National Institute of Standards and Technology

Proposed "NIST Ballistics Identification System" (NBIS) Using 3D Topography Measurements on Correlation Cells

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This talk is based on NIST Provisional Patent No. 61610029 filled on March 13, 2012.

Contents:

1. What is the Problem in Current Ballistics Identifications?
2. Basic Concept for Correlation Cells
3. Proposed “Congruent Matching Cells” (CMC) Method
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5. CMC for Ballistics Evidence Searches
6. Future work
7. Summary

What is the Problem in Current Ballistics Identifications?

- Need 3D topography measurements for ballistics identifications;
- Need a method to remove the “Invalid Correlation Area”;
- Need a “Universal Identification Criterion” for 3D ballistics identifications;
- Need an error rate reporting procedure;
- Need to increase correlation speed and eliminate manual operations.

Why topography, not imaging?

Ballistics signature = 2D Profile, $Z = F(x)$ or
3D Topography, $Z = F(x, y)$

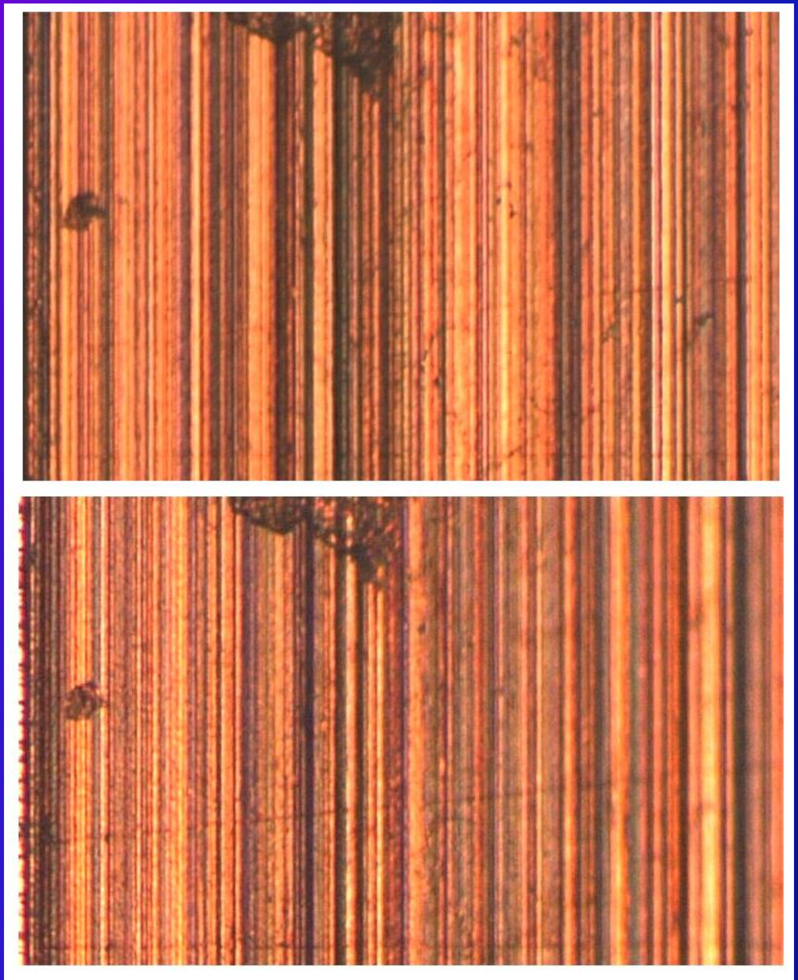
- lighting conditions,
- surface slope,
- shadowing effects,
- multiple reflections,
- changes in the optical properties, and
- color and reflection ...

↓

Optical image $I = \Phi(x, y) \neq$ Topography $Z = F(x, y)$

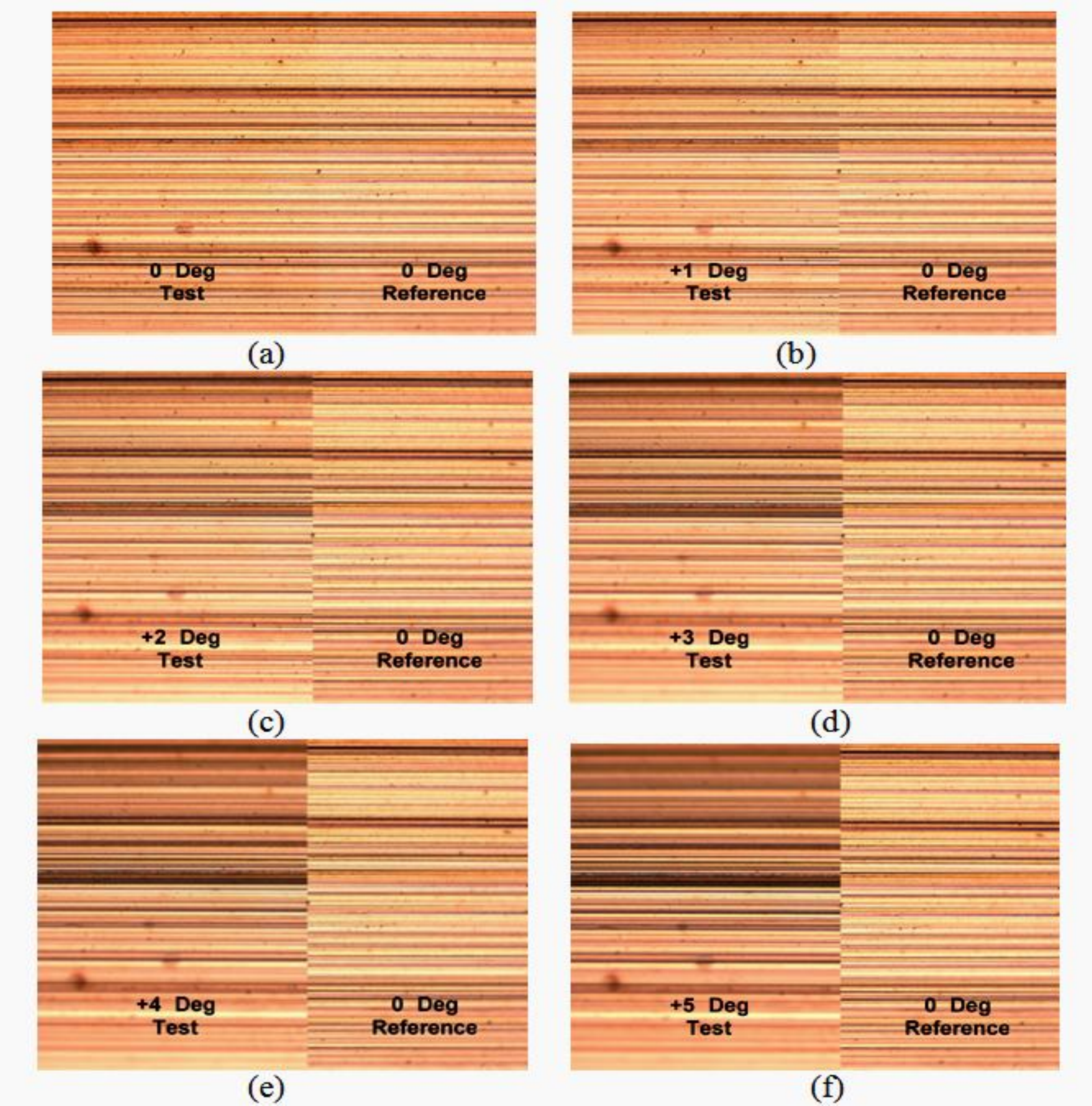
Optical image ≠ Ballistics signature

Effect of Lighting Direction- Matching, or Non-matching?



SRM 2460 #001
Land #1 vs. Land #1 with 6° difference in lighting direction

(By T.B. Renegar, NIST)



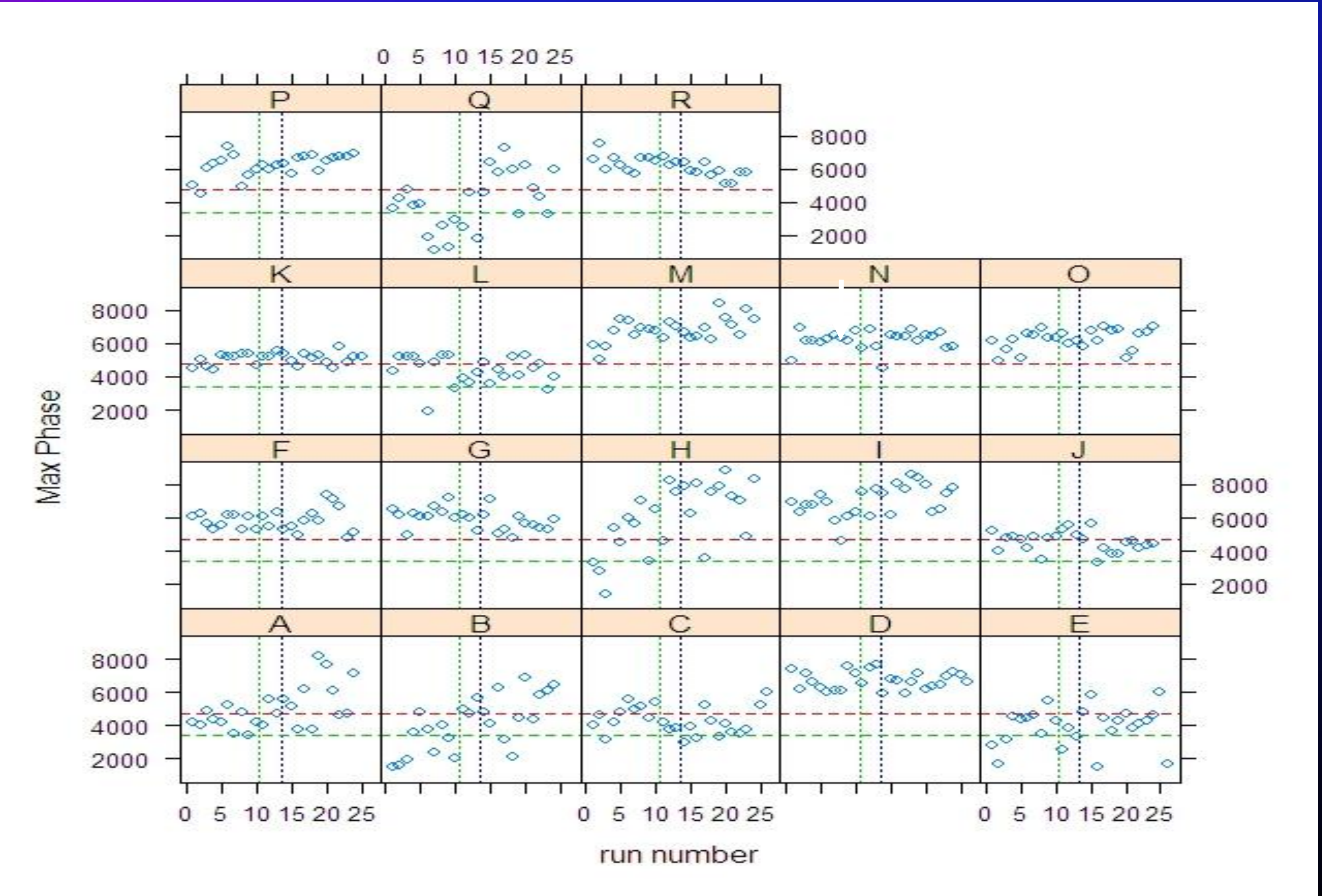
SRM 2460-038 Land #1 with 0° to 5° difference in lighting direction

