FACULTY OF SCIENCE

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Practical Issues in Electronic Voting

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“It’s not the people who vote that count.

It’s the people who count the votes.”

Attributed to Joseph Stalin

Contents

I. Background and Plan

Who is this guy?

- Professor in software security & correctness, at Nijmegen & Eindhoven, in NL.
- Early work in logic, type theory, category theory, coalgebra
  (most cited papers still in this area)
- Later work on semantics and verification for Java, esp. on smart cards
- Gradual shift to ***Security***

Security work

- Distinctly non-theoretical focus
  (with some exceptions)
- Involvement in e-government / identity managment, like biometric passports, voting, chipcards, privacy
- Advisory role to government, both formally and informally
- Regular presence in societal debates/media
- Genuine interest in societal aspects of computer security.

Most recently

- Severe vulnerabilities found at Nijmegen in Mifare Classic chipcard (one billion sold)
- To appear at Esorics'08 (oct; Malaga)
- Producer NXP tried to stop publication via court case — but failed.
- Also here "hands on" approach: attacks have been implemented & demonstrated
  (e.g. in London Tube)

Disclaimer: no crypto, but software person

Own involvement in voting in NL

- For internet voting in EU-'04: advisor & contractor for vote counting software
- Auditor for regional waterboard elections (RIES, '04) & independent counter ('04, '06)
- Papers & lectures about this
- Member of government committee
  (named after chairman/ex-minister *Korthals Altes*)
- Chairman of technical expert group
- Supervision of two PhD theses, on *trust in technology* (2008) and *vote counting* (20??).

Main developments in NL

- Early adoption of voting machines (early 90s)
  (useage 97% in 2006; no controversy until then)
- Various field experiments with internet voting
  (regionally and nationally, for expats)
- Strong campaign by action group against e-voting in 2007
- Complete return to paper voting in 2008.

NL is early adopter & early abolisher

Why NL relevant?

- E-voting issues are universal
- Trust in technology underlying problem
- Societal & political debates (on transparancy or voting as pilar of democracy) recognisable
- Inside story always bound to particular situation
- Hopefully instructive (& entertaining)

II. Requirements and Techniques

Requirements / safeguards

- transparancy
- verifiability
- integrity
- eligibility
- unicity
- vote secrecy
- vote freedom
- accessibility

- Not all can hold absolutely: balance needed
- Poll station gives most guarantees
- . . . but may require exceptions for severely disabled and/or expatriats
  (like voting by proxy, or by internet)

Poll station characteristics

- Separate space, free from political messages
- Multi-person, independent supervision
- Simple procedure for checking eligibility & unicity (marking names on a list)
- Personal, isolated voting boots
- Transparant, one-way storage (protecting confidentiality and integrity)
- Counting done locally (or after limted accumulation), in public, in principle.

Poll station analysis

- Check 8 requirements . . .
  (Accessiblity ☹)
- Distributed & low-tech character gives protection
- Fraud more likely “higher up” the vote processing chain
- Manual counting is error-prone / time-consuming / boring (after a long day)
- Possible confidentiality threats from small cameras

Voting machines I, in NL

Nedap

Sdu

Voting machines II

- Introduced in NL since early 90s; early 2006 used almost everywhere
- Votes stored in digital memory; internal mechanics is secret
- US terminology: “Direct-Recording Electronic voting machine” (DRE)
- Evaluation is required, done by independent organisation (TNO); reports are secret (and also partly missing)
- No meaningful recounts possible.

The main concern . . .

"Let's see how my vote is counted" ©Automatisering Gids 2003.

Voting machines III

Advantages

- automatic processing of results: efficient and fast (especially for local organisers: municipalities)
- vote expression is unambiguous

Disadvantages

- Voter cannot verify that the vote is registered correctly
- Recount only possible on already processed votes

Back then . . .

