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Ongoing Face Recognition Vendor Test (FRVT)

Part 1: Verification

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Specific hardware and software products identified in this report were used in order to perform the evaluations described in this document. In no case does identification of any commercial product, trade name, or vendor, imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose.

ABOUT THIS REPORT

This report is a draft NIST Interagency Report, and is open for comment. It documents the verification-track of the ongoing Face Recognition Vendor Test. The report will be updated continuously as new algorithms are evaluated, as new datasets are added, and as new analyses are included. Comments and suggestions should be directed to frvt@nist.gov.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

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FNMR(T) "False non-match rate"
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1 News

2017-10-03

- In 2018, NIST will run an evaluation of 1:N identification algorithms.
- The test will use N well in excess of 10^7.
- The test will proceed with a fixed participation deadline, likely in February 2018.
- The API and concept document is linked from here.

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2 Changelog

2017-11-16

- ▷ Added results for algorithms from 3DiVi, Dermalog, Neurotechnology and Ping An.
- ▷ Retired results for 3DiVi-000, dermalog-002, and neurotechnology-000 - FRVT lists only two algorithms per organization.
- ▷ Retired results for vcognition-001 as the algorithm was inoperable on at least one dataset.
- ▷ Added cross-pose recognition heatmaps for the wild images, Figures 10 and 11.
- ▷ Added Figure 14 to compare effect of providing whole vs. face-cropped child exploitation images.

2017-10-03

- ▷ Added results for algorithms from 3DiVi, Camvi, Idemia, Noblis, N-TechLab, and Visionlabs.
- ▷ Added partial results for two algorithms from Zhuhai Yisheng.
- ▷ The ntechlab-000 algorithm has been retired - FRVT lists only two algorithms per organization.
- ▷ Corrected fixed FMR operating point in the legends of some DET plots.

2017-08-22

- ▷ Added results for three additional algorithms, rankone-002, neurotechnology-001, and itmo-002.
- ▷ The algorithms dermalog-001 and rank-001 have been retired - FRVT lists only two algorithms per organization
- ▷ The algorithm tupel-001 has been retired as it is not operable on all datasets
- ▷ Clarified the tradeoff Figures 1 and 2 plot only genuine comparison durations.
- ▷ Corrected image type label in section 4.5

2017-08-07

- ▷ Added results for 5 new algorithms
- ▷ Added Figure 3 giving simulated example images.
- ▷ Added Figure 1 showing an alternative view of the same tradeoff data in Figure 2
- ▷ Added Figure 5 showing accuracy on visa images just for low FMR.
- ▷ Added Figure 23 showing impostor distribution shifts from certain country pairs. Section 5.6.1 in this and prior reports documents high false match rates for individuals from certain countries. That effect, however, is often not confined to anomalously high impostor scores in the tails of the distribution, but arises from systematic shifts of the whole distribution. These shifts sometimes reach 2σ.

2017-07-29

- ▷ Added results for 8 new algorithms
- ▷ Added results for a child-exploitation dataset
- ▷ Added Table 2 a standalone tabulation of false non-match rates
- ▷ We have received additional CPU algorithms - Results should appear August 4, 2017
- ▷ We have received additional GPU algorithms - Results to appear as computational resources are released from the Face Recognition Prize Challenge

2017-06-19

- ▷ Added five new algorithms, three of which remain in-process
- ▷ Added results for a "wild" dataset of images similar to non-cooperative photojournalism images
- ▷ Added Table 3 a standalone tabulation of failure to enrol rates
- ▷ Added Fig. 2 showing tradeoff between FNMR, template size, template generation time, and match duration.
- ▷ Added Fig. 19 showing how FMR is concentrated in certain images.
- ▷ Restated cross-region false match rates at nominal FMR = 0.0001 instead of 0.001
- ▷ Improved DET legends.

