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NASA EXPLORATION INFORMATION ONTOLOGY MODEL (NEXIOM) PRIMER AND VISION

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1.0 Introduction

Simulation-Based Acquisition (SBA) is an acquisition process in which NASA and Industry are enabled by robust, collaborative use of simulation technology that is integrated across acquisition phases. ESMD's use of SBA "…will foster better informed, timelier and more defensible decisions throughout the exploration systems acquisition life cycle."[1]

NExIOM, the NASA Exploration Information Ontology Model is the mechanism by which the ESMD SBA support office supports defensible decision-making through consistent, traceable and understandable data representation.

As acquisition program decisions become increasingly dependent on modeling and simulation, the need for complete, consistent and authoritative inputs and results throughout the modeling process becomes critical. NExIOM, the NASA Exploration Information Ontology Model, supports SBA by providing a unifying data model for describing simulation and analysis inputs and results and how they have been combined to justify design decisions.

The NExIOM data model will provide decision traceability from the program level down into the detailed, supporting engineering data. This includes system-engineering data (Requirements, Functions and Rationale), product data (Parts and Technologies) and mission data (Segments, Events and Processes). This data will be captured and stored in ESMD's Integrated Collaborative Environment (ICE) as a combination of NExIOM-format metadata, NExIOM-format application data and application-specific files. Access to this data will be reliable, authoritative, intuitive and independent of geography. NExIOM will represent the ESMD product architecture (that is, the vehicles and related mission plans) as well as the ESMD development and acquisition architecture (the engineering and acquisition processes).

SBA is an extended (NASA and Industry) enterprise-wide endeavor. Coordinating its implementation among the many design and analysis organizations involved and building the common IT infrastructure required is the responsibility of the SBA support office in collaboration with the ESMD Chief Information Officer (CIO). Similarly, data

[1] Steidle, C.E., "Simulation Based Acquisition (SBA) Implementation Strategy", NASA Exploration Systems Mission Directorate

modeling is a distributed responsibility, with the SBA NExIOM team providing coordination and building common infrastructure, e.g., ontologies and data dictionaries and web services based on them. The team will partner with the NASA and contractor engineering community to use or extend existing standards and terminology wherever possible. Therefore, NExIOM can be thought of as a combination of existing data models or data standards, new data models covering gaps, metadata needed to support decision tracking, and mappings between these things to allow interoperability.

NExIOM is under active development. This overview describes its goals and requirements and the development plans of the NExIOM team as of this writing. Feedback to Jeremy C. Vander Kam (Jeremy.C.VanderKam@nasa.gov) is encouraged.

2.0 Technical Challenges

NExIOM must address these primary technical challenges:

A. Providing decision traceability
B. Ensuring Consistent Analysis
C. Supporting information access, understanding and management by both humans and software agents

Providing Decision Traceability

Providing a data model for describing how analysis results impact decisions is NExIOM's first responsibility. To do this, we are drawing from past work, particularly JSF's JAMIS metamodel (JSF Authoritative Modeling Information Systems) and the DoD Discovery Metadata Standard.

NExIOM metadata will typically be implemented as a database record and/or OWL/RDF/other XML file(s) that describe an information asset. The metadata will include at a minimum:

1. Lineage metadata, describing how the asset was produced, by what process step and tool, under the supervision of whom and when;
2. Data Quality metadata, describing information required by ESMD's Verification, Validation and Accreditation (VV&A) policy such as fidelity

3. Use Constraint metadata, describing conditions under which use of the data item is valid, e.g., vehicle operating environment and design versions, types of analyses

Lineage Metadata is particularly critical because it supports decision tracking and analysis consistency audits (described below), and it helps determine what analysis products must be updated when inputs change.

Note that these metadata categories are partially overlapping. For instance, constraint metadata concerning design versions could be inferred by working back through the lineage to find which CAD files were used.

Data Quality metadata and Use Constraint metadata are mutually constraining, e.g., certain levels of fidelity are inappropriate for certain kinds of analyses. The appropriate level of redundancy is a time vs. space tradeoff that remains to be done.

