Towards unconditionally E2E verifiable elections: the making of Demos remote e-voting system

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2. **Privacy:** No one can learn how the voters have voted or control their free will.

Traditional elections

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2. Integrity is **indirect** and relies on faith assumptions (conflict of interests, trust in state representatives, etc.).

Motivation for adopting Electronic voting (e-voting)

- Increasing political participation and representation among traditionally underrepresented groups.
- Cost-efficient and better administered elections.

Types of Electronic voting systems

On-site e-voting

On-site e-voting

Remote e-voting (i-voting)

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- At on-site e-voting systems, voters are protected from coercion as in traditional elections. At remote e-voting systems, coercion resistance is a major challenge. Several solutions have been proposed (voting multiple times, misleading the coercer by using fake credentials or fake ballots).

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  - (ii). Recorded as cast.
  - (iii). Tallied as recorded.
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An e-voting system that satisfies these properties is called

End-to-end (E2E) Verifiable

E2E Verifiable e-voting systems

On-site E2E Verifiable e-voting systems:

- Prêt à Voter [Chaum, Ryan & Schenider - 2005].
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Remote E2E Verifiable e-voting systems:

- Helios [Adida - 2008].
- Remotegrity [Zagorski et al. - 2013].
- *Demos* [Kiayias, Zacharias & Zhang - 2014].

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- Remotegrity [Zagorski et al. - 2013].
- *Demos* [Kiayias, Zacharias & Zhang - 2014].

Demos is the only remote e-voting proven E2E verifiable in the standard model (does not assume the existence of an external truly random source).

The making of Demos remote e-voting system

The security framework

- We consider a single Election Authority (EA) that controls the whole system (all authorities and the voter clients are potentially corrupted and colluding).
- Our aim is E2E Verifiability in the standard model in the case that EA and a constant fraction of the voters is malicious.
- We require Voter Privacy against anyone but the Election Authority.

Code-voting 101

Election Authority

Candidate	Vote-code
Alice	AAAA-1111
Bob	BBBB-2222
Charlie	CCCC-3333
David	DDDD-4444

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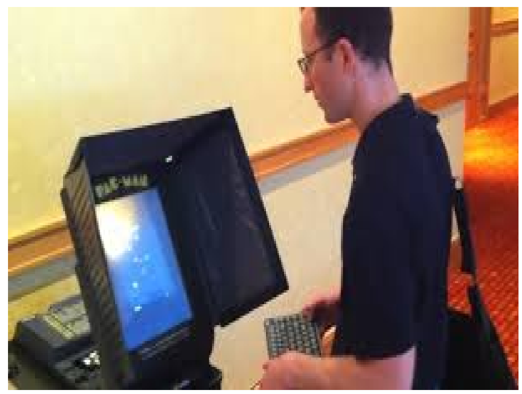

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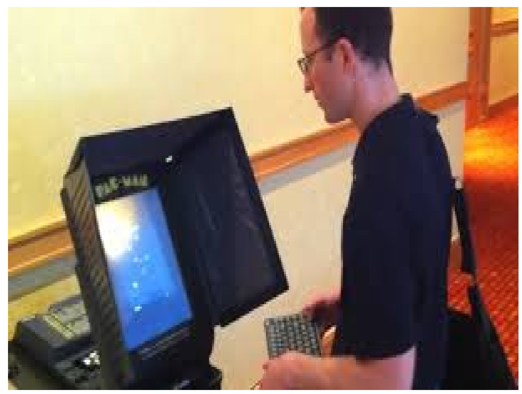

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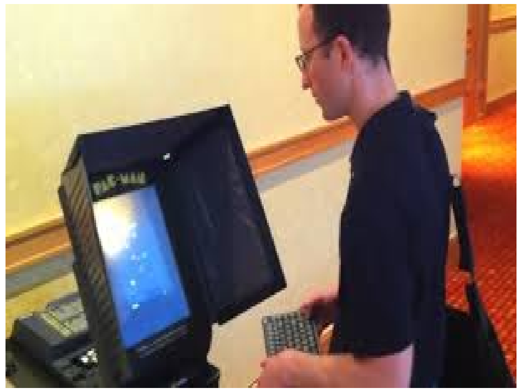