- The introduction of these voting machines in NL since early 90s was uncontroversial
- Optimisation (not big change) of procedures
- Openness (of software) was not an issue
- Much trust in technology (and in the state!)
- By now we know better about the unreliability and vulnerability of software and networks
- International controversy since 2004 (esp. relevant in IRL) without much effect in NL, . . . *at first* . . .

Adding a paper trail?

- Popular proposal: let machine print (behind glass) the voter's choice
- Should protect against software errors
- In experiments: difference between "electronic" and "paper" vote, eg. through mechanical problems
- Not clear what to do then . . .
- Often, electronic outcome is chosen!
- Simple idea, but involves difficult dilemma.

Crypto based approaches

- ***Basic techniques***
  - Mix-nets
  - Homomorphic encryption
  - Blind signatures
- ***In practice simpler techniques***
  - PKI-based (Estonia)
  - Randomised ballots
  - Hashes (RIES in NL, see later)

Mix networks

- Introduced by Chaum, to achieve untraceability via different proxy servers
- Uses multiple encryptions, for successive servers that mix (the order of) messages:

$$\text{PubEnc}_{K_{S1}}(\text{PubEnc}_{K_{S2}}(\text{PubEnc}_{K_{S3}}(C)))$$

- Servers must be trusted not to log connections or to drop messages
- Used nowadays for anonymous mailing / surfing ("onion routing", as in Tor)

Homomorphic Encryption I

- Illustration for El Gamal, with generator g, secret key x, public key $h = g^x$.
- $\text{PubEnc}_h(m) = (g^r, h^r \cdot m)$, with r random
- Decryption of (a, b) is $\frac{b}{a^x}$.
- Then:

$$\begin{aligned}&\text{PubEnc}_h(m_1) \cdot \text{PubEnc}_h(m_2)\\ =\ &(g^{r_1+r_2}, h^{r_1+r_2} \cdot m_1 \cdot m_2).\end{aligned}$$

Homomorphic Encryption II

- Fix public G; votes $v \in \{-1, 1\}$ (as in [CGS97])
- Encrypted vote is $(g^r, h^r \cdot G^v)$
- For tallying, multiply encrypted results:
  $(g^{r_1}, h^{r_1} \cdot G^{v_1}) \cdot (g^{r_2}, h^{r_2} \cdot G^{v_2}) = (g^{r_1+r_2}, h^{r_1+r_2} \cdot G^{v_1+v_2})$
- After decryption multiplications with G or G^{-1} yields result
- Additional protection needed:
  - encrypted vote must by signed by voter
  - vote $\in \{-1, 1\}$ via zero knowledge proof
  - secret sharing against early decryption

Blind signatures [Chaum]

- Let (N, e) public RSA key, with secret (N, d), so that $\text{PubEnc}_{(N,e)}(m) = m^e \bmod N$ and $\text{Sign}_{(N,d)}(m) = m^d \bmod N$
- Blinding: ask signature on $m \cdot r^e$ and get signature on m.
- After eligibility check, get anonymous (blindly signed) voting ticket
- Such tickets can be sold . . .

PKI-based envelopes

- Used in Estonia, where citizens have identity smart card with PKI (and readers)
- Vote for candidate C is sent in by voter i as:

$$\text{Sign}_{K_i}(\text{PubEnc}_{K_{auth}}(C))$$

- Test in 2005 (10K participants), actual use in 2007 for parliament (30K = 6% participants)
- 4 days of e-voting; 1 day of paper voting
- Multiple-vote option, against family fraud.
- Pragmatic, non-ideological approach.

Randomised ballots I

- Prêt-à-voter by P. Ryan, with 2-part ballots:

Idefix	
Asterix	X
Obelix	
	3874670

encodes order of candidates

- After separation the RHS is scanned and a signed copy is returned
- All copies are published, together with key, for counting

Randomised ballots II

- Various other options possible
- E.g. in internet voting:
  - number candidates, differently for each voter
  - vote via entering numbers
  - protects against viruses.
  - used in NL in '04 for first internet voting.

