Why Public Boards are Required in E-Voting Systems Based on Threshold Blind Signature

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UNIVERSITAS FRIBURGENSIS

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HASLERSTIFTUNG

Outline

1. Introduction
2. Blind Signature Voting Scheme
3. Multiple Authorities
4. Attack on Democracy
5. Solution
6. Conclusion

Why This Talk?

Default blind signature schemes...

- ...are simple and understandable
- ...are used in many E-Voting / E-Cash Protocols
- ...bear a severe weakness
  if used within a threshold protocol

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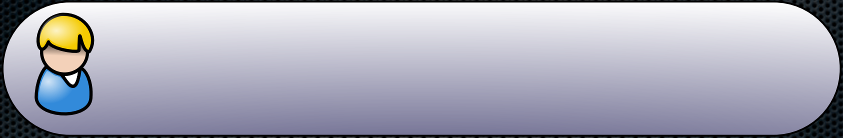
Voters Will



The voter...

- ...gets the ballot...
- ...declares the will onto the ballot.

Voters Will

Vote for one option:
□ Joe Smith
□ John Citizen
□ Jane Doe
□ Fred Rubble
□ Mary Hill
Authorization:

The voter...

- ...gets the ballot...
- ...declares the will onto the ballot.

Filling in the Ballot

Voters Will

Vote for one option:

☐ Joe Smith

☒ John Citizen

☐ Jane Doe

☐ Fred Rubble

☐ Mary Hill

Authorization:

The voter...

- ...gets the ballot...
- ...declares the will onto the ballot.

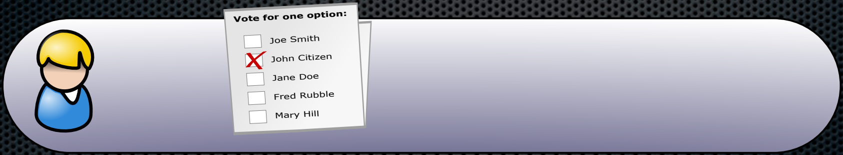
Blinding

Vote for one option:
□ Joe Smith
☒ John Citizen
□ Jane Doe
□ Fred Rubble
□ Mary Hill

The voter...

- ...blinds the vote for the voting authority...

Blinding



The voter...

- ...blinds the vote for the voting authority...

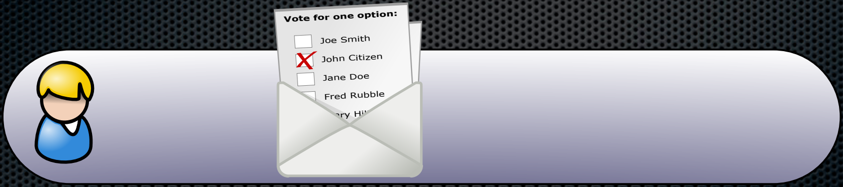
Blinding

Authorization:

The voter...

- ...blinds the vote for the voting authority...

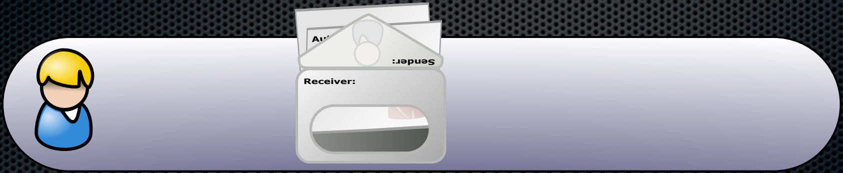
Blinding



The voter…

- …blinds the vote for the voting authority…

Blinding



The voter...

- ...blinds the vote for the voting authority...

Blinding

The voter...

- ...blinds the vote for the voting authority...

Voter - Signing

The voter...

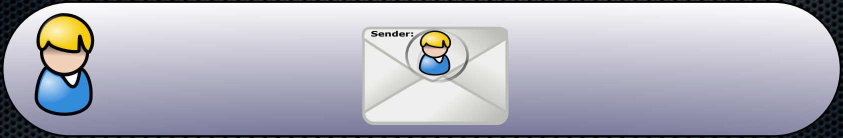
- ...signs the blinded vote...

Voter - Signing

The voter...

- ...signs the blinded vote...

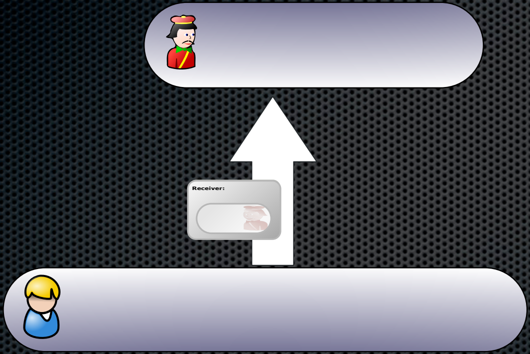
Voter - Signing



The voter...

- ...signs the blinded vote...

Transmission



The voter...

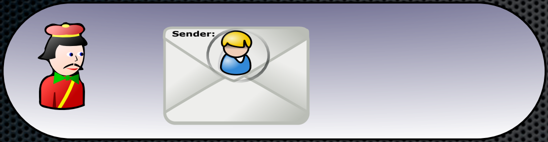
- ...sends the blinded vote to the authority.

Verifying the Eligibility

The authority...

