

# A LIGHT-WEIGHT SEMANTIC INTERPRETATION MECHANISM FOR A SKETCH-BASED LEARNING ENVIRONMENT

Stefan Weinbrenner, Jan Engler, Pouyan Fotouhi-Tehrani and H. Ulrich Hoppe  
*University of Duisburg-Essen, Department of Computer Science and Applied Cognitive Science  
Duisburg, Germany*

**Keywords:** Sketch Interpretation, Architectures for Learning Environments, Intelligent Tutoring Systems.

**Abstract:** Free-hand drawing of diagrams or sketches is a natural form of expression that is very useful in learning scenarios. It is easily supported by tablets or tablet PCs. Often such sketches are the basis of reasoning processes, also in collaborative scenarios. They can also indicate misconceptions. Therefore it is desirable to support a semantic interpretation of sketches in a way that could be easily combined with other parts of a learning environment or with an ITS. Our solution introduces a multi-agent architecture based on the blackboard paradigm. Inspired by the CogSketch system, it supports the introduction of user-defined "glyphs" as external representations of concepts, it provides a set of basic geometrical/topological primitives and allows for the addition of more domain-specific semantic relations.

## 1 INTRODUCTION

Visualization is an important means to aid the learning process. Describing procedures, objects, relations etc. can be done more easily and more intuitively using visual aids. Research results suggest that over 80% of information enters the brain through the eyes (Petty, 2004). However, this should not imply that words are less important. The key point lies in combining words and pictures to generate powerful messages (Lester, 2006).

To a large extent, efforts in the area of advanced visualization techniques for learning address the learner as a passive recipient. Sketching however can be an active means of expression and externalization in the hands of the learners themselves. Sketching has some characteristics that distinguish it from other visualization methods: Everyone can sketch, i.e. there is no need for preliminary skills. Sketching is natural, i.e. no need for more than a (digital) pen, and sketching allows for imperfection, i.e. additional communication can fill lack of presented information.

An imperfect sketch, e.g. a bike with rectangle tires, would still be understandable by the observer, if it is explained so by the subject. However, this natural vagueness and imprecision of sketches,

makes an automatic interpretation very hard. The main challenges in such an algorithmic approach of interpreting sketches would be to discover the components that the sketch is composed of and what these components of the sketch actually mean. In other words, the interpretation can be separated into segmentation and recognition.

Such an automatic interpretation can be used for similar purposes that usually need a human beholder that interprets the sketch. When drawing sketches in school classes, the teacher often has to judge whether a sketch is correct or shows some misconceptions of the learner. In the latter case, a teacher would give the learner hints, which concepts were misunderstood. In this case, after the interpretation the teacher assesses the sketch using his or her knowledge about the corresponding domain and gives feedback to the learner.

A system designed to interpret sketches and to help the learner in a similar way has to encompass automatic solutions to the tasks of segmentation, recognition, assessment and feedback generation.

The work presented in this paper aims at implementing supportive mechanisms capable of interpreting learner sketches by examining spatial relations between their components and giving appropriate domain-dependent feedback.

One can imagine scenarios, for which such a system can be utilized: in all subjects, where abstract or concrete concepts are thought using visual aids, this tutor can be used. It allows individuals to examine their acquired knowledge without directly being relied on the teacher. It may be part of an intelligent tutoring environment, which would include additional learner and domain modeling.

Our work has been inspired by CogSketch (Forbus et al., 2008), a sketching and sketch interpretation environment that uses a large universal ontology (OpenCyc) for semantic interpretation. On the surface level, the user introduces sketches called “glyphs”. These glyphs are mapped to semantic concepts “by hand”. By combining glyphs it is possible to visually represent statements such as “the DNA (a glyph) is inside the nucleus (another glyph)”. The derivation of such a statement does not require the ontology but is based on an analysis of geometrical relations of the sketch elements. The ontology, in turn, is used to check the semantic validity of such statements and to allow for further inferences. CogSketch does not use pattern recognition for identifying glyphs. They are only interpreted in the way explicitly declared by the user. In our work we have re-constructed the CogSketch with a different focus.

