**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.

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### A Cautionary Tale

<table>
<thead>
<tr>
<th>TOSHIBA NEDO PROJECT</th>
<th>POSSIBLE SOLUTION?</th>
<th>PERFORMANCE</th>
<th>INDEXING EXPERIMENT</th>
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</thead>
<tbody>
<tr>
<td>&quot;Practical Development of Large-scale System for Human Face Recognition&quot; (2009 – 2011).</td>
<td>Build large background set of control (non-target) images (~15P).</td>
<td>Toshiba face vector (\rightarrow) 2560 features.</td>
<td>Indices considered: LSH, Cover Tree, SASH, RCT,...</td>
</tr>
<tr>
<td>Goal: fast recognition of a limited number of target faces from video streams (10(^{12})–10(^{15})).</td>
<td>Combine targets and controls into a single index.</td>
<td>98%+ accuracy using sequential search.</td>
<td>Data sets considered:</td>
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<tr>
<td>Example: terrorist suspects from airport surveillance video.</td>
<td>For each query, return 2000 closest similar faces ((k = 10^{15}-10^{15})).</td>
<td>Time to execute a single query on 10(^{12}) faces: 25s!</td>
<td>o Toshiba Faces (10(^{10}) morphs generated from 9863 Toshiba employee ID photos).</td>
</tr>
<tr>
<td>Problem: avoid false positive identifications.</td>
<td>Within each query result, check for instances of target faces, and verify.</td>
<td>More efficient indexing strategy is needed...</td>
<td>o WikiFaces (2 (\times) 10(^{10}) public domain face images crawled from the Wikimedia Commons archive).</td>
</tr>
</tbody>
</table>

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### 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\(^{12}\)–10\(^{15}\) are indexable.
- Example: Reuters2 Corpus (subset): 554,651 documents, 420,647 keyword dimensions.

### 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.
- 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 \(k_2\):

\[
\frac{\log \text{Vol}(q, r_1) - \log \text{Vol}(q, r_i)}{\log r_i - \log r_1}
\]

- 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 \(z\) may not imply \(x\) similar to \(z\).
- Similarity measure supports matching but not transitivity.
- Conclusion: similarity values are meaningless across different individuals.

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### 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.

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**HYBRID INDEXING**

- Target set \(T\) of size \(m\).
- Number of hybrids per target: \(m\).
- Probability of level \(i\) containing no hybrids of a given target is at most

\[
P_i(H \cap T) \leq e^{-c N_i^{1/2}}
\]

- \(c \approx 1\) \(O(m)\) query time in index of lower intrinsic dimensionality.
- Classification: not yet assessed.

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**HYBRIDIZATION**

- "Urgent need for effective and efficient identification of individuals of special interest from huge video data sets".

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**CONCLUSION**

- "Overall, hybridization of targets and controls is a promising strategy for improving the efficiency and accuracy of face identification in large video databases."