The NASA Constellation Program Ontologies - how they are supporting NASA Constellation Program Data Architecture and its applications.

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Ralph Hodgson, CTO, TopQuadrant, Inc.

http://ontolog.cim3.net/cgi-bin/wiki.pl?ConferenceCall_2008_03_20
What there is to cover

- Introductions
- Ontology Work in the Constellation Program
- Constellation Data Architecture (CxDA)
- NASA’s CxDA Initiative
- NExIOM
- Examples from applications of the NExIOM ontologies
- Q & A
Introductions

- **Ralph Hodgson**
  - Co-founder and the CTO of TopQuadrant, Inc., a US-based company that specializes in semantic technology consulting, training, and tools.
  - Prior to starting TopQuadrant in 2001, held executive consulting positions at IBM Global Services where he was a founding member of Portal Practice and Object Technology Practice.
  - Prior to IBM, European Technology Director, founder, and Managing Director of Interactive Development Environments, which was an international CASE tools vendor.
What is a Data Architecture and the CxDA project

The Data Architecture (DA) provides guidance and a framework to a range of Constellation stakeholders that are data producers and consumers: engineers, managers, technicians, data architects, tool and process developers and users.

The CxDA project and its models, infrastructure, and services define consistent, unambiguous data representations and implement repeatable processes for data exchange in order to enable data sharing within and across Constellation Systems, Organizations, and Missions.
Ontology Work in the Constellation Program has explored many technologies and standards domain.
A Data Architecture answers questions of the following kinds

- Is this piece of data of this type?
- How is the data from this part of the organization related to data from another part of the organization?
- What are the security constraints on this data resource?
- How do I translate the data from this system for another system?
- Am I registered as a recipient to receive a specific data exchange package if I am working in a given context?
- Can I share this data with a specific party?
- Does this person have the right to perform this operation on this data?
- What are our organization’s obligations with respect to this data?
- Where did this data resource come from and what is its accreditation?
- Who owns this data and how many data exchange packages use it?
- Did this organization exchange data with this other organization?
- Are these tools accredited for this type of analysis

NASA CxDA and NExIOM Ontologies
Sounds like Metadata, then what does it mean to say “Metadata is Data about Data”?

- **Descriptive Metadata**
  - Format, Data types, Value ranges, Units of Measure

- **Provenance Metadata**
  - Who produced it, how and when it was produced, how it can be trusted

- **Relevance Metadata**
  - Who uses it and what value it has

- **Governance Metadata**
  - Who approves, reviews, and has stewardship
  - Who can access it, confidentiality, licensing and rights

- **Infrastructure Metadata**
  - The resources needed to manage and control data
  - Long term preservation metadata
But someone’s metadata is someone else’s data.

- What is metadata, what are attributes depends on the context of use
  - For example, the metadata that states that something is ITAR restricted is not metadata to someone that needs to have a system that provides controls on how documents become available to different parties.
  - The ITAR restricted flag is operational data in the context of a governed content management system.

- Hard to say when Metadata is Non-Operational Data
What is Metadata Really Then?

- Is it
  - Data needed to make Data?
  - Data needed to manage Data?
  - Data needed to relate Data?
  - The language (ala metamodel) needed to express Data?

