



Formally Counting Votes (But Still Only Trusting Paper)

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Joe Kiniry

KindSoftware Research Group

Systems Research Group

CASL: Complex and Adaptive Systems Laboratory

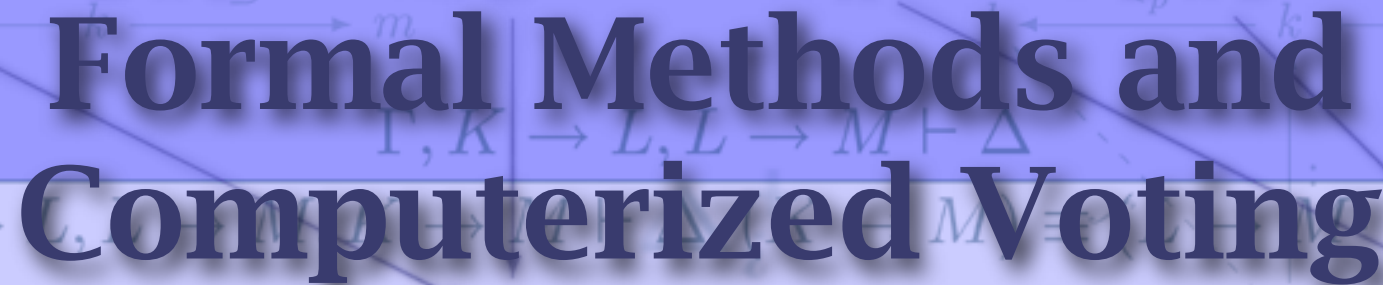
School of Computer Science and Informatics

University College Dublin, Ireland

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Acknowledgments

- ✧ Engelbert Hubbers, Bart Jacobs, Martijn Oostdijk, Wolter Pieters (RUN); Patrice Chalin (Concordia)
- ✧ UCD postgraduate students Dermot Cochran, Fintan Fairmichael and Alan Morkan
- ✧ UCD undergraduate students Barry Denby, Conor Gallagher, and Patrick Tierney



Formal Methods and Computerized Voting

- ✱ While we have experience in the application of formal methods in computer-based voting systems in the Netherlands and Ireland...
- ✱ We are *computer scientist activists* that have been fighting against the introduction of corporation-driven, untrustworthy, computer-based voting in NL, IE, USA, and elsewhere.
- ✱ *Computer-based voting must not be used for any important elections until we better understand its challenges and solutions.*



Our Work in “Solving” the Voting Problem

- ✧ Remote voting over a network incorporates many of the core challenges of trusted and trustworthy 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 contribution/foundation: Kiezen op Afstand (KOA)—a remote voting system developed for the Dutch government in 2003.



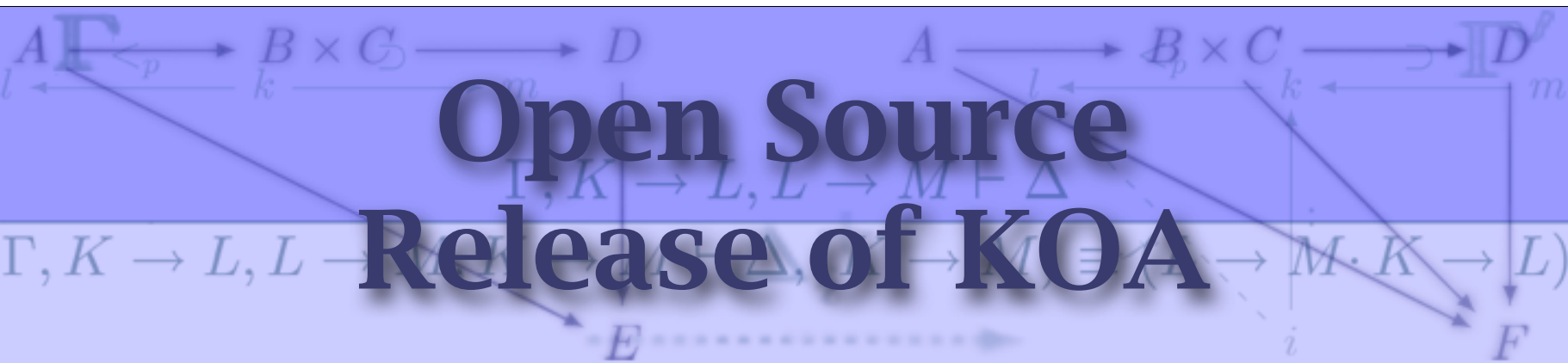
Formal Specification and Verification

- ✧ 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 has been partially 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.



