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Ongoing Face Recognition Vendor Test (FRVT)

Part 1: Verification

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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

2017-12-14

- In 2018, NIST will run an evaluation of 1:N identification algorithms.
- The test will use N well in excess of 10^7.
- Algorithms must be submitted to NIST on or after January 22 2018 and before the deadline on February 16 2018.
- The final API and concept document is linked from here.

2 Changelog

2017-12-14

- Added results for algorithms from Aware, RankOne, Shaman, and Tevian.
- Retired results for RankOne-000 - FRVT lists only the two most recent algorithms per organization.
- New description of wild images in section 5.2
- New Figure 23 showing FMR for impostors of same age, sex and worst-case region.

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 24 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.

	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	^{31}4096 ± 0	^{18}274 ± 47	Yes	^{7}636 ± 19	^{8}634 ± 16
2	3DiVi	3divi	002	2017-10-20	190867	^{33}4096 ± 0	^{19}279 ± 48	Yes	^{10}692 ± 22	^{11}707 ± 26
3	Aware	aware	000	2017-10-27	240240	^{18}1572 ± 0	^{32}655 ± 26	No	^{22}4030 ± 83	^{22}2984 ± 152
4	Aware	aware	001	2017-10-27	240240	^{19}1572 ± 0	^{33}656 ± 26	No	^{20}2902 ± 51	^{21}2810 ± 111
5	Ayonix	ayonix	000	2017-06-22	58505	^{13}1036 ± 0	^{1}18 ± 2	No	^{6}621 ± 23	^{7}620 ± 26
6	Camvi Technologies	camvitech	001	2017-09-13	118759	^{12}1024 ± 0	^{13}181 ± 6	No	^{4}481 ± 16	^{6}487 ± 23
7	Cyberextruder	cyberex	001	2017-08-02	121211	^{7}256 ± 0	^{38}893 ± 25	No	^{16}1083 ± 16	^{18}1079 ± 19
8	Dermalog	dermalog	003	2017-07-10	0	^{14}1043 ± 0	^{9}121 ± 22	No	^{30}22957 ± 93	^{32}22808 ± 131
9	Dermalog	dermalog	004	2017-10-26	0	^{2}128 ± 0	^{11}149 ± 5	No	^{5}490 ± 26	^{5}471 ± 26
10	Digital Barriers	barriers	000	2017-05-31	157794	^{23}2056 ± 0	^{6}104 ± 0	No	^{28}13232 ± 166	^{29}13226 ± 146
11	Digital Barriers	barriers	001	2017-07-20	236915	^{25}2056 ± 0	^{20}294 ± 1	No	^{27}12311 ± 164	^{28}12347 ± 197
12	ID3 Technology	id3	001	2017-08-04	225574	^{11}520 ± 0	^{14}238 ± 19	No	^{15}1058 ± 32	^{17}1049 ± 28
13	ID3 Technology	id3	002	2017-08-04	225574	^{10}520 ± 0	^{25}482 ± 34	No	^{17}1100 ± 59	^{16}1048 ± 32
14	Innovatrics	innova	000	2017-07-25	0	^{3}146 ± 0	^{26}578 ± 5	No	^{24}4964 ± 63	^{25}4665 ± 262
15	Innovatrics	innova	001	2017-07-25	0	^{9}284 ± 0	^{30}645 ± 5	No	^{25}5506 ± 131	^{26}4975 ± 308
16	Is It You	isityou	000	2017-06-26	48010	^{40}19200 ± 0	^{8}113 ± 5	No	^{40}237517 ± 1318	^{40}237374 ± 1279
17	ITMO University	itmo	001	2017-06-12	1923215	^{41}37997 ± 0	^{42}959 ± 18	No	^{31}28901 ± 1492	^{33}27517 ± 186
18	ITMO University	itmo	002	2017-08-07	1923215	^{35}4162 ± 0	^{29}611 ± 17	No	^{26}7423 ± 96	^{27}7451 ± 94
19	Idemia	morpho	000	2017-07-11	100806	^{1}116 ± 0	^{7}109 ± 1	No	^{14}993 ± 31	^{15}1000 ± 34