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	Developer	Short	Seq.	Validation	Config[1]	Template		GPU	Comparison Time (ns)[3]	
	Name	Name	Num.	Date	Data (KB)	Size (B)	Time (ms)[2]		Genuine	Impostor
1	3DiVi	3divi	001	2017-06-22	190867	^{28}4096 ± 0	^{17}274 ± 47	Yes	^{4}636 ± 19	^{5}634 ± 16
2	3DiVi	3divi	002	2017-10-20	190867	^{29}4096 ± 0	^{18}279 ± 48	Yes	^{7}692 ± 22	^{8}707 ± 26
3	Ayonix	ayonix	000	2017-06-22	58505	^{13}1036 ± 0	^{1}18 ± 2	No	^{3}621 ± 23	^{4}620 ± 26
4	Camvi Technologies	camvitech	001	2017-09-13	118759	^{12}1024 ± 0	^{13}181 ± 6	No	^{1}481 ± 16	^{3}487 ± 23
5	Cyberextruder	cyberex	001	2017-08-02	121211	^{7}256 ± 0	^{34}893 ± 25	No	^{13}1083 ± 16	^{15}1079 ± 19
6	Dermalog	dermalog	003	2017-07-10	0	^{14}1043 ± 0	^{9}121 ± 22	No	^{25}22957 ± 93	^{28}22808 ± 131
7	Dermalog	dermalog	004	2017-10-26	0	^{2}128 ± 0	^{11}149 ± 5	No	^{2}490 ± 26	^{2}471 ± 26
8	Digital Barriers	barriers	000	2017-05-31	157794	^{20}2056 ± 0	^{6}104 ± 0	No	^{23}13232 ± 166	^{25}13226 ± 146
9	Digital Barriers	barriers	001	2017-07-20	236915	^{22}2056 ± 0	^{19}294 ± 1	No	^{22}12311 ± 164	^{24}12347 ± 197
10	ID3 Technology	id3	001	2017-08-04	225574	^{11}520 ± 0	^{14}238 ± 19	No	^{12}1058 ± 32	^{14}1049 ± 28
11	ID3 Technology	id3	002	2017-08-04	225574	^{10}520 ± 0	^{24}482 ± 34	No	^{14}1100 ± 59	^{13}1048 ± 32
12	Innovatrics	innova	000	2017-07-25	0	^{4}146 ± 0	^{25}578 ± 5	No	^{19}4964 ± 63	^{20}4665 ± 262
13	Innovatrics	innova	001	2017-07-25	0	^{9}284 ± 0	^{29}645 ± 5	No	^{20}5506 ± 131	^{21}4975 ± 308
14	Is It You	isityou	000	2017-06-26	48010	^{36}19200 ± 0	^{8}113 ± 5	No	^{36}237517 ± 1318	^{36}237374 ± 1279
15	ITMO University	itmo	001	2017-06-12	1923215	^{37}37997 ± 0	^{38}959 ± 18	No	^{26}28901 ± 1492	^{29}27517 ± 186
16	ITMO University	itmo	002	2017-08-07	1923215	^{31}4162 ± 0	^{28}611 ± 17	No	^{21}7423 ± 96	^{22}7451 ± 94
17	Idemia	morpho	000	2017-07-11	100806	^{1}116 ± 0	^{7}109 ± 1	No	^{11}993 ± 31	^{12}1000 ± 34
18	Neurotechnology	neurotech	001	2017-08-07	280771	^{26}2718 ± 0	^{33}881 ± 46	No	^{33}69356 ± 684	^{33}69140 ± 579
19	Neurotechnology	neurotech	002	2017-11-02	280771	^{27}2718 ± 0	^{26}581 ± 6	No	^{31}68738 ± 748	^{32}68905 ± 993
20	Noblis	noblis	000	2017-07-05	713573	^{15}1061 ± 0	^{12}174 ± 20	Yes	^{15}1343 ± 45	^{17}1373 ± 56
21	N-Tech Lab	ntech	001	2017-05-10	691296	^{34}6744 ± 1	^{27}587 ± 11	No	^{30}67692 ± 833	^{31}67486 ± 244
22	N-Tech Lab	ntech	002	2017-08-23	894169	^{33}6744 ± 1	^{21}330 ± 11	No	^{34}82508 ± 213	^{34}82524 ± 220
23	Ping An Technology	Pingan	002	2017-09-25	442564	^{35}18436 ± 0	^{10}132 ± 7	Yes	^{17}3088 ± 32	^{18}3051 ± 28
24	Rank One Computing	rankone	000	2017-03-21	0	^{3}144 ± 0	^{3}82 ± 9	No	^{29}39932 ± 468	^{23}8722 ± 171
25	Rank One Computing	rankone	002	2017-08-18	0	^{6}224 ± 0	^{2}75 ± 1	No	^{32}69113 ± 3802	^{1}369 ± 26
26	Samtech InfoNet Limited	samtech	000	2017-05-02	109774	^{21}2056 ± 0	^{15}262 ± 2	No	^{18}4550 ± 26	^{19}4541 ± 28
27	TongYi Transportation Technology	tongyi	001	2017-04-01	625339	^{23}2058 ± 0	^{20}310 ± 20	No	^{24}17769 ± 74	^{26}17750 ± 63
28	TongYi Transportation Technology	tongyi	002	2017-07-15	625336	^{24}2058 ± 0	^{22}356 ± 35	No	^{27}29816 ± 281	^{27}17799 ± 127
29	VCognition	vcog	002	2017-06-12	3229434	^{38}61504 ± 5	^{23}357 ± 25	No	^{37}296154 ± 3077	^{37}296436 ± 4183
30	Vigilant Solutions	vigilant	001	2017-06-13	344685	^{17}1544 ± 0	^{36}921 ± 2	No	^{5}644 ± 13	^{6}649 ± 16
31	Vigilant Solutions	vigilant	002	2017-09-28	344137	^{25}2060 ± 0	^{32}844 ± 2	No	^{6}679 ± 10	^{7}680 ± 7
32	VisionLabs	visionlabs	001	2017-06-12	343661	^{5}204 ± 0	^{37}943 ± 8	No	^{16}1395 ± 45	^{16}1148 ± 53
33	VisionLabs	visionlabs	002	2017-09-08	591936	^{8}264 ± 0	^{16}265 ± 8	No	^{9}796 ± 35	^{10}799 ± 31
34	Vocord	vocord	001	2017-04-21	616989	^{32}6194 ± 0	^{35}908 ± 16	No	^{38}1094730 ± 64282	^{38}1107193 ± 66523
35	Vocord	vocord	002	2017-06-07	918292	^{16}1330 ± 0	^{31}782 ± 36	Yes	^{35}83063 ± 517	^{35}83072 ± 714
36	Zhuhai Yisheng Electronics Technology	yisheng	000	2017-08-17	122704	^{19}2048 ± 0	^{5}103 ± 1	Yes	^{8}790 ± 23	^{9}789 ± 20
37	Zhuhai Yisheng Electronics Technology	yisheng	001	2017-08-17	120112	^{18}2048 ± 0	^{4}103 ± 1	Yes	^{10}906 ± 31	^{11}905 ± 25
38	Shanghai Yitu Technology	yitu	000	2017-05-23	2211068	^{30}4130 ± 0	^{30}672 ± 2	No	^{28}35352 ± 114	^{30}37848 ± 1773

Notes	
1	The size of configuration data does not capture static data included in the libraries. We do not include the size of the libraries because some algorithms include common ancilliary libraries for image processing (e.g. openCV) or numerical computation (e.g. blas).
2	The median template creation times are measured on Intel®Xeon®CPU E5-2630 v4 @ 2.20GHz processors or, in the case of GPU-enabled implementations, NVidia Tesla K40.
3	The median comparison durations, in nanoseconds, are estimated using std::chrono::high_resolution_clock which on the machine in (2) counts clock ticks of duration 1ns. Precision is somewhat worse than that however. The ± value is the median absolute deviation times 1.48 for Normal consistency.

Table 1: Summary of algorithms and properties included in this report. The red superscripts give ranking for the quantity in that column.

