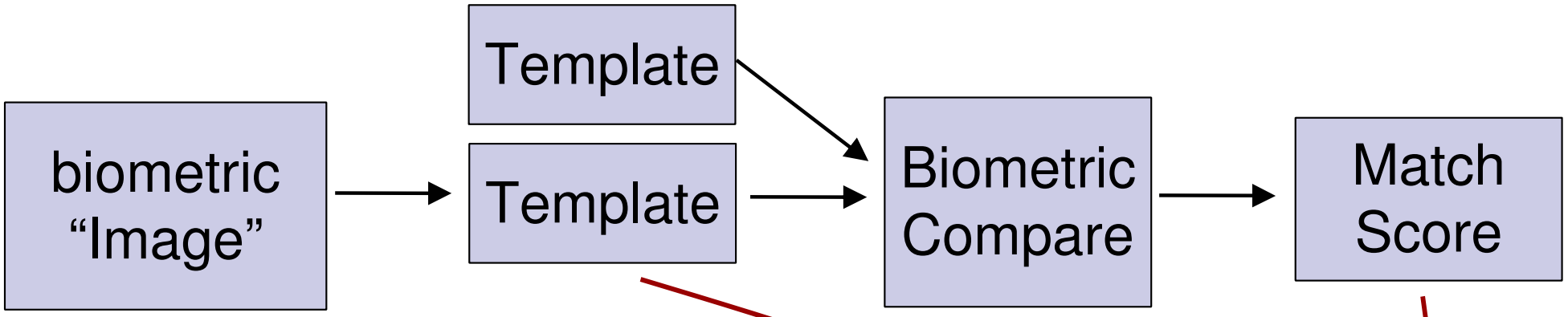
Can sample images be regenerated from biometric templates?

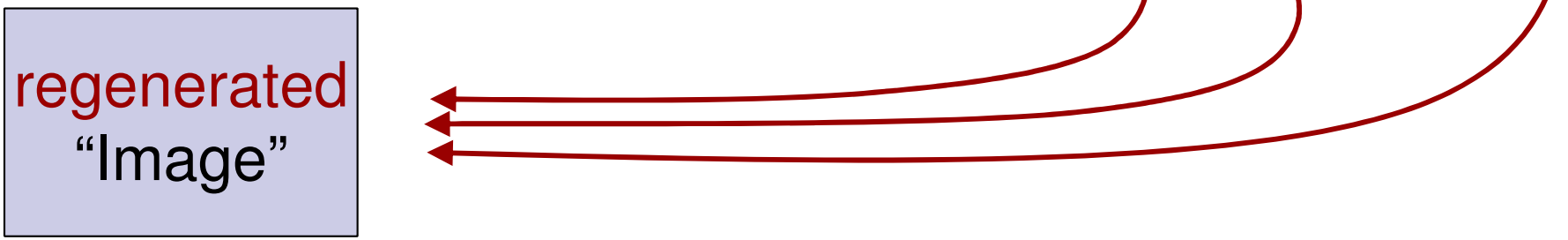
Andy Adler
School of Information Technology and Engineering
University of Ottawa

What do we mean *regenerated* ?

- Typical Biometric processing



- *Question*: Is this possible?



Regenerated images

International Biometric Group defined the following possibilities:

- Feature
  - an image which fools biometric algorithm
- Generic image
  - a rough resemblance to the original
- Image
  - virtually identical to the original

Source: www.ibgweb.com/reports/public/reports/templates_images.html

Traditional wisdom

Most biometric vendors have claimed its impossible or infeasible to recreate the image.

Reasons:

- templates record features (such as fingerprint minutiae) and not image primitives
- templates are typically calculated using only a small portion of the image
- templates are much smaller than the image
- proprietary nature of the storage format makes templates infeasible to "hack".

