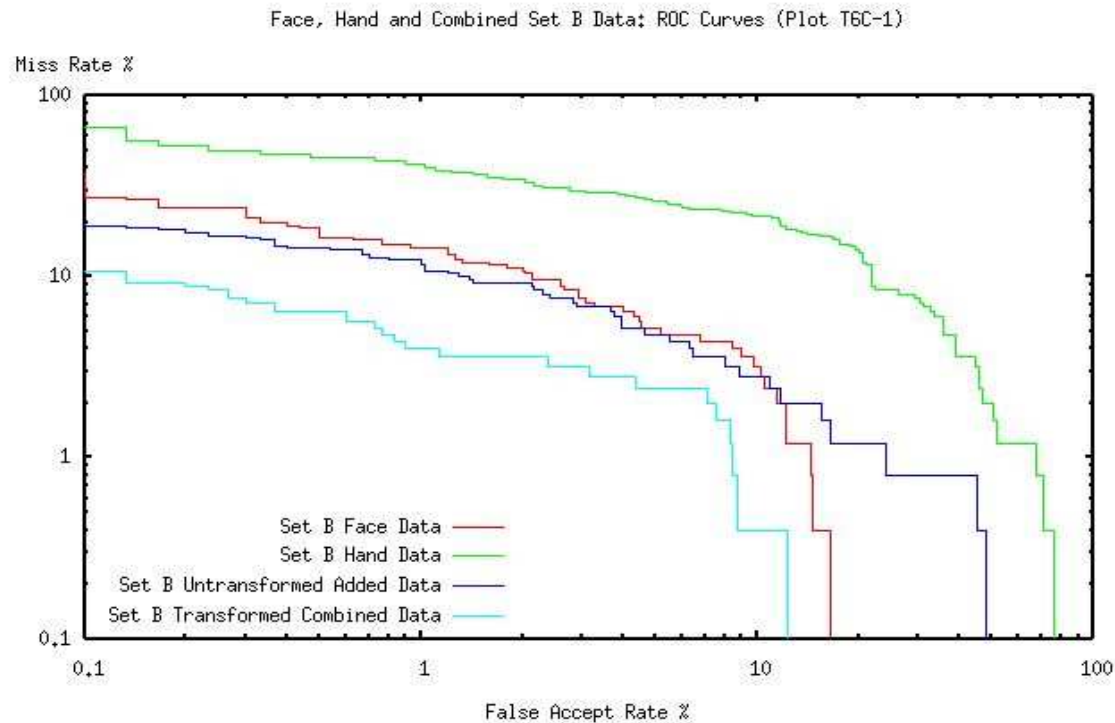


# The Need for Standardisation of Multi-Modal Biometric Combination

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# Questions on Standards for Multi-Modal Biometrics

- 1: What are multi-modal biometrics?
- 2: What does multi-modal capability offer to users of biometrics?
- 3: How do multi-modal biometrics work? An example.
- 4: What are the implications of multi-modal aspects for standardisation?
- 5: Is the technology for multi-modal biometrics understood well enough?
- 6: Is now the time for standardisation on multi-modal biometrics?
- 7: What standard(s) should be produced for multi-modal biometrics?

# A Multi-Modal Biometric System is:

- 1: A biometric system that incorporates 2 or more individual biometric devices (eg for hand identification and for face identification),
- 2: And incorporates a component that combines the output measures from the individual biometric devices (for each multi-modal attempt), to give a single measure for decision making.
- 3: And incorporates means for acquiring, in advance of operational use, characterisation information about the individual biometric devices and how best to combine their outputs.

In particular, this includes characterisation on the relative performance(s) of the individual biometric devices and the interpretation of their output measures.

# User Benefits

- 1: Significantly improved identification performance: miss rate (or false reject rate, FRR) versus false accept rate (FAR) at the chosen acceptance threshold.
- 2: Works for more persons, including those lacking the ability (or desire) to give some particular biometric measurements (at all or with reliability).
- 3: In negative identification scenarios (eg preventing multiple enrolments for national identity registration), greater robustness against self-mutilation attacks.

# How Multi-Modal Combiners Work

**Decision Combination.** Each individual biometric devices makes its own accept/reject decision. The multi-modal combiner fuses them together, eg by: voting, a weighted sum or some other means. **It does not work well enough, and often gives a combined decision worse than the decision from the best individual biometric device.**

**Score Combination.** Each individual biometric device outputs a score. The multi-modal combiner fuses these into a single score, which is then compared to the system acceptance threshold. If done correctly, it is guaranteed that the combined performance is no worse than the best of the individual performances. **This is the one to use.**

**Feature Combination.** This can be better than score combination, but only where there is correlation between the features measured by the individual biometric devices (which is unlikely). Otherwise, score combination can do as well (usually more simply). Also, the wide scope of feature combination approaches is beyond practical standardisation. **This one is rarely beneficial and standardisation is impractical.**

# Biometric Gain against Impostors (BGI) - 1 of 3

The BGI is a very useful concept. It is how many times more likely we believe it that the claimant is an impostor, after having made biometric measurements, than we believed it beforehand. The BGI is defined for each individual biometric device, and for any multi-modal combination. Its mathematical definition is the ratio of the *a posteriori* to the *a priori* probabilities of the claimant being an impostor.

Also, let us define the modified BGI as the likelihood ratio of impostor to genuine, for any single biometric device, or any multi-modal combination.

Now, it can be shown that, for J independent biometric devices:

$$\text{BGI}'(s_1, s_2 \dots s_j) = \frac{P(s_1, s_2 \dots s_j | I)}{P(s_1, s_2 \dots s_j | G)} = \text{BGI}'(s_1) \cdot \text{BGI}'(s_2) \dots \text{BGI}'(s_j) .$$

Where:  $\text{BGI}'(s_1, s_2 \dots s_j)$  is the modified BGI, given the scores from J biometric devices, and  $\text{BGI}'(s_j)$  is the modified BGI for the j'th single biometric device given score  $s_j$ ;

$P(s_1, s_2 \dots s_j | I)$ ,  
 $P(s_1, s_2 \dots s_j | G)$  are the probabilities of the J scores from the biometric devices given, respectively, that the claimant is known to be an impostor or known to be genuine; the equivalents for the j'th individual biometric device are  $P(s_j | I)$  and  $P(s_j | G)$ .