20	Neurotechnology	neurotech	001	2017-08-07	280771	^{29}2718 ± 0	^{37}881 ± 46	No	^{37}69356 ± 684	^{37}69140 ± 579
21	Neurotechnology	neurotech	002	2017-11-02	280771	^{30}2718 ± 0	^{27}581 ± 6	No	^{35}68738 ± 748	^{36}68905 ± 993
22	Noblis	noblis	000	2017-07-05	713573	^{15}1061 ± 0	^{12}174 ± 20	Yes	^{18}1343 ± 45	^{20}1373 ± 56
23	N-Tech Lab	ntech	001	2017-05-10	691296	^{38}6744 ± 1	^{28}587 ± 11	No	^{34}67692 ± 833	^{35}67486 ± 244
24	N-Tech Lab	ntech	002	2017-08-23	894169	^{37}6744 ± 1	^{22}330 ± 11	No	^{38}82508 ± 213	^{38}82524 ± 220
25	Ping An Technology	Pingan	002	2017-09-25	442564	^{39}18436 ± 0	^{10}132 ± 7	Yes	^{21}3088 ± 32	^{23}3051 ± 28
26	Rank One Computing	rankone	002	2017-08-18	0	^{5}224 ± 0	^{3}75 ± 1	No	^{36}69113 ± 3802	^{2}369 ± 26
27	Rank One Computing	rankone	003	2017-11-28	0	^{6}228 ± 0	^{2}37 ± 1	No	^{1}322 ± 20	^{1}324 ± 19
28	Samtech InfoNet Limited	samtech	000	2017-05-02	109774	^{24}2056 ± 0	^{16}262 ± 2	No	^{23}4550 ± 26	^{24}4541 ± 28
29	Shaman Software	shaman	000	2017-12-05	0	^{32}4096 ± 0	^{31}653 ± 16	No	^{2}380 ± 25	^{3}379 ± 31
30	Tevian	tevian	000	2017-12-10	455746	^{22}2048 ± 0	^{15}242 ± 14	No	^{3}430 ± 38	^{4}427 ± 23
31	TongYi Transportation Technology	tongyi	001	2017-04-01	625339	^{26}2058 ± 0	^{21}310 ± 20	No	^{29}17769 ± 74	^{30}17750 ± 63
32	TongYi Transportation Technology	tongyi	002	2017-07-15	625336	^{27}2058 ± 0	^{23}356 ± 35	No	^{32}29816 ± 281	^{31}17799 ± 127
33	VCognition	vcog	002	2017-06-12	3229434	^{42}61504 ± 5	^{24}357 ± 25	No	^{41}296154 ± 3077	^{41}296436 ± 4183
34	Vigilant Solutions	vigilant	001	2017-06-13	344685	^{17}1544 ± 0	^{40}921 ± 2	No	^{8}644 ± 13	^{9}649 ± 16
35	Vigilant Solutions	vigilant	002	2017-09-28	344137	^{28}2060 ± 0	^{36}844 ± 2	No	^{9}679 ± 10	^{10}680 ± 7
36	VisionLabs	visionlabs	001	2017-06-12	343661	^{4}204 ± 0	^{41}943 ± 8	No	^{19}1395 ± 45	^{19}1148 ± 53
37	VisionLabs	visionlabs	002	2017-09-08	591936	^{8}264 ± 0	^{17}265 ± 8	No	^{12}796 ± 35	^{13}799 ± 31
38	Vocord	vocord	001	2017-04-21	616989	^{36}6194 ± 0	^{39}908 ± 16	No	^{42}1094730 ± 64282	^{42}1107193 ± 66523
39	Vocord	vocord	002	2017-06-07	918292	^{16}1330 ± 0	^{35}782 ± 36	Yes	^{39}83063 ± 517	^{39}83072 ± 714
40	Zhuhai Yisheng Electronics Technology	yisheng	000	2017-08-17	122704	^{21}2048 ± 0	^{5}103 ± 1	Yes	^{11}790 ± 23	^{12}789 ± 20
41	Zhuhai Yisheng Electronics Technology	yisheng	001	2017-08-17	120112	^{20}2048 ± 0	^{4}103 ± 1	Yes	^{13}906 ± 31	^{14}905 ± 25
42	Shanghai Yitu Technology	yitu	000	2017-05-23	2211068	^{34}4130 ± 0	^{34}672 ± 2	No	^{33}35352 ± 114	^{34}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	13	0.020	4	0.030	12	0.001	12	0.046	20	0.492	6	0.549	4
2	3divi-002	0.154	12	0.021	6	0.033	15	0.001	14	0.049	23	0.495	7	-	42
3	aware-000	0.309	30	0.054	25	0.045	24	0.003	18	0.046	22	0.948	38	-	43
4	aware-001	0.309	31	0.054	24	0.045	25	0.004	21	0.046	21	0.993	40	-	39
5	ayonix-000	0.487	37	0.230	40	0.309	38	0.172	40	0.360	40	0.807	29	0.843	31