III. Controversy in NL

The trigger

- March 2006: municipal elections in NL
- City of Amsterdam uses voting machines (from Sdu) for the first time
- One citizen was shocked: ***Rop Gonggrijp***
- . . . and started a foundation:

wijvertrouwenstem computersniet.nl

"*wedonottrustvotingcomputers.nl*"

Foundation's main points

- Not "voting machines" but "voting computers"
- Voting computers (Nedap & Sdu) are not protected against manipulation—like eg. game computers are
- Voting results are not verifiable
- Paper copy of each vote required.

Foundation's approach

- Set up very informative webpage
- Exploit *freedom of information legislation* and put all results on the web
- Start effective media campaign & newsletter
- Gather knowledgeable volunteers
- Take legal actions against every government move.

BJ: sympathy with goals, but no direct involvement

Foundation's main stunt

- Purchase of two Nedaps:

- Legal, from left-over after municipal merger
- Including all software ("ISS") for running an election.

Nedap deconstruction

- Motorola M68000 processor from 80s
- Two removable memory chips (EPROM) with OS & vote counting software
- Removable flash memory for holding votes
- Software was reverse-engineered, and new software written for:
  - chess playing on Nedap
  - "false" counting

Killer events

- TV program *EenVandaag*, 4/10/'06, showing:
  - Easy manipulation of Nedap software
  - Sloppy storage of 500 Nedaps in Rotterdam
- Tempest: electromagnetic radiation
  - Vote can be read from dozens of meters
  - Tension with vote secrecy requirement
  - Basis for legal action by Foundation.

Foundation's direct impact

- Approval of Sdu's withdrawn before NL parliament elections of nov. '06
  - Nedap tempest within ad hoc limits
  - Paper voting returned to Amsterdam
- Two government committees:
  - **Looking back:** "Hermans", with report *Stemmachines, een verweesd dossier*, 4/07
  - **Looking forward:** "Korthals Altes", with report *Stemmen met vertrouwen*, 9/07. (English version *Voting with Confidence* available)

IV. Two government committees

Looking back committee (Hermans), I

- Voting machine initiatives in 80s came from industry (Nedap, TNO), for higher accuracy
- Requirements for voting machines:
  - only in late 90s
  - no steering by ministry or election council
  - focus on safety, not security/transparancy
  - vote counting software never covered
- Security and reliability concerns (like in IRL) ignored in NL, both nationally and locally

Looking back committee (Hermans), II

- Election council too dependent on (loose cannon) software supplier
- About the ministry
  - lack of technical expertise
  - not in control: too dependent on external (commercial) parties
  - has ignored signals of concern
- TNO wrote requirements & had evaluation monopoly
- Local authorities only want convenience

Official reaction

- Humble acceptance of conclusions
- Shift of “voting” within ministry, to department with more technical expertise
  (from CZW to BPR)
- Immediate redrafting of requirements for voting machines
  - Foundation sees attempt to save Nedaps
- Await “looking forward” report.

Paranoia?

- ***Paper ballots*** are a bad idea because voters leave fingerprints and governments have databases of fingerprints these days and can thus read individual votes
- ***Computer-based*** voting is a bad idea because government (intelligence) services are best at reading tempest signals, and can thus read individual votes

Paranoia!

- Those things don't happen in a civilised country like NL. We should assume a minimal level of trust.
- But NL should set an example, also for countries where such trust is maybe not justified!

Looking forward: who were involved

- FLTR: Barendrecht, Meesters, Korthals Altes (chair), Jacobs, van der Wel
- Active from jan. to sept. 2007.

