sketching this scenario is further complicated, because the description included some unusual objects, such as topographic elements (e.g., mountain) and time to express a distance (e.g., "three hours up this path"). The interpretation and drawing of such a sketch requires a great deal of imagination and provides insight into how people transform a written scene description into a sketch.

2.3 Analytical Setup

The examination of the sketches focused on elementary components, such as sketched objects, binary spatial relations between objects, and object annotations. All sketches of each participant were analyzed one after another and object-by-object. The assessment of each sketch was done manually and intermediate results were stored in a MS Access database consisting of four tables with forms, simplifying input.

The main table collects information about each identified object. Objects are classified according to a list of 44 object properties. The a priori defined coding and interpretation guidelines were used to obtain consistent results throughout the survey. These guidelines consist of rules for individual object parameters and transparent rulers to assess metric and directional information. Each object can have multiple written annotations that are stored in a separate table. All objects in a sketch are connected through a table that stores the answers to the six sketch questions and some general information about a sketch. The three sketches of each person are linked to each other with the forth table, storing the participant's answers to the general questionnaire.

For consistency reasons a single person examined and interpreted all surveys (i.e., the author). SQL was used to query the database and to link individual observations. MS Excel and MathCAD were used to visualize and interpret the results graphically.

3 Ingredients of a Sketch

Initially, our analysis focused on the set of elementary building blocks of a sketch. On an abstract level a sketch is a collection of line strokes. These strokes, however, are typically not considered individually, but grouped together and perceived as *sketched objects*, standing in specific spatial or conceptual relationships to each other. Our approach is, therefore, to investigate sketched objects and their *interrelations*. Sketched objects can be modeled using geometric attributes. Spatial relations between sketched objects, on the other hand, can be described by considering the topological, metrical, and directional components between entities in a sketch. Spatial relations have the main focus of our investigation; other interrelations, such as conceptual relations between objects (e.g., hierarchy, aggregation, or containment), are considered during the initial interpretation of the surveyed sketches.

The expressiveness of a sketch can be increased when the sketch's elements are semantically enhanced. Hence, people frequently use written or spoken annotations to add a specific meaning to an object or to avoid drawing certain complex objects at all (e.g., writing the word "France" instead of drawing an outline of that country). In response to this observation our analysis considers *sketch annotations* as well.

The following three sub-sections describe the results of our evaluation concerning the three building blocks of a sketch: *Sketched objects*, *spatial relations* between objects, and *annotations*.

3.1 Objects

Sketched objects are the logical entities in a sketch. An individual sketched object is the result of an interpretation of a set of sketched line strokes that contextually belong together.

Objects can be composed of multiple intersecting or non-intersecting strokes. However, it also is possible that an object contains no drawn elements, for instance, if it consists only of an annotation (e.g., the written statement "New York"). We define sketched objects without strokes as *virtual objects*. Virtual objects are treated like sketched objects, that is, they possess a spatial location, with one or more associated annotations and they can have spatial relations with other sketched objects.

Because objects are logical entities, an object may enclose multiple independent *components*. In analogy to the object-oriented approach, objects that are hosting other objects are referred to as *composite-objects*. An example of a composite-object is a town containing houses, where houses are the components.

Drawn objects are the primary building blocks in a sketch. Hence, knowledge about the type of objects in a sketch may already reveal a portion of a sketch's meaning. Information about objects can, therefore, be considered as *metadata* of a sketch. The term, *sketched object* stands for a multitude of drawn and non-drawn real-world representations, as there are no strict rules of how to represent objects of our environment in a sketch. For instance, someone's home could be described with a perceptive drawing of a house, a circle, a square, a front view, or one could just write *my house* without drawing anything. It is not trivial to perceive the meaning of sketched objects without some basic knowledge about how people sketch. On the other hand, we assert that there exist some common patterns of how people sketch, because otherwise nobody could interpret other people's sketches. It seems also legitimate to assume that besides the objects themselves it is their interrelation and the general context of a sketch that help people to read sketches.

3.2 Relations

A relation is the virtual link between two or more objects; a binary relation links exactly two objects. Higher relations can occur when, for instance, a poplar tree in an avenue is standing *in line* with its neighboring trees. A hierarchical relationship involves a set of objects that can either be abstracted into a higher-level object (e.g., aggregation or composition) or that have a specific relation to an object on another level (e.g., containment). In all cases it is possible to break down such a situation into multiple binary relations between participating objects. Another possibility is to use grouping mechanisms to describe relations between objects standing in a hierarchical relationship with each other. For our investigations we consider primarily *spatial relations*. While the number of possible binary relations between *n* objects grows with $O(n^2)$ (Equation 3.1), one can show that only a subset of all binary relations is necessary and relevant for a robust interpretation of a sketch (Blaser 2000b).

$$\frac{n^2 - n}{2} \tag{3.1}$$

For instance, there is most likely no direct relationship between two objects that are spatially disjoint, drawn on opposite sides of a sketch, and that have multiple other objects in between. This interpretation is also supported by Tobler's First Law of Geography, which states that although all geographic objects are related to each other, objects that are close have a stronger relationship (Tobler 1970). Our analysis focuses, therefore, primarily on binary spatial neighborhood relations (Blaser 2000a).

