# Boosting the Efficiency of Target Face Recognition through Image Hybridization

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## Why

**One of the great challenges in security is the ability to efficiently and accurately recognize individuals of interest from images or video streams. Face recognition of target individuals is problematic due to the high-dimensional representations of faces that are necessary for high accuracy, and the need to avoid the erroneous identification of targets.**

## What

**One popular way of reducing false positive errors is by searching for targets within a large database dominated by control images. We propose techniques for boosting the efficiency of handling identification queries by means of hybridizations between target faces and control faces. Hybridization improves indexability while still allowing for reasonable query times.**

## A Cautionary Tale

### TOSHIBA NEDO PROJECT

- "Practical Development of Large-scale Systems for Human Face Recognition" (2009 – 2011).
- Goal: fast recognition of a limited number of target faces from video streams ($10^2 \rightarrow 10^3$).
- Example: terrorist suspects from airport surveillance video.
- Problem: avoid false positive identifications.

### POSSIBLE SOLUTION?

- Build large background set of control (non-target) images (~$10^6$).
- Combine targets and controls into a single index.
- For each query, return $k$ most similar faces ($k = 10^2 \rightarrow 10^3$).
- Within each query result, check for instances of target faces, and verify.

### PERFORMANCE

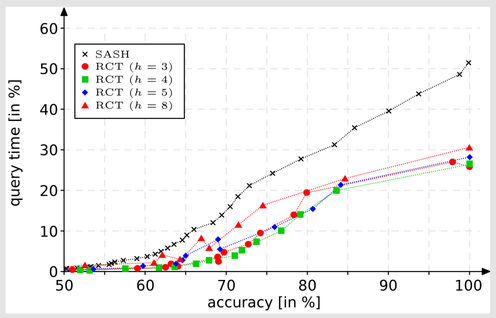
- Toshiba face vector $\rightarrow$ 2560 features.
- 98%+ accuracy using sequential search.
- Time to execute a single query on $10^6$ faces: 25s!
- More efficient indexing strategy is needed...

### INDEXING EXPERIMENT

- Indices considered: LSH, Cover Tree, SASH, RCT...
- Data sets considered:
  - Toshiba Faces ($10^6$ morphs generated from 9863 Toshiba employee ID photos).
  - WikiFaces (2* $10^5$ public domain face images crawled from the Wikimedia Commons archive)
  - Both vectorized using Toshiba features (2560 dimensions).

### OUTCOMES

- Uniformly poor!
- Trade-off between accuracy and time essentially no better than sequential search.
- However, some sets with dimensionality on the order of $10^5 \rightarrow 10^6$ *are* indexable.
- Example: Reuters2 Corpus (subset): 554,651 documents, 320,647 keyword dimensions.




- Question: why are some high-dimensional data sets indexable? Why are faces not?

### GENERALIZED EXPANSION DIMENSION

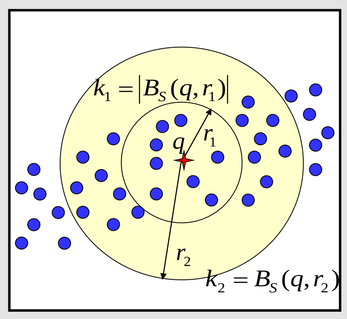
- Proposed measure of the intrinsic dimensionality of data, generalized from the expansion dimension of Karger & Ruhl.
- Dimension $m$ can be computed exactly from volume and radii of spheres.

$$m = \frac{\log \mathrm{Vol}(q, r_2) - \log \mathrm{Vol}(q, r_1)}{\log r_2 - \log r_1}$$

- In practice, volumes can be estimated by numbers of points enclosed in the balls.
- Distributional assumptions depend on similarity measure.
- Max expansion dimension: max value of $m'$ over range of choices of $k_1$ and $k_2$:

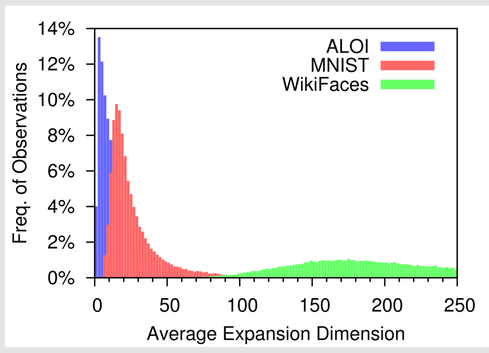
$$m' = \frac{\log k_2 - \log k_1}{\log r_2 - \log r_1}$$

- Average expansion dimension: useful for characterizing difficulty of data sets and difficulty of queries.




### INDEXABILITY

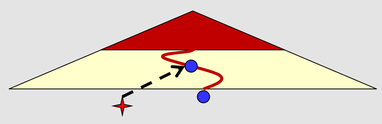
- Intrinsic dimension of face data is *much* higher than that observed in indexable data.




- Lack of transitivity: $x$ similar to $y$ and $y$ similar to $z \not\Rightarrow x$ similar to $z$.
- Similarity measure supports *matching* but not *transitivity*.
- Conclusion: similarity values are meaningless across different individuals.

## Hybridization Strategy

- Promote transitivity by replacing control faces by hybrids between targets and controls.
- Each target face is more similar to its hybrids than to other faces; other face relationships have no particular similarity.
- At lower levels of the index, positive queries require that the target have at least one hybrid node that is similar to the query.

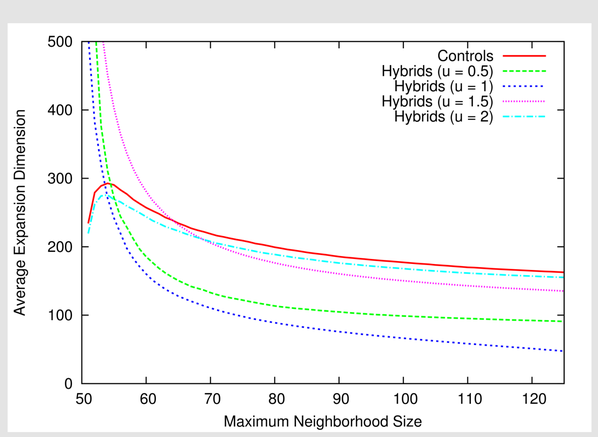


- Search:
  - Visit all nodes at top levels of the structure.
  - At lower levels, visit a limited number of nodes similar to the query.
  - Classify by voting among query result hybrids as to whether one target dominates.

- Hybrid index:
  - Target set $T$ of size $m$.
  - Number of hybrids per target: $m^u$.
- Probability of level $i$ containing no hybrids of a given target is at most

$$\Pr[H(v) \cap L_i] \le e^{-m^u / 2^i}$$

- $u$=1 $\Rightarrow$ O($m$) query time in index of lower intrinsic dimensionality.
- Classification: not yet assessed.

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