

Research Proposal:

Expressing Visual Queries for Image Databases

Supporting users with a Shape Thesaurus

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Abstract

The main focus of this research project is to evaluate how visual query specification towards an image collection can be aided through use of a thesaurus for shapes. Two main goals are identified; assisting users in expressing information needs as visual queries and how the shape thesaurus can be used to identify the objects in a user sketch, and assist the image retrieval system in retrieving images containing these objects, regardless if they have similarities to the actual objects drawn by the user. This will be studied through an initial pilot study evaluating currently available tools for visual query. Thereafter, an interface and image retrieval system based on a shape thesaurus will be built and examined to test its effect on visual query formulation through a laboratory experiment.

Keywords

Image Databases, Visual Query Specification, User Interfaces, User Interaction, Shape Thesaurus, Content Based Image Retrieval

1. Introduction

1.1. Project Context and Background

Technological developments in both hardware and computing power over the previous decade have made very large, electronic image collections possible. However, the tools for describing and retrieving images from these collections have not been proportionately developed.

Consider the case of a collection of images describing maritime life; marine animals and related activities. The images have been made available to the public through the internet, supporting all of the “standard” image description and retrieval techniques. Next, consider the case of a teacher preparing a lecture on dolphins; anatomy, habitat, feeding habits, activities and so on. The teacher wants to use images to illustrate his lecture, and approaches the aforementioned collection.

The teacher has certain *information needs*. He probably has an idea of the kind of images he wants to retrieve; what animals and other objects they should depict, how the objects are depicted, how these objects are arranged and so on. Furthermore, he might have need for images depicting dolphins from a specific angle, in a specific pose or involved in a certain activity. Next, the teacher has no idea of *which* images are contained in the collection, only the fact that it contains images of marine life, and maybe the number of images in the collection. The main problem facing the teacher is; how is he going to express his information need to the image collection and retrieve the desired images?

There are two major approaches to image description and retrieval. The first comes from the field of *information retrieval*, and is based on using textual descriptors. In our scenario, our teacher might express his information needs through free text, such as “Find images containing dolphins”, or through keyword specification; “Dolphin, feeding, surface”. Verbal query expression has a very high expressive power, and most general information needs can be expressed verbally. However, images are non-verbal in nature, and some image characteristics can be difficult to express verbally. Consider the two images in Figure 1.

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Figure 1 - Two different images of a "Dolphin Jumping"

Let us say our teacher wants an image similar to the first image, with a dolphin jumping out of the water, with only the high seas as background. Furthermore, due to the text he is illustrating, he wants to have the dolphin depicted in this pose. If he searches with "Dolphins Jumping", he might retrieve either both these images, one of them or none at all. Both images depict a jumping dolphin. Furthermore, how is our teacher going to describe the actual pose of the dolphin and the viewpoint and angle of the image? Furthermore, the result of text based query and retrieval is more often than not based on textual annotation of the image collection. If neither of the images is annotated with "jumping", or even "dolphin", neither of the images will be retrieved. If the image collection is large, it is unlikely that every image is annotated with enough information to satisfy the information need of our teacher. Furthermore, the annotations might be created using other terms, or might describe different image characteristics than our teacher is interested in. Following this, verbal image retrieval might not support, or allow, proper query specification and image retrieval.

Another approach comes from the field of *computer vision*. Rather than using text, images are described using mathematical and statistical representations of their low-level structural characteristics, such as colour distribution, texture, shapes present and the spatial distribution of these structures. Three approaches to query specification are possible for this approach. First, it is possible to specify certain colour distributions or by selecting from a set of textures. While this might be useful for some information needs, it is unlikely that our teacher can fully express his information needs through this.