## Biometric Gain against Impostors (BGI) - 2 of 3

The really good thing about the modified BGI is that it provides very simple multi-modal combination, just requiring multiplication of the modified BGI values from the (independent) individual biometric devices. This is the optimal combiner, according to (Bayesian) statistical theory.

Furthermore, for a single biometric device, the modified BGI is just a function (transformation) of the score. That is apart from some characterisation information for the biometric device.

$$\text{BGI}'(s_j) = P(s_j | I) / P(s_j | G)$$

The characterisation information is the 2 probability density functions (PDFs) for the individual biometric device. These PDFs can be approximated by mathematical models, parameterised according to data from evaluation trials.

The characterisation data required has exactly the same form as that required to report FAR/FRR performance using ROC curves.

# Biometric Gain against Impostors (BGI) - 3 of 3

From its definition, the true BGI is:

$$\text{BGI}(s_1, s_2 \dots s_J) = P(I | s_1, s_2 \dots s_J) / P(I)$$

The relationship between the true BGI and the modified BGI can be shown to be as follows:

$$\text{BGI}(s_1, s_2 \dots s_J) = \frac{1.0}{P(I) + P(G) / \text{BGI}'(s_1, s_2 \dots s_J)}$$

Where:

$\text{BGI}(s_1, s_2 \dots s_J)$	is the true BGI, given the scores from J biometric devices;
$P(I   s_1, s_2 \dots s_J)$ , $P(G   s_1, s_2 \dots s_J)$	are, respectively, the probabilities of the claimant being an impostor or genuine, given the J scores from the biometric devices (that is <i>a posteriori</i> ); they sum to 1.0;
$P(I)$ , $P(G)$	are, respectively, the probabilities of the claimant being an impostor or genuine, before having seen the biometric measurements (that is <i>a priori</i> ); $P(I)$ and $P(G)$ sum to 1.0 too.

In nearly all applications, we have no true measure of the *a priori* probability,  $P(I)$ , of a claimant being an impostor. However, we normally know that this probability is very small, and that (correspondingly) the probability of the claimant being genuine,  $P(G)$ , is very close to 1.0. In these circumstances, the ones usually applying, the modified BGI is a very close approximation to the true BGI.

# Biometric Gain against Impostors (BGI) - Derivation

Bayesian statistics, for biometric verification of claimed identity, shows that the *a posteriori* probability of the claimant being an impostor is the product of the *a priori* probability and the probabilities from the J individual (and statistically independent) biometric devices. This is after normalisation so that the probability of impostor plus the probability of genuine sums to 1.0.

$$P(I | s_1, s_2 \dots s_J) = \frac{P(I) \cdot P(s_1 | I) \cdot P(s_2 | I) \dots P(s_J | I)}{P(I) \cdot P(s_1 | I) \cdot P(s_2 | I) \dots P(s_J | I) + P(G) \cdot P(s_1 | G) \cdot P(s_2 | G) \dots P(s_J | G)}$$

Rearranging gives:

$$\frac{P(I | s_1, s_2 \dots s_J)}{P(I)} = \frac{1.0}{P(I) + P(G) \cdot \frac{P(s_1 | G)}{P(s_1 | I)} \cdot \frac{P(s_2 | G)}{P(s_2 | I)} \dots \frac{P(s_J | G)}{P(s_J | I)}} = \text{BGI}(s_1, s_2 \dots s_J) \text{ [by definition]}$$

Substituting for the modified BGI gives the equation seen earlier:

$$\text{BGI}(s_1, s_2 \dots s_J) = \frac{1.0}{P(I) + P(G) / \text{BGI}'(s_1, s_2 \dots s_J)}$$

# An Example of Multi-Modal Combination using the Modified BGI

In this example, 2 individual biometric devices are combined:

- Face: with an Equal Error Rate (EER) of 5.2%;
- Hand: with an EER of 16.6%.

The raw experimental data has been supplied, most kindly and helpfully, by Michigan State University (MSU): Professor Anil Jain and Dr Arun Ross. [Ref: *Information Fusion in Biometrics*, Arun Ross and Anil Jain, *Pattern Recognition Letters*, 24 (2003).]

Experiments with 50 subjects. Each enrolled with the system; I have not used (or seen) that enrolment data or raw samples; just the scores.

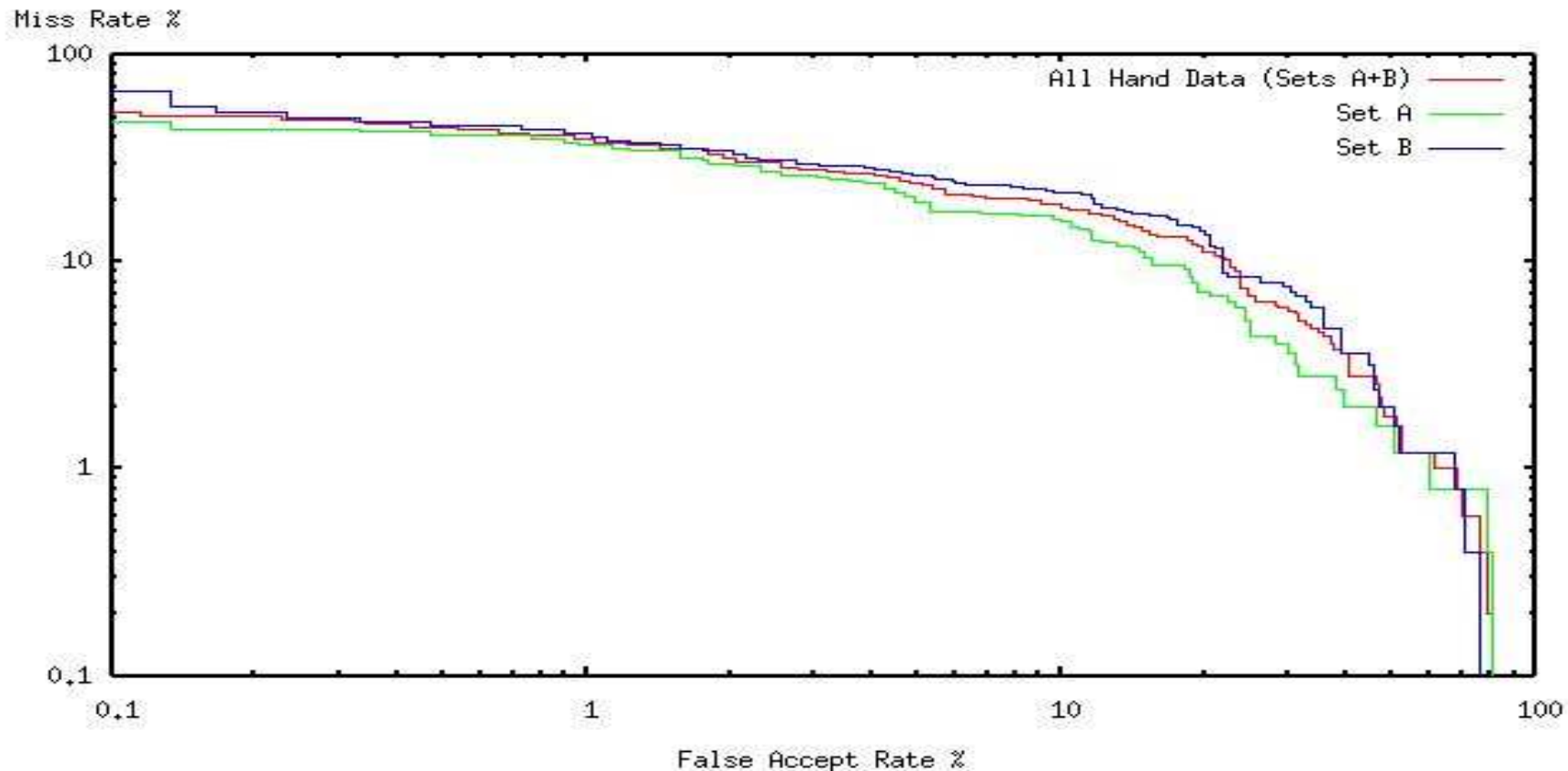
Genuine attempts: 10 per subject (total 500).

