A Probability-based Unified 3D Shape Search

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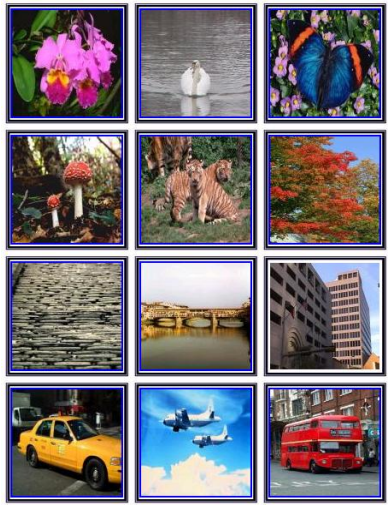
Presentation Outline

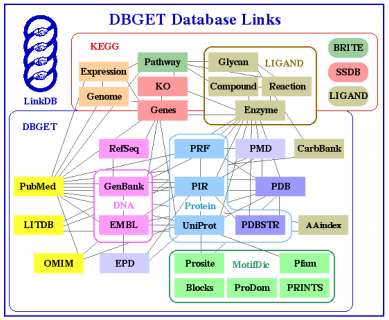
- Motivation
- Proposed method
- Experimental results and Implementation
- Conclusion and future work

Importance

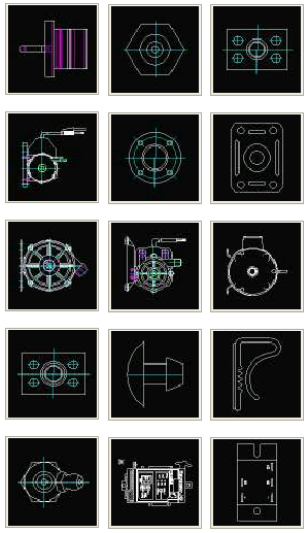
- Different media are becoming more popular. The search and reuse these materials is becoming important.



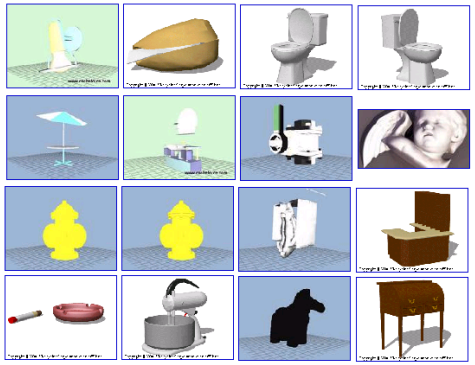
Pictures



Diagrams

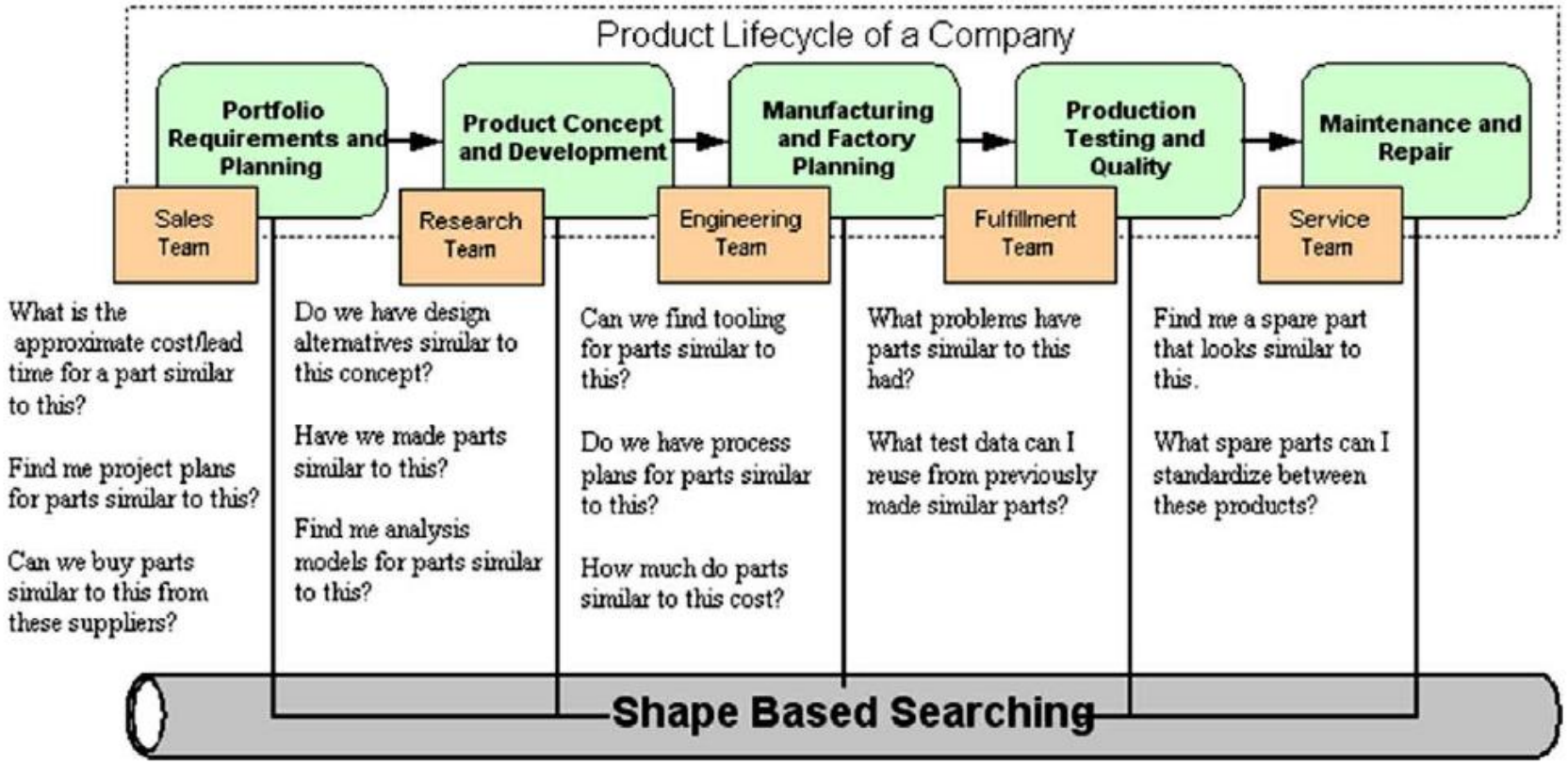


2D Drawings



3D Models

"Shape" is an intuitive criterion for similarity computation.


Product Lifecycle of a Company
Portfolio Requirements and Planning
Product Concept and Development
Manufacturing and Factory Planning
Production Testing and Quality
Maintenance and Repair
Sales Team
Research Team
Engineering Team
Fulfillment Team
Service Team
What is the approximate cost/lead time for a part similar to this?
Find me project plans for parts similar to this?
Can we buy parts similar to this from these suppliers?
Do we have design alternatives similar to this concept?
Have we made parts similar to this?
Find me analysis models for parts similar to this?
Can we find tooling for parts similar to this?
Do we have process plans for parts similar to this?
How much do parts similar to this cost?
What problems have parts similar to this had?
What test data can I reuse from previously made similar parts?
Find me a spare part that looks similar to this.
What spare parts can I standardize between these products?
Shape Based Searching

Why is it difficult ?

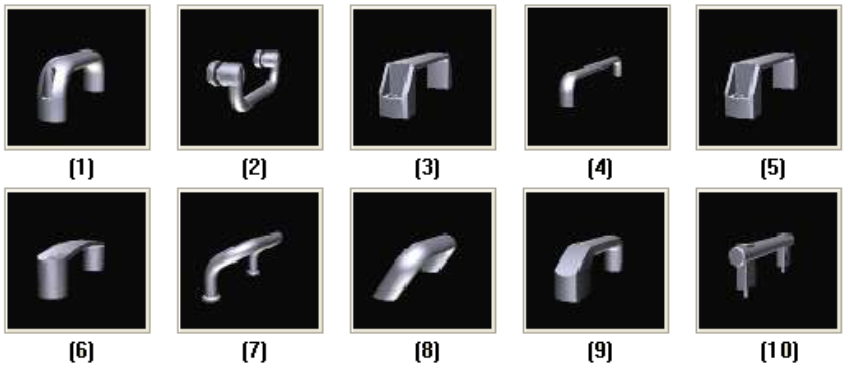
Reason: *We can not use a set of limited features to describe all kinds of 3D shapes.*

Therefore, how to

(1) represent & abstract 3D shapes, i.e., shape descriptor;

(2) balance between Global Shape vs. Local Shape.

