Biometric Ageing: Implications for Credentialing

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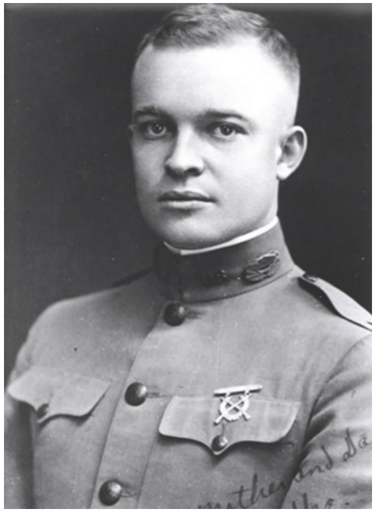
Time Dependence

Relevance of time dependence

- Some biometric applications are same-day.
  - Gatwick airport Common Departure Lounge
- Some biometric applications require identification over decades
  - LE + CT
- Typical access control
  - Credential re-issuance + re-enrollment possible, but there are costs…

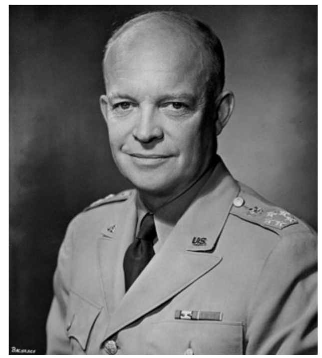
Kinds of time dependence

- Temporary effects
  - Diurnal illumination
  - Ambient illumination
  - Indoor / outdoor or seasonal humidity
- Secular trends through life
  - Face change
  - Finger ridges accrue scars
- Age-specific epochs
  - Growth in children
  - Geriatric effects + capability



Ageing: Permanent Appearance Change

Dwight D Eisenhower

ALGORITHM X	0.647	0.601	0.599	0.579
ALGORITHM Z	0.595	0.578	0.565	0.548

Green indicates successful 1:1 authentication at FMR = 0.001.

Red indicates failure.

FACE AGEING → DECREASED SIMILARITY.

IS THERE AN ANALOGOUS EFFECT FOR OTHER MODALITIES?

