Feature clusters for online recognition of graphic units in drawings

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Automated recognition of sketch drawings can provide the means for a natural interface between the designer and a design support system. Sketch drawing recognition is knowledge-intensive in the sense that the system must know what to look for in a drawing. In earlier work, we identified 24 different types of representations, termed graphic units. For recognition of graphic units we combine a multi-agent approach and online recognition. Each agent is specialised for one graphic unit. It continuously parses the online input stream for stroke features that fall within its scope. When an agent-specific threshold is reached, the agent puts a claim. Each agent has a specific cluster of features that can be viewed as distributed over a decision tree. The activation pattern of feature clusters over the decision tree is an indication which graphic unit is likely to be identified by the system. In this paper, we present the exhaustive set of features for agents and a binary decision tree over which the features are distributed.

Keywords: *Image recognition; sketches; graphic units; feature-based modelling.*

Introduction

Automated recognition of sketch drawings can provide the means for a natural interface between the designer and a design support system. Timely recognition what the designer is drawing gives clues what kind of information the designer may need. Furthermore, this may also support automated inference on the basis of the drawing without requiring the designer to interrupt the design process with manual input.

Sketch drawing recognition is knowledge-intensive in the sense that the system must know what to look for in a drawing. Without limitation to particular kinds of objects, a combinatorial explosion of possible shapes occurs. From previous research, we have identified twenty-four so-called graphic units: a group of graphic elements, drawn in a specific way, that has a meaning (Achten, 1997). Examples of graphic units are: *grid, axial system, contour, complementary contours*, etc. In our approach, drawing recognition is a process of both searching and recognizing graphic units in a drawing.

Image recognition mostly builds on multiple levels of (similar or mixed) recognisers that incrementally process information delivered from lower levels (Ng and Singh, 1998; Giacinto and Roli, 2001). As sketches show significant variation in the appearance of the drawing, a strategy is required which can deal with much uncertainty in the recognition process. We aim to combine two techniques to tackle the question of drawing recognition:

1. multi-agent approach
2. online recognition.

The multi-agent approach adds to the conceptual level of recognition a more autonomous role to each classifier. It acknowledges explicitly the limited capabilities per classifier; and that classifiers (in the guise of agents) should communicate with other classifiers to settle ambiguities (Vuurpijl and Schomaker 1998; van Erp et al. 2002). The parallelism inherent in multi-agent systems, in particular when multiple interpretations are possible, supports a weighed and balanced exchange of viewpoints. Within the context of graphic units, we define each agent in the system as specialized for recognition of one particular graphic unit.

Online recognition means that computer interpretation takes place while the architect is drawing. This approach is used often in handwriting recognition because of the high efficiency of the stroke direction feature (Liu et al., 2003). Similarly, we suppose that the stroke direction feature is also an important feature for sketch drawing recognition. Graphic unit recognizing agents therefore, reason on the basis of strokes. A stroke is described in a number of absolute and relative features. Absolute features are characteristics of the stroke itself, such as length, direction, and curvature. Relative features are defined with respect to earlier strokes, such as parallelism, alignment, and drawn consecutively. Each complete graphic unit is defined as set of absolute and relative features, which can be mapped on a decision tree.

As the architect draws, a stream of strokes is produced which forms the input for the agents that try to recognize their particular graphic unit in the stream. The stream is continuously parsed by the agents. Graphic unit recognition is mostly based on incomplete information since in most of the times the architect is in the process of constructing parts of the drawing. In earlier work (Achten, 2005), we have outlined a framework in which agents put markers in the stream: start and end markers to set the activation window, hypothesis marker to indicate partial recogntition, and claim marker to indicate recognition. When a claim marker is placed, convergation to a graphic unit is checked by the distribution of stroke features on the decision tree. In this paper we present the feature list and binary decision tree, and discuss further work.

Features of graphic units

Features are defined on the characteristics of strokes (absolute features FA_i) and relationships between features (relative features FR_i).

The quantifier "roughly" is a relative measure that is specific for each feature. It is used to deal with the variation from the sketching process. Typically, relative features deal with a subset of all strokes. Therefore, it is necessary to distinguish between the bounding area that contains all strokes so far and the bounding area that contains the subset of strokes under consideration.

List of absolute features

The absolute features FAx listed above are:

- FA_1 (straight line): A segment that is straight within a margin area.
- FA_2 (circle): A segment that forms a closed circle within a margin area.
- FA_3 (curve): A segment that is curved in any way other than circle or straight line.

