A Framework for Analyzing Verifiability in Traditional and Electronic Exams

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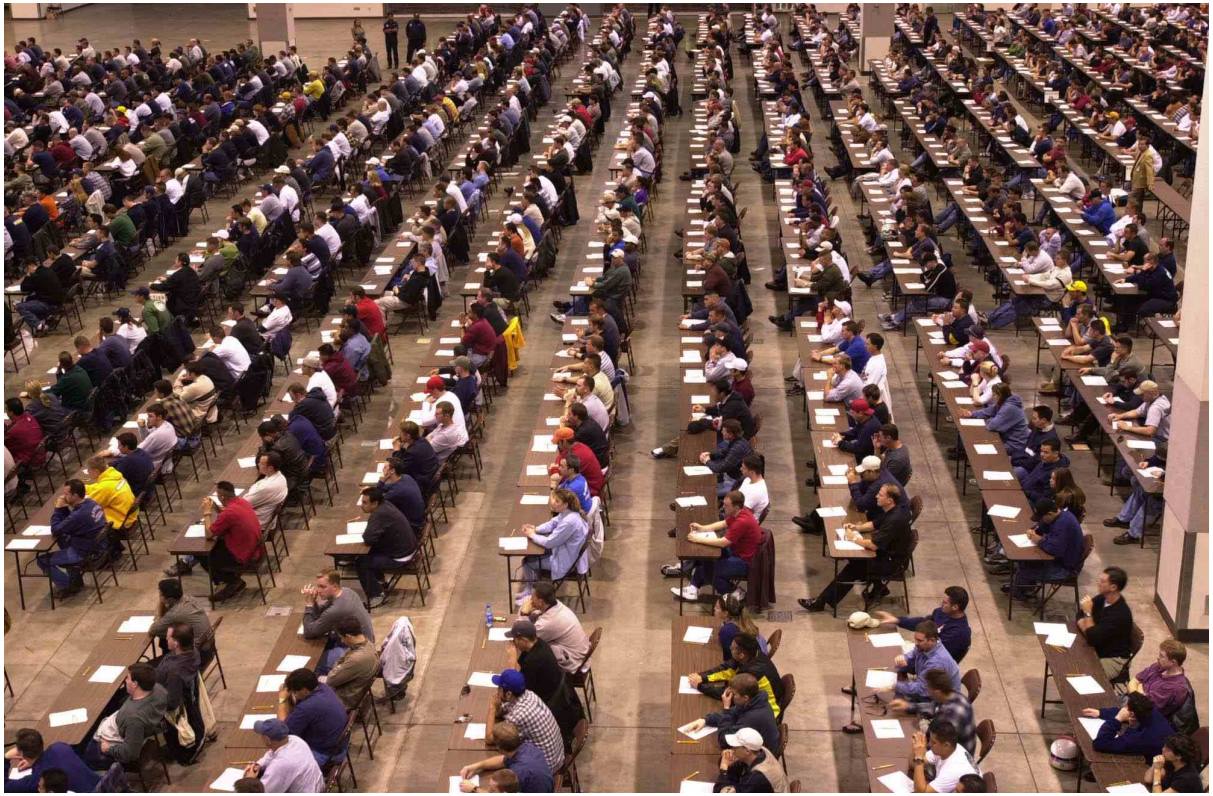
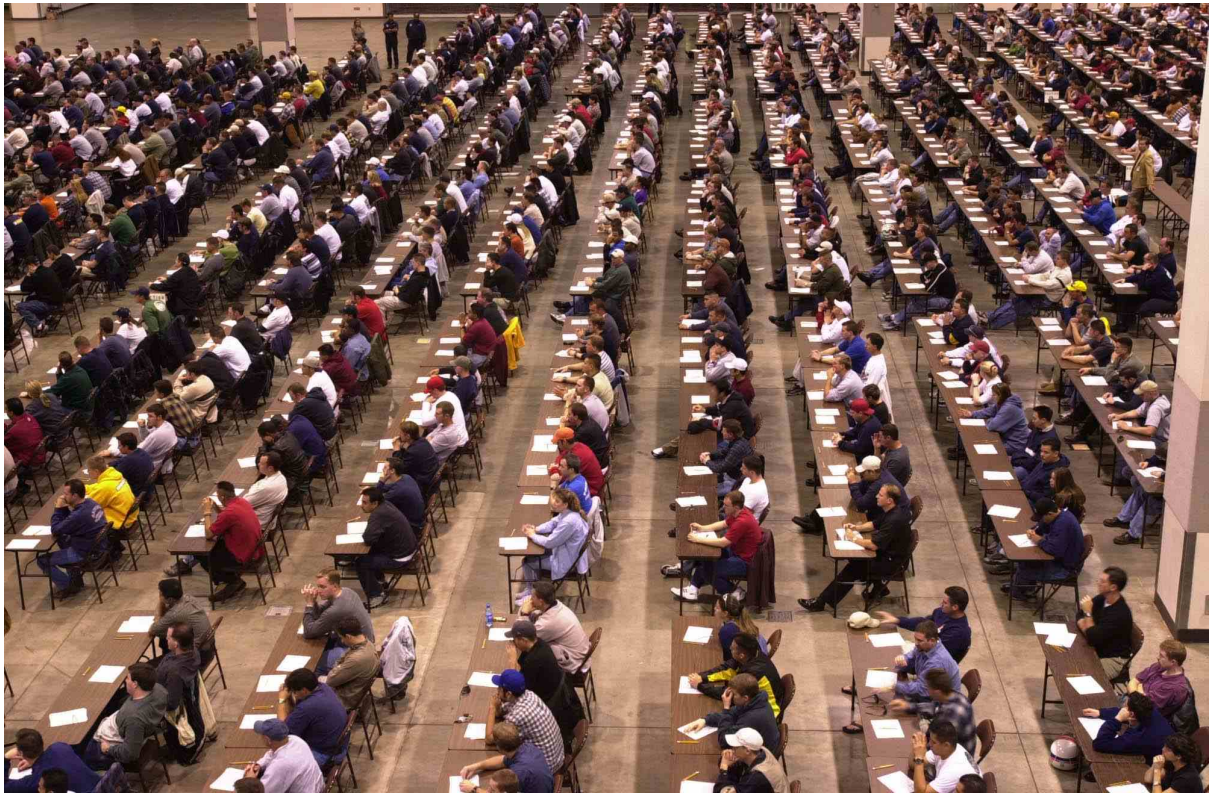
Exam