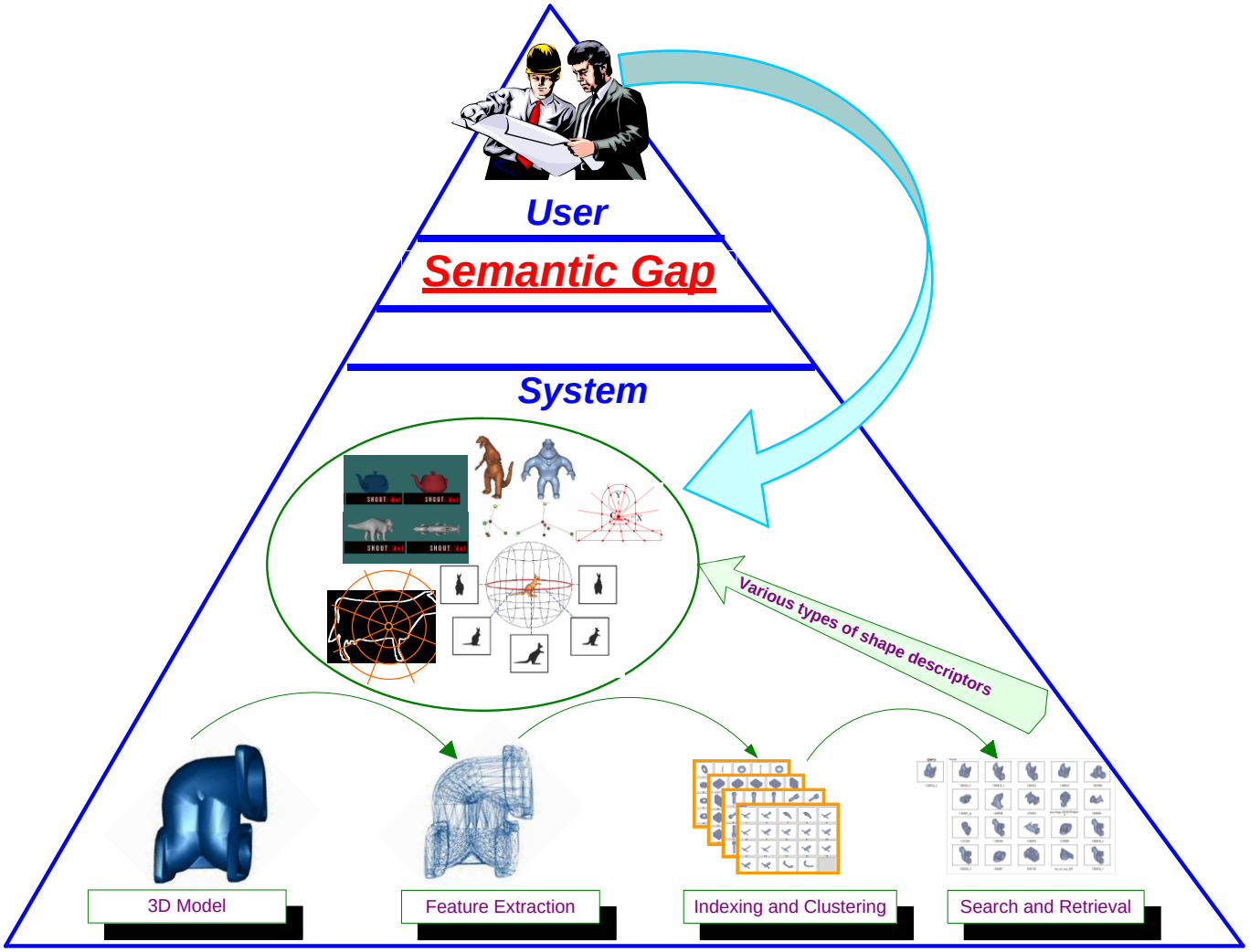
are key aspects of 3D model retrieval.



Global similarity but local difference

Iyer, N., Jayanti, S., Lou, K., Kalyanaraman, Y., and Ramani, K., (2005), "Three-dimensional shape searching: state-of-the-art review and future trends," Computer Aided Design, Vol. 37, No. 5, pp. 509-530

Background Introduction

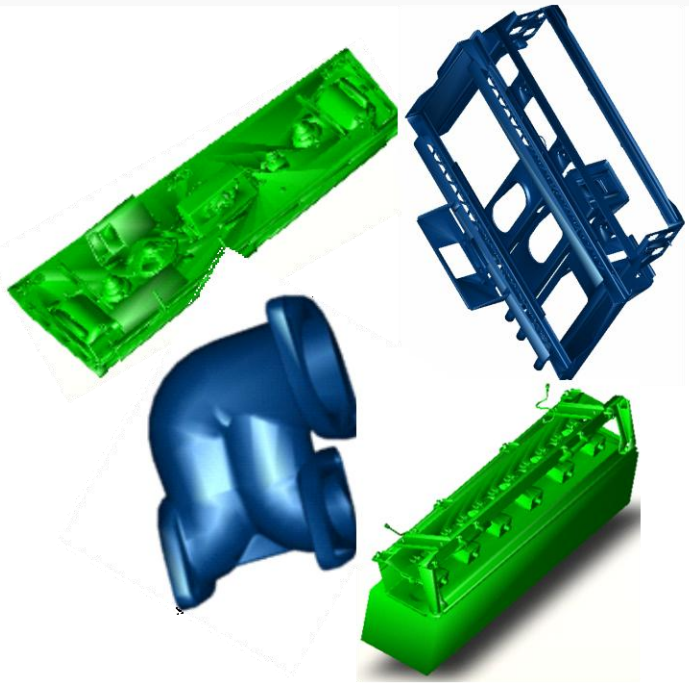


Motivation

Engineering semantics is an integral part for engineering shape search for:

- Reduce the semantic gap, improve the search effectiveness
- Restrict the search space, enhance the search efficiency
- Dedicate to better engineering knowledge reuse and better user satisfaction
- Embody engineering uniqueness

Engineering vs. Multimedia



Engineering 3D Model

?

Multimedia 3D Model

Engineers associate shape similarity with contexts, such as manufacturing process, function, etc.

Problem Statement

- Identification of applicable and valuable engineering semantics embedded in shape
- Development of appropriate approaches to utilize selected semantics for effective and efficient shape matching
- Integration of the framework to the shape search system seamlessly
- Design of effective means to actively reach user consent to reduce semantic gap
- Use of proper evaluation scheme to measure the performance

