Metrics for Benchmarking Computational Workload Reduction

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https://www.christoph-busch.de/about-talks-slides.html

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Overview

Agenda

- Problem description
- Techniques for computational workload reduction
- Standardised metrics for identification systems evaluation
- Future - what should be added to ISO/IEC 19795-1
- Conclusion
Problem Description
Biometric applications (as defined in ISO/IEC 2382-37)

- **Verification**: process of confirming a biometric claim through biometric comparison
  - computational trivial case of a 1:1 comparison

- **Identification**: process of searching against a biometric enrolment database to find and return the biometric reference identifier(s) attributable to a single individual
  - in the worst case: compare a probe against all enrolled references
Challenges of Identification Applications

Exhaustive search (naive approach)

• Increasing **risk of false positive decision**
  ‣ The probability becomes quickly unacceptable: linear increase with size $N$ of the database

• Increasing costs
  ‣ Faced by large scale deployments (e.g. forensic systems)
  ‣ Leading to upscaling of the infrastructure (**hardware costs**) and increasing **operational costs** (complexity of the infrastructure)
  ‣ Leading to reduced usability (**transaction time**) for instance for mobile police personnel requesting response from centralized forensic system
  ‣ Leading to delays in de-duplication tasks
Challenges of Identification Applications

Some examples of large databases

- single 1:1 transaction with COTS fingerprint system [Neu17]
- 1:N grows linearly, N:N grows quadratically

<table>
<thead>
<tr>
<th>Size (Size)</th>
<th>1:N (Time)</th>
<th>N:N (Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40k</td>
<td>0.03s</td>
<td>22m</td>
</tr>
<tr>
<td>600k</td>
<td>0.5s</td>
<td>3d</td>
</tr>
<tr>
<td>5M</td>
<td>4s</td>
<td>241d</td>
</tr>
<tr>
<td>500M</td>
<td>7m</td>
<td>&gt;6000y</td>
</tr>
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</table>
Techniques for Computational Workload Reduction -
a.k.a as Indexing Methods
Computational Workload Reduction Methods

- Cascading algorithms, Serial combination and Pre-selection
  - The probe is exhaustively compared to the enrolled templates using a computationally efficient (but somewhat inaccurate) comparator/algorithm.
  - A candidate (short)list (significantly smaller than the whole DB) is produced.
  - The candidate (short)list is searched exhaustively using the normal, accurate (but computationally expensive) comparator/algorithm [Gent2009]

Penetration rate can be reduced
Computational Workload Reduction Methods (2)

- Binning, Classification, Clustering

  - The DB is split into a number of bins/classes/clusters (e.g. based on metadata like sex, ethnicity, age, or statistical features of the templates).
  - Template comparisons are performed within the bin/class/cluster of the DB corresponding to that of the probe [Mhatre2005]

Penetration rate can be reduced
Computational Workload Reduction Methods (3)

- Hierarchical retrieval
  - An efficient search structure (e.g. trees, fuzzy hashing) for the DB is created.
  - The retrieval of candidate list/identity proceeds in sub-linear time [Proenca2017]

Penetration rate can be reduced
Methods can be combined (e.g. binning followed by indexing)
Computational Workload Reduction Methods (4)

- Efficient representations
  - The size or form of templates is changed (e.g. through binarisation) thus making them more compact or capable of utilising more efficient instructions, particularly the bitwise operators [Xu2008]
  - Other properties of templates are changed (e.g. exhibiting pose/alignment invariance, and thus not needing to compensate for those during comparisons, for instance as is the case for Iris-Codes and circular shifting) [Rathg2013]

- Efficient comparators
  - The comparator is augmented in some way (e.g. by taking advantage of some intrinsic template properties), thus requiring less computational workload [Rathg2016]

Computational cost of single template comparison can be reduced
Workload Reduction - An Overview

Relevance in system evaluations
(see FRVT-2018 presentation by Patrick Grother)

An evaluation shall report accuracy AND search duration
Standardised Metrics for Identification System Evaluation
Which Metrics do we have today?

Metrics to evaluate identification systems are defined in ISO/IEC 19795-1:2006

• **Accuracy** determined by recognition performance
  
  ‣ **false-positive identification-error rate (FPIR)**
  
  proportion of identification transactions by users not enrolled in the system, where an identifier is returned

  ‣ **false-negative identification-error rate (FNIR)**
  
  proportion of identification transactions by users enrolled in the system in which the user’s correct identifier is not among those returned

• **Search** duration only indicated by **penetration rate** and **pre-selection error** (p-s-e rate is the complement to the hit rate)
  
  ‣ **penetration rate**
  
  <pre-selection algorithm> measure of the average number of pre-selected templates as a fraction of the total number of templates

  ‣ If binning/classification/clustering is in place, then we report the **pre-selection error rate**
  
  proportion of genuine attempts where the enrolment template corresponding to the input sample is not in the pre-selected subset of templates that would be compared with the input sample
Why is this not sufficient?
As we can combine multiple computational workload reduction methods