Template are difficult to “hack”

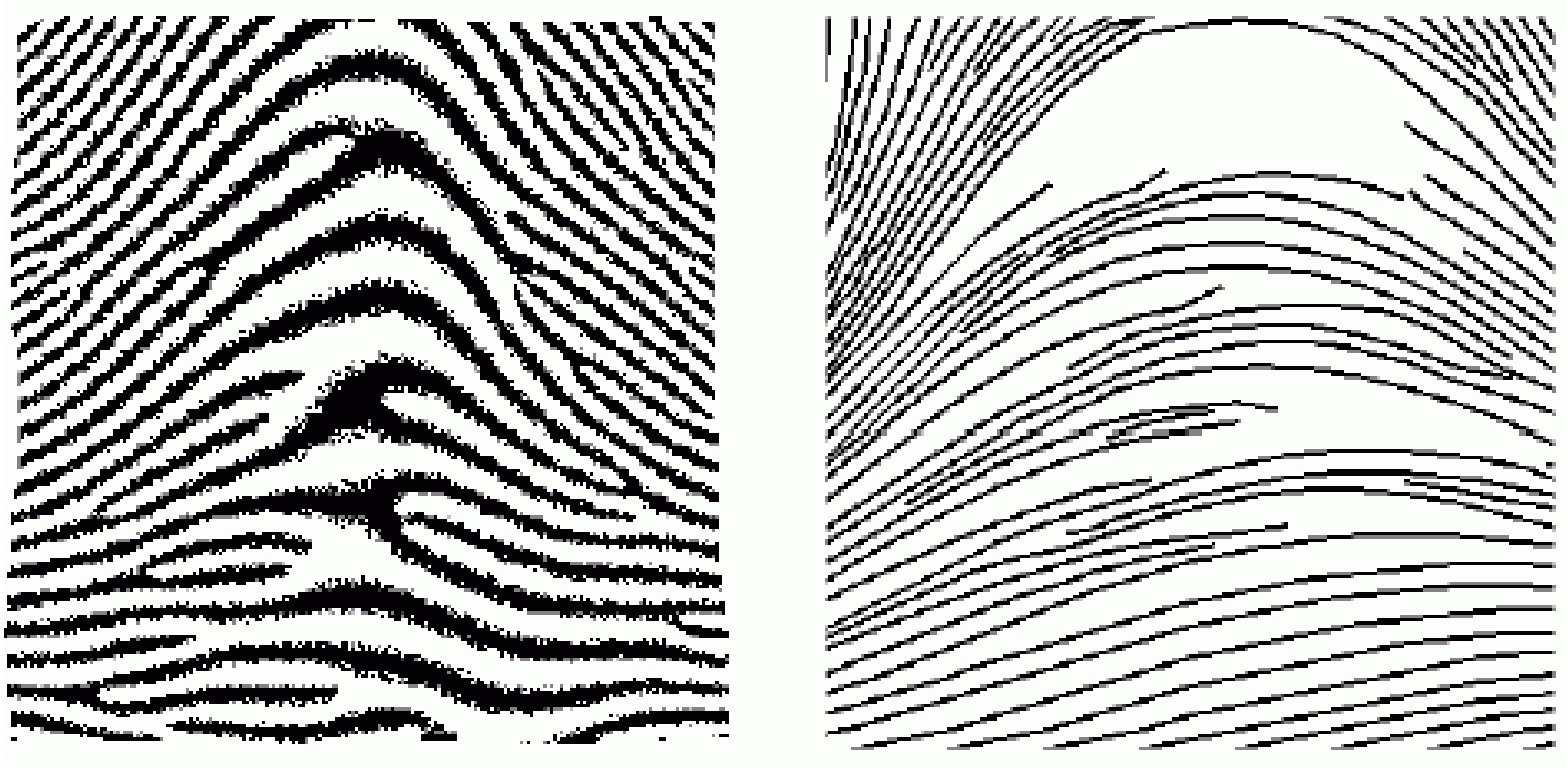
C. Hill reverse engineered the format of a particular (unspecified) fingerprint algorithm.

- Fingerprint images with “controlled differences” were presented and the differences in template observed

Software was developed to generate an image which would

- compare at high match score with the original,
- show characteristics of the original fingerprint.

“Hacked” fingerprint images



Original Image Generated Image

Source: C.J. Hill, 2001 http://chris.fornax.net/biometrics.html

Limits of “hacking” templates

- While this is obviously a powerful technique, it requires
  - Smart people (and lots of their time)
  - Access to the vendor code
- There are some simple countermeasures
  - Template Encryption

    Note that encrypted templates need a key somewhere. Often it is hidden in the biometric software, and is thus vulnerable

Automatic image *regeneration*

Question: is it possible to have generic software to regenerate image?