Filippo Galanti (Sora in Caserta 1852 - Buenos Aires 1953)

Exam



Exam



Electronic Exam: Information technology for the assessment of knowledge and skills.

Exam

- Evaluation of individuals
  - Educational assement
  - Skills test
  - Personnel selection
  - Project proposal
  - Public tender
  - Competition (e.g., games)
- Evaluation of groups
  - Organization performances
  - Country benchmarks
  - Societal census

Exam: Players and Organization

Roles:

Candidate

Exam Authority

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Question Committee

Invigilator

Examiner

...

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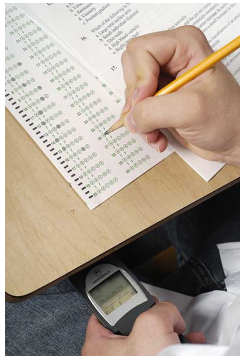
Four Phases:

1. Registration
2. Examination
3. Marking
4. Notification

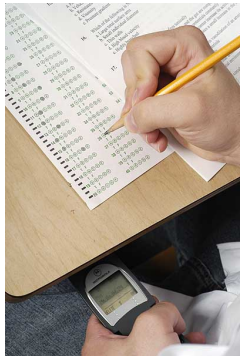
Threats. . .



- Candidate cheating
- Corrupted exam authority
- Unfair examiners
- Outside attackers

  - Data integrity
  - Fair marking
  - Privacy leaks

Threats. . .



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Real Threats!

- Atlanta Public Schools scandal (2009)
- Turkish Public Personnel Selection Exam (2010)
- UK student visa tests fraud (2014)

. . . and their Mitigation

Exam protocols employ some countermeasures mostly focusing on **student cheating**:

- Exam centres

- Software solutions, e.g. ProctorU

ProctorU
Real People.
Real Proctoring.

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Can we prevent exam frauds?

Towards Verifiability

Probably not. But we can check for the presence of irregularities.

