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Unlinkability of an Improved Key Agreement protocol for EMV 2nd Gen Payments

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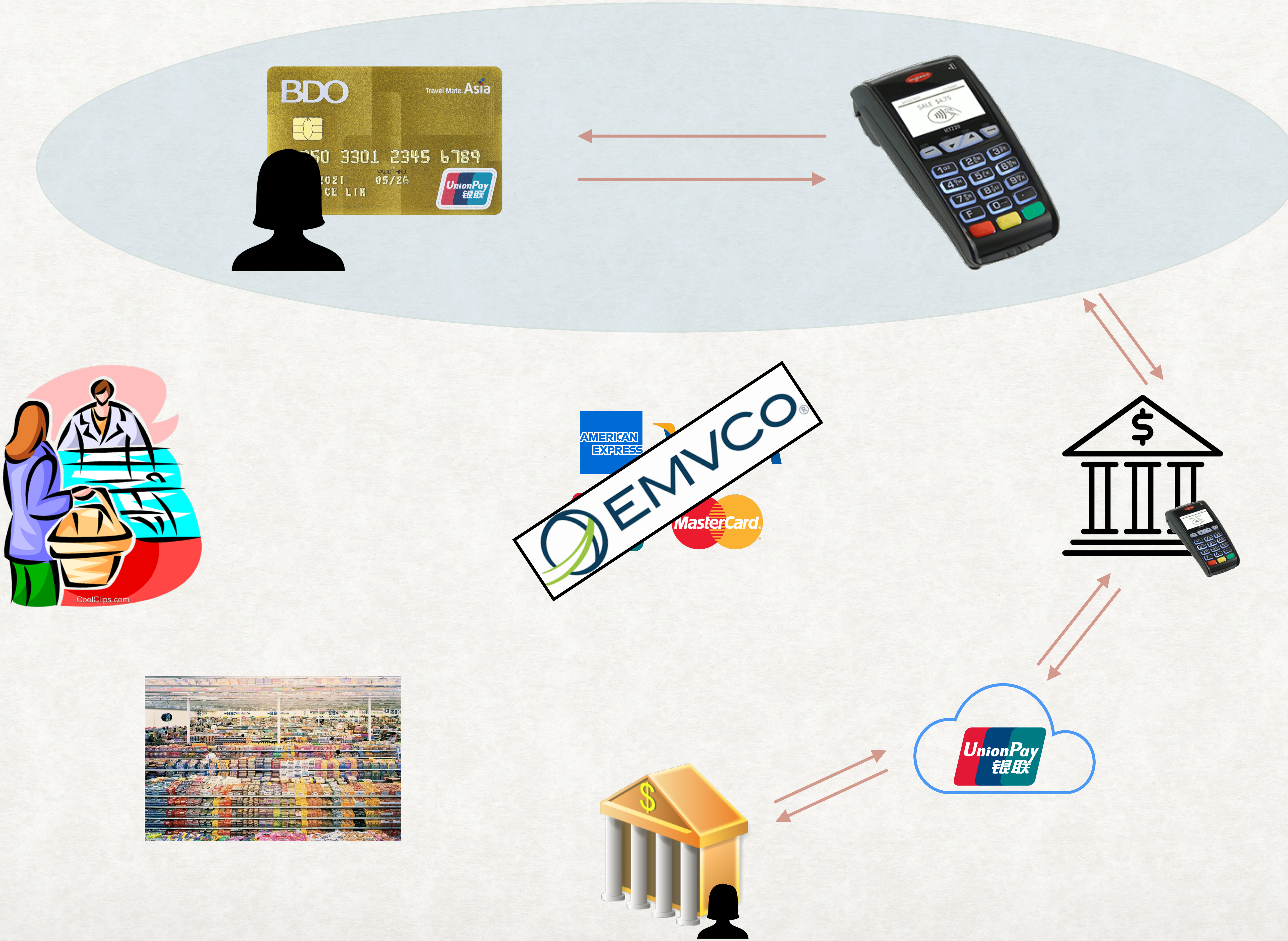
WHAT IS EMV?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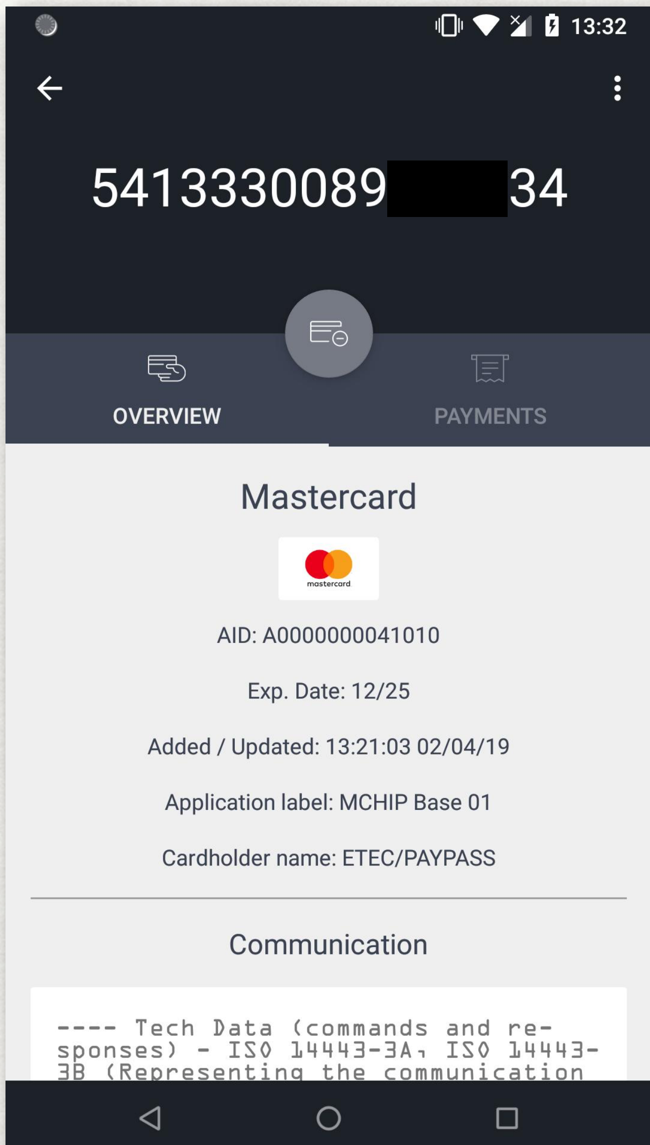