List of relative features

The relative features FRx listed above are summarised below. The set {F} of features in the description contains the features that are considered in the activation window of an agent. The notation {F} can be read as "the elements in set {F}".

- FR_1 (closed): {F} form a closed shape.
- FR_2 (equal length): {F} are of roughly the same length.
- FR_3 (one to many): {F} have one dissimilar element.
- FR_4 (equal distance): {F} have roughly similar distance between elements.

Graphic unit	Absolute features	Relative features
(1) Simple contour	FA_1 (straight line), FA_2 (circle).	FR_1 (closed), FR_2 (equal length), FR_{13} (medium to whole), FR_{14} (large to whole), FR_{17} (end-to-end connection).
(2) Contour	FA_1 (straight line), FA_3 (curve).	FR_1 (closed), FR_{13} (medium to whole), FR_{14} (large to whole), FR_{17} (end-to-end connection).
(3) Measurement device	FA_1 (straight line).	FR_3 (one to many), FR_2 (equal length), FR_4 (equal distance), FR_5 (line spaced), FR_{13} (medium to whole), FR_{20} (open).
(4) Elaborated structural contour	FA_1 (straight line), FA_2 (circle), FA_3 (curve).	FR_6 (few to many), FR_7 (zigzag), FR_8 (closed sub), FR_9 (inside closed), FR_{14} (large to whole).
(5) Complementary contours	FA_1 (straight line), FA_3 (curve).	FR_1 (closed), FR_5 (line spaced), FR_6 (few to many), FR_7 (zigzag), FR_9 (inside closed), FR_{10} (multiple closed), FR_{13} (medium to whole).
(6) Function symbol	FA_1 (straight line), FA_3 (curve).	FR_{11} (letterset), FR_{12} (numberset), FR_{15} (small to whole), FR_{16} (isolation), FR_{17} (end-to-end connection).
(7) Functional space	FA_1 (straight line).	FR_1 (closed), FR_{13} (medium to whole), FR_{14} (large to whole), FR_{23} (dashed line).
(8) Zone	FA_1 (straight line), FA_2 (circle), FA_3 (curve).	FR_{17} (end-to-end connection), FR_{18} (arrowhead), FR_{13} (medium to whole), FR_{20} (open).
(9) Modular field	FA_1 (straight line).	FR_2 (equal length), FR_{19} (perpendicular), FR_{21} (parallel), FR_{22} (similar direction), FR_{14} (large to whole).
(10) Grid	FA_1 (straight line).	FR_2 (equal length), FR_{19} (perpendicular), FR_{21} (parallel), FR_{22} (similar direction), FR_4 (equal distance), FR_{14} (large to whole), FR_{24} (many to many).
(11) Refinement grid	FA_1 (straight line).	FR_2 (equal length), FR_{19} (perpendicular), FR_{21} (parallel), FR22 (similar direction), F_{R4} (equal distance), FR_{13} (medium to whole).
(12) Tartan grid	FA_1 (straight line).	FR_2 (equal length), FR_{19} (perpendicular), FR_{21} (parallel), FR_{22} (similar direction), FR_4 (equal distance), FR_{14} (large to whole), FR_{24} (many to many), FR_{25} (displacement).
(13) Schematic subdivision	FA_1 (straight line).	FR_{18} (center overlap), FR_{19} (perpendicular), FR_{20} (open), FR_{14} (large to whole).
(14) Partitioning system	FA_1 (straight line).	FR_{18} (center overlap), FR_{19} (perpendicular), FR_{20} (open), FR_{14} (large to whole), FR_2 (equal length).
((15) Schematic) (16) Axial system	FA_1 (straight line).	FR_{18} (center overlap), FR_{17} (end-to-end connection), FR_{14} (large to whole), FR_{19} (perpendicular), FR_{13} (medium to whole).
((17) Combinatorial) (18) Element vocabulary	FA_1 (straight line), FA_2 (circle), FA_3 (curve).	FR_{13} (medium to whole), FR_{17} (end-to-end connection), FR_1 (closed).
(19) Structural element vocabulary	FA_1 (straight line) , FA_2 (circle), FA_3 (curve).	FR_{15} (small to whole), FR_{17} (end-to-end connection), FR_1 (closed), FR_7 (zigzag), FR_9 (inside closed).
(20) Proportion system	FA_1 (straight line), FA_3 (curve).	FR_1 (closed), FR_{17} (end-to-end connection), FR_{14} (large to whole).
(21) Circulation (22) (system)	FA_1 (straight line), FA_3 (curve).	FR_{20} (open), FR_{17} (end-to-end connection), FR_{18} (arrowhead).