NIST

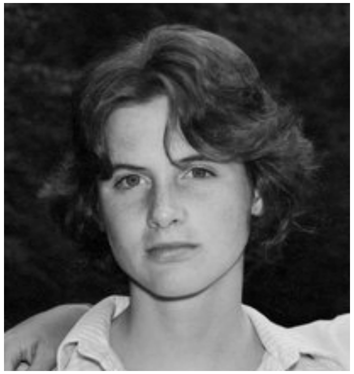
40 years

Photographs on exhibit at
Museum of Modern Art, NYC

See Susan Minot's text in
NY Times Magazine
Sunday Oct 3 2014

The Brown Sisters

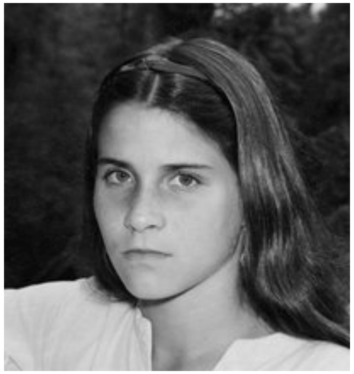
Photographed every year from
1975-2014



Ageing

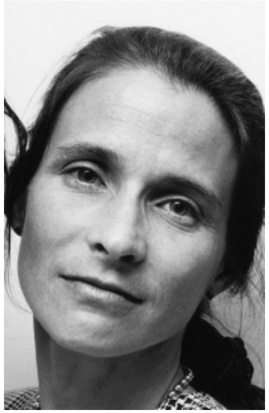
Brown Sister #1

	T ~ 5	T ~ 10	T ~ 20	T ~ 30	T ~ 40 Years
					
FR ALGORITHM X	0.632	0.608	0.584	0.602	0.576
Y	3004	2954	2755	2845	2781
Z	0.622	0.616	0.613	0.517	0.426



Ageing

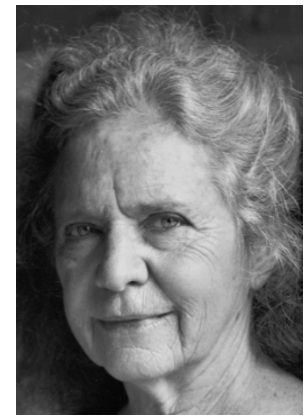
Brown Sister #2

FR ALGORITHM	T ~ 5	T ~ 10	T ~ 20	T ~ 30	T ~ 40 Years
X	0.648	0.601	0.600	0.610	0.605
Y	2863	2821	2758	2752	2824
Z	0.617	0.593	0.506	0.531	0.533

