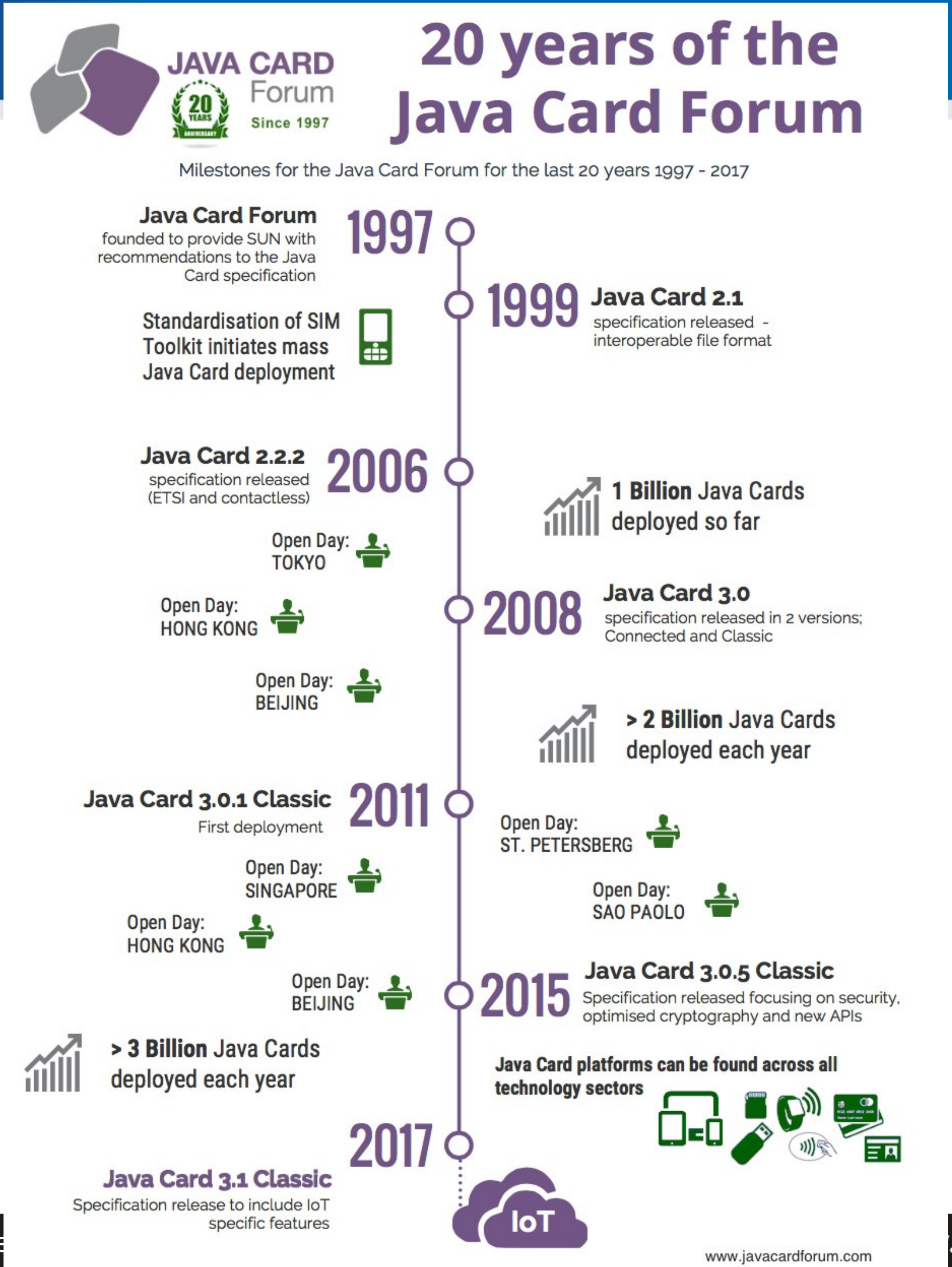
PV204 Security technologies

Secure authentication and authorization

Petr Švenda svenda@fi.muni.cz
Faculty of Informatics, Masaryk University

CRoCS
Centre for Research on Cryptography and Security


JAVA CARD Forum
20 YEARS
Since 1997
20 years of the Java Card Forum
Milestones for the Java Card Forum for the last 20 years 1997 - 2017
1997
Java Card Forum
founded to provide SUN with recommendations to the Java Card specification
1999
Java Card 2.1
specification released - interoperable file format
Standardisation of SIM Toolkit initiates mass Java Card deployment
2006
Java Card 2.2.2
specification released (ETSI and contactless)
1 Billion Java Cards deployed so far
Open Day: TOKYO
Open Day: HONG KONG
2008
Java Card 3.0
specification released in 2 versions; Connected and Classic
Open Day: BEIJING
> 2 Billion Java Cards deployed each year
2011
Java Card 3.0.1 Classic
First deployment
Open Day: ST. PETERSBERG
Open Day: SINGAPORE
Open Day: SAO PAOLO
Open Day: HONG KONG
Open Day: BEIJING
2015
Java Card 3.0.5 Classic
Specification released focusing on security, optimised cryptography and new APIs
> 3 Billion Java Cards deployed each year
Java Card platforms can be found across all technology sectors
2017
Java Card 3.1 Classic
Specification release to include IoT specific features
IoT
www.javacardforum.com

SECURITY PROTOCOLS

Security protocols

- Security protocol = composition of cryptoprimitives
- *"Security protocols are three line programs that people still manage to get wrong." (R. Needham)*

Security protocol aspects

- Entity authentication
- Key agreement, establishment or distribution
- Data encryption and integrity protection
- Non-repudiation
- Secure multi-party computation (SMPC)
