Cryptographic Sponges

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Outline

- Introduction
- Definitions
- Uses Examples
- Attacking sponges
- Indifferentiability
- Random sponge as a reference
- Constructing a sponge function
- Conclusion

Introduction

- Sponge functions model
  - the **finite state** of iterated cryptographic functions
    - as in iterated hash functions, stream ciphers, etc.
- Random sponges can be used
  - as a reference for (hash function) design
  - as an inspiration for (hash function) design
- Sponges are **simple**

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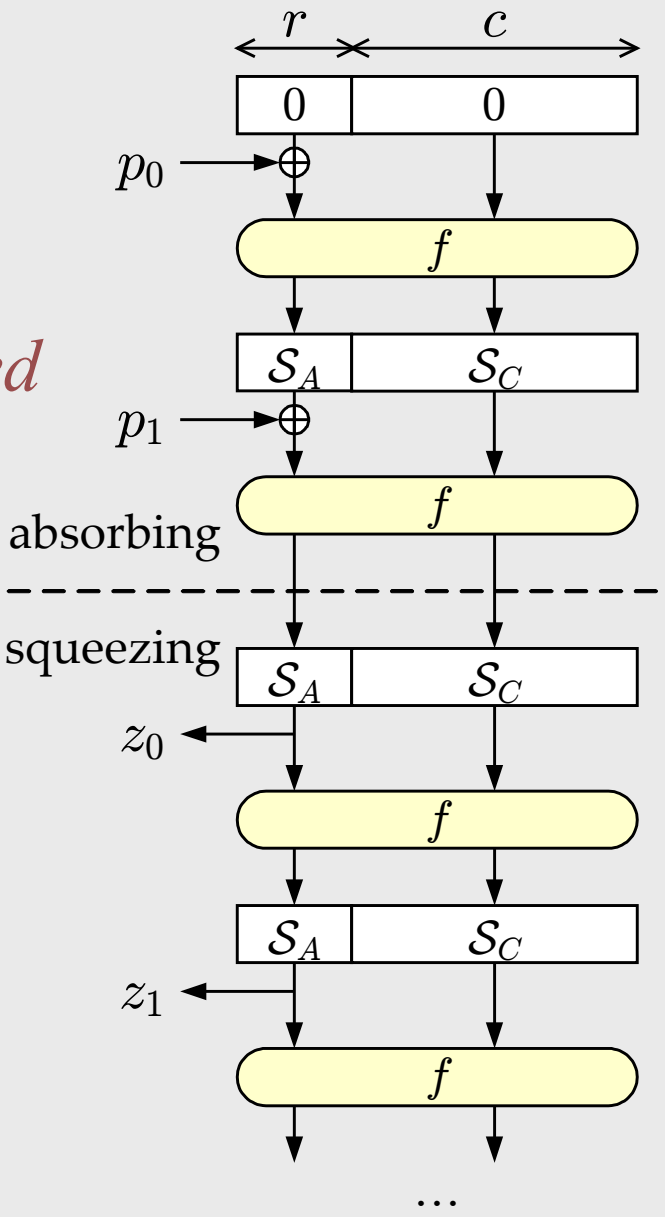
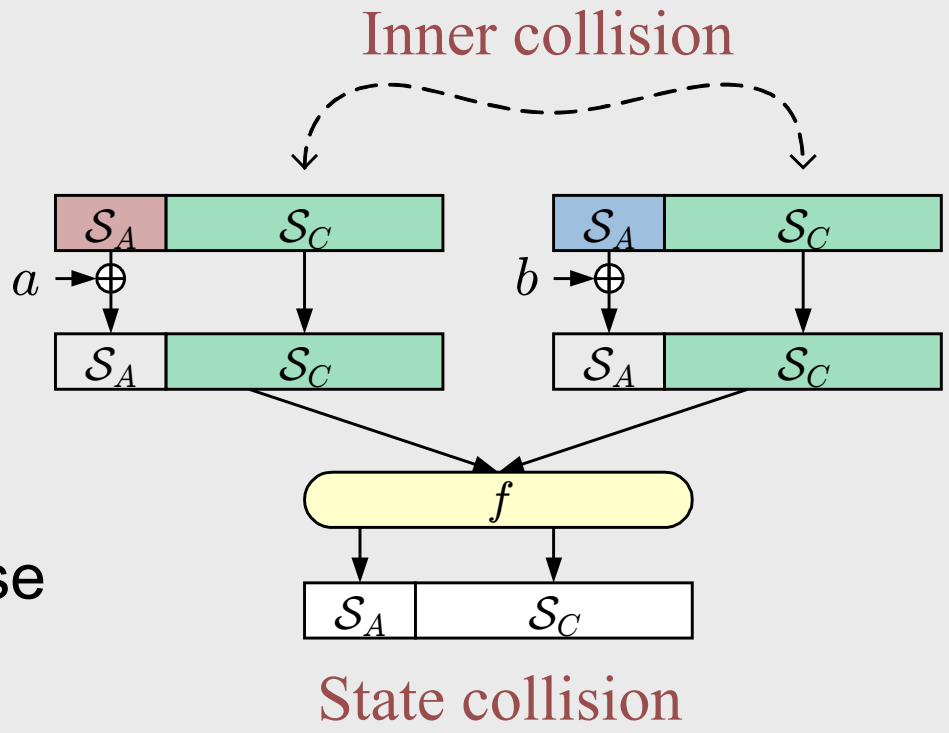
Sponge Construction