The ESMD Integrated Collaborative Environment (ICE) Windchill implementation supports some, but not all of the needed metadata. NExIOM metadata will be implemented by customizations to Windchill and potentially by inclusion in the ICE of additional data management services. Together with the ICE team, we will seek to minimize the impact on users of entering this metadata.

Ensuring Consistent Analysis

Analytical consistency means that participants performing mission or vehicle design, analysis or assessment share models and data in ways consistent in meaning and value. This includes consistent concept definitions, ground rules and assumptions as well as numerical design and operational data.

NExIOM will achieve this via (1) a program-wide data dictionary describing parameters exchanged between simulation and analysis process steps and (2) an XML-based file format for passing information between tools that holds data corresponding to this data dictionary and (3) a central data clearing house using that format that combines information from multiple disciplines for single mission architectures or scenarios under analysis. Use of the common file format and data clearing house exclusively will be encouraged but not required. (Very large and/or complex datasets such as aerothermal databases or full, application-native CAD representations are inappropriate for this format and will be wrapped with metadata only.) However, mapping all modeling and simulation data at some level to the program-wide data dictionary will be mandatory.

The data clearing house is depicted in Figure 1. This clearing house will enable each analysis participant to interface with a single, common data set instead of individually with every other participant in the process.

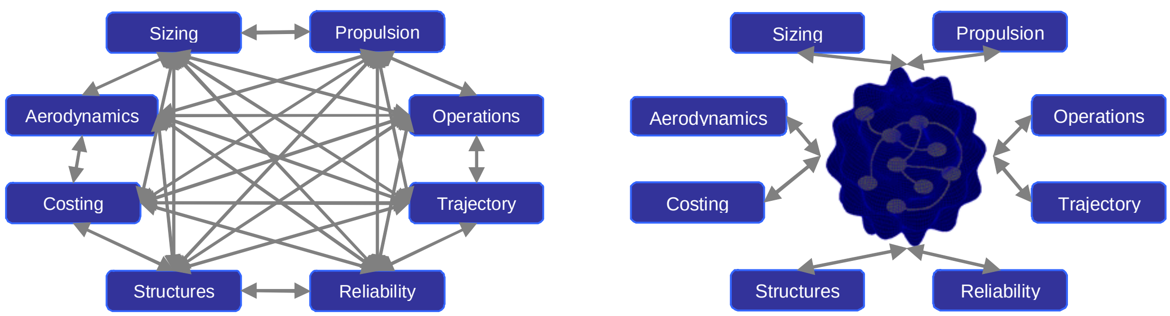

Figure 1: Private Interfaces Between Individual Resources are Replaced with a Common Data Set for the Team

Supporting Information Access, Understanding and Management by both Humans and Software Agents

Metadata stored to NExIOM's specifications will help ESMD and contractor personnel throughout the program find and understand data. As such, NExIOM shares goals with the DoD Discovery Metadata Standard. That standard defines metadata for searching for information resources posted to community and organizational shared spaces. These shared spaces are the ICE and contractor data warehouses. These NExIOM metadata standards will be employed consistently across ESMD, NASA and Industry. This capability will rely on a set of common ontologies and a defined set of views by which items that conform to that set are expressed.

As of this writing, ESMD is evaluating adoption of the Department of Defense Architecture Framework (DoDAF). "The Department of Defense (DoD) Architecture Framework (DoDAF), Version 1.0, defines a common approach for DoD architecture description development, presentation, and integration for both warfighting operations and business operations and processes. The Framework is intended to ensure that architecture descriptions can be compared and related across organizational boundaries, including Joint and multinational boundaries".

If DoDAF is adopted, NExIOM will incorporate the DoDAF Core Architecture Data Model (CADM), which defines the entities and relationships for architecture data elements. The NExIOM team is currently observing the DoDAF 2.0 effort and will work with ESMD's system engineering organizations to adapt DoDAF to fit NASA's environment.

To summarize, NExIOM will provide ontologies that supports ESMD and contractor personnel finding and understanding information resources and the relationships between them. These ontologies will be evolvable and provide visibility and accessibility into the decisions the ESMD makes.

Software systems are a tool for present day human understanding. The software systems supporting human understanding must also “understand” the information they present. This enables them to display appropriate human-oriented products in support of human understanding when queried. They also provide mediation, translation, traceability, and semantic consistency validation for software agents and systems. These agents and systems utilize inference engines across federated knowledge bases and data sources in order to provide broad and deep information and understanding to human operators.

