

Toward Criteria for Standardization of Multi-Party Threshold Schemes for Cryptographic Primitives

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Presentation on August 15, 2020 @ ACAS2020, Virtual event
2nd Workshop on **Advanced Cryptography Applications and Standards**

*At NIST as a Foreign Guest Researcher (Contractor, from Strativia)

Opinions expressed in this presentation are from the speaker and are not to be construed as official views of NIST.

1. Intro NIST standards
2. Update on the NIST Threshold Cryptography project
3. Some thoughts on standardization
4. Concluding remarks

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- ▶ **Non-regulatory** federal agency (within the U.S. Department of Commerce)
- ▶ **Mission:** ... innovation ... industrial competitiveness ... measurement science, standards, and technology ... economic security ... quality of life.



Aerial photo of Gaithersburg campus (source: Google Maps, August 2010)

NIST: Laboratories → Divisions → Groups



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→ Computer Security Division (**CSD**):

- **Cryptographic Technology Group (CTG)**: research, develop, engineer, and produce guidelines, recommendations and best practices for cryptographic algorithms, methods, and protocols.
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- ▶ Documents: FIPS, SP 800, NISTIR.
- ▶ International cooperation: government, industry, academia, standardization bodies.

Legend: FIPS = Federal Information Processing Standards; SP 800 = Special Publications in Computer Security; NISTIR = NIST Internal or Interagency Report.

Some examples:

- ▶ FIPS 186-5 (draft): RSA, ECDSA and EdDSA signatures
- ▶ FIPS 197: AES (block cipher)
- ▶ SP 800-56A/B: primitives for DLC/IFC pair-wise key agreement
- ▶ SP 800-90 series: DRBGs

Legend: AES (Advanced Encryption Standard); DLC: Discrete-Log Cryptography; DRBG (Deterministic Random Bit Generator); ECDSA (Elliptic Curve Digital Signature Algorithm); EdDSA (Edwards Curve Digital Signature Algorithm); IFC: Integer Factorization Cryptography; RSA (Rivest–Shamir–Adleman).

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Some guidance on Cryptography Standards:

- ▶ NISTIR 7977 (2016): NIST Cryptographic Standards and Guidelines Development Process
Formalizes several **principles** to follow: transparency, openness, balance, integrity, technical merit, usability, global acceptability, continuous improvement, innovation and intellectual property (and overarching considerations)
- ▶ SP 800-175: Guideline for Using Cryptographic Standards in the Federal Government
- ▶ FIPS 140-3: Security Requirements for Cryptographic Modules

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- ▶ Internal or interagency developed techniques
- ▶ Adoption of external standards
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- ▶ **Post-quantum Cryptography:** signatures, public-key encryption, key encapsulation
- ▶ **Lightweight Cryptography:** ciphers, authenticated encryption, hash functions
- ▶ **Threshold Cryptography:** threshold schemes for cryptographic primitives
- ▶ ... NIST also has projects for research (e.g., [Circuit Complexity](#)) and applications (e.g., [Randomness Beacon](#))

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This presentation: Threshold Cryptography project → “Multi-Party” track

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Crypto can be affected by vulnerabilities

- ▶ Attacks can exploit differences between ideal vs. real **implementations**
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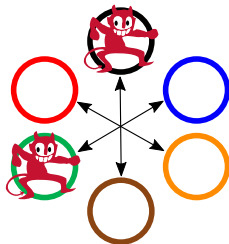


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The threshold approach



The red dancing devil is from
ctker.com/clipart-13643.html

At a high-level:

use redundancy & diversity
to mitigate the *compromise*
of up to a threshold number
(*f*-out-of-*n*) of components

A depiction of multi-party threshold decryption



- ▶ **Setup:** The decryption key is *secret shared* across 3 parties
- ▶ **Goal:** decrypt a ciphertext in a threshold manner
- ▶ **Interaction:** The parties may collaborate, but the *sub-keys* remain secret
- ▶ **Result:** The combined outputs derive the decrypted plaintext

Small adaptation from the [original](#) from N. Hanacek/NIST.

The Threshold Cryptography Project at NIST



Scope: standardization of threshold schemes for cryptographic primitives

<https://csrc.nist.gov/Projects/Threshold-Cryptography/>

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Steps:


1. March 2019: [NISTIR 8214](#): Threshold Schemes for Cryptographic Primitives: Challenges and Opportunities in Standardization and Validation of Threshold Cryptography
2. March 2019: [NTCW 2019](#): NIST Threshold Cryptography Workshop 2019
3. July 2020: [NISTIR 8214A](#): NIST Roadmap Toward Criteria for Threshold Schemes for Cryptographic Primitives
4. November 2020: [MPTS 2020](#): NIST Workshop on Multi-Party Threshold Schemes


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Characterizing threshold schemes

To reflect on a threshold scheme, start by characterizing **4 main features**:

- Kinds of threshold 


- Communication interfaces 


- Executing platform 


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The cliparts are from openclipart.org/detail/*, with $*$ \in {71491, 190624, 101407, 161401, 161389}

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


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Each feature spans distinct options that affect security in different ways.