The last block absorbed shall not be zero.



Inner Collisions, State Collisions



- State collision
  - Absorbing phase
    - Hash collision
  - Squeezing phase
    - Output periodicity

Random Sponges

- Random **T**-sponge
  - Randomly chosen in $(2^{c+r})^{2^{c+r}}$ **transformations** f
- Random **P**-sponge
  - Randomly chosen in $(2^{c+r})!$ **permutations** f

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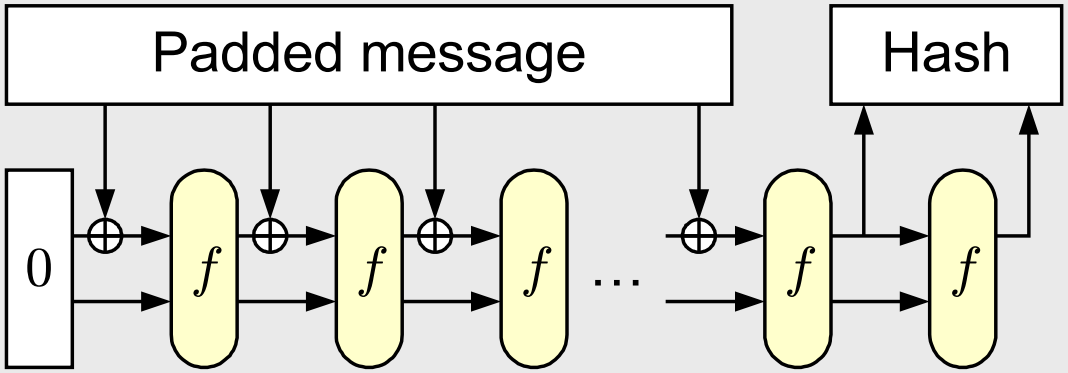
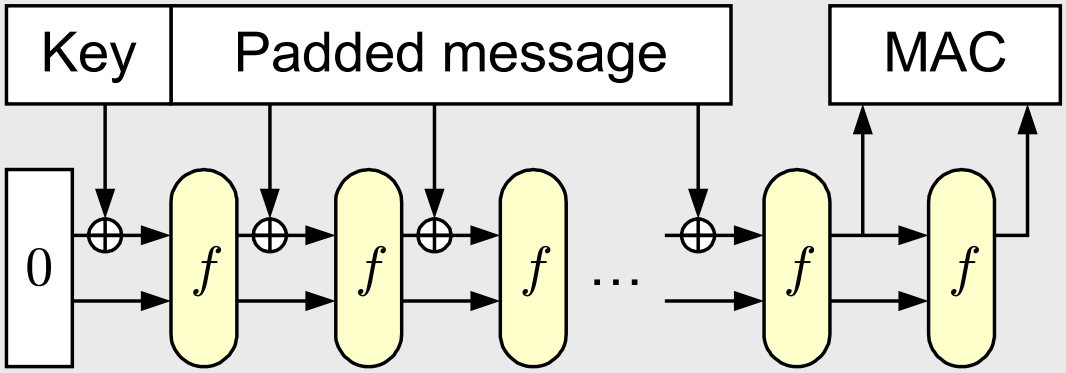
Uses Examples (1/5)

