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Voting Methods Models

A standard for precise specification of elections administration voting methods, counting, tabulation, and mathematical evaluation modules.

NIST Interoperability Public Working Group
Voting Methods Subgroup

Draft Version 0.1
08/03/2017

Lauren Lochridge, John Wack, Philip Stark, Editors

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Reports on Computer Systems Technology

The Information Technology Laboratory (ITL) at NIST promotes the U.S. economy and public welfare by providing technical leadership for the Nation's measurement and standards infrastructure. ITL develops tests, test methods, reference data, proof of concept implementations, and technical analyses to advance the development and productive use of information technology. ITL's responsibilities include the development of management, administrative, technical, and physical standards and guidelines for the cost-effective security and privacy of other than national security-related information in federal information systems. This document reports on ITLs research, guidance, and outreach efforts in Information Technology and its collaborative activities with industry, government, and academic organizations.

Abstract

This publication describes a standard for precise specification of elections administration voting methods and mathematical evaluation modules, including counting and tabulation. This specification is a set of voting methods elements where each element is a voting method mathematical model, with its corresponding unique identifier and description. Each element is a precise definition which can be referenced without ambiguity, reused, and understood by a variety of stakeholders including legislators, elections officials, analysts, systems and software manufacturers, and those performing testing and certification. Adoption of this standard supports vote selection Data Interoperability through a Common Data Format. This specification includes a reference implementation of select voting methods and description of process for knowledge acquisition and representation for domain modeling of counting and tabulation methods.

Keywords

Common data interoperability format; contest; district; election results; jurisdiction; overvote; political office; political party; precinct; undervote.

Acknowledgments

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Executive Summary

This publication is a specification of mathematical models of voting methods or modules that operate on elections data by common method. The elements of this specification are precisely defined mathematical models that support validation of a module operating on vote selection data. The models enable Data Interoperability and Data Integrity of elections data sets operated upon by modules performing counting, tabulation, mathematical evaluation or common vote selection data set operations.

The prevailing current practice is that Elections Administration (EA) system's voting, counting, and tabulation processes are specified in written legislation, statute, rules, or Request For Proposals (RFP) and other specifications produced by Elections Officials (EO) as an algorithmic plain language definition. Any spoken and written language, is naturally less precise than a mathematical specification. No matter how well crafted, when mathematical or constraint logic requirements of EA systems are specified in plain language, unintended under-specification or unplanned gaps in specification may occur. Under-specification or gaps may negatively impact validity of elections operations, and insufficiently support data interoperability and the integrity of elections data sets. Lack of a common precisely defined set of common voting method models for viting system modules causes unnecessary consumption of time and resources when stakeholders are caused to essentially repeat the same work for common voting methods, and to interpret unintended under-specified definitions.

The voting method models in this specification can be referenced without ambiguity, reused, and understood by EA's and the variety of stakeholders including legislators, elections officials, analysts, systems and software manufacturers, elections service providers, and testing and certification labs.

When each voting method or module that operates on elections data, is unambiguously defined as a mathematical model, its specification, characterization and properties are precisely known in support of accurate and reliable analysis of elections data. Precisely known mathematical characterization of systems components supports robust and correct voting systems and facilitates their development, operation, analysis, and testing.

Examples of typical EA processes that perform counting, tabulation or mathematical evaluation operations on elections data sets, include but are not limited to counting cast ballots, determining election outcome tabulation, performing aggregations to determine statewide elections counts or inter-jurisdiction elections data

analysis, auditing, verification, acceptance testing for new systems, capacity planning, and application of information security and information privacy requirements.

As an aide to understanding how to use the models this standard provides, this standard also provides example use cases, a reference process, and reference packaged tools for voting methods domain modeling, configuration, and validation and testing.

This specification is intended for the following audiences: Election officials, voting equipment manufacturers and service providers, election-affiliated organizations, election analysts, and the general public.

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1. Introduction

The Voting Methods Working Group (VM-WG) develops guidance and specifications of robust mathematical models,, and formalizations to fully describe a variety of voting methods, algorithmic modules and interoperable operations on elections data sets, for counting, tabulation, or operations on elections data sets as usually performed by systems that operate elections to determine counts and outcomes. VM-WG models may be used by voting equipment manufacturers and election administrators to more easily implement a given voting method and modules that operate on vote selection data in elections administration processes. VM-WG is also working to develop a reference set of tools to verify proper implementations of different voting methods and modules that operate on vote selection data sets, and identify gaps in legislation or administrative procedures that specify methods of counting, tabulation or mathematical evaluation. The models and use cases identified by the group can also be used to improve usability and understanding of voting methods by election administrators, legislators, and the public.