		FALSE NON-MATCH RATE (FNMR)													
	Algorithm	CONSTRAINED, COOPERATIVE								LESS CONSTRAINED, NON-COOPERATIVE					
	Name	VISA		VISA		MUGSHOT		WEBCAM		SELFIE		WILD		CHILD EXP	
	FMR	1E-06		0.0001		0.0001		0.0001		0.0001		0.0001		0.01	
1	3divi-001	0.154	11	0.020	3	0.030	9	0.001	10	0.046	17	0.492	6	0.549	4
2	3divi-002	0.154	10	0.021	5	0.033	12	0.001	12	0.049	18	0.495	7	-	36
3	ayonix-000	0.487	33	0.230	36	0.309	34	0.172	36	0.360	36	0.807	27	0.843	29
4	camvi-001	0.538	35	0.183	34	0.323	35	0.106	34	0.268	35	0.743	24	0.763	20
5	cyberextruder-001	0.255	23	0.076	24	0.165	29	0.029	27	0.144	31	0.853	30	0.780	24
6	dermalog-003	0.280	25	0.112	29	0.202	32	0.041	31	0.115	29	0.693	16	0.845	30
7	dermalog-004	0.240	21	0.093	27	0.131	28	0.016	23	0.121	30	0.996	37	-	38
8	digitalbarriers-000	0.463	32	0.161	31	0.184	31	0.045	32	0.170	32	0.741	23	0.771	22
9	digitalbarriers-001	0.502	34	0.155	30	0.041	17	0.029	28	0.115	28	0.678	14	0.731	12
10	id3-001	0.250	22	0.063	22	0.036	13	0.002	13	0.040	13	0.765	25	0.688	9
11	id3-002	0.239	20	0.057	21	0.032	11	0.003	15	0.037	11	0.810	28	0.686	8
12	innovatrics-000	0.191	16	0.034	13	0.046	22	0.001	8	0.040	12	0.720	19	0.852	32
13	innovatrics-001	0.183	15	0.034	12	0.043	19	0.001	9	0.043	14	0.643	11	0.815	28
14	isityou-000	0.703	37	0.414	37	0.680	37	0.690	38	-	38	1.000	38	-	33
15	itmo-001	0.441	30	0.174	33	0.256	33	0.069	33	0.199	33	0.932	35	0.797	27
16	itmo-002	0.287	27	0.050	20	0.047	23	0.036	29	0.069	25	0.892	33	0.783	25
17	morpho-000	0.134	8	0.026	8	0.028	6	0.007	17	0.012	2	0.893	34	0.846	31
18	neurotechnology-001	0.222	19	0.044	18	0.046	21	0.001	11	0.017	7	0.817	29	0.533	3
19	neurotechnology-002	0.166	13	0.036	15	0.041	16	0.000	4	0.020	9	0.427	4	-	37
20	noblis-000	0.542	36	0.212	35	0.349	36	0.153	35	0.239	34	0.875	31	0.757	18
21	ntechlab-001	0.083	7	0.025	7	0.030	8	0.003	16	0.014	5	0.319	1	0.472	2
22	ntechlab-002	0.065	4	0.021	4	0.023	4	0.003	14	0.014	4	0.324	2	0.459	1
23	pa-002	0.286	26	0.086	25	0.041	18	0.010	19	0.043	16	0.633	10	-	35
24	rankone-000	0.276	24	0.071	23	0.177	30	0.021	25	0.092	27	0.723	20	0.787	26
25	rankone-002	0.217	18	0.049	19	0.032	10	0.000	5	0.052	19	0.705	18	0.778	23
26	samtech-000	0.443	31	0.161	32	0.044	20	0.021	26	0.063	23	0.878	32	0.765	21
27	tongyitrans-001	0.072	6	0.038	17	0.041	15	0.009	18	0.063	21	0.704	17	0.743	13
28	tongyitrans-002	0.066	5	0.030	9	0.039	14	0.010	20	0.063	22	0.725	21	0.746	14
29	vcog-002	0.903	38	0.504	38	0.692	38	0.559	37	0.666	37	0.778	26	0.752	16
30	vigilantsolutions-001	0.348	29	0.105	28	0.101	27	0.016	22	0.061	20	0.729	22	0.730	11
31	vigilantsolutions-002	0.321	28	0.087	26	0.092	26	0.018	24	0.075	26	0.675	13	-	34
32	visionlabs-001	0.180	14	0.030	10	0.024	5	0.001	6	0.014	6	0.591	8	0.561	6
33	visionlabs-002	0.051	3	0.014	2	0.020	3	0.001	7	0.017	8	0.397	3	0.556	5
34	vocord-001	0.141	9	0.035	14	0.063	25	0.036	30	0.069	24	0.654	12	0.695	10
35	vocord-002	0.034	2	0.013	1	0.019	2	0.011	21	0.012	3	0.948	36	0.762	19
36	yisheng-000	0.199	17	0.037	16	0.029	7	0.000	2	0.035	10	0.686	15	0.749	15
37	yisheng-001	0.160	12	0.032	11	0.048	24	0.000	3	0.043	15	0.628	9	0.756	17
38	yitu-000	0.033	1	0.021	6	0.017	1	0.000	1	0.012	1	0.431	5	0.586	7

Table 2: FNMR is the proportion of mated comparisons below a threshold set to achieve the FMR given in the header on the fourth row. FMR is the proportion of impostor comparisons at or above that threshold. Note that the webcam and selfie values apply to images collected on the same day, and that will often yield optimisticlly low FNMR values.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 1: The points show false non-match rates (FNMR) versus the duration of the template generation operation. FNMR is the geometric mean of FNMR values for visa and mugshot images (from Figs. 4 and 6) at a false match rate (FMR) of 0.0001. Template generation time is a median estimated over 640 x 480 pixel portraits. The size of the points encodes template generation time - which spans one order of magnitude. The color of the points encodes one-to-one genuine template comparison duration - which span three orders of magnitude.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 2: The points show false non-match rates (FNMR) versus the duration of the template generation operation. FNMR is the geometric mean of FNMR values for visa and mugshot images (from Figs. 4 and 6) at a false match rate (FMR) of 0.0001. Template generation time is a median estimated over 640 x 480 pixel portraits. The size of the points encodes template size - which span two orders of magnitude. The color of the points encodes one-to-one genuine template comparison duration - which span three orders of magnitude.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

3 Metrics

3.1 Core accuracy

Given a vector of N genuine scores, u, the false non-match rate (FNMR) is computed as the proportion below some threshold, T:

$$\text{FNMR}(T) = 1 - \frac{1}{N}\sum_{i=1}^{N} H(u_i - T) \tag{1}$$

where $H(x)$ is the unit step function, and $H(0)$ taken to be 1.

Similarly, given a vector of N impostor scores, v, the false match rate (FMR) is computed as the proportion above T:

$$\text{FMR}(T) = \frac{1}{N}\sum_{i=1}^{N} H(v_i - T) \tag{2}$$

The threshold, T, can take on any value. We typically generate a set of thresholds from quantiles of the observed impostor scores, v, as follows. Given some interesting false match rate range, $[\text{FMR}_L, \text{FMR}_U]$, we form a vector of K thresholds corresponding to FMR measurements evenly spaced on a logarithmic scale

$$T_k = Q_v(1 - \text{FMR}_k) \tag{3}$$

where Q is the quantile function, and FMR_k comes from

$$\log_{10}\text{FMR}_k = \log_{10}\text{FMR}_L + \frac{k}{K}\,[\log_{10}\text{FMR}_U - \log_{10}\text{FMR}_L] \tag{4}$$

Error tradeoff characteristics are plots of FNMR(T) vs. FMR(T). These are plotted with $\text{FMR}_U \to 1$ and FMR_L as low as is sustained by the number of impostor comparisons, N. This is somewhat higher than the "rule of three" limit $3/N$ because samples are not independent, due to re-use of images.

4 Datasets

4.1 Child exploitation images

- ▷ The number of images is O(10^4).
- ▷ The number of subjects is O(10^3).
- ▷ The number of subjects with two images O(10^3).
- ▷ The images are operational. They are taken from ongoing investigations of child exploitation crimes. The images are arbitrarily unconstrained. Pose varies considerably around all three axes, including subject lying down. Resolution varies very widely. Faces can be occluded by other objects, including hair and hands. Lighting varies, although the images are intended for human viewing. Mis-focus is rare. Images are given to the algorithm without any cropping; faces may occupy widely varying areas.
- ▷ The images are usually large from contemporary cameras. The mean interocular distance (IOD) is 70 pixels.
- ▷ The images are of subjects from several countries, due to the global production of this imagery.
- ▷ The images are of children, from infancy to late adolescence.
- ▷ All of the images are live capture, none are scanned. Many have been cropped.
- ▷ When these images are input to the algorithm, they are labelled as being of type "EXPLOITATION" - see Table 4 of the FRVT API.