(By T.B. Renegar, NIST)

Example of Large Variation with Reflectance Microscope

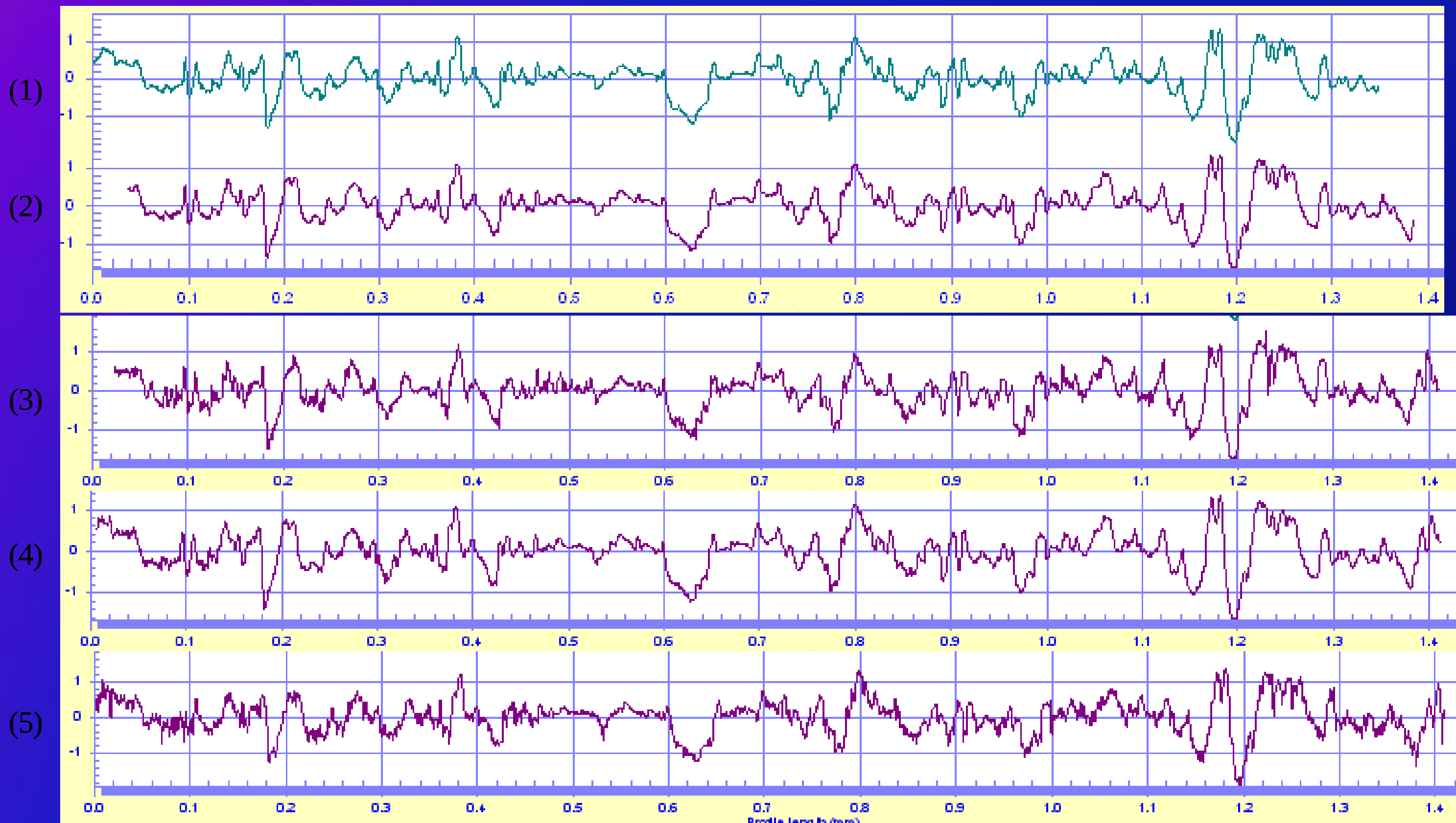
IBIS Max Phase scores for 18 examiners of standard bullets

Mean = 5662, S.D = 1373, Relative variation = 24.2%



Example of High Reproducibility of Topography Measurements

(1)
(2)
(3)
(4)
(5)



Measurement comparison of four techniques tracing the same SRM bullet:

(1) Virtual standard traced on a ATF master bullet used as a reference;

(2) Stylus instrument traces a SRM bullet: CCF_{max} = 99.6%;

(3) Interferometric microscope: CCF_{max} = 92.1%;

(4) Nipkow disk confocal microscope: CCF_{max} = 99.0%;

(5) Laser scanning confocal microscope: CCF_{max} = 95.3%.

CCFmax:
Mean = 96.5%
S.D. = 3.5%
Relative Var. = 3.6%

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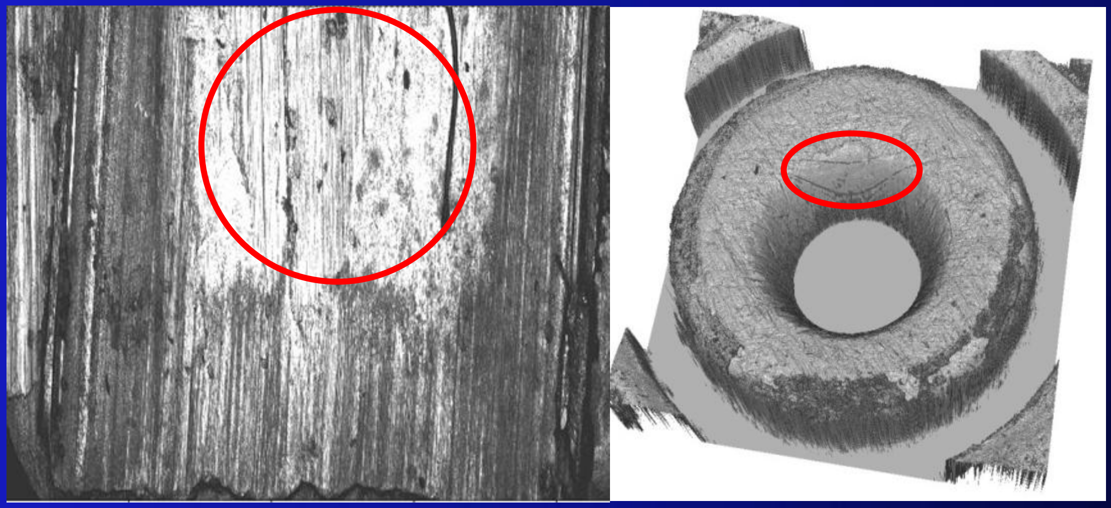
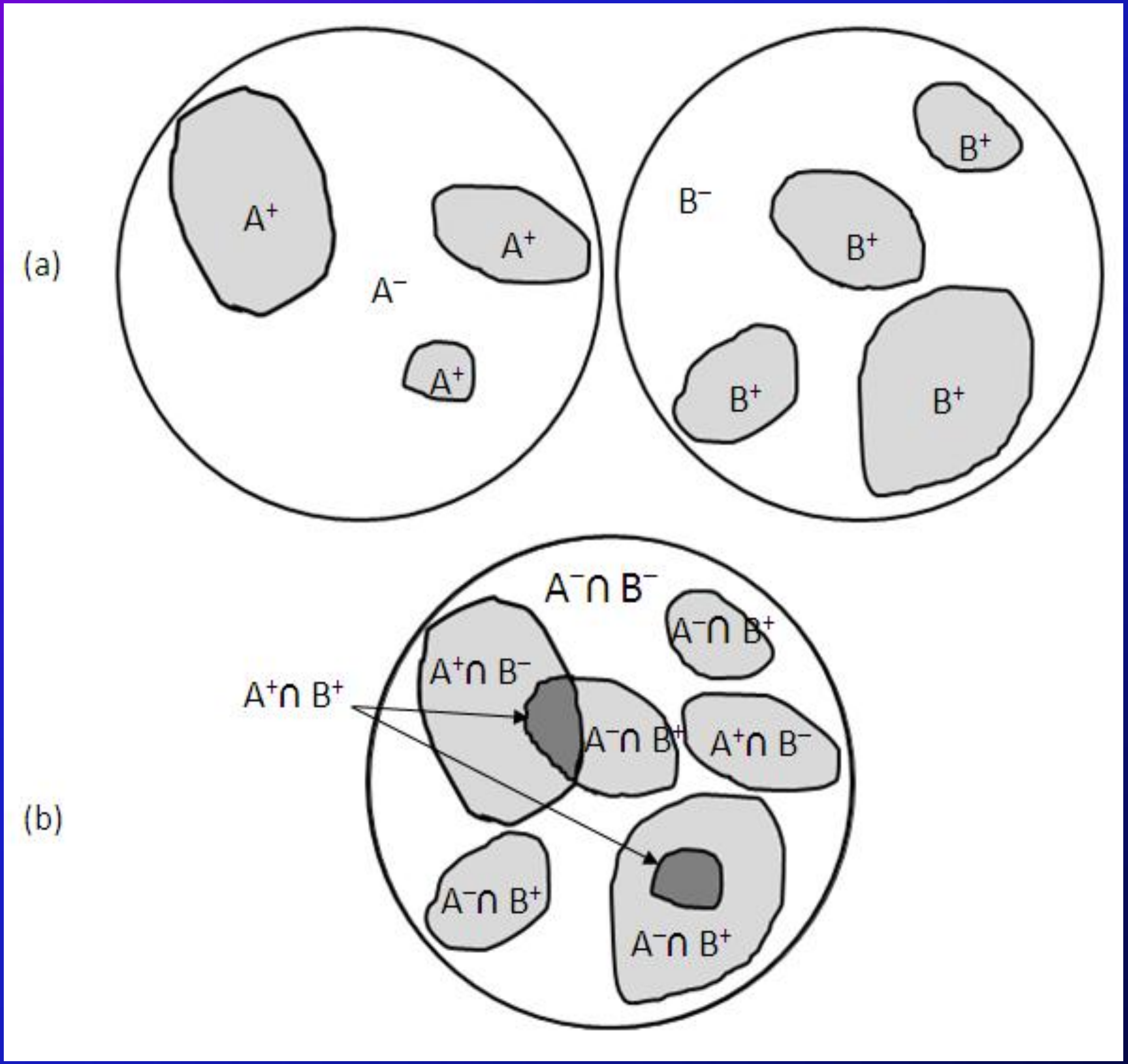
2.1. Valid and invalid correlation area