Our system is not a monolithic architecture for one standalone application, but we extended an already existing, powerful collaborative modeling environment and connected it to a loosely coupled blackboard architecture that integrates the key components as agents in a flexible and modular way. The blackboard architecture also allows for sharing glyphs among students and together with the existing synchronization features of the modeling environment additionally stresses the collaborative approach of our work. Moreover, we do not use a “heavy” external ontology that covers lots of different domains, but use a “light-weight” approach that is very specific for the domain. Currently we also use an ontology for storing the domain-specific knowledge, but due to its modularity an adaptation of the system to interpret other representations (e.g. simple csv files) would be very simple.

Be advised that papers in a technically unsuitable form will be returned for retyping. After returned the manuscript must be appropriately modified.

## 2 SCENARIO

Alice and Bob are students of a geography class that deals with the problems of planning and designing

the layout of modern cities. After getting familiarized with the fundamentals of Urban Design, the students are asked to design a city on an island, considering the following rules and constraints:

- The city is divided into three areas: at least one industrial area that consists of factories, one commercial area, where shops and business centers are located, and a residential area, where the inhabitants live.
- The city must have a waste treatment and disposal facility on the island, which is not near aforementioned areas.
- The island’s port has to be located on the western coast of the island. To save costs for transportation, the industrial area has to be situated in the vicinity of the island’s port.
- The commercial area must be somewhere within the residential area.

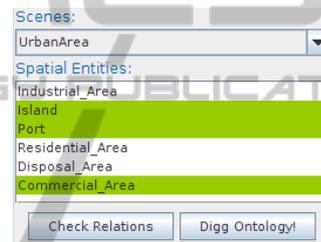


Figure 1: List of proposed concepts.

Other details are considered irrelevant and students are allowed to add other components (such as tourist attractions, infrastructural facilities etc.) as long as aforementioned rules are not broken. In the course of this exercise students are allowed to draw in any arbitrary shape for the areas and facilities. Moreover, there is no unique design for this city; rather there are many different designs, which conform to the rules and are all equally correct. To fulfill the task, the students have tablet PCs that run a sketching program.

Alice starts to draw the island and all required areas and facilities with the sketching tool. For each component of the sketching she uses a different color and groups them by a grouping mechanism of the sketching tool. When finishing the component, the tool asks her for a name and presents a list of proposed labels such as “Island”, “Port”, “Residential Area”, etc. (c.f. Figure 1). After a while, Alice’s sketch is finished and it looks like Figure 2. She clicks on a button labeled “Check Sketch” and after some seconds a dialog box pops up in the sketching tools and shows the message “Congratulations! Your sketch complies with the constraint of the assignment.”

Bob also adds one component after the other to his sketch and labels it according to the proposed labels. However, when he hits the button “Check Sketch”, the message tells him to check the location of the industrial area. He reflects on his sketch and reads the assignment again. After that, he notices that the industrial area within his sketch is not near the port, so he moves it closer to it. Then, he again runs the check and now he also gets the message that his sketch complies with the assignment.



Figure 2: Example sketch of an urban design.

### 3 APPROACH

As described in section 1, the overall process that is supported by the sketch interpretation system can be separated into the four tasks of segmentation, recognition, assessment and feedback generation.

In the work presented here, the first two tasks are in fact done by the learner, which has several reasons. First, automatically discovering segments and semantically analyzing them is difficult and error-prone. Even a teacher sometimes misinterprets the sketch of a learner and such an error results in wrong assessment and feedback (both false-positive and false-negative). The only person, who can define segments and explain the semantics of a sketch for sure, is the person that produced it. Additionally, from a pedagogical perspective, this encourages the learner to reflect on his sketch and its components.