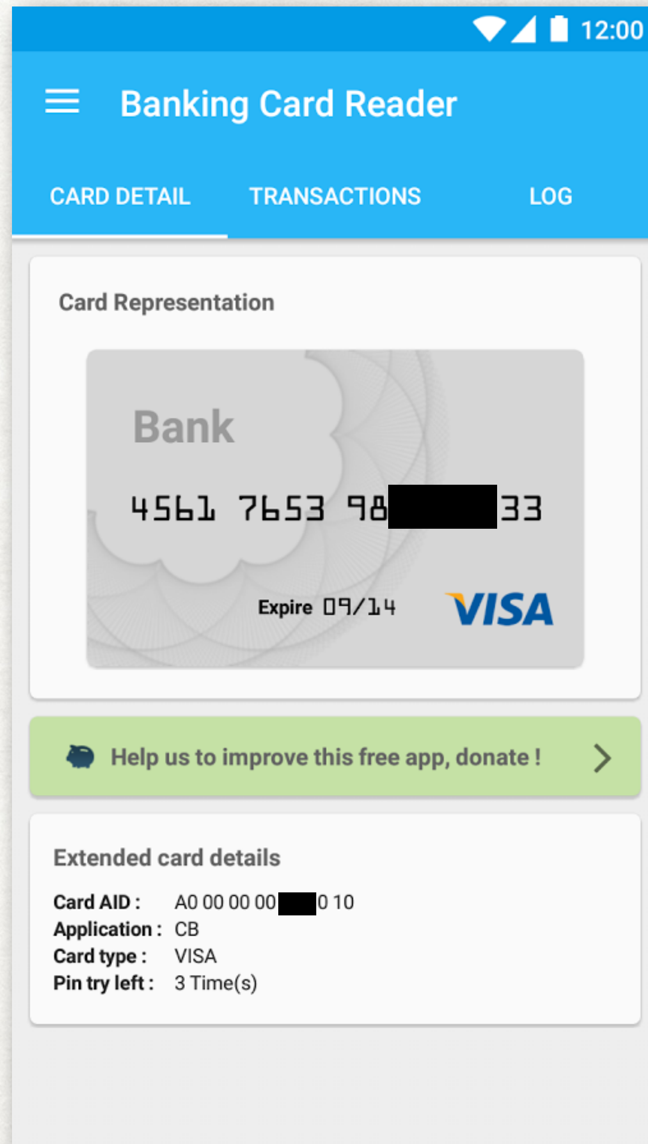
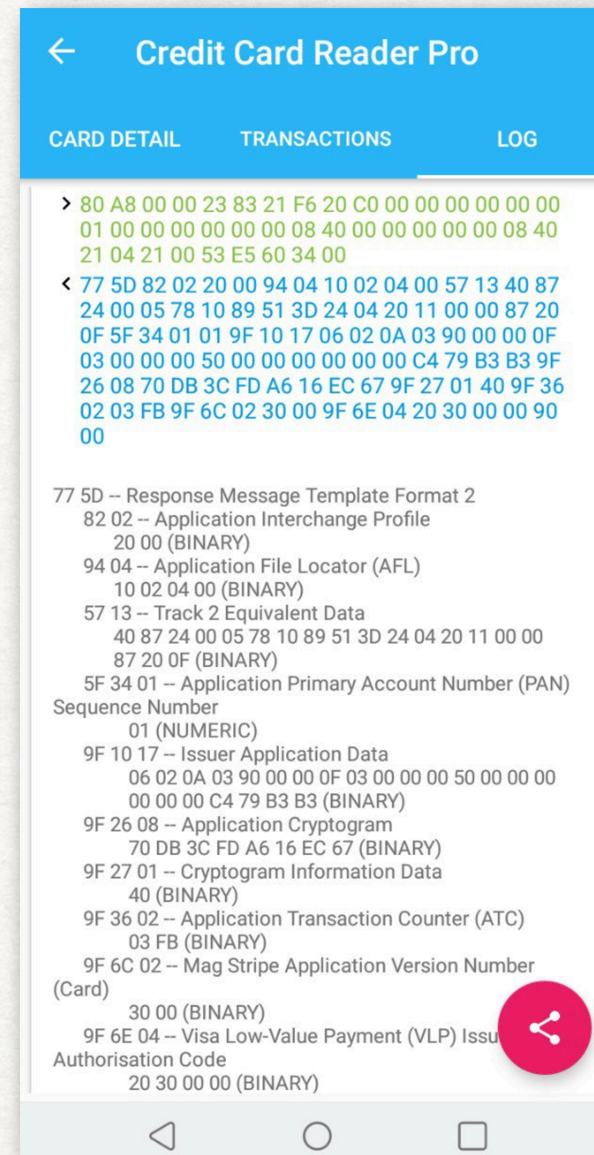
Travel Mate. Asia
3301 2345 6789
05/26
UnionPay 银联
AMERICAN EXPRESS
EMVCO
MasterCard
CoolClips.com
UnionPay 银联

THERE IS NO PRIVACY IN EMV







Unwanted data collection in contactless payments is straightforward.

