Biometric Liveness Detection: Framework and Metrics

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This Talk

- **Categories of Subversive Presentation Attacks**
- **Performance Metrics for Suspicious Presentation Detection Systems**
- **Relationship between Liveness Detection and Challenge-Response**

Non-Subversive Presentation

Live Capture Subject

Subversive Presentation*

ARTIFICIAL

Artefact
(e.g., fake finger, patterned contact, face photo)

HUMAN

Cadaver
(e.g., dismembered fingers)

Altered
(e.g., mutilated finger, surgical alteration)

Nonconformant
(e.g., facial expression changes, side of finger)

Conformant
(e.g., zero-effort attack)

Coerced
(e.g., unconscious)

**Some cases may also not be deliberate attacks (e.g., patterned contact for cosmetic reasons, non-conformant due to improper use of system, etc.)*

A detection system cannot infer intent, therefore, is called* ***Suspicious Presentation Detection System*

Introduction—Definitions

- **Subversive Presentation**
  - Presentation of human or artificial biometric characteristics to the biometric capture subsystem in a fashion that interferes with or undermines the correct or intended policy of the biometric system.
- **Suspicious Presentation**
  - Presentation of a human or artificial characteristic to the biometric capture subsystem in a fashion that could interfere with the intended policy of the biometric system
- **Suspicious Presentation Detection (SPD)**
  - Automated determination of a suspicious presentation.
- **Examples of SPD**
  - Liveness detection failure
  - Artefact detection
  - Altered biometric detection
  - Others terms that have been used: anti-spoofing, biometric fraud, spoof detection, authenticity detection, etc.

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Subversive Presentation*

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Also helps with this

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Altered Biometric Detection

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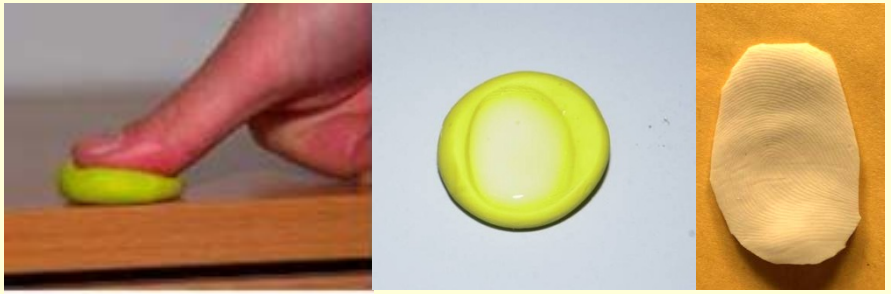
Categories for Subversive Presentation Attacks

Categories for Subversive Presentation Attacks

- **First step in development of scientific framework to evaluate suspicious presentation detection security systems**
- **Classification and brief description of known attack types on biometric authentication at the sensor**
- **Provide foundation for development of effective countermeasures**
  - Basis for performance assessment
  - Empirical testing of countermeasure effectiveness against known attacks
- **Not a recipe book for creating artificial biometric traits**
- **Procedure to create an artificial subversive presentation characteristic:**
  - Source of biometric characteristic – Obtain information to describe characteristic
  - Production of artefact – Process for creating artefact to present characteristic to sensor
- **Human – no artificial characteristics used**