4.2 Visa images

- ▷ The number of images is O(10^5).
- ▷ The number of subjects is O(10^5).
- ▷ The number of subjects with two images O(10^4).
- ▷ The images have geometry in reasonable conformance with the ISO/IEC 19794-5 Full Frontal image type. Pose is generally excellent.
- ▷ The images are of size 252x300 pixels. The mean interocular distance (IOD) is 69 pixels.
- ▷ The images are of subjects from greater than 100 countries, with significant imbalance due to visa issuance patterns.
- ▷ The images are of subjects of all ages, including children, again with imbalance due to visa issuance demand.
- ▷ Many of the images are live capture. A substantial number of the images are photographs of paper photographs.
- ▷ When these images are input to the algorithm, they are labelled as being of type "ISO" - see Table 4 of the FRVT API.

4.3 Mugshot images

- ▷ The number of images is O(10^6).
- ▷ The number of subjects is O(10^5).
- ▷ The number of subjects with two images O(10^5).

- ▷ The images have geometry in reasonable conformance with the ISO/IEC 19794-5 Full Frontal image type.
- ▷ The images are of variable sizes. The median IOD is 104 pixels. The mean IOD is 123 pixels.
- ▷ The images are of subjects from the United States.
- ▷ The images are of adults.
- ▷ The images are all live capture.
- ▷ When these images are input to the algorithm, they are labelled as being of type ”mugshot” - see Table 4 of the FRVT API.

4.4 Selfie images

- ▷ The number of images is below 500.
- ▷ The number of subjects is below 500.
- ▷ All subjects have a selfie image, and a portrait image.
- ▷ The portrait images are in reasonable conformance with the ISO/IEC 19794-5 Full Frontal image type.
- ▷ The selfie images vary: taken with camera above and below eye level, with one hand or two hands. Pitch angles vary more than yaw angles, which are frontal. Some perspective distortion is evident.
- ▷ The images have mean IOD of 140 pixels.
- ▷ The images are of subjects from the United States.
- ▷ The images are of adults.
- ▷ The images are all live capture.
- ▷ When these images are input to the algorithm, they are labelled as being of type ”WILD” - see Table 4 of the FRVT API.

4.5 Webcam images

- ▷ The number of images is below 1500.
- ▷ The number of subjects is below 1500.
- ▷ All subjects have a webcam image, and a portrait image.
- ▷ The portrait images are in reasonable conformance with the ISO/IEC 19794-5 Full Frontal image type.
- ▷ The webcam images are taken with camera at a typical head height, with mild pitch angles, low yaw angles, but some variation in range, such that low perspective distortion is sometimes evident.
- ▷ The images have mean IOD of 68 pixels (sd=12).
- ▷ The images are of subjects from the United States.
- ▷ The images are of adults.
- ▷ The images are all live capture.
- ▷ When these images are input to the algorithm, they are labelled as being of type ”MUGSHOT” - see Table 4 of the FRVT API.

(a) Visa (b) Mugshot (c) Webcam (d) Selfie (e) Wild

Figure 3: The figure gives simulated samples of image types used in this report.

4.6 Wild images

- ▷ The number of images is O(10^5).
- ▷ The number of subjects is O(10^3).
- ▷ The number of subjects with two images O(10^3).
- ▷ The images include many photojournalism-style images. Images are given to the algorithm using a variable but generally tight crop of the head. Resolution varies very widely. The images are very unconstrained, with wide yaw and pitch pose variation. Faces can be occluded, including hair and hands.
- ▷ The images are of adults.
- ▷ All of the images are live capture, none are scanned.
- ▷ When these images are input to the algorithm, they are labelled as being of type "WILD" - see Table 4 of the FRVT API.

5 Results

5.1 Test goals

- ▷ To state overall accuracy.
- ▷ To compare algorithms.

5.2 Test design

Method: For visa images:

- ▷ The comparisons are of visa photos against visa photos.
- ▷ The number of genuine comparisons is O(10^4).
- ▷ The number of impostor comparisons is O(10^{10}).

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

- ▷ The comparisons are fully zero-effort, meaning impostors are paired without attention to sex, age or other covariates. However, later analysis is conducted on subsets.
- ▷ The number of persons is O(10^5).
- ▷ The number of images used to make 1 template is 1.
- ▷ The number of templates used to make each comparison score is two corresponding to simple one-to-one verification.

For mugshot images:

- ▷ The comparisons are of mugshot photos against mugshot photos.
- ▷ The number of genuine comparisons is O(10^5).
- ▷ The number of impostor comparisons is O(10^7).
- ▷ The comparisons are fully zero-effort, meaning impostors are paired without attention to sex, age or other covariates.
- ▷ The number of persons is O(10^6).
- ▷ The number of images used to make 1 template is 1.
- ▷ The number of templates used to make each comparison score is two corresponding to simple one-to-one verification.

For selfie images:

- ▷ The comparisons are of selfie photos against portrait photos.
- ▷ The number of genuine comparisons is O(10^2).
- ▷ The number of impostor comparisons is O(10^8) selfies are compared with portraits of O(10^6) other subjects.
- ▷ The comparisons are fully zero-effort, meaning impostors are paired without attention to sex, age or other covariates.
- ▷ The number of persons is O(10^6).
- ▷ The number of images used to make 1 template is 1.
- ▷ The number of templates used to make each comparison score is two corresponding to simple one-to-one verification.

For webcam images:

- ▷ The comparisons are of webcam photos against portrait photos.
- ▷ The number of genuine comparisons is O(10^3).
- ▷ The number of impostor comparisons is O(10^9) webcams are compared with portraits of O(10^6) other subjects.
- ▷ The comparisons are fully zero-effort, meaning impostors are paired without attention to sex, age or other covariates.
- ▷ The number of persons is O(10^6).
- ▷ The number of images used to make 1 template is 1.

- ▷ The number of templates used to make each comparison score is two corresponding to simple one-to-one verification.

For child exploitation images:

- ▷ The comparisons are of unconstrained child exploitation photos against others of the same type.
- ▷ The number of genuine comparisons is O(10^4).
- ▷ The number of impostor comparisons is O(10^7).
- ▷ The comparisons are fully zero-effort, meaning impostors are paired without attention to sex, age or other covariates.
- ▷ The number of persons is O(10^3).
- ▷ The number of images used to make 1 template is 1.
- ▷ The number of templates used to make each comparison score is two corresponding to simple one-to-one verification.
- ▷ We produce two performance statements. First, is a DET as used for visa and mugshot images. The second is a cumulative match characteristic (CMC) summarizing a simulated one-to-many search process. This is done as follows.
  - We regard M enrollment templates as items in a gallery.
  - These M templates come from $M > N$ individuals, because multiple images of a subject are present in the gallery under separate identifiers.
  - We regard the verification templates as search templates.
  - For each search we compute the rank of the highest scoring mate.
  - This process should properly be conducted with a 1:N algorithm, such as those tested in NIST IR 8009. We use the 1:1 algorithms in a simulated 1:N mode here to a) better reflect what a child exploitation analyst does, and b) to do show algorithm efficacy is better than that revealed in the verification DETs.

