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Sketch-based 3D Object Retrieval with Skeleton Line Views – Initial Results and Research Problems

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Abstract

Hand-drawn sketches are a convenient way to define 3D object retrieval queries. Numerous methods have been proposed for sketch-based 3D object retrieval. Such methods employ a non-photo-realistic rendering step to create sketch-like views from 3D objects for comparison with the sketch queries. An implicit assumption here often is that the sketch query resembles a perspective view *of the 3D shape. However, based on personal inclination or the type of object, users often tend to draw* skeleton views *instead of a perspective one. In those cases, a retrieval relying on perspective views is not the best choice, as features extracted from skeleton-based sketches and perspective can be expected to diverge vastly.*

In this paper, we report on our ongoing work to implement sketch-based 3D object retrieval for skeleton query sketches. Furthermore, we provide an initial benchmark data set consisting of skeleton sketches for a selection of generic object classes. Then, we design a sketch-based retrieval processing pipeline involving a sketch rendering step using Laplacian contraction. Additional experimental results indicate that skeleton sketches can be automatically distinguished from perspective sketches, and that the proposed method works for selected object classes. We also identify object classes for which the rendering of skeleton views is difficult, motivating further research.

1. Introduction and Problem Statement

Recent advances in 3D acquisition and digitization methods have led to the creation of increasingly large collections of 3D data. Searching through such datasets and retrieving data of interest is a very important task for many industrial and scientific applications. In order to find a certain objects efficiently, specialized algorithms for content based 3D search and retrieval are required.

Sketch-based queries [LLG*14] are one of the most intuitive and efficient ways for a user to express a query for content-based 3D retrieval. The user draws a 2D sketch that resembles the desired object. Such queries can be formulated rather quickly and don't require specialized equipment. Existing sketch-based retrieval methods typically assume that input sketches represents either a full perspective view of the object or it's contours. However, especially full perspective sketches naturally take more time to create and might also require more artistic skills than simpler ones, such as contour sketches. For certain object classes, skeleton-based sketches are even more simple to create. Often they are very similar to how small children draw objects (e.g. legged animals or humans). However, for other classes, it is counter-intuitive to use a skeleton-based sketch (e.g. keys or snakes)

We present first results of our 3D object retrieval system specifically aimed to support skeleton-line sketch queries. This work can lead to more robust sketch-based retrieval systems supporting both perspective and skeleton user sketches. Specifically, a retrieval pipeline could detect the type of sketch style provided, and determine the appropriate view generation and feature computation steps to use. E.g., for perspective sketches, features from a perspective rendering of the target data should be used, while a skeleton renderer should be used for skeleton sketches. One of the first problems that we have encountered is that there is no retrieval benchmark data for skeleton line images and no comparative work done. Hence our contributions are:

- Provide an initial benchmark data set comprising sketches for perspective, contour and skeleton line sketches.
- Preliminary experiment to assess that classification of sketch type is possible.
- Preliminary experiment using the benchmark and one candidate skeleton renderer.
- We discuss next research steps towards improved content-based retrieval using skeleton sketch queries.

2. Related Work

A recent comparative review of Sketch-based Shape Retrieval (SBR) methods [LLG*14] shows that basically all methods assume