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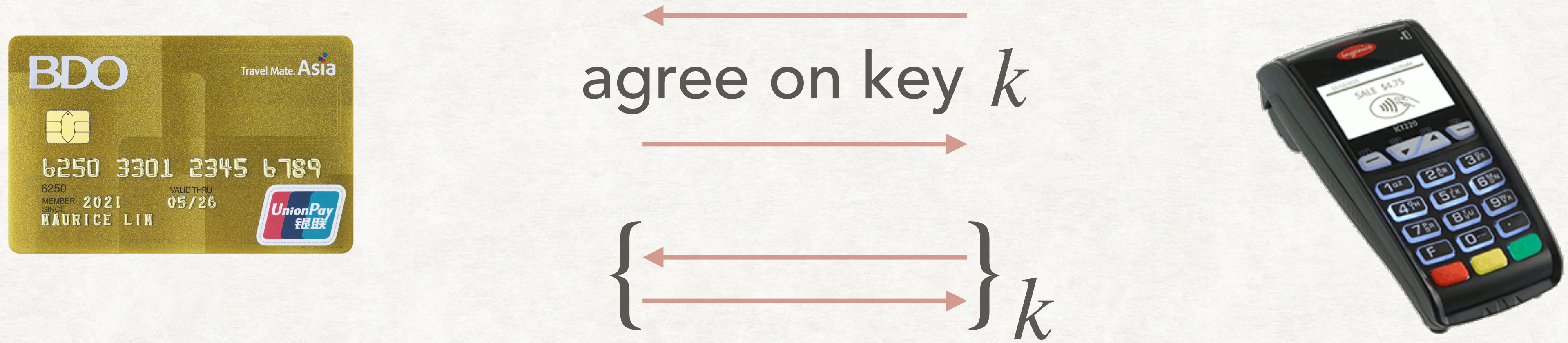
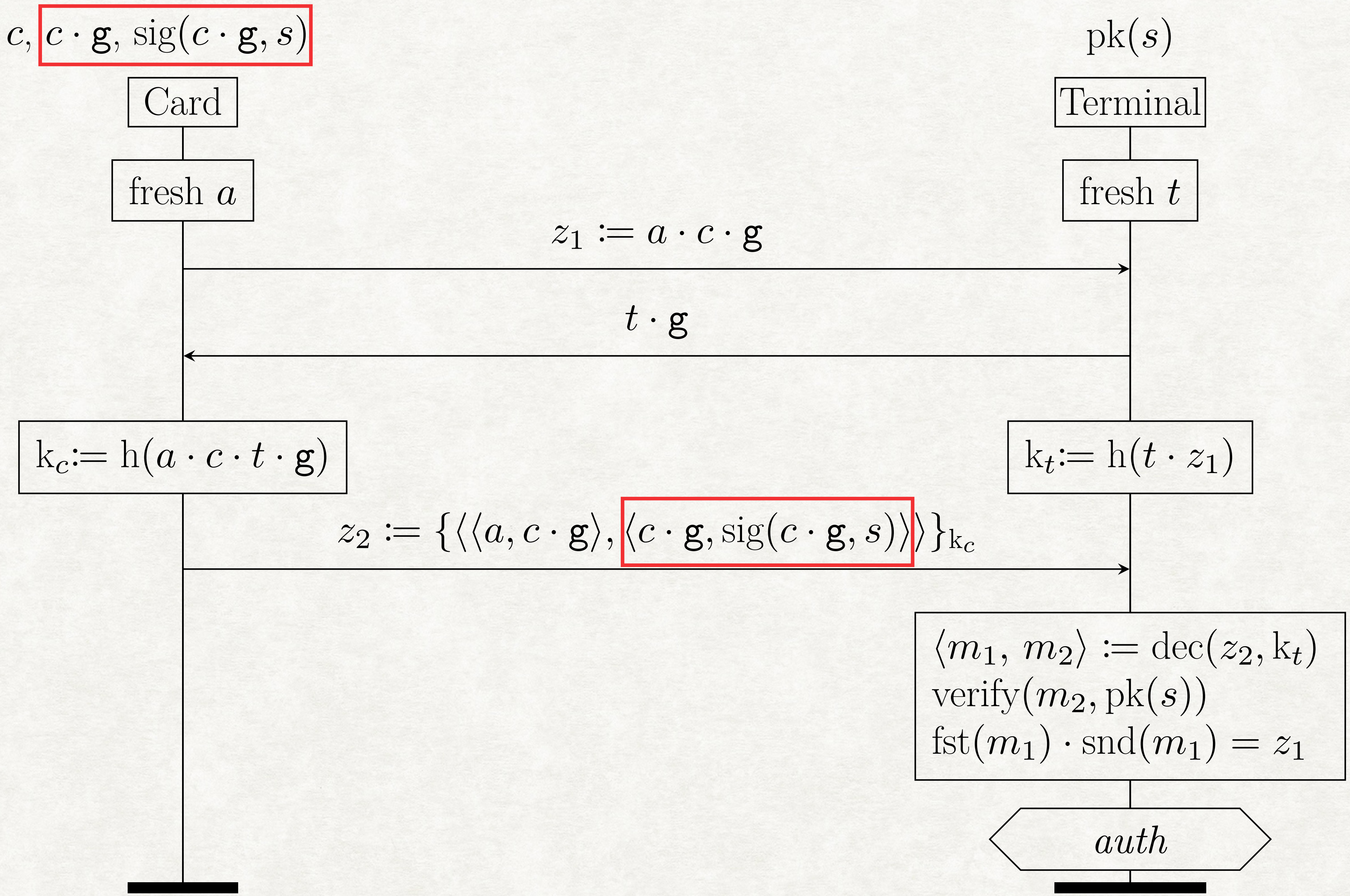
EMVCO PROPOSAL: KEY ESTABLISHMENT



