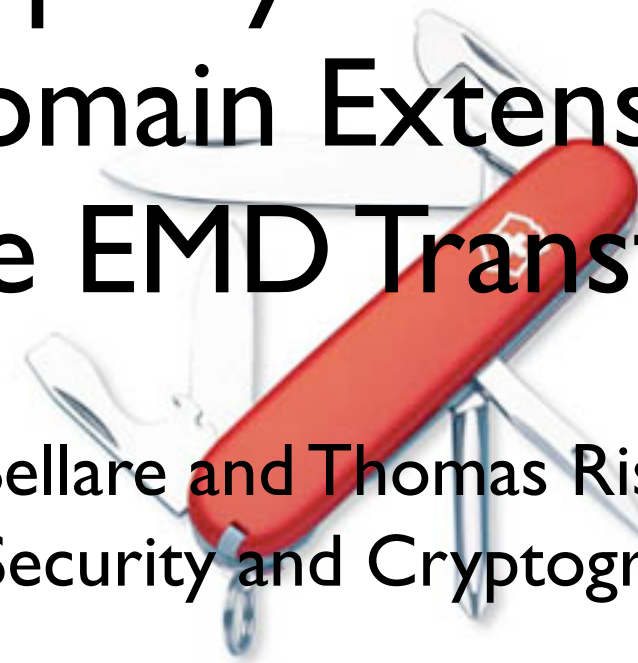
Multi-Property-Preserving Hash Domain Extension: The EMD Transform



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Expanding utility of hash functions

In the beginning, hash functions were designed for use in [Riv90]

digital signature schemes...

then used heuristically to [BeR93]

instantiate random oracles...

and hash functions were keyed to build [BCK96,Be06]

message authentication codes...

and now-a-days get used for

numerous disparate applications.

Hash functions are *used* like "Swiss Army Knives"

Whether hash function designers like it or not, hash functions are (and will continue to be) used in numerous different ways.

So what should hash function designers do?

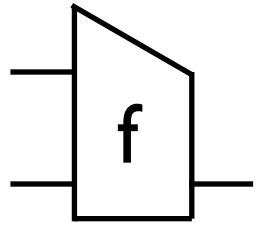
Design hash functions to be **like** "Swiss Army Knives"

The goal:

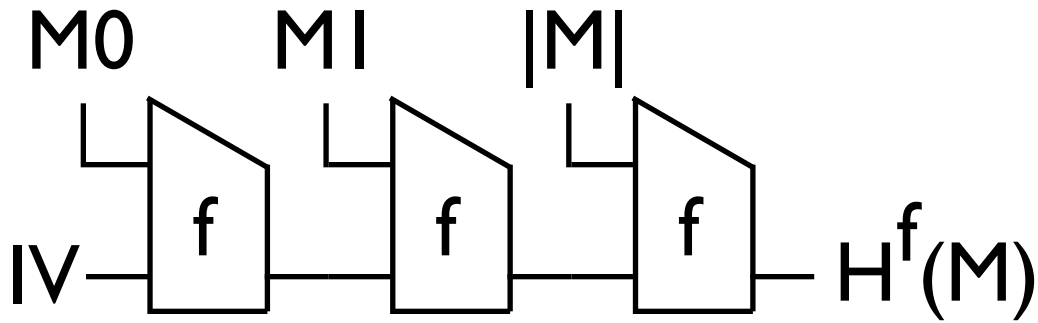
Build hash functions to be secure for **as many applications as possible**

Current design paradigm insufficient

1) Compression function



2) Compression function is iterated using MD w/ strengthening



All in-use hash functions use MD w/str. because:

$$f \text{ is } \mathbf{CR} \Rightarrow H^f \text{ is } \mathbf{CR}$$

But **CR** does not support usage for many settings!

Building stronger hash functions

- Point out limitations of a natural approach for designing strong hash functions, due to [CDMP05]
- Introduce a new design approach which utilizes **multi-property-preserving** (MPP) transforms
- Describe a provably-secure MPP transform, EMD, which can be used to build "Swiss Army Knives"

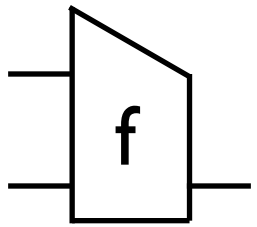
Before

After

A newer approach

[CDMP05] introduced new design paradigm for hash functions:

1) Assume compression function is a random oracle (RO)



2) Build domain extension transform H such that:

$$f \approx RO \Rightarrow H^f \approx RO$$

"**PRO**" "**PRO-Pr**"