5.3 Failure to enrol

Algorithm	Failure to Enrol Rate[1]											
Name	CHILD-EXPLOIT		MUGSHOT		SELFIES		VISA		WEBCAM		WILD	
3divi-001	0.2006	14	0.0019	22	0.0202	23	0.0007	17	0.0020	15	0.1898	23
3divi-002	-	40	0.0039	30	0.0376	28	0.0010	18	0.0027	22	0.2413	28
ayonix-000	0.0000	1	0.0109	38	0.0751	36	0.0137	41	0.0109	29	0.0000	3
camvi-001	0.3931	28	0.0033	28	0.0231	25	0.0010	20	0.0027	23	0.3767	34
cyberextruder-001	0.5338	34	0.0036	29	0.0376	27	0.0029	29	0.0205	33	0.5730	40
dermalog-003	0.0434	7	0.0007	9	0.0000	2	0.0025	27	0.0007	6	0.0701	13
dermalog-004	-	40	0.0031	27	0.0087	16	0.0090	39	0.0020	20	0.2050	25
digitalbarriers-000	0.5469	35	0.0043	32	0.0925	37	0.0019	25	0.0184	32	0.5170	39
digitalbarriers-001	0.5102	33	0.0044	33	0.0925	38	0.0018	24	0.0232	34	0.4593	38
id3-001	0.3411	23	0.0043	31	0.0260	26	0.0043	37	0.0014	14	0.2090	26
id3-002	0.3168	20	0.0030	26	0.0202	24	0.0032	31	0.0020	19	0.1496	15
innovatrics-000	0.3392	21	0.0013	15	0.0087	14	0.0004	11	0.0027	21	0.3337	32
innovatrics-001	0.3392	22	0.0013	16	0.0087	18	0.0004	12	0.0027	24	0.3337	33
isityou-000	0.4714	31	0.0022	25	0.0665	34	0.0010	19	0.0116	30	0.4586	37
itmo-001	0.5751	37	0.0114	39	0.0694	35	0.0047	38	0.0546	38	0.7410	43
itmo-002	0.5751	38	0.0068	36	0.0636	33	0.0029	30	0.0498	37	0.6985	41
morpho-000	0.0000	4	0.0000	3	0.0000	6	0.0000	5	0.0000	5	0.0000	7
neurotechnology-001	0.2962	18	0.0000	4	0.0000	3	0.0000	2	0.0000	2	0.0163	9
neurotechnology-002	-	40	0.0000	5	0.0058	12	0.0000	3	0.0014	12	0.1525	16
noblis-000	0.0000	2	0.0000	2	0.0000	4	0.0000	4	0.0000	3	0.0000	4
ntechlab-001	0.0926	13	0.0009	11	0.0029	9	0.0005	14	0.0007	9	0.0584	12
ntechlab-002	0.0926	12	0.0009	10	0.0029	8	0.0005	13	0.0007	7	0.0584	11
pa-002	-	40	0.0000	1	0.0000	1	0.0000	1	0.0000	1	0.0000	1
rankone-000	0.0187	6	0.0005	7	0.0000	7	0.0003	8	0.0007	11	0.2349	27
rankone-002	0.0009	5	0.0001	6	0.0000	5	0.0000	6	0.0000	4	0.0855	14
samtech-000	0.5474	36	0.0052	34	0.0491	31	0.0042	36	0.0252	35	0.7023	42
tongyitrans-001	0.0000	3	0.0068	35	0.0462	29	0.0040	34	0.0055	27	0.0000	5
tongyitrans-002	0.3609	26	0.0078	37	0.0462	30	0.0040	35	0.0055	28	0.0000	6
vcog-002	0.2209	15	0.0021	23	0.0087	17	0.0019	26	0.0007	10	0.1672	18
vigilantsolutions-001	0.3585	25	0.0010	14	0.0116	20	0.0004	10	0.0048	26	0.3262	31
vigilantsolutions-002	-	40	0.0010	13	0.0116	19	0.0004	9	0.0048	25	0.3262	30
visionlabs-001	0.2699	17	0.0014	17	0.0058	13	0.0014	23	0.0020	18	0.1803	21
visionlabs-002	0.3063	19	0.0021	24	0.0087	15	0.0026	28	0.0007	8	0.1865	22
vocord-001	0.4732	32	0.0158	40	0.0520	32	0.0038	33	0.0348	36	0.4494	36
vocord-002	0.3782	27	0.0015	18	0.0029	11	0.0037	32	0.0171	31	0.1992	24
yisheng-000	0.4277	30	0.0016	21	0.0173	22	0.0006	16	0.0020	17	0.1770	20
yisheng-001	0.4277	29	0.0016	20	0.0173	21	0.0006	15	0.0020	16	0.1770	19
yitu-000	0.3475	24	0.0015	19	0.0029	10	0.0013	22	0.0014	13	0.1591	17

Table 3: FTE is the proportion of failed template generation attempts. Failures can occur because the software throws an exception, or because the software electively refuses to process the input image. This would typically occur if a face is not detected. FTE is measured as the number of function calls that give a non-zero error code, OR that give a "small" template. This is defined as one whose size is less than 0.3 times the median template size. This second rule is needed because some algorithms incorrectly fail to return a non-zero error code when template generation fails.

[1] *The effects of FTE are included in the accuracy results of this report by regarding any template comparison involving a failed template enrollment to produce a low similarity score. Thus higher FTE results in higher FNMR.*

5.4 Recognition accuracy

Core algorithm accuracy is stated via:

- ▷ **Cooperative subjects**
  - The summary table of Figure 2;
  - The visa image DETs of Figures 4 and 5;
  - The mugshot DETs of Figure 6 ;
  - The selfie-portrait DETs of Figure 7;
  - The webcam-portrait DETs of Figure 8;
- ▷ **Non-cooperative subjects**
  - The photojournalism DET of Figure 9
  - The sensitivity of photojournalism FNMR to relative yaw angles in Figure 10.
  - The sensitivity of photojournalism FMR to relative yaw angles in Figure 11.
  - The child-exploitation DET of Figure 12;
  - The child-exploitation CMC of Figure 13.

Figure 18 shows dependence of false match rate on algorithm score threshold. This allows a deployer to set a threshold to target a particular false match rate appropriate to the security objectives of the application.

Figure 20 likewise shows FMR(T) but for mugshots, and specially four subsets of the population.