- Valid correlation area contains individual characteristics of ballistics signature that can be used for ballistics identification.
- Invalid correlation area does not contain individual characteristics and should be eliminated from ballistics identification.

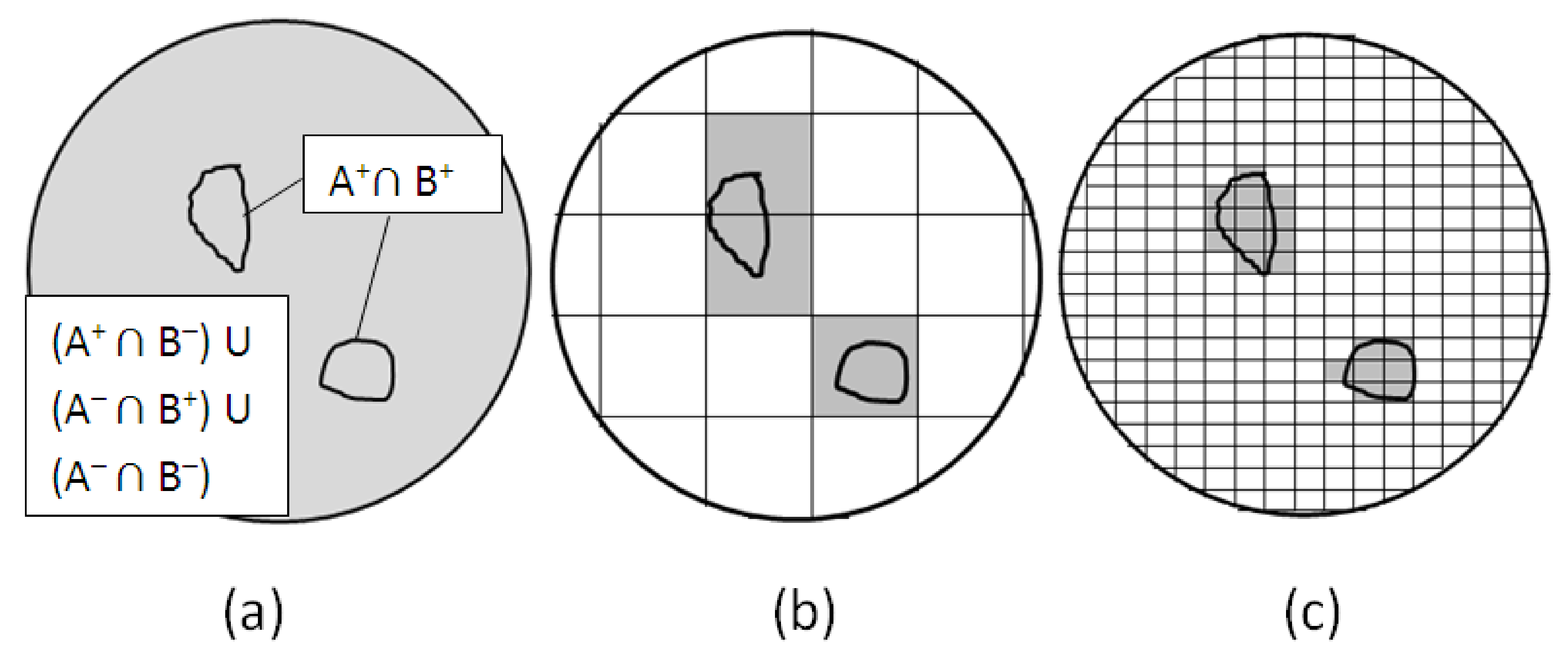




$$A = A^{+} \cup A^{-}, \quad B = B^{+} \cup B^{-}$$

$$[A \cap B] = [A^{+} \cap B^{+}] \cup [(A^{+} \cap B^{-}) \cup (A^{-} \cap B^{+}) \cup (A^{-} \cap B^{-})].$$

2.2. Correlation cells for increasing correlation accuracy



(a) [A ∩ B] correlated over the whole area, low accuracy;
(b) [A ∩ B] correlated over large cell areas, increased accuracy;
(c) [A ∩ B] correlated over small cell areas, even higher accuracy.

2.3. Cell size

- Not too large, not too small. To be determined by controlled experiments on paired known-match (KM) and known-non-match (KNM) topographies.
- As a start point for test, the cell size is estimated as:

  - For breech face correlations: in the range of (0.25 mm × 0.25 mm) to (0.5 mm × 0.5 mm);

  - For firing pin and ejector mark correlations: in the range of (0.08 mm × 0.08 mm) to (0.16 mm × 0.16 mm);

  - The total cell number is estimated between 50 to 200.
- Standardized and normalized cell size.

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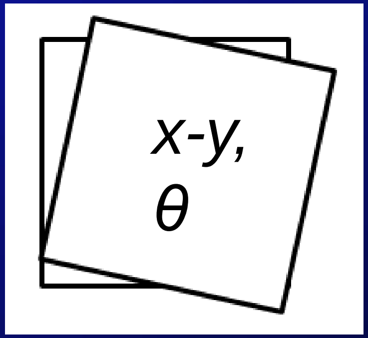
The Consecutively Matching Striae (CMS)Method

Proposed by A. Biasotti and J. Murdock in 1984 for correlation of bullet and toolmark signatures.

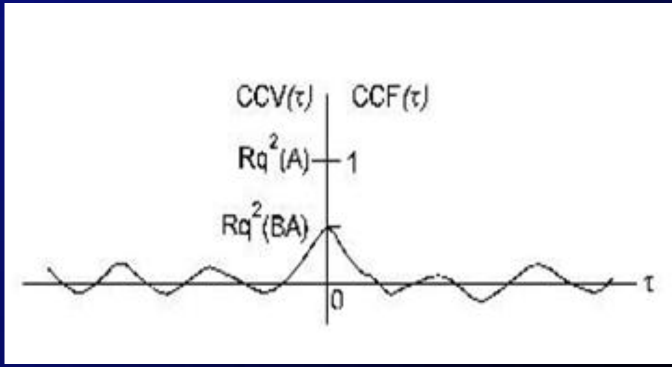
At least two groups of at least three consecutive matching striae (CMS) appear in the same relative position, or one group of six consecutive matching striae (CMS) are in agreement in an evidence toolmark compared to a test toolmark.

The Proposed Congruent Matching Cells (CMC) Method

Three characteristic parameters for the correlated cell pairs:



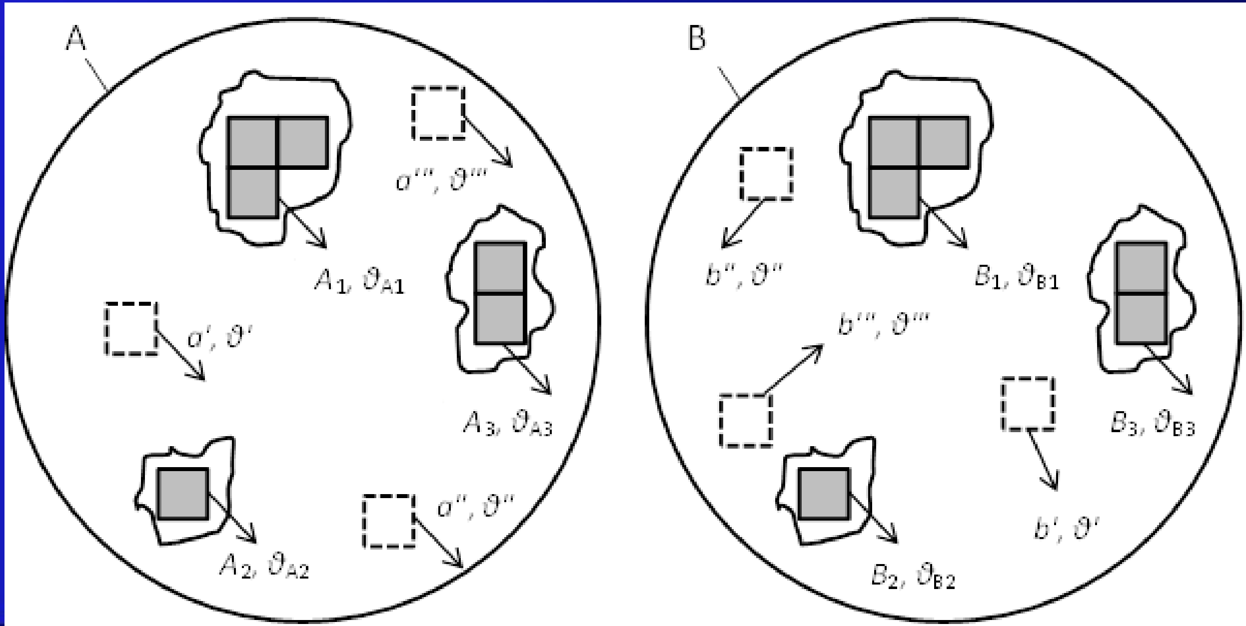
- *Registration position in x-y,*
- *Registration angle ϑ, and*
- *Correlation value CCF_{max} .*



Three check points for identification of valid and invalid correlation areas

Registration position in *x-y*, angle ϑ and CCF_{max}

- When correlation cells are located in the valid correlation areas, all three check points show positive results.
- When correlation cells are located in the invalid correlation areas, all three check points show negative results.