- Does not depend on specific vendor file format

Idea: begin with a guess, make small modifications; keep modifications which increase the score

Algorithm: Preprocessing

Given

Person ID in FR database

Preprocessing

Normalize local image database: LDB
Calculate eigenface representation: EF[k]

Determine starting image, Im[0]

Find image in local database with maximum match score against target

Algorithm: Regenerate image

Optimize image estimate, Im[k]:

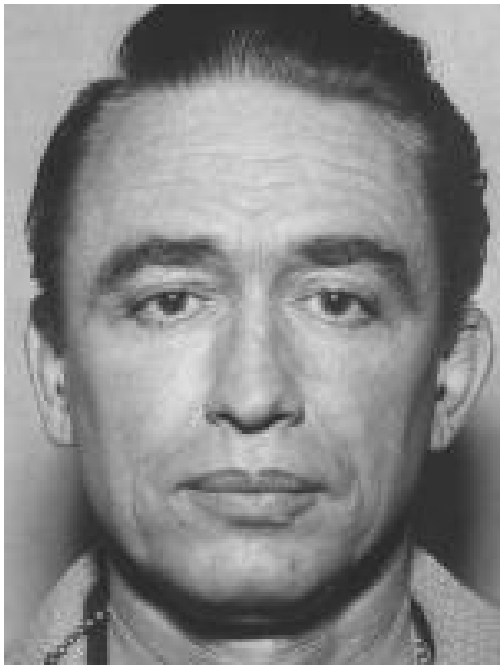
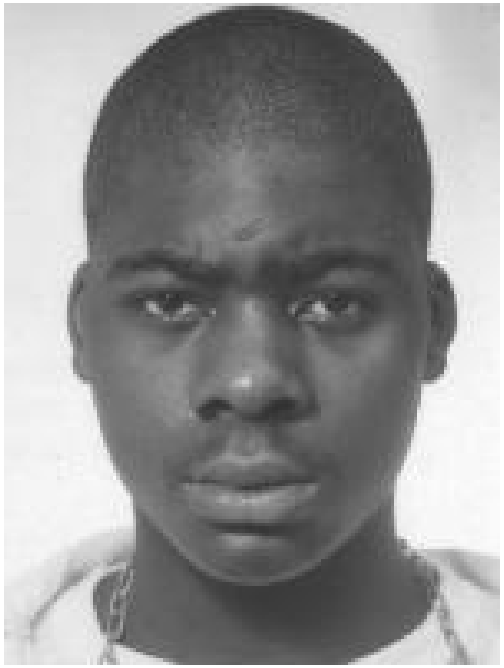
- loop (k)
  - Select an eigenface (*EF)*
  - find *c* to maximize:
    match_score(Im [k] + *c*×EF, target)
  - Im[k+1] = Im[k] + *c*×EF
  - crop Im[k+1] if values outside image bounds
- Stop when no further image improvement