Note that in both the mugshot and visa sets false match rates vary with the ethnicity, age, and sex, of the enrollee and impostor - see section 5.6.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 4: For the visa images, detection error tradeoff (DET) *characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show many decades of* FMR.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 5: For the visa images, but now just for low FMR, *detection error tradeoff* (DET) *characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show many decades of* FMR.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 6: For the mugshot images, detection error tradeoff (DET) characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show decades of FMR.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 7: For the selfie-to-portrait comparisons, detection error tradeoff (DET) characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show several decades of FMR. Caution: The FNMR values here are optimistic statements of accuracy because the image pairs were collected on the same day. This is known across biometrics to give better accuracy, and is operationally relevant only in special cases.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 8: For the webcam-to-portrait comparisons, detection error tradeoff (DET) characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show several decades of FMR. Caution: The FNMR values here are optimistic statements of accuracy because the image pairs were collected on the same day. This is known across biometrics to give better accuracy, and is operationally relevant only in special cases.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 9: For the wild image comparisons, detection error tradeoff (DET) characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show several decades of FMR.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 10: For wild images, the heatmap show FNMR *as a function of the yaw of the enrollment and verification images. The threshold is the same in all cells, and is set to the value that yeilds* FMR *= 0.003 on near frontal pairs i.e. where yaw is in the interval* $(-15, 15]$*. Poor algorithms give generally red figures. The better algorithms show a) diagonal dominance, indicating ability to authenticate when pairs have the same yaw angle, and b) off-diagonal cross-pose capability also. The yaw estimates are from an automated pose estimator, and are themselves noisy. The figure assumes that the pose estimates are not systematically incorrect.*

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 11: For wild images, the heatmaps show FMR *dependence on the yaw of the enrollment and verification images. The threshold is the same in all cells, and is set to the value that yields* FMR *= 0.003 on near frontal pairs, i.e. where yaw is in the interval* $(-15, 15]$*. Thus the center of each panel is grey. The desired behavior is that* FMR *does not vary with relative yaw. However, some algorithms gives elevated* FMR *when yaw differs. The yaw estimates are from an automated pose estimator, and are themselves noisy. The figure assumes that the pose estimates are not systematically incorrect.*

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 12: For child exploitation images, detection error tradeoff (DET) characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. The scales are logarithmic in order to show many decades of FMR. Accuracy is poor because many images have adverse quality characteristics, and because detection and enrollment fails.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 13: For child exploitation images, cumulative match characteristics (CMC) showing true positive identification rate vs. rank. This is simulation of a one-to-many search experiment - see discussion in section 5.2. The scales are logarithmic in order to show the effect of long candidate lists. Accuracy is poor but much improved relative to the 1:1 DETs of Fig. 12 because a search can succeed if any of a subject's several enrolled images matches the search image with a high score.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 14: For child exploitation images, cumulative match characteristics (CMC) showing true positive identification rate vs. rank for two cases: 1. Whole image provided to the algorithm; 2. Human annotated rectangular region, cropped and provided to the algorithm. The difference between the traces is associated with detection of difficult faces, and fine localization. The CMC is simulation of a one-to-many search experiment - see discussion in section 5.2. The scales are logarithmic in order to show the effect of long candidate lists. Accuracy is poor but much improved relative to the 1:1 DETs of Fig. 12 because a search can succeed if any of a subject's several enrolled images matches the search image with a high score.

Figure 15: For the mugshot images, error tradeoff characteristics for white females, black females, black males and white males. The grey lines correspond to fixed thresholds, showing how both FNMR and FMR vary at one operating threshold. Important: Many of the plots will naively be read as saying whites gives lower error rates than blacks because the blue traces lie beneath the red ones. However, this is misleading and incomplete: The grey lines show the traces are generally shifted horizontally. Thus for the dermalog-001 algorithm FNMR for whites is higher than for blacks at a fixed threshold but, at the same time, FMR is higher for blacks - see Figure 20. As access control systems almost always operate at a fixed threshold, the naive interpretation is incorrect.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 16: For the visa images, FNMR and FMR at six operating points along the DET characteristic. At each point a line is drawn between (FMR,FNMR)$_{\text{MALE}}$ and (FMR,FNMR)$_{\text{FEMALE}}$ showing how which sex has lower FMR and/or FNMR. The "M" label denotes male, the other end of the line corresponds to female. The six operating thresholds are selected to give the nominal false match rates given in the legend, and are computed over all impostor pairs regardless of age, sex, and place of birth. The plotted FMR values are broadly an order of magnitude larger than the nominal rates because FMR is computed over demographically-matched impostor pairs i.e individuals of the same sex, from the same geographic region (see section 5.6.1), and the same age group (see section 5.6.2).

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 17: For the wild image comparisons, detection error tradeoff (DET) characteristics showing false non-match rate vs. false match rate plotted parametrically on threshold, T. Error rates are higher here than in the generic wild DET (Fig 9) becuase the impostor pairs here are same-sex only. The scales are logarithmic in order to show several decades of FMR.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 18: For the visa images, the false match calibration curves show false match rate vs. threshold. These curves apply to zero-effort impostors. As shown later (sec. 5.6), FMR is higher for demographic-matched impostors.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 19: For the visa images, the curves show how false matches are concentrated in certain images. Specifically each line plots $FMR(k)$ with k the number of images rejected in decreasing order of how many false matches that image was involved in. $FMR(0) = 10^{-4}$. In terms of the biometric zoo, the most "wolf-ish" images are rejected first i.e. those enrollment or verification images most often involved in false matches. A flatter response is considered superior. A steeply descending response indicates that certain kinds of images false match against others, e.g. if hypothetically images of men with particular mustaches would falsely match others.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 20: For the mugshot images, the false match calibration curves show false match rate vs. threshold. Separate curves appear for white females, black females, black males and white males.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

5.5 Genuine distribution stability

5.5.1 Effect of birth place on the genuine distribution

Background: Both skin tone and bone structure vary geographically. Prior studies have reported variations in FNMR and FMR.

Goal: To measure false non-match rate (FNMR) variation with country of birth.

Methods: Thresholds are determined that give FMR = $\{0.001, 0.0001\}$ over the entire impostor set. Then FNMR is measured over 1000 bootstrap replications of the genuine scores. Only those countries with at least 140 individuals are included in the analysis.

Results: Figure 21 shows FNMR by country of birth for the two thresholds.

Caveats: The results may not relate to subject-specific properties. Instead they could reflect image-specific quality differences, which could occur due to collection protocol or software processing variations.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 21: For the visa images, the dots show FNMR by country of birth for two operating thresholds corresponding to FMR = $\{0.001, 0.0001\}$ computed over all $O(10^{10})$ impostor scores. The figures shows an order of magnitude variation in FNMR across country of birth; these effects are due to quality variations. The least accurate countries vary by algorithm.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

5.5.2 Effect of age on genuine subjects

Background: Faces change appearance throughout life. Face recognition algorithms have previously beeen reported to give better accuracy on older individuals (See NIST IR 8009).

Goal: To quantify false non-match rates (FNMR) as a function of age. We do not aim to quantify ageing effects here as the separation between two samples is limited to just a few years.

Methods: Using the visa images, thresholds are determined that give FMR = 0.001 and 0.0001 over the entire impostor set. Then FNMR is measured over 1000 bootstrap replications of the genuine scores.

Results: For the visa images, Figure 22 shows how false non-match rates for genuine users, as a function of age group.

The notable aspects are:

- ▷ Younger subjects give considerably higher FNMR. This is likely due to rapid growth and change in facial appearance.
- ▷ FNMR trends down throughout life. The last bin, AGE $>$ 72, contains fewer than 140 mated pairs, and may be affected by small sample size.

