Accuracy and Performance Assessment of the SRM Implementation

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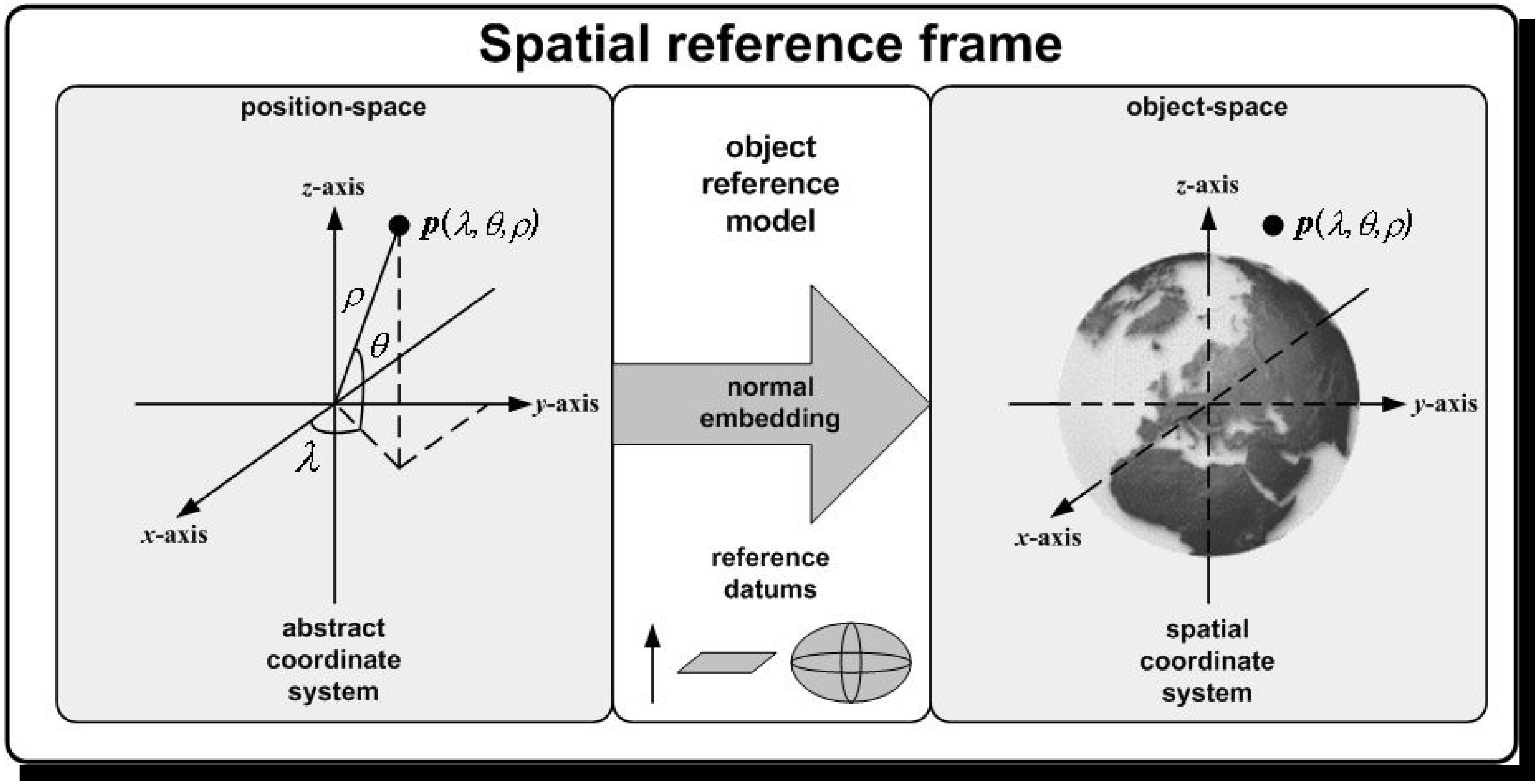
Introduction