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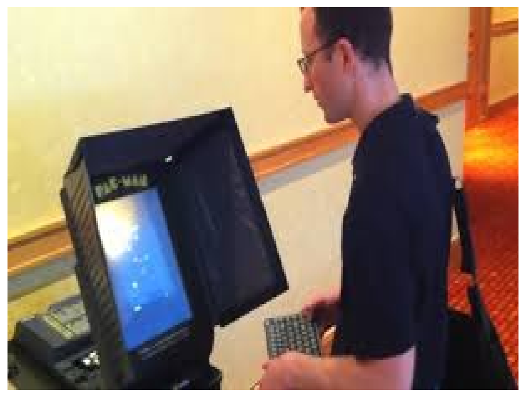

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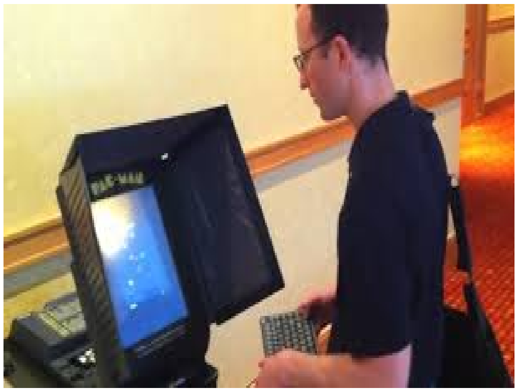

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The described e-voting system is simple and easy. Is it reliable?

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- Integrity of the system can be verified only at the minimum level.
  - The voters know that their vote was *cast-as-intended* by submitting the vote-code that corresponds to the candidates of their choice.
  - The voters cannot verify that their was *recorded-as-cast* (the vote-code could be not be accepted or altered due to system failure without any notice).
  - No audit information is published by the Election Authority, so the voters can verify that their vote was *tallied-as-recorded* or some party can verify the correct execution of the election.

Taking a step further: proving correct record of the votes

Election Authority

$\downarrow$

Candidate	Vote-code	Receipt
Alice	AAAA-1111	REC1
Bob	BBBB-2222	REC2
Charlie	CCCC-3333	REC3
David	DDDD-4444	REC4

Ballot No. 100

Taking a step further: proving correct record of the votes

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Each vote-code is paired with a (pseudo) randomly generated receipt.

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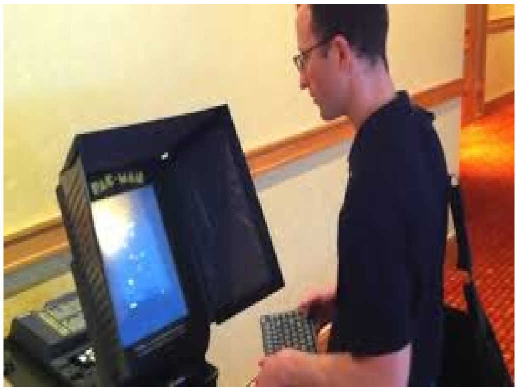

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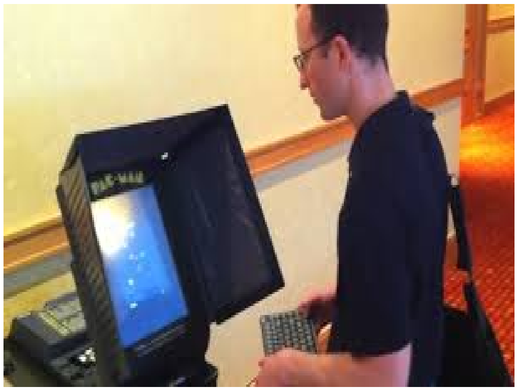