In our case, the environment differentiated between strokes and glyphs. As the most basic entity in sketching, a stroke is an arbitrary number of connected points that the user has drawn at once. In most sketching environments a stroke also has a width (in pixels) and a color, but these properties are not relevant for the purpose of this work. A glyph is a collection of strokes that also has a label attached to it. In Figure 2 the different glyphs are all drawn in different colors, but that is not necessarily the case and was done here just for clarity reasons.

The recognition is done by labeling the glyphs. The learner can enter arbitrary texts, but he is

encouraged to choose labels that are known to the system by displaying a list of labels, that shows already used ones in green (c.f. Figure 1).

The next part of the recognition comprises the spatial relationship between the segments or glyphs, because often it is not sufficient to just know **what** is presented in a picture, but also **where** it is located. This discovery of spatial relations is the first part, that is done automatically by the system. Spatial relations can be generally categorized in three of topological, orientation (or directional), and metric relations (Beaubouef and Petry, 2010):

- Topological are those relations which are invariant under topological transformations, i.e., translation, scaling and rotation (Egenhofer, 1989), e.g. disjoint, surrounded.
- Orientational are those relations which describe the position of objects in relation to each other (Hernández, 1994), e.g., left, under.
- Metrical are those relations, which are based upon distance of two objects, e.g. near, far.

The definition of spatial relations, in spite of seeming to be self-evident, presupposes some clarification. (Freeman, 1975) pinpoints various complexities in course of defining spatial relations. One problem, for example is to establish borders implied by a given word: where does being left start and where does it end. We calculate a value for each glyph pair and for each supported relation and then a threshold is introduced, which is used for decision making procedures. The supported relations are surrounded (topological), left, right, bottom, top (orientational) and near (metrical).

As soon as the spatial relations are known and the labels of the glyphs match pre-defined concepts, the system has finished the recognition and will start to assess the sketch. Since this process needs domain-specific knowledge about sketches, the necessary information is encoded in an ontology. This holds all the labels and spatial relations of the concepts of the given assignment. The ontology is rather simple and consists of the two classes “Scene” and “Spatial Entity” and supports all spatial relations as object properties of “Spatial Entity”. A scene represents the domain of an assignment and has “belongsTo” relations to all spatial entities that occur in this domain. A graphical example of an ontology that expresses the knowledge about our scenario assignment can be seen in Figure 3.

After comparing the relations among the learner’s glyphs and the expected relations in the ontology, the system can tell the learner exactly, which glyph is missing and which pair of glyphs is

not located in the correct spatial relation. This is displayed in the sketching environment so that the learner can act accordingly and rethink his sketch.

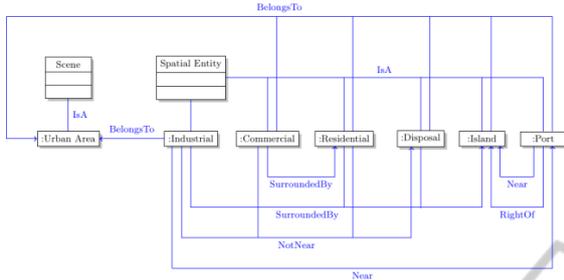


Figure 3: Graphical representation of the scenario's ontology.

## 4 IMPLEMENTATION

Our sketching tool has been implemented as an extension of the collaborative modeling environment FreeStyler (Hoppe and Gassner, 2002). In order to support the envisioned scenario, it was extended such a way that multiple strokes could be labeled and grouped to glyphs. Now, after clicking on the “Start Glyph” button, the glyph mode is activated and all following strokes are grouped. After clicking again this button, the user is asked for the name of the just finished glyph. The overall user interface (i.e., FreeStyler using the glyph mode and our sketch interpretation plug-in) can be seen in Figure 4.