6	camvi-001	0.538	39	0.183	38	0.323	39	0.106	38	0.268	39	0.743	26	0.763	23
7	cyberextruder-001	0.255	26	0.076	28	0.165	34	0.029	31	0.144	35	0.853	32	0.780	27
8	dermalog-003	0.280	27	0.112	33	0.202	36	0.041	35	0.115	33	0.693	19	0.845	32
9	dermalog-004	0.240	24	0.093	31	0.131	33	0.016	28	0.121	34	0.996	42	0.960	35
10	digitalbarriers-000	0.463	36	0.161	35	0.184	35	0.045	36	0.170	36	0.741	25	0.771	25
11	digitalbarriers-001	0.502	38	0.155	34	0.041	20	0.029	32	0.115	32	0.678	17	0.731	15
12	fdu-000	0.058	4	0.016	3	0.021	4	0.001	10	0.009	1	0.549	9	-	38
13	id3-001	0.250	25	0.063	27	0.036	16	0.002	16	0.040	16	0.765	27	0.688	10
14	id3-002	0.239	23	0.057	26	0.032	14	0.003	19	0.037	13	0.810	30	0.686	9
15	innovatrics-000	0.191	19	0.034	14	0.046	27	0.001	9	0.040	14	0.720	22	0.852	34
16	innovatrics-001	0.183	17	0.034	13	0.043	22	0.001	11	0.043	17	0.643	13	0.815	30
17	isityou-000	0.703	41	0.414	41	0.680	41	0.690	42	-	43	1.000	43	-	36
18	itmo-001	0.441	34	0.174	37	0.256	37	0.069	37	0.199	37	0.932	37	0.797	29
19	itmo-002	0.287	29	0.050	23	0.047	28	0.036	33	0.069	30	0.892	35	0.783	28
20	morpho-000	0.134	10	0.026	9	0.028	9	0.007	22	0.012	4	0.893	36	0.846	33
21	neurotechnology-001	0.222	22	0.044	21	0.046	26	0.001	13	0.017	9	0.817	31	0.533	3
22	neurotechnology-002	0.166	15	0.036	16	0.041	19	0.000	5	0.020	11	0.427	4	0.683	8
23	noblis-000	0.542	40	0.212	39	0.349	40	0.153	39	0.239	38	0.875	33	0.757	21
24	ntechlab-001	0.083	8	0.025	8	0.030	11	0.003	20	0.014	7	0.319	1	0.472	2
25	ntechlab-002	0.065	5	0.021	5	0.023	6	0.003	17	0.014	6	0.324	2	0.459	1
26	pa-002	0.286	28	0.086	29	0.041	21	0.010	24	0.043	19	0.633	12	0.722	12
27	rankone-002	0.217	21	0.049	22	0.032	13	0.000	6	0.052	24	0.705	21	0.778	26
28	rankone-003	0.184	18	0.038	20	0.028	8	0.000	4	0.040	15	0.674	15	-	37
29	samtech-000	0.443	35	0.161	36	0.044	23	0.021	30	0.063	28	0.878	34	0.765	24
30	shaman-000	0.977	43	0.913	43	0.968	43	0.992	43	0.997	42	0.995	41	-	40
31	tevian-000	0.129	9	0.036	17	0.022	5	0.002	15	0.009	2	0.500	8	-	41
32	tongyitrans-001	0.072	7	0.038	19	0.041	18	0.009	23	0.063	26	0.704	20	0.743	16
33	tongyitrans-002	0.066	6	0.030	10	0.039	17	0.010	25	0.063	27	0.725	23	0.746	17
34	vcog-002	0.903	42	0.504	42	0.692	42	0.559	41	0.666	41	0.778	28	0.752	19
35	vigilantsolutions-001	0.348	33	0.105	32	0.101	32	0.016	27	0.061	25	0.729	24	0.730	14
36	vigilantsolutions-002	0.321	32	0.087	30	0.092	31	0.018	29	0.075	31	0.675	16	0.722	13
37	visionlabs-001	0.180	16	0.030	11	0.024	7	0.001	7	0.014	8	0.591	10	0.561	6
38	visionlabs-002	0.051	3	0.014	2	0.020	3	0.001	8	0.017	10	0.397	3	0.556	5
39	vocord-001	0.141	11	0.035	15	0.063	30	0.036	34	0.069	29	0.654	14	0.695	11
40	vocord-002	0.034	2	0.013	1	0.019	2	0.011	26	0.012	5	0.948	39	0.762	22
41	yisheng-000	0.199	20	0.037	18	0.029	10	0.000	2	0.035	12	0.686	18	0.749	18
42	yisheng-001	0.160	14	0.032	12	0.048	29	0.000	3	0.043	18	0.628	11	0.756	20
43	yitu-000	0.033	1	0.021	7	0.017	1	0.000	1	0.012	3	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.