Caveats: None.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 22: For the visa images, the dots show FNMR by age group for two operating thresholds corresponding to FMR = $\{0.001, 0.0001\}$ computed over all $O(10^{10})$ impostor scores. Given a pair of face images taken at different times, we assign a false non-match to the bin that is the arithmetic average of the subject's ages. This plot shows only the effect of age, not ageing. The number of comparisons in each bin is generally in the thousands. However the FNMR for the first and last bins are each computed over fewer than 150 comparisons.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

5.6 Impostor distribution stability

5.6.1 Effect of birth place on the impostor distribution

Background: Facial appearance varies geographically, both in terms of skin tone, cranio-facial structure and size. This section addresses whether false match rates vary intra- and inter-regionally.

Goals:

- ▷ To show the effect of birth region of the impostor and enrollee on false match rates.
- ▷ To determine whether some algorithms give better impostor distribution stability.

Methods:

- ▷ For the visa images, NIST defined 10 regions: Sub-Saharan Africa, South Asia, Polynesia, North Africa, Middle East, Europe, East Asia, Central and South America, Central Asia, and the Caribbean.
- ▷ For the visa images, NIST mapped each country of birth to a region. There is some arbitrariness to this. For example, Egypt could reasonably be assigned to the Middle East instead of North Africa. An alternative methodology could, for example, assign the Philippines to *both* Polynesia and East Asia.
- ▷ FMR is computed for cases where all face images of impostors born in region r_2 are compared with enrolled face images of persons born in region r_1.

$$\text{FMR}(r_1, r_2, T) = \frac{\sum_{i=1}^{N_{r_1,r_2}} H(s_i - T)}{N_{r_1,r_2}} \tag{5}$$

  where the same threshold, T, is used in all cells, and H is the unit step function. The threshold is set to give FMR(T) = 0.001 over the entire set of visa image impostor comparisons.
- ▷ This analysis is then repeated by country-pair, but only for those country pairs where both have at least 1000 images available. The countries[1] appear in the axes of graphs that follow.
- ▷ The mean number of impostor scores in any cross-region bin is 33 million. The smallest number of impostor scores in any bin is 135000, for Central Asia - North Africa. While these counts are large enough to support reasonable significance, the number of individual faces is much smaller, O($N^{0.5}$).
- ▷ The numbers of impostor scores in any cross-country bin is shown in Figure 100.

Results: Subsequent figures show heatmaps that use color to represent the base-10 logarithm of the false match rate. Red colors indicate high (bad) false match rates. Dark colors indicate benign false match rates. There are two series of graphs corresponding to aggregated geographical regions, and to countries. The notable observations are:

- ▷ The on-diagonal elements correspond to within-region impostors. FMR is generally above the nominal value of FMR = 0.001. Particularly there is usually higher FMR in, Sub-Saharan Africa, South Asia, and the Caribbean. Europe and Central Asia, on the other hand, usually give FMR closer to the nominal value.
- ▷ The off-diagonal elements correspond to across-region impostors. The highest FMR is produced between the Caribbean and Sub-Saharan Africa.
- ▷ Algorithms vary.

[1] These are Argentina, Australia, Brazil, Chile, China, Costa Rica, Cuba, Czech Republic, Dominican Republic, Ecuador, Egypt, El Salvador, Germany, Ghana, Great Britain, Greece, Guatamala, Haiti, Hong Kong, Honduras, Indonesia, India, Israel, Jamaica, Japan, Kenya, Korea, Lebanon, Mexico, Malaysia, Nepal, Nigeria, Peru, Philippines, Pakistan, Poland, Romania, Russia, South Africa, Saudi Arabia, Thailand, Trinidad, Turkey, Taiwan, Ukraine, Venezuela, and Vietnam.

- We computed the same quantities for a global FMR = 0.0001. The effects are similar.

Caveats:

- The effects of variable impostor rates on one-to-many identification systems may well differ from what's implied by these one-to-one verification results. Two reasons for this are a) the enrollment galleries are usually imbalanced across countries of birth, age and sex; b) one-to-many identification algorithms often implement techniques aimed at stabilizing the impostor distribution. Further research is necessary.
- In principle, the effects seen in this subsection could be due to differences in the image capture process. We consider this unlikely since the effects are maintained across geography - e.g. Caribbean vs. Africa, or Japan vs. China.

Figure 23: For visa images, the heatmap shows how the mean of the impostor distribution for the country pair (a,b) is shifted relative to the mean of the global impostor distribution, expressed as a number of standard deviations of the global impostor distribution. This statistic is designed to show shifts in the entire impostor distribution, not just tail effects that manifest as the anomalously high (or low) false match rates that appear in the subsequent figures. The countries are chosen to show that skin tone alone does not explain impostor distribution shifts. The reduced shift in Asian populations with the Yitu and TongYiTrans algorithms, is accompanied by positive shifts in the European populations. This reversal relative to most other algorithms, may derive from use of nationally weighted training sets. The Visionlabs algorithm appears most insensitive to country effects. The figure is computed from same-sex and same-age impostor pairs.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 24: For algorithm 3divi-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 25: For algorithm 3divi-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 26: For algorithm ayonix-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 27: For algorithm camvi-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 28: For algorithm cyberextruder-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 29: For algorithm dermalog-003 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 30: For algorithm dermalog-004 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 31: For algorithm digitalbarriers-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 32: For algorithm digitalbarriers-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 33: For algorithm id3-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 34: For algorithm id3-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 35: For algorithm innovatrics-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 36: For algorithm innovatrics-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 37: For algorithm isityou-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 38: For algorithm itmo-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 39: For algorithm itmo-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 40: For algorithm morpho-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 41: For algorithm neurotechnology-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 42: For algorithm neurotechnology-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 43: For algorithm noblis-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 44: For algorithm ntechlab-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 45: For algorithm ntechlab-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 46: For algorithm pa-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 47: For algorithm rankone-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 48: For algorithm rankone-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 49: For algorithm samtech-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 50: For algorithm tongyitrans-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 51: For algorithm tongyitrans-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 52: For algorithm vcog-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 53: For algorithm vigilantsolutions-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 54: For algorithm vigilantsolutions-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 55: For algorithm visionlabs-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 56: For algorithm visionlabs-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 57: For algorithm vocord-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 58: For algorithm vocord-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 59: For algorithm yisheng-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 60: For algorithm yisheng-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 61: For algorithm yitu-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given region pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 62: For algorithm 3divi-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 63: For algorithm 3divi-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 64: For algorithm ayonix-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 65: For algorithm camvi-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 66: For algorithm cyberextruder-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 67: For algorithm dermalog-003 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 68: For algorithm dermalog-004 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 69: For algorithm digitalbarriers-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 70: For algorithm digitalbarriers-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 71: For algorithm id3-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 72: For algorithm id3-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 73: For algorithm innovatrics-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 74: For algorithm innovatrics-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 75: For algorithm isityou-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 76: For algorithm itmo-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 77: For algorithm itmo-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 78: For algorithm morpho-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 79: For algorithm neurotechnology-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 80: For algorithm neurotechnology-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 81: For algorithm noblis-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 82: For algorithm ntechlab-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 83: For algorithm ntechlab-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 84: For algorithm pa-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 85: For algorithm rankone-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 86: For algorithm rankone-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 87: For algorithm samtech-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 88: For algorithm tongyitrans-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 89: For algorithm tongyitrans-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 90: For algorithm vcog-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 91: For algorithm vigilantsolutions-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 92: For algorithm vigilantsolutions-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 93: For algorithm visionlabs-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 94: For algorithm visionlabs-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 95: For algorithm vocord-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 96: For algorithm vocord-002 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 97: For algorithm yisheng-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 98: For algorithm yisheng-001 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