Exam model

Very abstract model:

- Four **sets:**
  - $\{$  $\}$: candidate identities, subset $\{$  $\}_r$ registered candidates
  - $\{$  $\}$: questions, subset $\{$  $\}_g$ correct questions
  - $\{$  $\}$: answers
  - $\{$  $\}$: marks
- Three **relations:**
  - `Accepted` $\subseteq \{$  $\} \times (\{$  $\} \times \{$  $\})$
  - `Marked` $\subseteq \{$  $\} \times (\{$  $\} \times \{$  $\}) \times \{$$\}$
  - `Assigned` $\subseteq \{$  $\} \times \{$  $\}$
- A **function** `Correct` : $(\{$  $\} \times \{$  $\}) \to \{$$\}$
- An exam protocol is ***X*-verifiable**, if we have a **sound** and **complete** test for ***X***.

Defining **Individual Verifiability**

Each **candidate** knows

- her identity  ,
- question  ,
- answer  ,
- mark  ,
- and a log  .

Properties:

The candidate can verify that...

- Question Validity: ...she received questions generated by the question committee

$$\mathtt{QV}_{\mathtt{IV}}(\text{  }, \text{  }, \text{  }, \text{  }, \text{  }) \Leftrightarrow (\text{  } \in \{\text{  }\}_g)$$

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sound & complete

Defining Individual Verifiability Cont'd

The candidate can verify that...

- Marking Correctness: ...the mark attributed to her answer is correct.

$$\mathtt{MC}_{\mathtt{IV}}(\text{\textcircled{\textcircled{\textcircled{\textcircled{}}}}}, \text{\textcircled{?}}, \text{\textcircled{!}}, \text{\textcircled{A+}}, \text{\textcircled{LOG}}) \Leftrightarrow (\mathtt{Correct}(\text{\textcircled{?}}, \text{\textcircled{!}}) = \text{\textcircled{A+}})$$

- Exam-Test Integrity: ...her answer was accepted and marked as submitted.

$$\mathtt{ETI}_{\mathtt{IV}}(\text{\textcircled{\textcircled{\textcircled{\textcircled{}}}}}, \text{\textcircled{?}}, \text{\textcircled{!}}, \text{\textcircled{A+}}, \text{\textcircled{LOG}}) \Leftrightarrow ((\text{\textcircled{\textcircled{\textcircled{\textcircled{}}}}}, (\text{\textcircled{?}}, \text{\textcircled{!}})) \in \mathtt{Accepted} \wedge \exists m' : (\text{\textcircled{\textcircled{\textcircled{\textcircled{}}}}}, (\text{\textcircled{?}}, \text{\textcircled{!}}), m') \in \mathtt{Marked})$$

- Exam-Test Markedness: ...her answer was marked.

$$\mathtt{ETM}_{\mathtt{IV}}(\text{\textcircled{\textcircled{\textcircled{\textcircled{}}}}}, \text{\textcircled{?}}, \text{\textcircled{!}}, \text{\textcircled{A+}}, \text{\textcircled{LOG}}) \Leftrightarrow (\exists m' : (\text{\textcircled{\textcircled{\textcircled{\textcircled{}}}}}, (\text{\textcircled{?}}, \text{\textcircled{!}}), m') \in \mathtt{Marked}))$$

Defining Individual Verifiability Cont'd

The candidate can verify that...

- Marking Integrity: ...her registered mark is the one assigned by the examiner

$$\mathtt{MI}_{\mathtt{IV}}(\text{  }, \text{  }, \text{  }, \text{  }, \text{  }) \Leftrightarrow \exists m' : \big((\text{  }, (\text{  }, \text{  }), m') \in \mathtt{Marked} \wedge (\text{  }, m') \in \mathtt{Assigned}\big)$$

- Marking Notification Integrity: ...she received the assigned mark

$$\mathtt{MNI}_{\mathtt{IV}}(\text{  }, \text{  }, \text{  }, \text{  }, \text{  }) \Leftrightarrow (\text{  }, \text{  }) \in \mathtt{Assigned}$$

Universal Verifiability

An **outside auditor** only has access to some evidence  .

The auditor can verify that...

Properties:

- Registration: ...all the accepted answers were submitted by registered candidates.

$$\mathtt{R}_{\mathtt{UV}}(\text{LOG}) \Leftrightarrow \{\text{  }\}_r \supseteq \langle i : (i, x) \in \mathtt{Accepted} \rangle$$

- Marking Correctness: ...all the marks were calculated correctly.

$$\mathtt{MC}_{\mathtt{UV}}(\text{LOG}) \Leftrightarrow \forall (i, x, m) \in \mathtt{Marked}, \mathtt{Correct}(x) = m$$

Universal Verifiability Cont'd

The auditor can verify that...