- ...verifies the eligibility of the voter...
- ...by consulting and updating the voter roll...

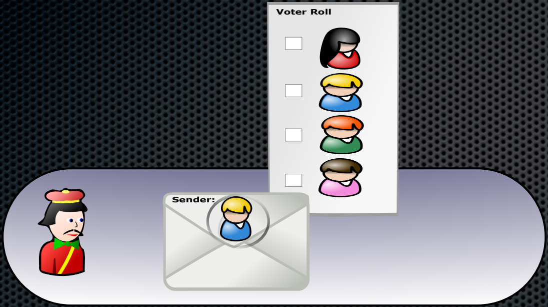
Verifying the Eligibility



The authority...

- ...verifies the eligibility of the voter...
- ...by consulting and updating the voter roll...

Verifying the Eligibility



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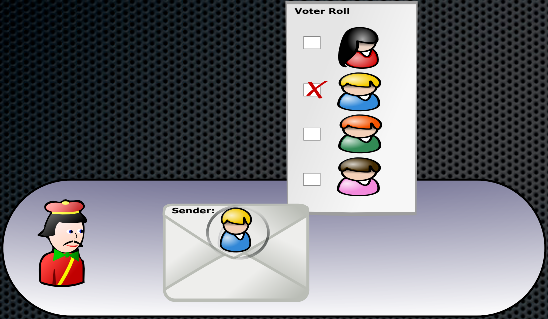
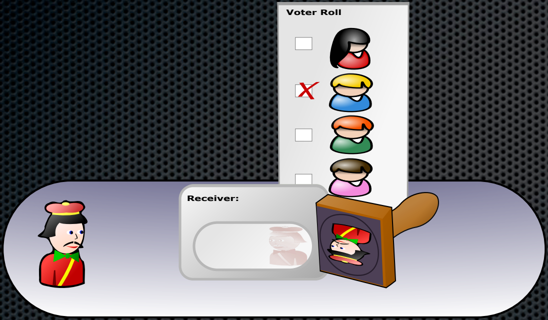
Verifying the Eligibility



The authority...

- ...verifies the eligibility of the voter...
- ...by consulting and updating the voter roll...

Authority - Signing



The authority...

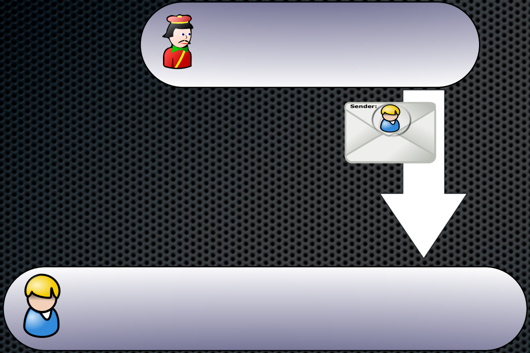
- ...blindly signs the vote in the envelope...

Authority - Signing

The authority...

- ...blindly signs the vote in the envelope...

Transmission



The authority...

- ...sends the blindly signed vote back to the voter.

Unblinding

The voter...

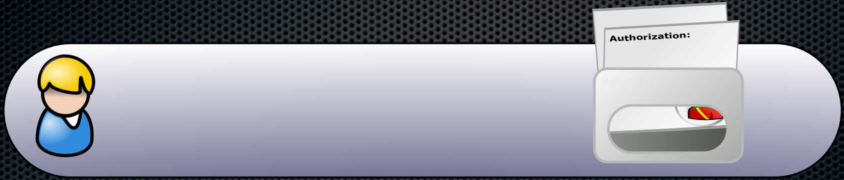
- ...unblinds the vote...
- ...is ready to cast an authorized anonymous vote.

Unblinding

The voter...

- ...unblinds the vote...
- ...is ready to cast an authorized anonymous vote.

Unblinding



The voter...

- ...unblinds the vote...
- ...is ready to cast an authorized anonymous vote.

Unblinding

Vote for one option:

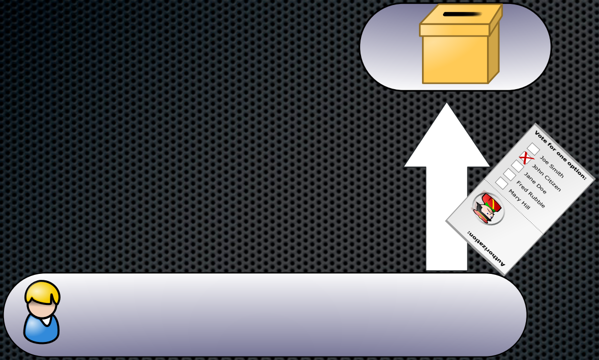
- □ Joe Smith
- ☒ John Citizen
- □ Jane Doe
- □ Fred Rubble
- □ Mary Hill

Authorization:

The voter...

- ...unblinds the vote...
- ...is ready to cast an authorized anonymous vote.

Transmission



The voter...

- ...sends the authorized vote to the ballot box...