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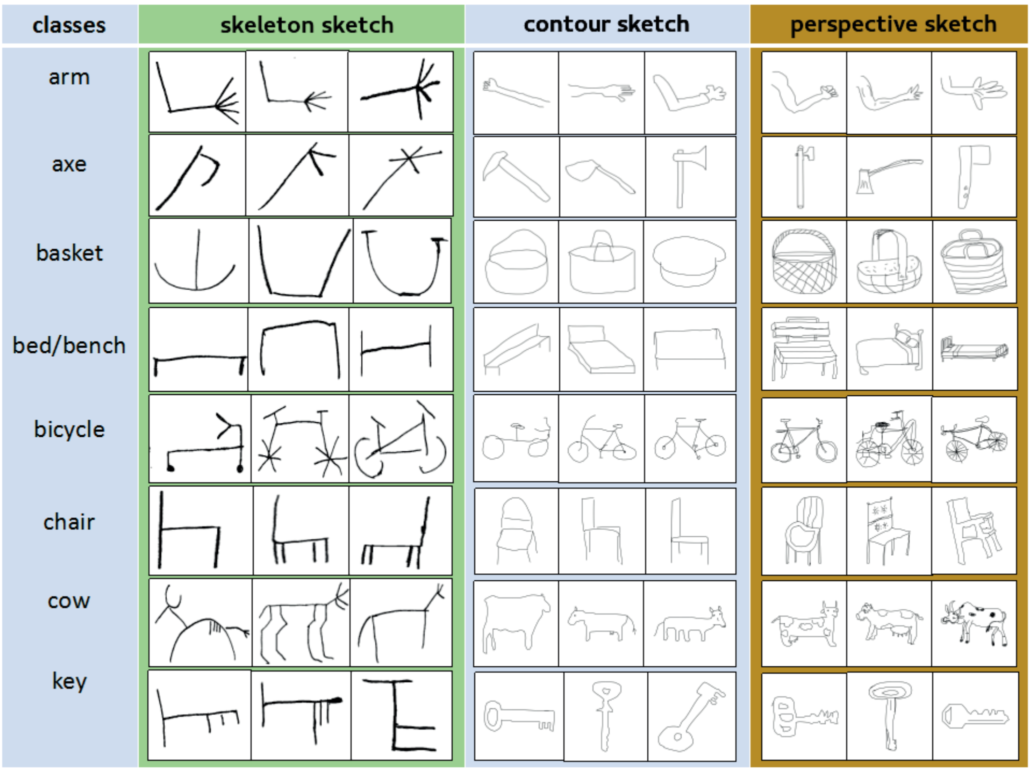

Figure 1: *A selection of skeleton, contour and perspective sketches in our test data set.*

the query sketch to be either an perspective or orthogonal view. Consequently, a perspective non-photorealistic (NPR) rendering stage for view feature extraction is used. Previous SBR benchmarks have been created and used for evaluation, including [EHA12], where a crowd-sourced approach was used to collect a large number of object sketches. Interestingly, only few to none skeleton images can be found in existing sketch benchmarks.

To support skeleton line retrieval, the NPR component in the SBR pipeline needs to be filled with an appropriate skeleton rendering method, to compute appropriate view-based features for the candidate objects to compare to a skeleton query. Skeletons can be extracted either from 2D views, or from 3D shapes, and many methods exist. In [TDS*16, CSM07] numerous skeletonization methods are classified and reviewed. Despite different methods proposed with promising results, practical application of skeletonization methods remains challenging, or as the authors in [TDS*16] explain: "Obtaining ready-to-use, robust, commercial-grade implementations is hard."

Custom skeleton extraction methods have been previously applied in 3D object retrieval. In [SSGD03], graph-based shape representations using 3D line skeletons are computed for comparing 3D objects with each other. In [LLC*15], 2D skeleton lines and contour features are used for an improved SBR approach. However, the performance of their method was evaluated using query sketches from standard SBR benchmarks and not for skeleton line queries in particular.

3. Skeleton Line Drawing Benchmark

To support further work on skeleton-based retrieval, we compiled a test data set by inviting 40 users to draw skeleton line images for a list of 20 selected classes occurring also [EHA12, LLG*14], and for which skeleton line images can be meaningfully created. We gave our users the list of class names with no further information than to ask them to draw a perspective, and contour, and a skeleton line sketch for 20 object classes (see Fig. 1). We collected a total of 691 sketch-based and 1822 contour or perspective sketches. We note that the distinction between perspective, contour and skeleton sketches is not always clear-cut, but mixed forms occur, and the classes are a selection that could be extended in the future. Each one of the collected hand-drawn images was scanned, cropped, filtered for noise, deblurred, and finally converted to a binary image. Our data can be downloaded from [Zha].

