E-Payment Systems and Cryptocurrency Technologies

https://course.ie.cuhk.edu.hk/~ierg4004

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Smartcard Technologies,
EMV, RFID, Contactless Payment Cards
and
Stored Value Facilities (SVF)

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- The slides used in this lecture are mostly adapted from the following sources. The copyrights and contribution of the original authors are hereby acknowledged and recognized:

  - The Electronic Payment Systems course by Prof. Michael Shamos, CMU
  - Matt Davies, "Hot Topics in Payments," Federal Reserve Bank of Dallas, Oct 2014
  - Leanne Phelps, "EMV, Tokenization and Apple Pay: The New Landscape," Oct 2014.
  - Seth Harrington et al, "What's NOT in your Wallet ?", Ropes & Gray, #iLAW Summit, Mar 2015.
  - Richard Martin, "Secure Mobile Payments: getting the balance right, " Sept 2013.
  - Guido Mangiagalli, "Wave and Pay – Visa Contactless," Visa Europe, 2005.
  - Smart cards : the developer's toolkit, Tim Jurgensen, Scott B. Guthery, Prentice Hall 2002
  - Smart Card Technology and Applications, Scott B. Guthery, Timothy M. Jurgensen, 2000.
  - Nguroho Gito, "Card Payment: Overview of Evolutions, Technology and Business", IBM, 2018.
  - Biometric Payment Cards, A Secure Technology Alliance Payment Council White Paper, March 2019.
  - Smart card handbook, 4th Edition, Wolfgang Rankl and Wolfgang Effing ; translated by Kenneth Cox, 2010.

Smart Cards

- **What is a Smart Card**[**] **?**
  - A small portable computer, without a display, keyboard or power-source ;
    - Integrate a 8-32 bit 30+ MHz microprocessor, upto 256KB's ROM and 1-8KB RAM, plus some Apps
  - *Often* the size of a credit card (common exception: SIM, micro SIM, nano SIM) ;
  - Use in conjunction with a Contact or Contactless reader
- What is it for: Securely Identify and Authenticate the Cardholder and 3rd parties who want to gain access to the card's info
- PIN-code or Biometric Data can be used for authentication
- Also provide a way to securely store data on card and protect communications with encryption
- Market: 30-50 Billions smartcard in circulation already ; Another 10 Billion expect to have been shipped during 2020.
- Major Players: Gemalto/THALES, Giesecke &Devrient, IDEMIA (formerly Oberthur Technologies and Morpho), NXP, Samsung, STMicroelectronics

[**] Sometimes, not-so-smart cards are also broadly referred to as "smartcards" as well, e.g.
   Magnetic stripe - 3 tracks, ~140 bytes, cost $0.20-0.75
   Memory cards - 1-4 KB memory, no processor, cost $1.00-2.50
   Optical memory cards - 4 megabytes read-only (CD-like), $7-12
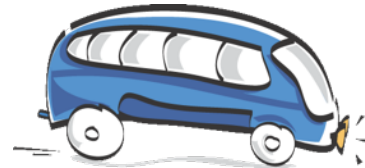
Smart Card Applications

E-Government

Banking

Mass Transit

Public Telephony

Mobile Telecommunications
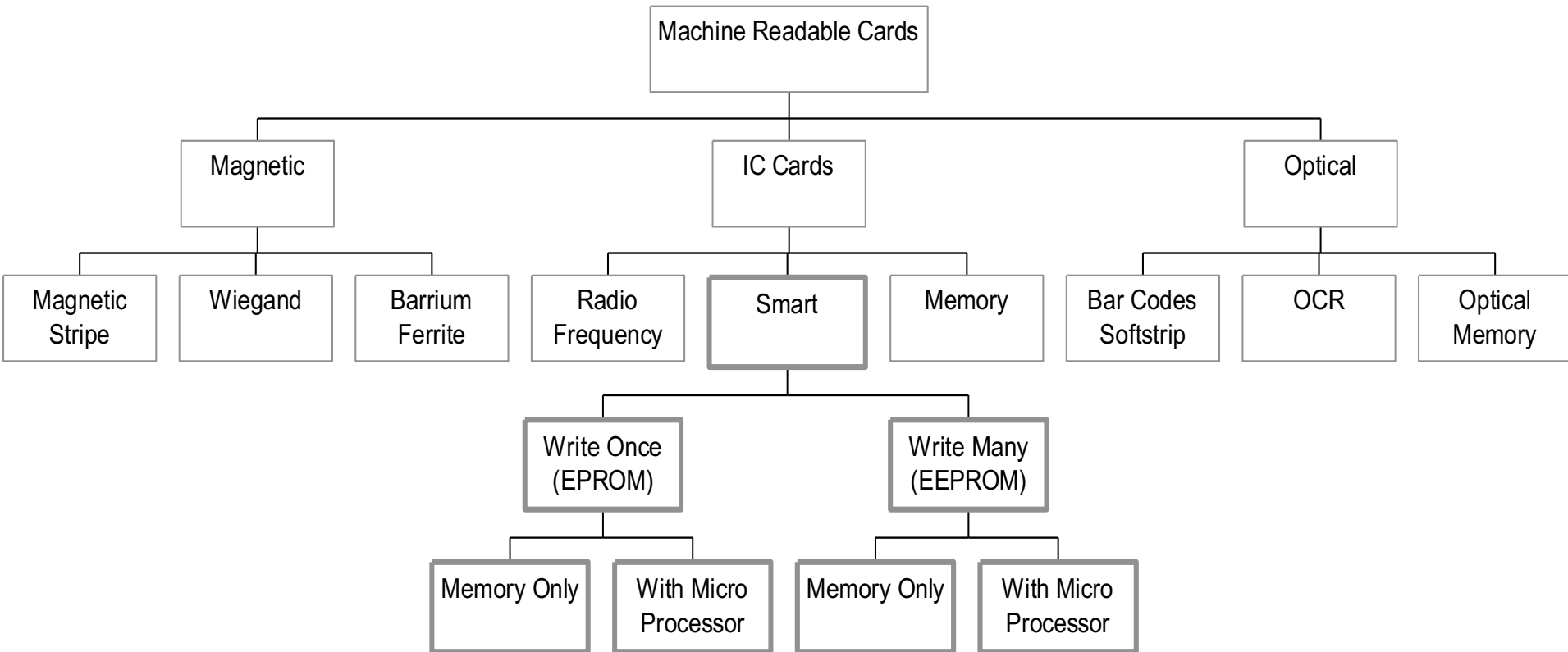
W-LAN

Pay TV

Retail

Access control

Enterprise Security

Digital Rights Management

Card Taxonomy (circa 2000)

History of Smartcards

- 1974: Roland Moreno patented the memory card.
- By 1977, three commercial manufacturers Bull CP8, SGS Thomson, and Schlumberger, started developing smart card products.
- In March 1979, Michel Hugon from Bull CP8 was the first to design and develop a microprocessor-based card combining a processor and local memory. He invented the computerized smart card.

1979: early developments for the banking sector

1995: first SIM cards

1999: first national eID card (Finland ID)

1999: first smart cards for transport

2001: The Department of Defense first issued Military CAC credentials for physical access control and secured logical authentication
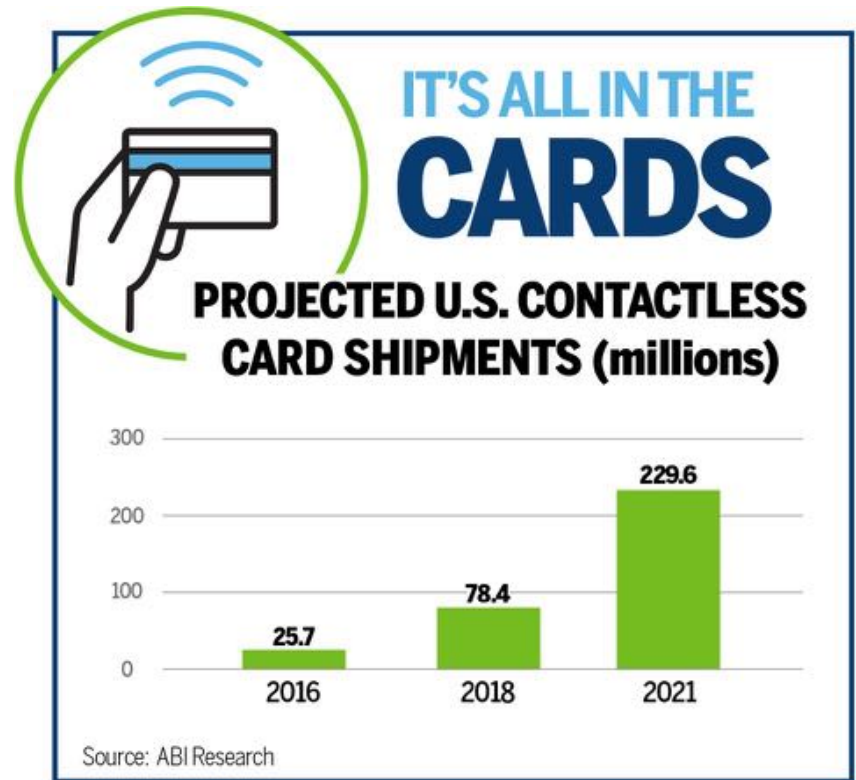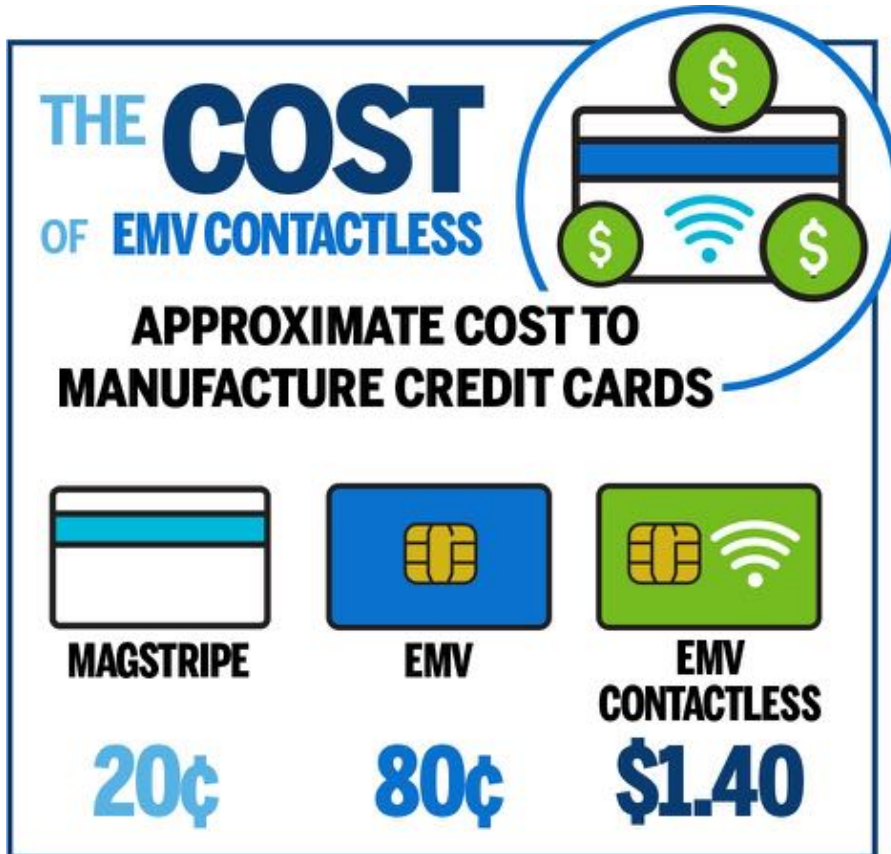
2003: Micro-SIM launched

2005: first ICAO-compliant electronic passport (Norway passport)

2012: Nano-SIM introduced

2018: first biometric contactless payment card, eSIM launched (thickness is <1 mm or 0.039 in)

2019 First 5G SIM available

SOURCE: https://www.thalesgroup.com/en/markets/digital-identity-and-security/technology/smart-cards-basics

Cost of Smart Cards

"Not-so-smart" Magnetic Stripe Cards

- Invented by IBM in 1969
- Three tracks: 1 & 3 at 210 bits/inch; 2 at 75 bpi
- Start sentinel (1 char): %
- Format code (1 char): B for bank/financial
- PAN, Primary Account Number (19 char)
  - Major industry identifier (1 or 2 char): 4, 5 for credit cards
  - Issuer (up to 5 char)
  - Individual account number (up to 12 char)
- Field separator (1 char): ^
- Name
- Field separator
- Expiration date (4 char): YYMM
- Proprietary fields, including Pin Verification Value (PVV)
- Authorization: **Online Only**

"Not-so-smart" Magnetic Stripe Cards

"Not-so-smart" Magnetic Stripe Cards

Banking Specific (Payment Cards)

1. Financial Information:
    1. Card Information, Stored in card & Card Management System
        1. PAN (Primary Account Number – 16/19 digits)
        2. Expiry Date
        3. CVV (stored in magnetic stripe) – Used for Card Present Transaction
           CVV2 (printed at card) – Used for Card Non Present Transaction
    2. Account Information
        1. Linked to Saving / Checque / Credit Card Account (Unsecured Loan)
2. Information Stored (Plain Text):
    1. Track1
    2. Track2
    3. Track3
3. Standards: ISO/IEC 4909, 7810, 7811, 7812, 7813, 4909, 8583
4. Reference https://en.wikipedia.org/wiki/Magnetic_stripe_card

Magnetic Stripe Examples

Track 1:

```
B5123456789121449^PADILLA/I.                    ^94011090001000000000^^XXX^^^^^^3^
---                    --              --   -        -            -       --
|||_ Card number  |||_ Card holder     ||   |        |           |_ CVV** ||_ LRC
||_ Format code   |_ Field separator   ||   |        |                    |_ End
sentinel                                                                   sentinel
|_ Start sentinel           Field separator _||   |        |_ Discretionary data
                            Expiration _|   |_ Service code
```

Track 2:

```
;1234567890123449789011230000000000000?
--              --    -    -            --
||_ Card number  ||    |    |_ Encrypted||_ LRC
|_ Start sentinel||    |       PIN***   |_ End sentinel
                 ||    |_ Service code
Field separator _||_ Expiration
```

Track 3:

```
;011234567891123448=7267261200000000000000000000000000000000L0=^^^^^^^^^^^^^^^=0000000000000000?
```

Source: http://sagan.gae.ucm.es/~padilla/extrawork/magexam1.html

Laser Optical Memory Card

Capacity: 1MB - 1GB

Overall card thickness .030 ± .003"

Receptive surface for dye transfer printing contains UV features, thickness 7μ
White polycarbonate .007"
Barcode
Electon beam cured adhesive
Screen printed graphics with uv feature
Clear polycarbonate .002"
Optical recording media on polyester base .004"
Electon beam cured adhesive
Clear polycarbonate .015"
Anti-abrasion coating 5μ
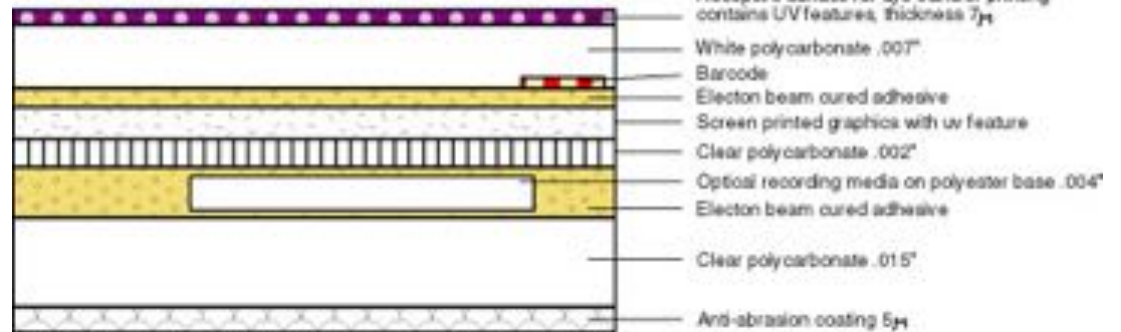
Other Smart Card Types

SIM card
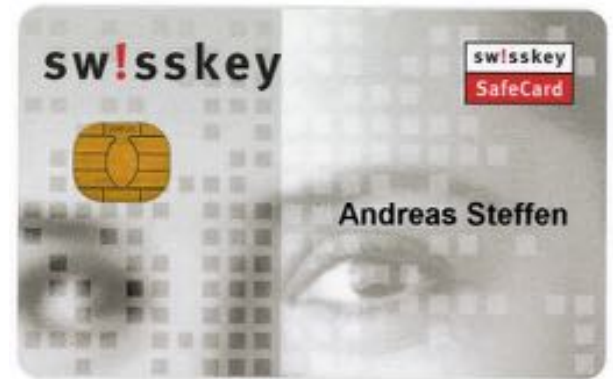
Crypto card

USB token

Java card

Memory card

Other Smart Card Types

dCVV

OTP

OTP key-board

dyn. mag. stripe

display card

multi card emulation

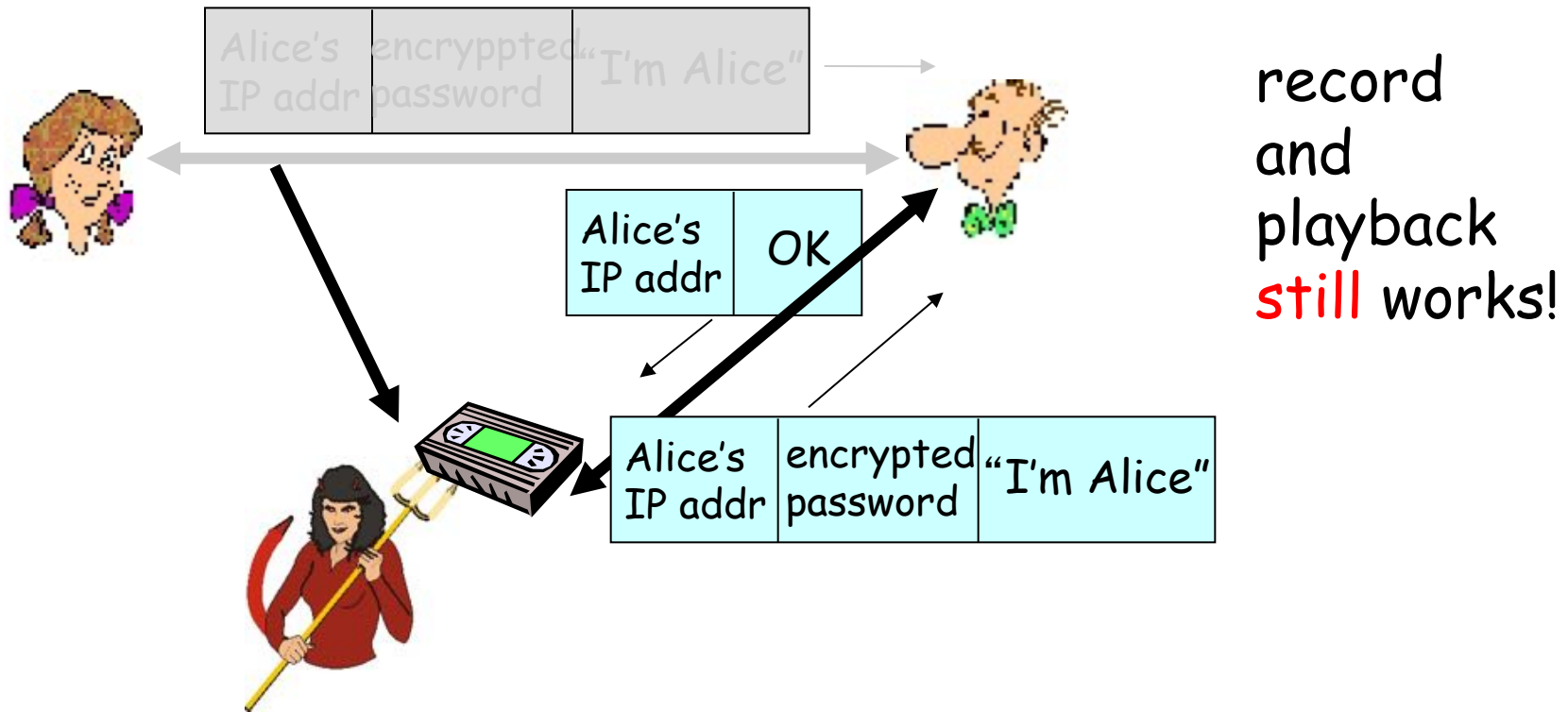display / BLE

LED

biometrics

BDR eID

Source: LINXENS

Hong Kong Smart ID

Why a Microprocessor-embedded Smart Card ?
Recall: Pitfalls of Authentication Handshake

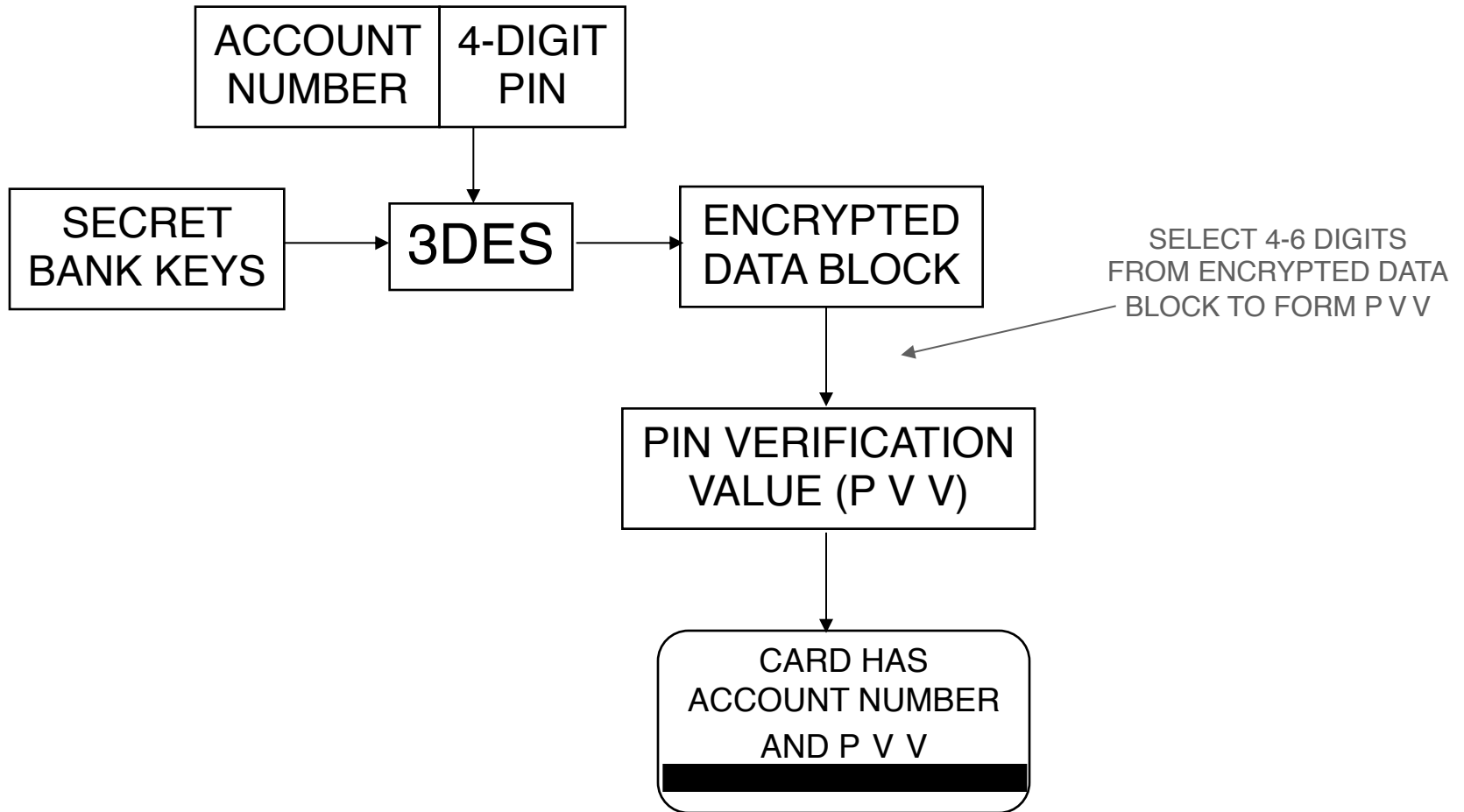Protocol ap3.1: Alice says "I am Alice" and sends her *encrypted* secret password to "prove" it.

record
and
playback
still works!

Sample Use Case of a Not-so-Smart Card: ATM and Debit Card Cryptography

- PIN cannot be stored anywhere in plaintext

- PIN cannot be reverse-engineered from the card or any database

- Generate a random 4-digit number (the PIN)

- Combine PIN with other data (account number) to form a data block

- Encrypt the data block using 3DES and secret bank keys

- Select several digits from the encrypted data to use as the Pin Verification Value (PVV)

Forming the Pin Verification Value

```
┌──────────────────┬─────────────┐
│   ACCOUNT        │  4-DIGIT    │
│   NUMBER         │    PIN      │
└──────────────────┴─────────────┘
                          │
                          ▼
┌──────────────┐   ┌──────────┐      ┌──────────────────┐
│   SECRET     │──▶│  3DES    │─────▶│   ENCRYPTED      │
│ BANK KEYS    │   └──────────┘      │   DATA BLOCK     │
└──────────────┘                     └──────────────────┘
                                              │
                                              ▼
                              ┌──────────────────────────┐
                              │   PIN VERIFICATION        │
                              │   VALUE (P V V)           │
                              └──────────────────────────┘
                                              │
                                              ▼
                              ┌──────────────────────────┐
                              │      CARD HAS             │
                              │   ACCOUNT NUMBER          │
                              │     AND P V V             │
                              │ ████████████████████████ │
                              └──────────────────────────┘
```

SELECT 4-6 DIGITS FROM ENCRYPTED DATA BLOCK TO FORM P V V

Using the Card

CARD HAS
ACCOUNT NUMBER
AND PVV

ATM MACHINE READS ACCOUNT
NUMBER AND P V V

USER TYPES PIN

MACHINE NOW HAS:

ACCOUNT NUMBER	4-DIGIT PIN	P V V

P V Vs MATCH?
    USER IS AUTHENTIC

P V Vs DIFFERENT?
    USER IS REJECTED

COMPARE CARD P V V
WITH COMPUTED P V V

MACHINE HAS BANK
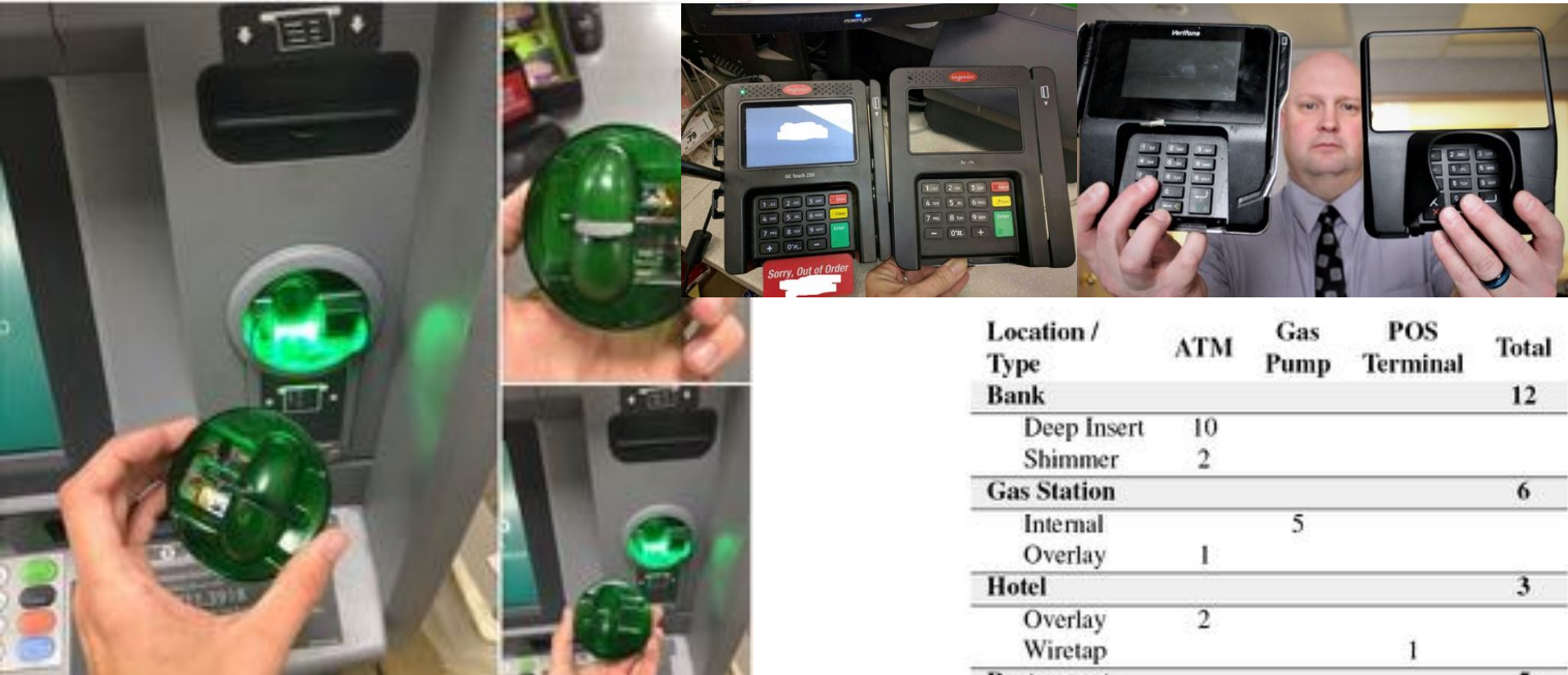KEYS IN HARDWARE:

| SECRET BANK KEYS | → | 3DES | → | DECRYPTED DATA BLOCK | → | P V V |

COMPUTE P V V

Skimming Magnetic Stripe Cards

Location / Type	ATM	Gas Pump	POS Terminal	Total
Bank				**12**
Deep Insert	10			
Shimmer	2			
Gas Station				**6**
Internal		5		
Overlay	1			
Hotel				**3**
Overlay	2			
Wiretap			1	
Restaurant				**5**
Overlay	5			
Retail				**9**
Deep Insert	1			
Overlay	5		3	
Total	26	5	4	35

Table 1: The breakdown of skimmer BOLOs by the NYPD Financial Crimes Task force between 2016-Jul-14 and 2017-Nov-11. ATMs were the most widely attacked device using both deep-insert and overlay skimmers.