2012: “Blinded Diffie-Hellman RFC”, EMVCo LLC

- provide authentication of the card by the terminal
- protect against eavesdropping and card tracking.

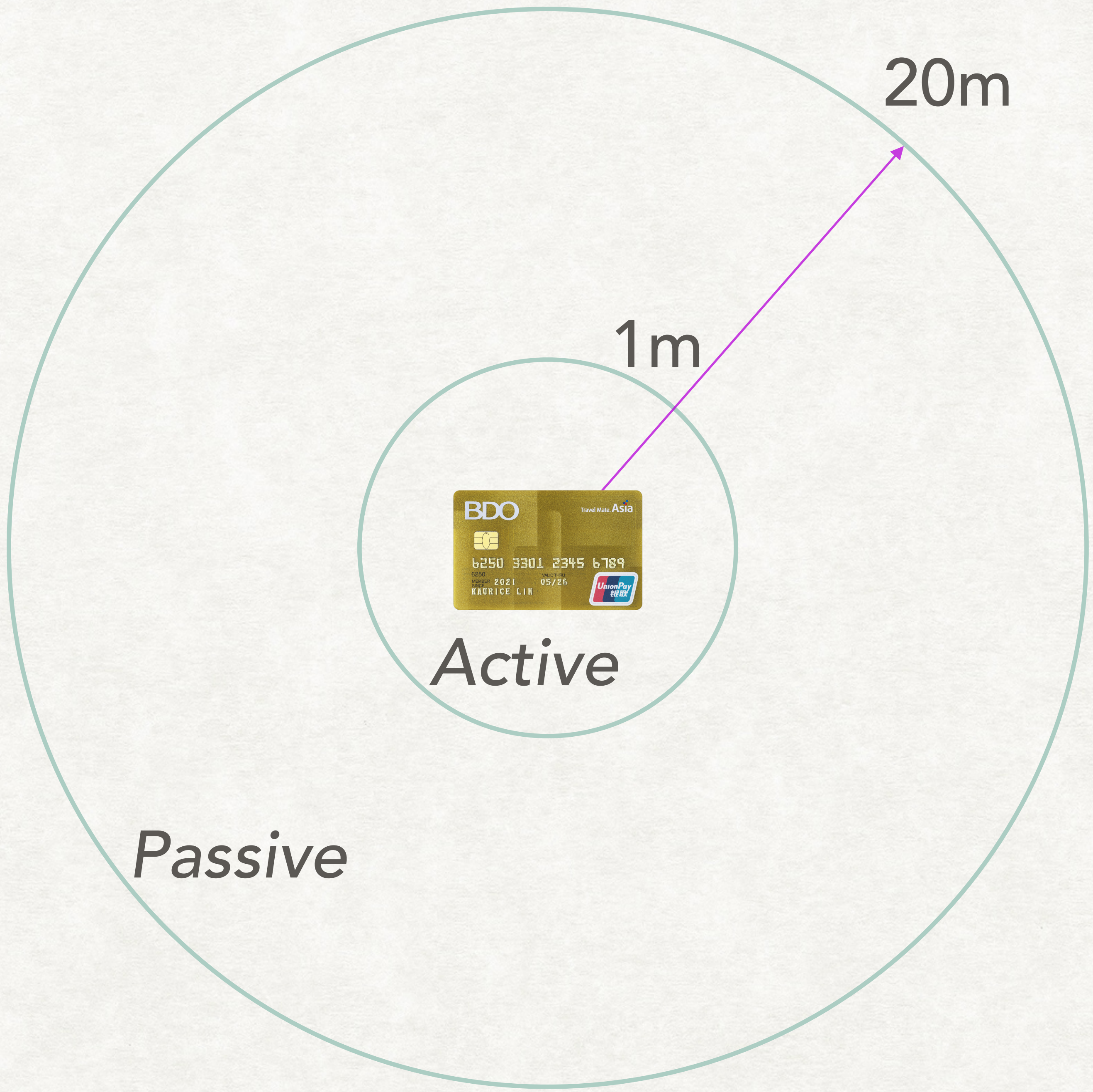
BLINDED DIFFIE-HELLMAN (BDH)



g the generator of the DH group, s PaySys signing key, $\mathrm{pk}(s)$ PaySys verification key

c card's secret key, $c \cdot \mathsf{g}$ card's public key, $\mathrm{sig}(c \cdot \mathsf{g}, s)$ signature on the card's public key