- Metadata quickly becomes ontology

NASA CxDA and NExIOM Ontologies
## A Data Maturity Model*

<table>
<thead>
<tr>
<th>Data Maturity</th>
<th>Data Fidelity</th>
<th>Metadata Type</th>
<th>Data Instance</th>
<th>Data Organization</th>
<th>Metadata Content</th>
<th>Technology</th>
<th>Data Autonomy</th>
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</thead>
<tbody>
<tr>
<td>5. Optimized</td>
<td>High Fidelity</td>
<td>Multi-layer</td>
<td>Ontology with brokering and mediation</td>
<td>Ontology</td>
<td>Inferred</td>
<td>Semantic Technology</td>
<td>Smart Data</td>
</tr>
<tr>
<td>Semantics</td>
<td></td>
<td>Markup</td>
<td></td>
<td></td>
<td>Relationships</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Managed</td>
<td></td>
<td>Entity &amp;</td>
<td>Taxonomies with horizontal integration of domain</td>
<td>Ontology</td>
<td>Named</td>
<td>Data Independent</td>
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<tr>
<td>Relationships</td>
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<td>Relationship</td>
<td>vocabularies</td>
<td></td>
<td>Relationships</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Defined</td>
<td></td>
<td>Entity</td>
<td>XML Documents</td>
<td>Taxonomy</td>
<td>Metadata</td>
<td>Filtering, Clustering,</td>
<td></td>
</tr>
<tr>
<td>Content</td>
<td></td>
<td>Markup</td>
<td></td>
<td></td>
<td>Content</td>
<td>Categorization</td>
<td></td>
</tr>
<tr>
<td>2. Repeatable</td>
<td></td>
<td>Structure</td>
<td>Schemas &amp; DTDs</td>
<td>Documents</td>
<td>Document</td>
<td>Database Tools</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td>Markup</td>
<td></td>
<td></td>
<td>Standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Chaotic</td>
<td>Low Fidelity</td>
<td>Unstructured</td>
<td>Text Documents &amp; Database Records</td>
<td>Proprietary</td>
<td>Non-Aligned</td>
<td>Search Tools</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Documents</td>
<td></td>
<td>Application</td>
<td>Properties</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Adapted from: Joel A. Gladding, “Data Maturity Model”, SAIC Lead, Defense Intelligence Data Architecture, Presentation April 2005

NASA CxDA and NExIOM Ontologies
Metadata expressed in Ontologies

- Still serves as a Data Standard
  - defining attributes and properties of data
  - Through precise specifications

- Still helps to
  - develop software applications, databases
  - By transformations

- In the form of
  - Models of data and their metadata linked with general relationships, constraints, and rule
  - As machine-intelligible representations
Cx Data Architecture integrates existing related DA work, fills in the gaps, provides overall DA guidance, generates common models, and develops common infrastructure.
CxDA Metamodels are built using OWL – think of this as XML++

- **OWL = Web Ontology Language**
  - A language for describing the “what” of a domain of interest
  - Classes of things, properties of things, relationships between things
  - A standard defined by the World-Wide Web Consortium (W3C)

- **How does it relate to XML?**
  - OWL can be serialized using XML
  - OWL is built on the Resource Description Framework (RDF)
  - OWL constructs allow us to say things that XML Schema does not accomplish very flexibly
The Need for Different Kinds of Models

If you are doing these activities

- Risk Analysis
- Design
- Decision Support
  - Impact analysis
  - Information Discovery
  - Information Merging

You need these Models

- Fault Trees
- FMEA Models
- PRA Models
- Architecture Models
  - UML Models
  - CAD Models
- Knowledge Models
The NASA NExIOM Ontologies connect Enterprise Architecture to Systems Engineering Models

**Enterprise Knowledge**
- Organization has Policies
- Organization has ProjectOffices
- ProjectOffice has Goals
- ProjectOffice uses System
- Organization defines Mission
- Mission has Phases

**Process Knowledge**
- Process has Activities
- Activity produces Workproduct
- Workproduct isApprovedBy Role
- Workproduct isProducedBy Tool
- Tool analyzes MissionRisk
- Tool calculates FigureOfMerit
- FigureOfMerit isSpecifiedIn Document
- Document isHeldIn System

**Engineering Knowledge**
- Engineering Concepts
- Other representations
- metadata
- semantics
- Part structures
- Cx Element

**System**
- CEV
- CLV

**Parameter**
- Mission
- Organization
- Lifecycle
CxDA “connects the dots” across Information Objects
The Cx Data Architecture is a framework for the definition, usage, preservation and management of the constellation program data.
NASA CxDA Framework

- CxP 70160 ANX10 Infrastructure Specification
- CxP 70160 ANX11 Application Programming Interface Specification
- CxP 70160 ANX14 Policy and Security Model

Constellation Data Architecture

- Governance
  - Provenance
  - Models
  - OWL
  - Algorithms & Equations
  - Information Structures
  - Information Types
  - Data Types
  - Names and Identifiers
  - Encoding Rules
  - Naming & Design Rules
  - XML
  - Metadata

NASA CxDA and NEXIOM Ontologies
NExIOM Models Allow Traceability from Constellation Elements to Component, Parameters, Values and Units