Card Skimmers Internals

Pinhole Camera   Microphone   Battery

Camera Storage

Data Retrieval Port   Card Data Storage

Head

1.5mm   Spring

(a) Top   (b) Bottom
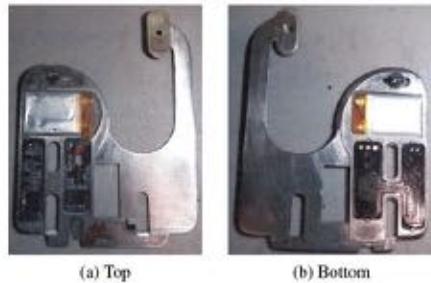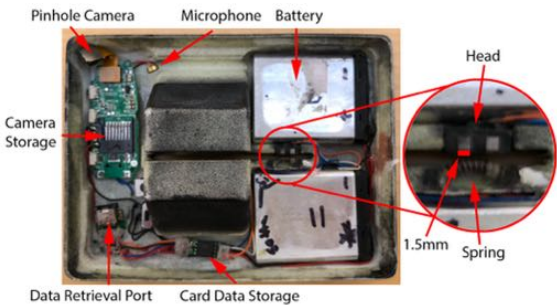
Figure 7: This deep-insert skimmer is machined to a custom fit for the targeted payment terminal.

rlay   (b) ATM Overlay   (c) ATM Overlay   (d) ATM Overlay

(e) ATM Overlay   (f) ATM Overlay   (g) POS Overlay

(h) ATM Door Access Overlay   (i) Deep-Insert   (j) Deep-Insert

(a) Front   (b) Rear   (c) Installed
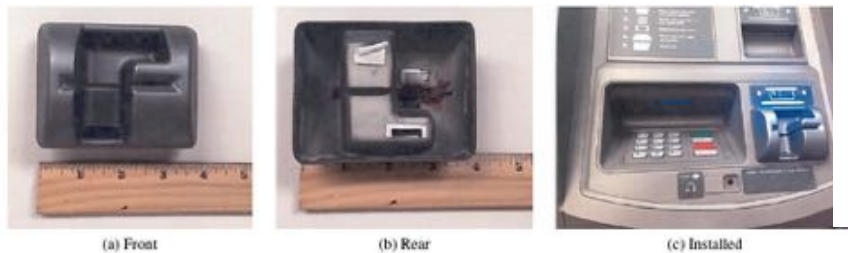
Figure 3: The front and rear of a typical overlay skimmer along with a photo of the skimmer installed on a real ATM, as captured by the NYPD. From the rear, the hardware for reading and storing the card data can be seen.

(a) PIN Pad Overlay   (b) Reverse

CANCEL

2016/11/24 23:32:41

Figure 4: This is a frame of video captured by a camera deployed alongside a skimmer. The adversary uses the camera to capture the victim's PIN upon entry. With both card data and the PIN, the card can be used to obtain cash.
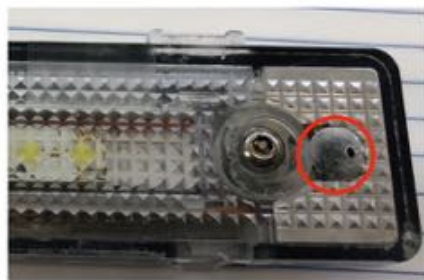
Figure 5: Adversaries modify original ATM light fixtures with pinholes for cameras, such as the one circled in red.

capture cards for months before detection.

3.2   Targets
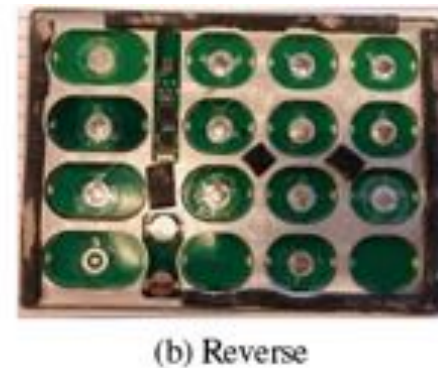
Source:
N. Scaife et al, "Fear the Reaper: Characterization and Fast Detection of Fast Card Skimmers" Usenix Security 2018

Card with Embedded-Microprocessor to enable Challenge-Response Handshake for Authentication:

<u>Goal:</u> Avoid playback attack

<u>Nonce:</u> number (N) used only *once –in-a-lifetime*

<u>ap4.0:</u> to prove Alice "live", Bob sends Alice nonce, N. Alice must return N, encrypted with shared secret key

"I am Alice"

N

$K_{A-B}(N)$

Alice is live, and only Alice knows key to encrypt nonce, so it must be Alice!
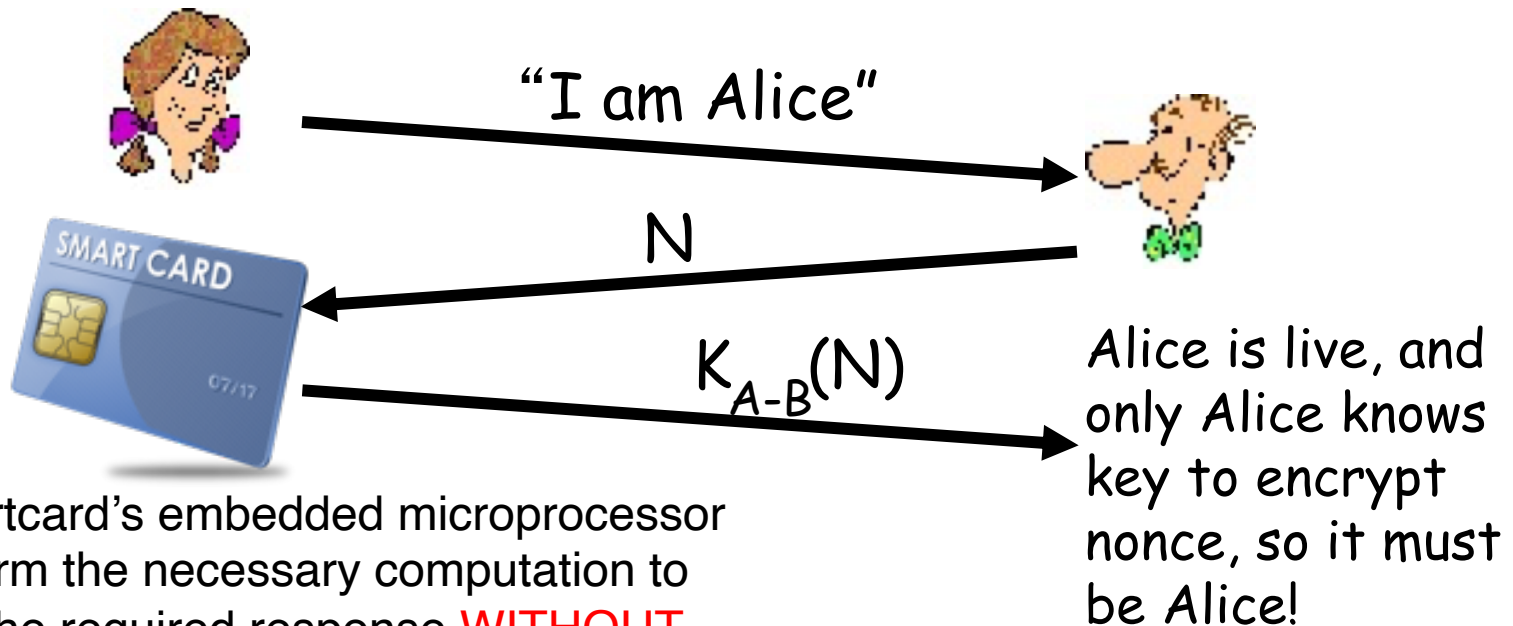
The Smartcard's embedded microprocessor can perform the necessary computation to produce the required response WITHOUT disclosing the user key/ PIN to the outside world !

A Prime Example: the EMV chip cards

EMV stands for **E**uropay, **M**asterCard and **V**isa, a global standard for inter-operation of integrated circuit cards (IC cards or "chip cards") and IC card capable point of sale (POS) terminals and automated teller machines (ATMs), for authenticating credit and debit card transactions.

Key Security Advantages:

- **Information stored in a more secure microprocessor chip**
    - Instead of a less secure magnetic stripe
- **Personalization of EMV cards is done using issuer-specific keys**
- **Card creates unique transaction data**
    - Any captured data cannot be used to execute new transactions (prevents card skimming and card cloning)
- **Cardholder verification**
    - Terminal will prompt the customer to sign (Chip and Choice in US) or enter a PIN (Chip and PIN in EU and is most common in other countries) to validate their identity.
    - Also supports other cardholder verification methods: offline PIN, online PIN, signature, or no cardholder verification method.

2 Ways of accepting EMV Chip Card Payments

- **Contact ("dipping" the card):**
  - ◆ Cardholder inserts card into POS device. Card remains in device until completion of the transaction. If customer removes card before the charge is approved, the transaction will fail and the customer will be required to provide the card again.

- **Contactless ("tap-and-go", e.g. Visa's PayWave):**
  - ◆ Cardholder waves the card by the chip card-enabled POS device to provide payment information. Once the transaction has been authorized, customer might then be prompted to enter PIN or sign a receipt, or no verification is needed if the amount is below certain threshold (e.g. < HK$300).

EMV chip cards Adoption

- The European Union was the first to Mandate the support of Chip-and-PIN.
- Deployment in US was lagging behind because US companies claimed that they already had enough Credit Card security/ Fraud detection mechanisms in place and they were reluctant to incur the large cost (est. US$12 billion) of deploying such new technologies.
  - But some high-profile security breaches invalidated such claims, e.g.
    - In late 2013, Target's system got hacked and lost 40 million credit/ debit card numbers of its customers, together with 70 millions of customer records.
- In October 19, 2014, President Obama signed executive order to speed up the adoption of EMV cards in the US by October 2015.
  - Newly issued and existing government credit/ debit cards would have chip technology.
  - All POS terminals at federal agencies would accept EMV.

Payment Media Evolution

Liability Shift after EMV

- **Before EMV, POS counterfeit fraud is largely absorbed by Card Issuers**
- Starting October 2015: Card Brand Networks' Liability Shift
  - *The party, either the issuer or merchant, who does not support EMV, assumes liability for counterfeit card transactions.*

Counterfeit Fraud Liability Shifts

Rewards investment in EMV
POS: October 1, 2015
AFD & ATM: October 1, 2017

- After Liability Shift: Liability shifts to the acquirer if **counterfeit fraud** occurs on a contact chip capable card and the merchant is not contact chip capable

- Liability Shift does **not** apply to contactless, card-not-present transactions, or lost/stolen fraud

- Covers domestic and cross-border transactions

Transaction Examples	Counterfeit Liability
Chip-on-chip transactions	Issuer holds the limited exposure that still exists
Mag-stripe cards at chip terminals	Issuer holds liability
Contact chip at mag-stripe terminals	Acquirer holds liability

Merchants Reliefs vs. Costs

- Relief from requirement to submit PCI compliance validation documentation (PCI security standard compliance cost ~ US$2K/yr vs. US$700/yr Card fraud cost at each store)
    - Effective Oct. 1, 2015, relief from financial liability for card-present fraud losses processed on EMV terminals.
    - Fuel-selling merchants had until Oct 1, 2017, before liability shift took effects at Automated Fuel Dispensers (AFD, i.e. Fuel Pumps), due to added expenses of updating (Ave cost for EMV conversion: US$6-10K per pump)
- Liability shift was also introduced for ATM transactions in the U.S. Oct 2016-2017
    - All ATMs needed to be EMV compliant
    - After October 2016/2017, FIs could hold ATM operators liable for fraudulent withdrawals and cash advances from debit and credit cards.
    - Approximately US$2,000 to upgrade an ATM to be EMV-capable (Aite)
        - Some ATMs could not take the upgrade for EMV and/or Windows (move from XP); US35k+ for a new ATM

Key EMV dates from Card Brands

VISA **MasterCard**

October: Visa & MasterCard waive PCI Data Security Audit Fee for merchants processing 75% or more POS transactions via EMV.

VISA **MasterCard**

April 1: EMV transactions must be supported by Acquirers and Sub-Processors.

VISA **MasterCard**

October: MasterCard and Visa shift fraud liability to least secure entity for all POS transactions except automated fuel dispensers.

VISA **MasterCard**

2017: Visa and MasterCard shift fraud liability to least secure entity for automated fuel dispensers.

2012 | 2013 | 2014 | 2015+

MasterCard

April 1: Maestro shifts counterfeit fraud liability to ATM owner when an EMV enabled card is used outside country of origin, and ATM authenticates via magnetic stripe.

MasterCard

October: MasterCard Only. Merchants processing 75% or more EMV POS transactions receive 50% Account Data Compromise relief.

MasterCard

October: MasterCard Only. Merchants processing 95% or more EMV POS transactions receive 100% Account Data Compromise relief.

MasterCard

2016: MasterCard shifts counterfeit fraud liability to ATM owner for all EMV enabled cards used at U.S. ATMs (Credit & Debit).

State Employees' Credit Union
There is a Difference!

Worldwide EMV Chip Card Deployment and Adoption*

Region	2016		2017		2018	
	EMV Cards	Adoption Rate	EMV Cards	Adoption Rate	EMV Cards	Adoption Rate
Africa & the Middle East	184M	68.7%	219M	74.8%	272M	87.8%
Asia Pacific	3,331M	38.8%	4,147M	45.7%	5,001M	51.0%
Canada, Latin America, and the Carribbean	717M	75.7%	820M	85.7%	848M	86.9%
Europe Zone 1	921M	84.9%	939M	84.4%	966M	85.5%
Europe Zone 2	243M	63.7%	276M	71.4%	301M	80.4%
United States	675M	52.2%	785M	58.5%	842M	60.7%

*Figures reported in Q4 of 2016, 2017, and 2018, respectively, and represent the latest statistics from American Express, Discover, JCB, MasterCard, UnionPay, and Visa, as reported by their member institutions globally.

Percentage of Card-Present Transactions that are EMV Chip

EMVCo

Region	July 2017 - June 2018	July 2018 - June 2019
Africa & The Middle East	91.19%	93.33%
Asia	66.43%	67.79%
Canada, Latin America, & The Caribbean	90.16%	93.45%
Europe Zone 1	98.76%	99.02%
Europe Zone 2	91.29%	93.92%
The United States	47.19%	59.23%

Legend:
- July 2017 - June 2018
- July 2018 - June 2019

X-axis: 0.00% 20.00% 40.00% 60.00% 80.00% 100.00%

Data represents the most accurate possible data that could be obtained by American Express, Discover, JCB, Mastercard, UnionPay and Visa for transactions processed by them during the noted period. The transaction data reflects an average of 12 months' data as reported by all members to take into consideration seasonal variations. To qualify as an 'EMV chip transaction' both the card and terminal used during a transaction must be EMV chip-enabled. Data is reported from the acquirer perspective. These figures may not include offline transactions, 'on us' transactions (defined as a transaction handled exclusively by another processor) and/or transactions processed by non-EMVCo member institutions, such as national payment networks.

Examples of Mobile Card Reader Providers

Provider	Region Available	Magnetic Stripe/EMV	Card Reader Cost	Transaction Fee Options
Intuit Go Payments	North America	Magnetic stripe	Free	Per transaction fee, or fixed monthly fee and lower per transaction fee
iZettle	Western Europe Latin America	EMV	Free for chip and signature Fee for chip and PIN	Per transaction fee
mPowa	Global	EMV	Fee for chip and PIN	Per transaction fee
PayAnywhere	North America	Magnetic stripe	Free	Per transaction fee
payleven	Western Europe Latin America	EMV	Fee for chip and PIN	Per transaction fee
PayPal Here	North America	Magnetic stripe	Free	Per transaction fee
Square	North America	Magnetic stripe	Free	Per transaction fee or fixed monthly fee
SumUp	Western Europe	EMV	Free	Per transaction fee

Global Smart Cards Market Size Through 2016 to 2026 (in Billion)

CAGR:- 8.9%

8.2

17.6

2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026
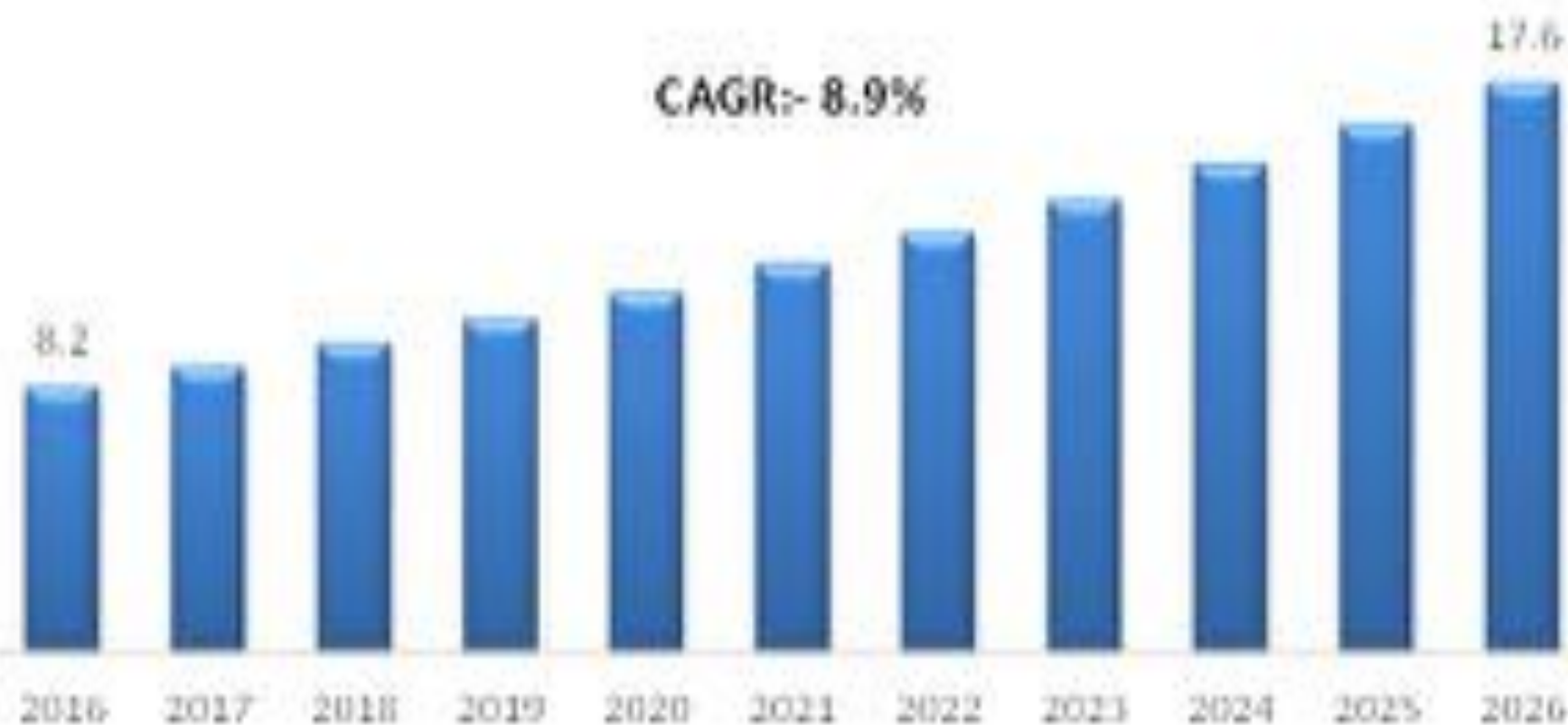
Secure elements shipments worldwide from 2010 to 2019 (in million units), by vertical
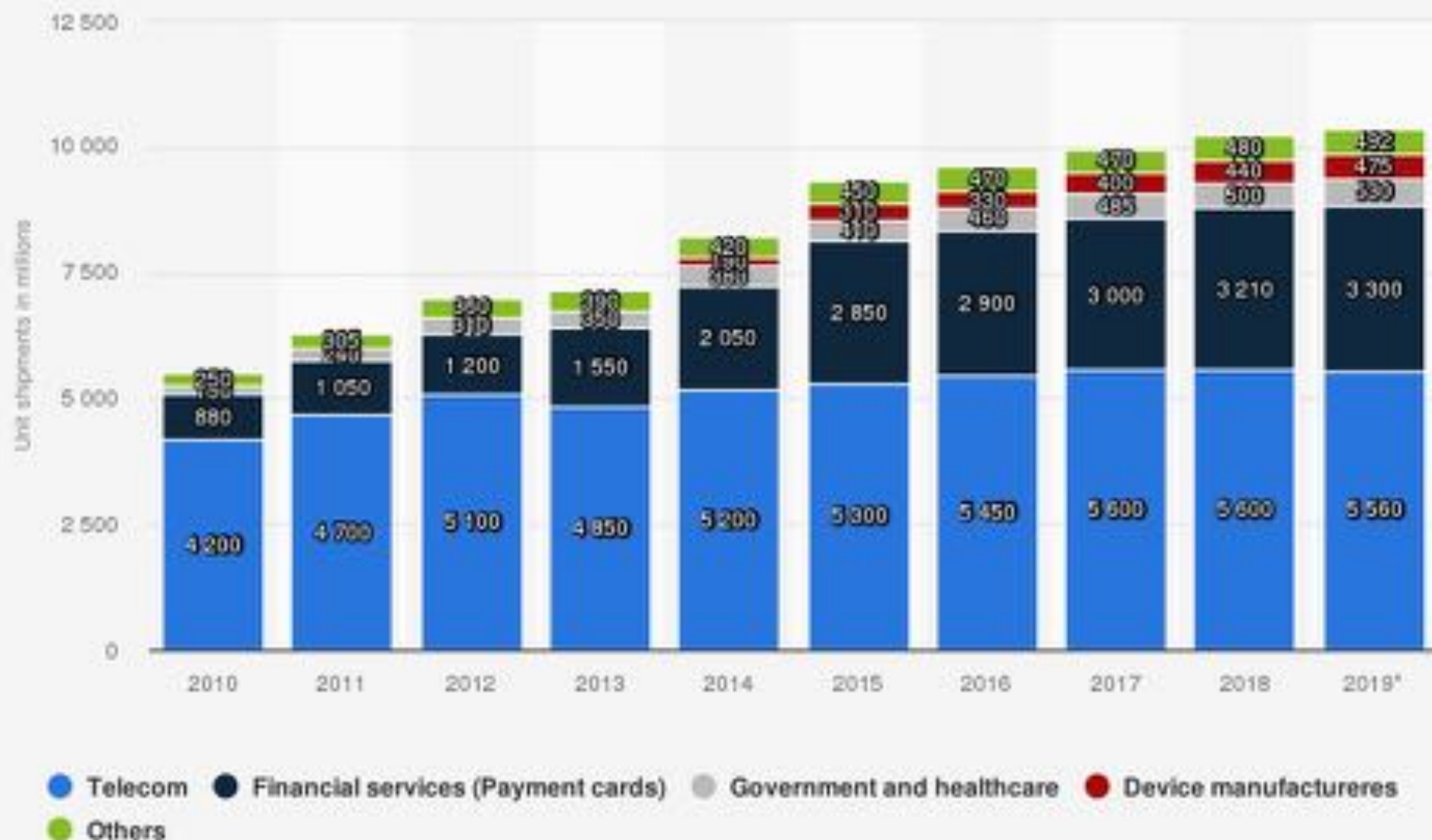
Unit shipments in millions

Year	Telecom	Financial services (Payment cards)	Others
2010	4 200	880	250
2011	4 700	1 050	305
2012	5 100	1 200	360
2013	4 850	1 550	
2014	5 200	2 050	420
2015	5 300	2 850	450
2016	5 450	2 900	470
2017	5 600	3 000	470
2018	5 600	3 210	480
2019*	5 560	3 300	492

● Telecom ● Financial services (Payment cards) ● Government and healthcare ● Device manufactureres
● Others

statista

U.S. smart card materials market size, by application, 2014 - 2025 (USD Million)

115.8   119.0

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

■ Telecommunication ■ BFSI ■ Retail ■ Government ■ Healthcare ■ Hospitality ■ Others
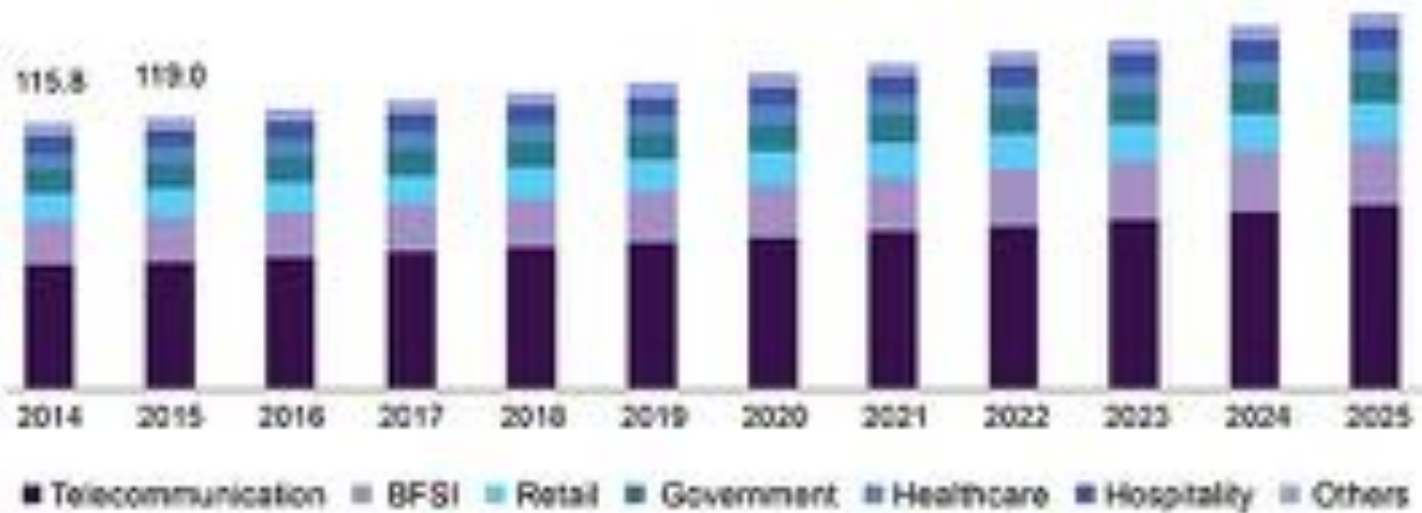
Russia Smart card Shipments (in million units)

172.4   183.6

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

■ Contact cards ■ Contactless cards ■ Multi component cards
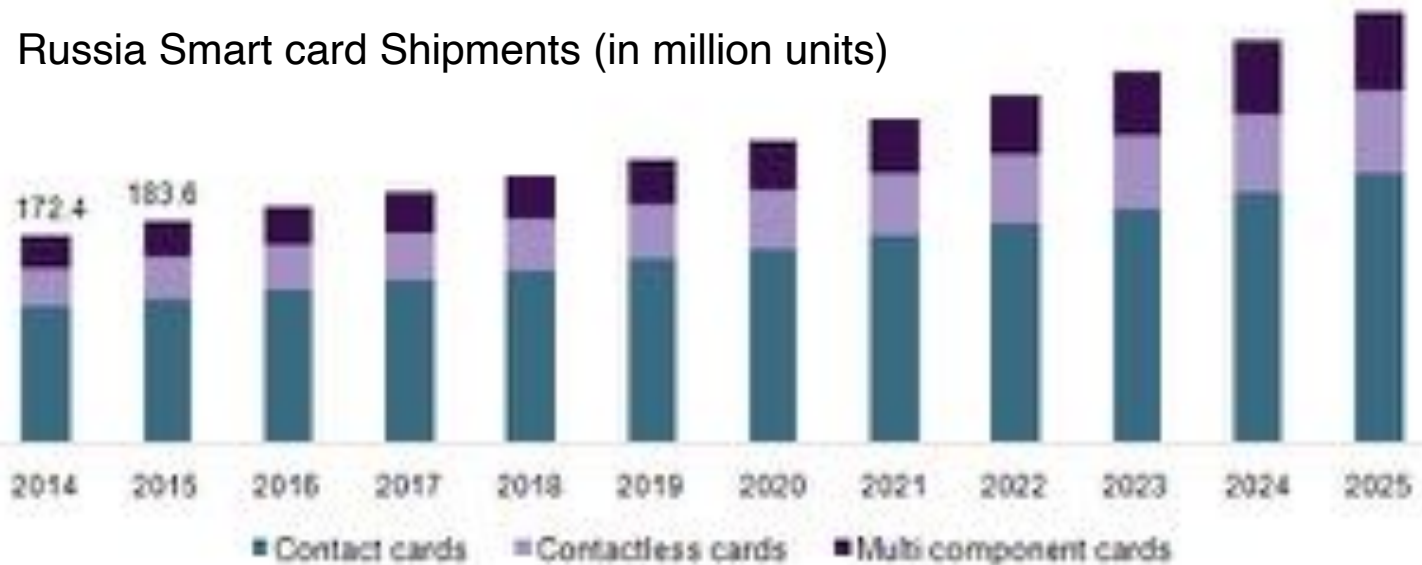
Yet another Card Taxonomy (circa 2000)

Chip Cards

- Contact Cards
- Combi Cards
- RF Cards (Contactless)
- Vault Cards

Memory Cards

Straight Memory
1K to 8 Megabit
EEPROM/Flash

Segmented/Protected Memory
1K to 16K Bit
EEPROM/Flash

Stored Value Memory
.20 to 1k Bit
EEPROM

Microprocessor Cards

8 Bit Low Performance OS
.5K to 8K bit User EEPROM

8 Bit High Performance OS
.5K to 16K bit User EEPROM
Private Key Encryption

8-16Bit High Performance OS
8K to 32K bit User EEPROM
with Math Coprocessor
Public Key Encryption

32 Bit MediumPerformance OS
32K bit User EEPROM
Private Key Encryption

32 Bit High Performance OS
32K bit User EEPROM
with Math Coprocessor
Public Key Encryption

Graphic Courtesy of
CardLogix Corporation

SOURCE: SMARTCARDCENTRAL.COM

Multi-Application Smart Card

SSL Secure Web

S/Mime Secure Mail

Customer PKI Application

Single Sign-On

Biometric Authentication

Local File Encrypt

Secure Screen Saver

Application Login

SOURCE: SECURITY DYNAMICS

SecurityDynamics

...because the Wolf is out ...re.

