New Approaches to Digital Evidence

Ueli Maurer

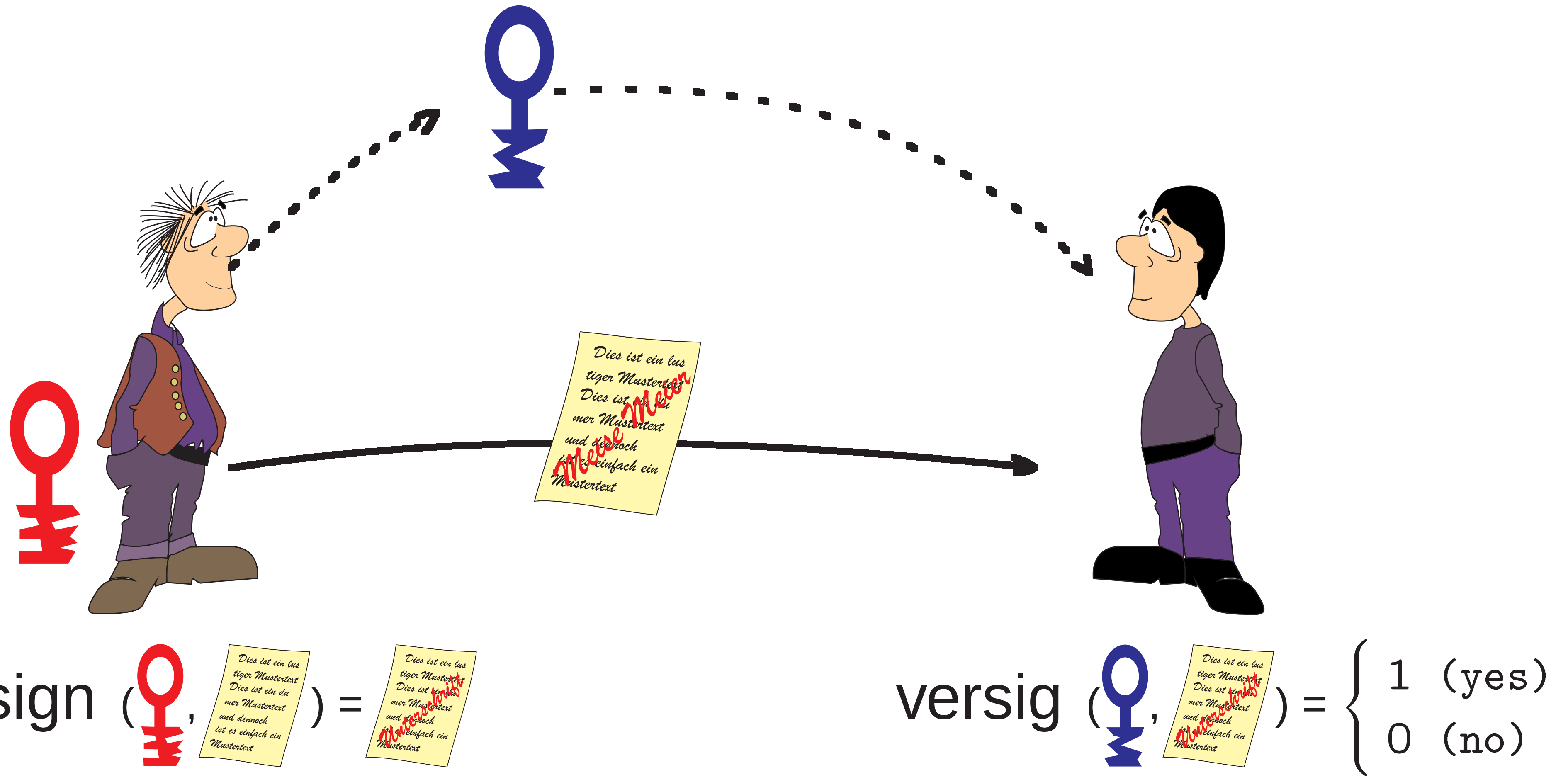
ETH Zurich

Carleton University, Ottawa, May 13, 2009

Overview

- Digital signatures and certificates
- Some provocative claims
- Digital evidence: A systematic treatment
- Fundamental dilemma in DS legislation
- Justification of claims
- The role of conventional signatures
- Digital declarations

Digital signatures



Public-key certificates

CA C confirms the binding of public key p_A to entity A.