- …

PROTOCOLS AND ATTACKS

Typical models of adversary

- Adversary controls the communication
  - Between all principals
  - Observe, alter, insert, delay or delete messages
- Adversary can obtain session/long term keys
  - used in previous runs
- Malicious insider
  - adversary is legitimate protocol principal
- Attacker can obtain partial knowledge
  - Compromise or side-channels
- …

Needham–Schroeder protocol: symmetric

- Basis for Kerberos protocol (AUTH, KE), 1978
  - Two-party protocol (A,B) + trusted server (S)
  - Session key K_{AB} generated by S and distributed to A together with part intended for B
  - Parties A and B are authenticated via S

1. $A \rightarrow S$: A, B, N_A
2. $S \rightarrow A$: $\{N_A, K_{AB}, B, \{K_{AB}, A\}K_{BS}\}K_{AS}$
3. $A \rightarrow B$: [redacted]
4. $B \rightarrow A$: $\{N_B, A\}K_{AB}$
5. $A \rightarrow B$: $\{N_B - 1\}K_{AB}$

Which part ensures:
Authentication
Key confirmatic
Freshness

Can you spot problem?

N-S symmetric: Problem?

- Vulnerable to replay attack (Denning, Sacco, 1981)
- If an attacker compromised older K_{AB} then
  - $\{K_{AB}, A\}K_{BS}$ can be replayed to B (step 3.)
  - B will not be able to tell if K_{AB} is fresh
  - Attacker will then impersonate A using old (replayed, compromised) key K_{AB}
- Fixed by inclusion of nonce/timestamp $\mathbf{N'_B}$ generated by B (two additional steps before step 1.)
  - Bob can now check freshness of $\{K_{AB}, A, \mathbf{N'_B}\}K_{BS}$

What is required attacker model?

What is required attacker model?

- Able to capture valid communication ($\{K_{AB}, A\}K_{BS}$)
- Able to compromise older K_{AB}
- Actively communicate with B (reply ($\{K_{AB}, A\}K_{BS}$)

But is assumption of compromise of old key realistic?