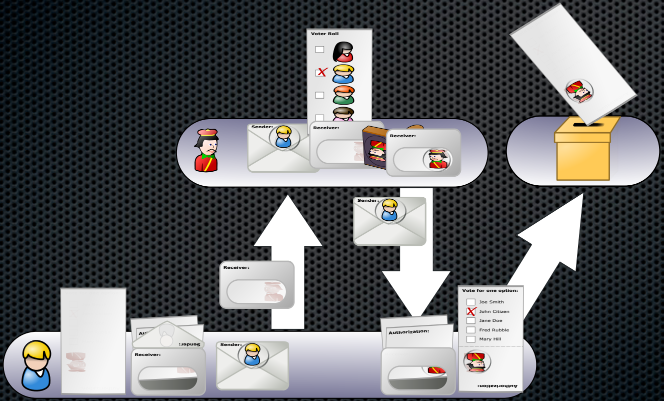
Vote Casting

Vote for one option:
□ Joe Smith
☒ John Citizen
□ Jane Doe
□ Fred Rubble
□ Mary Hill
Authorization:

The ballot box...

- ...accepts the authorized vote. (E2E-Verifiable)

Scheme Overview



Standard RSA-Blind Signature Scheme

Definition

$V =$ Voter

$A =$ Authority

$B =$ Ballot box

$v =$ Vote

$e, m =$ Public key of signing authority

$d =$ Private key of signing authority

$r =$ Random blinding factor

Scheme (everything $\mod m$)

$$V \rightarrow A : v' = vr^e$$
$$V \leftarrow A : s' = v'^d = v^d r^{ed} = v^d r$$
$$V : s = s' r^{-1} = v^d r r^{-1} = v^d$$
$$V \rightarrow B : (v, s)$$

Scheme in Action

A list of some protocols use this scheme:

A. Fujioka et al	A practical secret voting scheme for large scale elections. Advances of Auscrypt'92, LNCS 718:244?251, 1992.
T. Okamoto	An electronic voting scheme. Proceedings of IFIP'96, pages 21?30, 1996.
Zhe Xia, Schneider	S.A. (2007) A New Receipt-Free E-Voting Scheme Based on Blind Signature (Abstract) , IaVoSS Workshop on Trustworthy Elections (WOTE) , 2006
...	...

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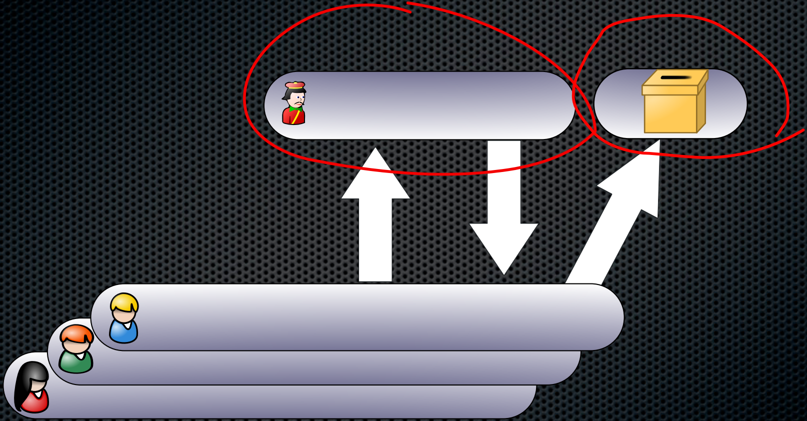
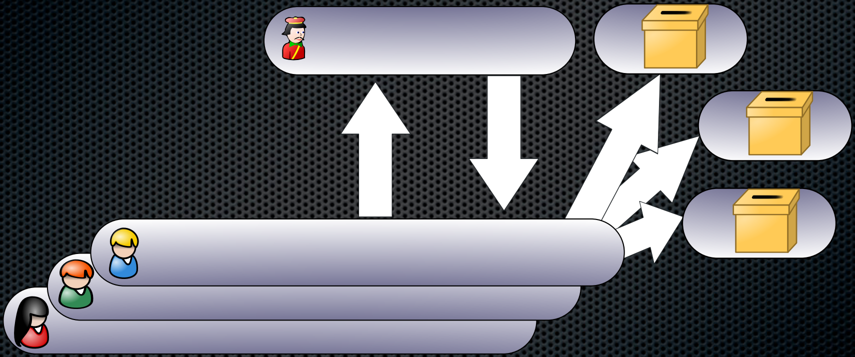
Single Point of Failure



Only one single...

- ...authority
- ...ballot box

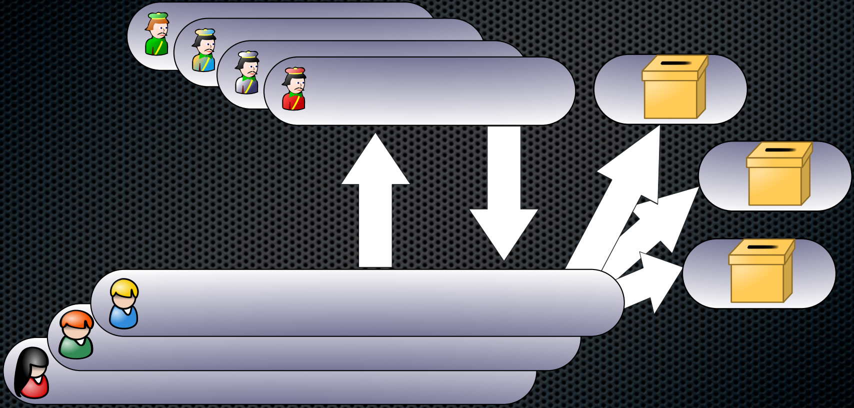
Multiple Ballot Boxes



The replication of the...