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- Motivation
- Proposed approach
  - **Unified 3D shape search**
  - **Nondeterminitistic classification**
  - **Classifier combination and AMCE**
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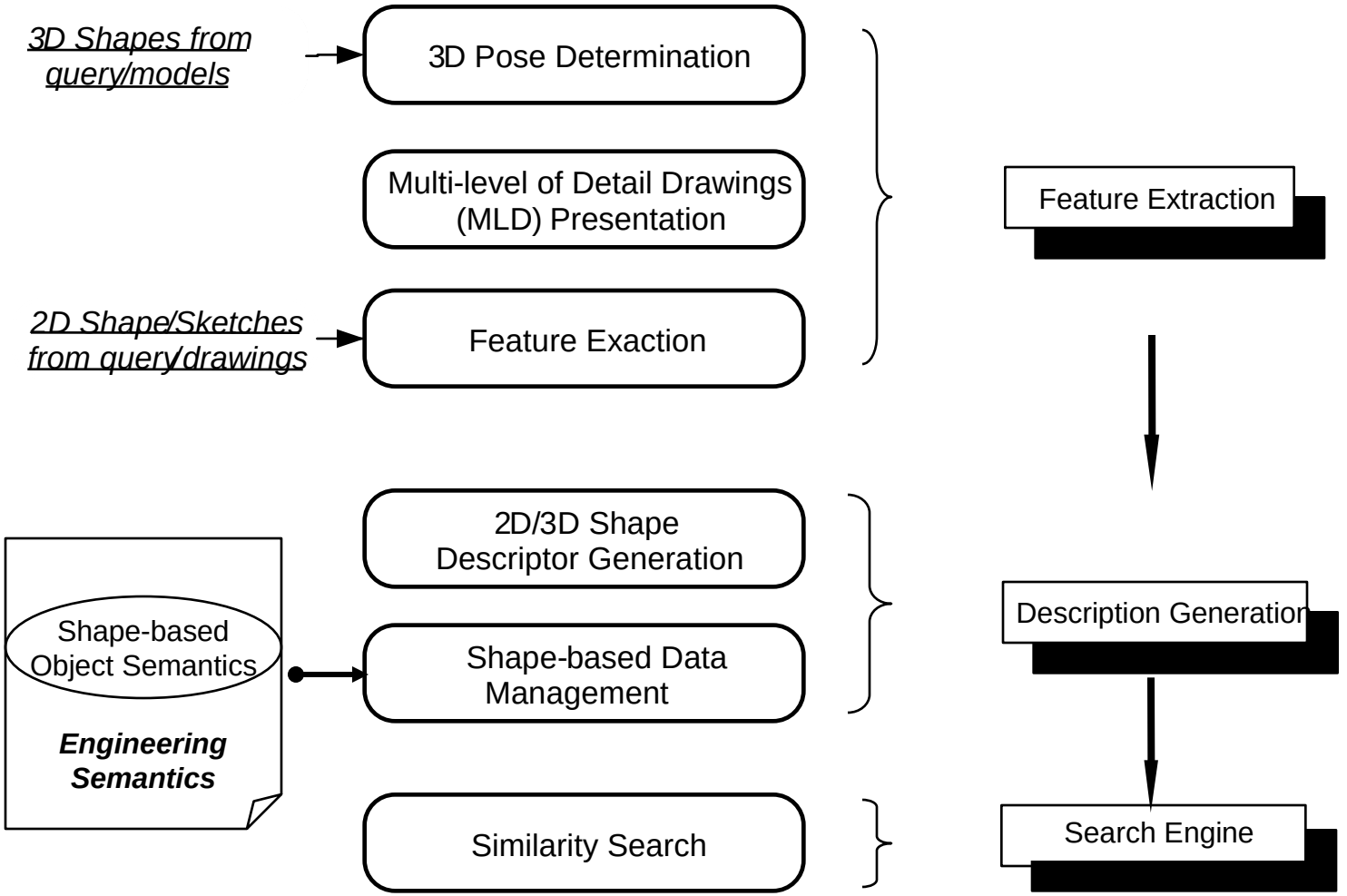
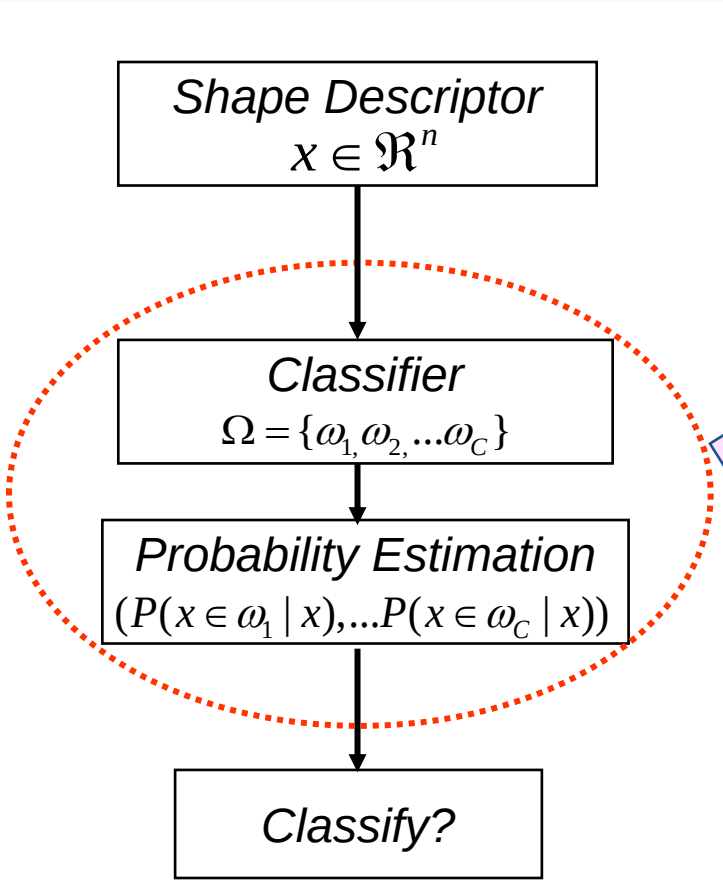
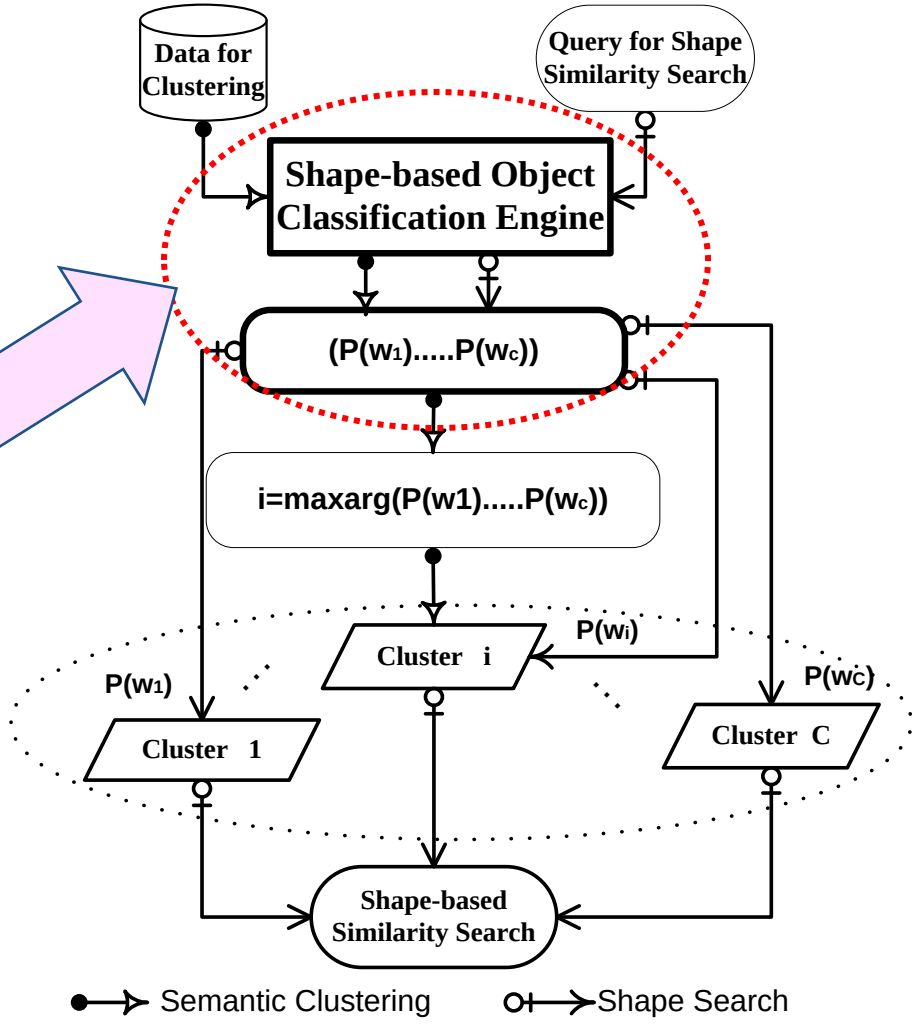
ShapeLab Framework