- Hash function



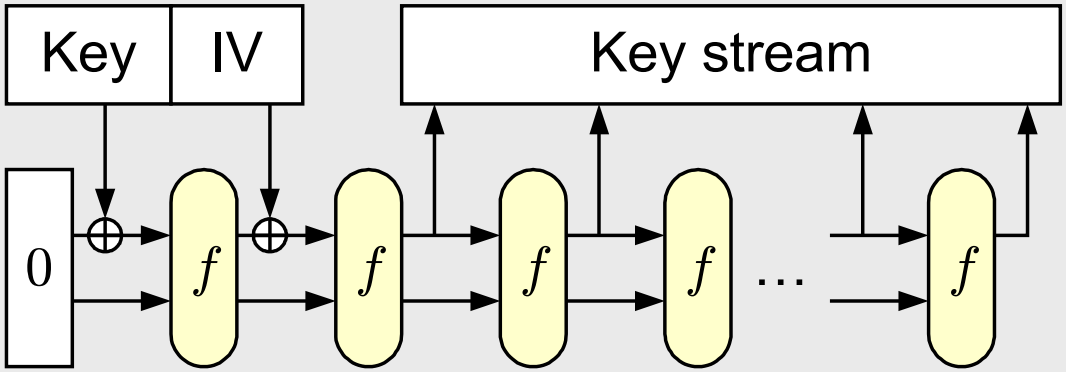
Uses Examples (2/5)

- Message authentication code



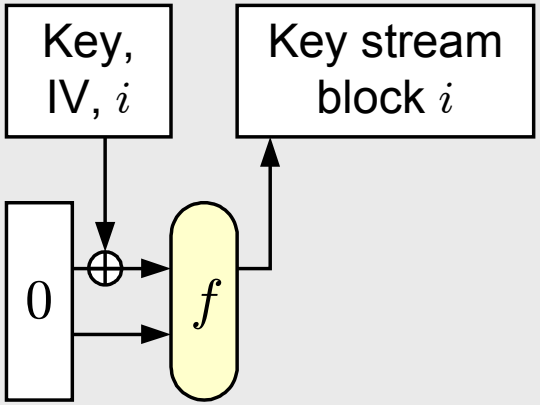
Uses Examples (3/5)

- Stream cipher



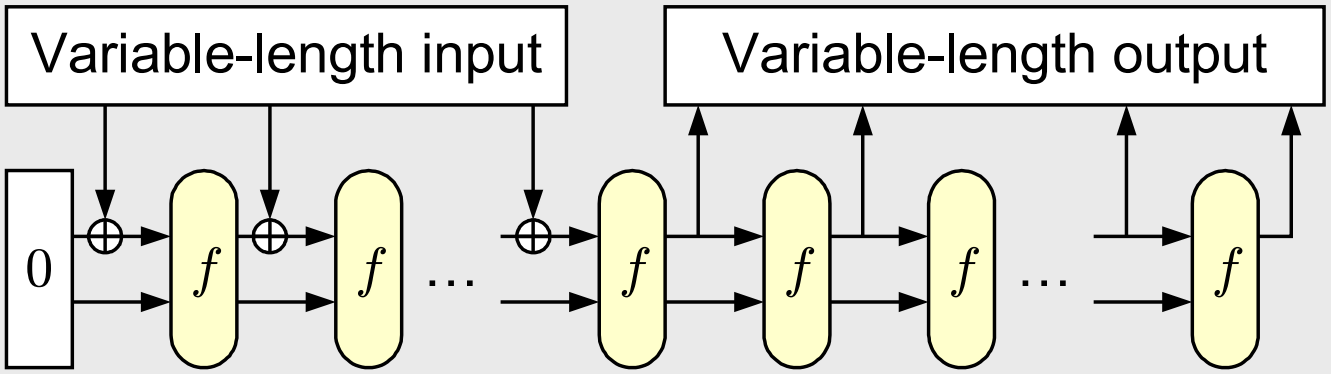
Uses Examples (4/5)