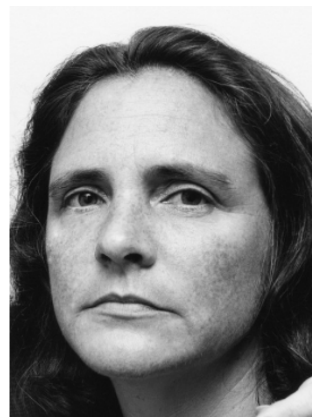
Ageing

Brown Sister #3

	T ~ 5	T ~ 10	T ~ 20	T ~ 30	T ~ 40 Years
					
FR ALGORITHM X	0.673	0.635	0.627	0.607	0.586
Y	2847	2649	2687	2637	2630
Z	0.610	0.511	0.524	0.595	0.472

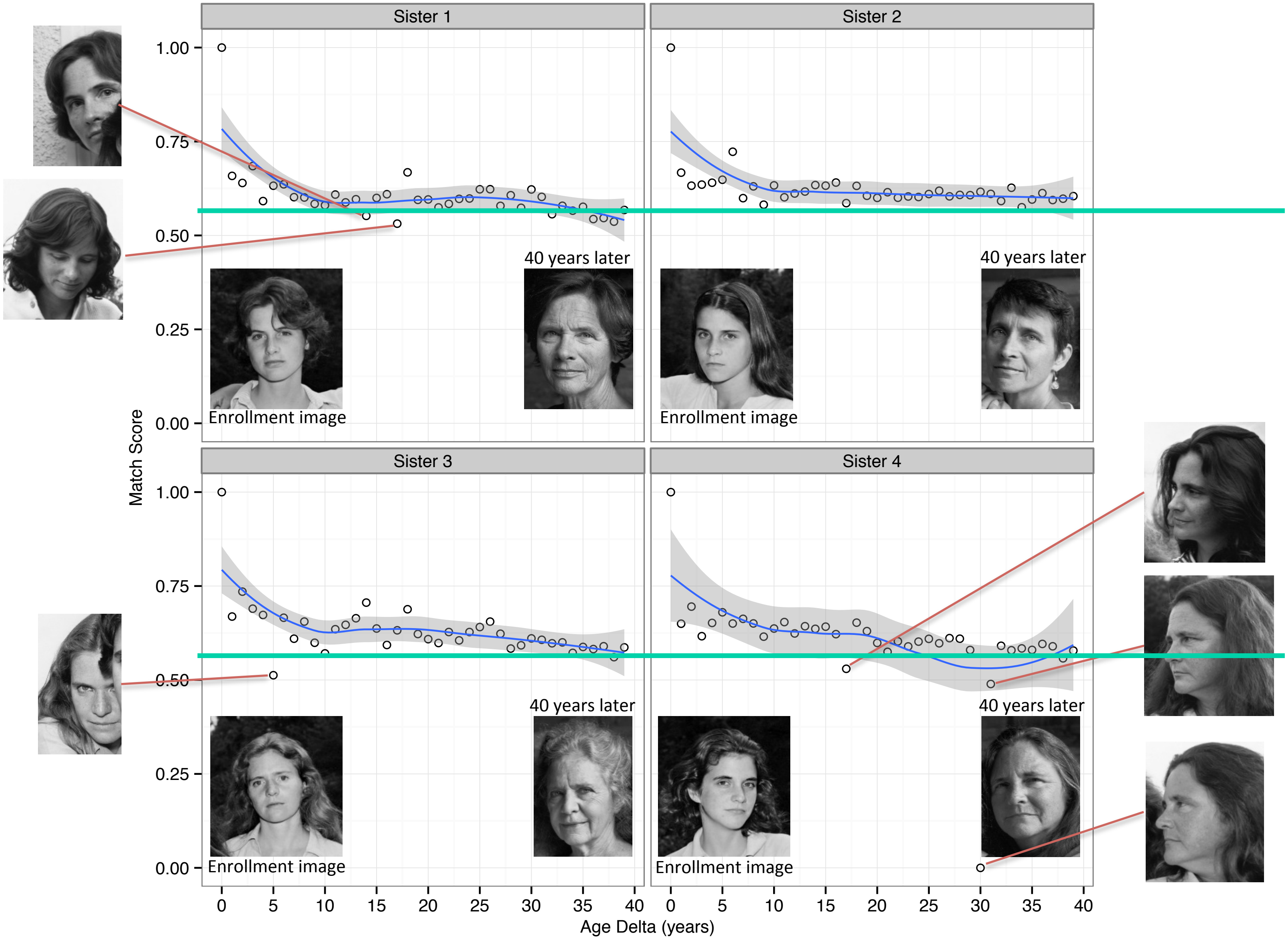
Ageing

Brown Sister #4



FR ALGORITHM	T ~ 5	T ~ 10	T ~ 20	T ~ 30	T ~ 40 Years
X	0.652	0.654	0.603	0.591	0.578
Y	3055	2795	2743	2847	2607
Z	0.632	0.516	0.475	0.524	0.432

Verification over 40 years



Reasoning about Ageing

» The simplest conception of ageing is that:
  - Accuracy = F(Time-of-Enrollment – Time-of-Recognition) = F(ΔT)

» And we all ageing "steadily":
  - Accuracy = a - b ΔT (if we're lucky, or simplistic, linear ageing)

» But … complications
  - Unsteady ageing:
    - Accuracy = F(Age-at-Enrollment; ΔT) or even
    - Accuracy = F(Age-at-Enrollment, Age-at-Recognition)
  - Nonlinear ageing:
    - Accuracy = F(polynomial(ΔT, n)) and probably
    - Accuracy = F(monotone polynomial(ΔT, n))
  - Person specific ageing (subscript i):
    - $\text{Accuracy}_i = F_i$(Age-at-Enrollment, Age-at-Recognition)

Parsing the NIST definition

ageing - irreversible changes to the **healthy** biometric source or neighboring anatomy that yield mated similarity **scores** that degrade **monotonically** with time-separation of the compared samples

» Why *healthy?*
- because while injury and disease can lead to arbitrarily rapid and serious changes, its prevalence and incidence are low or confined to certain small sub-populations

» Why *monotonic?*
- To separate temporary and reversible changes from permanent and irreversible ones

» Why scores degrade?
- Because changes cause metric distances to increase

» *Scores/algorithms* – why?
- Because that's what we care about operationally (now)

» Why *neighboring anatomy?*
- Because changes near the source might inhibit accurate localization of the source

Definitions: Ageing vs. Permanence

NIST Definition (adapted from iris)

- irreversible changes to the healthy biometric source or neighboring anatomy that yield mated dissimilarity scores that increase monotonically with time-separation of the compared images
- Favored term: Lack of permanence is an indictment to use of the biometric in long term identity management applications

