Quantifying Biometric Permanence Using Operational Data

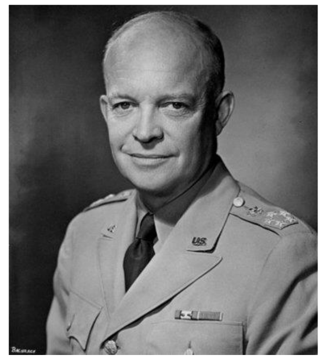
Longitudinal Analysis of Comparison Scores

Patrick Grother, James Matey, George Quinn + Elham Tabassi
Information Access Division
National Institute of Standards and Technology

IBPC 2014 :: NIST EAB Workshop on Lifetime Biometrics
Tuesday, April 4, 2014

Ageing

Dwight D Eisenhower



ALGORITHM E20A	0.647	0.601	0.599	0.579
ALGORITHM J20A	0.595	0.578	0.565	0.548

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

Ageing

Brad Wing

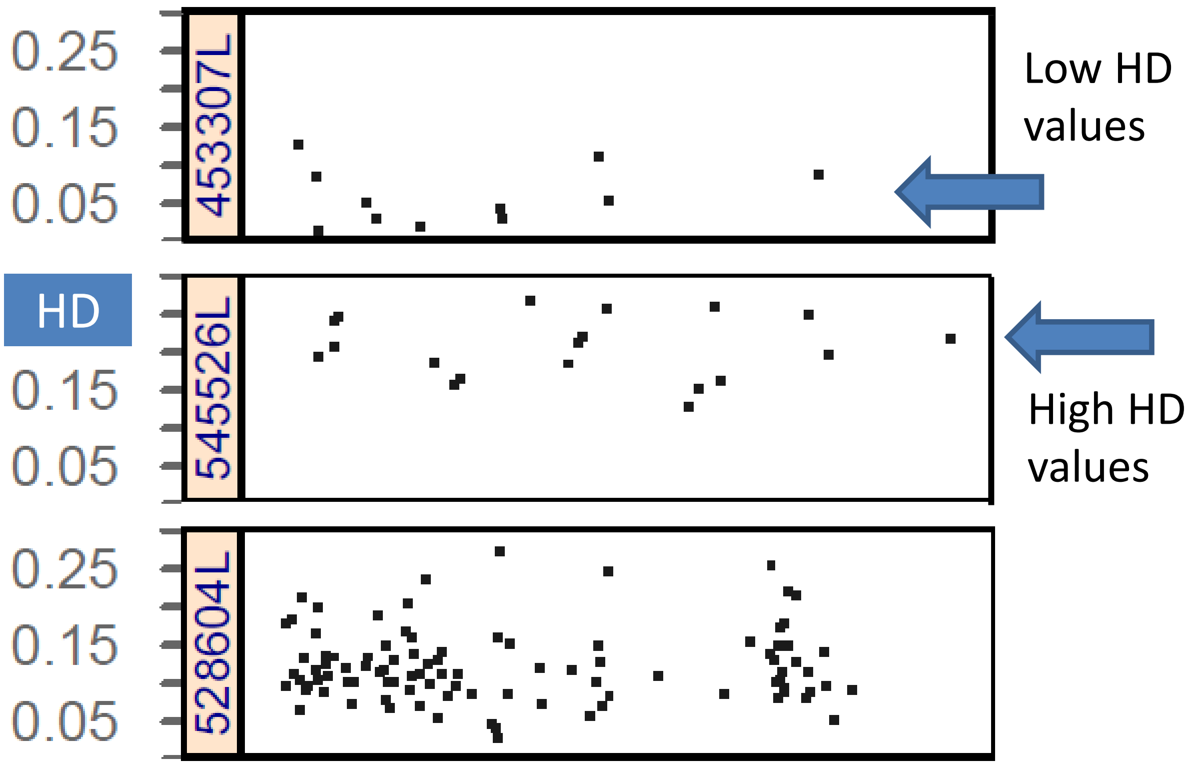



ALGORITHM E20A	0.617	0.578	0.532	0.541
ALGORITHM J20A	0.589	0.587	0.579	0.569

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

THE GOAL, SHARED WITH OTHER STUDIES IN THE FIELD, TO DETERMINE IF THERE'S AN ANALOG OF THIS FOR IRIS – IRREVERSIBLE CHANGE TO THE IRIS TEXTURE

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

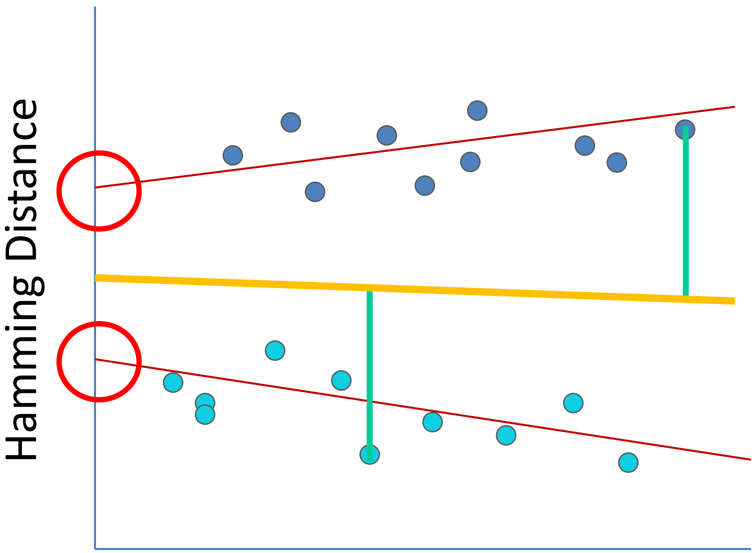
Nexus, Frequent Traveler Program

- As provided to NIST
  - 7.7 million log entries
  - 450K subjects
  - 680K eyes
  - Panasonic + LG cameras

- Positive ID
  - Usually token-less
  - 1:FIRST iris
- Pop: US/CA + Perm res.
  - Motivated frequent travelers
  - US/CA air, land, sea
- Equipment
  - Operational since 2002, Daugman alg, refresh, c. 2013.
  - Panasonic BM-330ET camera
  - LG Cameras (removed c. 2007)

- As used by NIST here
  - **1973761 log entries, from 29654 left eyes, those with 10 or more transactions, over at least 1460 days**
  - **Panasonic BM-330ET only**