Looking forward: what was done

- Formulate requirements / safeguards
  (mentioned before)
- Perform threat analysis
  (threat = risk * impact on safequard)
- Decide on basic form (poll station); establish exceptions
- Compare options within poll station
  (tempest is issue on its own, see later)
- Organisational matters
  (mostly ommitted)

Own emphasis here on technical angle

On the far side of being wrong

- Imagine “vote pillar”, eg. in train station, with:
  - Voter recognition via (biometric) passport
  - Vote expression via touch screen
  - Electronic storage of vote
  - Transmission to central office at end
- Sounds cool & convenient . . .
- Two fundamental problems: device may
  - store ***link*** between voter and vote
  - store or count votes ***incorrectly***

Basic idea of committee

- Create separation between phases
  - *identification*
  - *vote expression*
  - *vote storage*

  with individual voter as only connection!
- ***Within*** these phases use ICT as much as you like, but ***not inbetween***.

Implementation: “voteprinter”

- Vote expression via touchscreen
- Device stores nothing, but only prints individual vote in human readable manner
- Voter checks correctness of print:
  - **OK**, then print is deposited in ballot box
  - **NOT OK**, voter may vote again
    (upon repeated errors device is replaced)
- In the end votes are counted automatically
  (using optical character recognition, OCR)

Advantages voteprinter

- Recounts are possible, manually if preferred
- Actual vote casting is physical act (deposit)
- Software faults are detectable, by voters
- After failures, device can be replaced without effect on already cast votes (no internal state)
- Device can present many possible elections: vote anywhere, nationwide
- Voteprinter is flexible, fancy pencil
- Voting proces is centered around the voter

Main disadvantage: tempest risk

- Uncomfortable situation:
  - Expertise secretive (esp. intelligence services)
  - No public, but secret (NATO), norms
  - High demands on environment
  - High cost & evaluation per item
- Pragmatic recommendation:
  - Best effort, affordable technical measures
  - Repressive measures (punishable)

Additional recommendations

- Internet voting:
  - Transparancy, verifiability, freedom & secrecy insufficiently guaranteed
  - Incomparable with internet banking etc.
  - Research dust has not come down yet
  - At this stage advised only for expats
  - Knowledge & experience remains present
- Independent audit of every election:
  - Report within 3 days for election council
  - Within 3 months analysis & recommendations

At the presentation of the report

Responsible junior minister (*staatssecretaris Bijleveld*) decides:

- Remaining (Nedap) voting machines are dropped
- Paper voting returns until new voteprinter is introduced

Cabinet reaction (11/07)

- Safeguards accepted
- Voting in polling stations (anywhere within city)
- Paper should be basis
- Voteprinter + counter appealing, but requires further investigation $\longrightarrow$ new Expert Group
- Internetvoting experiment (for expats), depending on costs (later: “Not in 2009”, also because Parliament demands strict regulation)
- More centralised control, by Ministry (confined role for commercial parties)

Election council:

- Additional safeguard: “independence” wrt. decisions in election process
  (party registration, final outcome)
- Too much control by ministry, too little independent steering.
- Tempest must be handled via preventive measures

New expert group I

- Headed by BJ; active jan-june 2007
- Tempest main issue, studied by company GBS
  - public norm developed
  - prototype “voteprinter” built, with 5 meter norm
  - weight: over 100kg, due to heavy metal case.
- Unpractical, military-style restrictions:
  - regular (re)testing of each device (eg. after bump)
  - no other devices (like GSMs, MP3s) in poll station
  - no nearby parking / empty adjacent rooms
  - special anti-tempest software (moving images)

New expert group II

- Conclusion: Voteprinter is not feasible
- Experiment with counting support:
  - After reading out paper vote, manual entry via touch screen by poll station worker
  - Alternatively: entry via barcode reader, on special ballot (only used for counting)
  - Partial results must be clearly visible on screen.
- Cabinet accepted these recommendations
  - No more e-voting in NL for general elections!