- Random-access stream cipher



Uses Examples (5/5)

- Mask generating functions, key derivation



- See PKCS#1 and IEEE Std 1363a

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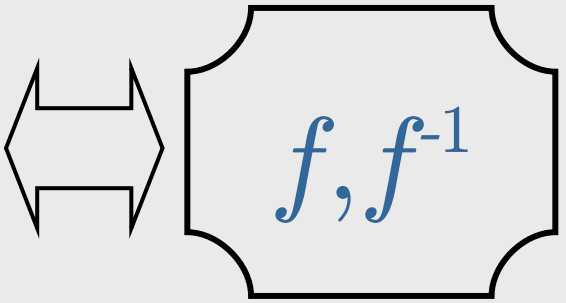
Distinguishing Random Sponges

- Adversary queries a **black box**, either RS or RO
  - Budget of N input and output blocks
- **Theorem:** A random sponge can only be distinguished from a random oracle by the presence of **inner collisions**.
  - When $N \ll 2^{c/2}$, inner collisions are unlikely

Attacking Random Sponges

- **White box** access to f (and f^{-1})
  - Budget of N function calls
- Expected workload for operations:
  - Producing inner collision
  - Finding a path to inner state
  - Producing output cycles
  - Binding an output string to a state
- **Upper bounds** for attacks:
  - Output collision
  - (Second) pre-image
  - Length extension



The expected workload is a function of: capacity c*, P/T-sponge, bitrate* r*.*

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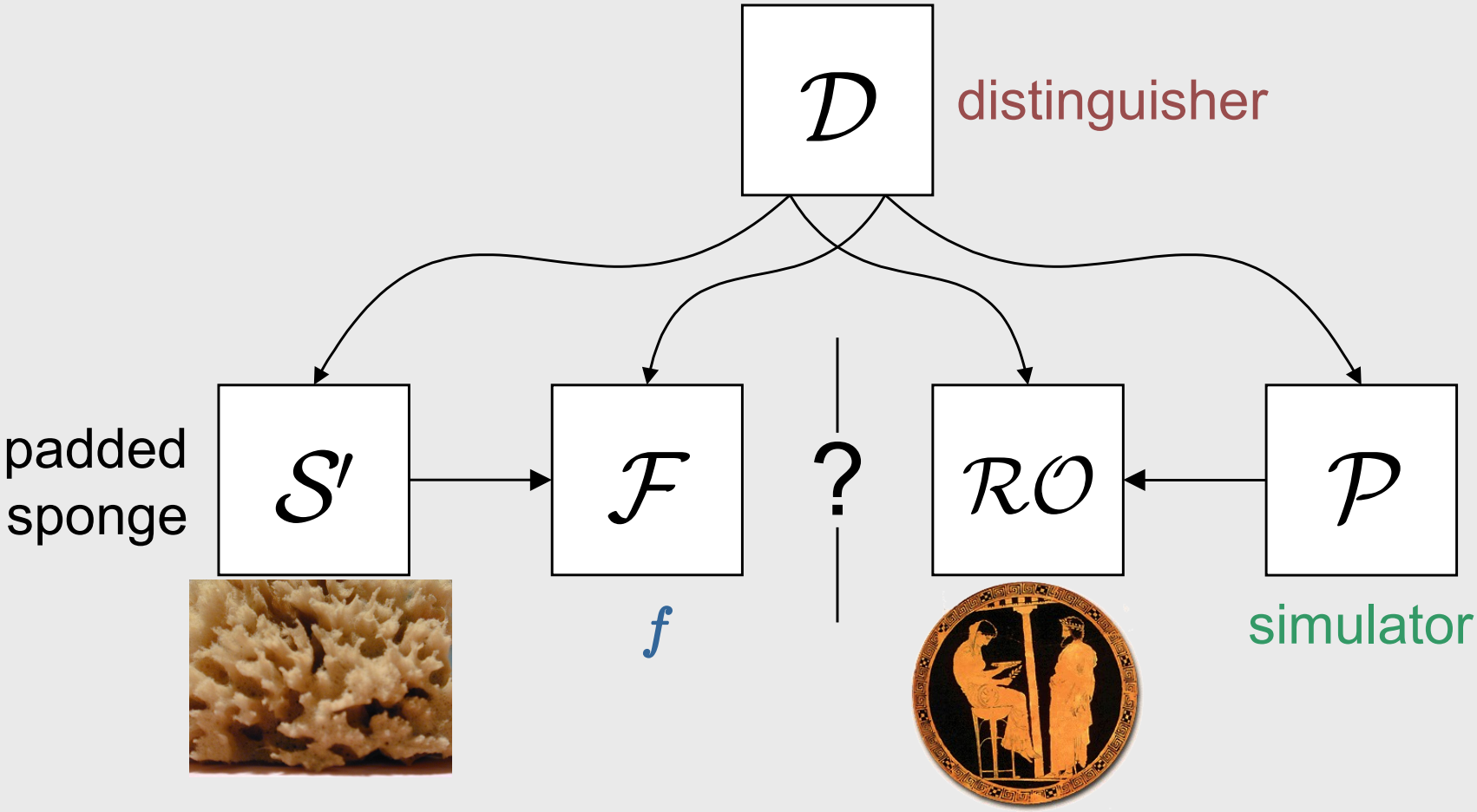
Indifferentiability Framework