- Hierarchical Identifier
  - Non-Arbitrary (from Names)
  - {Software+Human}-Oriented
  - Which "Occurrence"

- Cx Name
  - Descriptive
  - Human-Oriented
  - Which "Occurrence"

- Industry use of Identifiers as designators
  - Arbitrary (e.g., P/N 0612375-766-9845)
  - Logic-Oriented (e.g., Software)
  - Which "Instance"
CxDA System of Registries (SoR)

- Provide consistent definitions of data
  - across time, between organizations, between processes.
- Connect "silos" of information
  - captured within applications or proprietary file formats, through the use of standardized data definitions
- Support the exchange of information
  - Using formats and protocols - XML and Web Services
The Roles of the CxDA SoR - 1

- A source of authoritative information
  - Nomenclature, names, identifiers, schemas, types, terms, protocols, definitions, etc.
  - Instead of reading documents, expose granular details/specs of a file via model/schema -> allows querying by software and people

![Diagram of the CxDA SoR roles]

- UDDI Registry
- Metadata Registry
- Name and Identifier Registry
- XML Registry
- Database
- CASE Registry
- Telemetry and Command dictionary
- Recon Registry
- S/W Component Registry
- DSIL Registry
- Document Management System
- Ops Nom, CxID
- Table Column
- Packet ID
- Vehicle config
- In file
- Sim name
- Business object
- Business specification
- XMLtag
- S/W attribute

NASA CxDA and NExIOM Ontologies
The Roles of the CxDA SoR - 2

- A facility to relate information in multiple systems

Are these the same valves?

Hardware Nomenclature: Flow Control Valve

Software Nomenclature: 3-Way Mix Valve

Telemetry/Telecommand Nomenclature: Heat eXchanger Bypass valve

The Registries support answering these kinds of questions quickly, accurately, and provide a method of identifying/accessing the originating information.
The CxDA Namer uses an Ontology-Driven Grammar Engine

Name Manager
- Dialog Controller
- Query Manager

ANTLR Grammar
- Lexer
- Parser

CxDA Information Models
- Query Engine
- Inference Engines
- Ontologies
- Rules
- Data Brokers

CxDA Data Layer

NASA CxDA and NExIOM Ontologies
I want to name a Hydraulics Valve

Ontology and Grammar control the Dialog with the user

Constellation Names and Identifiers are generated
Namer uses Attribute Grammar with Java code making SPARQL queries on the Ontologies

```
computeCxSID(String m, int mark):
    {System.out.println(mark);}
    {m==null}? => 'Device Type' ID 'Effector Discipline' t=ID 'Effector Type' t1=ID
deviceSystemRole
systemOrComponentName
interfaceRole
effectorNamerCxSID[$t.text]
    {cxSID = $systemOrComponentName.cxSID + $deviceSystemRole.cxSID + $interfaceRole.cxSID + $effectorNamerCxSID.cxSID +
DeviceDataProvider.lookUpCxSIDFromTerm($t1.text);}
```

Grammar Rule

Device/System Role can be ‘main’, ‘auxiliary’, ‘primary’ or ‘secondary’

Interface Role depends on type of device. For a Valve can be ‘Inbound’ or ‘Outbound’

Consult the ontologies for vocabulary of terms associated with devices

Ontology of Devices

SPARQL queries

NASA CxDA and NExIOM Ontologies
What is NExIOM

NExIOM, the *NASA Exploration Initiatives Ontology Models* formalize the way machines (and people) refer to NASA Elements, their Scientific and Engineering disciplines, related work activities, and their interrelationships in the Enterprise. Through the use of agreed knowledge representations information become intelligible and actionable to machines, tools, and people. Information can be found, associated, aggregated and reasoned over to generate products and inform decisions within and across diverse organizational groups.

NExIOM consists of Models, a Semantic Infrastructure, and Services, integrated with operational tools and systems.
The NExIOM Ontologies

Level 2 Enterprise Architecture – databases, tools and systems used by organizations

Level 2 Integrated Modeling and Simulation – lifecycle based

Level 2 Constellation Elements

Level 2 C3I – Command, Control and Communications

Test → Operate → Maintain → Upgrade → Design → Manufacture

NASA CxDA and NExIOM Ontologies
NASA Enterprise Architecture Ontology (extract)
An ‘Information Asset’ is both a kind of ‘Governed Entity’ and an ‘Information Object’.