As an aide to understanding how to use the models this standard provides, this document provides example use cases, a reference process, and describes the set of reference packaged tools for voting methods domain modeling, configuration, and validation and testing.

1.1. Purpose

This guidance and standard supports Data Interoperability (DI) and data integrity, and enables Elections Administration Systems (EAS) that operate a variety of voting schemes, counting modules and modules performing common operations on voting data sets, to be valid to a high degree of confidence, accurate, fail-safe and cost effective, and to thereby support the Elections Administrator (EA) in producing valid operation of U.S. government elections for the public.

The purpose of this specification is to facilitate elections integrity through common and precise definitions of voting methods and EAS modules that perform counting, tabulation or mathematical evaluation operations on elections data sets, specifically vote selection data sets, and thereby enable Data Interoperability and verifiable correctness of operations on elections data sets.

Adoption of this specification enables manufacturers, elections administrators (EA), elections officials (EO), elections analysts, testing and certification labs, and seeks to inform the Technical Guidelines Development Committee (TGDC) of the Election Assistance Commission (EAC) and future versions of the Voluntary Voting System Guidelines (VVSG), and other stakeholders.

1.2. Scope and Objectives

1.2.1. This standard provides a set of rigorously and precisely defined mathematical models of voting schemes, voting methods, or modules where counting, tabulation, mathematical evaluation, or common operations on vote data sets are performed in Elections Administration (EA) systems.

1.2.2. Models of voting schemes in use, or projected to potentially become in use in U.S. government elections, over the life-cycle of this standard, are the primary focus of this standard. However, nothing about this standard's domain model, methodology and supporting reference set of tools is designed to prevent it from being applied to other elections administration use cases.

1.2.3. This standard specification and guidance is structured to enable the adopter to selectively adopt parts of the standard that pertain to the jurisdiction's use cases.

1.2.4. This standard's elements are mathematical models. The domain or universe being modeled is voting schemes, voting methods, or modules where counting, tabulation mathematical evaluation, or data set operations are performed in Elections Administration (EA) systems on election vote data sets. The inputs and references for modeling the EA domain are specifications in the form of written legislation, or an algorithmic plain language specification which typically may be the work product of legislators, Elections Officials (EO) or Boards or Commissions of Elections (BoE) (CoE).. Sources of existing specification also include RFIs or RFPs for EA systems manufacturers, and other documents such as voter facing instructions produced by elections officials.

1.2.5. Examples of research topic areas where mathematical definitions of voting methods are presented include research into social choice, vote power, voting system criteria, verifiable voting systems and auditable voting systems. Models presented in research publications largely focus on voting system criteria and vote power analysis, and are often metamodels , or higher level and more general models of the actual in-use voting methods of the EA domain.
Meta models or theoretical models are out of scope.

1.2.6. Definition of new voting system criteria, voting system metrics for use in specifically in comparison of or advocating for use of particular voting schemes, methods, systems implementation or modules, are out of scope.

1.2.7. Innovation of voting methods or schemes that are not in-use or projected to become in use in U.S. government operated elections is out of scope.

1.2.8. Voting schemes, methods, or particular modules for counting, tabulation, or mathematical evaluation within EA systems, are taken from existing public domain legislative specification (the legal text), or other forms of official documentation produced by or used by legislators, elections officials or administrators. Any other forms of reference documents for the purpose of modeling the EA universe are not in scope.

1.2.9. This specification is geared.towards the following audiences:

- Election officials,
- Voting equipmen tand systems manufacturers,
- Voting systems testing laboratories,

- Election-affiliated or associated organizations,
- Election analysts, and
- the public.

1.3. Motivation and Methodology

1.3.1. When each voting method is unambiguously defined as a mathematical model, its specification, characterization and properties are precisely known in support of accurate and reliable analysis of elections vote selection data. Precisely known mathematical characterization of systems components enables robust and correct voting systems and facilitates their development, analysis, and testing.

1.3.2. No complete compendium of mathematical models of the voting methods that are currently in-use today, exists. We consider in-use voting methods to be those specified to be used in currently applicable legislation or in elections officials specification, or as realized in systems that operate elections today, or that are reasonably projected to become in-use during the life-cycle of this standard.