Source of Biometric Characteristics

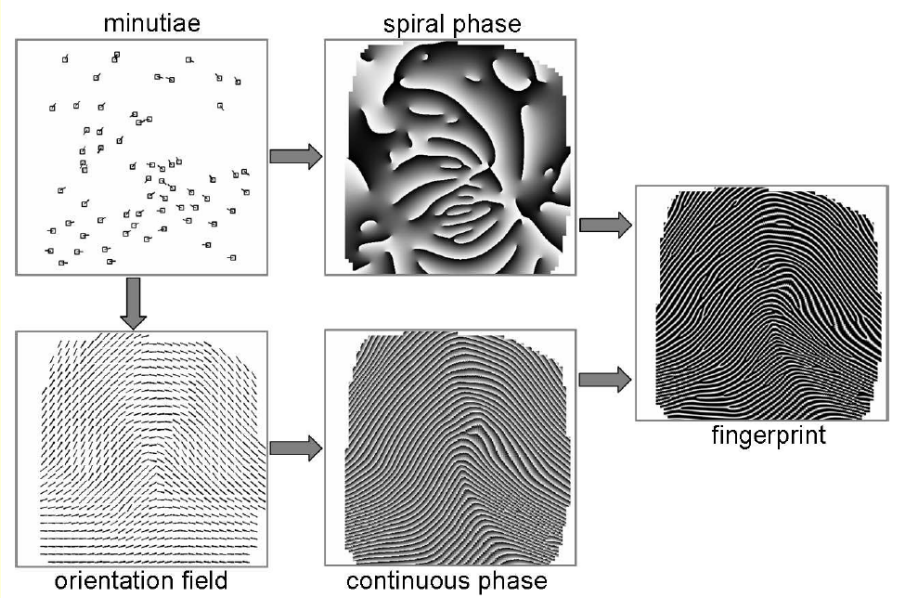
- **Cooperative**
  - Characteristic captured directly from individual with assistance (e.g. finger mold, hand mold, face mask)
- **Latent**
  - Characteristic captured indirectly through latent sample (e.g. latent fingerprint, latent palmprint, hair, skin, body fluid)
- **Recording**
  - Characteristic captured directly from individual onto media (e.g. photograph, video recording, audio recording)



Coli, et al, 2006.

Source of Biometric Characteristics

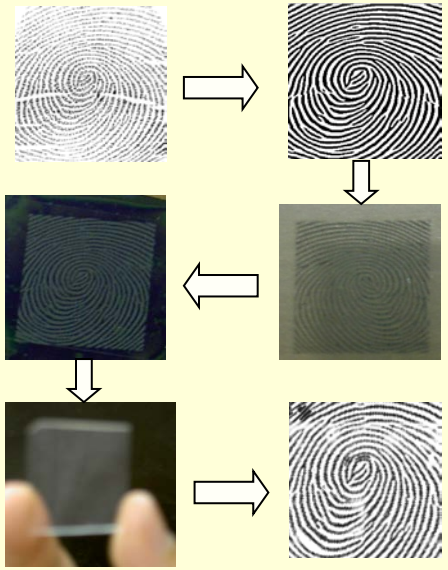
- **Template Regeneration**
  - Regenerate characteristic from template (e.g. fingerprint regeneration, face)
- **Synthetic**
  - Synthetic characteristic, not mapped to real person (e.g. synthetic fingerprint, iris, face, voice, wolf synthesized sample)
- **Impersonation**
  - Conversion of natural characteristic to another individual's with artificial assistance (e.g. computer assisted voice)



Feng and Jain, Advances in Biometrics article, 2009.

Production of Artefact

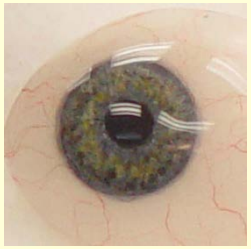
- **Mold/cast**
  - Create 3D representation of characteristic (negative)
  - Cast is reproduction created from mold (e.g. theatrical face mask, finger artefact of modeling clay, gelatin, silicone, latex, wood glue, glycerin, etc.)
- **Mask – modify or conceal characteristics (partially or completely) with artefact**



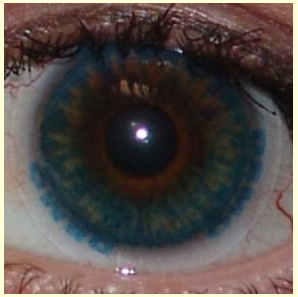
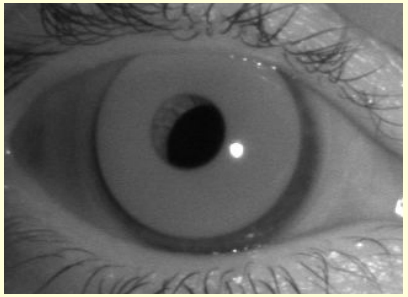
Production of Artefact

- **Direct rendering**
  - Printing 2D (e.g. photo of iris or face, fingerprint printed on transparency/paper)
  - Printing 3D (e.g. contact lens printed with pattern, prosthetic hand printed with vein pattern)
  - Etching (e.g. fingerprint etched on metal)
  - Painting – patterns and colors painted on prosthesis
- **Digital Media**
  - Computer screen – laptop or tablet to present image or video
  - Audio – recording of voice


Thalheim, et al, C'T article, 2002.