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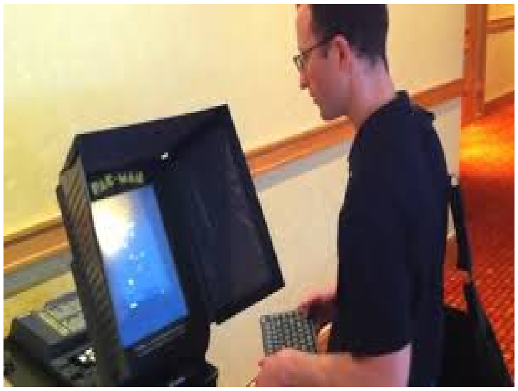

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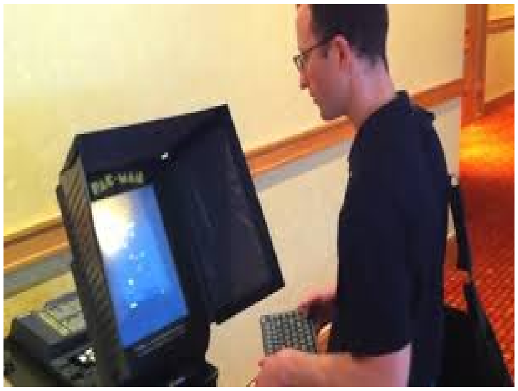

REC1

Election Authority

What do we gain using receipts

- Privacy remains at the same levels since including random receipts does not leak any information about the vote-code and candidate correspondence.
- The voters can verify that their vote was cast-as-intended and that it was recorded-as-cast (the only way that the system may reply with the correct receipt is that they read the correct vote-code).
- Still, lack of further audit information does not make any further verification possible (that the recorded vote was counted-as-intended and the election was executed properly).

Enabling audit: introducing the Bulletin Board

Election Authority

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Bulletin Board

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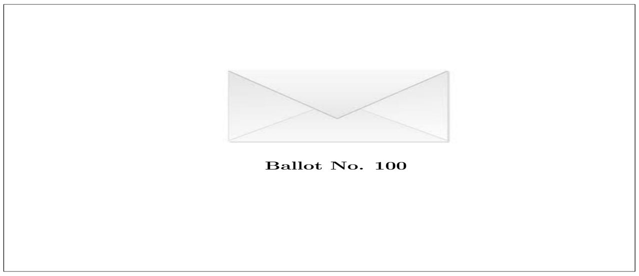

Bulletin Board

What we gain by using the Bulletin Board

- After voting ends, EA announces the result and opens the envelopes, so audit can be performed.
- The use of an electronic envelope prevents a malicious EA from posting audit information which is inconsistent.
- The electronic envelope is realised by a perfectly binding, computationally hiding and additively homomorphic **commitment scheme** $\mathrm{Com}(\cdot)$.

Exploiting the properties of a commitment scheme

The "envelope" effect:

(i). Binding: EA cannot open $\mathrm{Com}(m)$ to a message other than m, so the audit information is perfectly consistent.

(ii). Hiding: Any PPT algorithm that does not have the opening key cannot read m from $\mathrm{Com}(m)$, so sensitive information about the voters' ballots is not leaked.

Exploiting the properties of a commitment scheme

Computing the tally in a verifiable way:

(iii). Additively homomorphic:

$$\boxed{\mathrm{Com}(m_1) \cdot \mathrm{Com}(m_2) = \mathrm{Com}(m_1 + m_2)}$$

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- The EA encodes the candidates in “message” format and posts the pairs of vote-codes and encoded candidates in committed form.
- The EA opens all vote-code commitments and marks all the cast vote-codes and the commitments that are associated with them.
- The EA multiplies all the marked commitments, opens the result and posts the openings in the Bulletin Board (BB).
- Due to the binding property, anyone can verify that these computations were done correctly.

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- The corresponding audit information posted on the BB is $\big(\mathrm{Com}(C_1), \mathrm{Com}(\langle \mathrm{Alice} \rangle)\big)$, $\big(\mathrm{Com}(C_2), \mathrm{Com}(\langle \mathrm{Alice} \rangle)\big)$ and $\big(\mathrm{Com}(C_3), \mathrm{Com}(\langle \mathrm{Bob} \rangle)\big)$.