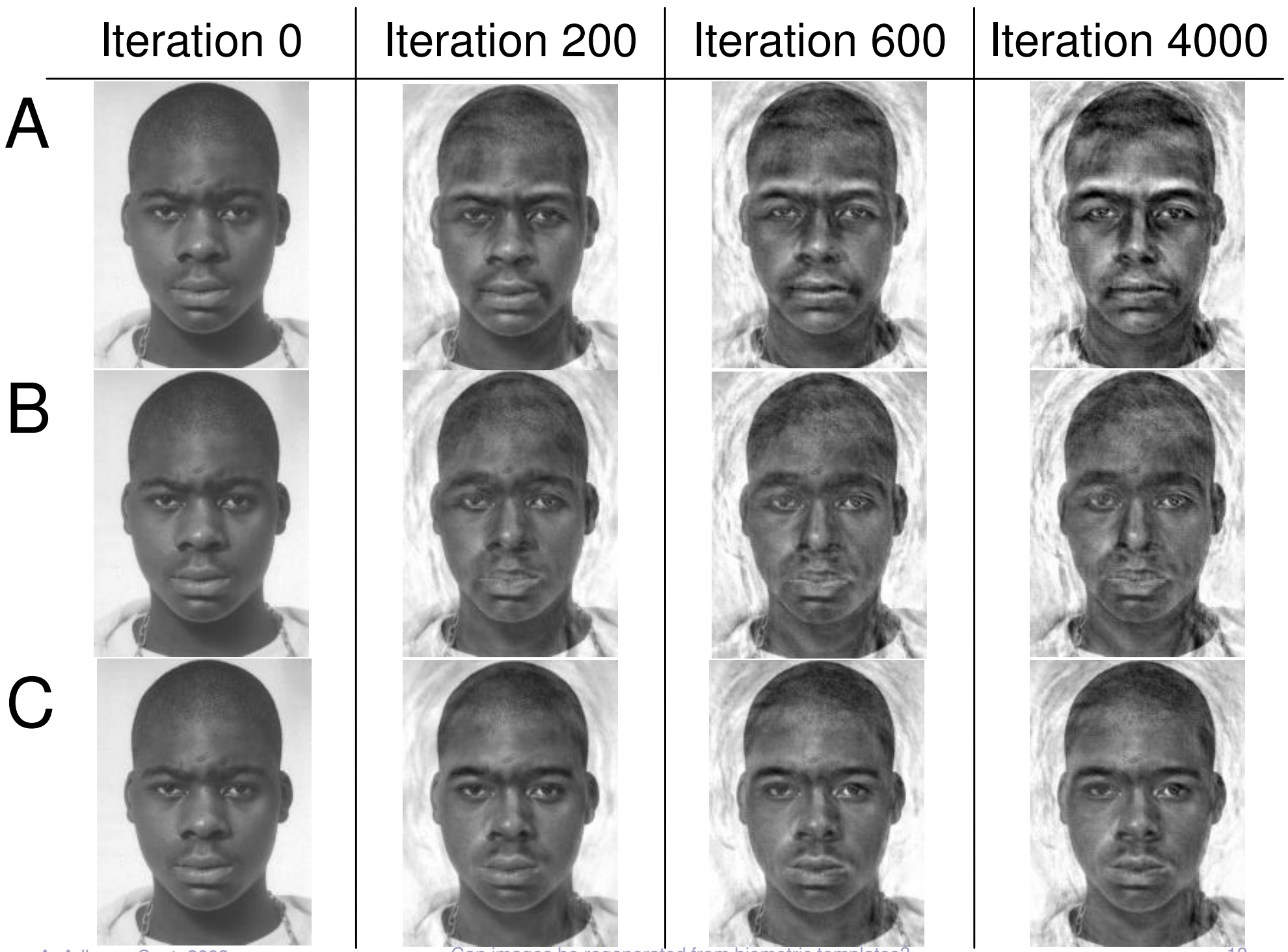
Results

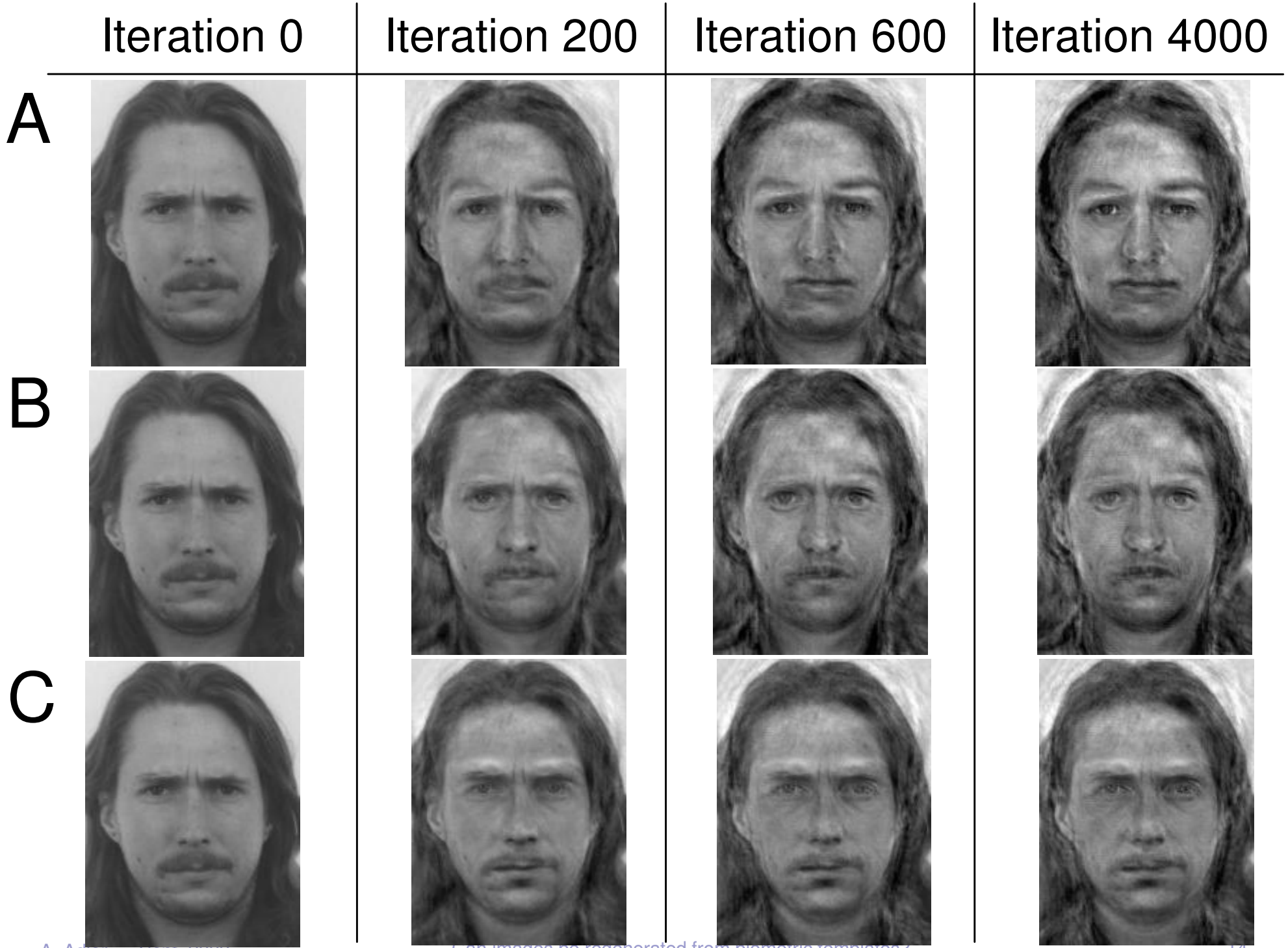
- Tests were performed against three different face recognition algorithms
  - All are recent products by well known commercial vendors of biometric systems.
  - Two of the vendors participated in the 2002 face recognition vendor test
- For all images and all biometric algorithms, the regenerated image compared at over 99.9% confidence

Results

- intentionally different initial images chosen

Target Person	Initial Image Estimate #1	Initial Image Estimate #2
		