The second approach is based on *Query-By-Example* (QBE). The use of QBE for query specification is one of the most used methods for visual query specification, and virtually all current CBIR systems now offer this form for searching. (Eakins and Graham 1999). However, the use of QBE is somewhat problematic, as it relies on the user having a suitable image at hand. Consider again the case of our teacher – if he already had images representing his information needs, he would no longer have use of the image collection. Furthermore, it might be *difficult* to find an image containing our exact information need. Even if our teacher has an image of a dolphin jumping, it might be different in structure from the images in the collection, as illustrated in Figure 1, above. The images are quite dissimilar in their structural characteristics, and a comparison between the two images is unlikely to return a high degree of structural similarity. Furthermore, it lacks some expressive power, such that the user cannot represent all intended features in his query.

The alternative approach is to accept user drawn sketches as basis for a query. This approach is known as *Query-By-Sketch* (QBS). Most of these approaches are based on the ideas originally developed for IBM's QBIC System (Flickner, Sawhney et al. 1995). QBS is based on letting the users sketch their own example images, either sketching the images by free hand or building seed images from images such as rectangles and circles.

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In our case, the teacher might attempt to either draw a freehand image, or use basic shapes and colours to create a simple example image illustrating his need. However, there are two problems with QBS. The actual tools and methods used to draw sketches might be primitive; most of us learned to draw before we could write. However, creating *good* drawings might be an entirely different matter. If our teacher has limited artistic abilities, he might not be able to create a freehand drawing looking anything like a dolphin. This problem was also experienced in my master thesis (Hove 2004). Furthermore, creating good representations using basic shapes such as circles and squares is not a very easy task.

Finally, the sketch drawn by the user is typically quite different from the target images. Depending on the domain of the image collection, the user might not know the structural composition of the images. Dolphins are not static structures; they can have close to an unlimited number of different poses and postures. For our teacher, it might be possible for him to retrieve images containing a dolphin with a similar shape to his drawing. However, it is unlikely that depictions of dolphins in *other* poses might be retrieved (Cho and Yoo 1998).

Despite these problems with QBS, it is believed that it allows the user a higher expressive power than QBE, as it gives the user more freedom when expressing a query, and does not require him to have access to images. Following this, we need to evaluate if, and how, visual query expression through user created example images can be further developed and improved. Two main goals are identified:

- Assist users in expressing information needs as visual queries
- Identify the objects in a user sketch, and assist the image retrieval system in retrieving images containing these objects, regardless if they have similarities to the actual objects drawn by the user.

The project will use the results from a pilot study performed in my master thesis project as a starting point. Further development of the approach will be based on state of the art research and technology.

1.2. Project Relevance

Proper description and retrieval of image, and other complex media, is an important problem area within the field of Information Science. The aforementioned technological development in computer hardware and computing power has led to a discrepancy between our capacity for storing and processing these data types, and the tools available for proper data management. Providing new and more efficient data management solutions is, and should be, one of the most important study areas within Information Science.

Furthermore, the issues described here are also equally relevant for Media Studies. There exists vast amounts of visual data material, and finding suitable tools and methods for description, storage and retrieval of these is essential if the material is to be made available to the public. The major difficulty is *how* this material should be made available.

2. Theoretical Framework

2.1. Image Retrieval and Description Techniques

When a person wants to find and retrieve one or more images from an image collection, we say that he or she has an *information need*. In order to actually retrieve the desired images, he or she must express this information need in a query, and put this to the image retrieval system, which then will attempt to interpret the query, search through the collection and return the images that are found to be relevant to the query. Query specification for image retrieval can broadly be classified as either *Verbal* or *Visual*. Similarly, the search and comparison techniques can also be classified by the same scheme (Dunckley 2003).