How (not) to reason about potential compromise

- NO: all my (many) keys are in secure hardware and therefore I'm secure (no compromise possible)
  – Nothing like perfect security exists

- YES: assume compromise and evaluate impact
  – Where are sensitive keys
  – How hard is to compromise them
  – What will be the impact of the compromise
  – Can I limit number/exposure of keys? For what price?

What if key is compromised?

- Prevention, detection (hard), reaction
- Prevention of compromise
  - Limit usage of a key
    - master key $\rightarrow$ session keys
    - Use PKI instead of many symmetric keys in trusted terminals
  - Limit key availability
    - Erase after use, no/limited copy in memory, trusted element
  - Limited-time usefulness of keys (key update)
    - (Perfect) forward secrecy: Information before is secure
- Reaction on compromise
  - stop using key, update and let know (revocation)

Needham–Schroeder protocol: asymmetric

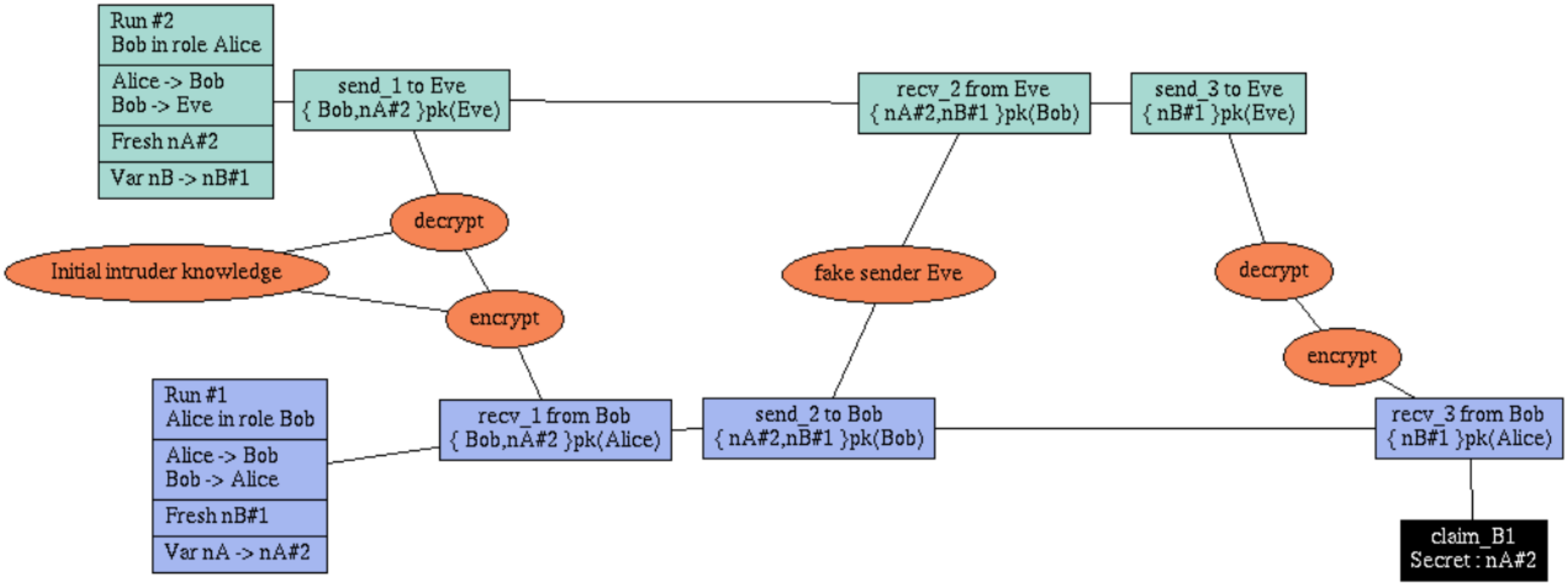
- Simple asymmetric AUTH & KE protocol
- Designed by R. Needham and M. Schroeder (1978)
  - (below is simplified version without PKI server S)

1. $A \rightarrow B: \{A, N_A\}PK_B$
2. $B \rightarrow A:$
3. $A \rightarrow B: \{N_B\}PK_B$

Which part ensures:
Authentication
Freshness
Key establishment

Can you spot the problem?