Impostor attempts: 5 per subject pair, with cross matching to other 49 subjects (total 12,250).

# Experimental Precursor: Separate the Characterisation Data from Evaluation Data

Done according to subject number. Set A (characterisation) contains subjects 1 to 25; Set B (evaluation) contains subjects 26 to 50.

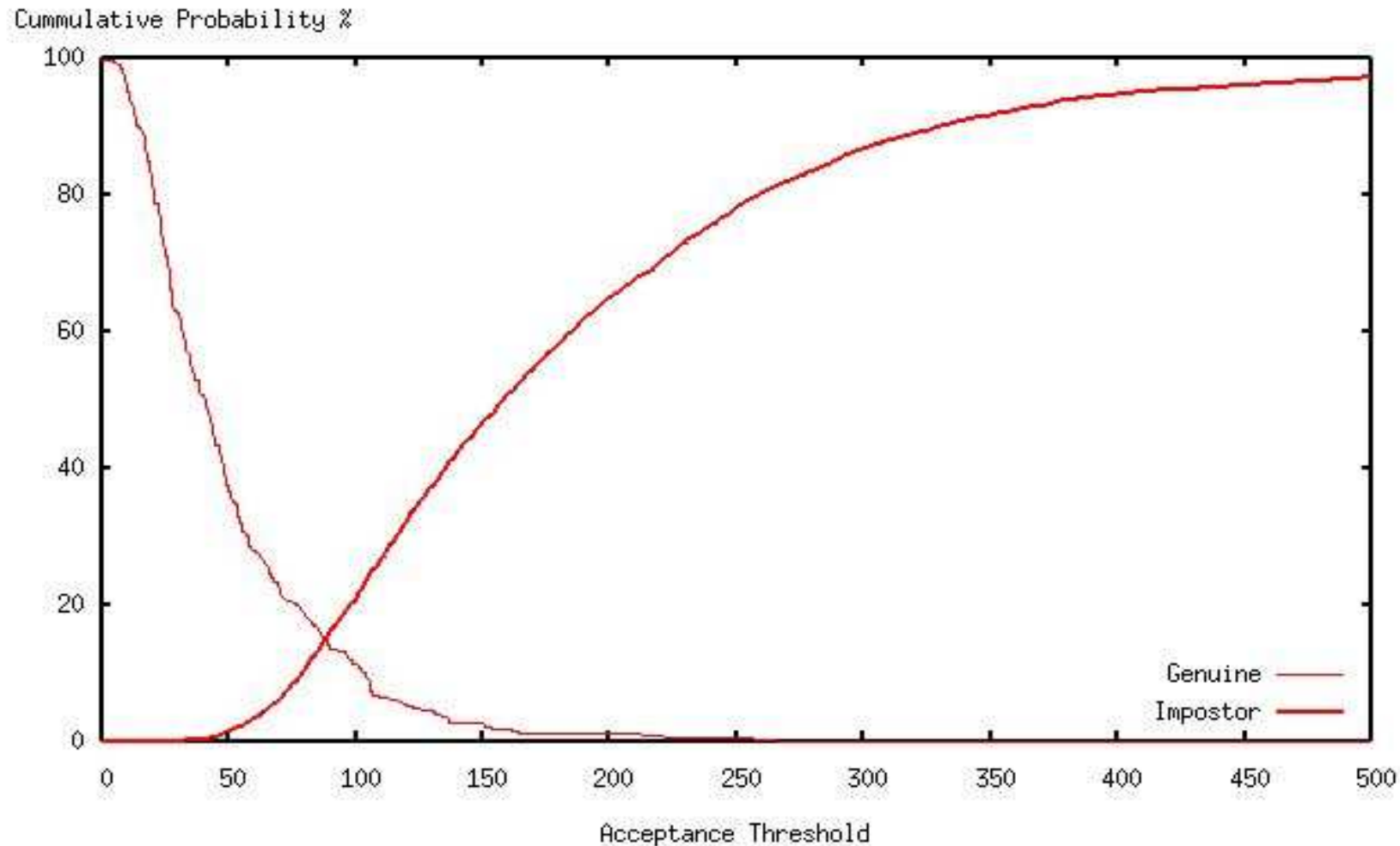
Hand Original Data and Sets A and B: ROC Curves (Plot T6H-5)