- Applications using different spatial reference frames, and required to interoperate or interchange spatial data, must be able to inter-convert that data
  - This inter-conversion must be accurate, but must also be fast in order to meet the demands of performance-sensitive applications
- The Spatial Reference Model (SRM) is an international standard (ISO/IEC 18026) for describing spatial concepts and operations including positions, directions, distances, and time
  - SRM development began in the mid 1990s in response to a growing need for environmental data in multiple spatial reference frames
  - SRM is a critical component of the SEDRIS technologies
  - SRM is designed to be used independently of other SEDRIS components
  - SRM provides the conceptual model for the description, representation, transformation, and conversion of spatial data across spatial reference frames
  - SRM supports the addition of new spatial reference frames, coordinate systems, and object reference models through registration

- This presentation discusses the process and results of assessing the accuracy and performance of the SRM implementations for a subset of the variety of spatial reference frames that the SRM supports

Spatial Reference Frames

- A spatial reference frame combines an abstract coordinate system with an object reference model to specify a spatial coordinate system that allows positions to be expressed relative to a spatial object of interest, such as the Earth



Background

- SRM implementations are provided as open source software development kits (SDKs)
- Programs that use the SRM implementations, such as TENA, OneSAF, Close Combat Tactical Trainer (CCTT), Brigade Combat Team Modernization (BCTM), WARSIM, and Synthetic Environment – Core (SE-Core), have specific performance requirements
- Tests were developed to assess the accuracy and performance of the SRM implementations
  - The accuracy tests use a large set of independently developed and verified position test data for specific spatial reference frames, and orientation test data for multiple representations of orientation values
  - The performance tests focus on coordinate conversions within a small subset of the spatial reference frames that SRM supports
  - Between 2006 and 2009, the SRM implementations were tested, improved, and retested to ensure that these requirements were met
- The SRM implementations have evolved to include fast and innovative algorithms for performing these computations

Implementations of the SRM

- SRM is implemented in C, C++, and Java
  - The C and C++ implementations share a core set of libraries and modules (written in C++) and differ only in their external interface; these were initially developed in the mid 90s, and evolved and improved along with the SRM standard
  - The Java implementation is a complete re-implementation of the core modules, using Java programming constructs and techniques
  - SRM implementations are provided as both pre-compiled binaries for specific platforms, and open source SDKs, through the SEDRIS web site (www.sedris.org)
- Support for rotations, orientations, and vectors were added to a separate branch of the SRM SDK baseline in 2006-09, and were released as SRM SDKs 4.3 and 4.4
  - The original SRM SDK baseline, version 4.1.x, does not include these new capabilities; it is maintained for compatibility with the other SEDRIS components
  - Core coordinate transformation modules in both baselines are identical
- Position accuracy tests reported here were performed in early 2010 using the SRM C++ and Java SDKs, both version 4.4
  - These results also apply to version 4.1.3
- Orientation accuracy tests reported here were performed in early 2010 using the SRM C++ and Java SDKs, both version 4.4

Position Accuracy Tests – Data

- These tests measure the position accuracy of coordinate conversion and transformation operations involving selected spatial reference frames (SRFs) supported by the SRM
- SMEs at the US National Geospatial-Intelligence Agency (NGA) developed the test data used in these tests by independently implementing coordinate conversion algorithms in Mathematica
  - The test data is available directly from NGA
  - The test data consists of a suite of 129 test files, each containing from several hundred to several thousand test vectors for a given spatial reference frame
  - Each test vector represents the coordinates of a unique position in the source reference frame with known coordinates in the target reference frame
- The test data is organized in three categories:
  - 111 test files dealing with projection reference frames, including Mercator, Transverse Mercator, Lambert Conformal Conic, and Polar Stereographic, using three different Earth reference models, each containing 300 test vectors
  - 10 test files dealing with 3D reference frames (geocentric and geodetic), using two different Earth reference models, each containing 600 test vectors, including positions above and below the Earth's surface
  - 8 test files (4 pairs) dealing with datum transformations between WGS 84 and 226 other datums (global and local), each containing 5000 test vectors