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 wild images:

- The comparisons are of wild photos against wild photos.
- The number of genuine comparisons is O(10^6).
- The number of impostor comparisons is O(10^7).

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.
- ▷ The number of persons is O(10^4).
- ▷ 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.

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}).
- ▷ 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	26	0.0202	27	0.0007	20	0.0020	16	0.1898	26
3divi-002	-	42	0.0039	35	0.0376	33	0.0010	21	0.0027	25	0.2413	30
aware-000	-	42	0.0018	25	0.0231	29	0.0005	16	0.0055	31	0.2444	31
aware-001	-	42	0.0010	14	0.0145	24	0.0002	9	0.0048	30	0.1431	17
ayonix-000	0.0000	2	0.0109	43	0.0751	41	0.0137	46	0.0109	34	0.0000	3
camvi-001	0.3931	31	0.0033	33	0.0231	30	0.0010	23	0.0027	26	0.3767	39
cyberextruder-001	0.5338	37	0.0036	34	0.0376	32	0.0029	34	0.0205	38	0.5730	45
dermalog-003	0.0434	7	0.0007	10	0.0000	2	0.0025	32	0.0007	8	0.0701	14
dermalog-004	0.3110	21	0.0031	32	0.0087	19	0.0090	44	0.0020	21	0.2050	28
digitalbarriers-000	0.5469	38	0.0043	37	0.0925	42	0.0019	30	0.0184	37	0.5170	44
digitalbarriers-001	0.5102	36	0.0044	38	0.0925	43	0.0018	29	0.0232	39	0.4593	43
id3-001	0.3411	25	0.0043	36	0.0260	31	0.0043	42	0.0014	15	0.2090	29
id3-002	0.3168	22	0.0030	31	0.0202	28	0.0032	36	0.0020	19	0.1496	18
innovatrics-000	0.3392	23	0.0013	18	0.0087	17	0.0004	13	0.0027	24	0.3337	36
innovatrics-001	0.3392	24	0.0013	19	0.0087	21	0.0004	14	0.0027	27	0.3337	37
isityou-000	0.4714	34	0.0022	29	0.0665	39	0.0010	22	0.0116	35	0.4586	42
itmo-001	0.5751	40	0.0114	44	0.0694	40	0.0047	43	0.0546	43	0.7410	48
itmo-002	0.5751	41	0.0068	41	0.0636	38	0.0029	35	0.0498	42	0.6985	46
morpho-000	0.0000	5	0.0000	4	0.0000	9	0.0000	6	0.0000	7	0.0000	8
neurotechnology-001	0.2962	19	0.0000	5	0.0000	3	0.0000	2	0.0000	2	0.0163	10
neurotechnology-002	0.2043	15	0.0000	6	0.0058	15	0.0000	4	0.0014	13	0.1525	19
noblis-000	0.0000	3	0.0000	3	0.0000	5	0.0000	5	0.0000	4	0.0000	5
ntechlab-001	0.0926	13	0.0009	12	0.0029	11	0.0005	17	0.0007	11	0.0584	13
ntechlab-002	0.0926	12	0.0009	11	0.0029	10	0.0005	15	0.0007	9	0.0584	12
pa-002	0.0000	1	0.0000	1	0.0000	1	0.0000	1	0.0000	1	0.0000	1
rankone-002	0.0009	6	0.0001	8	0.0000	7	0.0000	8	0.0000	6	0.0855	16
rankone-003	-	42	0.0001	7	0.0000	6	0.0000	7	0.0000	5	0.0855	15
samtech-000	0.5474	39	0.0052	39	0.0491	36	0.0042	41	0.0252	40	0.7023	47
shaman-000	-	42	0.0000	2	0.0000	4	0.0000	3	0.0000	3	0.0000	4
tevian-000	-	42	0.0011	17	0.0000	8	0.0012	26	0.0020	22	0.2661	32
tongyitrans-001	0.0000	4	0.0068	40	0.0462	34	0.0040	39	0.0055	32	0.0000	6
tongyitrans-002	0.3609	29	0.0078	42	0.0462	35	0.0040	40	0.0055	33	0.0000	7
vcog-002	0.2209	16	0.0021	27	0.0087	20	0.0019	31	0.0007	12	0.1672	21
vigilantsolutions-001	0.3585	28	0.0010	16	0.0116	23	0.0004	12	0.0048	29	0.3262	35
vigilantsolutions-002	0.3585	27	0.0010	15	0.0116	22	0.0004	11	0.0048	28	0.3262	34
visionlabs-001	0.2699	18	0.0014	20	0.0058	16	0.0014	28	0.0020	20	0.1803	24
visionlabs-002	0.3063	20	0.0021	28	0.0087	18	0.0026	33	0.0007	10	0.1865	25
vocord-001	0.4732	35	0.0158	45	0.0520	37	0.0038	38	0.0348	41	0.4494	41
vocord-002	0.3782	30	0.0015	21	0.0029	13	0.0037	37	0.0171	36	0.1992	27
yisheng-000	0.4277	33	0.0016	24	0.0173	26	0.0006	19	0.0020	18	0.1770	23
yisheng-001	0.4277	32	0.0016	23	0.0173	25	0.0006	18	0.0020	17	0.1770	22
yitu-000	0.3475	26	0.0015	22	0.0029	12	0.0013	27	0.0014	14	0.1591	20