The actual sketch interpretation has been implemented as a separate component (or agent) of a distributed system that uses the black board approach (Erman et al., 1980). In this case a FreeStyler plug-in has been developed that acts as one client among several others. In a blackboard architecture, all participating nodes only communicate via the blackboard, which is a central place for storing and reading information. The main advantage of a blackboard system is its inherent flexibility and robustness due to the loosely coupled design. Since the components only have minimal knowledge of the others a failure of one component will not directly affect the functioning of another. Such an architecture is naturally also more flexible, because a new agent with new features can be easily integrated, often without other agents being modified.

To implement such a blackboard system, we chose to use TupleSpaces (Gelernter, 1985). In a TupleSpace system there is one central server and several clients, that only send messages to the server. These messages are in tuple structure, i.e.

they consist of lists of typed data. As an implementation of the TupleSpaces idea we chose the SQLSpaces (Weinbrenner et al., 2007), since they offer a rich feature set and are multi-lingual and can therefore be used as a language switchboard (Bollen et al., 2008).

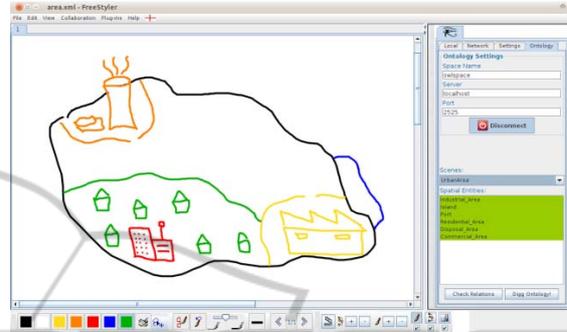


Figure 4: FreeStyler with the sketch interpretation plug-in.

The functionality of our semantic sketch interpretation system is encapsulated in two agents that are implemented in SWI Prolog and make use of the *tspl* interface that allows accessing an SQLSpaces server from Prolog clients. This is particularly interesting for tasks that are more naturally implemented using a specific programming language. In our case it makes sense to implement the relation checking and the ontology checking facility in Prolog because of its backtracking and logical problem-solving features in comparison to object-oriented languages like Java.

All in all, there are three components in our black board system, which communicate over two different subspaces. The overall architecture can be seen in Figure 5.

The first space  $\Psi$  contains all glyphs and is therefore connected to the FreeStyler plug-in. However, this plug-in does not only write glyphs into the space, but is also able to import glyphs back to the frontend. That way it is possible to exchange glyphs among learners and therefore to work collaboratively on assignments. The next agent that uses the glyph data is the relation inspector that works on the coordinates of the glyphs and adds the inter-glyph relations to the space. To determine the relations, the relation inspector uses algorithms for each relation category (c.f. section 3) that all result in a normalized value between 0 and 1. Unfortunately, there are several intuitive understandings of the “left-ness” or “surrounded-ness” of two glyphs, but in the end our brief definition is the following:

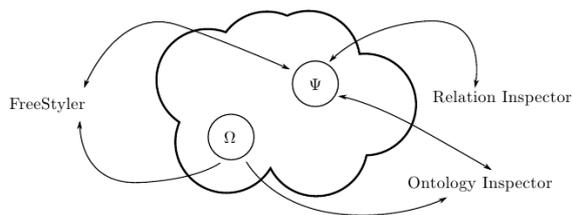


Figure 5: Overall interaction and data flow between the components.

- To determine if glyph A is left of glyph B, the ratio of ratio of points of glyph A that are left of the left-most point of glyph B to the amount of points of glyph B. Other orientational relations are calculated accordingly.
- To determine the extent to which glyph A is surrounded by glyph B, we calculate how many circular rays (360 rays, each arc degree one ray) from the centroid of A hit B. This is an adaptation of the visual surroundedness by (Rosenfeld and Klette, 1985).
- The calculation of the nearness of glyph A to glyph B is more complicated. If the minimal distance between A and B  $\min A, B$  is greater than the diagonal  $dB$  of the bounding box of B, the nearness is 0. Otherwise, the nearness is  $(dB - \min A, B) / dB$ .