Position Accuracy Tests – Procedure

- The position accuracy assessment application reads the test files and invokes the SRM implementation to perform the specified operation for each test vector
  - Not all of the SRFs contained in the NGA test data files are supported by the SRM
  - The SRM defines the concept of valid regions for each spatial reference frame; Thus only coordinates within the valid region can be used in a coordinate operation
- All tests are bi-directional
  - SRF A test data are converted to SRF B, and compared to expected SRF B values
  - SRF B test data are converted to SRF A, and compared to expected SRF A values
- Differences between the computed position and the expected position are computed for each test vector
- The following are computed for each test file:
  - The number of test vectors
  - The maximum difference value
  - The minimum difference value
- Two output files are generated:
  - One containing the results for map projection and 3D coordinate conversions
  - One containing the results for datum transformations

Position Accuracy Tests – Results

- The results of the position accuracy tests are available from the SEDRIS web site (www.sedris.org/srm.html)
- Since the tests measure different types of position accuracy, the results of each test must be evaluated within its proper context
- However, to provide a relative qualitative measure of the difference values across all tests:
  - The table below shows the ranges of minimum and maximum differences, in meters, as well as the total number of test vectors, for each category
  - The smallest minimum difference value is in the neighbourhood of $9.3x10^{-10}$ meters
  - The largest maximum difference value is in the neighbourhood of 0.05 meters
  - Note that these extreme values can be misleading; to gain a more complete understanding of the test results for a specific spatial reference frame, the actual position accuracy test data should be reviewed

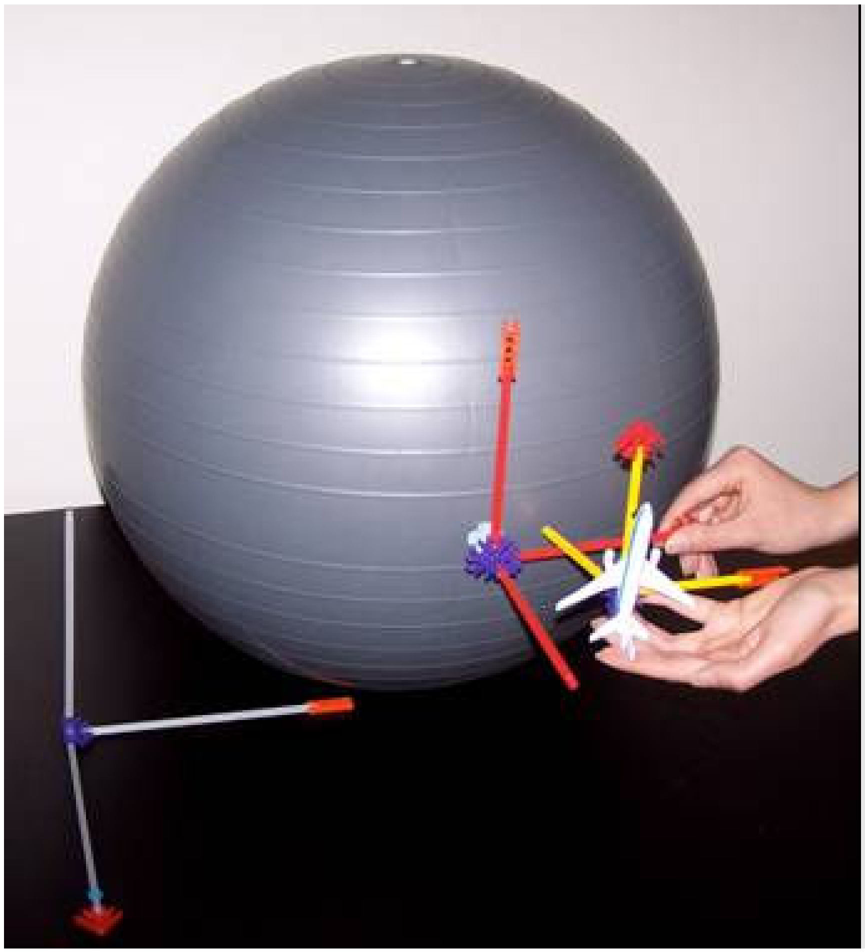
Test Data Category	Number of Test Sets	Number of Test Vectors	Minimum Differences		Maximum Differences	
			From	To	From	To
Projection Reference Frames	190	46817	0.000E+00	8.186E-03	0.000001	0.052897
3D Reference Frames	4	1830	0.000E+00	1.510E-07	0.000101	0.014140
Datum Transformation	452	10000	0.000E+00	4.771E-04	0.000083	0.000776