1.3.3. Reference models or definitions of voting schemes or methods typically exist in various forms and context including glossary definitions, RFPs by elections administration to systems and software manufacturers and systems, systems documentation, and also research works on social choice theory and voting theory. None of these varieties of existing definitions satisfy the need for a standard set of precise definitions of applied voting methods, as specified in application as plain language algorithmic statute or legislation, so that the voting methods specifications are commonly understood, without ambiguity, among the full spectrum of stakeholders in the applied operation and administration of elections.

1.3.4.

1.4. Document Structure

1.5. Future Work

1.5.1. Security specifications in legislation
1.5.2. Information privacy specifications in legislation
1.5.3. Voting Methods and Use Cases
1.5.3.1. Voting Methods
1.5.3.1.1. The initial version of the standard provides for a reasonable subset of the universe of voting methods. The voting methods current provided for this version are listed in Sections 3 and 4.
1.5.3.1.2. Future versions of this standard are planned to include additional voting methods and counting methods. For example, additions may include the

enumeration of "voting variations" found in the Election Results Reporting (ENR) Specification, NIST-1500-1...

1.5.4. Other

2. Background and Overview

The Voting Methods Models Public Working Group (VM-WG), is a subgroup of the NIST Interoperability working group (WG). The VM-WG participants originally began deliberating towards consensus in 2015, after initially being approved as an IEEE-SA standards development project, sponsored by NIST's Voting Systems Standards Committee (VSSC), and subsequently is operating as a subgroup of the NIST Interoperability public working groups.

In this section, we describe the work of the VM-WG, and how this standard fits in the ecosystem of Interoperability standards, specifications, and use cases that are part of NIST Elections and Voting Systems Interoperability, Common Data Format (CDF) project, and the other NIST elections and voting workng groups.

The VM-WG views the universe of elections and voting interoperability as having three layers or tiers. The layers are logical layers rather than physical layers. The layers are an abstraction, or "framework", for the generic elections administration domain and do not necessarily specify or correspond to a physical implementation of any specific hardware and software system.

The top layer contains the business processes of elections administration. A framework for the generic business processes needed to operate elections supports EA process interoperability.

The middle layer is the common data format and data transport layer. Multiple standards or specifications represent this layer. Standards or specifications correspond to different common data format or interchange use cases . Examples of standards and specifications at this layer include the election data reporting standard and the election logging (NIST SP 1500-100 Election Results CDF Specification published 2/9/2016 and NIST SP 1500-101 Election Log Export) and the NIST SP 1500-10X Cast Vote Record (CVR) specifications. Standards in the common data format and data transport interoperability layer are generally modeled in the Unified Modeling Language and implemented as XML data structures, or JSON, where the focus is on transport of data in an XML data structure common format, between systems or subsystems or as the means of delivering data to external consumers by a producer of the data.

The third layer, the data interoperability layer, is the layer of this standard. The standards and specifications in this layer are concerned with the interoperability of the elections data sets, and their data integrity. Standards in this layer support correct operations on data sets in separate modules or systems, when the data sets are transported or exported by the data transport , including for aggregations on data sets.

By specifying precise mathematical models for operating on the data sets, specifically vote selection data, this standard supports data interoperability for modules of EA systems or EA systems where counting, tabulation, mathematical operations or common data set operations are performed on vote selection data sets. In some use cases, vote selection data specifically, may be a subset of an operation being performed on a well circumscribed elections data set, and in those use cases, the operations for the election data set as a whole are addressed by this standard's model elements.

Through adoption of this standard, stakeholders are enabled to know that operations for counting, tabulation, and other calculations performed on elections data will produce predictably correct results. Predictable performance of operations for capacity planning and for testing, auditing, verifiability and other analysis relying on known standard operations that perform calculations, are supported. This voting models standard specifies precise models for operations on data sets, for the variety of different voting schemes or voting methods that are in use by U.S. jurisdictions for government operated elections today.

Figure 1. VM-WG view of the Interoperability Elections Systems eco-system

Nothing about the models within the EA Interoperability domain is intended to constrain adopters of this specification from implementing it either as a system of interoperating sub-systems, or as independent interoperating systems, or a mix of both, as the particular use-case as defined by Elections Officials (EOs) or Elections Administrators (EAs) may vary. Therefore, the VM-WG models are agnostic in regard to any particular elections adminsitration system architecture.

2.1. Standards and Specifications Adopted by This Standard

In this section we describe the relationship of this standard specification to other NIST Voting and Elections standards or specifications, and other frameworks, specifications or standards that are used by or adopted by this standard.