Private Key(s)

Digital Certificates

ACE (Active Customer Enrollment) Authentication

Biometric Data

Encryption Key

Employee Data

Password Cache

Employee Picture

Magnetic Stripe or RF Door Access

Smart Card Structure

Contacts:

Power—(Vcc)	(GND)—Ground
Reset—(RST)	(Vpp)—Optional
Clock—(CLK)	(I/O)—Input/Output
Reserved for future use—(RFU)	(RFU)—Reserved for future use

Microprocessor

Contacts

Card
(Upside-down)

Epoxy

Plastic

Contacts (8)

Old (8-bit) Smart Card Architecture

EEPROM: Electrically Erasable Programmable Read-Only Memory
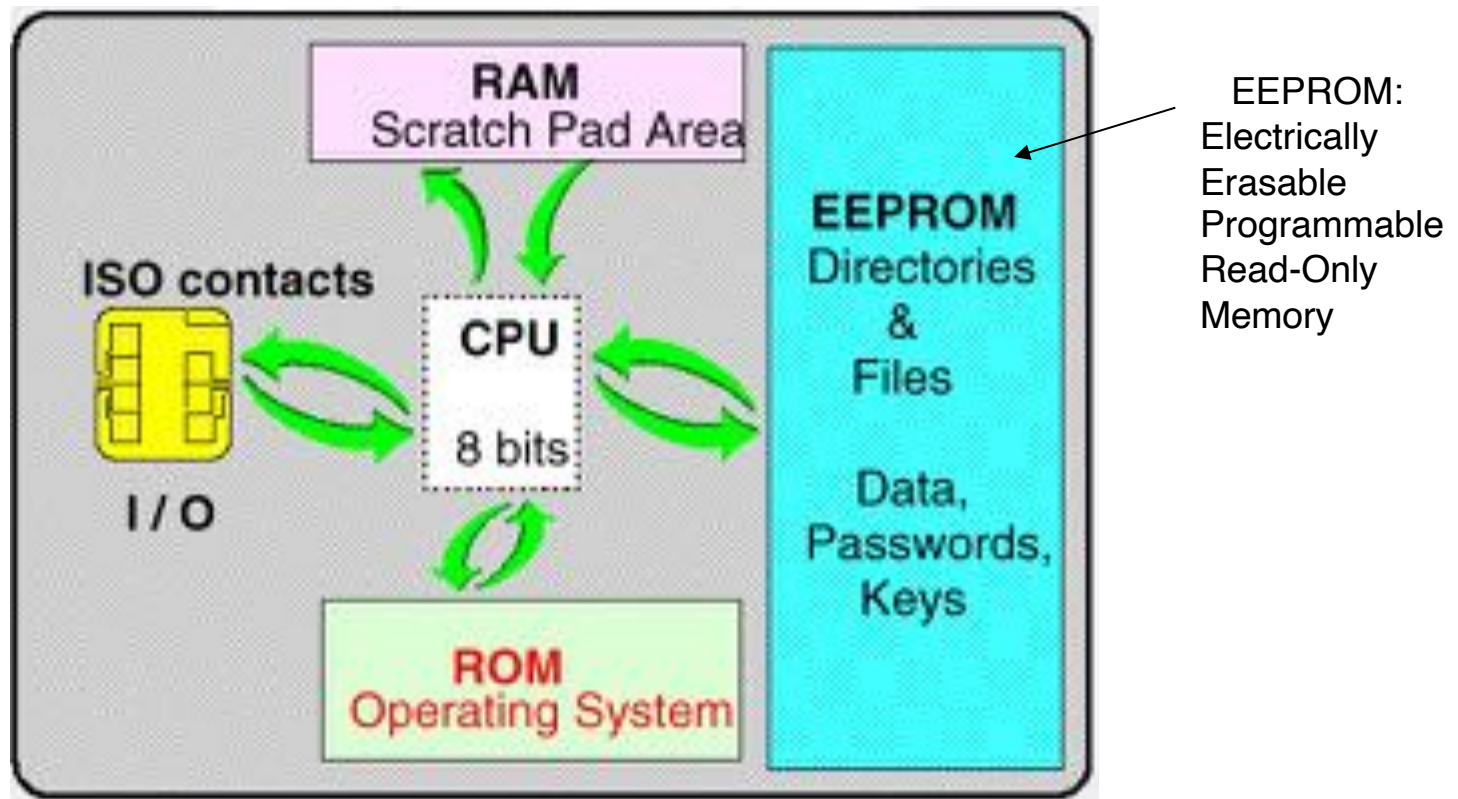
Smart Card Components

Processors

- 8-bit, typical clock speed: 5 MHz (8-bit)
- Optional cryptographic processor

- 32-bit, clock speed 300 MHz

- 64-bit, 600 MHz

Smart Card Components

ROM: Read Only Memory

- Used for storing fixed programs. Holds the operating system
- Typically varies from 2KB to around 16 KB
- Once written, cannot be changed
- Occupies the least area

Smart Card Components

EEPROM: Electrically Erasable Read Only Memory

- Stores variable data
- Holds various applications and their data.
- Can be read or written to subject to permissions.
- Typically: 2KB to 256 KB

RAM: Random Access Memory

- Used as temporary storage.
- Erased on power off.
- Typically 1000-8000 bytes of data

Smart Card Standards versus Specifications

- **Official Standards Bodies (e.g. ISO/IEC)**
  - Representatives of both producers and consumers
  - Typically very slow moving, particularly international standards
    - ✦ WG4 has been arguing about smart card voltages for years
  - often try to "grandfather in" existing products and thus are overly complex

- **Industry Consortia/Alliance (e.g. MULTOS, JavaCard, OpenCard)**
  - Rally commercial partners around some IP such as a Patent
  - Rules written to exclude particular parties

- **Issuer Consortia (e.g. EMV, CEPS)**
  - EMV (Europay MasterCard Visa) and CEPS (Common Electronic Purse Specifications) are the classic examples
  - proprietary variants tend to short-circuit inter-operability

- **User and Governmental Consortia**
  - not very effective since issuers are in charge

The Focus of Standards and Specifications

- **Standards homogenize, specifications differentiate**

- **Card-Edge Standards**
  - Enforcement
    - testing, test suites, test standards and certification
    - operational enforcement

- **API Specifications**
  - Documented interface to proprietary "stack"
  - Many underlying levels bound together
  - Don't de-couple applications from particular vendors
  - Very difficult to tell what happens where behind the API

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Examples of Official Smartcard Standards

- **ISO/IEC**
  - ISO 7816-1 through -15 are core smart card standards
  - -1, -2, and -3 deal with the physical (hardware) aspects of smart cards and are observed
  - -4 through -9 deal with the functionality (software) aspects of software and are by and large ignored
  - ISO/IEC 14443 defines Interface to Close Proximity (~ upto 10cm) Contactless Smartcards, operating at 13.56MHz.
  - ISO/IEC 15693 defines standards for "Vincity" cards (~ upto 1m)
  - ISO/IEC 18092 Near Field Communications (NFC) Interface and Protocol standards integrated into Mobile phones and other devices
    - Support backward compatibility with ISO/IEC 14443 Type A Contactless Cards as well as similar technologies, SONY FeliCa cards

- **ITU/ETSI/3GPP**
  - official body controlling the Telecommunications standards, e.g. GSM, 3G, 4G, 5G (which also include the SIM/ microSIM/ nanoSIM standards
  - In charge with coordinating all mobile SIMs
  - Important for standardizing algorithms and processes in which smart cards are used

- **ANSI-INCITS**
  - Biometric Standards, e.g. face recognition, finger-print, iris, hand-geometry etc, to enhance security and Privacy of ID standards

Examples of Supplier (Technologies) Specifications

- **MULTOS**
  - perhaps the oldest of the consortia
  - writes very detailed specifications for implementers of the Multos card which have delivered interoperable cards from multiple vendors

- **PC/SC**
  - specifications for attaching smart card readers to personal computers and workstations
  - compliance realized through a testing and certification process

- **Java Card Forum**
  - feeds recommendations for evolution of Java Card to Oracle

- **OpenCard Framework, PKCS, SIM Alliance, ...**

Examples of Issuer Specifications

- **EMV**
  - Multi-(credit/debit)-application architecture
  - A card-edge specification which includes card and terminal specification
  - Many variants exist (UKIS, VSDC, MCHIP)

- **G8 Health Standards**
  - Populating Personal medical info on Health card

- **ICAO (International Civil Aviation Organization)**
  - Machine Readable Travel Documents, e.g. ePassports

- **IATA (International Airline and Transportation Assoc)**
  - Smartcard-based ticketless travel

Software Architecture of a Smart Card

External API

I/O

Built-in Commands

Application Commands

Internal API

Base O/S

Built-in commands include a load application command
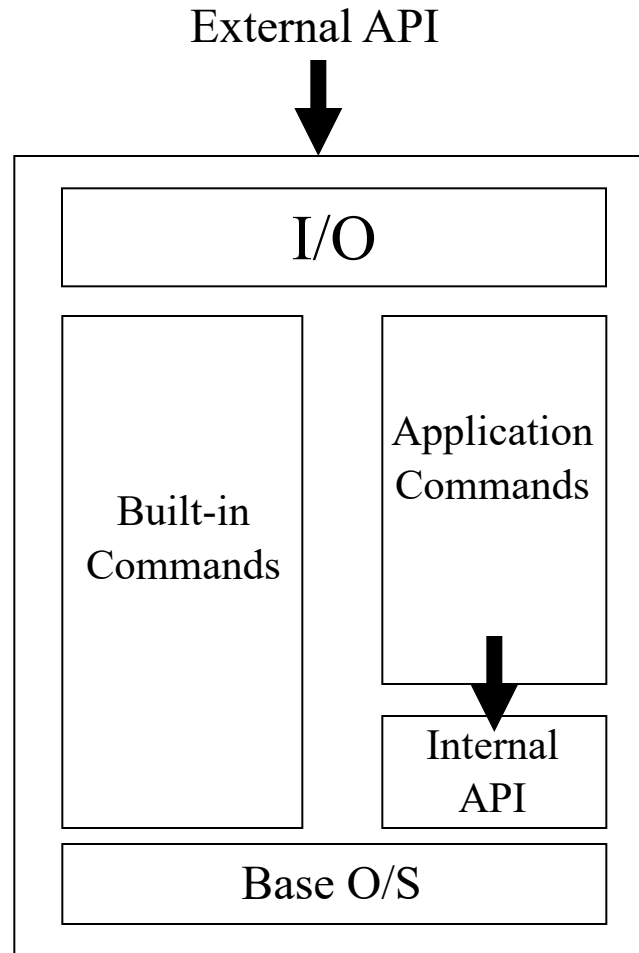
Card-Side Programming

Softmasks

Loadable
Modules

Shell Files

Native Code

Light-weight
Language - Forth

Medium-weight
Languages - C
and Basic

Heavy-weight
Language - Java

Virtual Machines
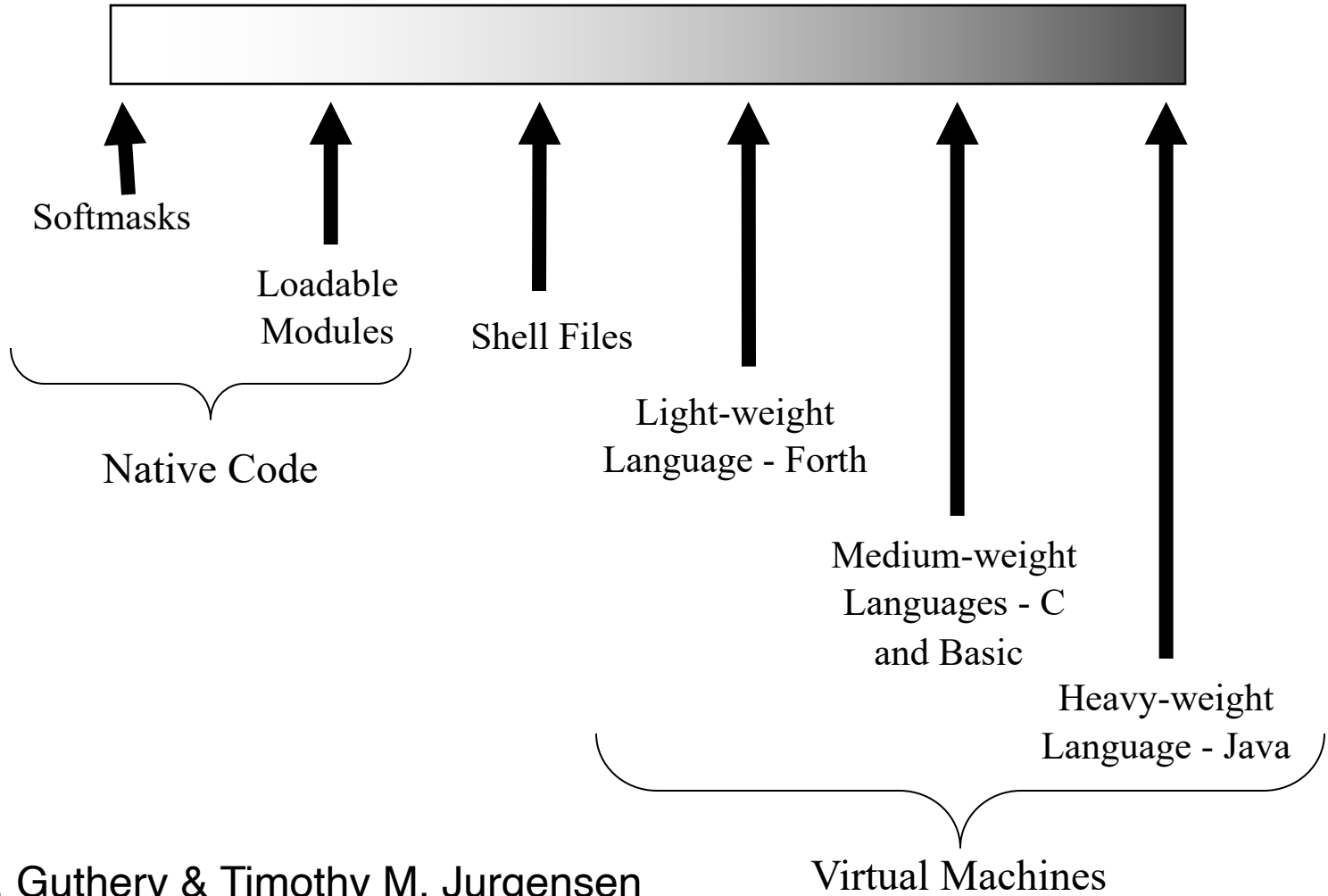
Softmasks

- Written in or compiled to native code

- Hook into the O/S loop at defined points
  - input byte, buffer full, pre-output, post-output, etc.

- Call O/S low-level routines

- Easy to add a command or modify an existing one

- Touching the manufacturer's "private parts"

Loadable Modules

- Written in or compiled to native code

- Well-defined (and modest) API - mostly the underlying commands; i.e. module is an on-card application

- Module "framework" of defined entry points

- Loading process varies from card to card

- Techniques for machine code verification can be applied

Virtual Machines

- Written in or compiled to VM byte code
- VM is typically a stack machine of some sort

```
PUSH A
PUSH B
ADD
```

- 20 to 200 times slower than native depending on amount of checking
- API between commands and low-level

VM Inner Loop

PICK NEXT BYTECODE

SET UP EXECUTION CONTEXT

CHECK SAFETY OF EXECUTING → **NOT OK** → ABORT

OK

CALL NATIVE CODE FOR THIS BYTE CODE

CLEAN UP EXECUTION CONTEXT
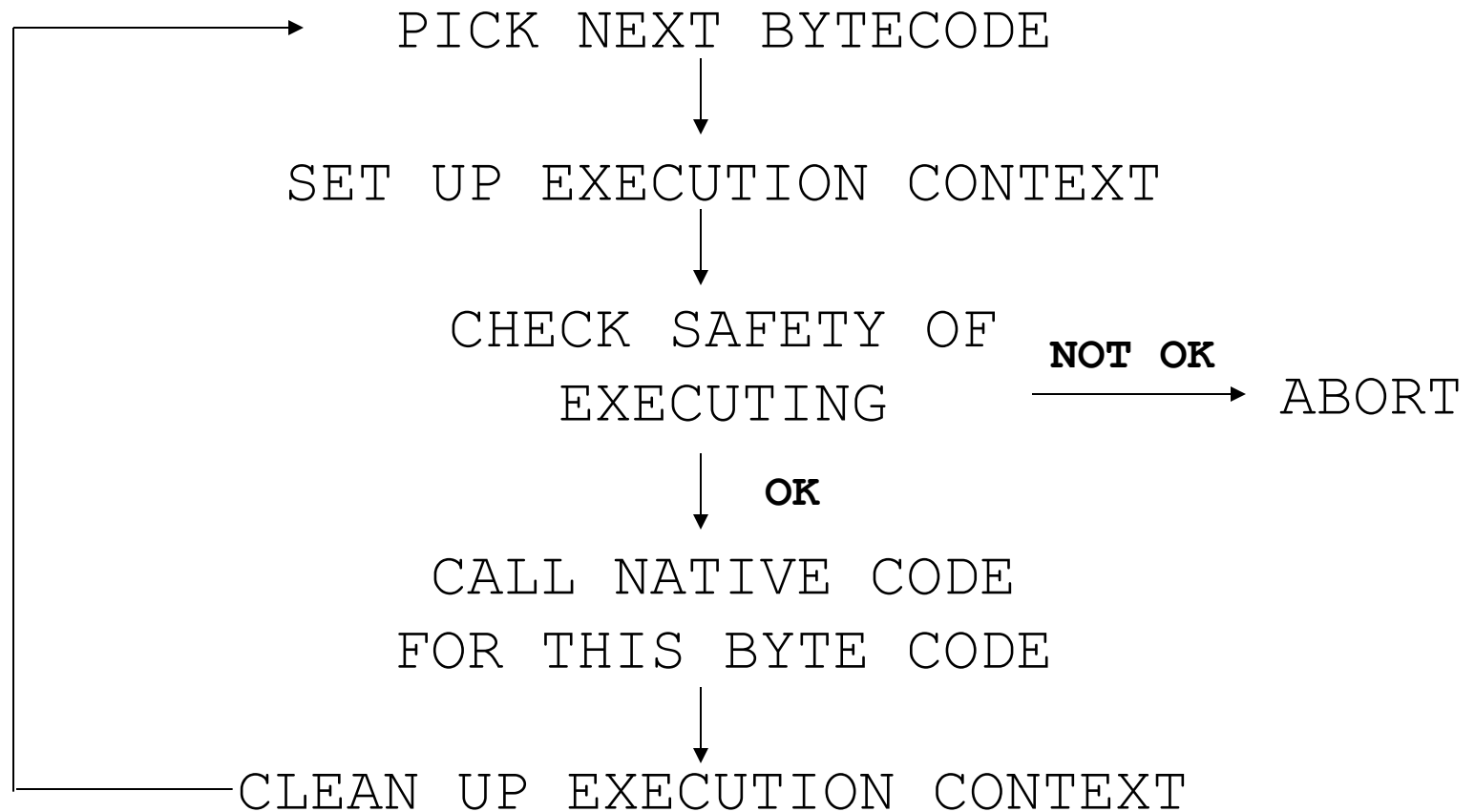
Java Card

- 18 ISO-7816 commands recast as 51 Java classes with 113 entry points

- Essentially an on-card version of OpenCard

- Partially defines a virtual ISO-7816 card

- No specification of search paths, security status modifications, file names, etc.

- Adds new non-ISO-7816 commands and data constructs

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MULTOS C

- Non-ISO-7816 operating system built for high-level languages

- C language runtime library file system semantics

- Mix (virtual) assembler and C

Basic Card

- ISO-7816-4 command template
  - build compliant ISO-7816 commands or roll your own

- Full-bodied Basic
  - volatile and non-volatile data
  - on-card P-code virtual machine

- T=1 communication with encryption

- Call *by reference* from host to card!

Smart Card Filesystem/ Database

■ **File structure (ISO 7816-4)**
- ◆ Cyclic files
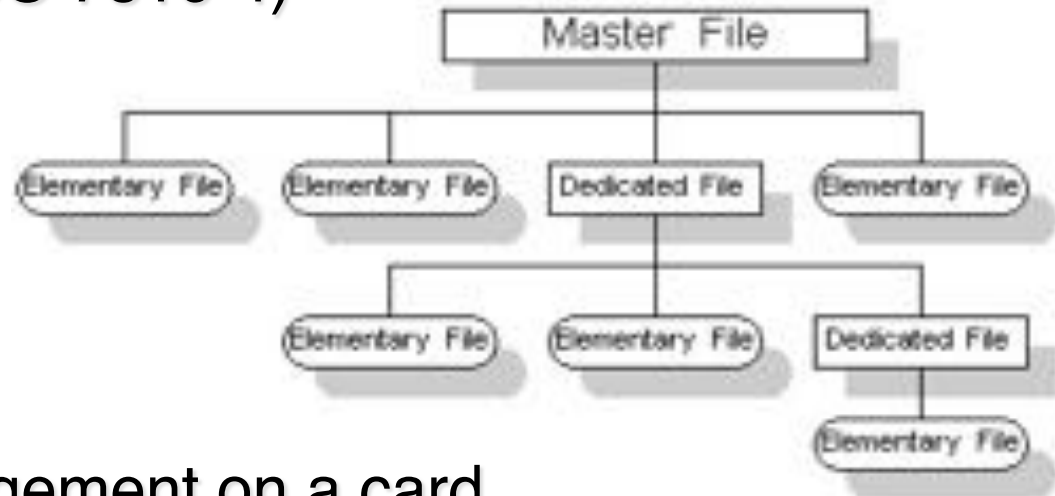
■ **Database management on a card**
- ◆ SCQL (Structured Card Query Language)
- ◆ Provides standardized interface
- ◆ No need to know file formatting details

Cyclic File

byte number

	1	2	3	4	5	6	7	8	9	• • •	m
1											
2											
3											
4											
• • •											
n											

record number
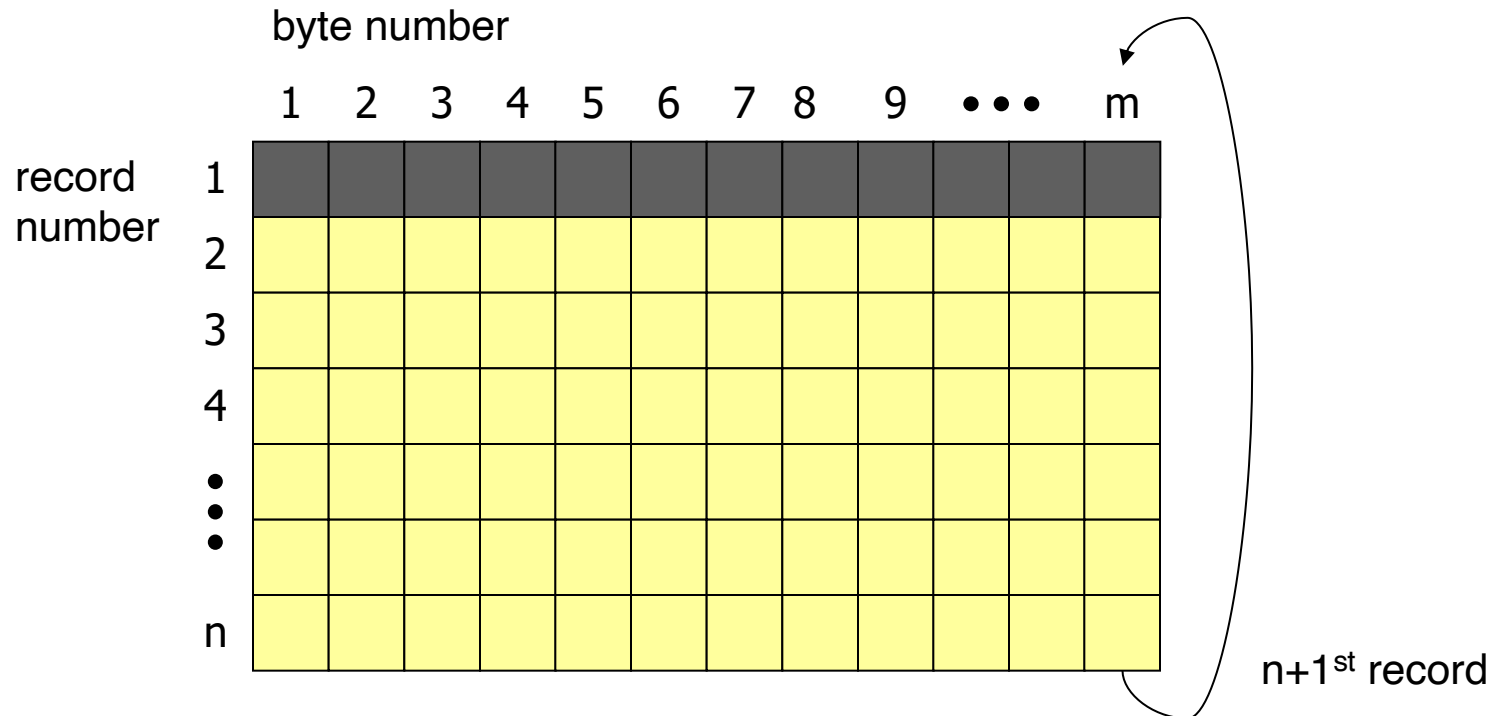
n+1st record

- READ gives the most recently written record
- Maximum number of records: 254
- When maximum is reached, first record is overwritten
- Record length: 1 .. 254 bytes