# Multi-Modal Characterisation

## Step 1: Look at Cumulative PDFs

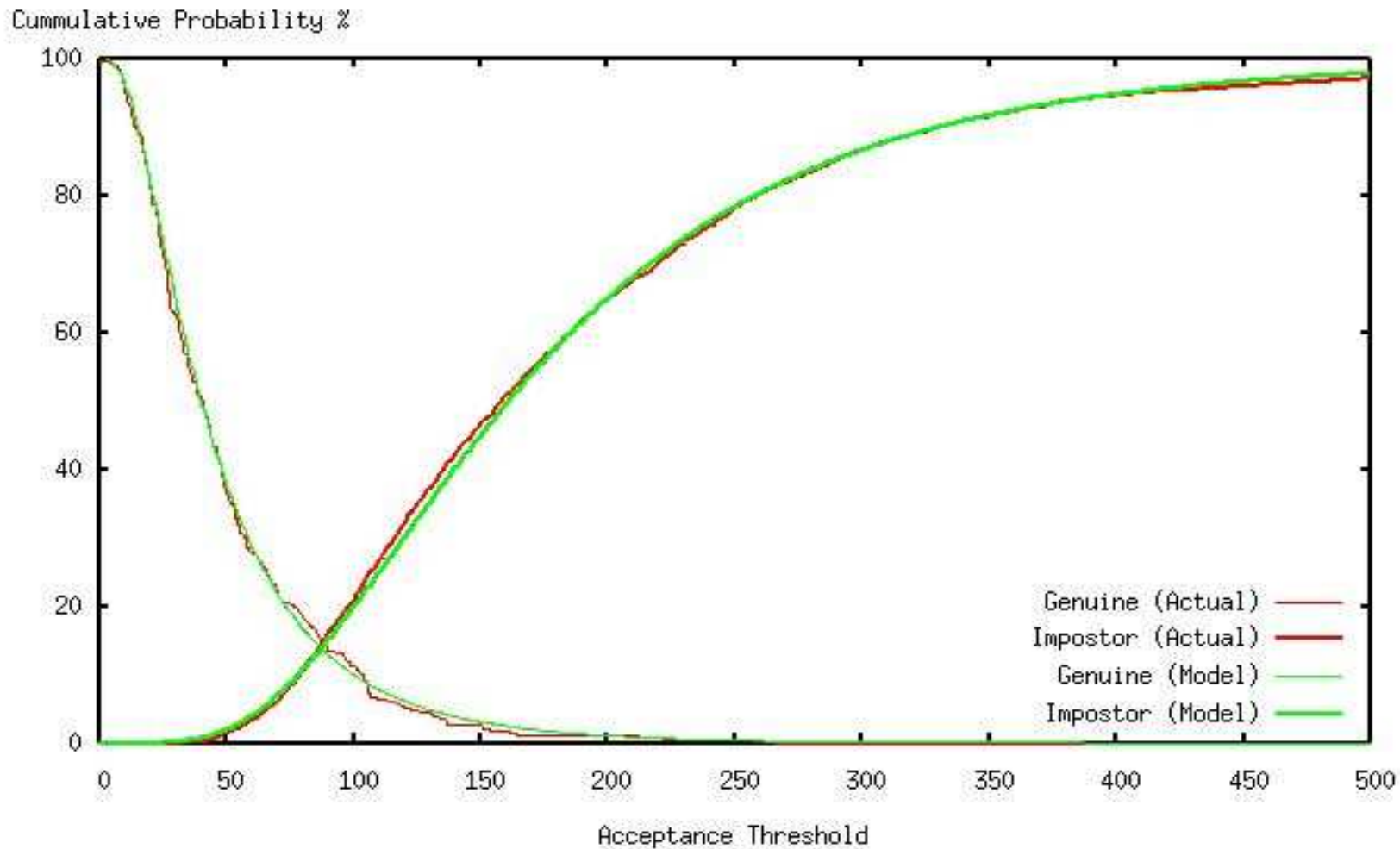
Hand Original Data: Cumulative Probabilities Against Acceptance Threshold (Plot T6H-2a)



# Multi-Modal Characterisation

## Step 2: Chose the PDF Models and Parameterise

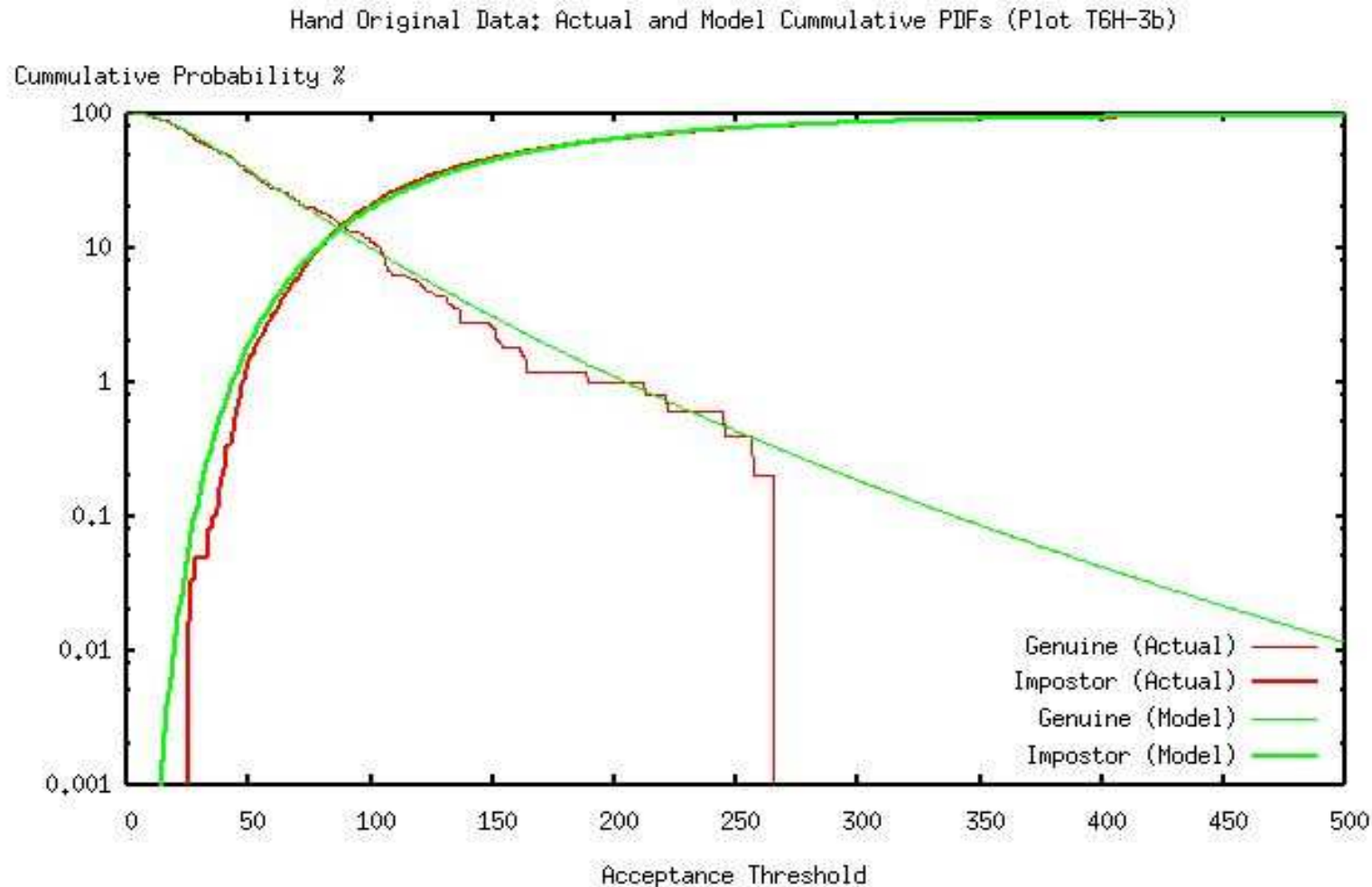
Hand Original Data: Actual and Model Cummulative PDFs (Plot T6H-3a)