ISO Testing Standard

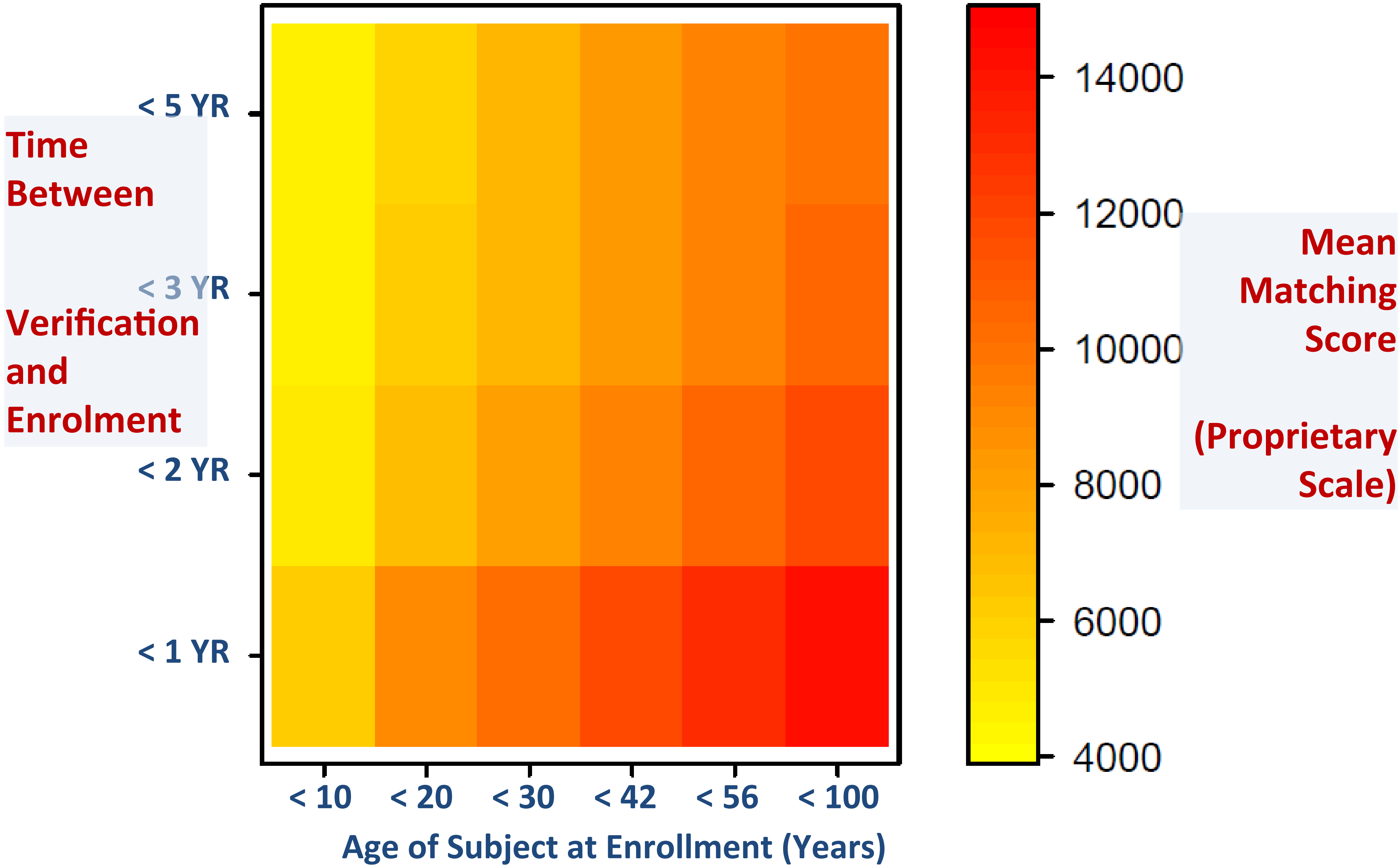
- "Longer time intervals generally make it more difficult to match samples to templates due to the phenomenon known as 'template aging'. This refers to the increase in error rates caused **by time-related changes in the biometric pattern, its presentation and the sensor**".
    - From 19795-1 aka Mansfield-Wayman
- NIST interpretation is that this is referring to mostly *irreversible* changes.