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 101.

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.

Figure 23: For the visa images, the dots show FMR for impostor comparisons of individuals of the same sex and same age group for the region of the world that gives the worst (highest) FMR when the threshold is set to give FMR = 0.001 (red vertical line) over all $O(10^{10})$ impostor scores i.e. zero-effort. The shift of the dots to right shows massive increases in FMR when impostors have the same sex, age, and region of birth. The color code indicates which region gives the worst case FMR. If the observed variation is due to the prevalence of one kind of images in the training imagery, then algorithms developed on one kind of data might be expected to give higher FMR on other kinds.

- ▷ 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.

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

Figure 24: 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 25: 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 26: 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 27: 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 28: 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 29: 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 30: 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 31: 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 32: 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 33: 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 34: 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 35: 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 36: 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 37: 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 38: 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 39: 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 40: 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 41: 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 42: 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 43: 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 44: 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 45: 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 46: 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 47: 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 48: 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 49: 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 50: 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 51: 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 52: 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 53: 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 54: 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 55: 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 56: 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 57: 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 58: 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 59: 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 60: 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 61: 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 62: 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 63: 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 64: 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 65: 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.

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

Figure 66: 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 67: 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 68: 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 69: 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.

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

Figure 70: 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 71: 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 72: 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 73: 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 74: 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 75: 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 76: 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 77: 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 78: 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 79: 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 80: 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.

Figure 81: 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 82: 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 83: 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 84: 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 85: 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 86: 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 87: 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 88: 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 89: 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.

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

Figure 90: 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.

Figure 91: 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 92: 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 93: 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 94: 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 95: 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.

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

Figure 96: 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 97: 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 98: 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 99: 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.

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

Figure 100: 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 101: 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 102: 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 103: 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 104: 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 105: 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 106: 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 107: 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 108: 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.

Figure 109: 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 110: 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 111: 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 112: 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 113: 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 114: 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 115: 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 116: 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 117: 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 118: 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 119: 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 120: 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 121: 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 122: 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 123: 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 124: 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 125: 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 126: 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"
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Figure 127: 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 128: 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"
FMR(T) "False match rate"

Figure 129: 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 130: 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"
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Figure 131: 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.

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FMR(T) "False match rate"

Figure 132: 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.

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FMR(T) "False match rate"

Figure 133: 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.

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FMR(T) "False match rate"

Figure 134: 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.

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Figure 135: 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 136: 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.

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Figure 137: 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.

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Figure 138: 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.

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Figure 139: 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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