Voting Methods Models

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

NIST Voting Public Working Group
Voting Methods Subgroup

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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 ITL’s research, guidance, and outreach efforts in Information Technology and its collaborative activities with industry, government, and academic organizations.

Abstract

This publication is a standard specification supporting Data Interoperability (DI) for Elections Administrator’s (EA) systems, and the integrity of data sets in elections systems, specifically vote data sets as they are operated upon by modules that perform counting, tabulation or mathematical evaluation, or operations on the data sets, for a variety of voting methods, and for the validity of those modules or systems, voting methods and processes.

EA voting, counting, and tabulation processes are typically specified in written legislation, statute, rules and guidelines, or Request For Proposals (RFP) and other specifications produced by Elections Officials (EO). The English language, or any spoken and written language, is naturally less precise than a mathematical specification. No matter how well crafted, when algorithmic, mathematical or constraint logic requirements of elections systems are specified in plain language, unintended under-specification or unplanned gaps or potential ambiguity occurs.

This specification enables DI within an electoral jurisdiction's systems and also inter-jurisdictional data and multiple-jurisdiction data aggregation and analysis, and may also apply to testing and certification analysis. It provides a set of rigorously and precisely defined mathematical models of voting schemes, voting methods, and modules where counting, tabulation, mathematical evaluation or operation on vote selection data is performed in elections systems.

Each element of this specification is a voting method mathematical model, with it's corresponding unique identifier and description. Each element is a precise definition which can be referenced without ambiguity, used, reused, and understood across the field by a variety of stakeholders including legislators, elections officials, analysts, systems and software manufacturers, and for testing and certification.

Legislators, elections agencies and elections officials may use the elements of this specification to unambiguously specify voting methods, modules, or mathematical or constraint logic requirements of elections systems. EA’s may precisely define requirements in RFPs, by incorporating the unique identifier or the entire model.

This specification includes a reference process for knowledge acquisition and representation, or domain modeling of EA counting and tabulation methods using written legislative specification as the primary source of domain knowledge.
Common data interoperability format; contest; district; election results; jurisdiction; overvote; political office; political party; precinct; undervote.

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Executive Summary

This publication is a specification of mathematical models of voting schemes, 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 (DI) 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 Administrator's (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 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 models for modules causes unnecessary consumption of time and resources when stakeholders are caused to interpret unintended under-specified definitions.
This specification of a common set of models for voting schemes and counting, tabulation, mathematical evaluation and vote selection data set common operations modules, each with a corresponding unique identifier, provides precise definitions. The models can be referenced without ambiguity, used, reused, and understood across the field by EA's and the variety of stakeholders including legislators, elections officials, analysts, systems and software manufacturers, and testing and certification labs.

When each voting method or module that operates on elections data, specifically vote selection data, to perform calculations, 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 vote cast ballots, 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 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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Analytics is the synthesis of knowledge from information.

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1. Introduction

The Voting Methods Models working group develops robust mathematical models, specifications, and formalizations to fully describe a variety of voting methods, modules and operations on elections data sets, where counting, tabulation, or operations on elections data sets are performed by systems that operate elections, also known as Elections Administration Systems (EAS). These models are 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 EAS. The group 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 new 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 a common and precise definition 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
NIST Voting Interoperability Framework: Voting Models

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 Administrator's (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 elections 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 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 manufacturer, 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 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 meta models, 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 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 EAS, 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 EAS universe are not in scope.

*RFIs or RFPs for EAS manufacturer,

1.3 Motivation and Methodology
1.3.1 Data Interoperability is complementary to Data Transport Formats or Data Interchange Interoperability. Both work together to enable EA systems to be valid to a high degree of confidence, accurate, fail-safe, and cost effective.

1.3.2 Data Interchange Formats provide for transfer of data between systems in a consistent way. Data Interoperability models provide for correct operations on the data, and the integrity of the data set as it is active or at rest in one or more systems, sub-systems, or in distributed systems, or over the life-cycle of data sets.

1.3.3 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.

1.3.4 No complete compendium of mathematical models of the voting methods that are currently in-use today, exists. In-use implies currently applicable legislation or 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.

1.3.5 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 definitions satisfy the need for a standard set of precise definitions, commonly understood, without ambiguity, among the full spectrum of stakeholders in the operation and administration of elections.

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 Other

2 Background and Overview

The Voting Methods Models Public Working Group (VM-WG), is a sub-group 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 sub-group 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 eco-system of Interoperability standards and specifications, that are part of NIST Elections and Voting Systems
NIST Voting Interoperability Framework: Voting Models

Interoperability, and more broadly where our work fits in the universe of elections and voting standards.

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 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 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 EAS or EA’s 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 systems that are in use by U.S. jurisdictions for government operated elections today.