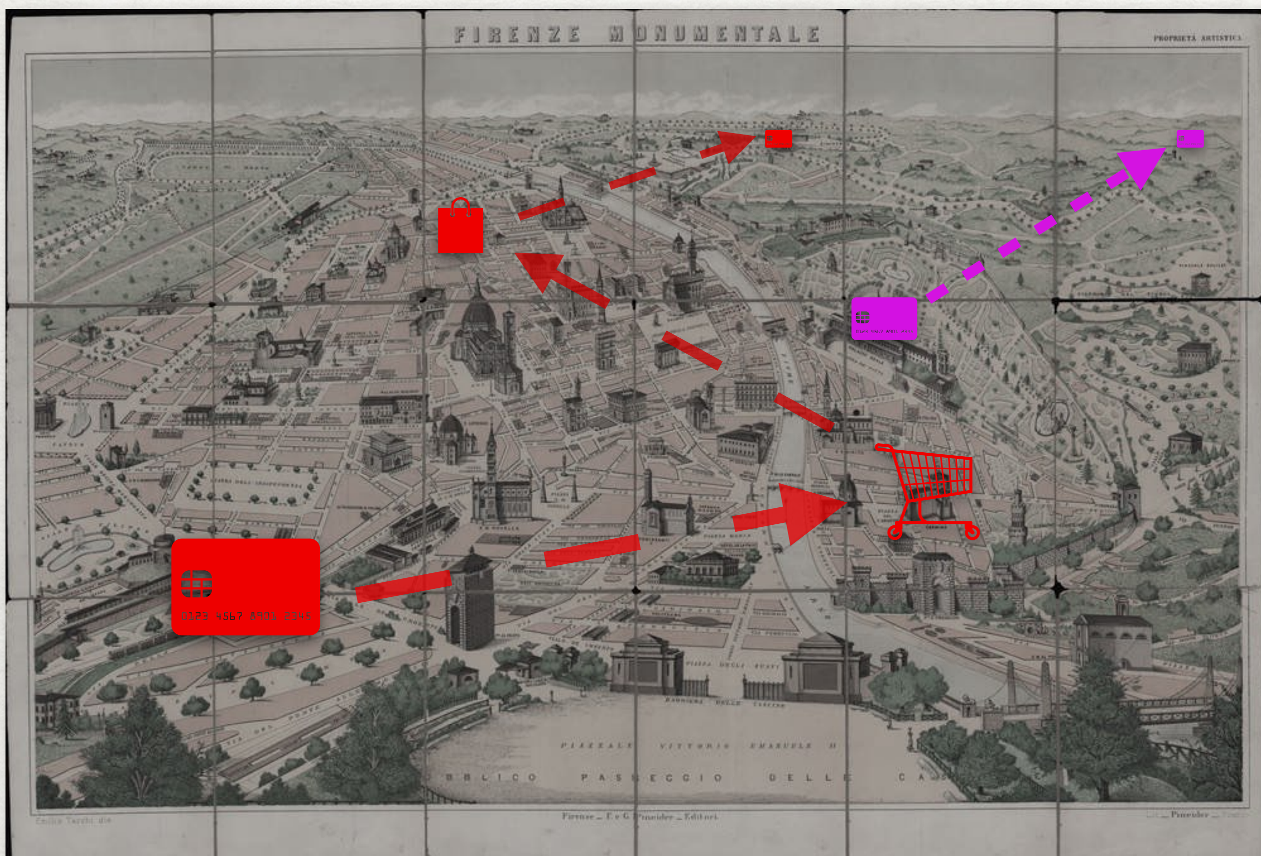
EAVESDROPPER → ACTIVE ATTACKER



1. An active attacker powers up the card
2. Establishes a symmetric key with the card
3. Obtains the long-term identities $\boxed{c \cdot \mathfrak{g},\ \mathsf{sig}(c \cdot \mathfrak{g}, s)}$