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*

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

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

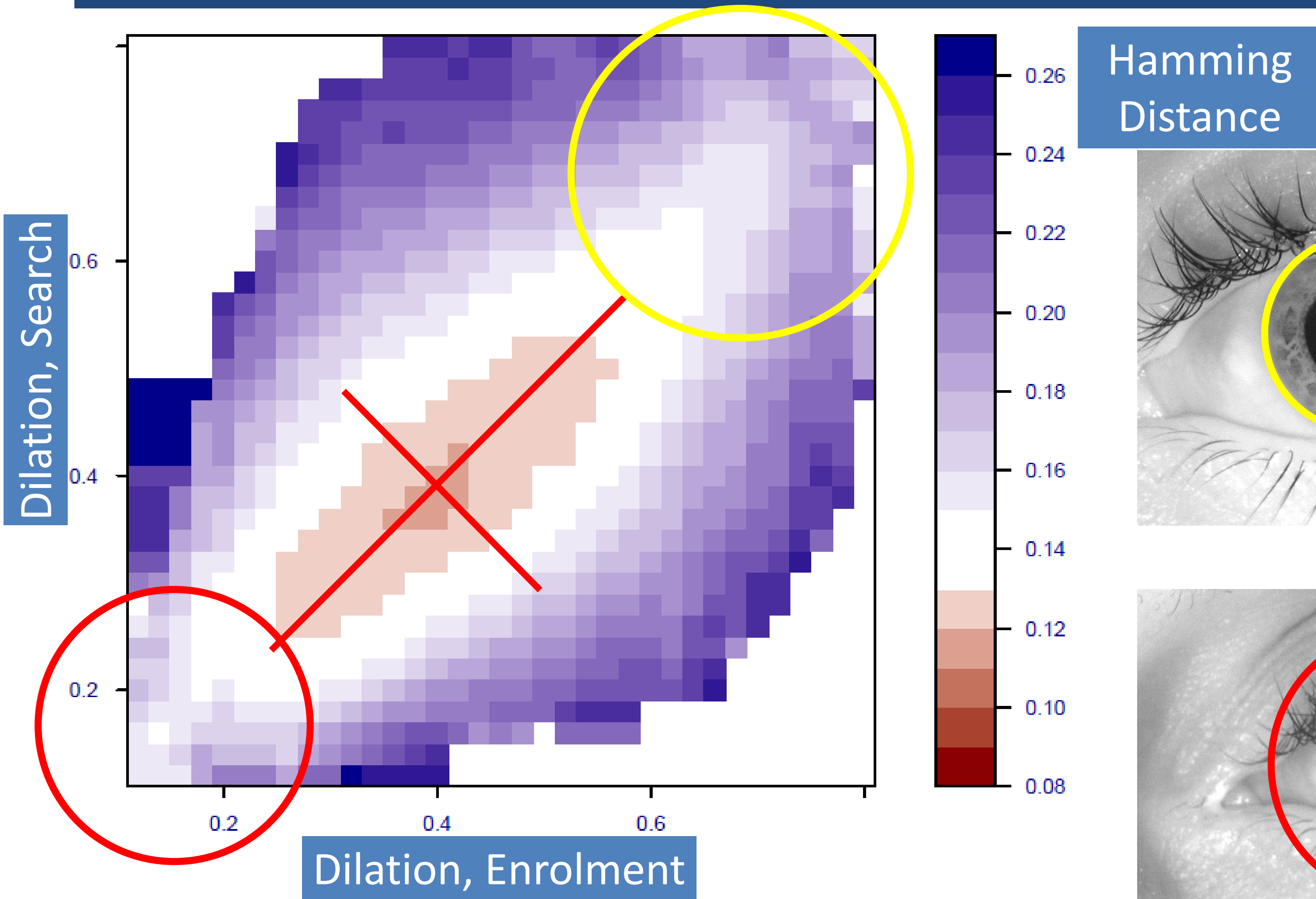
Subject to assumptions:

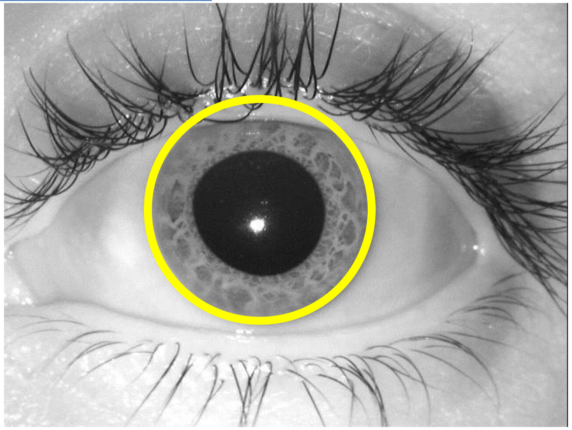
$$\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$$

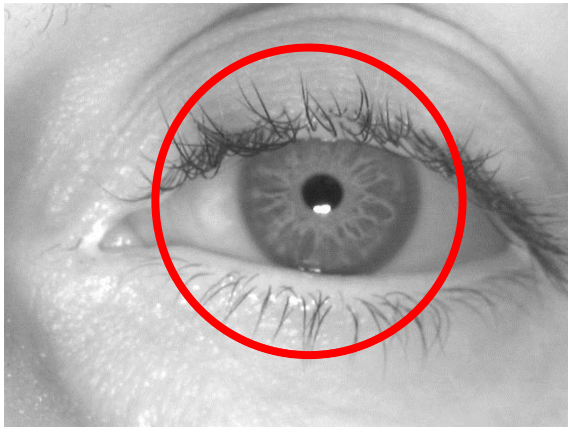
$$\begin{bmatrix} \psi_{0i} \\ \psi_{1i} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_0^2 & \sigma_{01}^2 \\ \sigma_{10}^2 & \sigma_1^2 \end{bmatrix} \right)$$