The third and last component is the ontology inspector that first retrieves the glyphs and their relations and maps them to concepts from the ontology. These concepts are stored in the space  $\Omega$  and are used to validate the glyph relations according to the assignment. In the case that a learner created a sketch that does not comply to the constraints of the assignment, the ontology inspector notifies the FreeStyler plug-in about the problems and FreeStyler shows a dialog to inform the learner. If the sketch does comply with all constraints, just a confirmative message is displayed to the learner.

The ontology inspector also is the instance that transfers the numerical results of the relation inspector to the boolean world of the ontology. This needs obviously to be done here, since the ontology either contains a relation or not. This transfer is done by applying a threshold to the numerical value. Currently, a value above 0.8 is interpreted as a confirmed relation, otherwise there is not enough evidence for the relation.

Finally, FreeStyler also reads the concepts from the space  $\Omega$  in order to propose meaningful glyph names as shown in Figure 1.

## 5 CONCLUSIONS AND FUTURE WORK

This paper describes a semantic sketch interpretation system. The implemented framework allows for checking for accordance between a sketch and its corresponding conceptual definition and to provide feedback. The conceptual definition represents a scene using spatial relations between spatial entities. Various tools have been utilized to realize this work: SQLSpaces is used as a middleware to connect the different components of the system in a loosely coupled way and to persist the sketches and their corresponding conceptual definitions to allow sharing of these artifacts. FreeStyler collects user input as glyphs and serializes them in tuples in the SQLSpaces server. Agents that have been realized in Prolog are notified by signal tuples and are responsible for a specific task. Two agents have been implemented: The Relation Inspector, which computes several spatial relations between spatial entities (glyphs) of a sketched scene, and the Ontology Inspector, which uses the outputs of the Relation Inspector and the ontological scene description to check a sketch against its corresponding conceptual definition. The Ontology Inspector also provides feedback if necessary.

The framework can be used in learning facilities, from schools to universities, as an aid for teachers and students. From the simplest subjects, such as cardinal directions, to more complicated subjects, such as anatomy of the human heart, this framework can help individuals to strengthen their knowledge and understanding. It can be utilized in teaching of nearly all subjects, which are taught using visual aids and sketches.

However, this system is still under development and there are a great number of features and functionalities, which can improve this framework.

One interesting extension of this work would be to turn FreeStyler into an authoring environment, which makes it possible for the user to directly export the conceptual definition of his sketches to a knowledge base (in this case an ontology). An interesting starting point for this is a visualization utility that was actually only implemented as a debugging tool during the development. This tool displays the results of the Relation Inspector agent, i.e. for all relations between all glyph pairs it will display a value between 0 % and 100 %. This visualization can be seen in Figure 6 (here only the surrounds relation is shown, otherwise the list would be too long).

Glyph 1	Relation	Glyph 2	Result
Commercial_Area	Surrounds	Island	0%
Residential_Area	Surrounds	Island	0%
Island	Surrounds	Residential_Area	99%
Island	Surrounds	Commercial_Area	100%
Commercial_Area	Surrounds	Residential_Area	20%
Residential_Area	Surrounds	Commercial_Area	53%

6/6

Figure 6: Visualization of the results of the Relation Inspector.

A possible workflow for an assignment author would be to draw a reference “expert sketch” without any ontology or agent support. This set of labeled glyphs could then first be inserted as unconnected instances into the ontology. After that the Relation Inspector agent could propose some relations that are found between the given glyphs for adding it to the ontology representation. However, the author would presumably not transfer all these relations to the ontology, since though many of them are evident, only some are probably necessary for the assignment. In the example of Figure 2 for instance, it would not be necessary to have the waste disposal facility in the north of the residential area. After importing these relations, the FreeStyler plugin for students could immediately interpret this newly defined assignment.