- Goal: obtain **lower bound** on generic attacks
- Distinguisher has to differentiate between:
  - the ideal system (Random Oracle), and
  - the construction (here, the Sponge),
  - **with access** to publicly-known function or parameter (here, the transformation f)
- If indifferentiable
  - cryptosystem using construction as strong as cryptosystem using ideal system
- Maurer et al., TCC 2004; Coron et al., CRYPTO 2005

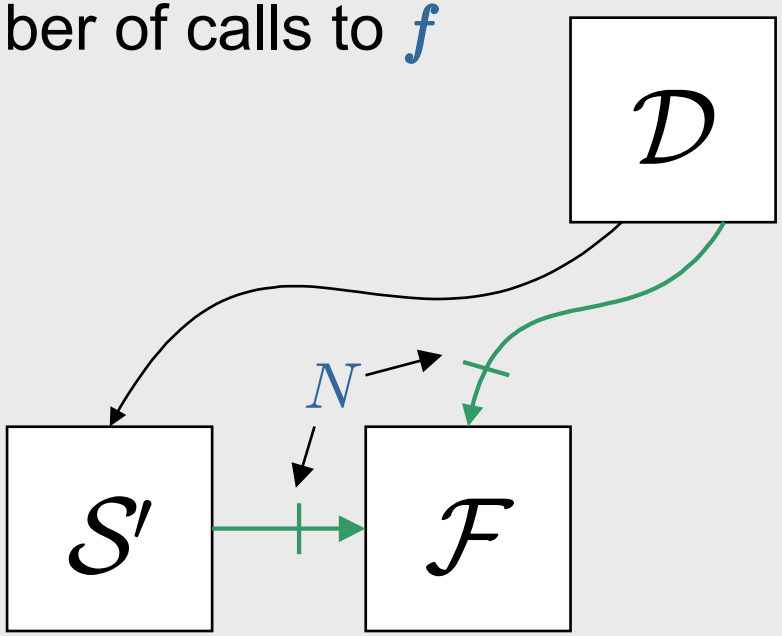
Differentiating Random Sponges



Differentiating Random Sponges