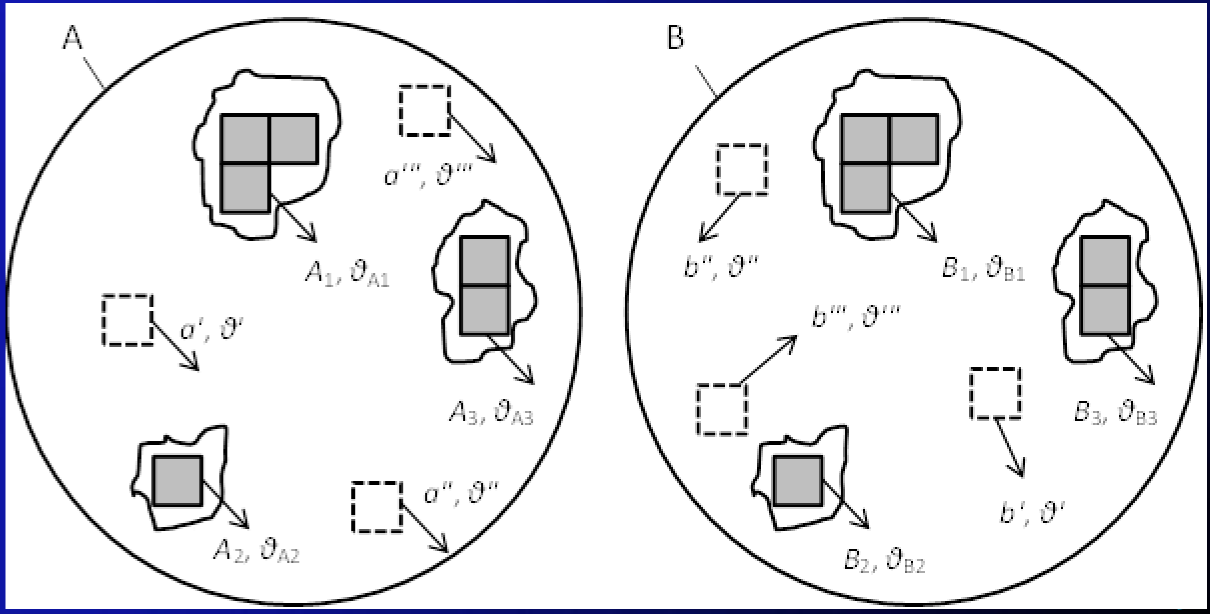


The "Congruent Matching Cells (CMC)"

The Congruent Matching Cells (CMC) are defined by

1) $A_1A_2A_3 \ldots \cong B_1B_2B_3 \ldots$ congruent *x-y* positions;
2) $\vartheta_1 = \vartheta_2 = \vartheta_3 \ldots$ same registration angle;
3) $CCF_{max} \geq CCF_{low}$, high correlation value.

(CCF_{low} is the low control limit to be determined.)

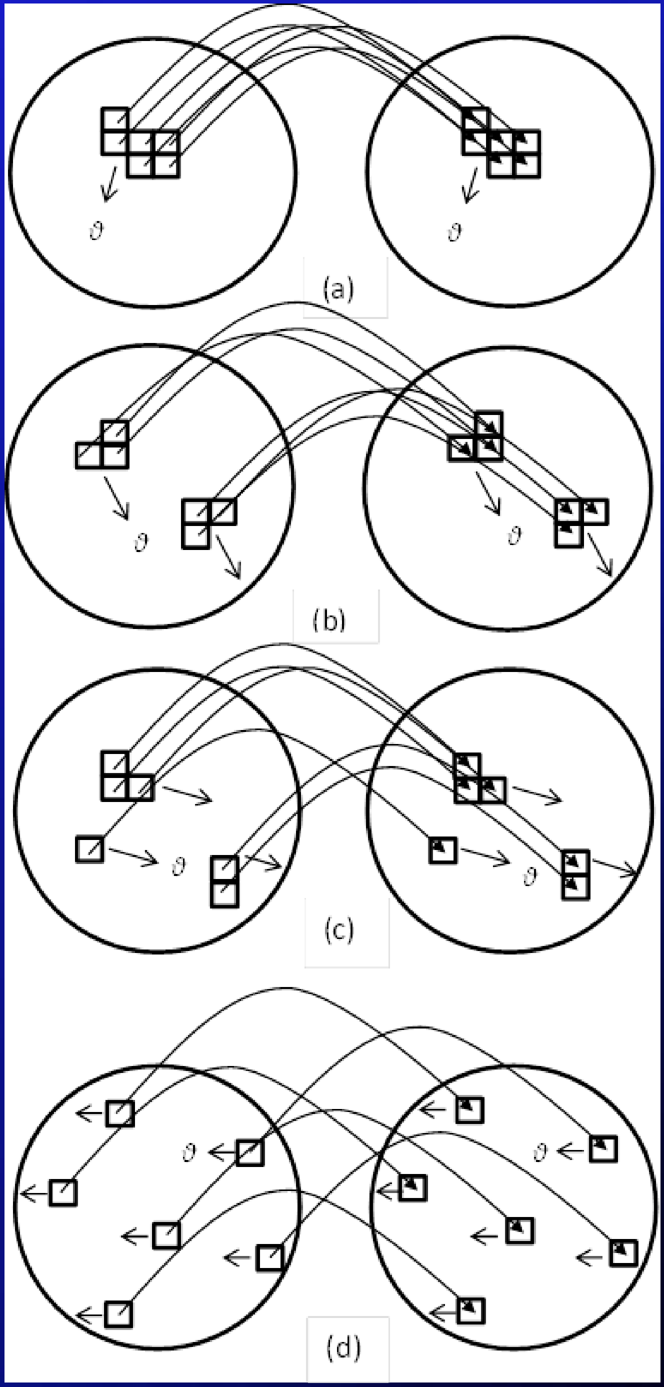


The numerical identification criterion C

- The numerical identification criterion *C*
  - When *CMC* ≥ *C*, Match;
    When *CMC* < *C*, Non-match or No-conclusion.
  - *C* is determined by controlled experiments on paired known-match (KM) and known-non-match (KNM) topographies.
  - At this point, we use *C* = 6 which may be a very conservative estimation to be revised.