V. RIES Internet voting

Background

- RIES = Rijnland Internet Election System
- By Dutch authority for water management
- Goals
  - Simple, cheap but secure internet voting system
  - Increase election turnout
- System should be at least as secure as their older ordinary mail voting system
- Independent audits by TNO, Cryptomathic, SURFnet, Madison Gurka, RU, TU/e, Fox-IT

RIES actual use

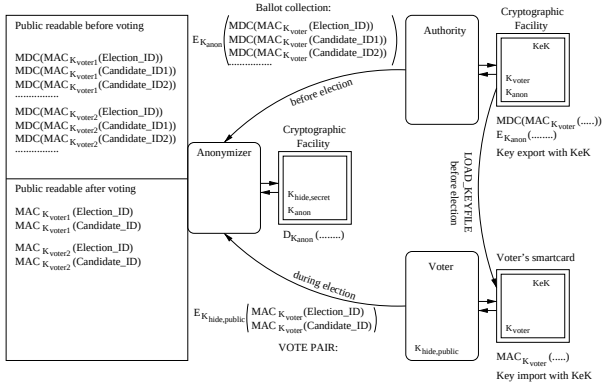
- In 2004/5 for regional waterboard elections (with > 1M possible voters; 100-200K actual)
- 2006: parliament elections, for expats (20K)
- 2008: intended for joint regional waterboards
  - But not deployed due to (action group) opposition and security vulnerabilities
- Among the largest used systems
- Produced valueable experience about how to run medium/large internet elections

The System I

- Designed by Maclaine Pont
- Based upon mastersthesis by Robers (1998)
- Clever but elementary use of hashes
  - MDC: key-less hash
  - MAC: hash with personal secret key
- Transparent
  - Pre-election and post-election tables imply verifiability
- Patented system

The System II

- Robers's smart card based system



The System III

- No smart cards by general public
- Crypto functionality replaced by Java Script
- Key-store functionality replaced by paper ballot, with printed voter key (56bit)
  (key must be entered manually in web form)
- Parallel ordinary mail voting system
- Different agents in each stage: TTPI, SURFnet, Voting office, Voters

Reference table & technical vote

Reference table
pre-election table

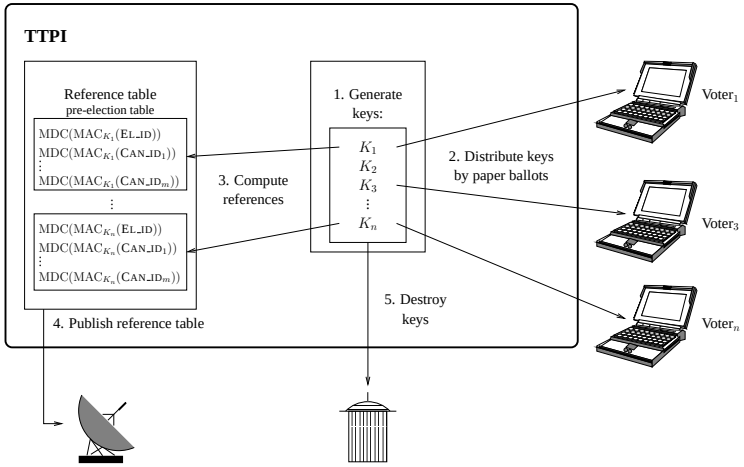
$\mathrm{MDC}(\mathrm{MAC}_{K_1}(\textsc{El\_id}))$
$\mathrm{MDC}(\mathrm{MAC}_{K_1}(\textsc{Can\_id}_1)) \simeq \textsc{Can\_id}_1$
$\mathrm{MDC}(\mathrm{MAC}_{K_1}(\textsc{Can\_id}_m)) \simeq \textsc{Can\_id}_m$

$\mathrm{MDC}(\mathrm{MAC}_{K_n}(\textsc{El\_id}))$
$\mathrm{MDC}(\mathrm{MAC}_{K_n}(\textsc{Can\_id}_1)) \simeq \textsc{Can\_id}_1$
$\mathrm{MDC}(\mathrm{MAC}_{K_n}(\textsc{Can\_id}_m)) \simeq \textsc{Can\_id}_m$