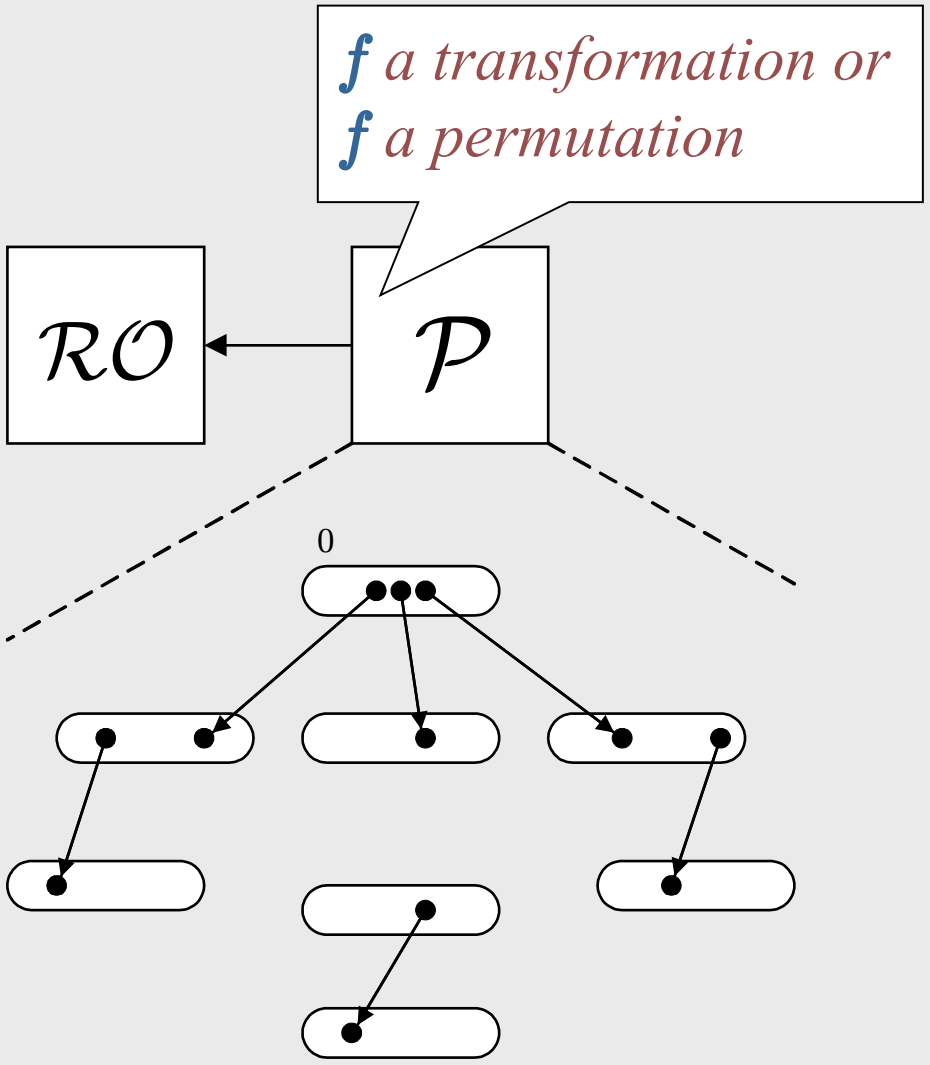
- **Theorem:** a random sponge can be differentiated from a random oracle only with probability $\approx N(N+1)/2^{c+1}$, with $N<2^c$.
  - Here N is the **total** number of calls to f

Generic attacks require $2^{c/2}$.



Proving the Indifferentiability

- Simulating f
  - Keeps memory of (input, output) pairs in a graph
- Properties
  - **Sponge-consistence** with what RO says
  - Similar **output distribution**
- Can be differentiated
  - By different distribution of simulator and random f