Such an authoring environment would be a bridge from a static, predefined knowledge base to a dynamic one. An authoring environment would also allow the user to modify already existing conceptualizations in the knowledge base. That means, adding, removing or updating spatial entities and spatial relations among them.

Beside these technical improvements a study could be conducted to investigate on the effect that this tutoring system has on the learning process of users. This study could compare students’ solution without the tutoring system and solutions that make use of the system in order to find out whether the usage of the system will lead to solutions that are fulfilling more restrictions of the assignment. As the system allows for sharing the glyphs between different users, the study could also investigate on advantages of a collaborative creation of glyphs. Another interesting question is the comparison between pen and paper based modeling and the usage of the presented system on tablet computers which could focus on usability issues of the system when using tablet computers.

## REFERENCES

- Beaubouef, T. and Petry, F., (2010). Fuzzy and rough set approaches for uncertainty in spatial data. In R. Jeansoulin, O. Papini, H. Prade, and S. Schockaert, (Ed.), *Methods for Handling Imperfect Spatial Information* (Vol. 256 of Studies in Fuzziness and Soft Computing, pp. 103-129). Berlin / Heidelberg: Springer.
- Bollen, L., Giemza, A. and Hoppe, H. U., (2008). Flexible analysis of user actions in heterogeneous distributed learning environments. In *Proc. of the European Conference on Technology Enhanced Learning 2008 (EC-TEL 2008)*, Maastrich, NL.
- Egenhofer, M., (1989). A formal definition of binary topological relationships. In W. Litwin and H.-J. Schek, (Ed.), *Foundations of Data Organization and Algorithms* (Vol. 367 of Lecture Notes in Computer Science, pp. 457-472). Berlin / Heidelberg: Springer.
- Erman, L. D., Hayes-Roth, F., Lesser, V. R. and Reddy, D. R., (1980). The Hearsay-II speech understanding system: integrating knowledge to resolve uncertainty. In *ACM Comput. Surv.* (Vol. 12(2), pp. 213-253.)
- Forbus, K., Usher, J., Lovett, A., Lockwood, K. and Wetzel, J., (2008). CogSketch: Open-domain sketch understanding for cognitive science research and for education. In *Eurographics Workshop on Sketch-Based Interfaces and Modeling*, Annecy, France.
- Freeman, J., (1975). The modelling of spatial relations. In *Computer Graphics and Image Processing* (Vol. 4(2): pp. 156-171, ISSN 0146-664X. doi:10.1016/S0146-664X(75)80007-4.)
- Gelernter, D., (1985). Generative communication in linda. In *ACM Transactions on Programming Languages and Systems* (Vol. 7, pp. 80-112).
- Hernández, D., (1994). *Qualitative representation of spatial knowledge*. New York: Springer-Verlag.
- Hoppe, H. U. and Gassner, K., (2002). Integrating collaborative concept mapping tools with group memory and retrieval functions. In *Proc. of the Int. Conference on Computer Supported Collaborative Learning*, Hillsdale (USA): Lawrence Erlbaum.
- Lester, P., (2006). *Visual communication: images with messages*. Thomson Wadsworth.
- Petty, G., (2004). *Teaching today: a practical guide*. Nelson Thornes.
- Rosenfeld, A. and Klette R., (1985). Degree of adjacency or surroundedness. In *Pattern Recognition* (Vol. 18(2), pp. 169-177, ISSN 0031-3203. doi: doi: 10.1016/0031-3203(85)90041-X).
- Weinbrenner, S., Giemza, A. and Hoppe, H. U., (2007). Engineering heterogeneous distributed learning environments using tuple spaces as an architectural platform. In *Proc. of the 7th IEEE Int. Conference on Advanced Learning Technologies ICALT 2007* (pp. 434-436, doi: 10.1109/ICALT.2007.139).