Over time, the NExIOM team will pursue this area through efforts in interoperability and ontology-aware systems via the creation of compatible machine-intelligible knowledge models across ESMD domains of interest. This includes techniques for digital ontology expression, inferential queries, and consistent view presentation. The NExIOM also defines the metamodels needed to support human and machine reasoning about the relationships and dependencies of the ESMD systems, organizations, and processes as they evolve over the program lifecycle.

Ultimately, we believe an effective data model can contribute to two very important impacts on the organization as a whole:

1. To improve the ability of all NASA and contractor personnel to engage in systems thinking, that is, the ability to understand and manage the system-wide consequences of their local decisions. This

depends upon being able to rapidly identify, understand and track consequences.

2. To stem the tide of 'corporate' knowledge loss as personnel change jobs. Over long duration programs like Shuttle, JSF and the Exploration Initiative, job change is a major contributor to cost and risk. We recognize that apprenticeship, i.e., person-to-person knowledge transfer, is the major means to prevent this loss. However, a 'work as modeling' approach can assist in improving this transfer.

3.0 NExIOM Team Processes and Interfaces

The work required to create NExIOM and the many additional models and databases it will reference can be divided up several different ways. Here, we divide it up by kind of knowledge, by what will be focused on when, and by who will do what work.

Knowledge Domains

NExIOM is divided into at least the following domains:

A. Systems Engineering, describing concepts of operation, mission, vehicle and engineering organizational requirements, mission, vehicle and engineering organizational architecture and so on. This may be implemented via a commercial database supporting requirements and potentially all of CADM, e.g., Cradle or Core.

B. Technology, describing current and projected future performance capabilities of technology options, plus cost and development risk estimates for the investments needed to reach goals. This is being done in partnership with the Exploration Systems Research & Technology Program (ESR&T) and will be extended to include information from industry sources where this doesn't conflict with competition.

C. Analysis, including an enterprise-wide modeling and simulation data dictionary, ontologies for describing information passed within and between analysis steps and engineering disciplines.

D. Components, describing the elements of the vehicle including histories of all parts. This will be implemented by the parts management capability of PTC's Windchill, which is the major constituent of the ICE. This will require customizations of and extensions to that capability.

E. Process, describing logistics and vehicle preparation processes associated with the vehicles.

Utilizing NExIOM to represent all of these items and the ICE to capture and manage them will enable NASA and contractor personnel to better understand the complex relationships amongst them, enabling greater efficiency in achieving program goals.

Figure 2 depicts how the NExIOM domains we're initially focusing on interact. Each domain satisfies the same functionality as a traditional, topical database.