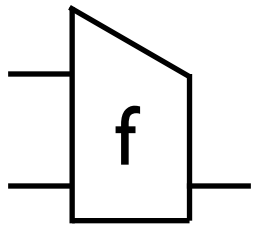
Great benefit: directly supports usage of hash functions for instantiating random oracles by fixing a previously-existing gap

4 transforms: [CDMP05] give transforms to enable this approach

A newer approach

[CDMP05] introduced new design paradigm for hash functions:

1) Assume compression function is a random oracle (RO)



2) Build domain extension transform H such that:

$$f \approx RO \Rightarrow H^f \approx RO$$

"**PRO**"

"**PRO-Pr**"

Behaving like a RO seems very strong...
is this all we need to build "Swiss Army Knives"?

No, security guarantees **worse** for most applications!

Limitations of PRO-Pr approach

PRO-Pr approach

$f \approx RO \Rightarrow H^f \approx RO$

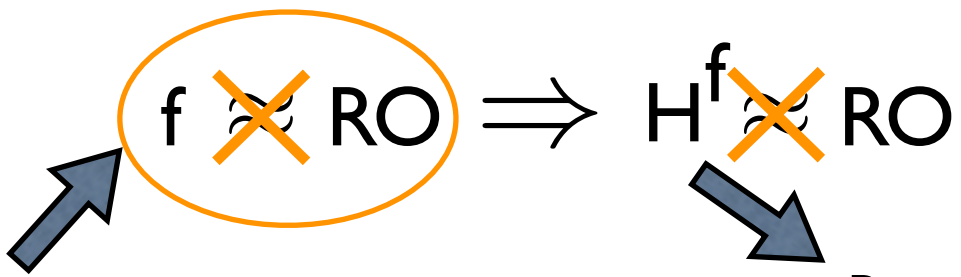
Resulting hash function is trivially **CR**, easily keyed to become **PRF**, etc....

PRO-Pr approach great for building hash functions to use for instantiating RO's

What about other settings?

Limitations of PRO-Pr approach

PRO-Pr approach



But: only under assumption that f is a **PRO**, which it is *provably* not! [CGH04]

Resulting hash function is trivially **CR**, easily keyed to become **PRF**, etc....

PRO-Pr, by itself, gives **worse** guarantee for **standard model properties**!

Limitations of PRO-Pr approach

Hash functions built using H that is *only* **PRO-Pr** give **worse** security guarantee than MD w/str

PRO-Pr approach

$f \approx RO \Rightarrow H^f \approx RO$

But: only under assumption that f is a **PRO**, which it is *provably* not! [CGH04]

Resulting hash function is trivially **CR**, easily keyed to become **PRF**, etc....

compared to...

MD w/str approach

f is **CR** $\Rightarrow$ H^f is **CR**

Limitations of PRO-Pr approach (cont.)

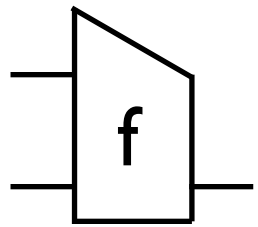
(Free) Translation: the [CDMP05] design approach results in hash functions which have **worse** security guarantees for applications beyond instantiating a RO

In fact: the 4 proposed transforms in [CDMP05] do **not** give guarantees for **CR** and (3 of the them) do **not** give guarantees for being a **PRF** (under standard assumptions)

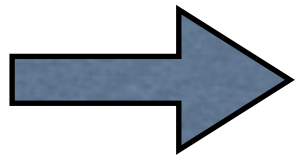
The problem is focusing only on **PRO-Pr**, and not explicitly including more standard preservation goals

Our approach: use MPP transforms

1) Construct compression function that is **CR**, "behaves like a **RO**", and is a good **PRF** (when keyed)



2) Build domain extension transform H such that:



$$f \text{ is } \mathbf{CR} \Rightarrow H^f \text{ is } \mathbf{CR} \quad (\mathbf{CR\text{-}Pr})$$

$$f \approx \mathrm{RO} \Rightarrow H^f \approx \mathrm{RO} \quad (\mathbf{PRO\text{-}Pr})$$

$$f \text{ is a } \mathbf{PRF} \Rightarrow H^f \text{ is a } \mathbf{PRF} \quad (\mathbf{PRF\text{-}Pr})$$

We call H a ***multi-property-preserving*** (MPP)

Note that we include **PRO-Pr**, because it's important for instantiating ROs.

MPP approach results in "Swiss Army Knife"

Build a single hash function H^f via the MPP approach and...