- ... ballot box does not affect blind signature scheme

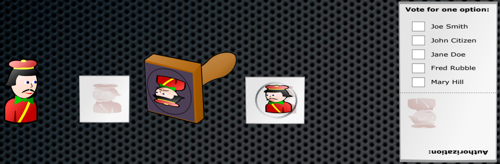
Multiple Authorities (Needs complete scheme re-design)



The replication of the...

- ...authority requires complete re-design of the signature scheme

Single Voting Authority



Vote for one option:

- □ Joe Smith
- □ John Citizen
- □ Jane Doe
- □ Fred Rubble
- □ Mary Hill

Authorization:

Instead of a single...

- ...authority...
- ...authority signature vote

… a multiple…

Multiple Instances…

- of authorities are needed.

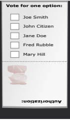
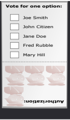
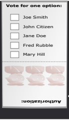
Amount of Required Signatures for n authorities

Is the protocol safe against...

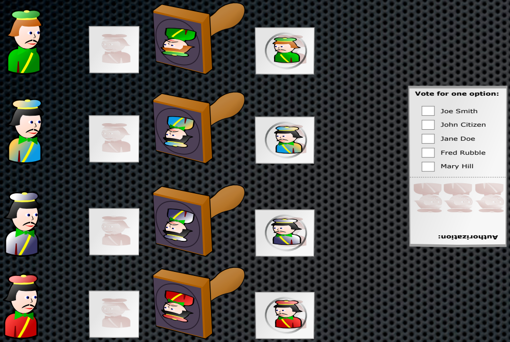
	Failure	Boycott	Masquerade

Amount of Required Signatures for n authorities

Is the protocol safe against...

	Failure	Boycott	Masquerade
 Vote for one option: ☐ Joe Smith ☐ John Citizen ☐ Jane Doe ☐ Fred Rubble ☐ Mary Hill Authorization: 1 out of n	Yes	Yes	No
 Vote for one option: ☐ Joe Smith ☐ John Citizen ☐ Jane Doe ☐ Fred Rubble ☐ Mary Hill Authorization: n out of n	No	No	Yes
 Vote for one option: ☐ Joe Smith ☐ John Citizen ☐ Jane Doe ☐ Fred Rubble ☐ Mary Hill Authorization: t out of n	Yes	Yes	Yes

Ballot For Threshold Voting Authorization



Vote for one option:

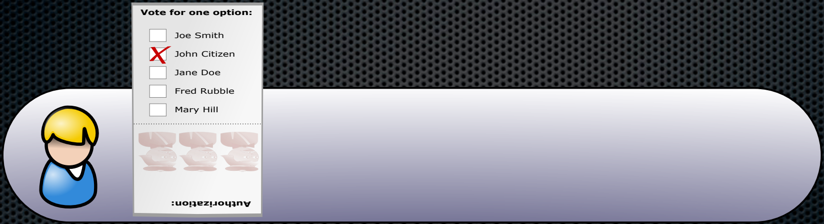
□ Joe Smith
□ John Citizen
□ Jane Doe
□ Fred Rubble
□ Mary Hill

Authorization:

Threshold

- … authority signature vote. (i.e. Less signatures required than authorities available)

Voting / Blinding



Vote for one option:

- □ Joe Smith
- ☒ John Citizen
- □ Jane Doe
- □ Fred Rubble
- □ Mary Hill

The voter...

- ...votes...
- ...blinds the vote for an arbitrary chosen authority...

Voting / Blinding

The voter...

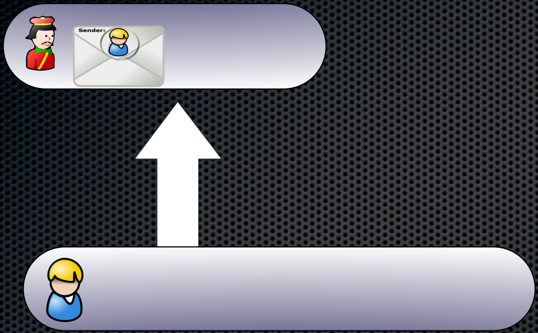
- ...votes...
- ...blinds the vote for an arbitrary chosen authority...

Signing / Sending

The voter…

- …signs the blinded vote
- …sends it to the chosen authority.

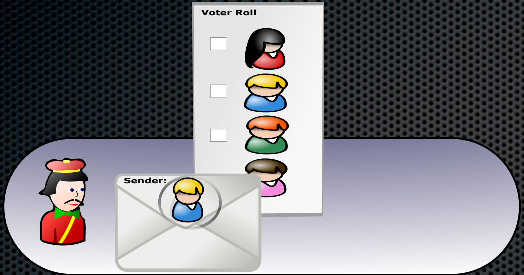
Signing / Sending



The voter...

- ...signs the blinded vote
- ...sends it to the chosen authority.