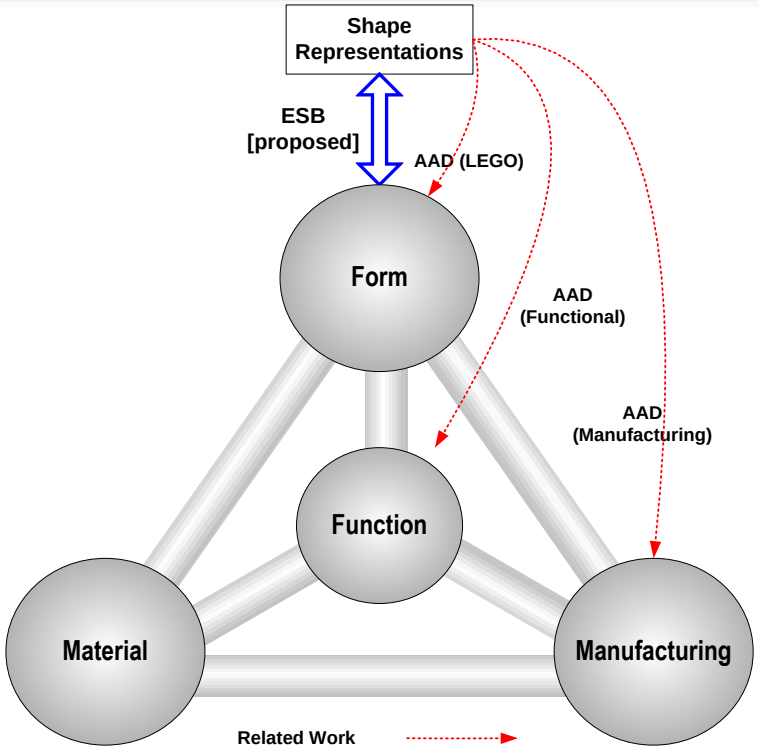


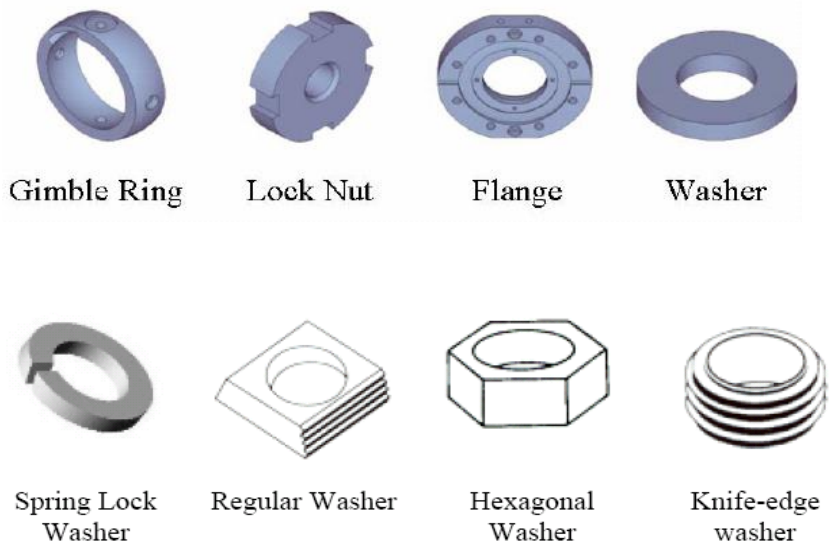
Unified Search Framework





Nondeterministic Classification



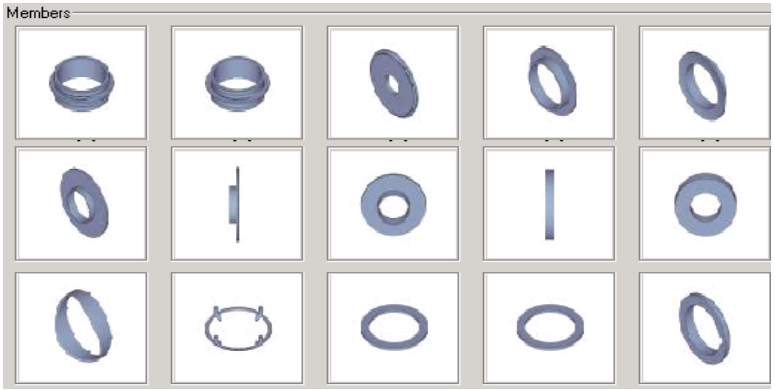


- No unified engineering classification schema
  - Different classes for an engineering model based on different standards
- Facilitative for post processing

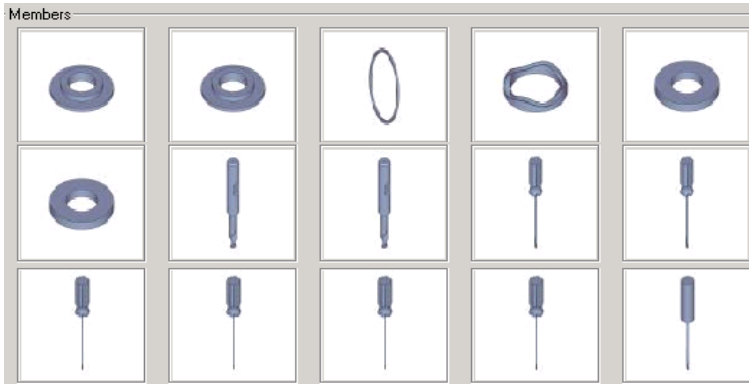
Advantages of Nondeterministic Classification

Query

Unified Search by Binary Classifier

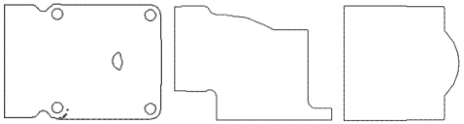
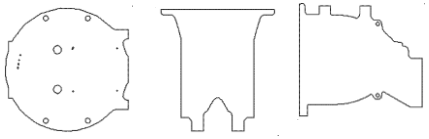
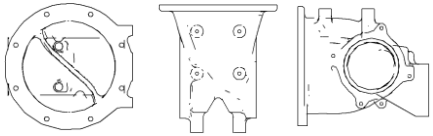
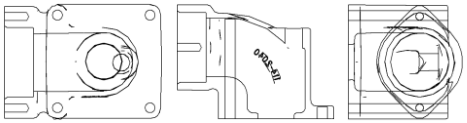
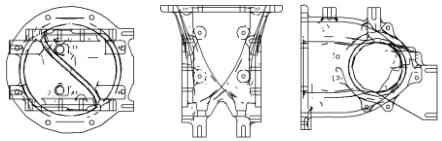


Unified Search by Probability Classifier



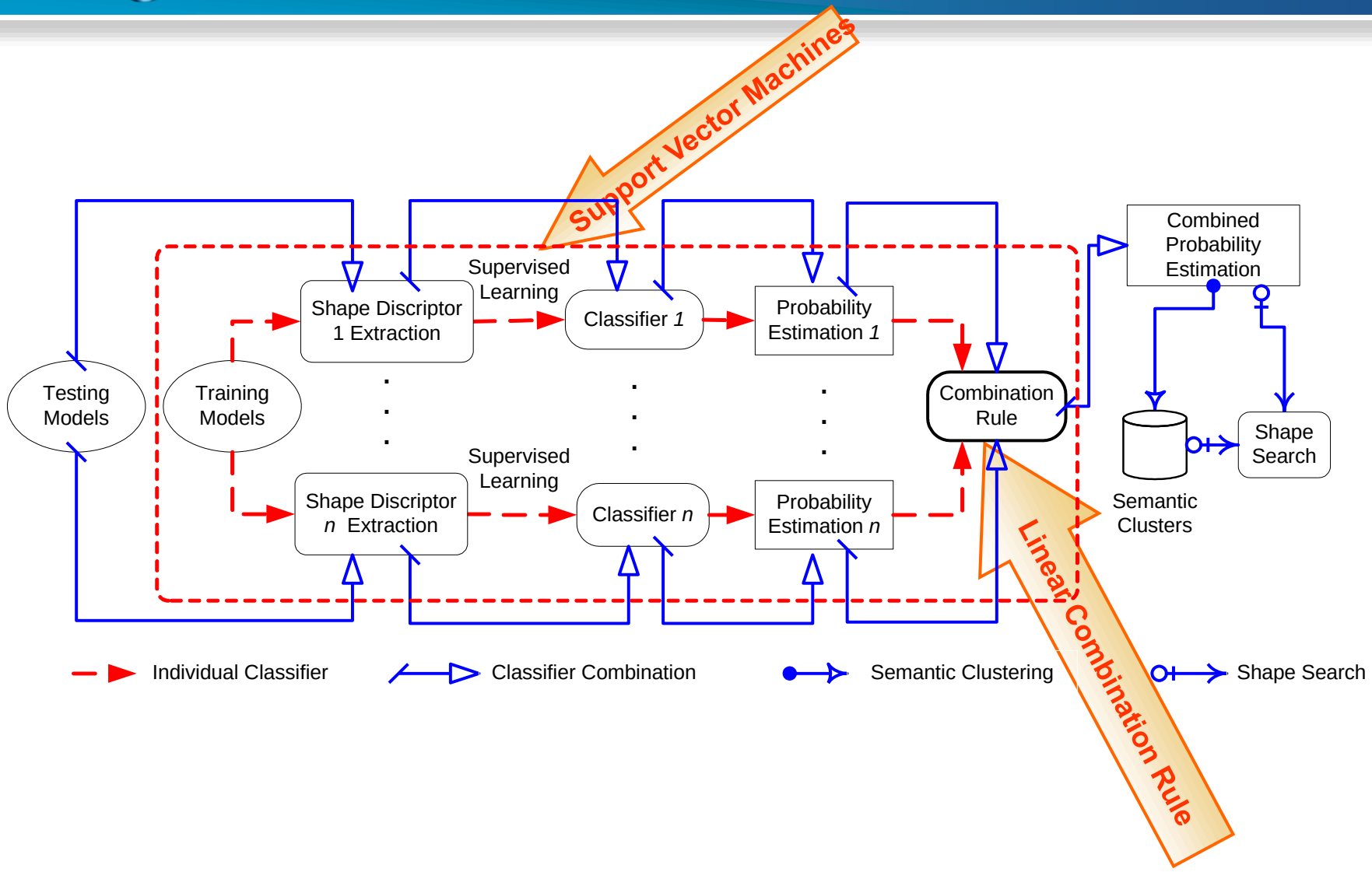
- Risk reduction from using binary classifier
- Efficient and effective user interactions
  - Limit the number of recommended classes