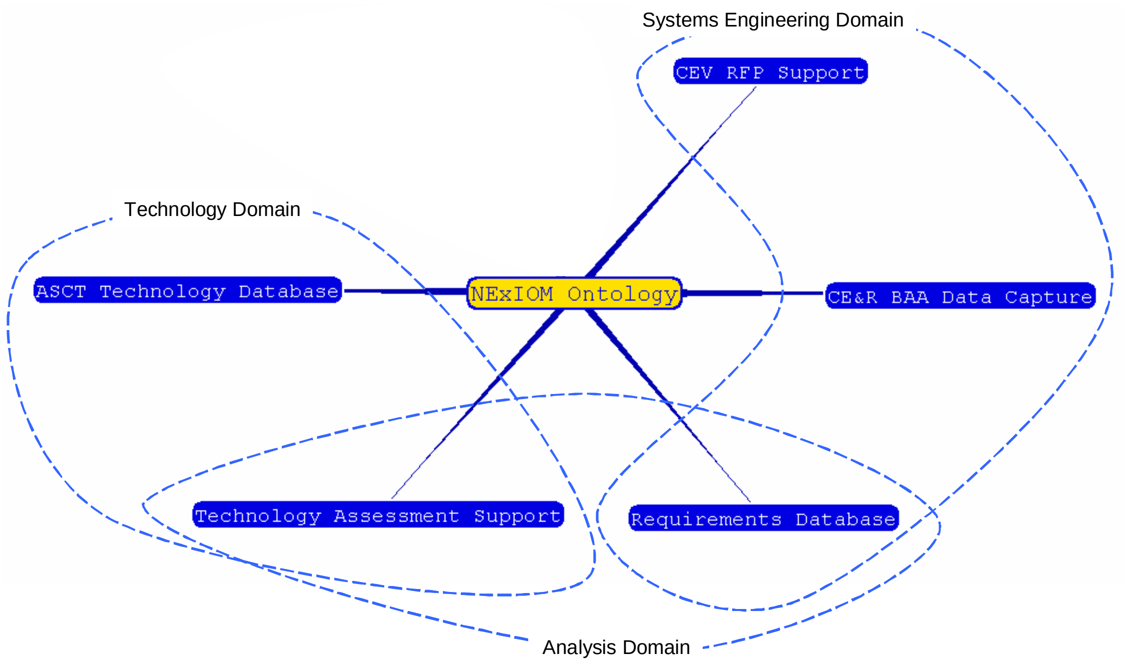

Figure 2: Domains

Notional Timeline

Figure 3 shows a very rough timeline to get across several high-level points about the way we expect NExIOM to evolve. The timeline distinguishes the pre-award period from the contract period of performance to a potential follow-up.

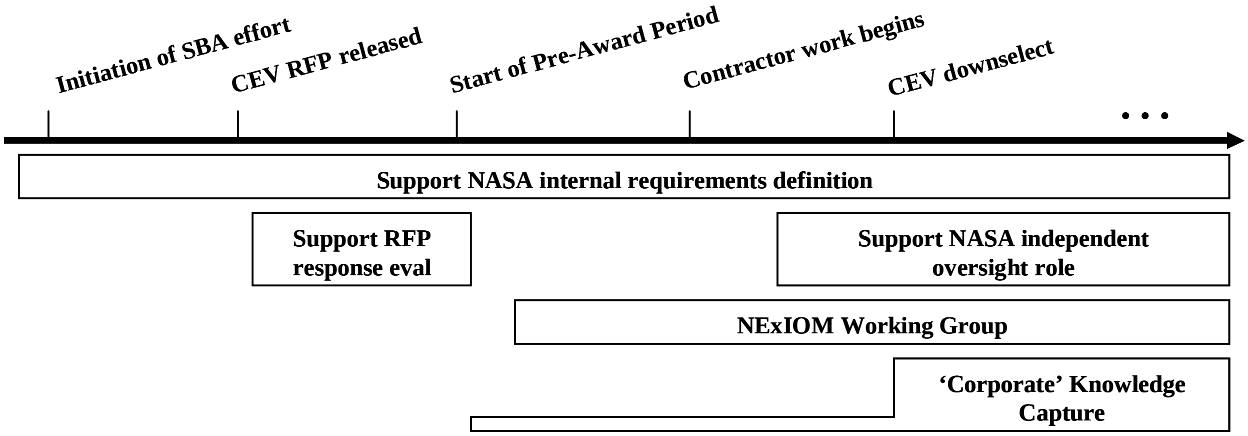

Figure 3: Notional Timeline

The NExIOM team is supporting NASA internal analysts doing trade studies to develop or vet CEV requirements. We are following this process, adapted from previous work done by this team under the Space Launch Initiative and by the ISS data integration team:

1. Identify the stakeholders (those who are a part of the process)
    a. Identify all related areas (process owners and data users)
    b. Identify data providers
    c. Identify database and application owners
    d. Identify potential downstream data users and applications in support of operations and sustaining engineering
2. Define and document the individual data exchange processes of each
3. Define and document the individual data dictionaries
4. Define and document the integrated data process and data dictionaries
5. Work with all parties to define the appropriate level-of-detail for NExIOM representations; Define and document requirements accordingly
6. Document the integrated data requirements definition to levy data delivery requirements on data providers
7. Develop plan to implement data set in appropriate repositories

NASA Internal Analysis Support

Internal to NASA, we are using XML files to exchange data between some analysis tools and processes, building on SLI heritage. The schema for these files is part of NExIOM and is based on the Launch

Vehicle Language[2]. In many cases, the information passed between tools boils down to a list of parameters with configuration-controlled names and definitions. These are typically exchanged via NExIOM-compliant XML. This is being done for a core set of analysis tools. This set will be expanded over time.