# Multi-Modal Characterisation

## Step 3: Look at PDF Model Fit in More Detail

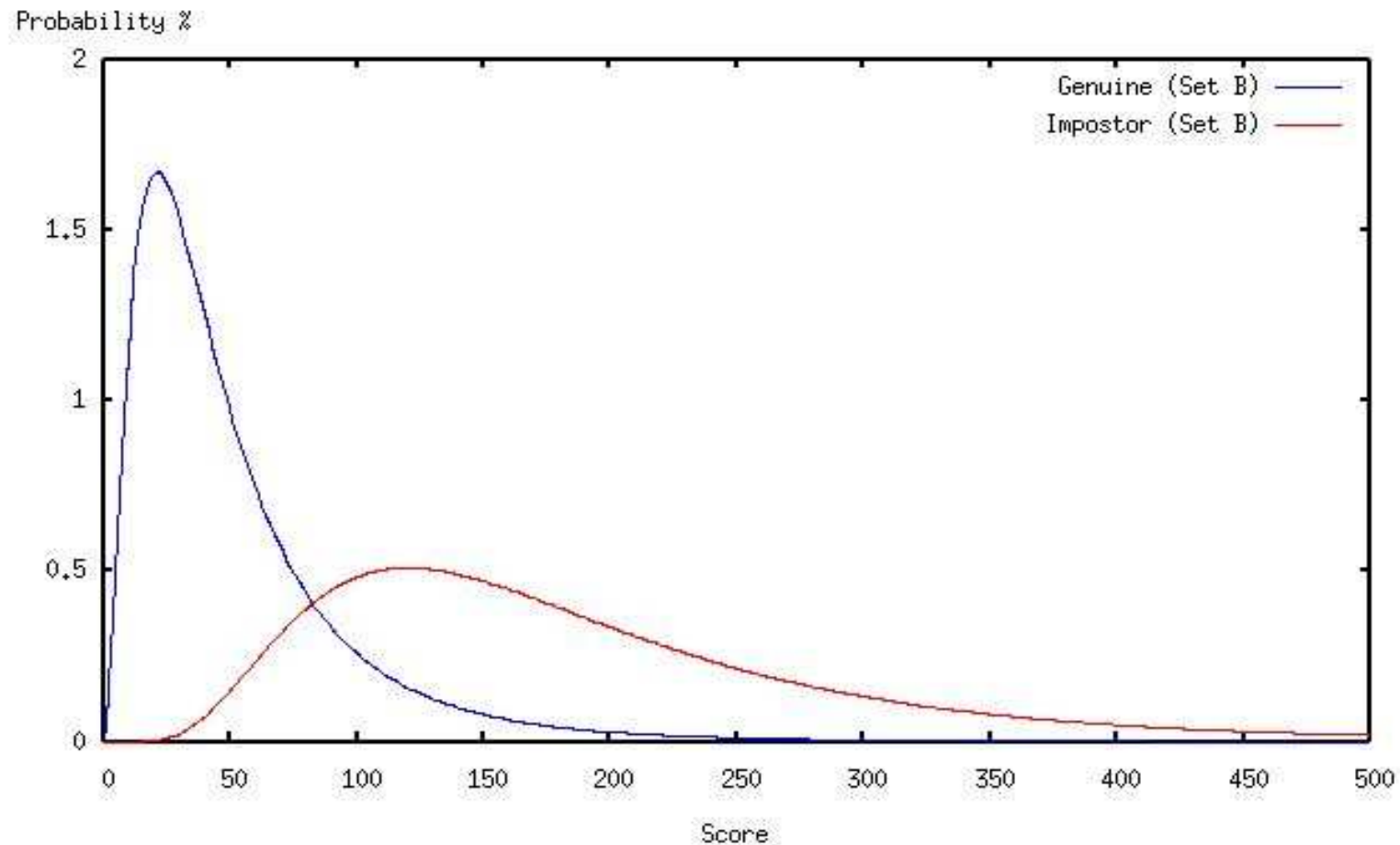
It's not perfect, which is only to be expected.