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$$\mathrm{Com}(\langle \mathrm{Alice} \rangle) \cdot \mathrm{Com}(\langle \mathrm{Alice} \rangle) \cdot \mathrm{Com}(\langle \mathrm{Bob} \rangle) = \\ = \mathrm{Com}(2 \cdot \langle \mathrm{Alice} \rangle + \langle \mathrm{Bob} \rangle).$$

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- EA posts the encoded result $2 \cdot \langle \mathrm{Alice} \rangle + \langle \mathrm{Bob} \rangle$, which is decoded as $\langle \mathrm{Alice} : 2, \mathrm{Bob} : 1, \mathrm{Charlie} : 0, \mathrm{David} : 0 \rangle$.

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We have to enhance the system with verification mechanisms that prevent a malicious EA from committing inconsistently.

Fixing the first weakness...

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Finalization of the construction of Demos: introducing the use of double ballots

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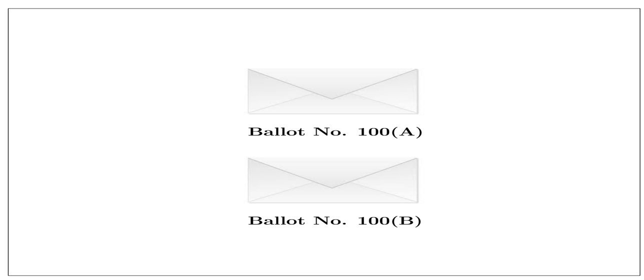
David	DDDD-4444	REC4

Ballot No.100(A)

Candidate	Vote-code	Receipt
Alice	EEEE-5555	REC5
Bob	FFFF-6666	REC6
Charlie	GGGG-7777	REC7
David	HHHH-8888	REC8

Ballot No.100(B)



Bulletin Board

Voting with double ballots

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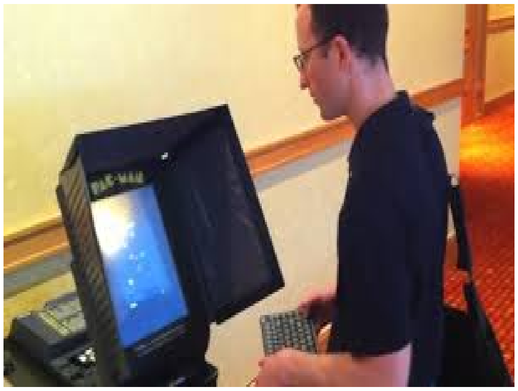

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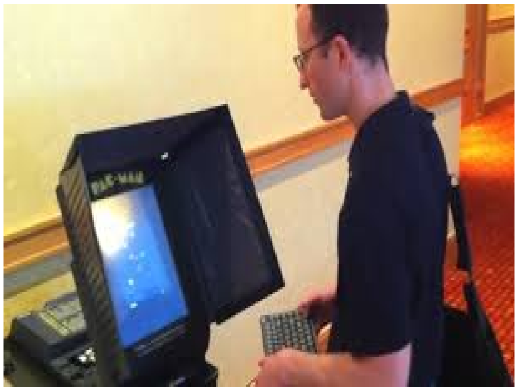

No. 100
AAAA-1111
Open (B)

Election Authority

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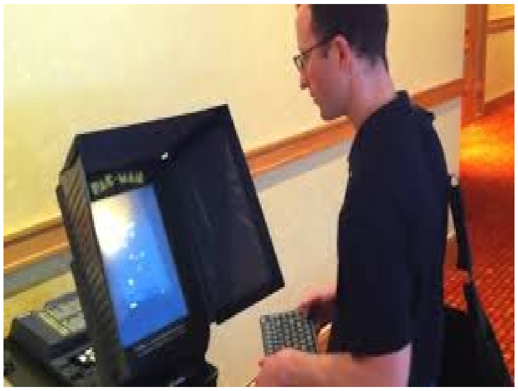