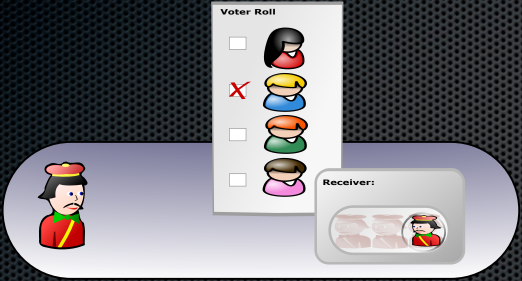
Requesting Authorization



The authority...

- ...verifies the eligibility of the voter...
- ...by consulting and updating the voter roll...

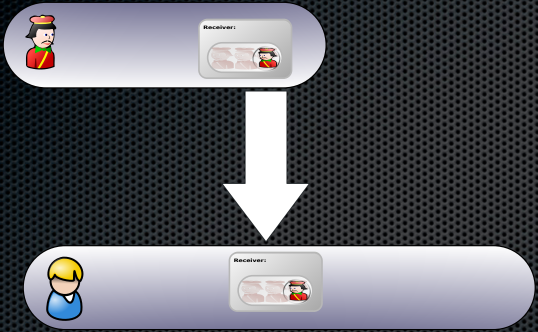
Requesting Authorization



The choosen authority...

- ...blindly signs the vote in the envelope...
- ...sends the blindly signed vote back to the voter.

Requesting Authorization



The choosen authority...

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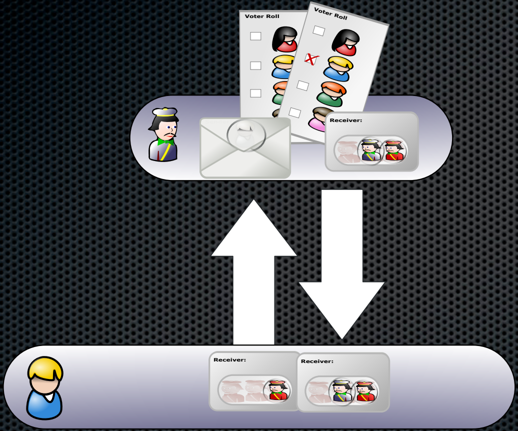
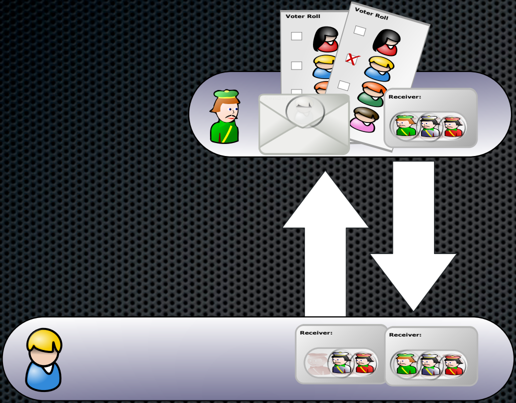


This procedure is repeated...

- ...with other arbitrary chosen authorities...
- ...until the authorization-signature threshold is reached

Requesting Authorization



This procedure is repeated...

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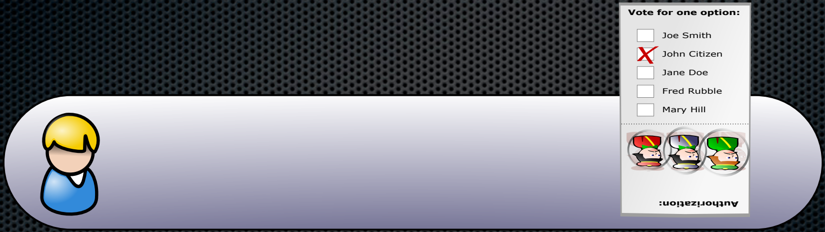

Vote for one option:

□ Joe Smith
☒ John Citizen
□ Jane Doe
□ Fred Rubble
□ Mary Hill

Authorization:

This procedure is repeated...

- ...with other arbitrary chosen authorities...
- ...until the authorization-signature threshold is reached

Modified Threshold RSA-Blind Signature Scheme

Definition

$V =$ Voter

$A_i =$ Authority

$B =$ Ballot box

$v =$ Vote

$e_i, m_i =$ Public key of signing authority

$d_i =$ Private key of signing authority

$r =$ Random blinding factor

Scheme

$$
\begin{aligned}
& V \rightarrow A_1 : v'_1 = vr^{e_1} \\
& V \leftarrow A_1 : s'_1 = v'^{d_1} = v^{d_1} r^{e_1 d_1} = v^{d_1} r \\
& \vdots \\
& V \rightarrow A_t : v'_t = vr^{e_t} \\
& V \leftarrow A_t : s'_t = v'^{d_t} = v^{d_t} r^{e_t d_t} = v^{d_t} r \\
& V \rightarrow B : (v, \{s_1, \ldots, s_t\}) \text{ where } s_i = s'_i r^{-1} = v^{d_i} r r^{-1} = v^{d_i}
\end{aligned}
$$

Scheme in Action

A list of some protocols use this scheme:

B. W. DuRette Multiple administrators for electronic voting. Bachelor thesis, Massachusetts (EVOC) Institute of Technology, Boston, USA, 1999.

R. Joaquim, A. Zuquete, and P. Ferreira REVS a robust electronic voting system. In IADIS International Conference e-Society 2003, pages 95103, Lisbon, Portugal, 2003

... ...