# Multi-Modal Characterisation

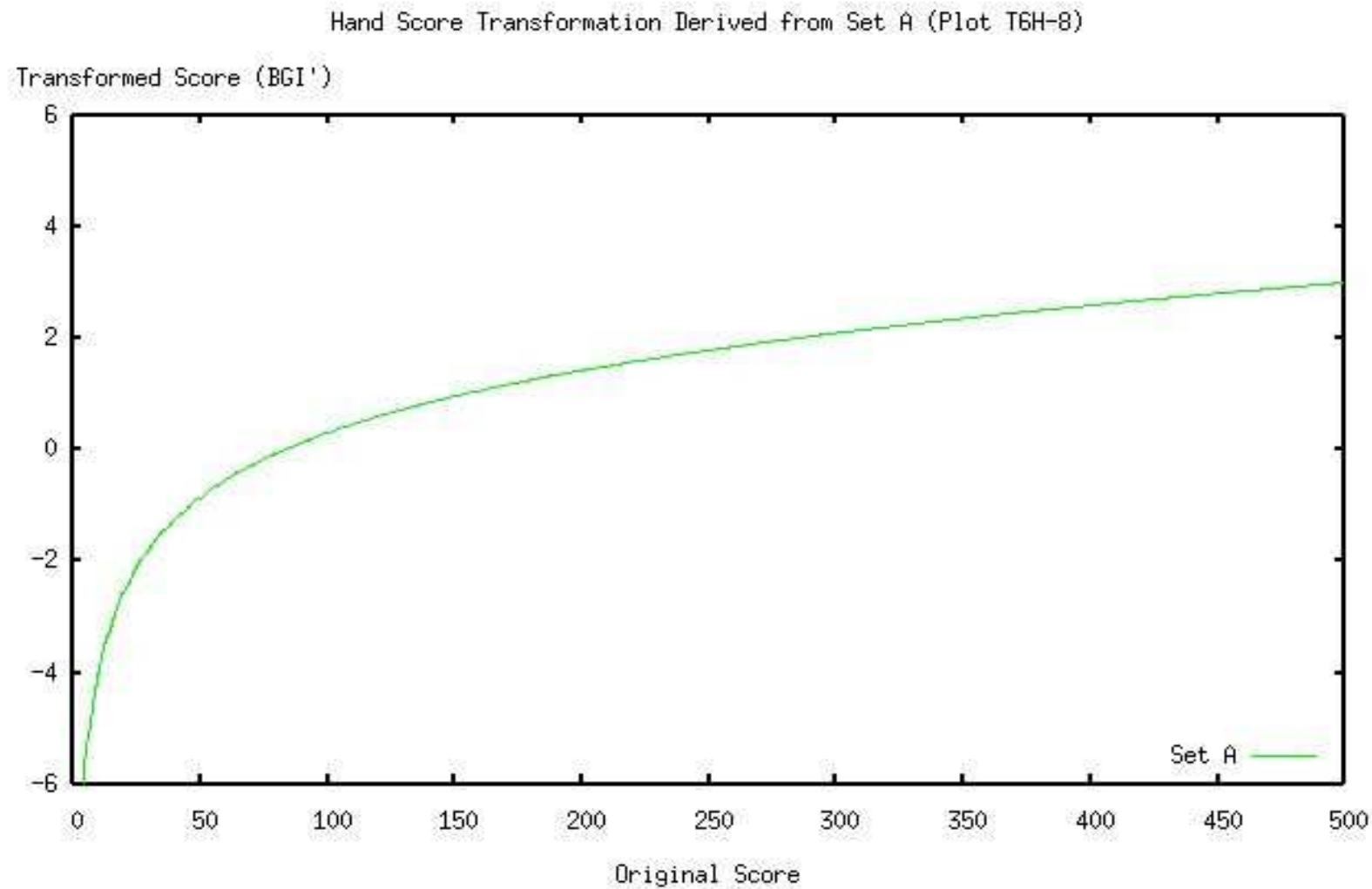
## Step 4: Look at PDF Models (Non-Cumulative)

Hand Set B: Modelled PDFs (Plot T6H-7a)



# Multi-Modal Characterisation

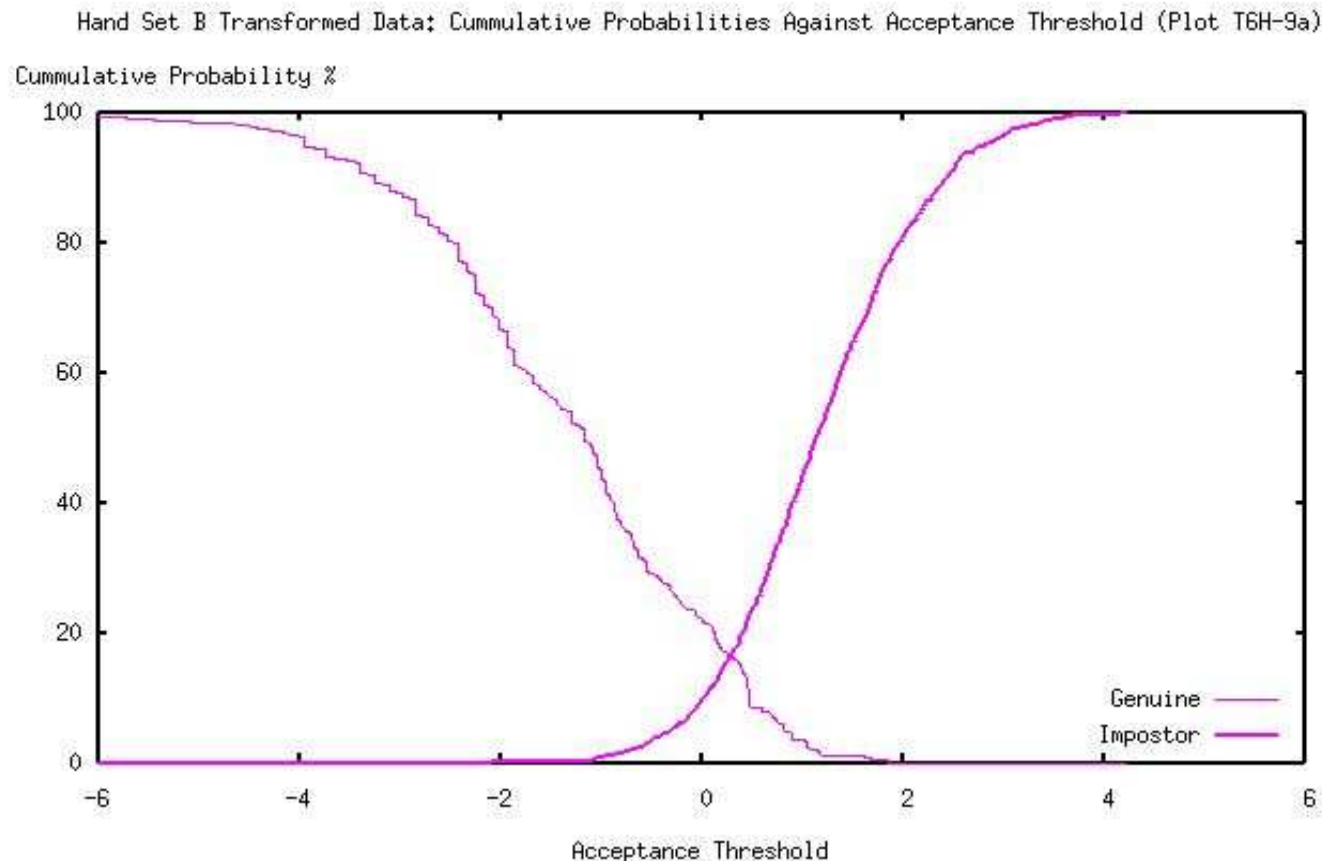
## Step 5: Look at the Score Transformation