MIXED EFFECTS MODEL RESPECT IDENTITY INFORMATION. SIMPLE LINEAR REGRESSION, IN YELLOW, DOES NOT

Accuracy vs. dilation and dilation change

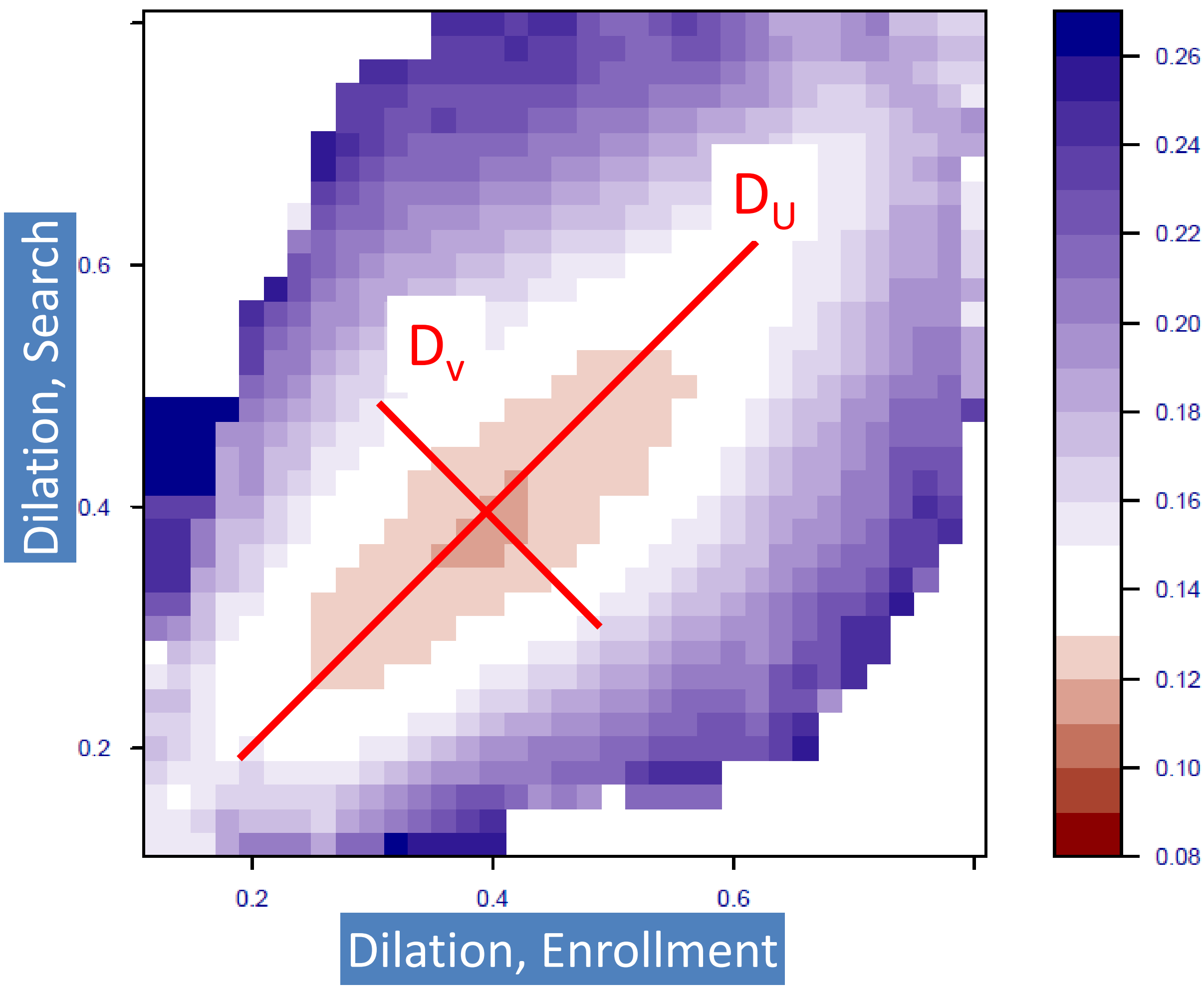






THE HEATMAP SURFACE IS A BOWL, NOT A V-SHAPED VALLEY.
THE NEXT SLIDE INTRODUCES ONE MODEL OF THIS SEPARABLE FUNCTION

Accuracy vs. dilation and dilation change



- Dilation is an explanatory variable in regression
- Include two orthogonal terms:
  - Dilation difference D_v
  - Dilation magnitude D_u

MODEL THIS AS A "QUADRATIC BOWL" POLY(D_U,2) + POLY(D_V,2).

THERE ARE ALTERNATIVES – FUNCTION APPEARS SEPARABLE SO $F(D_1)F(D_2)$

Model habituation too? It affects scores*

Habituation … acquisition of a motor skill involving learning of an internal model of the dynamics of the task+.

A: For the "i"-th eye, does the mean time between captures explain observed Hamming distances

B: The model could be extended to capture learning and "muscle memory" via memory of recent experience

$$\theta_i = \frac{1}{n_i} \sum_{j=2}^{n_i} T_{ij} - T_{ij-1}$$

$$\phi_{ij} = e^{-\frac{T_{ij} - T_{ij-1}}{\tau}}$$

FURTHER RESEARCH NEEDED

*As quantified by Eric P. Kukula, Stephen J. Elliott, Bryan P. Gresock, and Nathan W. Dunning. *Defining habituation using hand geometry*. In Proc. IEEE Workshop on Automatic Identification Advanced Technologies, pages 242–246, June 2007.

+ Adapted from Reza Shadmehr* and Henry H. Holcomb, *Neural Correlates of Motor Memory Consolidation,* Science, Vol 277, 1997-AUG-07

NEXUS Regression Permanence Statements

NIST

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

MODEL C: Unconditional growth model with habituation terms

$$HD_{ij} = \pi_{0i} + \pi_{1i}T_{ij} + \pi_{2i}\theta_{ij} + \pi_{3i}\phi_{ij} + \epsilon_{ij}$$

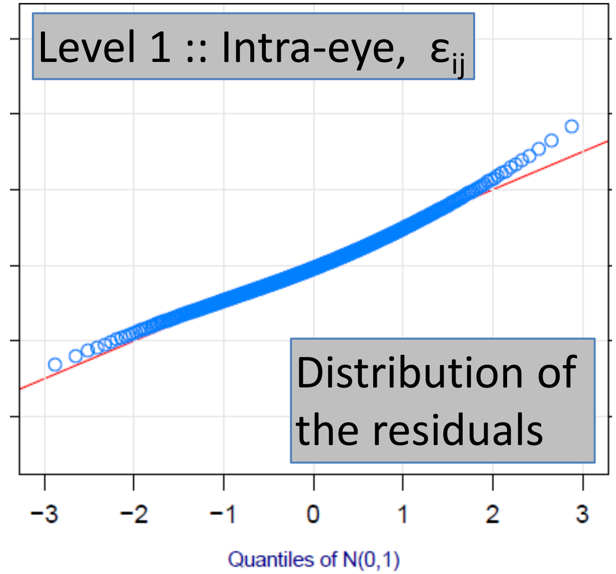
π_{1i} = -3 x 10^{-7} with p = 0.01

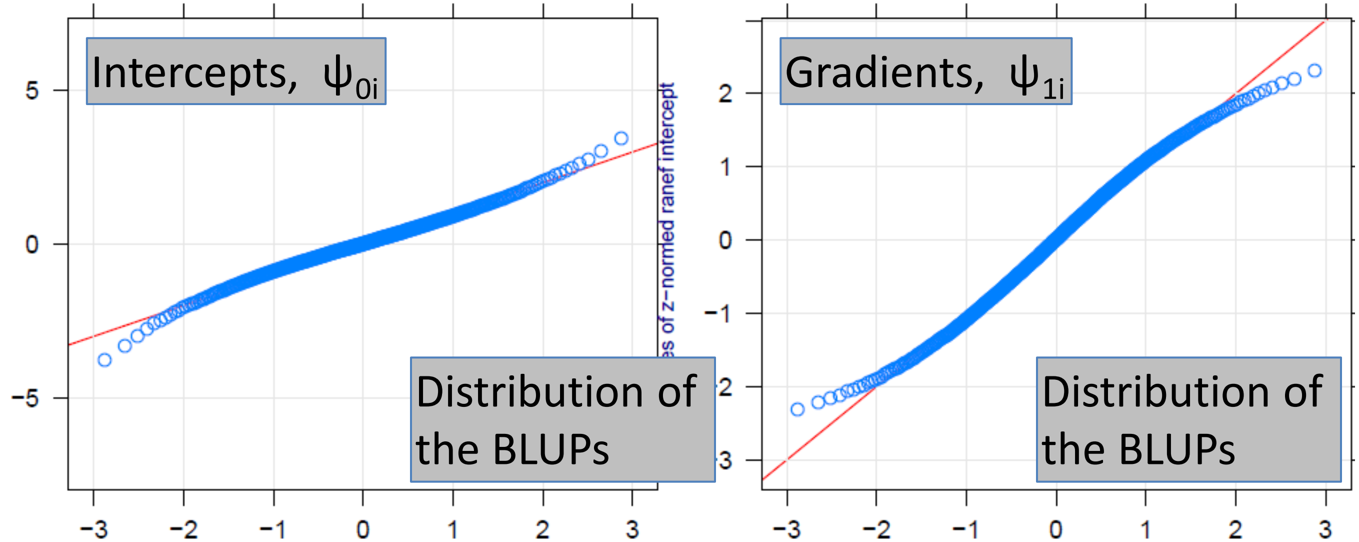
Hamming distance decreases!
Further modelling needed