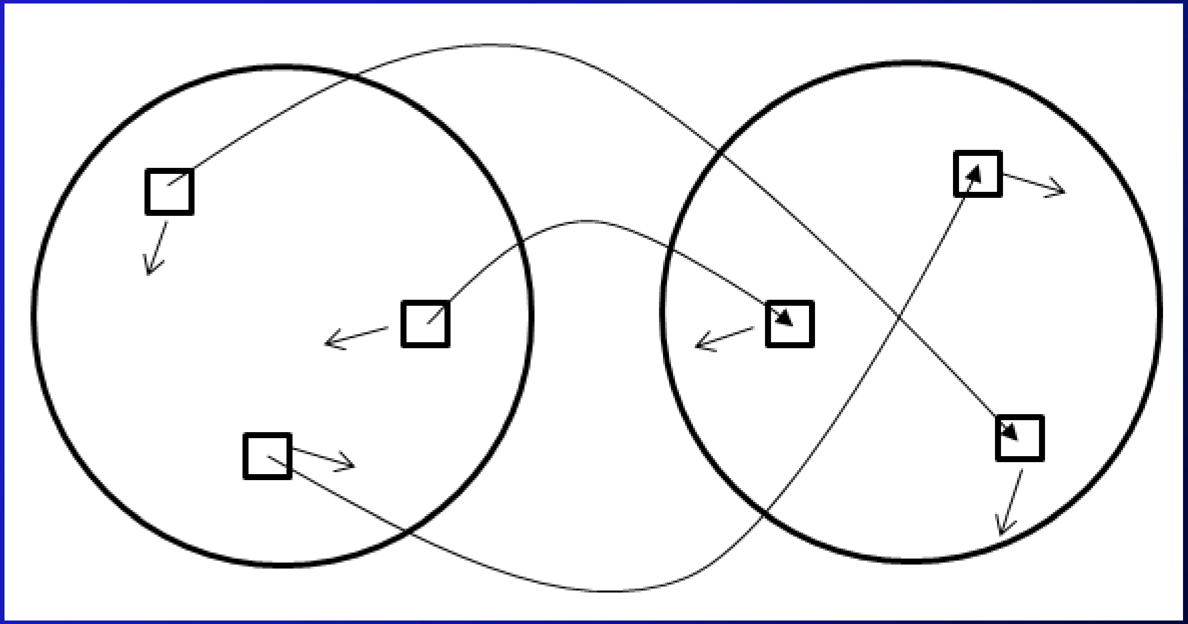
CMC for Ballistics Identification

CMC ≥ *C* = 6,
Match



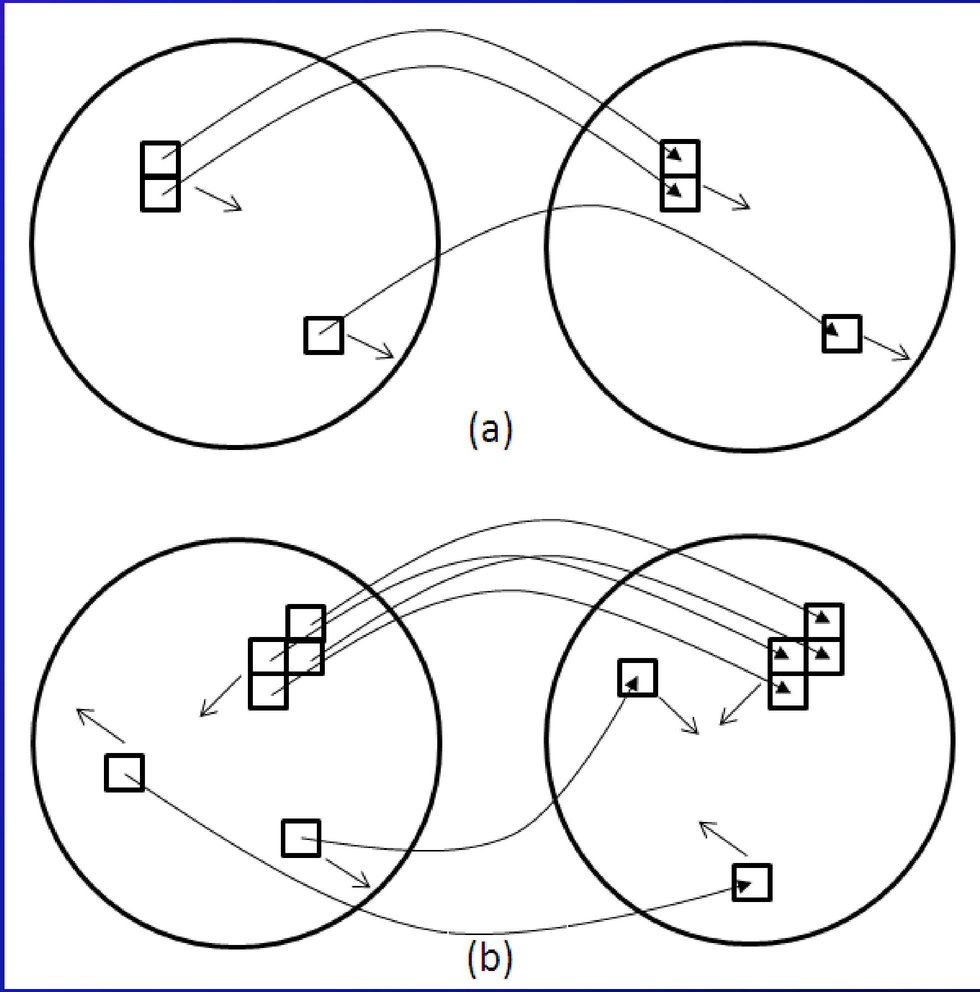
CMC for Ballistics Identification

CMC = *0* < *C* = 6, Non-match

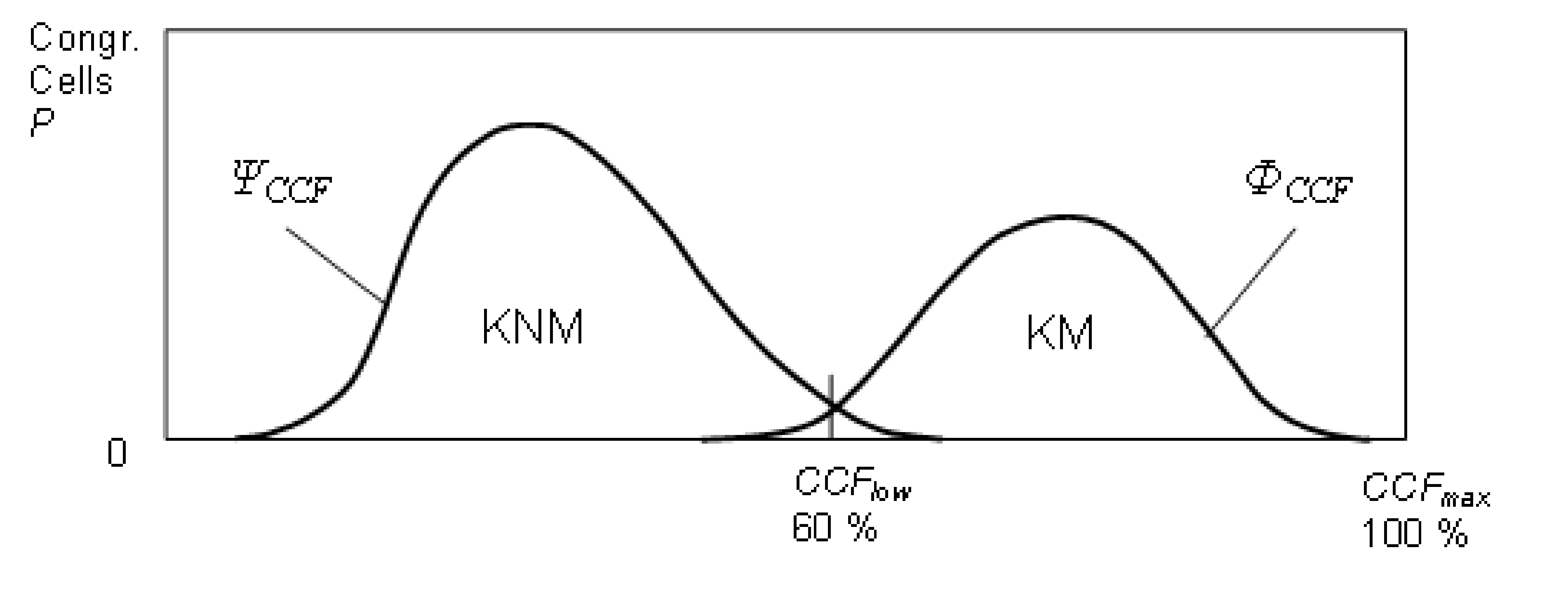


CMC for Ballistics Identification

CMC = *3* and *4* < *C* = 6, No-conclusion

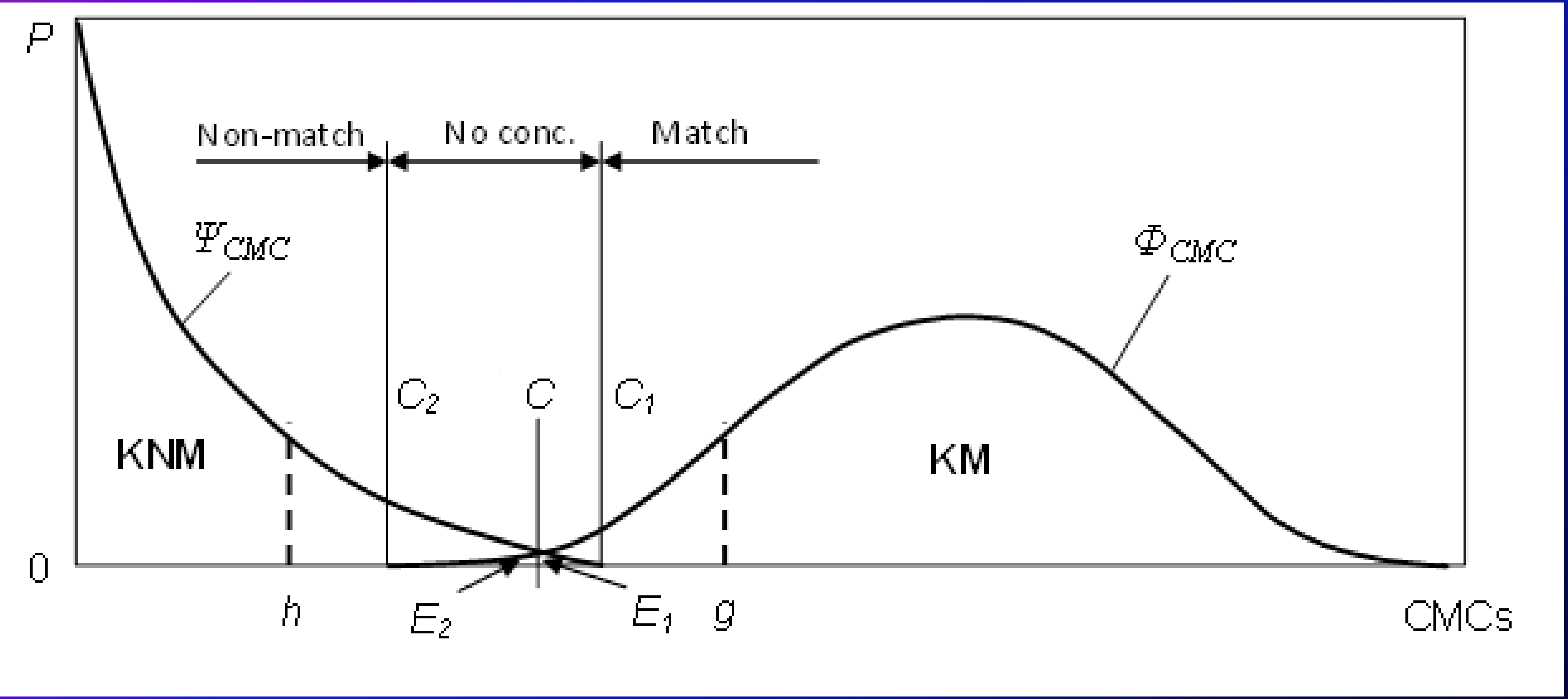


How to determine CCF_{low}



Assumed CCF_{max} distributions for the *"Congruent Cell Pairs"* of the paired KM and KNM topographies. As a start point, we use CCF_{low} = 60% for test.

How to determine numerical criterion "C"



Assumed CMC distribution for paired KM and KNM topographies. The CMC distribution for KNM topographies Ψ_{CMC} may be close to a logarithmic distribution.