Time variation in three modalities

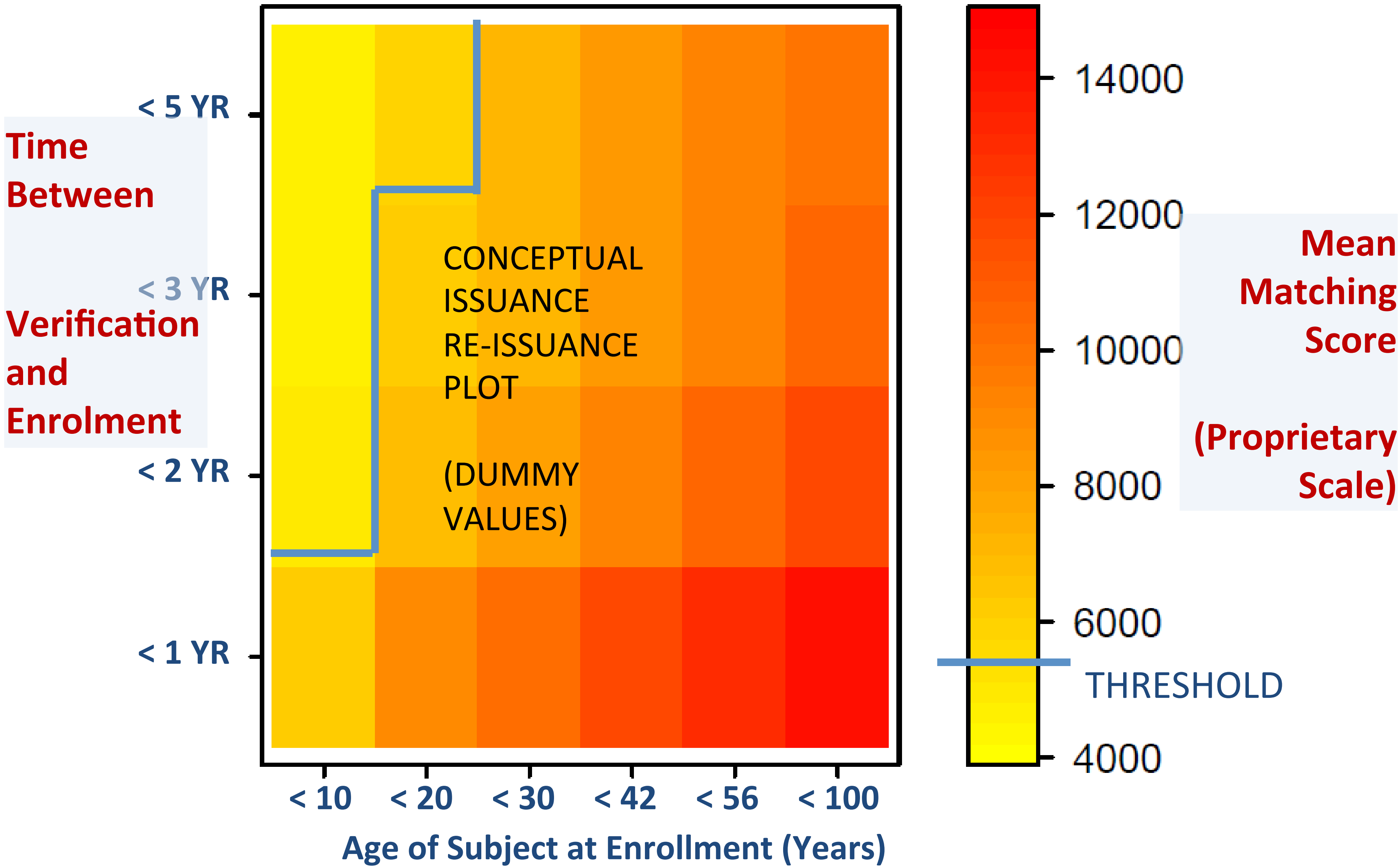
Iris	Fingerprint	Face
» Healthy • Blink occlusion • Gaze direction • Dilation varies with mood, consumption, ambient light » Cosmetic • Contact lenses • Glasses » Ageing • Pupil constriction • Palpebral aperture » Disease	» Healthy • Facial expression • Mouth movement • Head motion, head orientation • Facial hair » Cosmetic • Moisturizers » Ageing • Arthritic fingers	» Healthy • Facial expression • Mouth movement • Head motion, head orientation • Facial hair » Cosmetic • Makeup » Ageing • Soft tissue folds • Stoop – pitch forward