A characterization provides a better context for security assertions.

NISTIR 8214A

NIST Roadmap Toward Criteria for Threshold Schemes for Cryptographic Primitives

Luis T. A. N. Brandão
Michael Davidson
Apostol Vassilev

This publication is available free of charge from:
<https://doi.org/10.6028/NISTIR.8214A>

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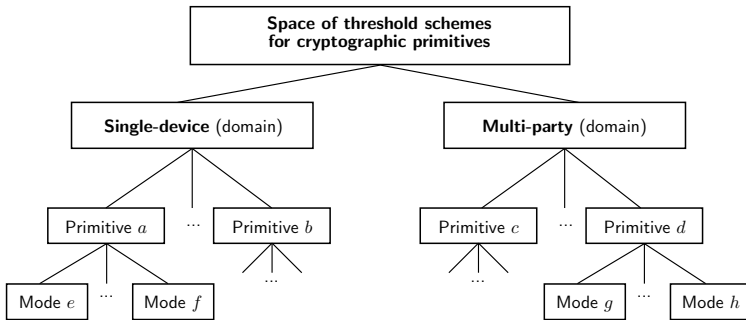
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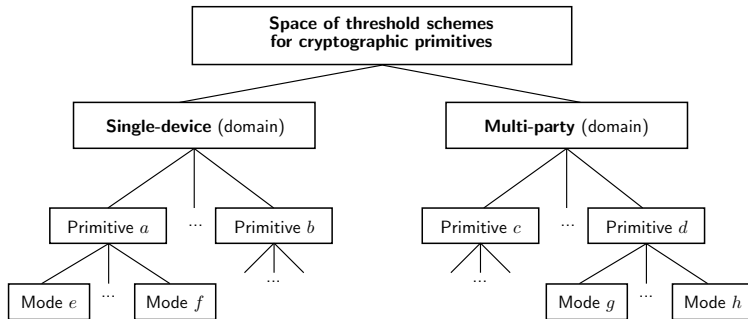
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1. **Coordinates** (domains, primitives, modes, features)
2. **Features** (security, configurability, validation, modularity)
3. **Phases** (of the development process)
4. **Collaboration** (need feedback from stakeholders)

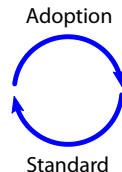
Mapping the space of potential “schemes”



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- ▶ *“Not every conceivable possibility is suitable for standardization”*
- ▶ *“Need to focus on where there is a high need and high potential for adoption”*
- ▶ *Best practices; minimum defaults; interoperability; innovation.*



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- ▶ Simpler thresholdization: RSA signing/decryption, ECC key-gen, ECC-CDH primitive.
- ▶ More complex thresholdization: RSA key-gen, ECDSA signing, EdDSA signing, AES.

Legend of acronyms: AES (Advanced Encryption Standard); Cofactor Diffie-Hellman (CDH); ECC (Elliptic Curve Cryptography); ECDSA (Elliptic Curve Digital Signature Algorithm); EdDSA (Edwards Curve Digital Signature Algorithm); Keygen (key generation); RSA (Rivest-Shamir-Adleman).

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Interchangeability. (A useful notion) Informally, the conventional primitive can be replaced by the threshold version of it, with respect to some subsequent operation, e.g., a threshold signature being verifiable by the conventional verification algorithm, even if not fully equivalent.

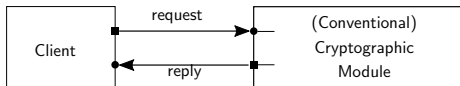
Threshold interface modes (in the perspective of the client)



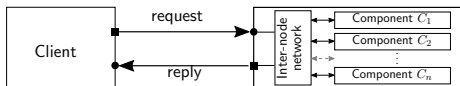
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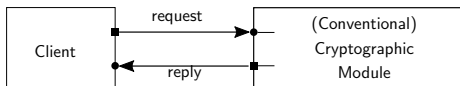
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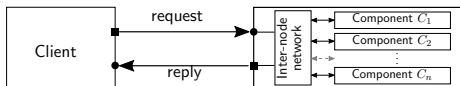
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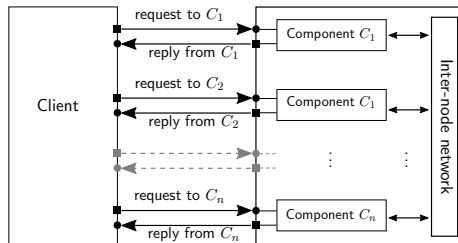
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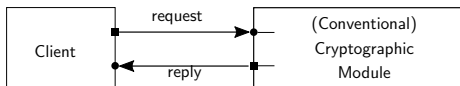
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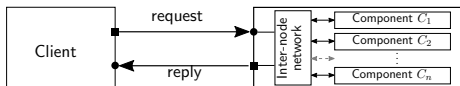
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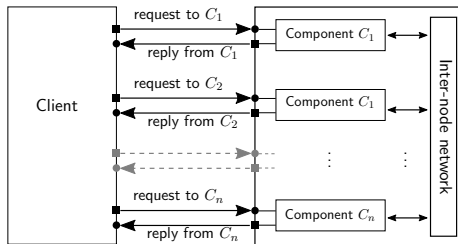
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Shared-I/O