Model Validation: Satisfying Normality Assumptions

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

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



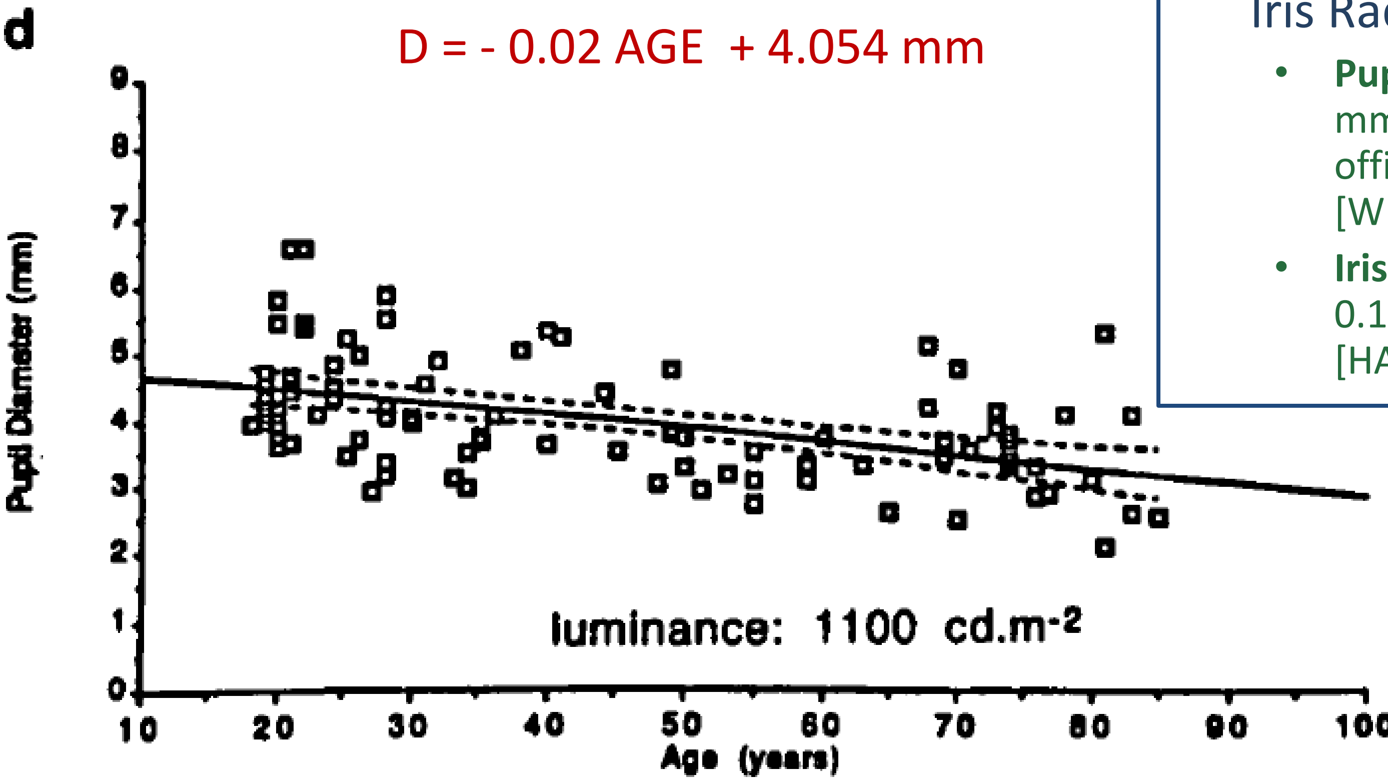


Pupil size over a lifetime

» Dilation = Pupil radius / Iris Radius

- **Pupil size** decreases by 0.2 mm per decade under office like illumination [WINN94]
- **Iris size** decreases by 0.13mm per decade [HALL04]

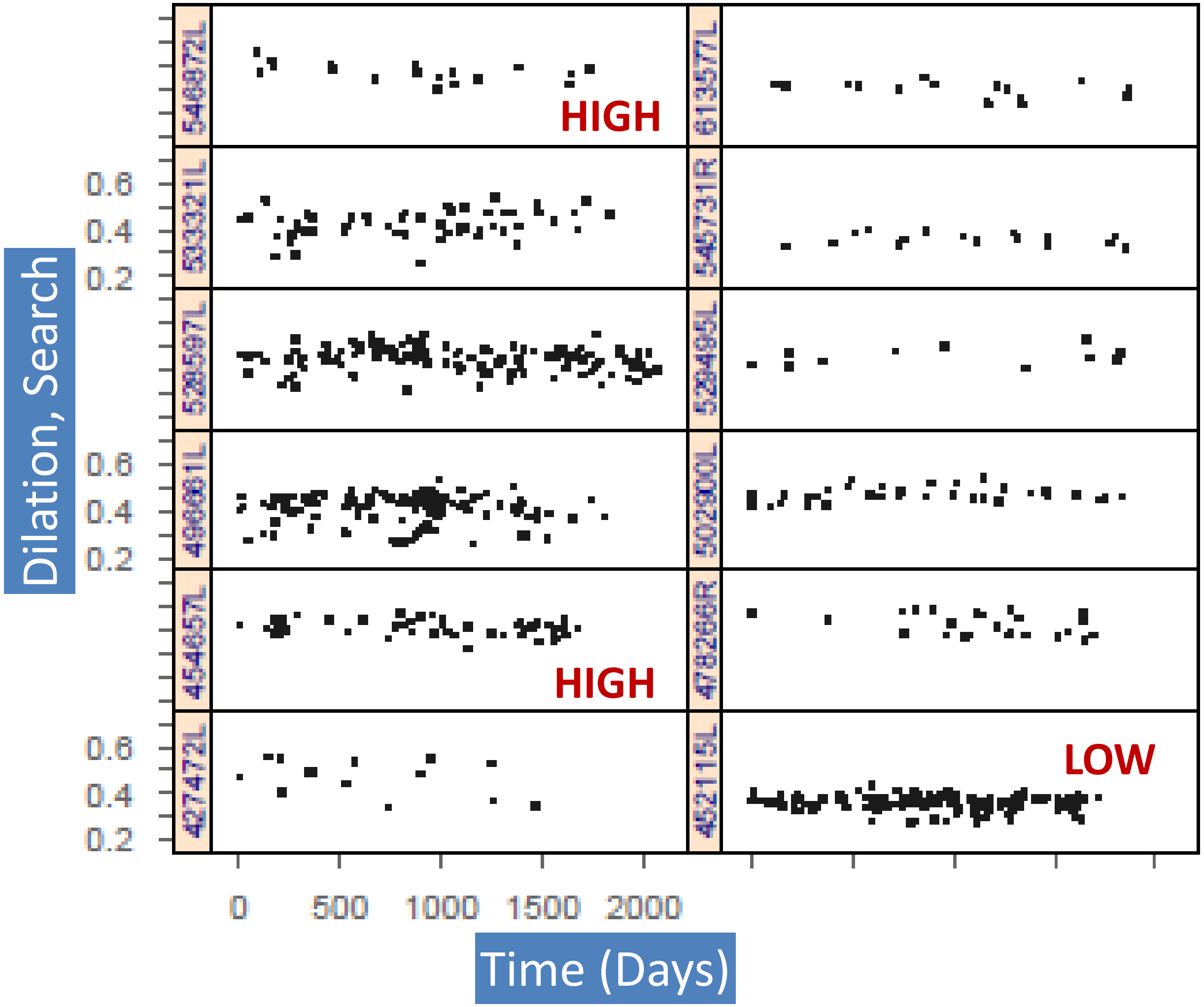
D = - 0.02 AGE + 4.054 mm



cf. office lighting

Source: Winn B, Whitaker D, Elliott DB, Phillips NJ. *Factors affecting light-adapted pupil size in normal human subjects.* Investigative Ophthalmology Visual Science, Mar 1994, Vol. 35, No. 3, pp. 1132-7.

NEXUS Dilation over time :: Real Examples



- Visually flat
- Considerable variance within eye
- Considerable variance between eyes

- Irregular sampling
- Imbalanced sampling
- ➡ Mixed effects models

OVER 7 YEARS, DILATION IS VISUALLY FLAT, THE DOWNWARD TREND OF PREVIOUS SLIDE IS DOMINATED BY “NOISE” ASSOCIATED WITH AMBIENT LIGHT, PHYSIOLOGY, MOOD, ETC.