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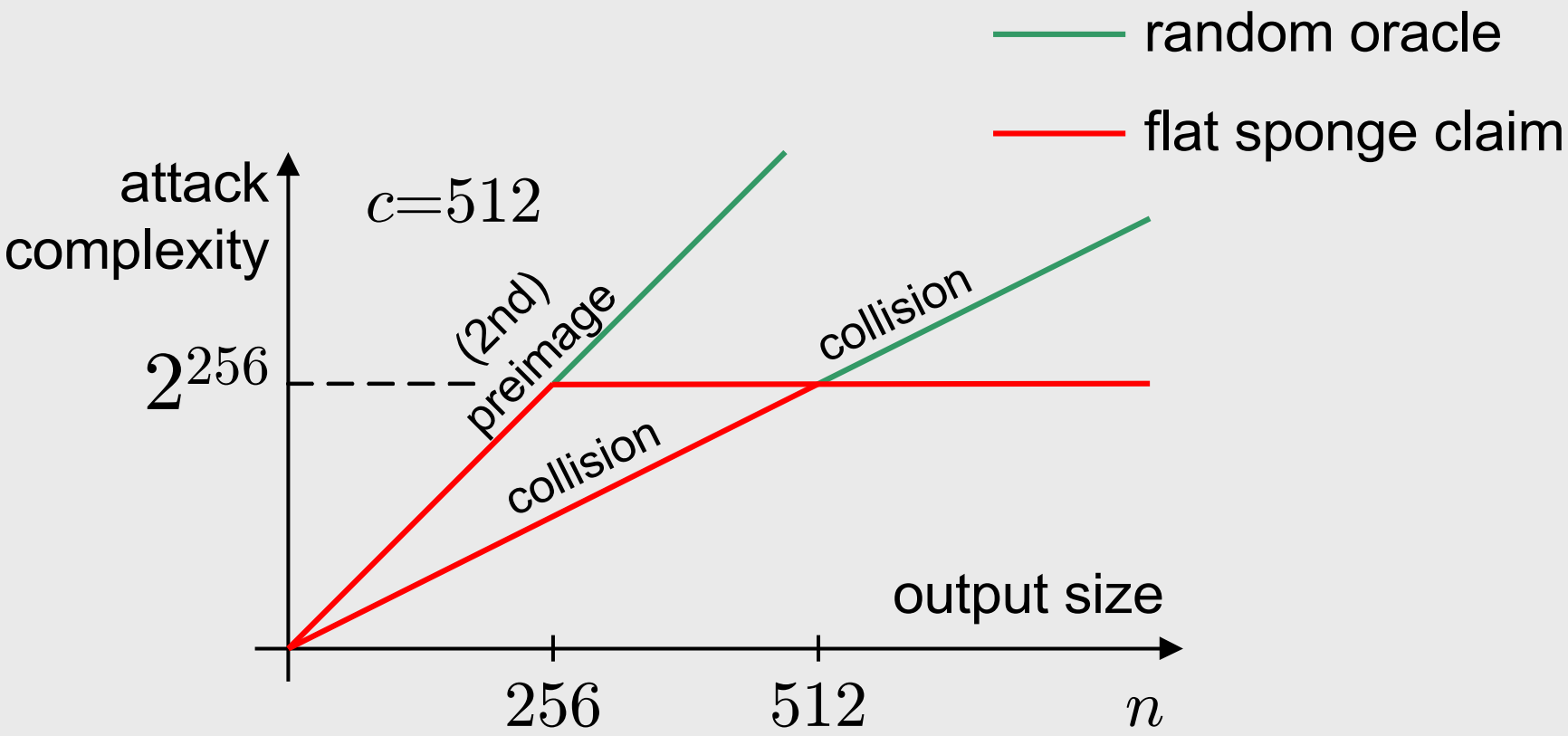
Random Sponge as a Reference

- Reference for concrete designs
  - External interface (input / output) only
- Automatically determines the complexity of attacks
  - Near-collisions, chosen target forced prefix pre-image, …
- Unlike the Random Oracle:
  - State collisions are modeled
- Parameters
  - Capacity c, T/P-sponge, bitrate r
  - Input/output size limitations

Flat Sponge Claim

- Expected workload: $\min(\text{Random Oracle}, 2^{c/2})$



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Constructing a Sponge Function

- Choose c, r
  - No generic attacks below $2^{c/2}$
  - Transformation or permutation over $c+r$ bits
- Construct a *random*(!) transformation?
- Construct a *random*(!) permutation!
  - It shall not have any special properties(!)
    - except its compact description
  - Other constructions build upon permutations: see also Snefru, FFT-Hash, SMASH, …

Advantages of the Sponge Construction

- Relative simplicity in design
  - Permutation similar to block cipher design
    - E.g., block cipher without key schedule
- Flexibility
  - One permutation can accommodate for several (c,r) pairs
- Simplicity
  - Simple model, simple proofs
  - Suitable for many applications
  - Variable-length output

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Conclusion

- Sponges are a simple model
  - to model the finite state of iterated primitives
- Sponges are a simple tool
  - for expressing compact security claims
  - for building hash functions and stream ciphers
- Sponges are fun!

Thank you for your attention!

References

- Bertoni et al., *Sponge Functions*, Ecrypt Hash Workshop 2007, May 2007; also as a public comment to NIST, http://www.csrc.nist.gov/pki/HashWorkshop/Public_Comments/2007_May.html
- Bertoni et al., *On the Indifferentiability of the Sponge Construction*, Eurocrypt 2008, to appear
- Web page under construction: http://sponge.noekeon.org/
  - It should appear end of January 2008