

SOLUTION OF EXERCISESHEET 8

Exercise 8-1

Lets assume towards contradiction that the MAC construction is not secure \Rightarrow Probability of forging this construction Π_{MAC} is a non negligible function:

$$Pr[MacForge_{A, \Pi_{MAC}} = 1] \leq \epsilon(\lambda)$$

where $\epsilon(\lambda)$ is a non negligible function.

That implies there exists an efficient adversary, A , able to generate a new message and tag pair (m^*, t^*) such that $m^* \notin Q$, and $Ver_k(m^*, t^*) = 1$ with a probability $\epsilon(\lambda)$.

We now consider B attacking the CCA-security. B runs A as subroutine. B only forward all encryption queries that A asks for to his own encryption oracle. Finally A outputs a message-tag-pair m^*, t^* . B then chooses two messages, lets say \widetilde{m}_0 as m^* and \widetilde{m}_1 as any other random message. If B gets the tag t^* as \widetilde{c}_b , it corresponds to $m_0 = m^*$ otherwise it corresponds to random message m_1 . This holds, because $Dec_k(t) = m \Leftrightarrow Enc_k(m) = t$.

B is efficient because it only forwards messages, which are of polynomial length (because A is efficient), chooses a random number and invokes A . Because A can break the MAC with non-negligible probability $\epsilon(\lambda)$ and B uses this in every case, B can break the CCA security also with non-negligible probability $\epsilon(\lambda)$. Because this a contradiction to the CCA security of Π , our assumption that such an adversary A against the collision resistance of Π_{MAC} exists, is false. So Π_{MAC} is a collision resistant MAC.

Exercise 8-2

- (a) Assume H is not collision resistant.

This means finding $x_0 \neq x_1$ so that $H^{s_0||s_1}(x_0) = H^{s_0||s_1}(x_1)$ is non-negl.

$$H^{s_0||s_1}(x_0) = H^{s_0||s_1}(x_1) \Leftrightarrow H_0^{s_0}(H_1^{s_1}(x_0)) = H_0^{s_0}(H_1^{s_1}(x_1))$$

Define $H_1^{s_1}(x_0) = y_0$ and $H_1^{s_1}(x_1) = y_1$.

For $H^{s_0||s_1}(x_0) = H^{s_0||s_1}(x_1)$ to have a collision either $y_0 = y_1 = y$

which makes $H_0^{s_0}(y_0) = H_0^{s_0}(y_1) = H_0^{s_0}(y)$ trivially true because $H_0^{s_0}$ gets the same input

or $H_0^{s_0}(y_0) = H_0^{s_0}(y_1)$ with $y_0 \neq y_1$

If H_0 is collision resistant but H_1 not, then the probability of finding $x_0 \neq x_1$ so that $H_1^{s_1}(x_0) = H_1^{s_1}(x_1) = y$ is non-negl.

Since H_0 gets the same input y in this case the probability for a collision for H is the same as for H_1 and is non-negl.

$\Rightarrow H$ is not collision resistant.

- (b) Assume H is not collision resistant.

This means finding $x_0 \neq x_1$ so that $H^{s_0||s_1}(x_0) = H^{s_0||s_1}(x_1)$ is non-negl.

$$H^{s_0||s_1}(x_0) = H^{s_0||s_1}(x_1) \Leftrightarrow H_0^{s_0}(x_0)||H_1^{s_1}(x_0) = H_0^{s_0}(x_1)||H_1^{s_1}(x_1)$$

We know that at least one H_i $i \in \{0, 1\}$ is collision resistant per definition.

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Assume H_0 is collision resistant but H_1 is not, making finding $x_0 \neq x_1$ so that $H_1^{s_1}(x_0) = H_1^{s_1}(x_1)$ is negl.

If $H_1^{s_1}(m) = c$ with c being a constant value for all m then $H^{s_0||s_1}(m) = H_0^{s_0}(m)||c$

This produces a string with the same collision resistance probability as H_0 since only a constant string c is added at the end.

If H_1 is some other function, the collision probability becomes even smaller since there are even more different strings produceable this way.

Assuming H_1 is collision resistant but H_0 is not, has the same result since it doesn't matter if the collision resistant part is added at first or second.

\Rightarrow contradiction: H can't be non-negl. since it has to have at least the collision resistant probability as the collision resistant H_i $i \in \{0, 1\}$ which is negl.

(c) $H'(m) = H^{c(m)}(r(m))$ with m of the format $0^n 1 || x$ and $c(m) = n$ and $r(m) = x$.

Since H^n is the n -times application of H we can construct the following attack on this Hash function to break the collision resistance:

$H^n(x) = y_0$ as one random example and

$H^1(y_0) = y_1$

We use $x_0 = 0^{n+1} 1 || x$ and $x_1 = 01 || y_0$ since

$H'(x_0) = H^{c(x_0)}(r(x_0)) = H^{n+1}(x) = H^1(H^n(x)) = H^1(y_0) = H^{c(x_1)}(r(x_1)) = H'(x_1)$.

$\Rightarrow H$ is not collision resistant.

Exercise 8-3

Exercise 8-4

To show: $H(m) : \{0, 1\}^{2k} \rightarrow \{0, 1\}^{k+n}$, $H(m) := m_0 || H'(m_1)$ is still a collision-resistant hash function when $m = m_0 || m_1$, $|m_0| = |m_1| = k$ and $k > n$. $H'(m) : \{0, 1\}^* \rightarrow \{0, 1\}^n$ is a collision-resistant hash function.

Proof by contradiction. We assume there is an adversary \mathcal{A} , who can break the collision-resistance of $H(m)$ with non-negligible probability. We now build an adversary \mathcal{B} against the collision-resistance of $H'(m)$ who invokes \mathcal{A} . \mathcal{A} then outputs two messages m^1, m^2 . \mathcal{B} computes his output by truncating the first half of m^1 and m^2 ($m^i = m_0^i || m_1^i, i \in \{1, 2\}$).

\mathcal{B} is an efficient adversary because \mathcal{A} is efficient, so the message length is poly and the call to \mathcal{A} needs only poly time and sampling and prepend m_0 and truncating bit from m^1 and m^2 can also be done in polynomial time.

To analyse the success, we know, that with non-negligible probability \mathcal{A} outputs two messages m^1, m^2 with $m^1 \neq m^2$ and $H(m^1) = H(m^2)$. \mathcal{B} outputs only the second half of m^1 and m^2 which results in m_1^1, m_1^2 . The probability that these are equal is $\left(\frac{1}{2}\right)^n$, because for each position

the probability that the bits are equal is $\frac{1}{2}$. In all other cases \mathcal{B} outputs two messages m_1^1, m_1^2



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with $m_1^1 \neq m_1^2$ and $H'(m_1^1) = H'(m_1^2)$. This holds because $H(m^1) = H(m^2) \Rightarrow H(m_0^1 || m_1^1) = H(m_0^2 || m_1^2) \Rightarrow m_0^1 || H'(m_1^1) = m_0^2 || H'(m_1^2)$.

$$Pr[HashColl_{\mathcal{B}}(\lambda) = 1] = Pr[HashColl_{\mathcal{A}}(\lambda) = 1] - Pr[x'_1 = x'_2] = \text{non-negl.} - \left(\frac{1}{2}\right)^k = \text{non-negl.}$$

Because this is a contradiction to the collision-resistance of $H'(m)$ such an adversary \mathcal{A} cannot exist.

It follows that $H(m)$ is a collision-resistant hash function.