An ‘Information Object’ is a kind of ‘Identifiable Concept’ – something that has names and identifiers.
The CxDA Model has support for NASA’s Security needs.

Producers and Consumers are Operational Nodes.

Type Categories

Information Object Class

The CxDA Information Object

- cxda:accessor : [0..1]
- cxda:characteristics : cxda:DataPackageCharacteristic
- cxda:consumedBy : cxda:OperationalNode
- cxda:hasInformationObjectType : cxda:InformationObjectType
- cxda:hasInformationStructure : cxda:InformationStructure
- cxda:hasInformationType : cxda:InformationType[1..1]
- cxda:informationStatus : infoasset:Status[1..1]
- cxda:modifiedBy : cxda:OperationalNode
- cxda:producedBy : cxda:OperationalNode[1..1]
- cxda:resultsFrom : cxda:DisciplineBasedInquiry
- data:hasFileType : data:FileFormat[0..1]
- data:hasMimeType : mime:MimeType[1..1]
- infoasset:hasAssetType
- nasa:about : nasa:IdentifiableConcept
- nasa:pointOfContact : org:Party
- org:level : org:Level
- repository:isStoredIn : [1..1]
- security:hasSecurityLevel : security:Security[0..1]
- nc:url : anyURI[0..1]
- security:ITARrestricted : boolean[0..1]
- security:proprietary : boolean[1..1]
CxDA Information Asset specializes CxDA Information Object with other Governance

Information Asset Class

Provenance Metadata as associations to other information assets

Data Assets are also governed by NASA’s processes for approvals, reviews and concurrence

NASA CxDA and NExIOM Ontologies
Data Exchanges occur between operational nodes – Organizational Units and Assigned Roles

- Data Exchange has characteristic properties and sending and receiving parties
- Data Exchange Package has producers and consumers
- Operational Node can be an Organizational Unit or an Assigned Role
- An Assigned Role is a person from an Organization performing a discipline (role)

Organizational Unit – a center, division, office, etc.
Cx Data Assets are registered in the CxDA Registry Using a rich set of Data Models that support the key DoDAF viewpoints.

A screenshot of the CxDA Data Capture and Modeling Environment.
CxDA Information Asset specializes Cxda Information Object with other Governance

Information Asset Class

Provenance Metadata as associations to other information assets

Data Assets are also governed by NASA’s processes for approvals, reviews and concurrence

NASA Cxda and NExIOM Ontologies
NASA Modeling and Simulation Teams for different Constellation Elements use tools that need to interoperate.

Shared Vocabularies and Semantics

Horizontal Integration among Capabilities within each Subsystem

Analyst Decision Support Tool
- Inputs: Assumptions, FOMs, Budget
- Outputs: Trades