- Exam-Test Integrity: ...all and **only** accepted test answers were marked.

$$\mathtt{ETI}_{\mathtt{UV}}(\text{LOG}) \Leftrightarrow \mathtt{Accepted} = \langle (i, x) : (i, x, m) \in \mathtt{Marked} \rangle$$

- Exam-Test Markedness: ...all accepted test answers were marked.

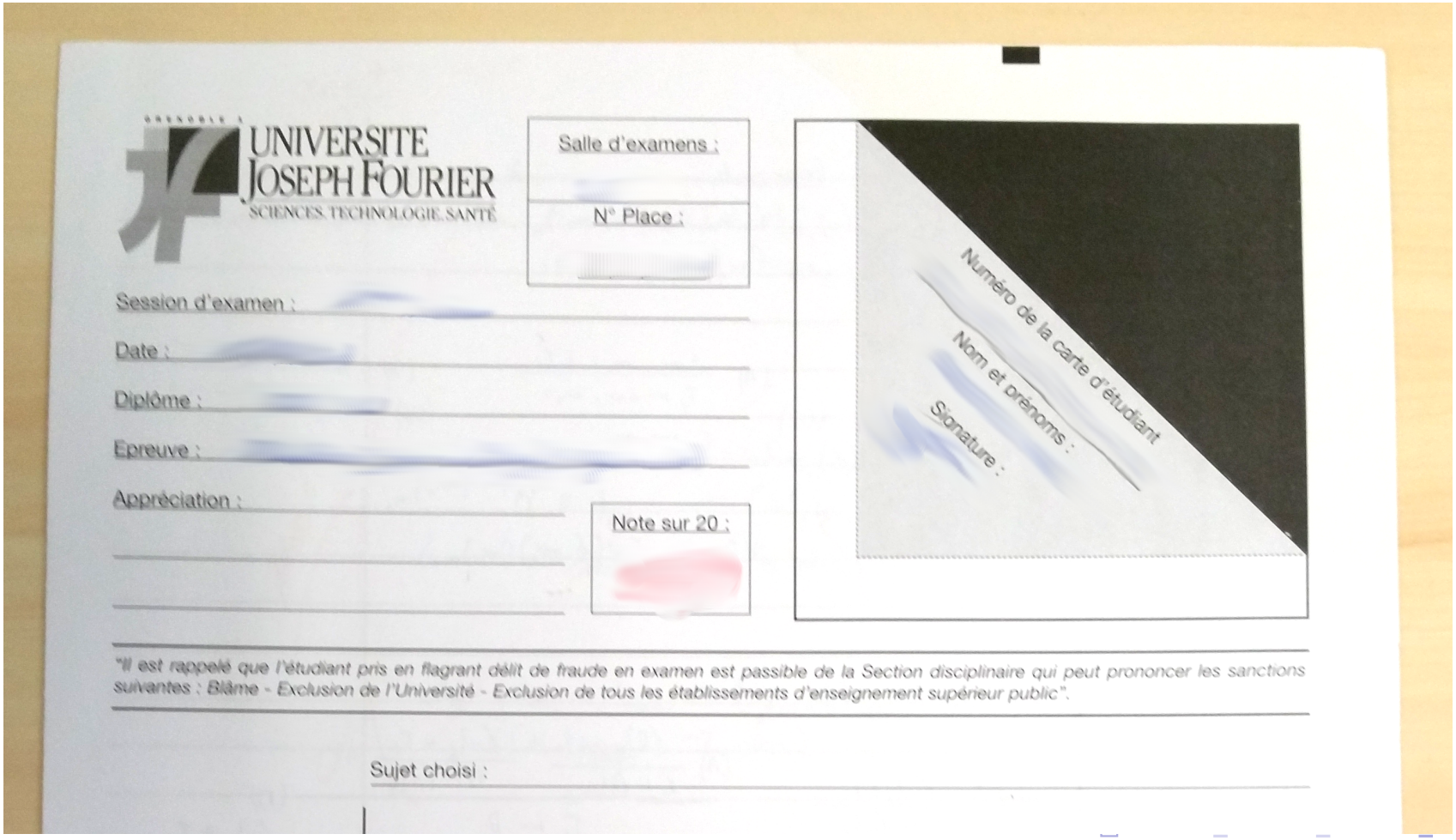
$$\mathtt{ETM}_{\mathtt{UV}}(\text{LOG}) \Leftrightarrow \mathtt{Accepted} \subseteq \langle (i, x) : (i, x, m) \in \mathtt{Marked} \rangle$$