# Multi-Modal Characterisation

## Step 6: Look at Transformed Actual Cumulative PDFs

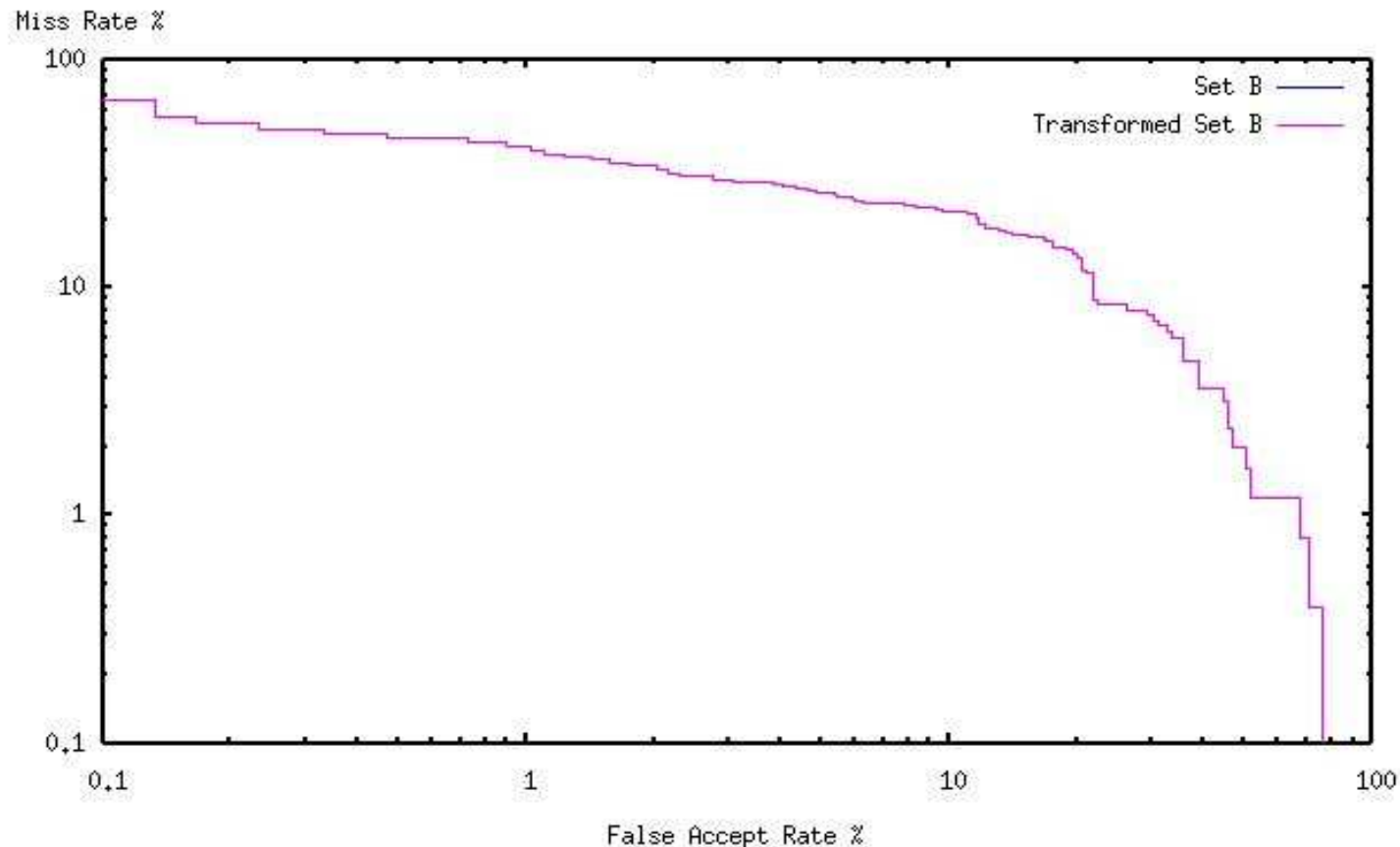
Note the crossover (EER) point is not quite where it should be, at a transformed threshold of zero. The probable causes are imperfect PDF models and Set A to B differences (maybe indicating more data needed).