N-S asymmetric: Problem?



- Discovered by G. Lowe 17 years after using formal verification method/tool

Formal verification of protocols

Negatives

- Specific attacker model
  - Different attacker (e.g., side-channels) => attack possible
- Assumes perfect crypto-primitives
- Sensitive to precise specification
- Hard to express real-world complex protocols
  - Search space too large

Positives

- Automated process
- Prevents basic and some advanced design flaws
- Favours simple solutions
  - Complexity is enemy of security

s formal verification panacea?

References

- Security Protocols Open Repository
  - http://www.lsv.ens-cachan.fr/Software/spore/
- C. Cremer, Scyther tool
  - https://github.com/cascremers/scyther/
- Cas Cremer's exercise sheet
  - https://www.cs.ox.ac.uk/people/cas.cremers/scyther/scyther-exercises.html

N-S asymmetric: Fix

- Fixed by addition of B's identity into second step

1. $A \rightarrow B$: $\{A, N_A\}PK_{(B)}$
2. $B \rightarrow A$: $\{B, N_A, N_B\}PK_{(A)}$
3. $A \rightarrow B$: $\{N_B\}PK_{(B)}$

AUTHENTICATED KEY EXCHANGE

Methods for key establishment

1. Derive from pre-shared secret (KDF)
2. Establish with help of trusted party (Kerberos, PKI)
3. Establish over insecure channel (Diffie-Hellman)
4. Establish over other (secure) channel
5. Establish over non-eavesdropable channel (BB84)
6. …

Methods for key confirmation

- Goal: ensure that parties use same key value(s)
- Implicit confirmation by use of valid key
  - E.g., MAC by session key on future message is valid
- Explicit confirmation by challenge-response
  - Dedicated steps in protocol

Option	Alice	Bob
1	$R_1 = \text{random}()$	$\text{random}() = R_2$
	$E_{K'}(R_1) \longrightarrow$	
	$\longleftarrow E_{K'}(R_1, R_2)$	
	$E_{K'}(R_2) \longrightarrow$	
2	$H(H(K')) \longrightarrow$	
	$\longleftarrow H(K')$	

http://www.themccallums.org/nathaniel/2014/10/27/authenticated-key-exchange-with-speke-or-dh-eke/

Diffie-Hellman key exchange

Which part ensures:
Key establishmen
Key confirmation
Authentication

Diffie-Hellman Key Exchange

Step	Alice	Bob
1	Parameters: p, g	
2	$A = \text{random}()$ $a = g^A \pmod{p}$	$\text{random}() = B$ $g^B \pmod{p} = b$
3	$a \longrightarrow$ $\longleftarrow b$	
4	$K = g^{BA} \pmod{p} = b^A \pmod{p}$	$a^B \pmod{p} = g^{AB} \pmod{p} = K$
5	$\longleftarrow E_K(data) \longrightarrow$	

http://www.themccallums.org/nathaniel/2014/10/27/authenticated-key-exchange-with-speke-or-dh-eke/

Diffie-Hellman in practice

- K is not used directly, but K' = KDF(K) is used
  1. Original K may have weak bits
  2. Multiple keys may be required (K_{ENC}, K_{MAC})
- Is vulnerable to man-in-the-middle attack (MitM)
  - Attacker runs separate DH with A and B simultaneously
  - (Unless a and b are authenticated)
- Be aware of particular p and g
  - If group g is widely used up to 1024b then precomputation is possible (Logjam, CCS15)
    - Huge precomputation effort, but feasible for national agency
    - Certain combination of g and p => fast discrete log to obtain A
  - If p is really prime and g has larger order (Indiscrete logs, NDSS17)