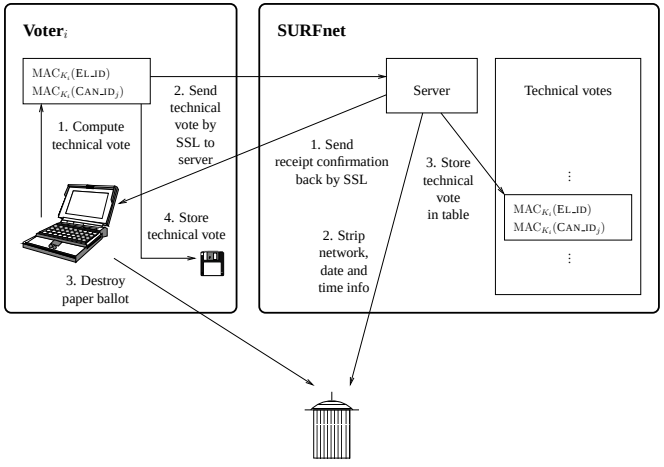
Technical vote

$\mathrm{MAC}_{K_i}(\textsc{El\_id})$
$\mathrm{MAC}_{K_i}(\textsc{Can\_id}_j)$

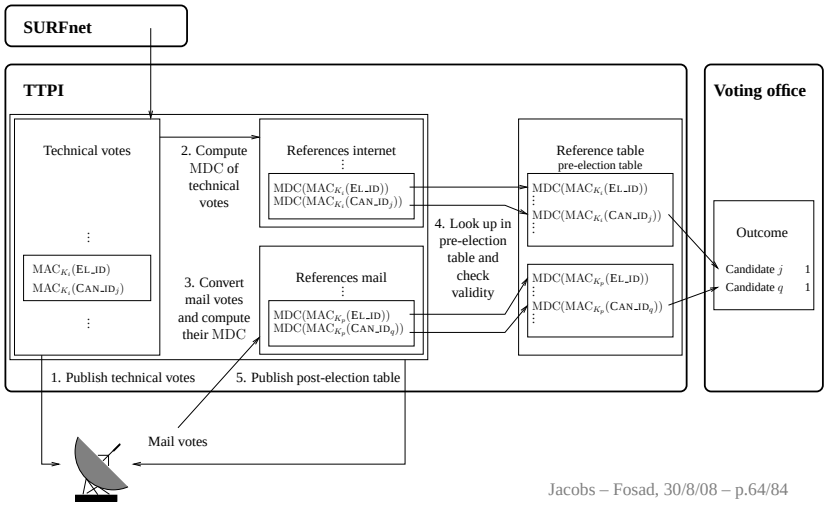
Before the voting



During the voting



After the voting



Verification I

- Voters can check their own vote by
  - Storing technical vote
  - Looking up technical vote in post-election table
  - Collecting hashed technical vote from post-election table
  - Looking up hashed technical vote in pre-election table
  - Checking candidate

Verification II

- Anyone can check total outcome by
  - Collecting all technical votes from post-election table
  - Computing MDC hash on each vote
  - Looking up hashed technical vote in pre-election table
  - Looking up candidate
  - Counting vote for this candidate
- DS group performed these checks and found identical outcomes.

Threats I

- Compromise vote integrity by local virus
  - \+ Modification can be detected
- Compromise privacy by local virus
  - \- Can only be prevented by a good firewall
- Compromise privacy from outside
  - \+ Secret keys do not leave client's machine
  - \+ No correlation between reference tables and specific voter

Threats II

- Compromise ‘public’ secrecy
  - \+ SSL connection prevents this
- Compromise ‘private’ secrecy
  - \- Purely the responsibility of the voter
- Family voting
  - \- Votings outside controlled environments always suffer from this

Threats III

- Compromise identity of vote server
  - \+ Certificates prevent this for `https://www.internetstemmen.nl`
  - \- But not for automatic redirecting `http://www.internetstemmen.nl`; user should go directly to `https` address
- Compromise integrity of vote server
  - \- Can never be prevented completely
  - \+ audit showed that SURFnet made this unlikely