Longitudinal Dilation Change

Eye-specific dilation change trajectory

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

And the coefficients are "fixed effects" + "random effects"

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

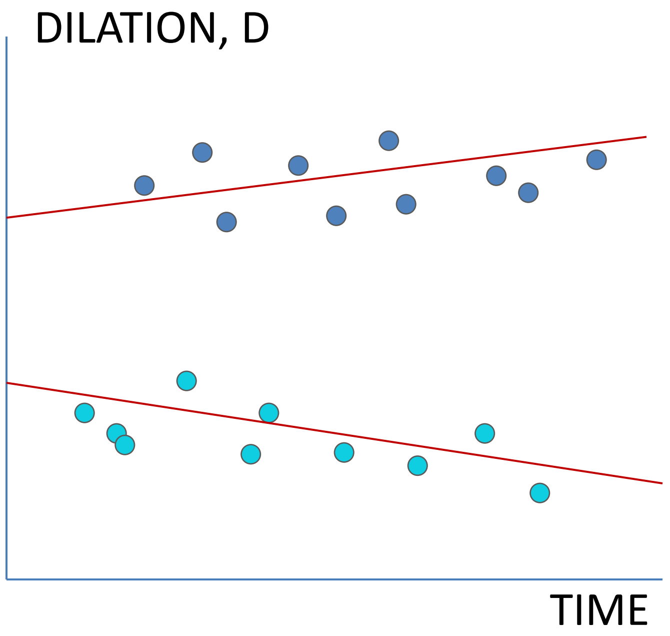
Population average intercept "fixed effect" (γ_{00})

Individual eye intercept "random effect" (ψ_{0i})

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

Population average growth rate "fixed effect" (γ_{10})

Individual eye growth rate "random effect" (ψ_{1i})

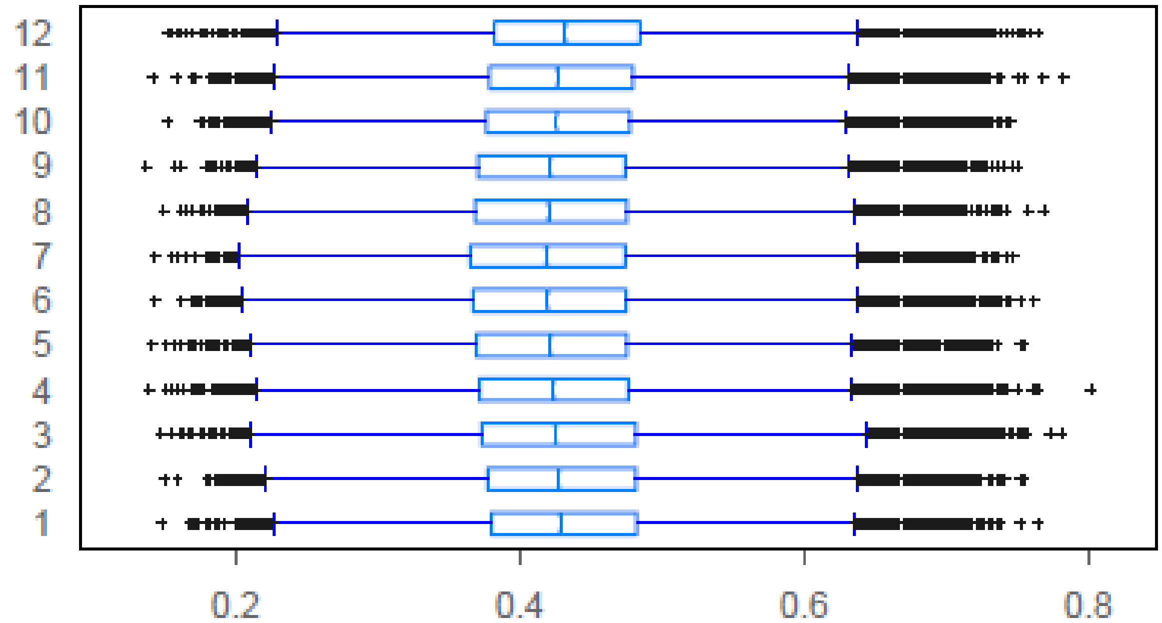


$$\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$$

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

MIXED EFFECTS MODEL QUANTIFIES "NOISE" *AND* TREND

Seasonal Dilation Variation



Dataset includes integer month of capture.

$$D_{ij} = \pi_{0i} + \pi_{1i} T_{ij} + \pi_{2i} \cos\left(\frac{2\pi(m_{ij} - 1)}{12}\right) + \epsilon_{ij}$$

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

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

$$\pi_{2i} = \gamma_{20}$$

Seasonality included only as a fixed effect i.e. it affects everyone equally

Likely cause: Length of day effects, travelers exposed to outdoor lighting. Latitude ~45 degrees N.

Magnitudes of NEXUS Dilation Variation

» Population average
- Fixed effect π_{0i} = 0.4344 +/- 0.0003

» Inter-eye variation (between people)
- Standard deviation of ψ_{0i} = 0.066

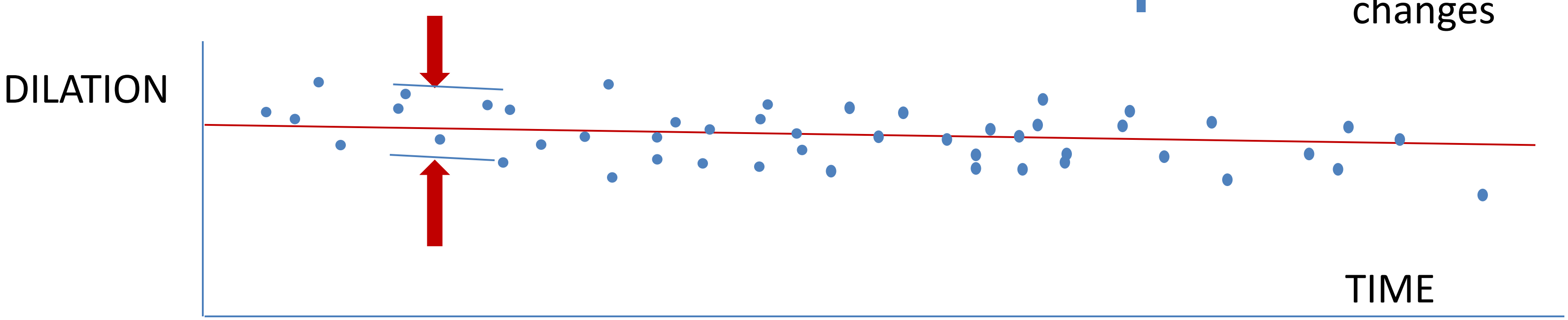
» Intra-eye variation (within eye)
- Standard deviation of ε_{ij} = 0.047