Orientation Accuracy Tests – Data

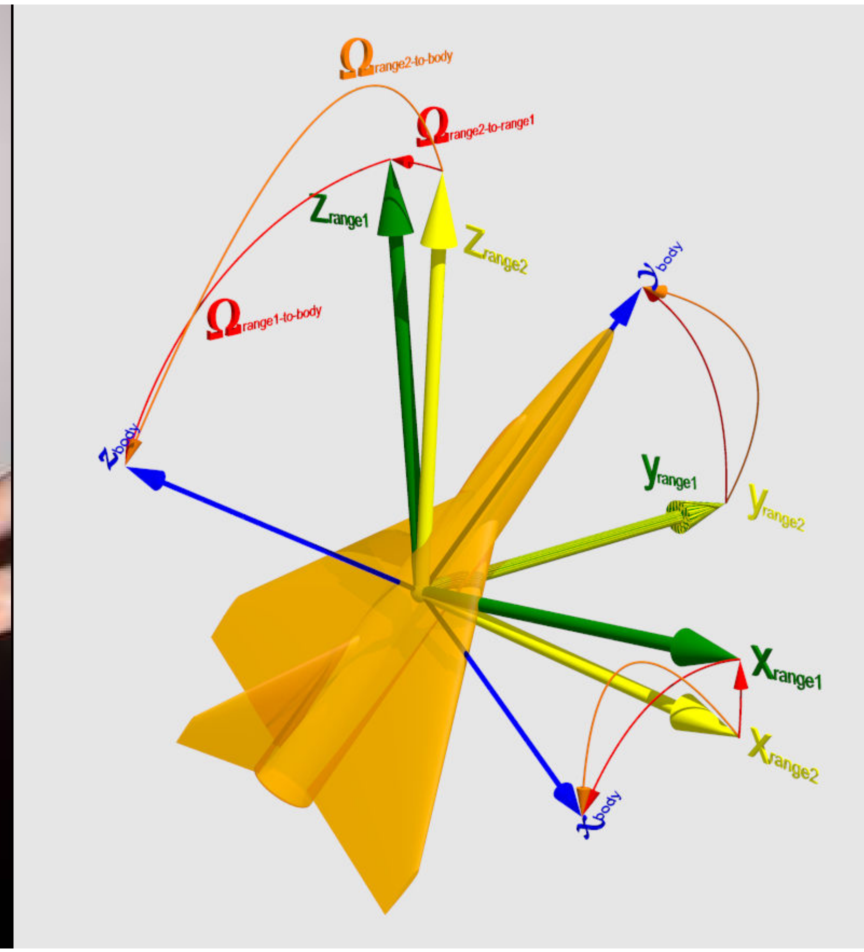
- Between 2006 and 2008, full support for orientations and vectors, including coupling orientations and vectors to any spatial reference frame, was added to the SRM implementation to support the requirements of the TENA program
- Five different representations of orientation values are currently implemented:
  - 3x3 matrix,
  - Axis-angle,
  - Euler ZYX convention,
  - Euler ZXZ convention, and
  - Quaternion
- SMEs at NGA developed a suite of test data to support testing the accuracy of conversion operations between these five representations
  - For each representation, a set of 3184 test vectors was produced, where each test vector represents a unique orientation value
  - The test suite consists of 5 files, one for each supported orientation representation, each containing 3184 test vectors

Orientation Accuracy Testing

Initial Orientation Testing Visualization



Enhanced Orientation Testing Visualization



Orientation Accuracy Tests – Procedure

- The orientation accuracy assessment application reads each of the five input files, and invokes the SRM implementation to convert each test vector from its source representation to each of the other four representations, as well as to itself
- The application compares the computed and expected orientation values, and a Boolean result of match or no match is recorded
  - Orientation representations differ significantly in how they represent the same orientation; for example, a matrix representation involves 9 values, whereas an Euler angle representation requires only 3 values
  - In general, the same orientation, using the same representation, can be expressed by more than one set of numerical values; it is therefore critical that the comparison process take this into account
- The result is a collection of 25 (5x5) output files, each containing 3184 test results
  - In each output file the computed value for a given conversion operation (in one direction) is listed alongside the expected reference value