Table 1
Feature list of graphic units.

- FR_5 (line spaced): {F} have elements located on a line.
- FR_6 (few to many): {F} are in two unequal sized groups of roughly similar elements.
- FR_7 (zigzag): {F} have end-to-end connected lines that form a zig-zag pattern.
- FR_8 (closed sub): {F} contain multiple small closed elements.
- FR_9 (inside closed): {F} form a zigzag pattern which fills an outer contour.
- FR_{10} (multiple closed): {F} contain multiple medium closed elements.
- FR_{11} (letterset): {F} are specific to letter shapes. This is a shorthand way to isolate specialised letter recognition.
- FR_{12} (numberset): {F} are specific to number shapes. This is a shorthand way to isolate specialised number recognition.
- FR_{13} (medium to whole): {F} are roughly half the size of the bounding area.
- FR_{14} (large to whole): {F} are roughly equal the size of the bounding area.
- FR_{15} (small to whole): {F} are roughly 1/10th the size of the bounding area.
- FR_{16} (isolation): {F} are distant from other elements. Distant means more than one times the length of an element in a particular direction to the next element in that direction.
- FR_{17} (end-to-end connection): {F} connect to each other by their ends.
- FR_{18} (arrowhead): {F} have arrowhead shaped lines.
- FR_{19} (perpendicular): {F} are oriented in straight angles to each other.
- FR_{20} (open): {F} do not form a closed shape.
- FR_{21} (parallel): {F} are roughly in parallel with each other.
- FR_{22} (similar direction): {F} are created in the same direction (begin- end point).
- FR_{23} (dashed line): {F} are constructed of dashed lines.
- FR_{24} (many to many): {F} are in two roughly equal sized groups.
- FR_{25} (displacement): {F} are in two roughly equal groups, with a similar displacement x,y vector.

Indetermination by means of absolute and relative features

The features identified above create identical sets of features for a number of graphic units: *schematic axial system* and *axial system, combinatorial element vocabulary* and *element vocabulary*, and *circulation* and *circulation system*. Therefore, these graphic units cannot be distinguished from each other.

The graphic unit *zone* is very narrowly defined as having an arrow head (following the notation established by SAR). The graphic unit *functional space* is very narrowly defined as having a dashed contour. For the graphic unit *proportion system*, it is difficult to determine which the proper relative features are.

	FA1	FR14	FR17	FA3	FR13	FR1	FR19	FR2	FR18	FA2	FR20	FR4	FR21	FR22	FR7	FR5	FR6	FR9	FR15	FR24	FR3	FR8	FR10	FR11	FR12	FR16	FR23	FR25
(1) Simple contour	1	1	1		1	1		1		1																		
(2) Contour	1	1	1	1	1	1																						
(3) Measurement device	1				1			1			1	1				1					1							
(4) Elaborated structural contour	1	1		1						1					1		1	1				1						
(5) Complementary contours	1			1	1	1									1	1	1	1					1					
(6) Function symbol	1		1	1															1					1	1	1		
(7) Functional space	1	1			1	1																					1	
(8) Zone	1		1	1	1				1	1	1																	
(9) Modular field	1	1					1	1					1	1														
(10) Grid	1	1					1	1				1	1	1						1								
(11) Refinement grid	1				1		1	1				1	1	1														
(12) Tartan grid	1	1					1	1				1	1	1						1								1
(13) Schematic subdivision	1	1					1		1		1																	
(14) Partitioning system	1	1					1	1	1		1																	
(15) Schematic axial system	1	1	1		1		1		1																			
(16) Axial system	1	1	1		1		1		1																			
(17) Combinatorial element vocabulary	1		1	1	1	1				1																		
(18) Element vocabulary	1		1	1	1	1				1																		
(19) Structural element vocabulary	1		1	1		1				1					1				1									
(20) Proportion system	1	1	1	1		1																						
(21) Circulation	1		1	1					1		1																	
(22) Circulation system	1		1	1					1		1																	
	22	12	12	11	11	8	8	7	7	6	6	4	4	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1

Figure 1
Frequency distribution of features (horizontal) over graphic units (vertical).