Diffie-Hellman in practice

- DH can be used as basis for *Forward secrecy*
- DH can be used as basis for *Password-Authenticated Key Exchange*
- Variant of DH based on elliptic curves used (ECDH)
  - ECDH is preferred algorithm for TLS, ePassport…
  - ECDH is algorithm of choice for secure IM (Signal)

Forward secrecy - motivation

- Assume that session keys are exchanged using long-term secrets
  1. Pre-distributed symmetric cryptography keys (SCP'02)
  2. Public key cryptography (TLS_RSA_...)
- What if long-term secret is compromised?
  - I. All future transmissions can be read
  - II. Attacker can impersonate user in future sessions
  - III. All previous transmissions can be compromised if traffic was captured
- Can III. be prevented? (Forward secrecy)
- Can I. be prevented? (Backward secrecy)

Forward secrecy – how to achieve

- (Perfect) Forward Secrecy
  - Compromise of long-term keys does not compromise past session keys
- Solution: ephemeral key pair (DH/RSA/…)
  1. Fresh keypair generated for every new session
  2. Ephemeral public key used to exchange session key
  3. Ephemeral private key is destroyed after key exchange
     - Captured encrypted transmission cannot be decrypted
- Long-term key is used only to authenticate ephemeral public key to prevent MitM

Use of forward secrecy: examples

- HTTPS / TLS
  - DHE-RSA, DHE-DSA, ECDHE-RSA, ECDHE-ECDSA…
- SSH (RFC 4251)
- Off-the-Record Messaging (OTR) protocol (2004)
- TextSecure v2 → Axolotl protocol (TextSecure app)
- TextSecure v3 now known as Signal protocol (2015)

PASSWORD-AUTHENTICATED KEY EXCHANGE (PAKE)

PAKE protocols - motivation

- Diffie-Hellman can be used for key establishment
  - Authentication ca be added via pre-shared key
- But why not directly derive session keys from pre-shared instead of running DH?
  1. Compromise of pre-shared key => compromise of all data transmissions (including past) => no forward secrecy
  2. Pre-shared key can have low entropy (password) => attacker can brute-force
- Password-Authenticated Key Exchange (PAKE)
  - Sometimes called Escalation protocols

PAKE protocols - principle

- Goal: prevent MitM <u>and</u> offline brute-force attack

1. Generate asymmetric keypair for every session
   - Both RSA and DH possible, but DH provides better performance in keypair generation
2. Authenticate public key by (potentially weak) shared secret (e.g., password)
   - And limit number of failed authentication requests!
3. Exchange/establish session keys for symmetric key cryptography using authenticated public key

Diffie-Hellman Encrypted Key Exchange

Step	Alice	Bob
1	Shared Secret: $S = H(password)$	
2	Parameters: p, g	
3	$A = \text{random}()$ $a = g^A \pmod p$	$\text{random}() = B$ $g^B \pmod p = b$
4a	$E_S(a) \longrightarrow$ $\longleftarrow E_S(b)$	
4b	$a \longrightarrow$ $\longleftarrow E_S(b)$	
4c	$E_S(a) \longrightarrow$ $\longleftarrow b$	
5	$K = g^{BA} \pmod p = b^A \pmod p$	$a^B \pmod p = g^{AB} \pmod p = K$
6	$\longleftarrow E_K(data) \longrightarrow$	

http://www.themccallums.org/nathaniel/2014/10/27/authenticated-key-exchange-with-speke-or-dh-eke/

SECURE INSTANT MESSAGING

Off-The-Record Messaging (OTR), 2004

- Protocol for protection of instant messaging
- Perfect forward and backward secrecy
  - Via use of ephemeral DH keys
  - Added OTR ratcheting (new DH key for every message)
- Plausible deniability of messages
  - Message MAC is computed, message send and received
  - MAC key used to compute MAC is then publicly broadcast
  - As MAC key is now public, everyone can forge past messages (will not affect legitimate users but can dispute claims of cryptographic message log in court)