Lefohn, et al, IEEE Computer Graphics & Applications article, 2003.

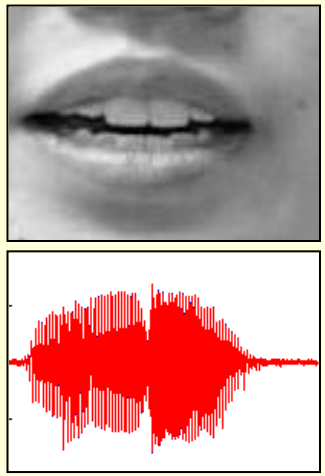



Seelen, "Countermeasures Against Iris Spoofing with Contact Lenses," Iridian Technologies Inc.

Categories of Human Subversive Presentations (Non-Artefact Methods)

- **Lifeless**
  - Cadaver
- **Altered**
  - Mutilation (e.g. scarring, amputation, acid)
  - Surgical modification (e.g. new fingerprint, nose job, face lift)
- **Non-Conformant**
  - Impersonation (e.g. voice mimicry, forged signature)
  - Presentation (e.g. hand shape control, facial expression/extreme, tip of side of finger)
- **Conformant**
  - Zero effort impostor attempt (e.g. any normal presentation)
- **Coerced**
  - Unconscious or under duress

Feng, et al, IEEE TIFS article, 2009.



Performance Metrics for Suspicious Presentation Detection Systems

State of Artefact Detection Performance Metrics

- Performance metrics for biometric systems – adapted unmodified for artefact detection assessment
  - Classification rate (percent correctly classified)
  - FAR/FMR – false accept rate/false match rate
  - FRR/FNMR – false reject rate/false non match rate
  - TAR/GAR – true accept rate/genuine accept rate
  - EER – equal error rate
  - ROC – receiver operating characteristic
  - DET – detection error trade-off
- Need to distinguish "**false accepts"** in ***matching*** from **"false accepts"** in ***artefact detection***
  - Need common set of vocabulary

Evaluation of suspicious presentation detection systems

- The ability to correctly identify suspicious presentation attacks is quantified by a dedicated set of performance metrics
- The suspicious presentation detection error rates are defined based on the specific purpose of the suspicious presentation detection module:
  - E.g., live vs non-live, altered vs non-altered, artefact vs non-artefact, etc.
  - Performance metrics are confined to the defined goal
- Metrics for assessing suspicious presentation detection detection performance differ from those used for assessing matching performance

General Model for Performance Evaluation

- **Suspicious Presentation Detection**: When the system states that the presentation characteristic is suspicious
- **Non-Suspicious Presentation Detection**: When the system states that the presentation characteristic is not suspicious