Orientation Accuracy Tests – Results

- In all cases, all computed values matched the corresponding expected values, within the specified tolerances
- However, testing conversion operations between different orientation representations is not enough
- Orientations can also be represented with respect to different spatial reference frames, using the same or different representation forms
- A different set of tests (and supporting test data) is needed to evaluate whether changes in spatial reference frames introduce any errors
  - These tests are more complex, and a validated set of test data has not yet been developed for these cases

Performance Tests – Data

- The C++ SDK was used to assess the performance of the SRM implementation
- The performance assessment involved only a small subset of the spatial reference frames supported by the SRM:
  - Celestiodetic (CD aka, geodetic) with the WGS 84 Earth reference model (ERM),
  - Celestiocentric (CC aka, geocentric) with the WGS 84 ERM, and
  - Augmented Universal Transverse Mercator (UTM) with the WGS 84 ERM
- These specific spatial reference frames were chosen because they are by far the most widely used spatial reference frames within a large number of applications in the simulation community
- The performance assessment used a set of 10 3D geodetic coordinate values (representing random positions around the globe)

Performance Tests – Procedure

- The performance assessment application performs pair-wise conversions between two of the three SRFs under test for each of the 10 test vectors
  - Each of these conversion operations is repeated 10 million times
- Minimum, maximum and mean times for each of these pair-wise conversions are computed
- The timing assessment is performed twice, once with the SRM coordinate validation function turned on, and once with it turned off
  - When the SRM validation function is turned on, the conversion operation checks the input (source) coordinate before the conversion takes place, and also checks the resulting output (target) coordinate to ensure they are both within the valid regions defined for the respective SRFs
  - When the validation mode is off, these checks are skipped, resulting in significantly faster performance in all cases; applications that can always rely on valid input data can take advantage of this
- Upon completion, an output file is created that contains the results
  - The output shows the time required for each of the 10 input positions, and for each six pair-wise conversion cases
  - The output also lists the minimum, maximum, and mean times over the 10 input positions for each of the six pair-wise conversion cases