A	p_A	parameters	$\text{Sign}_C([A, p_A, \text{parameters}])$

Certificate c when checked with public key p:

$\text{id}(p, c)$ = **identity**

$\text{pk}(p, c)$ = **public key**

$\text{exp}(p, c)$ = **expiration time**

$\text{lia}(p, c)$ = **liability bound**

Context

Is an entity A liable for a digital document d, as a consequence of a digital signature on d with respect to her public key p_{A}?

Context

Is an entity A liable for a digital document d, as a consequence of a digital signature on d with respect to her public key p_A?

A's possible objections:

1. **p_A is not my public key.**

Context

Is an entity A liable for a digital document d, as a consequence of a digital signature on d with respect to her public key p_{A}?

A's possible objections:

1. **p_{A} is not my public key.**
2. **I did not sign d (though p_{A} is my valid public key).**

Context

Is an entity A liable for a digital document d, as a consequence of a digital signature on d with respect to her public key p_A?

A's possible objections:

1. **p_A is not my public key.**
2. **I did not sign d (though p_A is my valid public key).**
3. **The signature was generated after I revoked p_A.**

Context

Is an entity A liable for a digital document d, as a consequence of a digital signature on d with respect to her public key p_{A}?

A's possible objections:

1. **p_{A} is not my public key.**
2. **I did not sign d (though p_{A} is my valid public key).**
3. **The signature was generated after I revoked p_{A}.**
4. **I am liable for p_{A}, but only for transaction values below that relevant in document d.**

Digital signatures: Promises

Digital signatures: Promises

Automation and digitization of many business and government processes!

Digital signatures: Promises

Automation and digitization of many business and government processes!

- **Easy to transmit, archive, search, and verify**
- **Unambiguous: Verification = math. function**
- **Higher security than conventional signatures**
- **Simpler dispute resolution**
- **Fewer disputes**

Digital signatures: Obstacles

- Non-repudiation services: Only isolated use of DS
- Lack of international PKI
- Lack of internationally applicable legislation
- Lack of standardization
- Difficult integration into business processes
- Technological challenges
- Slow user acceptance
- Abstractness and complexity

Digital signatures: Obstacles

- Non-repudiation services: Only isolated use of DS
- Lack of international PKI
- Lack of internationally applicable legislation
- Lack of standardization
- Difficult integration into business processes
- Technological challenges
- Slow user acceptance
- Abstractness and complexity
- Lack of understanding

Some provocative claims

- Certificates are (generally) irrelevant as evidence in a dispute.

Some provocative claims

- Certificates are (generally) irrelevant as evidence in a dispute.
- Roles of certification and time-stamping authorities are very different.

Some provocative claims

- Certificates are (generally) irrelevant as evidence in a dispute.
- Roles of certification and time-stamping authorities are very different.
- Public keys and certificates cannot be revoked.

Some provocative claims

- Certificates are (generally) irrelevant as evidence in a dispute.
- Roles of certification and time-stamping authorities are very different.
- Public keys and certificates cannot be revoked.
- Evidence expires, not public keys.

Possible objections

- **Judges are humans and can not be formalized. They make reasonable decisions based on all the available evidence.**

Possible objections

- Judges are humans and can not be formalized. They make reasonable decisions based on all the available evidence.

- This view does not conform with the current laws and is therefore not relevant in practice.