- the pure penetration rate is not sufficient to report about duration
- computational workload can be reduced irrespective of the penetration rate (e.g. different, more efficient template representations in an exhaustive search)

Duration of a single transaction depends on

- number of enrolled references (# of data subjects in the DB)
- computational workload (i.e. of the transaction in the biometric system under test)
  - workload is dependent on hardware (processor and memory available) on which the system is operating
  - this is not necessarily reproducible by another testing lab
- which workload reduction methods are combined

Therefore: for a given hardware environment (SOTA baseline) we need to measure workload reduction in terms of

- workload difference (w.r.t. to the selected baseline) @ defined number of enrolled references
ISO/IEC 19795-1:202x is currently under revision

- The 3rd Working Draft (WD) is
  - Waiting for comments by 2018-11-30
  - Containing a definition in Clause 4.29 for computational workload
    - total computational effort of a single transaction (or set of transactions) in a biometric system, including execution time, memory requirements, etc.
  - Indicating in Clause 8.10.2, what must be considered for identification systems
    - Generation of a biometric probe from the captured biometric sample
    - Pre-selection to reduce workload of identification search
    - Identification search over the reference database
    - Production of candidate list and deciding identification outcome

The proposed metrics should be **hardware independent**, if possible.

Therefore the **number of intrinsic operations** is more relevant than execution time: For example the number of bit or float comparisons will allow a cross-platform benchmark.
ISO/IEC 19795-1:202x is currently under revision

- The next Working Draft (WD) should also contain a new metric in Clause 8.10.2 for computational workload (CW)
  - which considers the number of enrollees $N$
  - the penetration rate $p$
  - the cost of a single feature vector comparison $C$
  - the cost of the pre-selection $c$
  - the costs for production of the candidate list and decision $l$

$$ CW = N \times p \times C + c + l $$

The cost for pre-processing (e.g. segmentation) is negligible, as it is conducted for the probe only.
ISO/IEC 19795-1:202x is currently under revision

• Then we have the illustrating new metric in Clause 8.10.3 for
  ‣ computational workload difference (CWD)
    - which is the proportion of workload w.r.t. to the baseline system (SOTA)
    - tested on a select hardware
    - takes into account the number $N$ of enrolees

\[
CWD(N) = 1 - \frac{CW_i}{CW_b}
\]

- where $CW_i$ is the $i$-th system under test
- where $CW_b$ is the baseline system chosen by the evaluator

We subtract the fraction of the computational workload reduction from the baseline, which is 1 or 100%
Example Evaluation
According to the proposed metric

- Suppose an iris identification system with $N = 1000$ enrollees and for the sake of simplicity assume the decision costs ($l$) such as candidate list sorting to be negligibly small.

- In the baseline scenario, a state-of-the-art iris-code based system is used with:
  - Template size of 10.240 bits
  - Hamming distance based comparator performing 17 circular shifts for alignment compensation, i.e. $C = 10.240 \times 17 = 174.080$ bit comparisons
  - Exhaustive search ($p = 1.0, c = 0.0$)

- Further, suppose a system with a pre-selection algorithm [Gent2009], where computationally efficient templates are used in the first step to create a candidate shortlist, followed by the aforementioned state-of-the-art algorithm in the second step operating on the shortlist only:
  - 5% of the original database size is pre-selected as a candidate shortlist, i.e. $p = 0.05$
  - The compact templates have the size of 2048 bits, are compared using Hamming distance, and require no alignment compensation. Hence, the pre-selection costs are: $c = 1000 \times 2048 = 2.048 \times 10^6$ bit comparisons
Example Evaluation

According to the proposed metric

- The computational workload of this baseline is then:
  \[ CW_b = 1000 \times 1.0 \times 174.080 + 0 = 1.7408 \times 10^8 \]
  bit comparisons

- The computational workload of the system is then:
  \[ CW_i = 1000 \times 0.05 \times 174.080 + 2.048 \times 10^6 = 1.0752 \times 10^7 \]
  bit comparisons

- Finally, the computational workload difference between the proposed system and a state-of-the-art baseline at 1000 enrollees is:
  \[ CWD(1000) = 1 - \frac{1.0752 \times 10^7}{1.7408 \times 10^8} = 93.82\% \]
  in other words, the proposed system reduces the computational workload by over 90% w.r.t. the baseline system
Future - What needs to be done?
In order to learn, where and how to improve identification systems, we need

- to measure computational workload reduction in terms of transaction duration
- and combine accuracy testing reports with duration testing reports

Future work

- There are numerous competitions on this topic, which should be aligned to a standardised metric, e.g.
  - Bologna: FIDX-TEST
    https://biolab.csr.unibo.it/fvcongoing/UI/Form/ICB2013FIDX.aspx
    https://biolab.csr.unibo.it/FvcOnGoing/UI/Form/PublishedAlgs.aspx
  - NIST: FRVT 1:N 2018 Evaluation
References

Publications

• [Drod2019] P. Drozdowski, C. Rathgeb, C. Busch: „Computational Workload in Large-Scale Biometric Identification Systems“, under review
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