Iteration 0
Iteration 200
Iteration 600
Iteration 4000
A
B
C


Iteration 0
Iteration 200
Iteration 600
Iteration 4000
A
B
C

Improved regenerated image: average 10 estimates

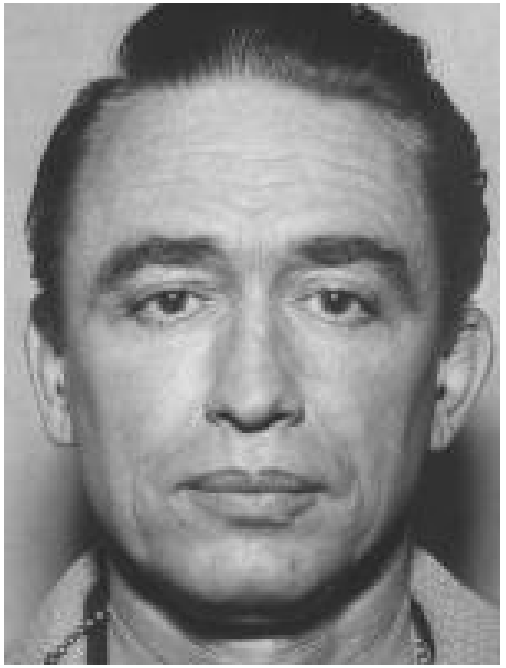
Algorithm A	Algorithm C	Original
		

Image estimate changes reflect information in the template

- Feature that are modified
  - Eyebrows
  - Eye shape
  - Nose shape
  - Head shape
  - Mouth expression *<= unexpected*
- Features that don't change
  - Hair
  - Moustache / Facial hair region
  - Image background