Face Ageing: Similarity score = F(Age, ΔT)

Face Visa Data :: Accuracy(Age, ΔT)



Face Visa Data :: Accuracy(Age, ΔT)



Longitudinal Analysis

Quantifying Permanence Using Data from a Large-Population Operational System

Ageing

Brad Wing

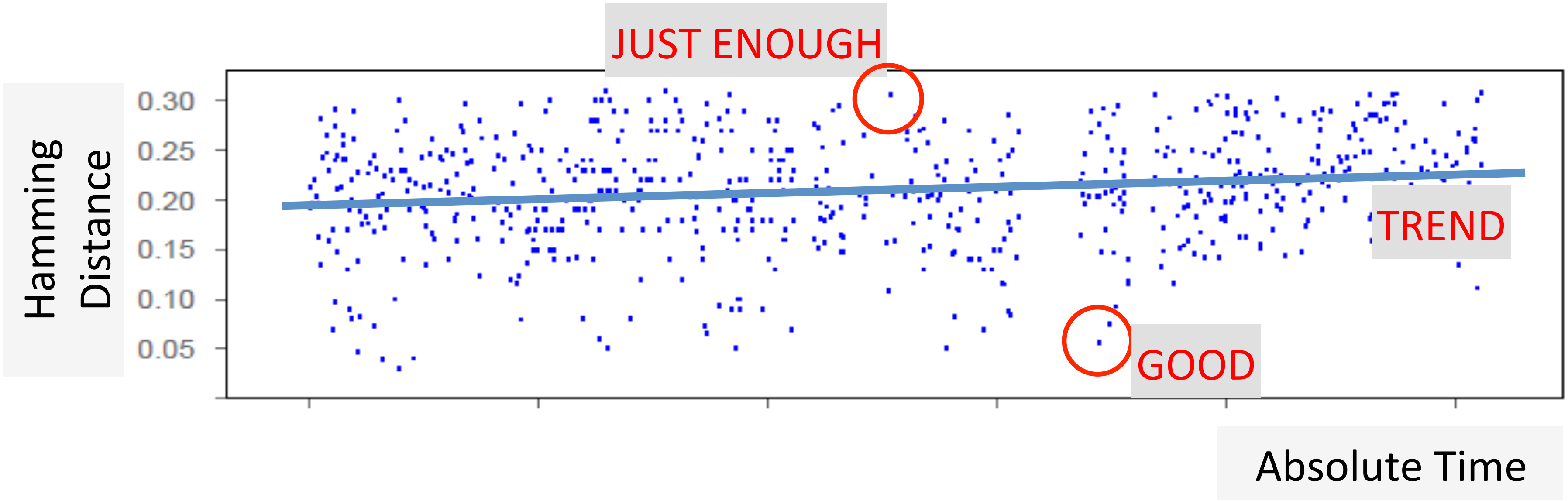
   

ALGORITHM E20A	0.617	0.578	0.532	0.541
ALGORITHM J20A	0.589	0.587	0.579	0.569

Green indicates successful 1:1 authentication at FMR = 0.001.
Red indicates failure.