Aggregate Results

NASA CxDA and NExIOM Ontologies
### OWL Model of a Tool

#### The class ‘TOOL’

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>data:degree: tool:ToolDegree[0..1]</td>
<td></td>
</tr>
<tr>
<td>gov:applicableDocument: nasa:InformationAsset</td>
<td></td>
</tr>
<tr>
<td>gov:hasOwner: nasa:Organization[1..1]</td>
<td></td>
</tr>
<tr>
<td>gov:informativeReference: nasa:InformationAsset</td>
<td></td>
</tr>
<tr>
<td>nasa:comparableTo: nasa:Tool</td>
<td></td>
</tr>
<tr>
<td>nasa:documentation: tool:ToolDocumentation</td>
<td></td>
</tr>
<tr>
<td>nasa:hasApplicabilityTo: technology:Discipline or nasa:System</td>
<td></td>
</tr>
<tr>
<td>nasa:hasAssumption: nasa:Assumption</td>
<td></td>
</tr>
<tr>
<td>nasa:hasConstraint: nasa:Constraint</td>
<td></td>
</tr>
<tr>
<td>nasa:isUsedBy: org:AssignedRole or nasa:CommunityOfPractice</td>
<td></td>
</tr>
<tr>
<td>nasa:pointOfContact: org:AssignedRole or person:PointOfContact</td>
<td></td>
</tr>
<tr>
<td>security:hasSecurityLevel: security:Confidentiality[0..1]</td>
<td></td>
</tr>
<tr>
<td>tool:author: nasa:Person[1..]</td>
<td></td>
</tr>
<tr>
<td>tool:hasAccuracy: tool:AccuracyUncertaintyMeasure</td>
<td></td>
</tr>
<tr>
<td>tool:hasDevelopmentParty: nasa:Party[1..1]</td>
<td></td>
</tr>
<tr>
<td>tool:hasDevelopmentPointOfContact: person:PointOfContact</td>
<td></td>
</tr>
<tr>
<td>tool:hasVerificationAndValidationPlan: infoasset:VerificationSpecification[0..1]</td>
<td></td>
</tr>
<tr>
<td>tool:isBasedOn: nasa:Model</td>
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<td>tool:method: tool:ComputationalMethod</td>
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<td>nasa:comments: string</td>
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</tr>
<tr>
<td>security:proprietary: boolean[1..1]</td>
<td></td>
</tr>
</tbody>
</table>

#### Object property ‘isUsedBy’ makes connection to ‘AssignedRole’ and/or ‘CommunityOfPractices’

#### Object property for the tool’s computational model

#### Data property attribute for ‘ITAR Restriction’

---

**NASA CxDA and NExIOM Ontologies**
A Software Tool has a Set of Inputs and a Set of Outputs

Software Tool \(\xrightarrow{\text{hasInputSet}}\) InputSet

Software Tool \(\xrightarrow{\text{hasOutputSet}}\) OutputSet

NASA CxDA and NExIOM Ontologies
Input and Output Sets are ‘ParameterSets’ – a class that specifies common properties, e.g. assumptions and constraints

NASA CxDA and NExIOM Ontologies
The FIAT Tool

hasInputSet

Input Set for the FIAT Tool

hasVariable ‘IV_FIAT_DEXP’
A System is modeled using an SBFI formalism

The NASA System Ontology extends SBF with other SE modeling constructs. Some SysML concepts are modeled directly others need to be “free-ed’ from their UML dependencies.
NExIOM Ontology Architecture for C3I

- Modular Architecture
- Reusable Models
- Different degrees of specificity
  - n1, n2, n3 ... models

NASA CxDA and NExIOM Ontologies
NExIOM models Missions and Maneuvers relating ConOps to Vehicle Elements, System Functions, Parameters and Units

Mission has Phase
Mission has Objective
Mission has Vehicle...

Maneuver requires Burn

NASA CxDA and NExIOM Ontologies
Part of the ORION Model

Use of OWL restrictions to build SBFI models

NASA CxDA and NExIOM Ontologies
Ontologies model and locate Devices in their Functional Hierarchies for checking out of launch sequence operations.
KSC Launch Control System: CxDA Ontologies generate XTCE for metadata exchange with ground systems.

**Diagram Description:**
- **MySQL Database:** Central to the diagram, acting as a repository for ontologies.
- **Ontology Repository:** Serves as the central hub for managing and sharing ontologies.
- **Tomcat/Sesame:** Likely servers or frameworks for managing the ontology repository.
- **IA SERVER:** An interface or server connecting various systems.
- **XTCE Generator Application Client:** Generates XTCE files, which are inputs for Harris OS-Comet.
- **SB116CIA.xml:** A specific XTCE file used as input.

**Summary:** The diagram illustrates the integration of CxDA Ontologies with ground systems using XTCE, emphasizing the role of the MySQL database and the XTCE Generator Application Client in facilitating metadata exchange.
In Conclusion

1. Ontologies and Ontology-Based registries enable precise specifications of enterprise data and its use.

2. Semantic web technologies provide flexibility for interoperability and generation of work-products.

3. Ontology-Based Grammar Engines enforce consistency of naming and identifier rules.

4. “Connecting the dots” across the enterprise needs support for federation and governance.

5. Federated Systems of Registries can be implemented using databases with Semantic Web Technologies.
Thank You

Ralph Hodgson
E-mail: rhodgson@topquadrant.com