Binary decision tree

In order to determine likely candidates for graphic units during the design process, we establish a binary decision tree. Features that occur with the highest frequency as necessary part of a graphic unit are used early to prune the decision graph, because they eliminate top branches first. Figure 1 below lists the frequency of occurrence of the features.

The frequency table can be used to create a binary decision tree, starting from the most frequent feature. Feature FA1 (straight line), occurs in all graphic unit definitions, so the decision tree starts with FR17 (end-to-end connection). Graphic units that have this feature branch to the left, and the other graphic units branch to the right. The next most-frequent features ares FR14 (large to whole) and FR17 (end-to-end connection). We first apply FR17 to both branches, and then FR14 to the next four branches, since they can occur in all following sets of graphic units. In this way we continue until we obtain the decision tree depicted in Figure 2.

The nodes in the decision tree only contains 11 features: FR_1, FR_2, FR_3, FR_4, FR_{13}, FR_{14}, FR_{17}, FR_{18}, FR_{19}, FR_{25}, and FA_3. This means that the other features only add additional detail to the graphic unit definition, but that they do not aid in distinguishing between sets of features (graphic units). Although this is a reason to check for redundancy among these features, it does not mean that they are completely superfluous. They in fact offer additional evidence for supporting the claim for one or the other feature. Con-

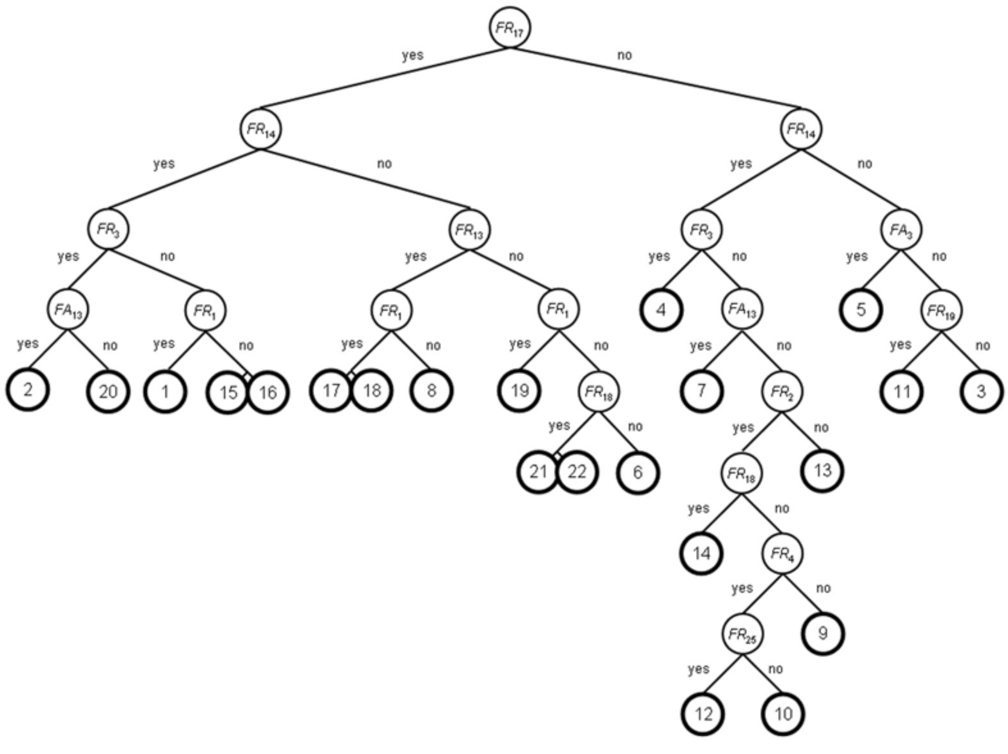
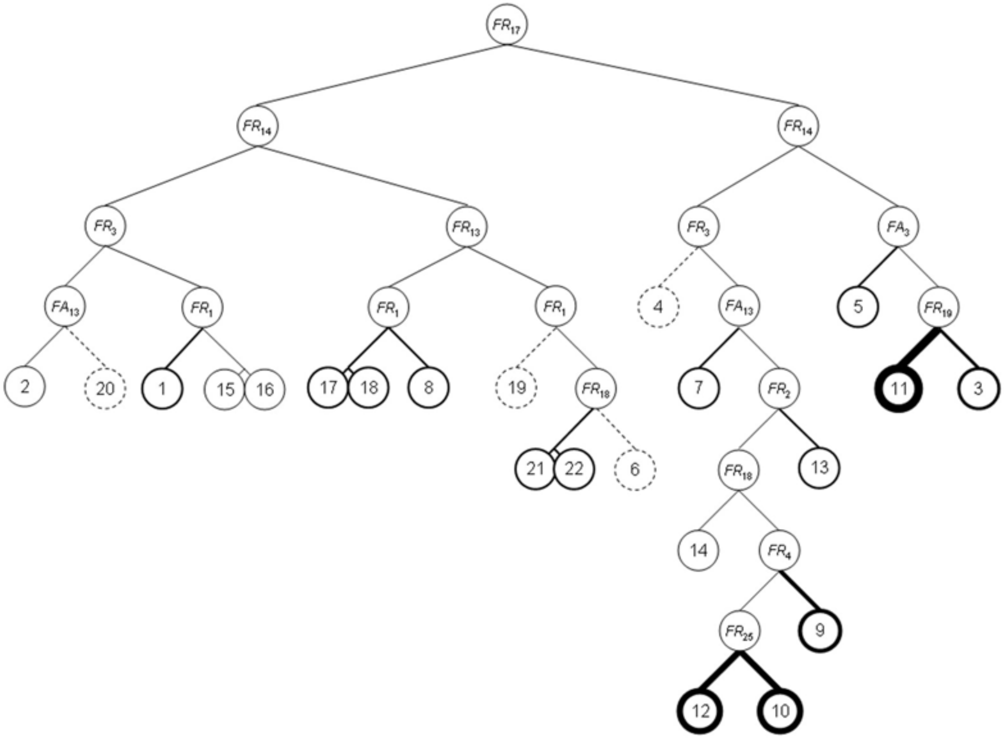