» Seasonal term
- Magnitude of π_{2i} = 0.00667 +/- 0.00005

» Elapsed time
- Magnitude of π_{1i} = -0.00143 +/- 0.00004 per year

x5

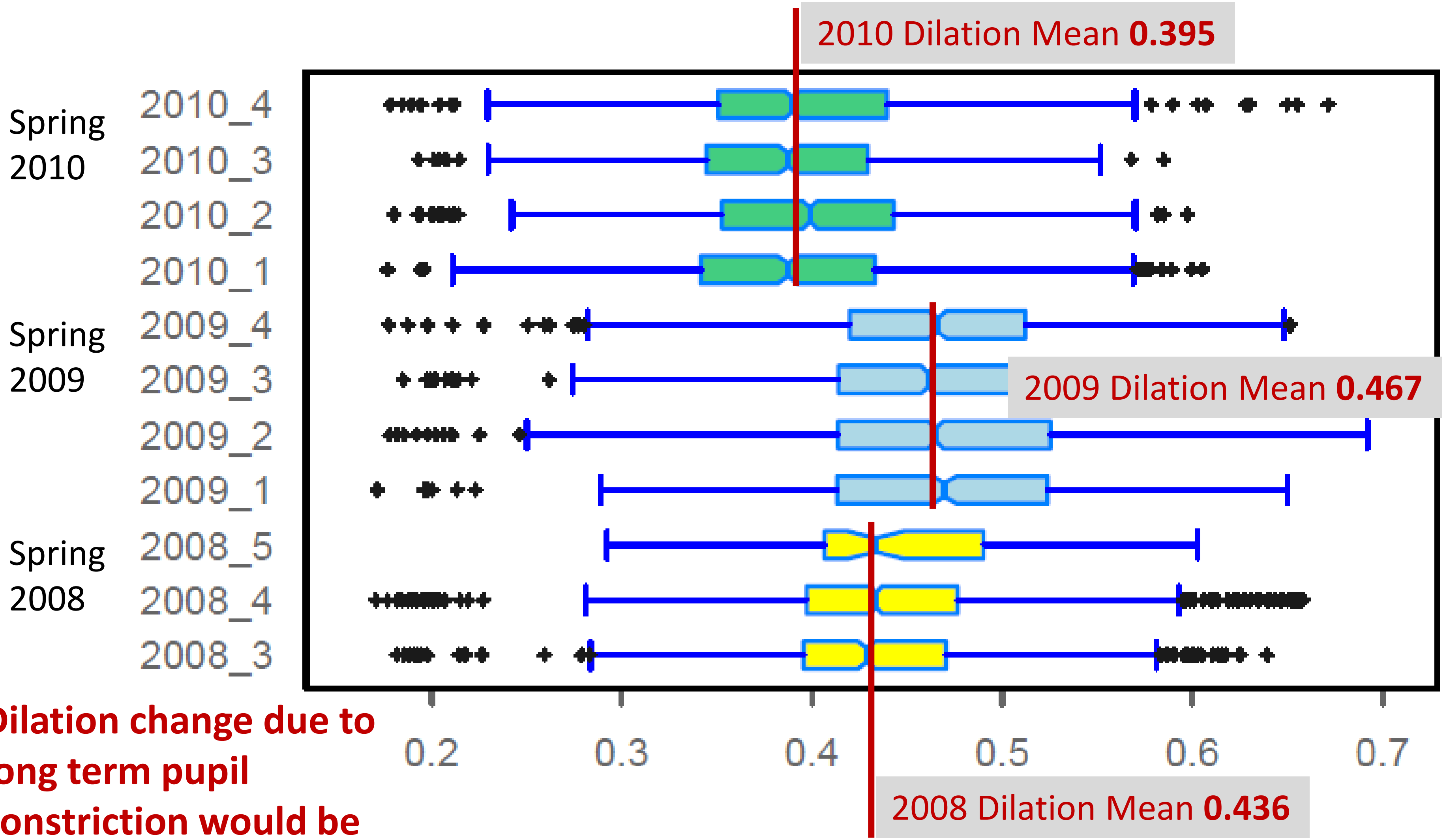
x32 so about 3 decades for magnitude of permanent constriction to be comparable with short term changes



An Explanation For the Notre Dame Results

1. Observed genuine comparison score distributions shift with time.
2. Observed dilation distributions shift also.
3. Dilation differences degrade comparison scores.

Systematic Dilation Changes in ND Images



Dilation change due to long term pupil constriction would be approx. -0.004

Source: NIST application of three commercial iris algorithms to ND images used in Fenker et al.

Adjusting ND Scores for Dilation

$$d'_{ij} = d_{ij} - \beta_{i2} \Delta D_{ij}$$

Adjusted dis-similarity score (d'_{ij})

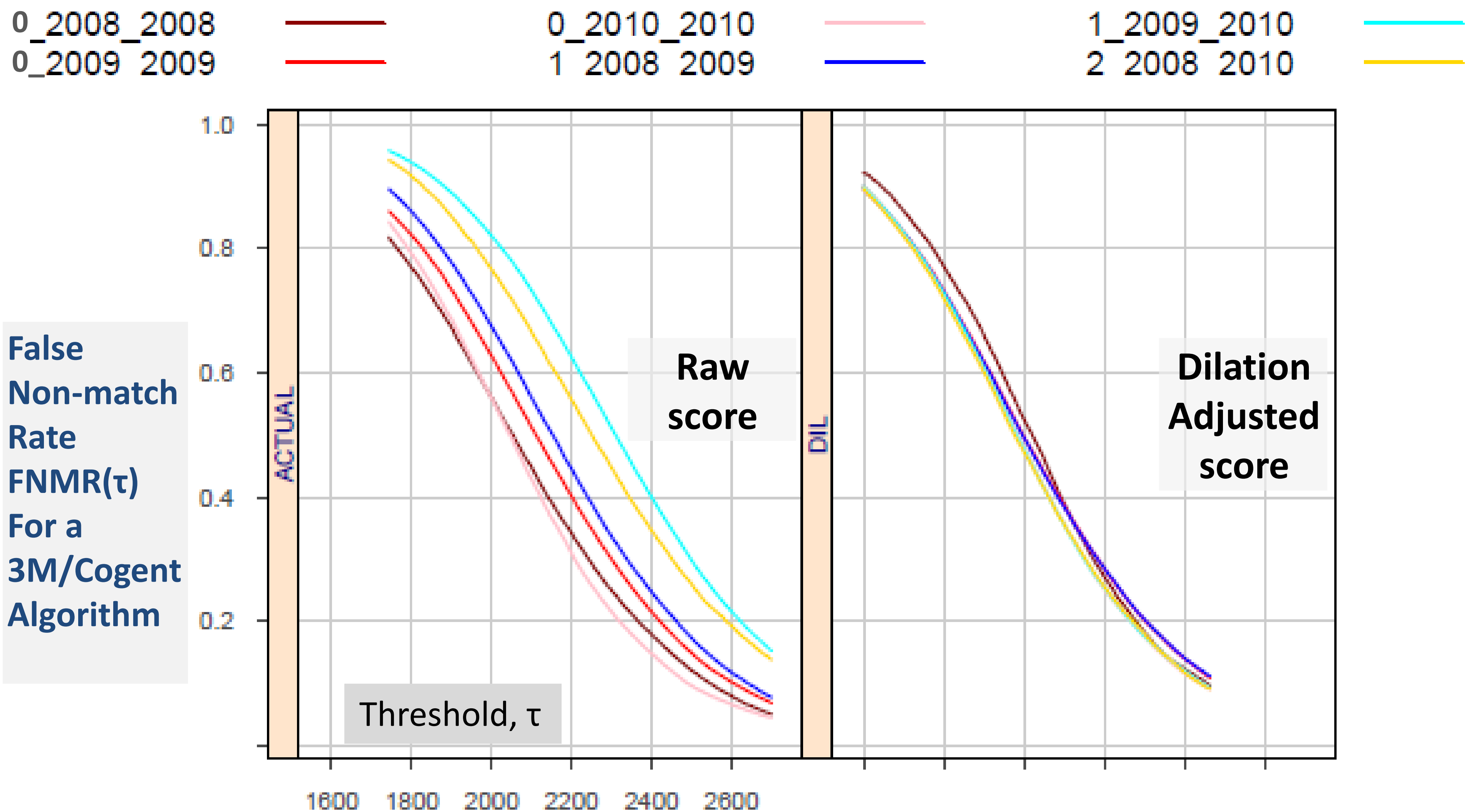
Dis-similarity score from comparison of the j-*th* pair of images from the i-*th* individual eye (d_{ij})