This description leaves us with four different categories of image query specification and retrieval, as illustrated in Figure 2:

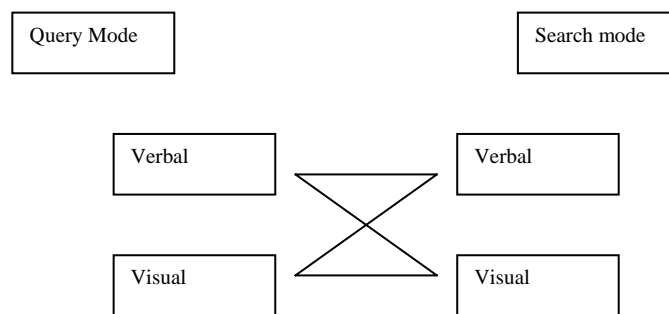


Figure 2 - Query and search modes for image retrieval systems. From (Dunckley 2003)

Naturally, which query techniques are available to use is dependent on the techniques and tools used to index and classify the images. Verbal queries are not applicable if the collection lacks any verbal description, and similarly for visual queries.

2.1.1. Image Description and Indexing Techniques

Verbal description is based on using textual descriptors for annotation and indexing of images. It has high expressive power; it can be used to describe almost any level of image content at varying degrees of complexity, and it is in principle easily extensible to accommodate new concepts.

However, the main problem with this approach is that it is a predominately *manual* technique. Image annotation has to be entered manually; no solution has yet been found for automatic extraction of an image's semantic content. As long as image collections were small, this did not pose a significant problem. However, larger image collections are prone to the problems of *volume* and *subjectivity*. The problem of *volume* refers to the fact that manual annotation of an image is a time consuming task. Indexing times quoted in literature range from about 7 minutes per image for stock photographs at Getty Images, to more than 40 minutes per image for a slide collection at Rensselaer Polytechnic (Eakins and Graham 1999).

Furthermore, the combination of rich image content and differences in human perception makes it possible for two individuals to have very diverging interpretations of the same image. As a result, the description is prone to be subjective and incomplete. This is called the problem of *subjectivity*.

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Finally, while text based description has a high expressive power, there are some limitations when dealing with objects that are visible in nature. Some structural image characteristics are difficult to describe with words. For example, although we have a set of terms describing the different colours, none of these terms are exact. Every colour has a broad range of different shades and intensities. Although most people are able to differentiate between two different shades, it is difficult to express the differences verbally without using fuzzy terms like “more” or “less” red. We call this the *problem explicability*.

Visual description is based on mathematical and statistical analysis of the structural image characteristics, such as colour, texture, shape and spatial structure. These characteristics are represented by statistical and mathematical means, and each characteristic may have several representations. *Feature extraction* is the process of analyzing an image, generating mathematical and statistical *descriptors* of an image’s structural characteristics and using these or storing them for future use.

The main problem of using structural characteristics for image description is that the descriptors do not capture the *semantic* content of the images they represent. For instance, there is no connection between a given colour distribution and the semantic concept of a *whale*. Furthermore, it is at best very difficult to describe abstract image content, such as activities, emotions and the *meaning* of the image.

2.1.2. Query Specification and Retrieval Techniques

As illustrated in Figure 2, there are two different approaches to query specification and retrieval from image collections; verbal and visual. Queries of the first type are usually in the form of keywords and free text specification. This has traditionally been the most widely used and accepted method for image retrieval. The enquirer expresses a query as keywords or free text, such as “Whale” or “Find images of Whales Jumping”.

Traditional image retrieval has been based on comparison between the specified query and the description in the database, either through exact matching or through similarity comparison. This represents the *Verbal to Verbal* mode in Figure 2. Assuming that the images are properly and fully annotated, that the query is expressed in a way that is suitable to the annotation and that there exist good tools for similarity searches, this approach can achieve very good search results. However, as noted above, it is difficult to articulate structural characteristics and variations verbally. This type of retrieval is based on techniques from traditional information retrieval, and a large body of literature describes these techniques (Baeza-Yates and Ribeiro-Neto 1999).

Visual queries are usually given as *seed images* used for *Query-by-example* and *Query-By-Sketch* searches. The enquirer supplies the retrieval system with an image representative of the images that are being sought. The traditional approach to these queries is to perform feature extraction on the seed image, and compare the resulting statistical descriptors to the descriptors of the image collection, and return images that have similar descriptors. This represents the *Visual to Visual* mode in Figure 2.