Figure 2
Decision tree to determine graphic unit.

Figure 3
Distribution of features belonging to graphic unit (12) tartan grid.



sider graphic unit (12) *tartan grid*. It has the features FR_2, FR_4, FR_{13}, FR_{19}, FR_{21}, FR_{22}, FR_{25}, FA_1. These features are also present in other graphic units (Figure 2). For example, graphic unit (11) *refinement grid*, has the features FR_2, FR_4, FR_{13}, FR_{19}, FR_{21}, FR_{22}, FA_1. The only difference with graphic unit (12) is feature FR_{25}, which it does not have.

Discussion

In the work up to now, we have defined three absolute features and 25 relative features. This corroborates a general intuition that graphic unit recognition does not depend so much on recognising what type of stroke has been created (absolute feature), but that it depends much on relationships between strokes.

The binary decision tree assists a multi-agent system to converge to a graphic unit. The decision tree currently does not distinguish between three pairs of graphic units: (15) *schematic axial system* and (16) *axial system*, (17) *combinatorial element vocabulary* and (18) *element vocabulary*, and (21) *circulation* and (22) *circulation system*. The difference between these three pairs lies in their meaning, not in the stroke features that they employ. This is a basic issue of the definition of graphic units, since it relies partly on meaning. It is not clear at the moment whether this can be resolved by adding additional relative features, or by introducing reasoning mechanisms for the agents involved. For the time being, we will leave the matter undecided and focus on those graphic units that can be distinguished on the basis of their features.

We found that the graphic unit *specified form* can be decomposed as graphic unit *measurement device* with graphic unit *(simple) contour*. The graphic unit *structural tartan grid* can be decomposed as *tartan grid* with *structural element vocabulary*. This means they should be considered as generic representations (combination of several graphic units) rather than as graphic units. Consequently, we have left them out of the further development of the decision tree.

Future work

There is very likely redundancy between the defined features. Indicators for such redundance are specialisation (a feature which is applicable to only one graphic unit) and similarity (features that basically do the same, but are named differently). Not all redundancy however, is bad. We have to look further in the current list to eliminate unnecessary features.

The features have to be further developed in terms of their parameters. It is necessary to establish good working values for assessing straight lines, circles, and curves. Also, the quantifier "roughly" needs to be defined per feature. It is also necessary to determine the bounding area, which establishes relative measures among elements.

After establishing a good working set of features, it is time to implement agents that will recognise the various features. Based on that, we can fine-tune the settings of feature parameters, and experiment with additional negatiation strategies among agents to settle into graphic unit-recognition.

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