3.3 Annotations

A sketch annotation is a written or spoken verbal statement that describes one or multiple entities, a relation between entities, or the context of a sketch. Annotations are frequently used to describe characteristics of objects that are difficult or impossible to formulate graphically, such as an address or a name of a building. Annotations can also be used to define specific properties of a relation between two objects. Specifying the time or distance to get from A to B is an example. Typically annotations and sketched objects are used in a complementary sense; however, they can also contradict each other (Egenhofer 1996a). The difference between an annotation and a virtual object (Sections 3.1 and 4.2.7) is that an annotation is always associated with a drawn object or with the entire sketched scene. A virtual object, on the other hand, is an independent element of a sketch that has a spatial component and is part of the relational network, but that has no drawn elements.

Every sketch can be analyzed in terms of objects, binary spatial relations, and annotations. Annotations are optional, while objects are mandatory and spatial relations are implied when more than one object is drawn.

4 Sketched Objects

The initial evaluation of a sketch focuses on sketched objects with respect to their affiliation to a *class*, their visual *portrayal*, and their intended *purpose*. The classification is conducted using our coding guidelines as an assessment schema (Section 2).

4.1 Object Classes

Since all sketches of the survey belonged to the same geo-spatial domain it was possible to define a set of object classes that covers most cases. An *object class* is defined as a category of objects with similar characteristics (Rodríguez *et al.* 1999), such as the class of *building* objects. Each object class may have multiple subclasses with a more specific description. The *school* class, for instance, is a specific *subclass* of the building class.

The total number of analyzed sketched objects is 832 (69% of all objects in the survey) and their distribution with respect to the 19 object classes is depicted in Figure 1. This classification includes all objects of the *Familiar* and *Unfamiliar Scenario*. The evaluation excludes objects of the *Imaginary Scenario*, because this scenario was based on an explicit list of objects that had to be drawn.

Figure 1

Observations:

- The two most frequently used classes (*building* and *road*) include 53% of all sketched objects; the first nine most frequent classes make up 90% of all objects. Depending on the field of application and the context of the sketch these classes will, of course, vary. However, we expect that for a specific field of application there is only a limited number of object classes necessary to interpret a sketch sufficiently. Besides domain specific sets of object classes, people appear to use a generic sketching terminology, which is domain independent. This standard set of object classes includes generic symbols, such as arrows or connecting lines (e.g., the *direction*, *symbol*, and *distance* object classes in Figure 1). Individual semantics of such generic symbol set, however, may partially differ from one domain to another.

- Some object classes, such as *buildings* have as many as eleven subclasses, while other similarly relevant object classes, do not show such a great diversity. The *road* class (*streets*) and the *body of water* class (*rivers*) are two examples.

- Natural objects, such as *body of water* (4%) or *vegetation* (1%), make up only a small part of the entire set of objects found in the *Familiar* and *Unfamiliar Scenario*. Artificial objects, such as *buildings* (30%) or *roads* (23%), on the other hand, occur much more frequently.

- Another interesting observation can be made with respect to objects conveying metric information. Only eight objects or less than 1% of all objects in the *Familiar* and *Unfamiliar Scenario* carry explicit metric information. Hence, most sketches use primarily topology and the arrangement of objects to describe a specific situation. This finding supports an earlier observation concerning spatial relations between objects in geographic space: *topology matters and metric refines* (Egenhofer and Mark 1995).

- A similar observation can be made with regard to topographic features in sketches. Only one person in the survey used topographic structures, such as a hill or a valley. Hence, it appears that people try to keep their sketches *flat*, like a map (Willauer 1993). There are two possible explanations for this observation. First, people may lack an appropriate representation for topographic features in sketches and second, they may simply not need topographic objects for an adequate description of a spatial scene–similarly to other natural objects.

4.2 Portrayal

Sketched objects are typically abstract and generalized representations of their real-world counterparts. A typical sketched object consists only of few line strokes that are single-colored and that abstract the object’s outline. This section looks into different approaches of object portrayal within geo-spatial sketches and attempts to develop an overview of how people visually express objects in their sketches.

4.2.1 Shape

The shape of a sketched object is evaluated in regard to its realism, judging the grade of abstraction. According to this classification, an object can fall into either of the following shape classes: *symbolic*, *semi-symbolic*, or *realistic.*

Objects are considered *symbolic* if their representation is based on a pure symbolic representation that has nothing in common with the visual appearance of the object in reality (Figures 2a and 2d). The association between sketched object and the original object is made through a symbol and not through the shape of the sketched object. *Realistic* objects, conversely, try to capture reality with the expression of unique or distinguishable features of an object (Figures 2.2c and 2.2f). Finally, objects that have both symbolic and realistic characteristics fall into the *semi-symbolic* category (Figures 2.2b and 2.2e).

Figure 2

Most objects were classified as either symbolic (42%) or semi-realistic (56%), with only few objects of type realistic (2%). This distribution does not change significantly when objects from the *Imaginary Scenario* are included.

Considering the type of abstraction of sketched objects one can further differentiate between line and region objects. Objects with primarily line characteristics are classified as *straight, curved*, or *complex*. Region objects can be of type *square, box, circle, oval, cross*, or *complex*. It is possible for one object to have components from multiple shape classes. Figure 3 reveals details about the distribution of object shapes.