Figure 4 illustrates a tool path that is representative of those under construction by the SBA support office.

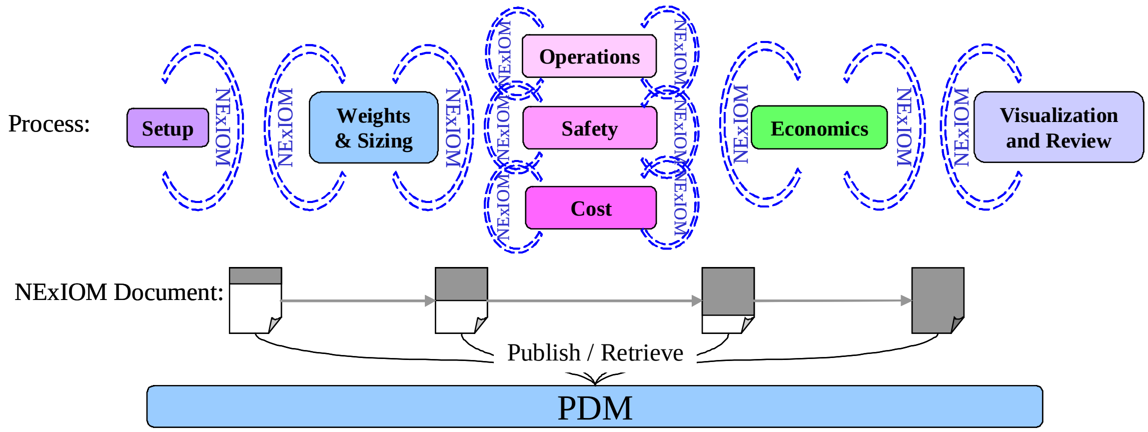

Figure 4: NASA Internal analysis tool path

The NExIOM Working Group and Organizational Interfaces

The NExIOM Working Group will consist of representation from the NASA NExIOM team contractor data modeling expertise, and the ESMD CIO ICE development team.

The CEV RFP Statement of work (Attachment J-2, Paragraph 2.1.2) talks about contractor participation in a NExIOM Working Group. The charter of this Group is to:

Collaboratively develop the NASA Exploration Information Ontology Model (NExIOM) by identifying the ESMD product, mission, rationale and organizational information required for a defensible decision trail while utilizing and/or extending existing standards and terminology where possible for the domains within that set of information.

[2] Vander Kam, J.C., Gage, P. "The Launch Vehicle Language (LVL) Data Model for Evaluating Reusable launch Vehicle Concepts", AIAA 2003-1330, 41st Aerospace Sciences Meeting and Exhibit, Reno NV, 6-9 Jan 2003

As part of this working group, we expect to follow a process similar to the one above in partnership with contractor data and process modelers to develop mappings at an appropriate level of detail between NASA and company data deliveries and processes. The definitions of terminology, formats and scope of the NExIOM domains above will utilize existing standards wherever possible. Groups that possess domain expertise and utilize current standards and protocols will be brought together via the NExIOM Working Group.

For each domain within the NExIOM, the Working Group will define the level of expression that NExIOM mandates. For some data resources, standards exist and are in common use. NExIOM will not attempt to redefine such standards. Where existing standards are deemed appropriate, the NExIOM may define metadata that enables retrieval data that utilizes it, but will not "penetrate" into the data set itself.

As an example, a particular software tool might be fed primarily by user inputs or an ASCII input file. Those parameters could be defined explicitly in the NExIOM schema for the appropriate domain. The same tool might also utilize a data file in a particular standard. In that case the NExIOM will define metadata about the standard and tag conforming data sets with that metadata, but will not penetrate into the data set itself.

NExIOM standards and specifications will evolve over time in response to the needs of the user community. The Working Group's goal is to find cost-effective ways to smooth the exchange of information between NASA and Industry.