Classifier Combination

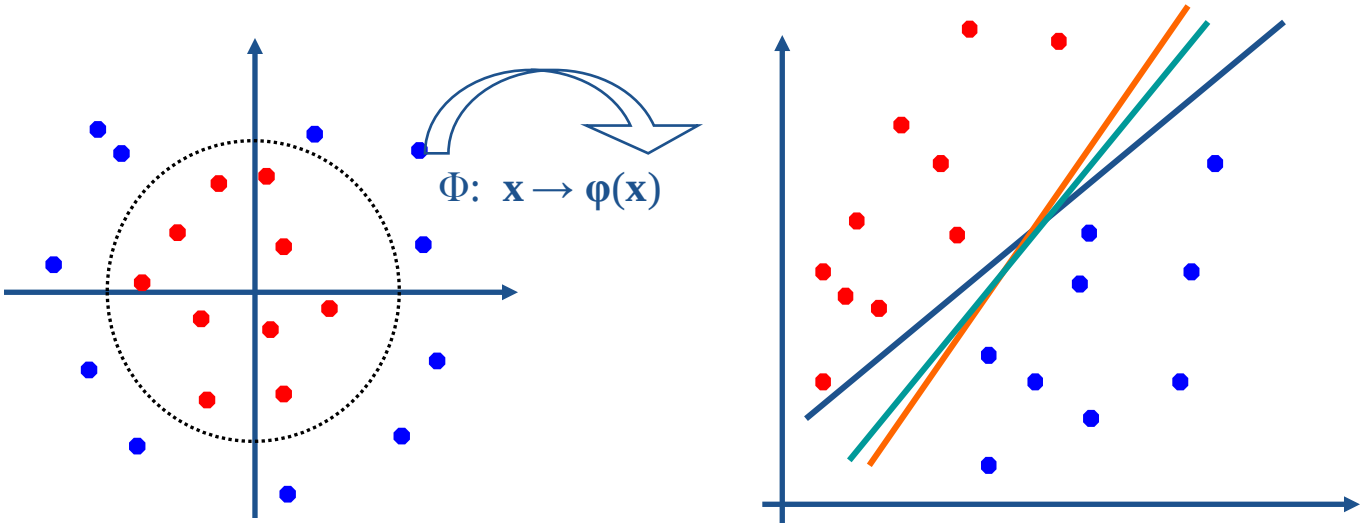
3D Model		
Contour Level		
Silhouette Level		
Drawing Level		

- Proved to perform better than monolithic classifier
- Increase classification accuracy, reduce ambiguity and uncertainty
- Select high-quality and complementary shape descriptors for classification

System Architecture

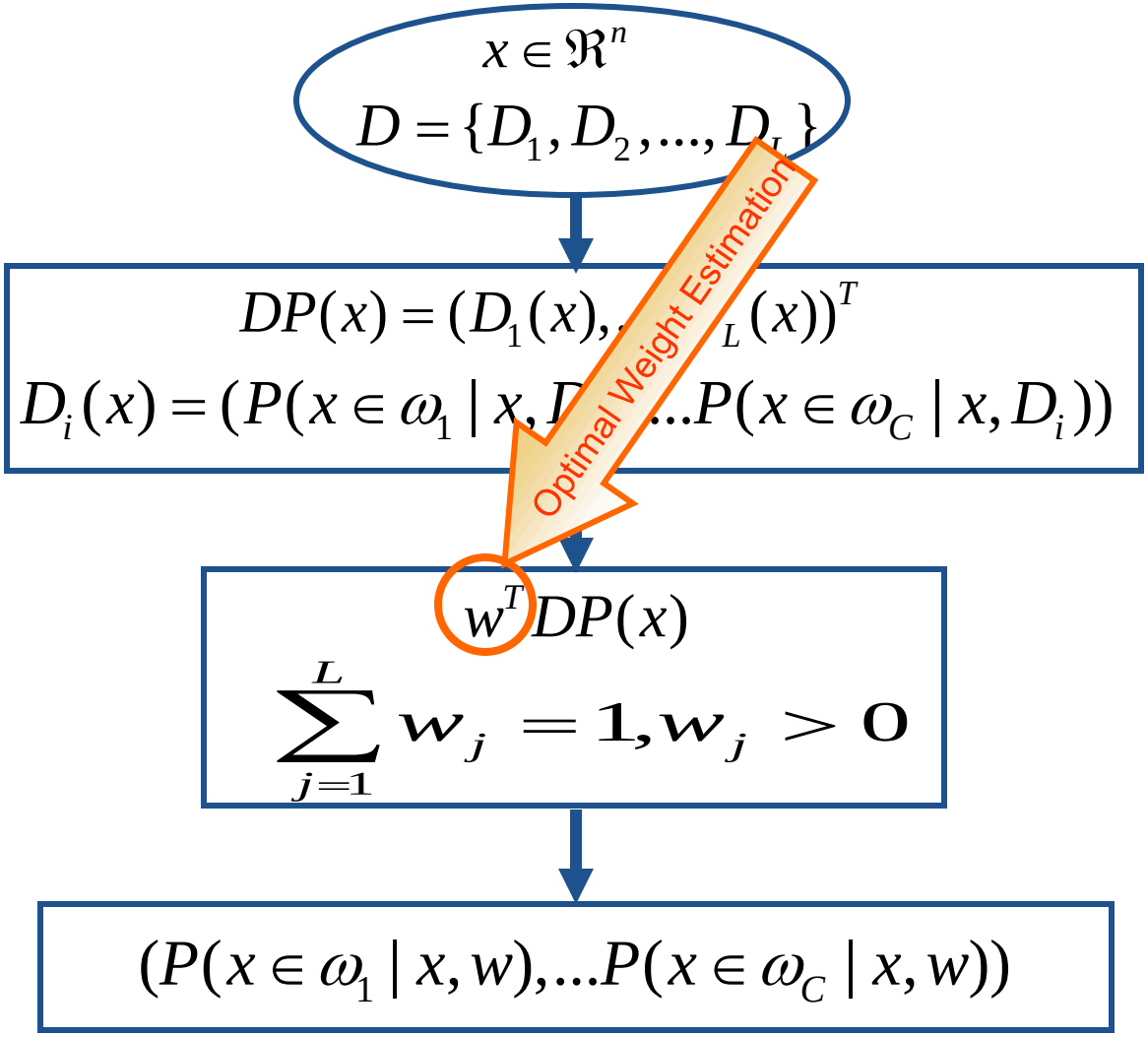


Support Vector Machines



- Nonlinear relationship between shape and the semantic classes
- No assumption on data distribution
- Efficient classifier representation using limited number of data
- Probability estimation through pair-wise voting scheme