Cyberflex™ Java Smart Card

- Complete 32-bit Java run-time environment on a card
- Utilities for compiling and loading cardlets onto the card from a PC

CARDLETS

| 1 | 2 | 3 |

JAVA VIRTUAL MACHINE

OPERATING SYSTEM

MICROPROCESSOR
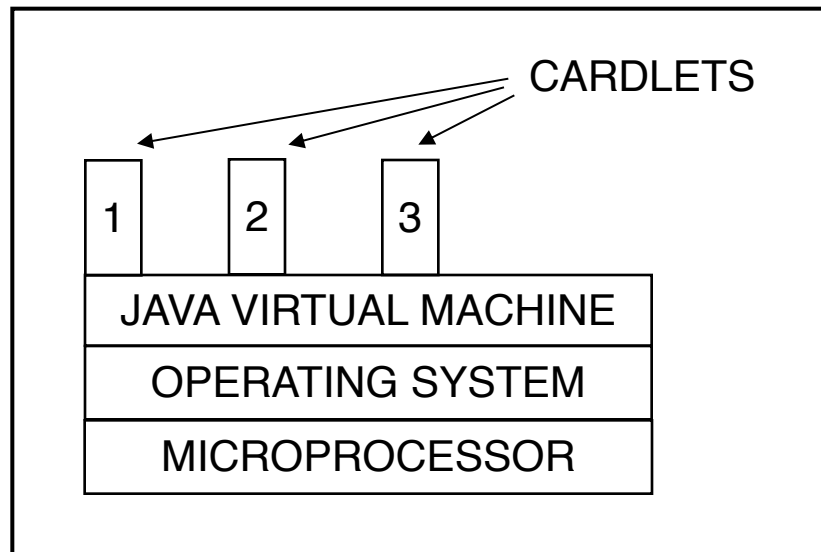
The (failed) Java Ring (late 90's)

- Java-enabled iButton

- Communicates by contact at 142 Kbps

- 64 KB ROM and 134 KB RAM

- Stores 30 digital certificates with 1024-bit keys

- Uses: authentication, epayment, access

- Cost: $15-30 in unit quantity

SOURCE: IBUTTON.COM

OpenCard Framework (OCF)

CardService Layer
(TALKS TO CARD)

CardTerminal Layer
(TALKS TO READER)

SOURCE: OPENCARD.ORG
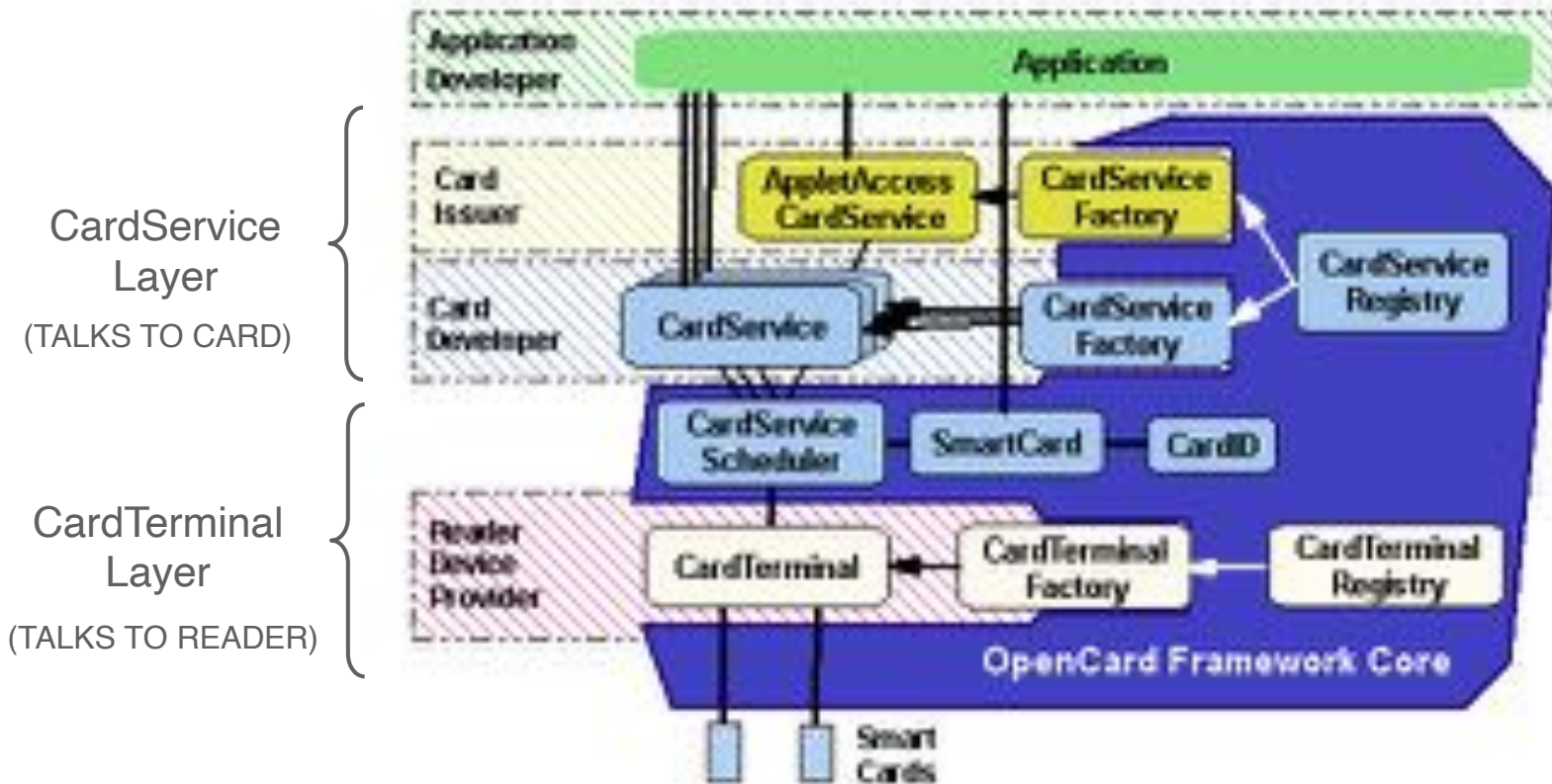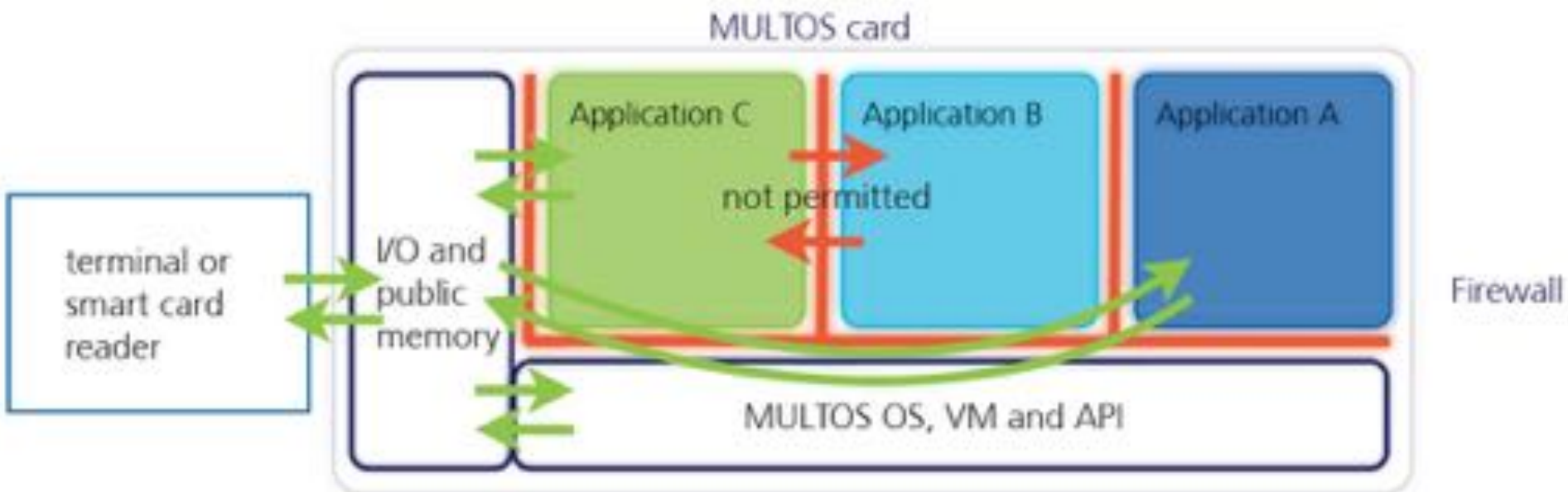
MULTOS Card

Hosting Multiple Applications on the same MULTOS Card

SOURCE: MULTOS
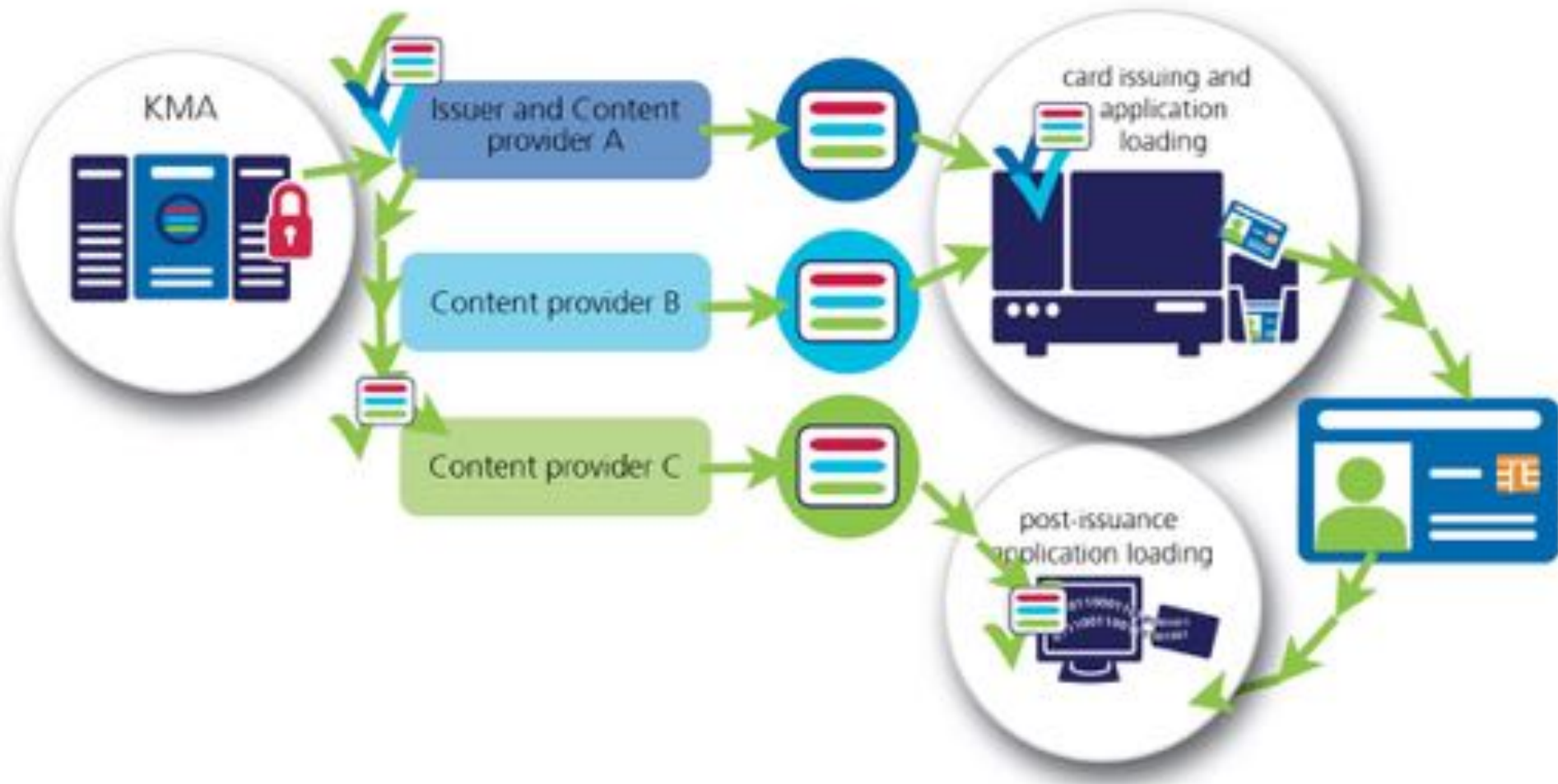
The MULTOS Scheme
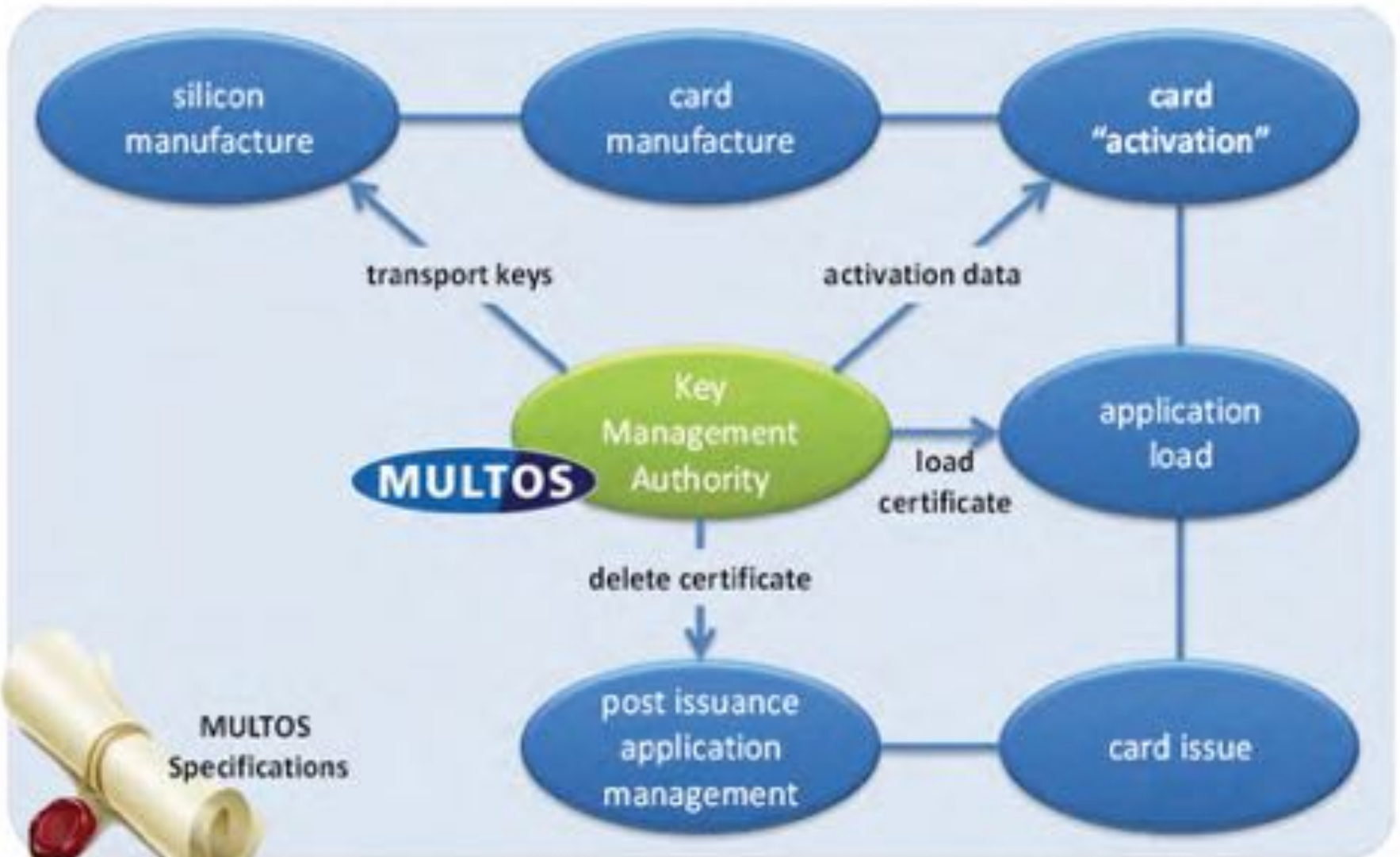
SOURCE: MULTOS

MULTOS Administration

14-COMPANY SMART CARD CONSORTIUM
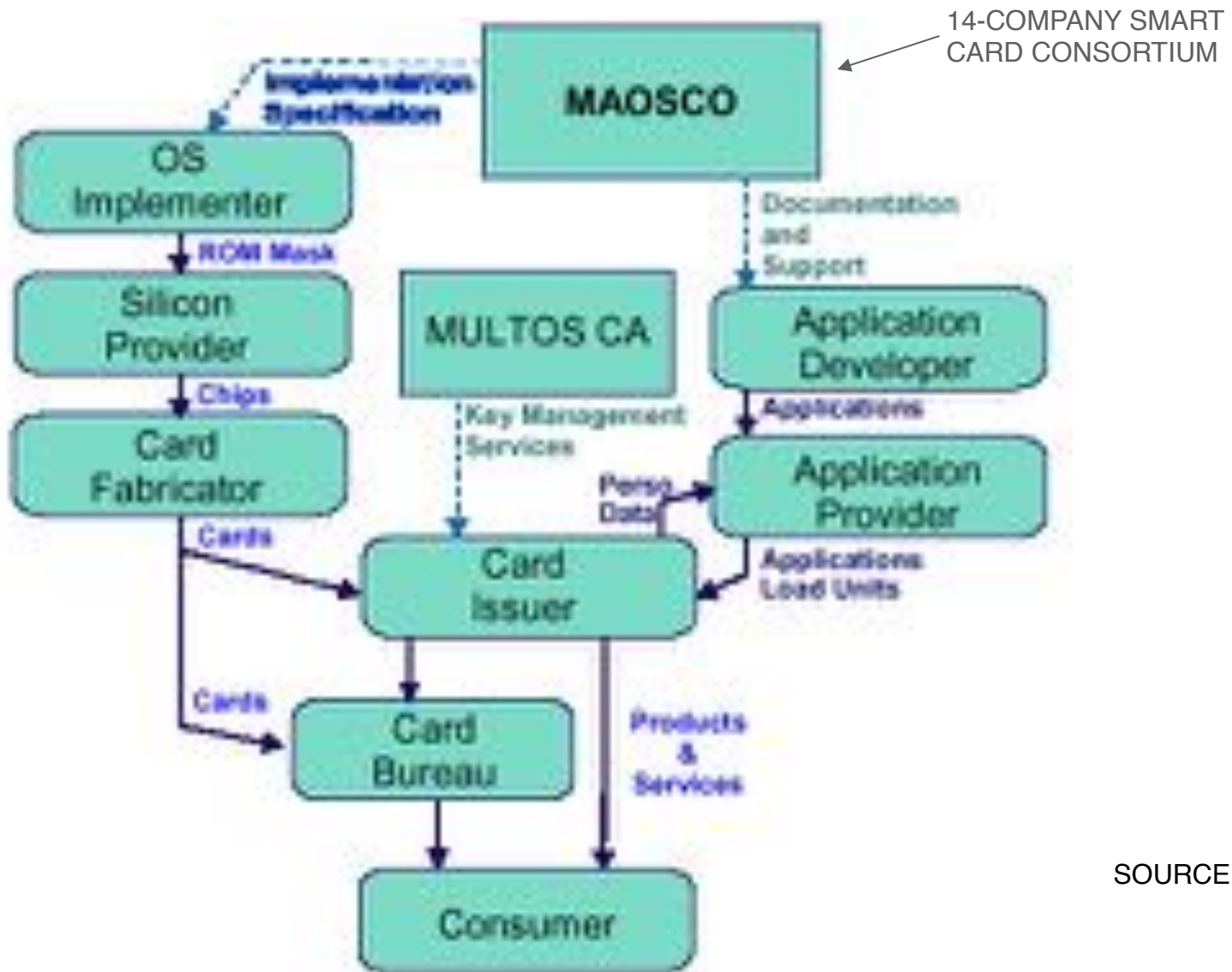
Card Management
Pre-Issuance: Manufacturing To Personalization

Module Construction

Wafer

Motorola, Atmel
Texas Instruments
SGS Thomson
Siemens, Hitachi

Probe

Dice

Die

Module

Protect

Assemble

Card Construction

Punch

Mill

Insert

Test - Serialize

Personalize

Example Card

Token Application	Loader Application			
JCRE	JCAPI	Card Management API		
Java Virtual Machine				
I/O	Crypto	Memory Mg'mt	Card Resource DB	Other Native Functions