Figure 3

Almost two thirds of all objects of the *Familiar* and *Unfamiliar Scenario* are represented by simple shape forms, such as straight lines or boxes (62% of all objects with a classifiable shape). Squares, circles, and ovals are used less frequently. 78% of all sketched objects in the *Familiar* and *Unfamiliar Scenario* have non-complex shapes (this includes the following shape forms: line, curved line, box, square, circle, and oval). This observation is important, because it is another indication that people tend to keep their *sketches simple* and their *objects abstract*. This finding also suggests that the context and the actual configuration of a sketch are more important than the representation of single objects (i.e., sketched objects taken out of their context have frequently no own meaning).

4.2.2 Type of Outline

A sketched object’s outline indicates something about a person’s sketching technique. In our analysis we distinguished between six different outline types (Figure 4). These outline types can by used to classify line and region objects.

Figure 4

Figure 5 shows the frequencies of the six different outline types over all three scenarios. Simple lines are most frequent (79%), followed by double-lines (9%). Simple lines are used for objects throughout the entire spectrum of object classes, whereas other line types are correlated with specific object types. Double-lines, for instance, are frequently used for waterways, but they were never used for boundaries. Multi-stroke lines seem to indicate an individual’s drawing style.

Figure 5

Despite the predominance of simple lines there are other outline types that are important for certain object classes. For instance, bodies of water, such as rivers or brooks, use double-lines in 37% of all cases. Double-lines are also often used for roads (24%) or railways (28%). Other object classes, such as paths (31%) and boundaries (22%), are sometimes drawn as dashed lines. These observations indicate that there is a relationship between an object’s type and its outline.

4.2.3 Number of Strokes per Sketched Objects

The number of strokes per sketched object is constant and independent from the sketching scenario according to our observations (Figure 6). Most sketched objects have only two strokes. The average number of strokes per object is between five and eight.

Figure 6

The number of strokes per object increases if the sketch complexity increases or if unusual objects are drawn, such as in the *Imaginary Scenario*. Conversely, if a sketch is simple or if objects are vague then the average number of strokes per object tends to decrease.

4.2.4 Completeness of Objects

The completeness of an object is used to describe the "physical" quality of an object. A complete object, for instance, has a closed outline with no gaps and its shape is easily recognizable. An incomplete object, on the other hand, is missing important parts, it has large gaps, and taken out of context, its type is likely impossible to determine. Such we can distinguish between *complete*, *partial complete*, and *incomplete* objects. The survey revealed that people tend to sketch carefully even if they try to be quick (Table 1). However, some individuals drew consistently more incomplete objects than others–an observation that we attribute to their sketching technique.

Table 1

With respect to the individual sketching scenarios, people seem to sketch more frequently incomplete objects if they are foreign with an environment, such as within the *Unfamiliar Scenario*.

4.2.5 Filling Pattern

Occasionally people use filling patterns, such as textures or symbolic sub-structures (e.g., a fish in a lake) to emphasis sketched objects or to give them additional meaning. The use of textures is fairly standardized: most textures involve either a hatch or a solid filling pattern. Approximately 60% of all surveyed participants used some sort of textures in their sketches; about 14% of all objects have simple filling patterns.

The set of employed symbolic sub-structures (e.g., wave symbols within a bounding line, indicating a lake) is much larger (Blaser 1998). Most people are quite creative in this respect. Despite the great variety of different symbolic substructures, there are a number of reoccurring sub-structures, such as crosses, arrows, or wavy lines for flowing waters. Some of these symbolic sub-structures have an unambiguous meaning, such as multiple tree symbols inside an area to indicate a forest. Other symbols, however, can have different purposes, such as a cross, marking the start or end point of a path, or setting the focus on an object.

4.2.6 View Point

In general people stay within the second dimension when they draw their sketches (Willauer 1993), that is, most sketches are drawn using a typical *map-style*. Under certain circumstances, however, unconventional representations of objects were used. We found three additional types of object representations in our survey: *flat front elevation*, *three dimensional representation*, and *mixed representation*. In the *Familiar* and *Unfamiliar Scenario* people were using primarily map-style object representations. (95% of all objects). The use of other, non map-style object representations increases, however, considerably in the *Imaginary Scenario* (23%). Objects that are frequently drawn using an alternative representation are cars, trains, traffic lights, or topographic structures, such as mountains. Of the three non map-style types, the front elevation was the most frequently used, followed by 3D representations. Mixed perspectives are rarely used. These findings suggest that both the type of an object and its context have an influence on how the object is drawn (Schlaisich 1998).

4.2.7 Virtual Objects

A virtual object is an object that has no drawn elements; instead, it is defined solely by a written annotation (Section 3.1). There were a total of 54 virtual objects (approximately 4.5% of all sketched objects) in our survey. A total of 24 participants (77%) used at least one virtual object within their sketches. Virtual objects are distributed over 36 of a total of 91 sketches (40%). There is no sketch with more than three virtual objects. The average is 1.5 virtual objects per sketch if virtual objects are used at all (with $\sigma = 0.6$). These numbers show that virtual objects are frequently used, but that their density per sketch is low. Virtual objects are often used to specify extended, area-like objects that are composed of different components or that are otherwise difficult to describe. Virtual objects can also be used to orient sketches, for instance, when a remote place is used to establish a reference direction for the sketch.