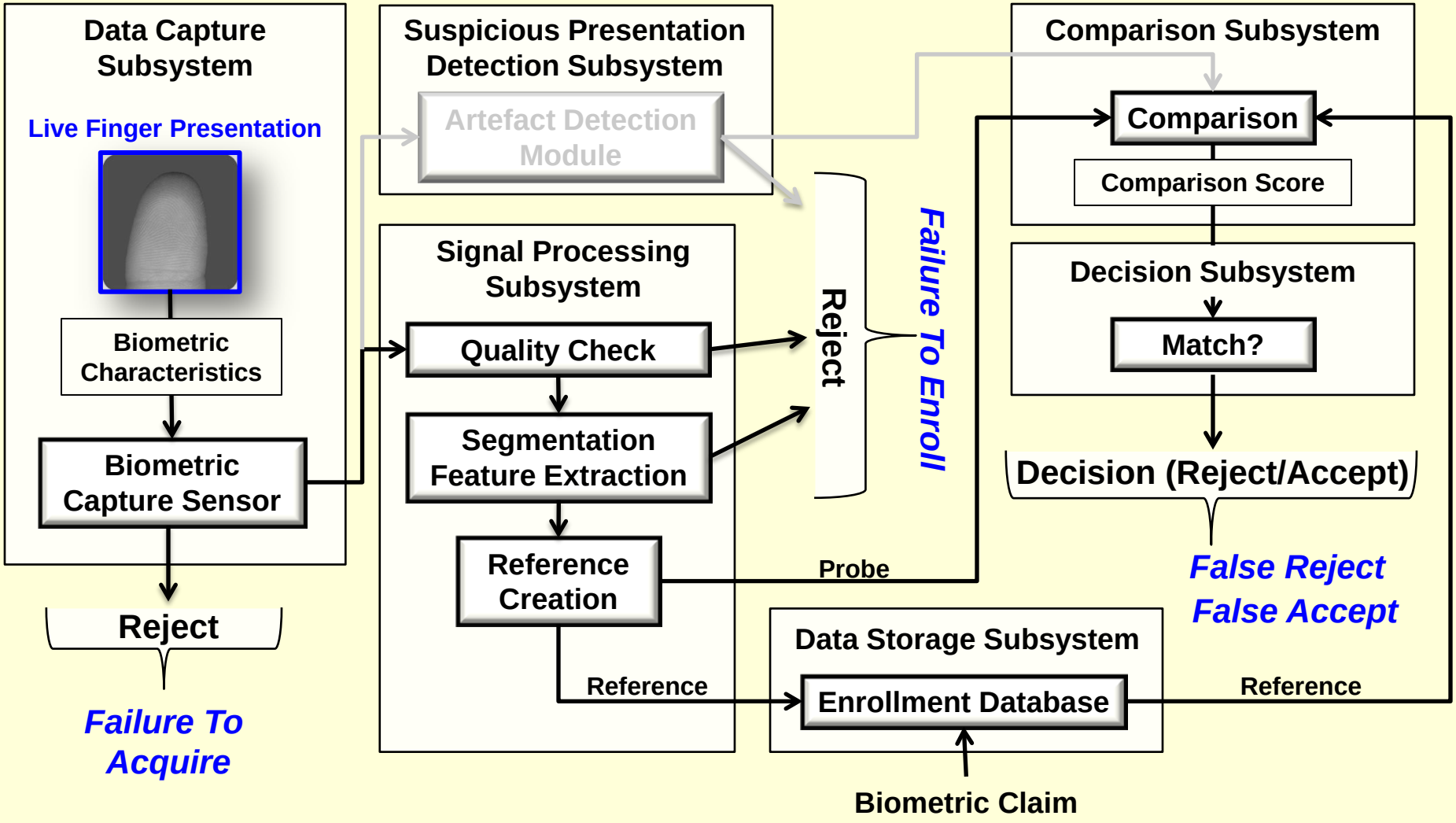
- **Metrics for error cases:**
  - **False Non-Suspicious Presentation Detection (FNSPD):** a suspicious presentation is incorrectly classified as being a non-suspicious presentation
  - **False Suspicious Presentation Detection (FSPD):** a non-suspicious presentation is incorrectly classified as being a suspicious presentation