- ▶ **Example:** Shared-Output may enhance secrecy of the output of a decryption process.
- ▶ **Auditability:** can the client prove (or be convinced) the operation was thresholdized?

* **Other modes:** In Shared-I and Shared-O, only the input and only the output are shared, respectively.

A sequence of phases:

1. **Devise criteria for standardization***
2. **Calls for contributions**
3. **Evaluation of threshold schemes**
4. **Publish standards***

*** Note:** The use of “Standards” and “Standardization” does not intend to imply FIPS. Final formats may, for example, include Recommendations and Guidelines (e.g., SP 800), reference definitions, ...

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Each phase is open to public feedback.

Upcoming: NIST Workshop on
Multi-Party Threshold Schemes
(MPTS2020, November 4–6)

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- ▶ **Goal:** Collect feedback for the multi-party track of the TC project.
- ▶ **How:** Invited *talks* (~20 min each) + Q&A; and submitted *briefs* (≤ 5 min).
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For questions or comments related to the workshop, please send an email to workshop-MPTS-2020@nist.gov.

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Important dates:

- ▶ August 16: Start of online registration: <https://csrc.nist.gov/events/2020/mpts2020>
- ▶ September 30: Deadline for early registration (free)
- ▶ September 30: *briefs* submission (title + short abstract)
- ▶ October 28: late registration (conditions TBA)

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1. configurability (threshold numbers, rejuvenation of components, ...);
2. practical feasibility (computational complexity, setup instantiation, ...);
3. security models (ideal functionalities, game-based definitions, ...);
4. security properties (e.g., termination options, breakdown after threshold, ...);
5. gadgets and modularity;
6. validation suitability.

(For more suggestions, see [NISTIR 8214A](#), Sections 2.1–2.5, 5, 6.1 and 7.2)

Some other relevant aspects (from Section 6.1 of [NISTIR 8214A](#)):

1. Definition of system model and threat model
2. Description of characterizing features
3. Analysis of efficiency and practical feasibility
4. Existence of open-source reference implementations
5. Concrete benchmarking (threshold vs. conventional; different platforms)
6. Detailed description of operations
7. Example application scenarios
8. Security analysis
9. Automated testing and validation of implementations
10. Disclosure and licensing of intellectual property

We welcome feedback on any of these items.

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- ▶ Protocols (with distributed systems) instead of single-side primitives?
- ▶ Many paradigms/options to choose from?
- ▶ Complex techniques/assumptions not previously standardized/scrutinized?
- ▶ Uncertainty of adoption or what approach to take?

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Moving toward standardization of Adv.Crypto can anyway benefit from preliminary work:

- ▶ Development of collaborative reference material (e.g., see ZKProof)
- ▶ Deployment of application use-cases, attesting feasibility and enabling benchmarking
- ▶ Promote improved “best practices” and interoperability

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For example, the process includes deciding:

- ▶ how to call for (which types of) contributions;
- ▶ what criteria to use to search for and to select items for standardization.

Humans are in the equation



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- ▶ Scrutinize the complex techniques being specified
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Also beware:

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- ▶ Standardization timelines should allow proper time for public scrutiny and feedback.

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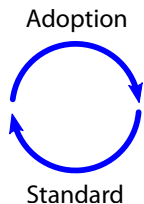
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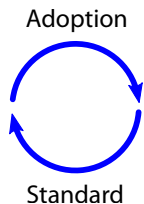
The end game: achieve trustworthy & trusted, globally accepted, adopted ... good standards

Standardization vs. adoption

What makes a standard *good*? A well-done specification ... and the context.



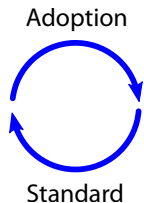
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A good standard can be a reference for:

- ▶ *best practices* and *minimum defaults*;
- ▶ *interoperability*;
- ▶ validation and certification;
- ▶ what to innovate upon.