Usage	Assumption on f	Hash function
digital signatures	collision-resistance	H^f
instantiating RO's	"behaves like a RO"	H^f
message authentication, key derivation	PRF	H^f

Minimal set of properties ... perhaps more?

Building an MPP transform

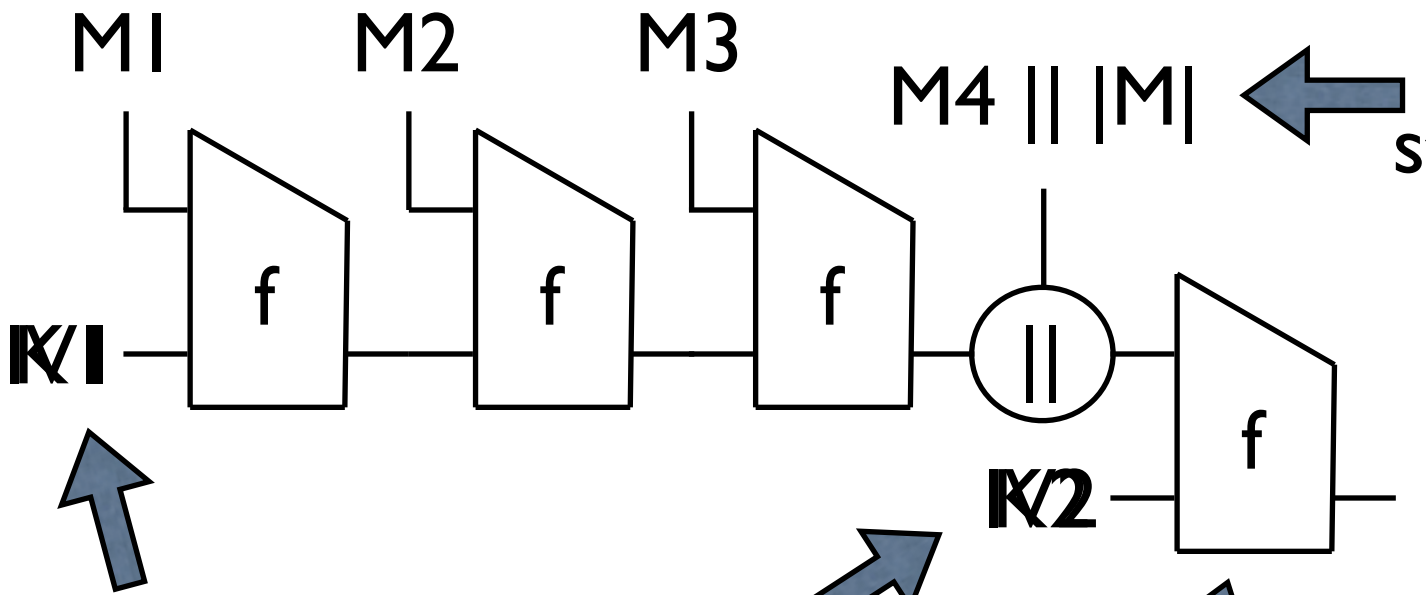
Unfortunately, the [CDMP05] transforms, as specified, are not MPP:

Prefix-free MD: specific prefix-free encodings give **CR-Pr**, and all prefix-free encodings give **PRF-Pr** [BCK96], but has other drawbacks (as described in [CDMP05])

Other 3 transforms: omit strengthening, not **CR-Pr**, and unclear whether **PRF-Pr**

Instead of these...build a new transform that combines techniques for preserving **CR**, **PRO**, and **PRF**

The EMD transform



Similar to NMAC in design

Provably...

CR-Pr **PRO-Pr** **PRF-Pr**

Slightly more efficient than [CDMP05] transforms

Transform	CR-Pr	PRO-Pr	PRF-Pr	Source
Plain MD	✗	✗	✗	[M89,D89]
Strengthened MD	✓	✗	✗	[M89,D89]
Prefix-free	✗	✓	✓	[CDMP05]
Chop solution	✗	✓	?	[CDMP05]
HMAC construction	✗	✓	?	[CDMP05]
NMAC construction	✗	✓	?	[CDMP05]
EMD	✓	✓	✓	[BeRi06]

Summary

- Motivated developing stronger hash functions, with **broader** security goals
- Pointed out insufficiency of [CDMP05] approach for building stronger hash functions
- Proposed the **multi-property-preserving** approach
- Introduced a proven MPP transform, EMD

Before

After

Before

Thank you!

After

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