Artefact Detection Case

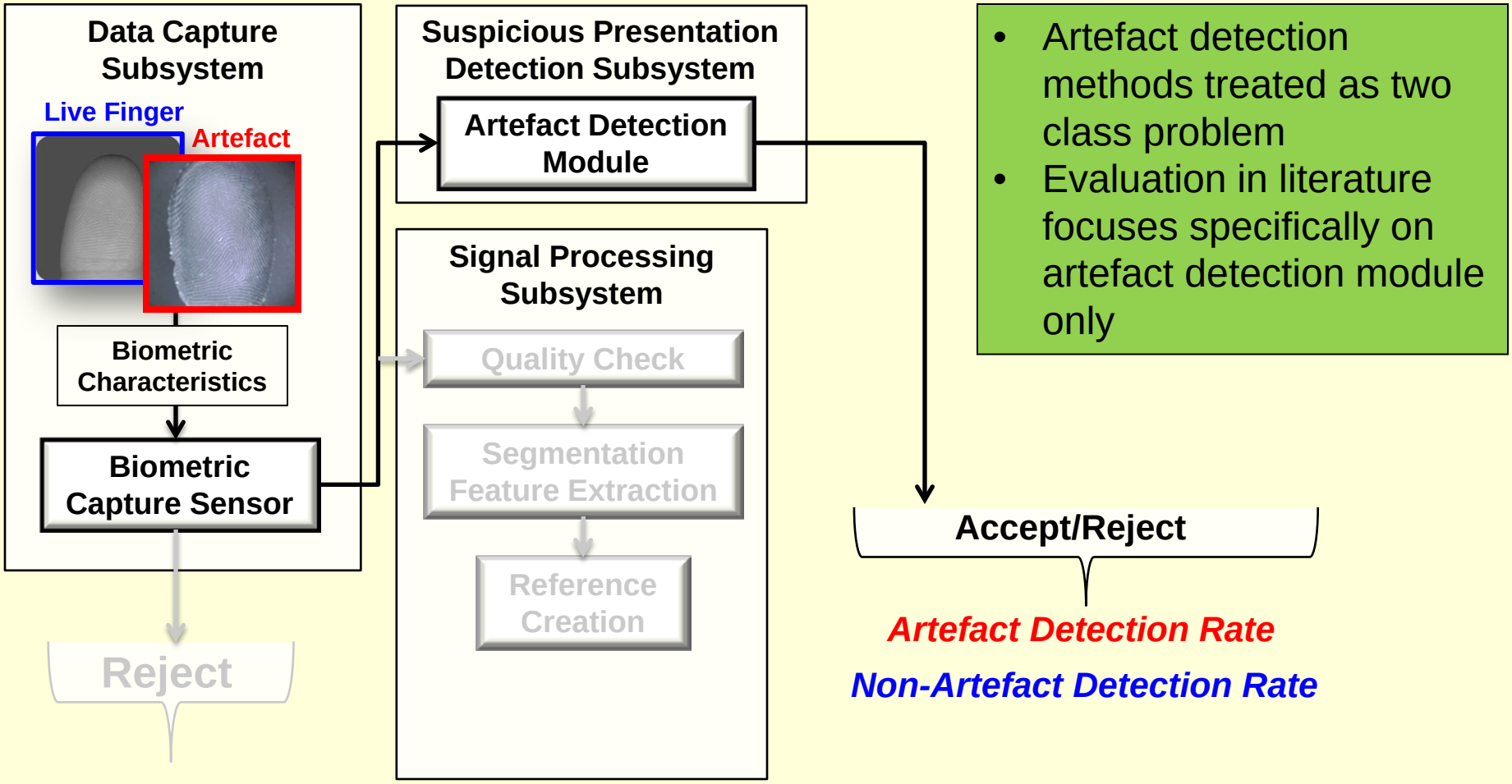
- **Goal:** Evaluation of module that is designed to distinguish the presentation of an artefact from a non-artefact
  - **Artefact Detection**: When the system states that the presentation characteristic is an artefact
  - **Non-Artefact Detection**: When the system states that the presentation characteristic is not an artefact

- **Metrics for error cases:**
  - **False Artefact Detection Rate (FADR):** proportion of non-artefact presentations incorrectly classified as being artefacts
  - **False Non-Artefact Detection Rate (FNDR)**: proportion of artefact presentations incorrectly classified as being non-artefacts

Traditional Metrics for Biometric Evaluation (Live Finger Input)