Digital Identity

16
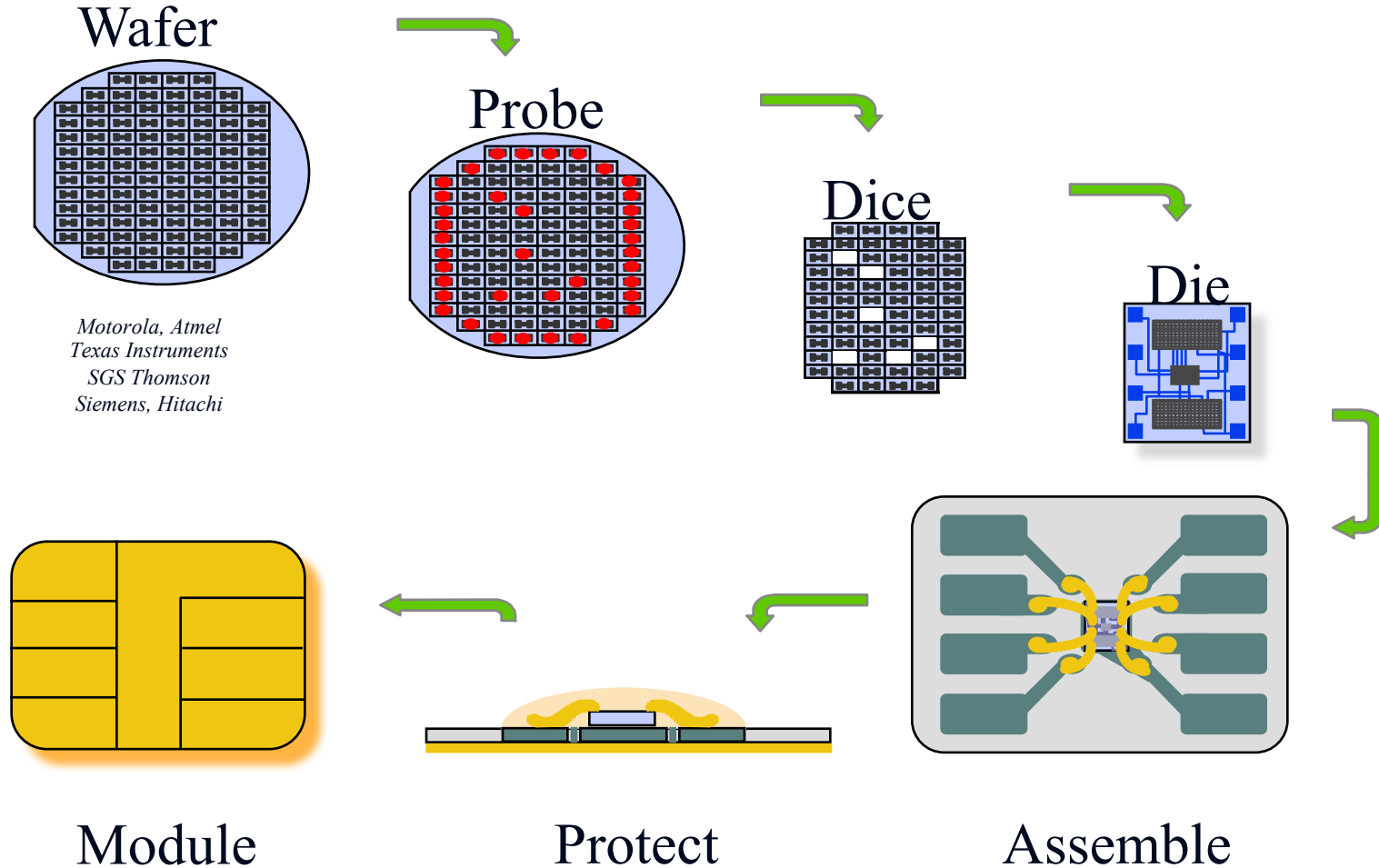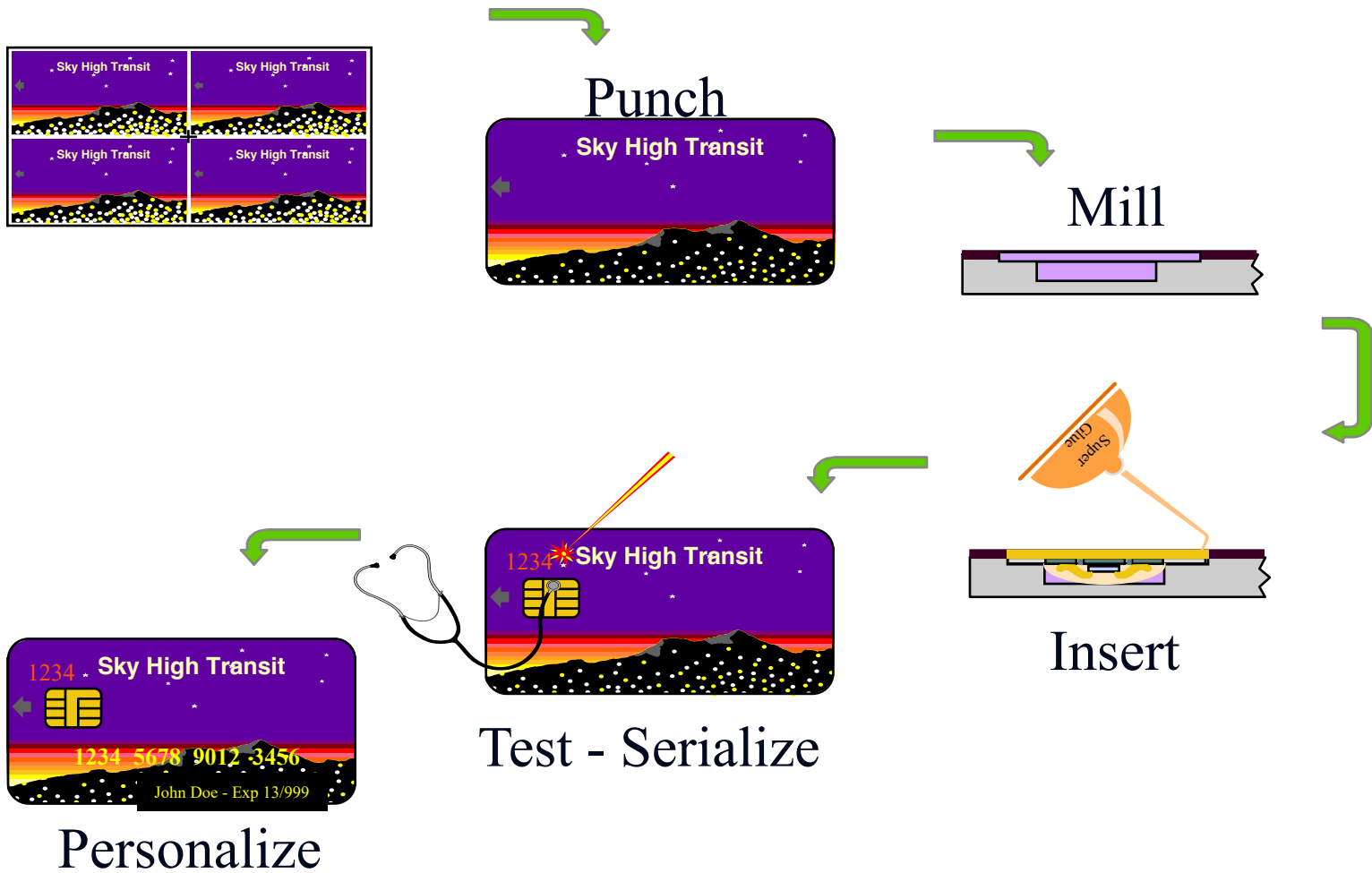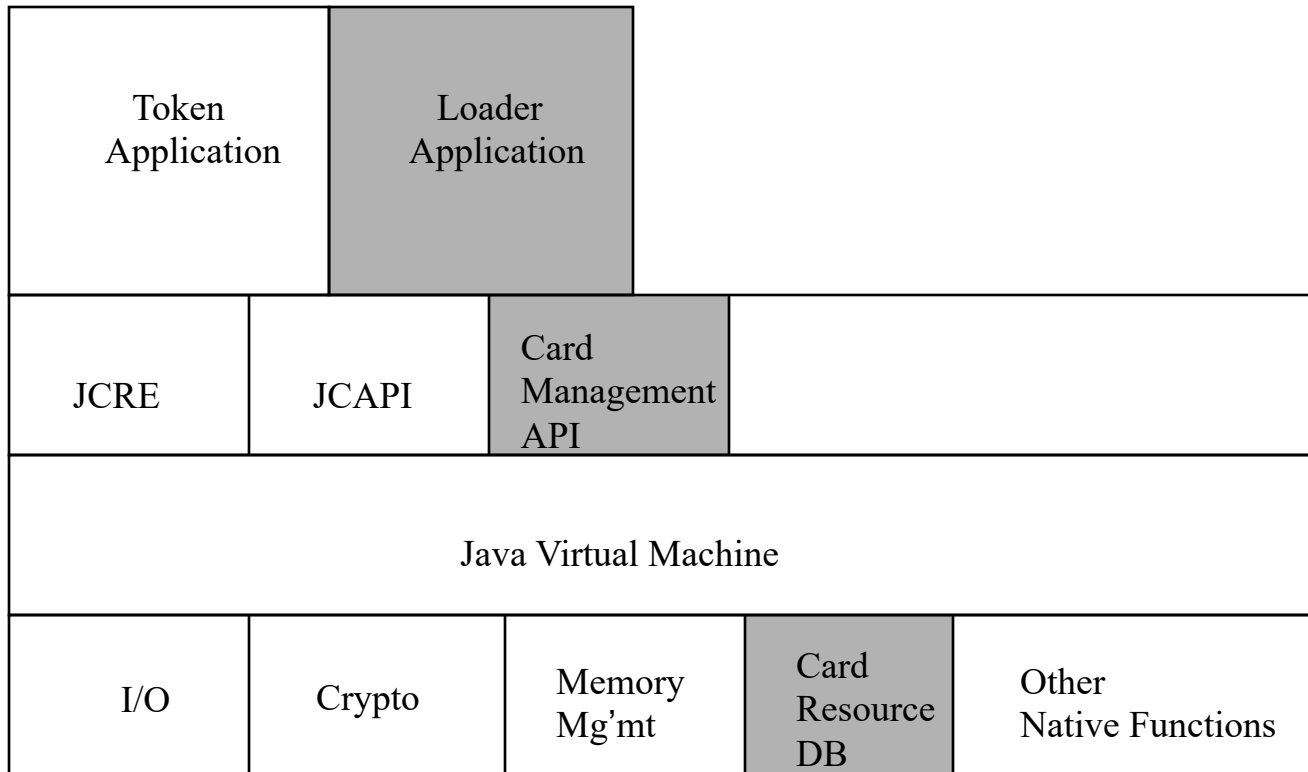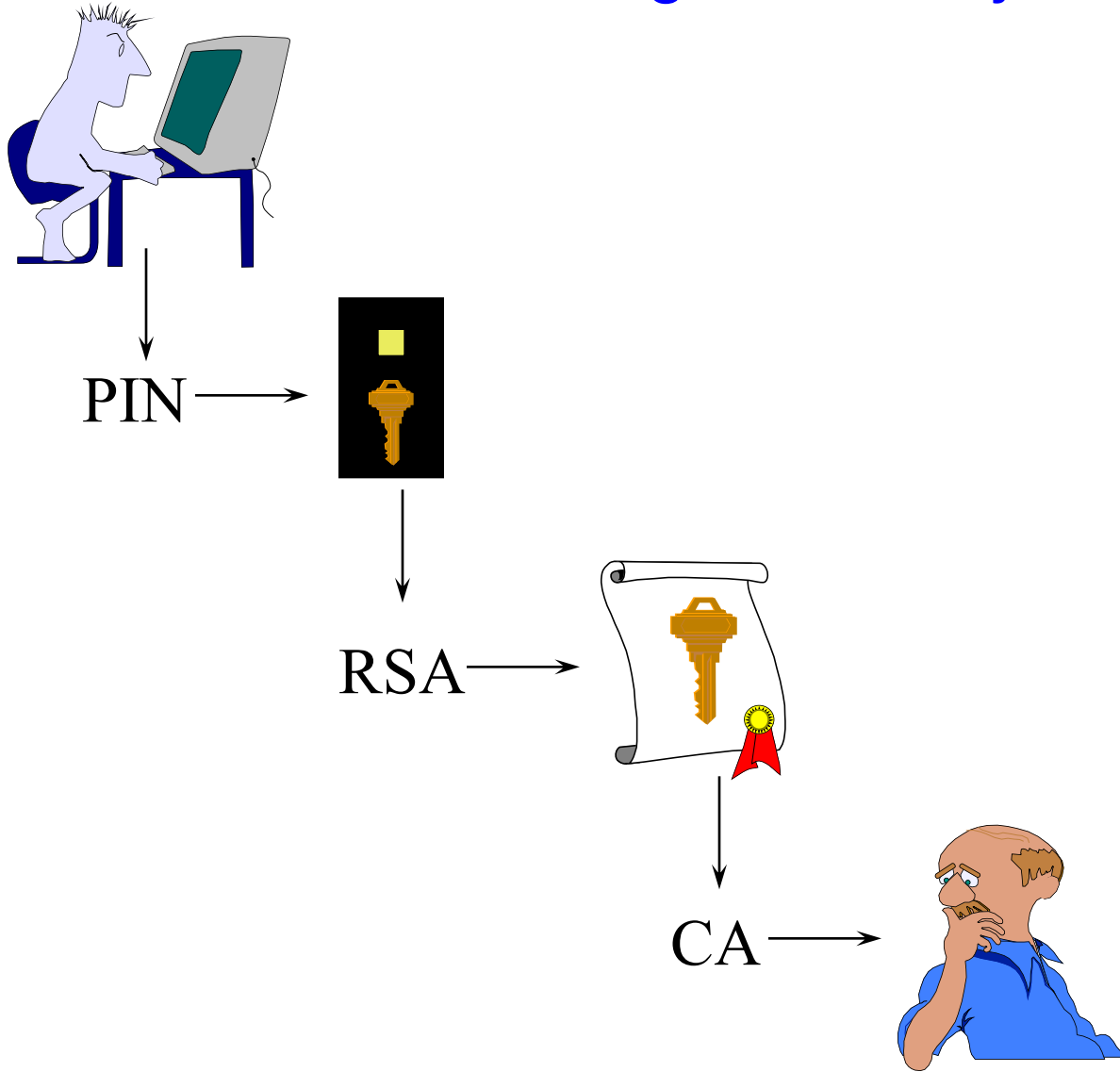
White Card Card Life Cycle
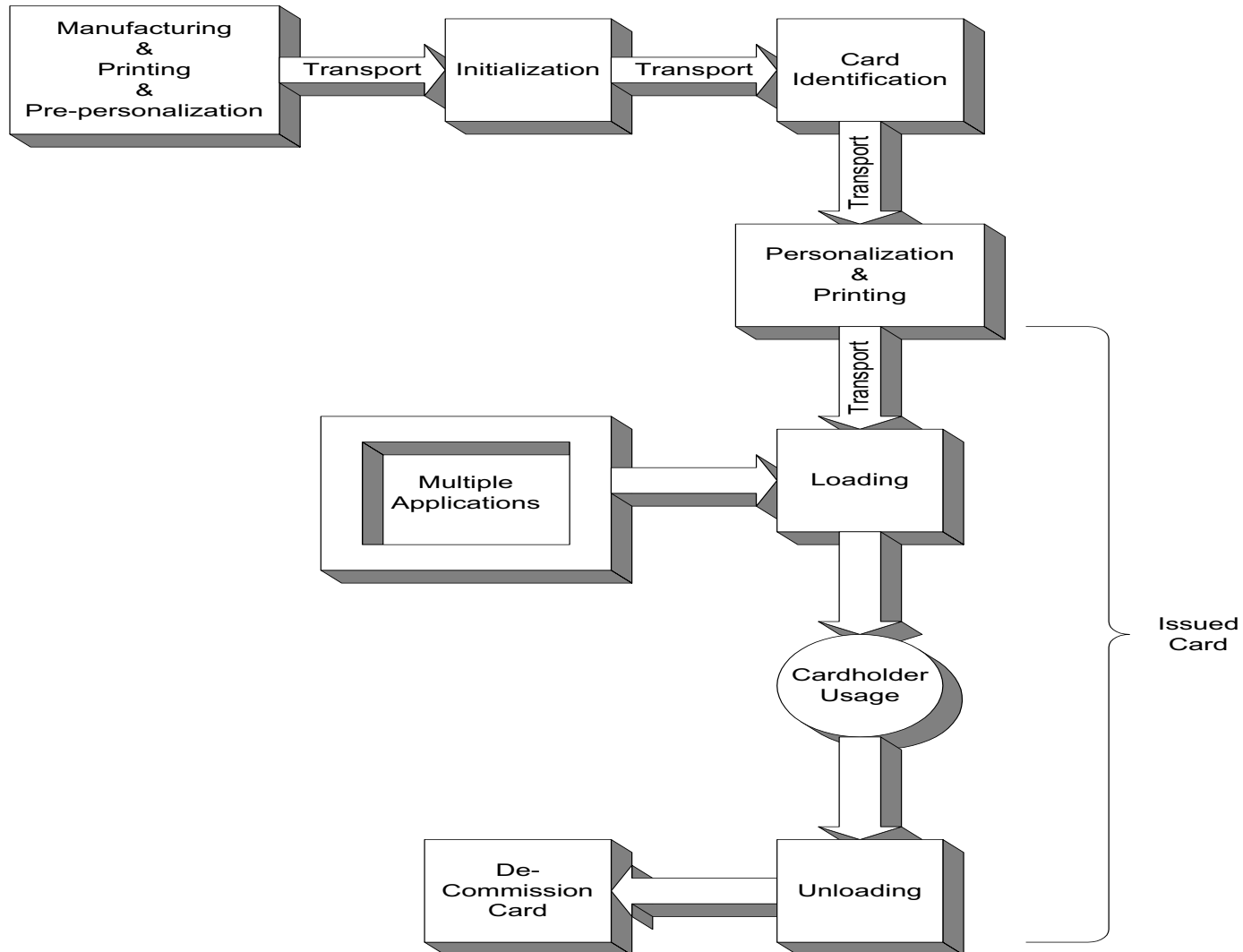
Smart Card Lifecycle

Chip Foundry

Card Manufacturer

Pre-personalization

Issuer

Personalization

Cardholder
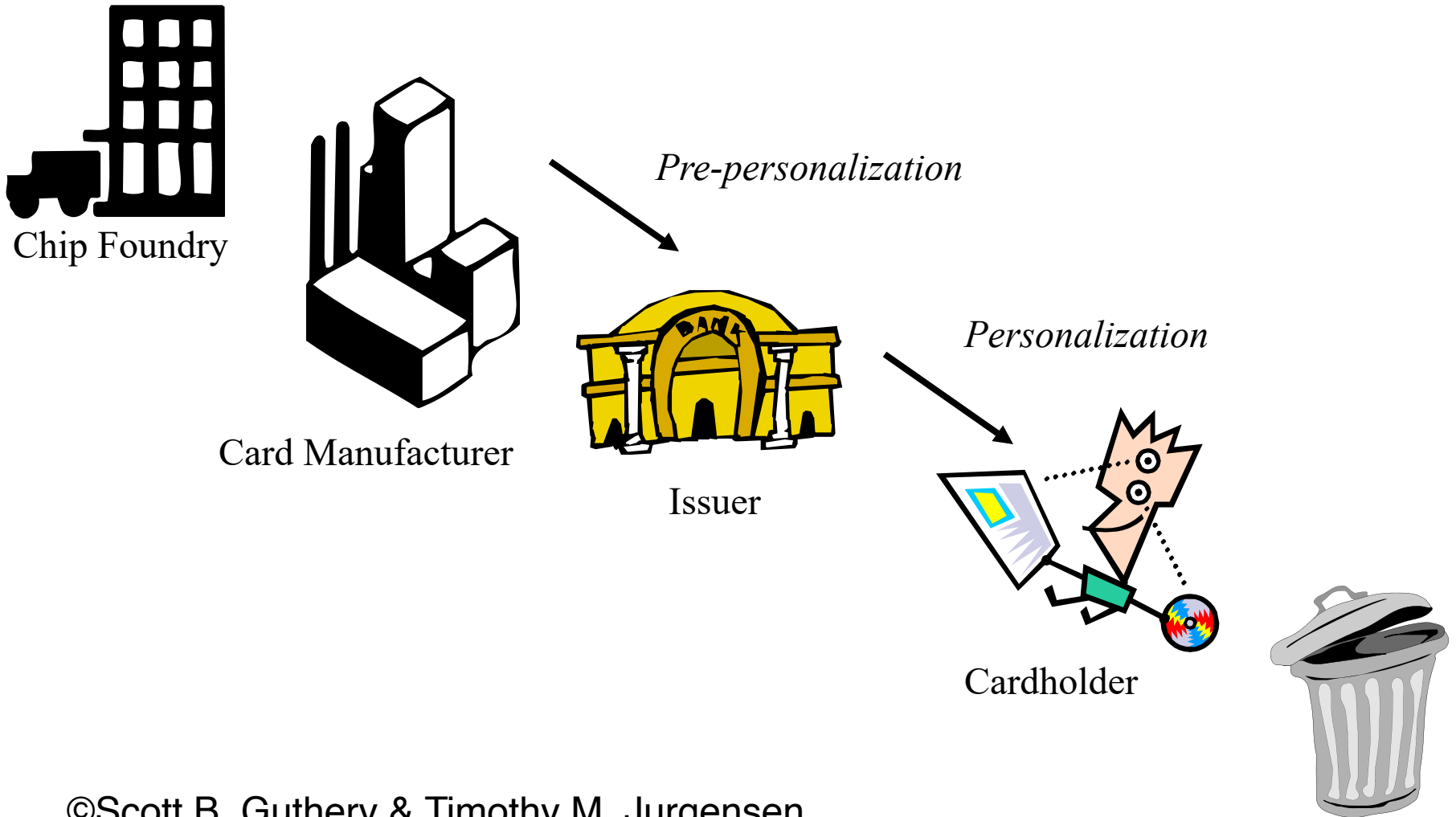
Smart Card Security

- **Observers**
- **Active defenses**
- **Attacks:**
- **Microprobing, microscopy**
- **Differential fault analysis**
  - ◆ (Boneh et al. 1997)
  - ◆ Induce errors, observe output differences
- **Differential power analysis**

SOURCE: Kömmerling et al.

Leaked Information:
Power consumption
Electromagnetic radiation
Other (Timing, errors, etc.)

INPUT MSG → Cryptographic processing (Encrypt / Decrypt / Sign / etc.) → OUTPUT MSG

Secret keys
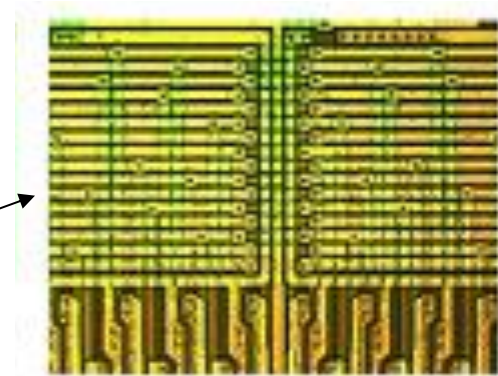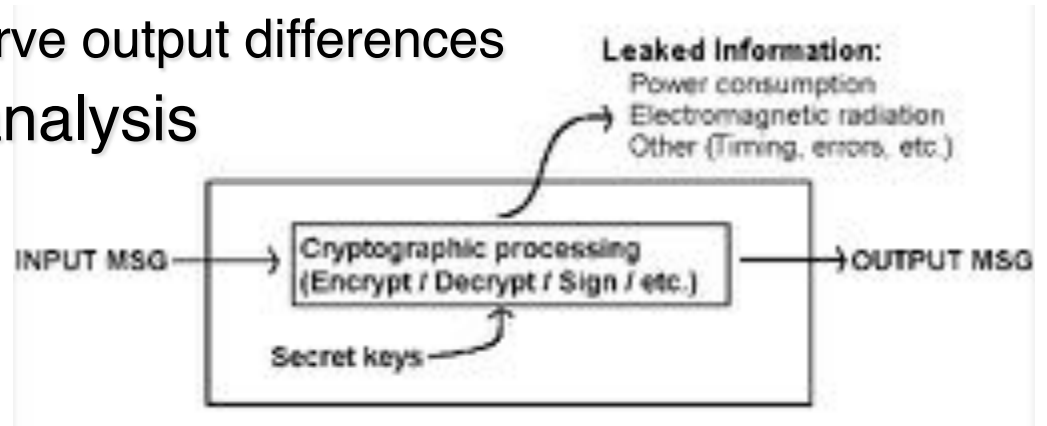
SOURCE: cryptography.com

Card Security Threats

Group 5
ATTACKS ON THE RUN-TIME ENVIRONMENT THROUGH THE CARD ACCEPTANCE DEVICE (CAD)

Group 6
THREATS FROM CARD APPS AND NEED TO SHARE RESOURCES

Group 7
THREATS BASED ON RTE IMPLEMENTATION

Clone

Future

Past

Current

Group 3
ATTACKS USING CARDS NOT YET ISSUED, OLD CARDS, CLONES

Group 1
DIRECT ATTACKS ON CHIP CIRCUITRY

Group 4
ATTACKS ON CARD'S INTERFACE TO THE OUTSIDE, E.G. PREMATURE REMOVAL

Group 2
INDIRECT ATTACKS ON CHIP CIRCUITRY

CAD

SOURCE: GAMMA

Power and Timing Analysis
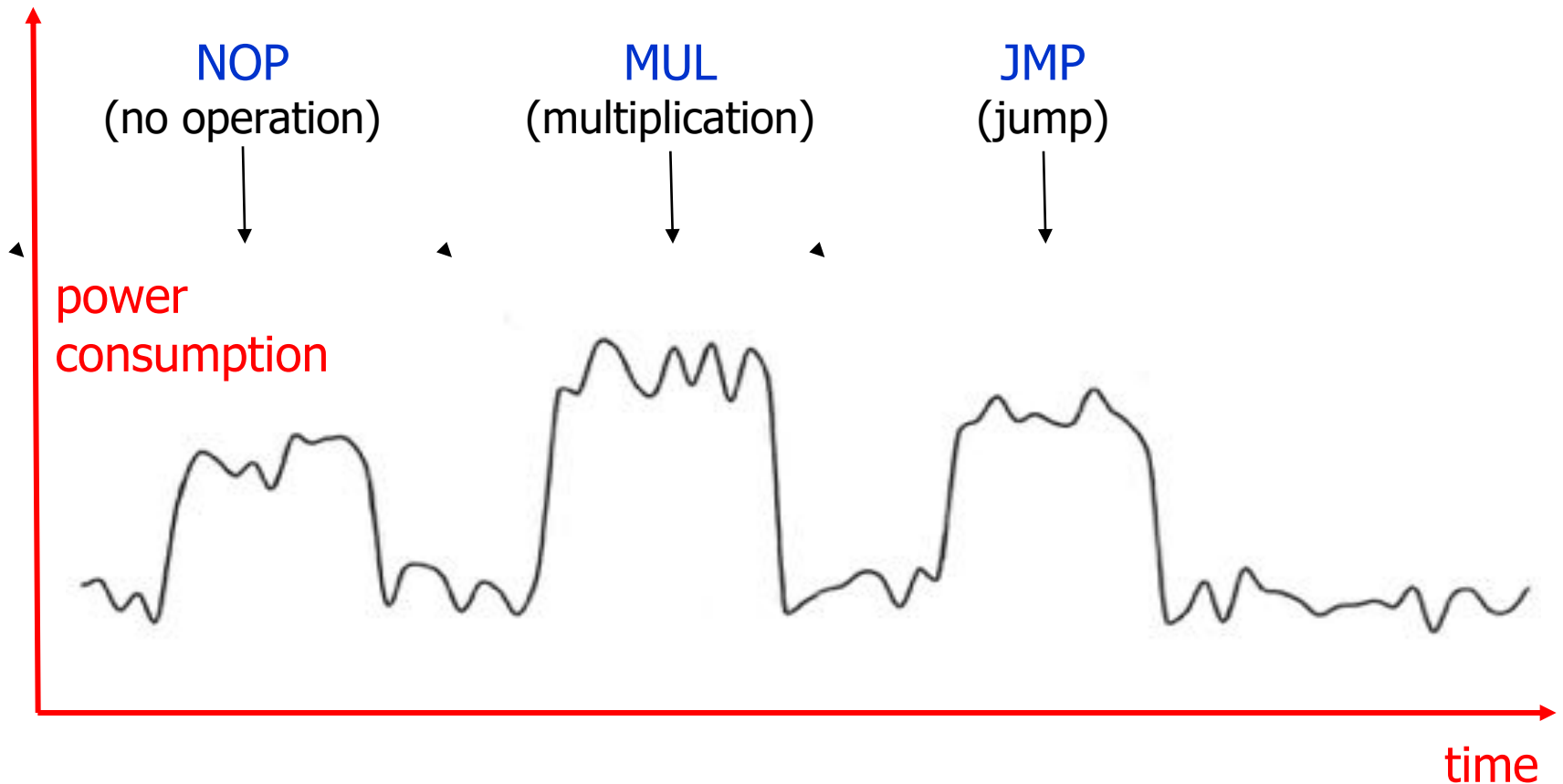
Source: Rankl and Effing, "Handbuch der Chipkarten", 2002

Differential Power Analysis

- **Send different inputs to the Smart Card to learn details of its encryption key**

- **When a correct key value is tried, the algorithm responds**

- **Incorrect keys have zero average response**

INITIAL PERMUTATION

SMART CARD POWER CONSUMPTION DURING DES ENCRYPTION

16 DES ROUNDS

FINAL PERMUTATION

EXPANDED VIEW OF ROUNDS 2 & 3
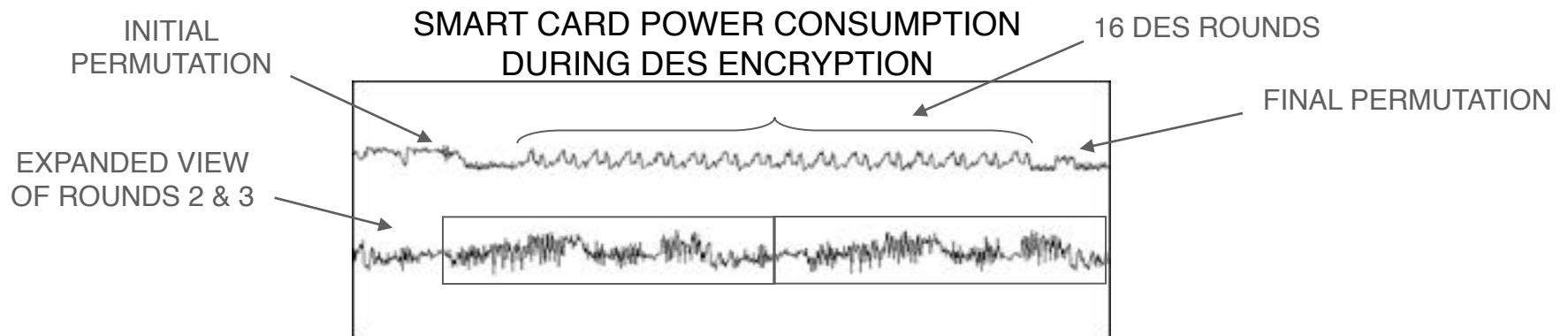
SOURCE: cryptography.com