Possible objections

- **Judges are humans and can not be formalized. They make reasonable decisions based on all the available evidence.**

- **This view does not conform with the current laws and is therefore not relevant in practice.**

- **These observations are trivialities.**

Possible objections

- **Judges are humans and can not be formalized. They make reasonable decisions based on all the available evidence.**
- **This view does not conform with the current laws and is therefore not relevant in practice.**
- **These observations are trivialities.**
- **This is complete nonsense.**

Bitstrings as evidence: Example

Digital check: A **authorizes bank** B **to pay** $\$100$ **from her account to anyone (the first) who presents a certain bitstring** c**.**

Bitstrings as evidence: Example

Digital check: A **authorizes bank** B **to pay** $100 **from her account to anyone (the first) who presents a certain bitstring** c**.**

How is c **specified?**

Bitstrings as evidence: Example

Digital check: A authorizes bank B to pay \$100 from her account to anyone (the first) who presents a certain bitstring c.

How is c specified? By a verification predicate

$$v : \{0,1\}^* \rightarrow \{0,1\}.$$

Bitstrings as evidence: Example

Digital check: A **authorizes bank** B **to pay** \$100 **from her account to anyone (the first) who presents a certain bitstring** c.

How is c **specified? By a verification predicate**

$$v : \{0,1\}^* \to \{0,1\}.$$

A **is liable if a bitstring** s **with** $v(s) = 1$ **is presented.**

Bitstrings as evidence: Example

Digital check: A authorizes bank B to pay $\$100$ from her account to anyone (the first) who presents a certain bitstring c.

How is c specified? By a verification predicate

$$v: \{0,1\}^* \to \{0,1\}.$$

A is liable if a bitstring s with $v(s) = 1$ is presented.

Realization based on a one-way function f:
Let $y := f(c)$.

$$v(s) = 1 \iff f(s) = y$$

General document space $\mathcal{D}$

A **wants to be able to authorize an arbitrary transaction, described by document** $d \in \mathcal{D}$**.**

Verification predicate: $v : \mathcal{D} \times \{0,1\}^* \to \{0,1\}$

String s **implies liability for** d **if and only if** $v(d,s) = 1$**.**

General document space $\mathcal{D}$

A **wants to be able to authorize an arbitrary transaction, described by document $d \in \mathcal{D}$.**

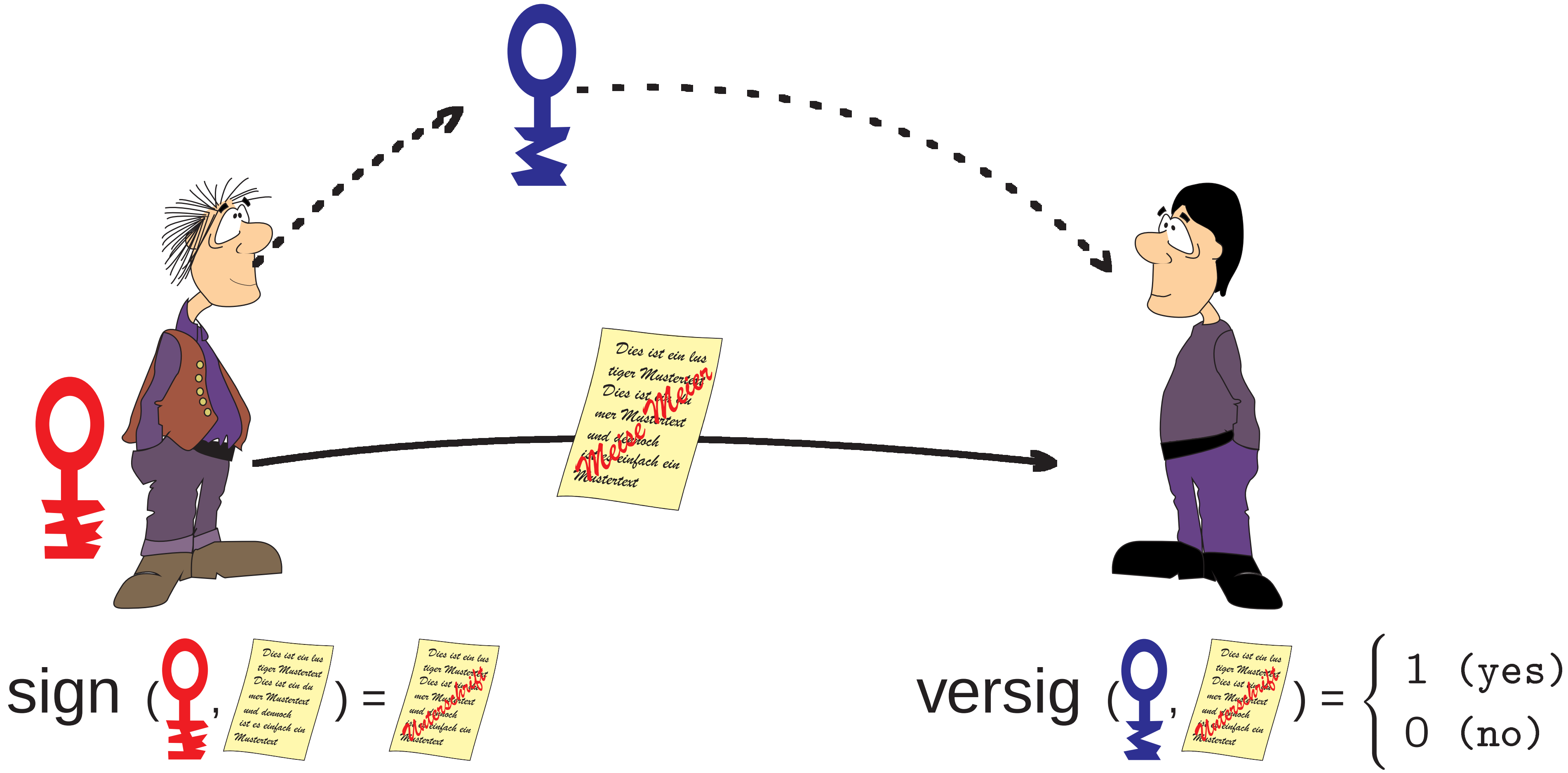
Verification predicate: $v : \mathcal{D} \times \{0,1\}^* \to \{0,1\}$