- 2.1.1. Elections Administration Business Process
- 2.1.2. Elections Data Transport Interoperability
- 2.1.3. Elections Data Interoperability
- 2.1.4. Elections Data Structures
- 2.1.5. Tabulation and Counting Methods
- 2.1.6. Operations on Cast Vote Data Sets

2.2. Overview of Use Cases

In this document, Use Cases are scenarios in which actors interact with a system or process or model being developed. The primary purpose of the use case is to help identify features or characteristics that the representation of the universe being modeled must satisfy in order to correctly perform some function or to satisfy requirements.

Use Cases covered in this standard include: auditability, verifiability, capacity planning, testing & certification, information security, information privacy, reportability, traceability & logging, aggregation and "roll up", encryption if required for a voting method or vote selection data set, and elections result reporting.

Use cases for the purpose of this standard, are

- of utility to Elections Officials and administrators

- aligned with the Elections Administrator's view of elections administration processes.

2.3. Elections Voting Methods Domain Modeling Methodology

In this section we describe the domain modeling methodology used to develop the models that are the elements of this standard.

2.3.1. Extracting Specification of Voting Methods From Legislative Text
2.3.2. Domain Representation
2.3.3. Voting Methods Universe Knowledge Acquisition & Domain Modeling
2.3.4. UML Model
2.3.5. Voting Method Flow Charts

3. Non-Mathematical Voting Method Definitions and References for Domain Modeling

In this section we describe the references and input sources that this standard specification uses to acquire knowledge about voting methods used in practice in the United States for the purpose of domain modeling.

7.1.1 Legislative Definitions
7.1.2 Election Administration Definitions
7.1.3 UML / Domain Model (for voting methods, counting, tabulation and operations on cast vote data sets)
7.1.4 Voting Method Variants
7.1.4.1 1-OF-M :VOTE FOR ONE / PLURALITY / FPTP
7.1.4.2 STRAIGHT PARTY
7.1.4.3 N-OF-M : MULTI-ROUND / Ranked-Choice-Voting / RCV
7.1.4.4
7.1.5 Election Administration Business Process Model
7.1.5.1 Mapping UML Voting Methods Domain to the EA Business Process Model
7.1.6 Other Definitions

3.1.1. Legislative Definitions
3.1.2. Elections Officials and Administrator’s Definitions
3.1.3. Election Administration Business Process Model
3.1.4. Voting Methods Process Models of Voting Method Variants
3.1.4.1. 1-OF-M :VOTE FOR ONE / PLURALITY / FPTP
3.1.4.2. STRAIGHT PARTY
3.1.4.3. N-OF-M
3.1.4.4. MULTI-ROUND / Ranked-Choice-Voting / RCV
3.1.5.
3.1.6.
3.1.7. Other Definitions

4. **Mathematical Models for Elections Administration Systems**
For each scheme/method/module that we define:

1.1 Unique Identifier, Numeric with Text Label

1.2 Text description of model element, brief with pointer to references

1.3 UML model index mapping module to EA Business Process

1.4 The written mathematical model in human readable specification language form

1.5 Set of test conditions and expected outcomes

1.6 Index into an example ballot library for the purpose of illustrating use, including configuration, or testing.

1.7 Notes briefly describing information if any that would be crucial for an adopter of this standard or that may be exceptional, and a pointer to detailed information or references if necessary.

APPENDICES

Appendix A **Terms and Definitions**

Analytics is the synthesis of knowledge from information.

Appendix B **Reference Model For Domain Model**

Appendix C **Model Diagrams**

Appendix D **Reference Process for Configuration**

Appendix E **Reference Process and Tool-set for Evaluation, Testing, and Validation**

Appendix F **Reference Configuration and Validation Tools Package**

Appendix G Resources

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[notes below here]

Possible table: index to data elements, UML/JSON/XML that we adopt or conform to from other NIST spec's:

From ENR, also adopted by CVR (CVR spec points to ENR elements for brevity, instead of repeating the same info within the standard doc

```
</xsd:simpleType>
<xsd:simpleType name="VoteVariation">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="1-of-m"/>
    <xsd:enumeration value="approval"/>
    <xsd:enumeration value="borda"/>
    <xsd:enumeration value="cumulative"/>
    <xsd:enumeration value="majority"/>
    <xsd:enumeration value="n-of-m"/>
    <xsd:enumeration value="plurality"/>
    <xsd:enumeration value="proportional"/>
    <xsd:enumeration value="range"/>
    <xsd:enumeration value="rcv"/>
    <xsd:enumeration value="super-majority"/>
    <xsd:enumeration value="other"/>
  </xsd:restriction>
</xsd:simpleType>
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