- Marking Integrity: ...all and **only** the marks assigned to test answers were registered.

$$\mathtt{MI}_{\mathtt{UV}}(\text{LOG}) \Leftrightarrow \mathtt{Assigned} = \langle (i, m) : (i, x, m) \in \mathtt{Marked} \rangle$$

Case Study I: Grenoble Exam

- **Paper-based** exam system at the University Joseph Fourier
- **Goal:** Privacy (Anonymous Marking)
- **Special exam paper** with corner that is folded and glued:



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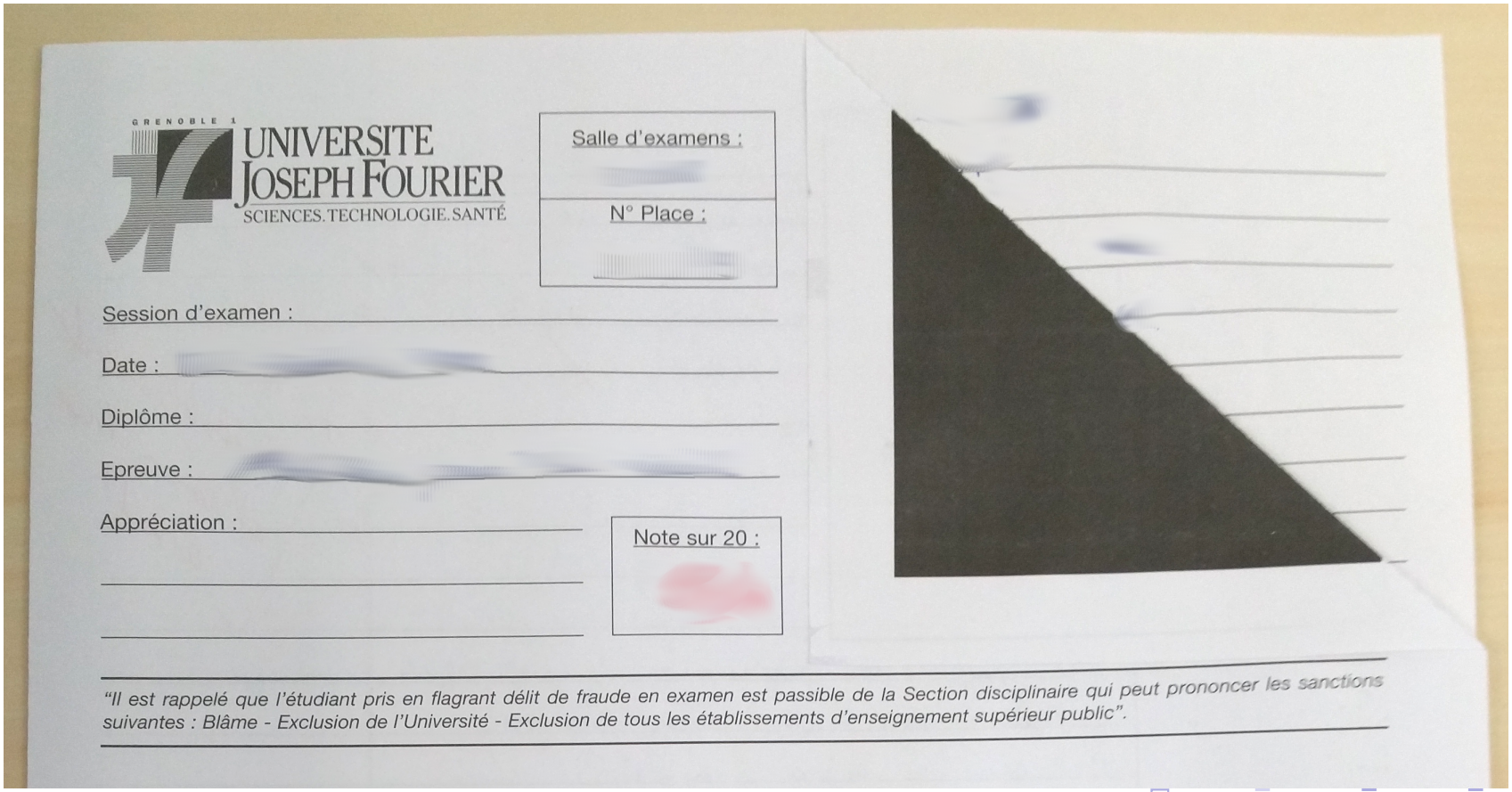