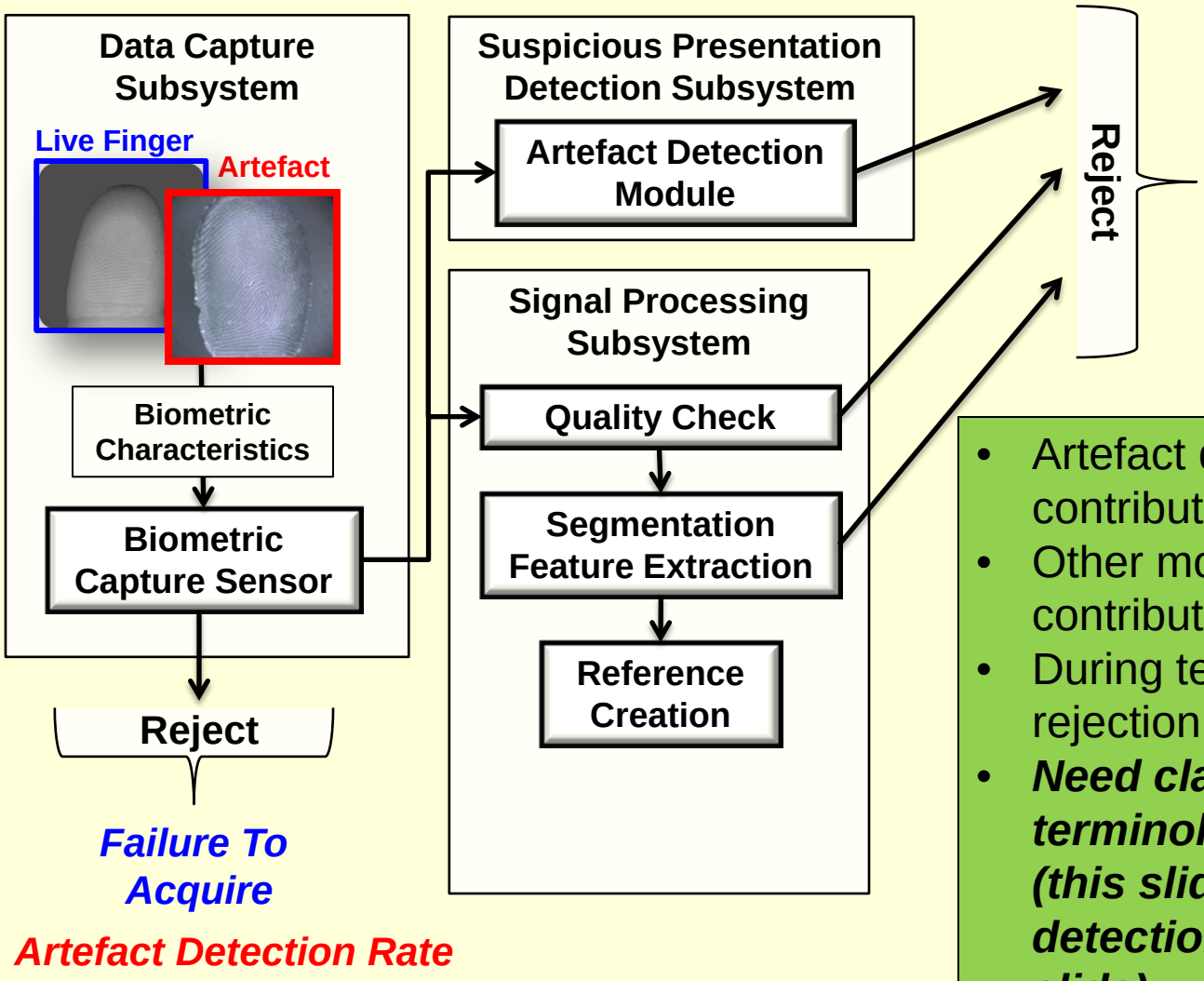


Additional Metrics (Artefact Input)