5 Spatial Relations

The term *relation* can be defined as "*Natural, logical, or virtual association between two or more things that are relevant to one another*" (Microsoft 1999). The interpretation of a relation is generally based on people's perception of a situation in reality, which makes a relation subjective, because reality itself depends on perception *and* interpretation. To describe relations between things more objectively, theories have been developed that focus on specific characteristics of a relation. Theories about *spatial relations* aim to formally describe the relation between objects on a geometrical basis. A *binary spatial relation* is the special case, where only two objects are involved. Because of their simplicity and their elementary character, binary relations are the type of relation most generally applicable for capturing spatial constraints.

5.1 Topology

The evaluation of topology in our survey is based on the 9-intersection (Egenhofer and Al-Taha 1992). In this context all sketched objects are considered as regions so that there are eight possible topological relationships. In the case of ambiguous situations, the surveyed participant's intention is considered and the intended relation is translated into the appropriate topological term. According to this interpretation, the road in Figure 7 meets with four houses. House (a) is considered disjoint, but it still carries the attributes along and parallel (Section 5.5).

Figure 7

Each object has n-1 binary relations with all other objects. The total number of possible relations in a sketch can be computed using Equation 3.1. Non-disjoint relations are relevant, because they indicate a *physical* connection between objects (Florence 1997). Disjoint relations are more difficult to classify (Shariff 1996; Goyal 2000). The evaluation of topology focuses, therefore, on all non-disjoint relations between object pairs (Figure 8).

Figure 8

Approximately two thirds of all objects (62%) stand in at least one non-disjoint relation with another object. This indicates that sketches are interlinked structures that form topologically connected networks. The non-disjoint relations that were recorded during our analysis represent 8.2% of the total possible number of binary relations. Figure 8 shows their distribution. The majority of spatial relations in the survey are of type *meet* and *overlap*. These relations are typically used to connect objects. Relations that represent containment (i.e., contains, inside, covers, and coveredBy) were less frequently used. The concept of equality is not an issue for sketched objects.

5.2 Orientation

An object’s orientation is its directional relation with a referencing system. The simplest frame of reference is the drawing device. Other referencing systems are the principal drawing direction of a sketch or that of a group of objects. The orientation of objects in our evaluation is measured with respect to the drawing device. The orientation values are assessed manually, using a transparent ruler, and they range from 0° to 170° degree (with 10° increments). Of the 1208 objects analyzed, 993 objects (82%) have at least one prominent orientation. On average each object has 1.2 orientation indications. Figure 9 shows the orientation graph for all objects including all scenarios. The values from 180° to 350° corresponds to those between 0° to 170° to improve the visual impression of the graph.

Figure 9

Object alignments along the north-south and east-west axis are most frequent. About 40% more objects are drawn with an east-west than with a north-south orientation. The distribution between the two main axes is regular, although there are slightly more objects with an orientation between 10° and 80° compared to those with an orientation between 100° and 170°.

5.3 Direction

In this section we examine objects that have one or more pointing directions. A direction can be implicit or explicit and an object can have more than one direction. In total there are 323 (27%) objects that qualified for this analysis. This number does also include objects that have a deduced direction, for instance, objects that inherit a direction from an associated arrow. Figure 10 depicts objects with an indicated direction. Figure 10d is particularly interesting, because it is ambiguous. The place named *Boston* could be at the end of the arrow, but it may as well lie outside the drawing area in the indicated direction.

Figure 10

The referencing system for the assessment of directions is again the drawing device. Figure 11 shows the spectrum of possible object directions and their frequencies. To reflect the different types of objects with an indicated direction, the graph distinguishes between (1) all explicit direction objects (north direction excluded), (2) all direction objects indicating north, and (3) all objects with either an implicit or explicit direction. The distribution of indicated directions is similar to the orientation of objects, in that cardinal directions show a significant higher frequency than non-cardinal directions.

Figure 11

Figure 11 shows that objects pointing north and east are twice as frequently used than objects pointing south. Those objects with a westerly direction score somewhere in between. The preferred non-cardinal directions lie between 10° and 70° (16%), while the three remaining sectors score only between 4% and 8% of the total number of directions. This observation supports the assumptions that many people have an inclination to write or sketch objects slightly tilted upwards and from left to right–a tendency that might be influenced by cultural heritage.

Focusing on north directions, it becomes evident that most of the surveyed participants orient their sketches by providing a north direction pointing towards the top of the drawing device (33%). The distribution of other than north directions is more symmetric compared to that of objects pointing north. The number of objects pointing east and west are similar, whereas objects with north and south directions are slightly less frequent.

5.4 Parallelity and Orthogonality

Human-built objects, such as buildings, roads, or malls that are close to each other are frequently in a specific angular configuration. To verify this observation we counted for each object the number of adjacent objects that were either parallel or orthogonal to the object in question. In order to qualify as an adjacent object, an object has to be in “direct unobstructed sight" and its distance to the referring object may not exceed this object's maximal dimension. Figure 12 suggests that sketched objects are frequently parallel or orthogonal to each other (particular for the *Familiar* and *Unfamiliar Scenario*). Two third of all objects have one or more neighboring object that is either parallel or orthogonal. The *Imaginary Scenario* has significantly less such angular conditions; however, still one out of three objects has at least one parallel or orthogonal neighbor.