PASSIVE ATTACKER

Without BDH: no privacy



With BDH: privacy

(CLOSE) ACTIVE ATTACKER

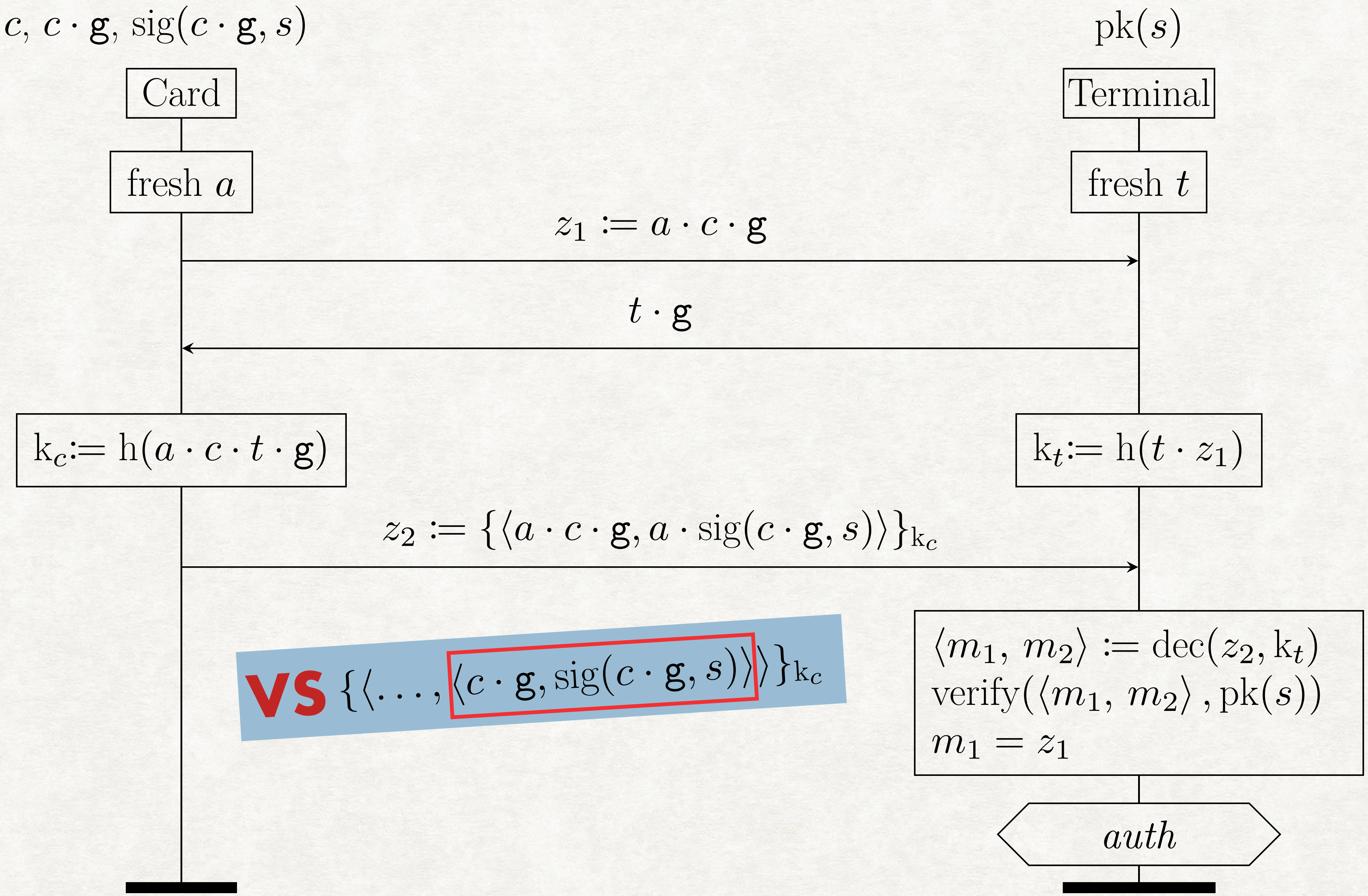
Without BDH: no privacy

With BDH: no privacy

NO DIFFERENCE!

UNLINKABLE BLINDED DIFFIE-HELLMAN (UBDH)

Verheul condition: $a \cdot \mathrm{sig}(M, s) =_E \mathrm{sig}(a \cdot M, s)$



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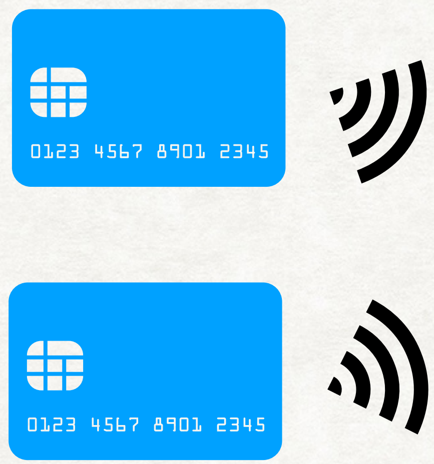
UNLINKABILITY