4. Classification of Drawing Style

Given our collected sketches, we assume that in a real-world scenario, depending on the object class and their personal inclinations, users might very often switch between different sketching styles. Hence our first step is geared to identify if a sketch is either sketch-based or not. Subsequently a different retrieval pipeline can be selected based on this classification.

For binary classification tasks, (supervised) Support Vector Machines(SVM) [CV95] can be considered a straight-forward approach. However, they can not readily operate on sketch images directly. Hence we first extract the well-known Histogram of oriented Gradient (HoG) features [DT05] from the 2D sketch images.

Table 1: *Classification results when using a SVM to distinguish between skeleton (S) and contour/perspective (CP) image classes. T refers to average time required.*

classes	S	C P	Correct Rate	T(sec)
Arm	39	81	0.7565	4.2469
Axe	37	89	0.6259	4.0897
Basket	33	91	0.8282	3.9749
Bell	24	92	0.6114	4.0908
Bed or bench	40	166	0.9138	7.0517
Bridge	38	87	0.9096	4.1217
Bicycle	38	99	0.7995	4.1792
Cat	36	85	0.7796	6.5460
Chair	38	77	0.6426	6.4875
Human	39	83	0.67	4.2259
Cow	31	85	0.9026	6.3067
Key	37	88	0.7364	6.3657
Rainbow	37	80	0.9065	6.6452
Sailboat	23	92	0.4355	6.5576
Scissors	21	94	0.7233	6.5897
Snake	36	82	0.7145	6.5655
Spider	34	89	0.7805	4.1713
Tree	39	84	0.8091	4.3302
Windmill	36	91	0.6052	4.0749
Wineglass	35	87	0.6750	4.0333

We then trained MATLAB's SVM implementation to solve the two-class problem. Table 1 provides our results of a classification. For training, the number of positive samples is $N/2$, and negative samples are the other half. This simple classifier already yields classification results between 60 and 90%, and we expect that significantly better results can be obtained by a further optimized combination of 2D image features and classifier.

5. Skeleton-based Retrieval

As target data set for the retrieval step, we chose a subset of classes from the Konstanz database [BKS*05] that match the classes of our skeleton images. From these 3D models, we generated skeleton images from 27 different views of each 3D object to compare each of them against the HoG features that were extracted from the query. However, robust extraction of line skeletons from 3D shapes is a difficult task [TDS*16]. For our initial experiment, we chose the Laplace Contraction method [CTO*10] to render skeletons from 3D objects. Note that our choice here is opportunistic due to the availability of implementation and a low number of parameters that reduce adoption effort. Other methods (see Section 2) might as well be used instead.

We compute HoG features for the query and target views and for each user query, we form a ranking of the best-matching view from each candidate object, using the L_1 norm.

Figure 1 illustrates the skeleton-based retrieval setup. During our initial experimental evaluation, we observed, that our approach works reasonably well for sketches resembling a human arm. However, we also found that although it also works for some of the other classes (e.g. axes or beds), it fails for a number of other classes (e.g., baskets, bicycles, or cats). After closer inspection, we observe that

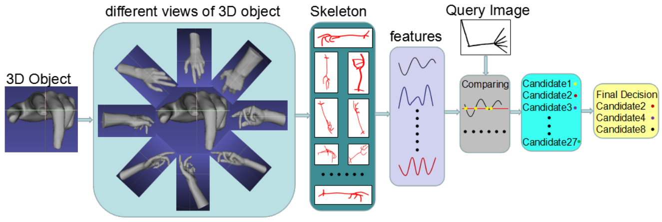

Figure 2: *Flowchart of our skeleton retrieval experiment. Several 2D projections are skeletonized. HOG features are computed for the views and user-provided skeleton sketches. A distance-based ranking is produced for the first best match of any view of an object to the query.*

the skeleton renderer in our current setup has severe problems to extract plausible skeletons here. The skeletons we obtained are very noisy (see Figure 3).