Figure 12

Parallel or orthogonal arrangements of objects appear to be frequently used concepts in our environment. Therefore, these concepts seems to be more dominant in sketches that represent urban settings, such as the *Familiar* and *Unfamiliar Scenario*, than in natural settings with less human influence, such as in the *Imaginary Scenario*.

A second observation derived from Figure 12 suggests that the majority of objects in a sketch are virtually connected to their immediate neighborhood through a particular spatial arrangement, in this case by means of an angular condition such as, parallelity or orthogonality. This connectedness can also be established by using certain non-disjoint topology relations or metric conditions, such as closeness. Our examination covered only parallel and orthogonal neighbor objects; we can, therefore, assume that the number of immediate object neighbors is greater or equal to the number indicated above. These observations and considerations suggest that *neighborhood relations* play an essential role within spatial sketches and that binary relations within a sketch are of great significance (Blaser 2000a; Blaser 2000b).

6 Sketch Annotations

Written annotations are frequently used to assign additional meaning to sketched objects. Approximately 60% of all objects in the survey have at least one written annotation. However, most people found that one annotation per object is sufficient (87%) and only few sketched objects have more than one written annotation. We found that certain types of objects are more frequently annotated than others (Blaser 1998). For instance, objects of the *distance* and *settlement* classes are typically annotated, while there is in general no annotation for symbolic objects or objects with a directional purpose. Our analysis suggests further that there are three primary reasons why people annotate objects in sketches:

- ***Significance***

  Objects that are of superior importance within a sketch, such as start or end points, have often written annotations that help to bring an object into focus.

- ***Ambiguity***

  If a sketch contains multiple objects that share a similar appearance, then an annotation can be used to distinguish between such instances.

- ***Simplicity/Complexity***

  For some objects there is no adequate sketched representation, for instance, because the object has complex semantics or because it has a challenging graphical representation. However, there may exist a commonly used term. A city's name is an example (e.g., New York).

Most written annotations in the survey are short, simple, and noun-based (70%) and only few individuals use entire sentences to describe a sketched scene (3%). The remaining annotations (27%) are short combinations of words, such as adjective and nouns. In regard of the content of written annotations, we found that the majority of annotations are specifying either name (36%), type (33%), or a combination of both (5%) of an object.

Most people place their annotations either entirely outside (60%) or entirely inside of an object (33%). 50% of all annotations have the same orientation as their affiliated object, 30% are drawn in one of the cardinal directions of the drawing device. For the remaining annotations, there is no directional link to the affiliated object. The affiliation to an object is for the most part accomplished by a particular placement of the annotation in relation to an object. Only 17% of all annotations use linking symbols, such as arrows or connecting lines. Asked about when they annotate objects, our participants indicated to annotate their objects either immediately after drawing an object or later during the sketching process.

7 Conclusions

The primary goal of this study was to gather enough information about the sketching behavior of people so that an automated sketch interpretation appears feasible. In this context we have analyzed a set of geo-spatial sketches upon their basic ingredients. Common sketching patters and specific sketching techniques were investigated as well. The result of this investigation suggests that it is possible to automatically assess sketches, primarily because the majority of sketched objects are simple and their spatial representations are abstract enough to be processed by a computer system. The following paragraphs summarize the major findings of our investigation. Additional interpretations can be found in the technical report of the survey (Blaser 1998).

- *People's sketches are simple and abstract.*

  A typical geo-spatial sketch contains only a *small number of objects*. Taken out of their context, sketched object have frequently no meaning, which is, because they are *highly abstract* representations of their real-world counterpart. Simple lines and boxes are the most frequently chosen object representations. Objects that are of a particular significance, ambiguous, or for which there is no simple drawn representation are often annotated. People draw objects with clear boundaries and they *prefer human-built* over natural objects. In our survey, sketched objects were always used in a positive way, that is, there was no evidence that people use negation in their sketches. This is true for objects and their properties.

- *Topology matters while metric and orientation refine.*

  When people draw a sketch they are primarily concerned with the *spatial arrangement* of objects and their *topology*. In the same context, people are careful when a specific object sequence or order is involved, such as when several objects are lined up along a road or when an object is between two other objects. The preferred topological non-disjoint relations in geo-spatial sketches are non-containment relations, such as *meet* or *overlap*. For *disjoint* relations, topology alone is not expressive enough. In such cases people use metric and relative orientation to describe and refine object-object relations. Metric and directionality, in this context, are used in an implicit way. Explicit statements, such as written metric annotations, are rarely used.

- *Sketches are structured into object neighborhoods.*

  People tend to arrange and cluster objects such that they are connected. This connectedness is achieved by tying objects physically, through vicinity, special arrangements, or via context to one another. Physical links are expressed with non-disjoint relations, such as *meet* and *overlap* (topology). Vicinity is established by drawing objects close to each other (metric). A specific object arrangement is introduced by using concepts, such as parallelity, orthogonality, inline-ness, in-between-ness, or similar forms of object arrangements. The context of a relation is more difficult to capture, because relations must be evaluated within the overall context of the entire sketch (a specific hierarchy between two objects is an example of a contextual relation). However, evaluating the general context of a sketch, based on the semantics of individual binary relations between objects appears to be a viable approach for this purpose.

- People have a specific sketching signature in their sketches.

  Although we did not explicitly investigate the sketching techniques of our participants, we found similarities between the three sketches of each individual participant. This includes the representation and rendering of specific objects types, the use of symbols, and people's sketching style with respect, for instance, to detail and complexity.