String s implies liability for d if and only if $v(d,s) = 1$.

Requirements:

- **Security:** **Infeasible to find d and s with $v(d,s) = 1$.**
- **Efficient verifiability:** **Check if $v(d,s) = 1$.**
- **Feasibility:** **For any $d \in \mathcal{D}$,** A **can efficiently compute c_d with $v(d, c_d) = 1$.**

Digital signatures



$$v(d, s) = \mathsf{versig}(p_{\mathsf{A}}, d, s).$$

Using certificates

Assume CA C**'s public key** p_{C} **is publicly known.**

$$\begin{aligned} v(d,s) = \quad & s = [\sigma, c] \\ & \wedge \ \mathsf{id}(p_{\mathsf{C}}, c) = \mathsf{A} \\ & \wedge \ \mathsf{versig}(\mathsf{pk}(p_{\mathsf{C}}, c), d, \sigma) \end{aligned}$$

Hierarchical certification

Assume root-CA R**'s public key** p_{R} **is publicly known.**

$$
\begin{aligned}
v(d,s) = \quad & s = [\sigma, c, c'] \\
& \wedge \ \mathsf{versig}(\mathsf{pk}(\mathsf{pk}(p_{\mathsf{R}}, c'), c), d, \sigma) \\
& \wedge \ \mathsf{id}(\mathsf{pk}(p_{\mathsf{R}}, c'), c) = \mathsf{A}
\end{aligned}
$$

Certificate expiration and time-stamping

Assume:

- **CA** C**'s public key** p_{C} **known.**
- **Time-stamping authority** T**'s public key** p_{T} **known.**

$$
\begin{aligned}
v(d,s) = \quad & s = [\sigma, c, \tau] \\
& \wedge\ \mathsf{id}(p_{\mathsf{C}}, c) = \mathsf{A} \\
& \wedge\ \mathsf{versig}(\mathsf{pk}(p_{\mathsf{C}}, c), d, \sigma) \\
& \wedge\ \mathsf{time}(p_{\mathsf{T}}, \tau) \leq \mathsf{exp}(p_{\mathsf{C}}, c) \\
& \wedge\ \mathsf{string}(p_{\mathsf{T}}, \tau) = \sigma
\end{aligned}
$$

Certificate revocation

Two mechanisms:

- **Certificate revocation list (CRL)**
- **On-line revalidation: revalidation certificate** r

  Two additional checks:

$$\mathsf{time}(p_{\mathsf{T}}, \tau) \leq \mathsf{time}(p_{\mathsf{C}}, r) + \Delta$$

$$\mathsf{pk}(p_{\mathsf{C}}, c) = \mathsf{pk}(p_{\mathsf{C}}, r)$$

Dilemma in DS legislation

What implies liability?