Integrated Collaborative Environment

The Integrated Collaborative Environment (ICE) is the primary ESMD data management system [See the CEV RFP Appendix 2 - ICE Operating Environment]. The ICE is for sharing, collaborating, integrating, accessing and controlling management information and product data. All of the products which are part of Exploration Systems are included in this scope. The ICE system will physically house or point to data according to the schemas and ontologies of the NExIOM. The ICE can be thought of as the data base that houses and points to NExIOM-compliant data and utilizes the NExIOM schemas. NASA and non-NASA entities will exchange information using the ICE system. The ICE is capable of applying strict access controls in order to maintain security and proprietary information.

Verification, Validation and Accreditation (VV&A)

The NExIOM will support and enable the Verification, Validation and Accreditation (VV&A) policies of the ESMD. This is manifested by meta information defined in the NExIOM and applied to ESMD product and product acquisition information. The type and amount of metadata applied to each NExIOM domain will be a function of the NExIOM Working Group.

4.0 NExIOM Implementation

The NExIOM will utilize many modeling technologies, ontologies being key among them. While not intended to be an expansive description, a brief overview of these concepts is provided below. For additional information, see the W3C Semantic Web Activity site at http://www.w3.org/2001/sw/.

The NExIOM expresses data and relationships amongst that data. This is accomplished using the following primary constructs: Classes, Relationships and their Properties.

A NExIOM Class defines a grouping of data. A Class describes a set of parameters that, when considered together, describe an intuitively discrete portion of data. Examples of classes are Components, Metrics and Functions. NExIOM classes conform to the concept of derivation. As an example, a simple NExIOM Component may contain data fields for mass. A derivation of that simple class may add geometric data. A further extension for a wing-type component might add a specific data such as wing area. This concept is illustrated in Figure 5.

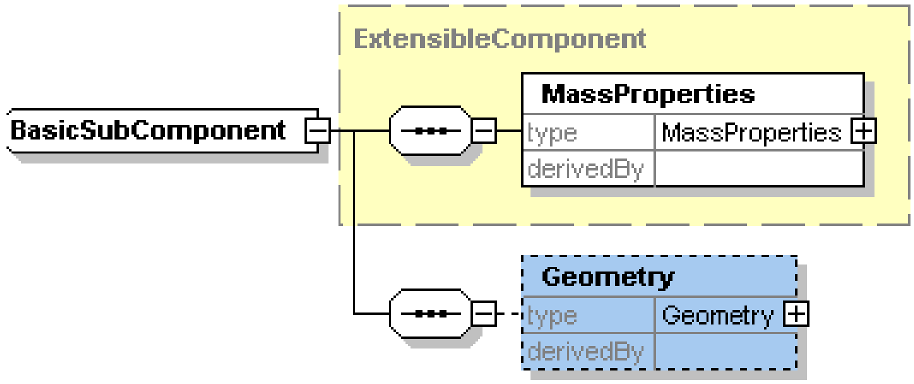

Figure 5: Class Derivation

Each class consists of terms, or parameters. These parameters define specific, valued, data items. For example, a wing class might prescribe wing area, in square meters, defined as the planform area including the carry-through as viewed from above the vehicle.

A class may also consist of metadata that describes data in an existing standard. For example, for detailed hardware data, an existing CAD format may be identified by the NExIOM Working Group as the accepted standard. Data in that format would be marked-up with NExIOM metadata and made available in the native CAD format. A particular CAD representation of a hardware part would be related to other data items represented in the NExIOM via NExIOM relationships.

The NExIOM contains Relationships. Relationships describe the influence of one type of class to another. For example, Component classes may contain “performs” relationships to Function classes. Conversely, Functions classes may contain “isPerformedBy” relationships to Component classes. In addition, classes may exhibit relationships amongst themselves. For example, Components may reference other Components via “child” and “parent” relationships. This concept is illustrated in Figure 6.