The Signal protocol

- State-of-the-art of instant messaging protocols
  - Used in Signal, WhatsApp, Facebook Messenger, Google Allo…
- The protocol provides:
  - confidentiality, integrity, message authentication,
  - participant consistency, destination validation,
  - forward secrecy, backward secrecy (aka future secrecy)
  - causality preservation, message unlinkability, message repudiation, participation repudiation and asynchronicity
  - end-to-end encrypted group chats
- Requires (untrusted) servers
  - relaying of messages and storage of public key material

https://en.wikipedia.org/wiki/Signal_Protocol

The Signal protocol implementation

- 3-DH with Curve25519, AES-256, HMAC-SHA256
- Authentication of users
  - 1) Trust on first use 2) Trusted party (PKI) 3) Fingerprint check using other channel (hex, QR code…)
- Protection of messages
  - 3-DH with perfect forward secrecy and backward secrecy
  - AE with deniability (MAC key later broadcast)
  - Support for offline messages with future ECDH keys (ratcheting)
- Protection of metadata (no strong anonymity as e.g., Tor)
  - Message delivery time and communicating parties available
  - Service provider (e.g., OpenWhisperSystem or WhatsApp) may choose to keep or delete this information

DESIGN OF PROTOCOLS

Design of cryptographic protocols

- Don't design own cryptographic protocols
  - Use existing well-studied protocols (TLS, EAC-PACE…)
  - Don't remove "unnecessary" parts of existing protocols
- Follow all required checks on incoming messages
  - Verification of cryptograms, check for revocation…
- Don't design and implement your own (if possible)
  - Potential for error, implementation attacks…
- But more likely you will need to design own protocol than to design own crypto algorithm
  - => can actually happen ☺

Design principles (Abadi & Needham) I.

- The conditions for a message to be acted should be clearly set out so reviewer can judge if they are acceptable.
  - Documentation, diagrams, formal specification
- Every message should say what it means, message interpretation should depend only on its content.
  - "This is 2nd message of SCP'02 from A to B"
  - No assumptions like next random chunk number should be encrypted 2nd message because I just received 1st message
- Mention name of principal ("Alice01")
  - Prevents (if checked) unintended parallel runs of protocol
  - Prevents reflection attack

Design principles (Abadi & Needham) II.

- Be clear about why encryption is being done
  - For confidentiality, not to “somewhat” ensure integrity
- When signing encrypted data, it should not be inferred that signing entity knows data content
  - No knowledge of encryption key
- Be clear about properties of nonce
  - random, never repeated, unpredictable, secret
  - Random $\rightarrow$ almost never repeated unintentionally

Design principles (Abadi & Needham) III.

- If predictable quantity is to be effective, it should be protected so that an intruder cannot simulate a challenge and later replay the message
  - Counter as challenge $\rightarrow$ counter freshness verification necessary $\rightarrow$ state
- If timestamps are used as freshness guarantees, then difference between local clocks at various machines must be much less then allowable age of message
  - Otherwise an attacker can replay within time window
- Key may have been used recently and yet be old and possibly compromised
  - Clear session state after session end, check freshness

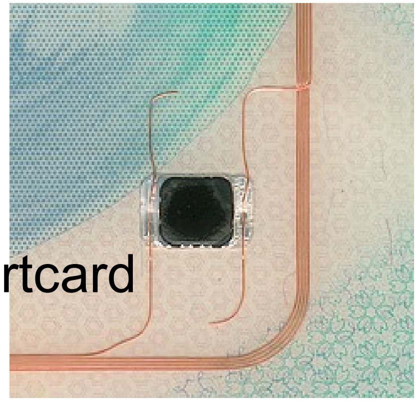
Design principles (Abadi & Needham) IV.