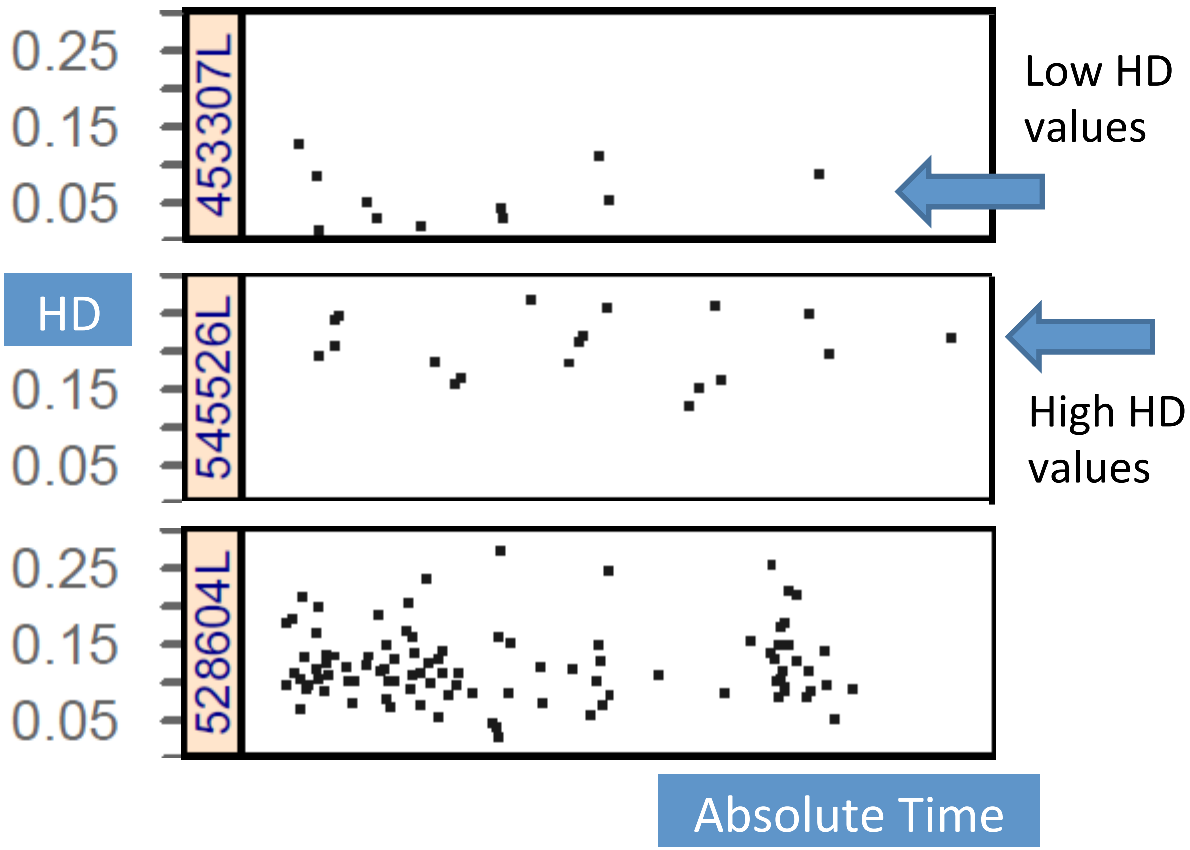
LONGITUDINAL ANALYSIS APPLIED TO ALGORITHM SCORE DATA

Longitudinal Data



- Scores from an iris-access control system
- Typically acquired daily
- Signal vs. noise concepts

Individual iris recognition HDs over time

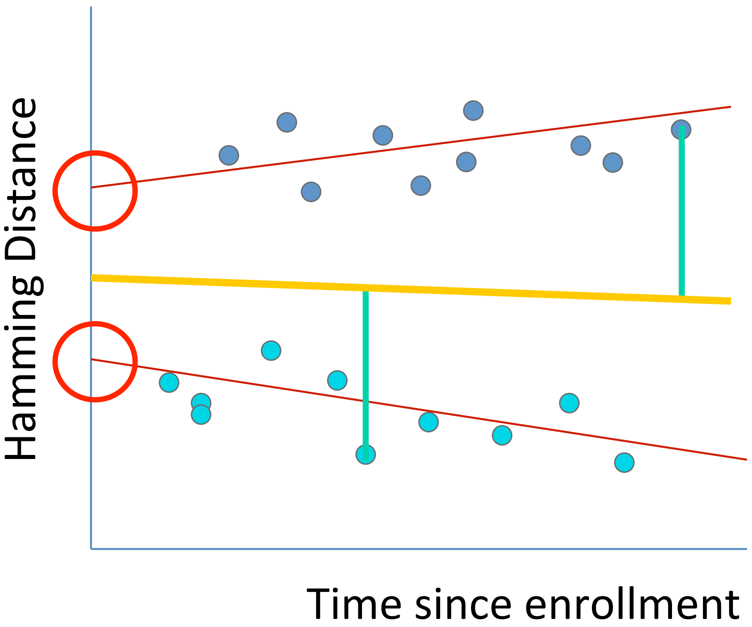


- Often, visually flat
- Considerable variance within eye
- Considerable variance between eyes