Reverse engineering
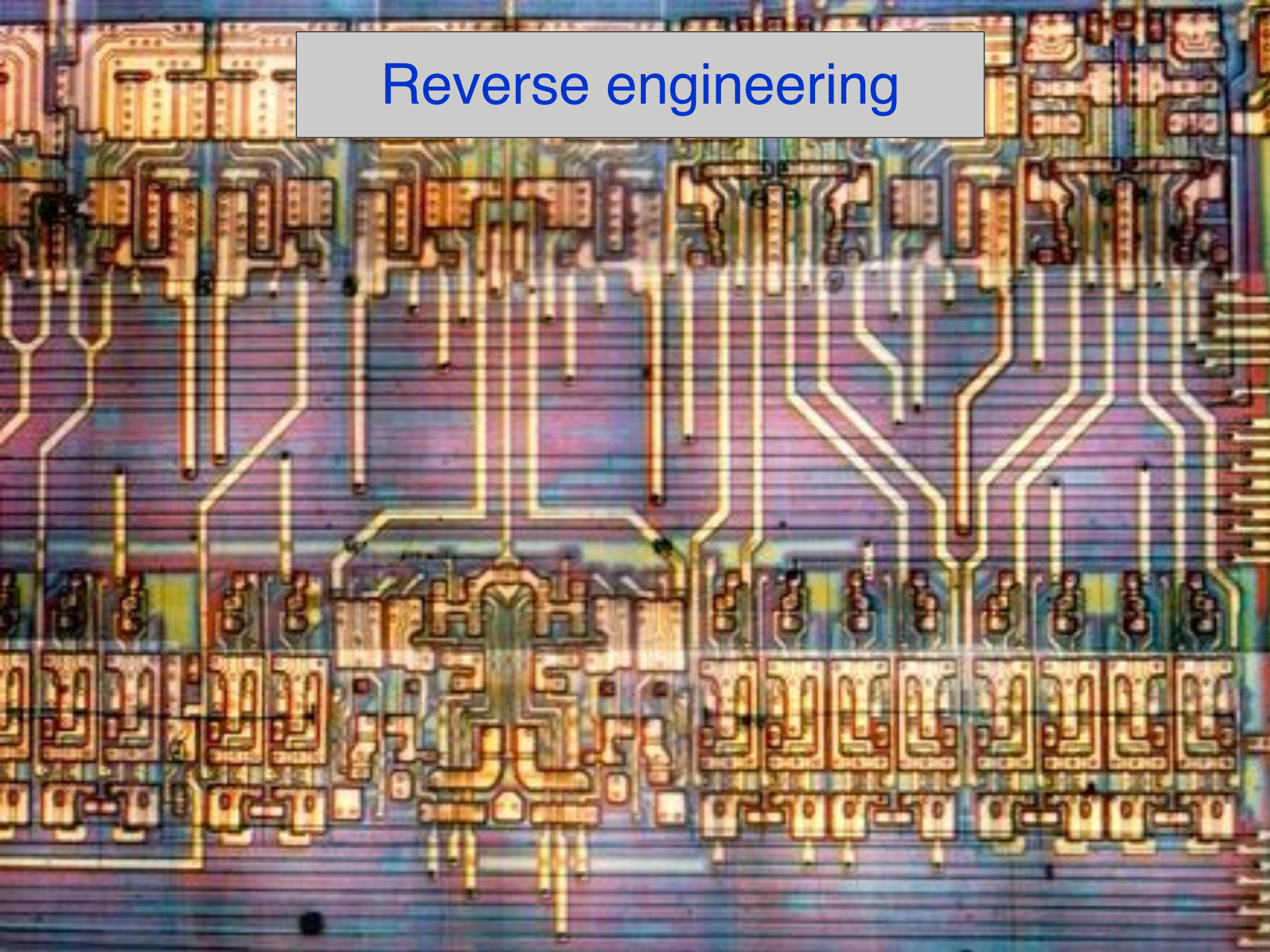
Probing with Needles
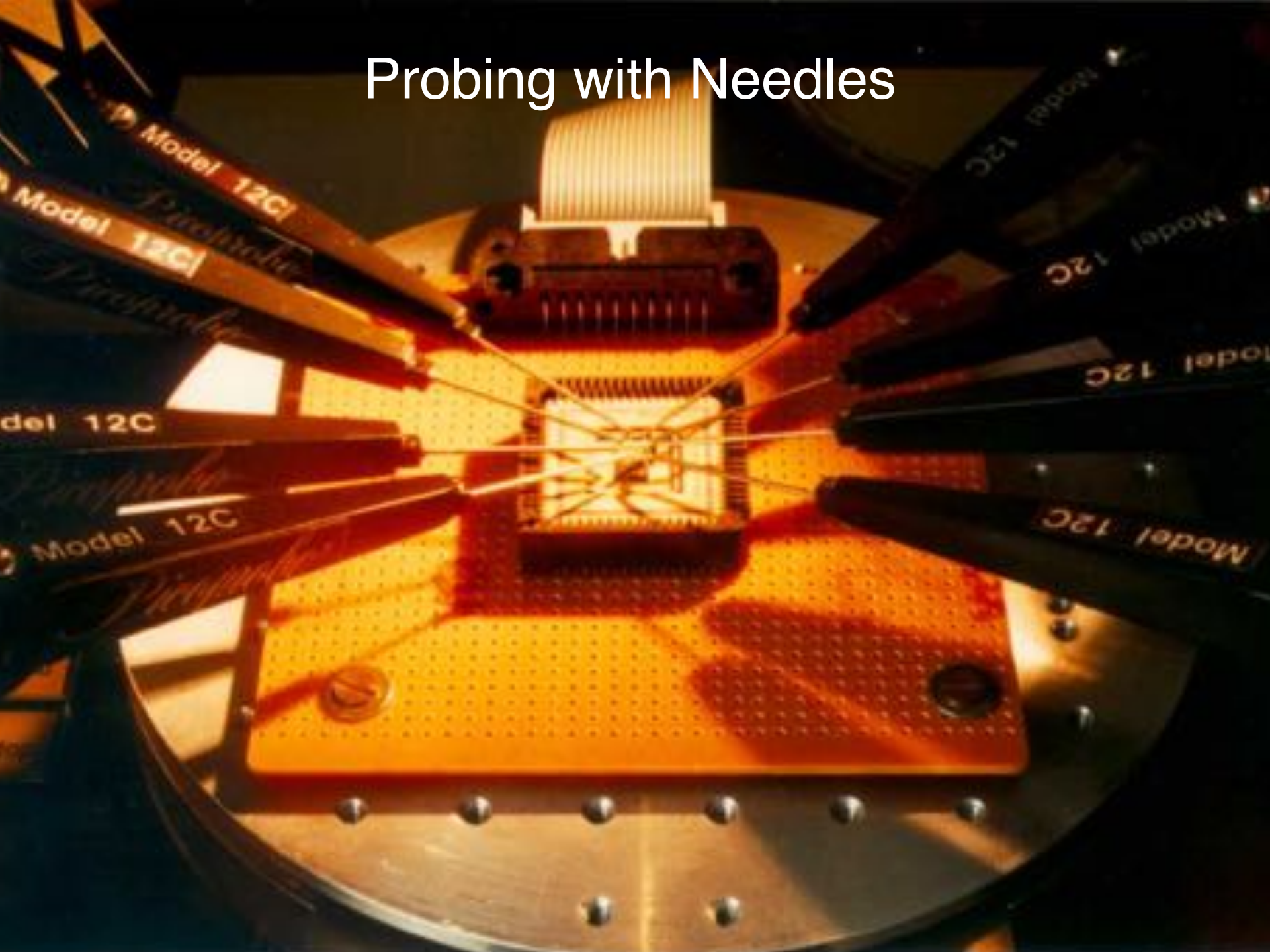
Security of the Protocol Messages

- Secure Messaging

- MACed Commands

- Payment Protocols

- Smart Card Transport

Secure Messaging

"… to protect (part of) the messages to and from a card by ensuring two basic security functions: data authentication and data confidentiality."

ISO 7816-4

SM - Authentication

Command N-1

Key

Command N
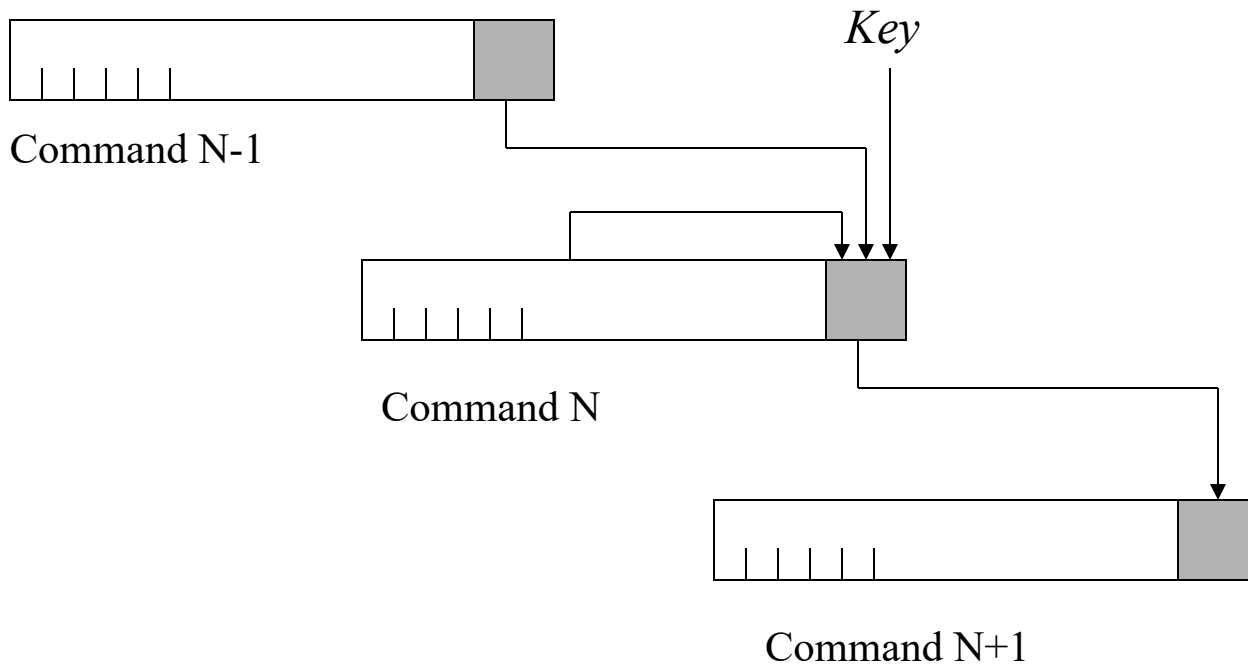
Command N+1

SM - Confidentiality

MACed Commands

Random Value

MACed Command

Key(Command || Random)
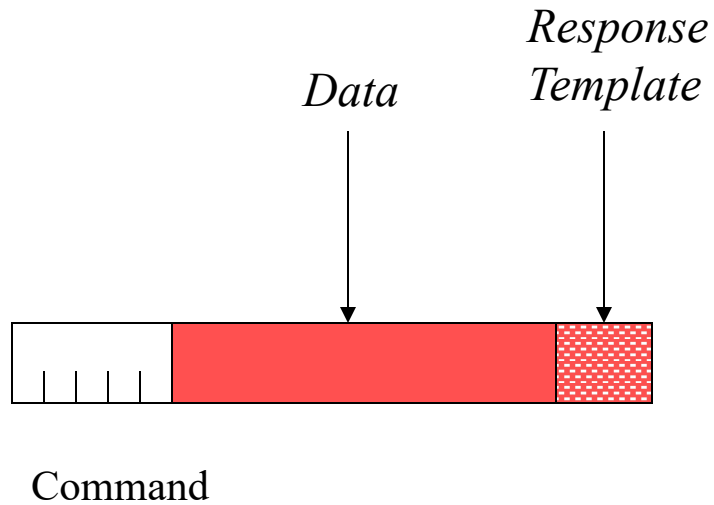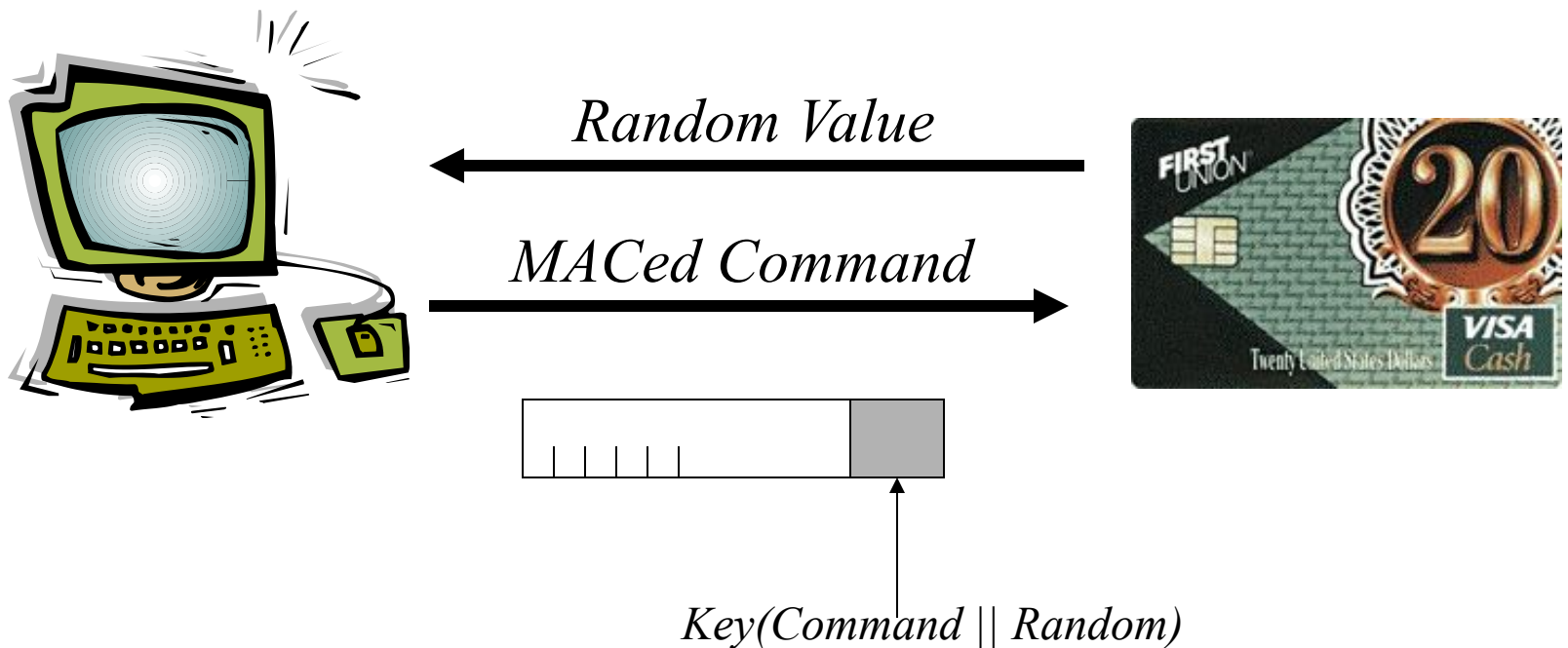
Trudy's Attacks

- Man-in-the middle (bucket brigade)
- Replay
- Reflection
- Overrun
- Wastepaper basket
- Rubber hose

Smart Card Transport

1) Lock with Foundry Key

Chip Foundry

1) Unlock with Foundry Key
2) Add serial number
3) Lock with Transport Key
4) Deactivate direct memory writing
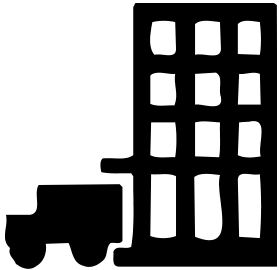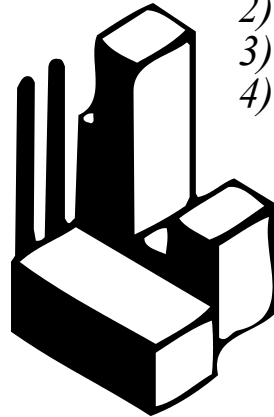
Card Manufacturer

1) Unlock with Transport Key
2) Add cardholder identity
3) Set unblocking keys and PIN
4) Activate special features

Issuer

1) Change PIN

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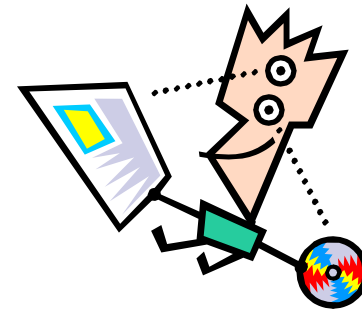
Cardholder

Smart Cards as Stored Value Facilities (SVF) for Micropayments

- Replacement of cash
  - Cheaper (cash very expensive to handle, stored, require anti-counterfeiting, with risk of loss/theft)
  - Electronic moves easier & faster (cash is not machine-readable, can't carry large amount)
  - Easier to count, audit, verify
- Small transactions, have low value, e.g. < US$1.00
  - Beverages, fast food, Phone calls, tolls, transportation, parking
  - Copying Machine, as well as Online/Internet content/ service
- Must process the transaction at low cost
- Technological savings:
  - Don't verify every transaction
  - No all use Public Key Technologies but pure symmetric encryption
- Float-preserving methods
  - Prepayment
  - Grouping
    - Aggregate purchases (to amortize fixed costs)
    - Provide float to processor
    - Partial anonymity (individual purchases disguised)

SVF vs. Prepaid Cards for Micropayments

- **Prepaid cards**
  - Issued by non-banks
  - Represent call on future service
  - Not money since usable only with one seller
- **Electronic purse (wallet)**
  - Issued by bank
  - Holds representation of real money
  - In form of a smart card (for face-to-face or Internet use)
  - In virtual form (computer file for Internet use)
  - The two forms are converging, e.g. wireless

Stored Value Facilities (SVF) aka E-Purses/Wallets
(Since mid-to-late 90's)

QIANFLEX (CHINA)

AUSTRIAN QUICK

PRISMERA

PEOPLE'S BANK OF CHINA ePURSE

CYBERFLEX JAVA CARD

Stored-Value SIM Cards

Payment Cards

- Java
- XML, smartX
- PC/SC and OCF OpenCard Framework
- MultOS
- Windows for Smart Cards
- Card-resident app, terminal-resident app
- Card interacts with Web

Payment Cards

- 8-128 Kb

- Data rate 115 Kb/sec

- ISO 7816 compliant

- Visa-certified

- PIN management and verification

- 3DES algorithm for authentication, secure messaging

- Epurse with payment command set (debit, credit, balance, floor limit management)

EMV =
EUROPAY INT'L,
MASTERCARD,
VISA

MPCOS =
MULTI PAYMENT CHIP
OPERATING SYSTEM

SOURCE: GEMPLUS

SVF (Electronic Purse) Issues

- Loading (charging) the purse with money
- Making a payment (removing money from the card)
- Clearance (getting money into the seller's account)

Smartcard Payment Protocols: Design Considerations

- **Mutual Authentication**
  - card and terminal must be part of same (closed) system
- **Particular Attention to Man-in-the-Middle Attacks**
  - design for and think in terms of off-line use
  - all authorized parties to the transaction have to be made and kept whole
- **Two-Stages**
  - debit then credit to avoid creating money in case something does go wrong
  - this is another example of built-in disincentives to tampering, experimentation and fraud

Smart Card Payment Protocol Patents

- **US4007355**: Data-transfer system (Moreno)

- **US4736094**: Financial transaction processing system using an integrated circuit card device (Yoshida)

- **US5623547**: Value transfer system (Jones, Higgins)

- **US5637859**: Method and apparatus for exchanging information with subscriber cards used in article vending machines (Menoud)

- **US5635695**: Chip card based payment system having an on-card flag for specifying proper completion of a prior card balance replenishment session (Feiken)

A Simple Dual-Card Protocol

- Security Access Module (SAM) is the representative of the merchant and the acquiring bank behind him ; SAM is usually installed inside the POS terminal like a SIM card

- Payment Card is the representative of customer and the issuing bank behind him, like our Octopus card

- In many cash and stored value systems, acquiring and issuing entity are the same; i.e. the keeper of the value pool

- Most protocols count on a shared secret between the Payment card and the SAM; i.e. they use symmetric keys

- *Diversified Key*: Payment cards all have different keys and SAM computes a card's key by applying a secret function in the SAM to the card's unique identification number.

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Simple Payment Protocol – Stage I: Debit

Payment Card to Terminal (e.g. Coke Machine): Here's a transaction no. and a nonce.

Terminal to Secure Access Module (SAM = Merchant's card): Cardholder wants to spend $1 and here's the transaction number and nonce from the Payment card.

SAM to Terminal: OK, here's a debit certificate consisting of the transaction number and nonce plus a debit flag and the amount.

Terminal to Payment Card: the cardholder wants to spend $1 and here's the permission from the *SAM* to debit the purse.

Payment Card to Terminal: I have checked the debit certificate and it's fine. So I'll debit the purse and remember the amount and the fact that I owe the *SAM (the Merchant)* a credit.

Simple Payment Protocol – Stage II: Credit

SAM to Terminal: Here's my transaction number and a nonce.

Terminal to Payment Card: the cardholder wants to spend $1 and here's the transaction number and nonce from the *Merchant (SAM)* .

Payment Card to Terminal: I see I have a credit outstanding for that amount so here's a credit certificate consisting of the transaction number and nonce plus a credit flag and the amount. Please deliver this credit to the Merchant (SAM) for me.

Terminal to SAM: the cardholder really wants to spend $1 and here's the permission from the payment card to credit your purse.

SAM to Terminal: It all checks out fine, so I'll credit the purse of Merchant. You can now dispense the Coke to the customer.

Diversified Keys

- Simple session key protocol for a one-to-many situation like a vending machine

- Unique key for each card without maintaining a list of card keys

```
Card Key = Crunch(Card Serial Number & Master Key)
```


Serial Number

Identity

Encrypted Message
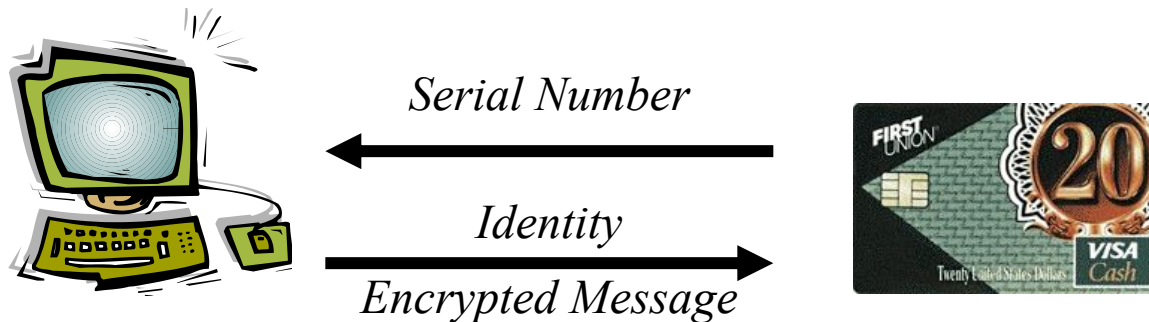
GeldKarte
(German: "Money Card")

- Issued by Zentraler Kreditausschuß (Germany) since 1996
- Card contains counters representing money value
  - Max balance 200 EUR ; Average transaction value = 3 Euros.
  - By 2009, 132 million Euros were spent through GeldKarte.
- Card is loaded through a loading terminal
  - Debits customer's bank account
- Spending at merchant terminal or on Internet
  - Amount deducted from card, added to merchant terminal (card)
  - No real-time authorization
- End-of-day: merchant uploads transactions
- Money credited to merchant account
- Bank fee: 0.3%, minimum USD 0.01
- Many banks now issue cards with Contactless GeldKarte functionalities (branded as Girogo).

Loading GeldKarte

LOADING TERMINAL (ATM)

1. LOAD REQUEST + PIN

8. VALUE TRANSFER

2. AUTHORIZATION REQUEST

5. AUTHORIZATION

SAM
LOADING MANAGER

7. SAM EXCHANGE

SAM
ISSUING BANK

9. OFFLINE FILE TRANSFER

4. AUTHORIZATION

3. AUTHORIZATION REQUEST

6. UPDATE ACCOUNTS

SAM = SECURITY APPLICATION MODULE

AUTHORIZATION SERVER

ACCOUNT DATABASE

SOURCE: SHERIF
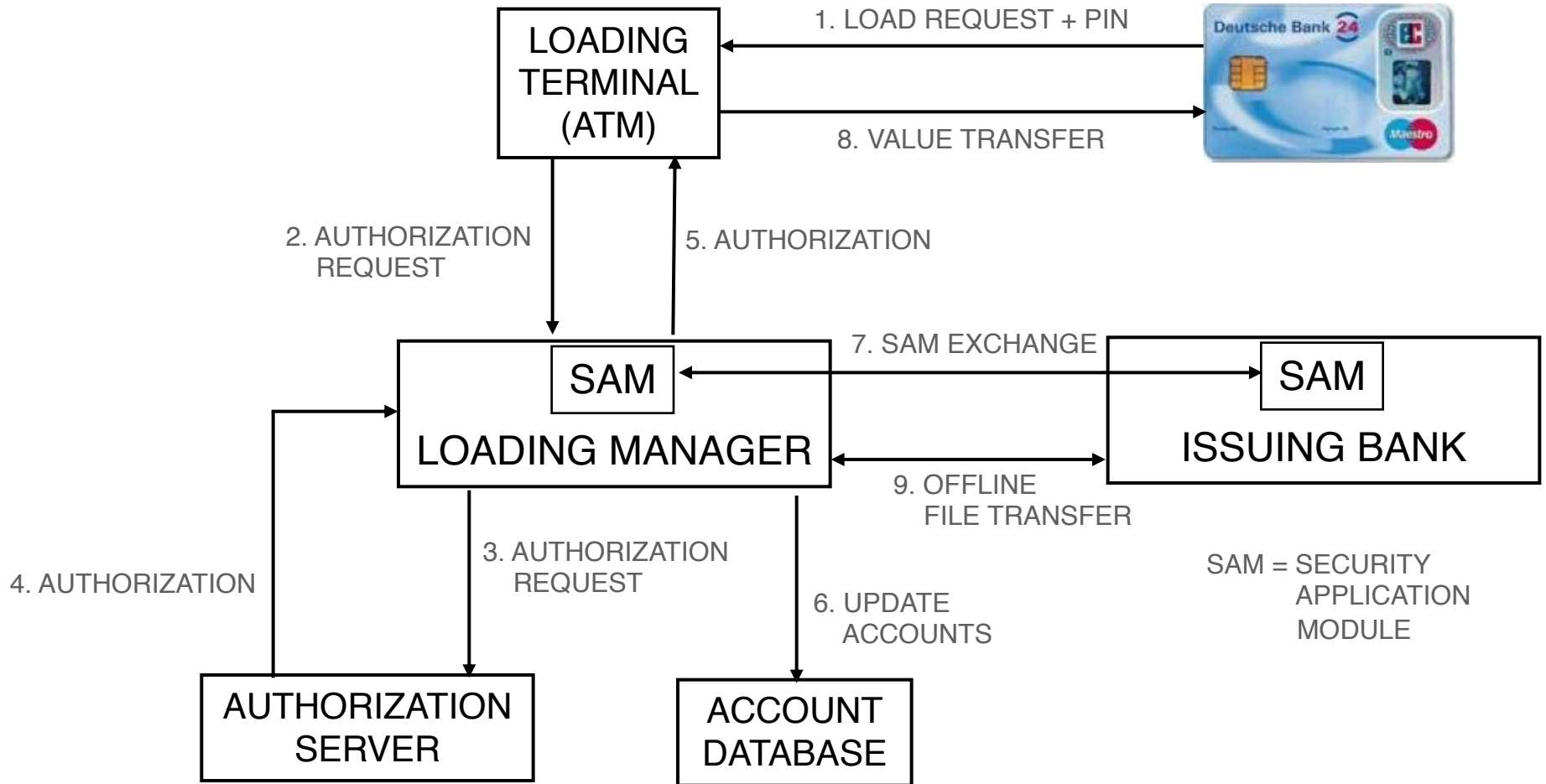
GeldKarte Payment

- Customer inserts GeldKarte in slot (at merchant terminal or PCMCIA card)
- Merchant authenticates customer card
- Customer authenticates merchant card

OFFLINE
(NO THIRD PARTY)

- Transfer purchase amount
- Generate electronic receipts

- (Later) Merchant presents receipt to issuing bank to obtain credit to merchant account
- No purse-to-purse transactions

GeldKarte Card Authentication

- Merchant SAM generates a random number RAND (to prevent replay attack), sends to customer card with request for customer card ID (CID)

- Card sends CID, a generated sequence number SNo, RAND, and H(CID) encrypted with a symmetric secret key SK_C (known to card, not customer)

- No public-key encryption

- Merchant computes SK_C from CID and his own secret key SK_M (known to card, not merchant)

- Merchant can now validate integrity of the card message by computing H(CID)

GeldKarte Value Exchange

- Customer sends StartPayment message

- Merchant sends MID, merchant's transaction number TNo, SNo, a MAC encrypted with SK_c, CID and the value M to be transferred, all encrypted with SK_c

- Customer can decrypt this message with SK_c and validate merchant

- Customer checks CID, M and SNo (prevent replay)

- Customer card verifies at least M remaining, subtracts M, increments SNo, records payment data, generates proof of payment and sends to merchant card:

$$\{ M, \quad MID, \quad SNo, \quad TNo, \quad ANo, \quad MAC \}$$

AMOUNT	MERCHANT ID	CUSTOMER SEQUENCE #	MERCHANT SEQUENCE #	CUSTOMER ACCOUNT #	MESSAGE AUTHENTICATION CODE

GeldKarte Value Exchange, cont.