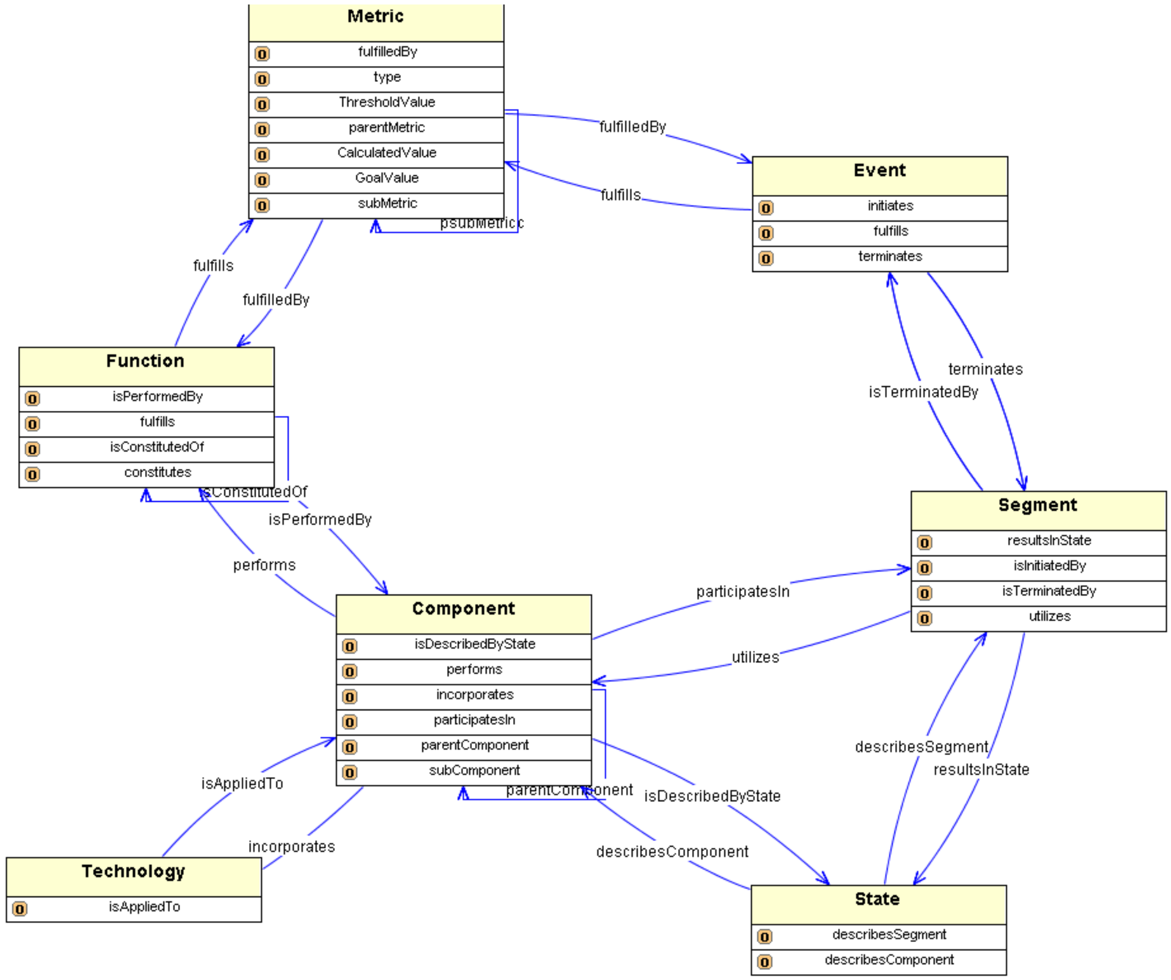

Figure 6: Relationships

The NExIOM is expressed using technologies such as eXtensible Markup Language (XML) Schema, Resource Description Framework (RDF) and Web Ontology Language (OWL) documents. These syntactical constructs enable expressive definitions for the classes and relationships that comprise the NExIOM.

A data set that conforms to the NExIOM is called a NExIOM instance. An instance may be realized via an XML document. Utilities provide a validity check of instance documents against the NExIOM definitions. In the case of a data set that is completely described by the NExIOM, one might interact with that data via an XML document utilizing NExIOM-defined elements and attributes. In the case where an existing standard is adopted, one would operate on that data set via the existing standard while identifying the data set using NExIOM metadata.

The NExIOM is supported by several software systems. These include viewers, editors, clients and web-based assets. These assets provide the capability for information exchange between parties using NExIOM instances. One manifestation of this is a system that allows industry entities to submit NExIOM-conformant instance documents to NASA via a web-interface. These systems also provide NExIOM data to analysis, modeling, simulation, reporting and management software tools.