6. Summary and Next Steps

We compiled and provide an initial benchmark for skeleton-sketch-based 3D Retrieval that is based on more than 2500 user-drawn sketches. Our approach shows some promising first results in both, classification and retrieval for at least some of the classes in the benchmark. We stress that our approach is work-in-progress, indicating that classification of skeleton images against perspective images is possible, and that HOG features can be useful for retrieval in combination with an appropriate skeletonization.
More research is needed to optimize the retrieval for skeleton sketch queries. A main challenge is to identify a suitable skeletonization algorithm that works more robustly for certain model classes as well as the sampling density and tessellation of their 3D models. Many methods have been proposed, which need to be evaluated for our data. Also, our provided data set is a starting point but more classes are needed. Also, the features to use could be changed. We chose HOG, but other features like shape context, eventually also learned features, are possible. We expect that for skeleton-sketches a reasonably optimized skeleton retrieval will be able to outperform standard sketch retrieval based e.g., on perspective rendering like Suggestive Contours [LLG*14], simply because the rendering step is closer to the abstraction made by the user when submitting sketch-based queries. Eventually, a full retrieval system should include a classification stage that detects the type of sketch including perspective, orthogonal or skeleton, and applies the best suited view generation and feature extraction to carry out the search.

References

[BKS*05] Bustos B., Keim D. A., Saupe D., Schreck T., Vranić D. V.: Feature-based similarity search in 3d object databases. *ACM Computing Surveys (CSUR) 37*, 4 (2005). 3

[CSM07] Cornea N. D., Silver D., Min P.: Curve-skeleton properties, applications, and algorithms. *IEEE Trans. Vis. Comput. Graph. 13* (2007). 2

[CTO*10] Cao J., Tagliasacchi A., Olson M., Zhang H., Su Z.: Point cloud skeletons via laplacian based contraction. In *Shape Modeling International Conference (SMI), 2010* (2010). 3

[CV95] Cortes C., Vapnik V.: Support-vector networks. *Machine learning 20*, 3 (1995). 2