# Multi-Modal Characterisation

## Step 7: Check for No ROC Distortion

Hand Set B and Transformed Set B: ROC Curves (Plot T6H-10)

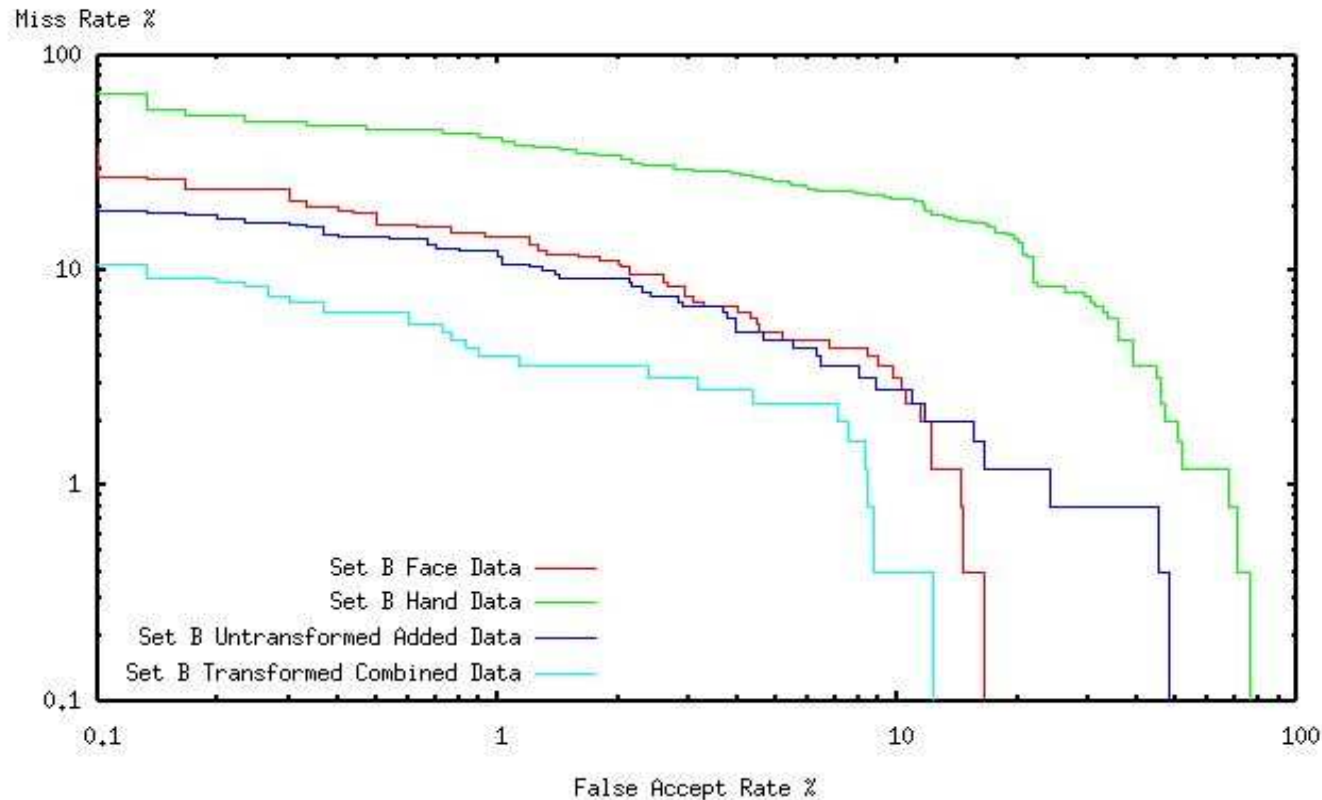


The plots for Set B (untransformed scores) and Transformed Set B are identical, so nothing has gone wrong.

# Multi-Modal Characterisation

## Step 8: Evaluate Characterisation

Face, Hand and Combined Set B Data: ROC Curves (Plot T6C-1)



The BGI combination (light blue) gives a good improvement over the whole range of operating thresholds, unlike just adding the scores (dark blue), which degrades performance at some operating thresholds.

# Performance Improvement in the Example

Original EER performance: face 5.2%; hand 16.6%.

EER performance with the optimal approach (BGI'): 3.2%

This is a 2% absolute improvement over the better of the original biometric devices (38% relative reduction).

Note, in particular, this improvement comes from combining with a relatively poor second biometric device. This shows that a poor secondary biometric device can contribute usefully, when used in conjunction with a significantly better primary biometric device.

The improvement is available over the whole operating range. Theoretically, performance is guaranteed to be no worse than the best of the individual biometric devices, at all acceptance thresholds. In practice, this requires sufficiently accurate PDF models.

# Implications for Multi-Modal Aspects of Standardisation

1. There is a need for multi-modal biometric combination, in terms of performance improvement and greater operational robustness.
2. A combining method exists, that is a statistically optimal approach. However, this does not seem to be as widely known as is desirable.
3. The optimal approach requires characterisation information, for each biometric device (generically or for each enrolled user), prior to use.
4. The optimal approach requires scores to be output by individual biometric devices, for use by the multi-modal combiner.
5. Communication of scores and of characterisation information impacts on standardisation aspects within the BioAPI and CBEFF.
6. Characterisation data may be provided by device manufacturers, independent assessment agencies, user organisations, etc.

# Is Multi-Modal Combiner Technology Well Enough Understood?

I believe it is well enough understood, as the BGI approach (ie using impostor/genuine likelihood ratios) is statistically optimal. [Note that this approach is not novel, but has been used to varying extents since at least the early 1980s.]

With the BGI approach, outstanding technical issues do remain. However, they are subsidiary issues rather than the primary issue.

In particular, there are the issues of defining and parameterising reliably, mathematical models of PDFs for particular individual biometric devices.

Next is characterisation by individual enrolled user, and whether and to what extent this is necessary for each individual biometric device.

There is also the important issue of the generality of any characterisation done on limited amounts of data, in different operational scenarios.

# Is Now the Time for Standardisation of Multi-Modal Biometrics?

Currently, there is significant interest in using biometrics for government purposes, particularly for international travel visas and for national identity schemes.

If (as I believe) technical performance of current biometric devices is borderline in its ability to satisfy these applications, the contribution of multi-modal biometrics combiners to performance (FAR/FRR) is important.

There is also a contribution to improved robustness and flexibility, given lack of suitability of some biometrics for some people (on physical and social grounds).

Standardisation (international for some cases) is key to the provision of equipment for some of these applications. This covers characterisation and scores, including issues of technical performance measurement and issues of communications / data transfer.

# Suggested Scope of Multi-Modal Biometric Standards

1. Architecture(s) for multi-modal combination. Is it sufficient to specify only the BGI approach?
2. Technical requirements for scores. What dynamic range is necessary for what level of performance improvement?
3. Characterisation Data. How much data for what level of performance, in terms of number of genuine and impostor attempts, for generic characterisation and for characterisation specific to each enrolled user?
4. Implications for communications and for data formats, as currently embodied in the BioAPI and CBEFF.

Finally, if standardisation is to be done, how should standards documents be best organised to avoid delay to work in progress, on standardisation applied to individual biometric devices?