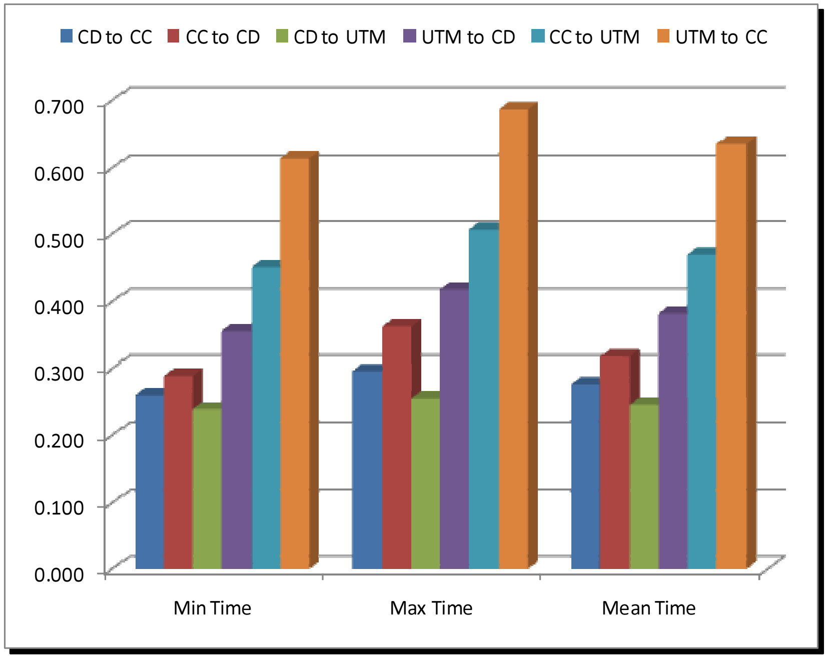
Performance Tests – Discussion

- Measuring the execution speed of any software is, in part, dependent on the hardware platform on which the tests are performed
- In addition, variables such as choice of compilers, optimization flags, and other factors (such as whether other processes are competing for resources on the test platform) will affect the performance of the software module under test
- As a result, it is critical to capture and report the specific hardware & software configuration used for testing, and to be able to determine the impact (if any) of the testing process on the module under test
- For each combination of input position and pair-wise conversion operation, the SRM performance assessment application:
  - Sets up the input value for the specific test cases,
  - Begins recording the elapsed time,
  - Iterates the conversion operation 10 million times by calling the appropriate SRM module, and
  - Captures the total elapsed time for that conversion case

Performance Tests – Results

- The test environment consisted of a Xeon 3.06 GHz CPU, with 512 KB (L2) & 0 MB (L3) cache, 1.5 GB DDR (266 MHz) RAM, running Linux RedHat 2.6.9-55.EL, and using the GCC v3.2.2 compiler
- Timing results shown below are for a single conversion operation, in microseconds, using SRM C++ version 4.3, without validation

Test Coord	CD to CC	CC to CD	CD to UTM	UTM to CD	CC to UTM	UTM to CC
Coord 1	0.282	0.312	0.248	0.418	0.462	0.639
Coord 2	0.286	0.300	0.239	0.371	0.454	0.622
Coord 3	0.280	0.323	0.241	0.355	0.464	0.631
Coord 4	0.262	0.362	0.250	0.414	0.506	0.686
Coord 5	0.284	0.311	0.239	0.360	0.476	0.626
Coord 6	0.296	0.289	0.242	0.364	0.466	0.654
Coord 7	0.283	0.323	0.247	0.358	0.464	0.633
Coord 8	0.260	0.324	0.244	0.357	0.452	0.614
Coord 9	0.263	0.305	0.251	0.404	0.488	0.638
Coord 10	0.266	0.322	0.255	0.415	0.473	0.619
Min Time	0.260	0.289	0.239	0.355	0.452	0.614
Max Time	0.296	0.362	0.255	0.418	0.506	0.686
Mean Time	0.276	0.317	0.246	0.382	0.471	0.636
Mean PPS (in Millions)	3.62	3.15	4.07	2.62	2.13	1.57



- Performance ranges from ~1.6 to ~4.1 million points per second (PPS), depending on the conversion operation being performed

What's Next?

- The current tests only cover a subset of SRM's capabilities
  - Selected subset of supported spatial reference frames
  - Conversion between different orientation representations, with respect to a single spatial reference frame
- Important next steps:
  - Developing position accuracy tests for all SRM-supported spatial reference frames
  - Developing orientation accuracy tests that address both changes in orientation representation, and conversion between different spatial reference frames
  - Developing performance tests that involve conversions between other less known or less used spatial reference frames
- One of the most difficult tasks is the creation of independently verified and validated test data
  - Requires independent development and implementation of algorithms that are as immune as possible to various sources of error
  - It is also necessary to ensure that the test data generation process itself is free of errors

- The development of comprehensive, independent, robust, and verified test data for the position and orientation accuracy of the other SRM-supported spatial reference frames is the next challenge

Summary

- Successful interchange of spatial data between applications that use different spatial reference frames is critically important to achieving interoperability
  - To ensure the integrity of such interchange, and to meet the performance requirements of those applications, software implementations of transformation operations must be subjected to rigorous and independently verifiable testing
- This presentation has provided an overview of the processes used in, and the results of, assessing the accuracy and performance of implementations of the Spatial Reference Model
  - These tests have been conducted by several independent users, and are available for anyone to download and execute for themselves (www.sedris.org)
- It has been shown that the SRM implementations perform very well, with respect to both accuracy and performance, for the test cases that have been conducted thus far
- More comprehensive test data is still needed to fully cover the variety of spatial reference frames supported by the SRM

- Questions? Email help@sedris.org

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