Figure 99: For algorithm yitu-000 operating on visa images, the heatmap shows false match rates observed over impostor comparisons of faces from different individuals who were born in the given country pair. False matches are counted against a recognition threshold fixed globally to give the target FMR in the plot title, computed over all $O(10^{10})$ impostor comparisons. If text appears in each box it give the same quantity as that coded by the color. Grey indicates FMR is at the intended FMR target level. Light red colors present a security vulnerability to, for example, a passport gate. Each +1 increase in log10 FMR corresponds to a factor of 10 increase in FMR. The matrix is not quite symmetric because images in the enrollment and verification sets are different.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 100: For visa images, the heatmap shows the count of impostor comparisons of faces from different individuals who were born in the given country pair.

5.6.2 Effect of age on impostors

Background: This section shows the effect of age on the impostor distribution. The ideal behaviour is that the age of the enrollee and the impostor would not affect impostor scores. This would support FMR stability over sub-populations.

Goals:

- ▷ To show the effect of relative ages of the impostor and enrollee on false match rates.
- ▷ To determine whether some algorithms have better impostor distribution stability.

Methods:

- ▷ Define 14 age group bins, spanning 0 to over 100 years old.
- ▷ Compute FMR over all impostor comparisons for which the subjects in the enrollee and impostor images have ages in two bins.
- ▷ Compute FMR over all impostor comparisons for which the subjects are additionally of the same sex, and born in the same geographic region.

Results:

The notable aspects are:

- ▷ Diagonal dominance: Impostors are more likely to be matched against their same age group.
- ▷ Same sex and same region impostors are more successful. On the diagonal, an impostor is more likely to succeed by posing as someone of the same sex. If $\Delta \log_{10} \text{FMR} = 0.2$, then same-sex same-region FMR exceeds the all-pairs FMR by factor of $10^{0.2} = 1.6$.
- ▷ Young children impostors give elevated FMR against young children. Older adult impostor give elevated FMR against older adults. These effects are quite large, for example if $\Delta \log_{10} \text{FMR} = 1.0$ larger than a 32 year old, then these groups have higher FMR by a factor of $10^1 = 10$. This would imply an FMR above 0.01 for a nominal (global) FMR = 0.001.
- ▷ Algorithms vary.
- ▷ We computed the same quantities for a global FMR = 0.0001. The effects are similar.

Note the calculations in this section include impostors paired across all countries of birth.

Figure 101: For algorithm 3divi-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 102: For algorithm 3divi-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 103: For algorithm ayonix-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 104: For algorithm camvi-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 105: For algorithm cyberextruder-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 106: For algorithm dermalog-003 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 107: For algorithm dermalog-004 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 108: For algorithm digitalbarriers-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 109: For algorithm digitalbarriers-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 110: For algorithm id3-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 111: For algorithm id3-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 112: For algorithm innovatrics-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 113: For algorithm innovatrics-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 114: For algorithm isityou-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 115: For algorithm itmo-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 116: For algorithm itmo-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 117: For algorithm morpho-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 118: For algorithm neurotechnology-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 119: For algorithm neurotechnology-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 120: For algorithm noblis-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 121: For algorithm ntechlab-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 122: For algorithm ntechlab-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 123: For algorithm pa-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 124: For algorithm rankone-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 125: For algorithm rankone-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 126: For algorithm samtech-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 127: For algorithm tongyitrans-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
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Figure 128: For algorithm tongyitrans-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

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Figure 129: For algorithm vcog-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 130: For algorithm vigilantsolutions-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 131: For algorithm vigilantsolutions-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 132: For algorithm visionlabs-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 133: For algorithm visionlabs-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 134: For algorithm vocord-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

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Figure 135: For algorithm vocord-002 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
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Figure 136: For algorithm yisheng-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
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Figure 137: For algorithm yisheng-001 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

FNMR(T) "False non-match rate"
FMR(T) "False match rate"

Figure 138: For algorithm yitu-000 operating on visa images, the heatmap shows false match observed over impostor comparisons of faces from different individuals who have the given age pair. False matches are counted against a recognition threshold fixed globally to give FMR = 0.001 over all $O(10^{10})$ impostor comparisons. The text in each box gives the same quantity as that coded by the color. Light colors present a security vulnerability to, for example, a passport gate.

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Accuracy Terms + Definitions

In biometrics, Type II errors occur when two samples of one person do not match – this is called a **false negative**. Correspondingly, Type I errors occur when samples from two persons do match – this is called a **false positive**. Matches are declared by a biometric system when the native comparison score from the recognition algorithm meets some **threshold**. Comparison scores can be either **similarity scores**, in which case higher values indicate that the samples are more likely to come from the same person, or **dissimilarity scores**, in which case higher values indicate different people. Similarity scores are traditionally computed by **fingerprint** and **face** recognition algorithms, while dissimilarities are used in **iris recognition**. In some cases, the dissimilarity score is a distance; this applies only when **metric** properties are obeyed. In any case, scores can be either **mate** scores, coming from a comparison of one person's samples, or **nonmate** scores, coming from comparison of different persons' samples. The words **genuine** or **authentic** are synonyms for mate, and the word **impostor** is used a synonym for nonmate. The words mate and nonmate are traditionally used in identification applications (such as law enforcement search, or background checks) while genuine and impostor are used in verification applications (such as access control).

A **error tradeoff** characteristic represents the tradeoff between Type II and Type I classification errors. For verification this plots false non-match rate (FNMR) vs. false match rate (FMR) parametrically with T.

The error tradeoff plots are often called **detection error tradeoff (DET)** characteristics or **receiver operating characteristic** (ROC). These serve the same function but differ, for example, in plotting the complement of an error rate (e.g. TMR = 1 – FNMR) and in transforming the axes most commonly using logarithms, to show multiple decades of FMR. More rarely, the function might be the inverse Gaussian function.

More detail and generality is provided in formal biometrics testing standards, see the various parts of ISO/IEC 19795 Biometrics Testing and Reporting. More terms, including and beyond those to do with accuracy, see ISO/IEC 2382-37 Information technology -- Vocabulary -- Part 37: Harmonized biometric vocabulary

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