8 Future Work

The analysis of our survey is based on manual methods that were subject to the interpreter's judgment. In this scope and using the results of our investigation it is desirable to verify the results by another, preferably automated analysis. Besides conducting an automated survey with a similar setup, it appears to be worthwhile capturing other relevant parameters as well. Recording the surveyed participants with video cameras (Hewett 1997) provides additional insights about an interaction between user and computer. Such recordings capture supplementary information, such as gestures or eventual verbal interaction with the system. Interesting questions in this context are, for instance:

- How frequently do people use verbal expressions during the sketching process?
- Do people sketch and talk simultaneously?
- Are sketched and verbal input synchronized? or
- How frequently are drawn objects modified once they have been drawn?

Sketching on paper with a pen and sketching with an electronic pen on a computer are conceptually similar, but not identical forms of interaction. It is, therefore, of interest to analyze how an electronic sketch compares to a paper and pencil sketch. Such an investigation could also involve a comparison of different sized sketching devices (e.g., comparing a handheld-sized device with a standard letter-sized device).

A final note: This survey was conducted as part of a preliminary study of a research project in GIS called *Spatial-Query-by-Sketch* (SQbS)(Egenhofer 1996b). This project aims to investigate fundamental theories and components of a system that can capture and interpret freehand sketches in the context of a GIS, and that is capable of translating sketched queries into query statements that can be processed against a spatial database. Besides conducting theoretical research and investigating the sketching behavior of people, it was also decided that a prototype application was to be developed so that the feasibility of such a system could be demonstrated. The resulting prototype application runs on a typical MS Windows platform. The application is capable of sequencing, simplifying, and consolidating sketched multi-stroke objects, considering their geometry and orientation. Objects can be annotated–by typing–and a semantic can be associated (Rodríguez *et al.* 1999). The interpretation of a sketch is based on the geometric and semantic similarity of object pairs and on an evaluation of neighborhood relations, considering topology, metric, and directional constraints between corresponding object pairs. Simple sketch databases with up to a thousand sketches have been successfully queried. The prototype application along with a number of documentations can be downloaded from http://ncgia.spatial.maine.edu/~abl/SQBS (Blaser 1999; Blaser 2000a; Blaser and Egenhofer 2000).

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Figures and Tables

Figures

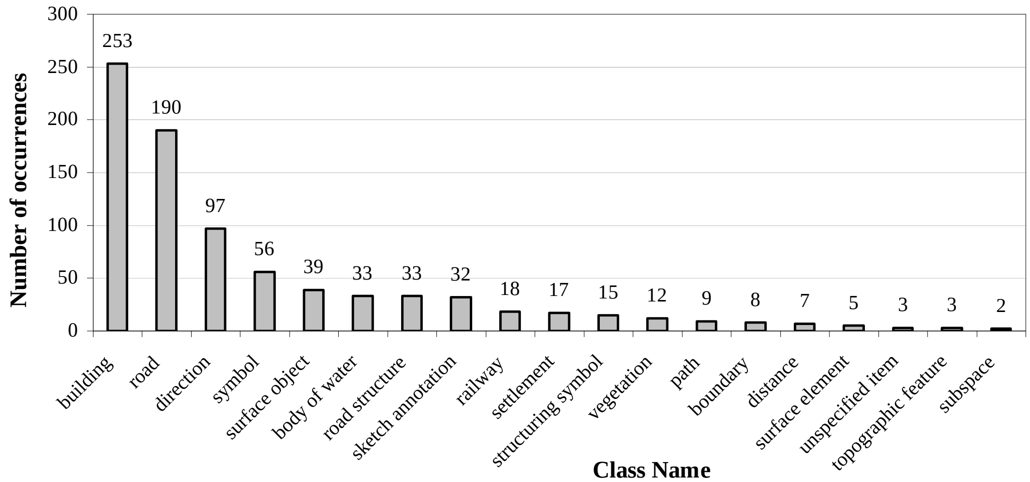

Figure 1 Frequency graph of the 19 object classes, sorted by size (*Familiar* and *Unfamiliar Scenario*).

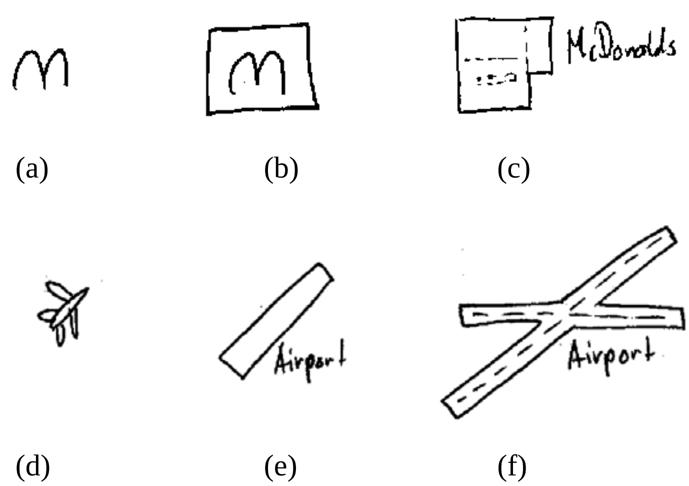

Figure 2 Two sequences of sketched objects with the same semantics but different portrayals.