Open Source Release of KOA

- ✧ 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.

Formal Specifications for KOA

- ✱ The tally application for the Dutch system consists of 30 classes, grouped into three categories:
 - ✱ data structures,
 - ✱ user interface, and
 - ✱ tasks.

Specifying Data Structures

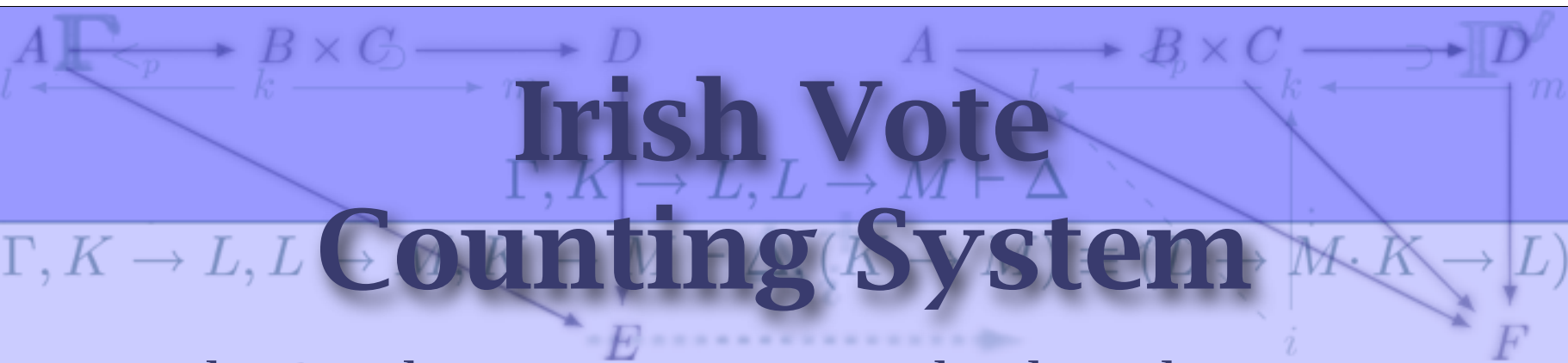
- ✱ The data structure classes represented an excellent opportunity to write JML specifications and perform verification.
- ✱ Typical concepts from the domain of voting such as candidate, district and municipality are modeled with detailed JML specifications.
- ✱ Simple models like arrays are used as 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



Irish Vote Counting Specification

- ✱ 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 transfered
 */

/*@ requires fromCandidate.getStatus() != Candidate.CONTINUING;
 @ requires toCandidate.getStatus() == Candidate.CONTINUING;
 @ requires numberOfVotes == getActualTransfers (fromCandidate, toCandidate) +
 @  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);

```


How Many Votes to Transfer?

/**

- * 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 transfered 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))) ==>
@ (\result == (\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);

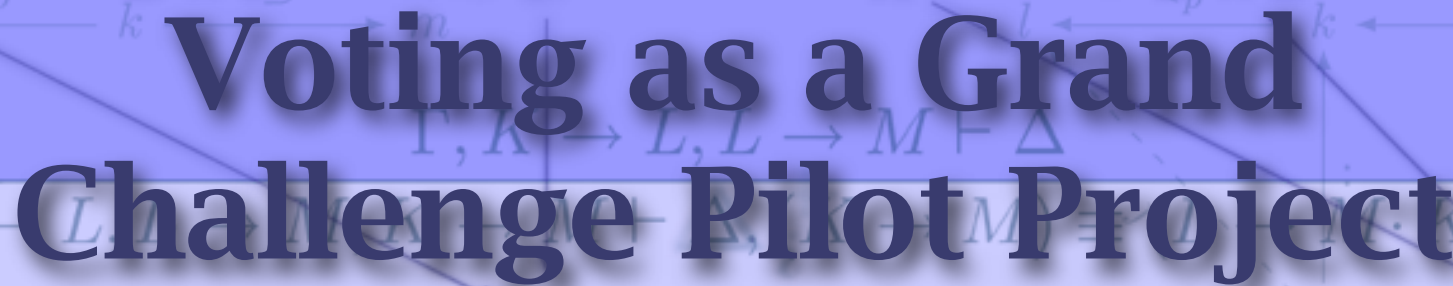
```

