KOA: An Experimental Platform for Trustworthy Computer-based Voting

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Acknowledgments

※ Engelbert Hubbers, Bart Jacobs, Martijn Oostdijk, Wolter Pieters (RUN)

※ postgraduate students Dermot Cochran, Fintan Fairmichael and Alan Morkan

※ undergraduate students Barry Denby, Conor Gallagher, and Patrick Tierney
Remote voting over a network incorporates many of the core challenges of trusted global computing.

Part of my reason for giving talks about this work is to recruit scientists to this very important work and help convince scientists decide to become activist scientists.

Our foundation: Kiezen op Afstand (KOA)—a GPLv2 remote voting system developed for the Dutch government in 2003/4.
In addition to being Open Source, KOA is also (partially) formally specified and verified.

The Dutch vote counting system was formally specified using JML and its correctness checked using ESC/Java2 and unit testing.

The Irish vote counting system has since been specified using JML (by MSc student Dermot Cochran), and is now being implemented and verified by a final year student (Patrick Tierney).
A Little History: e-Voting in NL

- NEDAP machines have been used in NL for over a decade for kiosk-based voting.

- The Dutch European Parliament elections in June 2004 permitted remote voting via the internet and telephone for expatriates.
  - The prior remote voting system was based upon postal ballots.

- KOA was designed, developed, tested, deployed, and managed by LogicaCMG under contract with the Dutch government.
The SoS Group at RUN was involved in a covert and overt security analysis of KOA.

Recommendations were made in two reports written for the minister & parliament.

In July 2004, the Dutch Government released the majority of the source code for the KOA system under the GNU General Public License (GPLv2), making it the first government-sponsored, fully implemented, Open Source internet voting system in the world.
The Remote Voting Process

※ When a citizen registers to use KOA, the voter chooses his or her own personal identification code.

※ This registration takes place in-person at a designated official location (e.g., city hall).

※ Each election candidate is assigned a set of unique random numbers (hashes).

※ A (possibly unique) vote summary paper is sent by mail to each voter.
<table>
<thead>
<tr>
<th>Voter Name</th>
<th>B.C. Helblauw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voter Address</td>
<td>1 Maarssen</td>
</tr>
<tr>
<td>Voter Number</td>
<td>608605566</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.F. Azuur</td>
<td>216504168</td>
</tr>
<tr>
<td>C. de Parelgrijs</td>
<td>994423603</td>
</tr>
<tr>
<td>Y.M. Blauw</td>
<td>292545046</td>
</tr>
<tr>
<td>G.M.H. Kersen-Rood</td>
<td>383274400</td>
</tr>
<tr>
<td>L. Crème</td>
<td>924398322</td>
</tr>
</tbody>
</table>
Vote Verifiable Audit Trail (VVAT)

- When a voter is finished, a transaction code is provided.
- This code is published to a write-only website/BBS.
- The voter checks this list to ensure their choices were included in the final tally.
Communication with the voting web site is secured with SSL.

Each vote is encrypted by a symmetric key per voter and a public key of the voting authority.

Only the individual responsible for the election can decrypt the votes to tally results.

All data is hashed and encrypted, so there is little opportunity for vote manipulation.
The KOA Remote Voting Process

Voter initiates connection to HTTPS website

Web browser presents site certificate which is confirmed by the voter by referencing their vote summary sheet

Voter supplies identity code and access code

Web server presents a voter login page

Web server denies access and logs failure if access code is not confirmed, otherwise the voting page is presented

For each election, voter enters the codes of the candidates for which they wish to vote

Candidate codes are transferred via SSL to server which encrypts and stores the vote

Web server presents the voter with a transaction code
The tally application for the Dutch system consists of 30 classes, grouped into three categories:

- data structures,
- user interface, and
- tasks.
The data structure classes represented an excellent opportunity to write JML specifications and perform verification.

Typical concepts from the domain of voting such as candidate, district and municipality are modeled with detailed JML specifications.

Simple models like arrays are used as well.
Specifying Tasks

- The different tasks associated with counting votes are mapped to individual Java classes.
  - e.g., initialization, clear votes, import candidates, read public/private keypair, decrypt votes, count votes, write report
  - After successful completion of a task, the application state is changed.
  - A task can only be started if the application is in an appropriate state.
Life Cycle Model

- The algorithm is specified in JML using an ASM, represented by a set of class and object invariants and constraints.
- The specification states that, on successful completion, the tally application went from “initial state” to “votes counted state”.
- Thus, the theorem encoded by the tally application is the conjunction of invariants in the final “report generated” state:
  - all legal votes in the encrypted ballots have been successfully counted and reported
Irish Vote Counting System

- the Dutch Voting system is a list based voting system
  - voters vote for parties, not individuals
- Ireland uses Proportional Representation with a Single Transferable Vote (PR-STV)
  - voters rank individuals by preference
- the Scottish system is very similar to Irish one
  - recently developed in Nijmegen by SoS Group
Example: 6 candidates for 3 seats

<table>
<thead>
<tr>
<th>Name</th>
<th>Party</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. Brady</td>
<td>Socialist</td>
<td>3</td>
</tr>
<tr>
<td>M. Collins</td>
<td>No Party</td>
<td>1</td>
</tr>
<tr>
<td>A. O’Connor</td>
<td>Urban Democrat</td>
<td></td>
</tr>
<tr>
<td>E. Quinn</td>
<td>Rural Democrat</td>
<td>5</td>
</tr>
<tr>
<td>O. Williams</td>
<td>Socialist</td>
<td>4</td>
</tr>
<tr>
<td>N. Youghal</td>
<td>No Party</td>
<td>2</td>
</tr>
</tbody>
</table>
39 formal assertions were identified in the Count Rules published by the Irish Government.