Coefficient applicable to all scores from the i-*th* eye (β_{i2})

Pupil dilation difference in the j-*th* pair of images (ΔD_{ij})

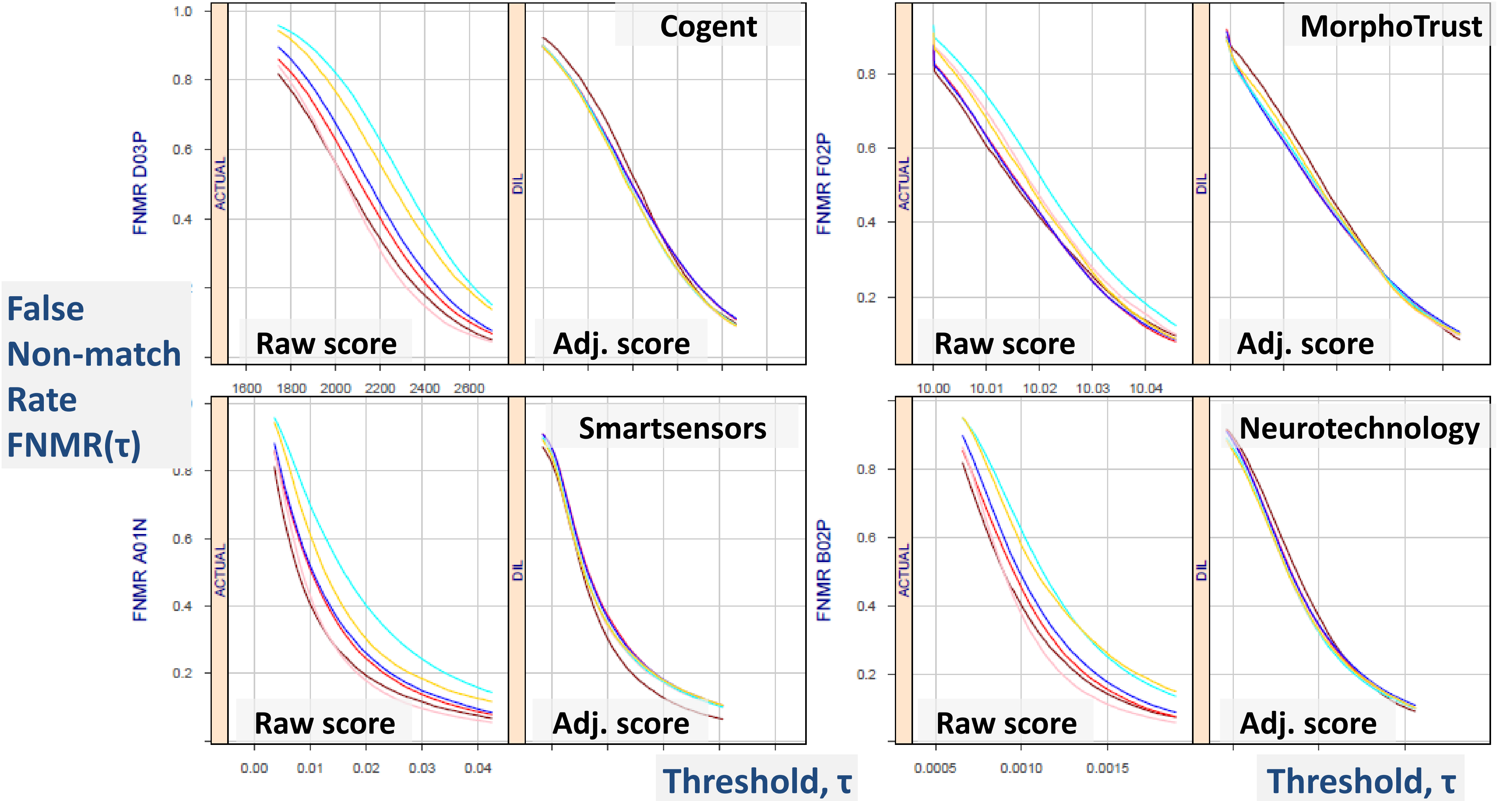
THIS REMOVES AN AMOUNT PROPORTIONAL TO SOLELY THE DILATION DIFFERENCE, OVER TWO YEARS, THE PUPIL CONSTRICTION IS NEGLIGIBLE