Linear Combination Model



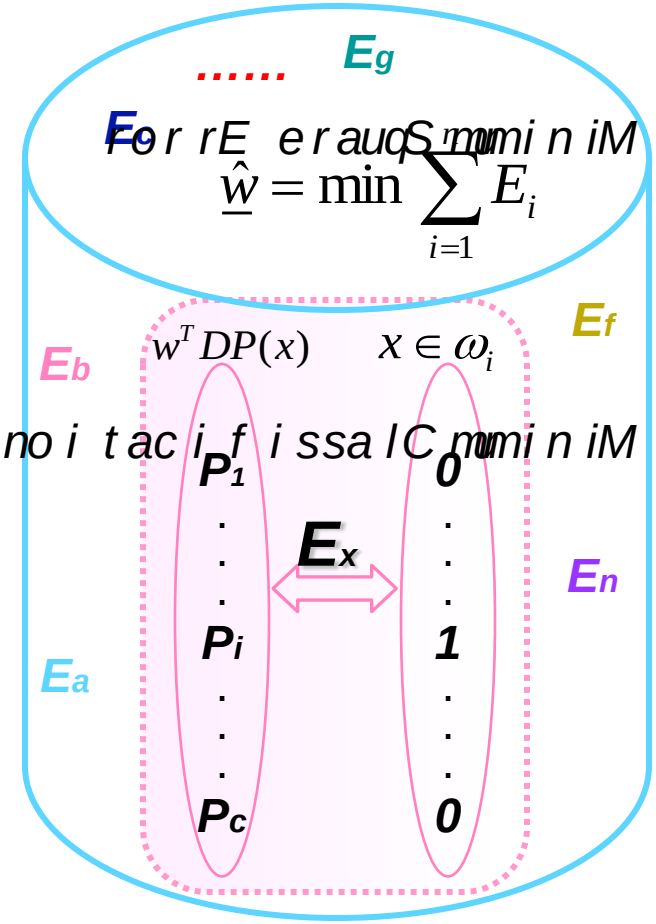
Query & Classifiers

Decision Profile for Query

Linear Combination Model

Combined Probability Estimation

Optimal Weight Estimation



$$\hat{\underline{w}} = \min \sum_{i=1} E_i$$

$$\hat{\underline{w}} = \arg\min_{w} \{ \sum_{i=1}^{N} \sum_{j=1}^{C} (w^T DP(x_i) - b_i)^2 \}$$

$$d_k(x,w) = -f^{(k)}(x,w) + \max_{j \neq k} f^{(j)}(x,w)$$

$$\hat{w} = \arg\min \{ \frac{1}{N} \sum_{i=1}^{N} \sum_{j=1}^{C} (\frac{1}{1+e^{\xi d_k(x,w)}} 1(x_i \in \omega_k) \}$$

Adapted MCE

- Concurrently minimize classification error and maximize likelihood estimation for the right choice

$$g(x_i;w) = -\log(d_{com,k}(x_i;w)) + \log(\max_{j\neq k} d_{com,j}(x_i;w)) - \delta\log(d_{com,k}(x_i;w))$$

$$= -(1+\delta)\log(d_{com,k}(x_i;w)) + \log(\max_{j\neq k} d_{com,j}(x_i;w)) \quad \text{when } x_i \in \omega_k, i = 1,\ldots N, \quad \delta > 0$$

$$l(x;w) = \log(b_k(x) - \log(d_{com,k}(x;w)) = -\log(d_{com,k}(x;w))$$

$$\text{where } \log(b_{ik}(x)) = 0 \text{ when } x \in \omega_k.$$

$$\uparrow P(x \in \omega_k) \overset{?}{=} \downarrow \max_{j\neq k} P(x \in \omega_j)$$

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Engineering Shape Benchmark

Flat Thin Wall Components	
Bracketlike parts	18
Clips	4
Contact Switches	8
Curved Housings	9
Doors	7
Rectangular Housings	14
Slender Thin Plates	12
Thin Plates	23
Total	**95**

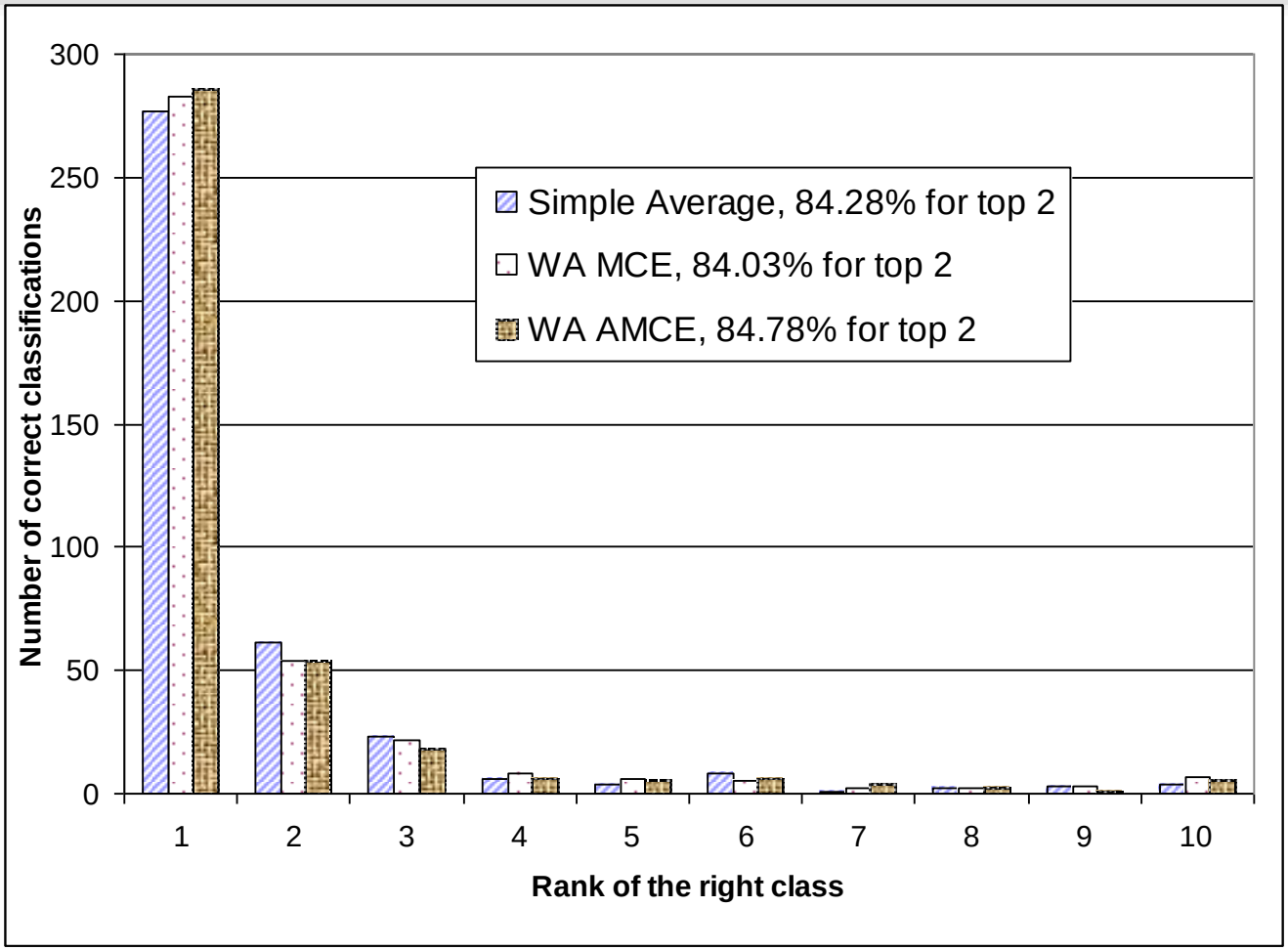
Prismatic Parts	
Bearing Blocks	7
Contoured Surfaces	5
Handles	18
L Blocks	7
Long Machine Elements	15
Machined Blocks	9
Machined Plates	49
Motor Bodies	7
Prismatic Stock	36
Rocker Arms (*)	10
Slender Links	13
Small Machined Blocks	12
T shaped parts	15
Thick Plates	12
Thick Slotted plates	20
U shaped parts	25
Total	**260**