Threats IV

- DDOS attack on vote server
  - \- Can never be prevented completely
  - \- DS audit showed that it is easy to drain disk storage by sending random data
  - \+ Overcapacity of 97% during elections
- Brute force attack
  - \- Personal keys are only 56bits long
  - \- Aug’08: Fox-IT showed: only 20 hours to get such key K_i from reference table entry $\mathrm{MDC}(\mathrm{MAC}_{K_i}(\textsc{El\_id}))$

Threats V

- Insider attacks
  - \- Insider attacks are possible on several places (abuse replacement votes; link votes . . .)
  - \+ Organisational controls
- Buying or selling votes
  - \- Voter can prove his vote, making buying or selling votes possible
  - \+ This situation is not worse than with the mail voting system

What went wrong?

- Fundamental design flaw: organisers can (in principle) vote on behalf of everyone
- Many organisational controls needed
- June'08: open source release showed vulnerabilities (like SQL injection, by Gonggrijp)
- Brute force vulnerability should have been noticed earlier (short key length is compromise)
- July'08: ministry decides not to allow RIES!

VI. Trust and technology

(after PhD Pieters)

Trust at stake

- It is essential for democracies that people trust the outcomes of elections
- Is opposition to new (electronic) forms of voting:
  - conservative, techno-fobic, luddite action?
  - rational, scientific attitude?
- Why is it so difficult to accept ICT-risks in voting (and less so in e.g. aviation software)?
- Focus here on security, not on safety

On trust, in general

- Common distinction:
  - **Rational trust**: based on risk evaluation and possible alternatives
  - **Blind trust**: no options available, risks unknown

  (Luhmann "confidence", to reduce social complexity)
- Security experts replace confidence by trust
- (Rational) trust does not involve objective, actual security
- Also security depends on perspective / context / formalisations / attacker model / . . .

Trust in voting systems

- Introduction of new (voting) techniques undermines confidence and requires trust
- Saying: “this voting system is secure” (or: “can be trusted”) is problematic
- Many (implicit) assumptions need to be made explicit — also for the negation
- Attacker models need to be updated constantly
- Permanent updates of security properties!

Technology & society

- New technologies (like GSM) do not just solve a (communication) problem
- They have profound social influence
- What is the influence of online voting?
- It will change our concept of democracy
  (and of autonomy & separation)
- Eg. direct links between candidate & voting sites: *not appropriate* or *convenient*?
- “Poll station ritual” versus “voting in your underwear” (while chatting)

Big questions about voting

- What are essential requirements, and what do they mean?
  - . . .
  - . . .
- What are the threats?
  - . . .
  - . . .
- Which techniques should be used to counter them?
  - . . .
  - . . .

VII. Seat distributions

(work in progress, with Wichers Schreur)

Background

- Calculating seat distributions in NL:
  - Performed by closed source software
  - never independently investigated
  - New open source software has now been commissioned, after heavy criticism
- Aims of this research
  - Formalise election law in logic (and remove ambiguities)
  - Establish appropriate properties of this formalisation
  - Generate executable code (reference implementation)

Basic properties

- Monotonicity: $\geq$ votes $\Rightarrow$ $\geq$ seats
- Neutrality: treat parties equally
- Completeness: allocate all available seats
- Challenges:
  - Sometimes: draw, resolved by chance
  - Modelled by (distribution) monad
  - Properties must be adapted accordingly

VIII. Conclusions

What we have seen

- E-voting broad, (scientifically) challenging topic: no dust down
- High profile, in media & politics
- NL early adopter . . . but also early abolisher
- Effective grass-root involvement in NL, against “wrong kind of ICT”
  (Which sector is next?)
- Killers: tempest & weak crypto
- Prevailing view: protection of individual autonomy remains necessary.

Thanks for your attention!