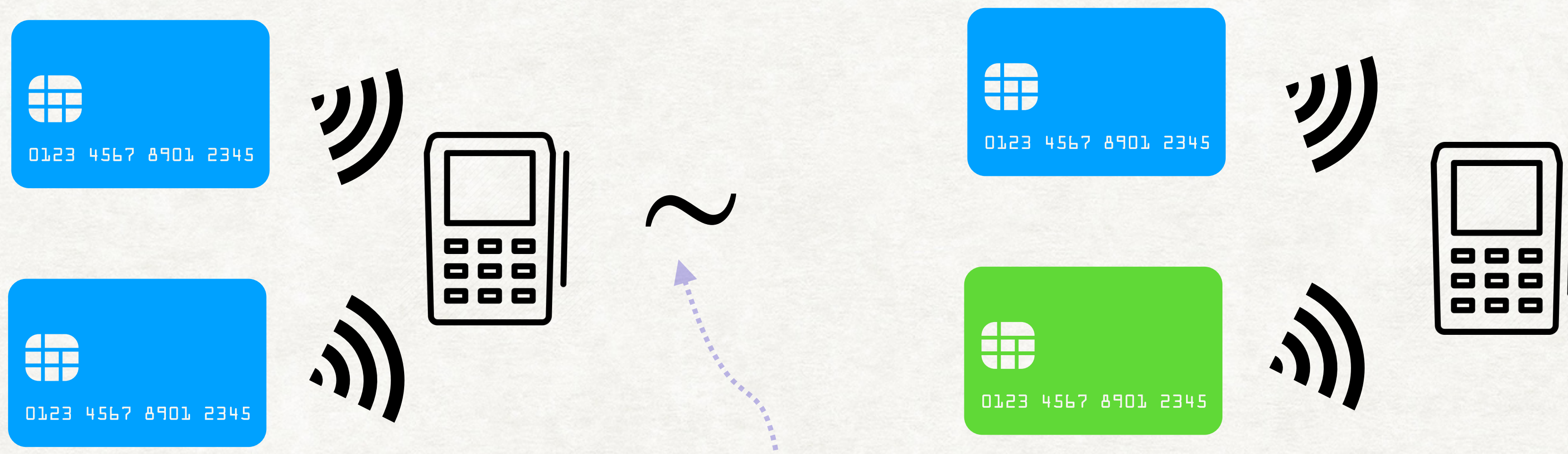


$\sim$

QUASI-OPEN BISIMILARITY

$$
\begin{aligned}
\mathit{Small\_Impl} \triangleq\ & \nu s. \\
& \overline{out}\langle \mathrm{pk}(s) \rangle. \\
& !\nu c. \\
& !\nu ch_c.\overline{card}\langle ch_c \rangle.C(s, ch_c, c)
\end{aligned}
\qquad \sim \qquad
\begin{aligned}
\mathit{Small\_Spec} \triangleq\ & \nu s. \\
& \overline{out}\langle \mathrm{pk}(s) \rangle. \\
& !\nu c. \\
& \nu ch_c.\overline{card}\langle ch_c \rangle.C(s, ch_c, c)
\end{aligned}
$$

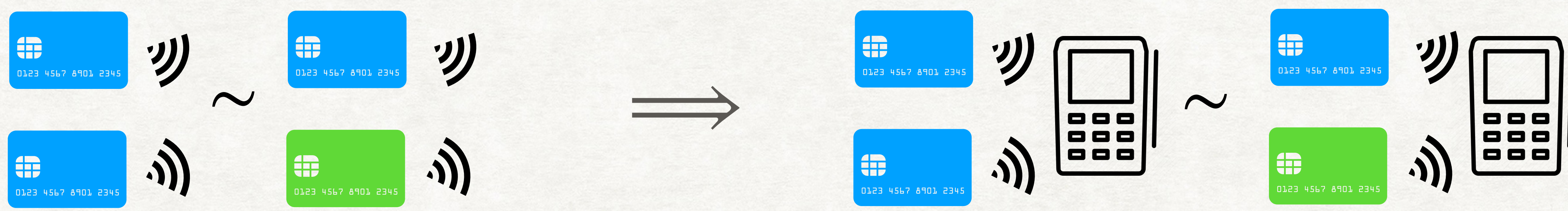
UNLINKABILITY



QUASI-OPEN BISIMILARITY

$$
\begin{aligned}
\mathit{Impl} \triangleq\ & \nu s. \\
& \big(!\nu c. \\
& !\nu ch_c.\overline{\mathit{card}}\langle ch_c\rangle.C(s, ch_c, c) \ \mid \\
& \overline{\mathit{out}}\langle \mathrm{pk}(s)\rangle. \\
& !\nu ch_t.\overline{\mathit{term}}\langle ch_t\rangle.T(s, ch_t) \ \big)
\end{aligned}
\quad \sim \quad
\begin{aligned}
\mathit{Spec} \triangleq\ & \nu s. \\
& \big(!\nu c. \\
& \nu ch_c.\overline{\mathit{card}}\langle ch_c\rangle.C(s, ch_c, c) \ \mid \\
& \overline{\mathit{out}}\langle \mathrm{pk}(s)\rangle. \\
& !\nu ch_t.\overline{\mathit{term}}\langle ch_t\rangle.T(s, ch_t) \ \big)
\end{aligned}
$$

RESULTS: CONGRUENCE ENABLES COMPOSITIONAL REASONING



Theorem 1: If *Small_Impl* ~ *Small_Spec*, then *Impl* ~ *Spec*.

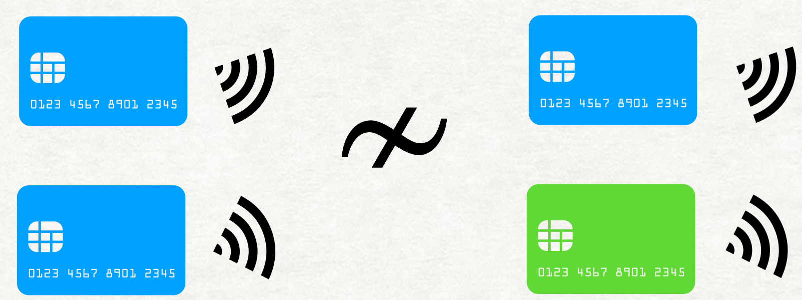
Proof.

- ~ is a congruence, hence is preserved by any context

- the context: $\nu out.\Big(\{\cdot\} \,|\, out(pk_s).\overline{out'}\langle pk_s\rangle ! \nu ch_t.\langle ch_t\rangle.T(pk_s, ch_t)\Big)$

■

RESULTS: BDH PROTOCOL IS NOT UNLINKABLE



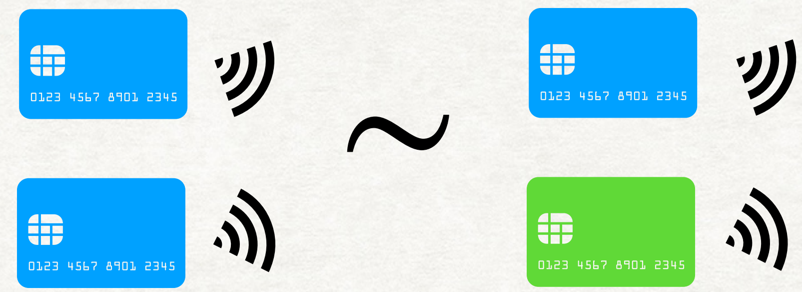
Theorem 2: *Small_Impl* $\not\sim$ *Small_Spec* for BDH.