The main strength of this approach is that it is predominately automatic. Very little manual effort is needed once the feature extraction and similarity mechanisms are in place. However, there is one major problem with this approach. This has been dubbed the *semantic gap*, after the gap between what we want the query to return, and what the similarity functions are capable of delivering (Eakins and Graham 1999).

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Depending on the quality of the algorithms and functions used to compare the statistical descriptors, as well as the descriptors themselves, this query type is capable of returning most images that are *structurally* similar to the seed image. However, it fails to return images that are similar in *semantic content*. This can be illustrated by the images in Figure 3, below:



Figure 3 – Seed image and possible results from a query-by-example search

Assuming that the first image is used as a seed in a query-by-example search, we should expect that the second image is returned, as it is structurally similar to the first image. However, the third image is unlikely to be retrieved, as it shares no structural similarities to the first image, although they both contain depictions of a dolphin.

Two combinations of the above query specifications are possible. *Verbal to visual* search is based on verbal query specification. These query terms are interpreted and used as a basis for a visual search. This has been implemented in a *texture thesaurus* (Manjunath and Ma 2002), in which the user might specify a certain landscape concept, such as a *parking lot*. The thesaurus consists of several different textures representing parking lots, and these are used to identify aerial images containing parking lots.

Finally, *visual to verbal* search is based on a visual query specification. The retrieval engine uses a seed image and tries to identify objects present in the image from the characteristics extracted from the seed image. Each of the identified objects is described in text, and this text is used as a basis for a text-based search through the image annotations.

2.2. A Shape Thesaurus

The *Shape Thesaurus* has been shown to be an effective tool for enhancing image retrieval (Hove 2004). A *Shape Thesaurus* consists of

- (1) *A precompiled list of important shapes representing visual objects in a given domain of knowledge*
- (2) *statistical descriptors of these shapes*
- (3) *a textual / semantic description of these shapes*
- (4) *for each shape, a set of related shapes.*

Image retrieval with a shape thesaurus is able to accept queries of both textual and visual nature. In the case of textual queries, the query interpretation process is simply a matter of text based information retrieval techniques. The textual input is compared to the semantic labelling of thesaurus objects, and if a match is found the system can perform either text based search through the image annotations, or perform a verbal-to-visual search based on the statistical descriptors. For visual queries, the retrieval system uses the shape thesaurus in an attempt to identify the object(s) present in the seed image, and use this data to perform either text based search through the image annotation, or structure based searches based on the statistical descriptors. The Shape Thesaurus is further detailed in (Hove 2004).

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The two most important parts of a shape thesaurus are the shape descriptors and the object relationships. The shape descriptors assist the retrieval system in identifying visual objects, both in a seed image and in an image collection. The object relationships define relationships between shapes, such as a “Whale-tail” being a “part-of” a “Whale”, and that one shape is a “variant-of” another shape, as illustrated in Figure 1. This allows the image retrieval system to retrieve images containing shapes semantically related to another shape, although they share no structural similarities.

One possible approach to creating shape descriptors, are *shape templates*. Important visual objects are described by a set of simple shapes, created from real images. A set of shape templates describing the object “Whale” is illustrated in Figure 4:

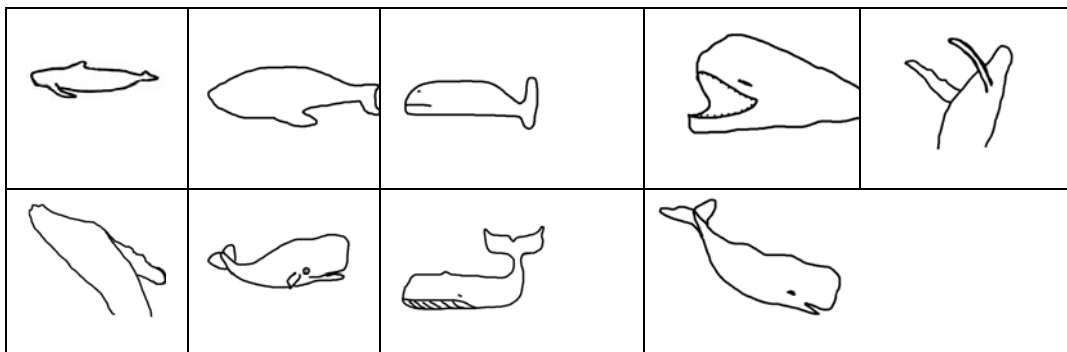


Figure 4 - Shape templates describing a “Whale”

These are images containing a simple shape representing a possible variant of a thesaurus object. Each thesaurus object can then be represented by a set of these shape templates. The shape templates can be based on actual images depicting the visual objects.

A shape thesaurus can be used to improve image retrieval (Hove, 2004) Another interesting question is whether it can also be used to assist users with formulation of visual queries, i.e. address the need identified in sec.1 above.

3. Study Objectives, Research Question and Hypotheses

The main objectives of this study are to study the potential gain from using a shape thesaurus as an aid during *visual query expression*. This is defined in the following research question:

How can inclusion of a Shape Thesaurus improve a user’s ability to formulate visual query specifications for image retrieval?

Visual Query Expression is defined as

the process of expressing an information need through creation of an example image used as a seed for visual image retrieval.

The above research question represents the principal study objectives in the proposed project. The question includes several smaller study objects, identified by the following set of partial research questions:

RQ1: What are the major difficulties with using a basic drawing interface for visual query specification?

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RQ2: Can a shape thesaurus assist users develop visual query expressions?

RQ3: Can the quality of image search results be improved by using a shape thesaurus as a support for visual query expression?

The first research question focuses on gaining an understanding of how users feel towards visual query expression; what do the users find difficult, why it is difficult, and what can be done to assist them. A *basic drawing interface* refers to drawing tools as found in currently available content based image retrieval systems, such as either IBM's QBIC, or interfaces similar to simple image processing software, such as Windows PAINT.

The first research question will be examined through testing the following hypothesis:

H1: Lack of functionality in the tools supporting query expression is the main problem in using a basic drawing interface for visual query expression.

The second research question focuses on evaluating if a shape thesaurus can help users overcome some of the difficulties connected with using basic drawing interfaces. This is related to the *utility* and the *ease of use* of a drawing interface enhanced with a shape thesaurus. This will be examined through the following hypothesis:

H2: Visual Query Expression, formed with the aid of a Shape Thesaurus will allow users to better express their information needs than using seed images created using a basic drawing interface.

The final research question focuses on IF visual query expressions, developed with a shape thesaurus, will have an effect on the actual search results achieved by an image retrieval system. This is related to the *quality* of the results achieved with visual query expression with the aid of a shape thesaurus. This will be examined through the following hypothesis:

H2: Visual Query Expressions, formed with the aid of a Shape Thesaurus, will achieve significantly better search results, in terms of recall and precision, than using seed images created using a basic drawing interface.

4. Research Strategy and Design

4.1. Methodological Approach and Research Design

The main study object in this project is the shape thesaurus, and how it can assist users while expressing visual queries. The shape thesaurus is still a research object, and there are no complete, fully implemented image retrieval systems that use this approach. As a result, it is not possible to evaluate the research question using real-world applications, or observe actual users using the system. Therefore, the data collection and hypothesis testing will have to be carried out as a laboratory design. In order to evaluate the research question, it will be necessary to develop a system which users can use for formulation of visual queries. This system will be used as an experiment tool for evaluating the hypotheses and research questions.

This approach follows the methodology classified as *design science* (March and Smith 1995). Design science methods consist of two basic activities; *build* and *evaluate*. Building is the process of constructing an artefact for a specific purpose. Building an artefact proves

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feasibility, and this artefact then becomes the object of study. The artefact is evaluated to determine if we have achieved any progress; how well does it work?