Raw, Adjusted Mate Score Distributions vs. τ



THIS ADVERSE SHIFT IN THE GENUINE DISTRIBUTION THRU TIME LARGELY DISAPPEARS ONCE DILATION DIFFERENCES ARE ACCOUNTED FOR

Raw, Adjusted Mate Score Distributions vs. τ



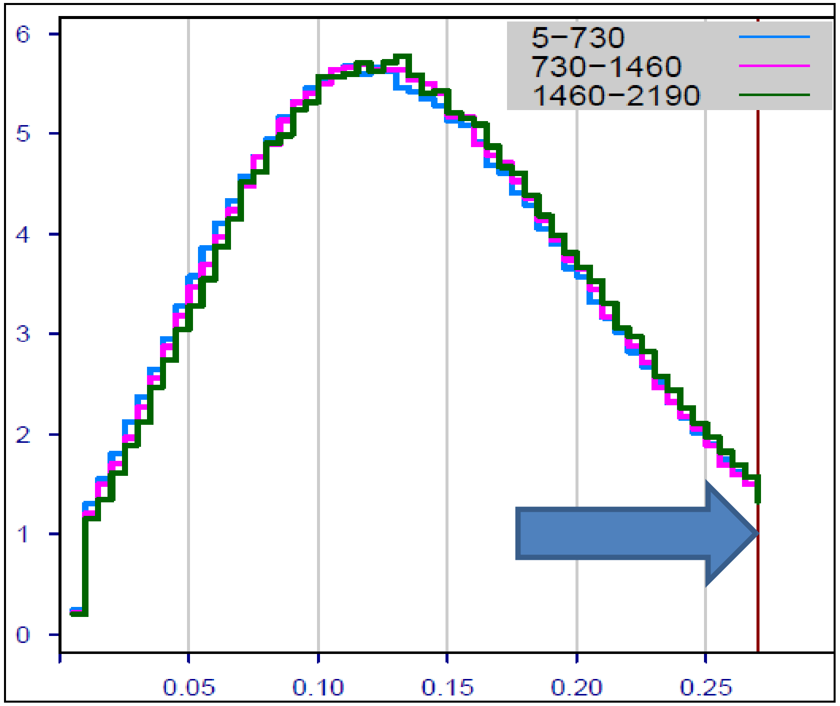
Images Notre Dame 08-10

THIS RESULT, PUBLISHED PREVIOUSLY IN IREX VI, HOLDS FOR OTHER ALGORITHMS TOO

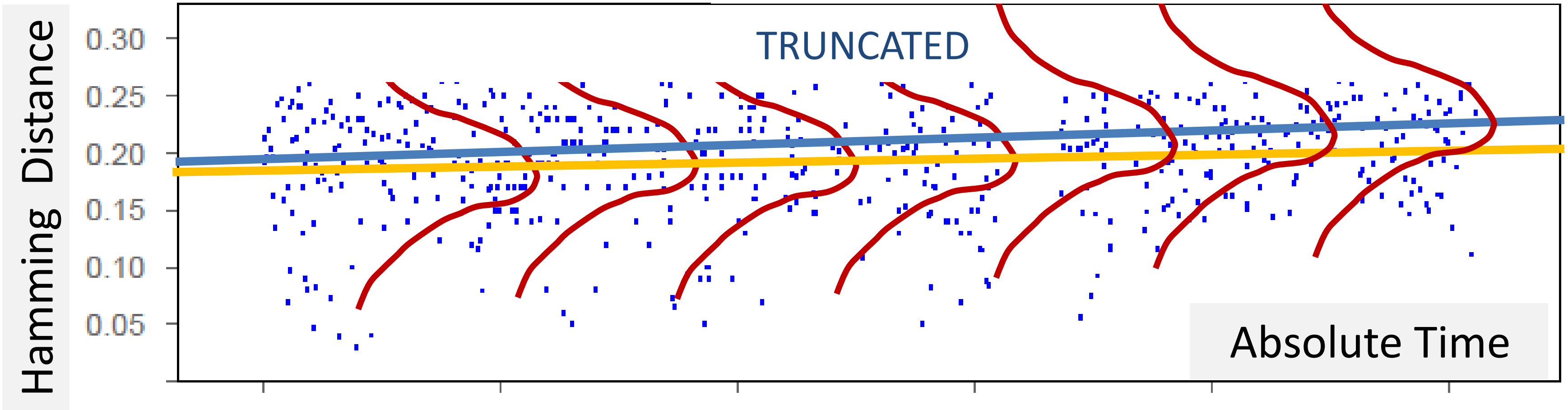
A Qualifier on the NEXUS Iris Log Data

1. Iris identification algorithms short circuit distance computations for speed.
2. Distances above 0.27 are not computed and not returned – the search returns no enrolled identity.

But the NEXUS data is thresholded at HD = 0.27



- The system doesn't return scores above τ ~ 0.27
  - when unenrolled eyes presented
  - when poor images are collected
  - if the camera is defective
  - if the iris has changed, or the cornea
  - This is done to expedite search
- Regression is potentially flawed by this system-specific feature:
  - Suppose scores were samples from a non-stationary distribution



Notes on why truncation Is not that influential

» 1. Estimating the center of the distribution is not that sensitive to tail truncation

- Analytic results
- Empirical results

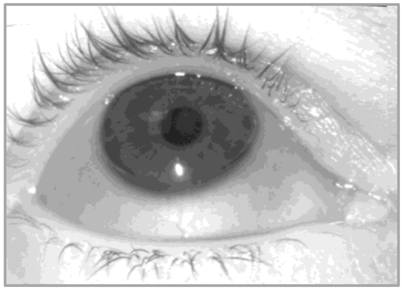
» p.76 IBG's exhaustive report[+] on the ITIRT iris recognition trial for the camera used in NEXUS

- 3% best of three attempts T-FRR
- 8% single image FNMR

» 2. Nature of what goes in the tail

- Mostly due to: motion blur, occlusion, gaze angle, specular on boundary, dilation

Occlusion

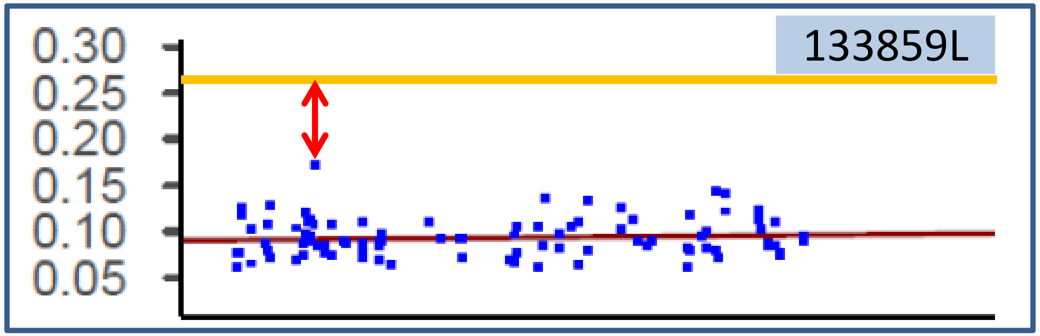


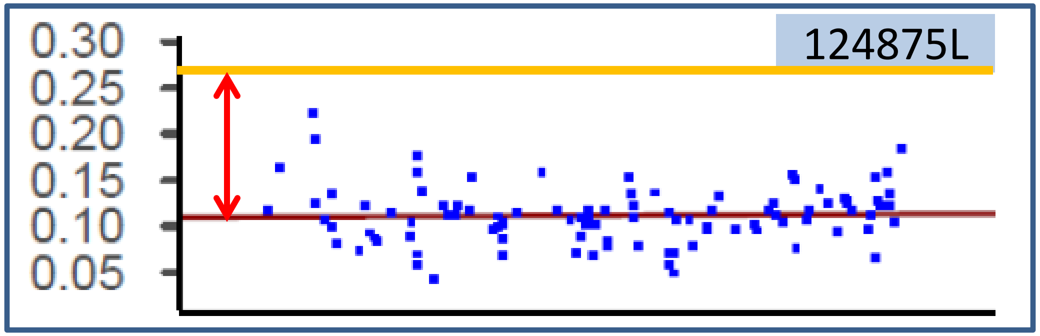
Gaze angle

[+]**M. Thieme, *Independent Testing of Iris Recognition Technology Final Report*, IBG, May '05**

Permanence in "High Achievers"

- 4. Many eyes emit scores well below threshold
  - The zoo, in part due to quality of the enrollment image





- For the whole population, HD degrades by 1×10^{-6} per day
  - For 15457 "high achievers", eyes that have **0.075 ≤ mean HD ≤ 0.135**, the HD degrades by 0.3×10^{-6} day^{-1}
  - For 7518 eyes that **never produce a HD above 0.21**, HD degrades by 0.2×10^{-6} day^{-1}

MIXED EFFECTS MODELS HEED IDENTITY:

ANALOGY: USING A 1.8M TAPE MEASURE DOESN'T PRECLUDE MEASURING HEIGHT OF SHORTER INDIVIDUALS

Face Ageing

Longitudinal Analysis of FRVT Scores Derived from Mugshot Images

Comparative evaluation of FR algorithms: Resistance to time lapse

- Vanilla mixed-effects model, without additional explanatory variables
- Problem: Scores exist on proprietary ranges, with little ability to interpret.
  - Option 1: Express growth rate as number of years before the mean genuine distribution would increase to, say, the FNMR = 0.1 threshold.
  - Option 2: Use z-norm on scores, express growth as "number of standard deviations per year".

Algorithm	Υ_{10} = fixed effect growth rate (yr^{-1})	P-value
A30A	-0.127 ± 0.002	Always zero
B30A	-0.172 ± 0.002	
E30A	-0.129 ± 0.002	
D30A	-0.162 ± 0.002	
J30A	-0.149 ± 0.002	

!! Work in progress !!

MIXED EFFECT MODELS CAN INVOLVE:

Time invariant covariates:
> Sex, race

Time varying covariates:
> Pose, age

Conclusions

- **For longitudinal analysis, mixed effects regression**
  - Is appropriate for longitudinal analysis of imbalanced, irregular, auto-correlated data, from individuals (eyes) with heterogeneous responses.
  - has been developed independently by (at least) NIST (IREX VI) and MSU (Soweon Yoon)
- **Permanence**
  - **For iris: No detectable population-wide shifts in scores in NEXUS data**
  - For face: Provisional work implies measureable shifts in genuine scores.
- **Habituation**
  - For iris, frequency of use and time-since-last-use give improved scores
- **Operational data**
  - It's volume affords excellent opportunities to detect and quantify effects
  - Is useful even in "logged" form, without images.
- **Dilation change**
  - Natural short term variance > seasonal-related variation > the first longitudinal estimate of dilation change (assoc. with pupil constriction)
  - Trend is barely observable in iris-ageing studies, so does not present a co-linearity hazard in regression analyses

Thanks