Error rate estimation – False negative error

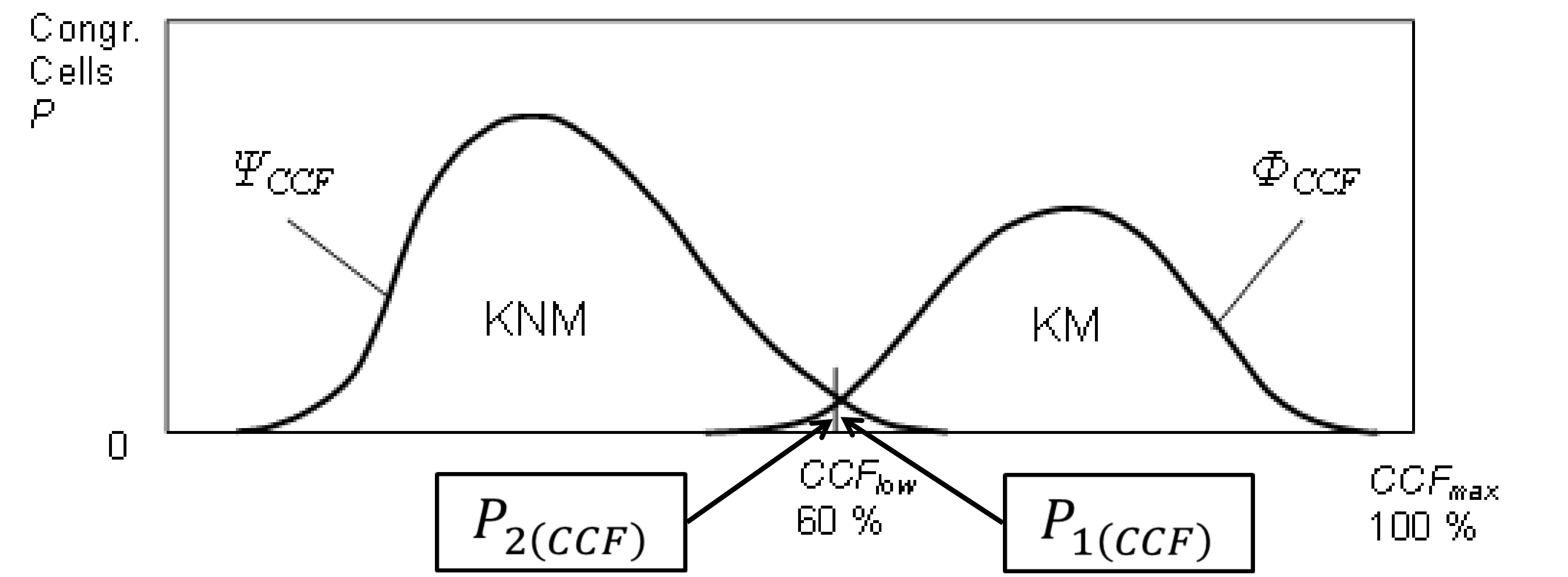
- $$E_2 = \sum_{g=C}^{g=N} E_{2(g)} = E_{2(g=C)} + E_{2(g=C+1))} + \cdots + E_{2(g=N)}$$

$$= 1 - (E_{2(g=0)} + E_{2(g=1)} + \cdots + E_{2(g=C-1)}).$$

$$E_{2(g)} = C_N^g \cdot (P_2)^g \cdot (1 - P_2)^{N-g}$$

Where E_2 is the false negative error rate, N is cell number, C is the numerical identification criterion of CMC (assuming C = 6). P_2 is the combined false negative identification probability of the CMC method.

$$P_2 = [P^{2}_{2(CCF)} + P^{2}_{2(\theta)} + P^{2}_{2(xy)}]^{1/2}$$



$$E_{2(g)} = C_N^g \cdot (P_2)^g \cdot (1 - P_2)^{N-g}$$

When N = 100, C = 6, P_2 = 0.01, E_2 = 0.054%;

When N = 100, C = 6, P_2 = 0.02, E_2 = 1.55%;

When N = 200, C = 6, P_2 = 0.01, E_2 = 1.60%;

When N = 100, C = 4, P_2 = 0.01, E_2 = 1.84%.

Error rate estimation – False positive error

- $$E_1 = \sum_{h=0}^{h=C-1} E_{1(h)} = E_{1(h=0)} + E_{1(h=1)} + \cdots + E_{1(h=C-1)}$$

$$E_{1(h)} = C_N^h \cdot (P_1)^h \cdot (1 - P_1)^{N-h}.$$

Where E_1 is the false positive error rate, N is cell number, C is the numerical identification criterion of CMC (assuming C = 6), P_1 is the combined false positive identification probability of the CMC method.

$h = 0$

a

$$E_{1(h)} = C_N^h \cdot (P_1)^h \cdot (1 - P_1)^{N-h}.$$

When N = 100, C = 6, P_1 = 0.01, E_1 = 7.2e-183;

When N = 100, C = 6, P_1 = 0.02, E_1 = 2.7e-154;

When N = 100, C = 6, P_1 = 0.02, E_1 = 2.7e-154;

When N = 200, C = 6, P_1 = 0.01, E_1 = 2.4e-181;

When N = 100, C = 4, P_1 = 0.01, E_1 = 1.6e-189;

When N = 100, C = 6, P_1 = 0.4, E_1 = 9.5e-32.

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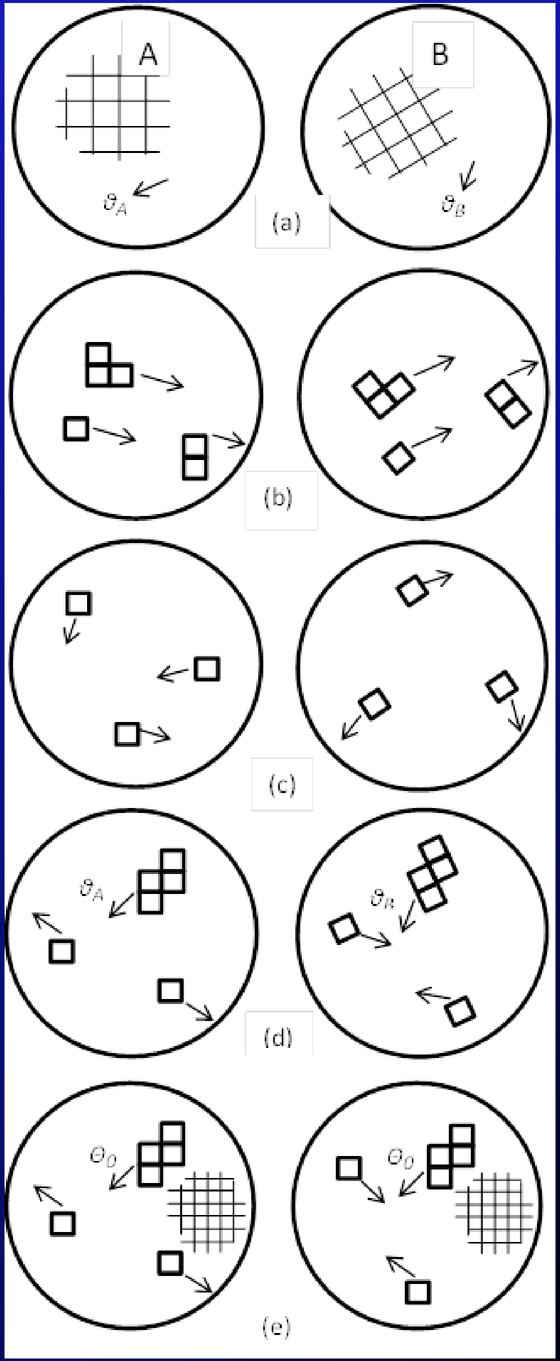
Proposed NIST Ballistics Identification System (NBIS)

a) Separate A and B in large cells for correlation;
b) CMC = 6, Matching;
c) CMC = 0, Non-matching;
d) CMC = 4, No-conclusion;
e) For the no-conclusion topographies, align A and B at their common phase angle Θ_0 and separate into small cells for accurate correlation.



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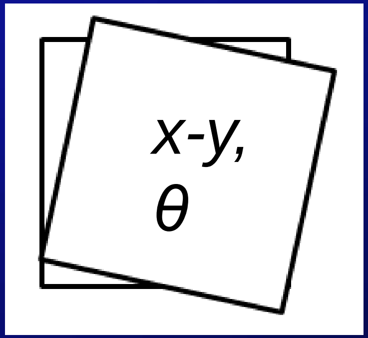
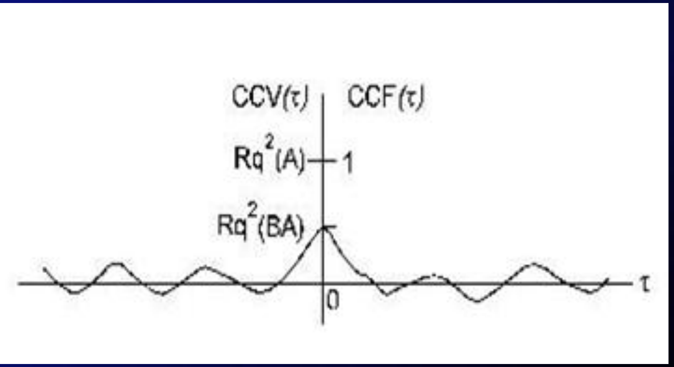
Three searching parameters of the paired correlation cells for ballistics evidence searches