Evaluation requires the use of metrics and measurement of the artefact according to those metrics. Metrics define what we are trying to accomplish. Finally, given an artefact whose performance has been evaluated, it is important to determine why and how the artefact worked within its environment. We *theorize* and then *justify* theories about the given artefact.

An evaluation of a shape thesaurus prototype in a query formulation setting will allow us to justify if it is actually able to assist users during visual query formulation.

4.2. Data Collection and Analysis

The three research questions and hypotheses naturally divide this project into three main tasks. The first research question will be examined first as a pilot study in order to gain a deeper understanding of the problems connected with visual query expression. This will be evaluated using a *qualitative approach*. A small set of users will be given a set of pre-defined information needs, and be asked to express these as visual queries. Figure 5 shows some examples of such information needs.

Find images depicting one or more 'dolphins' 'playing'
Find images depicting one or more 'whales' 'jumping'
Find images depicting one or more 'seagulls' 'eating'
Find images depicting a 'dolphin' 'playing' with a 'ball'

Figure 5 - Illustration of image composition with a Shape Thesaurus interface

The users will be asked to express the queries using an interface similar to what can be found in currently available QBS systems; freehand drawing and use of primitive shapes. *Microsoft Paint* is suggested as a suitable tool, as it supports this functionality. The hypothesis will be evaluated using theory and methods from the field of Human Computer Interaction and Activity Theory. Usability and user satisfaction from using the interface will be measured using a triangulation of methods such as Talk-aloud protocols, Video analysis, Heuristic evaluation and Semi-structured interviews. Test persons will be recruited from a population representative of potential users of image retrieval systems.

The second research question will be evaluated in a similar, qualitative manner. A similar group of users will be asked to perform similar query expressions, but using an interface supported with a shape thesaurus. A preliminary proposal for the functionality for the interface is given in the next chapter. Usability and user satisfaction with this system will be measured using the same tools as for the first research question. The hypothesis will be evaluated through a comparison of the results from the two interfaces.

The third research question will be evaluated using a *quantitative* approach. The query images from both previous experiments will be used as input to an image retrieval system. The resulting image sets will be compared to a list of relevant images, created by the users based on their interpretation of the information needs and the image collection. *Recall and precision* will be measured and used to compare the retrieval quality of the two approaches.

4.3. Sample Collection and Experiment Subjects

Two approaches to the sample collection and experiment subjects are proposed. The first approach is based on using a real image collection, either in existence or under development.

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The other approach is based on continuing the maritime case scenario used in my master thesis. The first approach is preferable, as it will be an opportunity to test the approach using an existing image collection and application. Furthermore, it might be possible to recruit respondents from the actual user population. However, no arrangements towards this have yet been made, and it possible that this will be difficult to arrange. This would have to be done after the project has begun.

The second approach will be used if no suitable image collection can be found. A scenario based on a museum of natural history will be used. This will be based on the image collection in the *Virtual Exhibits on Demand* project. The project has a sizeable collection of images related to this scenario. Respondents will have to be recruited from a population representative of potential users of such image collections, such as teachers or students from high school and junior high school will be preferred.

4.4. Prototype

The shape thesaurus tool was evaluated for information retrieval capability through a pilot study with a limited prototype, the VORTEX (Visible Object Retrieval – Thesaurus Extension). The results of this pilot study were positive, indicating that the tool could prove to be a valuable tool for image retrieval (Hove 2004).

However, query expression and the possibilities for user interaction with the thesaurus were not examined. The properties of the Shape Thesaurus indicate that it indeed might be useful for user interaction and query specification, and this will be evaluated through a new prototype, preliminary named VORTEX-2.