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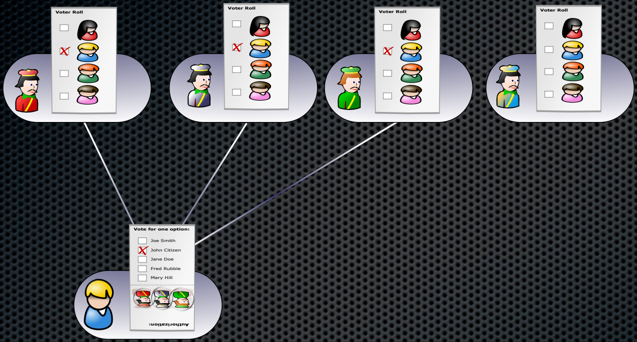
Colluding Voters

Imagine...

- 3-voters collude (whereas 3 is our sample threshold out of n=4)
- 3-voters create 4 valid votes.

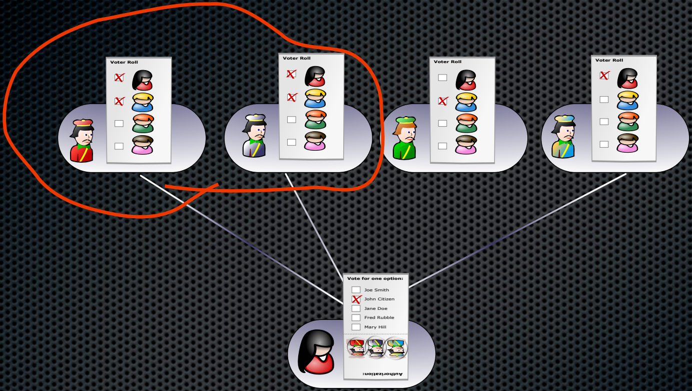
What the Authorities Know



After round 1

- 3 out of 4 authorities signed for voter 1
- 3 out of 4 authority do 'know' about voter 1

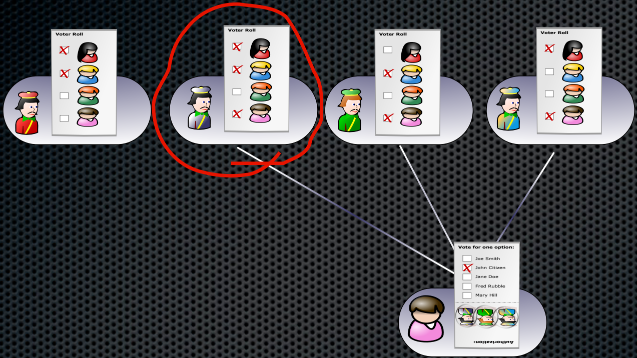
What the Authorities Know



After round 2

- 3 out of 4 authorities signed for voter 2
- 2 out of 4 authorities 'know' about both voters

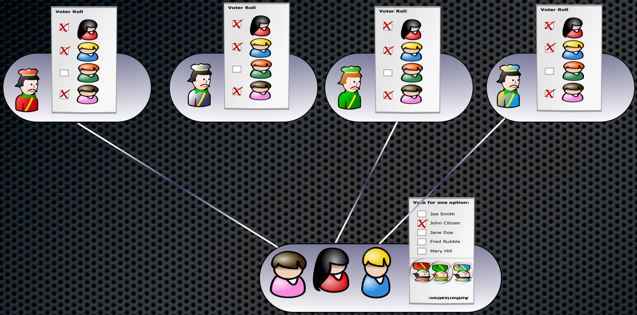
What the Authorities Know



After round 3

- 3 out of 4 authorities signed for voter 3
- only 1 authority 'knows' about all voters

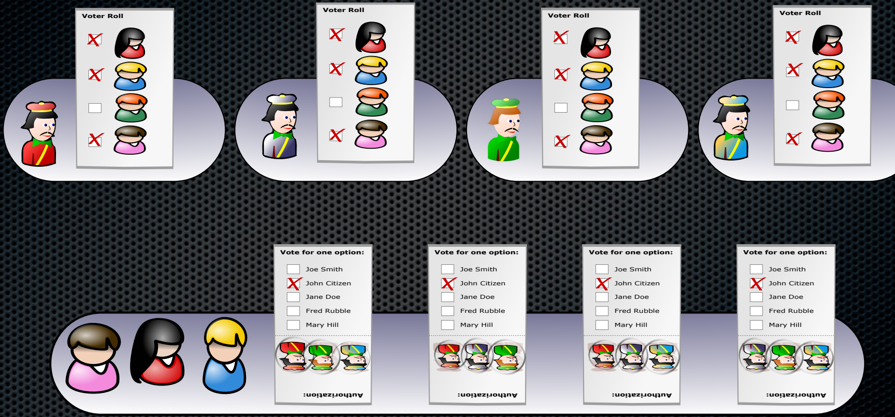
Breaking Democracy



After round 4

- The colluding three voters have a fourth vote signed
- 3 Voters Generated 4 Valid Votes

Breaking Democracy



After round 4

- The colluding three voters have a fourth vote signed
- 3 Voters Generated 4 Valid Votes

Impact on Democracy

Definition

v_+ = Amount of additional valid votes
N = Amount of authorities available
t = Threshold (Amount of authorities needed to get a valid vote)
V_c = Amount of colluding voters