- Merchant verifies payment:
  - compute actual payment amount M' from the proof of payment, compare with M
  - verify MID and TNo
  - increment TNo, increase balance by M
  - notify merchant of success
  - record transaction data with different secret key K_{ZD}
- Merchant requests payment from bank (later)
  - sends encrypted proofs of payment to bank
  - TNo prevents more than one credit per transaction

GeldKarte Clearing

■ Uses a "shadow account" (Börsenverechnungskonto) to track the contents of the card

  ◆ When card is loaded, shadow account is credited

  ◆ When money is spent, shadow account is debited

    ✦ online transactions immediately

    ✦ offline transactions later

■ If card is lost or damaged, money can be replaced

■ Problem: every transaction is recorded, no anonymity

■ Solution: "Weisse Karte." Bought for cash, not connected to any bank account

GeldKarte Security

- DES (customer), triple DES (merchant) (cipher block chaining or cipher feedback mode)
- 128-bit hashes
- Each card has unique ID, unique symmetric key, PIN stored in "secret zone" and in bank
- Unique transaction numbers

GeldKarte for Internet Payment and beyond

"Caroline" Trusted Wallet Device

GeldKarte Reader USB or Infrared Connection to PC

CASHMOUSE

■ Contactless Card supporting GeldKarte has become available ; branded as Girogo, as a "Prepaid" function supported by the Girocard (Debit-card)

girocard
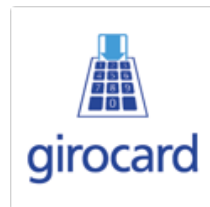
Other Smartcard-based Payment Systems/ Protocols

■ **Cash vs. Stored Value vs. Credit/Debit**

■ **Danmont and Mondex**

- ◆ the original smart card cash protocols
- ◆ Danmont is accounted, Mondex is anonymous

■ **VisaCash, Proton, GeldKarte, …**

- ◆ Danmont led to many follow-on systems

■ **EMV for debit/credit**

- ◆ EMV was first attempt at describing a multi-application card

■ **CEPS Protocol**

© Scott B. Guthery & Timothy M. Jurgensen

Payment Media Evolution

RFID Tags

IC Chip

Antenna
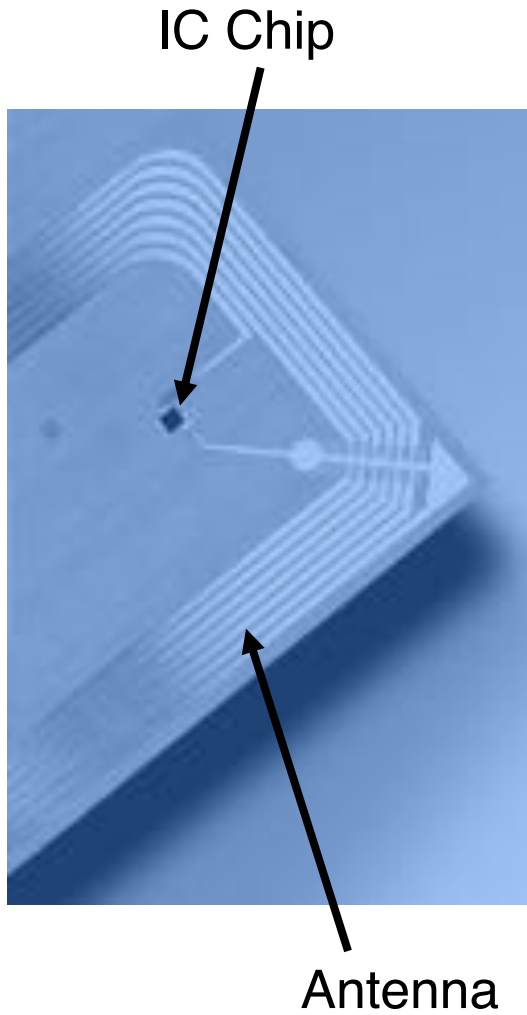
32mm and 23mm
capsule transponder

How RFID Works

- Tag enters RF field
- RF signal powers tag
- Tag transmits ID, plus data
- Reader captures data
- Reader sends data to computer
- Computer determines action
- Computer instructs reader
- Reader transmits data to tag

Antenna

Tag

Computer

RFID
Reader

SOURCE: PHILIPS
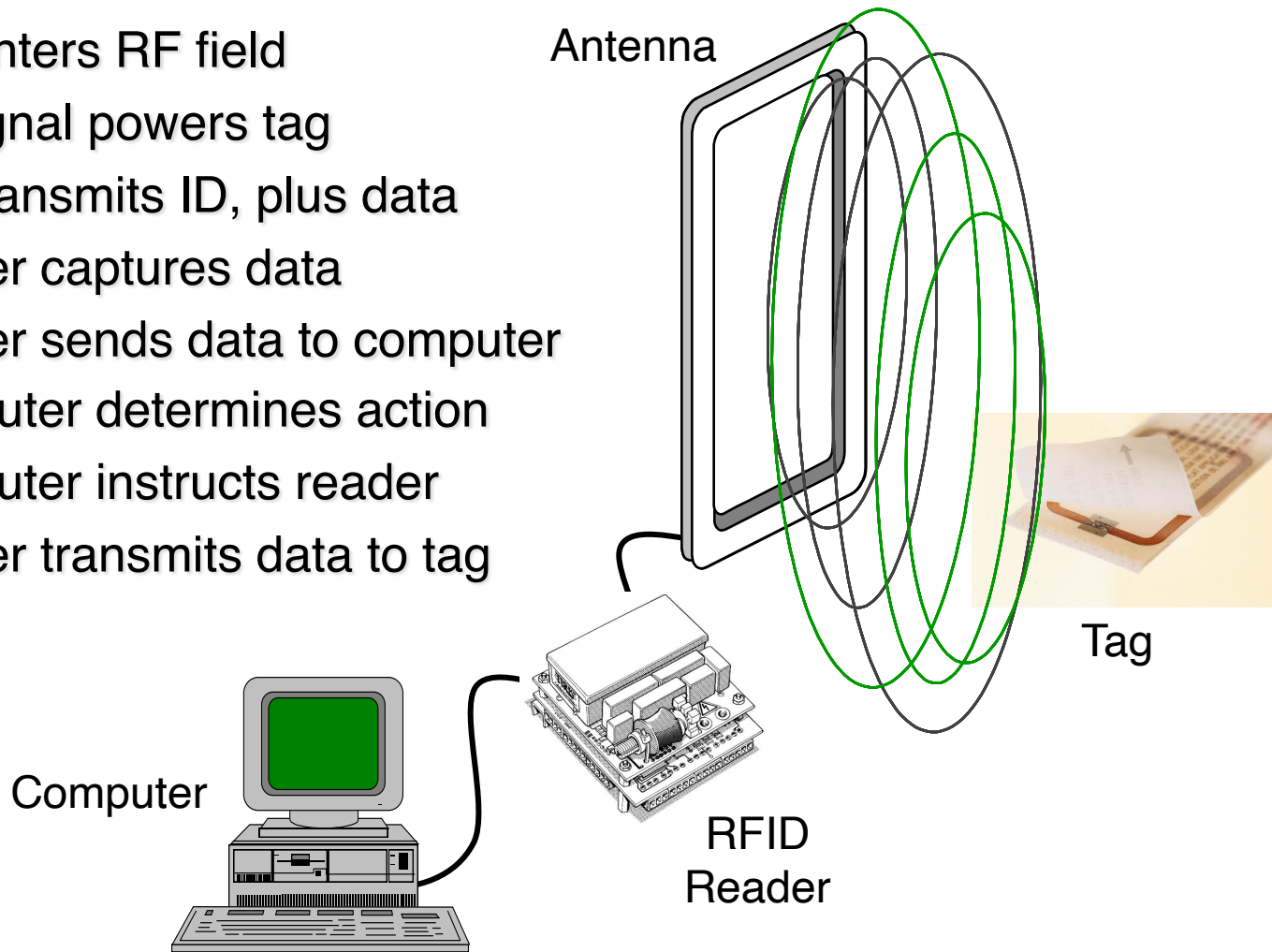
Euro Banknotes

■ In 2001, European Central Bank has announced planned to implant RFID tags in banknotes by 2005

• Uses
  – Anti-counterfeiting
  – Tracking money flows

■ BUT the plan NEVER materialize !

Typical spec for Contactless and RFID tags (circa 2005)

Class	Frequency	Speed	Storage	Apps	Memory
Proprietary	125-134 kHz	4kbps	8-2kbits	Access, Inventory	ROM, EPROM
Proprietary (EPC)	866-956 MHz	20-100kbps	512bits	Tolling, Inventory	ROM, EPROM
ISO18000	2.45GHz	40kbps	512bits	Tolling, Inventory	ROM, EPROM
ISO 14443	13.56Mhz	106, 212, 424, 848kbps	64bytes – 64kbytes	Access, Payment	ROM, RAM, EEPROM, FRAM
ISO 15693	13.56Mhz	26Kbps	1kbit, 2kbit, 16kbit	Access, Inventory	ROM, RAM, EEPROM, FRAM

Contactless Smart Cards

- **Communicates by radio**
- **Power supplied by reader**
  - Low Frequency (LF) Proximity (low-cost) Card: 125-134 kHz ; typical usage for Door Access
  - High Frequency (HF) at 13.56MHz (ISO 14443/ 15693 standards) for ID credentials, Passports, Bankcards (ISO 14443 standards)
  - Effective range: 10 cm, signals encrypted
  - Ultra High Frequency (UHF) operates at 433 to 953 MHz has longer range upto 30 feet, 10-15 feet for good accuracy ; commonly used in RFID tags for logistics applications and asset tracking
  - Data rate: from ~100 Kbit/sec upto 848 KByte/sec (NXP Mifare)
  - Read 2.5 ms, write 9 ms
  - 8 Kb EEPROM, unlimited read, 100,000 writes
  - Lifespan: 4-5 years vs. ~ 2 years of contact-card (data retention 10 years)
  - Two-way authentication, nonces, secret keys
  - Anticollision mechanism for multiple cards
  - Unique card serial number
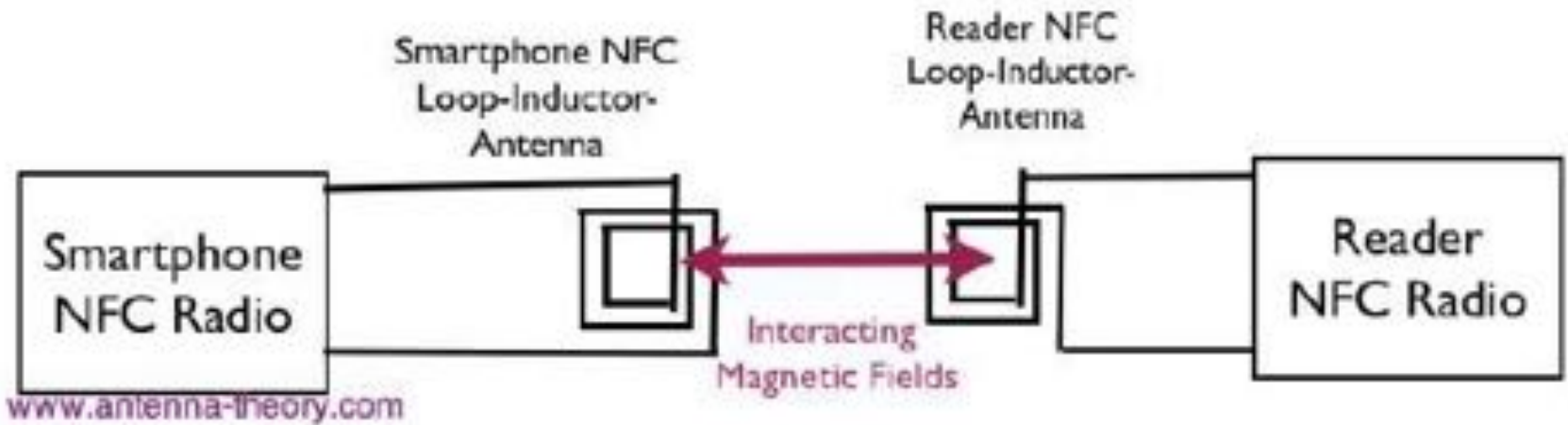
SOURCE: GEMPLUS ; https://www.secureidnews.com/news-item/tech-101-contactless-smart-cards/

Contactless Smart Cards Operating Sequence

Photo courtesy of Precise Biometrics

- Contactless smart card contains an antenna within the plastic body of the card

- When the card is brought into the EM field of the reader, the chip in the card is Powered ON

- Once the chip is powered on, a wireless protocol is initiated and established between the card and the reader for data transfer

- Two-step sequence:

  - Energy transfer to the card for powering the IC

  - Clock Signal Transfer

  - Data Transfer to the contactless smart card Card

  - Data Transfer from the contactless smart card

IC Chip

Antenna

Contactless Smart Card

Near Field Communications (NFC)

Smartphone NFC
Loop-Inductor-
Antenna

Reader NFC
Loop-Inductor-
Antenna

Smartphone
NFC Radio

Reader
NFC Radio

Interacting
Magnetic Fields

www.antenna-theory.com
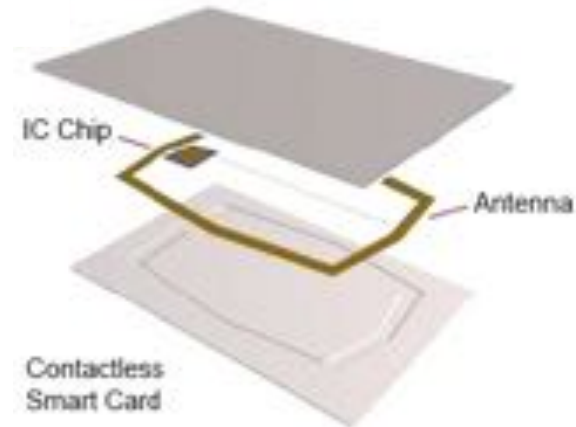
Relationship among EMVCo and Contactless Payment Specifications

Contactless Secure Elements Shipments worldwide (2014-2019) (in million units)

Legend: ● Financial services ● Government - healthcare ● Transport ● Others
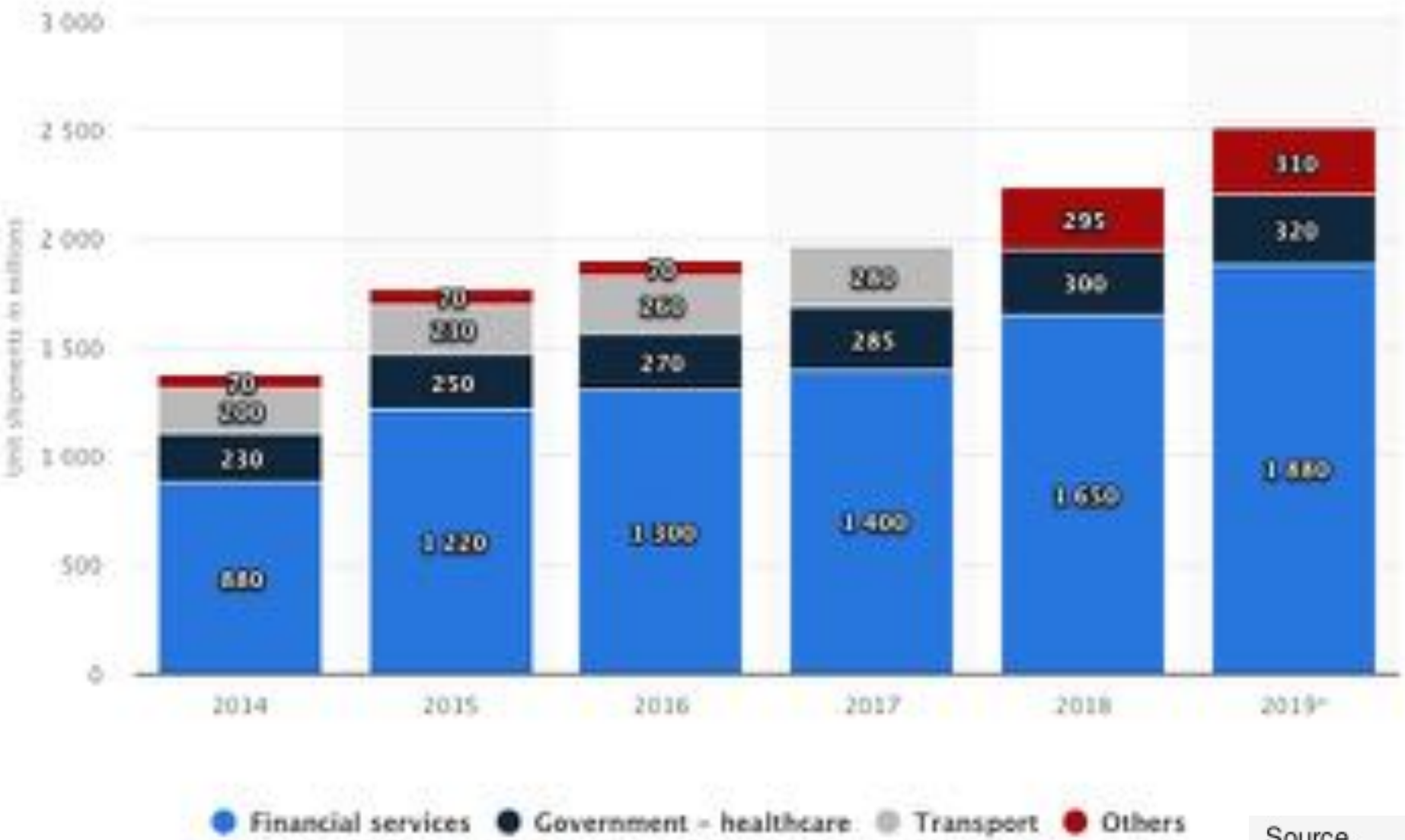
Contactless Smart Payment Association (SPA) Members Shipments Worldwide (2008-2015) (in million units)

ATM Components involved in a Contactless EMV Transaction
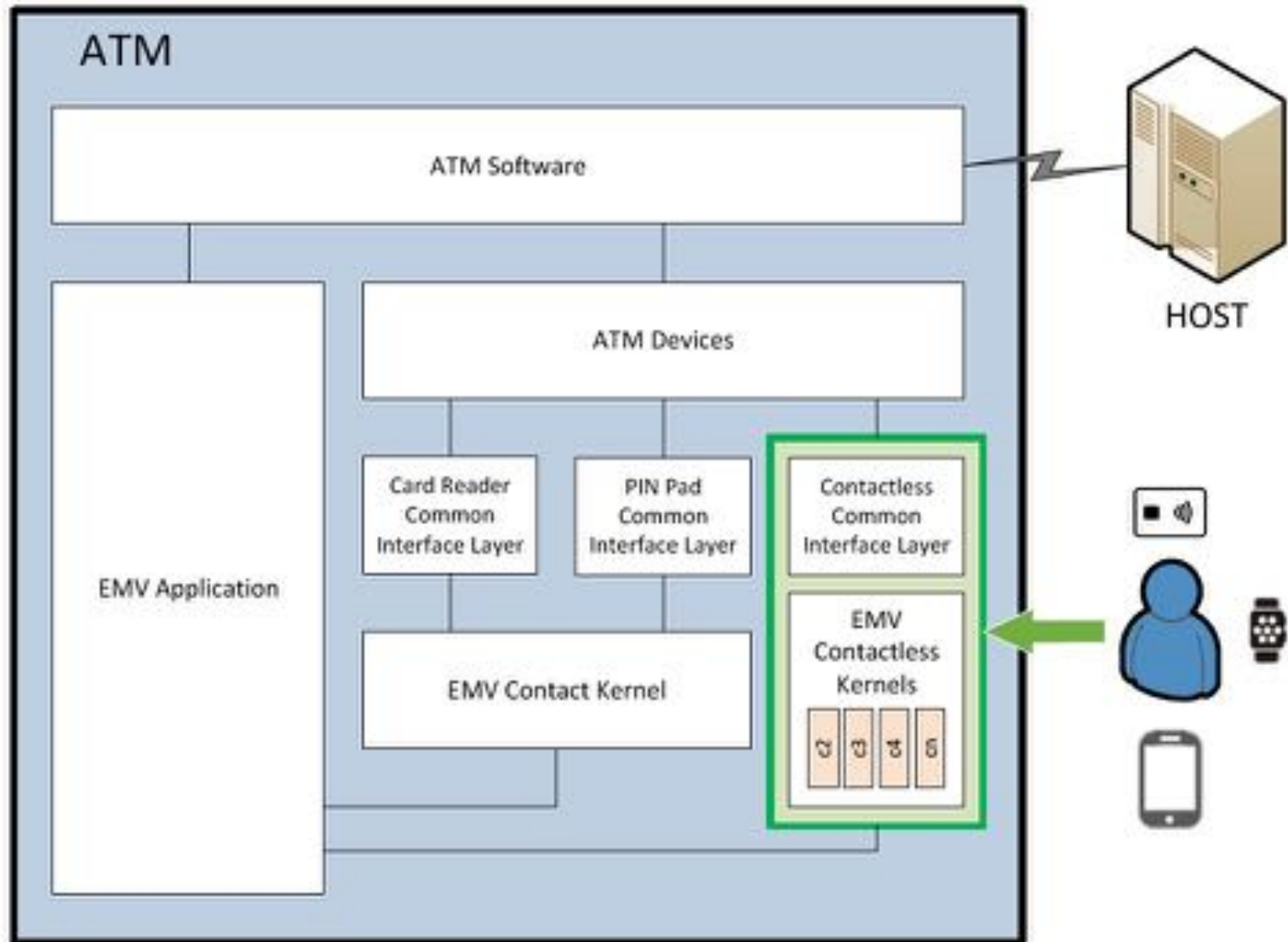
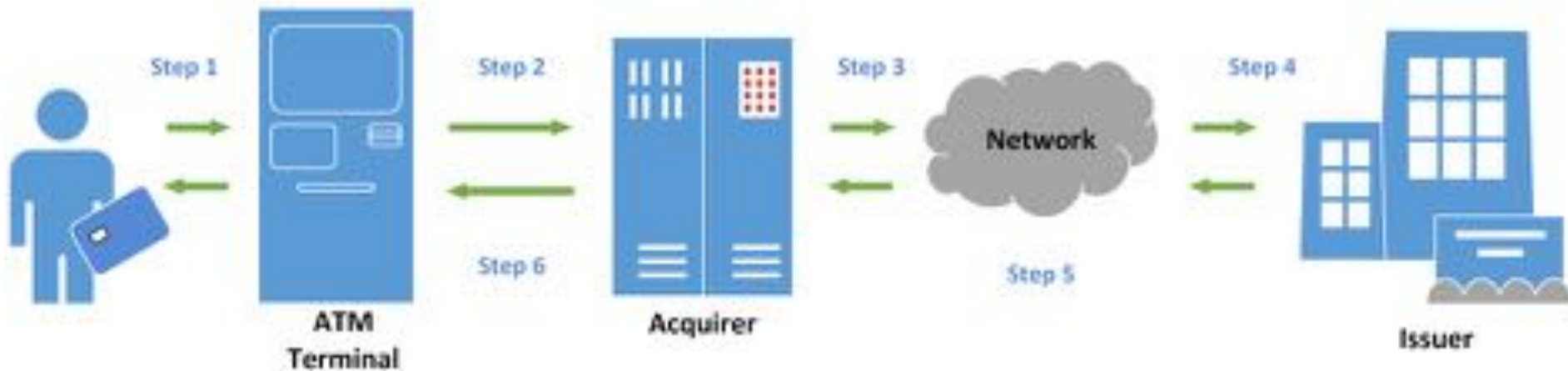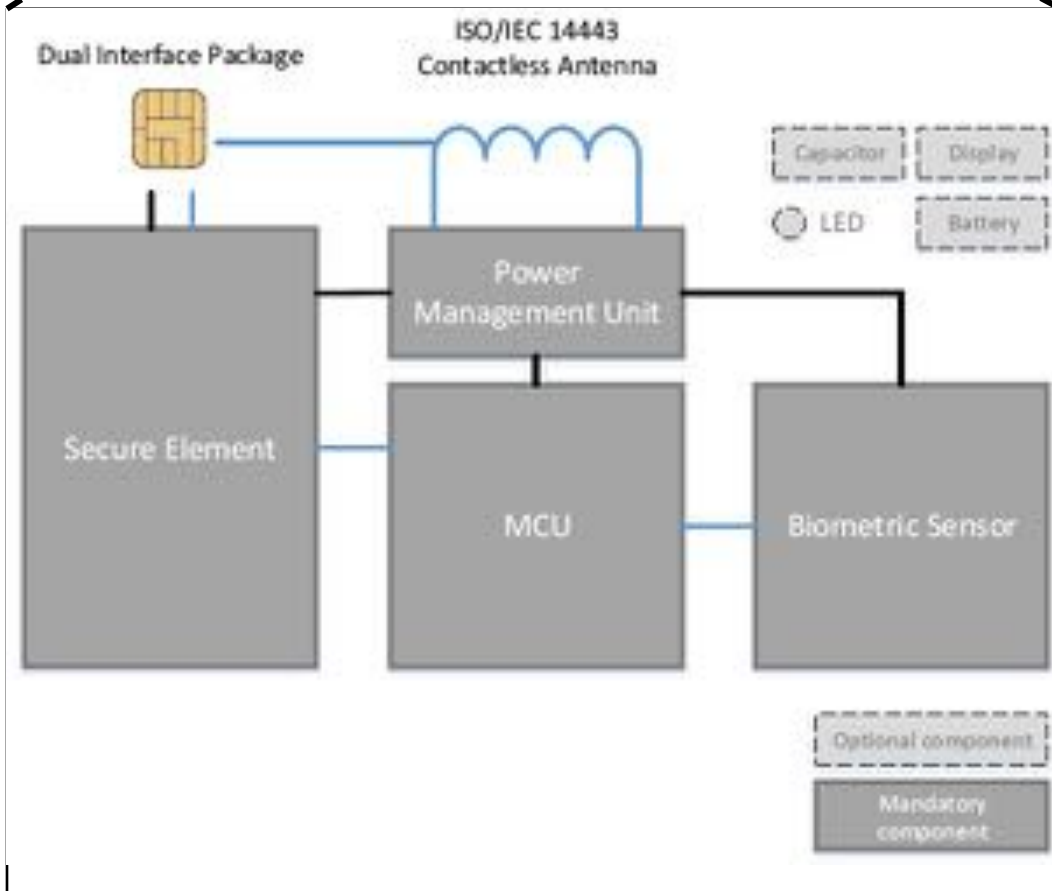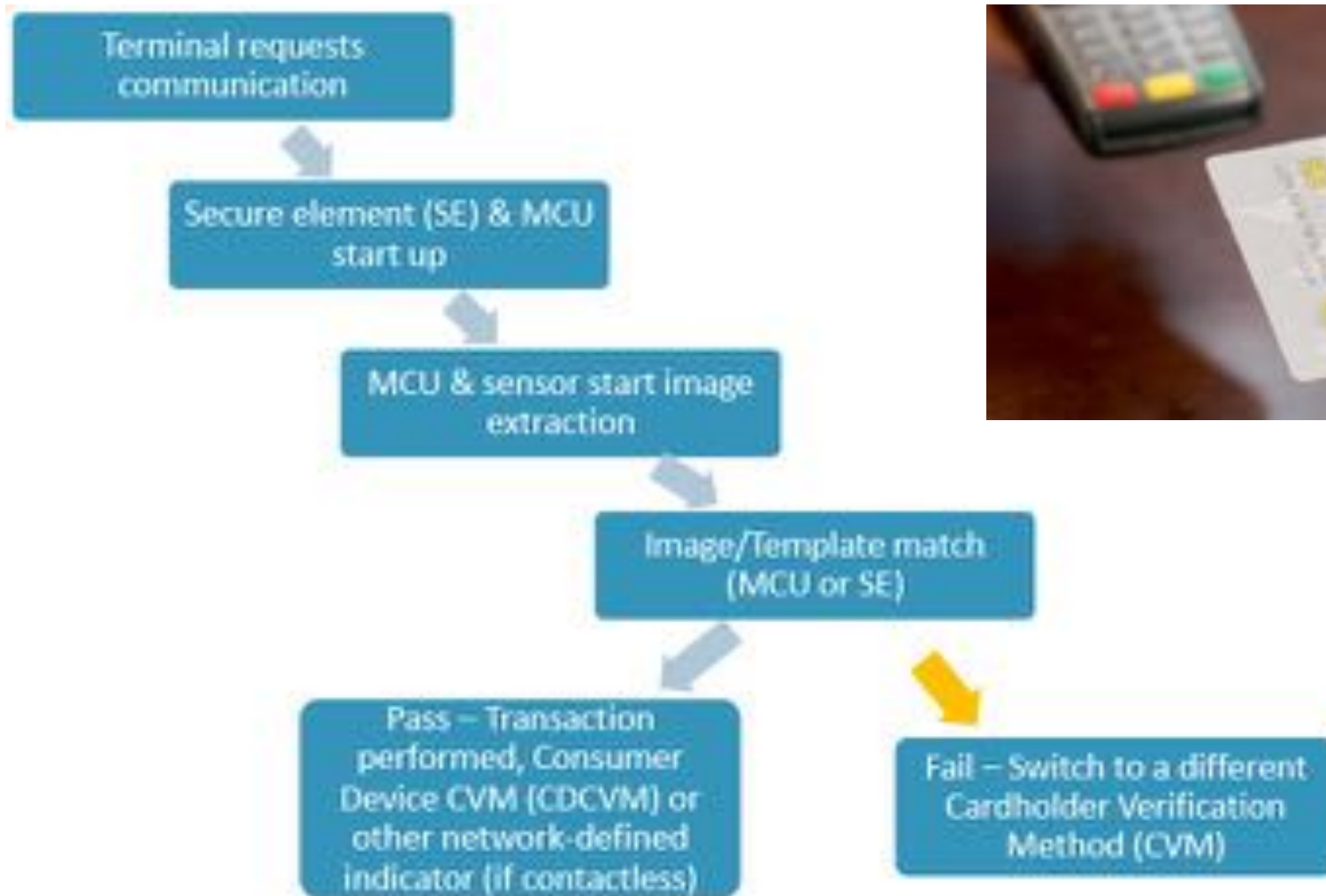# Transaction Flow for ATM via a Contactless Card