- It should be possible to deduce which protocol and which run of that protocol a message belongs to including order number in the protocol
  - Danger of parallel runs of same protocol
  - MAC and chaining with fresh session keys prevents message mixing
- Trust relation should be made explicit and there should be good reason for its necessity.
  - Less trust needed $\rightarrow$ better security achieved

ELECTRONIC PASSPORTS AND CITIZEN ID CARDS

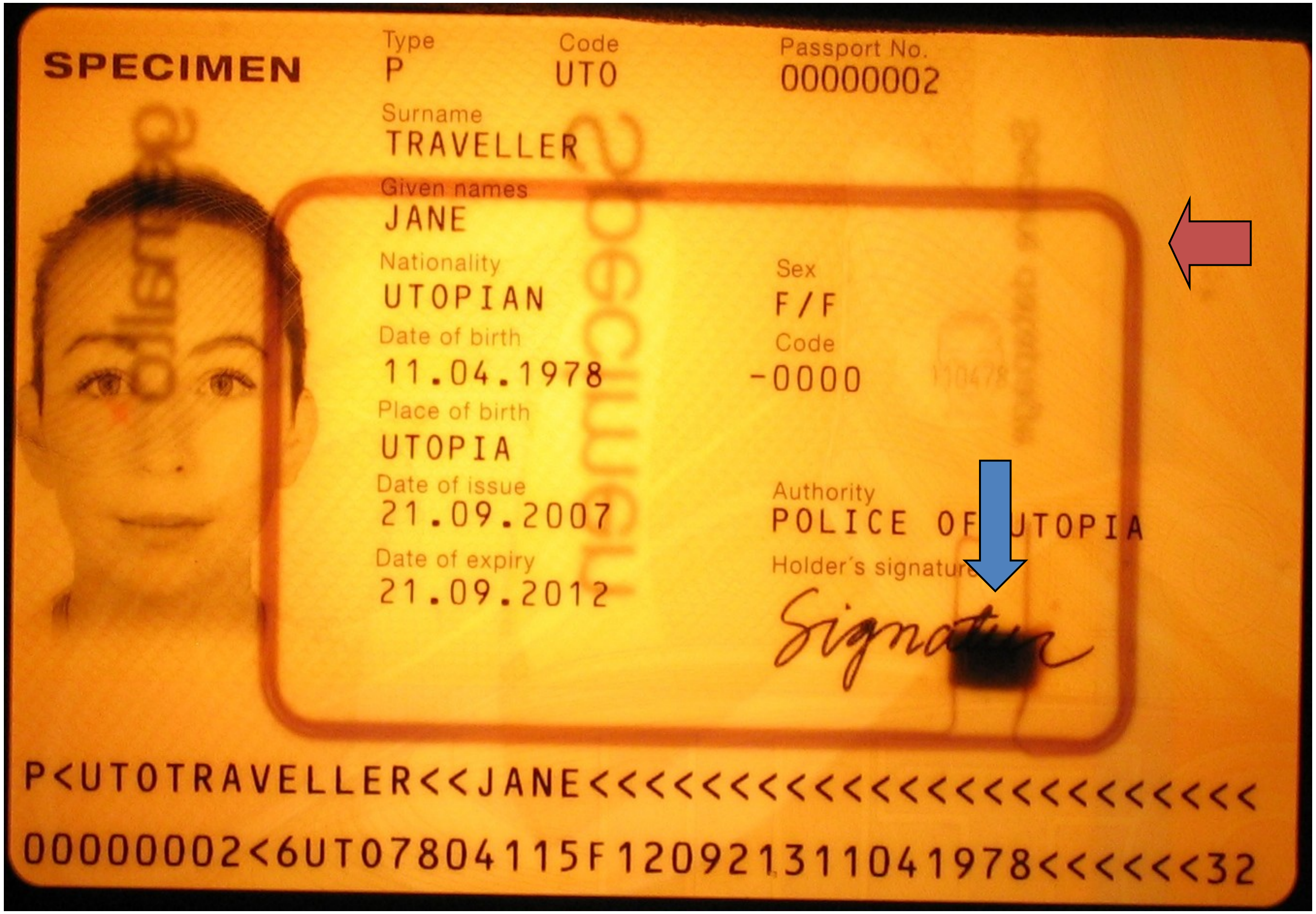
Credit: Slides partially based on presentation by Zdenek Říha