Dilemma in DS legislation

What implies liability?

1. Digital evidence?
   - Secret key could have leaked.
   - System vulnerability (e.g. a virus).
   - User interface ambiguous.
   - Cryptographic signature function broken.
   - False certificate.

Dilemma in DS legislation

What implies liability?

2. Willful act?

- Digital signature is only one piece of evidence.
- Which other evidence is considered?
- How can a user prove she did not sign?
- Should the other party present more than digital evidence?

Dilemma in DS legislation

What implies liability?

2. Willful act?

- Digital signature is only one piece of evidence.
- Which other evidence is considered?
- How can a user prove she did not sign?
- Should the other party present more than digital evidence?

Fundamental dilemma: It cannot be both!

Entering a contract

- Basic act in business and society
- Valid only if entered by both parties
- Requires each parties' consent, documented by a willful act
- Entities keep some evidence of willful act
- Legal system defines what constitutes valid evidence

Evidence for non-repudiation

- **Physical evidence**

Evidence for non-repudiation

- Physical evidence
- Statements by witnesses

Evidence for non-repudiation

- Physical evidence
- Statements by witnesses
- Digital evidence

Evidence for non-repudiation

- Physical evidence
- Statements by witnesses
- Digital evidence
  - Digital evidence strings (signatures, certificates, time stamps, revalidation certificates, ...)

Evidence for non-repudiation

- Physical evidence
- Statements by witnesses
- Digital evidence
  - Digital evidence strings (signatures, certificates, time stamps, revalidation certificates, ...)
  - Digital recordings of physical world; have human interpretation

Requirements for contract signing systems and legislation

- Practicality
- Unambiguity
- Security
- Low cost
- Low trust requirements
- Precise and simple legislation
- Smooth integration
- Wide usability and acceptance

Abstraction of the legal system

- Legal system = rules used to make decision
- Includes legislation and juridical practice
- Separation of ambiguous and unambig. issues

Abstraction of the legal system

- Legal system = rules used to make decision
- Includes legislation and juridical practice
- Separation of ambiguous and unambig. issues
- Unambiguous description of evidence: e

Abstraction of the legal system

- **Legal system = rules used to make decision**
- **Includes legislation and juridical practice**
- **Separation of ambiguous and unambig. issues**
- **Unambiguous description of evidence:** e
- **Ambiguous: - Interpretation of document** d
  - Does given evidence match e**?**

Abstraction of the legal system

- Legal system = rules used to make decision
- Includes legislation and juridical practice
- Separation of ambiguous and unambig. issues
- Unambiguous description of evidence: e
- Ambiguous: - Interpretation of document d
  - Does given evidence match e?
- Legal system can be abstracted as a function

$$\text{evidence} \quad \longrightarrow \quad \{0, 1\}$$

Liability function

$$\lambda : \mathcal{I} \times \mathcal{D} \times \mathcal{E} \times \mathcal{V} \rightarrow \{0,1\}$$

$\mathcal{I}$ = entity name space

$\mathcal{E}$ = space of evidence descriptions

$\mathcal{V}$ = set of predicates $\mathcal{D} \times \{0,1\}^* \rightarrow \{0,1\}$

A is liable for d if:

1. $\lambda(\mathsf{A}, d, e, v) = 1$
2. Evidence satisfying description e is presented.
3. A bitstring s satisfying $v(d, s) = 1$ is presented.