Figure 4. Contactless Card Form Factor (i.e., Non-Tokenized) Transaction Flow

Emerging Trend: Biometric Card

Internal Architecture of a Biometric Card

Operation Flow of a Biometric Cards

Terminal requests communication

↓

Secure element (SE) & MCU start up

↓

MCU & sensor start image extraction

↓

Image/Template match (MCU or SE)

↓ Pass – Transaction performed, Consumer Device CVM (CDCVM) or other network-defined indicator (if contactless)

↓ Fail – Switch to a different Cardholder Verification Method (CVM)

PAYMENT ON A KEYCHAIN

SMALL AND <u>CHEAP</u>

Automated Toll Collection

Octopus Card

- Dominant RFID payment card in HK
- Sony 13.56Mhz FeliCa RFID chip (not the ISO/IEC 14443 standards)
- Operating distance: 3-10 cm
- Bandwidth: 212 Kbit/sec
- Triple DES in 70 microsec
- EEPROM 1536 bytes
- 1KB to 64KB storage
- 128-byte data backup area
- 16-byte manufacturer ID; 16-byte issue ID
- Processing time: 50 msec on card, 300 msec overall
- Random access and cyclic files
- Anti-collision protocol

SOURCE: MITSUBISHI

Octopus

SONY RC-S833
CONTACTLESS SMART CARD

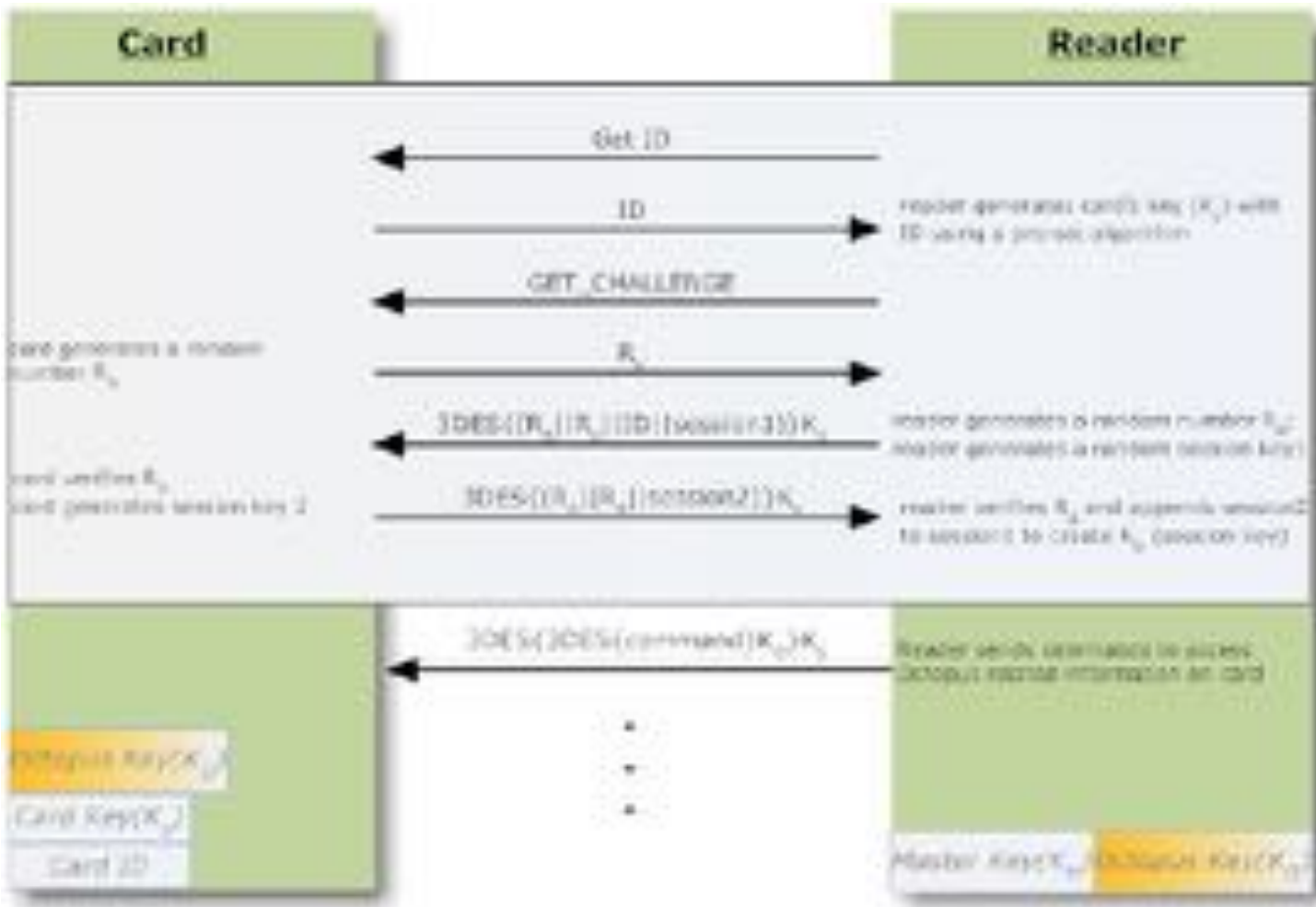SONY READER/WRITER

I/O SPEED: 212 Kbps

SOURCE: SONY

Octopus Card Security

Mutual Authentication Protocol between Octopus Card and its Reader

- 3-pass Mutual Authentication Protocol using Shared-Secret Access Key per ISO 9798-2

Security Measures for Octopus Card

- Certified by ISO/IEC15408 EAL4
- IC Software Support
  - Card does not support software download
  - Software could not be modified once loaded
  - => Reduce chance of inserting   malicious logic in the software of the IC
- Data Protection
  - Cash Value
  - Backup to non-volatile memory before Write
  - Restore Immediately if the transaction is interrupted during writing
- Card Information Protection
  - Octopus Key to protect the Card's Information
  - In different stages of the card life-cycle, the key is replaced and reloaded
    - Manufacturing
    - During Shipping
    - When the cards reach the Octopus Ltd company
  - => This can protect information on the card during shipping

Business Development of Octopus Card in HK
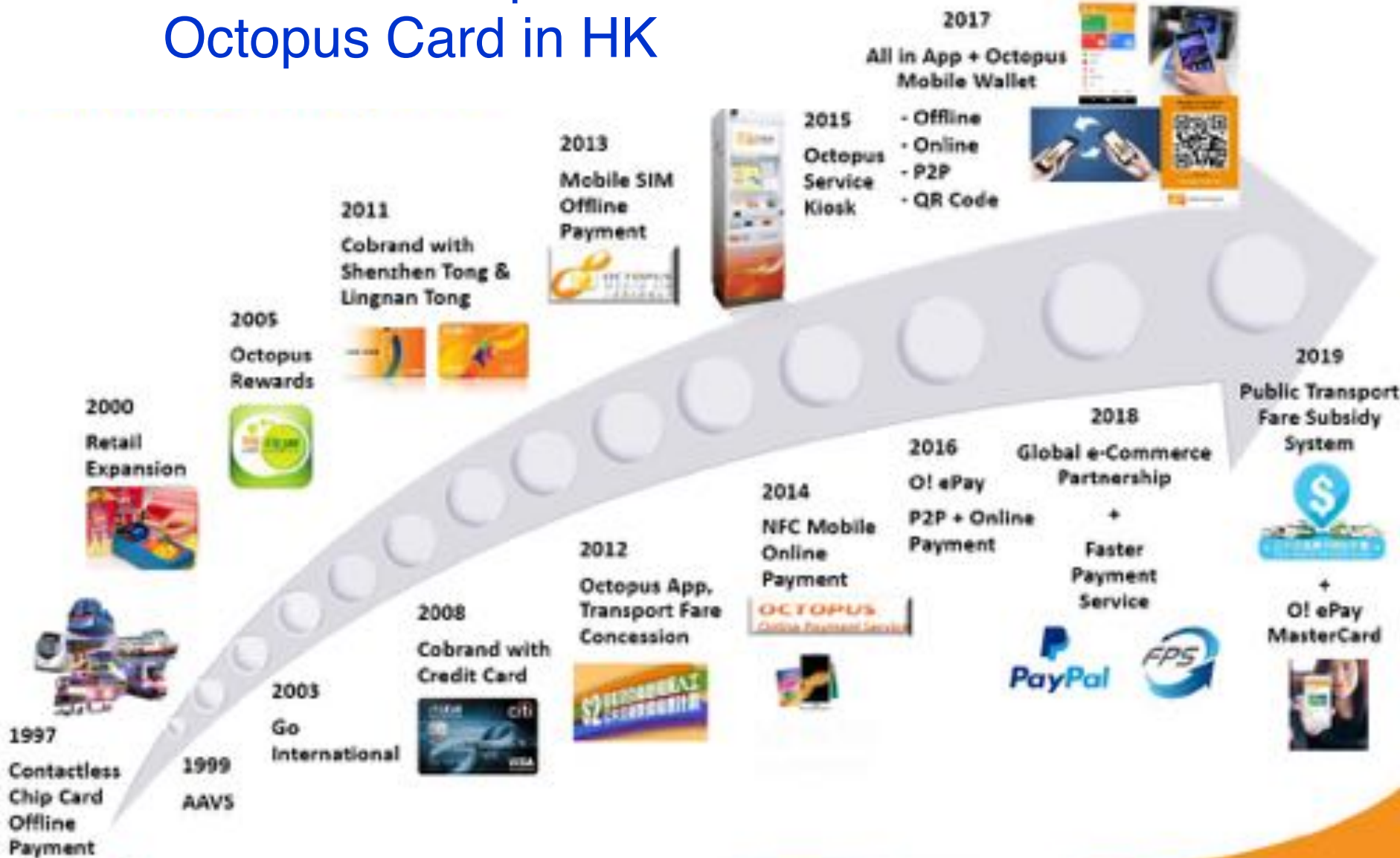
Octopus Business

- Over 99% of HK people aged 15-64 have an Octopus card
  - 36 Million cards in circulation (circa 2020)
- 15 million transactions per day
- Daily transaction value: HK$220 million
- Accepted by 35,000 retail outlets in HK
- Transaction fees: ??HK$0.02 + 0.75%??
  - => $10 transaction costs $0.095 (0.95%)
  - Alternatively, HKT Merchant services charges 1.7% per transactions
  - (vs. 1.5% for Alipay or WeChatPay transactions)
- Applications
  - Mass Transit, Road Toll, Parking Meter, Retail Point-of-Sale, Vending Machines, Access Control, P2P payment (via OePay)
- Anonymous / personalized
- How does money get to service providers?
  - Net settlement system operated by Octopus Holdings Limited

Estimated Market Size for Payment Business
- Major Mass Transportation: HK$56B
- Retail: HK$560B

Stored Value Facilities (SVF) & Credit Card Base
- 72M

Octopus 八達通

Smartphone Penetration (Aged 10 or above)
- 89%

Penetration of Population (Aged 15-64)
- Octopus Card: 99%
- Credit Card: 82%
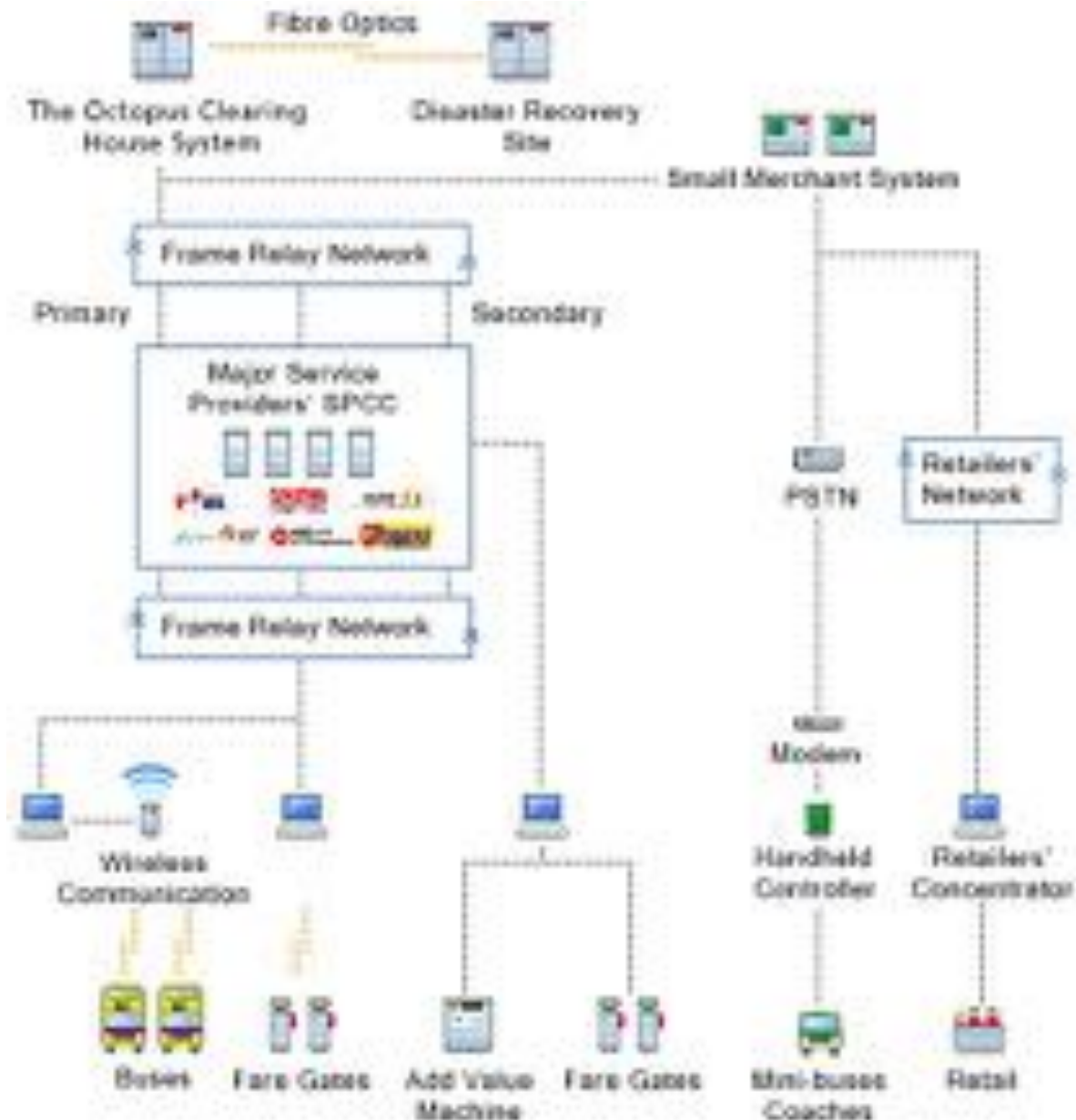
Octopus Expansion

- Identity card
- Access control
- Hotel room key
- Credit card
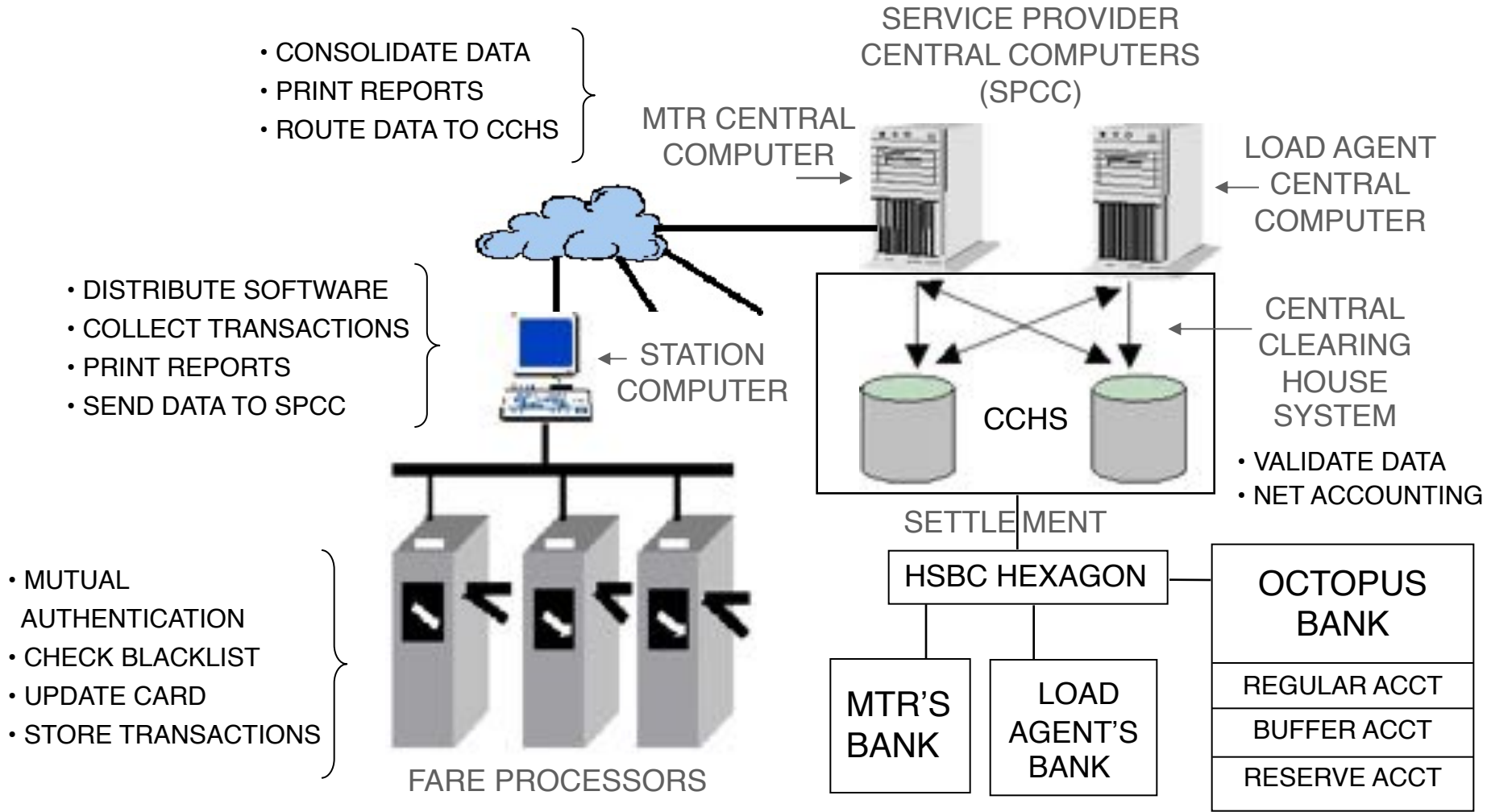- McDonalds
- Mobile phone
- Home readers

SOURCE: CREATIVE STAR

Octopus System Architecture

Octopus Settlement

SERVICE PROVIDER
CENTRAL COMPUTERS
(SPCC)

- CONSOLIDATE DATA
- PRINT REPORTS
- ROUTE DATA TO CCHS

MTR CENTRAL
COMPUTER

LOAD AGENT
CENTRAL
COMPUTER

- DISTRIBUTE SOFTWARE
- COLLECT TRANSACTIONS
- PRINT REPORTS
- SEND DATA TO SPCC

STATION
COMPUTER

CCHS

CENTRAL
CLEARING
HOUSE
SYSTEM

- VALIDATE DATA
- NET ACCOUNTING

SETTLEMENT

HSBC HEXAGON

OCTOPUS
BANK

- MUTUAL
  AUTHENTICATION
- CHECK BLACKLIST
- UPDATE CARD
- STORE TRANSACTIONS

FARE PROCESSORS

MTR'S
BANK

LOAD
AGENT'S
BANK

REGULAR ACCT

BUFFER ACCT

RESERVE ACCT

The (failed) Mondex card

- Subsidiary of MasterCard
- Smart-card-based, stored-value card (SVC)
- NatWest (National Westminister Bank, UK) et al.
- Secret chip-to-chip transfer protocol
- Value is not in strings alone; must be on Mondex card
- Loaded through ATM
  - ◆ ATM does not know transfer protocol; connects with secure device at bank
- Spending at merchants having a Mondex value transfer terminal
- Had a failed launch in HK (and elsewhere), commenced 11 months before Octopus's roll-out !

Mondex Components (Hitachi)

Cashless ATM

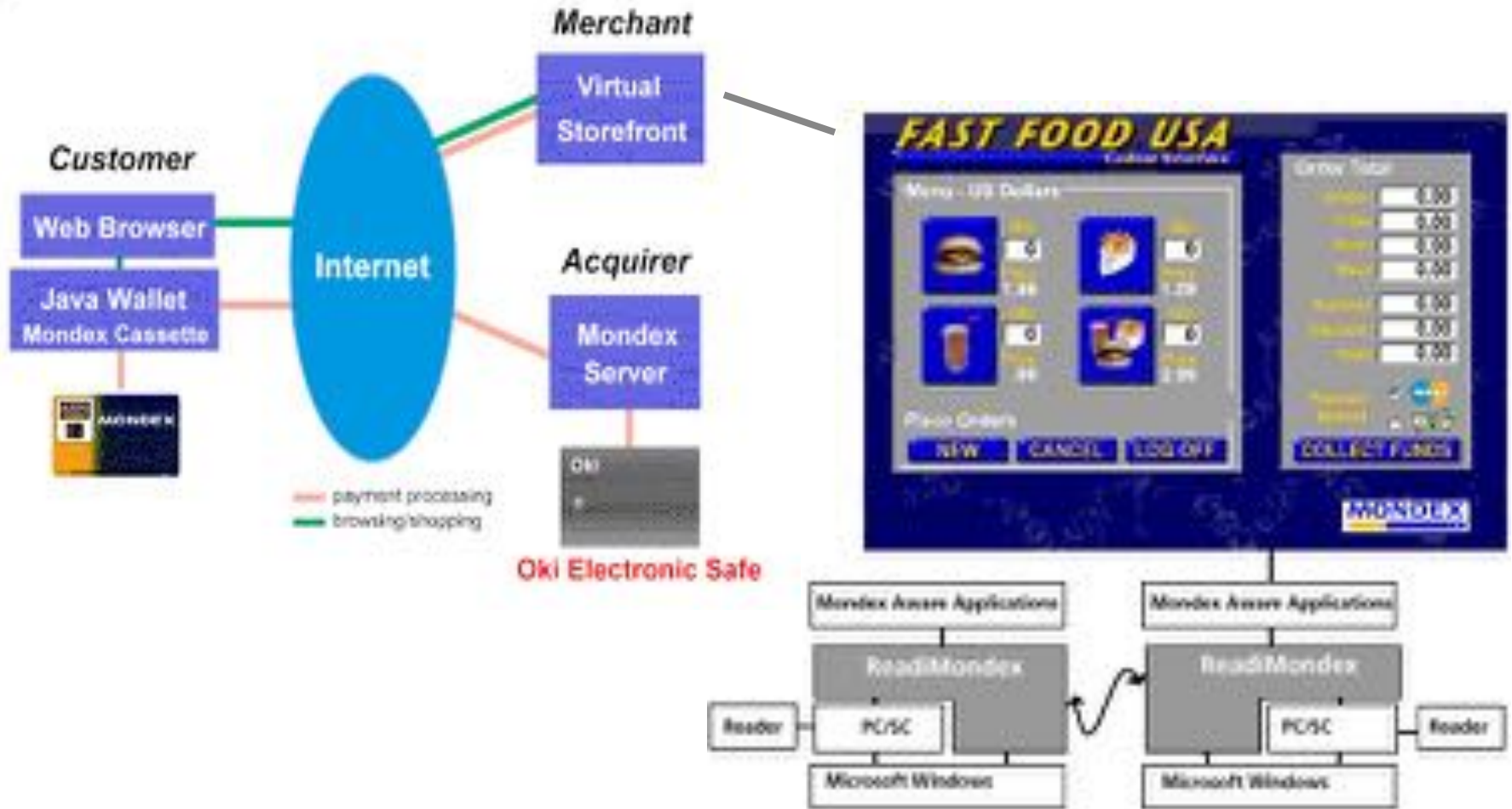PCMCIA Reader/Writer

Electronic Cash Register

Electronic Wallet

Key Fob Balance Reader

SOURCE: HITACHI

Mondex Overview

SOURCES: OKI, MONDEX USA

Mondex Security

- **Active and dormant security software**
  - Security methods constantly changing
  - ITSEC E6 level (military)

- **VTP (Value Transfer Protocol)**
  - Globally unique card numbers
  - Globally unique transaction numbers
  - Challenge-response user identification
  - Digital signatures

- **MULTOS operating system**
  - firewalls on the chip

Two different Fates: Octopus vs. Mondex in HK

Table 1: Background of the two electronic payment systems

	Mondex	Octopus
Founding members	Financial sector HSBC, Hang Seng Bank, Mastercard International	Transport sector Creative Star – joint venture between five transport companies
Local market share	HSBC issues 64.4% of Hong Kong's currency (2002) [14] HSBC and Hang Seng deposit 32.5% of Hong Kong's M2 money supply (2001)[3]	Mass Transit Railway (MTR): 11 million passenger journeys per day (total population was 6 million)
System cost	Information unavailable	US$53 million
Issuer	Licensed banks	Authorized deposit-taking organization (2000)

Source:
Leung Sea, Lucia SIU, "Coercing consensus: unintended success
Of the Octopus electronic payment system," PISTA IMSCI 2008.

Two different Fates: Octopus vs. Mondex in HK

Table 2: Outcome of user acceptance

	Mondex	Octopus
Cards issued	Pilot phase, trial quantity (1996) 0.19 million (Nov 1998) [6]	Pilot phase, trial quantity (1997) 4.6 million (Nov 1998)
	Below 0.1 million (Feb 2002) [13]	9 million (Feb 2002) [21] 17 million (Jun 2008)
No. of merchants	8000 [6] Most are retail shops	120 (2002) [21] Most were conglomerate chains Over 2000 (Jun 2008)
Daily transactions	Not disclosed	Over 7 million (Feb 2002) [21] Over 10 million, turnover HK$85 million (Jun 2008)
Profit	Never attained profit	HK$18 million (2000) [20]
Outcome	User resistance Low usage HSBC sold out all shares Hong Kong project terminated (2002) [1]	City-wide acceptance High regular turnover HKMA released previous 15% restriction on non-transport purposes (2000) [21]

Source:
Leung Sea, Lucia SIU, "Coercing consensus: unintended success
Of the Octopus electronic payment system," PISTA IMSCI 2008.

Two different Fates: Octopus vs. Mondex in HK

Table 3: Comparison on technical and marketing merits

	Mondex	Octopus
User cost	(+) Free (HK$100 fee waivered)	(-) HK$50 deposit (US$6.41)
Legal Status	(+) Full legal status of money	(-) Limited legal status / area of use
Launching time	(+) Oct 1996	(-) Sep 1997
Privacy concern	(-) Holds personal information, linked to bank account	(+) Contains no personal info (Later on optional varieties linked up with bank accounts and award programs)
Contact mode	(-) Need contact to read/write	(+) Contactless read/write
Speed	(-) Read/write time: 5 seconds Date transmission: 9.6 kbit/s	(+) Read/write time: 0.3 seconds Data transmission: 212 kbit/s
Specifications	MULTOS chip Patented issuance and update mechanism: STEP (Secure Trusted Environment Provisioning) Verification and encryption: KMA (key management authority)	Sony 13.56 MHz RFID (FeliCa radio frequency identification) chip Proprietary standard predating the ISO/IEC 14443 standard ERG (Australian) as system integrator PKI (public key infrastructure) encryption Two-way authentication

(+) Merit   (-) Disadvantage

Source:
Leung Sea, Lucia SIU, "Coercing consensus: unintended success
Of the Octopus electronic payment system," PISTA IMSCI 2008.

Major Ideas

- Embedded-microprocessor-based Smart cards prevent skimming attacks as the user secret/ key never leaves the card and difficult to be reversed engineered

- Powerful microprocessors allow

  - Cryptography ; certificates, authentication ; secure SVFs/wallets

- EMV standards as well as Liability-Shift policies speed up adoption of EMV-chip payment cards worldwide.

- Wireless (Contactless) cards enable new business models and competitive advantages

  - Require updates of Merchant-side devices as well

  - Contactless card is just one of the many solutions for Mobile Commerce; Alternative technologies/ Solutions keep coming, e.g. NFC, Tokenization, QR code, etc ;

  - Different Technologies has different implications on who have more control on the ecosystem: e.g. Card Issuers, Mobile Service Providers, BigTech companies, etc