Grenoble Exam: Results

Individual Verifiability:

- Input: the candidate's values
- Assumptions: `Correct` is published after the exam, and candidates can consult their copies
- Verification using ProVerif:

Property	Sound	Complete
Question Validity	× (EA)	✓
Test Answer Integrity	× (EA, E)	✓
Test Answer Markedness	× (E)	✓
Marking Correctness	✓	✓
Mark Integrity	× (EA, E)	✓
Mark Notification Integrity	× (EA)	✓

- No guarantee that the records are correct.

Grenoble Exam: Results Cont'd

Universal Verifiability:

- Assumption: the auditor gets access to the EA's and Es' records and the function `Correct`.
- Verification using ProVerif:

Property	Sound	Complete
Registration	× (EA)	✓
Exam-Test Integrity	× (EA, E)	✓
Exam-Test Markedness	× (EA, E)	✓
Marking Correctness	× (E)	✓
Mark Integrity	× (EA, E)	✓

- No guarantee that the records are correct, EA and E can make up fake records as long as they are coherent.

Case Study II: Remark!

Goal

- Authentication
  - signatures
- Privacy
  - ElGamal encryption
  - an exponentiation mixnet to create pseudonyms based on the parties' public keys
    $\Rightarrow$ allows to encrypt and sign anonymously
- **Verifiability**
  - a public append-only bulletin board

Assumptions

- The model answers are kept secret from the candidate until after the examination.
- At least one mix server is honest.

Remark!: Exponentiation Mixnet

Input				$\cdots$	**Output**
PK_1^0	$(PK^0_{\pi_1(1)})^{r_1} =: PK_1^1$		$(PK^1_{\pi_2(1)})^{r_2} =: PK_1^2$	$\cdots$	$(PK^0_{\pi(1)})^{\overline{r}}$
PK_2^0	$(PK^0_{\pi_1(2)})^{r_1} =: PK_2^1$		$(PK^1_{\pi_2(2)})^{r_2} =: PK_2^2$	$\cdots$	$(PK^0_{\pi(2)})^{\overline{r}}$
$\vdots$	$\vdots$		$\vdots$		$\vdots$
PK_n^0	$(PK^0_{\pi_1(n)})^{r_1} =: PK_n^1$		$(PK^1_{\pi_2(n)})^{r_2} =: PK_n^2$	$\cdots$	$(PK^0_{\pi(n)})^{\overline{r}}$
g	g^{r_1}		g^{r_2}		$g^{\overline{r}} =: h_C$

where $\overline{r} = \prod_{i=1}^{k} r_i$ and $\pi = \pi_1 \circ \pi_2 \circ \cdots \circ \pi_k$

Remark!: Results

Individual Verifiability:

- Input: the candidate's values and the messages on the bulletin board
- Assumption: `Correct` is published after the exam
- Verification using ProVerif:

Property	Sound	Complete
Question Validity	× (EA)	✓
Test Answer Integrity	✓	✓
Test Answer Markedness	✓	✓
Marking Correctness	× (EA)	✓
Mark Integrity	✓	✓
Mark Notification Integrity	✓	✓

Remark!: Results Cont'd

Universal Verifiability:

- Input: the messages on the bulletin board, the function `Correct`, as well as **additional data from the EA**
- Verification using ProVerif:

Property	Sound	Complete
Registration	✓	✓
Exam-Test Integrity	✓	✓
Exam-Test Markedness	✓	✓
Marking Correctness	× (EA)	✓
Mark Integrity	✓	✓

Conclusion

- General framework to analyse both electronic and traditional exam protocols
- Formal verification in ProVerif of most properties
  - Traditional exam: Grenoble
  - Electronic exam: Remark!
- Manual proofs needed for few properties

Future and Ongoing Work

- Design fully verifiable protocols
- CryptoVerif
- Accountability

Thanks!

Questions?