Solids of Revolution	
90 degree bends (*)	41
Bearing like parts	20
Bolt like parts	53
Container like parts	10
Cylindrical Parts	43
Discs	51
Flange like parts	15
Gearlike parts	36
Long pins	58
More than two openings (*)	9
Non 90 bends (*)	8
Nuts	19
Oil pans (*)	8
Posts	11
Pulley like parts	12
Round, Change at end	21
Shelled Tubes	16
Spoked Wheels	15
Total	**446**

http://purdue.edu/shapelab

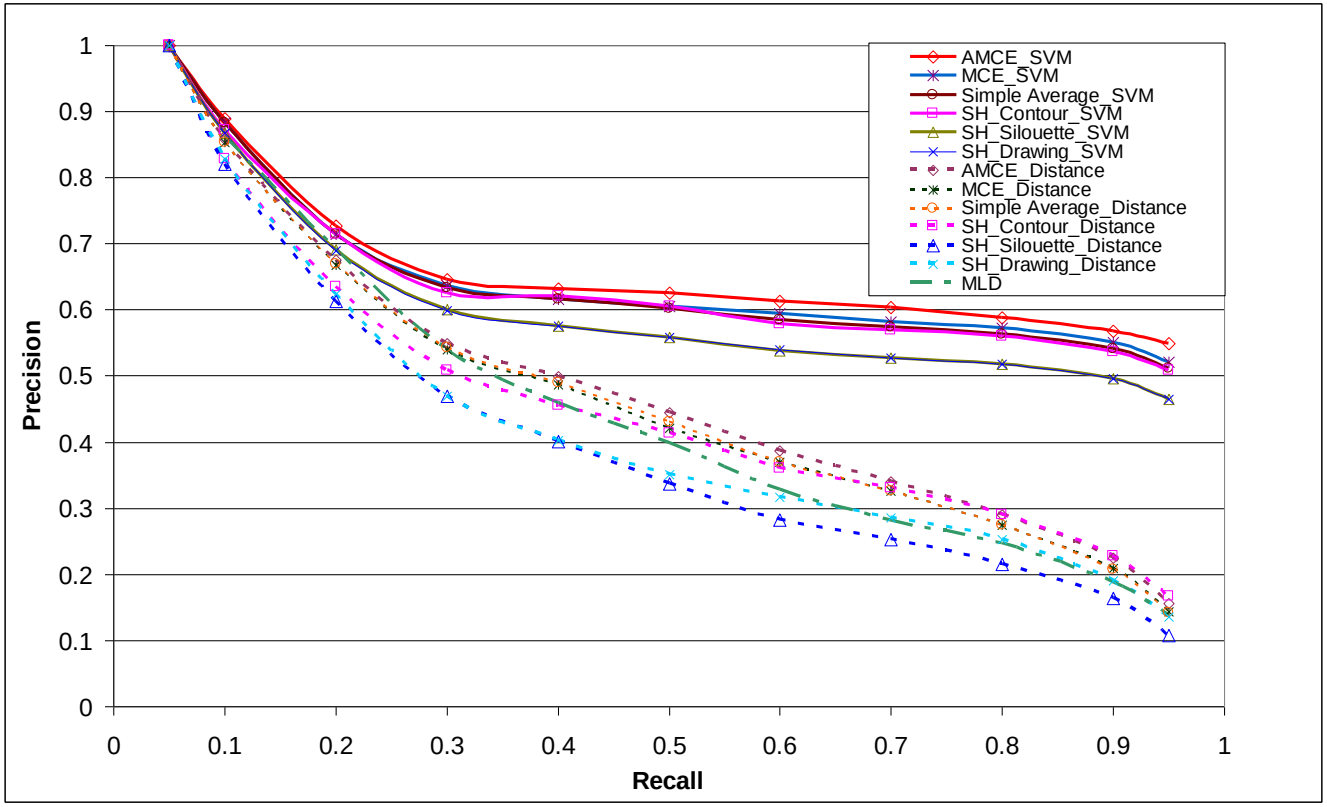
Jayanti S., Kalyanaraman Y., Iyer N.,and Ramani K., “Developing an Engineering Shape Benchmark for CAD Models", accepted by Journal of Computer Aided Design, special issue on shape similarity

Classification performance



Precision and Recall Curve

$$\text{Unified Distance}(x,y) = \frac{\text{Shape Similarity Distance}(x,y)}{P(x \in \omega_i \mid x,y \in \omega_i)} = \frac{MLD(x,y)}{P(x \in \omega_i \mid x,y \in \omega_i)}$$



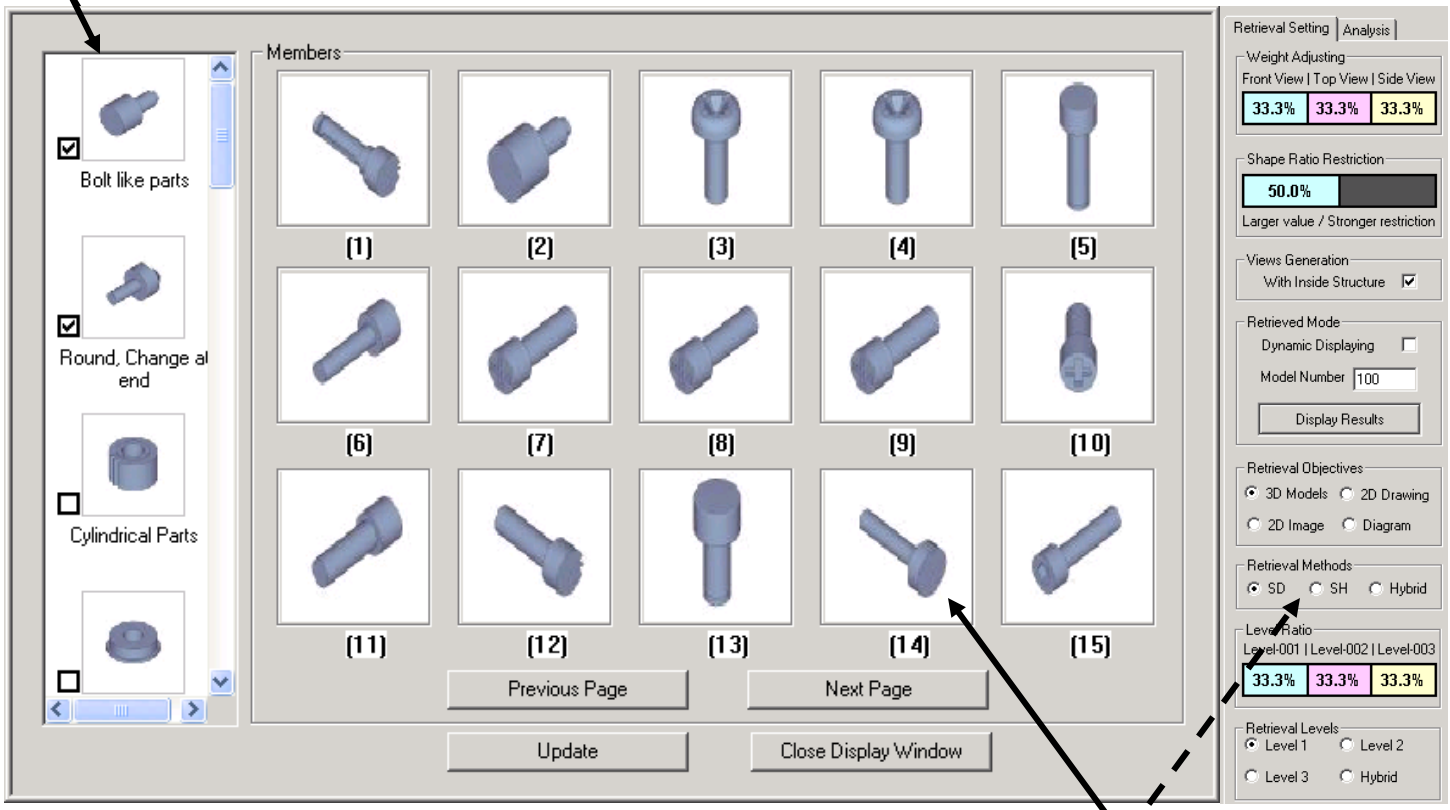
Classification Accuracy
Over 801 models
from 42 groups