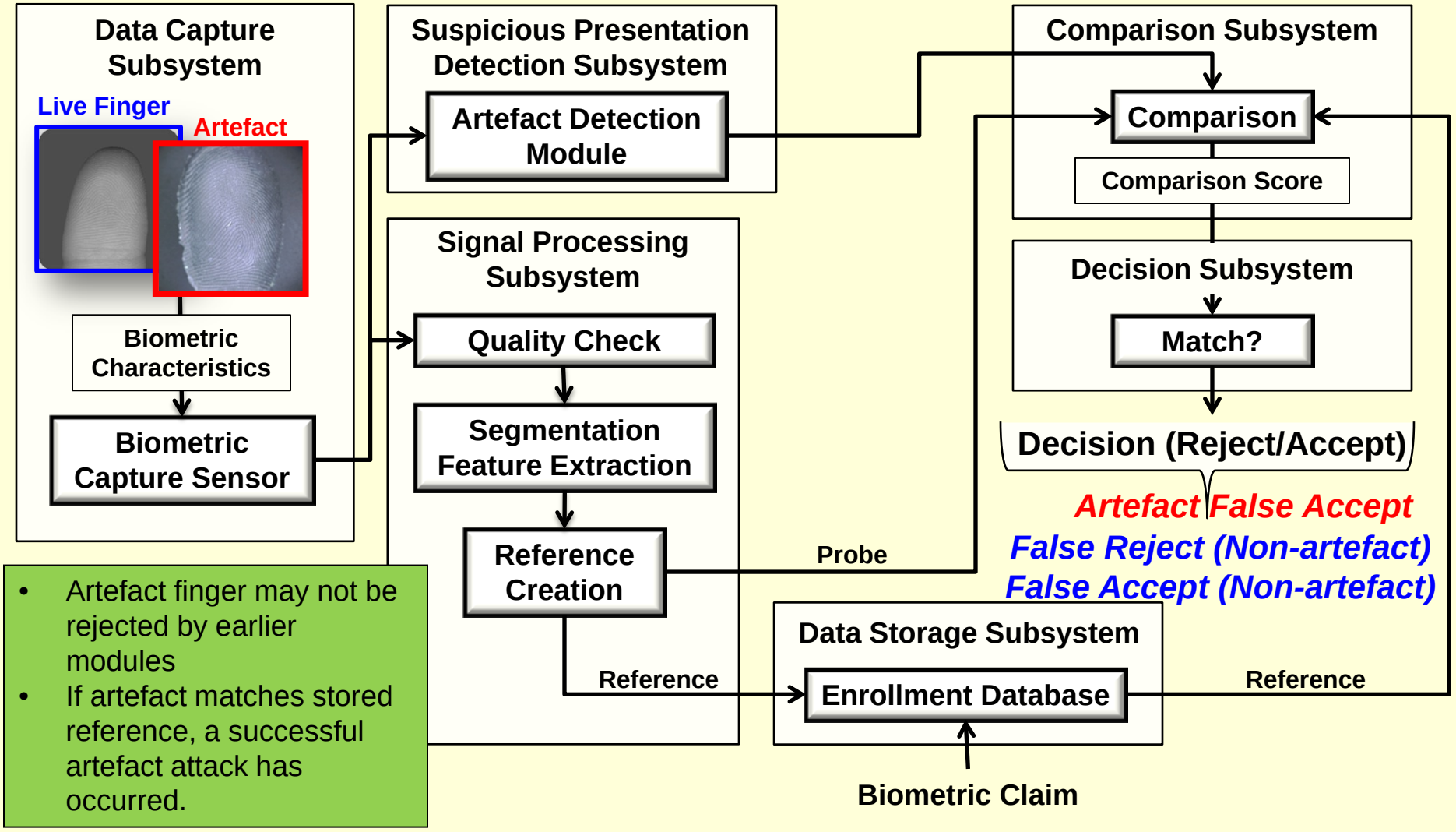
- Artefact detection methods treated as two class problem
- Evaluation in literature focuses specifically on artefact detection module only

Additional Metrics (Artefact Input)



- Artefact detection module will contribute to decision to reject
- Other modules (e.g. quality) may contribute
- During testing specific reason for rejection may not be known
- ***Need clarification in terminology for system testing (this slide) and artefact detection module testing (last slide)***

What about matching? (Artefact Input)



- Artefact finger may not be rejected by earlier modules
- If artefact matches stored reference, a successful artefact attack has occurred.