Proof.

$$\textit{Small\_Impl} \models \begin{array}{l} \langle \overline{out}(pk_s) \rangle \\ \langle \overline{card}(u_1) \rangle \langle \overline{u_1}(v_1) \rangle \langle u_1\, y_1 \cdot \mathrm{g} \rangle \langle \overline{u_1}(w_1) \rangle \\ \langle \overline{card}(u_2) \rangle \langle \overline{u_2}(v_2) \rangle \langle u_2\, y_2 \cdot \mathrm{g} \rangle \langle \overline{u_2}(w_2) \rangle \\ \left(\mathrm{snd}(\mathrm{dec}(\mathrm{h}(y_1 \cdot v_1), w_1)) = \mathrm{snd}(\mathrm{dec}(\mathrm{h}(y_2 \cdot v_2), w_2)) \right) \end{array} \not\models \textit{Small\_Spec}$$

$\blacksquare$

RESULTS: UBDH PROTOCOL IS UNLINKABLE



Theorem 3: *Small_Impl* ~ *Small_Spec* for UBDH.

Proof.

- Define a relation (hard)
- Verify it is quasi-open bisimulation (not hard)

$$UPD_{\text{spec}} \ \mathfrak{R} \ UPD_{\text{impl}}$$

$$UPD^{\Psi}_{\text{spec}}(\vec{Y}) \triangleq \nu s, c_1, \cdots, c_L, ch_1, \cdots, ch_L, a_{l_1}, \cdots, a_{l_K}.(\sigma \mid C_1 \mid \cdots \mid C_L \mid !\nu c.\nu ch.\overline{card}\langle ch\rangle.C_{\text{upd}}(s, c, ch))$$

$$\mathfrak{R}$$

$$UPD^{\Psi,\Omega}_{\text{impl}}(\vec{Y}) \triangleq \nu s, c_1, \cdots, c_D, ch_1, \cdots, ch_L, a_{l_1}, \cdots, a_{l_K}.(\theta \mid \cdots \mid C^d_l \mid \cdots \mid !\nu ch.\overline{card}\langle ch\rangle.C_{\text{upd}}(s, c_d, ch) \mid !\nu c.!\nu ch.\overline{card}\langle ch\rangle.C_{\text{upd}}((s, ch, c)))$$

$$C_l = \begin{cases} \mathcal{E}^l(ch_l) & \text{if } l \in \alpha \\ \mathcal{F}^l(ch_l, a_l) & \text{if } l \in \beta \\ \mathcal{G}^l(ch_l, a_l, Y_l\sigma) & \text{if } l \in \gamma \\ \mathcal{H}^l & \text{if } l \in \delta \end{cases}$$

$$C^d_l = \begin{cases} \mathcal{E}^d(ch_l) & \text{if } l \in \zeta^d \cap \alpha \\ \mathcal{F}^d(ch_l, a_l) & \text{if } l \in \zeta^d \cap \beta \\ \mathcal{G}^d(ch_l, a_l, Y_l\theta) & \text{if } l \in \zeta^d \cap \gamma \\ \mathcal{H}^d & \text{if } l \in \zeta^d \cap \delta \end{cases}$$

$$\begin{array}{ll} pk_s\sigma = \mathtt{pk}(s) & \\ u_l\sigma = ch_l & \text{if } l \in \{1, \cdots, L\} \\ v_l\sigma = \phi(a_l, \phi(c_l, \mathrm{g})) & \text{if } l \in \beta \cup \gamma \cup \delta \\ w_l\sigma = m^l(a_l, Y_l\sigma) & \text{if } l \in \delta \end{array}$$

$$\begin{array}{ll} pk_s\theta = \mathtt{pk}(s) & \\ u_l\theta = ch_l & \text{if } l \in \{1, \cdots, L\} \\ v_l\theta = \phi(a_l, \phi(c_d, \mathrm{g})) & \text{if } l \in \zeta^d \cap (\beta \cup \gamma \cup \delta) \\ w_l\theta = m^d(a_l, Y_l\theta) & \text{if } l \in \zeta^d \cap \delta \end{array}$$

$$\Psi := \{\alpha, \beta, \gamma, \delta\}, \ \ \Omega := \{\zeta^1, \cdots, \zeta^D\} \text{ are partitions of } \{1, \cdots, L\}$$

$$K := |\beta \cup \gamma \cup \delta| \qquad l_1, \cdots, l_K \in \beta \cup \gamma \cup \delta$$

$$pk_s, u_l, v_l, w_l \ \# \ \{card, s\} \cup \{c_l, ch_l, a_l | l \in \{1, \cdots, L\}\}$$

$$Y_l \ \# \ \{s\} \cup \{c_l, ch_l, a_l | l \in \{1, \cdots, L\}\}$$

$$\mathrm{fv}(Y_l) \cap (\{v_i | i \in \alpha\} \cup \{w_i | i \in \alpha \cup \beta \cup \gamma \cup \{l\}\}) = \varnothing$$

$\blacksquare$

CONCLUSIONS

D. **Unlinkable** authenticated EMV **key establishment** in the presence of active attackers **is feasible**.

Quasi-open bisimilarity allows

A. To express **attacks** on privacy properties using **intuitionistic modal logic formulas**.

B. To prove that a privacy property holds by providing a **proof certificate** that is easy to check.

C. To reason about protocols **compositionally** by considering a **subsystem**, hence reducing the amount of work.

Thank you!

PICS SRC

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