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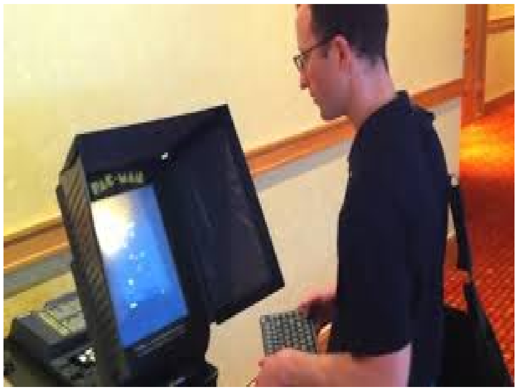

REC1

Election Authority

What we gain by using double ballots

Privacy preservation:

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Integrity:

- The EA cannot know in advance which side the voter is going to use, so any malicious behaviour will be detected with probability $1/2$ by the voter.
- If the EA attempts to alter t ballots, it will be caught with probability $1-(1/2)^t$.
- Assuming a large enough number of voters, we verify that almost all votes have been counted correctly with high probability.

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By injecting 1000 votes for Alice, EA could change the result significantly with 50% probability (the invalid encoding is not in the side of the ballot used for audit).

Fixing the last weakness

1. The voters can verify that the EA has not committed to a different vote-code and candidate correspondence at setup.
2. Anyone can verify that the commitments correspond to well-formed ballots, i.e. one commitment per (encoded) candidate in every side of all ballots.

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- ZK soundness requires a source of true randomness that could come from an external source (assuming a random oracle or a randomness beacon) but...
- We promised E2E verifiability in the standard model **for the first time**.

ZK soundness via human interaction

- When an honest voter chooses which side (A or B) she will use to vote, she concurrently inserts **1 bit of randomness** in the system by flipping a coin. This bit is public and cannot be altered by a malicious EA without being detected.

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- Assuming that a small fraction of the voters are not corrupted and vote successfully, we can extract true randomness from the voters' choice and apply it to the verification of the ZK proofs.

Overview of the construction of Demos

1. We generate code-based ballots for a private and simple voting procedure from the voters' side.
2. We associate the vote-codes with receipts, so that the voters are sure that their vote was accepted by the system.
3. We introduce a public BB, that contains all necessary audit information, consistently committed by the EA.
4. We provide the voters with double ballots, so that they can choose one side of the ballot to vote and the other to audit the election without revealing their votes.
5. We use the voters' coin flips to extract true randomness for the ZK proofs, thus maintening Demos E2E verifiable in the standard model.

Activities of the FINER research team:

Implementation of Demos and the European Elections 2014 experiment

The FINER research team members

Professors:

Alex Delis (DI&T), Aggelos Kiayias (DI&T), Charalampos Koutalakis (DPS&PA), Elias Nikolakopoulos (DPS&PA), Mema Roussopoulou (DI&T), Georgios Sotirellis (DPS&PA)

Postdoctoral researchers:

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Implementation of Demos by **Bingsheng Zhang**

- The server is implemented in *Django*.
- We implement Elliptic Curve ElGamal using the fastest elliptic curve crypto library *MIRACL*.
- We support ballot distribution in three ways: via CAS, paper or email.

The European Elections 2014 experiment

The European Elections 2014 experiment

- Two groups performed parallel pilot runs of Demos into two different polling places (Ilioupoli & Chalandri).
- The goal of the experiment was (i) to get the voters familiar with Demos and (ii) test the current implementation.
- The participants (747 in total) were issued paper ballots (one side of the double ballot was printed in one side of the paper) that contained a QR code in each side.
- The QR codes were scanned by the cameras of the tablets (two for each station) and the participants were prompted in a user-friendly (web page) environment to vote.
- After voting, the participants filled in a questionnaire.

The European Elections 2014 experiment

- A paper with the analysis of the results of the experiment under the title:
  "*Pressing the Button for European Elections 2014: Public Attitudes towards Verifiable E-Voting In Greece*"
  is accepted at the upcoming EVOTE2014 conference.
- The above paper and the election result of our experiment can be found in our website:

$$http://www.demos-voting.com$$

Thank you!

Towards unconditionally E2E verifiable elections: the making of Demos remote e-voting system

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