Delegation signatures

In order to make forgery of s more difficult, one requires one (or more) additional signature as evidence:

$$\begin{aligned} v(d,s) = \quad & s = [\sigma, \sigma'] \\ & \wedge \mathsf{versig}(p, d, \sigma) \\ & \wedge \mathsf{versig}(p', \sigma, \sigma') \end{aligned}$$

p' **is controlled by a party trusted (and chosen) by** A**.**

Possible semantics of certificates

Possible semantics of certificates

1. **Certificate proves that p_{A} is A's public key.**

Possible semantics of certificates

1. **Certificate proves that p_{A} is A's public key.**

2. **Certificates states that the CA holds evidence for the fact that A committed herself to p_{A}.**

Possible semantics of certificates

1. **Certificate proves that p_{A} is A's public key.**

2. **Certificates states that the CA holds evidence for the fact that A committed herself to p_{A}.**

   - **Certificate is irrelevant for the legal system.**
   - **Role of CA: manage physical evidence and witnesses.**
   - **Only recipient of signature, not A, must trust the CA.**
   - **Lower security requirements for CA.**
   - **New type of trusted entity $\longrightarrow$ new business models.**
   - **Name "certificate"?**

Commitment to verification predicate

- A user declares her commitment to a verification predicate, not a public key.
- The legal system defines which type of (physical) commitment declaration is required for which type of liability.
- Multi-level declarations possible.

Time-stamping makes little sense!

- **If $\lambda(\mathsf{A}, d, e, v) = 1$ and evidence matching description e is presented, then an arbitrary bitstring s with $v(d, s) = 1$ proves liability.**

Time-stamping makes little sense!

- If $\lambda(\mathsf{A}, d, e, v) = 1$ and evidence matching description e is presented, then an arbitrary bitstring s with $v(d, s) = 1$ proves liability.
- Irrelevant when, where, how, or by whom s was generated.

Time-stamping makes little sense!

- If $\lambda(\mathsf{A}, d, e, v) = 1$ and evidence matching description e is presented, then an arbitrary bitstring s with $v(d, s) = 1$ proves liability.
- Irrelevant when, where, how, or by whom s was generated.
- Interpretation: A time stamp is a special type of delegation signature.

Time-stamping makes little sense!

- If $\lambda(\mathsf{A}, d, e, v) = 1$ and evidence matching description e is presented, then an arbitrary bitstring s with $v(d, s) = 1$ proves liability.
- Irrelevant when, where, how, or by whom s was generated.
- Interpretation: A time stamp is a special type of delegation signature.
- Interpretation of expiration: Evidence expires, not public keys.

Time-stamping makes little sense!

- If $\lambda(\mathsf{A}, d, e, v) = 1$ and evidence matching description e is presented, then an arbitrary bitstring s with $v(d, s) = 1$ proves liability.
- Irrelevant when, where, how, or by whom s was generated.
- Interpretation: A time stamp is a special type of delegation signature.
- Interpretation of expiration: Evidence expires, not public keys.
- Revocation is impossible.

Time-stamping makes little sense!

- If $\lambda(\mathsf{A}, d, e, v) = 1$ and evidence matching description e is presented, then an arbitrary bitstring s with $v(d, s) = 1$ proves liability.
- Irrelevant when, where, how, or by whom s was generated.
- Interpretation: A time stamp is a special type of delegation signature.
- Interpretation of expiration: Evidence expires, not public keys.
- Revocation is impossible.
- Revalidation certificate = delegation signature.

The role of conventional signatures

- Conventional hand-written signatures work amazingly well.
- Signatures are quite easy to forge.
- Purpose of signature: Guaranteed user awareness.
- Meaningful to ask user to testify whether she signed.
- In sharp contrast to digital signatures.
- How can we achieve the same (or better) situation with digital evidence?

Digital declarations

- **Digital recording of the user's willful act.**
- **Examples: voice, image, video, any other technology.**
- **Human interpretation of recording.**
- **User can request a digital declaration to be presented.**
- **Forgery can be denied.**

Usefulness of digital declarations

- Guaranteed user awareness.
- Higher deterrence of misbehavior, fewer disputes.
- Improved security compared to conventional signatures.
- Lower cost due to reduced technical security requirements.
- Improved user acceptance of digital signature technology.
- Usability by moderately educated people.