In general

$$v_+ = \lfloor \frac{N-t}{t} V_c \rfloor$$

In our example, where $N = 4$ and $t = \frac{3}{4}N = 3$ and $V_c = 3$

$$v_+ = \frac{V_c}{3} = 1$$

In an example, where $t = \frac{2}{3}N$ and $V_c = 1000$

$$v_+ = \frac{V_c}{2} = 500$$

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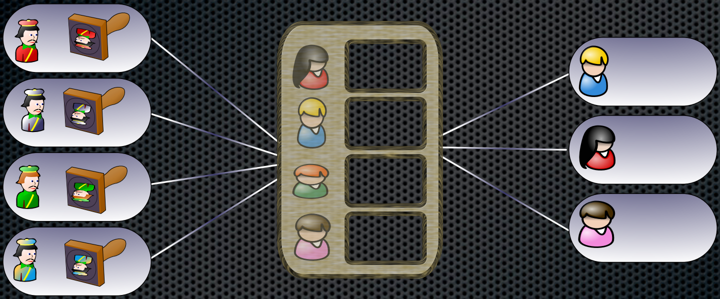
Public Bulletin Board

Common knowledge

- The knowledge of each authority must be universally accessible

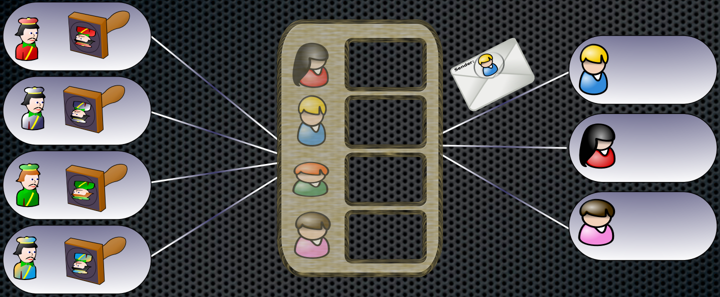
Graph of Knowledge



Common knowledge

- The public board manages the voter roll

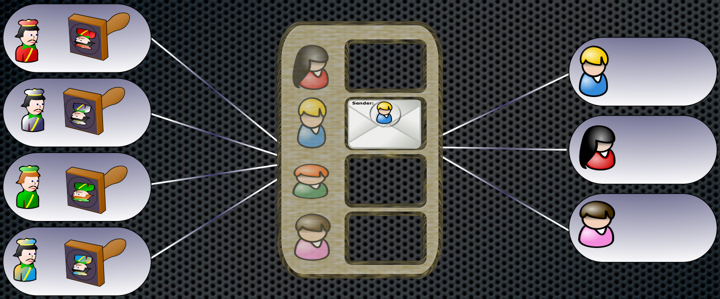
Granting The Right to Vote



The voter...

- ...transfers the blinded vote to the public board

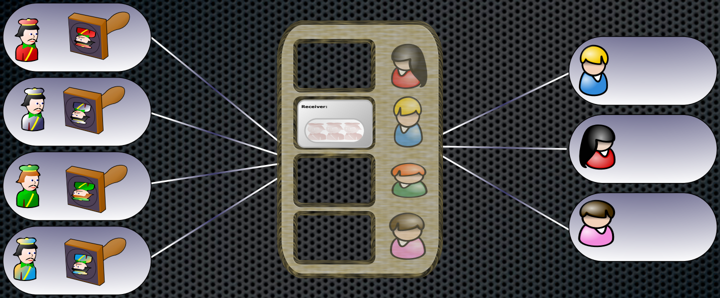
Granting The Right to Vote



The public board...

- ...accepts one vote per voter only

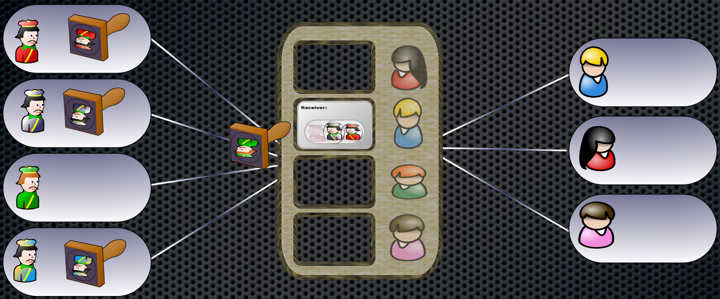
Granting The Right to Vote



The authorities...

- blindly sign the vote on the public board

Granting The Right to Vote



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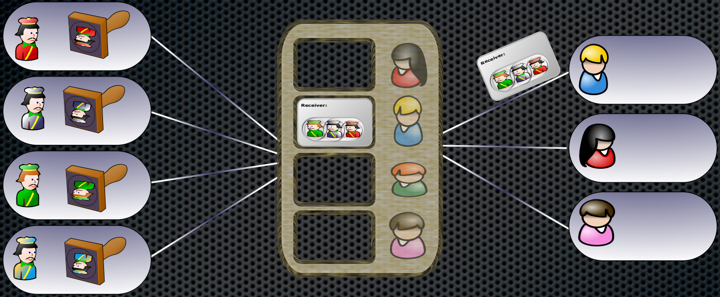
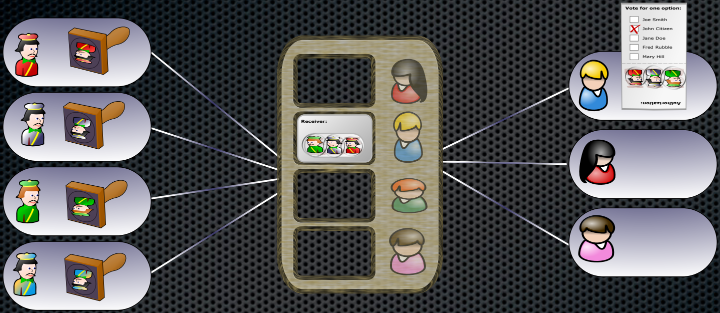
Granting The Right to Vote



The voter...