Passports of the first generation



- Electronic passport
  - Classical passport booklet + passive contactless smartcard (ISO14443, communication distance 0-10 cm)
  - Chip & antenna integrated in a page or cover
- Technical specification standardized by ICAO
  - Standard 9303, 6th edition
  - References many ISO standards
- Data is organised in 16 data groups (DG) and 2 meta files
  - DG1-DG16, EF.COM, EF.SOD
  - Mandatory is DG1 (MRZ), DG2 (photo), EF.COM and EF.SOD (passive authentication)

Chip and antenna



Data groups

Data group	Stored data
DG1	**Machine readable zone (MRZ)**
DG2	**Biometric data: face**
DG3	Biometric data: fingerprints
DG4	Biometric data: iris
DG5	Picture of the holder as printed in the passport
DG6	Reserved for future use
DG7	Signature of the holder as printed in the passport
DG8	Encoded security features – data features
DG9	Encoded security features – structure features
DG10	Encoded security features – substance features
DG11	Additional personal details (address, phone)
DG12	Additional document details (issue date, issued by)
DG13	Optional data (anything)
DG14	Data for securing secondary biometrics (EAC)
DG15	Active Authentication public key info
DG16	Next of kin

Protocols used in ePassports I.

I. Authentication of inspection system to chip [BAC]
   - Read basic digital data from chip (MRZ, photo)
   - SG: Passport provides basic data only to local terminal with physical access to passport
   - S: Auth. SCP, sym. crypto keys derived from MRZ [BAC]

II. Authorized access to more sensitive chip data
   - SG: Put more sensitive data on chip (fingerprint, iris), but limit availability only to inspection systems of trustworthy countries
   - S: Challenge-response auth. protocol [EAC,EAC-PACE], PKI + cross-signing between trustworthy states [EAC]

Protocols used in ePassports II.

III. Genuine data on passport
   - SG: Are data on passport unmodified?
   - S: digital signatures, PKI [passive authentication]

IV. Authentication of chip to inspection system
   - SG: Is physical chip inside passport genuine?
   - S: Challenge-response authentication protocol [AA, EAC-PACE]

V. Transfer data between chip and IS securely
   - SG: attacker can't eavesdrop/modify/replay
   - S: secure channel [EAC, EAC-PACE]

Authorization and passports

1. Inspection terminal to read basic info from chip
2. Inspection terminal to read biometric data from chip
3. You to enter country based on chip data

ELECTRONIC PASSPORTS - MORE DETAILS

How Signal and ePass compares?

- Completely different usage scenario
  – Instant messaging vs. person/terminal authentication
  – Frequent updates possible vs. 15 years passport validity
- Different trust relations and participants structure
  – N friends vs. many partially or fully distrusting participants
  – Mostly online vs. mixed offline/online (even without clock!)
- Underlying cryptographic primitives are shared
  – Forward secrecy, ECDH, AES, SHA-2…
  – Ratcheting and deniability not necessary for ePass

Conclusions

- Design of (secure) protocols is very hard
  - Understand what are your requirements
  - Use existing protocols, e.g., TLS, Signal or EAC-PACE
- Strong session keys established with weak passwords
  - Password-Authenticated Key Exchange
- Electronic passport uses variety of protocols
  - Interesting and complex usage scenarios
- Mandatory reading
  - M. Green, Noodling about IM protocols, http://blog.cryptographyengineering.com/2014/07/noodling-about-im-protocols.html
  - M. Marlinspike, Advanced cryptographic ratcheting https://whispersystems.org/blog/advanced-ratcheting/