The original VORTEX prototype was based on using the image descriptors and similarity functions provided by Oracle 9i interMedia. While this allowed for rapid software development, it imposed several limitations on the functionality and customizability of the prototype, as detailed in (Hove 2004). VORTEX-2 will be built as a stand-alone system, with two major changes from the original prototype.

First, the descriptors used for shape representation will be replaced with descriptors with open and customizable functionality. Likewise, the shape similarity search is performed by the Oracle's built-in similarity functions. These will be replaced with an artificial neural network (ANN). ANNs have been successfully used for different image retrieval purposes, and some initial testing during my master thesis indicated that this might be fruitful approach (Rowley, Baluja et al. 1998; Hove 2004; Solberg and Czajkowski 2004).

Next, a user interface will be created. The user interface will allow users to use the shape thesaurus framework to easily construct seed images using both their own drawings and selecting components from the shape descriptors in the thesaurus. Using these, the users will be able to compose images expressing their information need visually. Actual design and implementation of the interface will be detailed further during the course of the project depending on the results from the initial pilot study. A tentative interface design is illustrated in Figure 5 below.

The illustration shows the actual image composition, showing a visual query expression of a potential visual information request; "Find images with a dolphin beak and a seagull". The user selects shape components from the thesaurus representations (The seagull and the

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dolphin) in a *drag-and-drop* manner, and draws a wavy line and a fluffy blob by free hand, illustrating the surface of the sea and a cloud.

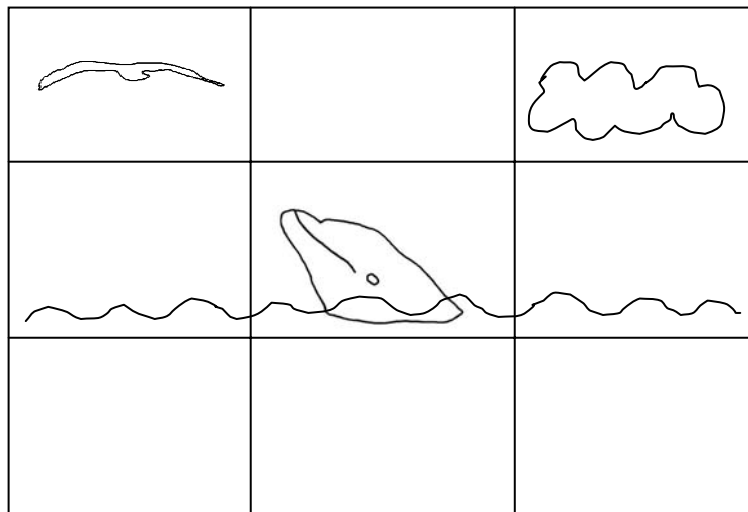


Figure 6 - Illustration of image composition with a Shape Thesaurus interface

The image interface is divided into several sections, representing the important parts of an image. Composing an image this way will help the user express his query. Furthermore, the mechanics of the shape thesaurus will enable the retrieval system to retrieve images which has the same composition, but with dissimilar shapes representing the visual objects in the composition.

5. Tentative Time Schedule and Project Plan

The project described in this proposal is planned as a three year effort over four years of time, with 25% of the time dedicated to teaching. The most difficult and demanding task is likely to be the development and improvement in the prototype. However, this is familiar ground as I have spent the last 18 months working with issues directly related to this.

Furthermore, it is intended to present the work in this thesis at both national and international conferences, within the fields of Image Processing and Information Retrieval.

My supervisor for the work on my master thesis has been associate professor Joan C. Nordbotten, at the Institute for Information Science and Media Studies. I am very satisfied with the supervision, and would like to continue this cooperation into this project.

Figure 7 shows a tentative time schedule outline for the project.

Task	Year			
	1	2	3	4
Literature review	█			
Prototype development	█	█		
Establishing test collection	█			
Pilot Study and Analysis	█	█		
Main experiment		█		
Data Analysis		█		
Conference and papers		█	█	█

Figure 7 - Tentative Time Schedule

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