SH_Level1	0.7229
SH_Level2	0.6667
SH_Level3	0.6629
AMCE	0.7513
MCE	0.7253
Simple Average	0.7266

AOD w.r.t MLD = 23.2%

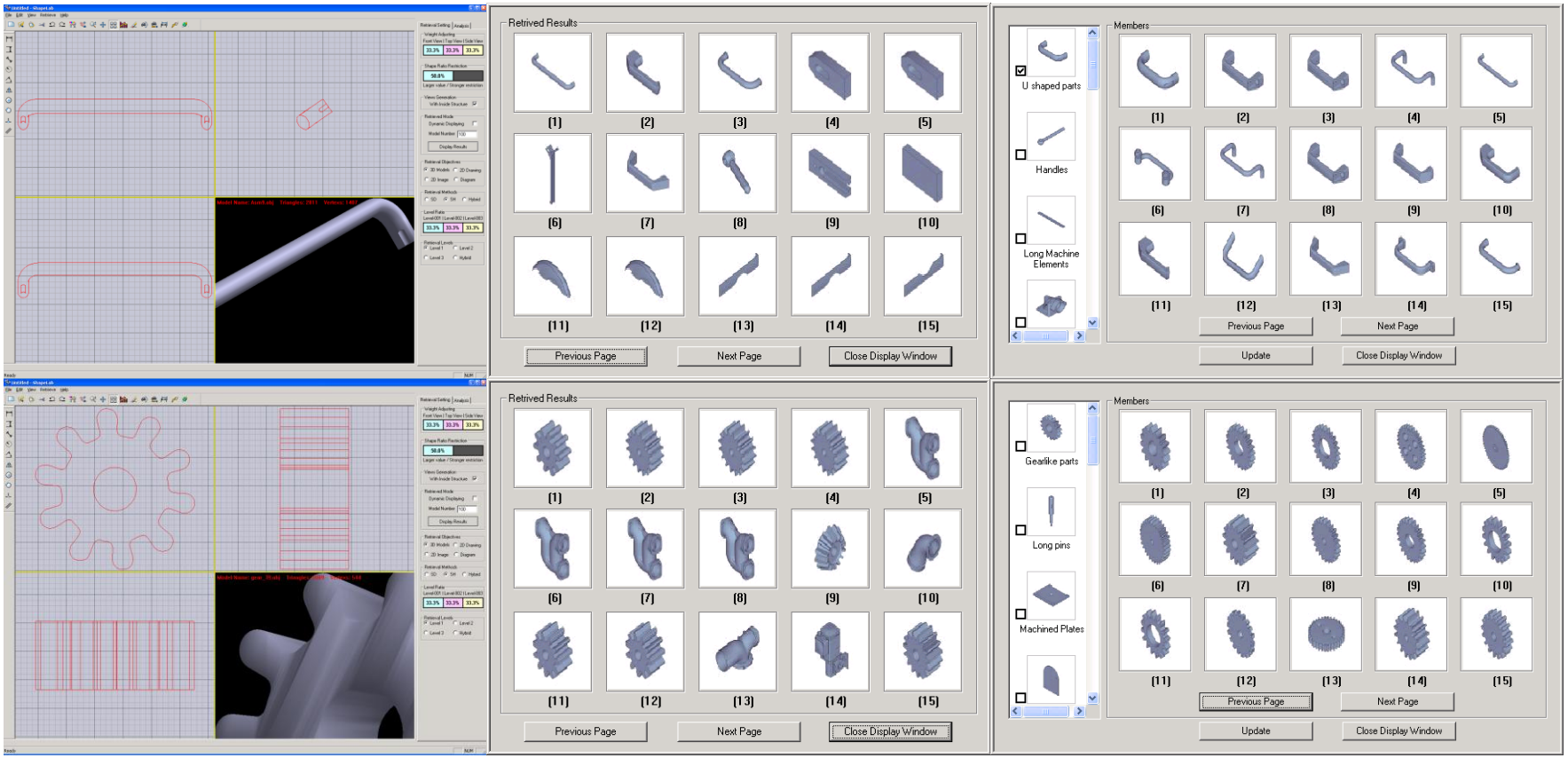
Probability-based Unified Search GUI

Recommended Class List



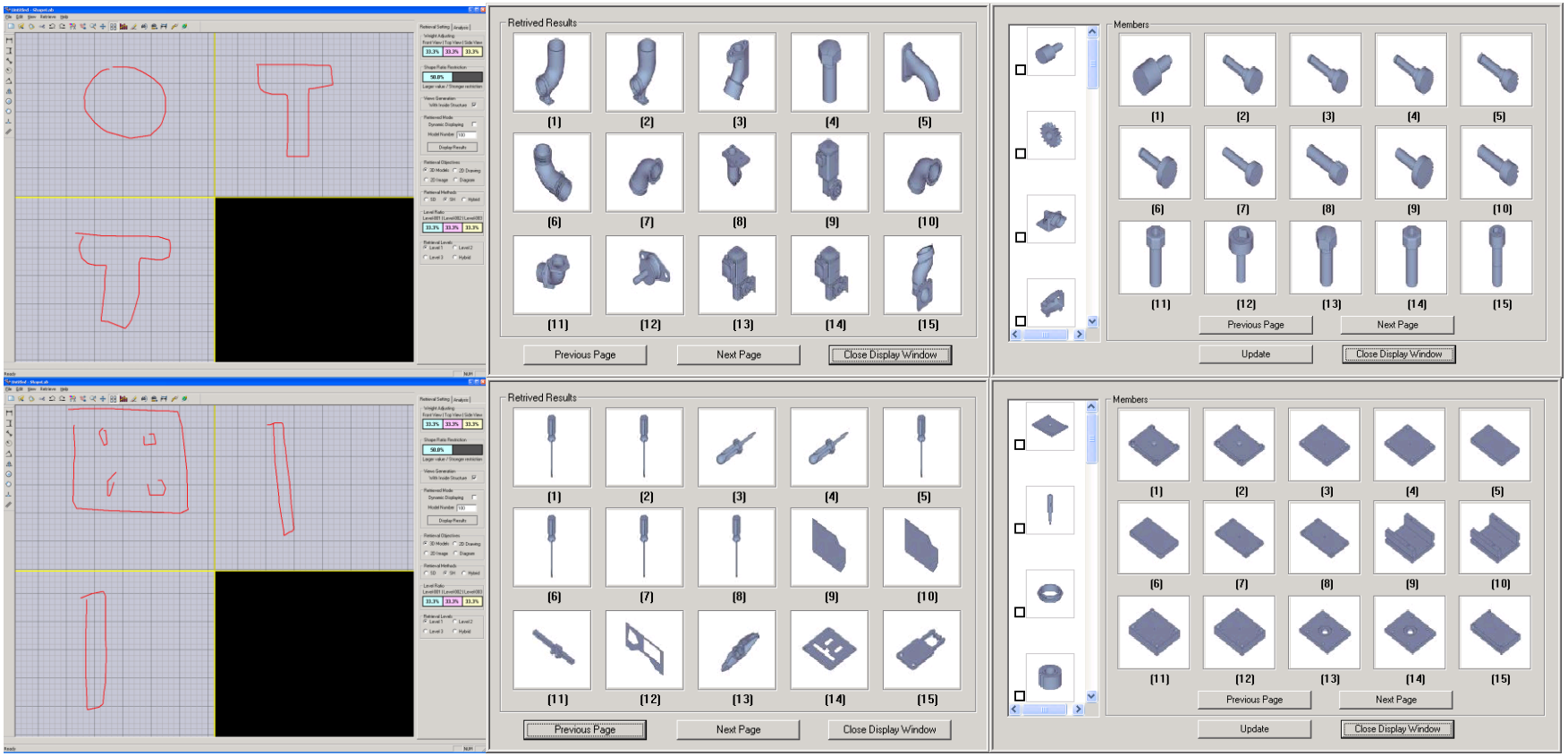
Customizable Shape Search Results within Selected Classes

Query by Examples



Query | Shape Search Only | Unified Search

Query by Sketches



Query | Shape Search Only | Unified Search

Conclusions

- Proposed unified shape searching framework with nondeterministic classifier combination
- Developed a improved probability-based combination rule
- Improved search performance by AOD of 23.2%
- Implemented a prototype with effective user interaction