- ...copies the blindly signed vote from the public board
- ...casts the signed vote.

Granting The Right to Vote



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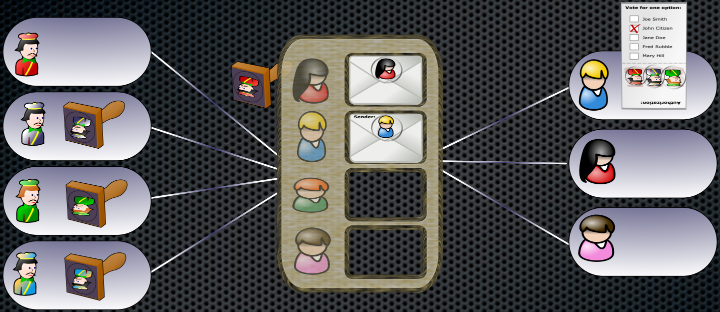
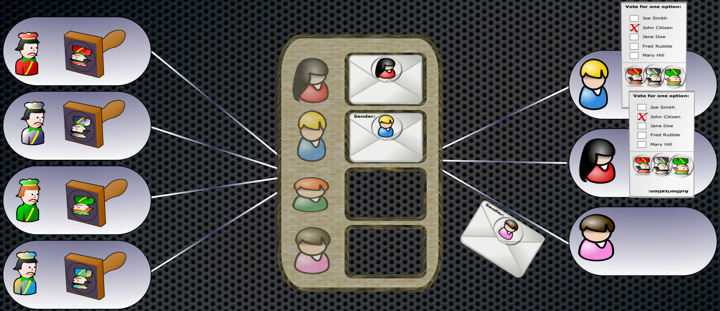


Every eligible voter...

- ...gets the signature this way

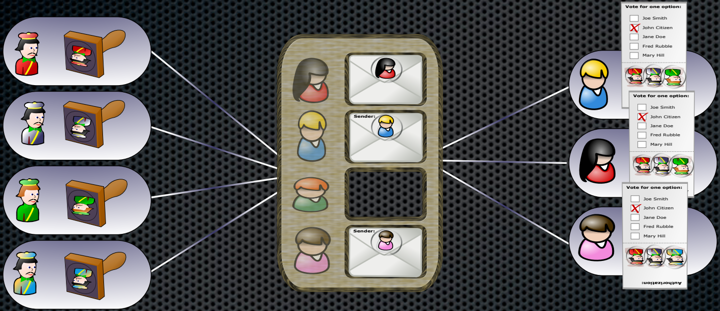
Granting The Right to Vote



After 3 rounds 3 voters...

- ...voted and can not do so a fourth time.

Granting The Right to Vote



After 3 rounds 3 voters...

- ...voted and can not do so a fourth time.

Modified threshold RSA-blind signature scheme maintaining democracy

Possible Threshold-Aware RSA-Blind Signature Scheme (using the same blinding-factor for every signer)

$$
\begin{aligned}
&V \rightarrow PB : v' = v r^{e_1 \cdots e_N}\\
&PB \leftrightarrow A_1 : s'_1 = v'^{d_1} = v^{d_1} r^{e_1 \cdots e_N d_1} = v^{d_1} r^{e_2 \cdots e_N} = v^{d_1} R_1\\
&\vdots\\
&PB \leftrightarrow A_t : s'_t = v'^{d_t} = v^{d_t} r^{e_1 \cdots e_N d_t} = v^{d_t} r^{e_1 \cdots \cancel{e_t} \cdots e_N} = v^{d_t} R_t\\
&V \leftarrow PB : \{s'_1, \ldots, s'_t\}\\
&V : s_1 = s' r^{-(e_2 \cdots e_N)} = v^{d_1} R_1 R_1^{-1} = v^{d_1}\\
&\vdots\\
&V : s_t = s' r^{-(e_1 \cdots \cancel{e_t} \cdots e_N)} = v^{d_t} R_t R_t^{-1} = v^{d_t}\\
&V \rightarrow B : (v, \{s_1, \ldots, s_t\})
\end{aligned}
$$

Outline

1. Introduction
2. Blind Signature Voting Scheme
3. Multiple Authorities
4. Attack on Democracy
5. Solution
6. Conclusion

Conclusion

Findings

- Blind signature schemes (RSA as well as ElGamal) are ready for single authority signature for a any information
- E-Voting protocols are not allowed to contain any single point of failure
- Maintaining democracy in threshold blind sig. schemes requires every authority to provably sign the very same information
- It is possible to render the blind signature schemes safe for democracy by using a public bulletin board

BUT: The prised simplicity of blind signature schemes does not longer hold true.