On the Relationship between Liveness Detection and Challenge-Response

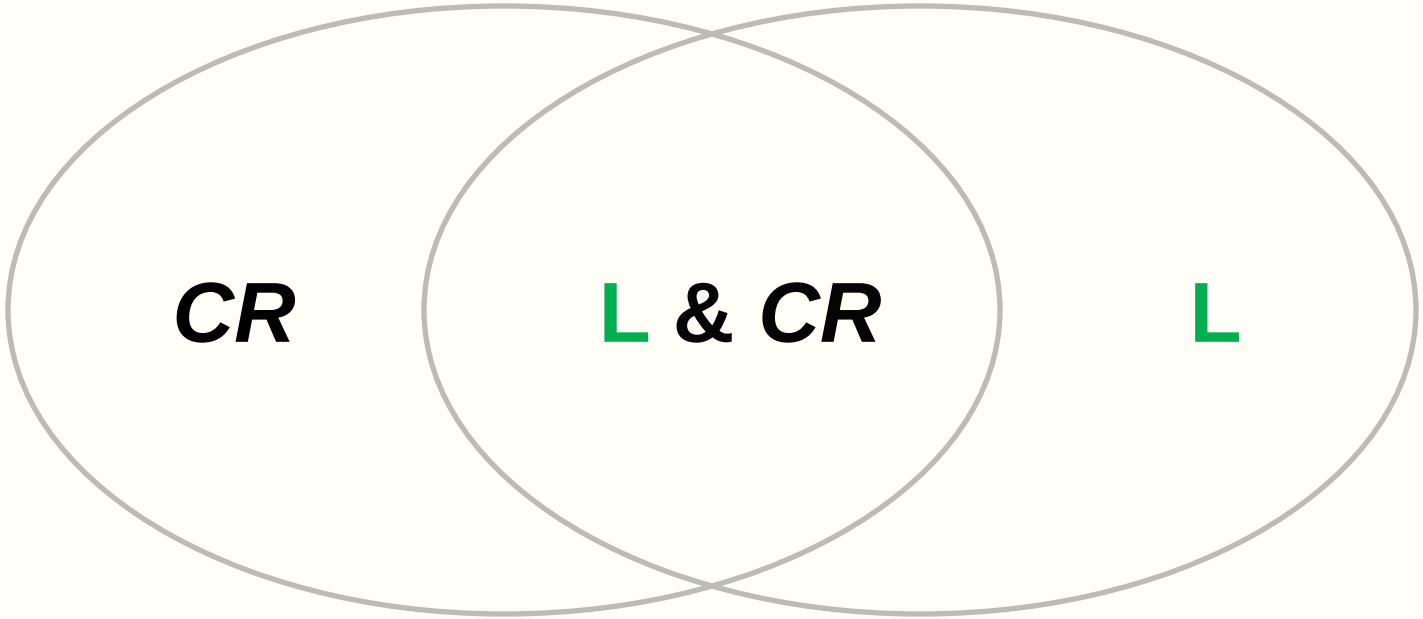
Motivation

Ways to strengthen Authentication Methods

- **Increase to multi-factors**
  - Biometrics
  - Knowledge
  - Possession (not addressed further, too application specific)
- **Add strength to biometrics with “liveness” (L)**
- **Add strength to Authentication with Challenge-Response (CR) schemes**

Relationship between L and CR

- **Some techniques combine L and *CR***



- ***See illustration in the following table***

L and CR relationship (overall)

LIVENESS

(BIOMETRIC CAPTURE SUBSYSTEM BASED)

Challenge →Response

Primary Examples "L & CR"

Controlled change illumination →Pupil size

Multispectral illumination →Absorption characteristics

Concepts:

Challenge →Response (based on Liveness)

Stimulated intentionally

"Passive"

Primary Examples "L"

Finger perspiration (over time)

Hippus (iris) motion/freq Pulse)

Concepts:

No stimulation (no "challenge")

Passive (receive only)

CR-BIOMETRIC SYSTEM LEVEL

(INVOLVES SOME ASPECTS EXTERNAL TO THE BIOMETRIC CAPTURE SUBSYSTEM)

Primary Examples "CR"

Finger order (random changes by system) → Correct presentation & matching

Digit order →Correct pronunciation & matching

Security question* →Correct answer (content) & matching

**** Combination of Knowledge and Biometrics***

Concepts:

Challenge logic in System (server/back-end)

Enrollment of all designed variations (multiple fingers, all digits 0-9)

CR-SYSTEM LEVEL

(DOES NOT INVOLVE BIOMETRIC CAPTURE)

Primary Examples (non-BIO)

Smart ID card (with authentication) + PIN

Login name + password + randomized security question

ID card + scramble pad PIN code*

**** this example has an added cognitive/human/alive aspect***

Concepts:

Involves authentication factors other than Biometrics

Challenge can take the form of device/card authentication (confirm digital cert)

Summary

- **Some Liveness approaches do not involve Challenge-Response (L)**
- **Liveness and Challenge-Response can be use together (L&CR)**
- **Some Challenge-Response approaches involve biometrics but not Liveness (CR)**
- **Some Challenge-Response approaches do not involve biometrics (non-BIO)**

Overall Summary

- **Categories of Subversive Presentation**
  - Artificial (Source and Production Methods)
  - Human (altered, coerced, non-conformant, conformant, cadaver)
- **Suspicious Presentation Detection**
  - Liveness Detection, Artefact Detection, Altered Finger Detection
- **Metrics for measuring performance**
  - False Suspicious Presentation Detection (FSPD)
    - e.g., False Artefact Detection (FAD)
  - False Non-Suspicious Presentation Detection (FNSPD)
    - e.g., False Non-Artefact Detection (FND)
- **Liveness and Challenge Response**