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

Nothing about the models within the EAS Interoperability domain is intended to constrain adopters of this specification from implementing it either as a system of interoprating sub-systems, or as independent interoprating systems, or a mix of both, as the particular use-case as defined by Elections Officials (EOs) or Elections Administrators (EAs) may vary.

For example, one common use-case for implementation of an EAS for a single jurisdiction, is as a single system which may or may not be composed of sub-systems. Alternatively, a state-wide system is logically composed of multiple jurisdiction data aggregation, in which case the
interoperability architecture would be implemented as multiple inter-operating systems, each of which may also be composed of sub-systems.

2.1 **VVSG and TGDC**
In this section we describe this working group's view of the relationship of this standard to the VVSG, other work of the TGDC and NIST in Voting and Elections standards or specification, and other frameworks, specifications or standards. We seek to orient the reader as to where this standard and its utility to the full spectrum stakeholders, fits in the landscape of guidelines, frameworks, standards for elections administration. We describe indexes, mappings, potential interfaces with other guidelines, frameworks, standards, specifications or models, and the potential for utility to the TGDC, VVSG, and EAC working groups.

2.1.1 **Elections Administration Business Process**
- 2.1.1.1 Elections Data Transport Interoperability
- 2.1.1.2 Elections Data Interoperability
- 2.1.1.3 Elections Data Structures

2.1.2 **Tabulation and Counting Methods**

2.1.3 **Operations on Cast Vote Data Sets**

2.2 **Use Cases**

2.2.1 **Overview**
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.

Mapping common practice for a generic universe domain modeling exercise, into the EAS domain, use cases are scenarios in which one or more models or reusable component models of counting, tabulation, mathematical evaluation or common operations on vote selection data sets are applied in real world elections administration processes of interest.

For example, scenarios include applying reusable component models in the context of particular requirements such as 'all EAS processes must be auditable', or requirements that a system must support end to end verifiability, or where encryption schemes are specified as part of a voting method specified in legislation, or reporting aggregations. Use cases may also be viewed as a set of the multiple contexts in a process will be applied.

Use Cases covered in this standard include: auditable, verifiability, capacity planning, testing & certification, security, information privacy, reportability, trace-ability & logging, aggregations and "roll up", encryption required for a voting method or vote data set, and common operations on vote data sets.

Use cases for the purpose of this standard, are of utility to Elections Officials and administrators, when they are aligned with the Elections Administrator's view of elections administration processes.

2.2.2 **Audits**
- 2.2.2.1 Risk Limiting Audits

2.2.3 **Aggregations and 'Rollups'**

2.2.4 **Verification**
2.2.4.1 End to end verification
2.2.5 Testing and Certification
2.2.6 Capacity Planning
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  2.2.11.4 Overvotes reported for the contest;
  2.2.11.5 Undervotes reported for the contest;
  2.2.11.6 Breakdowns of votes by various reporting units such as precinct or split precinct;
  2.2.11.7 Vote counts and ballot counts broken down by ballot type (absentee, early, etc.) and type of device (electronic, optical scan, etc.);
  2.2.11.8 Number of votes cast by party or the number of straight party selections
2.2.12 Tracing and Logging
2.2.13 Voting Methods Precise Specification for Legislation and Elections Officials Rules and Guidelines

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
  2.3.2.1 Domain Modeling Paradigms, Overview
  2.3.2.2 Domain Modeling Approaches, Evaluated
    2.3.2.2.1 UML Model

3 Non-Mathematical Definitions and Domain Modeling
In this section we describe the reference and input sources used for domain modeling.
  3.1.1 Legislative Definitions
  3.1.2 Election Administration Definitions
  3.1.3 UML Domain Model (for voting methods, counting, tabulation and operations on cast vote data sets)
  3.1.4 Election Administration Business Process Model
    3.1.4.1 Mapping UML Voting Methods Domain to the EA Business Process Model
3.1.5 Other Definitions

3.1.5.1 Manufacturers contributions illustrating how equipment or systems and devices operate on vote data sets. [E.g. Herb's definition as posted to the Interoperability Group, and others such as equipment manufacturer's documentation]

4 Mathematical Models for Elections Systems

For each scheme/method/module that we define:

4.1 Unique Identifier, Numeric with Text Label

4.2 Text description of model element,

4.3 brief pointer to references

4.4 Formula (math notation)

4.5 UML model index mapping module to EA Business Process

4.6 The written mathematical model in human readable specification language form

This is the actual executable language model element, written in the mathematical logic Domain Specific Language (DSL).

4.7 Set of test conditions and expected outcomes

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

4.9 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.

5 Reference Process for Domain Modeling

6 Reference Process for VMMS Configuration

7 Reference Process and Tool-set for Evaluation, Testing, and Validation

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
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