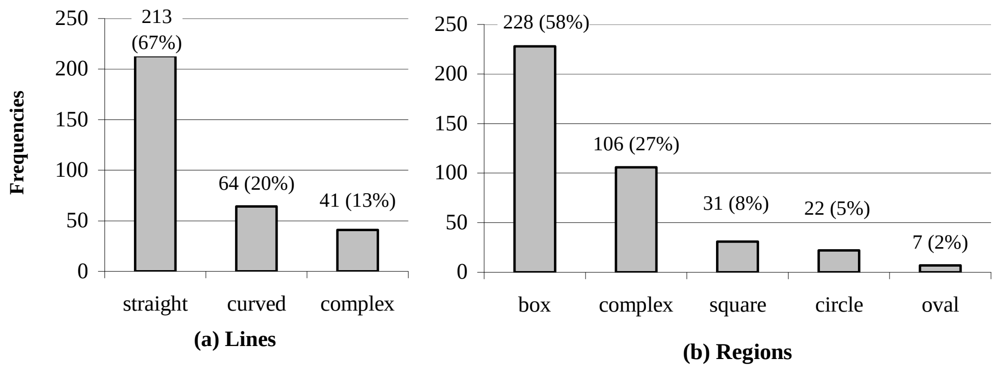

Figure 3 Frequency graph of the shapes of (a) lines and (b) regions (*Familiar* and *Unfamiliar Scenario*).

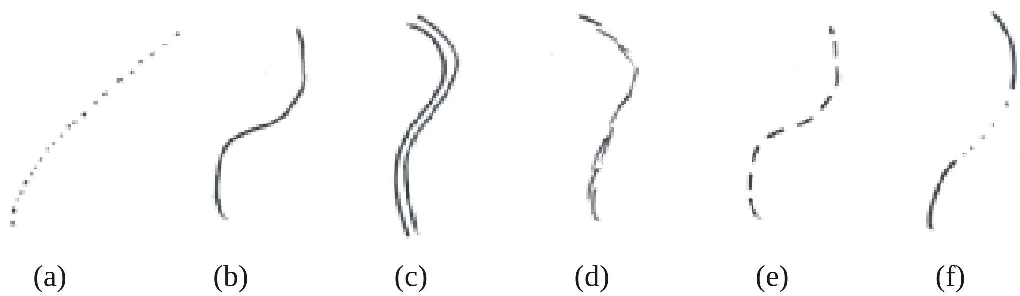

Figure 4 Six different outline styles: (a) dotted, (b) simple line, (c) double-line, (d) multi-stroke line, (e) dashed, and (f) mixed.

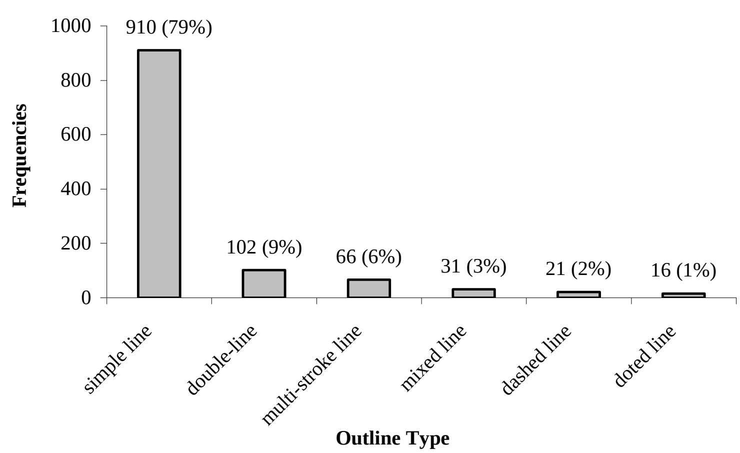

Figure 5 Histogram indicating the use of the six outline-types (All scenarios).

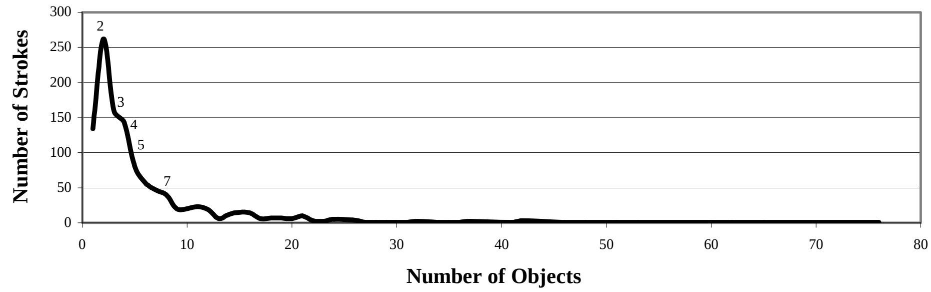

Figure 6 Number of strokes per object (All scenarios).

Figure 7 Sketch with five buildings along a road; four of them qualify for a *meet* condition (b) - (e), one house is disjoint (a).