Finding the Next Preference Candidate

```

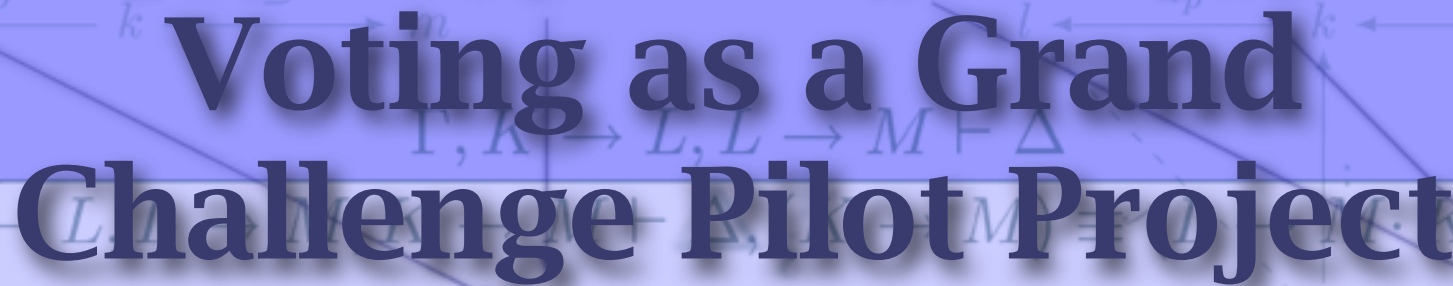
/**
 * Gets the next preference continuing candidate.
 *
 * @design This is the _nearest_ next preference i.e.
 * filter the list of preferences to contain continuing candidates and then
 * get the next preference to a continuing candidate, if any.
 *
 * @param ballot Ballot paper from which to get the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

```



Voting as a Grand Challenge Pilot Project

- * written in Java, fully Open Source (GPL)
- * 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.



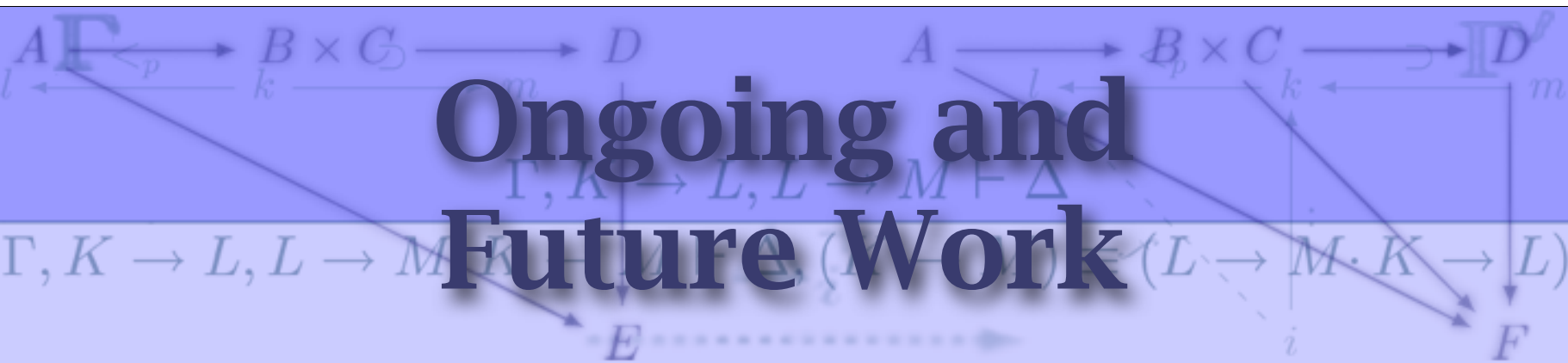
Voting as a Grand Challenge Pilot Project

- * 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.
- * system and tools to be contributed to the
Verified Software Repository



Alternative Systems

- * Dutch REIS system
 - * implemented in JavaScript
- * OpenVotingConsortium EVM system
 - * implemented in Python
- * eVACS from Australia
 - * implemented in C
- * Unfortunately, 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.)
- ✧ Hosting research visitors and work with IEEE.

Systems-level Challenges

- ✱ *Trustworthy voting is about much more than the software and hardware involved in the voting system and process.*
- ✱ The non-computational aspects of voting (people, parties, organizations, ballot design, polling place organization, etc.) are of paramount import to voting systems.
- ✱ How can we specify, validate, and verify these non-computational aspects?

Questions and Comments?

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