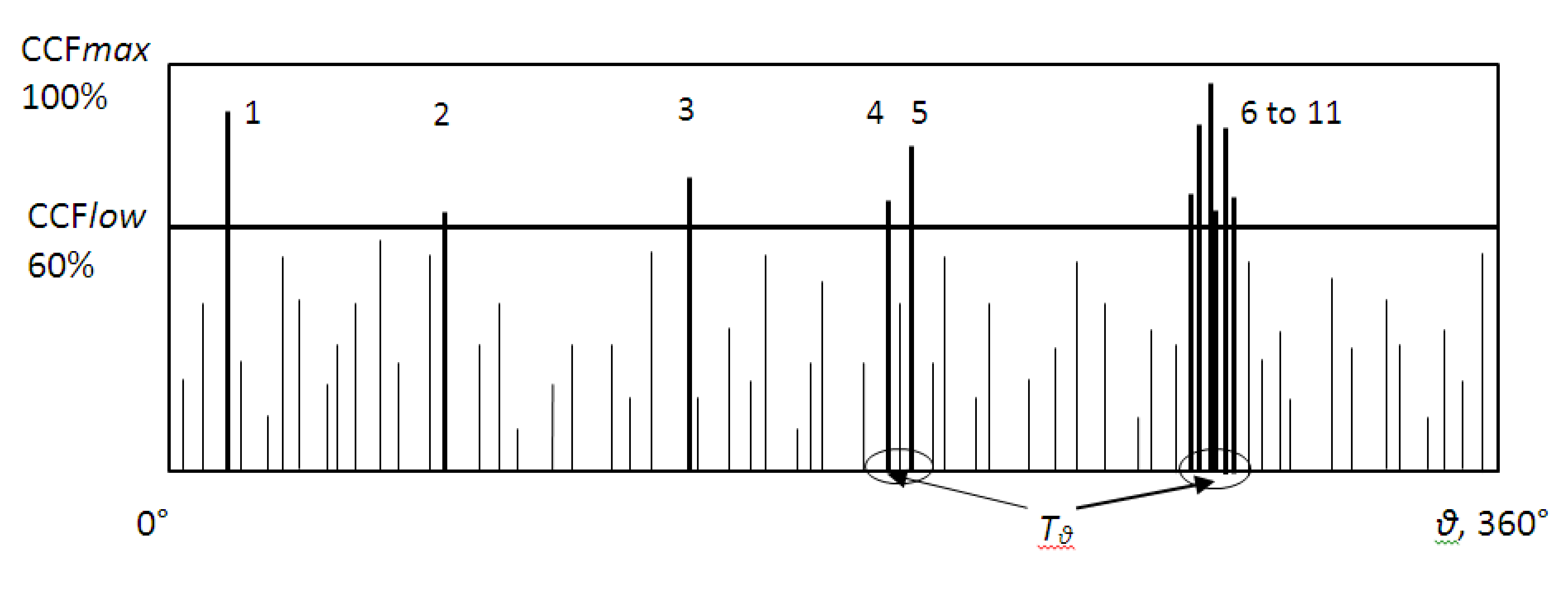
- *Registration position in x-y,*
- *Registration angle ϑ, and*
- *Correlation value CCF_{max} .*





Proposed procedure for ballistics evidence searches –

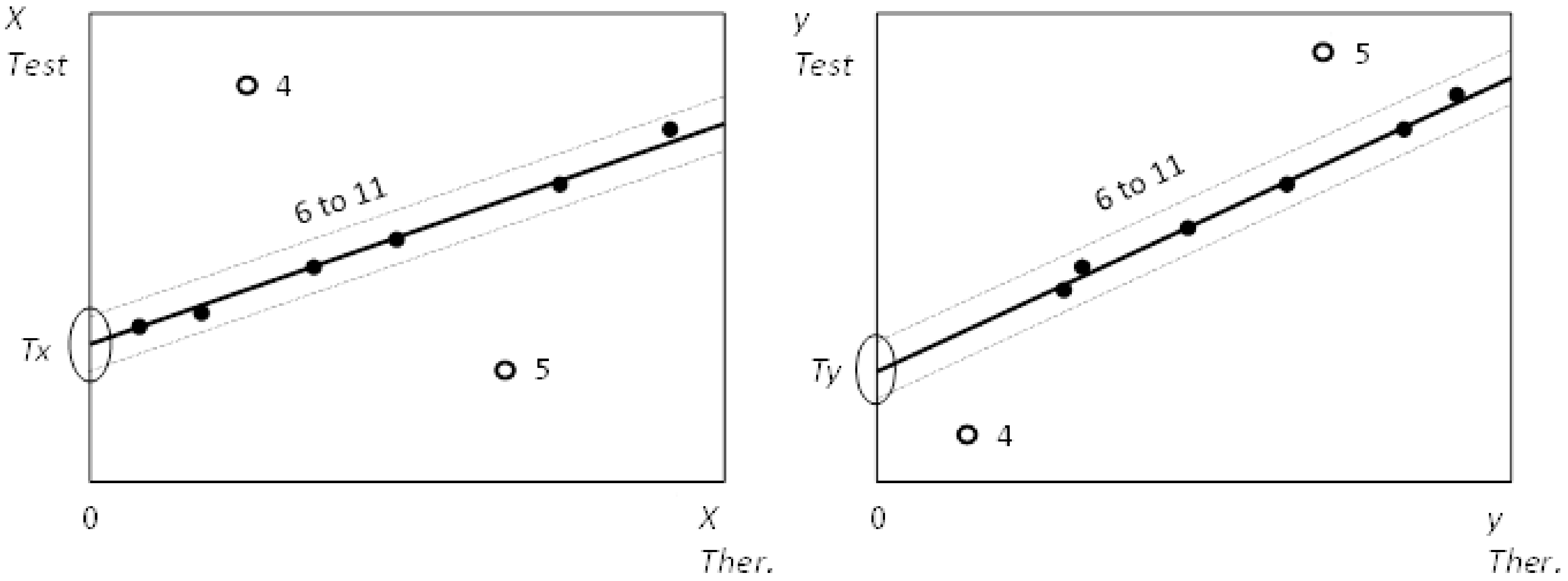
First step: CCF_{max} and ϑ searches



Ballistic evidence searches: CCF_{max} and ϑ searches.
T_{θ} is a threshold or a searching window for θ.

Proposed procedure for ballistics evidence searches –

Second step: x-y searches



Ballistic evidence searches: *x-y* searches. T_x and T_y are thresholds or searching windows for *x-y* searches .

What is the Problem?

- Need 3D topography measurements for ballistics identifications;
- Need a method to remove the "Invalid Correlation Area";
- Need a "Universal Identification Criterion" for 3D ballistics identifications;
- Need an error rate reporting procedure;
- Need to increase correlation speed and eliminate manual operations.

Can "3D topo-measurements on correlation cells" solve all these problems? Probably

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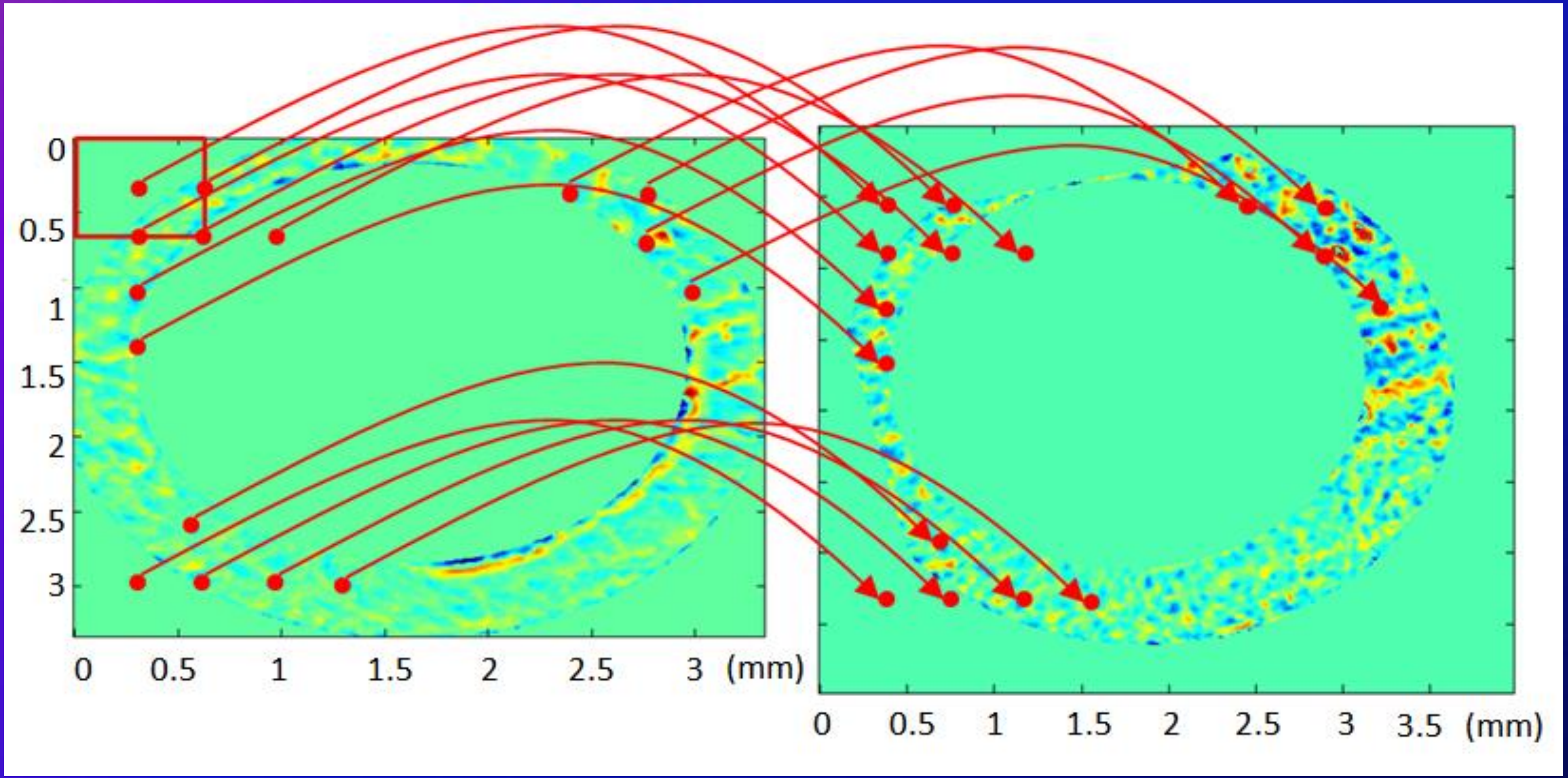
Future work

- Develop a correlation program using "synchronous processing" for dozens even hundreds cell correlations at the same time.
- Experimental verification of the proposed method using the KM and KNM topographies and optical intensity images.
- Optimize the correlation parameters: cell size n, cell number N, the low control limits CCF_{low} and the thresholds T_x, T_y and T_θ.