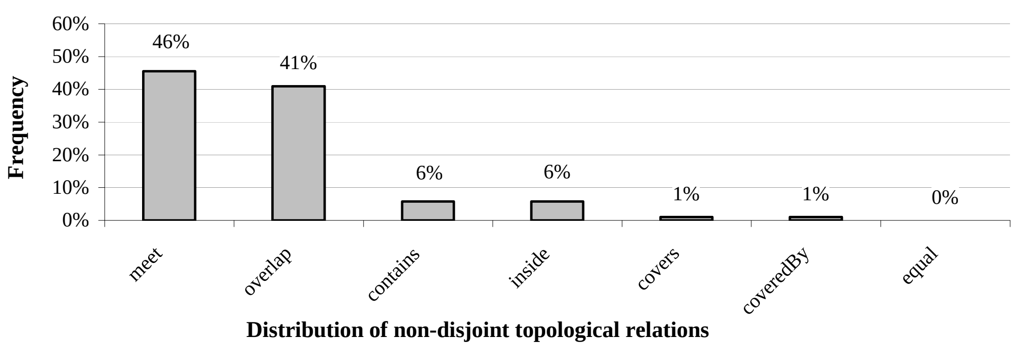

Figure 8 Frequency analysis of the recorded binary topological relations (*Familiar* and *Unfamiliar Scenario*).

Orientation of Objects	Count	%
0°	**312**	**26%**
10°	40	3%
20°	40	3%
30°	27	2%
40°	16	1%
50°	24	2%
60°	20	2%
70°	35	3%
80°	42	3%
90°	**438**	**36%**
100°	41	3%
110°	22	2%
120°	32	3%
130°	16	1%
140°	19	2%
150°	20	2%
160°	16	1%
170°	26	2%

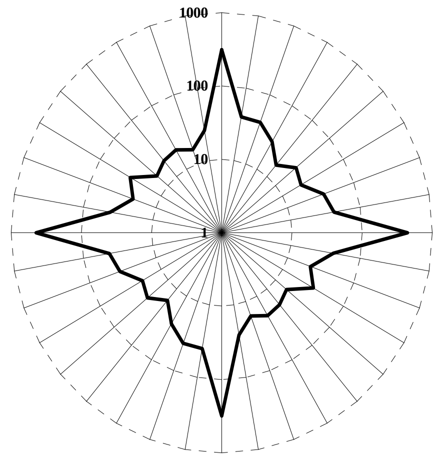

Figure 9 Object alignment with respect to the drawing device (All scenarios).

(a) (b) (c) (d)

Figure 10 Objects with an indicated direction: (a) a north arrow, (b) a street with an explicit flow or path direction, (c) a view symbol indicating the direction of the view, and (d) a virtual object with an indicated direction.

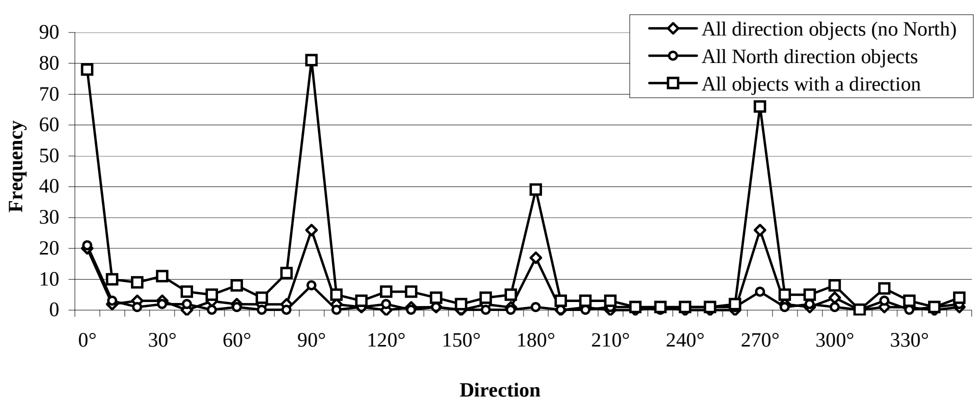

Figure 11 Distribution of indicated directions for all objects (All scenarios).

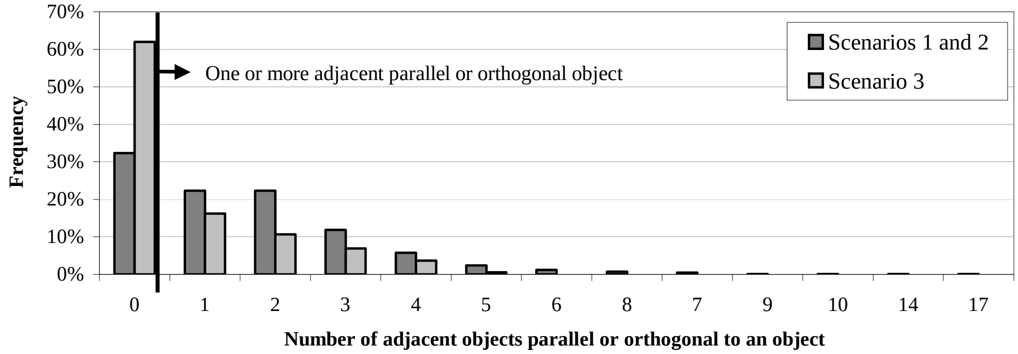

Figure 12 Frequency of objects with parallel or orthogonal neighbors (All scenarios).

Tables

Count	%	Category
538	50%	complete
487	45%	partial complete
53	5%	incomplete

Table 1 Average distribution of objects with respect to their completeness (All scenarios).