- Irregular sampling
- Imbalanced sampling
- Mixed effects models
  - Population part
  - Individual part

TRAJECTORIES INDICATE HETEROGENEITY – INTERCEPTS (AND GRADIENTS) VARY WITH QUALITY OF THE ENROLLMENT IMAGE cf. DODDINGTON's ZOO

Quantifying permanence via mixed-effects regression



Model for the j-th score from the i-th eye

$$HD_{ij} = \pi_{0i} + \pi_{1i}T_{ij} + \epsilon_{ij}$$

Intercept is sum of population average term, the *fixed effect*, and an eye-specific *random effect*

$$\pi_{0i} = \gamma_{00} + \psi_{0i}$$

Slope is sum of population average term, the *fixed effect*, and an eye-specific *random effect*

$$\pi_{1i} = \underline{\gamma_{10}} + \psi_{1i}$$

Permanence stated by the population wide rate at which Hamming Distances are increasing.

Subject to assumptions:

$$\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$$

$$\begin{bmatrix} \psi_{0i} \\ \psi_{1i} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_0^2 & \sigma_{01}^2 \\ \sigma_{10}^2 & \sigma_1^2 \end{bmatrix} \right)$$

MIXED EFFECTS MODEL RESPECT IDENTITY INFORMATION. SIMPLE LINEAR REGRESSION, IN YELLOW, DOES NOT AND HAS OTHER PROBLEMS

Iris Permanence Estimates

MODEL A: Unconditional growth model (without dilation)

$$HD_{ij} = \pi_{0i} + \pi_{1i} T_{ij} + \epsilon_{ij}$$

π_{1i} = 3 x 10^{-8} with $p = 0.8$

No detectable increase in Hamming distance

MODEL B: Unconditional growth model with quadratic dilation terms

$$HD_{ij} = \pi_{0i} + \pi_{1i} T_{ij} + \pi_{2i} D_u + \pi_{3i} D_u^2 + \pi_{3i} D_v + \pi_{4i} D_v^2 + \epsilon_{ij}$$

π_{1i} = 1 x 10^{-6} with $p = 0$

Hamming distance increases by 0.004 per decade

BENIGN!! SHARED, POPULATION-WIDE, TREND IS SLOW.

Recommendations on Measurement of Ageing

On laboratory collections

- Consider economics
- Consider how long subject pool is retained
  - Employees vs. students
- Careful controlled collections

On operational systems e.g. e-Gates

- Instrument and log operational systems
  - Retain similarity scores
  - Retain IDs
  - Retain date-stamps
  - Retain demographic + ethnic information
  - Avoid 1:FIRST and short-circuit distance computations
  - Assess prior P(Impostor)

Conclusions + Recommendations

1. Use mixed effects regression for longitudinal analysis
   - for imbalanced, irregular, auto-correlated data, from individuals with heterogeneous (biometric zoo) responses.
   - applied independently by NIST (iris) + MSU (fingerprint) + MSU (face, ongoing)
2. On new modalities: Check for evidence of permanence
   - From medical literature
   - From academic research
   - From dedicated collections…
   - From operational data…
3. Log your operational data!
   - excellent for detection and quantification of ageing and other time dependencies
   - useful even in "logged HD" form, without images.
4. Biometric ageing is not the problem in credentialing:
   - Ageing rates are slow enough (except in children) that you'll issue new credentials before the lifetime of the biometric.
   - Timescale for algorithms R&D and refresh < Timescale for ageing
   - Disease, and injury are rare enough that re-enrollment costs are manageable.

Thanks

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