Differences between algorithms

- Features modified by some but not other algorithms
  - Hair (Algorithm A)
  - Nose width (Algorithms A,C, not B)
- This probably reflects which features are encoded into the template:
  - This may be a way to reverse engineer details of a proprietary algorithm

Protection:

According to BioAPI

- "…allowing only discrete increments of score to be returned to the application eliminates this method of attack."

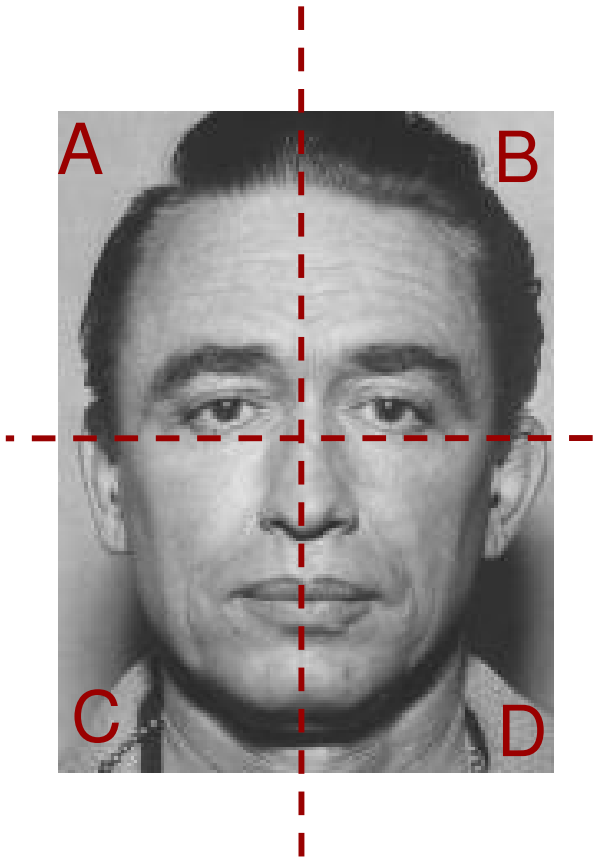
- This makes image regeneration more difficult, but not impossible

Source: BioAPI, version 1.1, p.21, http://www.bioapi.org

Discrete match scores

Preprocessing:

- Step 1: Divide the image into quadrants
- Step 2: From each EF image, calculate the part in each quadrant EF_A, EF_B, etc.



Discrete scores: regenerate image

loop (k)

- Select an eigenface in quadrant (e.g. EF_A)
- Select degrade image in opposite quadrant (DI_D)
- Find *k* such that
  match_score(Im[k] + *k*× DI_D, target)
  is one score lower
- find *c* to maximize:
  match_score(Im[k] + *k*× DI_D + *c*×EF_A, target)
- Im[k+1] = Img[k] + *c*×EF
- crop Im[k+1] if values outside image bounds

Discrete scores

- Information available is much less, so algorithm takes longer
- Image regeneration works because biometric algorithms “sum up” matching characteristics
  - Changes in quadrants are “independent”
  - Degrade image in one quadrant so that match score is in most informative range

Discussion

Images can be regenerated from biometric templates

- will fool biometric algorithm
- visually reflect important features

Approaches

- “Hack the template”
- “Grind through match scores”

So what?

Approaches shown are:

- Time consuming
  - needs 40,000 biometric comparisons
- Don’t produce great images
  - Neither fingerprint / facerec. images look much like the originals

Implications:

- Image regeneration *is* possible
- Smarter people can probably figure out better and faster ways to do it
- Look alike image could be used to
  - masquerade as target
  - Identify target person

Some privacy/security implications:

Biometric Data on ID documents:

- Not an issue for Face Rec. (holders photo is already on the document)
- However, some countries may put fingerprint / Iris template, but not be prepared to put image on document.

Security agencies may allow searches against watch list:

- Primary agency does not want to distribute images
- However, another agency may access these images through regeneration from match scores