Each assertion was expressed in JML and identified and cross-referenced by a Javadoc comment.

A state machine was specified so as to link the assertions together.
Specification of Vote Transfer Method

/**
 * Transfer votes from one candidate to another
 * @param fromCandidate Elected or excluded candidate
 * @param toCandidate Continuing candidate
 * @param numberOfVotes Number of votes to be transferred
 */

/*@ requires fromCandidate.getStatus() != Candidate.CONTINUING; @*/
/*@ requires toCandidate.getStatus() == Candidate.CONTINUING; @*/
/*@ requires numberOfVotes == getActualTransfers (fromCandidate, toCandidate) + @*/
/*@ requires getRoundedFractionalVote (fromCandidate, toCandidate) @*/
/*@ ensures fromCandidate.getTotalVote() == @*/
/*@ \old (fromCandidate.getTotalVote()) - numberOfVotes; @*/
/*@ ensures toCandidate.getTotalVote() == @*/
/*@ \old (toCandidate.getTotalVote()) + numberOfVotes; @*/

protected void transferVotes(/*@ non_null @*/ Candidate fromCandidate,
/*@ non_null @*/ Candidate toCandidate,
long numberOfVotes);
/**
 * Determine actual number of votes to transfer to this candidate, excluding
 * rounding up of fractional transfers
 *
 * @see requirement 21, section 7, item 3.1, page 24
 * @see requirement 22, section 7, item 3.2, page 25
 *
 * @design The votes in a surplus are transferred in proportion to
 * the number of transfers available throughout the candidates ballot stack.
 * The calculations are made using integer values because there is no concept
 * of fractional votes or fractional transfer of votes, in the existing manual
 * counting system. If not all transferable votes are accounted for the
 * highest remainders for each continuing candidate need to be examined
 *
 * @param fromCandidate Candidate from which to count the transfer
 * @param toCandidate Continuing candidate eligible to receive votes
 *
 * @return Number of votes to be transfered, excluding fractional transfer
 */
Votes Transfer Method

/*@ requires (state == COUNTING);
@ requires (fromCandidate.getStatus() == Candidate.ELECTED) |
@   (fromCandidate.getStatus() == Candidate.ELIMINATED)
@ requires toCandidate.getStatus() == Candidate.CONTINUING;
@ ensures ((fromCandidate.getStatus() == Candidate.ELECTED) &&
@   (getSurplus(fromCandidate) < getTotalTransferableVotes(fromCandidate))) ==>
@   (
result == (getSurplus (fromCandidate) *
  getPotentialTransfers (fromCandidate, toCandidate.getCandidateID()) /
  getTotalTransferableVotes (fromCandidate));
@ ensures ((fromCandidate.getStatus() == Candidate.ELIMINATED) ||
@   (getTotalTransferableVotes(fromCandidate) <= getSurplus (fromCandidate)))  ==>
@   (\num_of int j; 0 <= j && j < totalVotes;
  ballotsToCount[j].isAssignedTo(fromCandidate.getCandidateID()) &&
  getNextContinuingPreference(ballotsToCount[j]) == toCandidate.getCandidateID());
@*/

protected /*@ pure @*/ int getActualTransfers(/*@ non_null @*/ Candidate fromCandidate,
    /*@ non_null @*/ Candidate toCandidate);
Finding the Next Preference Candidate

/**
 * Gets the next preference continuing candidate.
 * 
 * @design This is the _nearest_ next preference i.e.
 * filter the list of preferences to contain continuing candidates and then
 * get the next preference to a continuing candidate, if any.
 * 
 * @param ballot Ballot paper from which to get the next preference
 * 
 * @return Candidate ID of next continuing candidate or NONTRANSFERABLE
 */

/*@ requires state == COUNTING; 
@ ensures (!result == Ballot.NONTRANSFERABLE) <=!=> 
  (\exists int k; 1 <= k && k <= ballot.remainingPreferences(); 
  (result == ballot.getNextPreference(k)) && 
  (forall int i; 1 <= i && i < k; 
  isContinuingCandidateID(ballot.getNextPreference(i)) == false)); 
@*/

protected long getNextContinuingPreference(/*@ non_null @*/ Ballot ballot);
KOA as a Case Study

- written in Java, fully Open Source
- critical application domain
- large but well-decomposed
  - ~550 classes but only ~36,000 NCSS
- small set of interesting core theorems
  - only eligible voters vote, they only vote once, all valid votes are counted, etc.
KOA as a Case Study

- demands modern techniques
- conservative use of concurrency
- non-interference
- confidentiality and declassification
- depends upon a set of useful APIs
- crypto, EJB, database, simple GUI, etc.
Alternative Systems

- Dutch REIS system
  - implemented in JavaScript
- OpenVotingConsortium EVM system
  - implemented in Python
- eVACS from Australia
  - implemented in C

none of these systems have any (even semi-)formal specifications!
Ongoing and Future Work

- The security properties, including a functional specification, for a MIDP-based remote voting application are in the process of being defined.

  - High-level requirements are defined, but have not yet been refined to low-level specifications.

- We are interested in collaborations to formally specify and verify other voting systems (e.g., Prêt à Voter, American, etc.)
Questions and Comments?

- next steps?
- potential collaborators?
- open theoretical challenges?
- tool limitations?
- funding opportunities?
- publications and public relations?