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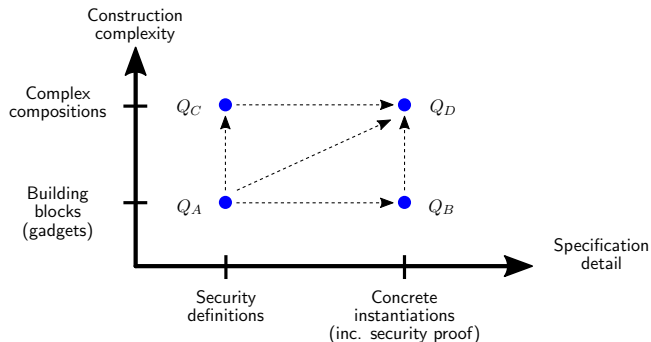
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If/when compliance is required, a standard can be bad if the technique:

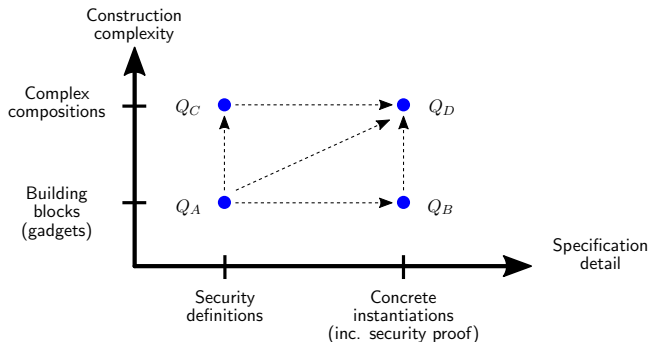
- ▶ is obsolete / outdated, or cannot be corrected / withdrawn / replaced (when it should);
- ▶ does not lend itself to suitable validation mechanisms.

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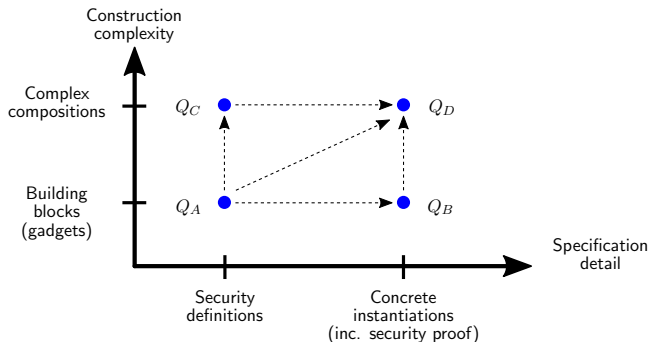
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Each has a place in the process, e.g.:

- Q_D as a goal;
- Q_C as a criterion;
- Q_B as a module;
- Q_A as a reference definition.

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Example gadgets:

- ▶ secret-sharing
- ▶ distributed/correlated RNG
- ▶ garbled circuits
- ▶ oblivious transfer
- ▶ commitments ...

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3. Not everything should be standardized, but some things should (enable security and interoperability, improve best practices).
4. Official standardization can be preceded by valuable phases (e.g., develop reference material, ...)
5. The development process matters, and it affects the end result of standardization
Collaboration between stakeholders is essential for a good result.

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6. MPTS 2020 (November 4–6): consider contributing with your point of view.
7. It's an exciting time to collaborate toward new standards!

**Which of today's developing standards will remain,
70 years from now, as building blocks of advanced crypto?**

The test of time

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Photo in 1948 *

Photo in 2018: https://www.nist.gov/sites/default/files/documents/2018/06/15/nist_gaithersburg_master_plan_may_7_2018.pdf

Thank you for your attention



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2nd Workshop on **A**dvanced **C**ryptography **A**pplications and **S**tandards

Feedback is appreciated

luis.brandao@nist.gov

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- 1 Cover (Toward Criteria ...)
- 2 Outline
- 3 NIST
- 4 NIST standardizes cryptographic primitives
- 5 Development of new standards
- 6 Outline
- 7 Why going for a threshold approach?
- 8 A depiction of multi-party threshold decryption
- 9 The Threshold Cryptography Project at NIST
- 10 Characterizing threshold schemes
- 11 NISTIR 8214A: A roadmap toward criteria
- 12 Mapping the space of potential “schemes”
- 13 Multi-Party track
- 14 Threshold interface modes
(in the perspective of the client)
- 15 Development process
- 16 NIST Workshop on Multi-Party Threshold Schemes
- 17 Some topics of expected feedback
- 18 (To read offline) More topics toward defining **criteria**
- 19 Outline
- 20 What is “advanced cryptography”?
- 21 Standardization endeavors as processes
- 22 Humans are in the equation
- 23 Standardization vs. adoption
- 24 Modularity and composability
- 25 Outline
- 26 Concluding remarks
- 27 The test of time
- 28 Thank you for your attention
- 28 List of Frames

List of Frames