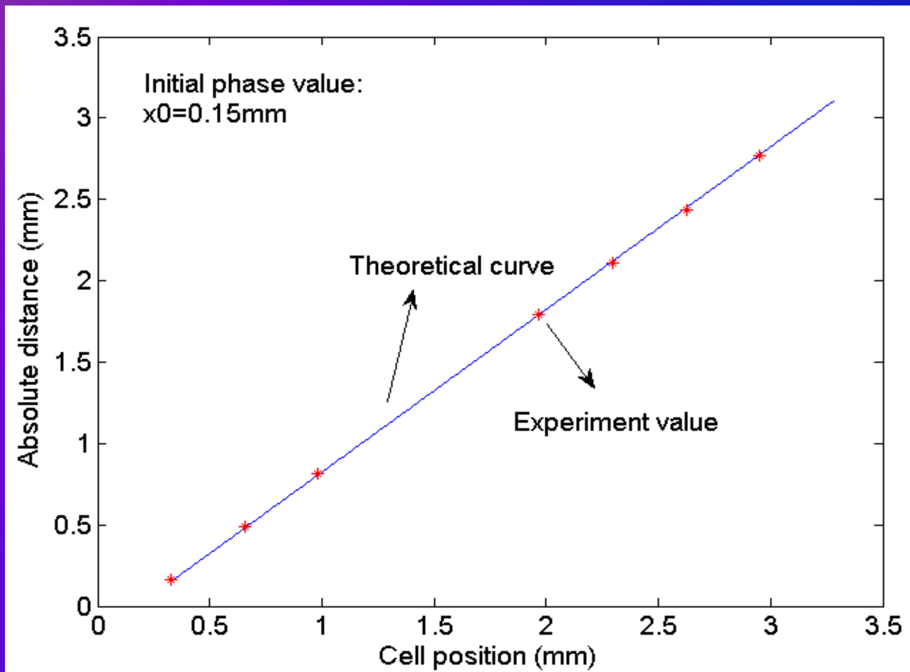
Future work

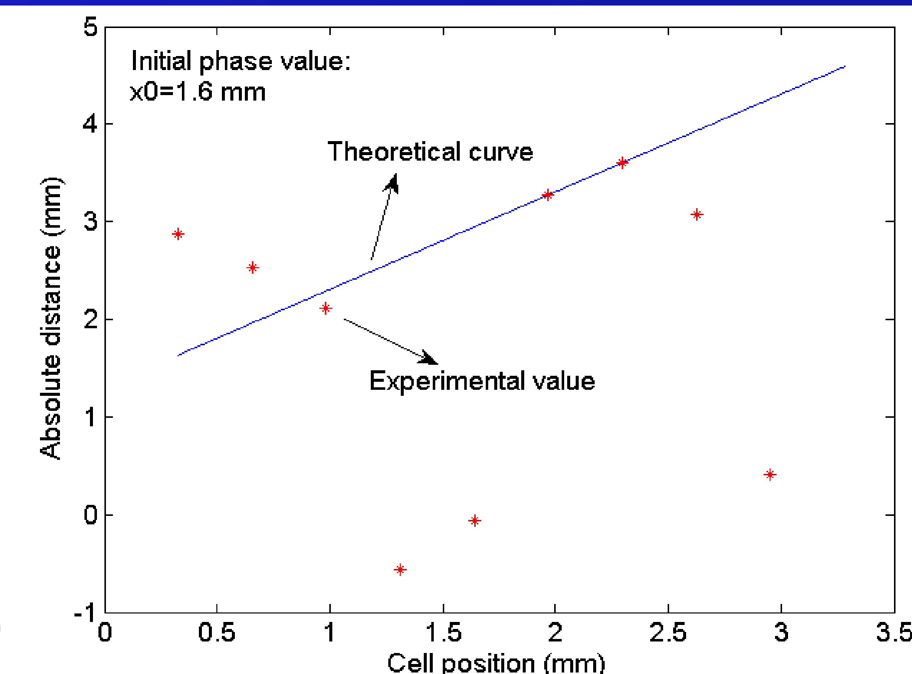
- Develop the numerical identification criterion *C* for proposed CMC method; develop an error rate report procedure.
- Develop the NIST Ballistics Identification System (NBIS).
- Test NBIS by KM and KNM topographies.
- Conduct evidence searches with the NIBIN database and estimate the error rate.



Initial test result: - For a pair of KM breech face signatures (#32 vs. #13), numerous paired correlation cells show high *CCFmax* values (> 60%) and the same spatial distribution pattern.
- For the KNM breech face signatures (not shown), no paired correlation cells show high *CCFmax* values (*CCFmax* < 60%, not shown).

By W. Chu





Initial test result:

- A strong correlation between the theoretical and tested registration positions of the paired cells from KM breech face signatures (#32 vs. #13, left).
- No correlation can be seen for KNM breech face signatures (#32 vs. #04, right).

By W. Chu

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Summary

- 3D topography measurement on correlation cells is proposed for NBIS. All parameters and algorithms are traceable to length standards, and are in the public domain subject to open tests.

- The proposed Congruent Matching Cells (CMC) using three identification parameters (*CCFmax*, *x-y* and *ϑ*) can promote high accuracy ballistics identifications and evidence searches. It can be used for correlation of both geometrical topographies and optical images.

Summary

- "Synchronous processing" of correlation cells can largely increase correlation speed.
- CMC can promote objective and fully automated identifications by eliminating manual operations (such as image trimming), and by combining breech face and firing pin correlations as a single step.
- An error rate report procedure will be developed as scientific support to ballistics identifications and court proceedings.

Comments and suggestions are welcome:

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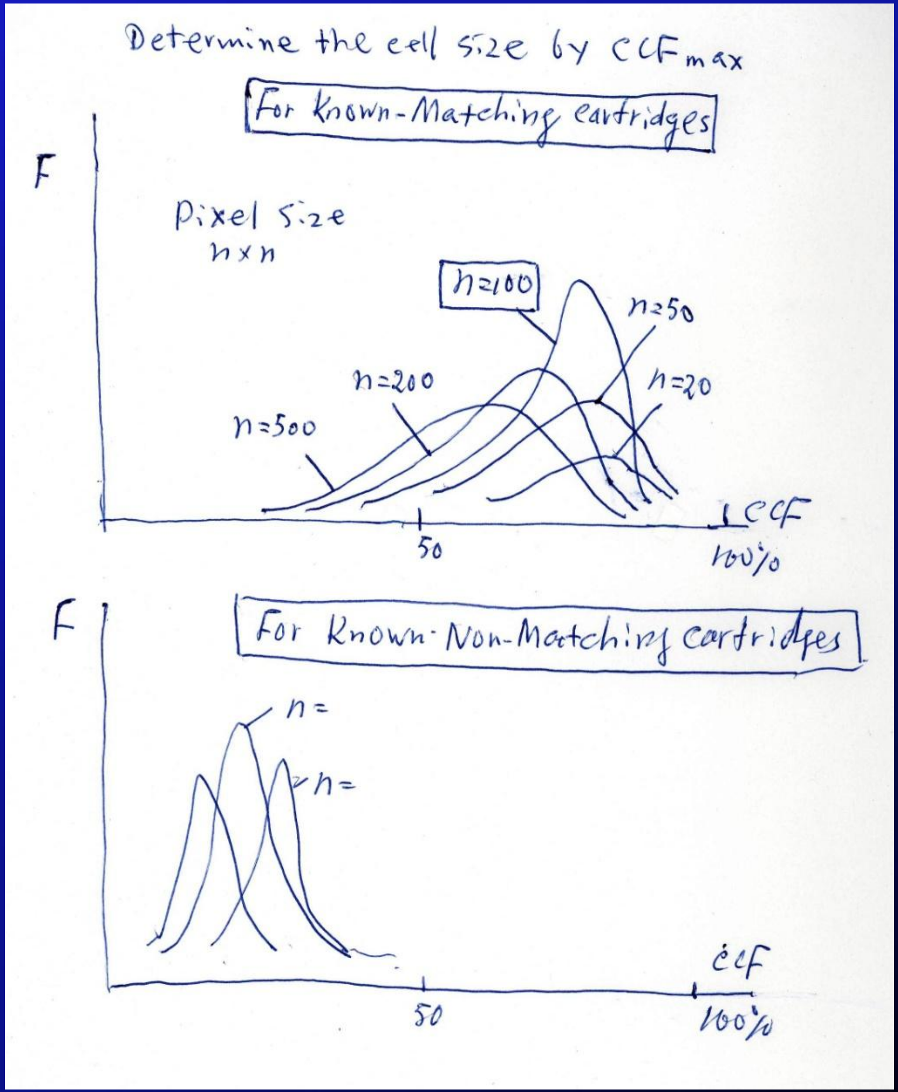
Email: Robert.Thompson@NIST.gov;
Phone: 301 975 2118

Questions?

(*Continued*)

- By using different cell sizes, each contains (n × n) pixels (n = 10, 20, 50, 100, 200, 500…), separate topography A and B as (r × s) arrays of cells A (r, s) and B (r, s) at their initial phase position (x_0, y_0, θ_0);
- Correlation of each corresponding paired cells A (r, s) and B (r, s);
- Draw frequency distribution curves for the paired cells for both the KM and KNM cartridges at different cell sizes;
- It is possible that the strong correlation between the cell size (n × n) and *CCFmax* only happens for the KM cartridges.
- Optimization of the cell size (n × n), by

  1) The highest *CCFmax* on the KM curves;
  2) The maximum separation between the KM and KNM distributions.



6.4 Registration reproducibility

- If the two correlated cartridges A and B are repeatedly measured and correlated from day to day, the variation range (k = 2) of their initial phase position (x_0, y_0, θ_0) represents the registration reproducibility $R(x_0, y_0, \theta_0)$

  $$R (x_0, y_0, \theta_0) = R (2\sigma x_0, 2\sigma y_0, 2\sigma_{\theta 0}) \quad (5)$$

  where σx_0, σy_0, $\sigma_{\theta 0}$ represent the standard deviation of x_0, y_0, θ_0.

- The registration reproducibility may be different with the type of signatures (breech face, firing pin and ejector mark); the type of guns and ammos and the type of matchings (matching or non-matching).