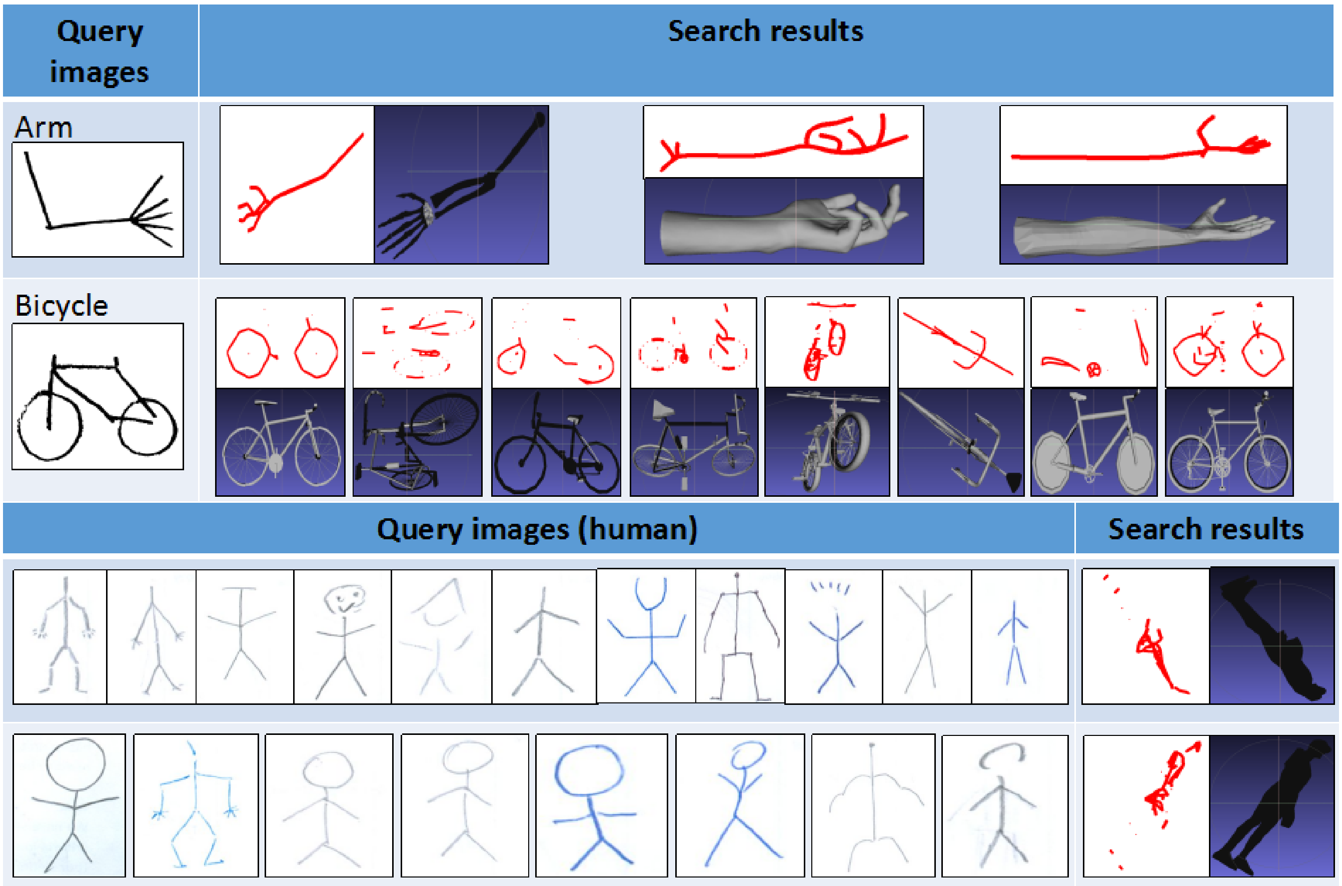

Figure 3: *Illustrative results from our experiments. The skeleton renderer and retrieval works reasonably for the arms (top). Skeletonization is problematic for some classes (bicycle, middle) and 3D models of humans.*

[DT05] Dalal N., Triggs B.: Histograms of oriented gradients for human detection. In *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)* (2005), vol. 1. 2

[EHA12] Eitz M., Hays J., Alexa M.: How do humans sketch objects? *ACM Trans. Graph. 31* (2012). 2

[LLC*15] Lei H., Li Y., Chen H., Lin S., Zheng G., Luo X.: novel sketch-based 3 model retrieval method by integrating skeleton graph and contour feature. *Advanced Mechanical Design, Systems, and Manufacturing 9*, 4 (2015). 2

[LLG*14] Li B., Lu Y., Godil A., Schreck T., Bustos B., Ferreira A., Furuya T., Fonseca M., Johan H., Matsuda T., Ohbuchi R., Pascoal P., Saavedra J.: A comparison of methods for sketch-based 3D shape retrieval. *Elsevier Computer Vision and Image Understanding* (2014). 1, 2, 3

[SSGD03] Sundar H., Silver D., Gagvani N., Dickinson S.: Skeleton based shape matching and retrieval. In *Proceedings of the Shape Modeling International 2003* (2003). 2

[TDS*16] Tagliasacchi A., Delame T., Spagnuolo M., Amenta N., Telea A.: 3d skeletons: A state-of-the-art report. In *Computer Graphics Forum* (2016), vol. 35. 2, 3

[Zha] Zhao X.: Skeleton Sketch Retrieval Benchmark Data. http://cgv.cgv.tugraz.at/3DOR-17/benchmark-data.zip. 2